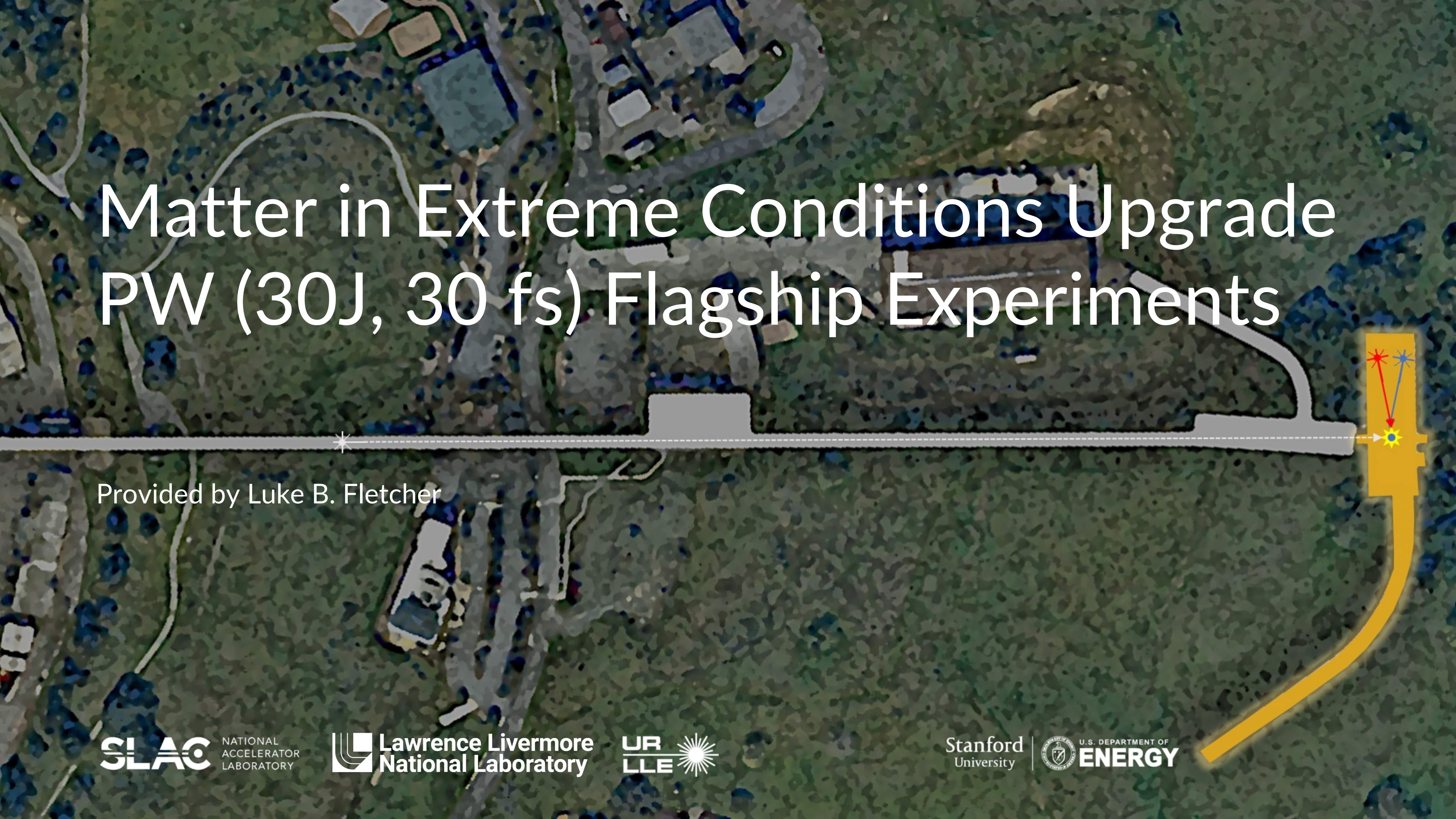
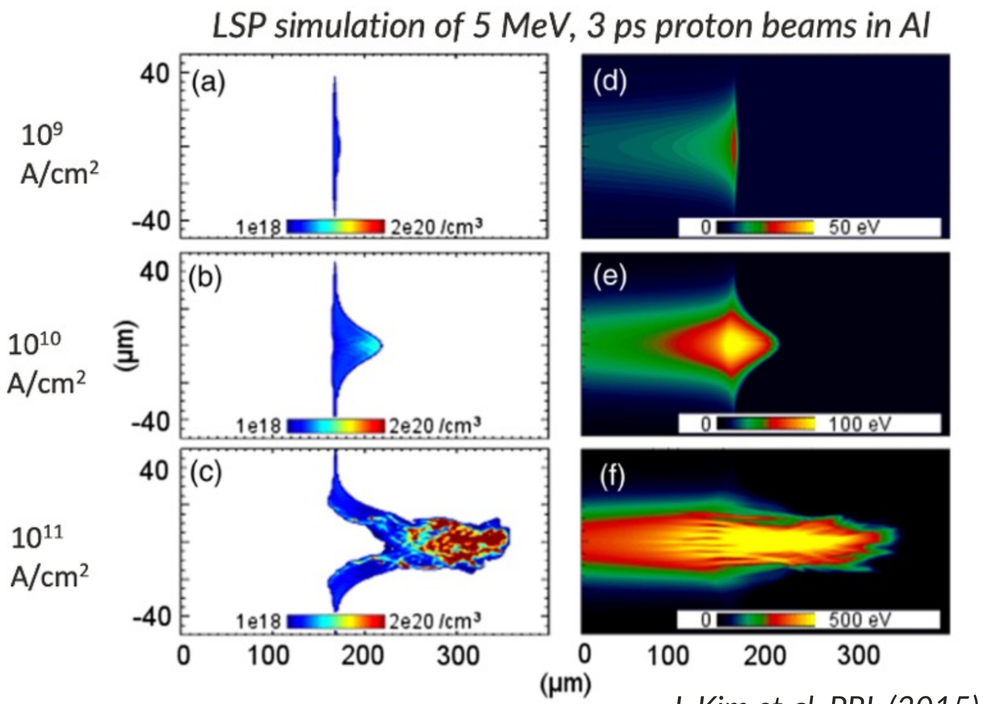


Matter in Extreme Conditions Upgrade PW (30J, 30 fs) Flagship Experiments

Provided by Luke B. Fletcher

SLAC NATIONAL ACCELERATOR LABORATORY
Lawrence Livermore National Laboratory
UR LLE
Stanford University
U.S. DEPARTMENT OF ENERGY

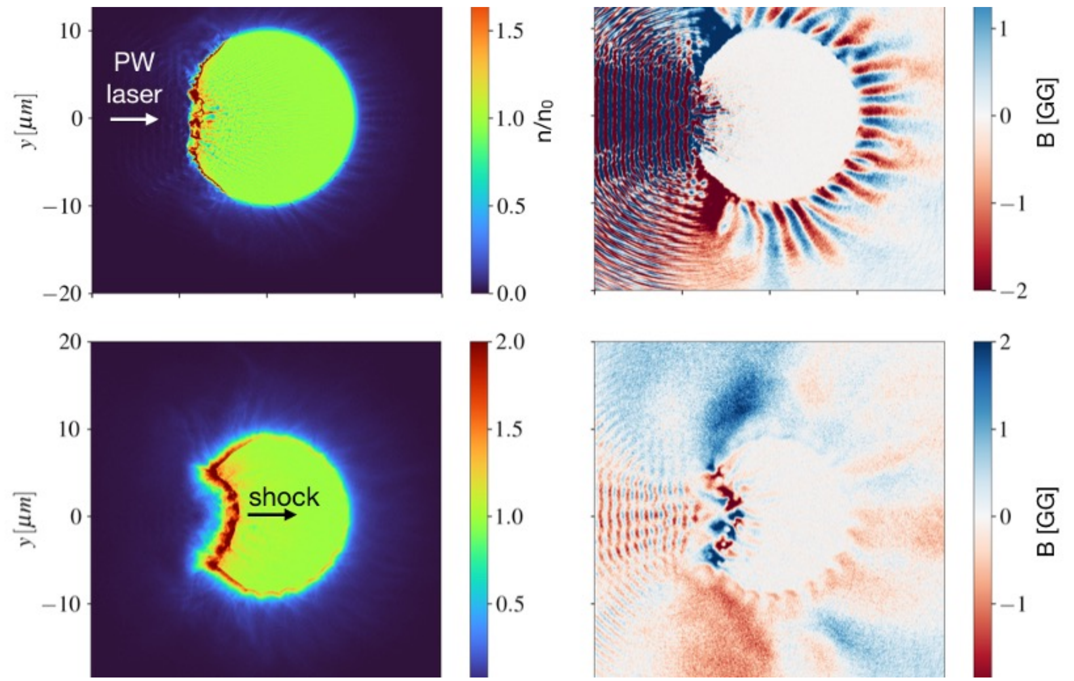
Status of current flagships with HAPLS-like PW*



J. Kim et al. PRL (2015)

Ion fast ignition physics

Proton/ion heating requires high flux. E = 30 J cannot generate enough flux to heat materials to inertial fusion relevant conditions. Future studies will be significantly impacted.



Courtesy of F. Fuiza, et al.

Petawatt laser-matter interactions

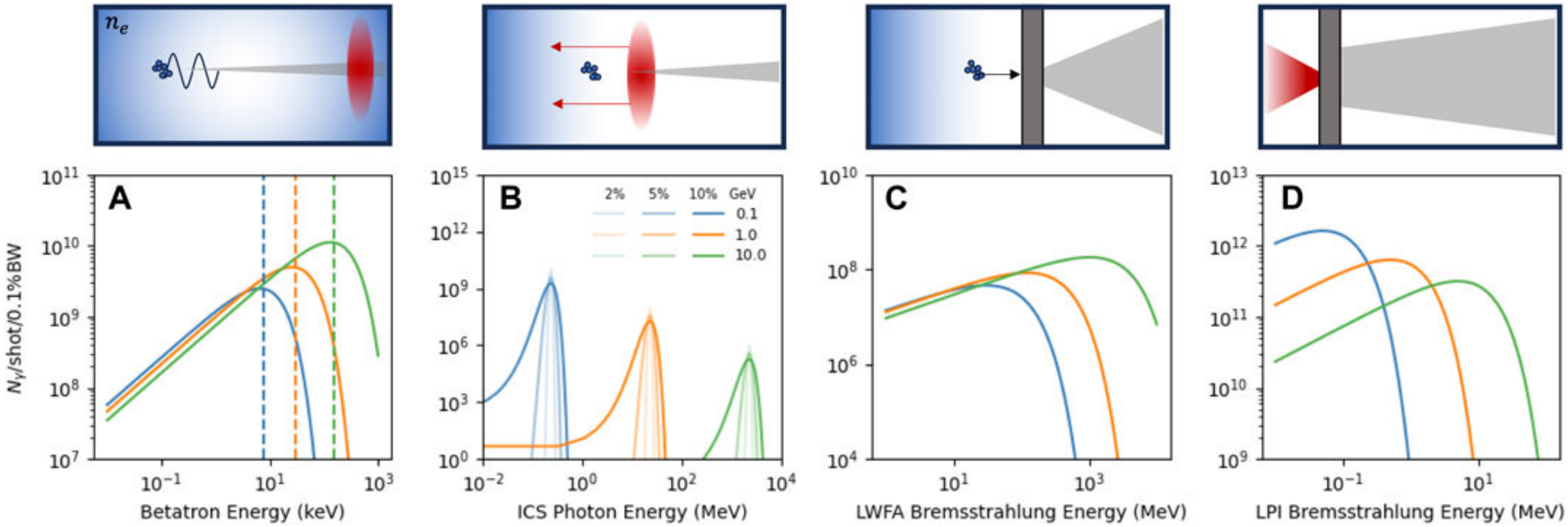
Collisonless shocks and filaments require long pulse durations. 30 fs is not long enough to generate necessary instabilities and shock generation. Future studies may not be possible.

***Does not include changes to High Rep-Rate Long Pulse laser as a consequence of reduced pulse energy**

Ultrafast science enabled by HAPLS-like PW

Femtosecond-scale broadband high energy X-ray sources that are coupled to XFEL pulse duration

Betatron radiation | **Inverse Compton** | **LWFA bremsstrahlung*** | **Bremsstrahlung***

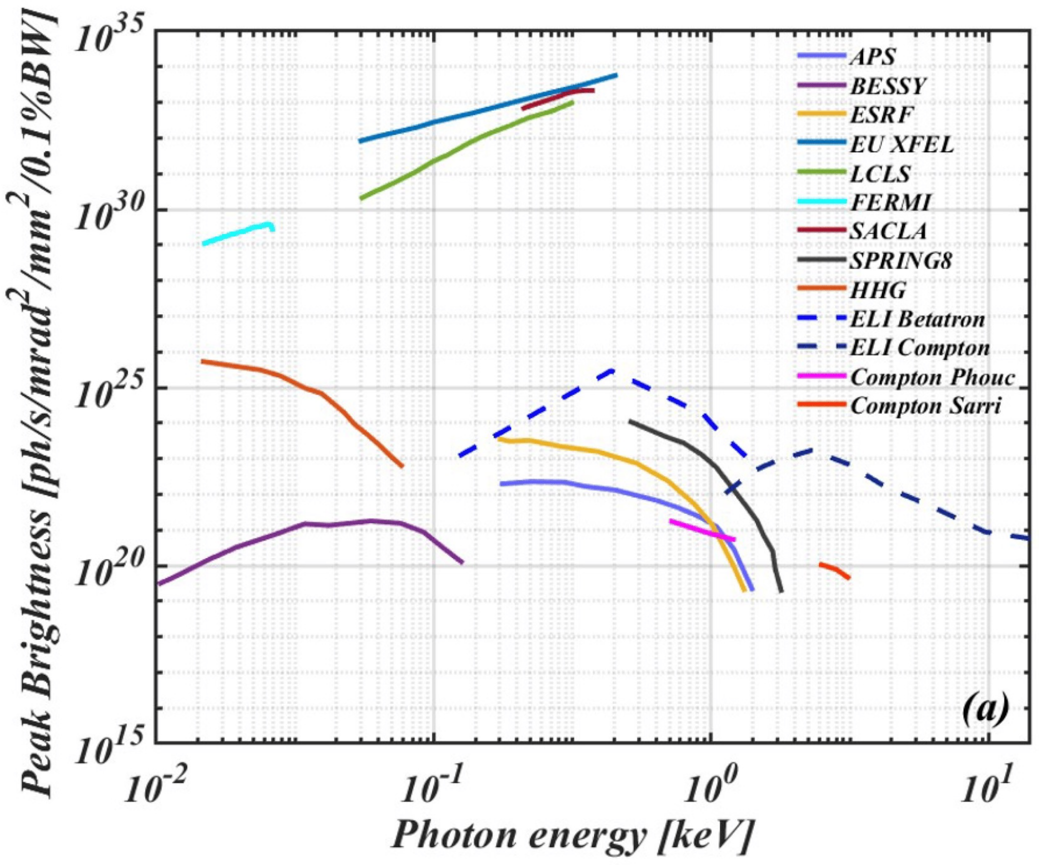


*Fs He-α and K-β sources may be possible with advanced backlighter target designs

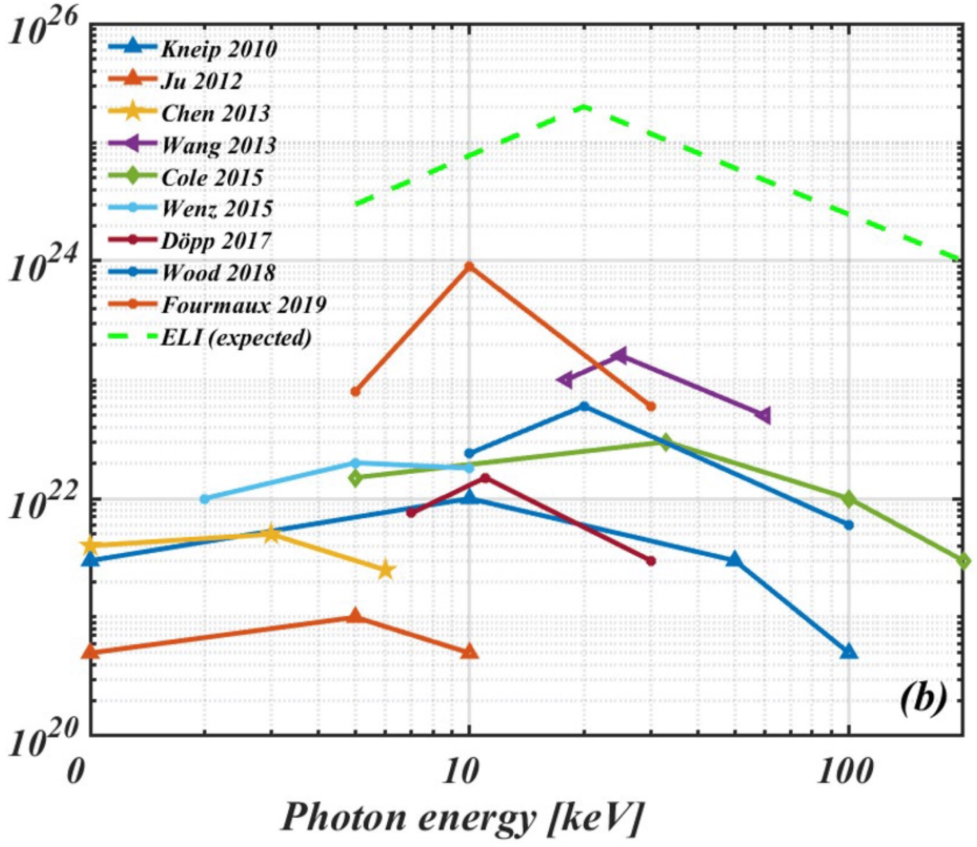
C. Armstrong et al., Frontiers in Physics 11 (2023)

Peak brightness with HAPLS-like laser is equivalent to ELI beamlines

Peak Brightness compared to Synchrotrons and XFELs



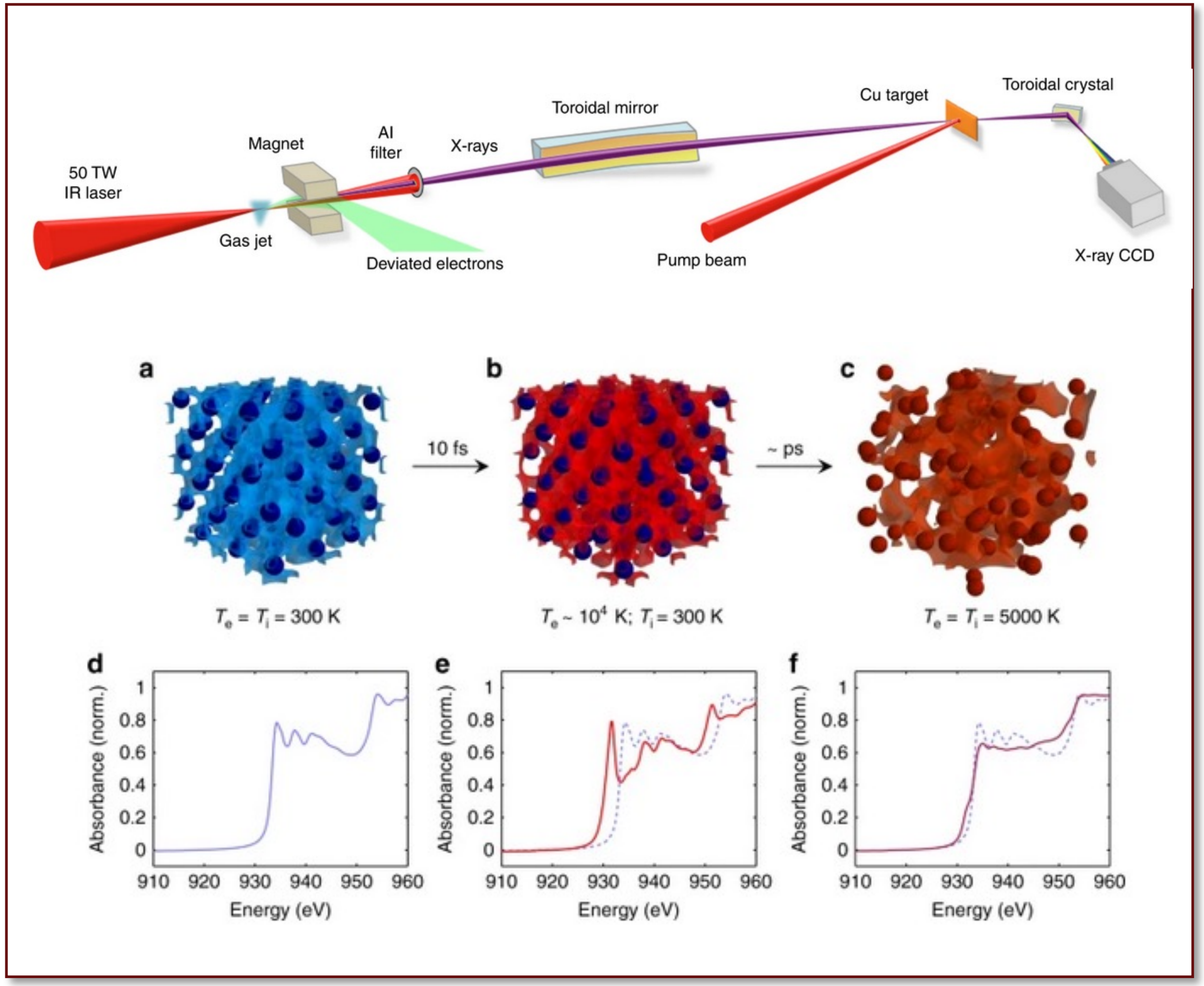
Peak Brightness compared to experiments



U. Chaulagain et al., Photonics 9 (2022)

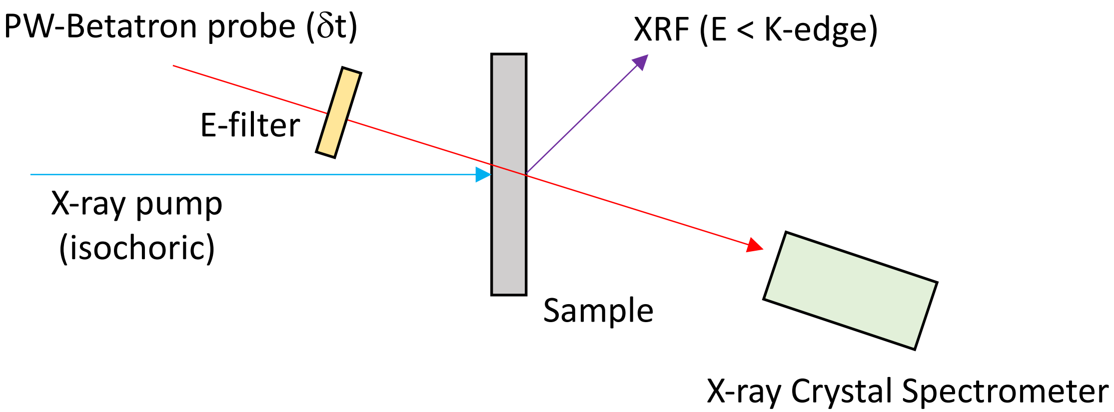
Single Shot Femtosecond X-ray Absorption Spectroscopy (FXAS)

Proof-of-principle scientific concept

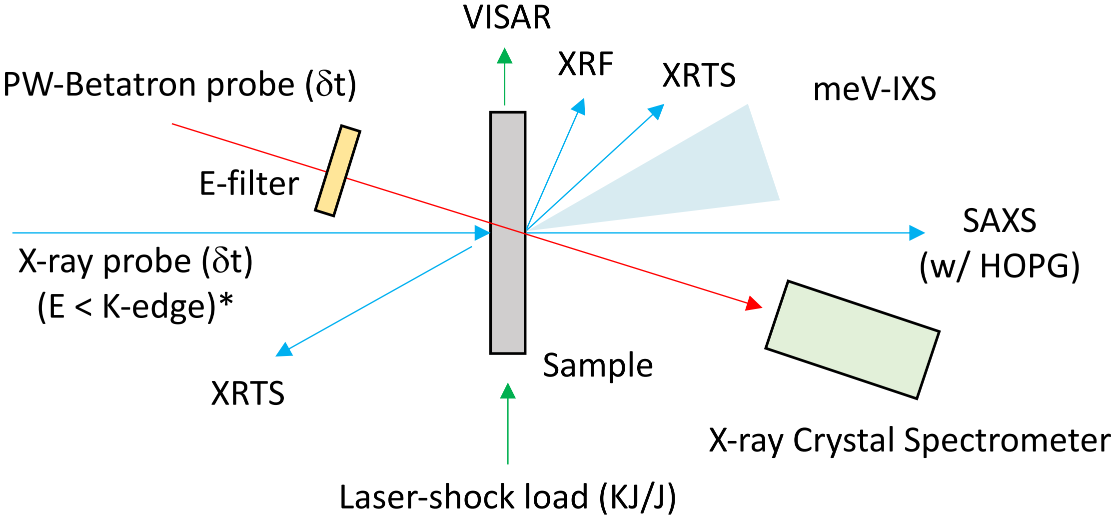


B. Mahieu et al., Nature Comms. 9 (2018)

Configuration 1 (isochoric heating)



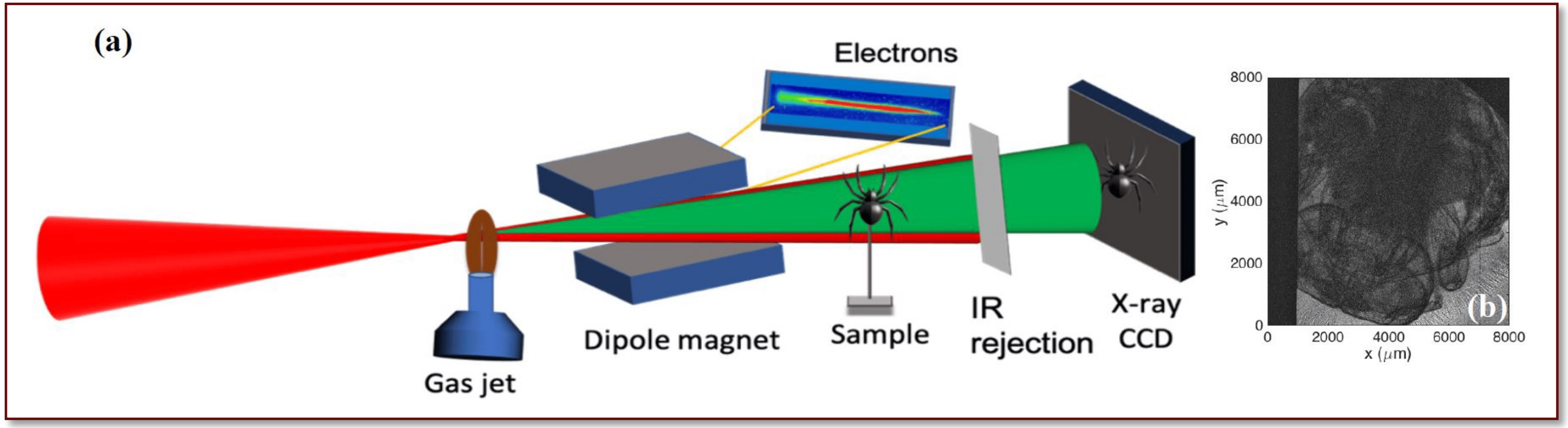
Configuration 2* (shock heating) - FG



**PW-Betatron can also be quasi-monochromatic allowing E_{probe} > K-edge

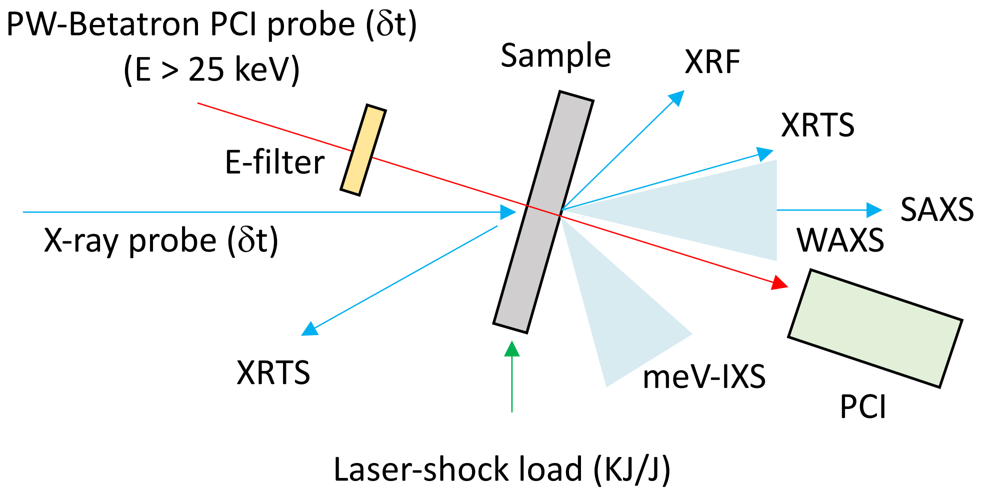
Hard X-ray Phase Contrast Imaging (HXPCI)

Proof-of-principle scientific concept

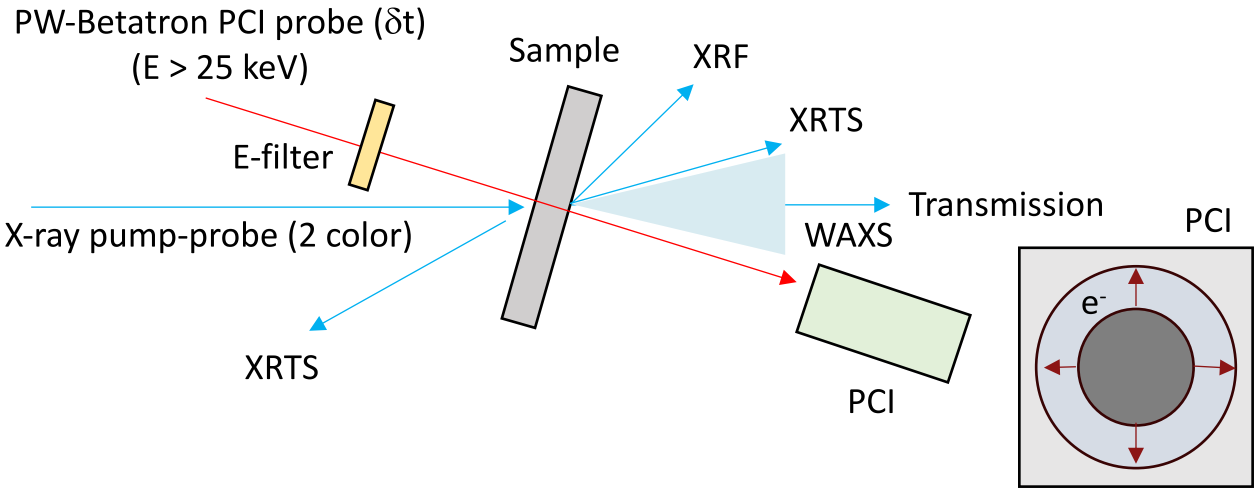


U. Chaulagain et al., Photonics 9 (2022)

Configuration 1 (PCI of dense materials/shocks) - FG

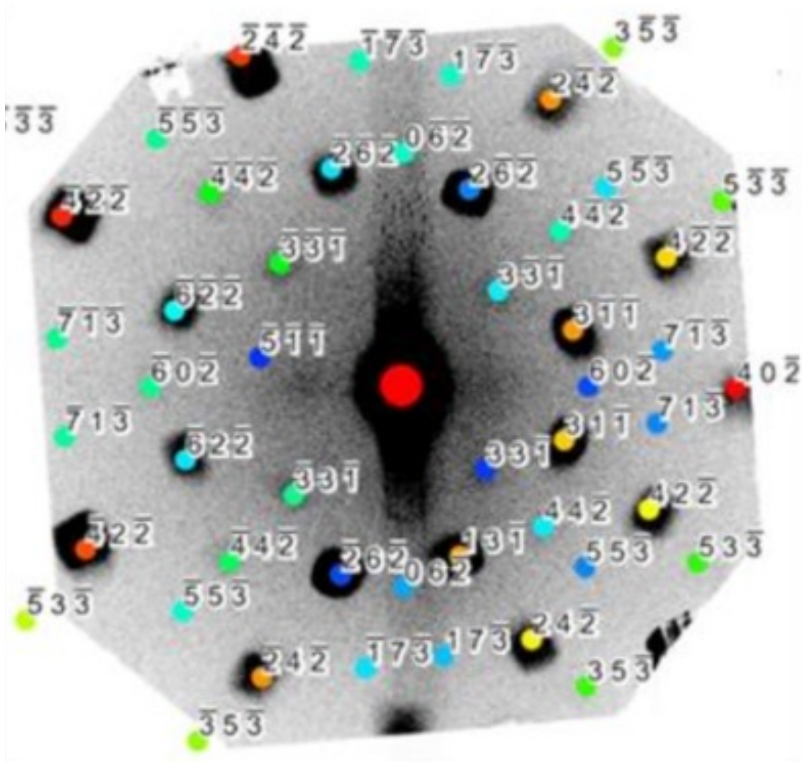


Configuration 2 (PCI of ultrafast ionization/heating)



Dynamic Hard X-ray Laue Diffraction

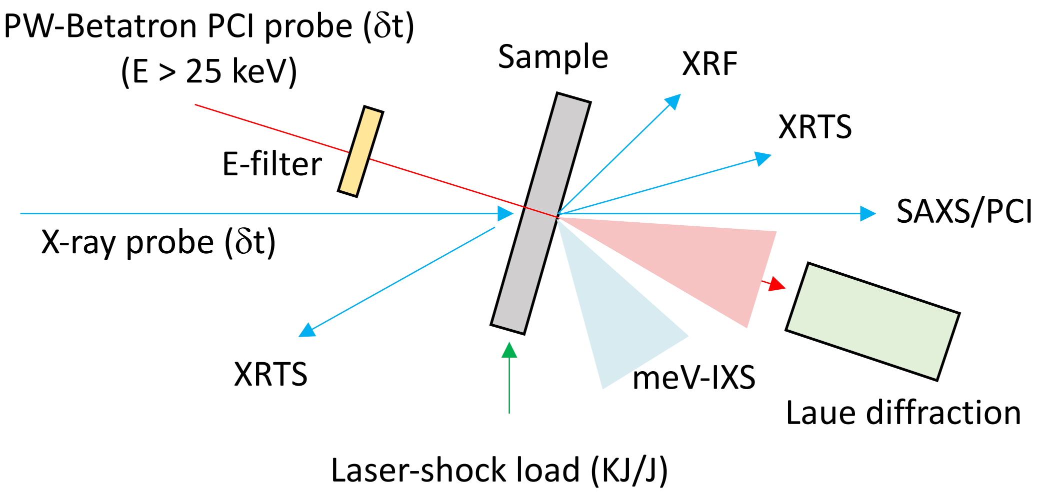
Proof-of-principle scientific concept



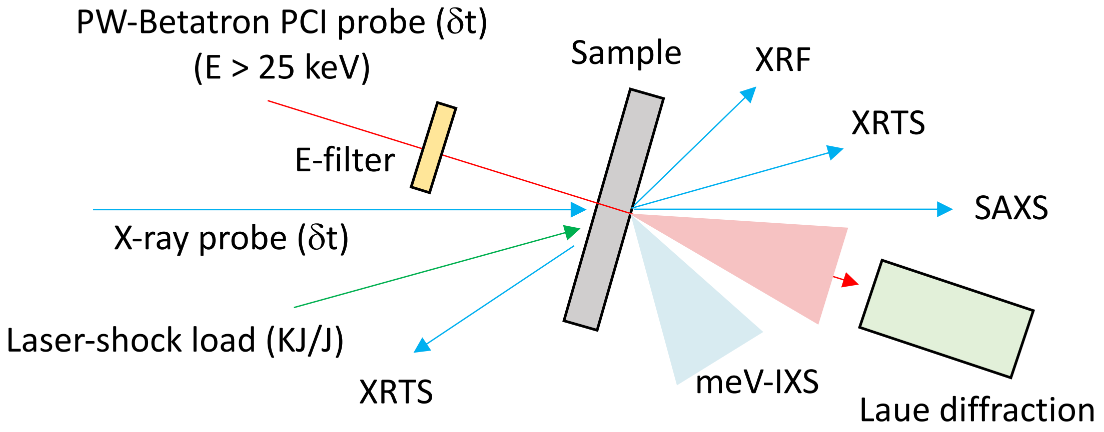
Laue diffraction from LiF, X-rays from 15 keV - 35 keV Mo X-pinch. The spectral photon flux (photons/eV/mrad^2) delivered by the betatron source is an order of magnitude more than the X-pinch source.

F. Zucchini et al., AIP Conf. Proc., 1793 (2017)

Configuration 1 (XRD of dense materials/shocks)

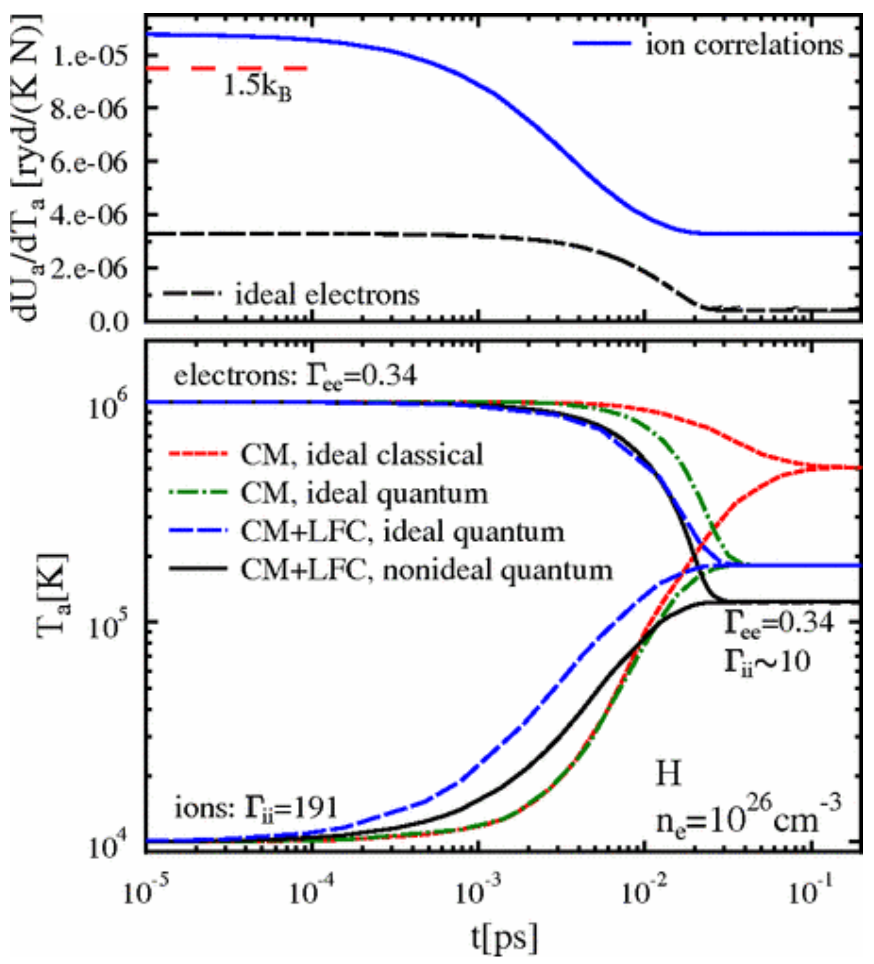


Configuration 2 (XRD of dense materials/shocks)



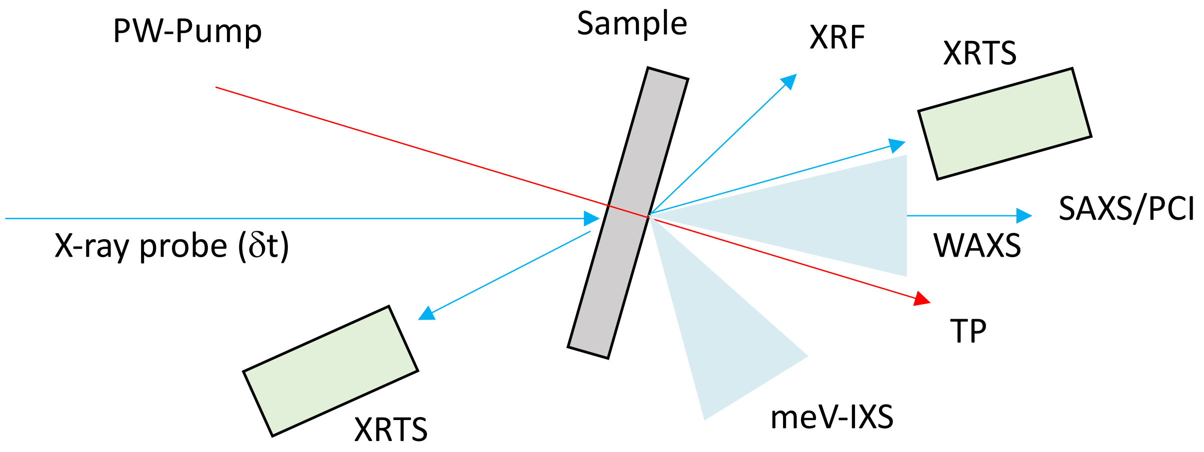
Non-Equilibrium/Energy Relaxation Physics

Theory concept



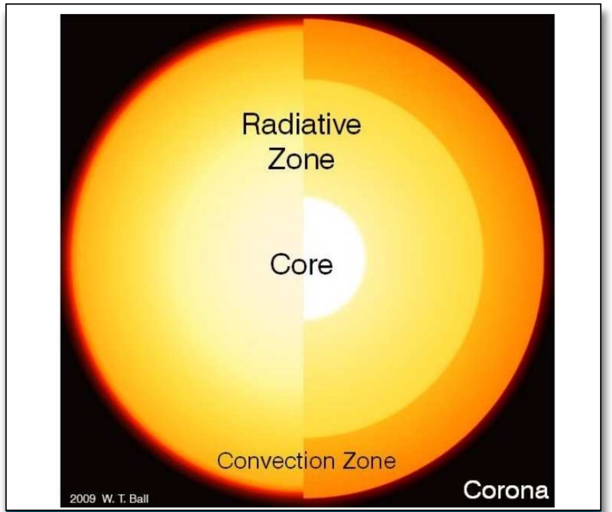
J. Vorberger et al., Phys. Rev. E (2010)

Configuration 1 (Two temperature energy relaxation) - FG



Science opportunities enabled

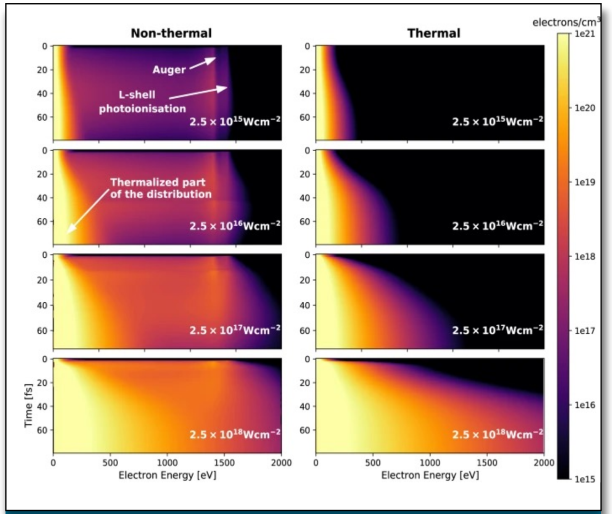
Stellar Opacities



K, L, M edge spectroscopy; continuum lowering, solar iron abundance and opacity measurements of dense plasmas relevant to IFE conditions

W. Ball (2009) – google images

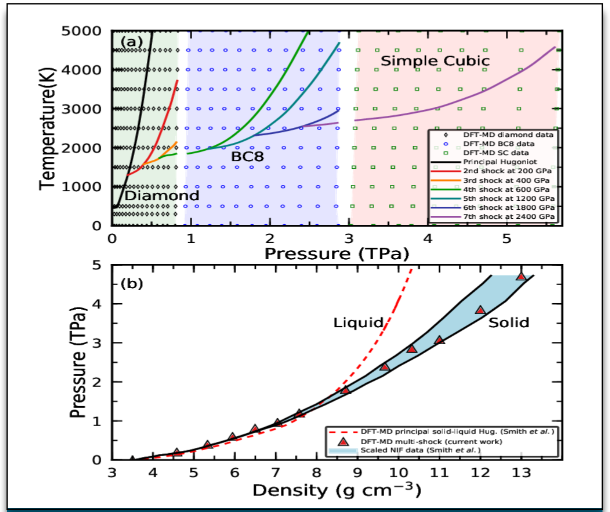
Non-LTE Physics



Ultrafast non-equilibrium dynamics; auger and fast electron kinetics, ionization rate equations of atomic transitions in HDM, radiation transport and conductivity of plasmas

S. Ren et al., Communications Phys. (2023)

Shock Dynamics of Dense Materials



Solid phase transitions; visualization of strength and plasticity under extreme shock compression, twinning and lattice dynamics in dense materials

F. González-Cataldo et al., Phys. Rev. B (2021)

Flagship (FG) experiment titles:

"Spectroscopic determination of the solar iron abundance"

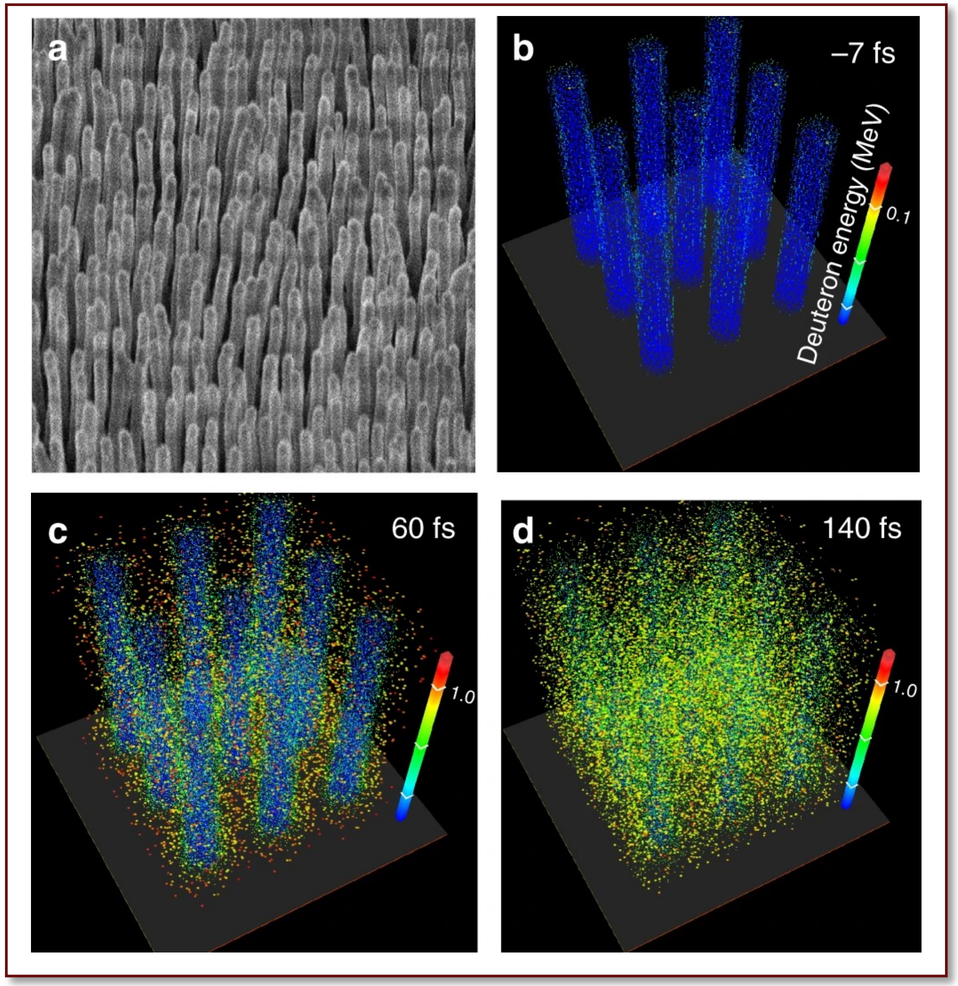
"Electron-Ion equilibration in dense hydrogen plasmas"

"BC8 phase transition in shock compressed diamond"

Nuclear Excitation by Electron Transition/Capture (NEET/NEEC)

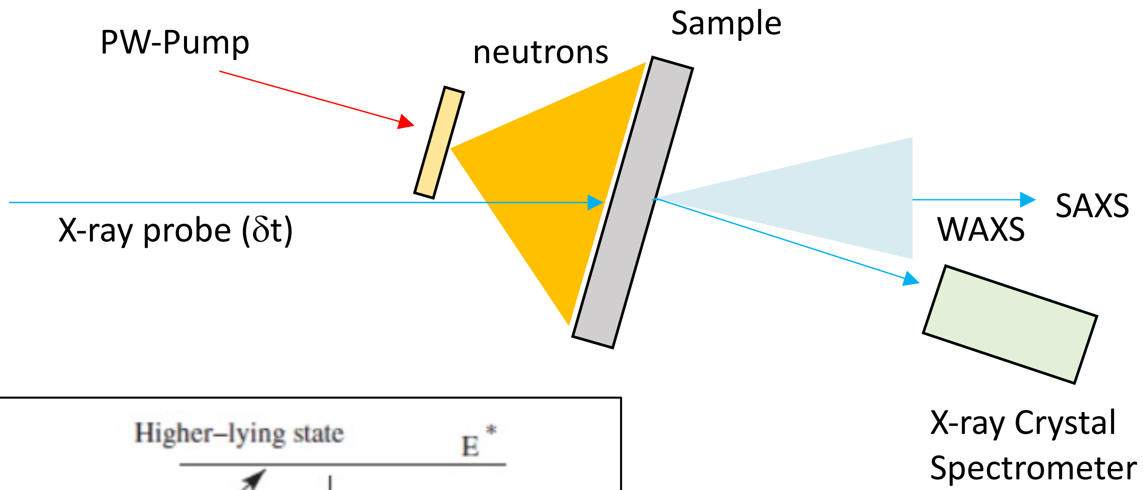
"stretch" flagship experiment

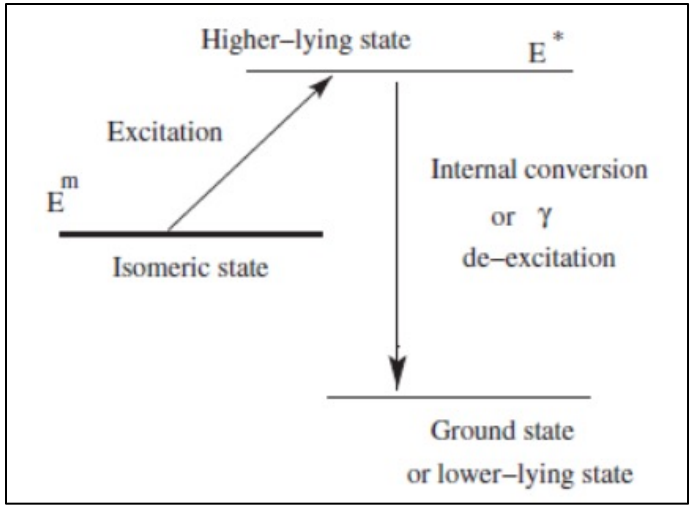
Micro-scale fusion from nanowire arrays



A. Curtis et al., Nature Comms. 9 (2018)

Configuration 1 (NEET/NEEC)





Extra slides

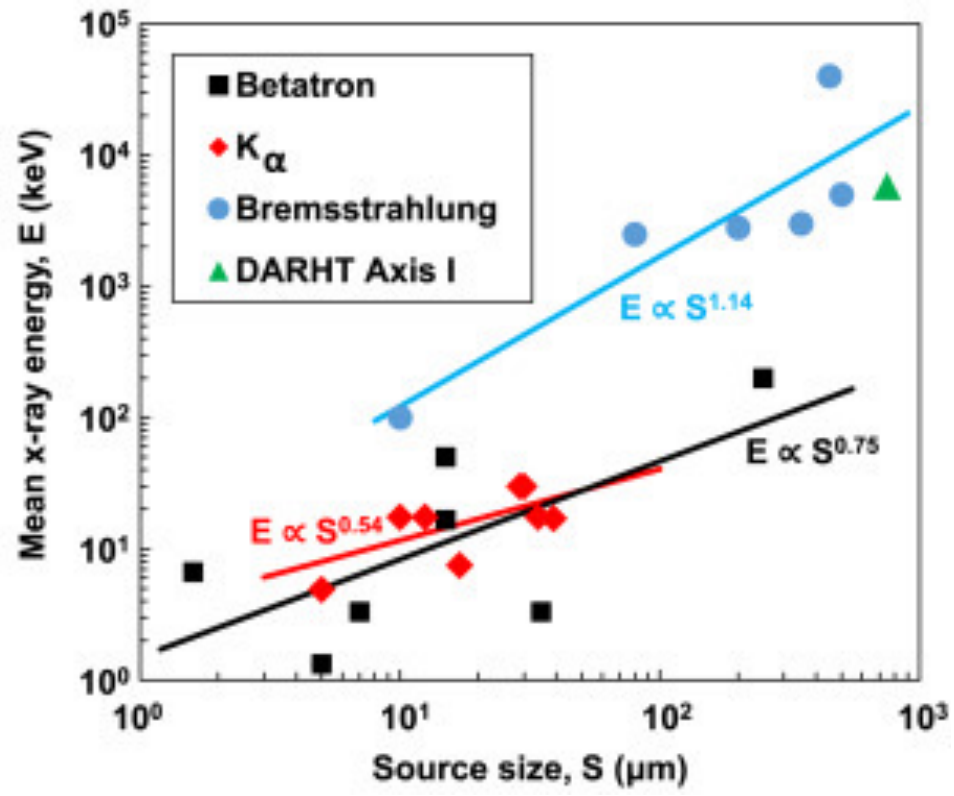
Preliminary KPPs

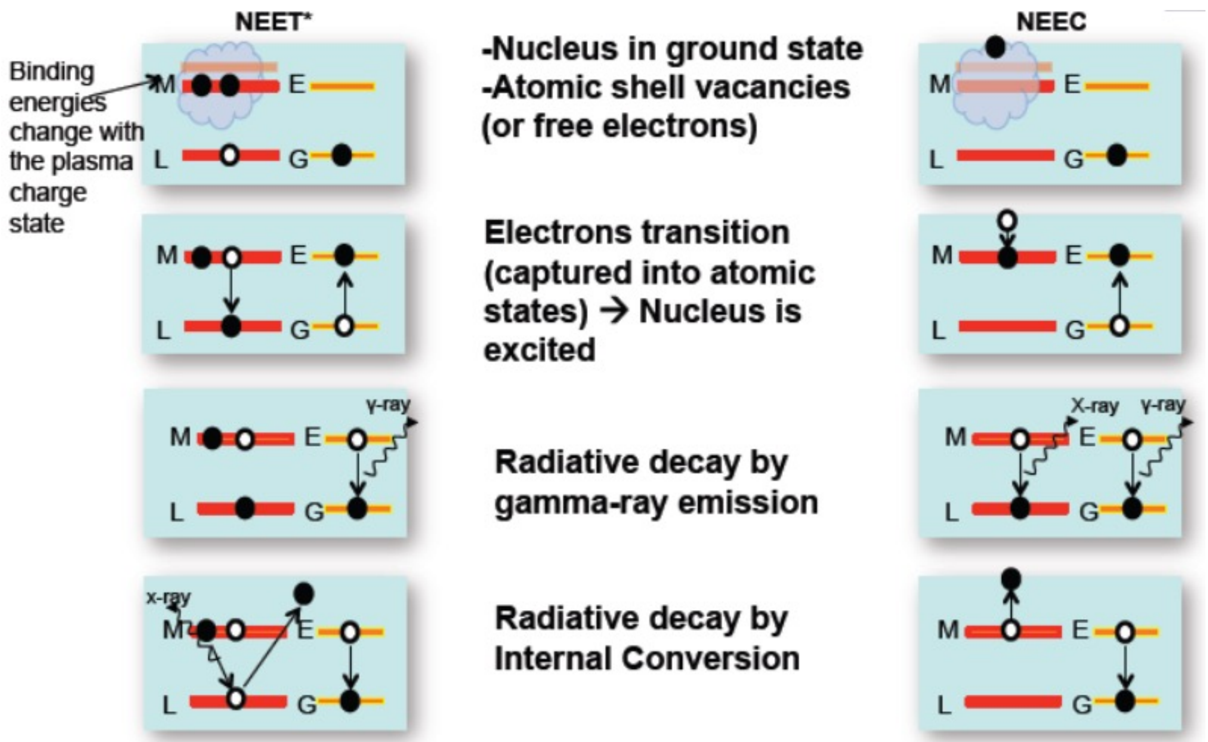
	Performance Measure	Threshold	Objective
Optical Laser Systems	High repetition rate short pulse laser	30 J 300 fs 1 Hz	150 J 150 fs 10 Hz
	High energy long pulse laser [1]	200 J 10 ns 1 shot per 60 min	1000 J 10 ns 1 shot per 30 min
X-ray Beam Delivery	Photon energy [2]	5-25 keV	5-45 keV
Experimental Systems	Re-entrant diagnostic inserters [3]	4	9

[1] 2nd harmonic and temporally square pulses.
[2] Requirement on MEC-U provided optics after LCLS mirror directing X-rays to target chamber center. The X-ray beam repetition rate is 120 Hz.
[3] Cost performance parameter.

Threshold KPPs define the mandatory high-level deliverables required for the completion of the MEC-U Project.
Objective KPPs define the full operational capabilities that are enabled by, but not necessarily demonstrated by the Project.

Extra slides





MEC-U is positioned to be a major facility for both HEDLP and IFE research

Fundamental plasma properties under ICF conditions

- "first-principles" temperature, viscosity, sound speed, atomic kinetics, structure, density, and thermal diffusivity with unmatched accuracy and precision

Driving towards true continuous high repetition rate plasma science

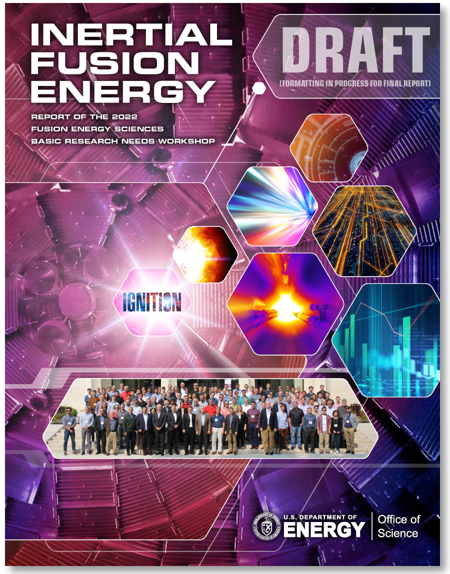
- Machine learning feedback loops from plasma data [1]
- Facility infrastructure built for multiple "mega-shot" petawatt experiments
- Continuous structured target feed

IFE ablator studies

- Microphysics of wetted foams: (multi-frame) imaging and tomography
- Diamond EOS and microphysics of defect evolution (single shot multi-frame)
- Motivates upgrade to 5 kJ and 3ω with converging beams for highest pressures

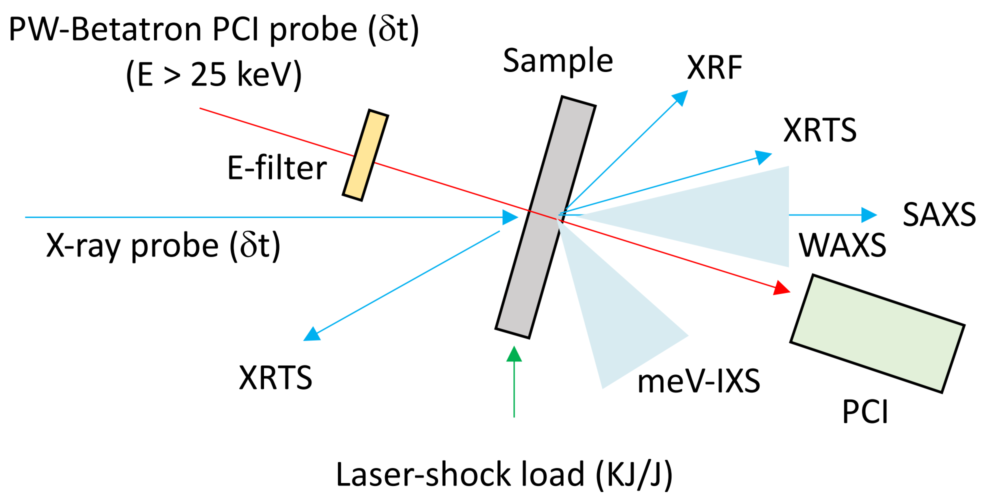
Ion fast ignition science

- Microphysics of high intensity laser matter interaction and particle acceleration
- Precise ion stopping power in compressed ICF-relevant states
- Can motivate both dual-beam PW and 5 kJ upgrades

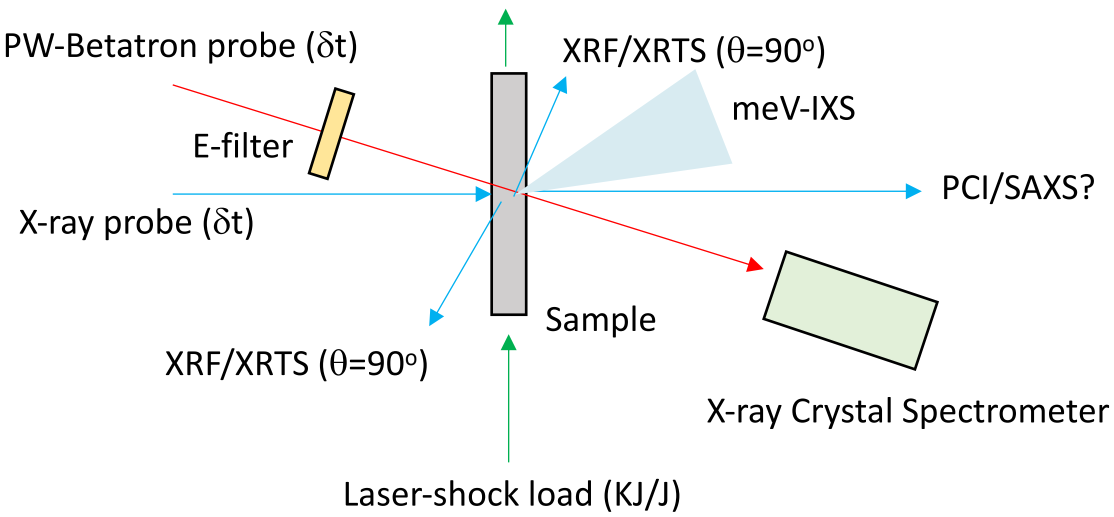


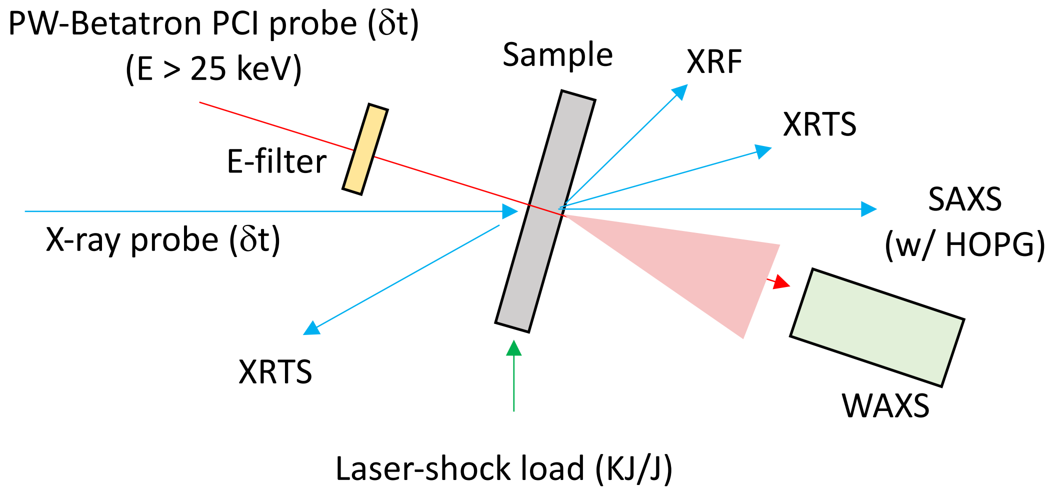
IFE BRN report

[1] T. Ma et al., Plasma Phys Contr F **63**, 104003 (2021).



Configuration 2





Configuration 2*