# Physics and Applications of High Brightness Beams

Monday 19 June 2023 - Friday 23 June 2023


# Book of Abstracts

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## Status update on Dielectric Trojan Horse experiment

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The Trojan Horse experiment demonstrated the concept of a laser initiated plasma photocathode within a plasma wakefield bubble. In a similar concept, the plasma photocathode is located within a dielectric wakefield accelerator. Although the fields in the dielectric are not as high as that of a plasma, GV/m fields are still attainable, and due to operation at lower frequency, timing requirements are reduced. In this paper, we present some of the first results in preparation for demonstration of the experiment at the Argonne Wakefield Accelerator.

**Plasma acceleration / 4**

## High-Brightness tuneable attosecond bunches with the Resonant Multi Pulse Ionization injection

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Recent advances with the Resonant Multi Pulse Ionization Injection scheme [1,2], which was already proven by simulations to be able to generate few femtosecond long 5GeV beams [3] with beam quality large enough to efficiently drive a FEL [4], move toward the generation of high-brigthness beams with duration of a few hudreds of attoseconds. At the same time, with the aid of an advanced model for the tunnel ionization process in the saturation regime [5], the optimization of the scheme lead to a reduction of the needed number of sub-pulses in the driving train from eight [3] down to two pulses, making the implementation of the scheme more simple and improving its robustness against laser/target imperfections. By just tuning the delay between the wakefield driving train and the ionization injection, it's possible to shape the longitudinal profile of the e-beam, thus adjusting its time duration down to a few hundreds of attoseconds, or even down to 100as if a post-compression technique is employed onto the ionization pulse.
Our test-case FB-PIC q-3D simulations with the simplified two-pulses driving scheme, show that >1GeV e-beam with about 10pC charge, projected energy spread <0.8% and length of about 500as can be generated with a single 200TW Ti:Sa laser system, the e-beam having 5D brightness exceeding 2x10^17 A/m^2 and 6D brightness exceeding 2x10^16 A/m^2/0.1%. The effect of a passive plasma lens placed right after the plasma downramp is also discussed. Finally, the potentiality of the simplified scheme with the usage of 1PW pulses with the aim of generating >1GeV e-beams will be discussed.

[1] P. Tomassini et al., "The resonant multi-pulse ionization injection", PoP 24, 103120 (2017); https://doi.org/10.1063/1.5000696

[2] P. Tomassini et al., "High quality electron bunches for a multistage GeV accelerator with resonant multipulse ionization injection", Phys. Rev. Accel. Beams 22, 111302 (2019)

[3] P. Tomassini et al., "High-quality 5 GeV electron bunches with resonant multi-pulse ionization injection", PPCF 62 014010
DOI 10.1088/1361-6587/ab45c5 (2020)

[4] P. Tomassini et al., "Brilliant X-ray Free Electron Laser driven by Resonant Multi-Pulse injection accelerator", proc. FEL22 conference (Trieste, I)

[5] P. Tomassini et al., "Accurate electron beam phase-space theory for ionization-injection schemes driven by laser pulses", High Power Laser Science and Engineering, (2022), Vol. 10, e15, doi: 10.1017/hpl.2021.56

**Ultrafast electron probes / 5**

## Shaping the collective interaction of relativistic electrons with matter

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In this talk, I will discuss how the collective field of a relativistic electron beam can be used to instigate novel quantum dynamics and allow us to study ultrafast physics beyond typical laser-excited systems. At LCLS, the beam-supported fields can be shaped into strong (V/A), broadband (0-10 eV), and/or microbunched pulses that are intrinsically synchronized and mutually coherent with a soft x-ray laser. Preliminary experience commissioning a photon-electron pump-probe experiment (PEPPEx) illustrates the opportunities and challenges associated with using a space-charge field for ultrafast science.

**FEL and coherent radiation / 6**

## First Light at the Israeli THz Superradiant Free Electron Laser

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We report first observation of terahertz super radiant emission from the Israeli Free Electron Laser. This is first demonstration of a THz FEL source based on the scheme of coherent spontaneous superradiant (SR) emission by an ultra-short e-beam bunch. The first measured radiation signal corresponds to a 3.5THz beam output of 180 nanoJ.
The Israeli superradiant FEL operates in the FEL center of Ariel and Tel-Aviv universities. It is based upon the ORGAD RF-LINAC at the Schlesinger Accelerator Center in Ariel. The accelerator is a compact RF gun of accelerating energies 3.5 to 8.5 MeV. The gun is 64 cm long. It produces an electron bunch of about 100 femto-seconds. Since the frequency of the emitted radiation is 3.5 Tera Hertz, the bunch duration is shorter than half a period of the radiation (290 ftSec), satisfying the condition for SR emission. In this case all electrons in the bunch emit in phase with each other, and the total emitted radiation energy is proportional to the square of the number of the electrons N2 and not to the number of electrons N as in conventional spontaneous emission. Based on a modal excitation theory we will estimates the short wavelength limits of SR.

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## A review of positron acceleration in plasma

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Plasma accelerators for future linear lepton colliders have been considered as a potential upgrade in accelerator technology. However, in recent years, the challenge in accelerating positrons in plasma has diverted much attention to other collider options. Many new ideas emerged with the concept of modifying the plasma or the drive beam to overcome this challenge. In this contribution, we review the ultimate positron problem in plasma, along with the historical and presential efforts on the topic. In addition, several proposals on different acceleration schemes are outlined. A parameter that scales with the collision luminosity per beam power is used to compare the proposed schemes. Finally, the proposed schemes are ranked with respect to the scaling parameter and discussed in terms of their potential and compatibility with high-energy colliders.

**Poster / 8**

## Effects of non-zero plasma temperature

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Most theoretical and simulation studies on plasma accelerators are performed with the assumption of cold plasma. However, with recent development in high-rep-rate acceleration in plasma, heat deposition from high-power, high-frequency beams can easily increase the ambient plasma temperature. Plasma electrons, given an initial momentum, have a locally "smeared out" distribution compared to the cold plasma case when perturbed. This change in plasma electron distribution in turn modifies the interaction between plasma electrons and the drive/accelerated beams. Several effects of finite plasma temperature on both the drive and the accelerated beam are observed. In particular, effects on beam emittance and transverse instabilities are discussed in this contribution.

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## SEALab's Superconducting Radio-Frequency Photoinjector: Enabling Advanced Accelerator Research for Ultrafast Scattering and Sustainable Accelerator Technology

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The SEALab accelerator test facility is currently commissioning the superconducting radio-frequency photoelectron injector (SRF photoinjector), which has the potential to cover a wide range of beam parameters. With the ability to accelerate electron bunches from femtoseconds to picoseconds in length, with a charge range from femtocoulombs to nanocoulombs, the SRF photoinjector can produce beam energies of up to a couple of MeV at MHz repetition rates. Leveraging the legacy of the energy-recovery linac (ERL) test facility bERLinPro, which is the foundation of SEALab, the SRF photoinjector can be operated at a very high repetition rate with energy recovery (ERL), providing a sustainable platform for fundamental accelerator research into novel, energy-efficient electron accelerators. This paper details the preparatory work for two applications, the first being the

use of the SRF photoinjector as a direct beam source for ultrafast scattering experiments with high six-dimensional (6D) coherence, and the second being experiments towards an ERL application for high-energy physics at high average current.

**Ultrafast electron probes / 11**

## Novel approaches and innovative modalities in ultrafast electron scattering applications with accelerators

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Ultrafast electron probing modalities offer unique experimental tools to access the structural dynamics of ultrafast photoinduced processes in materials and molecules, in liquid, gas, and condensed phase systems. Here we propose to capitalize on the exceptional and versatile electron beam parameters of the SEALAB Superconducting RF (SRF) photoinjector to develop a world-wide unique facility for ultrafast electron diffraction and imaging (UED and UEI), dedicated to experiments with high sensitivity in space, energy, and time. These applications highly demand not only extreme beam quality in 6-D phase space such as a few nanometer transverse emittances and femtosecond duration but also equivalent beam stability at MHz repetition rate. The talk with rationalize on beam dynamics driven design studies for different modlaities and discuss first results from preparatory measurements.

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## Intrabeam Scattering Effects in High-Brightness Photoinjectors

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The present study examines an approach for calculating intrabeam scattering (IBS) effects in a high-brightness electron beams, based on a thermodynamic model that considers slice-to-slice temperature variations within the bunch. Despite advances in computing, the estimation of granular space-charge effects in photoinjectors remains largely intractible for non-trivial bunch charges without significant computational resources. In this work, we approach the problem probabilistically to circumvent these restrictions and calculate the effects of IBS during the emittance compensation and acceleration processes in an ultra-high brightness FEL injector design, and compare our results to those computed from first principles in the General Particle Tracer (GPT) code. The study is motivated by the desire to evaluate the impact on efficacy of FEL lasing and transport stability: in particular, the so-called microbunching instability (MBI). The development of design tools that carry out such calculations efficiently is of increasing relevance to accelerator physicists as technology allows for unprecedented beam brightness.

**Beam dynamics and controls / 13**

## Predicting the transverse emittance of space charge dominated beams using the phase advance scan technique and a neural network

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The transverse emittance of a charged particle beam is an important figure of merit for many accelerator applications. One of the easiest to implement methods to determine the transverse emittance is the phase advance scan method using a focusing element and a screen. This method has been shown to work well in the thermal regime. In the space charge dominated laminar flow regime, however, the scheme becomes difficult to apply because of the lack of a closed description of the beam envelope including space charge effects. Furthermore, certain mathematical, as well as beamline design criteria must be met in order to ensure accurate results. This work shows that it is possible to analyze phase advance scan data using a neural network (NN), even in setups, which do not meet these criteria.

**Beam dynamics and controls / 14**

## C-band vs S-band: Minimizing Emittance in a High Charge TopGun Photoinjector

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The space charge emittance compensation in the C-band TopGun design has been demonstrated with 100 pC bunch charge. It has shown that a minimum emittance is limited by the intrinsic emittance at the cathode. Scaling this approach to higher bunch charges, however, requires a larger transverse size and a longer pulse duration. The rf emittance dilution due to the iris kick scales quadratically with the transverse size and linearly with the pulse duration. This effect becomes a determinant factor for the minimum emittance in the TopGun designs. The study of S-band TopGun will show the ease of the constraint imposed by the rf emittance. We will show if an intrinsic emittance will become a limiting factor for 250 pC case.

**Beam dynamics and controls / 15**

## Update on Electron Beam Manipulation at the Argonne Wakefield Accelerator Facility

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The Argonne Wakefield Accelerator (AWA) supports an extensive research portfolio along three themes: electron beam production, electron beam manipulation, and electron beam-driven wakefield acceleration. Current research activities focus on longitudinal distribution shaping and cross-plane manipulations for emittance redistribution between two and three degrees of freedom, such as one-dimensional manipulation based on photoemission laser-pulse shaping, selective transverse collimation combined with emittance exchange technique, and local cross-plane "bump" combining transverse-deflecting cavities with transverse collimation. Likewise, transverse phase-space control focuses on the generation and transport of magnetized beams for electron cooling of hadron beams and the production of flat beams for wakefield excitation in asymmetric structures. Finally, an experiment on emittance repartitioning between the three degrees of freedom is under planning with the ultimate goal of circumventing the need for an electron-damping ring in future linear colliders. In this presentation, we present recent research progress on bunch manipulation and discuss future research directions at the AWA.

**5th generation light source / 16**

## Measuring the dynamics of quantum materials over different length scales with X-ray free electron lasers

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Quantum materials exhibit complex interactions between electron, structural and spin degrees-of-freedom over a wide range of length scales, leading to exotic phenomenon that are challenging to study. Ultrafast excitation can disentangle these degrees-of-freedom, but resolving the different length scales remains challenging. Here I will present recent results using X-ray free electron lasers to resolve femtosecond electronic and structural dynamics in the quantum material vanadium dioxide from the picometer to micrometer length-scale. Hard X-ray total diffraction is used to study incoherent small polaron distortions which have been found to allow efficient seeding of light-induced phase transitions, while soft X-ray coherent imaging is used to measure nanoscale phase co-existence during the light-induced phase transition itself, shedding light on the nature of proposed out-of-equilibrium phases at the nanoscale [1].

[1] A.S. Johnson *et al.*, Nature Physics **19** (2), 215-220 (2023)

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## Beam dynamics inside a transversely asymmetric wakefield

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Flat or transversely asymmetric beams create transversely asymmetric wakefields. These wakefields are characterized by the creation of an elliptical cavity created by the evacuated plasma electrons and remnant ions. The potential inside these elliptical cavities is quadratic and yields transverse electric fields that are linear. Particle beams inside the blowout cavity can be matched to these asymmetric focusing fields and exchange energy with the electromagnetic fields. Simulations are performed

to investigate the beam dynamics inside this blowout cavity and the attainable parameter space is discussed.

**Ultrafast electron probes / 18**

## Sub-picosecond ultracold electron bunches

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The Ultra Cold Electron Source (UCES) being developed at Eindhoven University of Technology is based on near-threshold, femtosecond photoionization of a laser-cooled rubidium gas in a magneto-optical trap. The UCES accelerates bunches containing ~1000 electrons in a DC field up to energies of ~10 keV with a normalized emittance of ~1 nm·rad.
Recently, bunch lengths as short as 735±7 fs (rms) have been measured in the self-compression point of the DC source by means of ponderomotive scattering of the electrons by a 25 fs, 800 nm laser pulse. This is an improvement by more than an order of magnitude compared to the previous bunch length record. The observed temporal structure of the electron bunch depends on the central wavelength of the ionization laser pulse, in agreement with detailed simulations of the atomic photoionization process. This shows that the bunch length limit imposed by the atomic photoionization process has been reached.
To increase the range of applications of the UCES, the ultracold bunches have recently been accelerated in a standing wave RF cavity up to energies of 35 keV. During acceleration the transverse bunch quality was preserved as measured by diffraction on a single crystal gold foil. Transverse coherence lengths as high as 20 nm were obtained in a spot a few tens of microns across, paving the way towards applications such as ultrafast protein crystallography.

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## Empowering SRF Cavity by Data-Driven Resonance Control based on Dynamic Mode Decomposition

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Effective resonance control of superconducting radio frequency (SRF) cavities is critical for large machines like LCLS-II, as failure to achieve proper control can result in increased RF power consumption, higher cryogenic heat loads, and increased costs. To address this challenge, we have developed a machine learning (ML) model based on the dynamic mode decomposition method (DMD) to represent the forced cavity dynamics. Using this model, we designed a model predictive controller (MPC) and demonstrated through simulation that the MPC can effectively stabilize the amplitude and phase of SRF cavities using only a frequency actuator, even in the presence of multiple mechanical modes. The lightweight and explicit ML model make the controller suitable for direct implementation on field-programmable gate arrays (FPGA), unlocking the full potential of SRF linacs like LCLS-II, enabling higher beam power and energy, and also serving as an advanced motion controller for various applications, such as photon beamlines and storage rings.

**Advanced concepts and Conclusions / 20**

## Beam dynamics studies for a stable, reliable and reproducible plasma-based accelerator

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Plasma accelerators are emerging as formidable and innovative technology thanks to their compactness and reduced costs to drive of user facilities being able to sustain several GV/m accelerating gradients at normal conducting temperature.
The EuPRAXIA@SPARC_LAB collaboration is preparing a technical design report for a multi-GeV plasma-based accelerator with outstanding electron beam quality to pilot an X-ray FEL, the most demanding in terms of beam brightness. The beam dynamics has been studied aiming to a reliable operation of the RF injector to generate a so-called comb-beam with 500 MeV energy suitable as driver of the Beam-driven Plasma Wakefield Accelerator. A case of interest is the generation of a trailing bunch with 1 GeV energy, less than 1 mm-mrad transverse emittance and up to 2 kA peak current at the undulator entrance. The comb-beam is generated through the velocity bunching technique, an RF compression tool that enables high brightness beams within relatively compact machine. Since it is based on a rotation of the beam phase space inside the external RF fields, it could be particularly sensitive to amplitude and phase jitters in the RF injector. The electron beam dynamics and the machine sensitivity to the possible jitters are presented in terms of effect on the beam quality so to provide the basis for the alignment procedure and jitter tolerances. Numerical studies have been consolidated with experimental results obtained at SPARC_LAB, a test facility currently oriented to plasma acceleration physics where the velocity bunching scheme is routinely applied.

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## EUPRAXIA

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## High Efficiency FEL

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Strongly tapered free-electron lasers (FELs) offer a promising avenue towards achieving higher peak and average power radiation sources. Through the strong seeding of an input laser or microbunched electron beam, larger efficiencies can be achieved by adapting the undulator parameters to maintain resonance with the decelerated electrons. Additionally, the use of an oscillator cavity driven by a high repetition rate electron beam could enable power amplification from a weaker seed. In this context, we discuss ongoing research efforts and recent progress in developing high efficiency FELs, as well as the tools used to study these systems.

**CBB-sponsored student session / 27**

## Spectrotemporal shaping of attosecond x-ray free-electron laser pulses

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The development of attosecond methods at free-electron lasers has led to new possibilities in the probing and control of electronic dynamics in molecules. Beyond simple observation of ultrafast processes, one of the longstanding goals of atomic and molecular physics is control of the electronic wavefunction on attosecond timescales. This implies a need to go beyond impulsive excitation with isolated pulses: more general spectrotemporal pulse shaping is demanded. We present a method to shape the spectrotemporal characteristics of attosecond XFEL pulses in a two-stage scheme. First, an isolated attosecond pulse is generated using now-state of the art methods. That pulse then interacts with a fresh part of the electron beam in a second stage where control of the undulator taper leads to direct shaping of the output pulse. We highlight several example shaping options: pulse pairs with controllable time and color separation, isolated fs-scale pulses with controllable linear chirp, and trains of attosecond pulses with tunable spacing. We highlight one atomic physics application – to use pulse pairs to control and probe the decay of core-excited electronic wavepackets.

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## Towards PWFA-X-FEL

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We present a blueprint for an ultra-compact X-ray free-electron laser (X-FEL) powered by plasma wakefield acceleration (PWFA). The study shows in a high-fidelity S2E simulation how to produce and preserve ultra-high 6D brightness electron beams in a plasma photocathode PWFA stage. Then, a post-plasma beam transport line captures, isolates and refocuses these electron beams into an undulator without charge and quality loss. Inside the undulator, these electron beams emit attosecond duration coherent X-ray pulses down to the sub-Angstrom wavelength after 10 m of the undulator section [1]. We conclude with ongoing efforts of the experimental ecosystem and discuss novel scientific avenues arising from ultra-compact PWFA-X-FELs.

[1] Habib, A.F. et al. Attosecond-Angstrom free-electron-laser towards the cold beam limit. Nat Commun 14, 1054 (2023).

**Advanced concepts and Conclusions / 29**

## EuPRAXIA Advanced Photon Sources (EuAPS): a plasma-based betatron source

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The EuPRAXIA Advanced Photon Sources (EuAPS) project, led by INFN in collaboration with the CNR and the University of Tor Vergata, involves the construction of a laser-driven “betatron” X-ray user facility at the SPARC_LAB laboratory of the LNF. EuAPS also includes the development of high power (up to 1 PW at LNS) and high repetition frequency (up to 100 Hz at CNR Pisa) laser drives for EuPRAXIA.
In this talk we first examine the physics behind the dynamics of accelerated electron betatrons in plasma accelerator cavities: the betatron oscillations of relativistic electrons at very short scale lengths are responsible for the emission of ultrashort X-ray bursts.
Next, we present the current status of the experimental activity at the LNF, finally discussing the relevant results for the EuAPS project, highlighting the expected performance of the source for user applications.

**CBB-sponsored student session / 30**

## Detailed Phase Space Reconstruction from a Limited Number of Beam Measurements Using Neural Networks and Differentiable Simulations

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Characterizing the phase space distribution of particle beams is essential in the study of accelerator systems. As the accelerator community keeps pushing the brightness frontier, resolving fine details in the 6D beam phase space density has become important in the optimization and control of next-generation beamlines. However, conventional reconstruction-based techniques either use simplifying assumptions, reducing the level of detail, 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 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 focusing quadrupole and a limited number of measurements on a diagnostic screen. This technique allows for the simultaneous measurement of multiple correlated phase spaces, enabling simplified 6D phase space reconstruction diagnostics in the future.

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## Opportunities for Bright-Beam Generation at the Argonne Wakefield Accelerator (AWA)

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Bright electron beams have played a critical role in many recent advancements in accelerator technology, including free electron lasers and ultrafast electron diffraction/microscopy. Producing such beams via photoemission is ultimately limited by the maximum accelerating field that can be applied to a photocathode surface without degrading the beam brightness and the minimum achievable mean transverse energy of the electrons emitted from a photocathode. Moreover, photocathodes must operate under high laser fluences required to produce bright electron beams for high-current applications. This paper discusses the opportunity to generate bright electron beams using an upgraded version of the Argonne Wakefield Accelerator (AWA) photoinjector. The focus of this study is to examine optimal configurations of the photoinjector to produce 100-pC with 100-nm transverse emittance (corresponding to a brightness $\geq 10^{15} A.m^{-2}$). Optimizations of the AWA photoinjector including realistic electromagnetic-field maps are presented for the different photocathodes under consideration.

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## Parametric study of high-charge bunch generation in an L-band photoinjector

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The Argonne Wakefield Accelerator's main beamline – the drive-beam beamline – utilizes a $1+\frac{1}{2}$-cell radiofrequency photoinjector at 1.3 GHz to produce high-charge bunches. This contribution discusses an experiment to investigate photoemission from the RF gun over a wide range of operation parameters spanning different emission regimes. It especially demonstrates the generation of a $>50$-nC bunches using a $\sim 300$-fs UV laser pulse corresponding to an initial multi-kA peak current. The measurements are compared with numerical simulations performed with the ASTRA beam dynamics program. The transport and further acceleration of these bunches are investigated via numerical simulations.

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## A high-field X-band photoinjector for low-emittance electron-beam generation

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A path to producing bright electron beams consists of low mean-transverse-energy photocathodes subjected to a high electric field. Such an approach is currently being explored at the AWA facility where a proof-of-principle experiment recently demonstrated the reliable operation of an X-band radiofrequency (XRF) gun with $\sim 0.4$-GV/m electric field on the photocathode surface. *This paper discusses the short term activities to fully characterize the physics associated with photoemission from a copper photocathode in a high-field regime. We also describe the development and optimization of an integrated photoinjector coupling the available XRF gun to a compact X-band booster linac. Simulations of the beam dynamics and expected performances are presented along with the opportunities enabled by introducing low-MTE photocathodes in the XRF gun.*W.H. Tan et al., Phys. Rev. Accel. Beams 25, 083402 (2022).

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## PWFA-powered water-window FEL using a plasma photocathode

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Plasma photocathode injection in plasma wakefield acceleration (PWFA) has the potential to produce ultrahigh brightness beams with normalized emittance down to 10s of nm-rad and kA peak currents. Electron beams in PWFA may develop a large energy chirp due to the high accelerating gradient, which can be detrimental to beam quality preservation and prevent use in demanding applications such as free-electron lasers (FELs). Recent advancements suggest that the energy chirp can be compensated in a single PWFA-stage via the so-called 'escort-beam' approach [1] and drive an XFEL near the cold beam limit while preserving beam quality and charge [2]. Here, we present start-to-end simulations of a PWFA-driven FEL in the water window using a 'direct' beam-loading approach, in which energy-spread reduction occurs using a single bunch anticipated at SLAC FACET-II. These initial results inform the upcoming E-310 experiment, a successor of the E-210 program [3] at SLAC FACET-II, and indicate that a soft FEL could be driven with existing magnet and undulator technology.
[1] Manahan, G. & Habib, A.F. et al. Nat. Commun. 8, 15705 (2017)

[2] Habib, A.F. et al. Nat. Commun. 14, 1054 (2023)
[3] Deng, A. et al. Nat. Phys. 15, 1156–1160 (2019)

**Advanced concepts and Conclusions / 35**

## The Munich Compact Light Source (MuCLS) – a laboratory-size laser-undulator X-ray source for biomedical applications

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The Munich Compact Light Source (MuCLS) is a tuneable, brilliant and compact hard X-ray synchrotron source. Electrons are accelerated in a classical RF-accelerator and injected into a small storage ring (4.6 m circumference). X-rays are generated via a laser-undulator, realised as a short laser pulse circulating in an enhancement cavity. Thus, the MuCLS provides incoherently-produced brilliant quasi-monochromatic X-rays in the energy range 15 keV – 35 keV. The MuCLS's radiation has been exploited for biomedical research focussing on this source's particular advantages: partial spatial coherence, quasi-monochromaticity, milli-radian divergence angle and availability for longitudinal studies.
First, we present the MuCLS and its recent upgrades [1] before we highlight the value of compact synchrotron sources for biomedical applications, e.g. [2]. Results from phase-contrast imaging are shown, like improved detection of tumorous lesions in mammography and in vivo lung imaging in mice for the assessment of airway health or drug development. Furthermore, we demonstrate the benefit of K-edge subtraction imaging, e.g., for angiography and display the performance of the MuCLS for X-ray absorption spectroscopy.
[1] Günther, PhD-Thesis, Springer Cham, DOI: 10.1007/978-3-031-17742-2 (2023)
[2] Günther et al., J. Synch. Rad. 27, 1395-1414 (2020)

**Plasma acceleration / 36**

## Stable operation of SASE and Seeded FEL driven by a plasma accelerator

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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 sub-atomic 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 (3 cm) plasma 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.

**High brightness electron sources** / **37**

## Effect of molybdenum coatings on the accelerating cavity quality factor: a numerical study

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Methods for realizing resonant cavities with high field gradients have been studied in the last years. Cavities are often made of copper, which however has too low work function (WF) (thus eventually leading to dark currents) and tends to produce uncontrolled discharges (breakdowns) which might damage the copper surface, finally degrading the cavity performance. For this reason, the idea of lining the copper cavity with a layer of molybdenum/molybdenum oxides, characterized by a higher WF and greater resistance to stress than copper, has been being pursued for some years.
In this paper, we analyze the effect of the molybdenum coating on the cavity quality factor. To do this, an electromagnetic simulation is performed to evaluate the effect of a coating on the effective surface impedance of the cavity surfaces as a function of the thickness and resistivity of the coating. Since the quality factor is related to the impedance of the walls, the estimate of the impedance provides useful information on the possible variation of the cavity quality factor.

**Poster** / **38**

## Parasitic wakefield effects in multi-pulse driver beams for PWFA schemes

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Particle driven plasma wakefield acceleration (PWFA) exploits the intense wakefields excited in a plasma by a high brightness driver beam in order to accelerate a trailing, properly delayed witness beam. Moreover, multi-pulse driver beams with suitable spacing resonantly excite the plasma which enhances the amplitude of the accelerating field. However, before the injection into the plasma stage occurs, the pulsed beam is exposed to the action of parasitic wakefields induced by the surrounding beamline which can introduce significant energy spread and emittance dilution. Here we investigate the effects of short-range wakefields which are responsible for intra-beam coupling in the multi-driver time structure. Simplified approaches for the evaluation of the wakefield interaction in presence of space charge forces are utilized in a custom tracking code framework. Reference cases are illustrated to provide examples investigating the performance of state-of-the-art facilities.

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## FAST Low Energy Beamline Studies: Toward High Peak 5-D Brightness Beams for FAST-GREENS

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The FAST beamline is the injector for the under-construction Gamma-Ray Electron ENhanced Source (GREENS), which promises numerous scientific advances [1]. FAST-GREENS requires high 5-D peak brightness; transverse normalized projected emittances of 3 mm-mrad and a peak current of 600 A are the minimum nominal beam requirements for the FEL to lase. In this work, studies of the low energy section of the FAST beamline are presented toward these ends, including preliminary measurements of beam compression. Further, an effort toward a high-fidelity simulation model and studies of it are presented in order to optimize the beam for FAST-GREENS. FAST is also the injector for IOTA; IOTA and future experiments also stand to benefit from a high-fidelity simulation model.

[1] P. Musumeci et al. FAST-GREENS: A High Efficiency Free Electron Laser Driven by Superconducting RF Accelerator, in Proc. of IPAC 2022, Bangkok, Thailand

**Plasma acceleration** / **40**

## Developing a reliable test bed for laser plasma accelerator driven compact light sources

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The Hundred Terawatt Undulator (HTU) beamline at the BELLA Center is being used as a test bed for the development of compact laser plasma accelerator (LPA)-driven light sources, with a particular focus on developing a reliable LPA-driven FEL. While LPA technology is well established, hurdles remain to make it usable for practical light source applications. Stability and reliability are primary concerns. The laser plasma interaction that results in the trapping and accelerating of electrons involves various nonlinear physical processes making it sensitive to subtle variations. Furthermore, there is a basic requirement that the transverse jitter of an electron beam in an undulator should be a small fraction of its transverse beam size for an efficient FEL. This requirement imposes an onerous condition on the transverse stability of the high power lasers used to generate the electron beams.

I will discuss recent efforts undertaken at the BELLA Center to address some of these challenges. In particular, I will focus on recent results that demonstrated substantial improvement in the transverse stability of LPA generated electron beams as well as ongoing efforts to make stability improvements to our laser system that will improve shot-to-shot variation in e-beam charge. Progress on LPA-driven FEL lasing using the 4m VISA undulator will be also be presented.

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**Poster** / **41**

## Non-invasive, real-time diagnostic development at FACET-II

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Challenges for future accelerators include characterization of high current beams and the need for continual drift correction while delivering beams with non-trivial phase space correlations. Concomitantly, there is potential for Artificial Intelligence/Machine Learning to improve beam quality, increase delivery time to users and enable exotic beam configurations. Non-invasive diagnostics allow measurement of high-current beams that would destroy any intercepting materials as well as monitoring and manipulating a beam from source to user without interruption. Real-time diagnostics allow AI/ML algorithms to respond to on a shot-by-shot basis to drift and automate configuration changes during experiments. We report here on a non-invasive, real-time diagnostic based on edge radiation interference under development at FACET-II. We show data from a first implementation as a virtual diagnostic as a non-destructive measurement of emittance.

**Beam dynamics and controls** / **42**

## Physics-Informed Priors for Sample Efficient Models of Beam Transport with Intense Space Charge

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Highly accurate simulation tools have become a staple in the design and operation of high-brightness particle accelerators. These tools are not without limitations, however. They are often computationally expensive. Many codes are incompatible with automatic differentiation (for machine learning). It can also be unclear how to include real-world measurements in a way that improves the model. Many of these problems are solved with a data-driven approach. Surrogate models are fast to evaluate, differentiable, and treat data from simulations and particle accelerators uniformly. Unfortunately, surrogate models often require a large amount of (possibly expensive) training data for their creation. In this work, we bridge the gap between purely data-driven models and physics-based simulation tools by introducing physics-informed priors for accelerator surrogate modeling. By coaxing our models to obey the physical laws that govern charged particles in an accelerator, we can improve sample efficiency while maintaining the benefits of surrogate models. We present our initial results that directly compare the accuracy of conventional and physics-informed models trained with few samples.

**Advanced concepts and Conclusions / 43**

## Prospective methods for generating sub-picosecond long-wave infrared lasers for advanced accelerators

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The $\lambda^2$ scaling of the ponderomotive force underpinning laser-based particle accelerators encourages the use of long wavelengths in regimes such as laser wakefield acceleration of electrons at low plasma densities. High pressure $\mathrm{CO_2}$ amplifiers are the workhorse source of such lasers, able to achieve multi-TW peak powers and picosecond pulse lengths. We are developing wavelength conversion techniques utilizing stimulated Raman scattering, where the energy of a photon is modified by inelastically scattering with a coherent excited state of a material, employing calcite to generate the 9.2 $\mu\mathrm{m}$ seed, and ionic liquids, artificial salts that are liquid at room temperature, for the 4.3 $\mu\mathrm{m}$ pump. Additionally, we are examining the use of self phase modulation to broaden the spectrum after the amplifier, followed by chirp compensation/compression. Together, we anticipate that these techniques will generate 25 TW, 100 fs LWIR pulses, which have been shown in simulation to enable new regimes in laser wakefield acceleration, such as the blowout regime of laser wakefield accelerators with millimeter-scale plasma structures.

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## Experimental Demonstration of Commercial Dielectric Laser Accelerator

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We present experimental results using a tunable commercial dual grating dielectric laser accelerator (DLA). A 780 nm, 100 fs pulsed laser is used in a pulse-front-tilt configuration to maximize interaction length to an observed length of more than 750 um and energy gain of 150 keV. The two gratings are mounted independently with piezo controls, allowing structure tuning for maximal energy gain. Interferometric measurement is used in parallel to diagnose structure parameters without the need for beamtime.

**Poster / 45**

## THz driven fs-resolution streaking

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Longitudinal phase space measurements of high-brightness beams are limited by the streaking field strength and frequency of the RF source. Single cycle THz pulses generated through optical rectification have been proven to generate strong electric fields, offering significant improvement in field gradients while maintaining compactness for beam manipulation. We present experimental designs to couple micro-Joule level pulses with relativistic electron beams to perform longitudinal phase space measurements with fs-level resolution using 3D printed metal-coated structures. To achieve high interaction lengths, a zero-slippage IFEL scheme is demonstrated in which the electron beam velocity is matched to the group velocity of the THz radiation.

**High brightness electron sources / 46**

## Generation of Sub-femtosecond Electron Pulses Based on Photocathode RF Gun

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Ultra-short pulsed electron beam has a wide range of applications in accelerator-based X-ray sources, wakefield acceleration, ultrafast electron microscopy, etc. Using pump-probe technology, MeV ultrafast electron diffraction (MeV-UED) can reveal the ultrafast dynamic processes of matter changes at the atomic scale. Further improving its temporal resolution to few-fs or even sub-fs will open up new opportunities for frontier scientific research. We proposed two schemes for generating sub-fs electron beams based on photocathode RF gun. The first scheme involves modulating the electron beam close to the cathode surface using a radially polarized laser pulse. When the driving laser pulse is about 50 fs, an isolated attosecond electron pulse can be obtained. Furthermore, to improve the charge and reduce the time jitter of the pulsed electron beam, we proposed a scheme to modulate the electron beam using two radially polarized laser pulses of varying frequencies. Due to the diffraction effect of the laser pulse, several asymmetric acceleration and deceleration cycles are experienced by the electron beam near the focused laser focus, resulting in energy modulation. By using the current gigawatt-power-level laser systems, an electron beam with a pulse width of 3.3 fs (rms) and a time jitter of 1.35 fs (rms) can be obtained.

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## Modeling High Order Modes in Energy Recovery Linacs for Optimal FEL Performance

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High order modes (HOM) in linear accelerators (Linacs) can negatively affect the quality and stability of the electron beam, which is essential for Free Electron Lasers (FELs). To address this issue, the Compact HOMEN (High Order Mode Evolution based on Energy budget) model has been developed to accurately predict and analyze HOM effects on beam dynamics in superconducting cavities. This model enables the optimization of beam quality and stability, leading to significant advancements in high-brightness accelerated electron beam technology. The optimized beam quality and stability in Linacs can have a profound impact on the performance of FELs. FELs require a high-brightness electron beam to produce high-quality THz and X-ray emissions with crucial applications in advanced technological fields such as materials science, biophysics, and chemistry. Therefore, the studies on HOMs in Linacs have the potential to greatly benefit the work of FELs, enabling the production of high-quality emissions for various scientific and industrial applications.

**Poster** / **48**

## Measuring the statistics of high-brightness continuous electron beams with sub-ps resolution

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Measuring the fermion statistics of free electrons has been a considerable experimental challenge of fundamental interest for many years. The attempts up to now, such as by Tonomura, have remained inconclusive because of the limited temporal resolution of the available detectors. The fermion statistics experimentally show up as electron anti-bunching - i.e., as a changed coincidence rate on a detector compared to the classical Poisson distribution. A direct measurement of the fermion statistics requires determining the arrival time of each particle on a detector within the coherence time, which is in the order of a few fs at most. On the other hand, anti-bunching in an electron beam also occurs at larger time scales due to the Coulomb interaction. While measuring the fermion statistics is particularly relevant from a fundamental physics point of view, determining how the Coulomb interaction affects the beam statistics is of great interest in the growing field of quantum electron optics.
In this work, we propose a new method to detect the arrival time of single electrons from a continuous beam with sub-ps resolution, which overcomes the time resolution limits.
We present the first experimental measurement of the arrival time statistics of a high-brightness 200 keV continuous electron beam generated by the highly coherent Schottky field emission gun of a transmission electron microscope.

**Poster** / **49**

## Beam dynamics simulations with X-band linearizer cavity for the EuPRAXIA@SPARC_LAB RF injector

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The EuPRAXIA@SPARC_LAB RF injector provides high brightness electron beams accelerated and longitudinally manipulated in the velocity bunching regime (VB). The RF injector consists of a SPARC_LAB like S-band RF Gun (2.856 GHz) followed by four S-band TW accelerating structures with an overall length of 12.3 m. The RF injector works with the so called comb configuration, foresees a 30pC witness and a 200pC driver longitudinally compressed in the first two accelerating structures both operated in the VB regime. The beams quality can be improved by adding a High Harmonic Cavity to pre-correct the bunch Longitudinal Phase Space to shorten and flatter the charge distribution and manipulate the beams to reach proper transverse and longitudinal parameters. A X-band (11.424 GHz) SW RF structure interposed between the Gun and the first accelerating structure is proposed to do it. The paper reports on beam dynamics studies performed with the insertion of the X-band RF cavity that is proposed to shape the beam current distribution, linearizing the Longitudinal Phase Space, and stabilize it with respect to RF jitters.

**Poster / 50**

## An Analytical Study of Space Charge Fields in the Emittance Compensation Process

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Space charge forces are a major contributing factor that adversely affect beam quality in an RF-injector. The laser distribution sent to the photocathode plays a crucial role in the emittance compensation process, as evidenced by slice analysis. To derive self-induced force expressions for bunches with arbitrary charge distributions, a new model of space charge forces has been proposed. The model's efficacy is being analyzed in the low-charge regime by studying the fields' performance near the cathode. The model has been benchmarked against previously studied distributions and new ones. It has also been employed to optimize a C-band hybrid photoinjector, currently being commissioned, resulting in a factor of two reduction in emittance observed at the exit of the gun by changing the initial distribution at the cathode.

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## RF copper based devices with oxide coatings

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One of the most demanding development of the accelerating technologies is the manufacture of reliable RF devices suitable to withstand the highest accelerating gradients required by the design and the construction of the future accelerators [1]. Actually, RF cavities working at gradients of 100 MV/m or higher could be successfully used for the next generation of linear accelerators planned for research applications, but even to design compact and less expensive industrial accelerators, e.g., those that could be used in medicine or in the food industry.
Starting from well-established RF technologies based on copper devices, we are trying to improve performances of OFHC copper cavities, coating their internal surfaces with transition metals oxides, such as MoO3 [2]. This coating may allow to optimize the properties any RF device reducing field emission, breakdown rate, and thermal damage in the presence of high electric fields [3].
In order to characterize the properties of such coated devices and to test the damage induced by high electric fields on a RF cavity with a coated internal surface we developed the technology to coat and assemble a cylindrical cavity and a reliable protocol to irradiate metallic coated surfaces with a high intensity coherent THz beam generating an electrical gradient up to few GV/m. Then we assembled a real copper-coated RF cavity with a cylindrical shape made by 4 cylindrically shaped sections each one diamond milled to have internal walls with a roughness <10 nm and coated with a MoO3. layer about 100 nm tick.

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**Poster** / **52**

# Theory of Diffraction by Holes of Arbitrary Sizes

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New high-gradient accelerating RF cavities are nowadays developed in several national laboratories for high-energy physics applications. Ultra high gradients, up to the order of GV/m, can be achieved by using ultra compact accelerating structures up to the sub THz regime. Nevertheless, the experimental setup for measuring the main RF parameters for such compact structures is not trivial and can easily produce errors due to lack of accuracy. Moreover, Radio-Frequency (RF) simulations for these types of cavities can require a large amount of computational time. In particular, one of the main RF parameters that needs to be evaluated and measured for the accelerating structures is the reflection coefficient. In order to obtain a fast and accurate analytical estimation, we have developed the electromagnetic theory for the calculation of the coupling of a resonant cavity with an RF waveguide. This theory is based on the Bethe's small aperture polarization approach, also developed by Collin's. In this paper, we give an exact analytical expression of the reflection coefficient as function of the physics parameters of the cavity-waveguide system, which can be applied to any geometry, material and frequency.

**Poster** / **53**

## Modeling field electron emission from a flat Au(100) surface with density-functional theory

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Field electron emission, or electron tunneling through a potential barrier under a strong electrostatic field, is of broad interest to the accelerator physics community. For example, it is the source of undesirable dark currents in resonant cavities, providing a limit to high-field operation. The classical approach to field electron emission is the Fowler-Nordheim framework, which incorporates a simplistic surface potential to compute the electron transmission coefficient. We build a more realistic model using a density-functional theory (DFT) calculation. We use the potential and charge densities from an Au(100) surface to construct an improved one-dimensional potential barrier. This potential is used under the Wentzel–Kramers–Brillouin (WKB) approximation to find the electron transmission coefficient and emission current densities. Moving beyond the WKB approximation, we numerically solve Schrödinger's equation using the transfer matrix technique. Our results indicate that the WKB approximation is inaccurate for surface fields exceeding 10 V/nm as has been achieved in laser-field emission experiments.

**Poster** / **54**

## A Thermodynamic Study of Laser-Field Emission from Metallic Nanopatterned Cathodes

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Strong laser-field emission from metals is a growing area of study owing to its applications in high-brightness cathodes and potentially as a high harmonic generation source. Nanopatterned plasmonic cathodes localize and enhance incident laser fields, reducing the spot size and increasing current density. Experiments have demonstrated that the nanoblade structure outperforms nanotips in the peak fields achievable before damage is inflicted. With more intense surface fields comes brighter emissions, so investigating the thermomechanical properties of these structures is crucial in their characterization. For intense, ultrafast illumination the electronic thermal and non-thermal dynamics near the apex are the dominant dispersive mechanisms at play, as electron-phonon interactions take place over much longer timescales. We study electronic heating and dissipation through three lenses: the temperature-squared heat equation, a quantum kinetic Boltzmann equation, and as a solid density plasma. We compare the nanoblade's and nanotip's performance in their achievable peak fields.

**FEL and coherent radiation** / **55**

## Radiation detection and coherent harmonic generation for the PAX Experiment at FACET-II

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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. For this first stage of the experiment, PAX plans to demonstrate that <100 nm bunch length electron beams can be generated using the 10 GeV beam accelerated in the FACET-II linac and using the plasma cell to give it a percent-per-micron chirp. The strongly chirped beam is then compressed in a weak chicane to sub-100nm length, producing CSR in the final chicane magnet at wavelengths as low as 10s of nm. In this contribution we describe the results expected from this initial setup, as well as future iterations of the experiment in which we plan to use short undulators to drive coherent harmonic generation to produce attosecond, gigawatt X-ray pulses down to 1-2 nm.

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

**FEL and coherent radiation / 56**

## Terawatt-Scale Attosecond X-ray Pulses from a Free Electron Laser Cascade

**Authors:** Paris Franz[1]; Zhaoheng Guo[1]; Dorian Bohler[2]; David Cesar[None]; Taran Driver[2]; Joseph Duris[2]; Andrei Kamalov[2]; Siqi Li[2]; Ming-Fu Lin[2]; Razib Obaid[2]; River Robles[1]; Nick Sudar[2]; Anna Li Wang[1]; Zhen Zhang[2]; James Cryan[3]; Agostino Marinelli[None]

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High intensity, sub-femtosecond XFEL pulses are key to taking full advantage of nonlinear x-ray spectroscopies and advanced imaging methods. The X-ray Laser-Enhanced Attosecond Pulses (XLEAP) collaboration is an ongoing project for the development of attosecond x-ray modes at the Linac Coherent Light Source (LCLS). Here we report development of a high power attosecond mode via cascaded amplification in two undulator stages. In the first stage, a sub-femtosecond x-ray pulse is produced by enhanced self-amplified spontaneous emission (ESASE) by a femtosecond, high-current spike within the electron beam. A magnetic chicane delays the electron beam, allowing the x-ray pulse to slip onto a fresh slice of the bunch in the second undulator stage, where it undergoes further amplification. We experimentally demonstrate generation of sub-femtosecond duration soft x-ray free electron laser pulses with hundreds of microjoules of energy, and use angular streaking to characterize the pulse durations.
This work was supported by US Department of Energy Contracts No. DE-AC02-76SF00515

**Ultrafast electron probes / 57**

# Imaging gas-phase molecules with high temporal resolution by coherent electron diffraction

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Imaging time-resolved molecular dynamics demands atto- to few-femtosecond temporal and picometer spatial resolution. Laser-induced electron diffraction (LIED) is a strong-field method based on coherent laser-driven scattering with one of the target's own electrons after photoionization. In this way, LIED differs from conventional ultrafast electron diffraction (UED) with external electron beams, in which the electron pulse is scattered by many target molecules, causing incoherent scattering of hundreds (to tens of thousands) of electrons. LIED has demonstrated its ability to image the three-dimensional structure of a single gas-phase molecule in full kinematic coincidence with combined sub-atomic picometre and femtosecond spatiotemporal resolution. However, retrieving complex molecular systems becomes progressively difficult with increasing molecular structure and is a challenge for any diffraction-based imaging technique.
In my talk, I will present our state-of-the-art technical achievements on the LIED and their consequent experimental results to overcome the limitations of imaging complex molecules for highly time-resolved investigation.

**High brightness electron sources / 58**

# Status of the high-brightness photoinjector accelerator R&D and applications

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The Photo Injector Test facility at DESY in Zeuthen (PITZ) develops high brightness photocathode RF guns, advanced diagnostics and applications of the high brightness electron beams, which currently can be accelerated up to 22 MeV. In this talk, we will present the latest development at the L-band normal conducting photoinjector (e.g., new prototype RF gun Gun5.1, photocathode laser shaping and green cathode) and two applications: the worldwide first high-power THz SASE free-electron laser (FEL) and a new R&D platform (FLASHlab@PITZ) for FLASH radiation therapy and radiation biology.
The Gun5.1 was designed for the operation with an RF pulse length of 1 ms at a cathode gradient of 60 MV/m. It has been installed at PITZ since late 2021. The results from gun conditioning and its current performance will be discussed.
The THz SASE FEL aims at producing high power tunable narrow band THz pulses with an energy of hundreds of μJ per pulse. This can be realized by transporting and matching an electron beam with a bunch charge of 2 to 4 nC and a peak current up to 200 A into an undulator. Methods have been developed at PITZ for the beam envelop and trajectory optimization of the strongly space charge dominated electron beam. Results from the electron beam matching, THz lasing and seeding at 3 THz will be presented.
The R&D platform FLASHlab@PITZ for radiation therapy and radiation biology is being prepared at PITZ. PITZ can provide a uniquely wide parameter range for studying this newest modality of radiation treatment against cancer. A startup beamline has been installed, first successful experiments

have been done and an upgrade plan for exploiting the full capability of PITZ has been developed. All these will be summarized in the talk.

**Plasma acceleration / 59**

## Direct probing of fields inside an LWFA using a relativistic electron beam probe

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Laser wakefield accelerators (LWFA) have produced electron beams with up to ~10 GeV of energy in tens of centimeters. In addition to producing high accelerating gradients, theory predicts the existence of linear focusing forces when an LWFA is driven in the blowout regime, where all electrons behind the laser are expelled. Such linear fields are essential for maintaining an electron beam's emittance during acceleration. Here, we present a method for direct characterization of these fields within an LWFA driven in the blowout regime. The experiments leverage the unique terawatt $CO_2$ laser system ($\lambda \sim 9.2\mu$m) and the 55 MeV linac-driven electron beam at the Accelerator Test Facility (ATF) of Brookhaven National Laboratory. Transmission Electron Microscopy (TEM) grids were used to create electron "beamlets", which allowed for selective transverse illumination of the different portions of the wake. The resulting deflection and the location of the focal point of the probe beamlets can then be used to characterize the electric field strength within the wake. The analytical evaluation of the approach, supporting simulation results, and recent experimental progress will be presented and discussed.

**Beam dynamics and controls / 60**

## Energy spread increase by intrabeam scattering and microbunching in FEL injectors

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The energy spread is one of the properties that determine the brightness of electron beams and a fundamental parameter in X-ray free-electron lasers (FELs). In the last couple of years, measurements at different FEL injectors have shown energy spread values much larger than predicted by simulations. This talk will present high-resolution energy spread measurements at the SwissFEL injector as a function of the electron peak current, the optics, and the longitudinal dispersion of the

lattice. The measured dependences indicate that the energy spread increase is caused by intrabeam scattering and microbunching instability, effects not covered in the conventional modeling of FEL injectors. We will also show numerical calculations that reproduce the experimental data and a recipe to mitigate the energy spread deterioration. The work underlines the importance of considering the energy spread in the optimization and design of high-brightness electron beam sources and the need to develop new models to adequately understand and simulate the observed physics effects.

**High brightness electron sources / 61**

## CsSb atomically smooth thin films as novel visible light photocathodes

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The so-called "green photocathodes", based on alkali antimonide compounds, are characterized by high efficiency at green light wavelengths (1-10% at 500-550 nm) and excellent charge lifetime, but are easily poisoned in poor vacuum and are usually grown in form of disordered polycrystalline layers. Surface disorder is an extrinsic factor significantly contributing to enhance the MTE at the photocathode. State-of-the art deposition techniques have been successfully employed to create smooth and ordered alkali antimonides; for example, epitaxial Cs3Sb photocathodes have been grown by electron diffraction monitored molecular beam epitaxy. By focusing on structure rather than efficiency, we discovered that atomically smooth films of CsSb can be reproducibly grown on selected substrates. While the quantum efficiency at 505 nm is significantly lower than the Cs3Sb counterpart, this material is still a visible light photocathode (with QE~0.5-1% at 405 nm) and appears to be more robust against contamination. We report a detailed characterization of this phase via x-ray and UV photoemission spectroscopy, angle resolved photoemission spectroscopy and scanning tunneling microscopy.

**Ultrafast electron probes / 62**

## Establishing a Relativistic Ultrafast Electron Diffraction & Imaging Facility in the UK

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RUEDI (Relativistic Ultrafast Electron Diffraction & Imaging) is a proposed UK national facility in the which will deliver single-shot, time-resolved, imaging with MeV electrons, and ultrafast electron diffraction down to 10 fs timescales. RUEDI is being designed to enable the following science themes: dynamics of chemical change; materials in ex-treme conditions; quantum materials; energy generation, storage, and conversion; and in vivo biosciences. RUEDI is proposed to be built at STFC's Daresbury Laboratory in the UK. The Conceptual Design Review and Outline Instrument Design reports were published in November 2022 and summarised here, with a Technical Design Review report to follow in November 2023.

**High brightness electron sources / 63**

## Advancements in Sub-GV/m X-Band Photocathode Gun at the Argonne Wakefield Accelerator Facility

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The Argonne Wakefield Accelerator (AWA) supports an extensive research portfolio along three themes: electron beam production, electron beam manipulation, and electron beam-driven wakefield acceleration. Currently, AWA is developing a sub-GV/m X-band photocathode gun (Xgun) driven by ultra-short radiofrequency (rf) pulses. With a demonstrated gradient of 400 MV/m on the photocathode surface, the Xgun exhibits low dark current and breakdown rates. The Xgun is powered by high-power rf (300 MW) and short rf pulses (9-ns FWHM) from AWA's power and transfer structure based on two-beam acceleration (TBA). This development has several significant applications. In the short term, the Xgun will be employed to investigate photocathode emission physics in ultra-high-field environments (see E. Frame's presentation). In the medium term, it will be utilized as an injector for compact X-ray free electron lasers (X-FELs). Lastly, in the long term, it will serve as AWA's 500 MeV TBA demonstrator. This talk will highlight the recent progress and outline our research and development roadmap for the coming years.

**Poster / 64**

## ON THE BETATRON RADIATION IN CYLINDRICALLY SYMMETRIC PLASMA-ION CHANNELS

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The relativistic interaction of short pulsed lasers or electrons with plasma has recently led to the birth of a new generation of femtosecond X-ray sources. Radiations with properties similar to those that can be observed from a wiggler or undulator, can be generated by the oscillations induced in the exited plasma by electrons (PWFA) or by lasers (LWFA), making plasma an interesting medium both for the acceleration as well as for the radiation source, with properties of being compact, providing collimated, incoherent, femtosecond radiation. Thus a lot of effort is being made to understand and improve this new source to make it really competitive, This poster summarizes and shows some theoretical results and numerical simulations of a simplified model called plasma ion column, using as a starting point the parameters expected for the EuPRAXIA@SPARC_LAB facility, highlighting strengths, limitations and scaling laws, which allow for a comparison with other types of more consolidated sources of light as Compton, Synchrotron and Free Electron Lasers (FEL).

**Poster / 65**

## Beam perturbations effects on betatron radiation

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Betatron radiation spectroscopy is a valuable diagnostic technique for studying the interaction between a beam and a plasma in plasma wakefield acceleration (PWFA) experiments. In this project, we investigate the effects of beam perturbations on the betatron radiation. We analyze how perturbations can result in hosing, a transverse instability that can degrade the quality of the beam. We also study the spectral and angular characteristics of the betatron radiation emitted by the perturbed beam. Potential of betatron radiation spectroscopy as a non-invasive diagnostic technique for PWFA experiments is also highlighted.

**Ultrafast electron probes / 66**

## Resolving structural dynamics at multiple length and time scales with the Cornell high-brightness, ultrafast electron microdiffraction apparatus

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The out-of-equilibrium dynamics of engineered nanoscale systems, such as moiré materials, is an important domain for ultrafast science. Ultrafast electron diffraction (with high-angular magnification) is especially suited to investigating spatially coherent normal modes of oscillation in these systems, collective motion that could hold the key to novel device functionality. Nanometer and longer periodicities can appear as fine details in reciprocal space, only resolvable by a highly coherent (low momentum spread) probe. In the conjugate dimension, small probe spots are needed to obtain data from micron-sized material samples. To satisfy these two requirements simultaneously — high coherence and small probe size — requires a high-brightness electron beam. I describe early results of the kiloelectron-volt ultrafast electron diffraction apparatus at Cornell, and show with reference to an experimental case study in moiré materials that this machine meets demanding size and coherence requirements, thanks to a low emittance semiconductor photocathode source.

**Poster / 67**

## First simulations for the EuAPS betatron radiation source

**Author:** Andrea Frazzitta[1]

**Co-authors:** Alessandro Cianchi [2]; Illya Drebot [1]; Massimo Ferrario ; Vittoria Petrillo [1]; Marcel Ruijter ; Cristina Vaccarezza [3]; Andrea Rossi [1]

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X-rays production through betatron radiation emission from electron bunches is a valuable resource for various research fields. The EuAPS (EuPRAXIA Advanced Photon Sources) project, within the framework of the EuPRAXIA project, aims to provide 1-10 keV photons (soft X-rays) using a compact plasma-based system designed to exploit self-injection processes that occur in laser-plasma interaction (LWFA) to drive electron betatron oscillations. Since the emitted radiation spectrum, intensity, angular divergence, and possible coherence strongly depend on the properties of the self-injected beam, accurate preliminary simulations of the process are necessary to evaluate the optimal diagnostic device specifications. Electron trajectories from particle-in-cell (PIC) simulations are currently undergoing numerical analysis through the calculation of retarded fields and spectra for various plasma and laser parameter combinations. At the same time, an analytical approach is being examined to obtain an expression for the emitted spectrum, assuming linear or quadratic electron energy variation.

**Poster / 68**

## Beam dynamics of the RUEDI ultrafast electron diffraction beamline

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RUEDI is a proposed facility for ultrafast electron microscopy (UEM) and ultrafast electron diffraction (UED) which is currently being designed and would be built in the UK. It will have two beamlines, one for microscopy and one for diffraction, which share a common electron gun. The diffraction beamline will operate with a kinetic energy of 4 MeV meaning that both space charge and ballistic effects are important. To achieve good temporal resolution the diffraction beamline needs a short bunch and small time of arrival jitter at the sample location. This will be achieved by compressing the bunch using a four dipole variable R56 magnetic arc. This arc will also be tuned to suppress the timing jitter due to the electron gun RF phase jitter. Achieving compression and jitter suppression requires using the bunch's space charge forces to modify its chirp to compress the beam. In addition to the longitudinal dynamics, transverse emittance degradation through the arc must be minimised so that good quality diffraction patterns can be obtained. Simulations showing the bunch compression, jitter suppression and the achieved transverse emittance will be discussed.

**Plasma acceleration / 69**

## Density downramp injection in plasma-based acceleration and its applicaitons in XFELs

**Authors:** Xinlu Xu[1]; Thamine Dalichaouch[2]; Fei Li[3]; Chan Joshi[2]; Warren Mori[2]

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Generation of high-quality electron beams in plasma-based acceleration is a critical and active topic in the past decade. By conducting full-scale particle-in-cell simulations, we have shown that electron beams with ultra-high brightness (10^20 ~10^21 A/m^2/rad^2) and 0.1~1 MeV energy spread can be produced in density downramp injection in the three-dimensional blowout regime of plasma-based acceleration. Two underlying physical mechanisms that lead to the generation of high-quality electrons are uncovered: transverse deceleration and longitudinal mapping. Recently, we pointed out the injection in a slowly expanding bubble caused by the evolution of a laser pulse driver or an electron beam driver in a uniform plasma shares the same dynamics as downramp injection, thus can indeed produce high quality self-injected electron beams. Furthermore, we proposed to generate a high-quality electron beam with nanometer-scale current modulation in a density modulated downramp. These high-quality beams have many potential applications in X-ray free-electron lasers, such as drive a fully coherent XFEL in a short undulator.

**High brightness electron sources / 70**

## A Versatile High Brightness Travelling-Wave Radio-Frequency Photogun

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S-band Standing-wave RF Photoguns represent the current state of the art for high brightness electron sources. These devices significantly contributed to the development of high brightness accelerators. However, the push for even brighter electron sources presents a significant technological challenge. Aiming to continue to push the boundaries of high brightness electron beams, a travelling-wave (TW) C-band RF photogun is under development as part of the IFAST programme. This TW photogun offers the ability to significantly increase peak cathode fields up to 200 MV/m through the use of very short RF pulses and higher operational frequencies. These short pulses also open up the possibility of RF pulse repetition rates up to 1 kHz. Finally, the TW gun presents a path to higher frequency RF photoguns without the need for RF circulators which are notoriously complex to fabricate at high frequencies. This presentation will detail the RF and mechanical design of the TW RF Photogun along with its application to an FEL injector demonstrating its ability to increase the SwissFEL 5D brightness by a factor of 5.

**5th generation light source / 71**

## High brilliance Free-Electron Laser Oscillator operating at multi-MegaHertz repetition rate in the short-TeraHertz emission range

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We present the design study of an innovative scheme to generate high repetition rate
(multi-MHz-class) THz and X synchronized radiation pulses
by using an Energy Recovered Super Conducting Linac operating in Continuous Wave

mode driving a Free-Electron Laser Oscillator.
The FEL and X rays performances are illustrated for one and two color operation.
Start-to-end simulations are presented to assess the capability of this scheme for
typical values of wavelengths of interest
in the 10-50 um (6-30 THz) and 3-0.05 A.

**Advanced concepts and Conclusions / 72**

## Applications of laser-driven anti-resonant waveguides to electron beams

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Large-core anti-resonant fibers have recently found key applications in non-linear optics. Here we report on their applications to charged beams. We show that large energy modulations can be applied via a TM01-like mode, which can be further exploited to produce attosecond microbunches. We also report on the dipole HE11-like mode, to support high-power streaking resolutions for diagnostics purposes. Limitations, opportunities, and future plans are also discussed.

**Poster / 73**

## Beam Dynamics of the MeV Microscopy Line of RUEDI

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RUEDI is a proposed Relativistic Ultrafast Electron Diffraction and Imaging facility for the UK. It will deliver single-shot time-resolved imaging with MeV electrons, as well as ultrafast electron diffraction at 10 fs timescales. The few-MeV-scale imaging and microscopy line aims to deliver high charge (up to 10^8 electrons), ultra-low emittance electron bunches to a 10µm sample with minimal energy spread and transverse divergence, aiming for imaging resolutions at the 10nm scale. The physical layout of the imaging beamline will be discussed, along with a multi-dimensional study of the beam dynamics of the proposed design. The extreme requirements on the injector specification, and the limitations inherent in such systems, will be investigated, and potential upgrade paths explored in terms of both imaging resolution and technological feasibility.

**CBB-sponsored student session / 74**

## Transverse stability in an alternating gradient planar-symmetric dielectric wakefield structure

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In this work we present the result of a Dielectric Wakefield Acceleration (DWA) design that uses a longitudinally varying alternating gradient configuration of a planar-symmetric DWA structure to exploit the inherent quadrupole-mode transverse wakes to achieve second-order stability. We have designed and fabricated a new apparatus for positioning the DWA components in our setup. This allows us to precisely and independently control the gap in both transverse dimensions and consequently the strength of the respective destabilizing fields. We present the effect of various structure configurations on the transverse beam distribution and compare those results to simulation. Our results show that the use of alternating gradient structures in DWA can significantly improve its performance, offering a promising path forward for high-gradient particle acceleration.

**Poster / 75**

# Electron yields stabilization for the EuAPS betatron source

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The EuAPS project (EuPRAXIA Advanced Photon Source) aims at realizing an X-ray photon source for users applications. The photons will be produced by betatron radiation mechanism inside a laser plasma accelerator, exploiting an internal injection scheme. The source will produce short pulses of photons in the spectral range 1 - 10 keV for a wide set of applications ranging from imaging to spectroscopy to pump-and-probe. The presence of external users makes the source stability as important as the performances in terms of photon yield and spectral properties.
In this contribution, we will show numerical studies aimed at assessing the relative stability of different internal injection schemes together with attempts at optimizing the source performances by plasma target engineering.

**Advanced concepts and Conclusions / 76**

# Pathways & progress to ultrabright pulses from plasmas

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Hybrid combinations of lasers and electron beams allow LWFA->PWFA and plasma photocathodes to be realized. This is a pathway to ultrabright electron and photon pulses. Experimental progress on hybrid LWFA->PWFA, and on plasma photocathodes driven by linac-PWFA, and now also by the hybrid LWFA->PWFA approach, will be presented. Intrinsically synchronized, ultrabright electron and photon pulses e.g. via X-FEL from compact, all-optical setups then enable unique experimental constellations and applications of ultraintense IR–e-beam–X-ray interaction.

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**FEL and coherent radiation** / **77**

## Ponderomotive Microbunching for a Superradiant Thomson Source

**Authors:** Brian Schaap[1]; Coen Sweers[1]; Peter Smorenburg[2]; Jom Luiten[3]

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Compact sources offering high-brightness radiation in the extreme ultraviolet to X-ray regime are highly desired. Thomson scattering, in which an electron beam colliding with a laser pulse produces radiation, is a source of X-rays of increasing prevalence in modern labs, complementing large scale facilities like synchrotrons and X-ray free electron lasers. By imposing a density modulation on the electron beam the brilliance of a Thomson source can be enhanced by orders of magnitude via superradiant emission. However, microbunching at the electron beam energy relevant to Thomson sources is a challenge that has yet to be met. Here, we
show under which conditions sufficient density modulation is attained by the ponderomotive force from the copropagating beat wave formed by two laser pulses at different frequencies. In addition, we propose a coherent soft X-ray Thomson source based on ponderomotive bunching.

**High brightness electron sources** / **78**

## Status of high gradient C-band RF photoinjector project at LANL

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This talk will report on the status Cathodes And Radio-frequency Interactions in Extremes (CARIE) high gradient C-band RF photoinjector project at Los Alamos. Modern applications such as X-ray sources require electron beams with ultra-low emittance and very high brightness that may be

achieved by accelerating the electron beam produced in an RF photoinjector with electric field higher than 100 MV/m. At LANL we are putting together the high gradient photoinjector test stand capable of producing electric fields at the cathodes as high as 250 MV/m. The photoinjector will be powered by a 50 MW, 5.712 GHz Canon klystron. Adding capability to operate the photoinjector at cryogenic temperatures is considered. The construction of CARIE began in October of 2022. A concrete vault was renovated, capable to provide radiation protection for electron beams with beam power up to 20 kW. The klystron will be delivered in summer of 2023. All waveguide and vacuum components have been ordered. The all-copper photoinjector was designed and is currently in fabrication. The second version of the photoinjector will operate with replaceable high quantum-efficiency cathodes and produce an ultra-bright 250 pC electron beam accelerated to the energy of 8 MeV. The status of the facility, the designs of the photoinjector and the beamline, and plans for photocathode testing will be presented.

**Ultrafast electron probes / 80**

## Few-electron correlations after ultrafast photoemission from nanometric needle tips

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Free electrons are central to such diverse applications as electron microscopes, accelerators, and photo-emission spectroscopy. However, space charge effects of many electrons are often problematic and, when confined to extremely small space-time dimensions, already two electrons can interact strongly. Here, we demonstrate that the resulting Coulomb repulsion can also be advantageous, as it leads to strong electron-electron correlations. We show that femtosecond laser-emitted electrons from nanometric needle tips are highly anti-correlated in energy because of dynamic Coulomb repulsion, with a visibility of 56%. We extract a mean energy splitting of 3.3 eV and a correlation decay time of 82 fs. The energy-filtered electrons display a sub-Poissonian number distribution with a second order correlation function as small as g(2) = 0.34, implying that shot noise-reduced pulsed electron beams can be realized based on simple energy filtering. We also reach the strong-field regime of laser-driven electron emission and gain insights into how the electron correlations of the different electron classes (direct or rescattered) are influenced by the strong laser fields. Furthermore, we will also briefly show very recent results of coherent electron acceleration with laser light on a nanophotonic chip, with significant energy gain.

**Ultrafast electron probes / 81**

## Application of Low-Emittance Electron Beams for MeV UED

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Mega-electronvolt ultrafast electron diffraction (MeV-UED) is a complementary tool to X-ray based instruments that has enabled ground-breaking studies in condensed matter physics and chemical science. A significant opportunity exists for MeV-UED beyond current instrument capabilities in quantum materials, microelectronics and photo-chemical research. Further improvement in MeV-UED transverse emittance would allow access to longer-range electron correlations in quantum materials and to probe micron-sized homogeneous regions within complex heterogeneous materials.

To broaden the scientific opportunities, improved instrument performance of MeV UED has been heavily requested. We discuss plans at the SLAC MeV-UED facility to enable substantial near-term improvements in beam brightness, data acquisition rate, and temporal and momentum-space resolution.

**Beam dynamics and controls / 82**

## Virtual Diagnostics for High Brightness Accelerators

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Diagnostic methods that are enhanced with machine learning are improving the speed and detail with which beam behavior can be characterized on-the-fly in real accelerator systems. Detailed characterization can in turn improve both high-precision modeling of accelerator systems and high-precision optimization/control for high brightness beams. This talk will outline the state-of-the-art in machine learning enhanced diagnostics for accelerators, ranging from fast data-driven approaches for shot-to-shot prediction to methods that tightly couple machine learning and physics simulations for unprecedented fidelity in beam phase space reconstruction.

**Beam dynamics and controls / 83**

## Photoinjector transverse phase space linearization with sacrificial charge

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Compensating the emittance growth due to linear and nonlinear space charge effects in photoinjectors is critical for high-brightness electron beam applications ranging from XFELs to various ultrafast electron probes. While linear emittance compensation is extremely robust, nonlinear emittance compensation depends on the detailed nature of the charge distribution, and in general, producing simultaneous compensation of linear and nonlinear space charge effects is an ongoing challenge. This challenge will grow in importance as intrinsic emittance from photocathodes is further improved.

In this work, we will show results discovered via multiobjective optimization of various high-brightness photoinjectors equipped with scraping apertures. We find a new class of robust nonlinear emittance compensation that uses the space charge field of the sacrificial component of the beam to linearize the transverse slice phase space of the surviving component. We study this effect analytically and show excellent agreement with space charge simulation and extremely low emittance for charges relevant for XFEL injectors.

**84**

## CrYogenic Brightness-Optimized Radiofrequency Gun (CYBGORG) Beamline

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The pursuit of increased electron beam brightness implies multiple complementary research goals including increasing beam brightness at the cathode. Extremely high gradients (> 200 MV/m) have been shown in normal conducting copper cavities at cryogenic temperature (<77K). In addition, for photocathodes operating near their emission threshold material lattice temperatures begin to be the dominant contribution to minimum achievable intrinsic emittance. Cryogenic operation of a high gradient RF photoinjector then becomes a very enticing prospect. The physical emission phenomena associated with the production of photocurrent and RF gradient limiting breakdown are complex and require comprehensive study to be fully well understood and utilize in future beamlines such as an ultra-compact xray free electron laser (UCXFEL). To this end, we will present the case for the CrYogenic Brightness-Optimized Radiofrequency Gun (CYBGORG) beamline at UCLA as a useful cryogenic RF photocathode test bed for such studies. We present here the basic physics motivations for the CYBORG beamline and the commissioning status of the CYBORG beamline and preliminary results.

**Poster** / **85**

## Chromatic Emittance Evolution in Plasma-Based Accelerators

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We present the first analytic theoretical model describing the chromatic transverse dynamics of an electron beam in a nonlinear plasma-based accelerator that can account for the evolution of the projected, longitudinal sliced, and energy sliced emittance. Beginning with a description of single particle motion, the evolution of the beam moments and centroid position for each slice is calculated. In our approach, the longitudinal dependence of energy gain due to the beam loading of the wake is included. This permits a 6D, slice-by-slice (energy or longitudinal) analytic prediction of the beam evolution at any point within an adiabatic plasma source for the first time. It includes effects from both transverse mismatch and transverse offsets of the beam. We show that the amount of beam emittance growth in plasma ramps is directly related to the integrated plasma density profile independent of the ramp shape, so long as the ramp is adiabatic. We also show how our theory can predict the optimal length for a high-brightness plasma injector stage for a given target beam energy and energy spread. Using our theoretical framework, researchers will be empowered to design emittance-preserving plasma accelerators with less reliance on expensive particle in cell simulations. In addition, they will be able to better predict and interpret the observed behavior of the beam, permitting informed parameter adjustments for performance optimization.

**Advanced concepts and Conclusions** / **86**

## Underdense Passive Plasma Lens Experiments at FACET-II

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The underdense passive plasma lens (UPPL) has several features that make it uniquely attractive for the focusing high-energy electron beams. Nominally formed via laser ionization of gas in the outflow of a supersonic jet, it is a simple, ultra-compact, and easily tunable device. Because it operates in the nonlinear blowout regime, the focusing strength scales with the plasma density and lens thickness, which can be controlled via the gas jet backing pressure and the focal properties of the laser, respectively. In contrast to active plasma lenses, the UPPL always acts as a linear focusing optic, preserving emittance even for the most intense beams. Potential use cases include matching and staging for plasma accelerators, as well as the final focus for a future collider or for HED physics. By introducing a modest transverse density gradient, the UPPL can even behave like a "micro-dipole" or "micro-sextupole". We will present theoretical descriptions of the UPPL under various conditions, along with a summary of early commissioning data from FACET-II and future experimental plans.

**FEL and coherent radiation / 87**

# An open source platform for integrated design and control of compact radiation sources

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The international collaboration towards a 5th-generation lightsource should adopt an open source platform to enable a) instantaneous collaboration between distributed design teams; b) code benchmarking, multiphysics and code chaining for end-to-end simulation; c) multi-level user support for all relevant codes, from GUI to supercomputer; d) applicability to all subsystems individually, including support for surrogate model development; and e) automatic integration with control systems for testing, commissioning and operation. Sirepo is a framework for cloud computing, which partially or fully satisfies many of these demanding requirements today and has been openly developed on GitHub since its inception in 2015. Sirepo.com is a free scientific gateway for the worldwide community. The recently deployed Sirepo-Omega app demonstrates the integration of OPAL, elegant and GENESIS for end-to-end FEL modeling. Sirepo-Bluesky is an open source integration that is actively used for X-ray beamline controls at NSLS-II. Additional support for accelerator controls is planned. Recent work on relevant subsystems will be discussed: laser-plasma channels; LLRF for C-band linacs; thermal effects in high-rep-rate Ti:Sapphire laser amplifiers; beam loading in high-current linacs; radiation transport and shielding; as well as surrogate models for photoinjectors.

**CBB-sponsored student session / 88**

## The Ion Channel Laser: Physics Advances and Experimental Plans

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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 unique physics in the high K regime. We discuss recent advances in the physics of the ion channel laser as well as experimental plans at SLAC's FACET-II facility and the potential for future plasma plasma based light sources.

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**5th generation light source / 89**

## Seeding at SwissFEL

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SwissFEL at the Paul Scherrer Institute is a free-electron laser facility providing hard and soft X-rays, based on the SASE principle. In addition, the soft X-ray beamline Athos is currently extended for electron beam manipulation with external lasers, aiming to provide seeding capabilities based on the two-stage echo-enabled
harmonic generation (EEHG) scheme. Completion of the installation is foreseen in spring 2023. We present the initial results on the single-stage operation for ESASE and mode-locked lasing and give an outlook on the expected performance for seeding down to 1 nm.

**5th generation light source / 90**

## X-ray Regenerative Amplifier Free-Electron Laser

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Despite tremendous progress in X-ray free-electron laser (XFEL) science over the last decade, future applications still demand fully coherent, stable X-rays that have not been demonstrated in existing X-ray FEL facilities. In this talk, we review the progress toward an X-ray regenerative amplifier FEL (XRAFEL) to produce both high-peak and high-average power FEL pulses with full temporal coherence. We discuss electron beam and cavity optics requirements, as well as various mechanisms to outcouple maximum amount of radiation power. Finally, we illustrate how an XRAFEL can be applied to a high-repetition rate XFEL and an ultra-compact XFEL to significantly increase the X-ray brightness or the spectral photon flux.

**Poster / 91**

## Demonstration of Autonomous Emittance Characterization at the Argonne Wakefield Accelerator

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Transverse beam emittance plays a key role in the performance of high brightness accelerators. Characterizing beam emittance is often done using a quadrupole scan, which fits beam matrix elements to experimental measurements using first order optics. Despite its simplicity at face value, this procedure is difficult to automate due to practical limitations. Key issues that must be addressed include maintaining beam size measurement validity by keeping beams within the radius to diagnostic screens, ensuring that measurement fitting produces physically valid results, and accurately characterizing emittance uncertainty. We describe a demonstration of the Bayesian Exploration technique towards solving this problem at the Argonne Wakefield Accelerator, enabling a turnkey, autonomous quadrupole scan tool that can be used to quickly measure beam emittances at various locations in accelerators with limited operator input.

**Poster / 92**

## Measurement of the slice energy spread of the electron beam based on dispersion and on the optical klystron

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We present measurements of the slice energy spread of the electron beam using two methods. The first and more standard way consists in measuring the slice beam size of the electrons in a dispersive location. The second method is based on the optical klystron mechanism, where the radiation produced in undulator modules is enhanced with magnetic chicanes between the modules. In this approach, the energy spread can be derived from the chicane strength giving maximum radiation output. The measurements have been carried out at the soft X-ray beamline of SwissFEL, Athos. Both methods gave equivalent results: an energy spread of around 1 MeV for electron peak currents between 2 and 3 kA. The results validate the measurement based on the optical klystron, which can be especially useful to reconstruct low energy spread values where the conventional approach may be resolution limited.

**Poster / 93**

## Simulation studies of producing attosecond-terawatt X-ray FEL pulses using irregularly spaced current peaks at SwissFEL

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We present simulation results of a scheme to generate high-power and short FEL pulses using an electron beam with irregularly spaced current peaks. Such an electron beam produces a train of short pulses with low power in the first undulator section. In the next sections, the electron beam is delayed in a way that only one of the short pulses is continuously amplified to a very high power. The irregular spacing of the current peaks is obtained by using the ESASE mechanism, where the electron beam is modulated with a chirped optical laser and later compressed in a magnetic chicane. In comparison to previous proposals, we suggest to use a chirped electron beam to reduce the requirements on the optical laser chirp, and to transversely tilt the electron beam to select the number of current peaks able to lase for best final performance. The simulations are done for the soft X-ray beamline of SwissFEL, Athos, which has small magnetic chicanes placed within the undulator line suitable to delay the electron beam between the different amplification stages. Our simulation results show that soft X-ray FEL pulses with TW peaks power and hundreds of attoseconds pulse durations can be achieved in SwissFEL.

**Advanced concepts and Conclusions / 94**

## Enhancing XFEL Performance Through Laser-Based Manipulation

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While XFEL electron bunches can be manipulated for tailored x-ray generation via laser-electron interactions in select locations along the accelerator, such as laser heaters, XFEL performance is dominantly impacted by the electron bunch parameters directly after generation in the photoinjector. Optimal performance of the photoinjector requires excitation laser pulses, typically in the ultraviolet (UV), with non-Gaussian temporal intensity profiles and durations on the order of 10s of ps. We demonstrate a photoinjector laser shaping method with a numerical and experimental implementation to generate ~25 ps flat-top pulses in the ultraviolet designed for MHz-rate photoinjectors which have been shown in simulation to reduce transverse emittance by upwards of 25%. We achieve

upwards of 30% conversion efficiency during the nonlinear shaping stage allowing for applications of this method beyond XFELs to ones with higher bunch charge requirements. In supplement to the demonstrated experimental method, we show a machine learning extension aimed at kHz-level adaptive laser shaping for XFEL experiential multiplexing and fast-response machine performance optimization.

**Poster / 95**

## Commissioning of an S-Band Hybrid Photoinjector at UCLA

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We present the first results of commissioning of the S-Band hybrid photoinjector at the new accelerator facility at UCLA. Thorough characterization of the photoinjector is needed before installation of additional accelerating sections. These include measurements of high power RF cavity response, charge, beam energy, and bunch length. Of particular interest in this first round of studies is the effect of cavity temperature and RF phase on beam energy, energy spread, and bunch length, due to their effects on compression in the traveling wave section of the hybrid gun. Following full characterization of the photoinjector, a 1.5 meter linac is to be installed and experiments up to 30 MeV will begin.

**Plasma acceleration / 96**

## First laser plasma accelerator based seeded FEL

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Free Electron Lasers (FELs) are traditionally operated on Radio-Frequency Accelerators (RFAs). But the use of Laser Plasma Accelerators (LPAs), exhibiting much higher accelerating gradients, could enable to reduce the footprint of the FEL facilities, especially in the case of FELs operated in the X-ray range.
We report the first lasing of a seeded FEL fully driven by an LPA. The experiment was performed at HZDR (Germany), coupling the high quality electron beams of the HZDR's LPA with the versatile COXINEL beam manipulation beamline. Our results substantiate the continuous progress of LPA technology to enable FEL operation and finally bring temporal coherence to those compact promising sources.

**Poster / 97**

## Extending the functionalities of the ASTRA tracking code with the GIOTTO AI code

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ASTRA is a well-known tracking code able to simulate with high accuracy space charge dominated beams dynamics.
GIOTTO, on the other hand, is an AI code (based a genetic algorithm) used to optimize beam dynamics in the presence of strong nonlinear correlations, such as those introduced by space charge forces or more generally by complex collective effects.

GIOTTO was designed to natively integrate with ASTRA and drive it by interpreting its outputs, but it could potentially be integrated with any other simulation code.
In this work we present the recent developments in the GIOTTO code that allow ASTRA to be used for new types of optimizations.
These new features enable the ASTRA user to close dispersion in doglegs (even in the presence of space charge forces) and more generally to optimize beam parameters in rotated reference systems with respect to the machine main axis, optimize combed beams and perform phase space cuts before optimizing.

**Poster** / **98**

## An achromatic space charge dominated low energy dogleg

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Currently, Energy Recovery Linacs (ERLs) are gaining popularity due to their environmentally friendly and sustainable nature.
However, ERLs require a specialized low-energy injector, also known as a merger. The energy exiting the merger cannot be recycled and is ultimately dumped at the end of the process.
To maximize energy efficiency, it is necessary to reduce injection energy. However, a challenge arises due to the presence of space charge in the dispersive section at low-energy ERL injection, leading to dispersion leaks.

Various solutions for merger beamline design have been developed worldwide to address this issue. Here, we present a novel approach that employs a standard dogleg to create an ultra-low energy merger for an ERL. This was made possible by utilizing the GIOTTO AI code to optimize optics settings and achieve a proper achromatic configuration.

**Poster** / **99**

## Theory of THz superradiant waveguide FEL

**Author:** Amir Weinberg[1]

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Following first light measurement at the Israeli THz Superradiant waveguide FEL we developed theoretical analysis corresponding to the concept scheme. We use analytical expressions to calculate the spectrum and energy emited into the rectangular waveguide LSM (Longitudinal Sector Magnetic) modes. The results compare well with numerical simulations using UCLA GPTFEL and are consisted with the measured THz energy. GPT simulations of the e-beam transport show that the chirp provided by the hybrid photocathode RF gun can produce tight bunching at the wiggler bellow sigma=100ftS. The bunch duration limits the bunching factor, and consequently diminishes the superradiant emission. Phase-space analysis shows that tight bunching and consequent high THz frequency operation are limited by the energy spread of the beam in the gun. The superradiant scheme provides narrow bandwidth radiation of the radiation of the individual modes. We propose a Fourier optics scheme for spatial separation of the mode, and derive their diffraction patterns using Fresnel diffraction calculation.