20th Advanced Accelerator Concepts Workshop

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Book of Abstracts

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WG7: Radiation Generation and Advanced Concepts / 19

Status and Prospects for the Plasma-drived Attosecond X-ray (PAX) source experiment at FACET-II

Author: Claudio Emma[None]

Corresponding Author: cemma89@stanford.edu

Plasma-driven light source development has recently made significant progress with multiple demonstrations of plasma-FEL gain [1-2] and the ongoing work of various facilities dedicated to plasma-FEL development [3]. In this contribution, we report on the status and prospects for one-such plasma-driven light source effort, the Plasma-driven Attosecond X-ray (PAX) experiment at FACET-II [4]. This unique experimental thrust seeks to compress electron beams generated by plasma accelerators to 10s of nm bunch length and use these beams as drivers for an attosecond X-ray source. This approach is motivated by the possibility to generate ultra-short (10s of as) high power (TW) X-ray pulses, as well as the order-of-magnitude increased tolerances of this method to emittance, energy spread and pointing jitter compared to a plasma-driven XFEL starting from noise. We present recent experimental developments in the process of demonstrating this concept at FACET-II and discuss potential extensions of this method to scale towards shorter wavelengths in the future.

[1] W. Wang et al Nature 595, 516 (2021)
[2] R. Pompili Nature 605, 659–662 (2022)
[3] C. Emma et al High Power Laser Science and Engineering, 2021, Vol. 9, e57 (2021)
[4] C. Emma et al APL Photonics 6, 076107 (2021)

Acknowledgments:

WGs 2+7 Joint Session / 20

Spin and polarization-dependent Osiris QED module for the future strong field QED laser-plasma experiment

Author: QIAN QIAN[None]

Co-authors: Daniel Seipt [1]; Alexander Thomas [2]; Marija Vranic [3]; Thomas Grismayer [4]; Thomas Blackburn [5]; Christopher Ridgers [6]

[1] *Helmholtz Institut Jena, Fröbelstieg*

[2] *University of Michigan, Gérard Mourou Center of Ultrafast Optical Science*

[3] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa,*

[4] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa*

[5] *Department of Physics, University of Gothenburg*

[6] *6York Plasma Institute, Department of Physics, University of York*

Corresponding Author: qqbruce@umich.edu

With the rapid development of high-power petawatt class lasers worldwide, exploring the physics in the strong field QED regime will become one of the frontiers for laser-plasma interaction research. Particle-in-cell codes including quantum emission processes are powerful tools for predicting and analyzing future experiments, where the physics of relativistic plasma is strongly affected by strong-field QED processes. Here, we present the development of a full spin and polarization-included QED module based on the particle-in-cell code OSIRIS. In this module, the dynamics of the lepton's spin involve both the classical spin precession process described by the classical T-BMT equation and the quantum radiation reaction-induced spin transition process. The photon polarization-resolved quantum radiation rate allows us to assign the polarization state for each generated photon in the simulation. We also consider the influence of the lepton spin and pho-ton polarization on the Non-linear Breit-Wheeler pair production process calculation. Compared with state-of-the-art, most common

spin/polarization averaged QED modules, this full spin/polarization distinguished quantum module is able to more accurately simulate multi-staged processes like avalanche and shower type electron-positron pair production cascade processes. We also use this module to explore possible routines for generating polarized gamma-ray and lepton bunch through laser-plasma interaction.

Acknowledgments:

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WG5: Beam Sources, Monitoring, and Control / 21

Stabilization and manipulation of laser-driven plasma acceleration with a weak auxiliary laser pulse

Authors: Brant Bowers[1]; Ross Rudzinsky[1]; LaBerge Max[1]; Michael Downer[1]; Jurjen Couperus-Cabadag[2]; Yen-Yu Chang[2]; Arie Irman[2]; Thomas Püschel[2]; Patrick Ufer[2]; Ulrich Schramm[2]; Tianhong Wang[3]; Gennady Shvets[3]

[1] *The University of Texas at Austin*

[2] *Helmholtz-Zentrum Dresden-Rossendorf*

[3] *Cornell University*

Corresponding Author: downer@physics.utexas.edu

We show that uncontrolled phase fluctuations within an outer annulus of the near-field profile of a laser-wakefield drive pulse are primarily responsible for shot-to-shot fluctuations in the energy, charge, and pointing of wakefield-accelerated electrons. When a mask removes this unstable annulus, RMS fluctuations decrease by more than half without compromising average electron energy substantially. When light from the removed annulus is re-shaped into a co-polarized pulse that peaks on axis and co-propagates at controlled delays $-120 < \Delta t < 120$ fs with respect to the 10× more intense drive pulse, fluctuations in electron and betatron x-ray properties reappear, peaking in amplitude when the weak pulse overlaps either the drive pulse ($\Delta t = 0$) or accelerating electrons and the tail of the drive pulse ($\Delta t \approx 30$ fs). In the latter case, a net increase in average electron energy is observed. The results suggest the possibility of precisely and widely tuning the properties of laser-wakefield-accelerated electrons using a comparatively weak auxiliary pulse with a stable, independently controlled carrier envelope phase.

Acknowledgments:

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WG1: Laser-Plasma Wakefield Acceleration / 22

Data-driven modelling of laser-plasma experiments enabled by large datasets

Author: André Antoine[1]

Co-authors: Archis Joglekar [2]; Alexander Thomas [3]; Matthew Streeter [4]; Rob Shalloo [5]

[1] *University of Michigan*

[2] *University of Michigan, Ergodic LLC*

[3] *University of Michigan, Gérard Mourou Center of Ultrafast Optical Science*

[4] *Queens University Belfast*

[5] *DESY*

Corresponding Author: aantoine@umich.edu

Laser Wakefield Acceleration (LWFA) is a process by which high gradient plasma waves are excited by a laser leading to the acceleration of electrons. The process is highly nonlinear leading to difficulties in developing 3 dimensional models for a priori, and/or ab initio prediction.

Recent experiments at the Rutherford Appleton Laboratory's (RAL) Central Laser Facility (CLF) in the United Kingdom using the 5Hz repetition rate Astra-Gemini laser have produced new results in LWFA research, inviting analysis of data with unprecedented resolution. Additionally, data driven modeling, scaling laws and models can be extended into new ranges or refined with less bias.
We will present results of training deep neural networks to learn latent representations of experimental diagnostic data and validate the latent space by comparing the distribution of beam divergences and other metrics of randomly generated spectra against the distribution in the training data. We will discuss the ability of the model to generalize results to different conditions. This work will use architectures which rely on reparameterization using a small dense network connected to a larger, convolutional neural network.

Acknowledgments:

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WG1: Laser-Plasma Wakefield Acceleration / **23**

Stable injection into a laser plasma accelerator with colliding laser pulses

Author: Qiang Chen[1]

Co-authors: Tobias Ostermayr [1]; Robert Jacob [1]; Camille Woicekowski [2]; Remi Lehe [1]; Axel Huebl [1]; Jeroen van Tilborg [1]; Anthony Gonsalves [1]; Carl Schroeder [1]; Eric Esarey [1]; Cameron Geddes [1]

[1] *Lawrence Berkeley National Laboratory*

[2] *University of California, Berkeley*

Corresponding Author: qiangchen@lbl.gov

Colliding pulse injection of electron beams into a laser plasma accelerator (LPA), thus producing compact, stable, and monoenergetic electron beams, has important applications for narrow bandwidth Thomson gamma ray sources and novel x-ray free-electron lasers. The colliding laser pulses are independently optimized in terms of energy, beam size, and pulse compression. The spatiotemporal overlap of the femtosecond-duration colliding pulses in the underdense plasma is ensured with femtosecond shadowgraphy and top imaging of the plasma. High-quality, stable LPA electron beams from colliding pulse injection were demonstrated over consecutive 100's of shots. The absolute rms energy spread of the injected electron beam could be reduced down to just a few MeV (rms), at peak electron energy of ~150MeV. The peak energy is stably tunable over large respective ranges of the plasma density, gas jet positions, and injector pulse delays. Parameter scan of injection position and plasma density indicate the driver laser pulse depletion and/or diffraction at large plasma density, which causes the decrease of the maximum electron beam energy.

Acknowledgments:

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WG7: Radiation Generation and Advanced Concepts / 24

Multi-color operation via coherent harmonic generation in a plasma driven attosecond X-ray source

Authors: Rafi Hessami[1]; Mark Hogan[1]; Kirk Larsen[1]; Agostino Marinelli[1]; River Robles[1]; Claudio Emma[1]

[1] *SLAC National Accelerator Laboratory*

Corresponding Author: rafimah@stanford.edu

The ongoing Plasma-driven Attosecond X-ray source experiment (PAX) at FACET-II aims to produce coherent soft x-ray pulses of attosecond duration using a Plasma Wakefield Accelerator [1]. These kinds of X-ray pulses can be used to study chemical processes where attosecond-scale electron motion is important. As a future upgrade to this concept, we investigate scaling to shorter soft X-ray wavelength by cascading undulators tuned to higher harmonics of the fundamental in a coherent harmonic generation (CHG) configuration. This configuration leverages the increase in the bunching factor of the higher harmonics to produce radiation at the fifth and tenth harmonics, corresponding to radiation wavelengths of 2 nm and 1 nm. In this contribution, we consider two CHG schemes. The first consists of using three 20 period-long undulator stages tuned to the fundamental, the fifth harmonic, and the tenth harmonic respectively, while the second consists of 20 periods at the fundamental, then 40 at the tenth harmonic. We demonstrate in both of these schemes using undulators with retuned fundamental frequencies can produce TW-scale pulses of fifth and tenth harmonic radiation with tens of attosecond-scale pulse lengths, an order of magnitude shorter than current state-of-the-art attosecond XFELs.

[1] C. Emma, X.Xu et al APL Photonics 6, 076107 (2021)

Acknowledgments:

WG3: Laser and High-Gradient Structure-Based Acceleration / 25

High-Gradient 3 GeV Booster for Enhanced Proton Radiography at LANSCE

Author: Yuri Batygin[1]

Co-author: Sergey Kurennoy

[1] *Los Alamos National Laboratory*

Corresponding Author: batygin@lanl.gov

Increasing the proton beam energy from the present 800 MeV to 3 GeV will improve the resolution of the Proton Radiography Facility at the Los Alamos Neutron Science Center (LANSCE) by a factor of 10. It will bridge the gap between the existing facilities, which covers large length scales for thick objects, and future high-brightness light sources, which can provide the finest resolution. Proton radiography requires a sequence of short beam pulses (~ 20 x 80 ns) separated by intervals of variable duration, from about 200 ns to 1-2 μs. To achieve the required parameters, the high-gradient 3-GeV booster is proposed. Utilization of buncher-accelerator-debuncher scheme allows us to combine high-gradient acceleration with a significant reduction of beam momentum spread. Paper discusses details of linac design and expected beam parameters.

Acknowledgments:

WGs 1+2 Joint Session / 26

Acceleration of positrons generated via photon-photon collisions in a dense laser-irradiated plasma

Author: Alexey Arefiev[1]

Co-authors: Yutong He ; Kaoru Sugimoto ; Tom Blackburn ; Yasuhiko Sentoku ; Natsumi Iwata ; Toma Toncian

[1] *UC San Diego*

Corresponding Author: aarefiev@eng.ucsd.edu

In a typical laboratory plasma, there are no native positrons, which complicates attempts to develop a laser-driven positron accelerator. High-power high-intensity lasers provide an attractive opportunity to create positrons directly from light. While most attention has been focused on the multi-photon process, the process that involves two gamma-rays, the linear Breit-Wheeler (BW) process, has been overlooked due to a misconception that it is more difficult to realize. To objectively assess the linear BW process, we have developed a first-ever fully kinetic code for predictive simulations of the electron-positron pair production via this process in high-intensity laser-matter interactions and the subsequent positron acceleration. Using this new tool, we have discovered several regimes where one or two laser pulses propagating through a dense plasma form an effective self-organized collider of gamma-rays and an adjoining accelerator for the generated positrons. In contrast to the regimes proposed for the multi-photon process, our regimes only require a peak intensity that is already accessible at most flagship laser facilities to produce from tens of millions to billions of electron-positron pairs. The created positrons are emitted from the plasma as ultra-relativistic beams with a narrow divergence angle, which is likely to facilitate their use for applications.

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WG4: Beam-Driven Acceleration / 27

Beam-Beam Considerations for Highest-Energy Linear Colliders

Author: Spencer Gessner[1]

[1] *SLAC*

Corresponding Author: sgess@slac.stanford.edu

The AAC community proposed linear collider concepts with energies extending to 15 TeV center-of-mass and luminosities up to 50E34 cm^-2 s^-1 as part of the Snowmass process. The beam power required to reach these energies and luminosities is prohibitive. We discuss the results of initial investigations of strategies to increase luminosity per beam power, a key figure-of-merit for linear colliders.

Acknowledgments:

WG5: Beam Sources, Monitoring, and Control / 28

A Compact Source of Positron Beams with Small Thermal Emittance

Authors: Rafi Hessami[1]; Spencer Gessner[2]

[1] *SLAC National Accelerator Laboratory*

[2] *SLAC*

Corresponding Author: rafimah@stanford.edu

We investigate electrostatic traps as a novel source of positron beams for accelerator physics applications. The electrostatic trap is a simple device that accumulates and cools positrons produced by a radioactive source. Using well-established techniques, the positron beam is cooled down to or below room temperature. The thermal beam emittance is an order of magnitude smaller than beams produced by rf photocathodes [1]. The compact positron source can be built and operated at a fraction of the cost of traditional target-based positron sources. Despite these advantages, there are several features of electrostatic trap-based beams which limit their use to specialized applications. In this work, we study the features of positron beams from electrostatic traps. The positron bunch is first accelerated and compressed by an electrostatic buncher before being injected into an rf-cavity for further acceleration. We model the acceleration of the positron bunch up to an energy of 17.57 MeV with a transverse thermal emittance of 0.45 μm-rad, and bunch length of 0.21 mm. The beamline used in our model is about 1.5 meters long, which is comparable to an rf photocathode source, and far more compact than traditional target-based positron sources.

[1] B. J. Claessens, S. B. Van Der Geer, G. Taban, E. J. Vredenbregt, and O. J. Luiten, "Ultracold electron source," Physical Review Letters, vol. 95, no. 16, pp. 1–4, 2005.

Acknowledgments:

WG3: Laser and High-Gradient Structure-Based Acceleration / 29

High-Gradient Accelerating Structures for 3-GeV Proton Radiography Booster

Author: Sergey Kurennoy[1]

Co-authors: Yuri Batygin [2]; Eric Olivas [2]

[1] *Los Alamos National Laboratory*

[2] *LANL*

Corresponding Author: kurennoy@lanl.gov

Increasing energy of proton beam at the Los Alamos Neutron Science Center (LANSCE) from 800 MeV to 3 GeV will improve radiography resolution ~10 times. This energy boost can be achieved with a compact cost-effective linac based on normal conducting high-gradient (HG) RF accelerating structures. Such an unusual proton booster is feasible for proton radiography (pRad), which operates with short beam pulses at very low duty. The pRad booster starts with a short L-band section to capture and compress the 800-MeV proton beam from the existing linac. The main HG linac is based on S- and C-band cavities. An L-band de-buncher at the booster end reduces the beam energy spread. We present details of development of proton HG structures with distributed RF coupling for the booster. Operating such structures at liquid-nitrogen temperatures will significantly reduce the required peak RF power. A short test structure was fabricated and is being tested at the LANL C-band RF Test Stand.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / 30

Cryogenic Dielectric Accelerating Structures

Author: Chunguang Jing[None]

Corresponding Author: c.jing@euclidtechlabs.com

Shunt impedance is one of the most important parameters characterizing particle acceleration efficiency. It is known that RF losses are reduced at cryogenic temperatures. For example, a record high shunt impedance of 350 MΩ/m was demonstrated recently for all metal X-band accelerating structure, which is more than 2 times higher than that at room temperature. Here we present a novel hybrid dielectric structure which can achieve even higher shunt impedance due to the fact that losses in dielectric materials reduced much more than in pure copper.

Acknowledgments:

WG3: Laser and High-Gradient Structure-Based Acceleration / 31

Evaluation of DLC (diamond-like carbon) Coating on Multipactor Suppression

Author: Chunguang Jing[None]

Corresponding Author: c.jing@euclidtechlabs.com

Multipactor discharges in dielectric accelerating structures are a major limitation on the performance of this otherwise very promising technology for future high energy physics machines and other applications. Multipactor occurs when the Secondary Emission Yield (SEY) of the dielectric material used in accelerating structures is significantly higher than 1. In this work, we evaluated the effect of SEY reduction by means of amorphous Carbon (a-C) and Diamond-Like Carbon (DLC) coatings for different dielectric materials. We also report on the testing results for a DLC coated low energy dielectric accelerator.

Acknowledgments:

WGs 1+2 Joint Session / 32

HiPACE++: GPU-accelerated modeling of plasma wakefield accelerators

Authors: Severin Diederichs[1]; Carlo Benedetti[2]; Axel Huebl[2]; Rémi Lehe[2]; Andrew Myers[2]; Alexander Sinn[3]; Jean-Luc Vay[2]; Weiqun Zhang[2]; Maxence Thévenet[3]

[1] *DESY / LBNL*

[2] *LBNL*

[3] *DESY*

Corresponding Author: severin.diederichs@desy.de

Modeling plasma wakefield accelerators is computationally challenging. Using the quasi-static approximation allows for efficient modeling of demanding plasma wakefield accelerator scenarios. Here, the latest highlights of the performance-portable, 3D quasi-static particle-in-cell (PIC) code HiPACE++ are presented. HiPACE++ demonstrates orders of magnitude speed-up on modern GPU-equipped supercomputers in comparison to its CPU-only predecessor HiPACE. Thus, HiPACE++ enables fast and accurate modeling of challenging simulation settings, including the proton-beam-driven accelerator AWAKE or low-emittance positron acceleration schemes at unprecedented resolution.

Acknowledgments:

We acknowledge the Gauss Centre for Supercomputing for providing computing time on the Supercomputer JUWELS Booster. We acknowledge Funding by the Helmholtz Matter and Technologies Accelerator R&D Program, by the US Exascale Computing Project (No. 17-SC-20-SC), and by the Director, Office of High Energy Physics, of the DoE (No. DE-AC02-05CH11231).

Plenary / 33

From Compact Plasma Particle Sources to Advanced Accelerators with Modeling at Exascale

Authors: Axel Huebl[1]; WarpX & BLAST Team[2]; PIConGPU CAAR Team[3]; international modeling teams (contribution)[4]

[1] *Lawrence Berkeley National Laboratory*

[2] *LBNL, LLNL, SLAC, CEA, DESY, Modern Electron, CERN*

[3] *UDEL, HZDR, CASUS, OLCF*

[4] *UCLA, IST, CEA, MdlS, LULI, LLR, LANL, UTK et al.*

Corresponding Author: axelhuebl@lbl.gov

Research of plasma-based accelerators has achieved significant milestones over the last decade. Highlights include achieving nearly 8 GeV electrons in a single-stage source, demonstrating plasma-based FELs, reaching stable proton acceleration of ultra-short, nC-class pulses that enable studies into ultrahigh dose rate radiotherapy. As the exploratory aspect of the field benefits significantly from the elucidation of fundamental processes through simulations, transitioning from intriguing sources to scalable accelerators requires universally integrated, quantitatively predictive capabilities for design and operations.
In this presentation, we discuss that complex, reliable advanced accelerators require a coordinated, extensible, and comprehensive approach in modeling, from source to the end of the beam's lifetime. We will discuss approaches and highlights of ongoing Exascale Computing efforts in the community, both in the US and internationally. This includes laser-plasma modeling on an exaflop supercomputer using the US DOE Exascale Computing Project WarpX [1-4] as well as progress of PIConGPU in the OLCF Center for Accelerated Application Readiness (CAAR) project for the same machine, and further projects.
Leveraging developments for Exascale, the DOE SCIDAC-5 Consortium for Advanced Modeling of Particle Accelerators (CAMPA) will advance numerical algorithms and accelerate community modeling codes in a cohesive manner: from beam source, over energy boost, transport, injection, storage, to application or interaction. Such start-to-end modeling will enable the exploration of hybrid accelerators, with conventional and advanced elements, as the next step for advanced accelerator modeling. Following open community standards [5], one can initiate an open ecosystem of codes [6,7] that can be readily combined with each other and machine learning frameworks. These will cover ultrafast to ultraprecise modeling for future hybrid accelerator design, even enabling virtual test stands and twins of accelerators that can be used in operations.

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Poster Session and Reception - Board: F84 / **34**

Simulation of optimized TNSA via temporal pulse shaping under realistic laser contrast conditions

Authors: Marco Garten[1]; Jakob Wetzel[2]; Marvin E. Umlandt[2]; Ilja Goethel[2]; Thomas Miethlinger[2]; Brian E. Marré[2]; Tim Ziegler[2]; Thomas Pueschel[2]; Stefan Bock[2]; Karl Zeil[2]; Michael Bussmann[3]; Thomas E. Cowan[2]; Ulrich Schramm[2]; Thomas Kluge[4]

[1] *HZDR, LBNL*

[2] *HZDR, TU Dresden*

[3] *CASUS, HZDR*

[4] *HZDR*

Corresponding Author: mgarten@lbl.gov

Controlling the spatio-temporal coupling of laser energy into plasma electrons is crucial for achieving predictable beam parameters of ions accelerated from ultra-high intensity (UHI) laser-driven solid density plasmas. Especially for highest maximum energies, the most promising and readily available targets are foils of a few ten to hundred nanometers thickness. When working with targets of such small scales, meticulous control and precise metrology of the driving UHI laser pulses are paramount to avoiding premature plasma expansion that would lead to losses in absorption efficiency as well as lower accelerating fields. Recently, significant proton beam quality enhancement was reported from the Draco Petawatt facility at HZDR via spectral phase control of the driving laser pulse. In support of these experiments, we present a numerical simulation study with particle-in-cell codes taking into account realistic temporal intensity contrast features. In particular, we focus on the influence that manipulations of spectral phase terms applicable in laboratory experiments have on the acceleration of ions. We furthermore show how the state of the target and transient femtosecond plasma dynamics are encoded into time-integrated observables giving more insight into the previously obtained experimental results.

Acknowledgments:

WGs 2+5 Joint Session / **35**

Detailed Phase Space Reconstructions from Accelerator Beam Measurements Using Differentiable Simulations

Authors: Ryan Roussel[1]; Auralee Edelen[2]; Christopher Mayes[None]; John Power[None]; Juan Pablo Gonzalez-Aguilera[3]; Eric Wisniewski[4]; Seongyeol Kim[4]; Daniel Ratner[1]

[1] *SLAC National Accelerator Laboratory*

[2] *SLAC*

[3] *University of Chicago*

[4] *Argonne National Laboratory*

Corresponding Author: rroussel@slac.stanford.edu

Characterizing the phase space distribution of particle beams in accelerators is a central part of accelerator understanding and performance optimization. However, conventional reconstruction-based techniques either use simplifying assumptions or require specialized diagnostics to infer high-dimensional (> 2D) beam properties. In this work, we introduce a general-purpose algorithm that combines neural networks with differentiable particle tracking to efficiently reconstruct high-dimensional phase space distributions without using specialized beam diagnostics or beam manipulations. We demonstrate that our algorithm reconstructs detailed 4D phase space distributions with corresponding confidence intervals in both simulation and experiment using a single quadrupole and diagnostic screen. This technique allows for the measurement of multiple correlated phase spaces simultaneously, enabling simplified 6D phase space reconstruction diagnostics in the future.

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WG4: Beam-Driven Acceleration / 36

Proof of principle experiments of PV/m plasmonics using structured semiconductors

Author: Aakash Sahai[1]

Co-authors: Mark Golkowski [1]; Thomas Katsouleas [2]; Gerard Andonian [3]; Glen White [4]; Chandrashekhar J. Joshi [3]; Peter Taborek [5]; Daniele Filippetto [6]; Vijay Harid [1]; Joachim Stohr [4]; Andrea Latina [7]

[1] *University of Colorado Denver*

[2] *University of Connecticut*

[3] *University of California Los Angeles*

[4] *Stanford Linear Accelerator Center*

[5] *University of California Irvine*

[6] *Lawrence Berkeley National Lab*

[7] *CERN*

Corresponding Author: aakash.sahai@ucdenver.edu

A new paradigm of extreme plasmonics unearthed by our work opens the unprecedented possibility of PetaVolts per meter fields that make it possible to access 1,000,000 times the acceleration gradient in RF accelerators. Plasmonic accelerators and light-sources put forth in our work rely on these extreme plasmons over timescales where the ionic-lattice remains largely unperturbed. A specific realization of this concept uses ultrashort particle beams propagating inside tubes made of conductive walls. Beam fields excite the conduction band electrons and sustain a large-amplitude surface crunch-in plasmon which is critical to mitigate collision of the beam with the ionic lattice but at the same time access strong focusing fields along with acceleration gradient. We elucidate our proof-of-principle experiments based on "tunable semiconductor plasmons" excited in n-type doped Silicon tube to match with currently accessible beams from linacs such as FACET-II or laser wakefield accelerators. Experimental verification of principles underlying extreme plasmons will pave the way towards PV/m plasmonics.

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WGs 2+4 Joint Session / 37

Relativistically induced ballistic transport and novel effects underlying PV/m plasmonics

Author: Aakash Sahai[1]

[1] *University of Colorado Denver*

Corresponding Author: aakash.sahai@ucdenver.edu

PV/m plasmonics model pioneers extreme plasmons where the free electron Fermi gas constituted by the conduction band electrons in condensed matter is excited to its ultimate limits. Here we discuss novel physical mechanisms that begin to dominate the physics of extreme plasmons. For instance, relativistically induced ballistic electron transport helps explain earlier beam-metal interaction experiments where damage and solid-plasma formation were not observed when the SLAC electron beam was compressed to <100fs. Furthermore, as the conduction band electrons attain relativistic velocities, they are capable of freely tunneling across the surface especially when excited in a direction perpendicular to the surface giving rise to relativistic tunneling. Besides these prominent novel effects, we differentiate and describe several foundational principles that underlie the physics of extreme plasmons.

Acknowledgments:

Poster Session and Reception - Board: P47 / **38**

Programmable-Velocity Dephasingless Laser Wakefield Acceleration

Author: Manfred Virgil Ambat[1]

Co-authors: John Palastro [2]; Phil Franke [2]; Hans Rinderknecht [2]; Dustin Froula [2]; Jessica Shaw [2]

[1] *University of Rochester, Laboratory for Laser Energetics*

[2] *University of Rochester, Laboratory of Laser Energetics*

Corresponding Author: mvambat@ur.rochester.edu

In a laser wakefield accelerator, the ponderomotive force of an intense laser pulse propagating through a plasma excites a large amplitude plasma wakefield that can trap and accelerate electrons to relativistic energies. To prevent the electrons from outrunning the accelerating phase of the wakefield, spatiotemporal pulse shaping can be used to propagate the laser intensity at the vacuum speed of light in the plasma over long distances without the need for guiding structures. We present simulations of a novel optical configuration for spatiotemporal pulse shaping that combines a deformable mirror (DM), a spatial light modulator (SLM), and a reflective axiparabola. The DM imparts a radial group delay that controls the time at which each radius reaches its focus. The SLM corrects the unwanted phase front curvature imparted by the DM while retaining the desired delay. The axiparabola controls the longitudinal location at which each radius focuses. This flying focus improves upon previous designs by offering flexible programmability of the focal velocity with the DM and SLM.

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Poster Session and Reception - Board: P25 / **39**

Effects of a plasma ramp on an electron bunch seeding self modulation of a proton bunch

Authors: Jan Pucek[1]; Patric Muggli[1]; Livio Verra[2]; Tatiana Nechaeva[1]; Michele Bergamaschi[1]; Lucas Ranc[1]; Giovanni Zevi Della Porta[1]

[1] *Max-Planck Institute for Physics*

[2] *CERN*

Corresponding Author: jan.pucek@cern.ch

We study the propagation of an electron bunch travelling within a proton bunch through a plasma density ramp. The proton bunch charge density in the ramp is higher than the plasma density. In this nonlinear regime the bunch generates a high density, on-axis plasma electron filament. The filament is defocusing the externally injected electron witness bunch that can therefore be lost along the ramp. At AWAKE we have measured this effect by changing the relative timing between electron and proton bunches. When the electron bunch propagates in front of the proton bunch, the electron bunch seeds self-modulation and reaches the energy spectrometer, downstream of the plasma. When propagating within the proton bunch, seeding stops and the electron bunch does not reach the spectrometer. These results indicate that the presence of a plasma density ramp could prevent on axis injection of an electron witness bunch into a following acceleration plasma. We will present latest experimental data.

Acknowledgments:

Poster Session and Reception - Board: P48 / **40**

Radiation detection for the PAX Experiment at FACET-II

Authors: Rafi Hessami[1]; Claudio Emma[1]; Kirk Larsen[1]; Agostino Marinelli[1]; River Robles[1]; Mark Hogan[1]

[1] *SLAC National Accelerator Laboratory*

Corresponding Author: rafimah@stanford.edu

The ongoing Plasma-driven Attosecond X-ray source experiment (PAX) at FACET-II aims to produce soft x-ray pulses of attosecond duration with TW peak power using a Plasma Wakefield Accelerator [1]. These X-ray pulses can be used to study chemical processes where attosecond-scale electron motion is very important.

For this first stage of the experiment, PAX plans to demonstrate that sub 100 nm FWHM electron beams can be generated by taking the 10 GeV beam produced at the FACET-II photoinjector and using the plasma cell to give it a percent-per-micron chirp. Then, the chirped beam is sent into a chicane and compressed. Since the beam is on the order of 10s of nm long, the CSR radiation produced by the final bend magnet in the chicane contains coherent radiation as low as 50 of nm. After the radiation is produced, it is reflected into two spectrometers for measurement. Future iterations of the experiment plan to use a short undulator to produce significantly more radiation and to demonstrate coherent harmonic generation using an undulator tuned to a resonant wavelength of ~1-10 nm.

[1] C. Emma, X.Xu et al APL Photonics 6, 076107 (2021)

Acknowledgments:

WGs 7+8 Joint Session / 41

HIGHLY-EFFICIENT 20-MW L-BAND MULTI-BEAM KLYSTRON

Authors: Vladimir Teryaev[1]; Nikolay Solyak[2]; Xiangyun Chang[3]; Jay Hirshfield[3]

[1] *Budker Institute of Nuclear Physics*

[2] *Fermi National Accelerator Laboratory*

[3] *Omega-P R&D, Inc.*

Corresponding Author: jay.hirshfield@yale.edu

A new concept for a high-power L-band RF amplifier is described, namely a Two-Stage Multi Beam Klystron (TS-MBK) operating with 12 hollow beamlets. This configuration allows for a remarkably high RF electronic efficiency of up to 90%, with a compact electro-mechanical layout. We present a conceptual design for a 1.0 GHz, 20 MW peak-power TS-MBK; its predicted performance was determined using particle-in-cell computer simulations. The tube's efficiency—about 20% higher than conventional MBK's—is due to good bunching of its 12, 30-kV, 12-A, 2.31-μK perveance hollow beamlets; followed by 150 kV post-acceleration that results in 0.157-μK, 180 kV beamlets with a total power of 26 MW that drive the output cavity. It is notable that the required modulator for this tube needs to provide pulses of only 30 kV, since post-acceleration can be achieved using a compact and much lower cost dc power supply. Further, the post-acceleration electric field prevents electrons reflected in the collector from returning towards the cathode. One application for this tube could be as the RF source for the 3-TeV CLIC drive beam, for which about 1230, 1.0 GHz tubes supplying a total average power of 184 MW are required. Another application could be to supply the high peak and high average power to drive the emerging compact and efficient electron cyclotron resonance accelerator eCRA, producing beams for environmental remediation and replacement of radioactive sources for sterilization. The optimal operating frequency for eCRA could be about 1000 MHz, but the TS-MBK design presented here can be scaled to other L-band frequencies. The high efficiency of our TS-MBK for these applications would result in significant operating cost savings and significant reduction in waste heat from the beam collector.

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WG2: Computation for Accelerator Physics / 42

An Alternative Approach to Incorporating Laser Pulses in Particle-in-Cell Simulations

Authors: Kathleen Weichman[1]; Kyle Miller[1]; Bernardo Malaca[2]; Warren Mori[3]; Jacob Pierce[3]; Jorge Vieira[2]; Marija Vranic[2]; John Palastro[4]

[1] *University of Rochester Laboratory for Laser Energetics*

[2] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa,*

[3] *University of California Los Angeles*

[4] *University of Rochester, Laboratory of Laser Energetics*

Corresponding Author: kweic@lle.rochester.edu

Numerical modeling of electromagnetic waves is a critical component of particle-in-cell simulation of laser–plasma interactions. Traditionally, laser pulses have been either launched from simulated antennas or initialized in their entirety in the computational domain. Relying on the electromagnetic field update to advance the laser pulse, however, imposes needless computational expense and complexity for a number of emerging applications. As an alternative, we demonstrate that laser pulses can be incorporated using analytic expressions provided that numerical dispersion is

matched. The otherwise self-consistent treatment of the plasma reproduces 3-D–like focusing in lower-dimensional simulation, enables direct examination of approximate solutions to Maxwell's equations including Laguerre–Gaussian beams, and facilitates the modeling of novel laser pulses including the spatiotemporally shaped flying focus.

Acknowledgments:

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Poster Session and Reception - Board: `P14` / **43**

Optimizing the Discovery of Underlying Nonlinear Beam Dynamics in Angular Momentum and Space Charge Dominated Beams

Authors: Liam Pocher[1]; Alexander Einarsson[1]; Levon Dovlotyan[1]; Brian Beaudoin[1]; Santiago Bernal[1]; Irving Haber[1]; David Sutter[1]; Thomas Antonsen[1]; Patrick O'Shea[1]

[1] *University of Maryland*

Corresponding Author: lpocher@umd.edu

One of the Grand Challenges identified by the Office of High Energy Physic relates to the use of virtual particle accelerators for beam prediction and optimization. Useful virtual accelerators rely on efficient and effective methodologies grounded in theory, simulation, and experiment. Typically, virtual accelerators are created using either computationally expensive simulations or black box methods like Machine Learning (ML). The underlying nonlinear dynamics governing beam evolution can be challenging to interpret and understand with such techniques. Our work interweaves simulation, theory, and experiment to gain deeper insight into the constituent physics.
We are developing an experiment related to Derbenev's flat-to-round and round-to-flat transformations, designed to match electron beams from a high energy storage ring into and a solenoidal cooling channel. Our research focuses on discovering underlying nonlinear beam dynamics. We are using a linear transport system with a design optimized by applying a computationally efficient adjoint optimization technique developed by our group. We will explore cases of low and significant space charge with substantial angular momentum. We will concurrently be comparing simulations in WARP to beam measurements and reoptimizing the design as needed to test alternative experimental configurations. We will use an algorithm called Sparse Identification of Nonlinear Dynamical systems (SINDy) to learn the governing nonlinear beam dynamics. SINDy has not previously been applied to beam physics. We believe the SINDy methodology promises to simplify the optimization of accelerator design and commissioning, particularly where space charge is important. At NAPAC'22, as an example, we used SINDy to identify the underlying differential equations governing beam moment evolution. We compared discovered differential equations to theoretical predictions, results from WARP, and prior work using ML. Finally, we propose extending our methodology to the broader community's virtual and real experiments.

Acknowledgments:

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WG4: Beam-Driven Acceleration / **44**

Large Energy Depletion of a Beam Driver in a Plasma-Wakefield Accelerator

Author: Felipe Peña[1]

Co-authors: Carl A. Lindstrøm ; Judita Beinortaite ; Jonas Björklund Svensson ; Lewis Boulton ; Severin Diederichs [2]; J. M. Garland ; Pau González Caminal ; Gregor Loisch ; Sarah Schröder ; Maxence Thévenet [3]; Stephan Wesch ; Jonathan Wood ; Jens Osterhoff [3]; Richard D'Arcy

[1] *DESY/UHH*

[2] *DESY / LBNL*

[3] *DESY*

Corresponding Author: felipe.pena@desy.de

Beam-driven plasma-wakefield acceleration has the potential to reduce the size and construction cost of large-scale accelerator facilities, by providing accelerating fields orders of magnitude greater than that of conventional accelerating structures. To keep the running costs affordable, high energy-transfer efficiency from the wall-plug to the accelerated bunch has to be demonstrated. For this, drive bunches must be efficiently produced, strong decelerating fields must be sustained for the drive bunches until their energy is depleted, and the resulting accelerating fields must be strongly beam loaded by the trailing bunches. Here we address the second of these points, showing measurements performed at FLASHForward using a 500 MeV drive bunch where approximately half of its total energy is deposited into a 20 cm long plasma. This level of energy-transfer efficiency demonstrates that plasma accelerators hold the potential to become competitive with conventional accelerators. An experimental outlook of how to achieve this goal will conclude the talk.

Acknowledgments:

Plenary / 45

Snowmass Process Advanced Accelerator Concepts (AF6) Perspective

Authors: Cameron Geddes[1]; Pietro Musumeci[None]; Mark Hogan[2]; Assmann Ralph[3]

[1] *Lawrence Berkeley National Laboratory*

[2] *SLAC National Accelerator Laboratory*

[3] *DESY*

Corresponding Author: cgrgeddes@lbl.gov

Snowmass Accelerator Frontier topical group \# 6, Advanced Accelerator Concepts (https://doi.org/10.48550/arXiv.2208.13279), covered new R\&D concepts for particle acceleration, generation, and focusing at ultra high acceleration gradients (GeV/m and beyond). Leveraging these to efficiently harness the interaction of charged particles with extremely high electromagnetic fields at very high frequencies has the potential to enable future e+e- and $\gamma - \gamma$ colliders to and beyond 15 TeV energies. In addition to proven high gradient and ultra-bright beam generation, these systems have the potential to increase luminosity per unit beam power via short beams, for practical energy recovery to extend the reach of high energy physics, and for fast cooling. They hence have potential to reduce the dimensions, CO_2 footprint, and costs of future colliders, with added potential to reduce power consumption. Techniques range from laser and beam driven plasma and advanced structure accelerators to advanced phase space manipulations and generation of beams with extreme parameters. The last decade has seen tremendous progress including the demonstration of multi-GeV acceleration in a single stage, positron acceleration, efficient loading of the structure, the first staging of plasma accelerators, demonstration of beam shaping to improve efficiency in plasmas and structures, high gradient structures and greatly improved beam quality which recently culminated in the spectacular first demonstrations of laser-driven and beam-driven plasma based FELs. At the same time, solutions for potential collider issues have been identified. Conceptual parameter sets for colliders have been developed for e+e- and $\gamma\gamma$ colliders at a range of energies, which present potentially competitive options with prospects for future cost reduction. In addition to a strengthened ongoing R&D program, continuing to advance collider concepts in interaction with the collider and high energy physics communities, starting with an integrated set of parameters, is important as is development of technologies through nearer-term applications.

Acknowledgments:

We gratefully acknowledge the input of all of the members of the Accelerator Frontier 6 group of Snowmass, and of colleagues in other Accelerator, Energy, Community and other Frontiers, which went into this report. The report in particular draws on the many white papers submitted, as well as presentations at the Summer Study and preceding meetings, and we appreciate their authors. This work was supported by the Director, Office of Science, Office of High Energy Physics, of the U.S. Department of Energy under Contracts including No. DE-AC02-05CH11231 and DE-AC02-76SF00515, and by the National Science Foundation. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

Poster Session and Reception - Board: F72 / **46**

Distributed Coupling Linac for Efficient Acceleration of High Charge Bunches

Authors: Mohamed Othman[1]; Ankur Dhar[2]

Co-authors: Mei Bai [2]; Zenghai Li [2]; Emilio Nanni [2]; Sami Tantawi [2]; Glen White [3]

[1] *SLAC NATIONAL ACCELERATOR LABORATORY*

[2] *SLAC National Accelerator Lab*

[3] *Stanford Linear Accelerator Center*

Corresponding Author: mothman@slac.stanford.edu

Future colliders, such as the Electron Ion Collider (EIC) will require injector linacs to accelerate large electron bunches over a wide range of energies. Current designs are typically based around long travelling wave structures, where power is coupled on axis between cavities. We propose the use of a 1 m distributed coupling design as an efficient means of achieving high gradient acceleration. Distributed coupling allows power to be fed into each cavity directly via a waveguide manifold, avoiding on-axis coupling. A distributed coupling structure at S-band was designed to optimize for shunt impedance and large aperture size. This design provides greater efficiency, thereby lowering the number of klystrons required to power the full linac, as compared to known parameters and specifications of the travelling wave design planned for EIC. In addition, particle tracking analysis shows that this linac maintains lower emittance as bunch charge increases to 14 nC and wakefields become more prevalent. We present the design of this distributed coupling structure, as well as preliminary data from cold tests on the structure's real world performance.

Acknowledgments:

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WGs 7+8 Joint Session / 47

ELECTRON CYCLOTRON RESONANCE ACCELERATOR eCRA

Authors: Jay Hirshfield[1]; Xiangyun Chang[2]; Yong Jiang[2]; Mikhail Fedurin[3]; Mark Palmer[3]; Warren stern[3]

[1] *Particle Accelerator Research Foundation and Omega-R&D, Inc.*

[2] *Particle Accelerator Research Foundation and Omega-P R&D, Inc.*

[3] *Brookhaven National Laboratory*

Corresponding Author: jay.hirshfield@yale.edu

Solutions of the single-particle equations of motion for electrons in the fields of an idealized TE111 microwave cavity in an external magnetic field near cyclotron resonance show acceleration rates that substantially exceed the limits for the CARA interaction. We have dubbed this new accelerator "eCRA." Here, results are presented for realistic TE111 eCRA cavity geometry and finite space-charge beams that confirm the idealized solutions. The new features include cavity openings for RF inputs, beam injection, and pumping; RF input couplings that maximize efficiency; a thin window for exit of the accelerated beam; realistic magnetic field profiles; finite diameter multi-Ampere beams; and transient beam dynamics to model pulsed operation. One simulated eCRA example is for a copper cavity with Q0 of about 19,000, and a filling time of 85 ns due to strong external coupling. With RF input power at each of the two ports of 12.5 MW, an 8.0-A, 100 keV beam was shown to be accelerated to 2.2 MeV, giving a pulsed beam power of 17.6 MW and efficiency of 67%. Many applications are recognized for MW-class eCRA beams with energies in the range 1-10 MeV. Our first proof-of-principle demonstration of eCRA is to produce beams to generate intense X-ray fluxes to enable the replacement of radioactive sources now widely used for sterilization of medical supplies and foodstuffs. This demonstration will be based on use of available S-band components, although the optimal operating frequency for eCRA could be about 1000 MHz. In any case, the possibility of MW-level average power eCRA beams—even with predicted efficiencies >80%–will depend upon the availability of the required RF sources to drive eCRA. One candidate for this role is the 20-MW peak power two-stage multi-beam 1000 MHz klystron reported elsewhere in this Workshop.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / 48

Plasmonic Wakes in a Semi-conductor

Authors: Tom Katsouleas[1]; Aakash Sahai[2]; Maxime Pindrys[3]

[1] *U of Ct*

[2] *U of CO Denver*

[3] *U of CT*

Corresponding Author: thomas.katsouleas@uconn.edu

The possibility of exciting wakefields in a semi-conducting structure is discussed. The fundamental limitation of short mean free paths of electrons in the semi-conductor can be overcome above a threshold beam or laser driver intensity when the electrons are driven to sufficient velocities that their Coulomb collision cross-section drops precipitously. The wakes differ from those in either a plasma, non-conducting dielectric or metallic structure. The nature of those differences and their potential advantages for plasmonic wakes as novel particle accelerator structures are described.

Acknowledgments:

Poster Session and Reception - Board: P60 / **49**

Simultaneous Laser Temporal Shaping and Nonlinear Conversion for Driving Electron Photoinjectors

Authors: Randy Lemons[1]; Jack Hirschman[1]; Nicole Neveu[1]; Joseph Duris[1]; Agostino Marinelli[1]; Charles Durfee[2]; Sergio Carbajo[3]

[1] *SLAC National Accelerator Laboratory, Stanford University, 2575 Sand Hill Rd, Menlo Park, CA 94025, USA*

[2] *Department of Physics, Colorado School of Mines, 1500 Illinois St, Golden, CO 80401, USA*

[3] *Department of Electrical and Computer Engineering & Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA*

Corresponding Author: rlemons@slac.stanford.edu

The optimal performance of XFEL photoinjectors requires laser pulses, typically in the ultraviolet (UV), with non-Gaussian temporal intensity profiles and durations on the order of 10s of ps at photon energies higher than common ultrafast laser systems[1]. Achieving temporal shaping at these durations is non-trivial due to the limited spectral content for transform-limited (TL) pulses and a lack of devices to directly modify the temporal amplitude. Additionally, the necessity for pulses at UV energies can introduce intensity profile distortions during nonlinear conversion.
We present a novel framework to simultaneously generate laser pulses with tunable temporal intensity profiles simultaneously with nonlinear conversion for driving electron photoinjectors used for XFELs, ultrafast electron diffraction, and plasma wakefield acceleration (PWA) applications. Our method consists of a non-colinear sum frequency generation (SFG) scheme where the driving pulses are chirped with equal and opposite amounts of spectral phase that together generate a pulse having a duration and temporal profile roughly equivalent to the combination of the inputs[2]. This method imposes phase shaping on broadband pulses, bypassing TL picosecond pulse spectral bandwidth limitations, to produce intrinsically narrowband pulses with flat spectral phase providing resistance to temporal intensity profile distortion during propagation and nonlinear conversion. We also report an experimental implementation of 26 ps flat-top pulses in the UV from a 1024 nm, 1 MHz, 40 uJ driving laser designed for MHz-rate next-generation XFELs. We demonstrate upwards of 40% conversion efficiency during the nonlinear shaping stage from 1024 nm to 512 nm and 20% to the UV at repition-rates greater than 250 kHz. Lastly, we provide a simulation and possible experimental design of a nonlinear conversion chain to produce triangle-like UV pulses with sharp rise time and subsequent linear ramp towards driving few nanocoulomb electron bunches useful for PWA[3].
[1] Musumeci, Pietro et al. (2008). Physical Review Letters, 100(24), 244801. [2] Lemons, Randy et al. (2022). Physical Review Accelerators and Beams, 25(1), 013401. [3] Hu, Tianzhe et al. (2022). Proceedings NAPAC'22

Acknowledgments:

Poster Session and Reception - Board: P46 / **50**

X-ray source development for high energy density science via self-modulated laser wakefield acceleration

Author: Mitchell Sinclair[None]

Co-authors: Kyle Miller [1]; Isabella Pagano [2]; Adeola Aghedo ; Charlie Arrowsmith ; Nuno Lemos ; Jessica Shaw [3]; Félicie Albert ; Chan Joshi

[1] *University of Rochester Laboratory for Laser Energetics*

[2] *UT Austin*

[3] *University of Rochester, Laboratory of Laser Energetics*

Corresponding Author: mdsinclair@g.ucla.edu

We are demonstrating an X-ray source driven by a self-modulated laser wakefield accelerator (SM-LWFA) platform to generate bright, (10^10 photon/keV/sr), high energy (10 keV - 1 MeV) X-rays for use in high energy density science (HEDS) experiments. Over the years, this X-ray platform has been developed on Titan, Omega EP, and ARC lasers. An intense picosecond laser pulse propagates into a gas jet where it can excite both a multiple plasma periods plasma wave by the transverse self-modulation instability and produces a partially evacuated channel via relativistic self-focusing. We have shown that this regime can produce an extremely high charge (10s - 100s nC) relativistic electron beam via both the longitudinal electric field of the wake and the tightly focused laser pulse as well as the transverse electric field of the laser by the direct laser acceleration mechanism. We are now exploring if either the maximum electron energy or the peak electron current can be increased by employing plasma down/up ramps. We have used these high charge and energy electron beams to generate betatron-, inverse Compton scattering-, and bremsstrahlung radiation with photon energies up to several hundred keV range. Current work aims to improve the X-ray fluence particularly in the MeV energy range and use this platform for radiography of passive and active (HED) targets.

Acknowledgments:

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Poster Session and Reception - Board: P21 / **51**

A scheme for generation and measurement of spin polarized GeV electrons from a PWFA

Authors: Nainoa Nambu[1]; Zan Nie[1]; Fei Li[1]; Felipe Morales[2]; Serguei Patchkovskii[2]; Olga Smirnova[2]; Weiming An[3]; Chaojie Zhang[1]; Yipeng Wu[1]; Daniel Matteo[1]; Kenneth Marsh[1]; Frank Tsung[1]; Warren Mori[1]; Chandrashekhar J. Joshi[4]

[1] *UCLA*

[2] *Max Born Institute*

[3] *Beijing Normal University*

[4] *University of California Los Angeles*

Corresponding Author: nnambu@g.ucla.edu

The generation and acceleration of an electron beam with a high degree of spin polarization is desirable for future plasma-based high-energy colliders. Our recent theoretical and simulations work [1,2] has shown that spin polarized electrons can be produced from photoionization of 4f14 electrons of Yb III ions by a circularly polarized laser, and then accelerated to multi-GeV energies while maintaining their spin polarization in a beam-driven plasma wakefield accelerator (PWFA). An experimental realization of this scheme would require a method of measuring the spin polarization of the accelerated electrons. In our proposed scheme, Møller scattering polarimetry is used to measure the spin polarization of the beam, which involves scattering the beam off of a magnetized target and observing the yield of scattered electrons at specific angles. Measuring the spin polarization of a beam produced from a PWFA presents additional challenges due to the unpolarised drive beam that typically contains nC of charge and a lack of stability from shot to shot. Our spectrometer design addresses these challenges and provides a scheme for both producing and detecting high-energy spin polarized electrons accelerated in a beam-driven plasma-based accelerator.

References:
[1] Z. Nie, et. al., Phys. Rev. Lett. 126, 054801 (2021).
[2] Z. Nie, et. al., arXiv:2206.09017.

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WG4: Beam-Driven Acceleration / 52

Emittance preservation in a single PWFA-LC stage using adiabatic plasma density ramp matching sections in the presence of ion motion

Authors: Yujian Zhao[None]; Fei Li[1]; Lance Hildebrand[1]; Weiming An[2]; Xinlu Xu[None]; Chandrashekhar J. Joshi[3]; Warren Mori[3]

[1] *UCLA*

[2] *Beijing Normal University*

[3] *University of California Los Angeles*

Corresponding Author: zhaoyujian@ucla.edu

Plasma based acceleration (PBA) is being considered as a building block for a future linear collider (LC). In PBA a short pulse laser or particle beam creates a wakefield and a witness particle beam is accelerated in the wakefield. As the witness beam is accelerated its energy spread must be small and its emittance must be preserved. In some designs the witness beam parameters required by a linear collider are expected to trigger background ion motion which can lead to nonlinear focusing forces which vary along the witness beam. This can lead to emittance growth of the witness beam. To mitigate this, we propose to use an adiabatic plasma density ramp as a matching section. We match the witness beam to the low density plasma entrance, where the beam initially has a large matched spot size so the ion motion effects are relatively small. As the beam propagates in the plasma upramp (downramp), it is adiabatically focused (defocused) and its distribution evolves slowly towards an equilibrium distribution including the effects of the adiabatically changing ion motion. We present simulation results using QPAD which is a quasi-3D quasi-static PIC code based on the workflow of QuickPIC. Simulation results show that this method can reduce the projected emittance growth of a 25GeV, 0.1um emittance witness beam to only ~3% within a single stage, which includes adiabatic matching sections at both the entrance and exit. The trade-off among the length of the plasma density ramp, the adiabaticity of the plasma density ramp, and the plasma density at the entrance is also discussed. This is an important issue for later accelerating stages when the witness beam has an even higher energy.

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NSF 2108970

WG7: Radiation Generation and Advanced Concepts / 53

Status report on nonlinear Compton scattering study

Authors: Yusuke Sakai[1]; Atsushi Fukasawa[2]; Oliver Williams[2]; Karl Kusche[3]; Marcus Babzien[3]; Mikhail Fedurin[4]; Mikhail Polyanskiy[3]; Mark Palmer[4]; Igor Pogorelsky[3]; James Rosenzweig[None]

[1] *University of California Los Angeles*

[2] *UCLA*

[3] *BNL*

[4] *Brookhaven National Laboratory*

Corresponding Author: yusuke@physics.ucla.edu

Recent progress of fundamental study on nonlinear inverse Compton scattering (ICS) will be reported. Experiment has been performed in Brookhaven National Laboratory Accelerator Test Facility. Counter collision of TW CO2 laser and 60-70 MeV electron beam having 300 pC of charge per pulse induce clear structure of nonlinear electrodynamics in X-ray radiation characteristics. In addition, utilization of the near infrared YAG laser expands the study on bi-harmonic Compton interaction or general applications in medicine and material research at hard X-ray energy of 87.5 keV in single shot basis.

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Plenary / **54**

First SASE and Seeded FEL Lasing based on a beam driven wakefield accelerator

Author: Angelo Biagioni[1]

Co-authors: Maria Pia anania [2]; Marco Bellaveglia [2]; Enrica Chiadroni [3]; Alessandro Cianchi [4]; gemma costa [2]; Lucio Crincoli [2]; Martina Delgiorno [2]; Mario Galletti [5]; Luca Giannessi [2]; gribono anna [2]; lollo valerio [2]; mostacci andrea [2]; donato Pellegrini [2]; Giampiero Di Pirro [2]; Riccardo Pompili [2]; stefano romeo [2]; vladimir Shpakov [2]; cristina vaccarezza [2]; fabio villa [2]; zigler Arie [6]; Massimo Ferrario [2]

[1] *INFN*

[2] *infn*

[3] *Sapienza University of Rome*

[4] *Tor Vergat University of Rome*

[5] *Tor vergata University*

[6] *3Hebrew University of Jerusalem*

Corresponding Author: angelo.biagioni@lnf.infn.it

The breakthrough provided by plasma-based accelerators enabled unprecedented accelerating fields by boosting electron beams to GeV energies within few cm. This enables the realization of table-top accelerators able to drive a Free-Electron Laser (FEL), a formidable tool to investigate matter at subatomic level by generating X-UV coherent light pulses with fs and sub-fs durations.
So far, short wavelength FELs had to rely on the use of conventional large-size radio-frequency (RF) accelerators due to the limited accelerating fields provided by such a technology. Here we report the experimental evidence of a FEL driven by a compact plasma-based accelerator. The accelerated beams are characterized in the six-dimensional phase-space and have a quality comparable with state-of-the-art accelerators. This allowed the observation of amplified SASE radiation in the infrared range with typical pulse energy exponential growth, reaching tens of nJ over six consecutive undulators.
On the basis of these first amplification results starting from spontaneous emission (SASE), we upgraded the setup by seeding the amplifier with an external laser. Compared to SASE, the seeded FEL pulses are characterized by a higher pulse energy, two orders of magnitude larger (up to about 1 uJ) and an enhanced reproducibility (up to about 90%) resulting in a higher shot-to-shot stability.

Acknowledgments:

WGs 1+2 Joint Session / 55

Magnetohydrodynamic Modeling of Plasma Channels for Acceleration and Beam Transport

Authors: Nathan Cook[1]; Abdourahmane Diaw[2]; Stephen Coleman[1]; Jonathan Edelen[1]; Edward Hansen[3]; Petros Tzeferacos[3]

[1] *RadiaSoft LLC*

[2] *Oak Ridge National Laboratory*

[3] *University of Rochester*

Corresponding Author: nathan.m.cook@gmail.com

Structured plasmas present myriad opportunities for acceleration and control of electron and positron beams for advanced concepts accelerators. Modeling these systems is challenging, owing to the orders of magnitude disparities in the spatiotemporal scale lengths between beam or laser and background plasma evolution. We discuss the application of the FLASH code, a publicly available MHD software, to model capillary discharges for use as laser plasma acceleration stages and as active plasma lenses. We discuss system sensitivities to the use of varying initial conidtions, boundary conditions, and transport models. We also consider system scalings for different inputs, including the use of a laser heater. Lastly, we discuss the application of FLASH for modeling a different class of plasma channels known as hydrodynamic optical-field ionized plasmas, which show promise for future meter-scale plasma accelerator sources.

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WG5: Beam Sources, Monitoring, and Control / 56

Online Correction Of Laser Focal Position Via Deployable Machine Learning Models

Authors: Nathan Cook[1]; Joshua Einstein-Curtis[1]; Stephen Coleman[1]; Jeroen van Tilborg[2]; Samuel Barber[2]; Curtis Berger[2]; Jonathan Edelen[1]

[1] *RadiaSoft LLC*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: nathan.m.cook@gmail.com

Ultrafast lasers play an increasingly critical role in the generation, manipulation, and acceleration of electron beams. Laser plasma accelerators enable order of magnitude improvements in accelerating gradient and promise compact tunable GeV electron beam sources, while novel photocathode systems permit fundamental advances in electron beam manipulation for accelerator and radiation applications. Advances in fast feedback systems are required to stabilize laser performance at kHz repetition rate operation against environmental fluctuations. A field programmable gate array (FPGA) based digital control system, coupled with responsive optics, can provide rapid and precise stabilization of ultrafast lasers. Here we report on an effort to develop, test, and deploy these systems across a range of beamlines operating at >1 Hz repetition rate, including 1 kHz systems. Our initial efforts demonstrate the calibration of a fast, non-destructive focal position diagnostic in concert with a deployable correction scheme. The resulting prototype shows diagnostic responsiveness into the 100s of Hz.

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WG8: Advanced Laser and Beam Technology and Facilities / 57

Environmental Impact of Future Colliders

Author: Spencer Gessner[1]

[1] *SLAC*

Corresponding Author: sgess@slac.stanford.edu

We present the results of the Snowmass Implementation Task Force (ITF) analysis of future collider concepts. We consider both the environmental cost of construction (CO2 footprint per meter of tunnel) and the carbon footprint associated with collider power consumption. We discuss strategies to mitigate the power consumption of future high-energy colliders, such as energy recovery, and we discuss the benefits of specific advanced accelerator technologies for reducing power consumption.

Acknowledgments:

WG4: Beam-Driven Acceleration / 58

Focusing of a Long Relativistic Proton Bunch in Underdense Plasma

Authors: Livio Verra[1]; Patric Muggli[2]

Co-authors: Michele Bergamaschi [2]; Edda Gschwendtner [1]; Tatiana Nechaeva [2]; Jan Pucek [2]; Lucas Ranc [2]; Giovanni Zevi Della Porta [2]

[1] *CERN*

[2] *Max-Planck Institute for Physics*

Corresponding Author: livio.verra@cern.ch

In this contribution we show, with experimental and numerical simulation results, that a long, relativistic proton bunch can be focused to an equilibrium transverse size, when traveling in underdense plasma.
In the presence of the space-charge field of the bunch, the plasma electrons move towards the axis of propagation of the beam, generating a focusing force for the protons.
We observe that the transverse size of the bunch, measured downstream of the plasma exit, decreases when increasing the plasma electrons density, until it reaches a saturation value.
Moreover, the transverse size does not oscillate along the bunch, further suggesting that no transverse oscillation of the plasma electrons nor of the protons occurs, and that the plasma does not sustain wakefields.
When the plasma electron density becomes comparable to the peak density of the bunch, the effect of the self-modulation instability becomes observable on the proton bunch charge distribution.
This indicates the transition to collective motion of the plasma electrons and to the presence of wakefields, that can be used for high-gradient particle acceleration, as in the AWAKE experiment at CERN.

Acknowledgments:

Poster Session and Reception - Board: F78 / **59**

Self-Modulation Instability of a Wide and Long Relativistic Proton Bunch in Plasma

Author: Livio Verra[1]

Co-authors: Samuel Wyler [2]; Michele Bergamaschi [3]; Tatiana Nechaeva [3]; Jan Pucek [3]; Lucas Ranc [3]; Giovanni Zevi Della Porta [3]; Edda Gschwendtner [1]; Patric Muggli [3]

[1] *CERN*

[2] *EPFL*

[3] *Max-Planck Institute for Physics*

Corresponding Author: livio.verra@cern.ch

When a long relativistic charged particle bunch travels in plasma, it undergoes the self-modulation instability. The bunch is converted into a train of microbunches that can resonantly drive large amplitude wakefields.
The Advanced WAKefield Experiment (AWAKE) at CERN has proven that the instability can be seeded using a relativistic ionization front copropagating within the proton bunch or using a preceding electron bunch, and that electrons can be injected and accelerated in the plasma wakefields driven by the self-modulated proton bunch.
We present experimental results showing that, when increasing the transverse size of the long proton bunch propagating in a 10-m-long plasma (plasma electron density $n_{pe} = 10^{14}\ \mathrm{cm}^{-3}$) without seed wakefields, the microbunch train is visible only in the tail of the bunch.
This can be explained considering that the growth rate of the instability becomes smaller when decreasing the charge density of the bunch.
However, when seeding the instability with the relativistic ionization front, microbunches develop and seeded self-modulation occurs even at plasma electron densities on the order of $10^{12}\ \mathrm{cm}^{-3}$.
Preliminary results and implications of these effects for the design of a proton-driven plasma wakefield accelerator (AWAKE Run 2) will be discussed.

Acknowledgments:

WG5: Beam Sources, Monitoring, and Control / **60**

Low-emittance high-energy muon source based on plasma wakefield acceleration

Author: Vladimir Shiltsev[1]

[1] *Fermilab*

Corresponding Author: vladimir.shiltsev@gmail.com

Plasma wakefield acceleration (PWA) channels are characterized by very high accelerating gradients and very strong focusing fields. We propose to employ these properties for effective production of low emittance high energy muon beams, consider muon beam dynamics in the PWFA cell and analyze various options and potential of the PWA-based muon sources.

Acknowledgments:

Poster Session and Reception - Board: F87 / **61**

Towards a Pre-Pulse Cleaning Method In Ultrafast, High Peak Power Fiber Laser Systems

Authors: David Feng[1]; Leily Kiani[1]; Michael Messerly[1]

[1] *Lawrence Livermore National Laboratory*

Corresponding Author: feng7@llnl.gov

The application of ultrafast, high-peak power lasers for laser-driven plasma acceleration (LPA) can lead to more compact accelerators reaching sufficiently high-acceleration gradients and high particle beam energies. However, such accelerators often require tremendous electrical resources and modern commercial lasers often operate on wall-plug efficiencies less-than-30%. Coherently combined short-pulse fiber lasers offer competitive energies and repetition rates for LPA while operating on efficiencies above 30% [1], but there are challenges with the fiber-array approach, including the possible reduction of contrast due to pre-pulses. Our current work focuses on investigating approaches to eliminate pre-pulse during the amplification stage. We primarily look towards a nonlinear approach by propagating the pulses through a multicore fiber, which induces both strong reshaping of the pulse by selective coupling to adjacent cores, potentially leading to shortening and contrast improvement, as well as spectral broadening by high nonlinearity, which can be used to further compress the pulse and enhance peak-to-pedestal ratio [2]. We are currently building a custom source to test the concept and modeling the spatiotemporal dynamics of femtosecond pulses through the multicore fiber. Furthermore, we are also constructing a low-cost measurement device to measure the overall dispersion of the system after pre-pulse cleaning.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

[1] J. W. Dawson et al., "High average power lasers for future particle accelerators," AIP Conf. Proc., vol. 1507, no. 1, pp. 147–153, Dec. 2012, doi: 10.1063/1.4773687.
[2] A. V. Andrianov, N. A. Kalinin, M. Y. Koptev, O. N. Egorova, A. V. Kim, and A. G. Litvak, "High-energy femtosecond pulse shaping, compression, and contrast enhancement using multicore fiber," Opt. Lett., vol. 44, no. 2, pp. 303–306, Jan. 2019, doi: 10.1364/OL.44.000303.

Acknowledgments:

Lawrence Berkeley National Laboratory, University of Michigan, Contract DE-AC52-07NA27344

Poster Session and Reception - Board: P22 / **62**

Simulation Results of a Clamped Multicell Dielectric Disk Accelerating Structure

Author: Sarah Weatherly[1]

[1] *Illinois Institute of Technology, Argonne National Laboratory*

Corresponding Author: sweatherly@hawk.iit.edu

A method of decreasing the required footprint of linear electron accelerators and to improve their energy efficiency is utilizing short RF pulses (~9 ns) with Dielectric Disk Accelerators (DDA). A DDA is an accelerating structure that utilizes dielectric disks in its design to improve the shunt impedance. Two DDA structures have been designed and tested at the Argonne Wakefield Accelerator. A single cell clamped DDA structure recently achieved an accelerating gradient of 102 MV/m. A multicell clamped DDA structure has been designed and is currently being fabricated. Simulation results for this new structure show a 108 MV/m accelerating gradient with 400 MW of input power with a high shunt impedance and group velocity. Engineering designs have been improved from the single cell structure to ensure consistent clamping over the entire structure.

Acknowledgments:

Funding support provided by the U.S. Department of Energy (DOE) under Small Business Innovation Research Contract No. DE-SC0019864 and the U.S. DOE Office of Science under Contract No. DE-AC02-06CH11357.

WG3: Laser and High-Gradient Structure-Based Acceleration / 63

Simulation Results of a Clamped Multicell Dielectric Disk Accelerating Structure

Author: Sarah Weatherly[1]

[1] *Illinois Institute of Technology, Argonne National Laboratory*

Corresponding Author: sweatherly@hawk.iit.edu

A method of decreasing the required footprint of linear electron accelerators and to improve their energy efficiency is utilizing short RF pulses (~9 ns) with Dielectric Disk Accelerators (DDA). A DDA is an accelerating structure that utilizes dielectric disks in its design to improve the shunt impedance. Two DDA structures have been designed and tested at the Argonne Wakefield Accelerator. A single cell clamped DDA structure recently achieved an accelerating gradient of 102 MV/m. A multicell clamped DDA structure has been designed and is currently being fabricated. Simulation results for this new structure show a 108 MV/m accelerating gradient with 400 MW of input power with a high shunt impedance and group velocity. Engineering designs have been improved from the single cell structure to ensure consistent clamping over the entire structure.

Acknowledgments:

Funding support from the U.S. Department of Energy (DOE) under Small Business Innovation Research Contract No. DE-SC0019864 and the U.S. DOE Office of Science under Contract No. DE-AC02-06CH11357.

WG8: Advanced Laser and Beam Technology and Facilities / 64

Raman-based wavelength conversion for seeding and optical pumping of CO2 laser amplifiers

Authors: William Li[1]; Rotem Kupfer[2]; Furong Wang[1]; James Wishart[1]; Marcus Babzien[3]; Mikhail Polyanskiy[3]; Igor Pogorelsky[3]; Triveni Rao[1]; Luca Cultrera[1]; Navid Vafaei-Najafabadi[4]; Mark Palmer[1]

[1] *Brookhaven National Laboratory*

[2] *Lawrence Livermore National Laboratory*

[3] *BNL*

[4] *Stony Brook University*

Corresponding Author: wli4@bnl.gov

The long wavelength of long-wave infrared (LWIR) lasers suit them to applications relying on ponderomotive interactions, such as laser wakefield acceleration and high harmonic generation. The workhorse source of such wavelengths is the CO2 amplifier, providing the ability to reach TW peak powers and sub-ps pulse lengths. Two pathways to improve the performance of these amplifiers are to increase the energy by increasing the energy of the seed and to increase the repetition rate by optically pumping the gas instead of pumping with an electrical discharge. The wavelengths required,

9.2 um for the seed and 4.3 um for the pump, are outside the range of conventional millijoule-class, nanosecond laser sources, and must be obtained through nonlinear wavelength conversion processes. One such process is known as stimulated Raman scattering (SRS), where photons are inelastically scattered by a coherent excited state of a material. In principle, ionic liquids (ILs), artificial salts that are liquid at room temperature, are an excellent choice of material for SRS, as the vibrational modes and optical properties can be tailored with the choice of ions. Relatively efficient difference frequency conversion from visible/near-infrared to the seed and pump wavelengths can be achieved with Raman shifts of 1087 cm-1 and 2200 cm-1 respectively. We find that calcite crystals offer high efficiency conversion corresponding to the first Raman shift, from 800 nm Ti:Sa to 876 nm, and an ionic liquid, 1-ethyl-3-methylimidazolium dicyanamide (EMIM-DCA), provides the second, from 532 nm Nd:YAG to 603 nm. As a proof of principle, we measure a conversion efficiency in EMIM-DCA three times higher than that of water. Future work will consist of measuring conversion efficiencies in a variety of other ILs. Beyond upgrading the CO2 amplifiers, Raman shifting in ILs provide a pathway for efficient, simple, alignment-tolerant high-energy wavelength conversion.

Acknowledgments:

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WGs 4+5 Joint Session / 65

A scheme for generation and measurement of spin polarized GeV electrons from a PWFA

Authors: Nainoa Nambu[1]; Zan Nie[1]; Fei Li[1]; Felipe Morales[2]; Serguei Patchkovskii[2]; Olga Smirnova[2]; Weiming An[3]; Chaojie Zhang[1]; Yipeng Wu[1]; Daniel Matteo[1]; Kenneth Marsh[1]; Frank Tsung[1]; Warren Mori[1]; Chandrashekhar J. Joshi[4]

[1] *UCLA*

[2] *Max Born Institute*

[3] *Beijing Normal University*

[4] *University of California Los Angeles*

Corresponding Author: nnambu@g.ucla.edu

The generation and acceleration of an electron beam with a high degree of spin polarization is desirable for future plasma-based high-energy colliders. Our recent theoretical and simulations work [1,2] has shown that spin polarized electrons can be produced from photoionization of 4f14 electrons of Yb III ions by a circularly polarized laser, and then accelerated to multi-GeV energies while maintaining their spin polarization in a beam-driven plasma wakefield accelerator (PWFA). An experimental realization of this scheme would require a method of measuring the spin polarization of the accelerated electrons. In our proposed scheme, Møller scattering polarimetry is used to measure the spin polarization of the beam, which involves scattering the beam off of a magnetized target and observing the yield of scattered electrons at specific angles. Measuring the spin polarization of a beam produced from a PWFA presents additional challenges due to the unpolarised drive beam that typically contains nC of charge and a lack of stability from shot to shot. Our spectrometer design addresses these challenges and provides a scheme for both producing and detecting high-energy spin polarized electrons accelerated in a beam-driven plasma-based accelerator.

References:
[1] Z. Nie, et. al., Phys. Rev. Lett. 126, 054801 (2021).
[2] Z. Nie, et. al., arXiv:2206.09017.

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2108970, the Office of Naval Research (ONR) Multidisciplinary University Research Initiative (MURI) (4-442521-JC-22891) and National Natural Science Foundation of China, Grant No. 12075030.

WG7: Radiation Generation and Advanced Concepts / 66

Seeded FEL lasing of the COXINEL beamline driven by the HZDR plasma accelerator

Author: Arie Irman[1]

Co-authors: Alexander Debus [1]; Alexandre Loulergue [2]; Amin Ghaith [1]; Anthony Berlioux [2]; Bruno Leluan [2]; Carlos De Oliveira [2]; Cedric Thaury [3]; Charles Kitegi [2]; Christian Herbeaux [2]; Christoph Eisenmann [1]; Damien Pereira [2]; Driss Oumbarek-Espinos [2]; Eleonore Roussel [4]; Fabien Briquez [2]; Fabrice Marteau [2]; Francois Bouvet [2]; Frederic Blance [2]; Jean-Paul Ricaud [2]; Jean-Pierre Duval [2]; Jose Veteran [2]; Julien Gautier [3]; Jurjen Couperus Cabadag [1]; Keihan Tavakoli [2]; Klaus Steiniger [1]; Manh Huy N Guyen [2]; Marc Vandenberghe [2]; Marie Labat [2]; Marie-Emmanuelle Couprie [2]; Mathieu Valleau [2]; Maxwell LaBerge [5]; Michael Kuntzsch [1]; Mourad Sebdaoui [2]; Moussa El Ajjouri [2]; Nicolas Hubert [2]; Olena Kononenko [3]; Pascal Rousseau [3]; Patrick Rommeluere [2]; Patrick Ufer [1]; Philippe Berteaud [2]; Rene Gebhardt [1]; Richard Pausch [1]; Sebastien Corde [3]; Simon Grams [1]; Stefan Bock [1]; Stephane Le [2]; Susanne Schobel [1]; Thomas Puschel [1]; Ulrich Schramm [1]; Uwe Helbig [1]; Victor Malka [3]; Yannick Dietrich [2]; Yen-Yu Chang [1]

[1] *Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*

[2] *Synchrotron SOLEIL, L'Orme des Merisiers, 91191 Gif-sur-Yvette, France*

[3] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[4] *Univ. Lille, CNRS, UMR 8523{PhLAM{Physique des Lasers Atomes et Molecules, F{59000 Lille, France*

[5] *The University of Texas at Austin, Austin, TX 78712-1081, USA*

Corresponding Author: a.irman@hzdr.de

Laser Plasma Accelerators (LPAs), harnessing gigavolt-per-centimeter accelerating fields, can generate high peak current, low emittance and GeV class electron beams paving the way for the realization of future compact free-electron lasers (FELs). Here, we report on the commissioning of the COXINEL beamline driven by the HZDR plasma accelerator and experimental demonstration of FEL lasing at 270 nm in a seeded configuration[1]. Control over the radiation wavelength is achieved with an improved bandwidth stability. Furthermore, the appearance of interference fringes, resulting from the interaction between the phase-locked emitted radiation and the seed, confirms longitudinal coherence, representing a key feature of such a seeded FEL. These results are cross-checked with simulations, ELEGANT for beam optics and GENESIS for FEL radiation. We anticipate a navigable pathway toward smaller-scale free-electron lasers at extreme ultra-violet wavelengths.

[1] M. Labat, J.P. Couperus Cabadağ, A. Ghaith, A. Irman, "Seeded free-electron laser drive by a compact laser plasma accelerator" accepted Nature Photonics (2022)

Acknowledgments:

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Five, PI: V. Malka and Grant Agreement No. 715807, project M-PAC, PI: S. Corde). The laser-electron acceleration project at HZDR is fully supported by the Helmholtz association under program Matter and Technology, topic Accelerator Research and Development. M.E.C., M.Labat were partially financed during the experimental run via the user access program in Laserlab Europe V (contract no. 871124). A.G. is financed by the Germany's Federal Ministry of Education and Research (BMBF) through the Verbundforschung LADIAG. E.R. is supported by the METEOR CNRS Momentum grant, the LABEX CEMPI (ANR-11-LABX-0007), the Ministry of Higher Education and Research, Hauts de France council and European Regional Development Fund (ERDF) through the Contrat de Projets Etat-Region (CPER) Photonics for Society (P4S). E.R., M.E.C., M.Labat are supported by the Agence Nationale de la Recherche

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Poster Session and Reception - Board: P49 / **67**

The Effect of Laser Focusing Geometry on the Direct Laser Acceleration of Electrons

Author: Hongmei Tang[1]

Co-authors: Paul Campbell ; Brandon Russell [1]; Yong Ma ; I-Lin Yeh ; Kavin Tangtartharakul ; Alexey Arefiev [2]; Hui Chen ; Felicie Albert ; Jessica Shaw ; Philip Nilson ; Louise Willingale

[1] *University of Michigan*

[2] *UCSD*

Corresponding Author: tanghm@umich.edu

Direct laser acceleration (DLA) is capable of generating super-ponderomotive energy electrons to hundreds of MeV, as well as secondary particles and radiation from high-intensity picosecond laser pulses interacting with underdense plasma. The dynamic and complex process of DLA is strongly dependent on a combination of plasma and laser parameters. Experiments performed on the OMEGA EP facility using apodized beams and 2D particle-in-cell simulations study the effect of laser focusing geometry on DLA. Simulations reveal the laser channel creation, channel fields evolution, as well as the laser fields' contributions to the corresponding electron dynamics. Our results show an optimal laser focusing geometry and a path towards optimizing DLA conditions.

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Poster Session and Reception - Board: F88 / **68**

EEHG seeding scheme at the Athos branch of SwissFEL

Authors: Pavle Juranic[1]; Ganter Romain[2]; Aeppli Gabriel[3]; Braun Hans-Heinrich[2]; Calvi Marco[None]; Cavalieri Adrian[None]; Dijkstal Philipp[4]; Ferrari Eugenio[4]; Hiller Nicole[2]; Huppert Martin[2]; Kittel Christoph[2]; Liang Xiaoyang[2]; Neppl Stephan[2]; Prat Eduard[2]; Reiche Sven[2]; Trisorio Alexandre[2]; Vicario Carlo[2]; Voulot Didier[2]

[1] *Paul Scherrer Institut*

[2] *PSI*

[3] *PSI, ETH-Zurich*

[4] *DESY*

Corresponding Author: pavle.juranic@psi.ch

This presentation will showcase the newest work to add to the SwissFEL light generation capabilities. Two sets of modulators within which an overlap between an optical laser and relativistic electron beam are being installed and tested to produce new soft x-ray pulse structures and seeded

beams. The results from the installation and commissioning of the first structure, put into operation in 2022, are discussed, along with the expectations for the second structure performance and expectations.

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WG1: Laser-Plasma Wakefield Acceleration / 69

Polarization and CEP Dependence of the Transverse Phase-Space in Laser-Driven Accelerators

Authors: Andreas Seidel[1]; Matt Zepf[2]; Daniel Seipt[2]

Co-authors: Bifeng Lei [2]; Carola Zepter [3]; Malte Kaluza [2]; Alexander Sävert [2]

[1] *Friedrich-Schiller-University Jena*

[2] *Helmholtz-Institute, Jena, Germany*

[3] *Friedrich-Schiller-University, Jena, Germany*

Corresponding Author: seidel.andreas@uni-jena.de

We have conducted experiments at the JeTi-200 laser facility ($\lambda_0 = 800nm$, spotsize $w_0 = 22\mu m$, pulse length $\tau = 23fs$, $a_0 = 2.4$) to investigate the contribution of laser polarization and carrier envelop phase (CEP) -fluctuations on the electron beam pointing jitter in laser wakefield accelerators(LWFAs). Furthermore, we developed a theory describing the transverse dynamics of the trapped electrons inside the resonantly oscillating wakefield bubble.
LWFAs were studied extensively and many advances were made in important beam parameters such as bunch energy, charge, and emittance. However, with the emergence of QED and beam colliding experiments requiring very precise positioning of the electron beam the beam jitter and its control become very important. Until now, electron beam jitter was generally contributed to imperfections in the plasma target reproducibility. Here we report on a polarization and CEP-dependent mechanism that is intrinsic to LWFAs. The ponderomotive force of the laser pushes electrons aside and creates the well-known bubble structure. However, with few-cycle laser pulses or self-steepened longer pulses due to etching at the front the electron density in the trailing bubble can become asymmetric. The difference in phase and group velocity of the laser leads to an oscillation of the bubble centroid which couples to the trailing electron bunch. We measured the electron beam pointing in experiments with ionization and self-injection showing an increased beam-pointing jitter in the polarization direction regardless of the injection mechanism. In 2D PIC simulations we found controlling the CEP phase of the laser within $500mrad$ constrains the polarization-induced jitter to below $50\mu rad$.

Acknowledgments:

Poster Session and Reception - Board: P26 / **70**

Large Energy Depletion of a Beam Driver in a Plasma-Wakefield Accelerator

Author: Felipe Peña[1]

Co-authors: Carl A. Lindstrøm ; Judita Beinortaite ; Jonas Björklund Svensson ; Lewis Boulton ; Severin Diederichs [2]; J. M. Garland ; Pau González Caminal ; Gregor Loisch ; Sarah Schröder ; Maxence Thévenet [3]; Stephan Wesch ; Jonathan Wood ; Jens Osterhoff [3]; Richard D'Arcy

[1] *DESY/UHH*

[2] *DESY / LBNL*

[3] *DESY*

Corresponding Author: felipe.pena@desy.de

Beam-driven plasma-wakefield acceleration has the potential to reduce the size and construction cost of large-scale accelerator facilities, by providing accelerating fields orders of magnitude greater than that of conventional accelerating structures. To keep the running costs affordable, high energy-transfer efficiency from the wall-plug to the accelerated bunch has to be demonstrated. For this, drive bunches must be efficiently produced, strong decelerating fields must be sustained for the drive bunches until their energy is depleted, and the resulting accelerating fields must be strongly beam loaded by the trailing bunches. Here we address the second of these points, showing measurements performed at FLASHForward using a 500 MeV drive bunch where approximately half of its total energy is deposited into a 20 cm long plasma. This level of energy-transfer efficiency demonstrates that plasma accelerators hold the potential to become competitive with conventional accelerators.

Acknowledgments:

WG2: Computation for Accelerator Physics / 71

EZ: An Efficient, Charge Conserving Current Deposition Algorithm for Electromagnetic Particle-In-Cell Simulations

Author: Klaus Steiniger[1]

Co-authors: Rene Widera [1]; Sunita Chandrasekaran [2]; Axel Huebl [3]; Richard Pausch [1]; David Rogers [4]; Ulrich Schramm [1]; Jeff Young [5]; Alexander Debus [6]; Michael Bussmann [7]

[1] *Helmholtz-Zentrum Dresden-Rossendorf*

[2] *University of Delaware*

[3] *Lawrence Berkeley National Laboratory*

[4] *Oak Ridge National Laboratory*

[5] *Georgia Tech*

[6] *Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*

[7] *CASUS, HZDR*

Corresponding Author: k.steiniger@hzdr.de

We present EZ, a novel Current Deposition algorithm for particle-in-cell simulations, which calculates the current density on the grid due to macro-particle motion within a time step by solving the electrodynamic continuity equation. Being a charge conserving hybridization of Esirkepov's method and ZigZag, we refer to it as "EZ" as shorthand for "Esirkepov meets ZigZag".
The talk will detail the new method and show that EZ achieves the same level of charge conservation as the commonly used method by Esirkepov, yet reaches higher performance for macro-particle assignment-functions up to third-order. These results are obtained from Simulations of a warm, relativistic plasma with PIConGPU.
In addition, guide lines for its implementation aiming at highest performance on GPUs are provided.

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Poster Session and Reception - Board: F83 / **72**

Initial Results from a Laser-Heated Thermionic Cathode

Authors: Heather Andrews[1]; Anna Alexander[1]; Darrel Beckman[1]; Michael Holloway[1]; Angus Guider[1]; Jackson Moody[1]; Juan Moreno[1]; Gabriel Santana[1]

[1] *Los Alamos National Laboratory*

Corresponding Author: hlac@lanl.gov

There is increasing interest in developing accelerator technologies for space missions, particularly for fundamental science. In order to meet these mission needs, key accelerator technologies must be redesigned to be able to function in a remote and harsh environment. In this work we focus on a modest electron injector system, specifically the traditional thermionic cathode. Typically such cathodes are heated by a power supply that is floated at the cathode negative high voltage. We are pursuing laser heating a thermionic cathode in order to remove the heater power supply from the injector system, allowing for reduced engineering complexity and power requirements for the injector. To date we have shown that a simple tungsten disk cathode can be heated by a laser only, and can require much less laser power than heater power for the same emission current. Future work includes back-illuminating the cathode and illuminating with a CW laser diode.

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Plenary / **73**

Machine-learning control of coherent combining of fiber lasers for plasma accelerators

Author: Dan Wang[1]

Co-authors: Siyun Chen ; Qiang Du ; Russell Wilcox ; Tong Zhou ; Cameron Geddes ; Derun Li

[1] *LBNL*

Corresponding Author: qdu@lbl.gov

One of the most promising technical paths to high-average-power, high-peak-power, ultrafast lasers is coherent combination of fiber lasers, which could produce Joule/kHz laser pulses to drive next-generation laser-plasma accelerators (LPA), e.g. kBELLA (kilohertz Berkeley Lab Laser Accelerator). Advanced controls are essential for many-beam, many-pulse coherent combination, and to optimize the overall laser system by sensing, diagnosing, and controlling at high speed (as compared with perturbations). Advanced machine learning (ML) has proved to be advantageous over more commonly used algorithms for complex systems where errors are irretrievable from measured data (e.g. phase error from amplitude data), or the system has too many unknown, time-varying parameters and is highly nonlinear, preventing deterministic error prediction. We have created innovative solutions to address some of the key challenges in ML control, to enable ML to learn on an unstable system with noise and drift. We have, for the first time, demonstrated stabilizing laser power with ten times faster convergence speed than random dither-and-search algorithms and experimentally

demonstrated 0.4% stability with high combining efficiency when coherently combining 8 beams. Key features of our novel ML-based active feedback controls include scaling to many outputs while retaining high speed, and ability to actively re-learn while in operation. We are also implementing ML on Field-Programmable Gate Arrays (FPGA) to reduce the control latency to microseconds, to enable fast control over >10 kHz repetition rate and allow precision controls to reach optimal error reduction and stability. This approach will provide a robust technical path to active control of coherently-combined multi-kHz, high-power ultrafast lasers, achieving the power stability and combining efficiency needed for laser-based accelerators.

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WG3: Laser and High-Gradient Structure-Based Acceleration / 74

New, High Efficiency RF Sources

Authors: R Lawrence Ives[1]; Michael Read[None]; Brian Chase[None]; John Reid[None]; Chris Walker[None]; Jeff Conant[None]; Aaron Jensen[None]; Thomas Habermann[None]; David Marsden[None]; George Collins[None]; Thuc Bui[None]; Ho Ricky[None]; Jim Potter[None]; Henry Freund[None]

[1] *Calabazas Creek Research, Inc.*

Corresponding Author: rlives@calcreek.com

Several new, high efficiency, RF sources are available or in development at frequencies from 325 MHz to 1.3 GHz and higher. If successfully developed, these new devices will represent lower cost alternatives to conventional RF sources. The primary focus is RF power production at higher efficiency and lower cost than currently available from conventional vacuum electron devices and solid-state sources. All devices are predicted to achieve more than 80% efficiency and provide lower acquisition and/or operating costs. A magnetron system with phase and amplitude control was successfully tested, producing 100kW at more than 80% efficiency. This system was developed for superconducting accelerators requiring fast feedback control of the RF power. The cost is estimated at $1 per watt. A multiple beam power grid tube was recently completed, providing sufficient beam power to generate 200 kW of RF power from 325 to 500 MHz at an estimated cost of 50 cents per watt. This device, if successfully tested, will provide a dramatically more compact and lower cost alternative to solid state systems now being used in this frequency and power range. Simulations predict 150 MHz of mechanical tuning range, and RF power generation up to 1 GHz may be feasible. Final assembly is in progress on a 100 kW CW, 1.3 GHz klystron simulated to achieve 80% efficiency using a COM-based RF circuit. Seal-in should be completed by the end of October, and the tube will be baked when a station is available. Testing is scheduled for January 2023. A 700 MHz, multiple beam inductive output tube is being developed with an estimated efficiency exceeding 80%. This tube will use moly grids to avoid the availability, cost, and yield issues associated with pyrolytic graphite grids. A new input coupler is dramatically simpler and more compact than previous versions, reducing both the cost and the size of the tube. Parts procurement is in progress, and testing is scheduled for spring 2023. These new sources could significantly impact the cost of new accelerator and colliders systems, particularly those requiring many RF source or operating at high duty.

Acknowledgments:

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Poster Session and Reception - Board: F73 / **75**

Investigation of Terahertz Near-Fields Towards Efficient Particle Acceleration

Author: Annika Gabriel[1]

Co-authors: Mohamed Othman [2]; Matthias Hoffmann [1]; Fatima Osman [3]; Emilio Nanni [4]

[1] *SLAC National Accelerator Laboratory*

[2] *SLAC NATIONAL ACCELERATOR LABORATORY*

[3] *Santa Clara University*

[4] *SLAC National Accelerator Lab*

Corresponding Author: mothman@slac.stanford.edu

THz-frequency accelerating structures could provide the accelerating gradients needed for next generation particle accelerators with compact, GV/m-scale devices. Current THz accelerators are limited by significant losses during transport of THz radiation from the THz source to the acceleration structure. In addition, the broadband spectral properties of high-field laser-driven THz sources make it difficult to couple THz radiation into accelerating structures. A better understanding of the THz near-field source properties is necessary for the optimization of THz transport and coupling. One of the most promising THz generation techniques for accelerator applications is optical rectification in lithium niobate using the tilted pulse front method. We have developed a technique for detailed measurement of the THz near-fields and used it to reconstruct the full temporal 3D THz near-field close to the lithium niobate emission face. Analysis of the results from this measurement will guide the designs of novel structures for use in THz particle acceleration and improve coupling schemes toward enhancing acceleration efficiency.

Acknowledgments:

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WGs 5+7 Joint Session / 76

Plasma-accelerator-based linear beam cooling systems

Authors: Carl Schroeder[1]; Davide Terzani[1]; Carlo Benedetti[1]; Stepan Bulanov[1]; Eric Esarey[1]; Gerry Dugan[2]

[1] *LBNL*

[2] *Cornell University*

Corresponding Author: cbschroeder@lbl.gov

Plasma-based accelerators enable compact acceleration of beams to high energy and are considered a potential technology for future linear colliders. Conventional linear colliders require damping rings to generate the required beam emittance for high-energy physics applications. We propose and discuss a plasma-based linear radiation damping system that allows cooling of ultrashort bunches compatible with plasma-based accelerators, potentially removing the need for bunch compression. The ultra-high plasma accelerating gradients enable relatively compact linear damping systems, and there is a trade-off between system length and the achievable emittance reduction. Final asymptotic normalized beam emittance is shown to be independent of beam energy.

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Poster Session and Reception - Board: P36 / **77**

High-bandwidth image-based predictive laser stabilization via optimized Fourier filters

Author: Joseph Natal[None]

Co-authors: Samuel Barber [1]; Curtis Berger [1]; Fumika Isono [1]; Anthony Gonsalves [1]; Matthias Fuchs [2]; Jeroen van Tilborg [1]

[1] *LBNL*

[2] *University of Nebraska, Lincoln*

Corresponding Author: jnatal2@huskers.unl.edu

Producing stable particle beams with Laser Plasma Accelerators depends upon the stability of the driving laser (for example, in pointing). Vibrations from various sources (HVAC systems, chillers, motorized stages, among others) introduce laser pointing fluctuations which couple to the particle beam production, and degrade shot-to-shot stability. Luckily, active stabilization is an option, even on low-repetition rate systems due to the co-presence of CW alignment means and un-amplified kHz front-end beams. However, traditional PID systems are strongly limited in feedback bandwidth. Here we present a predictive, machine-learning control approach which drastically improves control bandwidth compared to traditional algorithms. By computing Fourier transform coefficients in real-time, along with efficient data pipelining and CMOS camera technology, vibration disturbances in laser pointing up to 500 Hz have been shown to be greatly reduced.

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WGs 2+5 Joint Session / **78**

ADJOINT OPTIMIZATION OF CIRCULAR LATTICES

Authors: Thomas Antonsen[None]; Levon Dovlatyan[1]; Alex Einarsson[1]; Irving Haber[1]; Patrick O'Shea[1]

[1] *University of Maryland*

Corresponding Author: antonsen@umd.edu

Design of circular lattices involves optimizing figures of merit (FoMs) characterizing the beam properties subject to the constraint that the beam distribution function be approximately periodic in trips around the lattice. We are developing an algorithm that accomplishes this with minimal computational effort. The algorithm takes advantage of recent developments in adjoint techniques that allow the derivatives of the FoM with respect to the many parameters describing the lattice to be evaluated. The present description of the accelerator is based on the 10 second moments of the beam distribution function in the transverse phase space. However, extensions to kinetic descriptions will be discussed. Our algorithm, which we name "Adjoint with a Chaser", works as three separate minimizations run concurrently. These three working together force the beam into a periodic state, while varying parameters to minimize an FoM. Examples relevant to the Maryland lattice UMER will be presented.

Acknowledgments:

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WG1: Laser-Plasma Wakefield Acceleration / 79

High-efficiency compact laser-plasma electron accelerator

Authors: Ping Zhang[1]; Jensen Kyle[1]; Matthew Robinson[1]; Yunhao Fan[1]; Tian Hu[1]; Tim Kawamoto[2]; Lake Larson[1]; Junzhi Wang[1]; Sudeep Banerjee[1]; Megan Hyun[3]; Donald Umstadter[2]; Brad A. Shadwick[2]; Martin Centurion[2]; Matthias Fuchs[2]

[1] *University of Nebraska - Lincoln*

[2] *University of Nebraska–Lincoln*

[3] *University of Nebraska Medical Center*

Corresponding Author: mfuchs@unl.edu

Laser-plasma accelerators (LPAs) operating in the bubble regime require driver lasers with relativistic intensities and pulse durations that are significantly shorter than the plasma wavelengths. This severely limits the laser technology that can be used to drive LPAs and with that their wide spread and the currently achievable LPA parameters, such as repetition rate. Here, we report a widely unexplored regime of laser-plasma electron acceleration that is based on the direct parametric excitation of plasma waves. This method markedly relaxes the driver laser requirements in terms of peak power and pulse duration. We show preliminary experimental data that demonstrates the generation of high-charge mildly relativistic electron bunches with laser-to-electron conversion efficiency of nearly 10% which is unprecedented in gas-phase targets. The electron beams were generated using a gas target that can reach near the critical plasma density using a driver laser with moderate intensity. The experimental results demonstrate a novel regime that opens LPA electron acceleration for a wide range of driver laser technologies and holds the promise for a path to high-repetition rate LPAs for future compact particle accelerators and secondary sources.

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Poster Session and Reception - Board: P50 / **80**

Advanced Laser-driven Betatron X-ray Generation

Author: Junzhi Wang[1]

Co-authors: Ping Zhang [1]; Kyle Jensen [1]; Tian Hu [1]; Shao Xian Lee [1]; Joseph Natal [1]; Reed Hollinger [2]; Zeev Shpilman [2]; Wang Shoujun [2]; Jorge Rocca [2]; Bradley Shadwick [1]; Matthias Fuchs [3]

[1] *University of Nebraska-Lincoln*

[2] *Colorado State University*

[3] *University of Nebraska, Lincoln*

Corresponding Author: junzhi.wang@huskers.unl.edu

Ultrafast high-brightness X-ray pulses have proven invaluable for a broad range of research. Such pulses are typically generated via synchrotron emission from relativistic electron bunches using large-scale facilities. Recently, significantly more compact X-ray sources based on laser-wakefield accelerated (LWFA) electron beams have been demonstrated. In particular, laser-driven betatron sources, where the radiation is generated by transverse oscillations of electrons within the plasma accelerator structure can generate highly-brilliant ultrashort X-ray pulses using a comparably simple setup. Here, we present experimental and simulation data that demonstrate significant enhancement of and control over the parameters of LWFA-driven betatron X-ray emission. With our novel Transverse Oscillating Bubble Enhanced Betatron Radiation (TOBER) scheme, we show a significant increase in the number of generated photons by specifically manipulating the amplitude of the betatron oscillations. We realize this through an orchestrated evolution of the temporal laser pulse

shape and the accelerating plasma structure. This leads to controlled off-axis injection of electrons that perform large-amplitude collective transverse betatron oscillations, resulting in increased radiation emission. Our concept holds the promise for a method to optimize the X-ray parameters for specific applications, such as time-resolved investigations with spatial and temporal atomic resolution or advanced high-resolution imaging modalities, and the generation of X-ray beams with even higher peak and average brightness.

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WG4: Beam-Driven Acceleration / 81

QPAD modeling of wake excitation and acceleration in meter-long beam-ionized plasma at FACET-II

Author: Zan Nie[1]

[1] *UCLA*

Corresponding Author: niezan0908@gmail.com

FACET-II, a new 10 GeV electron beam facility at SLAC National Accelerator Laboratory for R&D on beam physics and novel acceleration techniques [1, 2], has been commissioned this year. One major research effort is on further development of the Plasma Wakefield Acceleration scheme (E300). The experimental results from the first run of the E300 experiment at FACET-II has shown evidence of high-efficiency wake excitation and energy depletion of the drive beam in beam-ionized hydrogen or helium gases. This self-ionization of both hydrogen and helium came as somewhat of a surprise since the calculated peak current in the beam was not high enough to field ionize these atoms. Fortunately, multiple diagnostics showed that the drive beam frequently had much narrower, higher current peaks. We therefore model the drive beam as having an ~80 fs Gaussian temporal shape with a peak current of 4.7 kA that has a much higher current spike (>50 kA, ~4 fs). To explain these results, a quasi-3D quasi-static particle-in-cell code QPAD [3] was used. We find that such a beam with a high current spike can indeed ionize both gases via ADK (He) or MO-ADK (H2) ionization model. The current spike was placed such that up to 30 to 40% of the drive beam charges did not lose any energy to agree with experimental observations. Once the plasma was formed by the spike, the rest of the beam with nb>np, rapidly forms a wake and transfers up to ~70% of the remaining beam energy to the wake. The model qualitatively reproduced the maximum energy loss as a function of gas pressure, energy gain seen at high pressures, pump depletion and betatron oscillations seen in the experiment.

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Acknowledgments:

WGs 4+5 Joint Session / 82

Highly spin-polarized multi-GeV sub-femtosecond electron beams generated from single-species plasma photocathodes

Authors: Zan Nie[1]; Fei Li[1]; Felipe Morales[2]; Serguei Patchkovskii[2]; Olga Smirnova[2]; Weiming An[3]; Chaojie Zhang[1]; Yipeng Wu[1]; Noa Nambu[1]; Daniel Matteo[1]; Kenneth Marsh[1]; Frank Tsung[1]; Warren Mori[1]; Chan Joshi[1]

[1] *UCLA*

[2] *Max Born Institute*

[3] *Beijing Normal University*

Corresponding Author: niezan0908@gmail.com

High-gradient and high-efficiency acceleration in plasma-based accelerators has been demonstrated, showing its potential as the building block for a future collider operating at the energy frontier of particle physics. However, generating and accelerating the required spin-polarized beams in such a collider using plasma-based accelerators has been a long-standing challenge. Here we show that the passage of a highly relativistic, high-current electron beam through a single-species (ytterbium) vapor excites a nonlinear plasma wake by primarily ionizing the two outer 6s electrons [1, 2]. Further photoionization of the resultant Yb2+ ions by a circularly polarized laser injects the 4f14 electrons into this wake generating a highly spin-polarized beam. Combining time-dependent Schrodinger equation simulations with particle-in-cell simulations, we show that a sub-femtosecond, high-current (4 kA) electron beam with up to 56% net spin polarization can be generated and accelerated to 15 GeV in just 41 cm. This relatively simple scheme solves the perplexing problem of producing spin-polarized relativistic electrons in plasma-based accelerators.

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WG6: Laser-Plasma Acceleration of Ions / 83

Effects of Laser Polarization on Target Focusing and Acceleration in a Laser-Ion Lens and Accelerator

Authors: Roopendra Singh Rajawat[1]; Tianhong Wang[1]; Gennady Shvets[1]

[1] *Cornell University*

Corresponding Author: rr682@cornell.edu

Recently, a novel concept of Laser-Ion Lensing and Acceleration (LILA) [1] has been introduced for highly-efficient generation of monoenergetic low-emittance ion beams. The LILA scheme is based on the illumination of a solid-density target with radially-dependent thickness by an intense circularly polarized (CP) laser pulse, resulting in simultaneous acceleration and focusing of proton beams to a micron-sized spot. We extend the LILA concept to include elliptically polarized (EP) laser pulses. While it is well-known that elliptically polarized (EP) laser pulses cannot be used for radiation pressure acceleration (RPA) of planar targets because of strong electron heating [2], we find that the situation is qualitatively different for non-planar rapidly-converging targets. Three-dimensional PIC simulations, backed up by simple theoretical estimates, are used to optimize the target thickness and shape to realize the LILA scheme with EP laser pulses. Unexpectedly, even linearly polarized laser pulses can efficiently generate low-emittance focused ion beams when non-uniform thickness targets are used, with overall laser-to-ions energy conversion comparable to those achievable with CP laser pulses.

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WGs 5+7 Joint Session / 84

A compact laser-plasma based setup for positron production and collection

Author: Davide Terzani[1]

Co-authors: Carlo Benedetti [1]; Stepan Bulanov [1]; Carl Schroeder [1]; Eric Esarey [2]

[1] *LBNL*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: dterzani@lbl.gov

Development of compact, Laser Plasma Acceleration (LPA)-based sources for positrons is a key step in the R&D effort towards development of a TeV collider. The conventional production and collection schemes of positron beams cannot be easily transferred to an LPA setup. This is mainly due to the large distance required to transport particles from the production to the acceleration point and the inherently small transverse acceptance of the LPA stage. For such reasons, positron production schemes compatible with a plasma-based accelerator are still lacking. In this work, we present a compact, laser-based scheme for the production of positron beams. Positrons are produced via pair decay of the Bremsstrahlung radiation generated when a multi-GeV, laser-plasma accelerated electron beam interacts with a high-Z solid target. We explore the possibility of using the back of the target itself as a plasma mirror for an incoming laser, in order to generate a plasma wave able to trap and accelerate positrons as soon as they leave the target. A realistic phase-space distribution for the positrons is obtained by modeling the electron beam interaction with the solid target using the Monte Carlo code Geant4. We then study the trapping and acceleration efficiency of the subsequent plasma stage in order to find an optimum working point.

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WG4: Beam-Driven Acceleration / 85

Dominance of the seed from a tightly-focused electron bunch over the self-modulation of a long proton bunch in an over-dense plasma

Authors: Kook-Jin Moon[1]; Patric Muggli[2]; Moses Chung[1]

[1] *Ulsan National Institute of Science and Technology*

[2] *Max-Planck Institute for Physics*

Corresponding Author: kookjine@unist.ac.kr

The phase and growth rate of the self-modulation of a long proton bunch in over-dense plasma can be controlled by a preceding charged particle bunch. In order to selectively seed the growth of the proton bunch self-field, the dominance of seed over any undesired imperfections of the proton bunch is important. In this work, we investigate analytically and numerically the phase and growth rate of the long proton bunch self-modulation, including the effects of its gently rising current profile and of the wakefields of the tightly focused low energy electron seed at the early stage of the self-modulation. We also show that the low energy electron bunch simultaneously drives a single mode modulation along the entire long proton bunch, mitigating mode polarization with the anomalous phase shift of the long proton bunch self-modulation.

Acknowledgments:

WG4: Beam-Driven Acceleration / 86

High-efficiency wake excitation in beam-ionized plasmas at FACET-II

Authors: Chaojie Zhang[1]; E300 collaboration at FACET-II[None]

[1] *UCLA*

Corresponding Author: chaojiez@ucla.edu

FACET-II is a new 10 GeV electron beam facility hosted by the SLAC National Accelerator Laboratory and E300 is the flagship experiment aiming at demonstrating high-quality two-bunch PWFA [1, 2]. An important goal of E300 is to demonstrate efficient (40%) energy transfer from the drive to the trailing bunch [1]. This number in turn is the product of the drive beam to the wake (80%) and from the wake to the trailing bunch (50%) efficiencies. In order to obtain such a high drive beam to the wake energy transfer, the bulk of the particles must be nearly fully depleted of their energy. In this talk, we will present experimental results on high-efficiency wake excitation which is an important stepping stone for achieving overall high energy transfer efficiency. We show that up to 70% of the charge contained in the FACET-II beam can self-ionize static fill (up to 2 Torr) of hydrogen gas over greater than one meter and lose significant amount of its energy in driving a wake. Correlation measurements on the integrated plasma emission and the energy spectrum of the beam after interaction suggest a beam-to-wake energy transfer efficiency up to ~70%. The measurements also show evidence for that a portion of the 10 GeV drive beam has lost all its 10 GeV energy (pump depletion), which is necessary for achieving high beam-to-wake energy transfer efficiency.

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WG1: Laser-Plasma Wakefield Acceleration / 87

Generating pre-bunched electron beams using modulated density downramp injection

Authors: Chaojie Zhang[1]; Yipeng Wu[1]; Audrey Farrell[1]; Zan Nie[1]; Kenneth Marsh[1]; Xinlu Xu[None]; Qianqian Su[None]; Warren Mori[1]; Chan Joshi[1]

[1] *UCLA*

Corresponding Author: chaojiez@ucla.edu

One of the two long-term applications of plasma-based accelerators is to develop the fifth-generation light source such as a compact free electron laser (FEL), which requires the generation of ultrahigh brightness electron bunches [1]. Recently, self-amplified spontaneous emission (SASE) by bunches from both laser- and beam-driven plasma accelerators have been observed [2, 3]. If the drive electron bunch from a plasma accelerator is pre-bunched on the scale of the radiated wavelength, it is then possible to substantially enhance the longitudinal coherence of XFELs by superradiant amplified spontaneous emission. A possible way of generating pre-bunched electron beams is using modulated density downramp injection as recently proposed by Xu et al [4]. Here we show progress on a proof-of-concept experimental realization of this idea, with emphases on a practical method of generating a modulated density downramp by superimposing an ionization induced plasma grating [5] onto a shock front in a supersonic gas flow and the potential detection of bunched electrons using coherent transition radiation.

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Poster Session and Reception - Board: P1 / **88**

Phase- and polarization-controlled electron self-injection into laser plasma accelerators

Authors: Jihoon Kim[1]; Tianhong Wang[1]; Vladimir Khudik[2]; Gennady Shvets[1]

[1] *School of Applied and Engineering Physics, Cornell University*

[2] *Department of Physics and Institute for Fusion Studies, The University of Texas at Austin*

Corresponding Author: the.kvothe@gmail.com

An intense laser pulse propagating inside a plasma can generate a plasma bubble that can trap, accelerate, and focus electrons. These plasma bubbles undulate transversely according to its Carrier-Envelope-Phase (CEP) when (1) it is a near-single-cycle (NSC) pulse or (2) it undergoes steepening and forms a shock-like front. We demonstrate how this effect can be harnessed to control injection under both circumstances. For (1), two-color pulses are used: a long-wavelength NSC pulse as an injector, and a short wavelength longer duration pulse as a driver. For (2), a few-cycle pulse alone propagating in a pulse serves both the roles of injector and driver. We show via semi-analytical theory how the CEP effect can be used to inject electrons from the background plasma periodically, with or without the presence of bubble expansion. We clarify how the Periodically Undulating Bubble (PUB) can constructively or destructively interfere with the simultaneous bubble expansion to trigger or suppress trapping. Depending on the laser polarization, periodic or continuous injection of electrons from background plasma ensues, generating electron bunches with sub-fs to fs temporal scale, which can in turn generate femtosecond X-ray pulses. This injection mechanism is amenable

to several existing university-scale few-cycle to multi-cycle multi-TW laser pulses. Furthermore, we will discuss several phase-dependent experimental observables, such as the electron beam pointing, betatron radiation polarization, and intensity distribution. Thus, the laser phase may become a controlling knob for electron and X-ray beams.

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WG6: Laser-Plasma Acceleration of Ions / 89

Generation of focused high-energy ion beams via hole-boring radiation pressure acceleration of curved-surface low-density targets

Authors: Jihoon Kim[1]; Roopendra Rajawat[2]; Tianhong Wang[2]; Gennady Shvets[2]

[1] *Cornell University*

[2] *School of Applied and Engineering Physics, Cornell University*

Corresponding Author: the.kvothe@gmail.com

Relativistic ion beams have wide applications ranging from proton therapy, neutron beam/warm dense matter generation, and fast ignition of fusion pellets. In particular, generating a monoenergetic high energy flux ion beam is of great interest, since fast-ignition scheme of fusion targets require energy fluxes of ~GJ/cm^2. We show that a foam-based target with parabolically shaped front surface can be accelerated and focused to a micron-scale spot using available laser systems and targets. The focal length is controlled by the target front surface shape, and the ion energy: by laser intensity and target mass density. An analytic model based on Hole-Boring Radiation Pressure Acceleration mechanism is developed to explain the result. This scheme is scalable and can be used for a wide range of laser power and target densities to focus monoenergetic ions with different energy to variable focal lengths and can generate fs-scale ultrahigh energy density/flux beams. The mechanism is robust and can be implemented using realistic transverse laser profiles, multi-species targets, or targets with finite longitudinal step-like boundaries.

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WGs 1+8 Joint Session / 90

High-efficiency and high-quality laser-plasma accelerator stages for a plasma-based linear collider

Authors: Carlo Benedetti[1]; Davide Terzani[1]; Stepan Bulanov[1]; Carl Schroeder[1]; Eric Esarey[2]

[1] *LBNL*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: cbenedetti@lbl.gov

The viability of next generation plasma-based linear colliders relies on the possibility of accelerating high-charge and low-emittance bunches to high energies over short distances with high efficiency,

while keeping a small relative energy spread. Laser-plasma accelerators (LPAs) can operate in different regimes, namely, linear (or mildly nonlinear) stages, where laser guiding is achieved by means of an external waveguide such as a plasma channel, or nonlinear stages where the laser is self-guided through the plasma by means of relativistic self-focusing and plasma wave guiding. For the same laser driver energy, channel-guided and self-guided LPA stages are characterized by different accelerating gradients, lengths, optimal bunch parameters, and acceleration efficiencies. In this talk we present a systematic investigation of the properties of channel-guided and self-guided LPAs with fixed laser energy, and we discuss a self-guided LPA stage operating in the nonlinear regime providing high-gradient, high-efficiency, and quality-preserving acceleration of electron beams for collider applications.

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Poster Session and Reception - Board: P61 / **91**

Post-Compression of High-Power CO2 Lasers to sub-ps Levels Using an Ultrathin Tailored Nonlinear Element for Advanced Accelerator Applications

Authors: Daniel Matteo[1]; Sergei Tochitsky[1]; Chan Joshi[1]

[1] *UCLA Department of Electrical Engineering*

Corresponding Author: danielmatteo@ucla.edu

High-power long-wavelength infrared lasers (e.g. CO_2 laser) are of great interest for acceleration of electrons and ions. For LWFA, pulses as short as 300-500fs are required to drive relativistic plasma wakes at 10^{16}-10^{17} cm^{-3} densities. The shortest pulse length demonstrated so far in CO_2 lasers is 2ps; these multiterawatt pulses are generated using a multistage MOPA system at ATF BNL.

One way to generate sub-picosecond pulses is post-compression of longer pulses after final amplification. Current LWIR post-compression schemes involve two stages of bulk materials; the first stage provides spectral broadening via self-phase modulation, while the second stage with negative GVD compresses the pulse. This arrangement has been experimentally demonstrated [1,2]. A main drawback is inhomogeneity of compression along the beam's radial distribution, leading to inefficient use of energy and unwanted spatio-temporal coupling.

At UCLA, we have been studying nonlinear optical responses of LWIR transparent semiconductor materials over the last several years using picosecond CO_2 laser pulses and, recently, with a newly acquired sub-picosecond solid-state-based OPA/DFG system. We measure nonlinearities of GaAs, n-Ge, and ZnSe for <1ps long, 10µm pulses and show they are close to literature data, however the Kerr nonlinearity of Te, never reported before, is extremely high on the order of $\geq 5 \times 10^{-12}$ cm^2/W. We propose and numerically show how an ultrathin and radially engineered Te nonlinear optical chirping element can be used for generation of homogeneous spectral broadening of an initially picosecond CO_2 laser pulse.

Modeling of post-compression is done by solving the 2D nonlinear Schrödinger equation. Using 2ps Gaussian pulses containing 400mJ centered at 9.2µm, similar to that in [2], sufficient broadening is achieved in a Te layer ~50µm thick. A structured layer with Gaussian thickness is used to give identical spectral broadening across the full beam. The pulse is then numerically propagated through 5 cm of BaF_2, after which it is compressed to a pulse duration less than 300 fs, homogenous across the whole beam. This compression results in a several times increase in peak-power. One can foresee that thin film and etching technology could be used for fabrication of such a large aperture pulse compressor.

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WG1: Laser-Plasma Wakefield Acceleration / 92

kHz Laser-Driven Electron Beams up to 50 MeV at ELI-Beamlines.

Author: Carlo Maria Lazzarini[1]

Co-authors: Gabriele Maria Grittani [2]; Illia Zymak [3]; Michal Nevrkla [1]; Leonardo Vila Nova Goncalves [4]; Sebastian Lorenz [4]; Petr Valenta [3]; Roman Antipennkov [3]; Pavel Bakule [4]; Annika Grenfell [1]; Vaclav Sobr [1]; Alexander Spacek [1]; Wojciech Jerzy Szuba [1]; Uddhab Chaulagain [1]; Marcel Lamac [1]; Georg Korn [1]; Sergey Vladimirovich Bulanov [1]

[1] *ELI Beamlines*

[2] *ELI-Beamlines*

[3] *ELI Beamlines*

[4] *ELI Beamlinnes*

Corresponding Author: lazzarinicm@gmail.com

The extremely high electric fields sustainable by a plasma make the Laser Wakefield Acceleration (LWFA) the most compact technique to generate very highly relativistic electron beams up to the GeV regime. The limited repetition rate and low efficiency of this technology has, to date, prevented to unleash its full potential as a unique source for basic research, biomedical applications and high flux sources of secondary radiations as hard x-rays and gamma-rays. In recent years a new direction emerged showing the possibility to accelerate electron beams at 1 kHz repetition rate. All these works are based on commercial lasers, requiring laser pulse compression to single-cycle by fiber technology, having limits in terms of maximum available laser pulse energy and achievable electron beam energy.

Here I will show the generation of very collimated (2 mrad) relativistic quasi-monoenergetic (< 30% energy spread) electron beams accelerated to the highest energy (up to 50 MeV) ever reached up to date with a kHz laser. Said innovative results have been achieved in the new Laser Wakefield ALFA platform for user experiments, that has been fully integrated to the in-house developed L1-Allegra 1 kHz multi-cycle (15 fs FWHM) laser system. The acceleration was driven by 1,7 TW pulses but, thanks to its modular OPCPA (Optical Parametric Chirped Pulse Amplification) design, the system is scalable to above 5 TW. I will introduce both the laser and the ALFA platform with related diagnostics.

The electron beams reported in this work are a step forward towards the development of in-demand high brilliance X-ray sources for medical imaging, high dose rate machines for radiotherapy based on high energy electrons, and to the future realization of a kHz 1 GeV electron beamline.

Acknowledgments:

Plenary / 93

Experimental progress towards an energy-efficient, high-quality, high-repetition-rate plasma-wakefield accelerator

Author: Richard D'Arcy[None]

Corresponding Author: richard.darcy@desy.de

High-gradient plasma-wakefield acceleration represents an exciting route towards both boosting the energy and reducing the footprint of future particle colliders and free-electron lasers. At such facilities thousands or even millions of high-charge particle bunches with low energy spread and low emittance will need to be accelerated in an energy-efficient manner in order to outperform current machines in luminosity and brightness. In this contribution the latest results towards achieving this goal from the beam-driven plasma-acceleration experiment FLASHForward (DESY, Hamburg) will be presented. Highlights will include record values of the energy-transfer efficiency from drive beam to wake and from wake to the accelerating bunch; preservation of incoming bunch properties including charge, energy spread, and emittance; and first results in the direction of operating plasma accelerators at the repetition rates required for future high-energy-physics and photon-science applications.

Acknowledgments:

Poster Session and Reception - Board: P37 / **94**

An all-optical streak camera to measure the jitter between two beams in the single-digit femtosecond regime

Author: Marc Osenberg[1]

Co-authors: Michael Stumpf [2]; Georg Pretzler [2]

[1] *Heinrich-Heine-Universität Düsseldorf, Institut für Laser- und Plasmaphysik*

[2] *Heinrich-Heine Universität Düsseldorf, Institut for Laser- and Plasmaphysics*

Corresponding Author: marc.osenberg@hhu.de

We present a novel all-optical streak camera (AOSC) based on the Kerr-effect which measures the relative temporal position of a laser pulse and a second short pulse of arbitrary constituents (e.g. electrons, protons, light, or x-rays) in a single shot. Many modern accelerator concepts rely on the coupling of an electron beam with a laser beam, which must overlap with ultra-high temporal precision down to the low fs-regime. Our new device comes in at this point, measuring the temporal position of the electron pulse relative to the laser pulse for single shots, which will also show jitter or temporal drifts. We show results of a proof-of-principle experiment in which the AOSC was tested and characterized by an ultrashort laser pulse (7 fs FWHM). The apparatus resolution was shown to be < 2 fs, whereas the total temporal resolution is of the order of gating beam pulse duration.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / **95**

THz generation fro 3-D printed structures in accelerators

Authors: Pavle Juranic[1]; Rasmus Ischebeck[2]; Niedermeyer Uwe[None]; Raziyeh Dadashi[None]

[1] *Paul Scherrer Institut*

[2] *PSI*

Corresponding Author: pavle.juranic@psi.ch

The presentation will discuss advancements and new concepts on the topic of THz generation by 3-d printed structures in relativistic electron beams. A new concept has been developed that would greatly increase the efficiency of THz light generation, as well as allow for greater possibilities for control of the properties of the so generated Thz light. Wavelength, collimation and possibly pulse duration of the THz pulse could all be parameters that can be selected with the choice of a proper 3-D structure. This new concept would be more synchronized with the FEL beam than laser-based THz sources, and would take up less space and would be less expensive than THz undulators. The manufacture of the structures would be significantly simpler as well.

Acknowledgments:

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WG4: Beam-Driven Acceleration / 96

High average gradient in a laser-gated multistage plasma wakefield accelerator

Authors: Alexander Knetsch[None]; Igor Andriyash[1]; Max Gilljohann[1]; Olena Kononenko[2]; Aimé Matheron[1]; Yuliia Mankovska[1]; Pablo San Miguel Claveria[1]; Viktoriia Zakharova[1]; Erik Adli[3]; Sebastien Corde[2]

[1] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris*

[2] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[3] *Department of physics, University of Oslo*

Corresponding Author: alexander.knetsch@polytechnique.edu

Owing to the provision of GV/m accelerating fields, beam-driven plasma accelerators are a promising technology for the miniaturization of particle accelerators. Energy gains of GeV or even tens of GeV are already achievable so to extend this range to 0.1 - 1 TeV, a sequence of multiple plasma stages is being considered.
While plasma-accelerator stages itself are sufficiently small, beam-transport components and distances between stages can be among the biggest contributors to the total accelerator length and therefore decrease the average accelerating gradient of a plasma-accelerator linac.
A new concept to design beam lattices in beam-driven plasma accelerators will be presented. By taking advantage of the fs-ionization front, typical for laser-ionized plasmas, plasma wakefields are gated in, thereby allowing for different lattices - separated in the temporal domain.
When applying this method to staged beam-driven plasma accelerators, drive beams can propagate as a bunch train with a small spacing and in-and out-coupling is possible with compact magnetic chicanes. As a consequence, the total stage size can remain sufficiently short to maintain an accelerating gradient of about 1 GV/m, scalable to TeV energy gains.

Acknowledgments:

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WGs 4+7 Joint Session / 97

FACET-II E-305: Beam filamentation and bright gamma-ray bursts

Authors: E-305 collaboration[None]; Alexander Knetsch[None]

Corresponding Author: alexander.knetsch@polytechnique.edu

Relativistic streaming plasma instabilities and their growth rates are subject of research for the description of jet-like astrophysical plasmas due to their strong influence on energy transfer between plasma-constituent, electromagnetic fields and photons. Therefore, these instabilities are of relevance in the description of highly energetic astrophysical phenomena such as e.g. the formation of gamma-ray bursts.
Moreover, recent studies indicate that the magnetic fields arising from the transverse filamentation instability in relativistic electron beams can be harnessed to generate intense gamma-ray flashes from synchrotron-like radiation.
The E-305 collaboration aims to study relativistic beam-plasma instabilities with the 10 GeV electron beam of unprecedented intensity provided by FACET-II at SLAC National Accelerator Laboratory. By propagating the beam through solid-density targets and high-density gas jets the dynamic of instabilities will be probed and the efficacy of gamma-ray generation will be evaluated.
We report on the status of commissioning efforts and first experimental results attained in recent beamtime. Next steps, goals and prospects will be discussed.

Acknowledgments:

Plenary / 98

High energy proton acceleration at DRACO-PW and radio-biological applications

Authors: Karl Zeil[1]; Stefan Assenbaum[None]; Constantin Bernert[None]; Florian Brack[None]; Thomas Cowan[None]; Nick Dover[None]; Thomas Kluge[None]; Florian Kroll[None]; Josefine Metzkes-Ng[None]; Mamiko Nishiuchi[None]; Marvin Reimold[None]; Martin Rehwald[None]; Marvin Umlandt[None]; Milenko Vescovi[None]; Tim Ziegler[None]; Ulrich Schramm[None]

[1] *Helmholtz-Zentrum Dresden-Rossendorf*

Corresponding Author: k.zeil@hzdr.de

Exploiting the strong electromagnetic fields that can be supported by a plasma, high-power laser driven compact plasma accelerators can generate short, high-intensity pulses of high energy ions with special beam properties. By that they may expand the portfolio of conventional machines in many application areas. The maturation of laser driven ion accelerators from physics experiments to turn-key sources for these applications will rely on breakthroughs in both, generated beam parameters (kinetic energy, flux), as well as increased reproducibility, robustness and scalability to high repetition rate.

Recent developments at the high-power laser facility DRACO-PW enabled the production of polychromatic proton beams with unprecedented stability [1]. This allowed the first in vivo radiobiological study to be conducted using a laser-driven proton source [2]. Yet, the ability to achieve energies beyond the 100 MeV frontier is matter of ongoing research, mainly addressed by exploring advanced acceleration schemes like the relativistically induced transparency (RIT) regime.

In this talk we report on experimental proton acceleration studies at the onset of relativistic transparency using pre-expanded plastic foils. Combined hydrodynamic and 3D particle-in-cell (PIC) simulations helped to identify the most promising target parameter range matched to the prevailing laser contrast conditions carefully mapped out in great detail beforehand. A complex suite of particle and optical diagnostics allowed characterization of spatial and spectral proton beam parameters and the stability of the regime of best acceleration performance, yielding cut-off energies larger than 100 MeV in the best shots.

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Acknowledgments:

WG3: Laser and High-Gradient Structure-Based Acceleration / 99

Update on the status of the C-band high gradient program at LANL

Authors: Evgenya Simakov[1]; Alexander Anna[1]; Petr Anisimov[1]; Dimitre Dimitrov[1]; William B. Haynes[None]; Deepak Rai[1]; Tsuyoshi Tajima[1]; MD Zuboraj[None]

[1] *LANL*

Corresponding Author: smirnova@lanl.gov

This talk will report on the status C-band high gradient research program at Los Alamos National Laboratory (LANL). The program is being built around two test facilities: C-band Engineering Research Facility in New Mexico (CERF-NM), and Cathodes And Radio-frequency Interactions in Extremes (CARIE). Modern applications such as X-ray sources require accelerators with optimized cost of construction and operation, naturally calling for high-gradient acceleration. At LANL we commissioned a high gradient test stand powered by a 50 MW, 5.712 GHz Canon klystron. The test stand is capable of conditioning accelerating cavities for operation at surface electric fields in excess of 300 MV/m. CERF-NM is the first high gradient C-band test facility in the United States. CERF-NM was fully commissioned in 2021. In the last year, multiple C-band high gradient cavities and components were tested at CERF-NM. Currently we work to implement several updates to the test stand including the ability to autonomously operate at high gradient for the round-the-clock high gradient conditioning. Adding capability to operate at cryogenic temperatures is considered. The construction of CARIE began in October of 2022. CARIE will house a cryo-cooled copper RF photoinjector with a high quantum-efficiency cathode and produce an ultra-bright 250 pC electron beam accelerated to the energy of 10 MeV. The status of the facility and initial beam physics simulations of the beamline will be presented.

Acknowledgments:

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Poster Session and Reception - Board: P45 / **100**

Design Optimization of Permanent-Magnet Based Compact Transport Systems for Laser-Driven Proton Beams

Author: Jared De Chant[1]

Co-authors: Kei Nakamura [2]; Qing Ji [2]; Lieselotte Obst-Huebl [2]; Samuel Barber [3]; Antoine Snijders [2]; Thomas Schenkel [2]; Jeroen van Tilborg [4]; Cameron Geddes [3]; Carl Schroeder [4]; Eric Esarey [3]

[1] *Michigan State University*

[2] *Lawrence Berkeley National Lab*

[3] *Lawrence Berkeley National Laboratory*

[4] *LBNL*

Corresponding Author: dechantj@msu.edu

Laser-driven (LD) ion acceleration has been explored in a newly constructed short focal length beamline at the BELLA petawatt facility (interaction point 2, iP2). For applications utilizing such LD ion beams, a beam transport system is required, which for reasons of compactness be ideally contained within 3 m. The large divergence and energy spread of LD ion beams present a unique challenge to transporting them compared to beams from conventional accelerators. This presentation gives an overview of proposed compact transport designs satisfying different requirements depending on the application for the iP2 proton beamline such as radiation biology, material science, and high energy density science. These designs are optimized for different parameters such as energy spread and peak proton density according to an application's need. The various designs consist solely of permanent magnet elements, which can provide high magnetic field gradients on a small footprint. While the field strengths are fixed, we have shown that the beam size is able to be tuned effectively by varying the placement of the magnets. The performance of each design was evaluated based on high order particle tracking simulations of typical LD proton beams. A more detailed investigation was carried out for a design to deliver 10 MeV LD accelerated ions for radiation biology applications. With these transport system designs, the iP2 beamline is ready to house various application experiments.

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WGs 2+7 Joint Session / 101

First-Principle Simulations of Electron-Bunch Compression using a Large-Scale Lienard-Wiechert Solver

Author: Afnan Al Marzouk[None]

Co-authors: Philippe Piot [1]; Robert Ryne [2]

[1] *Northern Illinois University*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: afnan.almarzouk1@gmail.com

We present first-principle simulations of coherent synchrotron radiation (CSR) using the large-scale LW3D code [Ryne, R. D., et al. "Large scale simulation of synchrotron radiation using a Lienard-Wiechert approach." Proc. IPAC 46 (2012).] which computes the Lienard-Wiechert fields in 3D from the total number of particles in the bunch. We have applied a straightforward adaptation in the LW3D code to perform self-consistent CSR computations and simulated the resulting beam dynamics as the bunch travels throughout a single bend. We compare our results with the 1D theory and explore the self-consistent effects when simulating a bunch undergoing bunch compression.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / 102

Short Pulse High Gradient Accelerating Structures

Author: Sergey Kuzikov[1]

[1] *Euclid Techlabs, LLC*

Corresponding Author: s.kuzikov@euclidtechlabs.com

RF breakdown and pulse heating are the greatest obstacles to increasing the accelerating gradient. Numerous experiments have shown that the RF breakdown and pulse heating thresholds depend on the exposure time of the structure to the RF fields. The idea described here is to accelerate particles by short (nanosecond or subnanosecond) duration wakefields in a structure assembled of individually fed cells. Because there are no high-power efficient sources of such radiation, we focus on wakefield structures where witness bunches are accelerated by radiation generated by drive bunches. One of successful wakefield experiments has been carried out at Argonne Wakefield Accelerator facility. About 400 MV/m gradient was obtained at X-band photoinjector powered by 9 ns RF pulses. To substantially enhance the efficiency of short pulse structures we propose using of a periodic pulsed regime. In this regime the repetition rate of the excited RF pulses is equal to the repetition rate of the drive bunches and equal to the repetition rate of the witness bunches. In the optimal stationary conditions, the pulsed accelerating field is inversely proportional to losses of the structure. On the other hand, it was shown experimentally that at 45 K accelerating structures can sustain 25% higher gradient and have almost twice higher shunt impedance in comparison with structures at room temperature. The synergetic effect of short pulse technology and cryogenic technology would allow reaching world record gradients as well as high efficiency due to a higher wall conductance.

Acknowledgments:

WGs 3+5 Joint Session / 103

Development of High Brightness Photoinjector for AWA

Author: Sergey Kuzikov[1]

[1] *Euclid Techlabs, LLC*

Corresponding Author: s.kuzikov@euclidtechlabs.com

High brightness beams for XFELs and UEM essentially imply a high current and a low emittance. To obtain such beams we propose to raise the accelerating voltage in the gun mitigating repealing Coulomb forces. An ultra-high gradient is achieved utilizing a short-pulse technology. A successful experiment with an X-band photoinjector has been recently carried out at Argonne Wakefield Accelerator (AWA) facility. The carried-out test showed that the 1,5-cell gun was able to inject up to 6 MeV,100 pC electron bunches at room temperature being fed by 9 ns up to 300 MW pulses. As high as 400 MV/m cathode field was obtained. The gun had ~10-6 breakdown rate and showed low average dark current. We have been analysing emittance measurements and planning to develop a new gun. This plan includes an idea to fabricate the gun consisted of larger number of cells to increase the energy gain. One of possible solutions is a so-called open structure gun. It was shown that this multi-cell gun can provide excellent field balance and mode selection, easy access of laser to the cathode, easy fine tuning, and efficient pumping. The gun can be based on brazeless technology and can have the removable cathode. Additional appealing opportunity to increase the gradient substantially is to operate the gun at cryogenic temperatures.

Acknowledgments:

Plenary / 104

Prospects of Ultralow MTE photocathodes in Electron Guns

Author: Siddharth Karkare[None]

Corresponding Author: ssk226@cornell.edu

Brightness of electron beams is directly proportional to the accelerating electric field at the cathode and inversely proportional to the mean transverse energy (MTE) of electrons emitted from photocathodes. Thus, maximizing the brightness of electron beams requires the use of lowest possible MTE photocathodes in the highest possible electric fields. While the maximum electric field is limited by the electric breakdown and design of the electron gun, the MTE is a property of the cathode material, its surface and the laser used for excitation. MTEs of up to two orders of magnitude lower than those typically used in photoinjectors today have been demonstrated by using atomically ordered surfaces at cryogenic temperatures with photon energy very close to the emission threshold. In this talk, I will discuss the various hurdles in using such low MTE photocathodes in high field electron guns and elaborate on the recent progress towards achieving this.

Acknowledgments:

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WGs 7+8 Joint Session / 105

9.3 microns: Toward next-generation CO₂ laser for particle accelerators

Authors: Mikhail Polyanskiy[1]; Igor Pogorelsky[2]; Marcus Babzien[2]; Rotem Kupfer[3]; William Li[1]; Mark Palmer[1]

[1] *Brookhaven National Laboratory*

[2] *BNL*

[3] *Lawrence Livermore National Laboratory*

Corresponding Author: polyanskiy@bnl.gov

The ATF's long-wave infrared (LWIR) laser produces optical pulses that enable substantially different acceleration regimes compared to near-infrared lasers. A 2 ps pulse duration and 5 TW peak power at 9.2 µm are presently the best demonstrated performance of this laser. This is achieved via chirped-pulse amplification of a microjoule seed pulse in a series of two high-pressure, mixed-isotope CO₂ laser amplifiers operating at the 9R branch of the CO₂ gain spectrum.
Combining the spectral bandwidth of the 9R and 9P branches will reduce the pulse duration to 500 fs while preserving the pulse energy, thus increasing the peak power by a factor of four. The central wavelength of such a laser would be 9.3 µm. One prerequisite for the proposed laser's development is the increase in the energy of a seed laser to a millijoule level. Several schemes for generating high-energy LWIR seed pulses are currently being investigated. Nonlinear post-compression in bulk materials demonstrated recently in the sub-TW LWIR regime has the potential to further reduce the pulse duration to a few optical cycles (one cycle at 9.3 µm is 31 fs).
Achieving reliable 24/7 operation at a high repetition rate for future accelerators requires a quantum leap in the technology for pumping the high-pressure-gas active medium. In this regime, optical pumping at 4.3 or 2.8 µm is a promising alternative to electric discharge pumping. A kilojoule of optical energy must be deposited in the active medium of the CO₂ amplifier within a microsecond for multi-terawatt LWIR operation. Emerging mid-infrared sources, such as Fe:ZnSe laser and GaSb laser diodes, may help to overcome this challenge in the foreseeable future.

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Poster Session and Reception - Board: P38 / **106**

Multi-color operation via coherent harmonic generation in a plasma driven attosecond X-ray source

Authors: Rafi Hessami[1]; Mark Hogan[1]; Kirk Larsen[1]; Agostino Marinelli[1]; River Robles[1]; Claudio Emma[None]

[1] *SLAC National Accelerator Laboratory*

Corresponding Author: rafimah@stanford.edu

The ongoing Plasma-driven Attosecond X-ray source experiment (PAX) at FACET-II aims to produce coherent soft x-ray pulses of attosecond duration using a Plasma Wakefield Accelerator [1]. These kinds of X-ray pulses can be used to study chemical processes where attosecond-scale electron motion is important. As a future upgrade to this concept, we investigate scaling to shorter soft X-ray wavelength by cascading undulators tuned to higher harmonics of the fundamental in a coherent harmonic generation (CHG) configuration. This configuration leverages the increase in the bunching factor of the higher harmonics to produce radiation at the fifth and tenth harmonics, corresponding to radiation wavelengths of 2 nm and 1 nm. In this contribution, we consider two CHG schemes. The first consists of using three 20 period-long undulator stages tuned to the fundamental, the fifth harmonic, and the tenth harmonic respectively, while the second consists of 20 periods at the fundamental, then 40 at the tenth harmonic. We demonstrate in both of these schemes using undulators with retuned fundamental frequencies can produce TW-scale pulses of fifth and tenth harmonic radiation with tens of attosecond-scale pulse lengths, an order of magnitude shorter than current state-of-the-art attosecond XFELs.

[1] C. Emma, X.Xu et al APL Photonics 6, 076107 (2021)

Acknowledgments:

Poster Session and Reception - Board: P39 / **107**

A Compact Source of Positron Beams with Small Thermal Emittance

Authors: Rafi Hessami[1]; Spencer Gessner[2]

[1] *SLAC National Accelerator Laboratory*

[2] *SLAC*

Corresponding Author: rafimah@stanford.edu

We investigate electrostatic traps as a novel source of positron beams for accelerator physics applications. The electrostatic trap is a simple device that accumulates and cools positrons produced by a radioactive source. Using well-established techniques, the positron beam is cooled down to or below room temperature. The thermal beam emittance is an order of magnitude smaller than beams produced by rf photocathodes [1]. The compact positron source can be built and operated at a fraction of the cost of traditional target-based positron sources. Despite these advantages, there are several features of electrostatic trap-based beams which limit their use to specialized applications. In this work, we study the features of positron beams from electrostatic traps. The positron bunch is first accelerated and compressed by an electrostatic buncher before being injected into an rf-cavity for further acceleration. We model the acceleration of the positron bunch up to an energy of 17.57 MeV

with a transverse thermal emittance of 0.45 μm-rad, and bunch length of 0.21 mm. The beamline used in our model is about 1.5 meters long, which is comparable to an rf photocathode source, and far more compact than traditional target-based positron sources.

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Acknowledgments:

Poster Session and Reception - Board: P2 / **108**

Commissioning of BELLA PW second beamline with high-power plasma mirrors and a look towards laser-plasma accelerator staging

Author: Joshua Stackhouse[1]

Co-authors: Anthony Gonsalves [2]; Marlene Turner [2]; Alexander Picksley [2]; Kei Nakamura [3]; Lieselotte Obst-Huebl [3]; Liona Fan-Chiang [1]; Carlo Benedetti [2]; Carl Schroeder [2]; Jeroen van Tilborg [2]; Cameron Geddes [4]; Eric Esarey [4]

[1] *UC Berkeley*

[2] *LBNL*

[3] *Lawrence Berkeley National Lab*

[4] *Lawrence Berkeley National Laboratory*

Corresponding Author: jastackhouse@berkeley.edu

Since its installation in 2012, the petawatt (PW) facility at the Berkeley Lab Laser Accelerator (BELLA) Center primarily focused on the optimization of single-stage GeV-energy laser-plasma accelerators (LPAs). Recently, the PW facility completed an upgrade to install a new second beamline (2BL) and experimental target chamber. The installation of the second beamline enables BELLA PW to simultaneously deliver two high intensity laser pulses to the target area and provides the capability for newly accessible experiments including staging of two GeV-energy laser-plasma accelerators, guiding in optically ionized plasma channels, and two-color ionization injection. This poster will cover the commissioning process for the second beamline, the use of plasma mirrors for beam delivery at high power in the second beamline, and the plans for staging experiments on BELLA PW using the second beamline.

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WGs 1+2 Joint Session / **109**

Mesh refinement in QuickPIC

Authors: Qianqian Su[None]; Fei Li[1]; Weiming An[2]; Yujian Zhao[None]; Lance Hildebrand[1]; Viktor Decyk[1]; Paulo Alves[1]; Ann Almgren[3]; Warren Mori[1]

[1] *UCLA*

[2] *Beijing Normal University*

[3] *Lawrence Berkeley National Lab*

Corresponding Author: xpsqq@g.ucla.edu

The PWFA has emerged as a promising candidate for the accelerator technology used to build a future linear collider and/or light source. In this scheme witness beams are accelerated in the plasma wakefield created by a driver beam. The three-dimensional (3D) quasi-static (QS) particle-in-cell (PIC) approach, e.g., using QuickPIC, has been shown to provide high fidelity simulation capability and 2-4 orders of magnitude speedup over 3D fully explicit PIC codes. In some linear collider designs for the electron arm, the witness beam is accelerated in a wake excited in the blowout regime. In this regime the matched spot size of the witness beam can be 2 to 3 orders of magnitude smaller that spot size of the wakefield. To efficiently simulate such a disparity in length scales requires some mesh refinement capability. We describe a mesh refinement scheme that has been implemented into the 3D QS PIC code, QuickPIC. We use very fine (high) resolution in a small spatial region that includes the witness beam and a progressively coarser resolution in the rest of the simulation domain. A fast multigrid Poisson solver has been implemented for the field solve on the fine mesh. The code has been parallelized with both MPI and OpenMP, and the scalability has also been improved by using pipelining. The effects of the boundary between a course and fine mesh has been studied. We have also developed a preliminary adaptive mesh refinement algorithm for an evolving beam size. Several benchmark cases have been tested and it is found that the mesh refinement algorithm provides good agreement with previously published results and with simulations using a new quasi-3d QS PIC code called QPAD. For round beams QPAD operates as an 2D r-z code and we can use fine resolution throughout the entire simulation domain. Details of the algorithm and results on PWFA simulations will be presented.

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Poster Session and Reception - Board: P3 / **110**

Enhanced Spectral Flux of Synchrotron X-ray Beams from Laser Wakefield Accelerators

Author: Adam Hughes[1]

[1] *Imperial College London*

Corresponding Author: ajh119@ic.ac.uk

Due to the oscillation and subsequent emission of synchrotron radiation of electrons accelerated to GeV-order energies over centimetre scales, laser wakefield accelerators (LWFAs) have produced x-ray beams with a peak spectral flux up to 104 photons/pulse/mrad^2/0.1% BW. In a recent experiment performed by Wood, J. et al., an f/40 parabolic mirror was used to focus a 100 TW laser pulse into a plasma. A particle-in-cell simulation of the LWFA was performed, the accelerated electron trajectories and mometa were tracked and the spectral characteristics of the synchrotron radiation were modelled by calculating the Liènard-Wiechert fields from each tracked electron. Peak flux values over 10^4 photons/pulse/mrad^2/0.1% BW were both measured and simulated, which have not been observed in previous, similar experiments using smaller f-numbers.

From measurements and simulations of different plasma lengths up to 40 mm, the increased x-ray flux is shown to be produced by a sub-GeV electron bunch with a higher number of electrons and a larger oscillation amplitude. These electrons get accelerated to energies below 1 GeV in the laser wakefield after the first electron bunch behind the laser pulse reaches over 2 GeV, before dephasing. The increase in bubble length due to the wakefield of the multi-GeV bunch means that the sub-GeV bunch then gets accelerated at the back of this elongated bubble. The growth in oscillation amplitude of the sub-GeV bunch is studied using existing hose instability models. A hose instability model derived by Mehring, T. et al. [1] best describes the RMS amplitude growth in the simulation to 2 μm before this growth gets damped.

[1] T. Mehrling, R. Fonseca, A. Martinez de la Ossa and J. Vieira, "Mitigation of the Hose Instability in Plasma-Wakefield Accelerators," Physical Review Letters, pp. 1-5, 2017.

Acknowledgments:

Plenary / 111

Acceleration beyond 10 GeV of a 340 pC electron bunch in a 10 cm nanoparticle-assisted wakefield accelerator

Author: Constantin Aniculaesei[1]

Co-authors: Thanh Ha [2]; Samuel Yoffe [3]; Lance Labun [4]; Edward McCary [2]; Michael Spinks [2]; Hernan Quevedo [2]; Ou Labun [2]; Ritwik Sain [2]; Andrea Hannasch [2]; Rafal Zgadzaj [2]; Isabella Pagano [2]; Alexandro Franco Franco [2]; Martin L. Ringuette [2]; Erhard Gaul [2]; Scott V. Luedtke [5]; Ganesh Tiwari [6]; Bernhard Ersfeld [3]; Enrico Brunetti [3]; Hartmut Ruhl [7]; Todd Ditmire [2]; Sandra Bruce [2]; Michael E. Donovan [4]; Michael C. Downer [2]; Dino A. Jaroszynski [3]; Bjorn Manuel Hegelich [8]

[1] *The University of Texas at Austin*

[2] *UT at Austin*

[3] *U of Strathclyde*

[4] *Tau Systems Inc.*

[5] *LANL*

[6] *BNL*

[7] *Ludwig-Maximilians-Universität*

[8] *UT at Austin and Tau Systems Inc.*

Corresponding Author: constantin.aniculaesei@austin.utexas.edu

We present recent results from a proof-of-principle laser-plasma acceleration experiment that reveal a unique synergy between a laser-driven and particle-driven accelerator: a high-charge laser-wakefield accelerated electron bunch can drive a wakefield while simultaneously drawing energy from the laser pulse via direct laser acceleration. This process continues to accelerate electrons beyond the usual decelerating phase of the wakefield, thus reaching much higher energies. We find that the 10-centimeter-long nanoparticle-assisted wakefield accelerator can generate 340 pC, 10.4±0.6 GeV electron bunches with 3.4 GeV RMS convolved energy spread and 0.9 mrad RMS divergence. The nanoparticles control the amount of charge injected in the wakefield. This synergistic mechanism and the simplicity of the experimental setup represent a step closer to compact table-top particle accelerators suitable for applications requiring high charge at high energies, such as radiation sources producing muon and positron beams.

Acknowledgments:

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The contributions of A Hannasch, R Zgazdaj, I Pagano, JA Franco, and MC Downer were supported by the U.S. Department of Energy grant DE-SC0011617. DA Jarozynski, E Brunetti, B Ersfeld, and S Yoffe would like to acknowledge support from the U.K. EPSRC (EP/J018171/1, EP/N028694/1) and the European Union's Horizon 2020 research and innovation program under grant agreements no 871124 Laserlab-Europe and EuPRAXIA (653782). Simulation results were obtained using the ARCHIE-WeSt High-Performance Computer (www.archie-west.ac.uk) based at the University of Strathclyde, and the facilities of the N8 Centre of Excellence in Computationally Intensive Research (N8 CIR) provided and funded by the N8 research partnership and EPSRC (grant number EP/T022167/1), coordinated by the Universities of Durham, Manchester, and York.
Many thanks to Rémi Lehe of Lawrence Berkeley National Laboratory for his support in deploying and optimizing the FBPIC code.

WG2: Computation for Accelerator Physics / 112

Now that we are ready for Exascale, what can we do with it? PIConGPU for next generation accelerator research.

Authors: Michael Bussmann[1]; Alexander Debus[2]; Thomas Kluge[3]; Klaus Steiniger[2]; Rene Widera[4]; Richard Pausch[2]; Ulrich Schramm[4]; Nico Hoffmann[1]; Franz Poeschl[1]; Jan Nikl[1]

[1] *Helmholtz-Zentrum Dresden - Rossendorf*

[2] *Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*

[3] *HZDR*

[4] *Helmholtz-Zentrum Dresden-Rossendorf*

Corresponding Author: m.bussmann@hzdr.de

PIConGPU, like many other codes, is ready for the next Exascale supercomputers. Heterogeneous programming as the main ingredient enables effective use of these machines. Important challenges still ahead are timely analysis of large scale simulation data and complex workflows for multi-physics simulations and machine learning.

As experimental capabilities progress and high-repetition rate sources have become widely available, the role of simulations is shifting. Predictive capabilities are put to the test more often than ever. While simulations for high intensities still push the boundaries of known physics, the task to predict experimental outcomes for sources existing now has become more and more pressing.

The question arises which steps will be necessary to achieve good comparison with experiments. We will present our approach to work closely with experiment, lessons learned from this approach, what can be done better and how Exascale computing might help.

Acknowledgments:

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Research (BMBF) and by the Saxon Ministry for Science, Culture and Tourism (SMWK) with tax funds on
the basis of the budget approved by the Saxon State Parliament.

WGs 1+2 Joint Session / 113

PIConGPU + X – Building blocks for successful Exascale accelerator simulations

Authors: Michael Bussmann[1]; Alexander Debus[2]; Klaus Steiniger[2]; Rene Widera[3]; Thomas Kluge[4]; Richard Pausch[2]; Nico Hoffmann[1]; Ulrich Schramm[3]; Franz Poeschl[1]

[1] *Helmholtz-Zentrum Dresden - Rossendorf*

[2] *Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*

[3] *Helmholtz-Zentrum Dresden-Rossendorf*

[4] *HZDR*

Exascale computing is close to becoming a reality. As technology progresses, it has become clear that heterogeneous computing is going to stay and adapting to new hardware is an ongoing challenge. Since 2015 PIConGPU has paved the way to accelerating plasma simulations across compute

platforms using the Alpaka framework. This has enabled early adaption to new compute hardware and readiness for Exascale compute capabilities.
However, experience has shown that the real challenges are of a different nature. The first is in detailed analysis of the data produced in simulations. Here, we present our current work on I/O, code coupling, visual analytics and large-scale data analytics.
The second, and more pressing challenge, is comparison to experiment. Here, not only has the increasing quality of experiments put more demand on simulation quality, but more and more the damnd for fast, close to real time analysis has grown. This puts high quality simulations to the test, as runs on supercomputers tend to be costly. We present workflows to match experiment and simulations and a future look on how feedback loops between experiment and simulation can be optimized.

Acknowledgments:

This work was partly funded by the Center of Advanced Systems Understanding (CASUS) which is financed by Germany's Federal Ministry of Education and
Research (BMBF) and by the Saxon Ministry for Science, Culture and Tourism (SMWK) with tax funds on
the basis of the budget approved by the Saxon State Parliament.

WGs 4+5 Joint Session / 114

Direct measurements of emittance growth from Coulomb scattering on neutral gas atoms in a plasma lens

Authors: Jonas Björklund Svensson[1]; Lewis Boulton[None]; M. J. Garland[None]; Carl A. Lindstrøm[None]; Felipe Peña[2]; Sarah Schröder[None]; Stephan Wesch[None]; Jonathan Wood[None]; Jens Osterhoff[1]; Richard D'Arcy[None]

[1] *DESY*

[2] *DESY/UHH*

Corresponding Author: jonas.bjorklund-svensson@desy.de

Plasma lenses are of much interest to the plasma-accelerator community as their cylindrically symmetric and large focusing gradients facilitate beam-optics control of the highly divergent beams usually associated with plasma accelerators. However, a fundamental difference between plasma-based and conventional accelerators/focusing devices is that in the former the beams propagate through matter rather than a vacuum. This invariably leads to interactions such as Coulomb scattering between the beam and plasma particles, which in turn likely leads to emittance growth. Whereas the beam sizes inside plasma accelerators are comparatively small, limiting the induced emittance growth, the situation in plasma lenses is quite different as the beam size must be larger in these devices than in the accelerators to allow collimation or focusing. In particular, in active plasma lenses beam sizes must be large to avoid driving a wake, which in turn increases the induced emittance growth from scattering. This is further exacerbated by the fact that using gases of heavier elements, which scatter more strongly than their lighter counterparts, are preferable as they produce linear focusing gradients. However, direct measurements of the induced emittance growth from Coulomb scattering has hitherto not been shown for beam and lens parameters relevant for plasma-based focusing devices. In this work we show the measurements of emittance growth from scattering in neutral (i.e. un-ionized) argon, nitrogen and hydrogen over a range of pressures. Results from a corresponding set of simulations in GEANT4 and Ocelot, which represent the experimental environment, are also outlined.

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WGs 1+8 Joint Session / 115

Spatial temporal couplings and the generation of Stimulated Raman Side Scattering

Authors: Alexander Sävert[1]; Carola Zepter[2]; Andreas Seidel[3]; Matt Zepf[4]; Malte Kaluza[4]

[1] *Helmholtz Institute Jena*

[2] *Friedrich-Schiller-University, Jena, Germany*

[3] *Friedrich-Schiller-University Jena*

[4] *Helmholtz-Institute, Jena, Germany*

Corresponding Author: a.saevert@gsi.de

We report on experiments investigating the influence of spatio-temporal couplings (STCs) in the laser focus on stimulated Raman Side Scattering. We find a discrepancy between measured scattered angles and classical theory. At the same time, the angle changes with propagation of the driving laser pulse. This mismatch can be resolved if the pulse front tilt (PFT) of the laser pulse is taken into account. We developed an analytic model to describe the propagation of a Gaussian laser pulse exhibiting first order STC around the focal plane, which describes the observed behaviour. Using 2D-PIC Simulations we can reproduce the experimental results and observe phase matching between the driving pump pulse, the plasma k-vectors and the scattered light. As a result, the PFT of a laser pulse excites larger plasma k-vectors, which leads to a larger scattering angle.

Acknowledgments:

WG1: Laser-Plasma Wakefield Acceleration / 116

Observation of resonant wakefield excitation by pulse trains guided in long plasma channels

Authors: Aimee Ross[1]; Emily Archer[1]; James Chappell[1]; James Cowley[1]; Linus Feder[1]; Oscar Jakobsson[1]; Harry Jones[2]; Alexander Picksley[1]; Lewis Reid[2]; Wei-Ting (Warren) Wang[1]; Johannes van de Wetering[1]; Nicolas Bourgeois[3]; Laura Corner[2]; Roman Walczak[1]; Simon Hooker[1]

[1] *University of Oxford*

[2] *University of Liverpool*

[3] *Central Laser Facility*

Corresponding Author: aimee.ross@physics.ox.ac.uk

The multi-pulse laser wakefield acceleration (MP-LWFA) scheme [1] provides a route for GeV-scale accelerators operating at kilohertz-repetition-rates driven by picosecond-duration laser pulses such as those available from thin-disk lasers. We recently published theoretical work proposing a new scheme of GeV accelerator based on MP-LWFA, which we call the Plasma-Modulated, Plasma Accelerator (P-MoPA) [2]. In this scheme, trains of pulses are generated from a long, high-energy drive pulse via the spectral modulation caused by a low amplitude wakefield driven by a leading short, low-energy seed pulse. Our simulations show that temporal compression of the modulated drive pulse yields a pulse train that can resonantly drive a wakefield, allowing for acceleration of a test electron bunch to 0.65 GeV in a 100 mm long plasma channel [2].
In earlier work we demonstrated resonant excitation of a plasma wakefield in a 4 mm long gas cell by a train of N ~ 7 laser pulses [3]. In the present work we investigate resonant excitation of plasma waves by trains of N ~ 10 pulses guided in a long hydrodynamic optical-field-ionized (HOFI) plasma channel [4-6].
We present the results of recent experiments with the Astra-Gemini TA3 laser at the Central Laser Facility for parameters relevant to the accelerator stage of the P-MoPA scheme. We demonstrate

guiding of 2.5 J pulse trains in a 100 mm long plasma channel. Measurements of the spectrum of the transmitted laser pulse train show that a wakefield was resonantly excited in the plasma channel. We compare these experimental results with numerical simulations, which allows us to deduce the acceleration gradient of the plasma wakefield driven by the guided pulse train.
To our knowledge, these results are the first demonstration of resonant excitation of a plasma wakefield in a plasma channel.

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WG6: Laser-Plasma Acceleration of Ions / 117

Ion acceleration and neutron generation with few-cycle, relativistic intensity laser pulses

Authors: Karoly Osvay[1]; M. Füle[2]; T. Gilinger[2]; B. Kis[2]; P.K. Singh[2]; S. Ter-Avetisyan[2]; P. Varmazyar[2]; B. Biro[3]; L. Csedreki[3]; Zs. Dombrádi[3]; Z. Elekes[3]; A. Fenyvesi[3]; Zs. Fülöp[3]; Z. Halasz[3]; Z. Korkulu[4]; I. Kuti[3]; L. Stuhl[4]; A. Bembibre[5]; J. Benlliure[5]; J. Penas[5]; A. Borzsonyi[6]; J. Csontos[6]; A. Farkas[6]; A. Mohacsi[2]; T. Somoskői[6]; G. Szabó[6]; Sz. Tóth[6]

[1] *National Laser-Initiated Transmutation Laboratory, University of Szeged, Hungary*

[2] *National Laser-Initiated Transmutation Laboratory, University of Szeged, Szeged, Hungary*

[3] *Institute for Nuclear Research (ATOMKI), Debrecen, Hungary*

[4] *Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon, Korea*

[5] *Universidade de Santiago de Compostela, Santiago de Compostela, Spain*

[6] *ELI-ALPS Research Institute, ELI-HU Non-Profit Ltd., Szeged, Hungary*

Corresponding Author: osvay@physx.u-szeged.hu

Most of the ion acceleration experiments have been carried out with multi-cycle, Joule-class lasers in the TNSA and RPA regime. The recent developments of few-cycle laser systems with 100 W average power created the technological basis for the generation of ion current of tens of microA consisting of ultrashort particle bunches– something that many applications dream of. Here we present an experimental study of proton and deuteron acceleration in both forward and backward directions with ~30mJ, 12 fs laser pulses. With the use of adaptive mirror, the focused intensity of such laser pulses reaches ~10^19W/cm^2 intensity on target.
Protons were accelerated on thin foils made of various materials, with thicknesses ranging from 5 nm to 9 microns. The highest cut-off energy and conversion efficiency was 1.5 MeV, and 1.5 %, respectively, with a beam emittance as small as 0.00032 π-mm-mrad.
Deuterons were accelerated close to MeV by irradiating homemade 200 nm thin deuterated polyethylene foils on a rotating wheel target system. The laser was run at 1 Hz repetition rate in bursts of 75 shots. With a systematic change of the dispersion of the laser pulse, we have revealed that the optimum conditions for achieving the highest cut-off energy particles and the highest conversion efficiency of a particle bunch are significantly different.
The accelerated deuterons hit a 0.1 mm thick deuterated polyethylene disk and induced neutrons with a mean energy of 2.45 MeV. From the ToF signals of four plastic scintillators at various angles

around the chamber, we have concluded that an average of ~4000 fast neutrons were generated in a shot. With the development of high repetition rate primary-target systems including thickness optimization, the yield of neutrons in a second may exceed what can be achieved with state-of-the-art PW class lasers.

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WGs 1+2 Joint Session / 118

Accompanying the hybrid LPWFA experiment campaign with a computer simulation campaign: What we model, what we learn, and where we need to become better

Authors: Klaus Steiniger[1]; Richard Pausch[1]

Co-authors: Alastair Nutter [2]; Alberto Martinez de la Ossa [3]; Alexander Debus [1]; Alexander Knetsch ; Andreas Döpp [4]; Arie Irman [1]; Bernhard Hidding [2]; Florian Haberstroh [4]; Jurjen Couperus-Cabadag [1]; Maxwell LaBerge ; Michael Bussmann [5]; Moritz Foerster [4]; Olena Kononenko [6]; Patrick Ufer [1]; Ralph Assmann [3]; Sebastien Corde [6]; Stefan Karsch [7]; Susanne Schoebel [1]; Thomas Heinemann [8]; Ulrich Schramm [9]; Yen-Yu Chang [1]

[1] *Helmholtz-Zentrum Dresden-Rossendorf*

[2] *University of Strathclyde*

[3] *DESY*

[4] *LMU München*

[5] *CASUS, HZDR*

[6] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[7] *LMU Munich*

[8] *University of Strathclyde / DESY*

[9] *HZDR, TU Dresden*

Corresponding Author: k.steiniger@hzdr.de

The Hybrid Collaboration, a joint undertaking by HZDR, DESY, University of Strathclyde, LMU, and LOA, performed hybrid LPWFA experiments which utilize electron bunches from a laser wakefield accelerator (LWFA) as drivers of a plasma wakefield stage (PWFA) to demonstrate the feasibility of compact PWFAs serving as a test bed for the efficient investigation and optimization of PWFAs and their development into brightness boosters. To better understand the microscopic, nonlinear dynamic of these accelerators, the experiments were accompanied by 3D3V particle-in-cell simulations using PIConGPU.

Here, we present insights into the dynamics of the hybrid LPWFA that we gained from start-to-end simulations of the experimental setup at HZDR.
These regard electron injections due to hydrodynamic shocks, beam self-modulation and breakup, and cavity elongation - all backed-up by synthetic diagnostics that allow direct comparison with experimental measurements.
We discuss our approach to model these synthetic diagnostics directly within the PIConGPU simulation as well as modelling certain aspects of the experimental setup, such as the drive laser. Continuing this, the talk highlights a few recent technical advances in PIConGPU that enable better modelling of the micro-physics, experiment conditions, or signals of experiment diagnostics.

Acknowledgments:

Plenary / 119

RadiaBeam and lessons learned building an accelerator company

Authors: Sergey Kutsaev[1]; Alex Murokh[1]; Salime Boucher[1]

[1] *RadiaBeam Technologies, LLC*

Corresponding Author: kutsaev@radiabeam.com

The advanced accelerator community is well familiar with high-risk initiatives, which has led to multi-decade development programs before concepts are realized. What is less obvious is that building an accelerator company requires continuous development on a similar time scale, and is not entirely dissimilar in nature. RadiaBeam was spun off in 2004 from UCLA's advanced accelerator laboratory, and its foundation was in many ways an experiment, in and of itself. Just like in many advanced accelerator projects, the founders overestimated the progress that could be made in a few years; and yet completely underestimated the success that can be achieved in over a decade. By 2022 RadiaBeam became a vital part of the world accelerator community, contributing to the advancement of accelerator technology and applications in research, industry, medicine, and security. Unique among small accelerator manufacturers, RadiaBeam performs its own design, engineering, manufacturing, tuning, and testing, including "hot" testing, in-house. Yet, despite a considerable degree of self-sufficiency, RadiaBeam remains an organic part of the accelerator community and is ever more dependent on the ideas, skills, and sense of purpose propelling the entire field. Most of RadiaBeam's capabilities have been developed in collaboration with US national laboratories and universities under the realm of the DOE Small Business Innovation Research (SBIR) program.
Many RadiaBeam products are currently in service in laboratories, hospitals, and universities around the world. On the other hand, many of our R&D projects have either failed, or never been completed, or never obtained any traction with the market or funding agencies, and many important capabilities the company had aspired to achieve have yet to be realized. This necessary hard work of trial and error inevitably expresses itself in the ponderomotive nature of the company's growth and defines the long-term vision of RadiaBeam's mission as a business, and as a partner to the larger US accelerator community.
In this talk, we will discuss the company's development history, the role of the U.S. SBIR/STTR programs, the successes and failures of developing products for National Laboratories and industrial customers, and the fine balance between R&D and industrial production activities.

Acknowledgments:

WGs 1+8 Joint Session / 120

The BELLA PW iP2&2BL Upgrades – Radiation and Laser Safety considerations and implementations for safe and efficient user experiments

Authors: Csaba Toth[1]; Anthony Gonsalves[1]; Kei Nakamura[2]; Lieselotte Obst-Huebl[2]; Marlene Turner[3]; Alexander Picksley[3]; Sahel Hakimi[1]; Joshua Stackhouse[4]; Zachary Harvey[1]; Greta Toncheva[1]; Jeroen van Tilborg[1]; Carl Schroeder[1]; Cameron Geddes[1]; Eric Esarey[1]

[1] *Lawrence Berkeley National Laboratory*

[2] *Lawrence Berkeley National Lab*

[3] *LBNL*

[4] *UC Berkeley*

Corresponding Author: ctoth@lbl.gov

After a decade-long successful operations [1] and producing new results in the field of Laser Plasma Acceleration (LPA) research [2-4] by the Berkeley Lab Laser Accelerator (BELLA), the PW laser system's recent upgrades were completed in 2022. The first is the "Second Beamline" (PW-2BL), where

the fully amplified, stretched pulses are split before compression, enabling two independently adjustable laser pulses to interact with a variety of target arrangements in one target chamber with up to ~40 J total energy. The new BELLA PW 2BL provides the opportunity to conduct the next generation of LPA experiments, such as staging, laser-driven waveguides for increased electron energy, and positron acceleration. The other upgrade is labeled as "Interaction Point #2" (PW-iP2) [5], in which the already compressed PW laser pulses of the original beamline are transported (via a 1:1 reflective telescope using two long focal length OAPs) to a new target chamber allowing a short focal length (0.5 m) arrangement resulting in a small focal spot in the order of ~ 3 um and high laser intensity of >5×10^21 W/cm^2.
An overview of the special considerations, planning and implementation processes related to radiation shielding, laser and radiation interlock systems required for the safe and efficient operation of the new BELLA PW beamlines and conduction of the planned experiments will be presented. Specific topics include: analysis of hazards, development of appropriate hazard mitigation strategies, design details of new shielding components, radiation field monitoring, and interlocked radiation detector and laser beam shutter systems, conditions for high power operations – all matched to the expected particle beam parameters in new experiments.
This work was supported by the U.S. Department of Energy Office of Science, Offices of High Energy Physics and Fusion Energy Sciences under Contract No. DE-AC02–05CH11231. Commissioning experiments for iP2 are supported by LaserNetUS.

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WG4: Beam-Driven Acceleration / 121

Progress towards high-repetition-rate operation of a beam-driven plasma wakefield accelerator

Author: James Chappell[1]

Co-authors: Judita Beinortaite ; Gregory Boyle [2]; Severin Diederichs [3]; Brian Foster [1]; J. M. Garland ; Pau González Caminal ; Carl A. Lindstrøm ; Gregor Loisch ; Siegfried Schreiber [2]; Sarah Schröder ; Rob Shalloo [2]; Maxence Thévenet [2]; Stephan Wesch ; Matthew Wing [4]; Jens Osterhoff [2]; Richard D'Arcy

[1] *University of Oxford*

[2] *DESY*

[3] *DESY / LBNL*

[4] *University College London*

Corresponding Author: james.chappell@physics.ox.ac.uk

Beam-driven plasma-wakefield accelerators offer significant potential as compact, high-gradient, high-quality accelerators, either as the basis of a future plasma-based facility or as an 'after-burner' stage appended to conventional accelerators to boost their peak energy. To maximise applicability of such devices, plasma-based accelerators must be capable of operating at repetition-rates consistent with, or exceeding, existing state-of-the-art conventional accelerator facilities. This contribution discusses results obtained at the FLASHForward experiment at DESY: a plasma-wakefield-acceleration experiment driven by the FLASH accelerator, which is capable of providing nC-level, GeV-scale electron bunches to the plasma accelerator stage at up to 3 MHz repetition rates. Of these results, the

definition of the maximum possible repetition rate of a plasma-wakefield accelerator, as dictated by the time it takes for the plasma to recover to its initial state after a wakefield has been driven, will be highlighted. This result—indicating that repetition rates at the level of O(10 MHz) are attainable in future—makes it worthwhile to consider a high-repetition-rate after-burner stage for FLASH. This contribution will conclude with further results and concepts of how to achieve this goal.

Acknowledgments:

Poster Session and Reception - Board: F79 / **122**

Beam stability and reproducibility of a plasma-wakefield accelerator

Authors: Sarah Schröder[None]; Judita Beinortaite[None]; Lewis Boulton[None]; J. M. Garland[None]; Pau González Caminal[None]; Carl A. Lindstrøm[None]; Gregor Loisch[None]; Jonas Björklund Svensson[1]; Jonathan Wood[None]; Stephan Wesch[None]; Jens Osterhoff[1]; Richard D'Arcy[None]

[1] *DESY*

Corresponding Author: sarah.schroeder@desy.de

Beam-driven plasma-wakefield acceleration has the potential to significantly reduce the footprint of future linear colliders and free-electron lasers. Such applications place stringent demands on beam quality and stability. While great strides have been made towards the preservation of incoming transverse and longitudinal beam quality, first applications now require demonstration of useful shot-to-shot reproducibility and stable continuous operation over many days. Driven by the superconducting linear accelerator of the free-electron laser FLASH, FLASHForward is keenly positioned to identify limiting factors for stability in beam-driven plasma-wakefield accelerators. In this contribution, the state-of-the-art beam stability and reproducibility at the FLASHForward facility is presented and its limitations discussed.

Acknowledgments:

WG1: Laser-Plasma Wakefield Acceleration / 123

Laser Wakefield Acceleration to Electron Energies in the GeV Regime

Authors: Katinka von Grafenstein[1]; Stefan Karsch[1]

[1] *LMU Munich*

Corresponding Author: katinka.grafenstein@physik.uni-muenchen.de

For the creation of matter-antimatter pairs from the quantum vacuum via the Breit-Wheeler effect, an intense laser and energetic γ-rays need to interact with each other. At the Stanford Linear Accelerator Center the Breit-Wheeler experiment in the perturbative regime has been accomplished in 1997 but was not yet implemented in the non-perturbative regime, where the laser strength parameter a0»1 and pair production occurs when an electron from the negative energy Dirac-sea tunnels to positive energy levels. This experiment is at the moment in preparation in a fully laser-driven set-up with the ATLAS3000 laser at the Centre for Advanced Laser Applications in Munich. Laser Wakefield Acceleration (LWFA) will be used to accelerate electrons to high energies. This high energy electron beam will be sent onto a Bremsstrahlung converter to generate γ-rays that will interact with the intense laser. An electron beam with multi-GeV energies is needed for this. LWFA has been improved to reach multi-GeV electron energies in the recent years. However, building a reliable and stable source with low divergence and low pointing jitter with quasi-monoenergetic bunches over

2 GeV, as is needed for the Breit-Wheeler experiment, still holds challenges. Essential is the careful design of gas targets. These have to provide homogeneous gas densities over a distance of a few centimeters. In preparation for the Breit-Wheeler experiment, Computational Fluid Dynamic simulations were conducted to design centimeter-long gas nozzles. First LWFA results can be shown with electron energies reaching over 1.5 GeV using these nozzles and energies reaching over 2 GeV with a gas cell as target. Moreover, different injection techniques using these nozzles, or the gas cell were tested with the goal to obtain quasi-monoenergetic electron bunches in the GeV regime.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / 124

High Power Test Results of X-Band Dielectric Disk Accelerating Structures

Author: Ben Freemire[1]

Co-authors: Charles Whiteford [2]; Chunguang Jing ; D.S. Doran [2]; Eric Wisniewski [2]; Jiahang Shao [2]; John Power ; Sarah Weatherly [3]; Shashi Poddar [1]; Wanming Liu [2]

[1] *Euclid Beamlabs*

[2] *Argonne National Laboratory*

[3] *Illinois Institute of Technology, Argonne National Laboratory*

Corresponding Author: b.freemire@euclidtechlabs.com

As part of the Argonne 500 MeV short pulse Two Beam Wakefield Acceleration Demonstrator, several single cell X-band dielectric disk loaded accelerators (DDA) have been designed, fabricated, and tested at high power at the Argonne Wakefield Accelerator. The DDA should provide a short pulse (~20 ns) high gradient (>100 MV/m) accelerator while maintaining a reasonable r/Q and high group velocity. This will allow a larger RF-to-beam efficiency than is currently possible for conventional accelerating structures. Low loss ceramics with $\varepsilon_r \approx 50$ were selected based on simulation studies to optimize the RF-to-beam efficiency. One brazed and one clamped structure have been tested at high power, with the clamped structure reaching >100 MV/m accelerating gradient. The results of the high power tests will be presented.

Acknowledgments:

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WGs 4+5 Joint Session / 125

Longitudinal bunch shaping using transverse deflecting cavities at Argonne Wakefield Accelerator Facility

Author: Seongyeol Kim[1]

Co-authors: Chunguang Jing ; D.S. Doran [1]; Earnest Knight [2]; Eric Wisniewski [1]; Gonxiaohui Chen [1]; John Power ; Philippe Piot [3]; Sergey Kuzikov [4]; Wanming Liu [1]

[1] *Argonne National Laboratory*

[2] *Euclid Techlabs*

[3] *Northern Illinois University*

[4] *Euclid Techlabs, LLC*

Corresponding Author: seongyeol.kim@anl.gov

Longitudinal bunch shaping based on transverse deflecting cavities (TDCs) was first proposed in Tech. Rep. No. LBNL-2670E, 2009 and further elaborated in Phys. Rev. Accel. Beams 23, 072803, 2020. Bunch shaping takes place in a straight beamline configuration of TDCs and a shaping mask. Two potential advantages of TDC-based shaping, over other shaping methods, is that it does not use dipole magnets so it is CSR-free and it shapes an ultra-relativistic beam so space charge is minimized. In this paper, we will show a variety of longitudinal bunch shapes, and discuss the possible applications for high-gradient, beam-driven wakefield accelerators such as high-transformer ratio and quality preservation of the accelerated beam.

Acknowledgments:

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Poster Session and Reception - Board: P40 / **126**

Measurement of coherent substructures within laser-wakefield-accelerated electron beams

Authors: Maxwell LaBerge[None]; Omid Zarini[1]; Alex Lumpkin[2]; Andrea Hannasch[3]; Rafal Zgadzaj[3]; Brant Bowers[4]; Jurjen Couperus-Cabadag[5]; Yen-Yu Chang[5]; Susanne Schoebel[5]; Patrick Ufer[5]; Richard Pausch[5]; Alexander Debus[5]; Ulrich Schramm[6]; Arie Irman[5]; Michael Downer[4]

[1] *HZDR*

[2] *FNAL*

[3] *UT at Austin*

[4] *The University of Texas at Austin*

[5] *Helmholtz-Zentrum Dresden-Rossendorf*

[6] *HZDR, TU Dresden*

Corresponding Author: max.laberge@utexas.edu

Electron beams exiting laser wakefield accelerators (LWFAs) can have complicated substructures based on injection and interactions with the laser and accelerating cavity. Such structures could effectively pre-bunch the beam for a free electron laser (FEL). This would not only shorten the undulator length necessary for self-amplified spontaneous emission, but also improve the longitudinal coherence of the FEL . Indeed, the injection process can even be tailored to pre-modulate LWFA electron beams for just this purpose [1]. For such a goal to be realized, these microstructures must be measured and their origins understood. Here we use multispectral coherent optical transition radiation (COTR) imaging to experimentally diagnose LWFA accelerated electron beams. COTR is sensitive to the portion of the beam that is bunched at the measured wavelength. Multispectral

imaging obtains Fourier components of the microbunched substructure that help reveal composite features of the ensemble beam. These observed features correspond to features observed in PIC simulations. We have measured COTR from three different injection regimes – down-ramp, ionization, and self-injection – and identified characteristic radiation patterns from each regime. We identify likely origins of these structures in the LWFA process. Using information contained within these patterns we comment on the shape of the beam as well as the microstructures present. Using physically reasonable assumptions, we present a three-dimensional spatial reconstruction of the coherent portion of the beam.

[1] Xu, Xinlu, et al. "Generation of ultrahigh-brightness pre-bunched beams from a plasma cathode for X-ray free-electron lasers." Nature communications 13.1 (2022): 1-8.

Acknowledgments:

WGs 2+4 Joint Session / 127

Optimization of transformer ratio and beam loading in plasma wakefield accelerator with a structure-exploiting algorithm

Authors: Qianqian Su[None]; Jeffrey Larson[1]; Thamine Dalichaouch[2]; Fei Li[2]; Weiming An[3]; Lance Hildebrand[2]; Yujian Zhao[None]; Viktor Decyk[2]; Paulo Alves[2]; Stefan Wild[1]; Warren Mori[2]

[1] *Argonne National Laboratory*

[2] *UCLA*

[3] *Beijing Normal University*

Corresponding Author: xpsqq@g.ucla.edu

Plasma-based acceleration has emerged as a promising candidate as an accelerator technology for a future linear collider or a next-generation light source. We consider the plasma wakefield accelerator (PWFA) concept where a plasma wave wake is excited by a particle beam and a trailing beam surfs on the wake. For a linear collider, the energy transfer from the drive beam to the wake and from the wake to the trailing beam must be large, while the emittance and energy spread of the trailing bunch must be preserved. One way to simultaneously achieve this for accelerating electrons is to use longitudinally shaped bunches and nonlinear wakes. In the linear regime, there is an analytical formalism to obtain the optimal shapes. In the nonlinear regime, however, the optimum shape of the driver to maximize the energy transfer efficiency cannot be precisely obtained as there is at present no theory that describes the wake structure and excitation process for all degrees of nonlinearity, and because the plasma electron response at the beginning of the drive beam transitions from a linear to a nonlinear behavior. We present results using a novel optimization method to effectively determine a current profile for the drive and trailing beam in PWFA that provides low energy spread, low emittance, and high acceleration efficiency. We parameterize the longitudinal beam current profile as a piecewise linear function and define optimization objectives. For the trailing beam the algorithm converges quickly to a nearly inverse trapezoidal trailing beam current profile similar to that predicted by the ultra-relativistic limit of the nonlinear wakefield theory. For the drive beam, the algorithm-searched optimal beam profile in the nonlinear regime that maximizes the transformer ratio also resembles that predicted by linear theory. The current profiles found from the optimization method provide a higher transformer ratio compared with the linear ramp predicted by the relativistic limit of the nonlinear theory. We will present details of the optimization procedure and results on obtaining high energy transfer efficiency in a PWFA two bunch accelerator stage.

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WG5: Beam Sources, Monitoring, and Control / 128

Beam shaping using an ultra-high vacuum multileaf collimator and emittance exchange beamline

Authors: Nathan Majernik[None]; Gerard Andonian[1]; Walter Lynn[2]; Seongyeol Kim[3]; C Lorch[2]; Ryan Roussel[4]; D.S. Doran[3]; Eric Wisniewski[3]; Charles Whiteford[3]; Philippe Piot[None]; John Power[None]; James Rosenzweig[None]

[1] *UCLA / RadiaBeam*

[2] *UCLA*

[3] *Argonne National Laboratory*

[4] *SLAC National Accelerator Laboratory*

Corresponding Author: nmajernik@g.ucla.edu

We report the development of a multileaf collimator (MLC) for charged particle beams, based on independently actuated tungsten strips which can selectively scatter unwanted particles. The MLC is used in conjunction with an emittance exchange beamline to rapidly generate highly variable longitudinal bunch profiles. The developed MLC consists of 40 independent leaves that are 2 mm wide and can move up to 10 mm, and operates in an ultra high vacuum environment, enabled by novel features such as magnetically coupled actuation. An experiment at the Argonne Wakefield Accelerator, which previously used inflexible, laser-cut masks for beam shaping before an emittance exchange beamline, was conducted to test functionality. The experiment demonstrated myriad transverse mask silhouettes, as measured on a scintillator downstream of the MLC and the corresponding longitudinal profiles after emittance exchange, as measured using a transverse deflecting cavity. Rapidly changing between mask shapes enables expeditious execution of various experiments without the downtime associated with traditional methods. The many degrees of freedom of the MLC can enable optimization of experimental figures of merit using feed-forward control and advanced machine learning methods.

Acknowledgments:

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WG5: Beam Sources, Monitoring, and Control / 129

Single-shot, transverse self-wakefield reconstruction from screen images

Authors: Nathan Majernik[None]; Walter Lynn[1]; Gerard Andonian[2]; T Xu[3]; Philippe Piot[None]; James Rosenzweig[None]

[1] *UCLA*

[2] *UCLA / RadiaBeam*

[3] *NIU*

Corresponding Author: nmajernik@g.ucla.edu

A method to reconstruct the transverse self-wakefields acting on a beam, based only on screen images, is introduced. By employing derivative-free optimization, the relatively high-dimensional parameter space can be efficiently explored to determine the multipole components up to the desired order. This technique complements simulations, which are able to directly infer the wakefield composition. It is applied to representative simulation results as a benchmark and also applied to experimental data on skew wake observations from dielectric slab structures.

Acknowledgments:

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WGs 4+7 Joint Session / 130

Positron Driven High-Field Terahertz Waves via Dielectric Wakefield Interaction

Authors: Nathan Majernik[None]; Gerard Andonian[1]; Oliver Williams[2]; B O'Shea[None]; P Hoang[None]; C Clarke[None]; Mark Hogan[3]; V Yakimenko[None]; James Rosenzweig[None]

[1] *UCLA / RadiaBeam*

[2] *UCLA*

[3] *SLAC National Accelerator Laboratory*

Corresponding Author: nmajernik@g.ucla.edu

Advanced acceleration methods based on wakefields generated by high energy electron bunches passing through dielectric-based structures have demonstrated >GV/m fields, paving the first steps on a path to applications such as future compact linear colliders. For a collider scenario, it is desirable that, in contrast to plasmas, wakefields in dielectrics do not behave differently for positron and electron bunches. In this article, we present measurements of large amplitude fields excited by positron bunches with collider-relevant parameters (energy 20 GeV, and 0.7x10^10 particles per bunch) in a 0.4 THz, cylindrically symmetric dielectric structure. Interferometric measurements of emitted coherent Cerenkov radiation permit spectral characterization of the positron-generated wakefields, which are compared to those excited by electron bunches. Statistical equivalence tests are incorporated to show the charge-sign invariance of the induced wakefield spectra. Transverse effects on positron beams resulting from off-axis excitation are examined and found to be consistent with the known linear response of the DWA system. The results are supported by numerical simulations and demonstrate high-gradient wakefield excitation in dielectrics for positron beams.

Acknowledgments:

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WGs 2+7 Joint Session / 131

Near-Field CTR beam focusing and its application to Strong Field QED

Authors: Pablo San Miguel[1]; E-332 collaboration[2]

[1] *Laboratoire d'Optique Appliquée / Instituto Superior Técnico*

[2] *Institut Polytechnique de Paris, Max Plank Institute für Kernphysik, CEA, SLAC National Accelerator Laboratory, University of California Los Angeles, University of Colorado Boulder, University of Oslo, StonyBrook University*

Corresponding Author: pablo.san-miguel-claveria@polytechnique.edu

It has been recently shown that a high-current ultrarelativistic electron beam can undergo strong self-focusing due to the Near-Field Coherent Transition Radiation (NF-CTR) emitted when interacting with multiple submicrometer-thick conducting foils [A. Sampath *et al.*, Phys. Rev. Lett. 126, 064801 (2021)]. Particle-In-Cell simulations show that this self-focusing phenomenon is accompanied by efficient emission of gamma-ray synchrotron photons, leading to femtosecond collimated photon beams with number density exceeding that of a solid. Yet, this scheme requires beam parameters that

have not been experimentally achieved in an accelerator facility. In this talk we will present a study, based on analytical models and PIC simulations, that shows that with realistic beam parameters (such as the nominal beam parameters of FACET-II) we can achieve strong electron beam self-focusing in beam-multifoil collisions as well as to convert more than 10% of the beam energy into gamma rays.

Furthermore, the relative simplicity, unique properties, and high efficiency of this gamma-ray source open up new opportunities for both applied and fundamental research including laserless investigations of strong-field QED processes with a single electron beam. This talk will present the results of a simulation study that shows the potential of the NFCTR process to reach EM fields exceeding the Schwinger field strength in the electron rest frame, thus creating electron-positrons pairs that could be experimentally measured [A. Matheron et al., arXiv:2209.14280]. We will discuss several physical processes taking place during the beam-plasma collision such as field ionization when starting from a solid foil, plasma transparency when the bunch length is too small, excitation of a blowout cavity in the bulk of the plasma for overdense electron beams, and the influence of the beam shape on the reflection process.

Acknowledgments:

WGs 2+4 Joint Session / 132

Spatiotemporal dynamics of beam-plasma instabilities in the ultra-relativistic regime

Authors: Pablo San Miguel[1]; E-305 collaboration[2]

[1] *Laboratoire d'Optique Appliquée / Instituto Superior Técnico*

[2] *Institut Polytechnique de Paris, Max Plank Institute für Kernphysik, CEA, SLAC National Accelerator Laboratory, University of California Los Angeles, University of Colorado Boulder, University of Oslo, StonyBrook University*

Corresponding Author: pablo.san-miguel-claveria@polytechnique.edu

Relativistic beam-plasma instabilities play a crucial role in high-energy astrophysical sources, such as gamma-ray bursts or blazars, in particular to create the electromagnetic turbulence responsible for the synchrotron emission of accelerated particles in these sources. These instabilities are also important in certain experimental concepts of particle accelerators or ultra-intense photonic sources based on beam-plasma or laser-plasma interaction [A. Benedetti et al., Nat. Photon. 12, 319 (2018)].

In order to characterize, for the first time in the laboratory, their dynamics in the ultra-relativistic regime and their potential as sources of gamma radiation, a series of experiments (named E-305) is planned on the new accelerator FACET-II of the SLAC National Accelerator Laboratory. As part of this project, we will present a theoretical study of the evolution of the instabilities in the presence of a finite size beam as produced by an accelerator. A novel theory describing the spatiotemporal dynamics of electrostatic oblique modes will be presented [P. San Miguel Claveria et al., Phys. Rev. Research 4, 023085 (2022)]. For an ultra-relativistic beam, this model reveals, in good agreement with particle-in-cell simulations, the intrinsic spatiotemporal character of the instability, thus disproving the usual theories which suppose a purely temporal growth. Finally, we will determine the conditions for the instabilities to dominate over the beam self-focusing dynamics due to plasma wakefield excitation.

Acknowledgments:

WGs 4+7 Joint Session / 133

First X-ray and Gamma-ray measurements at FACET-II

Authors: Pablo San Miguel[1]; E-300 collaboration[2]; E-305 collaboration[3]; E-320 Collaboration[4]

[1] *Laboratoire d'Optique Appliquée / Instituto Superior Técnico*

[2] *SLAC National Accelerator Laboratory, University of California Los Angeles, Institut Polytechnique de Paris, University of Colorado Boulder, University of Oslo, StonyBrook University*

[3] *Institut Polytechnique de Paris, Max Plank Institute für Kernphysik, CEA, SLAC National Accelerator Laboratory, University of California Los Angeles, University of Colorado Boulder, University of Oslo, StonyBrook University*

[4] *Carleton University, Aarhus University, Ecole Polytechnique, Max-Plank-Institute fur Kernphysik, Helmholtz-Institute Jena, Universidade de Lisboa, Imperial College London, Queen's University Belfast, California Polytechnic State University, Lawrence Livermore National Laboratory, SLAC National Accelerator Laboratory, Stanford University, University of California Los Angeles, Universidad de Colorado Boulder, University of Nebraska - Lincoln*

Corresponding Author: pablo.san-miguel-claveria@polytechnique.edu

The upgraded Facility for Advanced Accelerator Experimental Tests (FACET-II) at SLAC has started delivering the first electron beams for the initial phase of several experimental campaigns hosted at the facility. During these first runs, the users have been able to test and commission different elements of their set-up, but also to obtain preliminary data to characterise the experimental conditions. For most of these experiments, the X-ray and gamma radiation detectors installed at the end of the FACET-II beam line have provided a very useful insight of the different beam-plasma and beam-laser interactions. In this talk we will present the initial design, commissioning phase, and first preliminary data of the X-ray and gamma radiation diagnostics taken during these initial runs.

This presentation will cover the use of these detectors in the context of three different experiments. First, the E300 (PWFA) experiment~[C. Joshi \emph{et al.}, Plasma Phys. Control. Fusion 60, 034001 (2018)] will rely on these detectors to measure the matching dynamics of the accelerated trailing beam in the plasma~[P. San Miguel Claveria \emph{et al.}, Phil. Trans. R. Soc. A 377, 20180173 (2019)]. During the initial runs, a beam-ionised H_2 plasma of several meters of length was used to produce betatron radiation and measure it with the detectors, enabling the characterisation of the spatial and spectral distribution of the radiation at different plasma densities. This, together with the comparison of the data taken at FACET-I, confirms the physical basis of the working principle of the detectors. Similarly, in the context of the E305 experiment (Beam filamentation and bright gamma-ray bursts) the radiation produced in the beam-plasma interaction using a laser-ionised high density plasma has been measured at different gas-jet backing pressures. Finally, preliminary measurements of the bremsstrahlung radiation emitted in the interaction of the electron beam with solid foils and inverse-Compton radiation emitted in the beam-laser collision (E320, Strong-Field QED experiment) will be presented.

Acknowledgments:

Poster Session and Reception - Board: P51 / **134**

THz Smith-Purcell Radiation from Laser Wakefield Accelerated Electron Bunches

Author: Ross Rudzinsky[1]

Co-authors: Alexander Debus [2]; Jan-Christoph Deinert [3]; Arie Irman [3]; John Michael Klopf [3]; Maxwell LaBerge ; Sergey Kovalev [3]; Michael C. Downer [4]; Thomas E. Cowan [5]

[1] *The University of Texas at Austin*

[2] *Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*

[3] *Helmholtz-Zentrum Dresden-Rossendorf*

[4] *UT at Austin*

[5] *HZDR, TU Dresden*

Corresponding Author: rrudzinsky@utexas.edu

Smith-Purcell Radiation (SPR) is a special case of diffraction radiation produced when a charged particle passes just over the top of a grating surface. The wavelength of emitted radiation is dispersed as a function of angle and order. Laser Wakefield Accelerators (LWFAs) produce highly-energetic, temporally-short electron bunches that could provide an unusually strong, coherent, superradiant source of SPR in the THz regime for nonlinear optical applications. I will present calculations showing that 300 MeV, 0.5 nC, 10 fs electron bunches (common LWFA beam parameters at Helmholtz-Zentrum Dresden-Rossendorf) paired with a chosen metallic grating can produce a pulse of light with a central frequency of 30 THz and a peak electric field strength close to 100 MV/cm (assuming full coherence of electron bunch, a 2° collection angle, and pulse duration of 100 fs). With such a field strength, nonlinear processes such as high-harmonic generation from Graphene or topological insulators and THz sum-frequency processes for infrared vibrational spectroscopy are expected to become available. I will describe planned experiments at HZDR aimed at characterizing LWFA-generated SPR and realizing its potential applications.

Acknowledgments:

Plenary / 135

Hosing of a long relativistic particle bunch induced by an electron bunch

Author: Tatiana Nechaeva[1]

Co-authors: Livio Verra [2]; Jan Pucek [3]; Michele Bergamaschi [3]; Lucas Ranc [3]; Giovanni Zevi Della Porta [3]; Patric Muggli [3]

[1] *Max-Planck-Institut fur Physik (DE)*

[2] *CERN*

[3] *Max-Planck Institute for Physics*

Corresponding Author: tatiana.nechaeva@cern.ch

Hosing of particle bunches [1] (or laser pulses) driving or experiencing wakefields in plasma may impose limits on the quality and efficiency [2] of the acceleration process. Understanding and measuring hosing is therefore important and interesting. We present an experimental study of hosing of a long proton bunch in plasma. We induce hosing with the relative misalignment between the trajectory of a short electron bunch driving initial wakefields, and that of the proton bunch following it. The effect of the wakefields on the proton bunch is thus non-axi-symmetric. This asymmetry leads to transverse oscillation of the proton bunch centroid position in the plane of misalignment. Self-modulation (SM) takes place in the perpendicular plane. SM [3] and hosing are induced and are thus reproducible from event to event. They grow from similar amplitudes of the transverse wakefields, and with similar predicted growth rates[4]. They are thus coupled. While SM occurs as an instability without the electron bunch, hosing does not (except at much lower plasma densities). We observe hosing and SM on time-resolved images of the proton bunch density distribution, obtained at a screen 3.5m downstream from the exit of the 10m-long plasma. The amplitude of hosing increases along the bunch. It depends on the charge of the proton bunch, as well as on the extent of misalignment. The direction of hosing reverses with the direction of misalignment. The frequencies of hosing (oscillation of centroid position) and of SM (modulation of the bunch density, no detectable oscillation of centroid position) are close to plasma electron frequency and thus scale with plasma density. We will introduce the AWAKE experiment, describe the experimental setup and give an overview of the latest experimental results.

[1] D. Whittum et al., Phys. Rev. Lett. 67, 991 (1991)
[2] V. Lebedev et al., 20, Phys. Rev. AB 20, 121301 (2017)
[3] L. Verra et al. (AWAKE Collaboration), Phys. Rev. Lett. 129 024802 (2022)
[4] C. B. Schroeder et al., Phys. Rev. E 86, 026402 (2013)

Acknowledgments:

Poster Session and Reception - Board: P15 / **136**

Simulations of laser-plasma interactions and electromagnetic pulse generation

Authors: Kathryn Wolfinger[None]; Valentina Lee[None]; Gregory Werner[None]; Michael Litos[None]; John Cary[None]

Numerical simulations of laser-plasma interactions demonstrate the generation of axially polarized electromagnetic pulses (EMPs) that radiate away energy in an initial transition state and a later steady state. This is confirmed by full 2D electromagnetic particle-in-cell simulations, as well as by a ponderomotively-driven reduced model that captures the EMP generation essentials and allows for simulations of the steady state. Investigations of uniformly or regionally pre-ionized plasma show radiation only in the transition state, while steady state radiation is still seen in the case of a laser-ionized plasma. When the laser's pulse length matches the plasma wavelength, that pulse's fractional energy losses to the wakefield are independent of the pulse width, while the losses to the EMP are inversely dependent on the pulse width.

Acknowledgments:

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WG4: Beam-Driven Acceleration / 137

Observation of Skewed Electromagnetic Wakefields in an Asymmetric Structure Driven by Flat Electron Bunches

Authors: Walter Lynn[1]; Tianzhe Xu[None]; Gerard Andonian[2]; Ha Gwanghui[None]; Nathan Majernik[None]; Philippe Piot[3]; John Power[None]; James Rosenzweig[None]; Charles Whiteford[4]; Eric Wisniewski[4]; Scott Doran[4]

[1] *UCLA*

[2] *UCLA / RadiaBeam*

[3] *Northern Illinois University*

[4] *Argonne National Laboratory*

Corresponding Author: walter.j.lynn@gmail.com

Relativistic charged-particle beams which generate intense longitudinal fields in accelerating structures also inherently couple to transverse modes. The effects of this coupling may lead to beam break-up instability, and thus must be countered to preserve beam quality in applications such as linear colliders. Beams with highly asymmetric transverse sizes (flat-beams) have been shown to suppress the initial instability in slab-symmetric structures. However, as the coupling to transverse modes remains, this solution serves only to delay instability. In order to understand the hazards of transverse coupling in such a case, we describe here an experiment characterizing the transverse effects on a flat-beam, traversing near a planar dielectric lined structure. The measurements reveal the emergence of a previously unobserved skew-quadrupole-like interaction when the beam is canted transversely, which is not present when the flat-beam travels parallel to the dielectric surface. We deploy a multipole field fitting algorithm to reconstruct the projected transverse wakefields from the data. We generate the effective kick vector map using a simple two-particle theoretical model, and particle-in-cell simulations provide further insight for realistic particle distributions.

Acknowledgments:

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WG1: Laser-Plasma Wakefield Acceleration / 138

GeV-scale accelerators driven by plasma-modulated pulses from kilohertz lasers.

Author: Roman Walczak[1]

Co-authors: Oscar Jakobsson [1]; Simon Hooker [1]; Emily Archer [1]; James Chappell [1]; James Cowley [1]; Linus Feder [1]; David McMahon [1]; Alexander Picksley [1]; Aimee Ross [1]; Johannes van de Wetering [1]; Wei-Ting (Warren) Wang [1]

[1] *University of Oxford*

Corresponding Author: roman.walczak@physics.ox.ac.uk

The energy required to drive a large-amplitude plasma wave can be delivered over many plasma periods, rather than in a single period, if the driving pulse is modulated. This approach opens up plasma accelerators to novel laser technologies which can provide the required energy at high pulse repetition rates, and with high wall-plug efficiency. We recently proposed [PRL 127, 184801 (2021)] that the required modulation can be achieved in a two-step process: (i) spectral modulation of the long drive pulse by co-propagation with a low-amplitude plasma wave driven by a short, low-energy seed pulse; (ii) conversion of the spectral modulation to temporal modulation by a dispersive optical system to generate a train of short pulses suitable for resonantly driving a plasma accelerator. We demonstrate the physics of this Plasma-Modulated Plasma Accelerator (P-MoPA) with numerical simulations, and show that the spectral modulation is well described by a 1D analytic model. We find that existing, efficient thin-disk lasers could be used to accelerate electrons to GeV level energies at kHz-repetition-rate. For example, particle-in-cell show that the pulse 1.7 J, 1 ps drive pulse, modulated by a 140 mJ, 40 fs seed pulse in a 120 mm long plasma channel, can generate a pulse train capable of accelerating electrons to an energy of 0.65 GeV in a 100 mm long accelerator stage.

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Poster Session and Reception - Board: P27 / **139**

Transverse Stability in an Alternating Gradient Planar Dielectric Wakefield Structure

Authors: Walter Lynn[1]; Gerard Andonian[2]; Nathan Majernik[None]; Sean O'Tool[1]; James Rosenzweig[None]; Seongyeol Kim[3]; John Power[None]; Eric Wisniewski[3]; Philippe Piot[None]; Charles Whiteford[3]; Scott Doran[3]

[1] *UCLA*

[2] *UCLA / RadiaBeam*

[3] *Argonne National Laboratory*

Corresponding Author: walter.j.lynn@gmail.com

Dielectric Wakefield Acceleration (DWA) as a practical means of realizing next-generation accelerators is predicated on the ability to sustain the beam-structure interaction over experimentally meaningful length scales. This goal is complicated by the fact that the beams in question inherently couple to transverse modes in addition to the desired longitudinal modes which, if left unaccounted for, lead to a beam breakup instability. We attempt to, in part, address this issue by tackling the quadrupole mode excited in a planar-symmetry dielectric structure. We do so by periodically alternating the orientation of said structure in order to alternate the orientation of the excited quadrupole wake causing the tail of the beam to experience sequential focusing and defocusing fields, stabilizing the interaction. We examine this technique computationally and lay out a planned experiment at the Argonne Wakefield Accelerator to verify it experimentally.

Acknowledgments:

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WGs 3+5 Joint Session / 140

Report on experimental results of a sub-GV/m photocathode gun

Author: Gongxiaohui Chen[1]

Co-authors: Scott Doran [1]; Seongyeol Kim [1]; Wanming Liu [1]; John Power [1]; Charles Whiteford [1]; Eric Wisniewski [1]; Chunguang Jing [2]; Earnest Knight [2]; Sergey Kuzikov [3]; Xueying Lu [4]; Philippe Piot [5]

[1] *Argonne National Laboratory*

[2] *Euclid Techlabs*

[3] *Euclid Techlabs, LLC*

[4] *NIU / ANL*

[5] *Northern Illinois University*

Corresponding Author: b288079@anl.gov

A program to develop a sub-GV/m rf photocathode gun is underway at Argonne Wakefield Accelerator (AWA) facility as a pathway towards producing brighter electron bunches. The X-band rf gun is powered by high-power, short rf pulses (9-ns FWHM), which, in turn, are generated by AWA's high-current drive beam. In a previous proof-of-principle experiment, an unprecedented gradient of 400 MV/m on the photocathode surface was demonstrated. In this talk, we present recent progress and our R&D roadmap for the next several years.

Acknowledgments:

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Poster Session and Reception - Board: P28 / **141**

Underdense Plasma Lens Commissioning at FACET-II and Future Experimental Plans

Author: Christopher Doss[1]

Co-authors: Valentina Lee [1]; Claire Hansel [1]; John Cary [1]; Andrew Sutherland [2]; Bernhard Hidding [2]; Alexander Knetsch ; Sebastien Corde [3]; Robert Ariniello [4]; Henrik Ekerfelt [4]; Elias Gerstmayr [4]; Doug Storey [4]; Brendan O'Shea [4]; Spencer Gessner [5]; Christine Clarke [4]; Mark Hogan [4]; Michael Litos [1]

[1] *University of Colorado Boulder*

[2] *University of Strathclyde*

[3] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[4] *SLAC National Accelerator Laboratory*

[5] *SLAC*

Corresponding Author: christopher.doss@colorado.edu

With the commissioning of the 10 GeV FACET-II accelerator underway, early experimental shifts of the plasma lens have been taken. These shifts use a single electron bunch propagating through a laser-ionized elongated gas jet, with an electron beam imaging spectrometer set up to disperse the beam in energy for one transverse axis and image the beam directly in the other. Currently, a laser co-propagating to the electron beam axis is used to ionize the gas jet at the focus of an axilens. Here we discuss the early findings of these plasma/electron beam interactions and state future experimental upgrades and plans. The most important of these upgrades are modifications of the laser in order to ionize a small thickness plasma lens, the upgrading of FACET-II to accommodate a drive and witness bunch, and investigating the effects of a transverse plasma density gradient due to the gas jet density profile.

Acknowledgments:

This work was funded by the U.S. Department of Energy grant number DE-SC0017906.

WGs 4+5 Joint Session / 142

Underdense Plasma Lens Commissioning at FACET II and Future Experimental Plans

Author: Christopher Doss[1]

Co-authors: Valentina Lee [1]; Claire Hansel [1]; John Cary [1]; Andrew Sutherland [2]; Bernhard Hidding [2]; Alexander Knetsch ; Sebastien Corde [3]; Robert Ariniello [4]; Henrik Ekerfelt [4]; Elias Gerstmayr [4]; Doug Storey [4]; Brendan O'Shea [4]; Spencer Gessner [5]; Christine Clarke [4]; Mark Hogan [4]; Michael Litos [1]

[1] *University of Colorado Boulder*

[2] *University of Strathclyde*

[3] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[4] *SLAC National Accelerator Laboratory*

[5] *SLAC*

Corresponding Author: christopher.doss@colorado.edu

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This work was funded by the U.S. Department of Energy grant number DE-SC0017906.

Poster Session and Reception - Board: P29 / **143**

Investigating the Transverse Trapping Condition in Beam-Induced-Ionization-Injection in Plasma Wakefield Accelerators

Authors: Jiayang Yan[1]; Xuan Zhang[1]

[1] *Stony Brook University*

Corresponding Author: jiayang.yan@stonybrook.edu

Plasma wakefield accelerators (PWFA) have demonstrated acceleration gradients of tens of GeV per meter. For injecting high-quality electron beams, a method called beam-induced ionization injection (B-III) is proposed. In this method, the drive beam field increases as its slice envelope oscillates to its minimum value due to the betatron oscillation and releases impurity plasma electrons that are then injected. Controlling the trailing beam qualities requires an understanding of a transverse trapping mechanism. In this poster, we will present our research based on the injection of the ultrashort, femtosecond electron beams using B-III.
To investigate the formation of a trailing beam, we will track ionized electron motions in the Particle-In-Cell(PIC) simulation field maps using our eTracks code. The trailing beam quality will be shown based on the simulation results. We will also present that a critical Hamiltonian has to be satisfied for the trapped electrons. This critical condition can also be noticed as a transverse trapping condition in the transverse phase space. We are investigating the formalism for the threshold Hamiltonian value or the critical condition in transverse phase space.

Acknowledgments:

We acknowledge the support by the U.S. Department of Energy, Office of High Energy Physics (HEP) program under Award No. DE-SC-0014043 and resources of NERSC facility, operated under Contract No. DE-AC02-5CH11231

WG4: Beam-Driven Acceleration / **144**

Gigaelectronvolt Acceleration of Captured Electrons in a Positron Beam-Driven Plasma Wakefield Accelerator

Author: James Allen[1]

Co-authors: Erik Adli [2]; Weiming An [3]; Christine Clarke [1]; Christopher Clayton [4]; Sebastien Corde [5]; Jean-Pierre Delahaye [6]; Joel Frederico [1]; Spencer Gessner [7]; Selina Green [1]; Mark Hogan [1]; Chandrashekhar J. Joshi [8]; Nathan Lipkowitz [1]; Michael Litos [9]; Wei Lu [10]; Kenneth Marsh [11]; Warren Mori [11]; Margaux Schmeltz [12]; Dieter Walz [1]; Vitaly Yakimenko [1]; Gerald Yocky [1]; Xinlu Xu [13]

[1] *SLAC National Accelerator Laboratory*

[2] *Department of physics, University of Oslo*

[3] *Beijing Normal University*

[4] *University of California, Los Angeles*

[5] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[6] *CERN*

[7] *SLAC*

[8] *University of California Los Angeles*

[9] *University of Colorado Boulder*

[10] *Tsinghua Univeristy*

[11] *UCLA*

[12] *Paul Scherrer Institute*

[13] *Peking University*

Corresponding Author: jmallen@slac.stanford.edu

Positron acceleration in plasma is a topic of interest for future applications of plasma-based linear colliders. At FACET, we investigated the acceleration of positrons in plasma under a variety of regimes including linear, non-linear, and hollow channel configurations. Over the course of these experiments, we observed the acceleration of plasma electrons captured in a positron beam-driven wake. The positron drive beam conditions were varied to determine the capture threshold of the plasma electrons. Simulations performed using OSIRIS 4.0 are in good agreement with the experiment which allows for a detailed analysis of the capture dynamics.

Acknowledgments:

Work supported by the U.S. Department of Energy under contract numbers DE-AC02-76SF00515 and FG02-92-ER40727. The authors would like to acknowledge the OSIRIS Consortium, consisting of UCLA and IST (Libson, Portugal) for providing access to the OSIRIS 4.0 framework. Work supported by NSF ACI-1339893.

Poster Session and Reception - Board: P30 / **145**

Gigaelectronvolt Acceleration of Captured Electrons in a Positron Beam-Driven Plasma Wakefield Accelerator

Author: James Allen[1]

Co-authors: Erik Adli [2]; Weiming An [3]; Christine Clarke [1]; Christopher Clayton [4]; Sebastien Corde [5]; Jean-Pierre Delahaye [6]; Joel Frederico [1]; Spencer Gessner [7]; Selina Green [1]; Mark Hogan [1]; Chandrashekhar J. Joshi [8]; Nathan Lipkowitz [1]; Michael Litos [9]; Wei Lu [10]; Kenneth Marsh [11]; Warren Mori [11]; Margaux Schmeltz [12]; Navid Vafaei-Najafabadi [13]; Dieter Walz [1]; Vitaly Yakimenko [1]; Gerald Yocky [1]; Xinlu Xu [14]

[1] *SLAC National Accelerator Laboratory*

[2] *Department of physics, University of Oslo*

[3] *Beijing Normal University*

[4] *University of California, Los Angeles*

[5] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[6] *CERN*

[7] *SLAC*

[8] *University of California Los Angeles*

[9] *University of Colorado Boulder*

[10] *Tsinghua University*

[11] *UCLA*

[12] *Paul Scherrer Institute*

[13] *Stony Brook University*

[14] *Peking University*

Corresponding Author: jmallen@slac.stanford.edu

Positron acceleration in plasma is a topic of interest for future applications of plasma-based linear colliders. At FACET, we investigated the acceleration of positrons in plasma under a variety of regimes including linear, non-linear, and hollow channel configurations. Over the course of these experiments, we observed the acceleration of plasma electrons captured in a positron beam-driven wake. The positron drive beam conditions were varied to determine the capture threshold of the plasma electrons. Simulations performed using OSIRIS 4.0 are in good agreement with the experiment which allows for a detailed analysis of the capture dynamics.

Acknowledgments:

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Poster Session and Reception - Board: P16 / **146**

Relativistic Vlasov-Poision Solver with Ponderomotive Driver

Author: Roland Hesse[1]

Co-authors: Bradley Shadwick [1]; Carl Schroeder [2]

[1] *University of Nebraska-Lincoln*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: roland.hesse@my.wheaton.edu

Introducing a minimal numerical framework capable of simulating intense laser-plasma kinetic interactions. The Vlasov-Maxwell Hamiltonian system is naturally constrained to simulate driving-laser ponderomotive effects on electron and ion kinetics along the direction of laser propagation, without discarding the impact of the relativistic transverse momentum on longitudinal dynamics. Structural conditioning at the Poisson Bracket level is necessary to maintain compatibility with variational discretization and proves key to avoid breaking critical invariants associated to phase-space advection. Implementation of this scheme through composed finite-difference integrators qualifies our model as both time-implicit and Eulerian. We apply this solver to demonstrate relativistic dispersion and laser-driven particle trapping. The techniques we outline are highly extensible.

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WG8: Advanced Laser and Beam Technology and Facilities / **147**

Status and prospects of optically pumped high-pressure CO2 amplifiers

Author: Sergei Tochitsky[None]

Co-authors: Dana Tovey [1]; Jeremy Pigeon [1]; Igor Pogorelsky [2]; Chand Joshi [1]; Dimitri Martyshkin [3]; Vladimir Fedorov [3]; Sergey Mirov [3]

[1] *UCLA*

[2] *BNL*

[3] *UAB*

Corresponding Author: sergei12@ucla.edu

Multiple advanced accelerator concepts such as electron and ion acceleration from plasmas, inverse FEL's, and Compton sources would benefit from the development of high-repetition-rate and short-pulse but high-energy mid-IR lasers. However, this intense-field mid-IR is still extremely difficult to access, since solid-state laser sources in this spectral region are limited in power. CO2 lasers systems are currently the most promising strategy towards the generation of such pulses, as the CO2 molecule is capable of storing Joules of energy for 10 μm amplification and does not face the damage threshold limitations that inhibit optical parametric amplifiers from reaching high peak powers at these wavelengths. Picosecond CO2 gain modules are typically pumped with an electric discharge, however, the voltage required at the high pressures (>10 atm), needed for a smooth gain bandwidth, is prohibitively high and it is extremely difficult to maintain a stable electric discharge in large volumes.
Funded by the DOE Accelerator Stewardship grant, a UCLA/BNL/UAB team launched a program towards development of a compact multiatmopshere CO2 amplifier optically pumped by pulses of a 4.3 m Fe:ZnSe laser. Switching from the traditional electrical discharge pumping to an optical pumping of a high-pressure CO2 amplifier could drastically decrease the size of a CO2 MOPA system and the pulse length to ~ 300-500 fs, simultaneously increasing the repetition rate to 10-100 Hz. To this end, a novel Fe:ZnSe laser generating ~50mJ pulses around 4.1-4.8 μm [1] was tested as a pump source. In this scheme of optical pumping, the upper laser level in the 10 m lasing channel 001-100 of a CO2 molecule is pumped directly from the ground state and in recent proof-of-principle experiments lasing was observed up to 15 atm pressure and the optical-to-optical conversion efficiency reached 10% at ~10 atm [2]. Simulations of amplification of a 10 uJ seed showed possibility to reach a few GW power level in a palm-size regenerative amplifier [3]. Current activities and future prospects will be discussed.

1. V. Fedorov et al, Opt. Express 27, 13934-13941(2019).
2. D. Tovey et al, Opt. Express, 29, 31455-31464(2021).
3. D. Tovey et al, Appl. Opt. 58, 5756-5763(2019).

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Department of Energy Office of Science (DE-SC0018378)

WG4: Beam-Driven Acceleration / 148

Plasma-based longitudinal phase space manipulation

Authors: Yipeng Wu[1]; Jianfei Hua[2]; Zheng Zhou[2]; Jie Zhang[2]; Shuang Liu[2]; Bo Peng[2]; Yu Fang[2]; Zan Nie[1]; Chaojie Zhang[1]; Yingchao Du[2]; Wei Lu[3]; Warren Mori[1]; Chan Joshi[1]

[1] *UCLA*

[2] *Tsinghua University*

[3] *Tsinghua Univeristy*

Corresponding Author: wuyipeng@ucla.edu

High-brightness electron beams are crucial for tremendous scientific applications, such as linear colliders, free-electron lasers (FEL) and accelerator-based coherent terahertz (THz) radiation sources. For these applications, precise manipulation of the beam longitudinal phase space (LPS), namely shaping the beam temporal and energy profiles, is of great importance. Here we present a novel method for tailoring the beam LPS by means of self-generated plasma wakefields. Physically, the passage of the beam through a plasma section excites a strong longitudinal wakefield that acts to remove or imprint any time-energy correlation. Based on this solution, we experimentally demonstrate that a plasma-based passive "dechirper" can be utilized to remove the beam's linear energy chirp, leading to a tenfold reduction in the beam energy spread. Additionally, we demonstrate that by properly adjusting the density, the plasma can also act as a tunable "linearizer" to significantly compensate for the nonlinear energy chirp imprinted on the beam, resulting in a fourfold reduction in energy spread. Furthermore, we propose that a plasma-based "modulator" can also imprint a sawtooth periodic energy modulation on the beam. Such energy modulation is then effectively converted into the beam density modulation by means of magnetic optics, forming micro-bunches with tunable picosecond spacing and a bunching factor as high as 0.8, which can be used to produce narrowband THz radiation with energies ranging from mJ to 10 mJ. These plasma-based advanced LPS manipulation techniques will significantly improve the performance of accelerator-based scientific facilities.

Acknowledgments:

Poster Session and Reception - Board: P17 / **149**

Machine Learning for Designing Flying Focus Optics

Authors: Grace Kim[1]; John Palastro[2]; Tanner Simpson[2]; Thomas Clement[1]

[1] *Stony Brook University*

[2] *University of Rochester, Laboratory of Laser Energetics*

Corresponding Author: gjkim309@gmail.com

Meter scale plasma channels are a crucial component of plasma wakefield accelerators. Creating a meter-scale plasma requires distributing the energy of the laser over that length while maintaining a high local intensity along the channel. One method for generating such a channel is by using a method known as the "flying focus". Flying focus uses a diffractive optic on a chirped laser pulse, so that a travelling ionization wave with controlled velocity can be generated. Since the phase imparted on the laser pulse by the diffractive optic governs the spatial characteristics of the plasma channel, an important aspect of this problem is to determine the required phase of the diffractive optic. Our approach for determining the phase of a flying focus optic is through the use of machine learning (ML), specifically zeroth order descent. The input of the ML algorithm will be the desired laser intensity profile and the algorithm will return an optic (or phase plate) that will result in this intensity profile. Zeroth order descent is an iterative approach like gradient descent which optimizes a cost function to reach the global solution. The first step towards creating this ML algorithm involves a ray tracing problem which optimizes the surface of an optic to create an optimal focal spot. This poster presents the results of the zeroth order descent method on the 1D case which is to find the optimal conic constant of the optic and then describes the multi-dimensional case, where each discrete point of the optic can be individually optimized to result in the desired focal spot.

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WGs 4+7 Joint Session / 150

First results from the E332 Experiment Studying the Near-Field-CTR-based Self-Focusing Effect with High Intensity Electron Beams at FACET-II

Authors: Doug Storey[1]; Igor Andriyash[None]; Sebastien Corde[2]; Max Gilljohann[3]; Alexander Knetsch[None]; Olena Kononenko[2]; Yuliia Mankovska[3]; Aimé Matheron[3]; Pablo San Miguel Claveria[3]; Viktoriia Zakharova[3]; Christoph H. Keitel[None]; Samuele Montefiori[None]; Archana Sampath[None]; Matteo Tamburini[None]; Xavier Davoine[None]; Jerome Faure[None]; Laurent Gremillet[None]; Stylianos Passalidis[None]; Henrik Ekerfelt[None]; Claudio Emma[1]; Frederico fiuza[None];

Elias Gerstmayr[1]; Spencer Gessner[4]; Mark Hogan[1]; Agostino Marinelli[1]; J. Ryan Peterson[None]; Brendan O'Shea[1]; Xinlu Xu[None]; V Yakimenko[None]; Chandrashekhar J. Joshi[5]; Kenneth Marsh[6]; Warren Mori[6]; Noa Nambu[6]; Zan Nie[6]; Yipeng Wu[6]; Chaojie Zhang[6]; Robert Ariniello[1]; John Cary[7]; Christopher Doss[7]; Keenan Hunt-Stone[None]; Valentina Lee[7]; Michael Litos[7]; Erik Adli[8]; Jiawei Cao[None]; Jiayang Yan[None]; Navid Vafaei-Najafabadi[9]

[1] *SLAC National Accelerator Laboratory*

[2] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[3] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris*

[4] *SLAC*

[5] *University of California Los Angeles*

[6] *UCLA*

[7] *University of Colorado Boulder*

[8] *Department of physics, University of Oslo*

[9] *Stony Brook University*

Corresponding Author: dstorey@slac.stanford.edu

The Near-Field Coherent Transition Radiation (NF-CTR) generated in the passage of an intense, highly compressed electron beam through a foil produces surface fields that can provide a strong self-focusing force back on the beam itself, and the intense emission of gamma-rays by the beam. This self-focusing effect can be enhanced by passing the beam through multiple foils of order micrometer thickness. The E332 experiment taking place at FACET-II at the SLAC National Accelerator Laboratory will investigate this interaction using the unprecedented beam intensities that will be provided by the facility. In the initial experimental run of FACET-II, the experiment used single foils of varying thickness to develop beam delivery and diagnostic tools, to understand the damage mechanism to the foils by the high intensity beams, and to search for evidence of the NF-CTR focusing effect. The status, first results, and future plans of the E332 experiment will be discussed. The mechanism and observations of beam heating damage to the foils will also be presented.

Acknowledgments:

Poster Session and Reception - Board: P18 / **151**

A Toy Model of Numerical Cherenkov Radiation

Authors: Adam Higuet[1]; Bradley Shadwick[2]

[1] *University of Nebraska - Lincoln*

[2] *University of Nebraska-Lincoln*

Corresponding Author: adam.higuet@huskers.unl.edu

The discretization of electromagnetic equations of motion can lead to changes in the dispersion relations such that particle velocities can meet or exceed the effective speed of light, even in vacuum. Numerical Cherenkov Radiation results from a resonance response between the electromagnetic potentials and superluminal charge. To assess the effects of numerical Cherenkov radiation on variational macro-particle models, we have developed a toy model. Analyzing this model of a single macro-particle moving through vacuum, we use Discrete Fourier Analysis to produce equations of motion consistent with a Lagrangian formulation in a discretized domain and show that the resonant behavior leads only to secular growth. We then claim that further complications to the toy model only serve to decrease the effect of Numerical Cherenkov Radiation on the growing solutions.

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WG1: Laser-Plasma Wakefield Acceleration / 152

Single-Shot Reconstruction of Electron Beam Phase-Space in a Laser Wakefield Accelerator

Authors: Yong Ma[1]; Matthew J.V. Streeter[2]; Felicie Albert[3]; Nicolas Bourgeois[4]; Silvia Cipiccia[5]; Jason M. Cole[2]; Stephen J. D. Dann[4]; Elias Gerstmayr[2]; Isabel G. Gonzalez[6]; Andrew Higginbotham[7]; Amina E. Hussein[1]; Dino A. Jaroszynski[8]; Katerina Falk[9]; Brendan Kettle[2]; Karl Krushelnick[1]; Nuno Lemos[3]; Nelson C. Lopes[2]; Caroline Lumsden[7]; Olle Lundh[6]; Stuart P. D. Mangles[2]; Kyle Miller[10]; Warren Mori[10]; Zulfikar Najmudin[2]; Qian Qian[1]; Pattathil. P. Rajeev[4]; Daniel Seipt[11]; Mohammed Shahzad[8]; Michal Smid[12]; Spesyvtsev Roman[8]; Dan R. Symes[4]; Gregory Vieux[8]; Louise Willingale[1]; Jonathan C. Wood[2]; Alec G. R. Thomas[1]

[1] *University of Michigan*

[2] *Imperial College London*

[3] *Lawrence Livermore National Laboratory*

[4] *Central Laser Facility*

[5] *Diamond Light Source*

[6] *Lund University*

[7] *University of York*

[8] *University of Strathclyde*

[9] *Helmholtz-Zentrum Dresden-Rossendorf*

[10] *UCLA*

[11] *Helmholtz Institut Jena*

[12] *ELI Beamlines*

Corresponding Author: yongm@umich.edu

We report on a single-shot longitudinal phase-space reconstruction diagnostic for an electron beam in a laser wakefield accelerator via the experimental observation of distinct periodic modulations in the angularly resolved spectrum. Such modulated angular spectra arise as a result of the direct interaction between the ultra-relativistic electron beam and the laser driver in the presence of the plasma wakefield. A constrained theoretical model for the coupled oscillator, assisted by a machine learning algorithm, can recreate the experimental electron spectra, and thus fully reconstructs the phase-space distribution of the electron beam. In particular, it reveals the slice energy-spread of the electron beam, which is important to measure for applications such as XFELs. In our experiment, the root-mean-square *slice* energy spread retrieved is bounded at 17 MeV, corresponding to 1.7-4.2% relative spread, despite the overall GeV energy beam having ~100% relative energy spread.

Acknowledgments:

Poster Session and Reception - Board: P52 / **153**

High repetition-rate K-alpha x-ray source from a low-density gas target

Authors: Jon Murphy[1]; Nicholas Peskosky[None]; Milos Burger[None]; John Nees[None]; Karl Krushelnick[1]

[1] *University of Michigan*

Corresponding Author: jmmurph@umich.edu

Potential applications for laser-driven x-ray sources benefit from operation at high repetition-rate. Here, 15 mJ CPA pulses are generated at 480 Hz repetition-rate and tightly focused onto a gas target for the generation of K_α x-rays from a number of noble gases. The continuously-flowing nature of the gas jet meant that the target density was below the threshold for clustering and ensured an easier-to-implement target design. A robust experimental analysis of this debris-free x-ray source

is presented including measurements of its performance while varying a number of parameters and how the source's output scales under different experimental conditions. Calculations that suggest the x-ray pulse duration being on the fs time-scale in the forward direction are shown. Investigation of potential applications of the source and future improvements are discussed as well.

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WGs 4+5 Joint Session / 154

Progress Toward a Laser-Ionized, Unconfined Gas PWFA at FACET-II

Author: Michael Litos[1]

Co-authors: Robert Ariniello [2]; Christine Clarke [2]; Sebastien Corde [3]; Christopher Doss [1]; Henrik Ekerfelt [2]; Elias Gerstmayr [2]; Spencer Gessner [4]; Claire Hansel [1]; Mark Hogan [2]; Chandrashekhar J. Joshi [5]; Valentina Lee [1]; Brendan O'Shea [2]; Pablo San Miguel Claveria [6]; Doug Storey [2]

[1] *University of Colorado Boulder*

[2] *SLAC National Accelerator Laboratory*

[3] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[4] *SLAC*

[5] *University of California Los Angeles*

[6] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris*

Corresponding Author: michael.litos@colorado.edu

We present the progress made toward a plasma wakefield accelerator using a laser-ionized, unconfined gas plasma source for the E301 experiment at FACET-II. One advantage of this plasma source is that the density profile can be semi-arbitrarily defined via controlled focusing of a terawatt class laser pulse, allowing for the creation of entrance and exit ramps that can match the beam into and out of the PWFA, preserving its emittance. Another advantage is the rapid tunability of the plasma density and length, permitting parameter scans for detailed studies of PWFA physics. In addition, this type of plasma source permits the introduction of multiple localized gas species via the placement of gas jets along the length of the primary plasma filament. This is useful for many high-brightness injection schemes. The plasma is also highly accessible to diagnostics due to being unconfined inside a large vacuum chamber. Finally, this type of plasma source is a stepping-stone toward a laser ionized, meter-scale gas jet with supersonic transverse flow. Such a plasma source may be the only means of efficiently dealing with residual heat left in the plasma/gas from the PWFA when operating at high repetition rates.

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Poster Session and Reception - Board: P53 / **155**

Ion and Neutral Particle Balance in AWAKE Helicon Plasmas

Authors: Michael Zepp[1]; Birger Buttenschoen[2]; Barret Elward[3]; Marcel Granetzny[3]; Oliver Schmitz[3]; Alban Sublet[4]

[1] *University of Wisconsin - Madison*

[2] *Max Plank Institute for Plasma Physics, Greifswald, Germany*

[3] *UW-Madison, Dept. of Engineering Physics, Madison, WI, USA*

[4] *CERN, Geneva, Switzerland*

Corresponding Author: mzepp@wisc.edu

A moderately high plasma density (>10^{20} m^{-3}) with very high axial uniformity is needed to achieve wakefield acceleration of electrons in the GV/m range in AWAKE plasmas. While helicon plasmas are capable of reaching sufficient densities at the beginning of a 5 ms pulse, it is not known if they meet the strict uniformity requirement of 0.25% for use in AWAKE. Laser induced fluorescence (LIF) is a versatile diagnostic capable of measuring ion and neutral densities, flow velocities, and temperatures. Recent LIF measurements in the new Madison AWAKE Prototype (MAP) indicate the presence of the expected helicon mode propagating in the plasma. Having confirmed the presence of the helicon mode, particular attention is devoted to understanding the axial density profile and its formation, through an investigation of the particle balance derived with LIF. A new high speed LIF diagnostic is being developed to investigate the startup regime, which is known to reach higher densities than the equilibrium regime reaches. The new diagnostic opens the door for a startup regime particle balance, which will give insight into the physics of ion and neutral dynamics that establish the axial density profile. In particular, the plasma pressure gradient that could cause a depletion of neutral particles on axis could have a significant impact on the axial density profile especially in limiting the achievable density in a helicon.

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Poster Session and Reception - Board: P4 / **156**

Stability of high-brightness electron beam foci for precision coupling to small aperture structures using different LPA injection mechanisms

Author: Kyle Jensen[1]

Co-authors: Samuel Barber [2]; Curtis Berger [2]; Finn Kohrell [3]; Carl Schroeder [3]; Eric Esarey [2]; Jeroen van Tilborg [3]

[1] *UNL, LBNL*

[2] *Lawrence Berkeley National Laboratory*

[3] *LBNL*

Corresponding Author: kyle.jensen@huskers.unl.edu

Laser plasma accelerator (LPA) electron beams need to be controllably transported and focused for applications requiring coupling of high-brightness charge beams into small apertured structures, such as free-electron lasers (FEL) or high-gradient wakefield structures. A critical challenge faced by LPAs is the intrinsic shot-to-shot fluctuations in generated electron beam pointing, transverse position, and emittance, and coupling the energy-spread beams into a chromatic transport line. The BELLA Center's HTU beamline supports variable LPA injection mechanisms and boasts an advanced beam transport system capable of precision energy filtering and controlled electron delivery to a high-brightness focus. Here we present a study of electron beam stability at a downstream focus using variable electron energy filtering and two injection mechanisms: ionization injection and shock-induced down-ramp injection. Furthermore, we discuss a scheme for precision coupling of LPA beams into small aperture structures.

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WGs 2+4 Joint Session / 157

Witness beam realignment in plasma wakefield accelerators in the linear collider regime

Authors: Lance Hildebrand[1]; Yujian Zhao[None]; Weiming An[2]; Fei Li[3]; Xinlu Xu[None]; Warren Mori[3]; Chandrashekhar J. Joshi[4]

[1] *University of California, Los Angeles*

[2] *Beijing Normal University*

[3] *UCLA*

[4] *University of California Los Angeles*

Corresponding Author: hildebrand.lance6@gmail.com

Beam driven plasma wakefield acceleration (PWFA) has shown the ability to accelerate electron beams with high acceleration gradients ~50 GeV/m, high efficiency, and low energy spread. This has inspired future linear collider (LC) designs where witness beams are accelerated over a series of plasma stages. In the LC regime, the witness beam emittance is ~100 nm and the charge is ~1 nC. With these parameters, the ion collapse will be drastic and lead to emittance growth. An et al. (2017) [1] showed this emittance growth is tolerable when using a wide driver and assuming no witness beam offset. Mehrling et al. (2018) [2] showed hosing of the witness beam is suppressed in this regime, due to the non-linear focusing created by the ion motion caused by the witness beam itself. Hildebrand et al. (2018) [3] showed that the on-axis ion density formed by a high density
(small spot size) drive beam can fully eliminate the witness beam hosing and realign it with the drive beam at the cost of emittance growth. We will show that using adiabatic density ramps can match the beam with the presence of ion motion and realign an offset witness beam with tolerable emittance growth. We do this by running self-consistent simulations of a full lithium plasma stage in the LC regime using the code QPAD, a quasi-static PIC code with azimuthal decomposition.

Acknowledgments:

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WGs 1+8 Joint Session / 158

Updates and Commissioning results of the Second Beamline Upgrade to BELLA PW

Authors: Alex Picksley[1]; Anthony Gonsalves[1]; Marlene Turner[2]; Kei Nakamura[3]; Lieselotte Obst-Huebl[3]; Csaba Toth[1]; Joshua Stackhouse[4]; Liona Fan-Chiang[4]; Stepan Bulanov[2]; Carlo Benedetti[2]; Davide Terzani[2]; Sahel Hakimi[1];

Samuel Barber[1]; Curtis Berger[1]; Qiang Chen[1]; Jeroen van Tilborg[2]; Carl Schroeder[1]; Cameron Geddes[1]; Eric Esarey[1]

[1] *Lawrence Berkeley National Laboratory*

[2] *LBNL*

[3] *Lawrence Berkeley National Lab*

[4] *UC Berkeley*

Corresponding Author: apicksley@lbl.gov

The petawatt (PW) facility at Berkeley Lab Laser Accelerator (BELLA Center) has successfully performed several experiments since its installation in 2012 [1], primarily focusing on optimization of single stage, high energy gain laser-plasma accelerators (LPAs) [2,3]. Recently, the facility has undergone two significant upgrades: i) a new second beamline (2BL) delivered into the existing experimental chamber, and ii) a new experimental chamber providing capabilities for experiments in tightly focused geometries [4]. This talk focuses on the installation of the new second beamline. To form this, the PW laser pulse is split before compression, and passed through a new compressor chamber, making it capable of delivering up to 500 TW at 1 Hz, synchronous with the existing beamline (1BL). Currently installed is a f=13.5m off-axis parabola, matching the existing beamline, although focusing optics ranging from f=18.5m to short focal length geometries are possible. We show results from low- and high-power commissioning of 2BL, demonstrating temporal compression to 37 fs, high quality focal mode (measured Strehl ratio ⊠ 0.8), and good shot-to-shot timing stability between 1BL and 2BL (RMS jitter of 8 fs). We outline plans for three upcoming dual-beam campaigns made possible by this upgrade: staging of 2 LPAs; PW guiding in optically formed plasma channels; and two-color ionization injection.

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WG1: Laser-Plasma Wakefield Acceleration / 159

GeV electron bunches in low-density plasma channels by all-optical density transition injection

Authors: Alex Picksley[1]; James Chappell[1]; Emily Archer[1]; Nicolas Bourgeois[2]; James Cowley[1]; Linus Feder[1]; Oscar Jakobsson[1]; Aimee Ross[1]; Wei-Ting (Warren) Wang[1]; Roman Walczak[1]; Simon Hooker[1]

[1] *University of Oxford*

[2] *Central Laser Facility*

Corresponding Author: alexander.picksley@physics.ox.ac.uk

Hydrodynamic [1,2] and conditioned hydrodynamic [3,4] optical-field-ionised plasma channels are promising candidates to support low-density, high repetition-rate multi-GeV laser wakefield accelerator (LWFA) stages. They are generated by focusing an ultrashort pulse into neutral gas, forming a hot column of plasma via optical field ionization, which expands hydrodynamically to form a plasma

channel. Because they are freestanding, they can be operated at high repetition-rate [5]. An advantage of optically generated channels is the potential to sculpt the plasma density along the LWFA stage, for example to promote injection. Here we explore the use of a density down-ramp generated between neutral gas immediately prior to the channel and the channel itself to trap electrons. We present results of a recent experiment at the Gemini TA3 laser (RAL) in which ~ 1 GeV bunches, with percent-level energy spread, were generated by sub-100 TW laser pulses. The effect of the longitudinal and transverse position of the drive pulse focus on the generated electron bunches was investigated. These results, and particle-in-cell simulations, demonstrate that the channel entrance down-ramp is responsible for electron injection.

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WG8: Advanced Laser and Beam Technology and Facilities / 160

Advanced Lasers for accelerators at Colorado State University: advances in kW average power cryogenicallycooled ultrafast Yb:YAG lasers

Authors: Jorge Rocca[1]; Wang[1]; Kristian Dehne[1]; Chi Han[1]; Hanchen Wang[1]; Tarkan Tarkil[1]; Bruno Schmidt[2]; Vladimir Savichev[None]; Vladimir Chvykov[1]; Aaron Davenport[1]; Carmen Menoni[1]

[1] *Colorado State University*

[2] *few cycle inc*

Corresponding Author: jorge.rocca@colostate.edu

The petawatt-class multi-Hz Ti:Sa laser ALEPH developed at Colorado State University has recently enable major advances in laser wakefield acceleration [1]. However, progress on laser driven-particle accelerators for applications depends on the development of compact, more efficient lasers capable of producing of high energy ultrashort laser pulses at greatly increased high repetition rate. A promising laser gain material for such lasers is Yb-YAG, which has the advantages of millisecond upper level lifetime, low quantum defect, and high thermal conductivity that in combination facilitate high repetition rate operation. We have demonstrated a kW average power laser that generates picosecond pulses with energy up to 1.1 J at 1 kHz repetition rate [2]. The system uses cryogenically cooled Yb:YAG active mirror amplifiers to generate pulses >1.2 J energy at a repetition rate of 1kHz. After compression 1.1J pulses with < 4.5ps duration are obtained with good beam quality and shot-to-shot stability. To shorten the pulse we are investigating spectral broadening in a gas-filled hollow core fiber. In addition, we demonstrated the efficient generation of Joule-level λ=515nm ns laser pulses at 1kHz repetition rate by frequency doubling in LBO crystals [3], a result that is of interest for pumping high average power femtosecond lasers. The seed pulses are generated by an arbitrary-waveform laser which can be programmed to produce square pulse shapes at the end of the amplifier chain for efficient doubling. The total 515 nm average power reached 1.04 kW (1.04J pulses at 1 kHz) in a beam with a measured M^2= 1.3-1.4.

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Acknowledgments:

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WG1: Laser-Plasma Wakefield Acceleration / 161

Arbitrarily Structured Laser Pulses

Authors: Jacob Pierce[1]; John Palastro[2]; Fei Li[1]; Bernardo Malaca[3]; Dillon Ramsey[4]; Jorge Vieira[3]; Kathleen Weichman[4]; Warren Mori[1]

[1] *UCLA*

[2] *University of Rochester, Laboratory for Laser Energetics*

[3] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Téecnico*

[4] *University of Rochester / Laboratory for Laser Energetics*

Corresponding Author: jacobpierce@physics.ucla.edu

Spatiotemporal control refers to a class of optical techniques for structuring a laser pulse with space-time dependent properties, including moving focal points, dynamic spot sizes, and evolving orbital angular momentum. These structured pulses have the potential to enhance a number of laser-plasma applications, including laser wakefield acceleration (LWFA) [1,2]. Here we introduce the concept of arbitrarily structured laser (ASTRL) pulses which generalizes techniques for spatiotemporal control [3]. The ASTRL formalism employs a superposition of prescribed pulses to create a desired electromagnetic field structure. Explicit ASTRL solutions of Maxwell's equations in vacuum simplify field initialization in simulations of laser-plasma interactions with structured light, expediting study of novel concepts such as dephasingless LWFA with flying focus pulses. The ASTRL framework also enables design of new classes of laser pulses which may enable novel techniques in laser wakefield acceleration and laser-driven ion acceleration.

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Acknowledgments:

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Poster Session and Reception - Board: F68 / **162**

Porting the particle-in-cell code OSIRIS to GPU-accelerated architectures

Authors: Roman Lee[1]; Jacob Pierce[1]; Kyle Miller[2]; Adam Tableman[None]; Viktor Decyk[1]; Ricardo Fonseca[3]; Warren Mori[1]

[1] *UCLA*

[2] *Laboratory for Laser Energetics*

[3] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico*

Corresponding Author: jacobpierce@physics.ucla.edu

Furthering our understanding of many processes in plasma physics, including laser-wakefield acceleration and laser-driven ion acceleration, requires large-scale kinetic simulations using particle-in-cell (PIC) codes. However, these simulations are extremely demanding, requiring that contemporary PIC codes be designed to efficiently use a new fleet of exascale computing architectures, which are increasingly GPU based. We discuss a GPU algorithm for PIC codes which we implemented on the code OSIRIS [1]. A limited-feature production code based on CUDA C is complete. Our implementation features dynamic GPU-GPU load balancing and a custom memory-management scheme which enables safe utilization of maximal device memory.

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Plenary / **163**

Advanced Ion Acceleration Mechanisms

Author: Stepan Bulanov[1]

[1] *LBNL*

Corresponding Author: sbulanov@lbl.gov

Abstract: One of the main applications of high power laser facilities is particle acceleration. It is due to the fact that ultrashort laser pulses in plasma are able to generate electromagnetic fields exceeding those typical for the conventional accelerators by many orders of magnitude. Laser ion acceleration is of particular interest due to unique beam properties and its potential application in basic and material science, medicine, industry, etc. There are several possible regimes where different ion acceleration mechanisms may be accessed, depending on target and laser parameters. The most well known of them is Target Normal Sheath Acceleration. However, the quest for more efficient acceleration of ion beams having different spectral features gave rise to several other advanced ion acceleration mechanisms, such as Magnetic Vortex Acceleration and Radiation Pressure Acceleration. Here the basic theoretical concepts for several advanced ion acceleration mechanisms will be presented as well as recent analytical and computer simulation results.

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WGs 5+7 Joint Session / **164**

High intensity laser driven sources of gammas and positrons using BELLA PW Laser Dual Beamlines

Authors: Marlene Turner[1]; Stepan Bulanov[1]; Carlo Benedetti[1]; Anthony Gonsalves[1]; Kei Nakamura[2]; Davide Terzani[1]; Jeroen van Tilborg[1]; Carl Schroeder[1]; Cameron Geddes[3]; Eric Esarey[3]

[1] *LBNL*

[2] *Lawrence Berkeley National Lab*

[3] *Lawrence Berkeley National Laboratory*

Corresponding Author: sbulanov@lbl.gov

Recent commissioning of the second laser pulse transport line at the BELLA PW facility enables strong-field quantum electrodynamics (SF-QED) experiments where an intense laser pulse collides with a GeV-class laser-wakefield-accelerated electron beam. An overview of the upgraded BELLA PW facility with a SF-QED experimental layout is presented. According to the simulation results these experiments can lead to the generation of an efficient source of high energy gammas and positrons via Compton and Breit-Wheeler processes as well as enable the study of the transition of the laser-particle interactions from the classical to the SF-QED regime.

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Poster Session and Reception - Board: P19 / **165**

Characterizing hot electrons in ensemble PIC simulations of high-intensity, laser-plasma interactions with machine learning.

Author: André Antoine[1]

Co-authors: Blagoje Djordjevic [2]; Alec G. R. Thomas [1]; Gerald Jackson Williams ; Tammy Ma [2]; Derek Mariscal [2]

[1] *University of Michigan*

[2] *Livermore National Lab*

Corresponding Author: aantoine@umich.edu

In the interaction of high-intensity lasers with over-dense plasmas, the hot electron population dictates system dynamics, driving ion acceleration and x-ray generation, and fast ignition, for example. The primary method for modeling these systems are particle-in-cell simulations (PIC), where macroparticles approximate the kinetics of a distribution of particles. A problem shared with experiments, PIC simulations are inherently noisy given the statistical nature of the algorithm, particularly at lower fidelities. Individual electron energy distributions are easily analyzed with expert examination, but 'by hand' analysis is impractical for the hundreds of thousands of case examples produced by ensemble simulations, and this is exacerbated by noisy data. In this work, data from an ensemble of PIC simulations is analyzed and quantified using machine learning (ML) techniques to more reliably extract the hot electron temperature and other physical parameters. We present the dependency of the hot electron temperature and other electron sheath properties on various input parameters such as laser intensity and pulse length across a wide parameter space (~10^18-10^21 W/cm^2, 30-500 fs).

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Poster Session and Reception - Board: P54 / **166**

Towards a soft x-ray PWFA-FEL via Trojan Horse single bunch injection

Authors: Lily Berman[1]; Habib Ahmad Fahim[2]; Bernhard Hidding[1]; Andrew Sutherland[1]; Thomas Heinemann[3]; David Campbell[1]; Alex Dickson[1]; Grace Manahan[1]; Adam Hewitt[1]

[1] *University of Strathclyde*

[2] *University of Strathclyde and Cockcroft Institute*

[3] *University of Strathclyde / DESY*

Corresponding Author: lily.berman@strath.ac.uk

A barrier to realizing a plasma-based XFEL is the energy chirp of the accelerated electron bunch. If such a chirp is not removed prior to extraction it is difficult to maintain bunch qualities during transport to the undulator stage, and the FEL performance will be degraded or inhibited entirely. The Trojan Horse (TH) injection method uses a plasma photocathode approach to release and trap electrons directly inside the blowout of a PWFA stage [1], as demonstrated during the FACET-I campaign at SLAC [2]. The E310 experiment at FACET-II will aim to demonstrate ultrahigh brightness beam production via the efforts of multiple UK and US collaborators [3]. TH injection may produce low-charge electron beams with kA peak current and unprecedented emittance as low as 20 nm rad. Maintaining such ultralow emittance through a transport line may be possible via the multi-bunch dechirping scheme, which has already been developed [4]. Here, we present simulation-based efforts towards an alternative chirp-suppression scheme using a single injected electron bunch of higher charge. Exploiting the tunable nature of TH injection, we attempt to optimize an electron bunch for optimum beam-loading to remove projected energy spread while producing a multi-kA peak current, maintaining low emittance of a few hundred nm rad and few 0.1 % slice energy spread. Such a beam would have the potential to produce soft XFEL radiation using existing undulator technology.

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Acknowledgments:

WGs 5+7 Joint Session / **167**

Coherent 3D microstructure of laser-wakefield-accelerated electron bunches

Authors: Maxwell LaBerge[None]; Omid Zarini[1]; Alex Lumpkin[2]; Andrea Hannasch[3]; Rafal Zgadzaj[3]; Brant Bowers[4]; Jurjen Couperus-Cabadag[5]; Yen-Yu Chang[5]; Susanne Schoebel[5]; Patrick Ufer[5]; Richard Pausch[5]; Alexander Debus[5]; Ulrich Schramm[6]; arie irman[5]; Michael Downer[4]

[1] *HZDR*

[2] *FNAL*

[3] *UT at Austin*

[4] *The University of Texas at Austin*

[5] *Helmholtz-Zentrum Dresden-Rossendorf*

[6] *HZDR, TU Dresden*

Corresponding Author: max.laberge@utexas.edu

Recent breakthroughs in laser wakefield accelerator (LWFA) technology have allowed them to drive free-electron lasers (FELs) [1]. This is made more impressive by the relative lack of phase-space control in plasma accelerators when compared to conventional linear accelerators. However, the complicated phase spaces and microstructures in LWFA beams could be harnessed to accelerate the self-amplified spontaneous emission (SASE) process. Pre-bunched beams have been shown to achieve gain with shorter saturation length than conventional beams [2]. Because of the nature of the LWFA process, electron beams from LWFAs emerge from the plasma with preformed microstructures. The parameters of the accelerator dictate the shape, size, and coherence of these features. There is interest in creating and harnessing such substructures for the next generation of X-ray FEL [3]. However, to use these structures they must be measured and characterized. Coherent optical transition radiation (COTR) can diagnose such microfeatures in electron beams. We present experimental results across three different LWFA injection regimes demonstrating regime dependent levels of visible COTR. In each regime, we examined near field COTR images at eight different wavelengths from a foil directly after the end of the accelerator. Depending on the injection regime, we observe different levels of bunch substructure. How this structure evolves across optical wavelengths is also regime dependent. Wavelength-dependent variations in the size and radial distribution of the TR images can be correlated with features in the bunch longitudinal profile. Observed multispectral COTR images corroborate injection-regime-dependent beam substructures predicted by three-dimensional particle in cell (PIC) simulations. Moreover, with the aid of physically reasonable assumptions about the bunch profile, we present reconstructions of the three-dimensional electron bunch density distribution.

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Acknowledgments:

WG1: Laser-Plasma Wakefield Acceleration / 168

External injection of electrons into a laser-driven plasma wakefield at the CLARA facility

Author: Laura Corner[1]

Co-authors: Lewis Reid [1]; Harry Jones [2]; Miles Radford [1]; Jonathan Christie [1]; Alex Morris [1]; Lewis Boulton [3]; Alex Knetsch [4]; Elisabetta Boella [5]; Bernhard Hidding [6]

[1] *Cockcroft Institute, University of Liverpool*

[2] *Cockcroft Institute, University of Liverpool (now DESY)*

[3] *Cockcroft Insitute, University of Strathclyde*

[4] *LOA, ENSTA Paris, CNRS, France*

[5] *Cockcroft Institute, University of Lancaster*

[6] *Cockcroft Institute, University of Strathclyde*

Corresponding Author: laura.corner@liverpool.ac.uk

We report on the injection of 35MeV electron bunches into a laser-driven plasma wakefield at the CLARA linear accelerator, Daresbury Laboratory, UK. In this initial proof-of-principle experiment,

we observed the broadening of the energy spectrum of 6ps electron bunches injected into a plasma, demonstrating successful acceleration/deceleration of electrons within the wakefield. We discuss further planned experiments on external injection at the upgraded CLARA/FEBE facility.

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WG2: Computation for Accelerator Physics / 169

Traveling-wave electron accelerators – towards scalable laser-plasma accelerators beyond 10GeV

Author: Alexander Debus[1]

Co-authors: Klaus Steiniger [1]; Rene Widera [1]; Bastrakov Sergei [2]; Finn-Ole Carstens [2]; Felix Meyer [2]; Richard Pausch [2]; Marco Garten [3]; Thomas Kluge [2]; Jeffrey Kelling [2]; Benjamin Hernandez Arreguin [4]; Jeffrey Young [5]; Franz Poeschl [6]; Axel Huebl [3]; David Rogers [7]; Guido Juckeland [2]; Sunita Chandrasekaran [8]; Michael Bussmann [9]; Ulrich Schramm [10]

[1] *Helmholtz-Zentrum Dresden-Rossendorf*

[2] *Helmholtz-Zentrum Dresden-Rossendorf (HZDR)*

[3] *LBNL*

[4] *Oakridge National Laboratories (ORNL)*

[5] *Georgia Institute of Technology*

[6] *Center for Advanced Systems Understanding (CASUS), HZDR*

[7] *Oak Ridge National Laboratories (ORNL)*

[8] *University of Delaware*

[9] *CASUS, HZDR*

[10] *Helmholtz-Zentrum Dresden-Rossendorf (HZDR), TU Dresden*

Corresponding Author: a.debus@hzdr.de

Traveling-wave electron acceleration (TWEAC) is an advanced laser-plasma accelerator scheme, which is neither limited by dephasing, nor by pump depletion or diffraction. Such accelerators are scalable to energies beyond 10 GeV without the need for staging and are candidates for future compact electron-positron colliders based on existing CPA lasers. TWEAC utilizes two pulse-front tilted laser pulses whose propagation directions enclose a configurable angle. The accelerating cavity is created along their overlap region in the plasma and can move at the vacuum speed of light. The oblique laser geometry enables to constantly cycle different laser beam sections through the interaction region, hence providing quasi-stationary conditions of the wakefield driver.

The TWEAC geometry enables to access to a wide range of regimes, which are customizable in cavity geometry, laser-to-electron energy efficiency and the required laser properties at different plasma densities, making the scheme suitable for high-rep rate lasers at low energies per pulse to multi-PW laser facilities. Exploring these regimes in high-fidelity simulations is computationally highly demanding, as these need to include large plasma volumes in 3D at high-resolution over an extended acceleration distance. Since even "small" test simulations need hundreds of GPUs, TWEAC simulations require exascale compute resources.

We present recent progress in TWEAC simulations and various technical advances in the 3D3V particle-in-cell code PIConGPU that enable running on the upcoming Frontier cluster, most notably support of the HIP computational backend allowing to run on AMD GPUs, as well as openPMD, PICMI and algorithmic developments. These advances are mainly driven by our participation in OLCF's Frontier Center for Accelerated Application Readiness providing access to the hardware platform of the Frontier exascale supercomputer. We show performance data and recent applications of PIConGPU profiting from these developments.

Acknowledgments:

WGs 4+5 Joint Session / 170

Towards a soft x-ray PWFA-FEL via Trojan Horse single bunch injection

Authors: Lily Berman[1]; Andrew Sutherland[1]; Bernhard Hidding[1]; Habib Ahmad Fahim[2]; Thomas Heinemann[3]; David Campbell[1]; Alex Dickson[1]; Grace Manahan[1]; Adam Hewitt[1]

[1] *University of Strathclyde*

[2] *University of Strathclyde and Cockcroft Institute*

[3] *University of Strathclyde / DESY*

Corresponding Author: lily.berman@strath.ac.uk

A barrier to realizing a plasma-based XFEL is the energy chirp of the accelerated electron bunch. If such a chirp is not removed prior to extraction it is difficult to maintain bunch qualities during transport to the undulator stage, and the FEL performance will be degraded or inhibited entirely. The Trojan Horse (TH) injection method uses a plasma photocathode approach to release and trap electrons directly inside the blowout of a PWFA stage [1], as demonstrated during the FACET-I campaign at SLAC [2]. The E310 experiment at FACET-II will aim to demonstrate ultrahigh brightness beam production via the efforts of multiple UK and US collaborators [3]. TH injection may produce low-charge electron beams with kA peak current and unprecedented emittance as low as 20 nm rad. Maintaining such ultralow emittance through a transport line may be possible via the multi-bunch dechirping scheme, which has already been developed [4]. Here, we present simulation-based efforts towards an alternative chirp-suppression scheme using a single injected electron bunch of higher charge. Exploiting the tunable nature of TH injection, we attempt to optimize an electron bunch for optimum beam-loading to remove projected energy spread while producing a multi-kA peak current, maintaining low emittance of a few hundred nm rad and few 0.1 % slice energy spread. Such a beam would have the potential to produce soft XFEL radiation using existing undulator technology.

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Acknowledgments:

WG6: Laser-Plasma Acceleration of Ions / 171

Proton acceleration with a CO2 laser at the Accelerator Test Facility

Authors: Igor Pogorelsky[1]; Oliver Ettlinger[2]; Nicholas Dover[2]; Emma Ditter[3]; Mikhail Polyanskiy[4]; Marcus Babzien[1]; Mark Palmer[4]; Zulfikar Najmudin[3]

[1] *BNL*

[2] *Imperial College*

[3] *Imperial College London*

[4] *Brookhaven National Laboratory*

Corresponding Author: igor@bnl.gov

Long-wave infra-red lasers, like the TW CO2 laser at the Accelerator Test Facility (ATF), offer a number of benefits in studying laser-driven ion acceleration, including favorable scaling of the critical density, and the ability to access relativistic regimes at lower intensities. We present recent work studying hole-boring radiation pressure acceleration (HB-RPA) and collisionless shock acceleration at near-critical densities with a0~1. We demonstrate spectrally peaked, MeV level protons for shaped, near-critical density hydrogen gas targets, showing good agreement with the predicted HB-RPA energy scaling. We also report on decreasing proton energy spreads with increasing target density, down to 5%. Finally, we report on the new opportunity for shock imaging via a 100fs Ti:sapphire probe capability available now at the ATF.

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Department of Energy under Contract No. DE-SC0012704

WG5: Beam Sources, Monitoring, and Control / **172**

Plasma-photonic diagnostic of plasma-based accelerators.

Author: Andrew Sutherland[1]

Co-authors: Habib Ahmad Fahim [2]; Thomas Heinemann [3]; Grace Manahan [1]; Lewis Boulton [4]; Alex Dickson [1]; Lily Berman [1]; Bernhard Hidding [1]; Christopher Doss [5]; Michael Litos [5]; Alexander Knetsch ; Henrik Ekerfelt [6]; Robert Ariniello [6]; Mark Hogan [6]; Christine Clarke [6]; Brendan O'Shea [6]

[1] *University of Strathclyde*

[2] *University of Strathclyde and Cockcroft Institute*

[3] *University of Strathclyde / DESY*

[4] *Cockcroft Insitute, University of Strathclyde*

[5] *University of Colorado Boulder*

[6] *SLAC National Accelerator Laboratory*

Corresponding Author: andrew.sutherland@strath.ac.uk

Reliable and versatile diagnostic methods are essential for modern accelerator facilities to successfully experiment with energetic particle bunches. Conventionally, an expansive network of tools is implemented in and around interaction points for optimization of experimental conditions; this is true for plasma-based accelerator experiments, with added restrictions to intercepting diagnostics due to the volatile plasma and increasingly intense fields of particle bunches. Here, we present a novel diagnostic that utilizes the afterglow light emitted from the plasma after interacting with an electron beam, demonstrate its utility to provide spatio-temporal synchronization between electron beam and plasma generating laser pulse, and discuss how it can be used for optimization of many plasma-based accelerator experimental parameters.

Acknowledgments:

WGs 4+5 Joint Session / **173**

Trojan Horse-II at FACET-II: prospects and experimental plans.

Authors: Adam Hewitt[1]; Alex Dickson[1]; Alexander Knetsch[None]; Andrew Sutherland[1]; Bernhard Hidding[1]; Brendan O'Shea[2]; Christine Clarke[2]; Christopher Doss[3]; Claire Hansel[3]; David Campbell[1]; Doug Storey[2]; Gerard Andonian[4]; Grace Manahan[1]; Habib Ahmad Fahim[5]; Henrik Ekerfelt[2]; James Rosenzweig[None]; Lily Berman[1]; Lorne Rutherford[1]; MONIKA YADAV[6]; Mark Hogan[2]; Michael Litos[3]; Michael Stumpf[7]; Pratik Manwani[8]; Robert Ariniello[2]; Spencer Gessner[9]; Thomas Heinemann[10]

[1] *University of Strathclyde*

[2] *SLAC National Accelerator Laboratory*

[3] *University of Colorado Boulder*

[4] *UCLA / RadiaBeam*

[5] *University of Strathclyde and Cockcroft Institute*

[6] *University of Liverpool*

[7] *Heinrich-Heine Universität Düsseldorf, Institut for Laser- and Plasmaphysics*

[8] *University of California, Los Angeles*

[9] *SLAC*

[10] *University of Strathclyde / DESY*

Corresponding Author: andrew.sutherland@strath.ac.uk

Plasma photocathodes aim for the tunable production of compact electron beams with normalized emittance and brightness many orders of magnitude better than conventional sources. Experimental realization of such beams would open numerous prospects for transformative plasma wakefield accelerator applications based on ultrahigh-brightness beams. Developing a plasma capable of high-gradient acceleration but also as a source of practical electron bunches is paramount. Here, we present details of the upcoming E-310: Trojan Horse-II program at FACET-II specifically reporting on the development of a preionized plasma channel suitable for optimizing charge injection and stable energy gain.

Acknowledgments:

WG8: Advanced Laser and Beam Technology and Facilities / 174

The Argonne Wakefield Accelerator Beam Test Facility for Novel Accelerator Research

Author: John Power[None]

Co-authors: Philippe Piot ; Chunguang Jing ; Xueying Lu [1]; Wanming Liu [2]; D.S. Doran [2]; Eric Wisniewski [2]; Seongyeol Kim [2]; Gonxiaohui Chen [2]

[1] *NIU / ANL*

[2] *Argonne National Laboratory*

Corresponding Author: jp@anl.gov

The Argonne Wakefield Accelerator (AWA) is a beam test facility at Argonne National Laboratory. It consists of a 65 MeV L-band photoinjector beamline, 3 additional independent photoinjector beamlines, and multiple flexible experimental areas. Its program is composed of three research themes: (1) Advanced Accelerator Concepts (AAC), (2) Beam Manipulation, and (3) Beam Production. The AAC theme focuses on primarily on Structure Wakefield Acceleration but also has a substantial Plasma Wakefield Acceleration program. The Beam Manipulation theme develops several manipulation methods including emittance exchange, flat-round beam transformations, transverse deflecting cavity based shaping and laser shaping. Beam production efforts include the operation of the world's

high charge (100nC) photoinjector (AWA's Drive Gun) and a recently developed X-band gun demonstrated to operate at 400 MV/m. Research at the AWA operates on a collaborator model and is carried out by both in-house researchers and collaborators drawn from universities, national laboratories and industry from around the world. This talk will present recent research results, research capabilities and planned upgrades of the AWA facility.

Acknowledgments:

WG1: Laser-Plasma Wakefield Acceleration / 175

Experimental demonstration of Hydrodynamic Optical-Field-Ionized plasma channels at kHz repetition rate

Authors: Aaron Alejo[1]; James Cowley[2]; Alexander Picksley[2]; Roman Walczak[2]; Simon Hooker[2]

[1] *Instituto Galego de Fisica de Altas Enerxias, Universidade de Santiago de Compostela, Spain*

[2] *John Adams Institute for Accelerator Science and Department of Physics, University of Oxford*

Corresponding Author: james.cowley@physics.ox.ac.uk

Many potential applications of plasma accelerators - such as light sources and future particle colliders - require the stable generation of multi-GeV electron bunches at high (>kHz) repetition rate. A consequent goal for current research into laser-driven plasma accelerators involves the development of waveguides capable of operating at densities of ~10¹⁷ cm⁻³, over lengths of several centimetres or more, guiding laser pulses at kHz repetition rate. Whilst guiding structures such as capillaries are not well suited to this repetition rate due to laser damage and heating, plasma waveguides formed from hydrodynamic optical-field-ionized (HOFI) channels can potentially meet the requirements. Guiding of high intensity laser pulses in HOFI channels has been demonstrated previously at on-axis densities of 1 × 10¹⁷ cm⁻³ over lengths of >10 cm, whilst in this work we demonstrate experimentally that HOFI channels can be generated at kHz-scale repetition rates for an extended period of time. Using a pump-probe arrangement, we show via transverse interferometry that the properties of two HOFI channels generated 1 ms apart are essentially the same, and that HOFI channels can be generated at a mean repetition rate of 0.4 kHz for a period of 6.5 hours without degradation of the channel properties. The results suggest that HOFI channels are ideal for future high-repetition rate, multi-GeV laser-plasma accelerator stages.

Acknowledgments:

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WGs 2+8 Joint Session / 176

Efficient propagation of electromagnetic pulses through high-power solid state laser amplifiers

Authors: David Bruhwiler[1]; Jeroen van Tilborg[2]; Csaba Toth[3]; Cameron Geddes[3]; Boaz Nash[1]; Dan Abell[1]; Gurhar Khalsa[1]; Qiang Chen[3]; Nicholas Goldring[4]; Robert Nagler[1]

[1] *RadiaSoft LLC*

[2] *LBNL*

[3] *Lawrence Berkeley National Laboratory*

[4] *STATE33 Inc.*

Corresponding Author: bruhwiler@radiasoft.net

There is currently a lack of broadly available modeling software that self-consistently captures the required physics of gain, thermal loading and lensing, spectral shaping, and other effects required to simulate and optimize high-intensity lasers (100 TW to multi-PW) with ultra-short pulse lengths (< 100 fs) [1]. In recent work [2], we showed that low-resolution wavefront sensor (WFS) images could be used to construct native SRW [3] wavefront objects. We propagate these general 2D wavefronts via linear canonical transforms (LCT) [4], using the decomposition of Pei and Huang [5] to recast a standard ABCD matrix into three, each of which SRW can use to transform the wavefront with physical optics. We present an operator splitting approach, which divides both the crystal and the amplified laser pulse into slices, so that the algorithms remain 2D for an intrinsically 3D problem. We also discuss work on a new Python library for LCTs, which will enable wavefront propagation via more general ABCD matrices. Comparisons with experimental data are presented.

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WGs 5+7 Joint Session / **177**

Application of Optical Stochastic Cooling Mechanism to Beam Shaping

Author: Austin Dick[1]

Co-author: Philippe Piot

[1] *Northern Illinois University*

Corresponding Author: z1852211@students.niu.edu

Stochastic Cooling is a feedback system for cooling particle beams in storage rings which uses radiation produced by the beam to correct the average deviation of temporal slices with a duration inversely proportional to the bandwidth. Optical Stochastic Cooling (OSC) uses optical wavelengths which decreases the duration of each slice and, therefore, reduces the incoherent noise each individual particle observes. Particles pass through an undulator (the pickup) where they emit radiation which is amplified and reintroduced downstream in another undulator (the kicker). The optical delay and amplification system, in combination with the relatively short sample slices, provides a potential

tool to shape the phase-space of a beam. We outline and simulate two potential methods for shaping the longitudinal phase-space (LPS) of a beam using the OSC mechanism. The first modulates the amplification of the undulator radiation each turn which can be used to focus the cooling into a specific degree of freedom and produce flat beams in LPS. The second non-uniformly amplifies longitudinal sections of the undulator radiation pulse. This may target cooling to specific regions of the beam. Using the two techniques together we demonstrate how the OSC setup can be used to produce micro-bunches with arbitrary separation.

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Poster Session and Reception - Board: F80 / **178**

Optimized setup for a laser-induced Plasma Photocathode

Author: Michael Stumpf[1]

Co-author: Georg Pretzler [1]

[1] *Heinrich-Heine-Universität Düsseldorf, Institut für Laser- und Plasmaphysik*

Corresponding Author: michael.stumpf@uni-duesseldorf.de

We present different possible ionization volumes/shapes inside a Plasma Wakefield to realize the Trojan Horse Injection method. Our all-optical setup uses tailoring of the laser near field to produce an adjusted laser focus profile and therefore an optimized ionization volume and state. Different initial beam profiles show different behaviors in our simulations hence we showcase various potential witness bunches.

Acknowledgments:

This project was partially funded by Germany's BMBF under the Contract Number 05K19PFA.

WGs 1+2 Joint Session / **179**

Latest advances in the Particle - In - Cell code WarpX for efficient modeling of plasma accelerators at Exascale

Author: Jean-Luc Vay[1]

[1] *Lawrence Berkeley National Laboratory*

Corresponding Author: jlvay@lbl.gov

The electromagnetic Particle-In-Cell (PIC) code WarpX has been developed within the the U.S. Department of Energy's Exascale Computing Project toward the modeling of plasma accelerators for future high-energy physics colliders on Exascale Supercomputers. We will present the latest multi-GPU capable physics features, such as a Coulomb collision module and a QED module. We will also report on the latest algorithmic advances that enable full PIC modeling of plasma accelerators with higher efficiency: a time-averaged pseudo-spectral PIC solver that enables larger timesteps, a hybrid nodal-staggered PIC loop that provides improved stability, an algorithm to handle particles crossing Perfectly Matched Layers, application of mesh refinement to the modeling of ion motion

in a plasma accelerator. All presented features are fully CPU and GPU (Nvidia/AMD/Intel) capable. The status, examples of applications and future developments will be discussed, and thoughts toward the establishment of a 10-year roadmap for advanced accelerator concepts computation will be given.

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Poster Session and Reception - Board: P5 / **180**

Third harmonic generation for two-color ionization injection in laser-plasma accelerators

Authors: Liona Fan-Chiang[None]; Anthony Gonsalves[1]; Alexander Picksley[1]; Davide Terzani[1]; Christopher Pieronek[1]; Carlo Benedetti[1]; Carl Schroeder[1]; Samuel Barber[2]; Jeroen van Tilborg[1]; Curtis Berger[1]; Anthony Vazquez[1]; Cameron Geddes[2]; Eric Esarey[2]

[1] *LBNL*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: liona@berkeley.edu

Laser plasma accelerators (LPAs) have promise to be the next generation accelerator for colliders, as well as drive a number of basic science, industry, security and medical applications. Many applications require high brightness electron beams enabled by low emittance. One proposal to achieve ultra-low emittance from an LPA is a two color laser configuration, where a long wavelength laser, with large ponderomotive force, is used to excite a plasma wakefield, while another trailing short wavelength laser is used to ionize inner shell electrons, injecting them in the accelerating phase of the wake [1]. The short wavelength allows for a high electric field for ionization, with low ponderomotive force. Most LPAs use Ti:Sapphire based lasers with central wavelength 0.8 µm. We will present experiments and simulations performed at the BELLA Center on generating the third harmonic of short (45 fs), high fluence (30 mJ/cm2), Ti:Sapphire based laser pulses for the purpose of ionization injection in a quasi-linear wake. Features and challenges unique to short pulse, high fluence harmonic generation and characterization as well as how those challenges were addressed will also be presented.

Acknowledgments:

Poster Session and Reception - Board: F74 / **181**

HIGH GRADIENT TESTING RESULTS OF THE C-BAND BENCHMARK a/λ=0.105 CAVITIES AT LANL

Authors: Muhammed Zuboraj[1]; Wesley Hall[2]; Dmitry Gorelov[2]; Mark Middendorf[2]; Deepak Rai[2]; Evgenya Simakov[2]; Tsuyoshi Tajima[2]

[1] *Los Alamos National Laboratory*

[2] *LANL*

Corresponding Author: zuboraj@lanl.gov

This presentation will report results of high gradient testing of two C-band accelerating cavities fabricated at Los Alamos National Laboratory (LANL). LANL has successfully commissioned a C-band

Engineering Research Facility of New Mexico (CERF-NM) which now serves for testing accelerating cavities at C-band. The test stand is powered by a 50 MW, 5.712 GHz Canon klystron and offers a unique capability of conditioning and testing accelerating cavities for operation at surface electric fields at the excess of 300MV/m,. Recently, we fabricated and tested two benchmark copper cavities at CERF-NM. The goal of the test was to establish a benchmark for high gradient performance at C-band. The cavities were a direct scale of the similar test structures fabricated and tested by other institutions at the frequencies of X-band and S-band. The geometry of the cavities consisted of three cells with one high gradient central cell and two coupling cells on the sides. The ratio of the radius of the coupling iris to the wavelength was $a/\lambda=0.105$. The two tested cavities were made of pure soft alloy copper, and these benchmark results can be later compared to other tests of cavities fabricated with different alloys and different fabrication methods. Both cavities were conditioned up to the peak surface field of approximately 250MV/m. At the end of conditioning both cavities could operate at this field level with no measurable breakdowns over several hours of operation.

Acknowledgments:

Plenary / **182**

ACE3P – Multi-Physics Modeling, Enabling Technologies, and Code Integration

Author: Liling Xiao[1]

[1] *SLAC*

Corresponding Author: liling@slac.stanford.edu

ACE3P is a comprehensive set of parallel finite-element codes for multi-physics modeling of particle accelerators. Running on massively parallel computer platforms for high fidelity and high accuracy simulation, ACE3P enables rapid virtual prototyping of accelerator rf component design, optimization, and analysis. Recent advances of ACE3P have been achieved through the implementation of advanced numerical algorithms, enhancement of multi-physics modeling capabilities, integration with beams dynamics (IMPACT) and particle-matter interaction (Geant4) codes toward start-to-end simulation, and improvement of code performance on state-of-the-art high-performance computing (HPC) platforms for large-scale computation. ACE3P has been applied to the design and optimization of many DOE accelerator projects nationwide. In this paper, we will focus on ACE3P applications to high brightness injectors and high gradient accelerators. Using ACE3P enhanced multi-physics modeling capabilities, rf performance has been fully evaluated covering cavity shape design, multipacting, thermal and mechanical analysis for the NC and SRF guns in LCLS-II and LCLS-II-HE, respectively. A3PI, an integrated ACE3P-IMPACT workflow, provides realistic studies of beam performance for the LCLS-II Low Emittance Injector (LEI) accelerator system from start to end including gun cavity imperfections. ACE3P has been used to design and optimize the novel high gradient distributed-coupling accelerator cavity for the proposed Higgs factory C3 using Cool Copper C-band technology. The implementation of an integrated ACE3P-Geant4 workflow is underway with the ultimate objective of determining dark current radiation effects in high gradient accelerator systems. Furthermore, SLAC has collaborated with Kitware and Simmetrix through SBIR to make ACE3P more accessible to a broader accelerator community by the development of enabling technologies in GUI, simulation workflow for HPC systems, and advanced meshing techniques for automatic shape optimization. All the simulations presented in this paper have been performed on the computing resources at the National Energy Research Scientific Computing Center (NERSC).

Acknowledgments:

Poster Session and Reception - Board: F65 / **183**

Improving electron dephasing of an all-optical multi-GeV laser

wakefield accelerator

Authors: Bo Miao[1]; Jaron Shrock[1]; Ela Rockafellow[1]; Howard Milchberg[1]

[1] *University of Maryland, College Park*

Corresponding Author: bmiao@umd.edu

Laser plasma accelerators can generate acceleration gradients of 10~100 GeV/m and have delivered multi-GeV electron beams. In a recent experiment, we demonstrated electron acceleration up to 5 GeV in a 20-cm plasma waveguide, formed via self-waveguiding pulses in a low density hydrogen gas jet [1,2]. The long optical guiding of multi-100 TW pulses causes complex evolution of the laser driver envelope and spectrum, which entails further study to improve the accelerated electron bunch quality. In this work we investigate numerically the additional dephasing due to pump depletion during laser propagation in a plasma waveguide. We propose ways to alleviate this effect by pulse shaping and present numerical simulations validating the proposed methods.

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Poster Session and Reception - Board: F69 / **184**

Symplectic surrogate models for beam dynamics in conventional and advanced accelerators

Author: Chengkun Huang[1]

Co-authors: Qi Tang [2]; Joshua Burby [2]; Yuri Batygin [2]; Sergey Kurennoy [2]; Oleksii Beznosov [2]; Anastasiia Kim [2]; Yanzeng Zhang [2]

[1] *Los Alamos National Lab.*

[2] *LANL*

Large scale particle accelerator facilities play essential roles in advancing the frontier of particle & nuclear physics, photon science and material research. The existing software for modeling the dynamics of these particle beam that can achieve fast turn-around time is either limited to linear analysis or only provides the preliminary lattice design evaluation, while first-principle codes (e.g., for coherent synchrotron radiation [1]) for detail study or spot-checking are too expensive for tackling inverse problems, parameter optimization and data-intensive applications. On the other hand, advanced accelerator concepts typically employ highly nonlinear interaction, often from high intensity lasers, to accelerate or control beams with high current density or brightness. The successful deployment of surrogate models for such beam dynamics can significantly help the design and optimization of both types of accelerators. We pursue design and development of novel structure-preserving neural networks [2] for practical accelerator applications. The robustness of the machine-learning surrogate model will be ensured by embedding fundamental symplectic constraints to the interaction and evolution of the beam. We demonstrate the advantage of these symplectic surrogate models [3] and discuss promising applications for realistic accelerator problems.

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WGs 2+7 Joint Session / 185

Radiation Diagnostic for OSIRIS: Applications in coherent betatron emission

Authors: Miguel Pardal[1]; Ricardo Fonseca[2]; Jorge Vieira[3]

[1] *GoLP/IPFN, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal*

[2] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico*

[3] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa,*

Corresponding Author: miguel.j.pardal@tecnico.ulisboa.pt

Radiation emission plasmas is often a result of collective effects associated with the dynamics of relativistic charged particles. A common numerical approach to model their motion involves the Particle-In-Cell scheme which solves the full set of Maxwell's equations and the relativistic Lorentz force for the charged particles.

The Radiation Diagnostic for OSIRIS (RaDiO) can retrieve the emitted spatiotemporal electromagnetic field structure of the emitted radiation in OSIRIS simulations, even at wavelengths smaller than the PIC resolution, by relying on the Liénard-Wiechert Potentials. These codes can run with a high level of efficiency in most of the largest CPU-based supercomputers [M. Pardal et al, submitted (2022)]. Nevertheless, GPU accelerator boards are nowadays employed in supercomputers to the point where some of the most powerful machines nowadays are GPU-based systems. Recently, the radiation algorithm has been adapted to the GPU architecture, and this adaptation was integrated into OSIRIS. This allowed for a deeper study of new radiation generation schemes in plasma accelerators.

In this work, we use RaDiO to generalize the ion channel laser concept towards superradiant betatron emission from plasma accelerated electrons in plasma channels. This is made possible by the use of generalized superradiance, which allows arbitrarily diluted beams to radiate coherently, exploiting the optical shocks coming from superluminal particle beam structures. We show that by resonantly combining betatron oscilations with the effect of a low frequency laser pulse, a plasma accelerated electron beam may acquire the modulation with a superluminal phase speed required by the onset of generalized supperadiance. The generalized ion channel laser concept can then be seeded by more traditional infra-red laser pulses, and lead to temporally coherent, broad-band radiation that can extend all the way up to x-ray frequencies. Here we show how the use of RaDiO allowed us to model radiation emission in these scenarios and determine the necessary conditions to obtain superradiant betatron emission.

Acknowledgments:

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WG6: Laser-Plasma Acceleration of Ions / 186

Theoretical and numerical investigation of ion acceleration in the interaction of high intensity attosecond pulses with solid proton-Boron targets

Authors: Emmanuel d'Humieres[1]; Xavier Ribeyre[1]; Rémi Capdessus[1]; Florent Brun[1]; Jonathan Wheeler[2]; Gérard Mourou[2]

[1] *CELIA, Univ. Bordeaux*

[2] *DER-IZEST, Ecole Polytechnique*

Corresponding Author: emmanuel.dhumieres@u-bordeaux.fr

Several setups have recently been proposed to generate ultra-short laser pulses in the 10-100 as range with high energies (0.1-10 J) and a wavelength in the EUV-X range (1-100 nm), either by broadening the spectrum of near-infrared laser pulses to obtain single-cycle pulses that can be converted to single cycle attosecond pulses by a plasma mirror, or by directly using Doppler-boosted petawatt-class lasers. The corresponding photon energy range is from 10 eV to 1 keV. Such high energy photons are able to propagate even inside solid density targets and will allow to study the propagation of such pulses in matter, and to explore new regimes of laser-matter interaction with strong application potential as the laser energy involved will be limited and the repetition rate will be high. Another unique feature of this regime will be the ultra-high intensities that will be reached thanks to the very short duration of the pulse itself, and to the small focal spots reachable at these wavelengths.
These new unexplored regimes of interaction have the potential to achieve considerable breakthroughs in high efficiency laser particle acceleration, high efficiency and high energy radiation sources, ultra-high amplitude magnetic field generation and ultra-high pressures. Applications in fundamental physics and extreme laboratory astrophysics will therefore arise linked to high field quantum electrodynamics, nuclear physics and general relativity. We have investigated the interaction of high energy attosecond pulses with solid proton–Boron targets and the associated electron acceleration, ion acceleration, and radiation generation supported by Particle-In-Cell simulations. We demonstrate the efficiency of single–cycle attosecond pulses in comparison to multi–cycle attosecond pulses for transverse ion acceleration and magnetic field generation, making this regime of interaction promising for proton–Boron fusion. We also discuss the influence of the laser and target parameters to optimize longitudinal ion acceleration and high energy radiation generation.

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WG3: Laser and High-Gradient Structure-Based Acceleration / 187

ACHIP experiments at the ARES linac

Author: Willi Kuropka[1]

Co-authors: Frank Mayet [1]; Hannes Dinter [1]; Assmann Ralph [1]; Blae Stacey [1]; Burkart Florian [1]; Thomas Vinatier [1]; Huseyin Cankaya [1]; Kärtner Franz [2]; Ingmar Hartl [1]; Christoph Mahnke [1]; Sonja Jaster-Merz [1]

[1] *Deutsches Elektronen-Synchrotron DESY*

[2] *Center for Free-Electron Laser Science*

Corresponding Author: willi.kuropka@desy.de

ARES is a linear particle accelerator at Deutsches Elektronen-Synchrotron DESY capable of producing high-quality, low-emittance electron beams dedicated to accelerator research and development. As an introduction we will present the achieved and projected performance of the ARES linac. An overview of the research activities on ultra-short electron bunch diagnostic methods, electron imaging and beam manipulation will be given.

The focus of this contribution will be the dielectric laser acceleration (DLA) campaign in the framework of the Accelerator on aCHip International Program (ACHIP) funded by Gordon and Betty Moore Foundation at ARES. We are employing a 2.05um wavelength Ho:YLF laser amplifier system to drive fused silica microstructures with the same periodicity manufactured by our collaborators at Stanford University. The goal of the experimental campaign is the improvement of transmitted charge compared to previous experiments while maintaining the acceleration gradient in the *GV/m* regime. Also, the ARES linac is foreseen to produce electron bunches exhibiting bunch lengths of less than *2fs*, short enough to fit an acceleration bucket at the aforementioned wavelength, which corresponds to *6.8fs* period. The arrival time jitter of the electrons at the interaction point will be larger than the laser period. To mitigate this a micro-bunching scheme was developed to synchronize a micro-bunch train with the DLA interaction. We will present the status and the recent achievements of the ACHIP DLA campaign.

Acknowledgments:

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WGs 2+5 Joint Session / 188

Experimental results for machine learning based diagnostics and optimization at FACET-II

Authors: Claudio Emma[None]; Auralee Edelen[1]; Glen White[2]; Spencer Gessner[1]; Miskovich Sara[1]; Willie Neiswanger[3]; Ryan Roussel[4]; Mark Hogan[4]

[1] *SLAC*

[2] *Stanford Linear Accelerator Center*

[3] *Stanford*

[4] *SLAC National Accelerator Laboratory*

Corresponding Author: cemma89@stanford.edu

This contribution addresses recent progress in machine learning based diagnostics and optimization at the FACET-II facility at SLAC National Accelerator Laboratory. We focus the discussion around three examples: longitudinal phase space diagnostics [1-2], new algorithms for 20x speedup in optimization of beam emittance, and automated sextupole tuning to reduce minimum spot sizes in the FACET experimental area. We also present results describing the application of machine learning based characterization methods to efficiently explore high-dimensional parameter spaces [3], as compared to traditional parameter scans, in the context of emittance optimization of the FACET-II photoinjector. We will show results obtained during the last experimental run and discuss plans for deployment of these tools in future runs, along with their potential to aid in beam setup for experimental configurations, reduce tuning time, and improve beam stability. While we focus on applications at FACET-II, most of these tools can be readily used at other facilities through our open-source software packages (e.g. see [4,5]); we will briefly highlight the current capabilities of these software packages.

[1] C. Emma and A. Edelen, M.J. Hogan, B. O'Shea, G. White, and V. Yakimenko , Phys. Rev. Accel. Beams 21, 112802 (2018)
[2] C. Emma, A. Edelen, A. Hanuka, B. O'Shea, A. Scheinker, Information 2021, 12(2), 61; https://doi.org/10.3390/info12020061
[3] Ryan Roussel, Juan Pablo Gonzalez-Aguilera, Young-Kee Kim, Eric Wisniewski, Wanming Liu, Philippe Piot, John Power, Adi Hanuka & Auralee Edelen Nature Communications volume 12, Article number: 5612 (2021)
[4] C. Mayes, R. Roussel, H. Slepicka, Xopt. 10.5281/zenodo.6991160
[5] C. E. Mayes and P. H. Fuoss and J. R. Garrahan and H. Slepicka and A. Halavanau and J. Krzywinski and A. L. Edelen and F. Ji, W. Lou and N. R. Neveu and A. Huebl and R. Lehe and L. Gupta and C. M. Gulliford and D. C. Sagan and J. C. E and C. Fortmann-Grote, IPAC'21, THPAB217.

Acknowledgments:

WG2: Computation for Accelerator Physics / 189

Eulerian Finite-Difference Vlasov Solver with a Non-Uniform Momentum Grid

Author: B. A. Shadwick[1]

Co-author: Roland Hesse

[1] *Univ of Nebraska - Lincoln*

Corresponding Author: shadwick@unl.edu

An Eulerian finite-difference method solving the Vlasov equation is developed with a static, non-uniform momentum grid. The computational cost of this transformation differs negligibly from the uniform case with the same number of grid points. A general grid parametrization is tested against classic instabilities and driven cases and is found to provide significant efficiencies over the uniform grid case. This technique allows for the distribution of computational resources based on the relativce importance of kinetic activity in phase-space while preserving variationally conserved quantities from the formal bracket. This method can be readily extended to multiple dimensions and is compatible with dynamically adapting the momentum grid.

Acknowledgments:

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WG6: Laser-Plasma Acceleration of Ions / 190

Ultra-short pulse laser acceleration of protons from cryogenic hydrogen jets tailored to near-critical density

Authors: Martin Rehwald[1]; Constantin Bernert[1]; Florian-Emanuel Brack[1]; Michael Bussmann[2]; Thomas E. Cowan[3]; Chandra B. Curry[4]; Frederico Fiuza[4]; Marco Garten[5]; Lennart Gaus[1]; Maxence Gauthier[4]; Sebastian Göde[6]; Ilja Göthel[1]; Siegfried H. Glenzer[4]; Lingen G. Huang[1]; Axel Huebl[5]; Jongjin Kim[4]; Thomas Kluge[1]; Stephan Kraft[1]; Florian Kroll[1]; Josefine Metzkes-Ng[1]; Markus Loeser[1]; Lieselotte Obst-Huebl[5]; Marvin Reimold[1]; Hans-Peter Schlenvoigt[1]; Christopher Schoenwaelder[4]; Ulrich Schramm[3]; Mathias Siebold[1]; Franziska Treffert[4]; Long Yang[1]; Tim Ziegler[1]; Karl Zeil[1]

[1] *HZDR*

[2] *CASUS, HZDR*

[3] *HZDR, TU Dresden*

[4] *SLAC*

[5] *LBNL, HZDR*

[6] *European XFEL*

Corresponding Author: m.rehwald@hzdr.de

Laser plasma-based particle accelerators attract great interest in fields where conventional accelerators reach limits based on size, cost or beam parameters. However, despite the fact that first principles simulations have predicted several advantageous ion acceleration schemes, laser accelerators have not yet reached their full potential in producing simultaneous high-radiation doses at high particle energies. The most stringent limitation is the lack of a suitable high-repetition rate target

that also provides a high degree of control of the plasma conditions which is required to access these advanced regimes.
Here, we demonstrate that the interaction of petawatt-class laser pulses with a micrometer-sized cryogenic hydrogen jet plasma overcomes these limitations. Controlled pre-expansion of the initially solid target by low intensity pre-pulses allowed for tailored density scans from the overdense to the underdense regime. Our experiment demonstrates that the near-critical plasma density profile produces proton energies of 80 MeV. This energy presents more than a factor of two increase compared to the solid hydrogen target. Our three-dimensional particle in cell simulations show the transition between different acceleration mechanisms and suggest enhanced proton acceleration at the relativistic transparency front for the optimal case.

Acknowledgments:

WG7: Radiation Generation and Advanced Concepts / 191

Superradiance and temporal coherence in the non-linear blowout regime

Authors: Bernardo Malaca[1]; Miguel Pardal[2]; Dillon Ramsey[3]; John Palastro[4]; Jacob Pierce[5]; Kathleen Weichman[6]; Warren Mori[5]; Ricardo Fonseca[7]; Igor Andriyash[8]; Jorge Vieira[9]

[1] *GoLP/Instituto Superior Técnico, University of Lisbon*

[2] *GoLP/IPFN, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal*

[3] *University of Rochester / Laboratory for Laser Energetics*

[4] *University of Rochester, Laboratory for Laser Energetics*

[5] *UCLA*

[6] *University of Rochester Laboratory for Laser Energetics*

[7] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico*

[8] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris*

[9] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Téecnico*

Corresponding Author: bernardo.malaca@tecnico.ulisboa.pt

Well known light emitting mechanisms (e.g. betatron radiation and non-linear Thomson scattering) are based on the motion of single-particles. Experiments demonstrated that these mechanisms can lead to the emission of bright radiation bursts, with frequencies extending up to the x-rays and beyond. These sources have intrinsic limitations: the electron velocity is always lower than the speed of light, and the acceleration that can imparted to an electron is not arbitrary.

Here, we consider instead the radiation emitted by collective excitations such as plasma waves. We show theoretically that the trajectory of the centroid of a plasma fully determines the temporal coherence features of the emitted radiation, just as if it were a real particle executing the same trajectory. A key feature of this concept is that the trajectory of a collective excitation such as a plasma wave can be arbitrary: it can go faster than light and have arbitrarily large accelerations. Instead of relying on electric and magnetic fields to accelerate particles, these features are a result of a coordinated reorganisation of the light emitting medium.

To illustrate the concept, we performed 2D and 3D simulations using the particle-in-cell code OSIRIS (including the Radiation Diagnostic for OSIRIS - RaDiO) to purposefully design wave trajectories which are inaccessible to single particles, with both examples of broadband and narrow band emission. We show that a superluminal laser/plasma wakefield will generate an optical shock at the Cherenkov angle. The emission is superradiant for all frequencies, thus potentially leading to a plasma-based source of temporally coherent broadband radiation. In contrast, a laser propagating in a sinusoidally modulated plasma density profile results in a periodic motion of the plasma wave centroid that results in temporally coherent narrow-band emission. Here we observe the generation of temporally coherent harmonics at the double doppler shifted frequency of the plasma wave centroid trajectory. This leads to a narrow frequency spectrum and to temporally coherent emission up to 100-1000 times the plasma frequency.

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WG7: Radiation Generation and Advanced Concepts / **192**

Laser-Plasma Acceleration Driven Electron Radiography of High Energy Density Materials on the OMEGA-EP Laser

Author: Jessica Shaw[1]

Co-authors: Gerrit Bruhaug ; Matthew Freeman ; J. Ryan Rygg ; Frank Merril ; Carl Wilde ; Levi Neukirch ; Mingsheng Wei ; Gilbert Collins ; Hans Rinderknecht

[1] *University of Rochester Laboratory for Laser Energetics*

Corresponding Author: jshaw05@lle.rochester.edu

Contact and projection electron radiography using a laser-plasma electron accelerator driven by the OMEGA-EP laser are shown for static targets. Initial electron radiographs of laser-driven foils are shown along with a discussion of future experiments and applications. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856 and the U.S. Department of Energy under Awards DE-SC00215057.

Acknowledgments:

Poster Session and Reception - Board: P41 / **193**

Compact high-resolution multi-GeV electron spectrometer for PW-laser-driven plasma accelerators

Author: Xiantao Cheng[1]

Co-authors: Aaron Bernstein [1]; Andrea Hannasch [2]; Maxwell LaBerge ; Michael Downer [3]; Rafal Zgadzaj [2]; Yen-Yu Chang [4]

[1] *University of Texas at Austin*

[2] *UT at Austin*

[3] *The University of Texas at Austin*

[4] *Helmholtz-Zentrum Dresden-Rossendorf*

Corresponding Author: chengxiantao@utexas.edu

With the availability of petawatt lasers, the space required to generate beams of electrons to GeV-levels by laser-plasma acceleration has reduced to that of the university laboratory [1]. However, measuring these electrons in the relatively compact space of a vacuum chamber that can be supported by the typical university laboratory is challenging, as it typically requires large magnets (peak magnetic field B = 1.25T, 40s cm length) [2]. For example, a spectrometer with a magnet of ~1T extending 5 cm will yield an uncertainty 200 MeV around a 1GeV peak for an electron launch angle variation of ±4mrad.
Here we report on a compact, high-resolution electron spectrometer with a resolution of ±XXX MeV for measuring 4 GeV electrons, which uses a 1.48T magnet, made possible by using two sets

of tungsten wires, each at a different propagation distance beyond the magnet. The wires, placed with ~100-micron accuracy, act as fiducials by introducing shadows on both the electron beams and their associated betatron X-rays, to determine the electron energy, source position and launch angle. The spectrometer was used to measure ~4 GeV electrons from recent TPW LWFA experiments. The results were compared with the two-screen method and showed a good agreement.
We also studied the high-energy electron shadows of tungsten wires under different electron energy, both in experiments and GEANT4 simulations. A wire is scattering less electrons when the electron energy is higher. We provided a formula summarized from a series of GEANT4 simulations as a guidance of a high energy (>10GeV) spectrometer design. And detailed error analysis for this kind of spectrometer was made, which showed its ability to measure electron spectrum with more 10 GeV energy.

[1] X. Wang et al., Nature Communications 4, 1988 (2013)
[2] K. Nakamura et al., Review of scientific instruments 79, 053301 (2008)

Acknowledgments:

WG4: Beam-Driven Acceleration / 194

An Analytic Theory of Chromatic Emittance Growth in a Plasma Wakefield Accelerator

Authors: Robert Ariniello[1]; Christopher Doss[2]; Valentina Lee[2]; Claire Hansel[2]; John Cary[2]; Michael Litos[2]

[1] *SLAC National Accelerator Laboratory*

[2] *University of Colorado Boulder*

Corresponding Author: rariniel@stanford.edu

Preserving the emittance of an electron bunch as it is accelerated by a plasma wakefield accelerator is one of the major challenges that needs to be overcome for these accelerators to replace conventional techniques. Energy spread in the bunch primarily drives the emittance growth through the process of chromatic phase spreading. The chromatic effects are complicated by the acceleration process; the different particles in the bunch are accelerated at different rates depending on how well the witness beam loads the wake. We present an analytic theory describing this evolution that includes the effects of nonuniformity in the accelerating field, the witness beam's initial energy spread, and mismatch between the beam and the plasma. We discuss some of the interesting features that emerge including the evolution of the longitudinal and energy slices.

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High Energy Physics under Award No. DE-SC0017906.

WGs 2+8 Joint Session / 195

Thermal Modeling and Benchmarking of Crystalline Laser Amplifiers

Authors: Dan Abell[1]; David Bruhwiler[1]; Paul Moeller[1]; Robert Nagler[1]; Boaz Nash[1]; Qiang Chen[2]; Cameron Geddes[2]; Csaba Tóth[2]; Jeroen van Tilborg[3]; Nicholas Goldring[4]

[1] *RadiaSoft LLC*

[2] *Lawrence Berkeley National Laboratory*

[3] *LBNL*

[4] *STATE33 Inc.*

Corresponding Author: dabell@radiasoft.net

Detailed thermal modeling of crystal amplifiers is a prerequisite for rapid improvement—higher pulse quality, higher average power at maximum achievable peak intensity, better repeatability, etc.—of high-intensity lasers (100 TW to multi-PW) with ultra-short pulse lengths ($<$ 100 fs). In recent work [1], we used the open-source, finite-element code FEniCS [2] to solve the linear partial differential equation for thermal transport across a cylindrical Ti:Sapphire crystal, assuming a 532 nm Gaussian pump laser illuminating the crystal from one side at 1 kHz. From the experimentally measured thermal time scale of approximately 150 ms, we inferred a room-temperature thermal diffusivity of about 0.29 cm^2/s. This value does not agree well with those calculated directly from thermal conductivity and specific heat capacity values found in the literature. Sources of uncertainty include (a) the pump laser power absorbed as heat by the crystal (which depends on both the absorption coefficient and the fractional thermal heat load), and (b) variations of the thermal conductivity and specific heat capacity (which vary with both temperature and details of the titanium doping). In order to address these uncertainties, we have generalized our FEniCS model to include nonlinearities associated with temperature variations of the thermal conductivity and specific heat capacity, across a wide range of temperatures. We will present recent work, comparing linear and nonlinear simulations, at cryogenic temperatures and also at room temperature.

[1] D.T. Abell *et al.*, Proc. IPAC'22, THPOTK062, https://jacow.org/ipac2022/papers/thpotk062.pdf.
[2] The FEniCS Computing Platform, https://fenicsproject.org.

Acknowledgments:

This work is supported by the US Department of Energy, Office of High Energy Physics under Award Numbers DE-SC0020931 and DE-AC02-05CH11231.

WGs 2+5 Joint Session / 196

A Non-Invasive, Single-Shot Emittance Diagnostic, Using Edge-Radiation and a CNN Based Inference Model

Authors: Robbie Watt[1]; Brendan O'Shea[1]

[1] *SLAC*

Corresponding Author: rwatt@slac.stanford.edu

Accelerators are moving towards higher repetition rates with extremely high current and brightness beams.
Advanced control techniques using machine learning are required for the optimisation and operation of such accelerators.
These techniques greatly benefit from having single-shot beam measurements.
However, high intensity beams present an issue for conventional diagnostics as they will destroy any material placed in the beamline.
Therefore, single-shot, non-invasive diagnostics are highly desirable.

Edge-radiation is produced in the fringe fields of bending magnets and is common to both linear and circular accelerators.
The radiation is both sensitive to the beam parameters and non-intercepting, making it an ideal candidate for future diagnostics.
Here, we will present experimental results of an edge-radiation based diagnostic at FACET-II.
This diagnostic collects edge-radiation and uses machine learning to characterize the beam.

We will discuss the image processing techniques used and demonstrate how a convolutional neural network can predicts the emittance in a single-shot.

Acknowledgments:

WG4: Beam-Driven Acceleration / 197

Wakefield Acceleration in Nanostructures: The E336 Experiment at FACET-II

Authors: Robert Ariniello[1]; Sebastien Corde[2]; Xavier Davoine[None]; Henrik Ekerfelt[1]; Frederico fiuza[None]; Max Gilljohann[3]; Laurent Gremillet[None]; Yuliia Mankovska[3]; Henryk Piekarz[None]; Pablo San Miguel Claveria[3]; Vladimir Shiltsev[4]; Peter Taborek[5]; Toshiki Tajima[None]

[1] *SLAC National Accelerator Laboratory*

[2] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, 15 Institut Polytechnique de Paris, 91762 Palaiseau, France*

[3] *LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris*

[4] *Fermilab*

[5] *University of California Irvine*

Corresponding Author: rariniel@stanford.edu

When a high intensity electron beam is passed through a structured nano target, the solid-state density plasma created can support ultra-high accelerating gradients, on the order of 1-10 TeV/m. The similarly strong transverse focusing fields are expected to produce beams with small equilibrium emittance. Driving these extreme wakefields in the self-modulated regime requires high energy and high-density electron bunches. Such bunches are now within reach at the FACET-II facility at SLAC National Accelerator Laboratory. The E336 experiment at FACET-II is a proof of principle experiment that will utilize the high-density electron beams produced by the facility to demonstrate the unique processes expected to occur in structured solid targets. We discuss the motivation, status, and future plans for the experiment.

Acknowledgments:

WG7: Radiation Generation and Advanced Concepts / 198

HIGH-BRILLIANCE COMPTON LIGHT SOURCES BASED ON CO2 LASERS

Authors: Igor Pogorelsky[1]; Mikhail Polyanskiy[2]; Timur Shaftan[1]

[1] *BNL*

[2] *Brookhaven National Laboratory*

Corresponding Author: igor@bnl.gov

Inverse Compton scattering (ICS) from relativistic electron beams colliding with laser pulses can be used for relatively compact and affordable x-ray and gamma sources complementing conventional synchrotron light sources (SLSs). Several proposals have been put forward on converting electron accelerators to Inverse Compton Scattering (ICS) gamma sources. Different types of particle accelerators have been considered including superconducting energy recovery linacs (S-ERL) and a synchrotron storage rings. A common approach implies combining e-beams with near-IR solid state lasers operating at multi-megahertz repetition rate inside Fabri-Perot optical cavity.
We evaluate here a complementary method of using a long-wave-IR (LWIR) CO2 gas laser of a novel

pulse-burst architecture by examples of perspective ICS sources based on a synchrotron accelerator DAΦNE and an S-ERL CBETA, each paired either with a near-IR solid state laser or with CO2 gas laser. For each of these schemes, we show that a LWIR laser with its 15 kHz cumulative pulse repetition rate can produce average spectral fluxes and brightness competitive with the approach based on state-of-the-art multi-MHz solid state laser. Simultaneously, the LWIR laser driver will provide about four orders of magnitude higher x-ray peak characteristics. This can be achieved due to considerable increase in acting laser pulse energy, combined with an order of magnitude higher number of laser photons per Joule. Operated at 50-500 keV photon energy with peak brilliances 1020-1021 ph/s-mm2-mrad2-0.1%BW the proposed ICS sources will become indispensable for pump-probe and other ultra-fast material studies that require building up meaningful data sets from a single x-ray pulse at the energy scale of atomic interactions.

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WG6: Laser-Plasma Acceleration of Ions / 199

OPPORTUNITIES FOR ADVANCED ACCELERATOR RESEARCH WITH FEMTOSECOND LONG-WAVELENGTH LASERS

Authors: Igor Pogorelsky[1]; Marcus Babzien[1]; Mikhail Polyanskiy[2]; Mark Palmer[2]; Mikhail Fedurin[1]; William Li[2]

[1] *BNL*

[2] *Brookhaven National Laboratory*

Corresponding Author: igor@bnl.gov

Ultra-intense lasers are the driving force of the advanced accelerator research (AAR). Extension of their spectral reach from the presently achievable near-IR into the long-wave IR (LWIR) domain opens opportunities to explore new regimes of particle acceleration, gaining deeper insight into laser-plasma interactions, and improve laser accelerator parameters. Longer laser wavelength facilitates low density regimes of laser plasma accelerators where bigger plasma bubbles are created for laser wake field electron acceleration or gas jets can be used for monoenergetic shock-wave ion acceleration.
BNL Accelerator Test Facility (ATF) traditionally offers users an access to a terawatt class picosecond CO2 laser operating at 9 μm. The present-day ATF's state-of-art laser system features the most advanced configuration that includes a solid-state, femtosecond, optical parametric amplifier front end, a chirped pulse amplification (CPA), and the use of multiple CO2 isotopes in a chain of laser amplifiers. This laser is capable to deliver 5 TW peak power in a single 2 ps pulse. However, realization of the LWFA bubble regime requires reduction in the laser pulse duration down to 500 fs or shorter and an increase in peak power over the present ATF laser system. Such upgrade is the target of the ATF's two-year modernization program that includes two parallel approaches: The first thrust is the nonlinear post-compression where spectrum of the laser pulse is broadened by a self-phase modulation in a nonlinear optical material. The resulting chirped pulse can be compressed to 500 fs at 10 TW by a dispersive optical element. Another approach includes developing a source for the 500 fs, 10 mJ, 9 μm seed pulse that should allow to reach 20 TW in the CPA regime. A combination of these two approaches holds the promise of achieving 100 TW at 100 fs. The combination of such LWIR laser with also available at ATF electron linac and near-IR lasers will empower a unique state-of-the-art science program at the forefront of AAR.

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WG1: Laser-Plasma Wakefield Acceleration / 200

Optical mode filtering and electron injection in multi-GeV laser wakefield acceleration

Authors: Jaron Shrock[1]; Bo Miao[None]; Ela Rockafellow[2]; Howard Milchberg[2]

Co-authors: Alexander Picksley [3]; Reed Hollinger [4]; Shoujun Wang [4]; Jorge Rocca [4]

[1] *University of Maryland*

[2] *University of Maryland, College Park*

[3] *LBNL*

[4] *Colorado State University*

Corresponding Author: jshrock@terpmail.umd.edu

Recent experiments [1] have demonstrated acceleration of electron bunches up to 5 GeV in long (20 cm) low density (~10^17 cm^-3) ionization-injected plasma waveguides [2]. The spectra of the recorded electron bunches showed multiple quasi-monoenergetic peaks with resolution limited energy spreads ~15%. For eventual development of a 10 GeV laser wakefield acceleration (LWFA) module for a staged electron accelerator, it is essential that the lower energy peaks in the spectra be eliminated. Analysis of the results in [1] suggests that the multiple peaks correspond to localized injection enhancement (or suppression), exacerbated by fluctuations in the drive laser pointing and longitudinal waveguide variations, both of which strongly affect the guided mode evolution. Here, we present experimental results and particle-in-cell simulations detailing the linear and non-linear effects contributing to guided mode evolution and electron injection. We discuss how the early part of a meter-scale plasma waveguide can be used as a 'mode filter' to ensure controllable electron injection in multi-GeV LWFAs.

[1] B. Miao et al., "Multi-GeV electron bunches from an all-optical laser wakefield accelerator", arXiv:2112.03489 (2021).

[2] L. Feder et al., "Self-waveguiding of relativistic laser pulses in neutral gas channels", Phys. Rev. Res. 2, 043173 (2020).

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WGs 7+8 Joint Session / 201

FULFILLING THE MISSION OF BROOKHAVEN ATF AS A DOE'S FLAGSHIP USER FACILITY IN ACCELERATOR STEWARDSHIP

Authors: Igor Pogorelsky[1]; Marcus Babzien[1]; Mikhail Fedurin[2]; William Li[2]; Mikhail Polyanskiy[1]; Mark Palmer[2]

[1] *BNL*

[2] *Brookhaven National Laboratory*

Corresponding Author: igor@bnl.gov

Over last three decades, BNL Accelerator Test Facility (ATF) pioneered the concept of a proposal-based user facility for lasers and electron beam-driven advanced accelerator research (AAR). This

has made ATF, operating as an Office of Science National User Facility and a flagship DOE facility in Accelerator R&D Stewardship, an internationally recognized destination for researchers who benefit from access to unique experimental capabilities not otherwise available to individual institutions and businesses. The high-peak-power long-wave infrared (LWIR) laser is a unique tool available at ATF for experimental study of wavelength scaling of strong-field phenomena and testing of laser driven acceleration regimes that are more difficult to achieve at shorter wavelengths. Other ATF capabilities include high-brightness electron linac and a facility for ultra-fast electron diffraction and microscopy experiments. ATF pursues an ambitious upgrade plan for its lasers and electron beam infrastructure. The scope of the ATF upgrade is designed to enable advances in three key areas:
Laser R&D program: CO2 laser power upgrade to 20 TW peak power with pulse-width <500 fs will enable a world-leading program in AAR. Completing in-vacuum NIR and LWIR laser beam transport to ensure the best beam quality delivered to user experiments.
Electron Beam: Continue to move towards providing more highly compressed beams (~10 fs bunch) together with exploiting and expanding short bunch diagnostic capabilities.
UED/UEM: Improve system performance with wavelength-flexible OPA pump laser; Apply AI/ML techniques to both beam line tuning and real-time structural analysis.
A combination of these upgrades will pave the way for a range of scientific initiatives – from ion acceleration, which is relevant for future radiotherapy methodologies, to novel opportunities for investigating LWFA of electrons. This includes integrated multi-beam research in laser wakefield accelerators, such as the two-color ionization injection, with the promise of an all-optical scheme for generating collider-quality electrons beams.
This will ensure that the ATF user community will continue successful R&D in accelerator technology and conducting experiments at the forefront of AAR, which are key elements of the Accelerator Stewardship mission.

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Poster Session and Reception - Board: P6 / **202**

Hydrodynamic channel guiding of Helium laser driven wake with downramp injection

Author: Jason Brooks[None]

Co-authors: Ross Rudzinsky ; Timothy Araujo [1]; Zgadzaj Rafal ; Michael Downer [1]

[1] *The University of Texas at Austin*

Corresponding Author: jasonbrooks@utexas.edu

Plasma waveguides improve shot-to-shot consistency of laser wakefield accelerators (LWFAs) and extend acceleration length to multiple Rayleigh ranges. Recent work [1] has explored the use of waveguides down to low 1e17cm^{-3} densities and accelerated electron energies up to 5 GeV. Both experimentally and through simulations we will combine waveguide generation techniques with a separate technique from Ref. [2] that utilizes strong shockwaves to facilitate sharp downramp injection in a plasma inside a guided channel at any arbitrary position inside the waveguide. This technique is achieved by aiming a longer duration (100+ fs), small gaussian focus at the downramp injection location timed before the shorter (40fs) axicon beam. The colder optical field ionized (OFI) plasma from the gaussian focus and the hotter axicon OFI-heated plasma collide to create a sharp shock 10's of um wide to facilitate downramp injection as the 800 nm, 700 mJ, 40fs drive beam propagates through the 3mm long Helium-plasma waveguide.

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[2] J. Faure et. al. Phys. Plasmas 17, 083107 (2010)

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WG4: Beam-Driven Acceleration / **203**

Beam-Driven Dielectric Wakefield Acceleration with a plasma photocathode at the AWA

Authors: Gerard Andonian[1]; Nathan Cook[2]; Gwanghui Ha[3]; Tara Hodgetts[4]; Seongyeol Kim[3]; Walter Lynn[5]; Nathan Majernik[None]; John Power[None]; James Rosenzweig[None]; Eric Wisniewski[3]

[1] *UCLA/Radiabeam*

[2] *RadiaSoft LLC*

[3] *Argonne National Laboratory*

[4] *Radiabeam*

[5] *UCLA*

Corresponding Author: gerard.andonian@gmail.com

The Trojan Horse experiment has recently demonstrated the plasma photocathode concept at SLAC FACET, with a two-gas mixture where on species is ionized for wakefield generation and the other for precision witness beam generation within the plasma bubble. In an experimentally similar approach called the 'Dielectric Trojan Horse', the plasma accelerator component is replaced with a solid-state dielectric structure for the wakefield medium. The dielectric structure is filled with a gas that is ionized by an injection laser to generate the witness beam for the plasma photocathode process. While the peak accelerating field if sacrificed compared to the plasma accelerator, the hybrid method may provide low emittance beam generation that is maintained through transport. Here, we described the design and implementation of this experimental scenario at the Argonne Wakefield Accelerator (AWA) where the concept of a bunch brightness transformer can be realized. In the AWA experiment, a bunch train resonantly excites the fundamental mode in the dielectric wakefield accelerator and a precision laser ionizes Xe-gas, filled into the structure, to generate the witness beam. Proposed experimental methods and diagnostic capabilities and are discussed.

Acknowledgments:

DE-SC0017690,DE-SC0022797

Poster Session and Reception - Board: F89 / **204**

Environmental Conditions Effect on Optical Components Performance and Cleaning Techniques

Authors: Viviana Vladutescu[1]; Takahisa Jitsuno [2]; Stefania Ionescu[2]; Ivan Kotov[3]; Andrei Naziru[2]; Abdul Rumaiz[4]; Joseph Ibrahim[5]; Emanie Maitland[5]; Laura Mihai[6]; Vicentiu Iancu[2]

[1] *NYCCT/ELI-NP*

[2] *ELI-NP*

[3] *Instrumentation Division*

[4] *Instrumentation Division, BNL*

[5] *NYCCT*

[6] *CETAL/INFLPR*

Corresponding Author: vivianavladutescu@yahoo.com

Laboratory working conditions and unproperly set experimental designs highly impact the instruments' performance and shortens their life. Several studies have been conducted on the performance of optical components in ultrafast high-power lasers and metrology equipment. The work presented is a study of different types of damages observed on stretcher and compressor diffraction gratings used in an ultrafast high-power laser system. It was found that short term exposure and operation of the systems at relative humidity and temperatures outside the operating range can damage the systems' components irremediably. The effects of different cleaning techniques are presented along with measurements of the diffraction efficiency of the gratings using a monochromator. Among the cleaning techniques, the 5 min, 75-100% power oxygen plasma cleaning has been found to be the least invasive technique.

Acknowledgments:

WG7: Radiation Generation and Advanced Concepts / 205

High Resolution Radiography with Self-Modulated and Blowout Regime Laser Wakefield Acceleration generated X-ray sources

Author: Isabella Pagano[1]

Co-authors: Nuno Lemos [2]; Paul King [1]; Mitchell Sinclair ; Adeola Aghedo ; Andrea Hannasch [3]; Thanh Ha [3]; José Alejandro Franco Altamirano [4]; Hernan Quevedo [3]; Michael Spinks [3]; Constantin Aniculaesei [4]; Shahab Khan [5]; Bjorn Manuel Hegelich [6]; Michael Downer [4]; Chandrashekhar J. Joshi [7]; Felicie Albert

[1] *UT Austin/LLNL*

[2] *Lawrence Livermore National Laboratory*

[3] *UT at Austin*

[4] *The University of Texas at Austin*

[5] *LLNL*

[6] *UT at Austin and Tau Systems Inc.*

[7] *University of California Los Angeles*

Corresponding Author: ipagano@utexas.edu

We aim to develop a diagnostic capable of high spatio-temporal resolution, specifically to be used in High Energy Density Science (HEDS) experiments. A Self-Modulated laser wakefield acceleration (SM-LWFA) driven broadband X-ray source was observed at the Titan target area, Jupiter Laser Facility. The spectral range was between 10 KeV to > 1 MeV, and took advantage of Betatron, Inverse Compton Scattering, and Bremsstrahlung processes to create X-rays. In order to design an X-ray source we can apply to dynamic radiography in HEDS experiments, we must thoroughly examine spectral and spatial attributes. Our results include a comparison of spectral output and source size for each method of generating X-rays from SM-LWFA. An inertial confinement fusion hohlraum and modified Air force resolution target were imaged to demonstrate potential for applications. The radiographs are also used to determine the X-ray source size, or resolution capability. The modified Air Force target is approximated as a "knife edge" and the Fresnel diffraction formalism is used to model the diffraction pattern at different source sizes, and compare to the experimental data. In order to minimize error induced by misalignment in the z plane [1], a curved object (the hohlraum) was also used to determine source size. A modified X-ray ray tracing code creates a line out of a curved object radiograph. In the future, we will apply these analysis tools to compare blowout regime wakefield with other injection schemes and potentially SM-LWFA on the Texas Petawatt.

[1] R. Tommasini et al. POP 24, 053104 (2017).

Acknowledgments:

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Additional support from DoE/NNSA grant DE-NA0004081, and the Directed Energy Professional Society, Graduate Student Scholarship program.

Poster Session and Reception - Board: P31 / **206**

Shallow angle probing of beam driven wakes at the FACET II facility

Authors: Jason Brooks[None]; Rafal Zgadzaj[1]

Co-author: Michael Downer [1]

[1] *The University of Texas at Austin*

Corresponding Author: jasonbrooks@utexas.edu

At the SLAC National Accelerator Laboratory we are focusing on probing particle driven wakes on both short (100s of ps) and long (100+ μs) timescales utilizing the 10 GeV electron beamline at SLAC's FACET II facility. Plasma shapes on the short timescales have potential applications in future positron accelerators [1] and on long timescales studies into the relaxation time of the accelerator are important for determining maximum repetition rates of these accelerators; we plan to build on the work from Ref. [2] to further explore these limits and compare these results with findings from Ref. [3].

[1] T. Silva et. al. Phys. Rev. Lett. 127, 104801 (2021)
[2] R. Zgadzaj et. al. Nat Commun 11, 4753 (2020)
[3] R. D'Arcy et. al. Nature 603 58-62 (2022)

Acknowledgments:

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Plenary / **207**

Breakdown insensitive acceleration regime in structure wakefield acceleration

Author: Xueying Lu[1]

Co-authors: Dillon Merenich [2]; Jiahang Shao [3]; Maomao Peng [4]; Gonxiaohui Chen [3]; Scott Doran [3]; Gwanghui Ha [3]; Chunguang Jing ; Wanming Liu [3]; John Power ; Charles Whiteford [3]; Eric Wisniewski [3]

[1] *NIU / ANL*

[2] *NIU*

[3] *Argonne National Laboratory*

[4] *ANL*

Corresponding Author: xylu@niu.edu

Structure wakefield acceleration is an advanced accelerator concept which employs short drive electron bunches as compact power sources to accelerate witness bunches. It is promising to raise the

accelerating gradient, which is limited to about 100 MV/m in conventional RF accelerators due to RF breakdowns, by confining an intense wakefield in short RF pulses. Based on the extensive research in the high gradient acceleration community, using short RF pulses could mitigate the risk of RF breakdown and increase the operating gradient as a result. In a few recent experiments at the Argonne Wakefield Accelerator (AWA), including an X-band single-cell metallic structure, and an X-band metamaterial accelerating structure, we discovered evidence for a new operating regime, named the breakdown insensitive accelerating regime (BIAR), where the RF pulse for acceleration (or the accelerating field in the structure) is not disrupted in a breakdown event. The pulse length is short, on the order of a few nanoseconds. The BIAR regime could lead to high-gradient acceleration as well as breakthrough in understanding RF breakdown physics.

Acknowledgments:

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the U.S. DOE award DE-SC0020379.

Poster Session and Reception - Board: P32 / **208**

Observation of Skewed Electromagnetic Wakefields in an Asymmetric Structure Driven by Flat Electron Bunches

Authors: Walter Lynn[1]; Tianzhe Xu[None]; Gerard Andonian[2]; Scott Doran[3]; Gwanghui Ha[3]; Nathan Majernik[None]; Philippe Piot[None]; John Power[None]; James Rosenzweig[None]; Charles Whiteford[3]; Eric Wisniewski[3]

[1] *UCLA*

[2] *UCLA/Radiabeam*

[3] *Argonne National Laboratory*

Corresponding Author: walter.j.lynn@gmail.com

Relativistic charged-particle beams which generate intense longitudinal fields in accelerating structures also inherently couple to transverse modes. The effects of this coupling may lead to beam break-up instability, and thus must be countered to preserve beam quality in applications such as linear colliders. Beams with highly asymmetric transverse sizes (flat-beams) have been shown to suppress the initial instability in slab-symmetric structures. However, as the coupling to transverse modes remains, this solution serves only to delay instability. In order to understand the hazards of transverse coupling in such a case, we describe here an experiment characterizing the transverse effects on a flat-beam, traversing near a planar dielectric lined structure. The measurements reveal the emergence of a previously unobserved skew-quadrupole-like interaction when the beam is canted transversely, which is not present when the flat-beam travels parallel to the dielectric surface. We deploy a multipole field fitting algorithm to reconstruct the projected transverse wakefields from the data. We generate the effective kick vector map using a simple two-particle theoretical model, and particle-in-cell simulations provide further insight for realistic particle distributions.

Acknowledgments:

The authors acknowledge insightful discussions and contributions from S. Baturin. This work is supported by the U.S. Department of Energy, Office of High Energy Physics, under Contracts DE-SC0017648 (UCLA), DE- SC0018656 (NIU), and DE-AC02-06CH11357 (ANL).

WG4: Beam-Driven Acceleration / 209

Transverse Stability in an Alternating Gradient Planar Dielectric Wakefield Structure

Authors: Walter Lynn[1]; Gerard Andonian[2]; Nathan Majernik[None]; Sean O'Tool[1]; James Rosenzweig[None]; Scott Doran[3]; Seongyeol Kim[3]; John Power[None]; Eric Wisniewski[3]; Philippe Piot[None]; Charles Whiteford[3]

[1] *UCLA*

[2] *UCLA/Radiabeam*

[3] *Argonne National Laboratory*

Corresponding Author: walter.j.lynn@gmail.com

Dielectric Wakefield Acceleration (DWA) as a practical means of realizing next-generation accelerators is predicated on the ability to sustain the beam-structure interaction over experimentally meaningful length scales. This goal is complicated by the fact that the beams in question inherently couple to transverse modes in addition to the desired longitudinal modes which, if left unaccounted for, lead to a beam breakup instability. We attempt to, in part, address this issue by tackling the quadrupole mode excited in a planar-symmetry dielectric structure. We do so by periodically alternating the orientation of said structure in order to alternate the orientation of the excited quadrupole wake causing the tail of the beam to experience sequential focusing and defocusing fields, stabilizing the interaction. We examine this technique computationally and lay out a planned experiment at the Argonne Wakefield Accelerator to verify it experimentally.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / 210

Modulation of dense electron beams in nanostructures: A simulation study in preparation of the FACET-II E-336 experiment

Authors: Alexander Knetsch[None]; E-336 collaboration[None]

Corresponding Author: alexander.knetsch@polytechnique.edu

Fields arising during the propagation of highly intense electron beams in structured targets of nanometer scale such as carbon-nanotubes can contain accelerating gradients of up to 10 TV/m with similarly strong focusing fields. Studies of beam-nanotarget interaction are therefore of interest as they may lead to an acceleration method with extremely high single-stage energy gains for electron or muon beams. The FACET-II E-336 experiment at the SLAC National Accelerator Laboratory aims to take advantage of the extreme beam densities available with the FACET-II electron beams to study its interaction with a grid of nanotube material. A simulation study with the Particle-In-Cell code CALDER was performed in preparation of the experimental campaign, illuminating transverse dynamics, such as magnetic trapping of beam particles in the tubes or deflection of the beam as a consequence of nanotube tilt. Additionally, the simulations indicate that nanotubes can act as an effective seed for beam-plasma instabilities. We will present the scientific goals of the project, report on simulations results and discuss how the observations can be translated into accessible observables.

Acknowledgments:

WG4: Beam-Driven Acceleration / 211

Experimental Opportunities for the Plasma Wakefield Acceleration in a Narrow Plasma Channel

Authors: Valentina Lee[1]; Carlo Benedetti[2]; Severin Diederichs[3]; Eric Esarey[4]; Spencer Gessner[5]; Mark Hogan[6]; Michael Litos[7]; Jens Osterhoff[8]; Carl Schroeder[2]; Maxence Thévenet[8]

[1] *University of Colorado, Boulder*

[2] *LBNL*

[3] *DESY / LBNL*

[4] *Lawrence Berkeley National Laboratory*

[5] *SLAC*

[6] *SLAC National Accelerator Laboratory*

[7] *University of Colorado Boulder*

[8] *DESY*

Corresponding Author: valentina.lee@colorado.edu

The stability of the drive electron beam in plasma wakefield acceleration (PWFA) is critical for the realization of many applications. The growing instability of a drive electron beam can couple into the plasma wake and further impact the transverse dynamics of the witness beam, rendering the emittance and energy spread to grow. Applications like positron acceleration in an electron-driven blowout wake require a stable drive beam to produce an experimentally usable accelerating phase for the positrons at the tail of the wake.
Recent theoretical developments show that finite radius plasma columns suppress the hosing instability introduced by a tilted drive beam or by a transversely misaligned drive beam. This theoretical work motivates our experimental study. We present experimental opportunities at the Facility for Advanced Accelerator Experimental Tests II (FACET-II) E333 experiment to study the longitudinal dynamics of an electron beam propagating in a laser-ionized plasma column with a finite radius smaller than its blowout radius. Various widths of the plasma column will be formed in the experiment to study the acceleration gradient and energy transformer ratio of a narrow plasma column PWFA and further understand the relationship between beam stability and acceleration efficiency in a finite plasma channel.

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WGs 5+7 Joint Session / 212

Electron source bunch length characterization based on chicane-decompressed coherent transition radiation emission

Authors: Jeroen Van Tilborg[1]; Sam Barber[1]; Curtis Berger[1]; Finn Kohrell[1]; Kyle Jensen[1]; Bricker Ostler[2]; Quinn Marksteiner[2]; Nikolai Yampolsky[2]; Carl Schroeder[1]; Eric Esarey[1]

[1] *Lawrence Berkeley National Laboratory*

[2] *Los Alamos National Laboratory*

Corresponding Author: jvantilborg@lbl.gov

Laser plasma accelerators (LPAs) are capable of producing electron bunches as short as a few femtoseconds at percent-level energy spread. However, measuring the bunch length is not straightforward, let alone unraveling source correlations between the longitudinal position and momentum distribution. Here we present the theoretical framework and preliminary experimental demonstration of a multi-shot technique that applies a chicane decompression scan and records the emitted Coherent Transition Radiation (CTR) pulse energy. Comparing the measurement of CTR energy vs

chicane R56 to accurate modeling of CTR generation allows us to diagnose the longitudinal emittance in a manner that is analogous to retrieving the transverse emittance from a quadrupole scan. The combination of chicane-decompressed CTR emission and chromatic transport of energy-spread electron beams yields CTR emission in a regime where the longitudinal and transverse coherent radiation form factors are not separable, thus forcing a more rigorous treatment to match experimental data to the theory and simulations. Analytic expressions in a simplified scenario are presented, highlighting the diagnostic sensitivity to position-momentum source correlations. The experimental demonstration was performed at the BELLA Center 100 TW HTU laser plasma accelerator, producing electron beams at 100 MeV, coupled into a beam line consisting of a quadrupole triplet, chiance, CTR screen, and CTR energy detector.

Acknowledgments:

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Poster Session and Reception - Board: P42 / **213**

Numerical Studies of Phase Diversity Electro-Optic Sampled Relativistic Electron Bunches

Authors: Spencer Kelham[1]; Philippe Piot[2]

[1] *Northern Illinois University Graduate Student*

[2] *Northern Illinois University*

Corresponding Author: z1904611@students.niu.edu

The measurement and recording of terahertz (THz) electric fields is of special interest to beam physics, as the electric fields of temporally short relativistic electron bunches have frequency components that extend into the THz range. These frequency components are challenging to measure using conventional methods, as this range of frequencies are too high for electronic systems, and are too low for (most) optical systems. Various pump-probe methods have been developed to record such fields, from the scanning electro-optic sampling technique to the spectral encoding/decoding technique in the field of terahertz time domain spectroscopy. In this paper, we present numerical simulations and studies of the phase diversity electro-optic sampling (DEOS) technique. This involves the treating the THz electric field pulse under interest and a pre-stretched (chirped) femtosecond laser pulse as wave packets co-propagating through an electro-optically active crystal, such as Zinc Telluride and Gallium Phosphide. The phase retardance is then calculated for each frequency in the chirped laser pulse, due to the Pockels effect induced by the pulse with THz frequency components. This pulse is then propagated through a series of optics, and the data on the spectrometers are simulated. Using the maximum-ratio combining technique, we retrieve the electric field and compare the retrieved field to the original field for different crystal lengths and materials. The results of this work will inform the table top DEOS setup, and will inform our eventual designs for an electro-optic sampling setup at the Argonne Wakefield Accelerator.

Acknowledgments:

Poster Session and Reception - Board: P43 / **214**

Modelling nonequilibrium Thomson scattering from above-threshold ionized plasma

Authors: Audrey Farrell[1]; Chaojie Zhang[1]; Yipeng Wu[1]; Zan Nie[1]; Mitchell Sinclair[None]; Nainoa Nambu[1]; Kenneth Marsh[1]; Chandrashekhar J. Joshi[2]

[1] *UCLA*

[2] *University of California Los Angeles*

Corresponding Author: audfarrell@ucla.edu

Optical Thomson scattering is now a mature diagnostic tool for precisely measuring local plasma density and temperature. These measurements typically take advantage of a simplified analytical model of the scattered spectrum, which is built upon the assumption that each plasma species is in equilibrium and Maxwellian. However, this assumption fails for plasmas produced using high field ionization of atoms via ultrashort laser pulses. For example, in the above-threshold ionization (ATI) process, electrons are produced with several narrow and equally spaced peaks in energy corresponding to the number of photons absorbed above the ionization threshold. These electrons are born with momentum along the polarization of the laser, and are essentially cold in the two transverse directions. In other words, the plasma is not only nonthermal but also grossly anisotropic. This ATI plasma is unstable to several kinetic instabilities that are not taken into account in the conventional Thomson scattering model. We present a new method for extracting the Thomson scattered spectrum from any plasma (equilibrium or nonequilibrium) directly from fully kinetic particle-in-cell simulations, without simulating the probe laser itself. With this method we can predict the spectrum measured from an ATI plasma, revealing new features in the collective Thomson spectrum that cannot be predicted by Maxwellian Thomson theory.

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WGs 5+7 Joint Session / 215

High Flux Polarized Positron Production based on high efficiency FEL and high gradient IFEL

Author: Pietro Musumeci[None]

Corresponding Author: musumeci@physics.ucla.edu

In this paper we discuss the design of polarized positron source for an e+e- linear collider based on polarization transfer from circularly polarized gamma-ray photons in a conversion target. A very high flux of gamma-ray photons can be obtained via inverse compton scattering a high current ultra-relativistic electron beam with an intense laser pulse circulating in an optical cavity. In order to sustain interactions at MHz-scale repetition rates, the electron beam is laser-accelerated to 1 GeV in a tapered helical undulator using the same laser which drives the ICS interaction and right after the ICS interaction is laser-decelerated to replenish the energy in the optical beam. The design of the tapered undulator system and the estimates for the gamma ray flux, spectrum and polarization are presented. The results suggest that positron beams with currents up to 30 uA (well in excess of the International Linear Collider requirements) and polarization of up to 70 \% could be obtained with this scheme.

Acknowledgments:

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WGs 3+5 Joint Session / 216

Sub-fs beam generation at the UCLA Pegasus Laboratory

Author: Pietro Musumeci[None]

Corresponding Author: musumeci@physics.ucla.edu

We present the design of an experiment aiming at the generation of a moderate energy (4 MeV) single sub-fs electron beam from an RF photoinjector for application in UED and injection in advanced accelerators. The design is based on an envelope equation-based approach to obtain analytical scaling laws for the shortest pulse length achievable using radiofrequency (RF) based bunch compression. The derived formulas elucidate the dependencies on the electron beam energy and beam charge and reveal how relativistic energies are strongly desirable to obtain bunches containing 1 million electrons with single-digit fs pulse lengths. An additional higher frequency RF cavity is implemented, which linearizes the bunch compression, enabling the generation of ultrashort beams in the sub-femtosecond regime. A range of options to measure the sub-fs bunch length will be discussed.

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WG4: Beam-Driven Acceleration / **217**

Wakefield-based afterburner for increasing the spectral range of X-FELs

Author: Pietro Musumeci[None]

Corresponding Author: musumeci@physics.ucla.edu

Advanced accelerator techniques based on collinear wakefield accelerations have demonstrated the capability of achieving very high accelerating fields. These schemes are based on passing a high charge driver electron beam in a plasma or near field structure which results in high rate energy extraction. In this process a strong wakefield is left behind that can be used for high gradient acceleration of a properly injected trailing electron bunch. Generation of tunably spaced high energy bunches is in fact common in modern XFEL beamlines which strive to provide pump and probe and multi-color capabilities to the most advanced X-ray users. In this paper, we propose to leverage some of these developments and take advantage of the many shaping techniques developed at FEL beamlines to generate a bunch pair suitable to be injected into a collinear wakefield-based high gradient acceleration section. This will result in a significant boost in the beam energy of the trailing beam which can be used to ease lasing (and increase the radiated power) at very short wavelengths or even to extend the spectral reach of current XFELs.

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Poster Session and Reception - Board: F90 / **218**

Training capability of the Brookhaven National Laboratory Accelerator Test Facility

Authors: Mikhail Fedurin[1]; Mikhail Polyanskiy[2]; Igor Pogorelsky[2]; Karl Kusche[2]; Marcus Babzien[2]; Mark Palmer[1]; Dmitry Kayran[1]; Vladimir Litvinenko[3]; Navid Vafaei-Najafabadi[4]; Viviana Vladutesku[5]

[1] *Brookhaven National Laboratory*

[2] *BNL*

[3] *Professors, Stony Brook University*

[4] *Stony Brook University*

[5] *City University of New York*

Corresponding Author: fedurin@bnl.gov

Brookhaven Laboratory Accelerator Test Facility has a long history as a training site for graduate and undergraduate students. Young professionals are working on experiment setup during the active phases of the user program and assist engineers in design, build and repair of equipment during shutdowns.
Stony Brook University Center for Accelerator Science and Education and City University of New York have educational programs like "Ernest Courant Traineeship" to bring students on site for classroom lectures and facility tours. University students and young scientists get experience as linac operator trainees when linear accelerator provides e-beam for experiments. Future professionals learn to run the accelerator and to deliver beams to experiment chambers. Hands-on experience in running beams at ATF provides good experimental background while it is complementary to the of study laser physics and accelerator beam dynamics in university courses.
In this talk we will show the ATF from the perspective of serving the community for educational purposes, will provide statistics and discuss the ATF potential as a training center.

Acknowledgments:

WGs 4+5 Joint Session / **219**

Investigating the Transverse Trapping Condition in Beam-Induced-Ionization-Injection in Plasma Wakefield Accelerators

Authors: Jiayang Yan[1]; Xuan Zhang[1]; Navid Vafaei-Najafabadi[1]

[1] *Stony Brook University*

Corresponding Author: jiayang.yan@stonybrook.edu

Plasma wakefield accelerators (PWFA) have demonstrated acceleration gradients of tens of GeV per meter. For injecting high-quality electron beams, a method called beam-induced ionization injection (B-III) is proposed. In this method, the drive beam field increases as its slice envelope oscillates to its minimum value due to the betatron oscillations and releases impurity plasma electrons that are then injected. Controlling the trailing beam qualities requires an understanding of a transverse trapping mechanism. In this poster, we will present our research based on the injection of the ultrashort, femtosecond electron beams using B-III.
To investigate the formation of a trailing beam, we will track ionized electron motions in the Particle-In-Cell(PIC) simulation field maps using our eTracks code. The trailing beam quality will be shown based on the simulation results. We will also present that a critical Hamiltonian has to be satisfied for the trapped electrons. This critical condition can also be noticed as a transverse trapping condition in the transverse phase space. We are investigating the formalism for the threshold Hamiltonian value or the critical condition in transverse phase space.

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Poster Session and Reception - Board: P7 / **220**

Emittance preservation of a CO2-laser driven wakefield acceleration with external injection

Authors: Yuxuan Cao[1]; Rafal Zgadzaj[2]; Michael C. Downer[2]

[1] *University of Texas at Austin*

[2] *UT at Austin*

Corresponding Author: ycaophysics@utexas.edu

We explore the possibility of self-guided CO2-laser driven wakefield accelerator with external injection from a linear accelerator. Since long-wavelength CO_2 laser pulse enables a lower power threshold for self-guiding, nonlinear LWFA at a lower plasma density with larger wakefield size can be achieved, making longer acceleration and external injection easier. We aim to find the optimal conditions for emittance preservation of externally injected electrons with simulations. We'll discuss different ways that the emittance of externally injected electron beams can be impacted during cm scale propagation, including density ramp and injection phase. This will provide guidance for future experiments conducted at ATF facility in the Brookhaven National Laboratory.

Acknowledgments:

WG2: Computation for Accelerator Physics / 221

Efficient algorithms for multi-level ionization of high-atomic-number gases and applications

Authors: Aiqi Cheng[1]; Roman Samulyak[None]

Co-authors: Rotem Kupfer [2]; Navid Vafaei-Najafabadi [1]

[1] *Stony Brook University*

[2] *Lawrence Livermore National Laboratory*

Corresponding Author: aiqi.cheng@stonybrook.edu

An efficient numerical algorithm for multi-level ionization of high-atomic-number gases has been developed. It is based on analytical solutions to the system of differential equations describing evolution of ionization states. The algorithm fully resolves multiple time scales associated with ionization processes coupled to electromagnetic processes of laser-plasma interaction. The effects of the orbital quantum numbers and their projections are also examined. The algorithm efficiency is improved by using a locally reduced system of differential equations. The multi-level ionization algorithm has been implemented in SPACE, a parallel, fully relativistic, three-dimensional particle-in-cell code. In addition to Vlasov-Maxwell equation solvers, SPACE implements a novel, highly adaptive particle method for Vlasov-Poisson equations called Adaptive Particle-in-Cloud (AP-Cloud) that replaces the traditional PIC mesh with octree data structures. Verification and validation problems for the multi-level ionization algorithm in SPACE will be presented. The code has been applied to the study of ionization injection of electrons into laser-driven plasma wakefields. Comparison of simulations with BNL-ATF experiment on ionization-injection will also be discussed.

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WG8: Advanced Laser and Beam Technology and Facilities / 222

Development of Coherent Spatially and Temporally Combined Fiber Laser LPA Driver Concept – Progress of the kW-Average and TW-Peak Power System Demonstraton

Authors: Alexander Rainville[1]; Mathew Whittlesey[1]; Christopher Pasquale[1]; Yanwen Jing[1]; Mingshu Chen[1]; Siyun Chen[None]; Hanzhang Pei[None]; Qiang Du[2]; Almantas Galvanauskas[1]

[1] *University of Michigan*

[2] *Lawrence Berkeley National Laboratory*

Corresponding Author: rainvila@umich.edu

Next generation particle accelerators based on laser plasma interactions are a promising path towards achieving GeV gradients in small volumes, thus substantially reducing the size of accelerators needed for both frontier science and practical applications from materials science to medicine. These accelerators will require laser drivers with ultrashort pulses, joule energy levels and 10s kHz repetition rates (100s-kW average power), a trio of requirements beyond current laser technology. We are developing a scalable laser approach based on coherent temporal and spatial combining of large core fiber amplifiers. It is based on coherent pulse stacking amplification (CPSA), a time domain technique that allows an arbitrary number of pulses to be time-domain combined into a single pulse. In conjunction with chirped-pulse amplification (CPA) CPSA allows for near full energy extraction from large core fiber amplifiers, increasing achievable energies by two orders of magnitude compared to traditional fiber CPA. This reduces the number of spatially combined parallel amplification channels used for power and energy scaling by ~100 times – a substantial reduction of the system size and complexity.
We have been validating this approach in a power scalable demonstration system, aiming to achieve ~100mJ and ~1kW coherently combined pulse energies and average powers from a 10-12 parallel-channel spatially combined CPSA system. We demonstrated robust temporal combining in CPSA architecture of 81 pulses to a single pulse with high efficiency and compressibility to approximately 300fs. At present, we have carried out 4-channel coherent spatial combining of 81-pulse CPSA bursts, achieving >25mJ at 2kHz (50W average power) in a combined beam. Pulse energy scaling of individual amplification channels is achieved by using 85μm chirally-coupled-core (CCC) fibers, which store more than 10mJ per fiber and provide high-efficiency extraction at multi-kHz repetition rates. Additionally, we have also demonstrated techniques for controlling gain narrowing, dispersion, and in-burst saturation control for achieving ~100fs duration pulses. Ongoing work is exploring simultaneous operation of coherent spatial and temporal combining at high energies and powers. Further work will extend system size from 4 to 10 channels and will carry out first high-intensity laser-matter interaction experiments with this table-top laboratory demonstration system.

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WG6: Laser-Plasma Acceleration of Ions / 223

Exploring potential of 3D printed structures in PW laser driven ion acceleration experiments

Authors: Sergei Tochitsky[1]; Dan Haberberger[2]

Co-authors: Nuno Lemos [3]; Raspberry Simpson [3]; Derek Mariscal [3]; Elizabeth Grace [3]; Art Pak [3]; Jason Chou [4]; Frederico Fiuza [4]; Alex Haid [5]; Chand Joshi [1]

[1] *UCLA*

[2] *Laboratory for Laser Energetics*

[3] *Lawrence Livermore National Laboratory*

[4] *SLAC National Accelerator Laboratory*

[5] *General Atomics*

Corresponding Author: sergei12@ucla.edu

Laser-produced ion beams from 1 um laser-plasma interactions have been a focus of high-energy density physics studies for several decades. Traditionally, these beams have been accelerated via the target normal sheath acceleration (TNSA) mechanism, which has a rootlike scaling of the maximum kinetic energy of protons Ep∞√I, where I is the laser intensity. To enhance TNSA via increase in coupling efficiency of radiation into hot electrons, beyond the ponderomotive potential of the laser, the current trend is to utilize very thin ~100-200 nm foils. Here, as was shown experimentally in a PW laser-plasma interactions, a relativistic induced transparency and associated flux of superthermal electrons can result in increase in proton energy to near-100 MeV with a particle yield of ~10e9 (MeVxSr)-1. However, survival of such an ultrathin target irradiated by picosecond prepulse becomes a true limiting factor in wide usage of this approach. To develop a robust platform for ion acceleration in PW laser-solid target interactions, we explore a novel target design, laser-printed 2PP structures with and without regular organization of elements. Use of a relatively thick low-density target (~10-50l, where l is the laser wavelength) can improve the absorption of the laser energy, substantially drop requirements for the pulse contrast and facilitate generation of a relativistic plasma with electron temperature, Te≥1MeV in which different mechanisms of ion acceleration both in the bulk and boundary parts may play a role.
In the experiments, a 0.7 PW OMEGA EP laser beam was focused to an average intensity of ~5x1020 W/cm2 onto a 3D printed log-pile or stochastic target made of ~1 μm size wires. We tested both 10 and 50 μm thick structures with and without foils at the exit side. For a shorter log-pile target, protons with energies up to ~80 MeV were measured by the RCF stack and that correlated well with the Thomson spectrometer data, which detected both protons and C6+ ions. 2D PIC modeling revealed that the laser interacts with a family of microstructured overdense plasmas and sheath acceleration is the dominant mechanism. The results and future activities will be discussed.

Acknowledgments:

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WG3: Laser and High-Gradient Structure-Based Acceleration / 224

RF Cavity Needs for Future Muon Accelerators

Author: Ben Freemire[1]

[1] *Euclid Beamlabs*

Corresponding Author: b.freemire@euclidtechlabs.com

The future of high energy colliders beyond the high luminosity upgrade to the LHC is presently unclear. Physics and economics arguments are being made for hadrons vs. leptons and circular vs. linear machines. A muon collider is now being considered in Europe as a potential Future Circular Collider at CERN. Among the technological challenges inherent to a muon accelerator are beam cooling and acceleration. The RF cavity requirements for each differ, and were studied under the US Muon Accelerator Program, which concluded in 2017. Renewed interest in muon accelerators has warranted the results of this R&D program be revisited. This presentation will review the designs and progress made on cooling channels and acceleration schemes, the logical next steps for each, and how these pertain to advanced accelerator concepts.

Acknowledgments:

Plenary / 225

Multi-GeV electron bunches from an all-optical laser wakefield accelerator

Authors: Bo Miao[1]; Jaron Shrock[2]; Ela Rockafellow[2]; Howard Milchberg[2]

[1] *University of Maryland*

[2] *University of Maryland, College Park*

Corresponding Authors: bmiao@umd.edu, jshrock@terpmail.umd.edu, erock22@terpmail.umd.edu

Conventional RF electron accelerators are limited by breakdown potentials to ~100 MeV/m. This poses significant economic and practical obstacles for the construction of new, high energy particle accelerators which can be used as advanced light sources, or as colliders to probe new fundamental physics regimes. Laser Wakefield accelerators (LWFAs), which can achieve acceleration gradients 1000 times greater, offer a promising alternative for the next generation of accelerators.

LWFAs use the plasma waves (wakes) driven by an ultra-intense laser pulse to accelerate electron bunches to near luminal velocities. For maximal energy gain, the wave needs to be driven over tens of centimeters in a low-density (~$1 \times 10^{17} cm^{-3}$) plasma. This poses a natural problem since an ultra-high intensity laser pulse will diffract on a much shorter scale, reducing the intensity below that required to drive a wake in the plasma. We have recently demonstrated two methods, based on optical field ionization (OFI), to generate low-loss, meter-scale plasma waveguides (in hydrogen plasma) where high intensity guided modes can propagate hundreds of Rayleigh lengths [1,2].

In this talk we will discuss the methods for optically generating plasma waveguides to enable meter scale LWFAs and the first successful implementation of the technique to accelerate electron bunches up to 5 GeV in a 20 cm all-optical LWFA [3]. We will present transverse plasma interferometry, guided mode images and optical spectra, electron beam profiles, and electron spectra collected during experimental campaigns on the ALEPH laser at Colorado State University, as well as particle in cell simulations to supplement the physical picture of the acceleration process.

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WGs 1+2 Joint Session / 226

Simulations of Hydrodynamic Optical-Field-Ionised Plasma Channels

Authors: Rob Shalloo[1]; Mathis Mewes[1]; Gregory Boyle[2]; Christopher Arran[3]; Laura Corner[4]; Jens Osterhoff[1]; Roman Walczak[5]; Simon Hooker[5]; Maxence Thévenet[1]

[1] *DESY*

[2] *James Cook University*

[3] *University of York*

[4] *University of Liverpool*

[5] *University of Oxford*

Corresponding Author: rob.shalloo@desy.de

Recent results have demonstrated hydrodynamic optical-field-ionised plasma channels as being a promising plasma source for efficient, high-repetition-rate laser plasma accelerators.

Understanding the dynamics of these plasma waveguides is critical to improving their performance and for tailoring their modal properties to fit a given experimental setup. This can be challenging as the important physical processes span multiple orders of magnitude with ionisation/heating on femtosecond timescales, thermalisation on picosecond timescales, and expansion/waveguide formation on nanosecond timescales.

Here, we present simulation results capturing the key dynamics of these plasma structures from ionisation to waveguide formation and benchmark the results against experimental data. Further, we explore how key experimental parameters can be used to tune the waveguides properties.

Acknowledgments:

Poster Session and Reception - Board: P20 / **227**

Active non-perturbative Stabilization of the laser-plasma-accelerated electron beam source

Author: Curtis Berger[1]

Co-authors: Samuel Barber [2]; Kyle Jensen [1]; Joseph Natal ; Fumika Isono [2]; Anthony Gonsalves [2]; Jeroen van Tilborg [2]

[1] *Lawrence Berkeley National Laboratory*

[2] *LBNL*

Corresponding Author: curtisberger@lbl.gov

Laser plasma accelerators have the ability to produce high-quality electron beams in compact, all-optical-driven configurations, with the electron beams uniquely suited for a wide variety of accelerator-based applications. However, fluctuations and drifts in the laser delivery to the mm-scale plasma target (the electron beam source) will translate into electron beam source variations that can limit their utility for demanding applications like light sources. Based on previous work developing a non-perturbative diagnostic for the high-power laser delivery at focus, we present experimental commissioning results of a full four-dimensional PID-active-stabilization system for stabilizing a 100TW pulse-laser system and show that by doing so, the electron beam source is stabilized. This is confirmed through the use of an energy resolved imaging system for the electron beam that directly monitors the jitter in transverse electron beam source location.

Acknowledgments:

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WG6: Laser-Plasma Acceleration of Ions / **228**

New capabilities of the iP2 beamline for laser-solid interaction studies at the BELLA PW facility

Authors: Sahel Hakimi[1]; Lieselotte Obst-Huebl[1]; Kei Nakamura[1]; Axel Huebl[1]; Stepan Bulanov[1]; Anya Jewell[1]; Jared De Chant[2]; Antoine Snijders[1]; Csaba Toth[1]; Anthony Gonsalves[1]; Carl Schroeder[1]; Jeroen van Tilborg[1]; Jean-Luc Vay[1]; Eric Esarey[1]; Cameron Geddes[1]

[1] *Lawrence Berkeley National Laboratory*

[2] *Michigan State University*

Corresponding Author: sahelh@lbl.gov

The newly commissioned short focal length, high intensity beamline, named iP2, at the BELLA Center enables frontier experiments in high energy density science. This 1 Hz system provides a focused beam profile of <3 micron in FWHM, resulting in an on-target peak intensity greater than 5e21 W/cm^2 , and a pointing fluctuation on the order of 1 micron. A temporal contrast ratio of <1e-14 on the nanosecond timescale is expected with the addition of an on-demand double plasma mirror setup in the near future. This beamline is well suited for studies requiring ultra-high intensity and substantial control over the temporal contrast, such as investigation of novel regimes of advanced ion acceleration and their applications. The recent results from iP2 commissioning experiments will be presented as well as the outlook for in vivo radiobiological studies at ultra-high dose rates. In preparation for an experimental campaign to investigate the magnetic vortex acceleration regime, a series of 3D simulations using the WarpX code were performed to optimize the target design and guide the development of diagnostics. We studied the acceleration performance with different laser temporal contrast conditions at normal and oblique laser incidence angles. The simulation results will be presented along with an overview of the planned experimental setup at iP2.

Acknowledgments:

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WG1: Laser-Plasma Wakefield Acceleration / 229

CO2-laser-driven wakefield acceleration

Authors: Rafal Zgadzaj[1]; A. Cheng[2]; P. Kumar[2]; V. N. Litvinenko[2]; Irina Petrushina[3]; Roman Samulyak[None]; Chandrashekhar J. Joshi[4]; Marcus Babzien[5]; Mikhail Fedurin[6]; Rotem Kupfer[7]; Mark Palmer[6]; Mikhail Polyanskiy[5]; Igor Pogorelsky[5]; Michael Downer[1]

[1] *The University of Texas at Austin*

[2] *Stonybrook University*

[3] *Stony Brook University*

[4] *University of California Los Angeles*

[5] *BNL*

[6] *Brookhaven National Laboratory*

[7] *Lawrence Livermore National Laboratory*

Corresponding Author: rafal@physics.utexas.edu

To date only solid-state laser pulses of wavelength ⊠ ~ 1 micron have been powerful enough to drive laser wakefield accelerators (LWFAs). Chirped-pulse-amplified multi-terawatt, ~1 ps laser pulses of ⊠ ~ 10 μm are now emerging from mixed-isotope, high-pressure CO_2 laser technology [1]. Such

pulses open new opportunities to drive large ($R_b \sim 300$ μm) bubbles in low-density ($n_e < 10^{17}$ cm^{-3}) plasma more efficiently, and to preserve energy spread and emittance of accelerated electrons better, than is possible using conventional ~1 μm drive pulses [2]. At the previous AAC we reported observations of wakes driven by sub-terawatt (sub-TW) CO_2 laser pulses in plasma of density down to 5×10^{17} cm^{-3} via collective Thomson scatter of a probe pulse. However, no electrons were accelerated in those experiments. Here we report new experiments in which copious relativistic electrons emerge from high-amplitude, self-modulated wakes driven in plasma of density down to $n_e < 10^{17}$ cm^{-3} driven by 5- to 10-TW, 2 ps CO_2 laser pulses. Measurements and simulations of wake structure and e-beam properties as conditions change detail the physics of long-wavelength-infrared self-modulated wakefield acceleration. Peaked electron spectra observed on many shots indicate that we are close to generating strongly nonlinear wakes, portending future higher-quality accelerators driven in the bubble regime [2] by yet shorter (0.5 ps), more powerful (⊠ 20 TW) CO_2 laser pulses [3]. Experiments are carried out at Brookhaven National Laboratory's Accelerator Test Facility.

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[2] P. Kumar, K. Yu, R. Zgadzaj, M. C. Downer, I. Petrushina, R. Samulyak, V. N. Litvinenko and N. Vafaei-Najafabadi, Phys. Plasmas 28, 013102 (2021).
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Plenary / 230

Positron Acceleration in Plasmas

Author: Severin Diederichs[1]

[1] *DESY / LBNL*

Corresponding Author: severin.diederichs@desy.de

Stable acceleration of high-quality beams is a critical task for the realization of a plasma-based, linear collider. However, in plasma accelerators, the acceleration of collider-relevant positron beams is challenging even conceptually. Recently, many new positron acceleration schemes have been proposed to overcome this issue. In this talk, we review the latest advances on plasma-based positron acceleration concepts and their respective challenges. The path to collider-relevant beam parameters is discussed.

Acknowledgments:

We acknowledge the Gauss Centre for Supercomputing for providing computing time on the Supercomputer JUWELS Booster. We acknowledge Funding by the Helmholtz Matter and Technologies Accelerator R&D Program, by the US Exascale Computing Project (No. 17-SC-20-SC), and by the Director, Office of High Energy Physics, of the DoE (No. DE-AC02-05CH11231).

WG1: Laser-Plasma Wakefield Acceleration / 231

Spatiotemporal optical vortices (STOVs) and relativistic optical guiding

Authors: Manh Le[1]; John Palastro[2]; George Hine[3]; Howard Milchberg[4]

[1] *University of Maryland*

[2] *University of Rochester, Laboratory for Laser Energetics*

[3] *Oak Ridge National Laboratory*

[4] *University of Maryland, College Park*

Corresponding Author: mle1234@umd.edu

We study the generation of spatiotemporal optical vortices (STOVs) from self-focusing processes in plasma and their role in mediating intrapulse energy transport in intense, self-guided laser pulses using fully three-dimensional, particle-in-cell simulations.
In previous work, STOVs were observed both in experiment and in simulation to emerge from self-focusing collapse arrest from filamentation in air using lower-intensity femtosecond pulses (~10^13-10^14 W/cm^2), and they have been generated linearly using a pulse shaper [1-2]. In the case of atmospheric filamentation, n2 of air induces an intensity-dependent refractive index within the laser pulse that leads to runaway self-focusing until collapse arrest via plasma generation [3]; phase shear between the higher-intensity, self-focusing core and the lower-intensity periphery of the laser was found to spawn these vortices [1]. These STOVs then proceed to mediate intrapulse electromagnetic energy flow during filamentation [1].
In plasmas, analogous though distinct mechanisms such as from relativistic and ponderomotive effects that are relevant for high-intensity, self-guided pulses (>10^18 W/cm^2) impose a similar intensity-dependent refractive index and induce self-focusing. Understanding the interaction of relativistically intense laser pulses with plasma would be of use for laser wakefield acceleration experiments, which tend to operate in this regime. In this work, we simulate relativistic self-guiding of an intense laser pulse and show, for the first time, the generation of STOVs in plasma by nonlinear phase shear from relativistic and ponderomotive effects. We observe, in three dimensions, the nucleation of STOVs at points around the pulse, their expansion, reconnection, and evolution into a pair of vortex rings. Finally, we find that these vortices mediate the flow of electromagnetic energy within the pulse and illustrate how this influences the broader propagation of the laser.

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Poster Session and Reception - Board: F86 / **232**

Time Resolved Measurements of the Polarization State of Supercontinuum Generated in a Monatomic Gas

Authors: Lucas Railing[1]; Manh Le[1]; Fatholah Salehi[1]; Jiahui Gu[2]; Miroslav Kolesik[2]; Howard Milchberg[1]

[1] *University of Maryland College Park*

[2] *University of Arizona*

Corresponding Author: lrailing@umd.edu

In previous work [1] we found that circularly polarized few-cycle pulses were more effective at accelerating low divergence, quasi-monoenergetic electron beams than their linearly polarized counterparts. These pulses were generated by sending initially elliptically polarized pulses which evolve

to circular after propagation through a hollow core fiber differentially pumped with Helium and compressed afterward with a chirped mirror compressor. While temporal and spectral effects due to polarization ellipse rotation due to nonlinear effects from bound electrons are well understood [2], illustrated by its use as a mode locking technique [3] and compression technique [4,5], the temporal effects due to ionization from the laser pulse during supercontinuum generation have only been studied in simulations [6]. In this work we study the effect of ionization on the temporal polarization state of supercontinuum by measuring its temporal electric field before and after broadening. The dynamics of interest have implications for the generation of complex temporal polarization structures on a femtosecond scale.

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WG4: Beam-Driven Acceleration / 233

Progress towards Energy Doubling and Emittance Preservation through Beam Driven Plasma Wakefield Acceleration at FACET-II

Author: Doug Storey[1]

[1] *SLAC National Accelerator Laboratory*

Corresponding Author: dstorey@slac.stanford.edu

The E300 experiment at FACET-II aims to demonstrate energy doubling of a witness bunch to 20 GeV through beam-driven plasma wakefield acceleration (PWFA) while preserving emittance and narrow energy spread. This talk will describe the status of the experimental setup including the current and expected accelerator parameters, the plasma source and associated differential pumping system, and post-interaction beam diagnostics. These diagnostics include single- and multi-shot emittance measurements using energy-dispersed beam profile measurements, energy resolved profile measurements to measure energy depletion and acceleration, and betatron gamma ray detectors that will be used to infer information about beam dynamics within the plasma. The first results will be discussed from the initial commissioning runs and from the first self-ionized PWFA interactions in helium and hydrogen gases.

Acknowledgments:

Poster Session and Reception - Board: P8 / **234**

Simulated Particle-in-Cell Results Demonstrating Multi-GeV Energy Quasi-monoenergetic Electron Beams and Adjustable Charge

Author: Ela Rockafellow[1]

Co-authors: Bo Miao ; Jaron Shrock [2]; Howard Milchberg [2]

[1] *University of Maryland College Park*

[2] *University of Maryland, College Park*

Corresponding Author: erock22@umd.edu

Recent experiments [1] have demonstrated laser wakefield acceleration (LWFA) of quasi-monoenergetic electron bunches with energy up to 5 GeV, bunch charge up to tens of picocoulombs, and beam divergence down to milliradians using 20 cm long, low density ionization-injected plasma waveguides [2] using 240 TW peak power laser drive pulses. We present 3D particle-in-cell simulation results that expand the technique used in [1,2] to a longer (40 cm) low density plasma waveguide with the added features of a density up-ramp to mitigate dephasing and a narrowed (4 mm) injection section, demonstrating ~12 GeV electron beam with a charge of 8 pC and <20% energy spread. We also present results using the same laser parameters, delivering a 10X higher bunch charge of 83 pC in a quasi-monoenergetic 5 GeV beam with <5% energy spread. Such LWFA modules are key to the development of a multi-stage electron accelerator.

[1] B. Miao et al., Multi-GeV electron bunches from an all-optical laser wakefield accelerator, Phys. Rev. X 12, 031038.

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WGs 1+2 Joint Session / **235**

A preliminary analysis for efficient laser wakefield acceleration

Author: Gaetano Fiore[1]

[1] *INFN, Sezione di Napoli, and Università Federico II, Napoli*

Corresponding Author: gaetano.fiore@na.infn.it

Adopting a recently developed simplified model of the impact of a very short and intense laser pulse onto an inhomogeneous diluted plasma, we analitycally derive preliminary conditions on the input data (initial plasma density $\widetilde{n_0}$ and pulse profile) allowing to control the wave-breaking of the laser-driven plasma wakefield and to maximize the energy transfer to small bunches of self-injected electrons. The model is a fully relativistic plane hydrodynamic one: The pulse is a plane wave propagating in the z-direction hitting a cold plasma at rest with $\widetilde{n_0} = \widetilde{n_0}(z)$; as long as the depletion of the laser pulse is small the system of the Lorentz-Maxwell and continuity PDEs is reduced to a family (parametrized by $Z > 0$) of decoupled systems of non-autonomous Hamilton equations with

1 degree of freedom 1 and the light-like coordinate $\xi = ct - z$ (instead of time t) as an independent variable; each Z is the initial z-coordinate of a layer of electrons, whose motion is ruled by the corresponding system. Wave-breaking (and self-injection) start when the Jacobian $J = \partial z/\partial Z$ vanishes. In the more realistic situation of a finite, but not too small, laser spot radius R, the results will approximately hold for the part of the plasma close to the axis $\vec{z}$ of cylindrical symmetry of the spot, and may be used to preselect interesting regions in the input parameter space where to perform, by PIC simulations, more accurate analysis of the wakefield acceleration.

Acknowledgments:

Poster Session and Reception - Board: F77 / **236**

Prototyping of distributed coupling accelerators at mm-wave frequencies

Authors: Emma Snively[1]; Mohamed Othman[2]; Annika Gabriel[1]; Jordan Wong[1]; Ann Sy[1]; George Wehner[1]; Emilio Nanni[3]

[1] *SLAC National Accelerator Laboratory*

[2] *SLAC NATIONAL ACCELERATOR LABORATORY*

[3] *SLAC National Accelerator Lab*

Corresponding Author: mothman@slac.stanford.edu

We present on the fabrication and testing of a 16-cell distributed coupling accelerator operating at 95 GHz. The π-mode standing wave cavities are designed with a side-coupled aperture that enables flexible optimization of the beampipe iris between cells. Simulations of the optimized cavity geometry predict a room temperature shunt impedance exceeding 400 MOhm/m. We also discuss techniques for cold testing and tuning mm-wave accelerators. High power testing of this distributed coupling structure design will be conducted with pulses from a MW gyrotron oscillator, including active pulse compression techniques to achieve higher peak power. With an input power of 1 MW, an energy gain of 3 MeV would be achieved for a relativistic electron beam in this 25 mm linac.

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Poster Session and Reception - Board: P62 / **237**

Systematic Control for Coherently-combined High Energy Fiber Laser

Author: Mahek Logantha[1]

Co-authors: Tong Zhou ; Qiang Du [2]; Russell Wilcox ; Carl Schroeder [3]

[1] *Lawrence Berkeley National Lab, University of California, Berkeley*

[2] *Lawrence Berkeley National Laboratory*

[3] *LBNL*

Corresponding Author: mlogantha@lbl.gov

High-impact laser plasma accelerators (LPA) applications such as scientific discovery, medical radiation therapy, industrial and security screening require LPAs operating at kilohertz repetition rates

or higher while today's LPAs are limited to a few Hertz repetition rates. We propose coherently combining short pulse fibers to achieve highly stabilized high energy ultrashort pulses at high repetition rates. One key challenge in reaching this objective is developing a precise feedback control system for the required pulse stability and quality. Hence, we propose to develop an integrated complex, multi-layer control system for the coherently-combined high energy fiber laser currently being built at LBNL, by using comprehensive optical system modeling, state-of-the-art digital hardware and algorithms to meet the accelerator driver stability and precision needs.

To reach the ideal high energy and high repetition rate, the following steps will be followed to develop a comprehensive controls system:
1. Develop controls for a fiber-based pulse generation and amplifier chain operating at high output power. A range of feedback control needs include thermal drifts and multi-GHz stretched-pulse programming.
2. Extend controls to multiple, parallel spectral channels and control multidimensional coherent combination. Power amplifiers will be combined into one beam.
3. Optimize overall system performance, especially compressed pulse quality. Drive accelerator experiment with resultant pulse. The output will be the highest energy from an ultrafast fiber laser.

While the temporal pulse stacking in the fiber laser combination approach has been proven to work with flat mirror stacking cavities, we propose using Herriott cells as stacking cavities to increase control stability and compactness of the system. Using Zemax modeling and an experimental setup, proof-of-concept for an improved optical stacking cavity using a Herriott cell has been established, demonstrating initial progress in optical system modeling for control system development.

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Poster Session and Reception - Board: P55 / **238**

Feasibility of LWFA's for X-ray induced acoustic computed tomography

Author: José Alejandro Franco Altamirano[1]

Co-authors: Andrea Hannasch [2]; Michael Downer [1]

[1] *The University of Texas at Austin*

[2] *UT at Austin*

Corresponding Author: downer@physics.utexas.edu

X-ray induced Acoustic Computed Tomography (XACT) is an imaging modality that combines the high absorption contrast and penetration depth of x-rays with the 3D propagation advantages provided by high-resolution ultrasound waves. Absorbed x-rays in a sample cause a localized heating (<mK) and thermoelastic expansion inducing a detectable ultrasonic emission. Effective generation of sound waves require that the energy deposition happens in a period shorter than the stress confinement time of the material ($\tau_s \approx$ ns for most applications). Until now, XACT experiments have been performed with industrial x-ray tubes (up to 270kvp) with low energy tunability, broad energy spectra and high beam divergences (40°). Laser Wakefield Accelerators (LWFA) on the other hand, can generate radiation with narrower energy widths, smaller divergences, and better energy tunability. Here, we study the energy deposition (and thus the acoustic response) of betatron, bremsstrahlung and inverse Compton scattering radiation spectra generated by a LWFA and compare them with a commercial x-ray generator for different systems of interest in biomedical applications and discuss the feasibility of these sources to perform future XACT experiments

Acknowledgments:

WG8: Advanced Laser and Beam Technology and Facilities / 239

Coherent temporal stacking of tens-of-fs laser pulses towards plasma accelerator applications

Authors: Lauren Cooper[None]; Dan Wang[1]; Qiang Du[2]; Mathew Whittlesey[3]; Siyun Chen[None]; Deepak Sapkota[4]; Jeroen van Tilborg[1]; Eric Esarey[2]; Derun Li[None]; Cameron Geddes[2]; Russell Wilcox[None]; Almantas Galvanauskas[3]; Tong Zhou[4]

[1] *LBNL*

[2] *Lawrence Berkeley National Laboratory*

[3] *University of Michigan*

[4] *Lawrence Berkeley National Lab*

Corresponding Author: lacoop@umich.edu

A laser-plasma accelerator (LPA) could reach high energies with an accelerating length orders-of-magnitude shorter than in conventional RF accelerators. Compact LPAs will enable high-impact applications in science, medicine, security, and industry. As LPA applications will require new driver lasers with kHz to 10s kHz repetition-rates at high energy and efficiency [1], one promising laser approach is to combine many ultrashort pulses from high-power, high-efficiency fiber lasers, in space, time, and spectrum [2].

Coherent pulse stacking (CPS) temporally stacks many amplified laser pulses into a high energy pulse using cascaded reflecting cavities [3]. This largely reduces the number of spatial fiber channels needed, e.g. to a practical 100 level for Joule pulse energies. However, while LPA needs 30-100fs driver laser pulses, CPS has only been demonstrated experimentally with ~300fs pulse lengths and longer [3,4]. Thus, we propose to validate and demonstrate broadband CPS that can stack tens-of-fs laser pulses with high fidelity, critical for showing CPS is applicable to driving LPAs.

The main challenge associated with broadband CPS, limiting its stacking fidelity, is the unmatched dispersions accumulated for pulses undergoing different cavity roundtrips upon stacking. However, we validated via simulation that by using very low dispersion dielectric mirrors for stacking cavities, high fidelity CPS could be achieved for : 1) 4-cavity stacking of ~9 pulses at 30fs pulse lengths; 2) 8-cavity stacking of ~81 pulses at 50fs pulse lengths.

We experimentally demonstrated stacking of ~10 pulses with broad bandwidth supporting ~50fs transform-limited pulse lengths. The broadband CPS setup consists of a nonlinearly broadened source, pulse modulation and amplification, 4 stacking cavities, and diagnostics. With one cavity, we achieved stacking of ~3 broadband pulses with a pre-pulse contrast of 40:1. Using four cavities, we stacked ~10 broadband pulses with a pre-pulse contrast of 8:1, which is expected to be further improved after ongoing optimization of cavity alignment and phase control.

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Acknowledgments:

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Poster Session and Reception - Board: P9 / **240**

Optimizing down-ramp injection to generate stable and tunable electron bunches for an LPA driven FEL

Authors: Finn Kohrell[1]; Samuel Barber[2]; Kyle Jensen[3]; Curtis Berger[2]; Carl Schroeder[2]; Eric Esarey[2]; Jeroen van Tilborg[1]

[1] *LBNL*

[2] *Lawrence Berkeley National Laboratory*

[3] *UNL, LBNL*

Corresponding Author: finnkohrell@lbl.gov

The mission to achieve free electron lasing using electron bunches generated from an LPA source calls not only for exceptionally high quality and stability in electron beam properties, but also tunability of the laser-plasma interaction and therefore the particle beam parameters. As an alternative to self-trapping, utilizing a density down-ramp in the gas jet density profile has gained a lot of attention to realize this goal. At the BELLA Center HTU system, we use a 100 Terawatt Ti:Sa laser system capable of producing 40 fs pulses with 4 J energy that are subsequently focused into a helium gas jet set up for down-ramp injection. We will present detailed analysis of the jet parameters as well as positioning of the blade, coupled to investigations of the consequential plasma density profiles that allow us to achieve precise control over the properties of the electron bunches and operate our source with high energy stability and charge over hundreds of shots. For example, the optimum separation of the blade from the jet orifice and laser focus was studied in great detail, revealing dramatic improvements in down-ramp sharpness.

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Poster Session and Reception - Board: F66 / **241**

Characterization of the fields inside the CO2-laser-driven wakefield accelerators using relativistic electron beams

Author: Irina Petrushina[1]

Co-authors: Rafal Zgadzaj [2]; Igor Pogorelsky [3]; Marcus Babzien [3]; Mikhail Fedurin [4]; Rotem Kupfer [5]; Karl Kusche [3]; Mikhail Polyanskiy [3]; Mark Palmer [4]; Roman Samulyak ; Chaojie Zhang [6]; Michael C. Downer [7]; Chan Joshi [6]; Vladimir Litvinenko [8]; Navid Vafaei-Najafabadi [1]; Evan Trommer [1]; Kyle Miller [9]; Yipeng Wu [6]; Audrey Farrell [6]; Marisa Petrusky [10]; Nicholas Manzella [1]

[1] *Stony Brook University*

[2] *The University of Texas at Austin*

[3] *BNL*

[4] *Brookhaven National Laboratory*

[5] *Lawrence Livermore National Laboratory*

[6] *UCLA*

[7] *UT at Austin*

[8] *Professors, Stony Brook University*

[9] *Laboratory for Laser Energetics*

[10] *University of Colorado Boulder*

Corresponding Author: irina.petrushina@stonybrook.edu

The CO_2 laser at the Accelerator Test Facility of Brookhaven National Laboratory is a unique source generating 2 ps-long, multi-TW pulses in the mid-IR regime. This rapidly evolving system opens an

opportunity for generation of large bubbles in low density plasmas (~10^{16} cm^{-3}) that are ideal for acceleration of externally injected electron beams. A new generation of diagnostic tools is needed to characterize the fields inside such structures and to improve the means of external injection. In recent years, the electron beam probing technique has shown to be successful in direct visualization of the plasma wakefields. Here we present a new method utilizing the electron beam probing and Transmission Electron Microscopy (TEM) grids that will allow us to selectively illuminate different portions of the wake and to characterize the electric field strength within the wake based on the location of the focal point of the probe beamlets. The analytical evaluation of the approach, supporting simulation results, and recent experimental progress will be presented and discussed.

Acknowledgments:

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Poster Session and Reception - Board: P10 / **242**

Arbitrary Wave Shaping for Controlled Electron Injection Using Co-Propagating Laser Pulses

Author: Nicholas Ernst[1]

Co-authors: Yong Ma [1]; Alexander Thomas [2]; Karl Krushelnick [1]

[1] *University of Michigan*

[2] *University of Michigan, Gérard Mourou Center of Ultrafast Optical Science*

Corresponding Author: npegyf@umich.edu

We introduce a novel method of controlled electron injection for Laser Wakefield Acceleration (LWFA) operating in the high-intensity "bubble" regime. In this scheme, a fraction of a high-intensity "driver" pulse is diverted and compressed into a low power, few-cycle "satellite" pulse co-propagating alongside the driver. This satellite is tightly focused off-axis where it acts to perturb bubble formation and drive an asymmetric plasma wave before stabilizing on-axis. Doing so allows for manipulation of the particle Hamiltonian; creating a trigger to overcome the wave-breaking injection threshold and lead to efficient particle trapping and acceleration. 2D and quasi-3D Particle-in-Cell (PIC) simulations support this concept, demonstrating that systematic investigation of the two-beam parameter space (e.g. temporal delay, beam displacement, etc.) leads to controllable variance in the electron beam phase space. Results indicate this method could be used to induce self-injection in wakefields at plasma densities and driving laser intensities well below theoretical predictions. Further, adding additional co-propagating satellites proves to distort the initial plasma wave formation in a predictable manner, allowing a controllable mechanism to alter the phase space of injected electrons. Pulses can be placed to increase the transverse momentum on injected electrons which leads to enhanced betatron emission or mitigated for longitudinal injection suitable for mono-energetic acceleration. The results show promise for an all-optical knob to transition between high charge, mono-energetic, GeV particle accelerators to enhanced x-ray sources using betatron radiation through independent tuning of the satellite pulses.

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WG8: Advanced Laser and Beam Technology and Facilities / **243**

Ultra-broadband spectral combination of fiber lasers with synthesized pulse shaping to reach short pulse lengths for plasma accelerators

Authors: Siyun Chen[1]; Qiang Du[1]; Dan Wang[2]; Jeroen van Tilborg[2]; Carl Schroeder[2]; Eric Esarey[3]; Derun Li[None]; Cameron Geddes[3]; Russell Wilcox[None]; Tong Zhou[3]

[1] *Lawrence Berkeley National Lab*

[2] *LBNL*

[3] *Lawrence Berkeley National Laboratory*

Corresponding Author: siyunchen@lbl.gov

Laser-plasma accelerators (LPA) can significantly reduce the large sizes of conventional accelerators, showing great potential, but they are challenged by today's low operation repetition-rates (Hertz class). Achieving kilohertz repetition-rates is necessary to enable high impact applications in science, security, and medicine [DOE Basic Research Needs Workshop report, 2019].

One recognized laser technology towards kilohertz LPA drivers is multidimensional fiber laser combination [DOE Brightest Light Initiative report, 2019], due to its advantages in wall-plug efficiency and thermal management. While achievable pulse lengths from fiber lasers are limited by gain narrowing and high order fiber dispersions in high energy systems, coherently combining multiple fiber output spectra has been demonstrated to generate shorter pulses, with a shortest 97fs at one-micron wavelength [Proc. SPIE 9728, 2016]. However, LPAs need driver lasers with pulse lengths much shorter than ~100fs.

Thus, we propose ultra-broadband spectral combining of fiber lasers to reach short pulse lengths beyond the state of the art, using spectrally synthesized pulse shaping. We demonstrated a 54-fs, two-channel spectrally-combined fiber laser system, with two pulse shapers operating at different but partially-overlapped spectrum in each channel to control the spectral intensity and phase. Coherent synthesis of the two shapers was achieved by phase-synchronizing the two channels at the overlapped spectrum. 94.5% combining efficiency was obtained through an SPGD-based feedback loop.

To the best of our knowledge, 54fs is the shortest pulse length from a spectrally combined fiber system at one-micron wavelength, and we achieved the first demonstration of coherent spectral synthesis of two pulse shapers [accepted by Advanced Solid State Lasers (Dec 2022) and Photonics West (Jan 2023) as oral presentations]. We recently completed a three-spectral-channel combination setup, with a fiber amplifier in each channel and two synthesized pulse shapers covering all three spectra. We have demonstrated an 80nm spectrum combined from three channels, with a flat spectral phase, corresponding to <40fs transform-limited pulse length. Phase synchronization of all channels is in progress.

This ultra-broadband, energy-scalable approach of spectral combination with synthesized pulse shaping paves the way to high energy, tens-of-fs fiber lasers for driving plasma accelerators.

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Poster Session and Reception - Board: F81 / **244**

Measurements of the amplitude of plasma wakefields using plasma light

Authors: Patric Muggli[1]; Michele Bergamaschi[2]; Jan Pucek[2]; Livio Verra[3]; Tatiana Nechaeva[2]; Giovanni Zevi Della Porta[2]; Lucas Ranc[2]

[1] *Max-Planck-Institut for physics*
[2] *Max-Planck Institute for Physics*
[3] *CERN*

Corresponding Author: muggli@mpp.mpg.de

Measuring the amplitude of plasma wakefields is challenging. It is however essential for AWAKE [1], since the proposed self-modulation mechanism suggested to drive large amplitude wakefields [2] with a long particle bunch must be seeded to be reproducible in phase [3,4] and in amplitude. Also, the amplitude of the wakefields evolves significantly during the growth of the self-modulation process from seed wakefields, to saturation and beyond [5,6]. Numerical simulation results suggest that this evolution can be influenced with a plasma density step to force wakefields to maintain a large amplitude over a long distance beyond their saturation point [7]. Previous experimental results suggest that the amount of atomic plasma light emitted as wakefields dissipate, is proportional to the energy deposited by the drive bunch in the plasma [8]. Local plasma light measurements could then yield local measurements of the amplitude of wakefields.
Preliminary experimental results show that the amplitude of plasma light signals measured at the plasma entrance and exit indeed depends on whether the self-modulation process is seeded or not. It also depends on the amplitude of seed wakefields and on the amount of proton bunch charge that drives wakefields.
We will introduce the experimental setup, display preliminary results, and present the measurement plan to extract in future experiments [9] essential information about self-modulation physics.

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AWAKE Collaboration

Plenary / **245**

European Roadmap Reports for Advanced Accelerators

Authors: Ralph Assmann[1]; Edda Gschwendtner[2]

[1] *DESY & INFN*
[2] *CERN*

Corresponding Author: ralph.assmann@desy.de

In recent years Europe had an intense discussion on roadmaps for accelerator R&D and research infrastructures. Several roadmaps were published and prominently include advanced accelerators. Of particular visibility are the 2021 Roadmap Update of the government-led European Strategy Forum for Research Infrastructures (ESFRI) and the 2022 publication of the European Roadmap on Accelerator R&D for Particle Physics. For the first time an advanced accelerator facility project, namely EuPRAXIA, was selected for the ESFRI roadmap. Also for the first time, advanced accelerators have been recognised as one of several pillars of the European particle physics accelerator R&D roadmap, relating to various national projects and the CERN AWAKE collaboration. The conclusions and advanced accelerator R&D directions of the recently published roadmaps are presented. Future R&D work and approved European facilities in advanced accelerator research are discussed.

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WG1: Laser-Plasma Wakefield Acceleration / 246

First results of the two-color LWFA experiments at ATF

Authors: Navid Vafaei-Najafabadi[1]; Irina Petrushina[2]; Rotem Kupfer[3]; Igor Pogorelsky[4]; Mikhail Polyanskiy[4]; Marcus Babzien[4]; Mikhail Fedurin[5]; Karl Kusche[4]; William Li[5]; Mark Palmer[5]

[1] *Stony Brook University, Brookhaven National Laboratory*

[2] *Stony Brook University*

[3] *Lawrence Livermore National Laboratory*

[4] *BNL*

[5] *Brookhaven National Laboratory*

Corresponding Author: nvafaeina@bnl.gov

Two-color ionization injection is a promising method for realizing an all-optical, plasma photocathode. In this method, a nonlinear plasma wakefield is driven by a long-wavelength laser, and the ionization injection occurs using a second, high-intensity laser pulse with a short wavelength. Recent upgrades at the Accelerator Test Facility (ATF) of the Brookhaven National Laboratory has provided an ideal opportunity for this experiment by integrating a long-wave infrared (LWIR) CO_2 laser pulse (λ~9.2 μm) with a Ti:Sapphire (λ~0.8 μm) laser pulse at the interaction point. Previous simulations have shown the potential for this combination of lasers to produce bright electron beams with normalized emittance of tens of nm [1,2]. In this talk, we present the first results on the impact of a transverse Ti:Sapphire laser pulse on the electrons generated in the CO_2-driven LWFA in the self-modulated regime using a ~2.5 TW, 2 ps CO_2 laser and a ~ 5 mJ Ti:Sapphire laser. This work lays the foundation towards the realization of the all-optical plasma photocathode experiment as the facility plans upgrades towards >10 TW, sub-ps CO_2 pulses and terawatt class Ti:Sapphire lasers.

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Poster Session and Reception - Board: P11 / **247**

EMP from LWFA with two collinear, time-separated laser beams

Author: Joshua Latham[1]

Co-authors: Mayr Marko [2]; Yong Ma [1]; Paul Campbell ; QIAN QIAN ; André Antoine [1]; Mario Balcazar [1]; Jason Cardarelli [1]; Rebecca Fitzgarrald [3]; Andrew McKelvey [1]; Galina Kalinchenko [1]; Bixue Hou [1]; Anatoly Maksimchuk [1]; John Nees ; Alexander Thomas [4]; Peter Norreys [5]; Karl Krushelnick [1]

[1] *University of Michigan*

[2] *Clarendon Laboratory, University of Oxford*

[3] *University of MIchigan*

[4] *University of Michigan, Gérard Mourou Center of Ultrafast Optical Science*

[5] *Rutherford Appleton Laboratory*

Corresponding Author: joshla@umich.edu

Measurements of Radio Frequency (RF) emission may be a useful diagnostic for electron dynamics in laser-plasma interactions. Such radiation can also be detrimental as a significant source of noise for other diagnostics. EMP measurements were made during interactions of high-power short-pulse lasers with gaseous density targets at the University of Michigan. In a nitrogen-doped helium target experiment with two collinear, time-separated laser beams, EMP was maximized at a particular timing between the two beams. The increase in RF was correlated with the X-ray signal. However, there was also a population of shots where simultaneous increases in the X-ray and electron signal were observed, but the RF was not significantly increased. Potential explanations for this phenomenon will be discussed, using results from particle-in-cell (PIC) simulations to identify the physical mechanisms.

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WG7: Radiation Generation and Advanced Concepts / 248

The Ion Channel Laser: Physics Advances and Experimental Plans

Authors: Claire Hansel[1]; Jacob Pierce[2]; Christopher Doss[1]; Valentina Lee[1]; Zhirong Huang[3]; Mark Hogan[4]; Warren Mori[2]; Michael Litos[1]

[1] *University of Colorado Boulder*

[2] *UCLA*

[3] *Stanford University/SLAC*

[4] *SLAC National Accelerator Laboratory*

Corresponding Author: claire.hansel@colorado.edu

The ion channel laser (ICL) is an alternative to the free electron laser (FEL) that uses the electric fields in an ion channel rather than the magnetic fields in an undulator to transversely oscillate a relativistic electron beam and produce coherent radiation. The strong focusing force of the ion channel leads to a Pierce parameter more than an order of magnitude larger than the typical values associated with FELs. This allows the ICL to lase in an extremely short distance while using electron beams with an energy spread of up to a few percent. The ICL may thus be able to accommodate beams that can be produced by laser wakefield accelerators today. ICLs have several practical challenges, however, including stringent constraints on the beam's transverse phase space and the creation of a wakeless ion channel of sufficient length. We discuss recent advances in the physics of the ion channel laser as well as experimental plans for the first demonstration of an optical wavelength ICL at SLAC's FACET-II facility and to potential future x-ray laser devices.

Acknowledgments:

The authors would like to acknowledge the OSIRIS Consortium, consisting of UCLA and IST (Lisbon, Portugal) for providing access to the OSIRIS 4.0 framework. Work supported by NSF ACI-1339893. Work supported by the National Science Foundation through grant NSF-2047083 and the US Department of

Energy through grant DE-SC0017906.

Poster Session and Reception - Board: P56 / **249**

The Ion Channel Laser: Physics Advances and Experimental Plans

Authors: Claire Hansel[1]; Jacob Pierce[2]; Christopher Doss[1]; Valentina Lee[1]; Zhirong Huang[3]; Mark Hogan[4]; Warren Mori[2]; Michael Litos[1]

[1] *University of Colorado Boulder*

[2] *UCLA*

[3] *Stanford University/SLAC*

[4] *SLAC National Accelerator Laboratory*

Corresponding Author: claire.hansel@colorado.edu

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The authors would like to acknowledge the OSIRIS Consortium, consisting of UCLA and IST (Lisbon, Portugal) for providing access to the OSIRIS 4.0 framework. Work supported by NSF ACI-1339893. Work supported by the National Science Foundation through grant NSF-2047083 and the US Department of Energy through grant DE-SC0017906.

WG8: Advanced Laser and Beam Technology and Facilities / 250

Diode-Pumped Tm:YLF Lasers for Advanced Accelerators

Author: Leily Kiani[1]

Co-authors: Issa Tamer [1]; Brendan Reagan [2]; Thomas Galvin [1]; Frantisek Batysta [1]; Emily Sistrunk [1]; Drew Willard [1]; Andrew Church [2]; Hansel Neurath [2]; Justin Galbraith [1]; Glenn Huete ; Thomas Spinka [1]

[1] *LLNL*

[2] *LLNl*

Corresponding Author: kiani2@llnl.gov

High peak power laser systems with architectures that are scalable in average power are essential to drive the next generation of advanced, compact electron accelerators. For this purpose, the Big Aperture Thulium (BAT) laser concept is designed to simultaneously operate at PW-class peak powers and multi-100kW average powers through the use of an energy extraction regime that scales in efficiency with repetition rate. The gain material Tm:YLF exhibits a long radiative lifetime of 15 ms and can be directly pumped with peak power limited CW diodes, while efficiently amplifying broadband pulses at low fluences. In this work, we report on the current status of Tm:YLF laser development, including energy extraction demonstrations of pulse energies >21J in 20ns (>1GW peak power) in a 4-pass amplifier, as well as 108J pulse energies in a long duration pulse using a 6-pass configuration of the same amplifier. Additionally, we describe upcoming experimental demonstrations, including high energy chirped pulse amplification of ultrashort pulses in Tm:YLF, to support the high peak and average power potential of the BAT laser concept.

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WG7: Radiation Generation and Advanced Concepts / 251

High-energy two-color terahertz generation

Authors: Tanner Simpson[1]; Jeremy Pigeon[2]; Mervin Lim Pac Chong[3]; Robert Boni[2]; Dillon Ramsey[4]; Kathleen Weichman[5]; Dustin Froula[6]; John Palastro[6]

[1] *Laboratory for Laser Energetics, University of Rochester*

[2] *University of Rochester, Laboratory for Laser Energetics*

[3] *University of Rochester, Laboratory for Laser Energetics*

[4] *University of Rochester / Laboratory for Laser Energetics*

[5] *University of Rochester Laboratory for Laser Energetics*

[6] *University of Rochester, Laboratory of Laser Energetics*

Corresponding Author: tsim@lle.rochester.edu

A laser pulse composed of a fundamental and properly phased second harmonic exhibits an asymmetric electric field that can drive a time-dependent current of photoionized electrons. The current produces a near-single-cycle burst of terahertz (THz) radiation. Experiments using ~1-TW ultrashort laser pulses observe optimal THz energies (~10-uJ) when the "two-color" pulse undergoes filamentary propagation in low pressure gas. Here we use simulations to investigate the optimal conditions for two-color THz generation driven by >100-TW ultrashort laser pulses. Simple scalings indicate that the number of photoionized electrons is independent of gas pressure. As a result, use of a low-pressure, small nonlinear refractive index, high-ionization potential gas such as helium can mitigate multiple filamentation of the high-power pulse, while strengthening the field experienced by electrons at the instant of ionization, thereby increasing the current and THz energy. A high-energy (~1-mJ), THz source would enable access to a novel physics regime in which bound electron nonlinear optics and relativistic plasma physics coexist.

Acknowledgments:

WG7: Radiation Generation and Advanced Concepts / 252

Nonlinear Thomson Scattering with Ponderomotive Control

Authors: Dillon Ramsey[1]; Antonino Di Piazza[2]; Martin Formanek[3]; Phil Franke[4]; Dustin Froula[4]; Bernardo Malaca[5]; Miguel Pardal[5]; Tanner Simpson[4]; Kathleen Weichman[6]; Jorge Vieira[7]; John Palastro[8]

[1] *LLE/UR*

[2] *Max-Planck-Institut fur Kernphysik*

[3] *ELI-Beamlines, Institute of Physics of Czech Academy of Sciences*

[4] *University of Rochester, Laboratory of Laser Energetics*

[5] *GoLP/Instituto Superior Técnico, University of Lisbon*

[6] *University of Rochester Laboratory for Laser Energetics*

[7] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa,*

[8] *University of Rochester, Laboratory for Laser Energetics*

Corresponding Author: dram@lle.rochester.edu

In nonlinear Thomson scattering, a relativistic electron reflects and reradiates the photons of a laser pulse, converting optical light to x rays or beyond. While this extreme frequency conversion offers a promising source for probing high-energy-density materials and driving uncharted regimes of nonlinear quantum electrodynamics, conventional nonlinear Thomson scattering has inherent trade-offs in its scaling with laser intensity. Here we discover that the ponderomotive control afforded by spatiotemporal pulse shaping enables novel regimes of nonlinear Thomson scattering that substantially enhance the scaling of the radiated power, emission angle, and frequency with laser intensity. By appropriately setting the velocity of the intensity peak, a spatiotemporally shaped pulse can increase the power radiated by orders of magnitude. The enhanced scaling with laser intensity allows for operation at significantly lower electron energies and eliminates the need for a high-energy electron accelerator. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856 and by OFES under Award Number DE-SC0019135 and DE-SC00215057.

Acknowledgments:

WG3: Laser and High-Gradient Structure-Based Acceleration / 253

Energy Modulation in a Commercial Dual Grating Dielectric Structure

Author: Sophie Crisp[1]

Co-authors: Alexander Ody [1]; Pietro Musumeci

[1] *UCLA*

Corresponding Author: sophiecrisp@physics.ucla.edu

We present the latest experimental results using a dual grating dielectric laser accelerator (DLA) to modulate 6 MeV electrons. The structure is composed of two commercially available gratings, mounted independently with variable gap size controlled by 3 piezo motors. A 780 nm laser is used to drive the 800 nm periodic structure with gap size on the order of 1 um. These gratings are 4 mm long, enabling future long interaction experiments.

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Poster Session and Reception - Board: P23 / **254**

Energy Modulation in a Commercial Dual Grating Dielectric Structure

Author: Sophie Crisp[1]

Co-authors: Pietro Musumeci ; Alexander Ody [1]

[1] *UCLA*

Corresponding Author: sophiecrisp@physics.ucla.edu

We present the latest experimental results using a dual grating dielectric laser accelerator (DLA) to modulate 6 MeV electrons. The structure is composed of two commercially available gratings, mounted independently with variable gap size controlled by 3 piezo motors. A 780 nm laser is used to drive the 800 nm periodic structure with gap size on the order of 1 um. These gratings are 4 mm long, enabling future long interaction experiments.

Acknowledgments:

WGs 2+5 Joint Session / **255**

Simulating electron beams in RF cavities with beam loading

Authors: David Bruhwiler[1]; Sergey Kutsaev[2]; Robert Nagler[1]; Ilya Pogorelov[1]; Garret Sugarbaker[1]; Yury Eidelman[3]

[1] *RadiaSoft LLC*

[2] *RadiaBeam Technologies, LLC*

[3] *consultant*

Corresponding Author: bruhwiler@radiasoft.net

High-brightness electron photoinjectors and electron linacs are fundamental to many advanced accelerator concepts and associated applications (see e.g., Ref. [1] and references therein). The industrial, medical and homeland security markets for low-to-moderate energy electron linacs are growing rapidly. To meet the design challenges for these divergent applications, with modest software development resources, a simulation code must meet the following requirements: a reduced-model algorithm that includes beam loading in rf cavities; phase space conserving algorithms; a single-source implementation that executes efficiently on many CPUs, on one or more GPUs, and on heterogeneous supercomputing architectures; as well as easy benchmarking with high-fidelity community codes.
We present recent work with the open source Hellweg code [2-4], which is routinely used to design TW electron linacs, showing 1000x speedup as compared to CST Particle Studio. We plan to refactor Hellweg's C++ source code to make effective use of the AMReX framework [5,6], joining an ecosystem of massively parallel accelerator physics codes under development at Berkeley Lab. The reduced model algorithms in Hellweg will play an important role, in concert with other more high-fidelity PIC codes.
We will describe the underlying algorithms in Hellweg, as well as recent and ongoing generalizations. Recent work on traveling wave linac simulation and design will be presented. Time will also be devoted to a discussion of future plans, which include treatment of Touschek scattering, thermionic and photocathode electron guns, and a modified algorithm to conserve phase space.

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Plenary / 256

Cool Copper Collider Design and Plans

Author: Mohamed Othman[1]

[1] *SLAC NATIONAL ACCELERATOR LABORATORY*

Corresponding Author: mothman@slac.stanford.edu

C3 – the Cool Copper Collider – is a concept for a e+e− Higgs factory at 250 GeV center of mass, with a potential upgrade to 550 GeV in the same footprint. C3 leverages novel advancements in high-gradient cryogenic copper accelerator structures which operate with high rf to beam efficiency. The C3 main linac requires significant R&D effort for the rf and cryogenic systems, beam delivery, and beam alignment. The C3 demonstration plan is aimed at mitigating risks associated with technical, schedule, and cost with the goal of commissioning a full high gradient cryomodule with beam loading. This talk will cover recent rf accelerator R&D efforts in terms of distributed coupling structures and cryogenic structure design, as well as the status of high gradient tests, cryomodule design and beam dynamics.

Acknowledgments:

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WG4: Beam-Driven Acceleration / 257

Acceleration and Focusing of Positrons Using Elongated Bubbles in Warm Plasmas

Author: Gennady Shvets[1]

[1] *Cornell University*

Corresponding Author: gshvets@cornell.edu

Plasma wakefields produced by high-charge electron bunches are attractive for lepton colliders because they combine high-gradient acceleration and, in the regime of full electron blowout, emittance preserving linear focusing of the accelerated electrons by the remaining positively charged ions. Achieving the same for positrons is more challenging because it requires producing a uniform high-density filament of plasma electrons. I will discuss a novel approach to creating such filaments behind the driver-generated plasma "bubble" by adding a trailing escort bunch. Initial plasma temperature, as well as the electric charge and time delay of the escort bunch, determine the size of the filament region favorable to simultaneous focusing/acceleration of witness positrons. I will further discuss how efficient energy transfer from the driver to the positrons, combined with emittance preservation, can be achieved for such elongated bubbles in warm plasmas.

Acknowledgments:

Poster Session and Reception - Board: F70 / **258**

Recent Developments on QuickPIC

Authors: Weiming An[1]; Qianqian Su[None]; Weiyu Meng[1]; Rong Tang[1]; Yueran Tian[1]; Yueluo Wang[1]; Viktor Decyk[2]; Lance Hildebrand[2]; Yujian Zhao[None]; Fei Li[2]; Warren Mori[2]

[1] *Beijing Normal University*

[2] *UCLA*

Corresponding Author: xpsqq@g.ucla.edu

QuickPIC has been an open source code since 2017 [1]. As a 3D parallel quasi-static PIC code, QuickPIC has been widely used for efficiently modeling the plasma based accelerator problems. Recently, a new field ionization module has been merged into the open source QuickPIC. Instead of the mesh ionization method, the new module is developed based on the particle ionization method, which can include mobile ions when simulating the field ionized plasma. We have also recently implement a module for calculating the beam's betatron radiation in QuickPIC. In addition, we will present the progress on the GPU version of QuickPIC. Details on mesh refinement routines in a development branch for QuickPIC will also be included.

Acknowledgments:

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WG4: Beam-Driven Acceleration / **259**

Plasma heating and expansion in PWFA experiments FACET

Authors: Kenneth Marsh[1]; E200 and E300 FACET Collaboration[2]

[1] *UCLA ECE*

[2]

Corresponding Author: kamarsh@g.ucla.edu

In PWFA experiments, like at FACET, most of the beam energy can be transferred into the wake and trailing plasma oscillations. These oscillation in turn lead to intense plasma heating and expansion. As a practical matter, to reach high average current the heat must be removed between electron bunches. Interestingly, the rapid plasma expansion is unstable and can produce filamentary structures and corresponding large magnetic fields. These types of magnetic field structures are studied in astronomical phenomenon but difficult to produce in the laboratory. In our case, the magnetic filamentary structures are embedded in the plasma and last longer than the plasma recombination time. This allows the structures to be imaged along the beam axis by observing the hydrogen plasma recombination fluorescence at 656 nm. The images show helical structures consistent with radial expansion and plasma filamentation instability.

Acknowledgments:

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Poster Session and Reception - Board: F82 / **260**

Generation and optimization of high quality multi-GeV electron beams using an evolving electron driver in the nonlinear blowout regime

Authors: Thamine Dalichaouch[1]; Fei Li[1]; Xinlu Xu[2]; Frank Tsung[1]; Warren Mori[1]

[1] *UCLA*

[2] *Peking University*

Corresponding Author: tdalichaouch@gmail.com

Plasma-based acceleration (PBA) is a promising approach for generating high quality ultrarelativistic beams to drive next-generation x-ray light sources and particle collider experiments. Over the years, research has largely focused on injection methods that use a density down ramp or field ionization to generate such beams. Recently, we proposed and demonstrated new methods of controllable injection that use evolving electron drivers to excite nonlinear plasma wakefields [1,2]. In the first method, wake expansion and injection are triggered by focusing the electron driver in the nonlinear blowout regime [1]. We describe the physics of this process and present a predictive model to characterize injection in the self-focusing regime. The model is used to describe how the wake evolution and final injected beam parameters scale with the driver parameters. Parameter scans of particle-in-cell (PIC) simulations using OSIRIS are presented and compared with the model predictions for different driver parameters. In the second method, high quality beams are generated utilizing a "flying focus" produced by a drive beam with an energy chirp [2]. The evolution of the wake is determined by the speed of the density centroid, which can be superluminal or subluminal. Using PIC simulations, we demonstrate that a wake driven by a superluminally propagating flying focus of an electron beam can trigger injection. Simulation results indicate that GeV-class electron bunches with high normalized brightnesses (>10^{19} A/m^2/rad^2) and low projected energy spreads ($< 1\%$) can be produced using both methods.

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WGs 2+4 Joint Session / **261**

Optimal beam loading to 20 GeV through wakefield slope rotation using an evolving electron driver

Authors: Thamine Dalichaouch[1]; Xinlu Xu[2]; Fei Li[1]; Adam Tableman[None]; Frank Tsung[1]; Warren Mori[1]

[1] *UCLA*

[2] *Peking University*

Corresponding Author: tdalichaouch@gmail.com

The goals of plasma-based acceleration (PBA) are high gradient, high efficient acceleration and high quality beam generation. Various synchronized injection schemes utilizing PBA have been proposed and investigated to generate beams capable of driving a compact x-ray free electron laser (XFEL). In each of these ideas, the main challenge is how to maximize the energy transfer to the injected bunch and minimize its projected energy spread. Using particle-in-cell (PIC) simulations, we demonstrate a new approach to optimal beam loading that relies on wakefield slope rotation triggered by an evolving electron driver. Injection is triggered by self-focusing an electron driver in the nonlinear blowout regime. As the driver loses energy following injection, its evolution alters the shape of the wake and accelerating field loaded by the injected bunch. For high current injected bunches, the slope of the accelerating field can fully rotate from negative to positive over the course of pump depletion so that the average acceleration field has near-zero slope. We also examine beam loading effects at different stages of the acceleration and explain the results using nonlinear theory. PIC simulations using OSIRIS indicate that injection and optimal beam loading can be achieved until the drive beam fully pump depletes. Based on simulation results, the injected beams can be efficiently accelerated with energies up to 20 GeV, projected energy spreads of 0.5%, and peak normalized brightness of $10^{20}\mathrm{A/m^2/rad^2}$.

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Poster Session and Reception - Board: P57 / **262**

Polarized Photoelectrons from Converging Vector Waves

Authors: Daniel Younis[1]; Bahman Hafizi[2]; Daniel Gordon[2]

[1] *University of Rochester, Department of Physics & Astronomy*

[2] *U.S. Naval Research Laboratory*

Corresponding Author: danyounis85@gmail.com

We investigate the photoelectron spin characteristics when hydrogenic ions are centro-symmetrically irradiated with converging vector waves — a non-paraxial form of structured light. A photon with given total angular momentum j and azimuthal mode number m generates photoelectrons with both helicities, in contrast to the fixed helicity produced by left- or right circularly polarized light. The angular distribution of the degree of polarization is broadly tunable through the radiation mode numbers, and the opposite helicities can be extracted in synchronism.

Acknowledgments:

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WG8: Advanced Laser and Beam Technology and Facilities / **263**

Nonlinear Coherent Pulse Stacking enabling energy scalable several optical cycle pulses for the next generation drivers of laser plasma accelerators

Authors: Tayari Coleman[None]; Alex Rainville[1]; Mohamed Azzouz[2]; Matthew Whitlesey[1]; Lauren Cooper[None]; Yanwen Jing[1]; Almantas Galvanauskas[1]

[1] *University of Michigan*

[2] *Stanford*

Corresponding Author: tayaric@umich.edu

Laser-wakefield plasma accelerators (LWFA) promise compact sources of highly energetic electrons and photons, but for their practical use they need efficient and high repetition rate laser drivers. The current standard is the Ti:sapphire CPA system, which can produce multi-J pulses with bandwidths supporting ~30 fs pulses, but it has low wall plug efficiency (WPE) and ~Hz repetition rates. Fiber laser systems can operate with high WPE at 10's of kHz and are scalable to high energies and powers using spatial and temporal coherent combining but have bandwidths sufficient for only 50-100fs pulses. Additional spectral combining can extend this bandwidth, but by increasing overall complexity of the fiber laser driver. We propose a Nonlinear Coherent Pulse Stacking (N-CPS) technique, which could enable achieving several cycle pulses comparable to those of Ti:sapphire, while maintaining multi-kW power and the multi-J energy scalability of coherently combined fiber laser arrays with only a minor increase in the overall complexity of the system.
Coherent Pulse Stacking Amplification (CPSA) is critical for reducing spatially-combined fiber laser array sizes by approximately two orders of magnitude. In demonstrated CPSA systems [1] a stacking-burst of stretched pulses extracts nearly-all stored energy from the final amplification stage and is temporally combined (using GTI cavities) into a single stretched pulse for compression to the bandwidth-limit at the system output.
We show that N-CPS can extend CPSA by compressing the amplified stacking-burst first, then spectrally broadening each individual compressed pulse in, for example, a Herriott-cell gas chamber [2], and only then stacking the burst into a single pulse, which is subsequentially compressed using chirped mirrors to durations much shorter than fiber gain bandwidth supports. Stacking-burst in this case allows both near-complete energy extraction during amplification and overcoming individual pulse energy limitations (~10-20mJ) of the spectral broadening step. We also show via numerical simulations that N-CPS needs only a minor increase in a CPSA system complexity, because it can reshape unequal-amplitude saturated bursts from final amplifiers into equal amplitude burst necessary for spectral broadening using only a couple of additional GTI stages. We will report on the experimental progress demonstrating this new N-CPS technique.

Acknowledgments:

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Poster Session and Reception - Board: F71 / **264**

QPAD: Highly efficient quasi-static particle-in-cell algorithm based on azimuthal decomposition

Authors: Fei Li[1]; Weiming An[2]; Qianqian Su[None]; Thamine Dalichaouch[1]; Yujian Zhao[None]; Frank Tsung[1]; Viktor Decyk[1]; Warren Mori[1]

[1] *UCLA*

[2] *Beijing Normal University*

Corresponding Author: tdalichaouch@gmail.com

High fidelity modeling of plasma based accelerators (PBA) requires the use of 3D, fully nonlinear, and kinetic descriptions based on particle-in-cell (PIC) method. Compared to the computationally intensive full 3D explicit PIC code, the quasi-static PIC codes are able to speed up the simulations by orders of magnitude, which allows for modeling the physical problems requiring massive computing resource, such as hosing instability and ion motion effect in PBAs. In addition to the quasi-static approximation (QSA), the Fourier azimuthal decomposition is another effective speedup technique which has been applied into some general-purpose PIC codes. Recently, a new hybrid QSA PIC algorithm that combines the Fourier azimuthal decomposition, QPAD, has been proposed and implemented. QPAD decomposes the electromagnetic fields, charge and current density into azimuthal harmonics and only the Fourier coefficients need to be updated, which reduces the algorithmic complexity of a 3D code to that of a 2D code. Modeling the laser-plasma interaction in a 3D PIC algorithm is also very computationally expensive due to the enormous disparity of physical scales to be resolved. Using ponderomotive guiding center (PGC) approach in QSA algorithm can speed up the simulation by orders of magnitude. We have implemented a azimuthal decomposed PGC algorithm compatible for QPAD. This algorithm permits time steps orders of magnitude larger than the cell size and it can be asynchronously parallelized. Benchmarks and comparisons between a fully 3D explicit PIC code is presented. QPAD provides a highly efficient PIC code for modeling PBAs with long distance or/and ultra-fine spatial resolution. It is also suitable for parameter scanning and optimization problems.

Acknowledgments:

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WGs 4+5 Joint Session / 265

Optical visualization of e-beam-driven plasma wakes at FACET-II

Authors: Rafal Zgadzaj[1]; Jason Brooks[None]; T. Silva[2]; Vadim Khudyakov[3]; Michael Litos[4]; Jorge Vieira[5]; Konstantin Lotov[3]; Mark Hogan[6]; V Yakimenko[None]; Michael Downer[7]

[1] *UT at Austin*

[2] *Instituto Superior Técnico, Lisboa, Portugal*

[3] *Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia*

[4] *University of Colorado Boulder*

[5] *GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Téecnico*

[6] *SLAC National Accelerator Laboratory*

[7] *The University of Texas at Austin*

Corresponding Author: rafal@physics.utexas.edu

The goal of the E-324 experiment (”Optical visualization of e-beam-driven wakes”) at SLAC’s 2nd-generation Facility for Advanced Accelerator Science and Experimental Tests (FACET-II) is to observe and understand electron- and ion-density structures that arise during, and at delays up to ~ms after, e-beam-driven production of strongly nonlinear plasma wakefields. The current set-up interrogates the plasma with a probe pulse (⊠ = 0.8 µm, 50 fs) that is temporally synchronized with the 10 GeV e-beam driver and impinges on the wake at grazing angle ⊠ < 1° to its propagation direction, thereby achieving high-sensitivity to structures of density $n_e \leq 10^{16}$ cm^{-3}. Recent time-resolved diffractometry measurements with this setup have identified the principal physical mechanisms, and quantified the dominant dynamical pathways, by which nonlinear wakes release their stored electrostatic energy into the surrounding plasma on ps to ns time scales [1], and have bench-marked large-scale simulations of these dynamics [2]. Clear optical signatures of residual plasma heat at tens of µs delays have been observed [1], well beyond the ~60 ns “lower limit” plasma recovery time determined by 2-pulse wake excitation measurements alone [3]. Full understanding of this recovery time is essential to designing future high-luminosity plasma-based accelerators. We will also discuss current efforts to simulate and detect warm hollow-channel ion-density structures that form within tens of ps following nonlinear wake excitation, and that are promising for plasma-based positron acceleration [4].

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WG4: Beam-Driven Acceleration / **266**

Flat beam plasma wakefield accelerator

Authors: Pratik Manwani[1]; Gerard Andonian[2]; Nathan Majernik[None]; James Rosenzweig[None]; Joshua Mann[None]; Havyn Ancelin[3]; Yunbo Kang[3]; Derek Chow[3]; John Power[None]; Tianzhe Xu[None]

[1] *University of California, Los Angeles*

[2] *UCLA / RadiaBeam*

[3] *UCLA*

Corresponding Author: pkmanwani@g.ucla.edu

Particle beams with highly asymmetric emittance ratios are employed at accelerator facilities and are expected at the interaction point of high energy colliders. These asymmetric beams can be used to drive wakefields in dielectric structures and can be used to drive high gradient wakefields in plasmas. In plasma, the high aspect ratio of the drive beam can create a transversely elliptical blowout cavity and the asymmetry in the ion column creates asymmetric focusing in the two transverse planes. The ellipticity of the blowout depends on the ellipticity and normalized charge density of the beam. Simulations are performed to investigate the ellipticity of the wakefield based on the initial driver beam parameters and the parameter space for the two cases at the AWA and FACET facilities.

Acknowledgments:

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work used computational and storage services associated
with the SCARF cluster provided by the STFC Scientific
Computing Department.

Poster Session and Reception - Board: P63 / **267**

Synchronous Ultrashort Off-Color Laser for Arbitrary Delay Backlighting of Intense Laser Plasma Interactions

Authors: Christopher Pasquale[1]; Alexander Rainville[2]; Nicholas Peskosky[3]; Karl Krushelnick[2]; Almantas Galvanauskas[2]

[1] *Univeristy of Michigan*

[2] *University of Michigan*

[3] *Univeristy of Michigan*

Corresponding Author: chrispas@umich.edu

Spatio-temporally synchronized light sources form the backbone of various laser plasma acceleration (LPA) experimental diagnostic tools including transverse shadowgraphy, schlieren imaging and

interferometry. In common practice, electronic pulse picking or physical beam splitting are used to derive sources of synchronized ultrashort probe light from the high-power drive laser. Practical cavity engineering imposes a ~100MHz repetition rate limitation on most solid-state mode-locked oscillators, which require multi-meter delay lines to control the time delay of the probe pulse. These delay lines are prone to temporal jitter and spatial pointing instability. Furthermore, use of on-band or harmonics of the fundamental of the primary drive laser can significantly limit imaging signal-to-noise ratio due to plasma induced light scattering or coupled non-linear processes. In this work, we propose a fiber-based architecture for an off-band femtosecond backlight system with arbitrary delay ranging from ms to fs timescales. Interrogation of intense light matter interactions with off-band but temporally synchronized light is achieved by application of gain managed nonlinearity (GMN) amplification, edge filtering and subsequent nonlinear frequency conversion. In our setup, a 0.977 GHz mode-locked Yb-oscillator will generate the common ultrashort seed pulse for both the high-energy LPA driver and GMN backlighter. Synchronous timing delay down to nanosecond duration will be achieved by electro-optic and acousto-optic pulse picking in tandem with compact free space delay lines that allow for arbitrary delay down to ps and fs timescales. The spectrally broadened GMN output pulse will be electronically picked, and the spectral content that is shifted to longer wavelengths will be isolated with spectral filters and frequency doubled via efficient second harmonic generation. The upconverted backlight signal will be centered at 540 nm, and output pulses are expected to have an energy of 500nJ and sub-100 fs pulse duration. In contrast, the LPA driver will be centered at 1035nm and its second harmonic at 517.5nm. Our GMN architecture avoids the complexity of free space optical parametric systems and necessitates a fraction of the physical footprint of a comparable hollow capillary nonlinear broadening setup. With the exception of the frequency doubling crystal, the entire backlighter system could be fully fiber-integrated.

Acknowledgments:

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WGs 1+2 Joint Session / 268

GPU accelerated simulations of channel formation via laser gas interaction for LWFA

Author: Jarrod Leddy[1]

Co-authors: Steven Lanham [1]; Scott Sides [1]; Gregory Werner ; Ilya Zilberter [1]; John Cary [2]

[1] *Tech-X Corporation*

[2] *University of Colorado Boulder*

Corresponding Author: jleddy@txcorp.com

Lasers of sufficient intensity passing through a neutral gas will ionize the gas creating a plasma channel in its wake. A shock can propagate from this locally heated region through the created plasma and background gas, however the density of the plasma will determine the dynamics of the plasma. For collisional (high density) plasmas this can be modeled with a fluid code, however a kinetic simulation is required for low collisionality. The Vorpal code [1] allows for self-consistent modeling of the laser pulse, plasma formation via field ionization, laser-plasma interaction, and subsequent plasma dynamics via particle-in-cell and EM simulation. It also includes a reaction framework that enables the simulation of collisional dynamics such as elastic collisions, impact ionizations, and charge exchange reactions. Because of the computational expense of kinetic (particle-in-cell) codes, we have made use of modern hardware through GPU acceleration of the field and particle dynamics as well as the reactions. We will show results for these laser-plasma interactions in low density regimes, and we will also present the performance we see in moving to GPU simulations.

Acknowledgments:

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Poster Session and Reception - Board: P33 / **269**

Flat beam plasma wakefield accelerator

Authors: Pratik Manwani[1]; Nathan Majernik[None]; Derek Chow[2]; Havyn Ancelin[2]; James Rosenzweig[None]; Tianzhe Xu[None]; Gerard Andonian[3]; Gerard Andonian[4]; Joshua Mann[None]; John Power[None]; Yunbo Kang[2]

[1] *University of California, Los Angeles*

[2] *UCLA*

[3] *UCLA/Radiabeam*

[4] *UCLA / RadiaBeam*

Corresponding Author: pkmanwani@g.ucla.edu

Particle beams with highly asymmetric emittance ratios are employed at accelerator facilities and are expected at the interaction point of high energy colliders. These asymmetric beams can be used to drive wakefields in dielectric structures and can be used to drive high gradient wakefields in plasmas. In plasma, the high aspect ratio of the drive beam can create a transversely elliptical blowout cavity and the asymmetry in the ion column creates asymmetric focusing in the two transverse planes. The ellipticity of the blowout depends on the ellipticity and normalized charge density of the beam. Simulations are performed to investigate the ellipticity of the wakefield based on the initial driver beam parameters and the parameter space for the two cases at the AWA and FACET facilities.

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This work was performed with the support of the US Department of Energy, Division of High Energy Physics under Contract No. DE-SC0017648 and DE-SC0009914. This work used computational and storage services associated with the SCARF cluster provided by the STFC Scientific Computing Department.

WG1: Laser-Plasma Wakefield Acceleration / **270**

Self-injection process in laser-wakefield accelerator driven by CO_2 laser pulses

Author: Arohi Jain[1]

Co-authors: Irina Petrushina [1]; Roman Samulyak ; Vladimir Litvinenko [2]; Rafal Zgadzaj [3]; Michael Downer [4]; Navid Vafaei-Najafabadi [1]

[1] *Stony Brook University*

[2] *Professors, Stony Brook University*

[3] *UT at Austin*

[4] *The University of Texas at Austin*

Corresponding Author: arohi.jain@stonybrook.edu

The study of laser wakefield acceleration (LWFA) using long wavelength infrared laser drivers is a promising path for future laser-driven electron accelerators when compared to traditional near-infrared laser drivers operating at $0.8 - 1$ μm central wavelength [1,2]. For a fixed laser intensity I, lasers with longer wavelengths λ have larger ponderomotive potential ($\propto$ I λ^2). Stronger wakes can be generated at relatively low laser intensities by using a long wavelength laser driver (i.e. $\lambda = 9.2$ μm CO_2 laser) due to its very large ponderomotive potential. LWFA driven by CO_2 laser may have significant advantages to applications requiring compact and industrially robust accelerators and radiation sources.

In this work, we use particle-in-cell (PIC) simulations to investigate the self-injection process in CO_2 laser-driven wakefield acceleration for various laser and plasma parameters in the blowout regime. PIC code FBPIC [3] is used to extend the results obtained in [1] to model the interaction of a sub-picosecond CO_2 laser pulse with wavelength $\lambda = 9.2\ \mu\mathrm{m}$ and pre-ionized uniform plasma with a_0 ranging between 2 and 5. We have explored a wide range of parameters like pulse durations, laser amplitudes, spot size, and plasma densities to determine the self-injection mechanisms through bubble evolution. The accelerating bubble structure of LWFA is dynamic and highly sensitive to the local laser and plasma properties. It can expand and contract as it responds to the evolution of the laser and plasma fields. We report a parameter range that suppresses self-injection in fully blown-out bubbles which is an essential requirement in the experiments of controlled injection in LWFA.

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Poster Session and Reception - Board: P64 / **271**

Coherent Stacking of Few Cycle Pulses from a Gain-Managed Nonlinear Amplifier for CPA-free Energy and Power Scalable Drivers of High-Intensity Laser-Matter Interactions

Authors: Lauren Cooper[None]; Tayari Coleman[None]; Siyun Chen[None]; Mathew Whittlesey[1]; Alex Rainville[1]; Pavel Sidorenko[2]; Frank Wise[2]; Almantas Galvanauskas[1]

[1] *University of Michigan*

[2] *Cornell*

Corresponding Author: lacoop@umich.edu

Coherently combined fiber lasers are considered to be among the most promising pathways towards developing power and energy scalable drivers for laser plasma accelerators (LPA) and other applications of high-intensity laser-matter interactions. Coherent pulse stacking amplification (CPSA) technique is a time-domain coherent combining using Gires-Tournois Interferometers (GTI) of multiple pulses that enables energy scaling per each individual parallel fiber amplification channel. CPSA involves coherent combining of a burst of ~1ns stretched pulses into a single pulse with subsequent compression to femtosecond durations in a conventional diffraction – grating based pulse compressor. CPSA essentially is an extension of the chirped pulse amplification (CPA), and is intended for achieving multi-J femtosecond pulse LPA drivers.

Here we propose a different coherent stacking approach, which does not rely on CPA for pulse energy scaling, but instead uses high energy amplification and simultaneous nonlinear spectral broadening of several ultrashort pulses in a Gain Managed Nonlinear fiber amplifier with subsequent coherent stacking with GTI cavities, followed by ps-short pulse compression with a compact compressor [1]. This technique offers advantages of much more compact power and energy scalable systems with much shorter pulse durations of several optical cycles compared to CPSA based systems. Even with lower energies than those achievable from CPSA systems, this approach can be very beneficial for high-intensity laser-matter interaction applications (e.g. HHG based attosecond sources), where compact laser driver size is required to produce few-cycle pulses at moderately-high average powers and pulse energies.

A recently proposed method of spectral broadening, termed Gain Managed Nonlinearity (GMN), was demonstrated that allows record-high uJ levels of energy from a single amplifier with sub 30fs bandwidths [1]. Using this method, we have been able to demonstrate 0.5uJ, 40fs compressed pulses from an LMA fiber at 40 MHz, with further refinement expected to improve the energies to several uJ per pulse and the pulse duration to sub 30fs. Coherent pulse stacking of 10-100 of such pulses is in progress, aiming to achieve 100s uJ to ~1mJ per single stacked pulse. Further power and energy scaling could be achieved via spatial coherent combination of several GMN fiber amplification channels.

Acknowledgments:

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Poster Session and Reception - Board: P34 / **272**

Experimental Opportunities for the Plasma Wakefield Acceleration in a Narrow Plasma Channel

Authors: Valentina Lee[1]; Carlo Benedetti[2]; Severin Diederichs[3]; Eric Esarey[4]; Spencer Gessner[5]; Mark Hogan[6]; Michael Litos[7]; Jens Osterhoff[8]; Carl Schroeder[2]; Maxence Thévenet[8]

[1] *University of Colorado, Boulder*

[2] *LBNL*

[3] *DESY / LBNL*

[4] *Lawrence Berkeley National Laboratory*

[5] *SLAC*

[6] *SLAC National Accelerator Laboratory*

[7] *University of Colorado Boulder*

[8] *DESY*

Corresponding Author: valentina.lee@colorado.edu

The stability of the drive electron beam in plasma wakefield acceleration (PWFA) is critical for the realization of many applications. The growing instability of a drive electron beam can couple into the plasma wake and further impact the transverse dynamics of the witness beam, rendering the emittance and energy spread to grow. Applications like positron acceleration in an electron-driven blowout wake require a stable drive beam to produce an experimentally usable accelerating phase for the positrons at the tail of the wake.
Recent theoretical developments show that finite radius plasma columns suppress the hosing instability introduced by a tilted drive beam or by a transversely misaligned drive beam. This theoretical work motivates our experimental study. We present experimental opportunities at the Facility for Advanced Accelerator Experimental Tests II (FACET-II) E333 experiment to study the longitudinal dynamics of an electron beam propagating in a laser-ionized plasma column with a finite radius smaller than its blowout radius. Various widths of the plasma column will be formed in the experiment to study the acceleration gradient and energy transformer ratio of a narrow plasma column PWFA and further understand the relationship between beam stability and acceleration efficiency in a finite plasma channel.

Acknowledgments:

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Poster Session and Reception - Board: P58 / **273**

High Resolution Radiography with Self-Modulated and Blowout Regime Laser Wakefield Acceleration generated X-ray sources

Author: Isabella Pagano[1]

Co-authors: Nuno Lemos ; Paul King [1]; Mitchell Sinclair ; Adeola Aghedo ; Andrea Hannasch [2]; Thanh Ha [2]; José Alejandro Franco Altamirano [3]; Hernan Quevedo [2]; Michael Spinks [2]; Constantin Aniculaesei [3]; Shahab Khan [4]; Bjorn Manuel Hegelich [5]; Michael Downer [3]; Chandrashekhar J. Joshi [6]; Felicie Albert

[1] *UT Austin/LLNL*

[2] *UT at Austin*

[3] *The University of Texas at Austin*

[4] *LLNL*

[5] *UT at Austin and Tau Systems Inc.*

[6] *University of California Los Angeles*

Corresponding Author: ipagano@utexas.edu

We aim to develop a diagnostic capable of high spatio-temporal resolution, specifically to be used in High Energy Density Science (HEDS) experiments. A Self-Modulated laser wakefield acceleration (SM-LWFA) driven broadband X-ray source was observed at the Titan target area, Jupiter Laser Facility. The spectral range was between 10 KeV to > 1 MeV, and took advantage of Betatron, Inverse Compton Scattering, and Bremsstrahlung processes to create X-rays. In order to design an X-ray source we can apply to dynamic radiography in HEDS experiments, we must thoroughly examine spectral and spatial attributes. Our results include a comparison of spectral output and source size for each method of generating X-rays from SM-LWFA. An inertial confinement fusion hohlraum and modified Air force resolution target were imaged to demonstrate potential for applications. The radiographs are also used to determine the X-ray source size, or resolution capability. The modified Air Force target is approximated as a "knife edge" and the Fresnel diffraction formalism is used to model the diffraction pattern at different source sizes, and compare to the experimental data. In order to minimize error induced by misalignment in the z plane [1], a curved object (the hohlraum) was also used to determine source size. A modified X-ray ray tracing code creates a line out of a curved object radiograph. In the future, we will apply these analysis tools to compare blowout regime wakefield with other injection schemes on the Texas Petawatt.

[1] R. Tommasini et al. POP 24, 053104 (2017).

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WG8: Advanced Laser and Beam Technology and Facilities / **274**

Robust and Efficient Temporal Pulse Combining Enabling Practical Coherent Pulse Stacking Amplification Systems

Authors: Matthew Whitlesey[1]; Yanwen Jing[1]; Hanzhang Pei[None]; Qiang Du[None]; Almantas Galvanauskas[1]

[1] *University of Michigan*

Corresponding Author: ywjing@umich.edu

Practical use of laser plasma accelerators will require drivers with high peak power and high repetition rate. Spatially and temporally coherently combined fiber laser arrays offer one of the most promising pathways to such drivers. Temporal combining of ~100 stretched pulses, implemented as a coherent pulse stacking amplification (CPSA) technique [1], enables near-complete extraction of stored energy in each fiber channel with low nonlinear phase per pulse, and reduces fiber-array size approximately by 100-fold as necessary for making this approach practical. However, stacking a large number of pulses robustly and efficiently is a challenging technical problem.
We report achieving high robustness and efficiency when stacking 81 pulses with multiplexed Gires-Tournois Interferometer (GTI) cavities. This performance was achieved by carrying-out theoretical analysis for finding the required degree of system stability and GTI-cavity alignment accuracy, implementing advanced hardware and fast algorithms for multi-dimensional robust control of this complex system, and developing methods and automated techniques for high accuracy optical alignment of GTI stackers. For large beams in a stacker supporting high energy and power the two critical alignment dimensions are far-field angular, and piston-error alignments of each individual GTI cavity. Far-field angular alignment accuracy depends on the beam size, and for ~6mm diameter beam supporting ~1J stacked pulses it requires better than +-5 µrad precision. Piston errors not exceeding ~1µm (i.e. one optical wavelength) are universally required. We determined metrics for quantitatively tracking the GTI cavity alignment errors, and developed automated alignment hardware and algorithms for achieving and maintaining this required high-degree of alignment precision in real time, which is also crucial for running such coherently combined system in practice. To ensure high degree of stacking stability, we actively locked the "master" 1GHz repetition-rate mode-locked oscillator by referencing it to a rubidium frequency standard whose long-term stability is <1ppb.
Utilizing these techniques we demonstrated highly repeatable day-to-day operation of 81-pulse burst stacking (compatible with ~10mJ per channel) from 85µm core fiber amplifiers, with stacking efficiencies >83% and stacked-pulse peak power stability of <1%. This demonstrates the practicality of the CPSA technique as the key enabler of high energy and power LPA drivers.

Acknowledgments:

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Poster Session and Reception - Board: P12 / **275**

Calibration of GeV wakefield-accelerated electron energies by bremsstrahlung cut-off calorimetry

Author: José Alejandro Franco Altamirano[1]

Co-authors: Andrea Hannasch [2]; Xiantao Cheng [3]; Maxwell LaBerge ; Brant Bowers [1]; Isabella Pagano [4]; Michael Spinks [2]; Hernan Quevedo [2]; Thanh Ha [2]; Constantin Aniculaesei [1]; Rafal Zgadzaj [2]; Bjorn Manuel Hegelich [5]; Michael Downer [1]

[1] *The University of Texas at Austin*

[2] *UT at Austin*

[3] *University of Texas at Austin*

[4] *UT Austin/LLNL*

[5] *UT at Austin and Tau Systems Inc.*

Corresponding Author: josefranco@utexas.edu

We reconstruct the spectral cut-off of bremsstrahlung x-rays generated by GeV laser-wakefield-accelerated electrons with 10% accuracy using a compact, modular x-ray stack calorimeter. Unfolded cut-off energies range from 1GeV to 3GeV and increase in accuracy with increasing energy, opposite to the trend for conventional magnetic spectrometers. Consequently, bremsstrahlung cut-off calorimetry will become increasingly important for calibrating electron energies approaching and exceeding 10 GeV which otherwise require large expensive magnets for equivalent measurement accuracy.

Acknowledgments:

Poster Session and Reception - Board: F67 / **276**

Laser Pulse Compression for Applications in Compact Wakefield Accelerators

Author: Hao Ding[1]

Co-authors: Anthony Gonsalves [2]; Alexander Picksley [1]; Joshua Stackhouse [3]; Rémi Lehe [1]; Cameron Geddes [2]; Russell Wilcox ; Jeroen van Tilborg [1]; James E. Clayton [4]; Tong Zhou ; Eric Esarey [2]

[1] *LBNL*

[2] *Lawrence Berkeley National Laboratory*

[3] *UC Berkeley*

[4] *Varian Medical Systems*

Corresponding Author: hao.ding@lbl.gov

Few-cycle laser pulse generation [1] is an enabling technology for making the most compact laser-plasma accelerators. Few-cycle pulses are usually generated by spectral broadening and subsequent compression of originally 30-40 fs long laser pulses. One common spectral broadening approach is via self-phase modulation in a noble gas-filled hollow-core fiber. Using this technique, we have demonstrated compression of ~40 fs pulses down to <4 fs. Resonantly driving plasma waves with few-cycle laser pulses, a few mJ of energy is sufficient to generate MeV-level electron beams in a sub-millimeter plasma [2,3]. An alternative pulse compression approach using solid plates at near field is currently being explored. By carefully matching the solid plate thickness with the near-field intensity profile of the laser beam, a spatially homogeneous broadened spectrum can be obtained. This new technique paves the way towards driving laser-plasma accelerators with high average power and high wall plug efficiency fiber laser systems.

[1] Ouillé, M., et al. Relativistic-intensity near-single-cycle light waveforms at kHz repetition rate. Light Sci. Appl. 9, 47 (2020).
[2] Faure, J., et al. A review of recent progress on laser-plasma acceleration at kHz repetition rate. Plasma Phys. Control. Fusion 61 014012 (2018).
[3] Salehi, F., et al. Laser-Accelerated, Low-Divergence 15-MeV Quasimonoenergetic Electron Bunches at 1 kHz. Phys. Rev. X 11, 021055 (2021).

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Plenary / **277**

FACET-II: Status of the first experiments and the road ahead

The FACET-II facility at SLAC National Accelerator Laboratory conducts a broad science program based on the interaction of low-emittance high-current 10 GeV electron beams with lasers, plasmas and solids. FACET-II operates as a National User Facility while engaging a broad User community to develop and execute experimental proposals that advance the development of plasma wakefield accelerators. The FACET-II facility has completed construction, initial commissioning and began first experiments in the summer of 2022. The special features of FACET-II will be shown and the status of the first experiments invited for beam time will be presented.

Acknowledgments:

WG1: Laser-Plasma Wakefield Acceleration / 278

Nearly collinear optical injection of electrons into wakefield accelerators

Author: Qiang Chen[1]

Co-authors: Dominika Maslarova [2]; Junzhi Wang [3]; Shao Xian Lee [3]; Vojtech Horny [4]; Donald Umstadter [5]

[1] *Lawrence Berkeley National Laboratory*

[2] *Institute of Plasma Physics of CAS; Czech Technical University*

[3] *University of Nebraska-Lincoln*

[4] *Chalmers University of Technology; LULI-CNRS*

[5] *University of Nebraska–Lincoln*

Corresponding Author: qiangchen@lbl.gov

We show the recent results of electron injection into the laser wakefield accelerators by interfering two intense, nearly colinear laser pulses in underdense plasma [1, 2]. In the experiment, electrons could be injected into either laser wakefields, or both, depending on the relative delay between two laser pulses' arrival time to the interference point. Particle-in-cell simulations revealed that the interference ponderomotively drives a relativistic
plasma grating and triggers the delay-dependent injection. Such injection occurs in later acceleration buckets other than the leading ones and can potentially be combined with optimal plasma tapering, and the dephasing limit of such unprecedented electron beams could be potentially increased by an order of magnitude. Other injection phenomenon like electron beam splitting and ring electrons are also discussed.

[1] Q. Chen, D. Maslarova, J. Wang, S. X. Lee, V. Horný, and D. Umstadter, Transient Relativistic Plasma Grating to Tailor High-Power Laser Fields, Wakefield Plasma Waves, and Electron Injection, Phys. Rev. Lett. 128, 164801 (2022).
[2] Q. Chen, D. Maslarova, J. Wang, S. X. Lee, and D. Umstadter, Injection of electron beams into two laser wakefields and generation of electron rings, Phys. Rev. E. (Accepted).

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Plenary / **279**

Plasma-based Attosecond X-ray Pulses

Author: Agostino Marinelli[1]

[1] *SLAC National Accelerator Laboratory*

Corresponding Author: marinelli@slac.stanford.edu

Attosecond science has emerged as a major research direction in X-ray free-electron laser science. X-ray free-electron lasers can routinely generate attosecond pulses with a peak power in the tens to hundreds of GW and are employed for time-resolved experiments with sub-fs resolution.

Plasma-based injectors have the potential revolutionize ultrafast science thanks to their ability to generate high current bunches with a brightness that is orders of magnitude larger than conventional photoinjectors.

In my talk I will discuss our ongoing R&D efforts towards plasma-based attosecond X-ray pulses. By employing the strong accelerating field of plasma-based accelerators, we propose to chirp and compress high-brightness electron bunches to nm-scale lengths. The resulting charge distribution can emit coherently in the soft X-ray range, resulting in few-cycle pulses with TW peak powers.

This experiment can combine the bandwidth of state-of-the-art harmonic sources with the peak power of X-ray free-electron lasers, and open new directions in attosecond science.

Acknowledgments:

WG2: Computation for Accelerator Physics / **281**

Opportunities and Issues with the Unitary Particle Pusher

Author: Daniel Gordon[1]

Co-authors: Bahman Hafizi [1]; Daniel Younis [2]

[1] *U.S. Naval Research Laboratory*

[2] *University of Rochester, Department of Physics & Astronomy*

Corresponding Author: daniel.gordon@nrl.navy.mil

By using the spinor representation of four-vectors, it is possible to write a simple expression for the momentum change of a charged particle in an arbitrary crossed field. It can be evaluated exactly if transcendental function evaluations are tolerable, or in an invariant-preserving expansion otherwise. We discuss progress in incorporating this approach into a particle-in-cell framework.

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The GARD Program - A Retrospective View

Corresponding Author: lklen@verizon.net

Understanding the history and evolution of a program can often provide valuable information and a foundation on which to plan a strategy for future successes. It is with this view in mind that a retrospective discussion of the General Accelerator Research and Development (GARD) program at the Office of High Energy Physics, U.S. Department of Energy, of which the Advanced Accelerator Concepts Thrust is a part, will be presented. GARD's origin can be traced to the HEP Advanced Technology R&D subprogram. Its portfolio and research scope have evolved over the years through several reorganizations within the Office of High Energy Physics. A historical perspective of the program, including its research strategy and management process together with the R&D activities it supports will be presented.

Acknowledgments:

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Summary of the Snowmass Accelerator Frontier - AAC Role and Vision

Corresponding Author: tor@slac.stanford.edu

Snowmass is the name for a decadal planning exercise by the US high particle physics community. It provides an opportunity for the entire particle physics community to come together to identify and document a scientific vision for the future of particle physics in the U.S. and its international partners. The Snowmass exercise takes roughly a year (2 years including the impact of Covid) and defined the most important questions for the field of particle physics and worked to identify promising opportunities to address them. The exercise is organized into 10 Frontiers, one of which is the Accelerator Frontier. The Accelerator Frontier was focused on accelerator science and technology that may be able to address the important questions in particle physics. This talk will describe the Snowmass exercise and will summarize some of the conclusions from the Accelerator Frontier.

Acknowledgments:

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Panel Discussion

Discussion of the AAC Vision and Future

Panel: Tor Raubenheimer, Vladimir Shiltsev, Cameron Geddes, Pietro Musumeci, Mark Hogan, and LK Len

Acknowledgments:

WGs 5+7 Joint Session / 285

High repetition-rate K-alpha x-ray source from a low-density gas target

Corresponding Author: jmmurph@umich.edu

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Working Group 8 Award Winner

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Working Group 1 Summary

Corresponding Authors: marleneturner@lbl.gov, irina.petrushina@stonybrook.edu, yongm@umich.edu

Laser-Plasma Wakefield Acceleration

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Working Group 2 Summary

Corresponding Authors: bruhwiler@radiasoft.net, aarefiev@eng.ucsd.edu

Computation for Accelerator Physics

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Working Group 3 Summary

Corresponding Authors: xylu@niu.edu, sbelomes@fnal.gov

Laser and High-Gradient Structure-Based Acceleration

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Working Group 4 Summary

Corresponding Authors: sgess@slac.stanford.edu, jens.osterhoff@desy.de

Beam-Driven Acceleration

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Working Group 5 Summary

Corresponding Authors: yinesun@anl.gov, sbarber@lbl.gov

Beam Sources, Monitoring, and Control

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Working Group 6 Summary

Corresponding Authors: lobsthuebl@lbl.gov, igor@bnl.gov, nishiuchi.mamiko@qst.go.jp

Laser-Plasma Acceleration of Ions

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Working Group 7 Summary

Corresponding Authors: jpal@lle.rochester.edu, j.mikhailova@princeton.edu

Radiation Generation and Advanced Concepts

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Working Group 8 Summary

Corresponding Authors: svmilton@me.com, babzien@bnl.gov

Advanced Laser and Beam Technology and Facilities

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Closing Comments

Corresponding Author: mpalmer@bnl.gov

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Bunch Shaping in Electron Linear Accelerators

Corresponding Author: yinesun@anl.gov

Electron beam generated by an injector is often characterized by a set of parameters such as rms normalized emittance, bunch length, peak current, energy etc.. For different applications, the requirement for the beam parameters can be very different. In addition, some beam applications require finer control of the electron distribution such as specific shapes for its projection along a particular coordinate. The control of the beam distribution at the single-particle level could enable new opportunities in accelerator science. This tutorial review is based on our recent review paper [1] on electron bunch shaping for different applications. Experimental and theoretical developments of electron-bunch shaping will be discussed.

[1] G. Ha, K-J. Kim. P. Piot, J. G. Power and Y. Sun, "Bunch Shaping in Electron Linac Accelerators," REVIEWS OF MODERN PHYSICS, VOLUME 94, APRIL–JUNE 2022.

Acknowledgments:

Student Tutorials / 306

Particle Trapping and Beam Loading Physics in Plasma-Based Accelerators

Corresponding Author: nvafaeina@bnl.gov

With accelerating gradients of tens of GeV/m, plasma accelerators have a great potential for replacing RF cavities in future colliders and FEL light sources. However, the beams generated by these accelerators need to satisfy stringent quality metrics before they can be considered for the aforementioned applications. One such metric is the relative energy spread ΔE/E, which needs to be at a sub-percent level for colliders and on the order of 10-3 for FEL applications. In this tutorial, the physics of beam loading required for achieving low energy spread will be discussed in the context of a highly nonlinear plasma wakefields. This discussion will be followed with an overview of the physics of injection mechanisms for electrons in laser-driven and beam-driven plasma-wakefield accelerators as well as methods for reducing the energy spread of the generated electron beams. A review of the co-moving coordinate system, the equations of electrodynamics in this coordinate system, and the Hamiltonian as the constant of motion will be presented at the beginning of the tutorial as well.

Acknowledgments: