Matter in Extreme Conditions

At LCLS

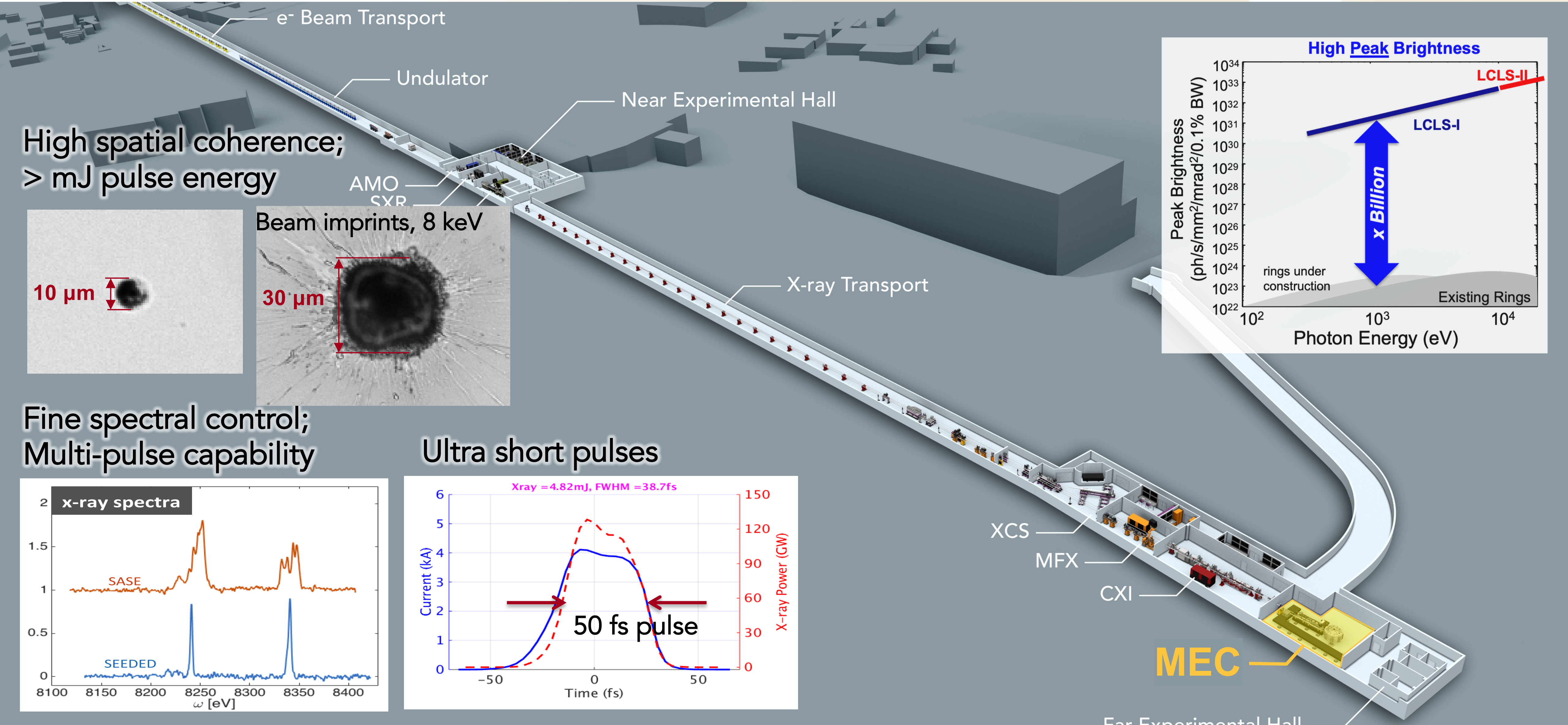
Gilliss Dyer

Department Head, MEC

DyCoMaX Workshop

January 14, 2021

LCLS is a powerful tool for high energy density science



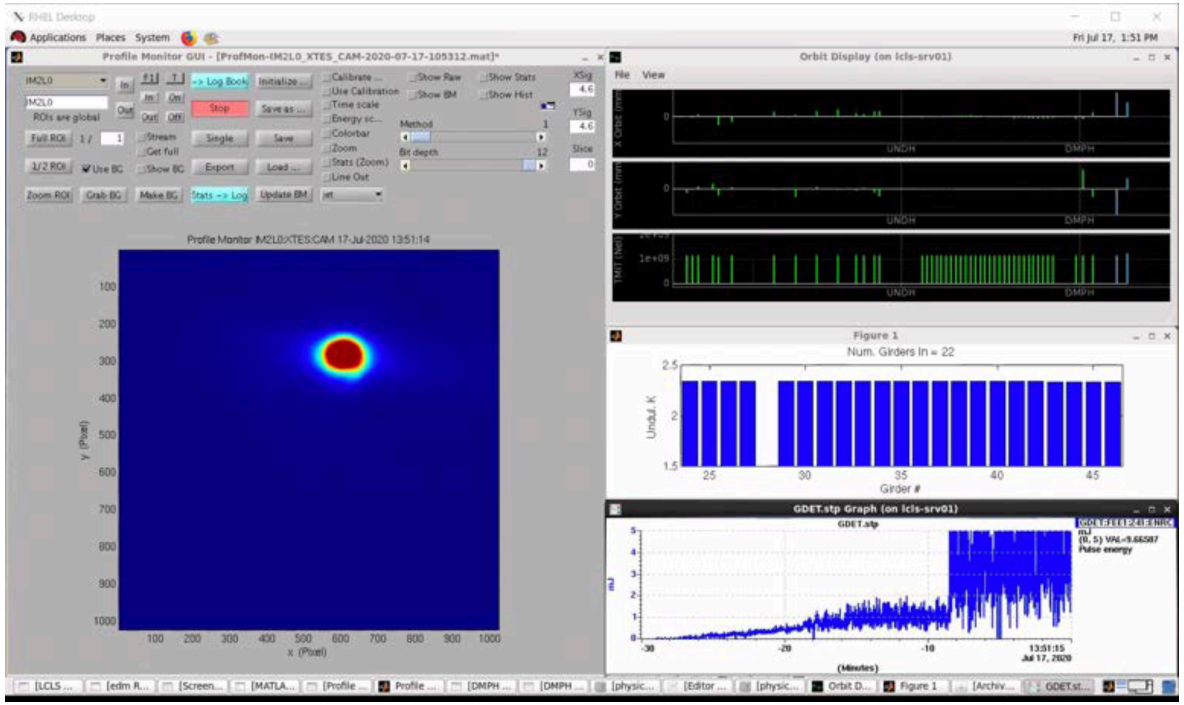
LCLS's long downtime was made even longer by 2020

Start LCLS-II down

10th anniversary

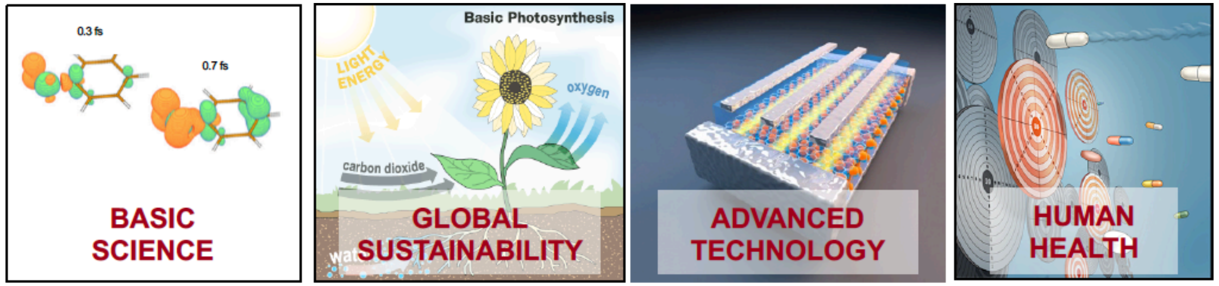
Scheduled restart

Actual restart

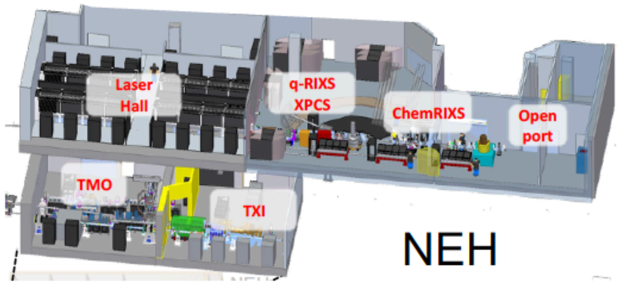


17 July, 2020: First HXU light

LCLS is currently engaged in three major project efforts

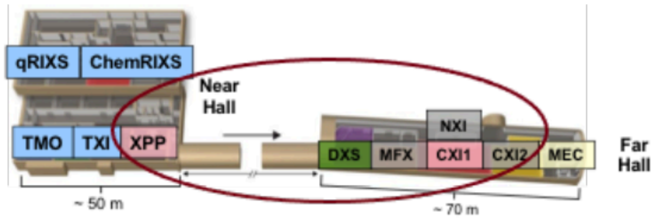


Soft X-ray (LCLS-II)



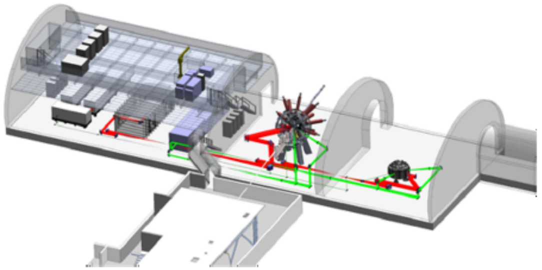
- Atomic physics
- Photo-catalysis
- Surface chemistry
- Quantum materials
- Single Particle Imaging
- Nonlinear X-ray science

Hard X-ray (LCLS-II-HE)



- Complex materials
- Semiconductors
- Biological function & dynamics
- Chemical catalysis
- Gas phase chemistry
- Quantum materials

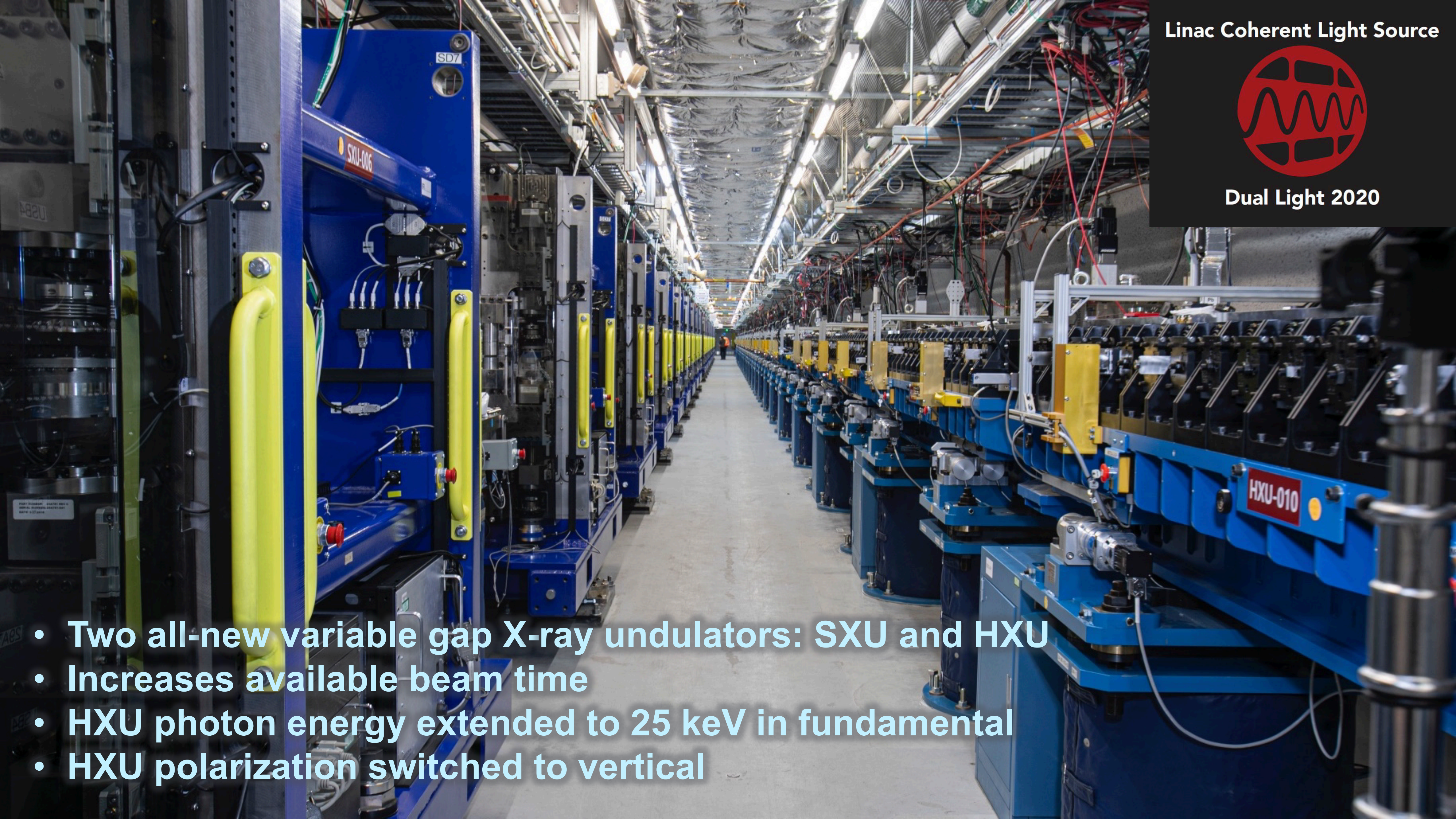
MEC Upgrade



- Plasma physics
- High field science
- Extreme materials
- Lab astrophysics

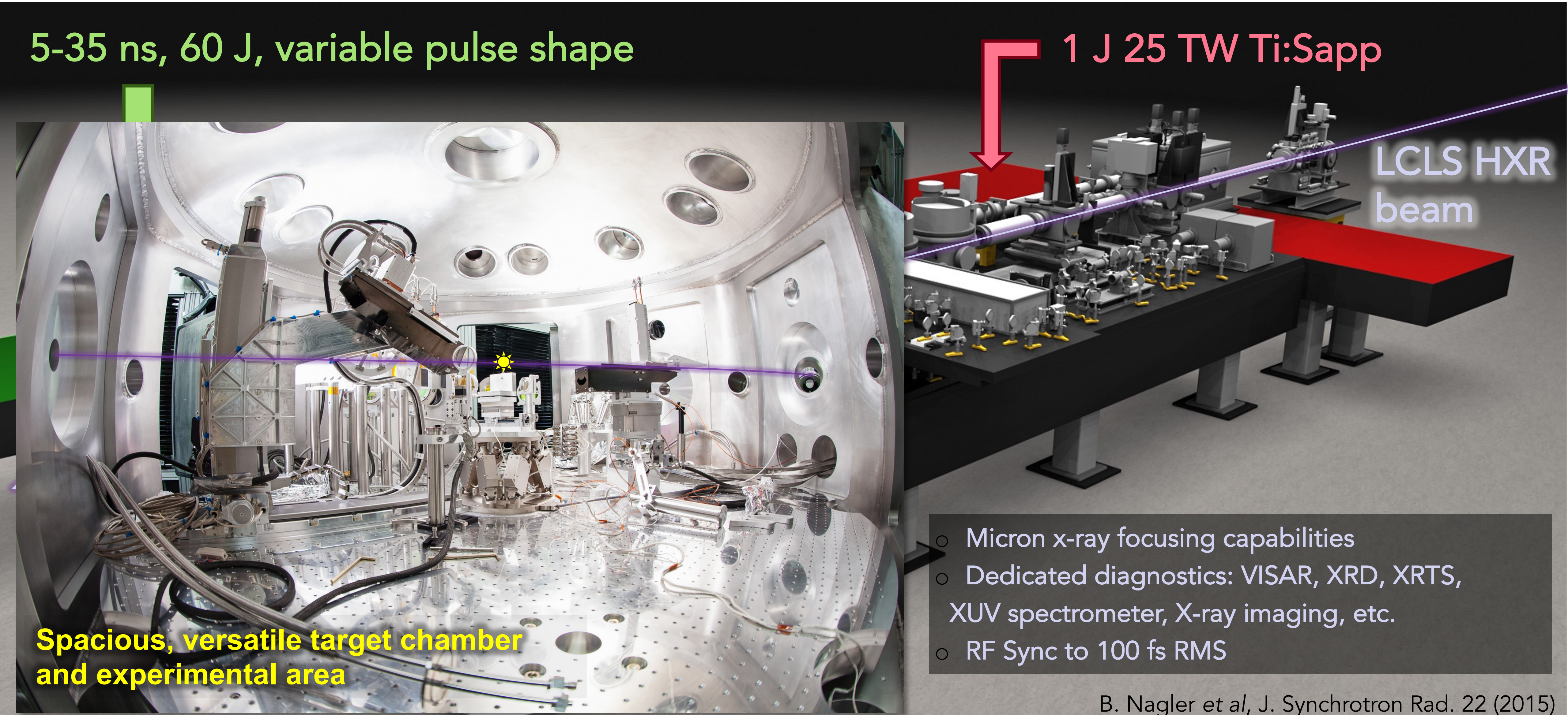
Linac Coherent Light Source

Dual Light 2020



- Two all-new variable gap X-ray undulators: SXU and HXU
- Increases available beam time
- HXU photon energy extended to 25 keV in fundamental
- HXU polarization switched to vertical

MEC combines the sub-micron focusable hard X-ray beam with high power and high energy lasers

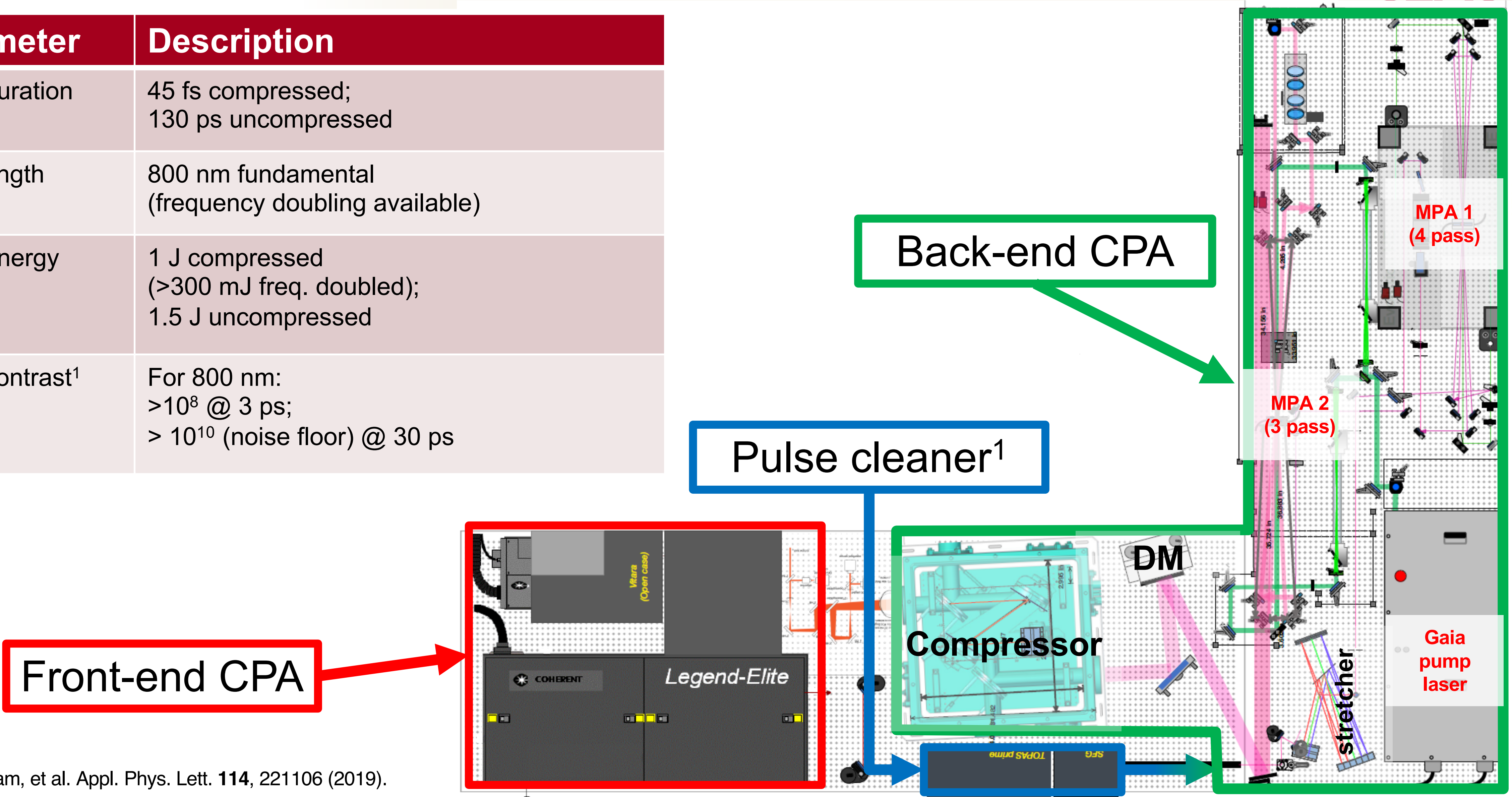


- Micron x-ray focusing capabilities
- Dedicated diagnostics: VISAR, XRD, XRTS, XUV spectrometer, X-ray imaging, etc.
- RF Sync to 100 fs RMS

B. Nagler *et al*, J. Synchrotron Rad. 22 (2015)

The short pulse laser is a double CPA Ti:Sapp system

Parameter	Description
Pulse duration	45 fs compressed; 130 ps uncompressed
Wavelength	800 nm fundamental (frequency doubling available)
Pulse energy	1 J compressed (>300 mJ freq. doubled); 1.5 J uncompressed
Pulse contrast[1]	For 800 nm: $>10^8$ @ 3 ps; $> 10^{10}$ (noise floor) @ 30 ps



[1]E. Cunningham, et al. Appl. Phys. Lett. **114**, 221106 (2019).

The long pulse laser delivers two high energy beams

50 mm glass amp

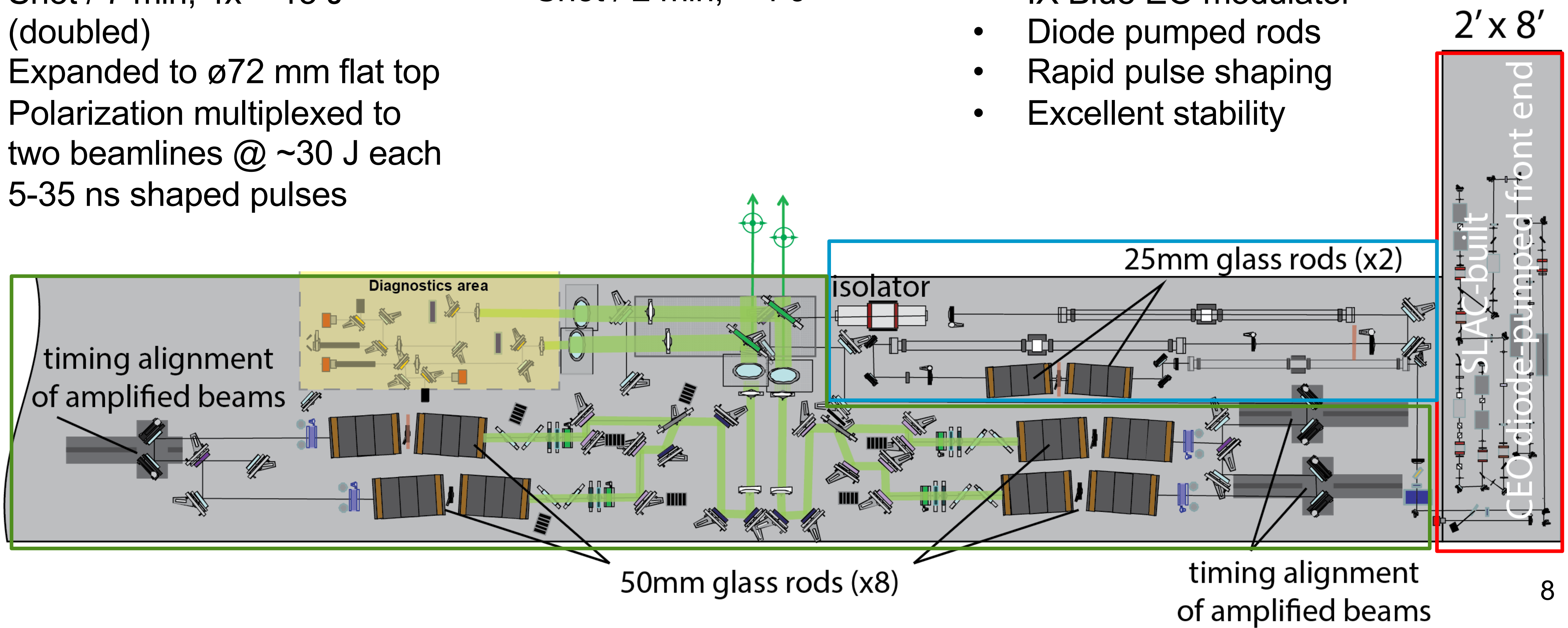
- Flashlamp pumped
- Shot / 7 min, 4x ~ 15 J (doubled)
- Expanded to ø72 mm flat top
- Polarization multiplexed to two beamlines @ ~30 J each
- 5-35 ns shaped pulses

25 mm glass amp

- Flashlamp pumped
- Shot / 2 min, ~ 1 J

Diode pumped front end

- Highland waveform gen.
- IX Blue EO modulator
- Diode pumped rods
- Rapid pulse shaping
- Excellent stability



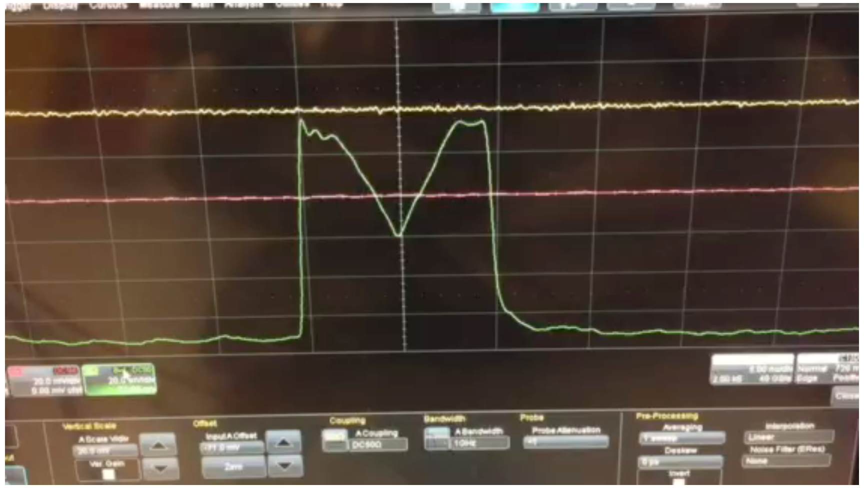
Developments to pulse shaping algorithms and monitoring are moving towards user control

From upgrade project:

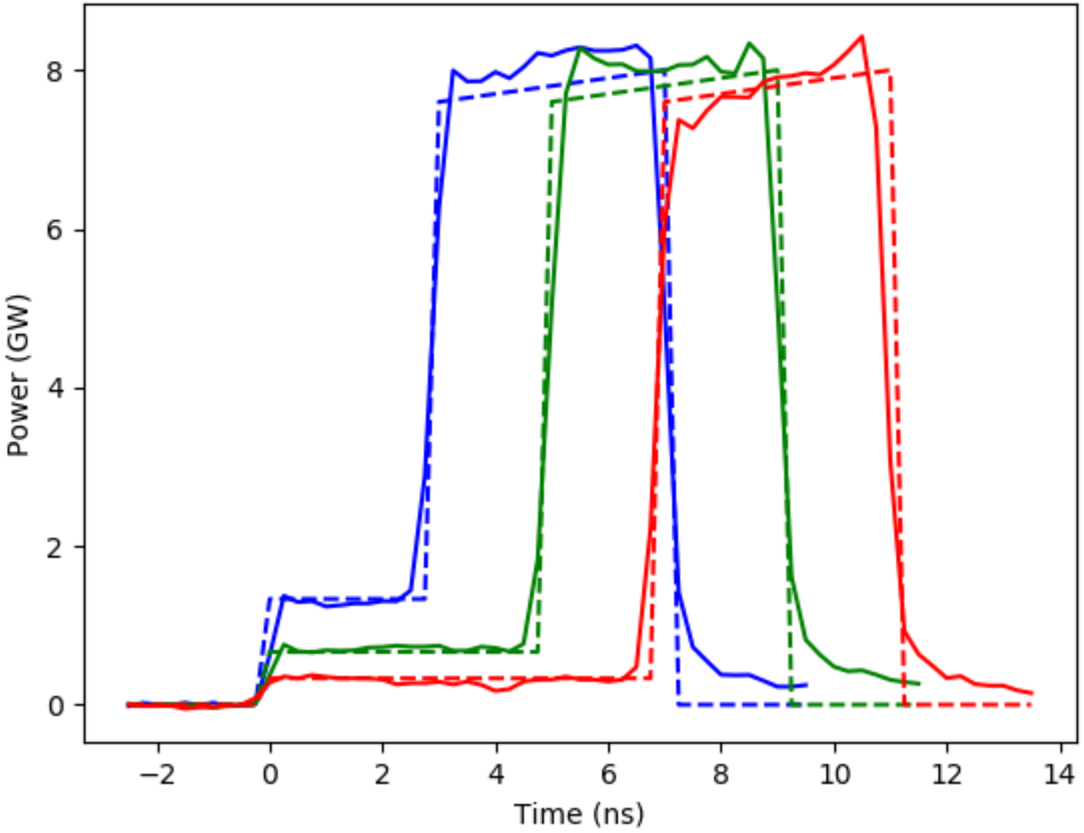
- NIF-guided architecture
- Diode pumped front-end

Development since:

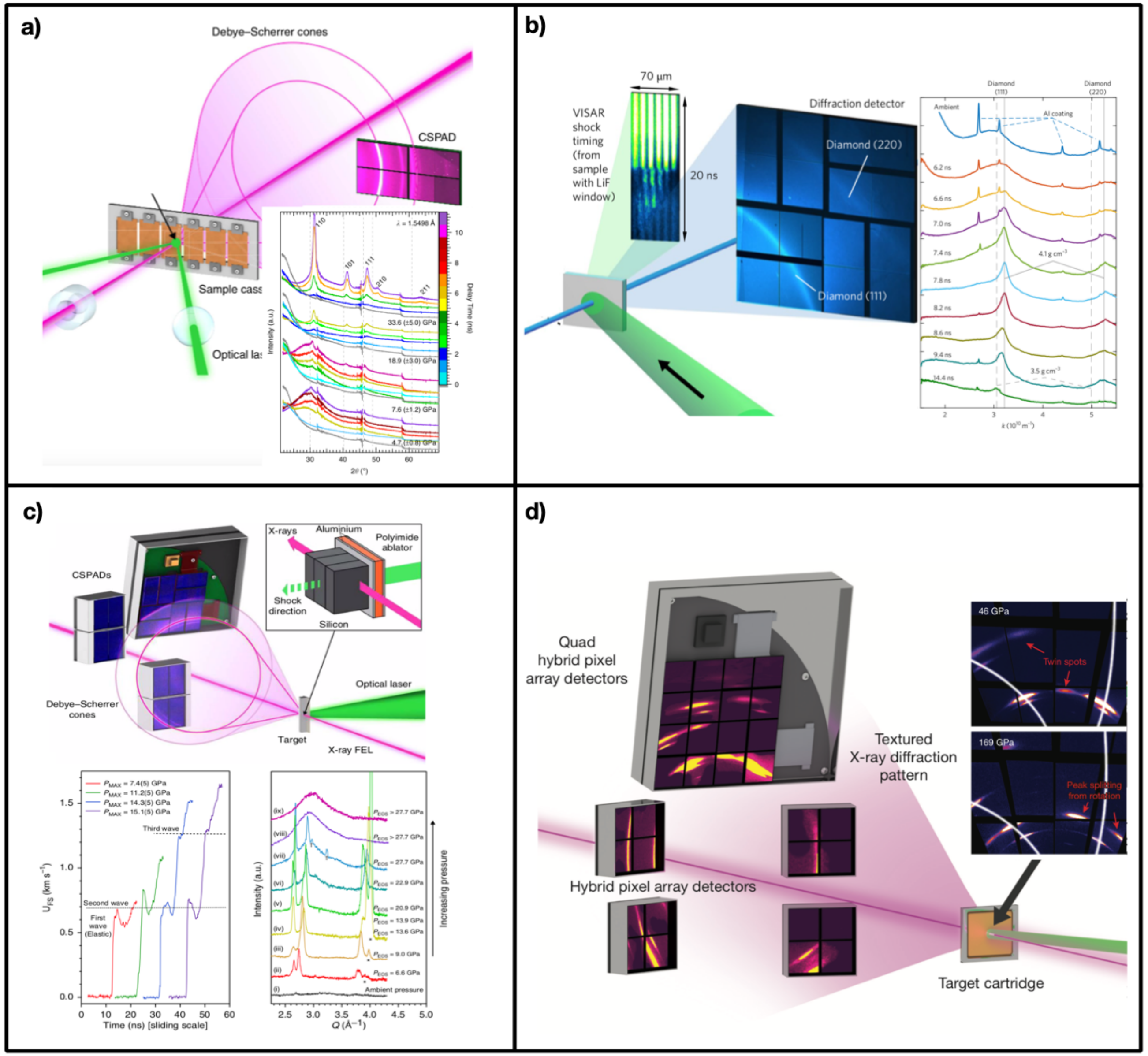
- Smarter algorithms
- More thorough diagnostics



Example delivered pulses



X-ray diffraction of shocked materials has been central to many high-impact MEC user publications



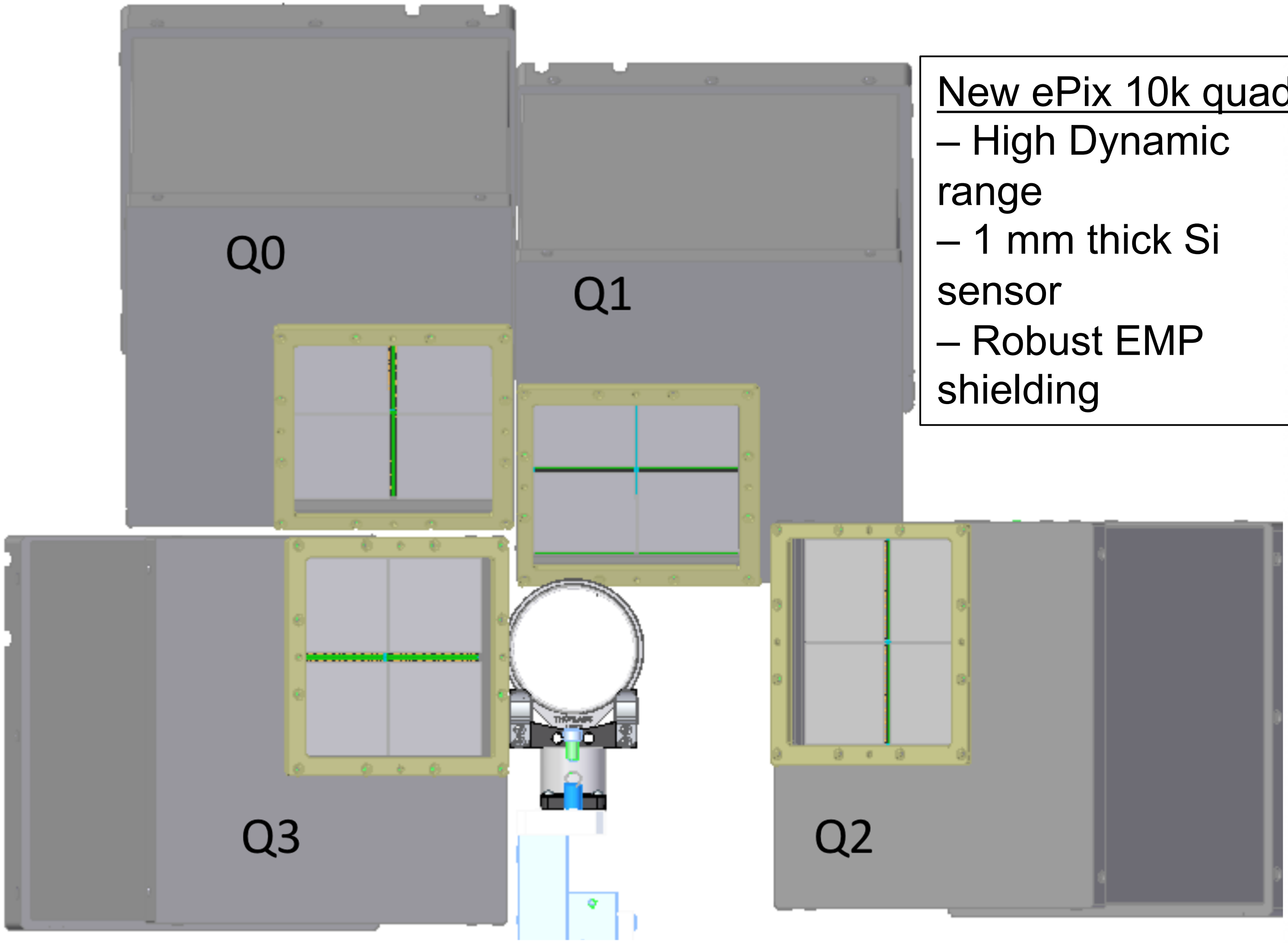
A. Gleason et al., Nature Communications. (2015)
Ultrafast visualization of crystallization and grain growth in shock-compressed SiO2

D. Kraus et al., Nature Astronomy, (2017)
Formation of diamonds in laser-compressed hydrocarbons at planetary interior conditions

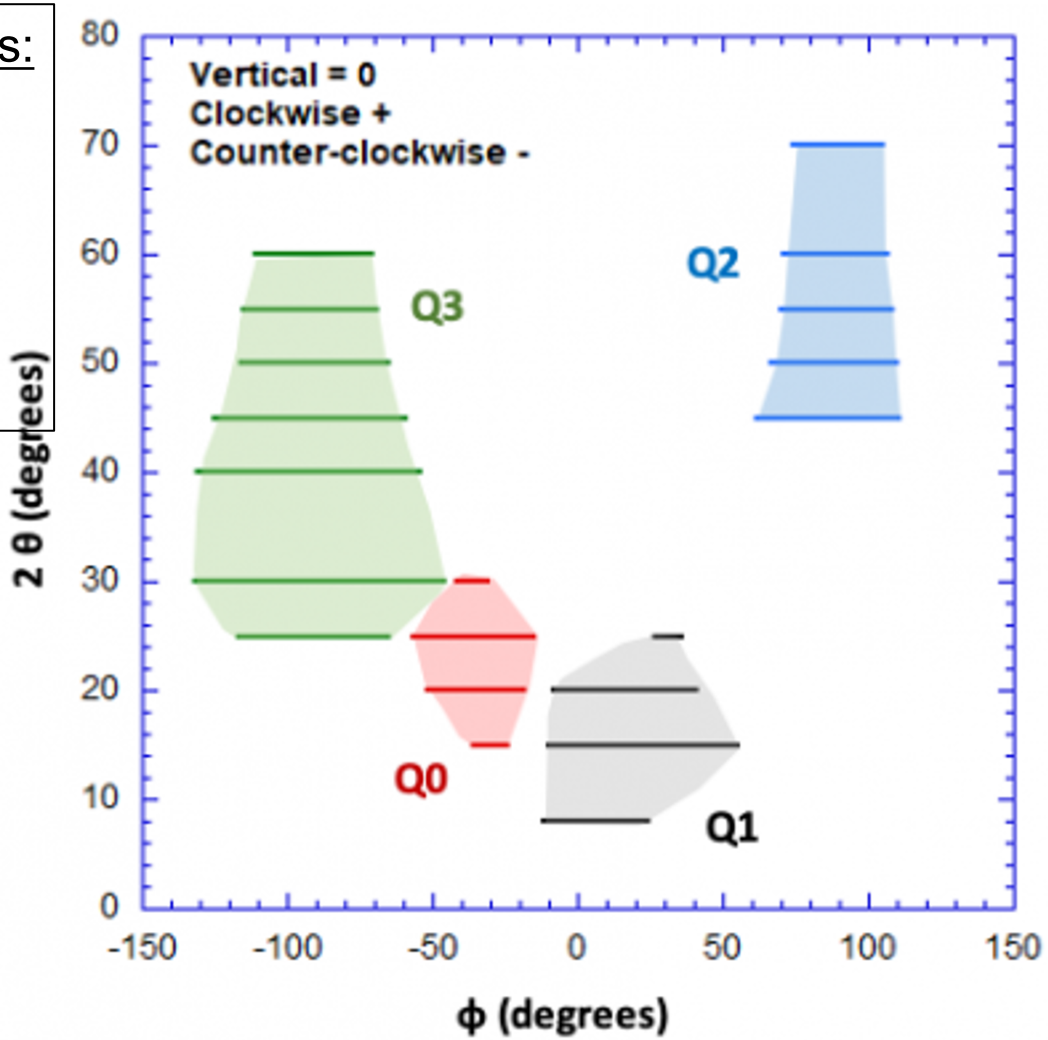
E. E. McBride et al. , Nature Phys. (2019)
Phase transition lowering in dynamically compressed silicon

C. E. Wehrenberg et al., Nature (2017) *In situ X-ray diffraction measurement of shock-wave-driven twinning and lattice dynamics*

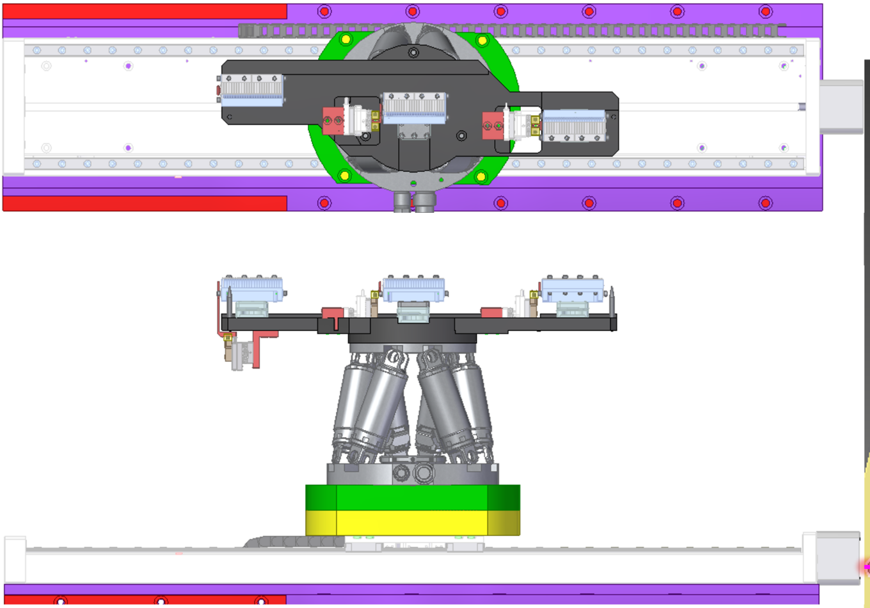
The XRD standard platform is optimized for liquid diffraction at high photon energy



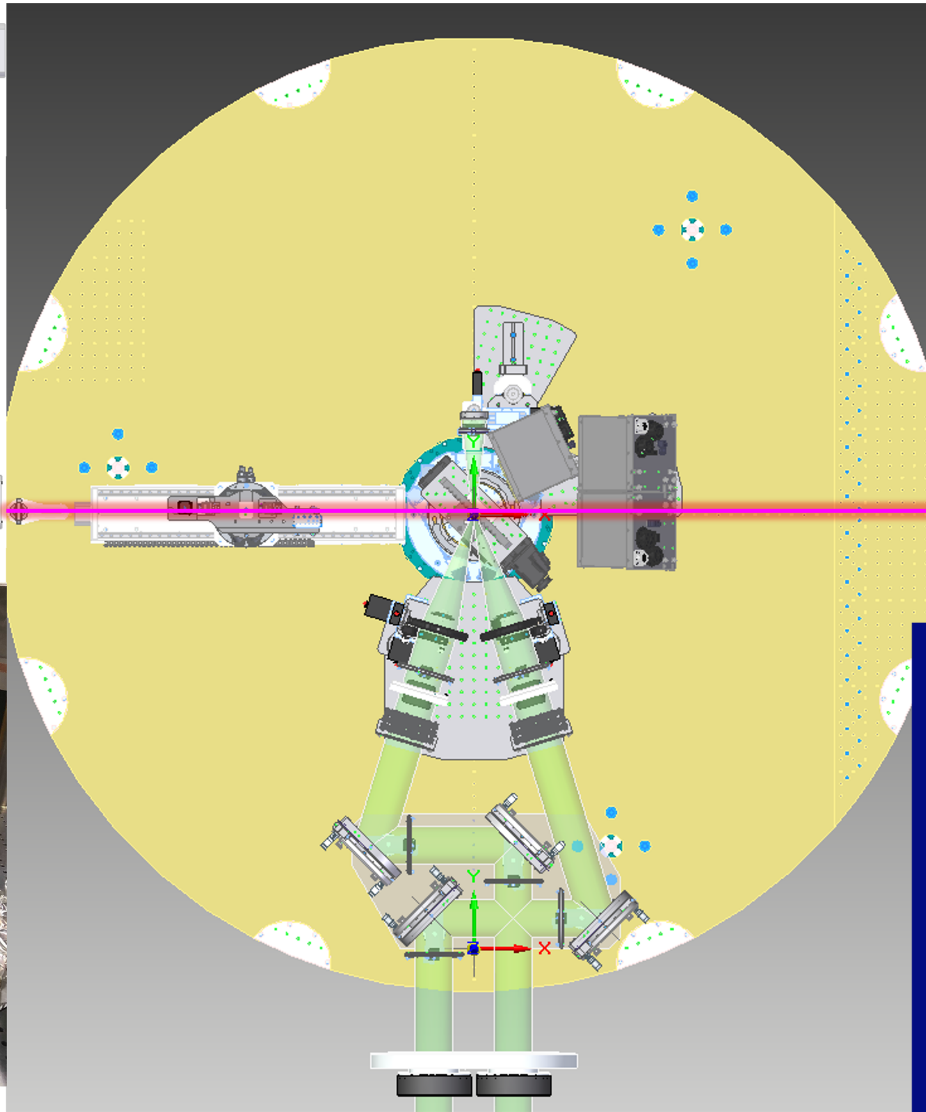
<u>New ePix 10k quads:</u>
– High Dynamic range
– 1 mm thick Si sensor
– Robust EMP shielding



We have deployed a new X-ray imaging system with a standard configuration for imaging



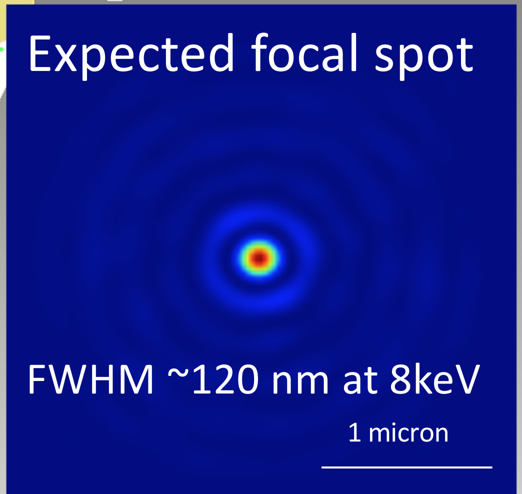
MXI



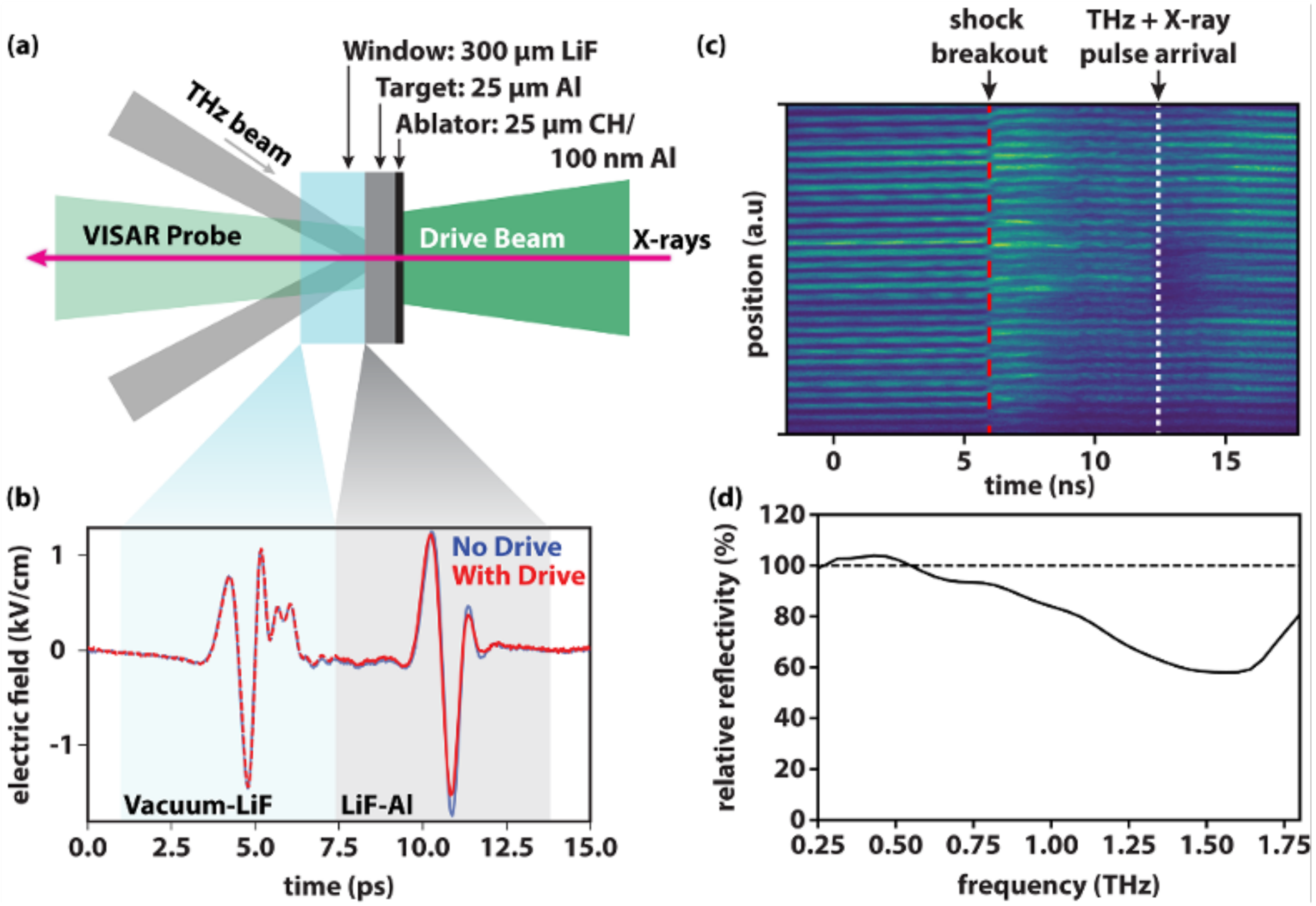
Compound refractive lenses with static phase correctors

Shown in phase contrast imaging arrangement

Option to use 3rd harmonic for diffraction on shot



Simultaneous measurement of THz and optical reflectivity, and X-ray diffraction and Thomson scattering on WDM



Reflectivity of the sample is related to the refractive index

$$\tilde{r} = \frac{\tilde{n}_2 \cos(\theta) - \tilde{n}_1}{\tilde{n}_2 \cos(\theta) + \tilde{n}_1}$$

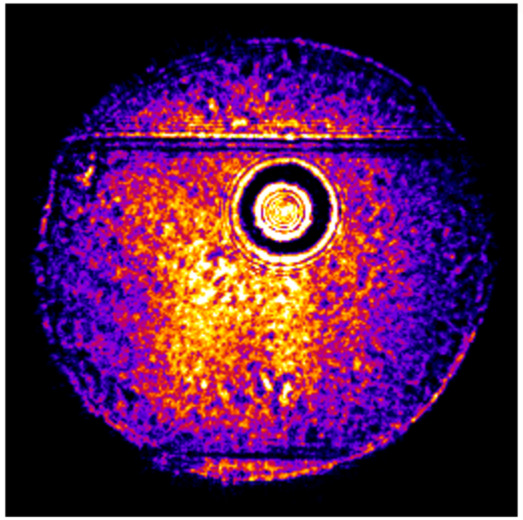
The refractive index is in turn used to calculate the conductivity

$$\tilde{\sigma}(\omega) = -i\omega\epsilon_0 \left[\tilde{n}_2^2(\omega) - 1\right]$$

First use of shock drive with short pulse-based probe enabled with the help of a LaserNetUS campaign

Preliminary results show a drop in reflectivity indicating a drop in conductivity.

Maiden voyage of Ultrafast X-ray Imaging (UXI) camera + LCLS pulse train -- compressive wave transiting a void sample

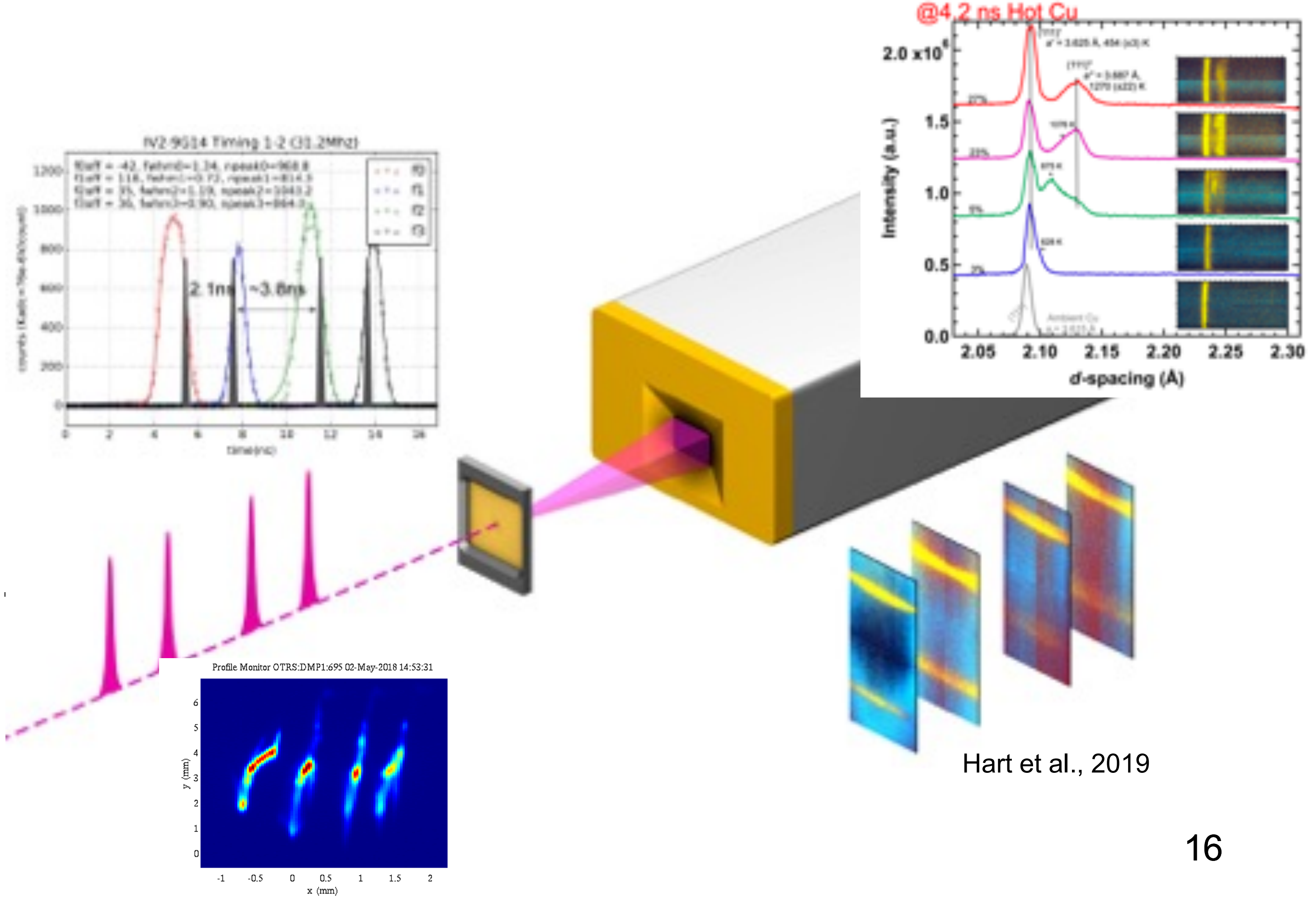


Preliminary results: 4-pulse train from LCLS at 8.2 keV probes single target during passage of compressive wave!

-Static (first frame) and 2 dynamic images from UXI detectors (last two frames had very low signal. Timing on frames is (1) preshot static, (2) nominal 0. ns delay, (3) 2.1 ns later, (4) 3.85 ns delay. Images are on same intensity scale and background subtracted.

Run 18 MEC (11/2020) Gleason et al. Team from SNL, LLNL, BYU, LANL, SLAC, Stanford Univ., U. Rochester

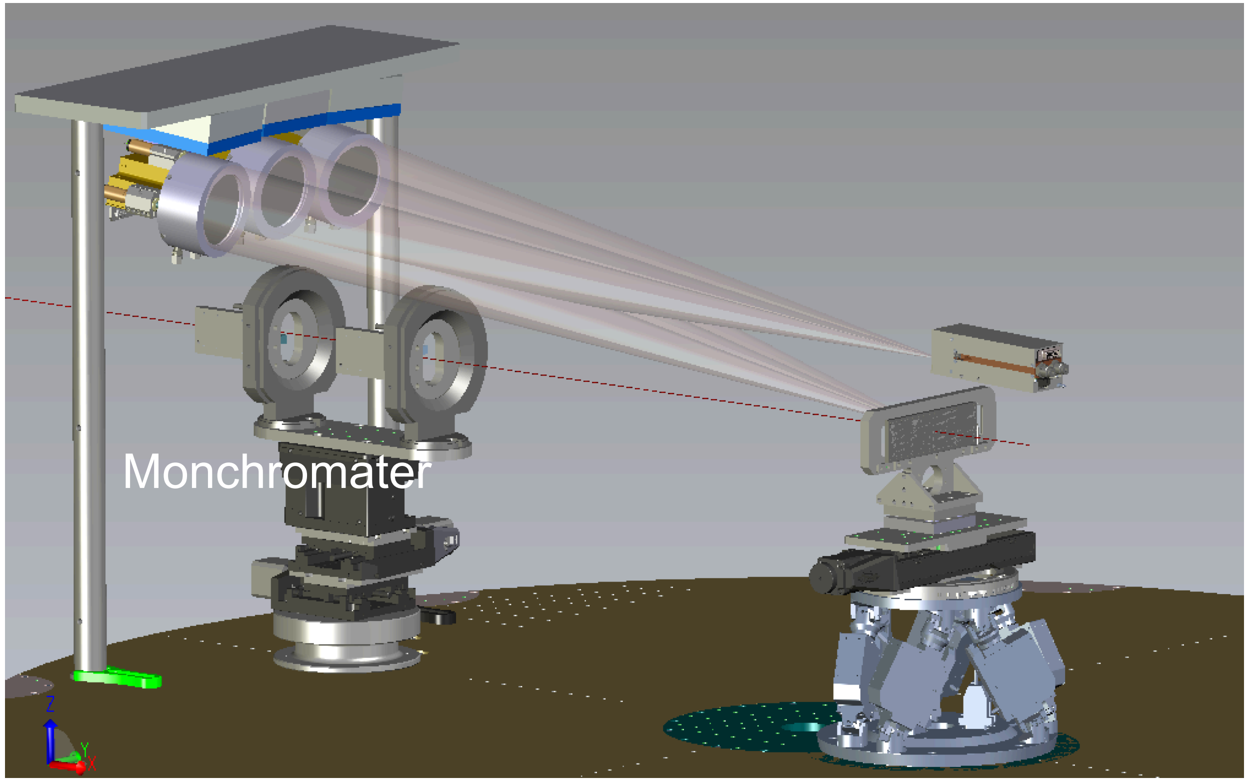
New gated detector deployed at LCLS in 2019 measures nanosecond Cu heating



Hart et al., 2019

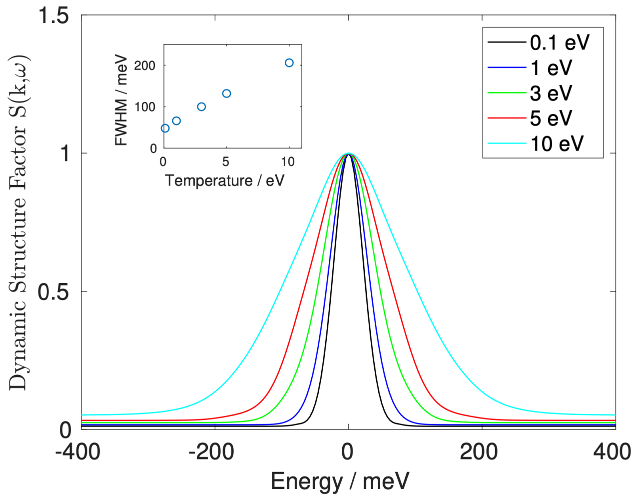
Electron-ion Equilibration and ion temperature measurement using high resolution scattering spectroscopy

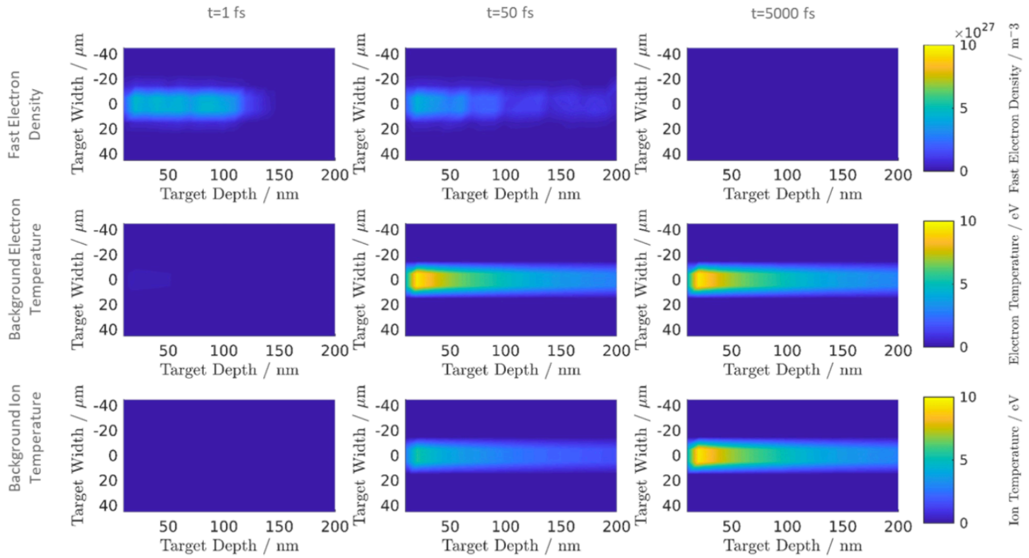
Si 533 Bartels type monochromator and
Diced Analyzer
(collaboration. with ESRF, EuXFEL)



T. White, A, H. J. Lee, E. Galtier, E. Cunningham, S. Glenzer, E. McBride, G. Gregory, G. Dyer, J. Hastings, U. Zastrau, K. Appel, S. Goede, S. Yunus, D. Khaghani, L. Fletcher, C. Sahle, G. Monaco, and B. Nagler, “”Electron-Ion equilibration in Warm Dense Gold”, in preparation, 2021.

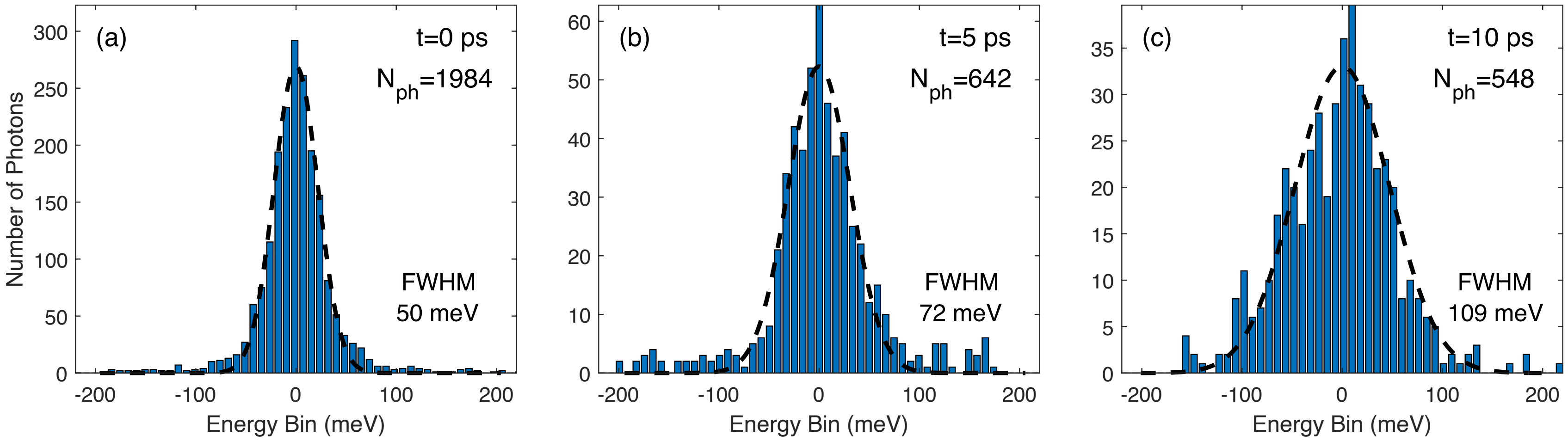
Electron-ion Equilibration and ion temperature measurement using high resolution scattering spectroscopy





Targets heated with frequency-doubled short pulse laser at a few mJ

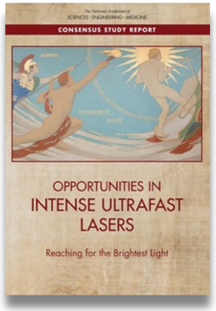
Preliminary data

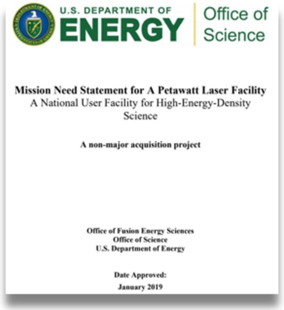


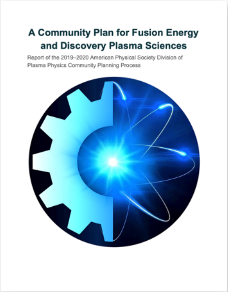
SLAC's vision for leadership in HED science: A versatile facility with world-class capabilities

SLAC

- In response to **National Academy of Sciences report**
- **Building on 7 years of user community consultation**
    - High Power Laser workshops
- **Strongly supported by HED science community**
    - Brightest Light Initiative (BLI) workshop, APS-DPP-CPP, Light Source Enhancements Workshop
- **Combine LCLS-II with 10x higher power (petawatt laser) and energy (kilojoule laser)** to enable extreme matter physics.
- **Designed to ensure long-term scientific leadership** with world leading capabilities and upgrade pathways







HPL workshops 2013-2019

The upgraded MEC facility at LCLS will position the FES program beyond any other XFEL in HEDS science capability

High-level performance requirements fulfill the FES mission

SLAC

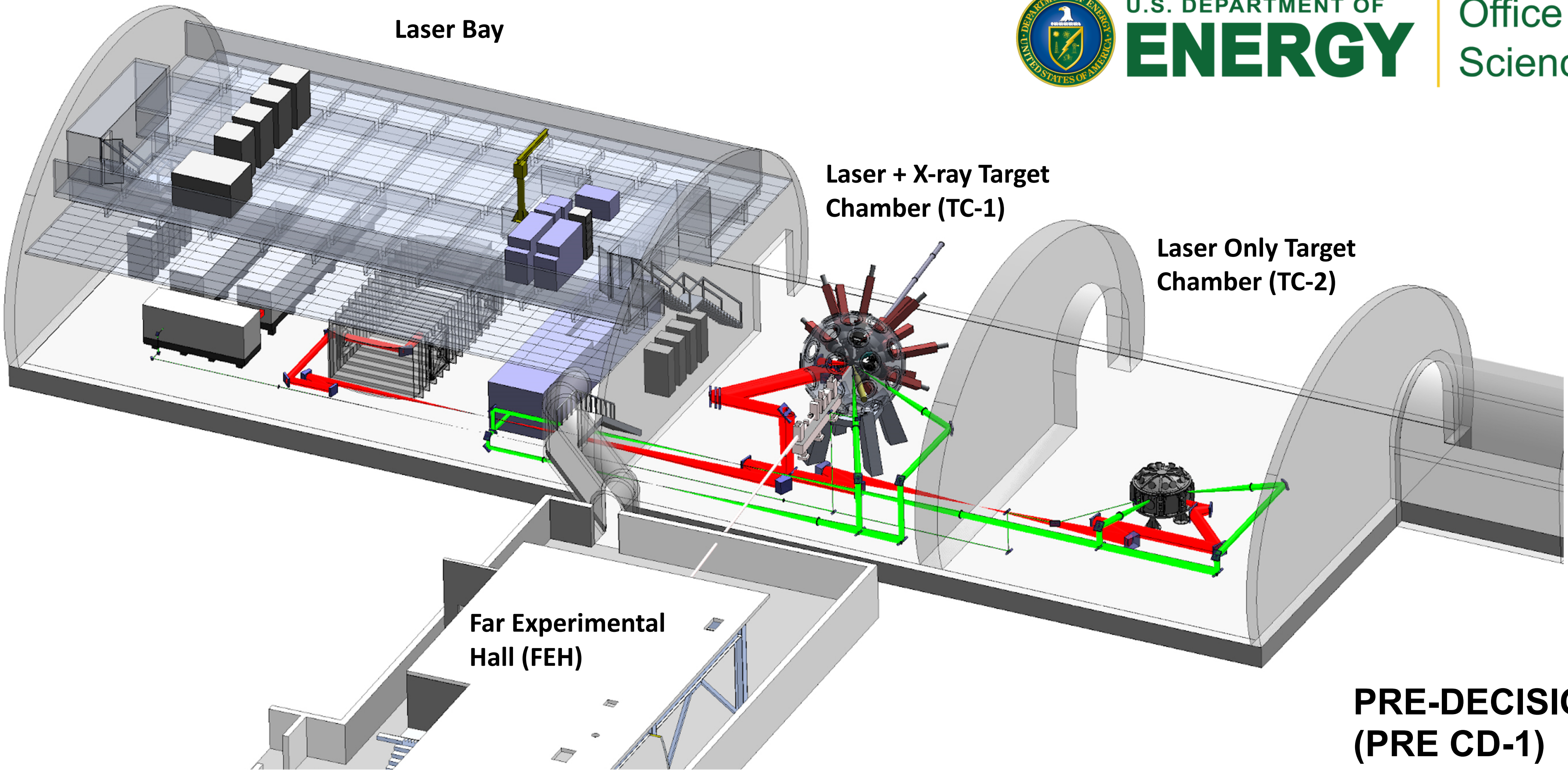
- **Independent cavern east of FEH**
- **Laser systems**
  - High rep-rate short pulse: 10 Hz, 150 J, 150 fs, 1 PW
  - High rep-rate long pulse: 10 Hz, 200 J @ 2ω @ 10ns; programmable pulse shape
  - High energy long pulse: ~2 shots/hour, > 1 kJ @ 2ω @ 10ns; programmable pulse shape
  - LCLS XFEL (5 to 45 keV)
- **X-ray + laser target chamber**
  - Beam delivery for laser systems and X-rays
  - Optimized to serve a broad plasma physics community (high experimental throughput, rapid reconfiguration, range of X-ray and laser illumination geometries and diagnostics)
- **Laser-only target chamber**
  - Beam delivery for laser systems
  - Optimized for flexibility, training, exploration, development

PRE-DECISIONAL (PRE CD-1)

MEC Upgrade: The Premier Facility for Laser Plasma Science

SLAC

U.S. DEPARTMENT OF ENERGY | Office of Science



PRE-DECISIONAL (PRE CD-1)