

High Energy Density Science at SLAC

Siegfried H. Glenzer (SLAC/Stanford)

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Presentation to:

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PATHWAYS AND PROGRESS TOWARD FUSION POWER



SLAC's fusion program is developing a new area of dense plasmas and extreme material science

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- SLAC's fusion program is a leader in fusion discovery science
 - World-class X-ray laser for scattering/diffraction on atomic scales
 - Cryogenic targets deliver precision through high-repetition rate (1m shots)
- Significant scientific output: 7 Nature papers, 5 Letters; examples:
 - The evolution of the ion feature in warm dense matter
 - Diamond formation from CH
- Unique opportunity for Fusion Material Science
 - Characterization of radiation damaged materials has begun
 - Laser upgrade to stay ahead of significant international competition

Our program is highly visible in the scientific community and is poised to deliver new understanding of radiation damage in fusion research

Linac Coherent Light Source at SLAC

X-FEL based on last 1-km of existing 3-km linac

1.5-15 Å
(14-4.3 GeV)

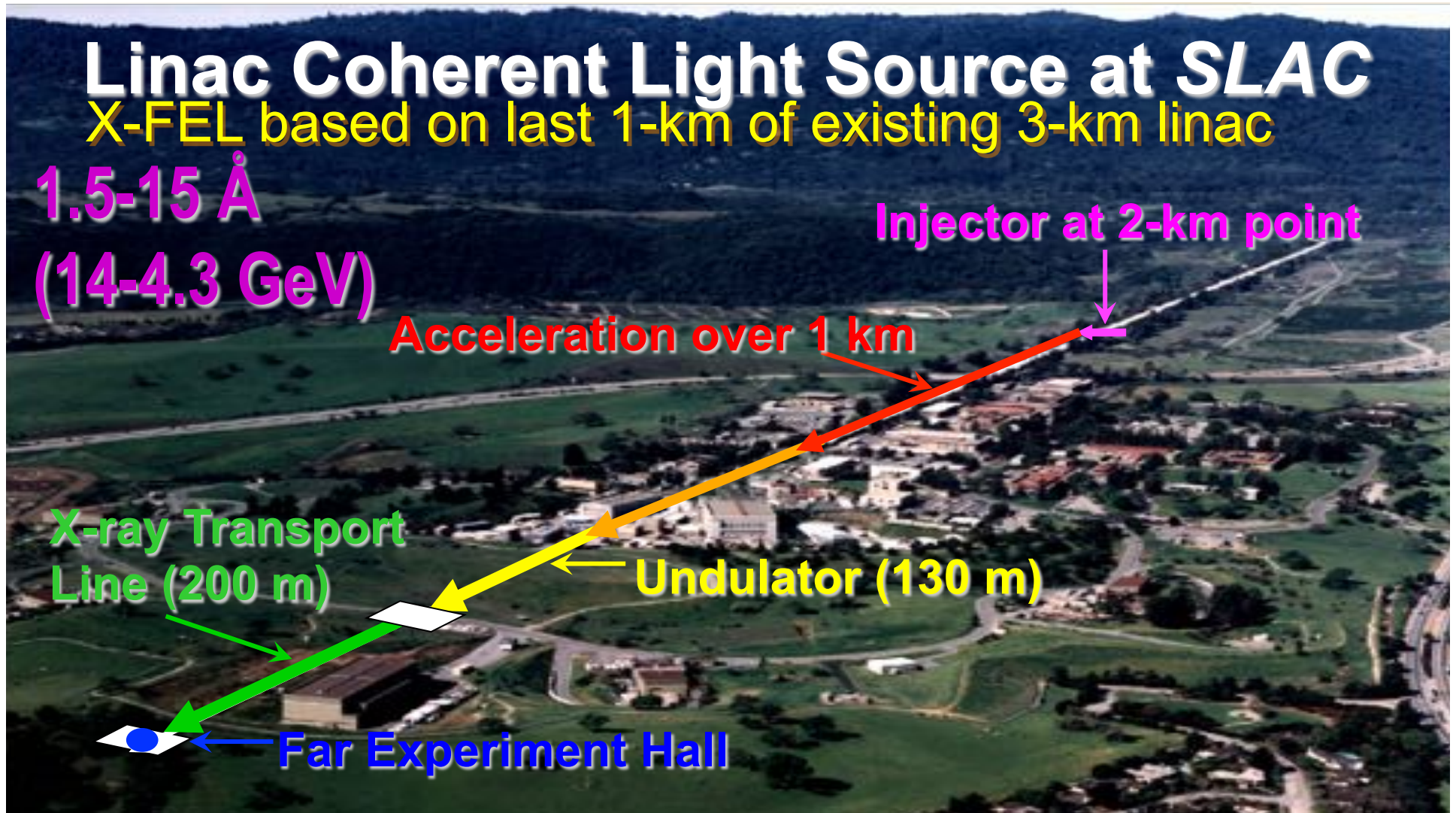
Injector at 2-km point

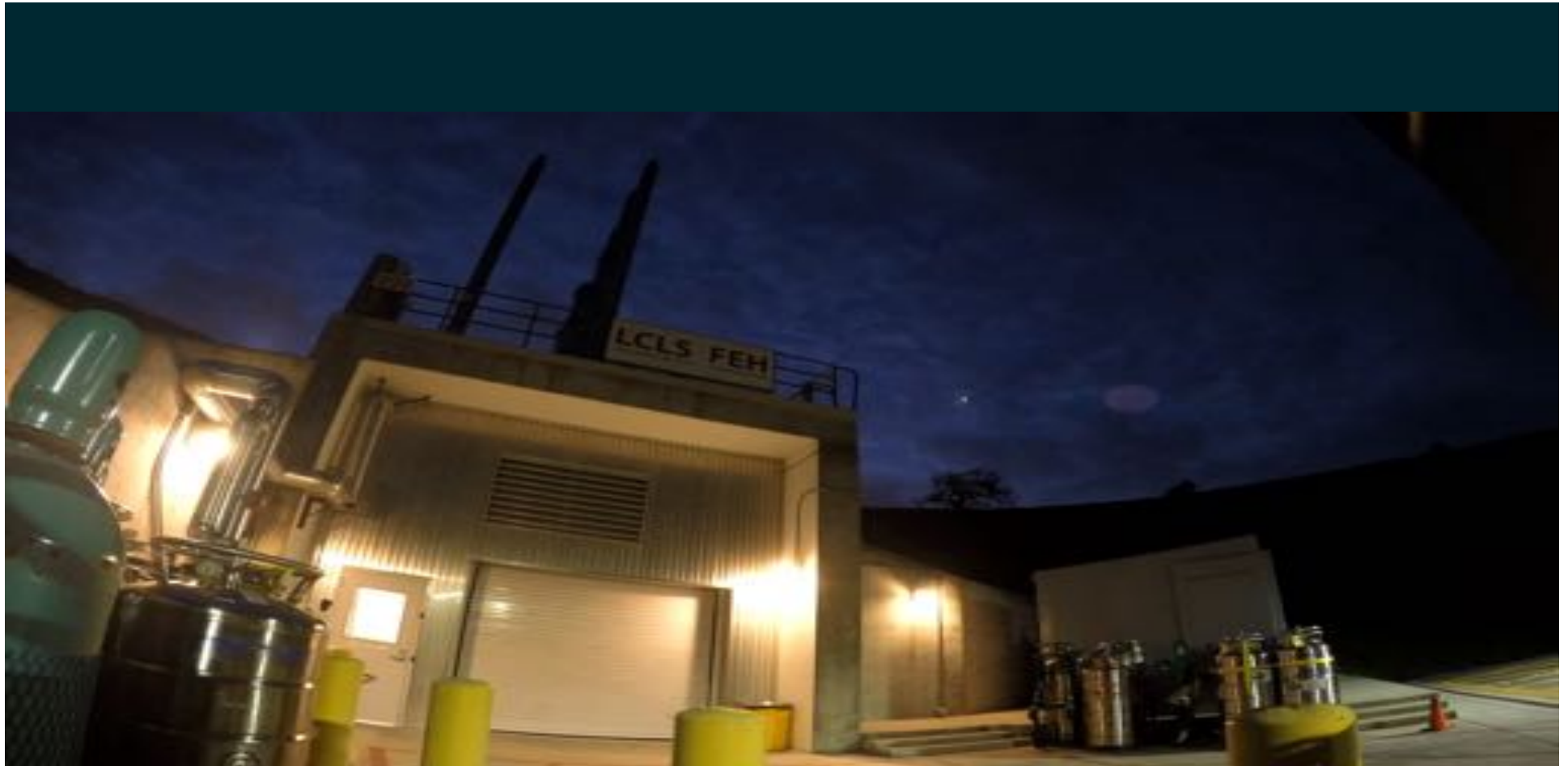
Acceleration over 1 km

X-ray Transport
Line (200 m)

Undulator (130 m)

Far Experiment Hall

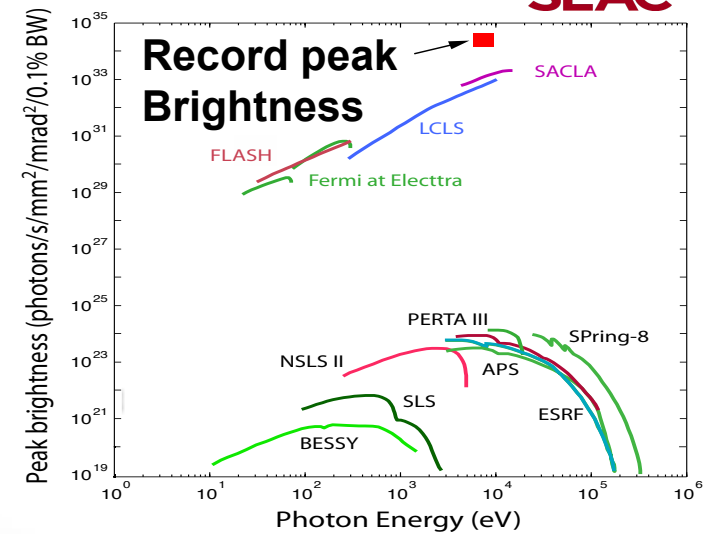
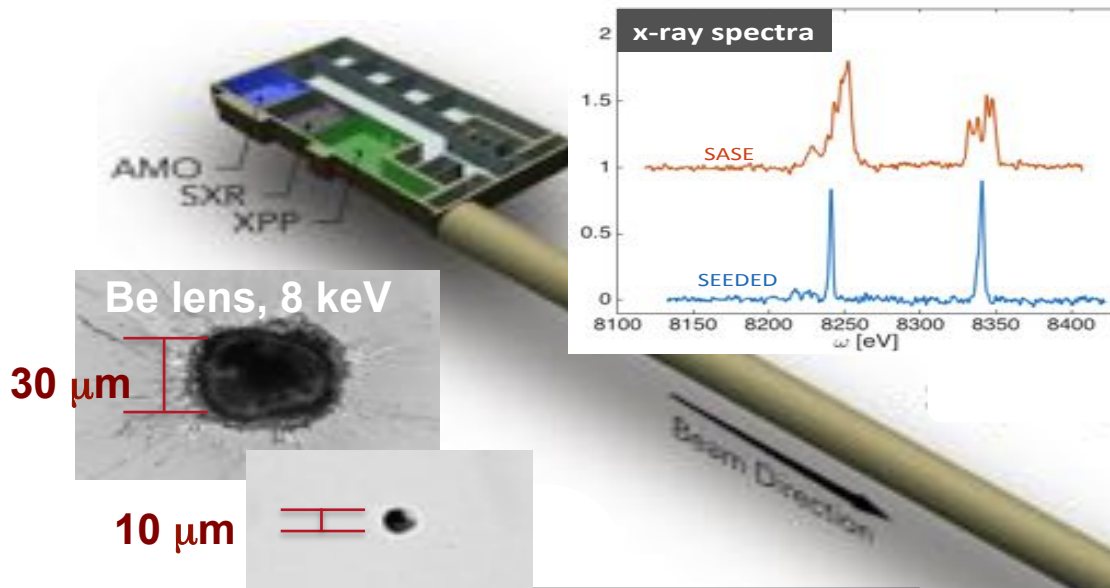




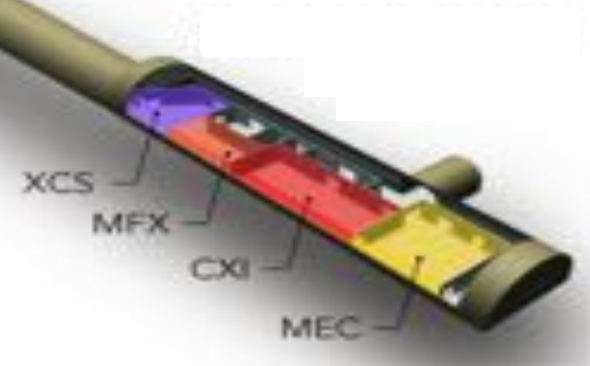
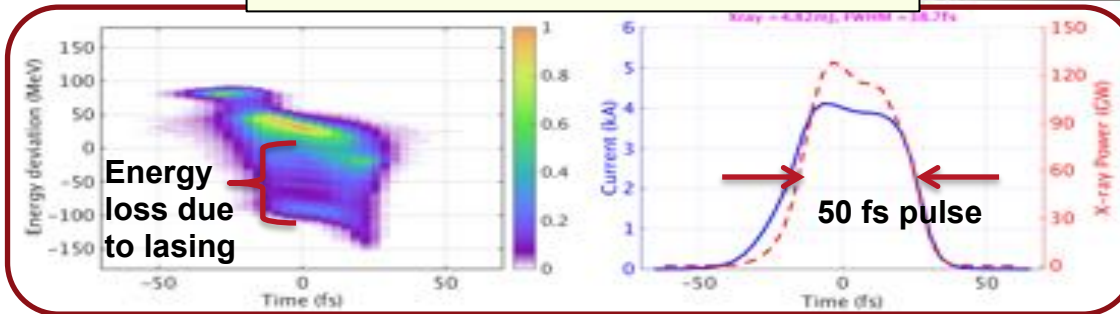
Matter in Extreme Conditions (MEC)

LCLS is a unique tool to investigate extreme conditions

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Electron beam streak measurement

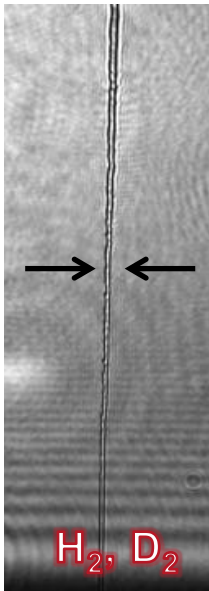


Rapid progress in cryogenic Jets development enabled high-repetition rate studies matched to LCLS [120 Hz]

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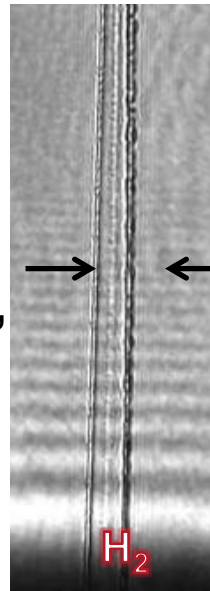
Cylindrical H₂ Jet

2-20 μm
diameter



Flat H₂ Jet

30 μm wide,
1 μm thick
[patented]



Droplet H₂ Jet

5 μm radius

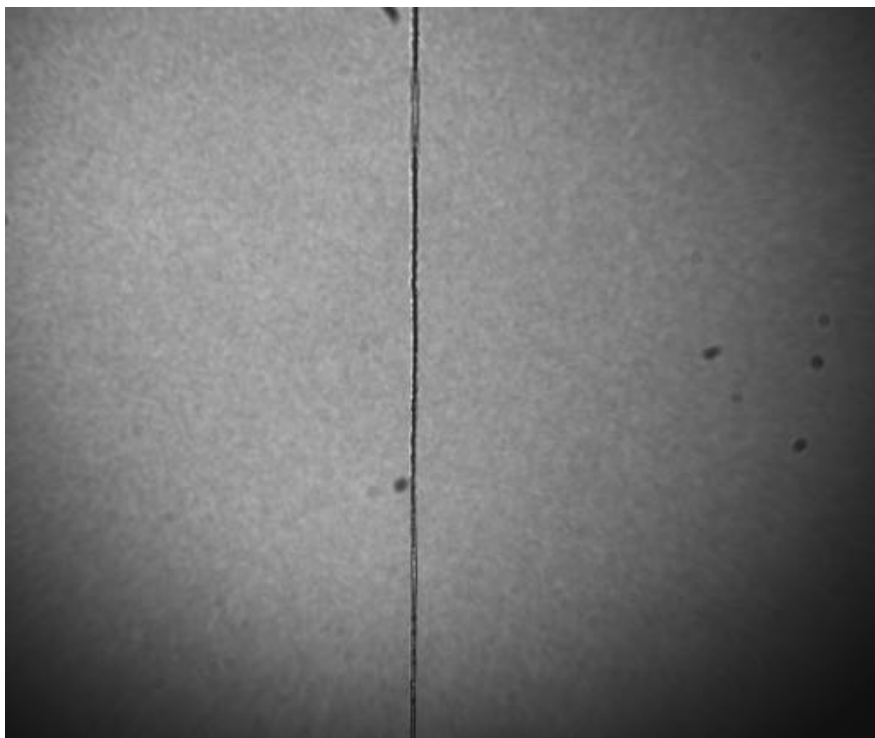


Cryogenic jets [H₂, D₂, Ar, CH₄] are excellent tools for precision in HED physics

Experiments are successful at high repetition rates

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Cryogenic Ar jet at 120 K at LCLS



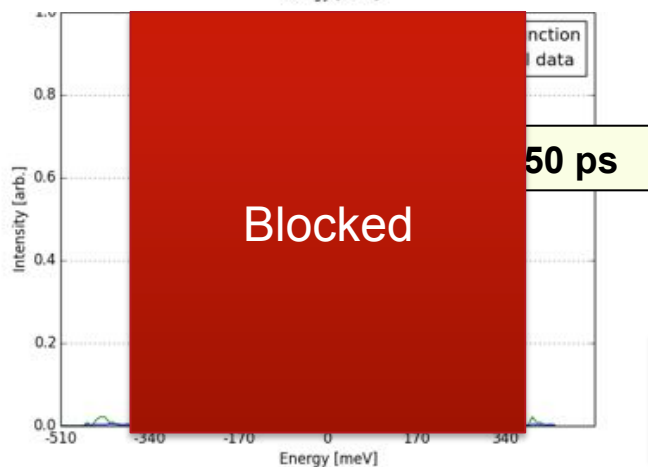
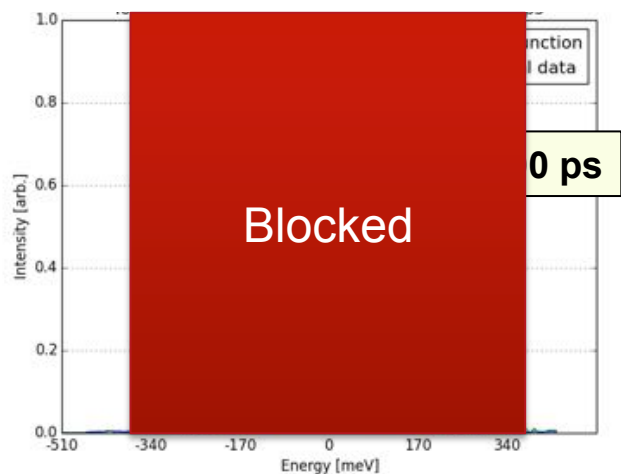
Ion Feature from warm dense Ar for ~10,000 shots



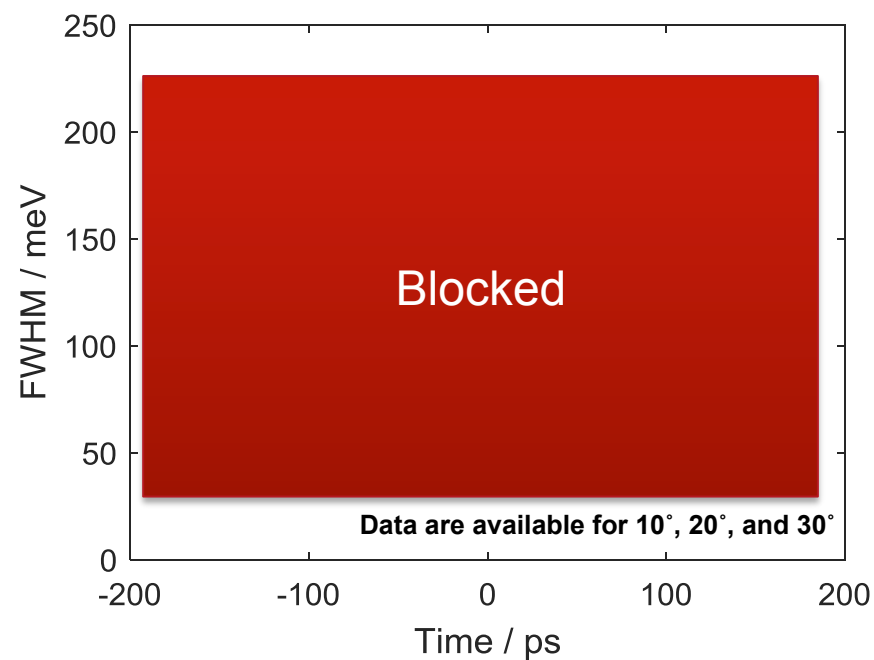
Unprecedented high repetition rate experiments at high n_e and T

1 millions shots resolve the ion feature in warm dense matter

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Experiments resolve plasma heating dynamics of argon from ion feature broadening



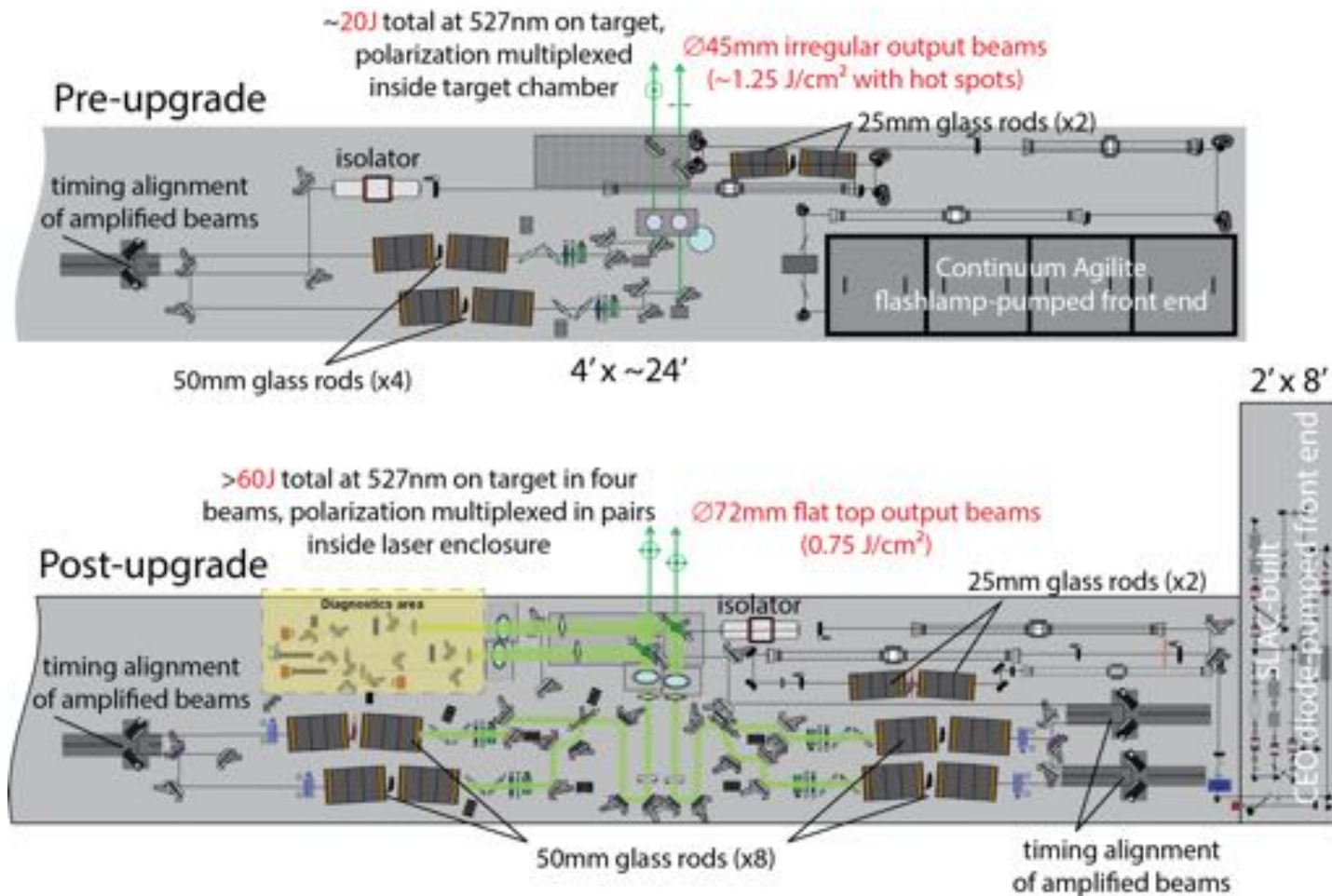
Experiments succeeded with Ar and CH₄

Runs 315-324

Optical Laser Energy ~ 400 mJ
Pulse length ~ 150 ps

Long-pulse laser: pre- and post-upgrade systems

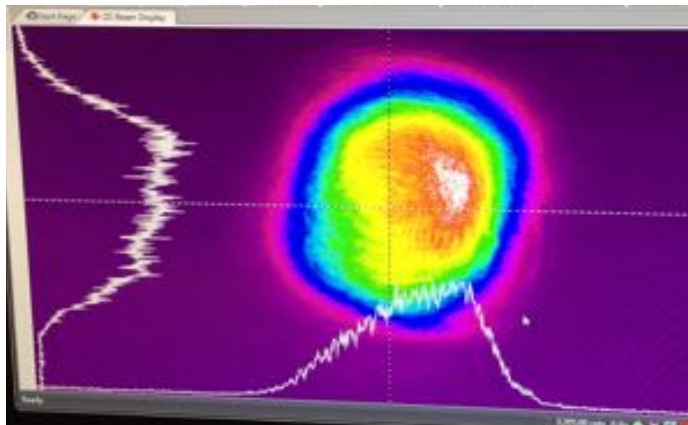
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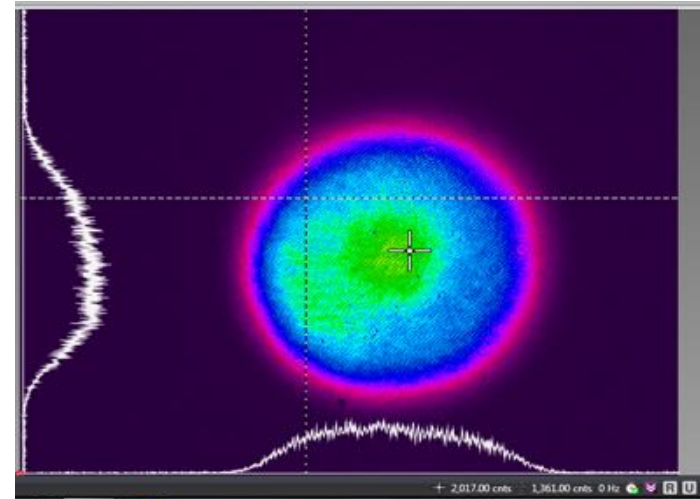
New front end spatial mode for laser compression studies with improved uniformity

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Pre-upgrade – after serrated aperture and spatial filter



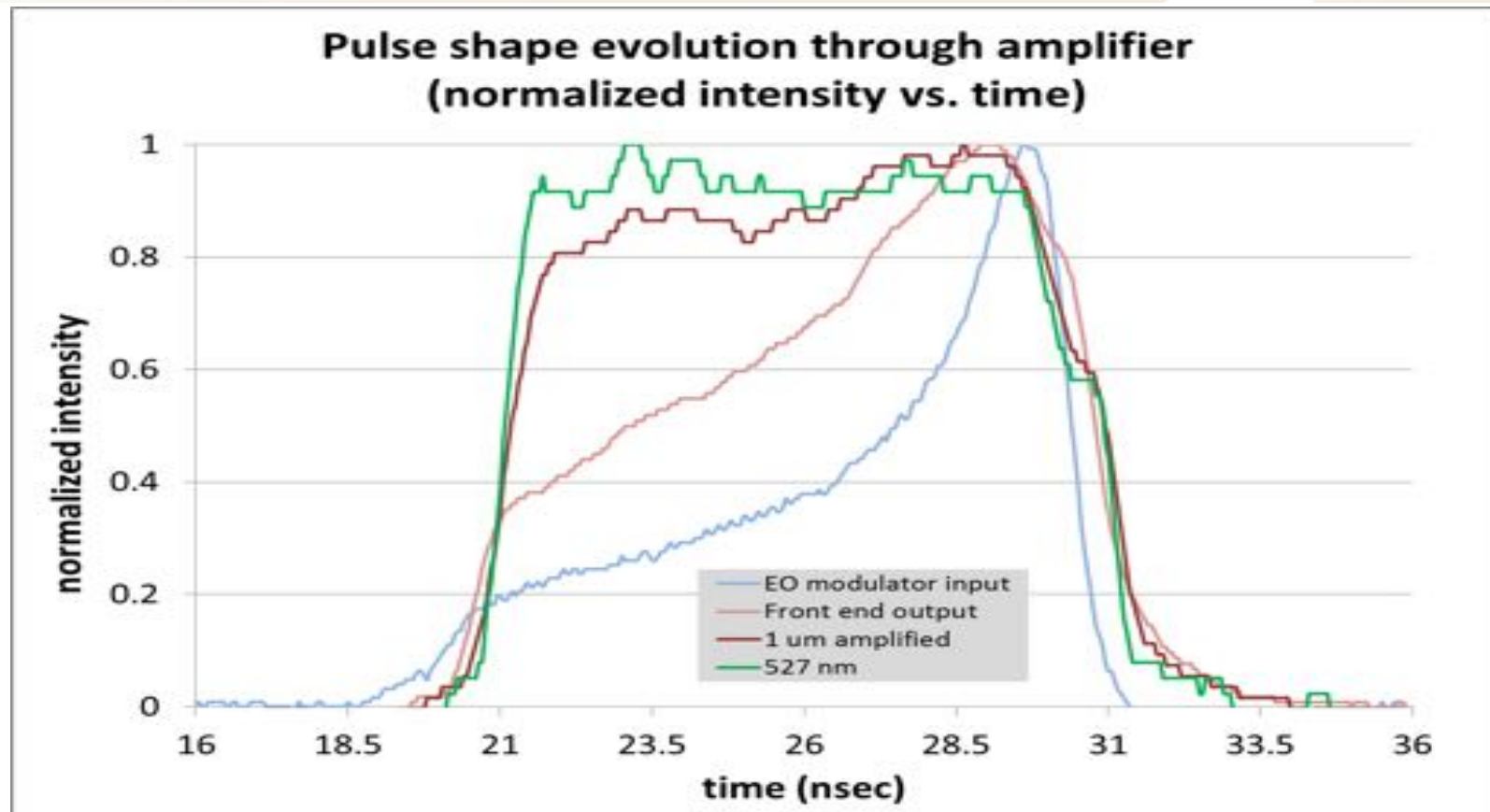
Upgraded system – after serrated aperture and spatial filter



*Prior to upgrade, spatial mode was variable, while the upgraded system has a stable, reliable spatial mode

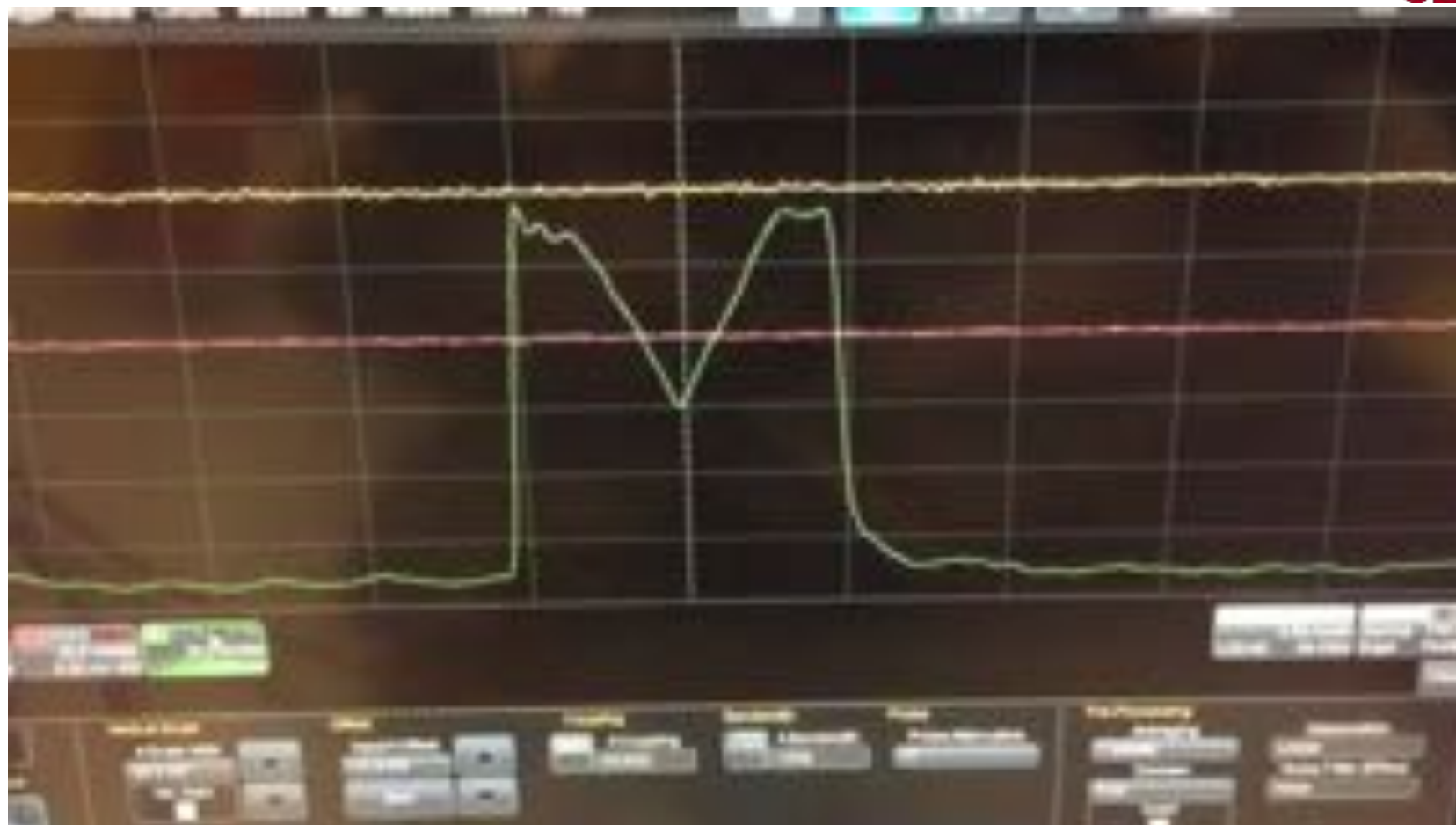
New long pulse laser provide precision pulse shaping for shock and near isentropic compression

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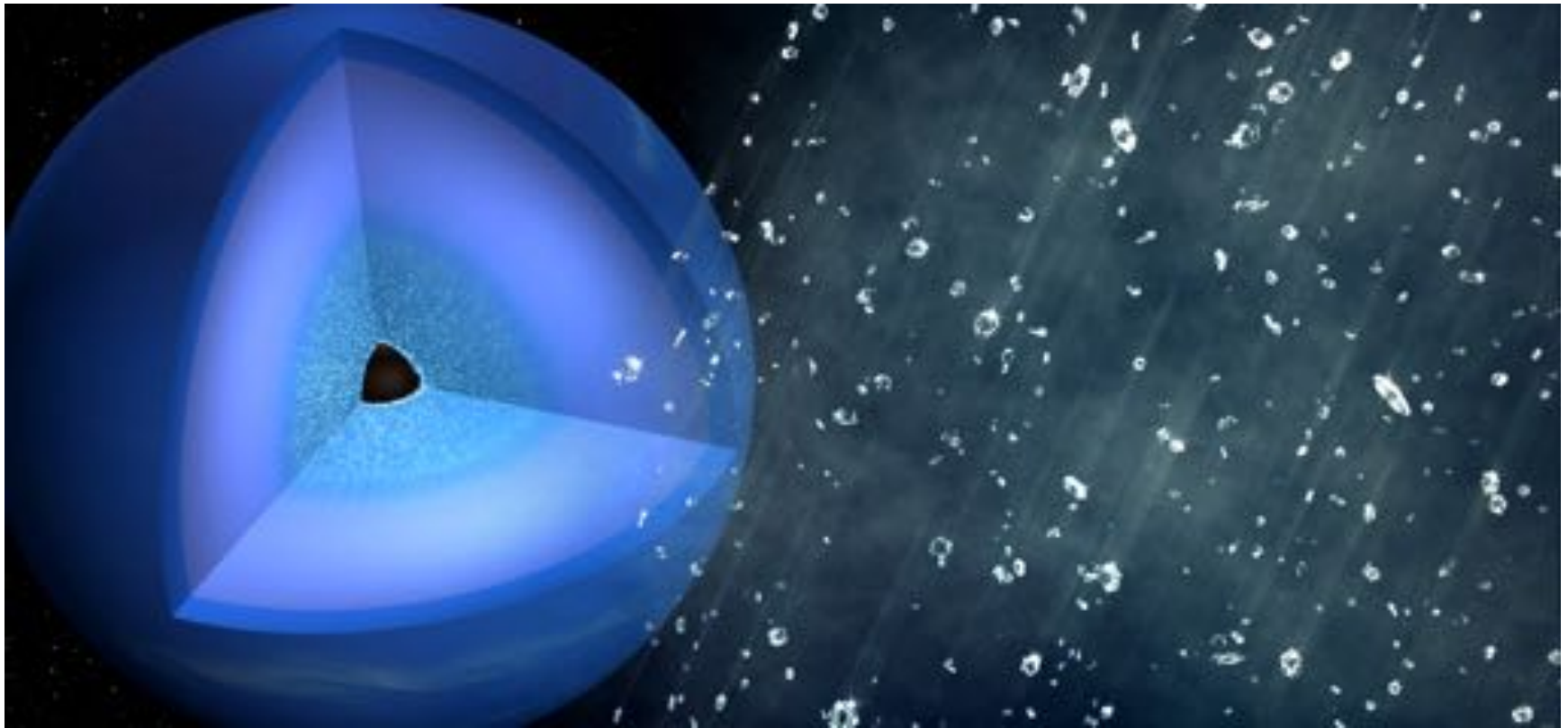
Arbitrary pulse shapes (<10 sec convergence at 10 Hz)

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Diamond formation in laser compressed plastic indicates diamond rain towards the cores of Neptune and Uranus

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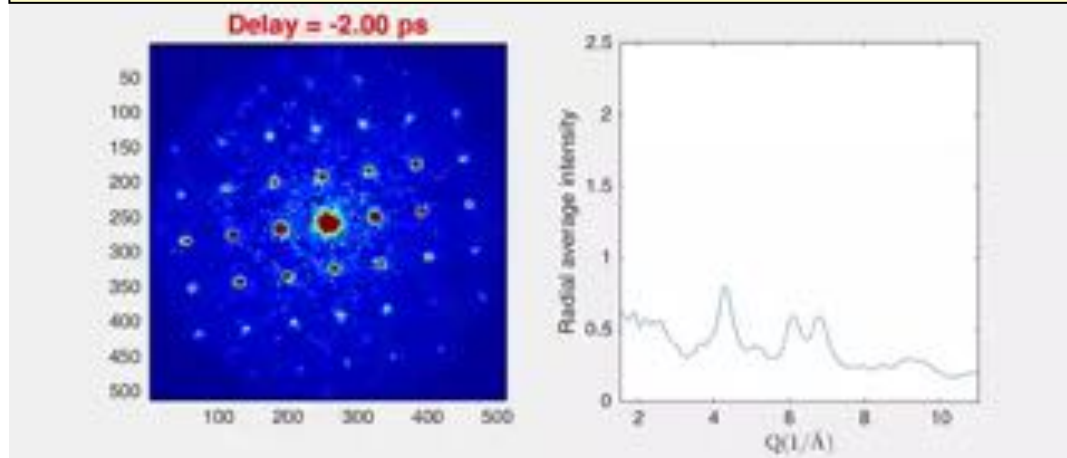




Diffraction has visualized the heterogeneous to homogeneous melting transition

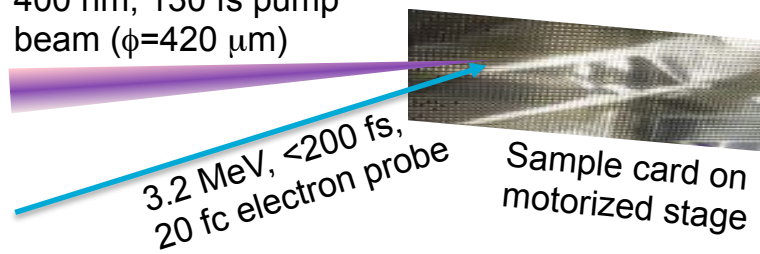
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Observation of melting and formation of WDM

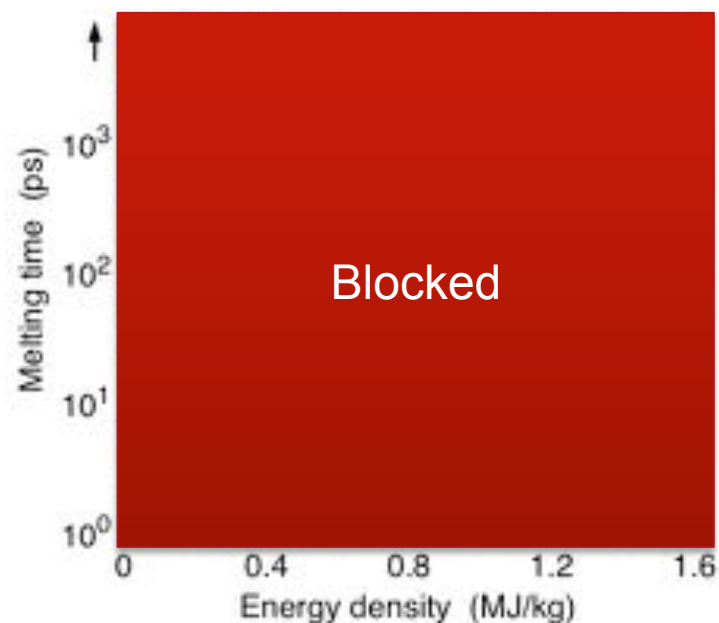


Data for 900 J/m² on Au

400 nm, 130 fs pump
beam ($\phi=420\text{ }\mu\text{m}$)

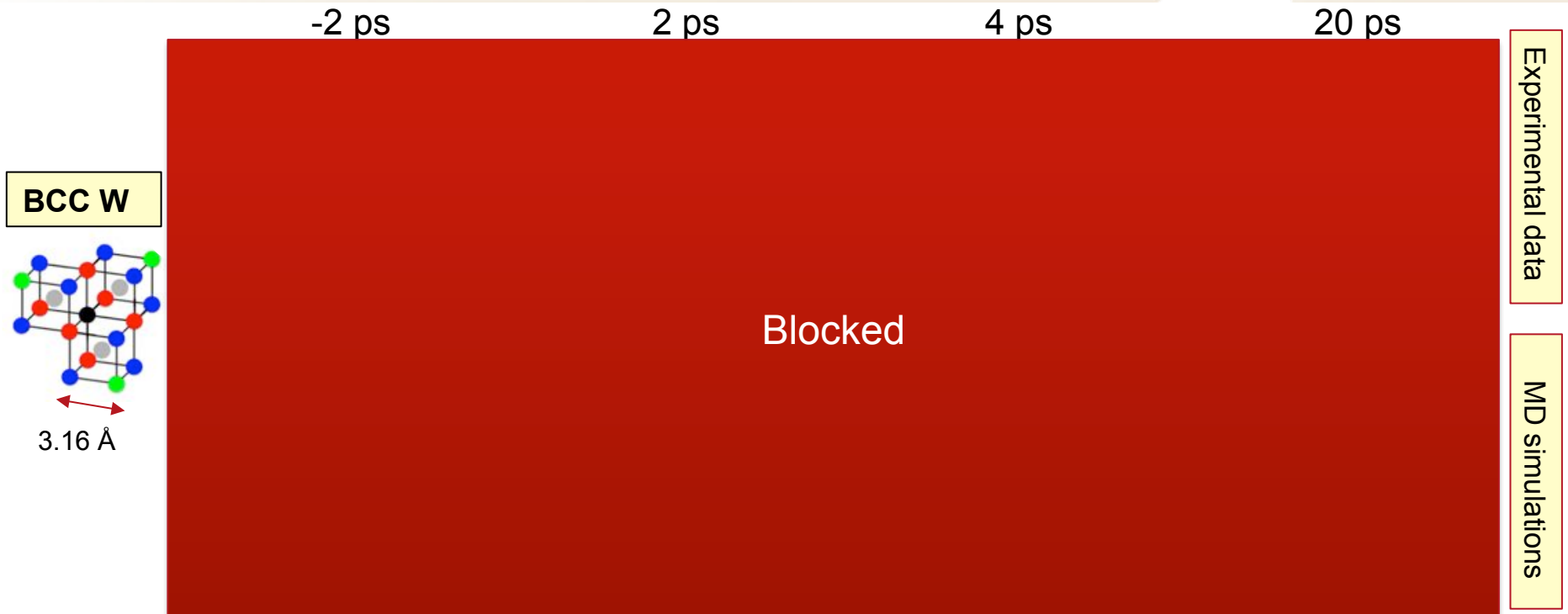


Sensitive to nucleation sites (blue)



Radiation-damaged tungsten shows loss of solid structure after ultrafast heating consistent with MD

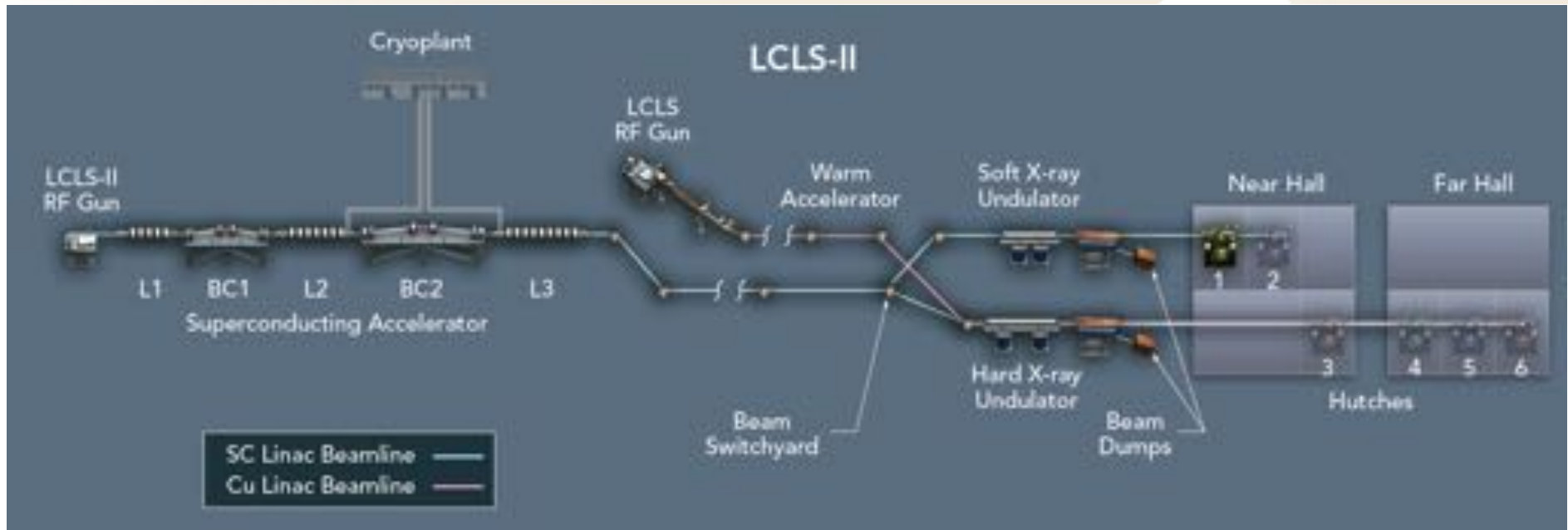
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Opportunity to resolve dislocation dynamics and test fusion materials

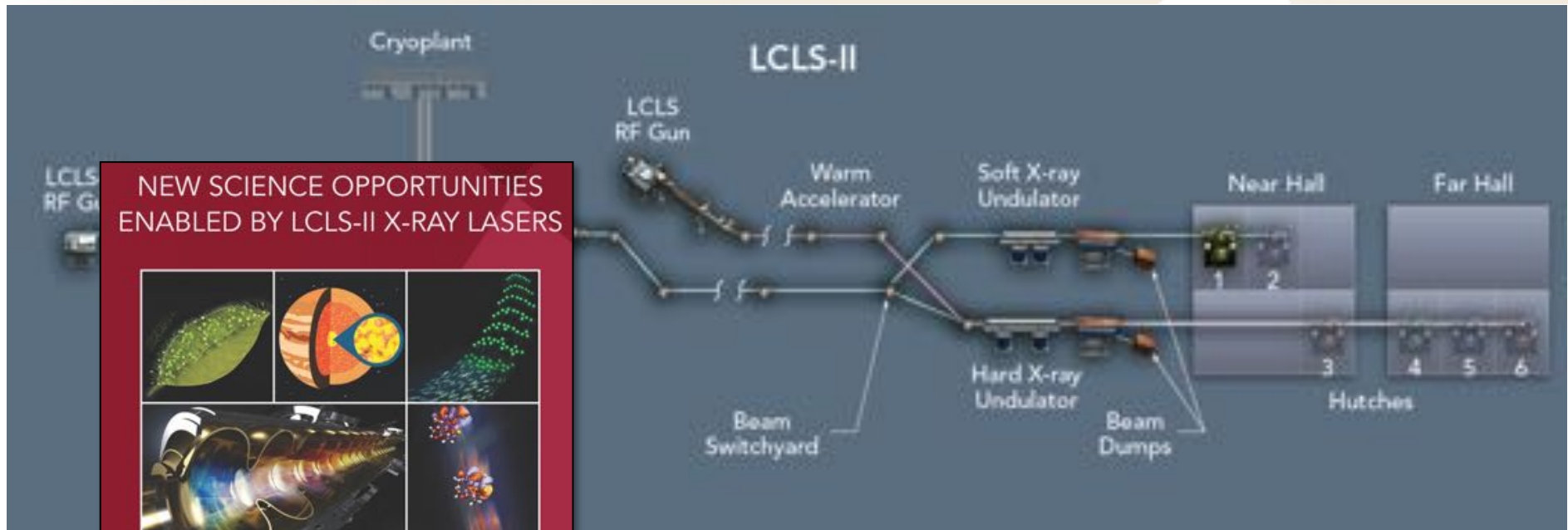
LCLS-II will greatly enhance x-ray capabilities for fusion research

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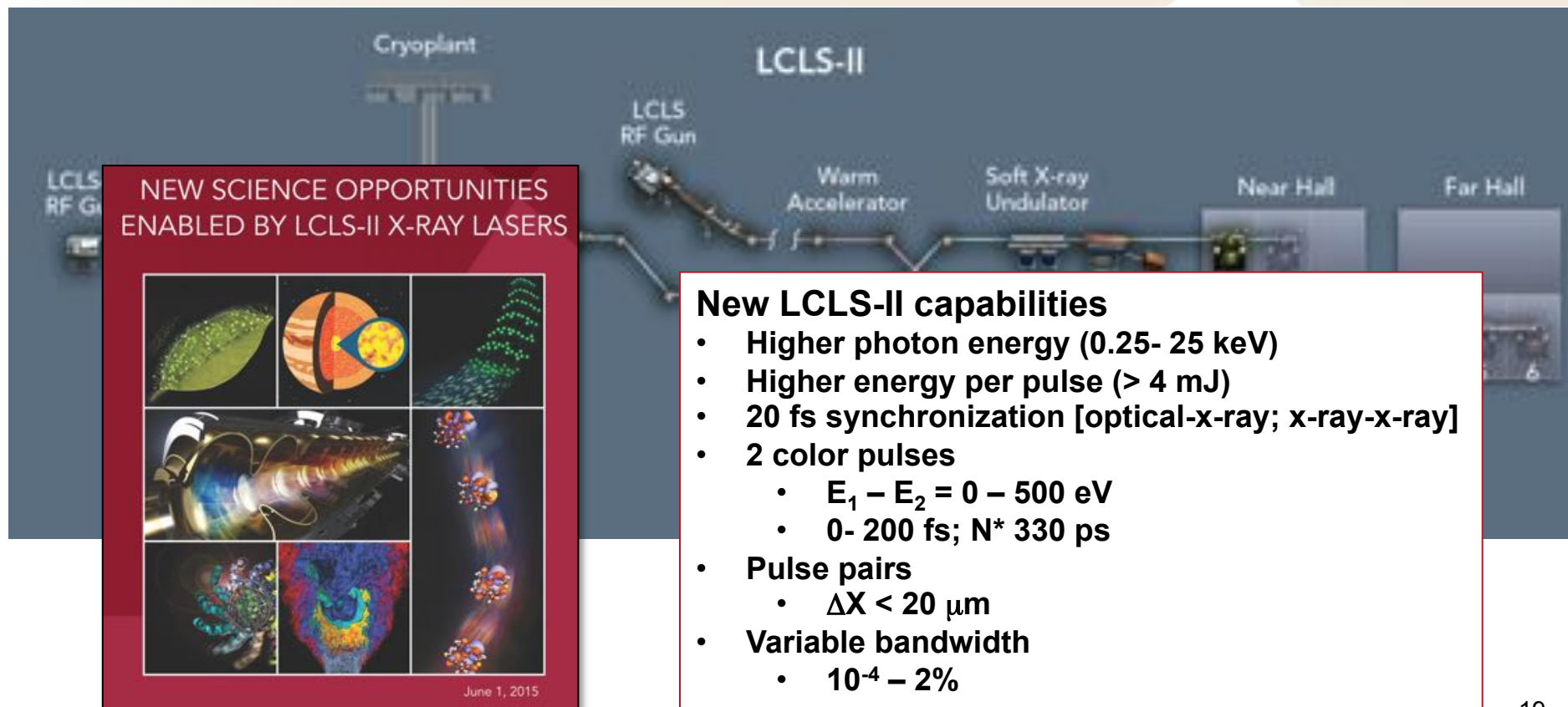
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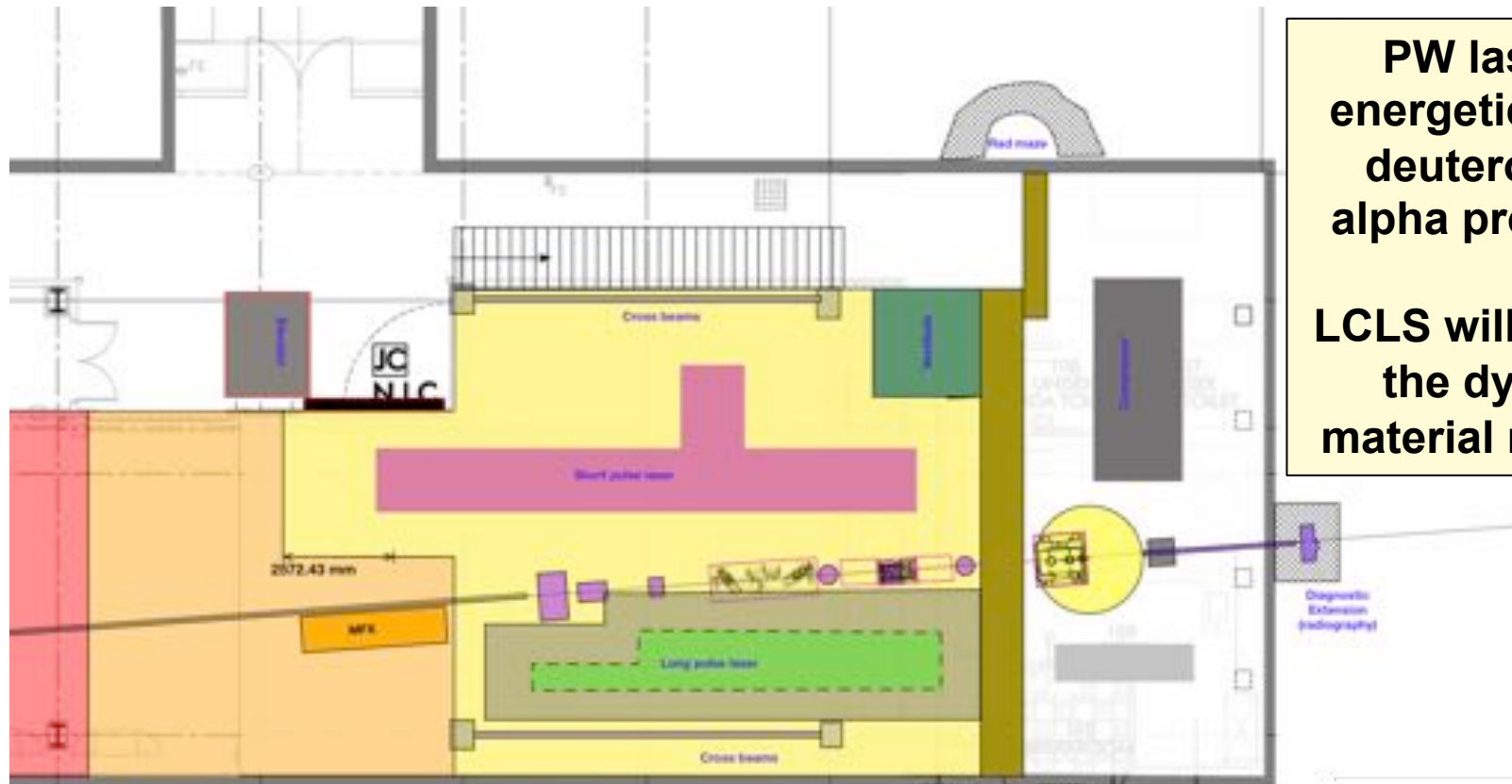
LCLS-II will greatly enhance x-ray capabilities for fusion research

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LCLS-II-HE reconfiguration provides opportunity for fusion radiation science capability

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PW laser for energetic proton, deuteron, and alpha production

LCLS will measure the dynamic material response

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