AAC'22 Advanced Accelerator Concepts Workshop

November 6 - 11, 2022

Hyatt Regency Long Island, NY

Working Group 8 Summary

Advanced Laser and Beam Technology and Facilities

Marcus Babzien

AAC'22 Advanced Accelerator Concepts Workshop
November 6 - 11, 2022
Hyatt Regency Long Island, NY

IEEE CSC Council on Superconductivity

WG8 Invited Speakers

Mark Hogan, SLAC

FACET-II: Status of the first experiments and the road ahead

Ralph Assmann, DESY

European Roadmap Report for Advanced Accelerators

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Development of Coherent Spatially and Temporally Combined Fiber Laser LPA Driver Concept – Progress of the kW-Average and TW-Peak Power System Demonstration

Alexander Rainville[1,*], Mathew Whittlesey[1], Chris Pasquale[1], Yanwen Jing[1], Mingshu Chen[1], Siyun Chen[1,2], Hanzhang Pei[1], Qiang Du[2] and Almantas Galvanauskas[1]

[1]Gerard Mourou Center For Ultrafast Optical Science, University of Michigan

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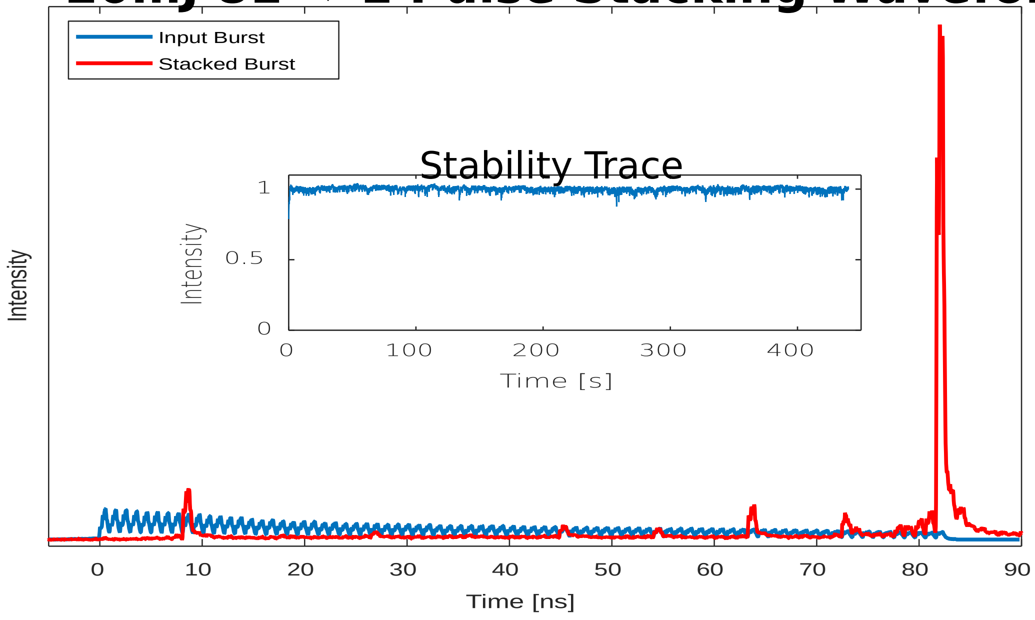
Progress of the kW/TW Coherently Combined Fiber Laser System

- Next Generation LPA Drivers Require:
  - 1-10J, <30-100fs, 1-50kHz Pulses
- Coherently combined fiber lasers are a power and energy scalable solution
  - Coherent temporal combining using CPSA enables up to 10mJ per channel

    → practically small array sizes
- In this work we validate:
  - Simultaneous spatial and temporal combining of 4 fiber amplifiers to 20mJ with high efficiency and stability
- Enabling Next Steps:
  - **Scaling to 100mJ in 2023, @ 2-10kHz**
  - Bandwidth control for <100fs pulses
  - High pre-pulse contrast techniques

20mJ 81 → 1 Pulse Stacking Waveform



Temporal 81 → 1 Pulse Locking of 7mJ from Single Fiber

- Searching for locking point takes ~15s
- Locking maintains ~1% RMS (measured over 6.5min, observed for "forever")

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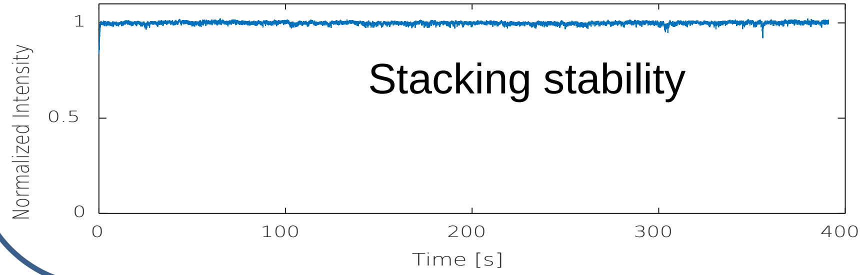
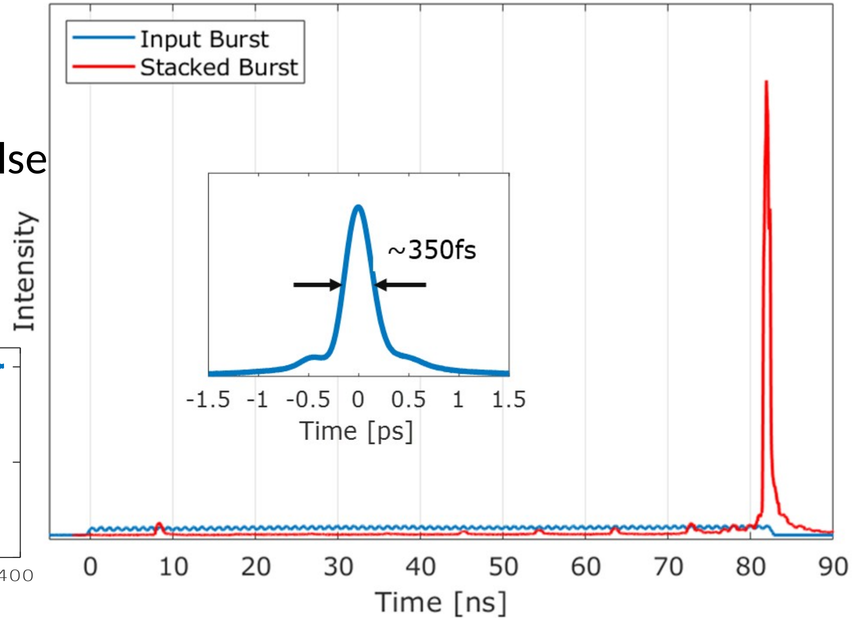
Robust and Efficient Temporal Pulse Combining Enabling Practical Coherent Pulse Stacking Amplification Systems

Mathew Whittlesey[1], Yanwen Jing[1], Hanzhang Pei[1], Qiang Du[2], and Almantas Galvanauskas[1]
[1]Center for Ultrafast Optical Science, University of Michigan, USA
[2]Lawrence Berkeley National Laboratory, USA

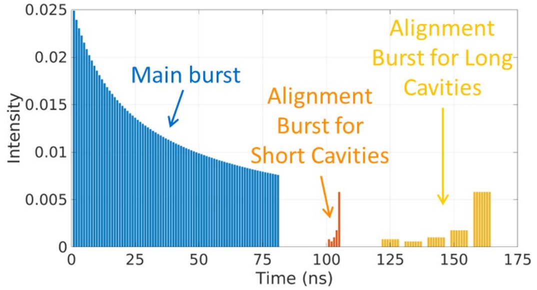
- Temporal combining using CPSA enables compact coherently combined fiber laser arrays
- Here we demonstrate high-accuracy automated alignment technique of 81-pulse CPSA stacker
- 81 pulses are stacked by 4+4 GTI cavities robustly and efficiently



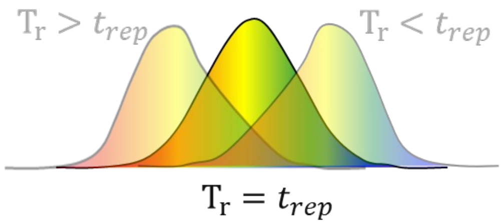
Input Burst vs Stacked output



- Angular alignment to $< 6\ \mu rad$

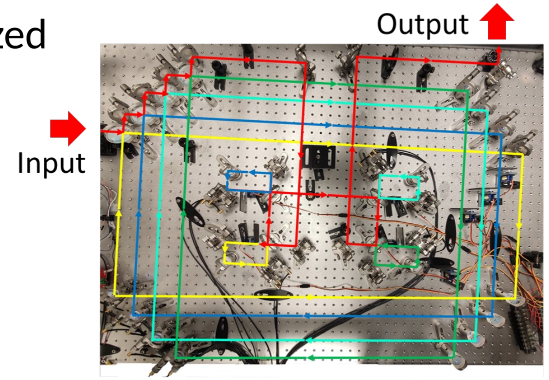


- Piston alignment to $< 2\ \mu m$ using spectral-temporal mapping



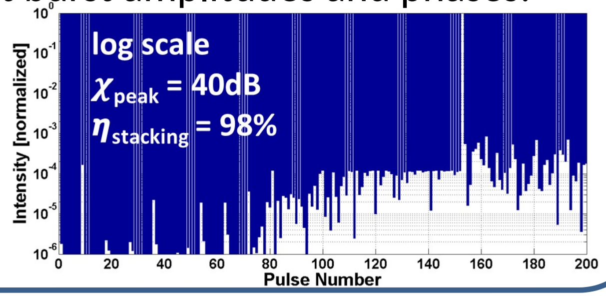
- Oscillator locked to a Rubidium frequency standard

- Optimized 4+4 GTI cavities stacker



- Future work: achieving high pre-pulse contrast by controlling input burst amplitudes and phases:

Simulation result:



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CENTER FOR ULTRAFAST OPTICAL SCIENCE
UNIVERSITY OF MICHIGAN

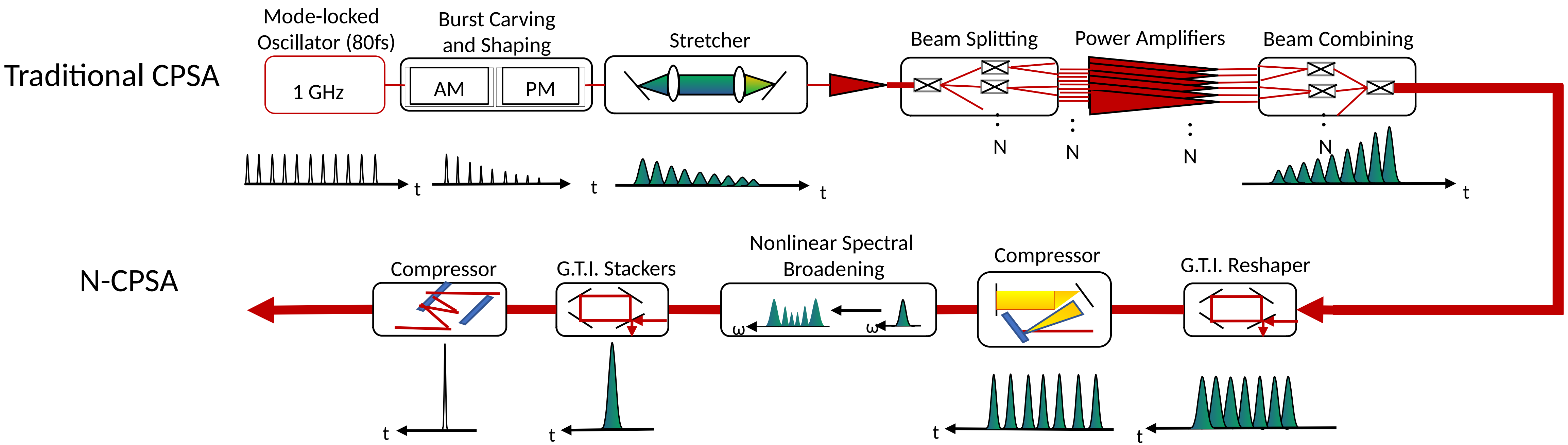
Nonlinear Coherent Pulse Stacking (N-CPS)

CPSA + N-CPS

Three important stages:
- Burst reshaping
- Compress and Broaden
- Stack and compress

Experimental objectives:

- Use a Herriott type Multipass Cell (MPC) to nonlinear broaden laser pulse spectrum
- Short term: 20 pulses with ~20mJ broadened, stacked and compressed to ~30fs
- Long term: 20-100 pulses with up to 100mJ broadened, stacked and compressed to <30fs

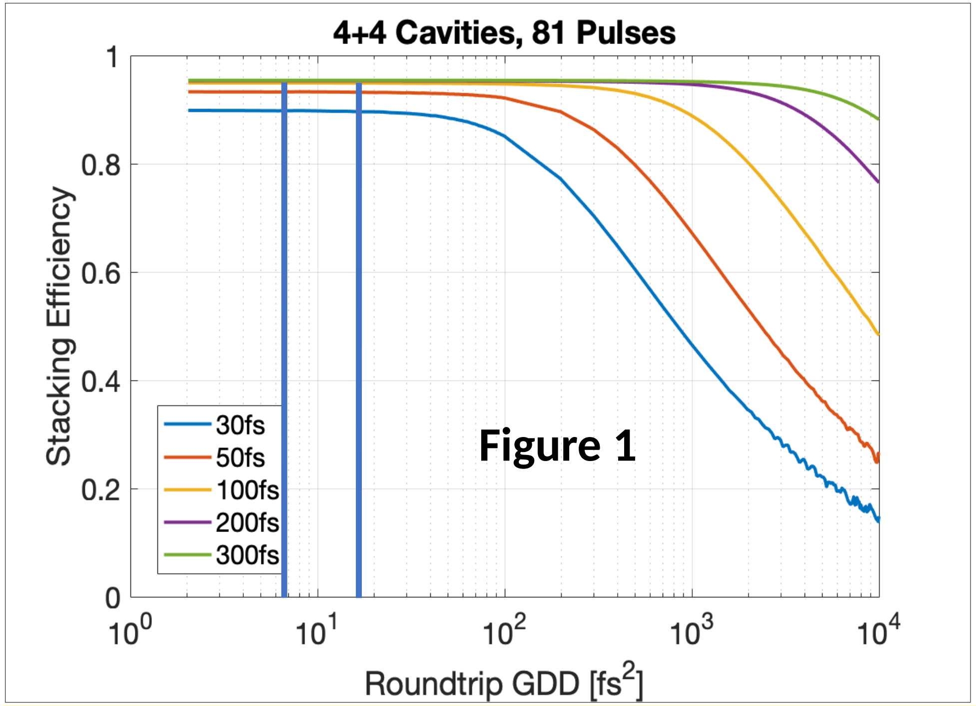


Coherent Temporal Stacking of tens-of-fs Laser Pulses Towards Plasma Accelerator Applications

Lauren Cooper[1,2], Dan Wang[1], Qiang Du[1], Mathew Whittlesey[2], Siyun Chen[1], Deepak Sapkota[1], Jeroen van Tilborg[1], Eric Esarey[1], Derun Li[1], Cameron Geddes[1], Russell Wilcox[1], Almantas Galvanauskas[2], Tong Zhou[1]

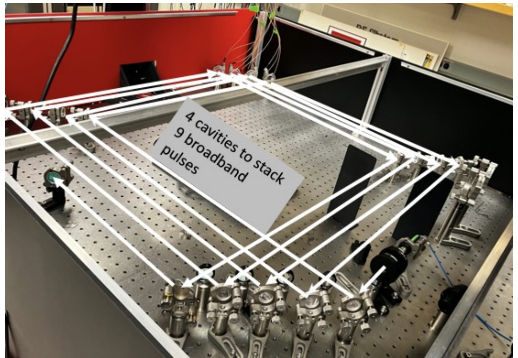
[1] Lawrence Berkeley National Laboratory, [2] Univ. of Michigan

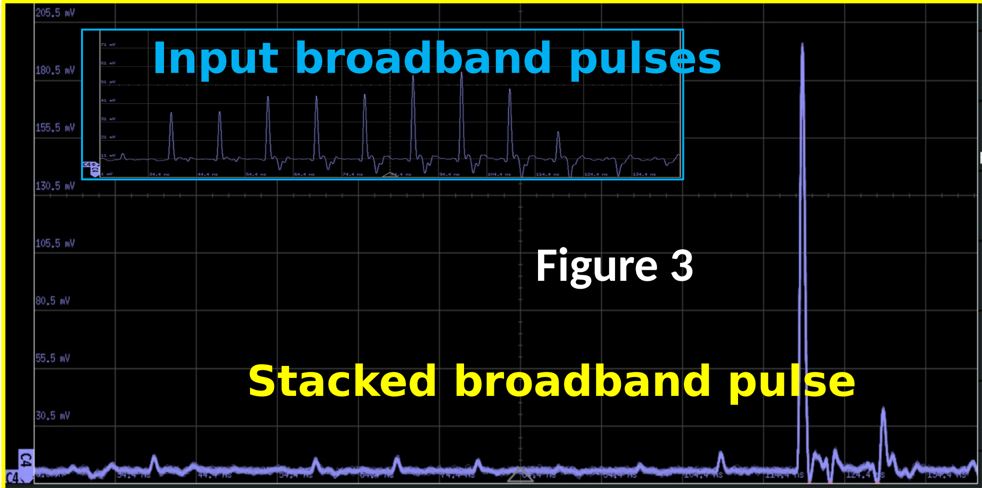
- Temporal pulse stacking is a key enabler of the fiber laser approach for driving laser plasma accelerators (1-50kHz, 3-300kW).
- Theory predicts efficient stacking of laser pulses as short as 30fs.
- We experimentally validate this prediction: demonstrate high efficiency stacking of 9, 50fs bandwidth pulses.



- **Background**
  - 30-100s fs laser pulse lengths are required for laser plasma accelerators (LPA)
  - Fiber laser approach needs to demonstrate stacking such short pulses
- **Theory**
  - Pulse stacking uses optical cavities -> Broadband pulses accrue different dispersion upon stacking -> Need to simulate the dispersion effects on stacking efficiency
  - With off-the-shelf, low-dispersion mirrors, efficient stacking of 81 pulses can be achieved with pulse lengths down to 30fs (**Figure 1**)!
- **Experiment**
  - 50fs bandwidth pulses were used in a 4-cavity, 9-pulse stacking setup (**Figure 2**)
  - High efficiency stacking was demonstrated with 30:1 pre-pulse contrast (**Figure 3)**

Figure 2:





Supported by DOE HEP & ARDAP, Moore Foundation

Ultra-broadband spectral combination of fiber lasers with synthesized pulse shaping to reach short pulse lengths for plasma accelerators

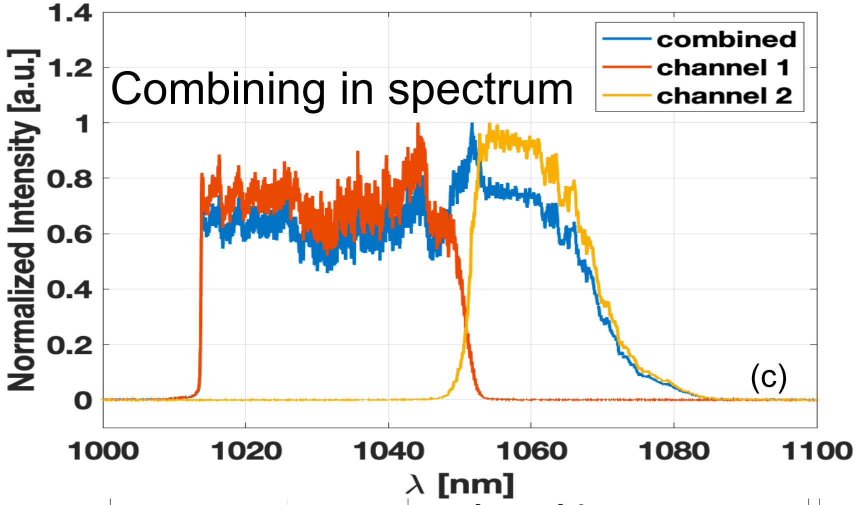
Siyun Chen, Qiang Du, Dan Wang, Jeroen van Tilborg, Carl Schroeder, Eric Esarey, Derun Li, Cameron Geddes, Russell Wilcox, Tong Zhou
Lawrence Berkeley National Laboratory

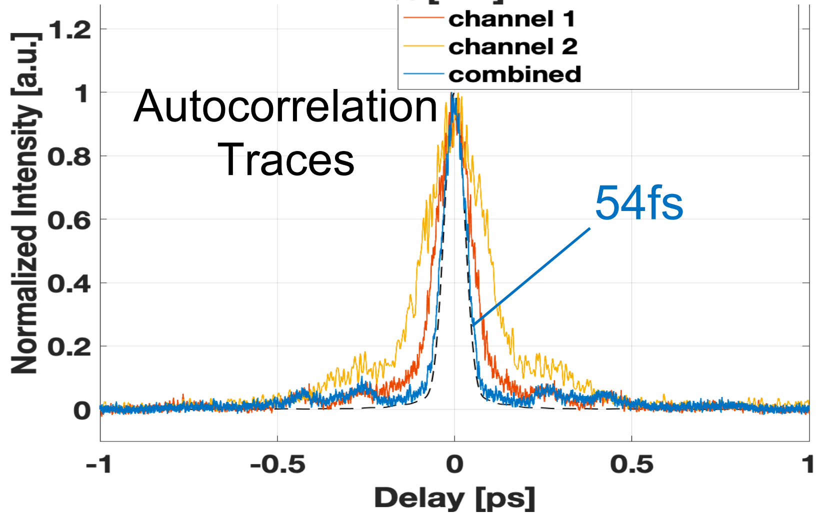
Background:
- Spectral combining of fiber lasers, together with spatial and temporal combining, provide a path to 30-50 fs, multi-Joule, 100's kW lasers for driving plasma accelerators.
- Prior Art: the shortest laser pulse from 1-micron fiber lasers was 130-fs without spectral combining, and 100-fs with spectral combining.
- Need to demonstrate spectral combining to generate 30-50 fs pulses.

Proof of principle experiment:
- Achieved 54-fs pulses (70nm bandwidth) from 2-channel spectral combining.
- 54fs is the shortest pulse duration from a spectrally-combined fiber laser at 1-micron.
- This is the first demonstration of spectral synthesis of pulse shapers, key approach to achieve short pulses.

Latest:
- Achieved >80nm bandwidth combining 3 spectral channels.
- Expect to demonstrate <40fs pulses.

- Supported by DOE HEP, DOE ARDAP, Moore Foundation





BERKELEY LAB
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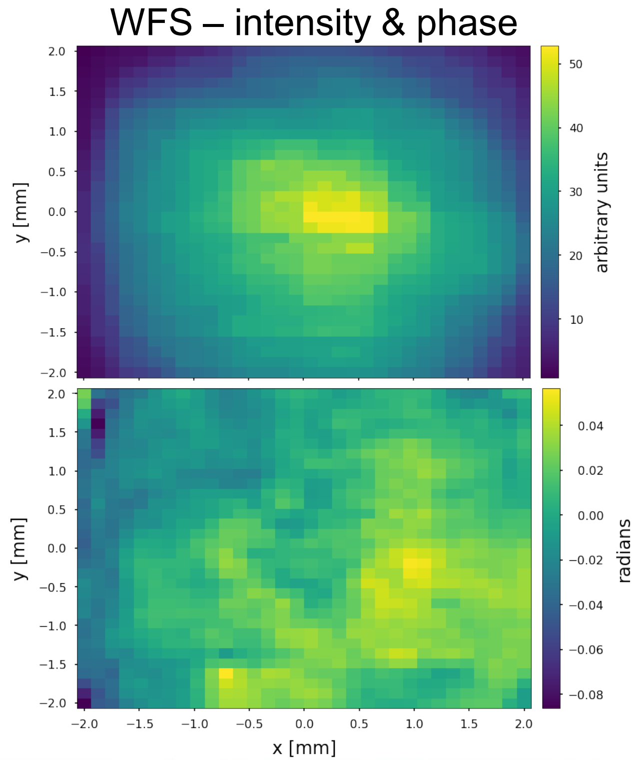
U.S. DEPARTMENT OF ENERGY | Office of Science

Simulation of electromagnetic pulses through high-power solid state laser amplifiers

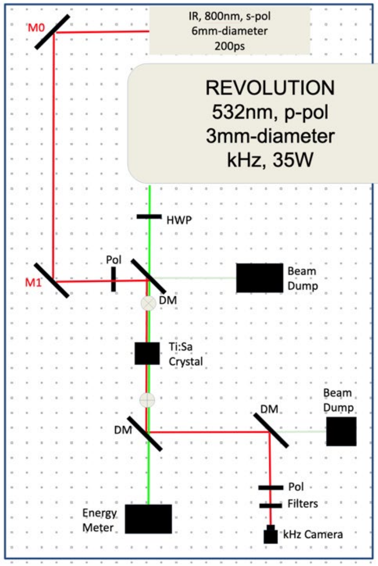
David L. Bruhwiler,* Boaz Nash, Dan T. Abell, Gurhar Khalsa and Robert Nagler (RadiaSoft)

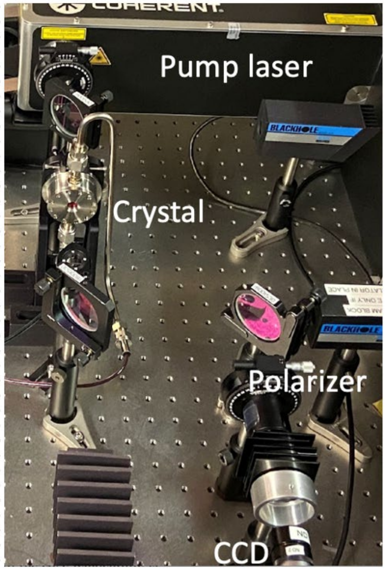
Jeroen van Tilborg, Qiang Chen, Csaba Tóth, and Cameron G.R. Geddes (LBNL)

Nicholas B. Goldring (STATE33 Inc.)



- PW lasers are moving toward KHz rep rates
  - software is needed for crystal amplifiers
  - Python library, https://github.com/radiasoft/rslaser/
  - Sirepo.com UI is being developed to support these capabilities
- Experiments at the BELLA Center enable validation
  - experimentally observed thermal focusing at 1 KHz is stronger than expected
  - possible explanations are being explored





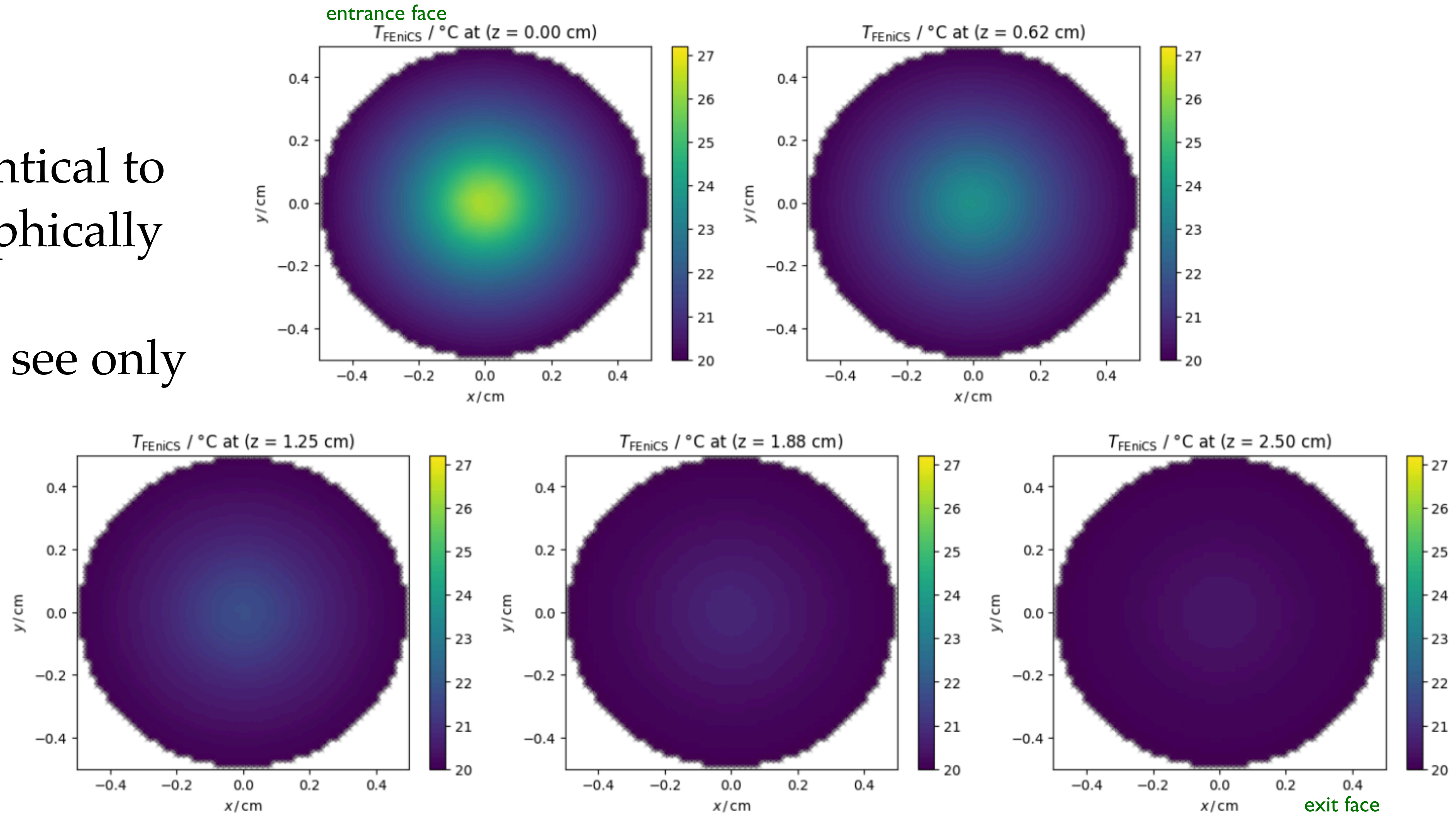
Thermal Modeling and Benchmarking of Crystalline Laser Amplifiers

At high power/intensity, thermal gradients can induce thermal lensing, astigmatism, and thermal bulging, as well as modify the birefringence.

Nonlinear heat equation: $\dot{u} = \nabla\cdot\left(\underbrace{\frac{\kappa(\theta)}{\rho(\theta)c_p(\theta)}}_{\alpha(\theta)\to\alpha(u)}\nabla u\right) + \frac{\kappa}{(\rho c_p)^2}\frac{\partial\rho}{\partial\theta}|\nabla u|^2 + \frac{1}{\rho}\dot{\varepsilon}(\vec{r},t)$

Use specific heat capacity $c_p = \partial u/\partial\theta$ to connect u to θ.

- Near room temperature, these results appear nearly identical to those of the linear case. (Temperature lineouts appear graphically identical.)
- At an $\times 5$ power level—but still room temperature—we see only mild difference between the linear and nonlinear cases.



Lessons Learned: Obtain thermal data characteristic of *your* crystal.

Next Steps: Explore cryogenic temperatures, anisotropic heat conduction, and thermal expansion.

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

9.3 microns

Toward next-generation CO_2 laser for particle accelerators

Misha Polyanskiy, Igor Pogorelsky, Marcus Babzien,
Rotem Kupfer, William Li, Mark Palmer

2022-11-10

AAC, Long Island, NY

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

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State of the art: 5 TW @ 9.2 µm, 2 ps

- Solid-state seed (µJ)
- High-pressure, mixed-isotope CO_2 amplifiers
- CPA

Next gen: 25 TW, @ 9.3 µm, 100 fs

- Solid-state seed **mJ**
- Post-compression
- *Optical pumping (next-next gen)*

Status and prospects of optically pumped high-pressure CO_2 amplifiers

Sergei Tochitsky, Dana Tovey, Jeremy Pigeon, Chan Joshi
Department of Electrical Engineering, UCLA

Igor Pogorelsky, Mikhail Polyanskiy
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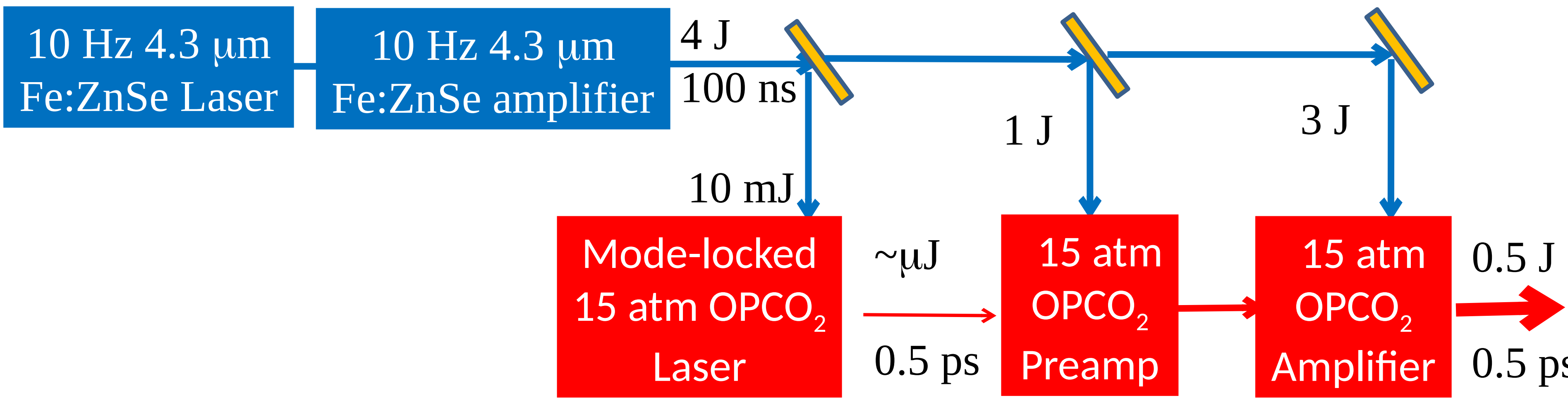
UCLA

Compact OP CO_2 TW Laser



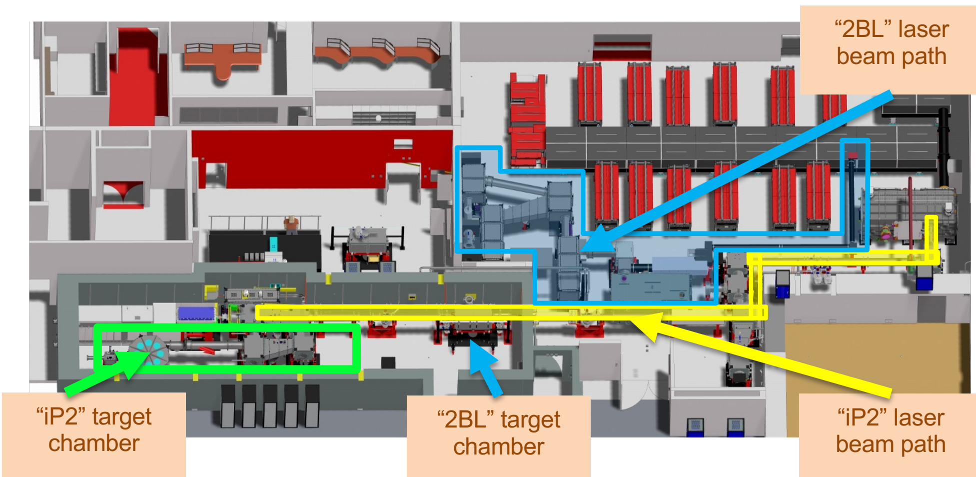
+++) Table-top electrical discharge-free compact TW LWIR laser system is suitable for advanced accelerators and self-guiding in air over kms.

+++) Optical-to-optical conversion efficiency 0.1-0.4 is far above any state-of-the-art LWIR OPA.

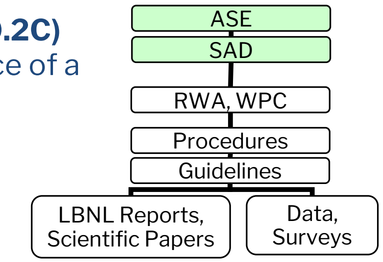
- - -) Laser hysics of Optically Pumped high-pressure CO_2 medium needs to be studied.

Optically pumped high-pressure CO_2 lasers can be the game changer in LWIR USP:100 ns pump and 0.3-3 ps LWIR pulse

The BELLA PW 2BL and iP2 beamline upgrades – enhanced with recently commissioned laser & radiation protection systems – enable new experiments in LPA staging and in strong field physics



DOE Accelerator Safety Order (ASO 420.2C) requires the development and maintenance of a Safety Assessment Document (SAD), Accelerator Safety Envelope (ASE), established Credited Controls, and continuous Safety Assurance process



The combined "laser & radiation" Personnel Protection System (PPS) consists of old and newly-installed interlocked gamma and neutron monitors, and laser shutters. The PPS ensures that the dose rate outside of the target caves never goes beyond the regulation limit of 5 mrem/h.

The DOE regulated planning, design, and implementation includes:

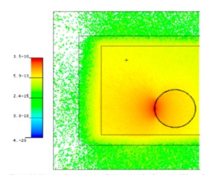
a) analysis of hazards (originated from new beam paths)

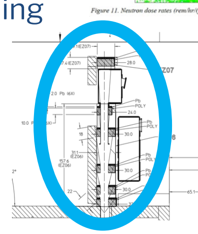
b) development of hazard mitigation strategies (new shielding components, laser shutters and interlocked monitors)

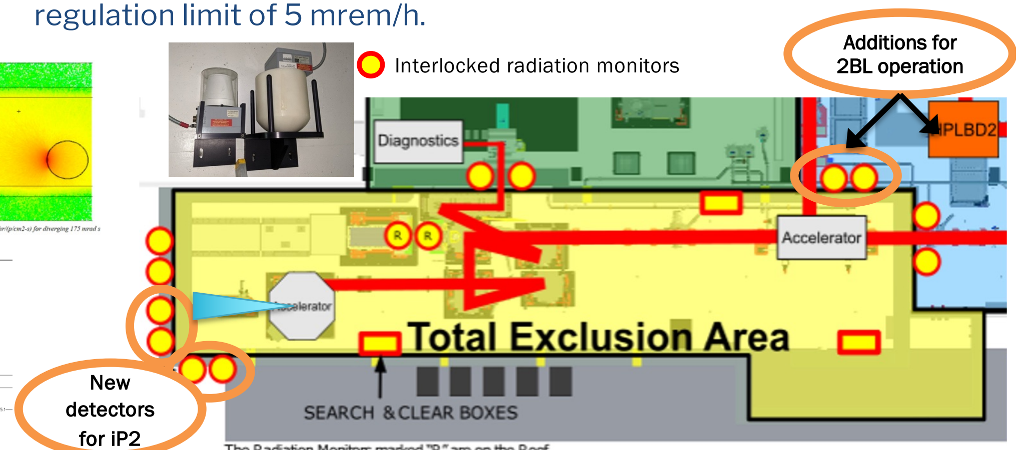
c) clear separation and control of low- and high-energy operation modes (LAM vs. HEM); online telemetry

d) configuration control and commissioning procedures

e) rigorous training and periodic checks of safety systems







AAC 2022

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

Igor Pogorelsky (ATF)

co-authors: M. Babzien, M. Fedurin, W. Li, M. N. Polyanskiy and M. A. Palmer (ATF)
N. Vafai-Najafabadi (Stony Brook University)

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The Accelerator Test Facility

ATF Current Capabilities & Potential Upgrade Paths

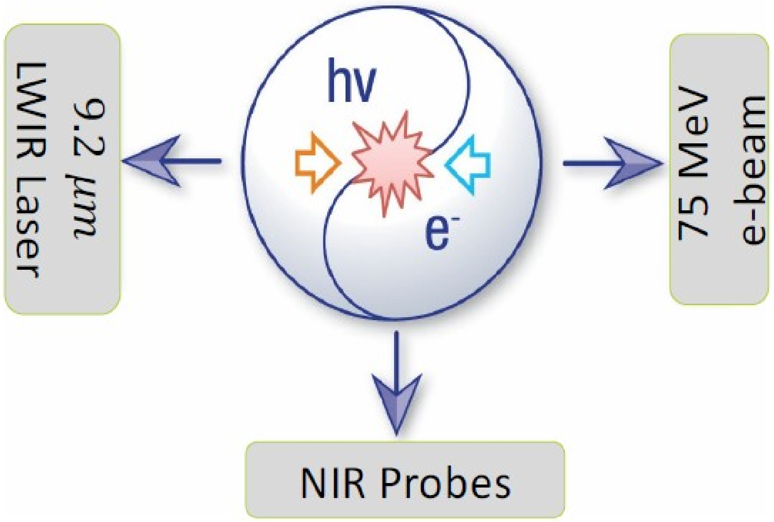
Current Capability

5 TW, 2 ps CO_2 laser pulses at the output of the final amplifier, up to 2.5 TW delivered to users

Upgrades

Current Efforts: 5 TW delivered to users

3 Year Goal: 10-20 TW of CO_2 laser power with sub-ps pulse length delivered to users



Current Capability

0.1-2 nC, pulse length down to ~ 100 fs, ϵ_n~1 mm-mrad, repetition rate of 1.5 Hz

Future Upgrade

3 Year Goal: Bunch length ~ 30 fs

Desired Upgrades: energy to ~ 125 MeV, T-CAV on both user beam lines

Current Capability

Nd:YAG: 1-5 mJ, 1-15 ps pulse length delivered

Ti:Sapphire: 15 mJ, ≤100 fs pulses delivered

Commissioning underway

Ti:Sapphire: 100 mJ energy upgrade

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