Resolving Ultrafast Dynamics in Warm Dense Matter

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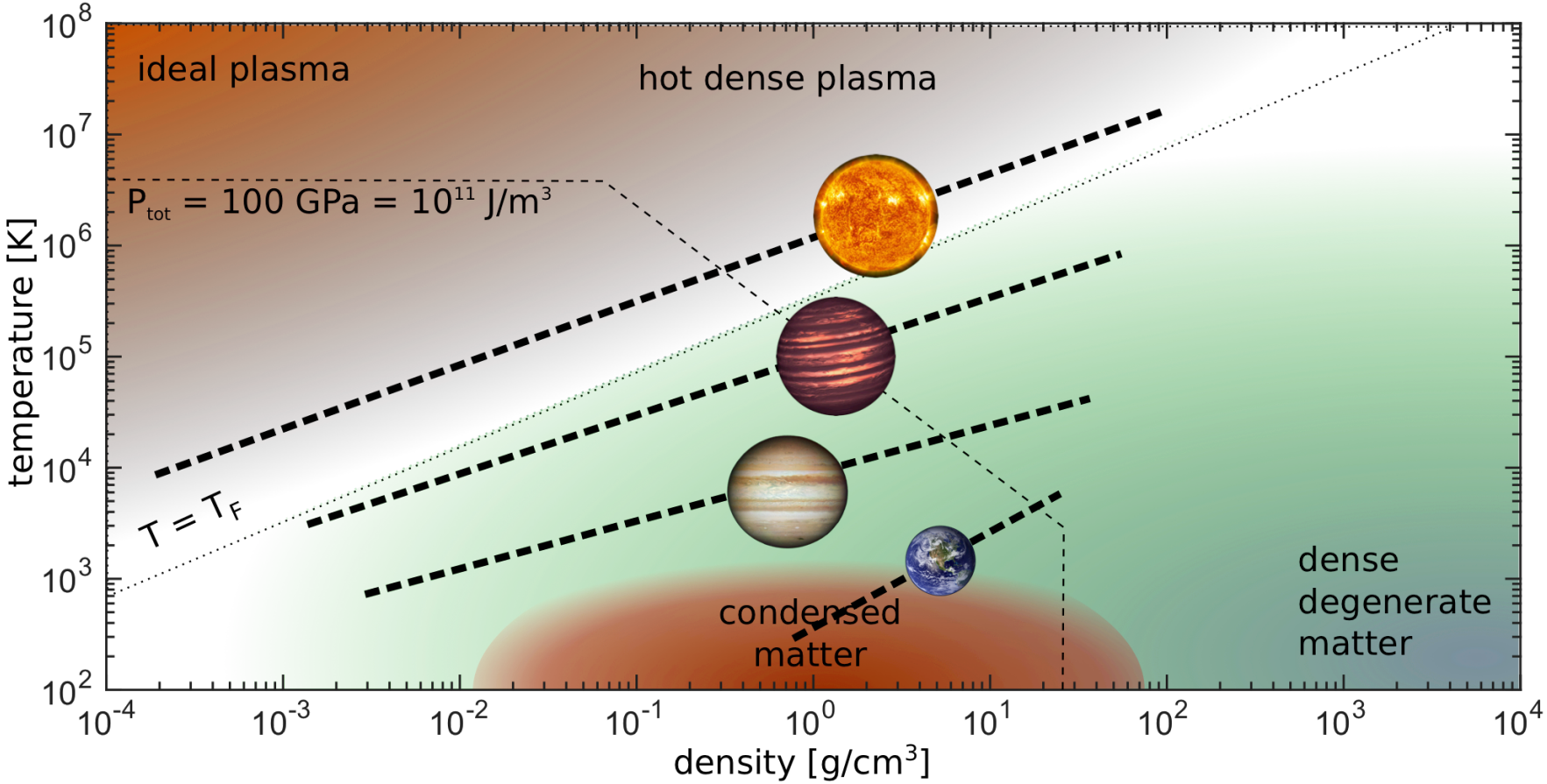
Motivation | High energy density matter



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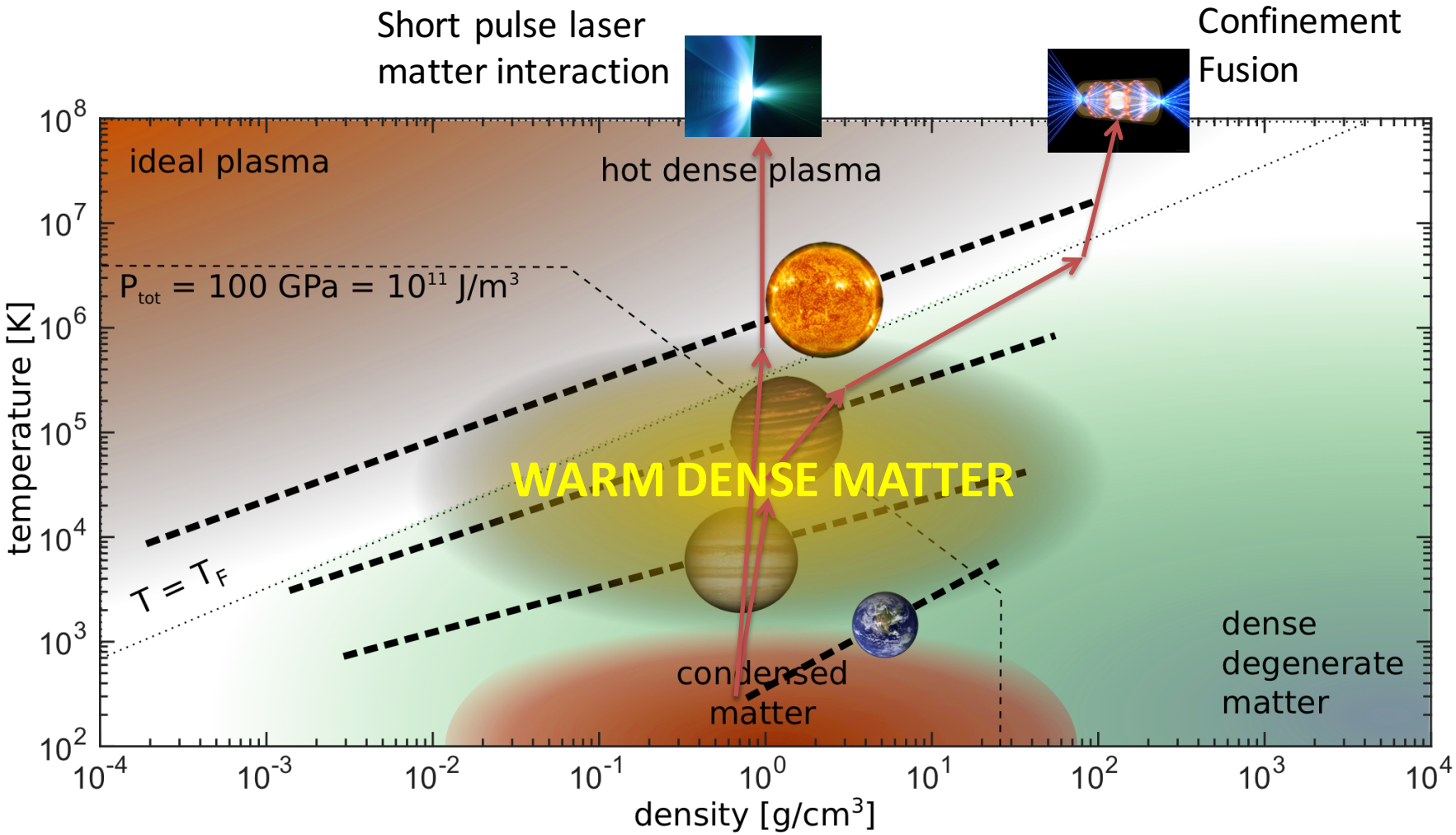


Motivation | Warm dense Matter (WDM)

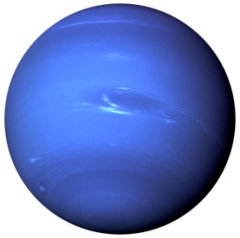
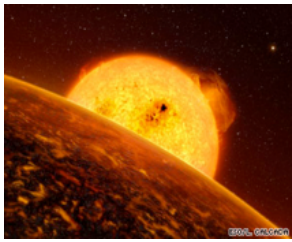
transition regime

solid state $\Longleftrightarrow$ hot dense plasma

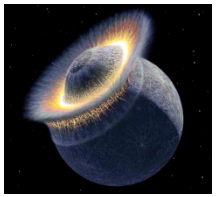
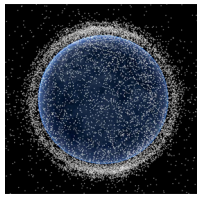
properties:

- 0.1 – 10 times solid state density
- temperature: ~5000 K up to ~10^6 K
- pressure: ~1 GPa up to ~10 TPa
- partially ionized
- partially degenerate $n_e \lambda_{th}^3 \approx 1$
- strongly coupled ions

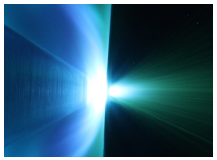
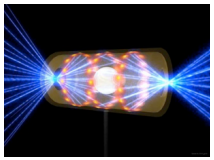
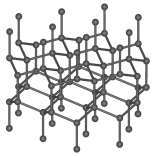
gas giants / ice giants / brown dwarfs

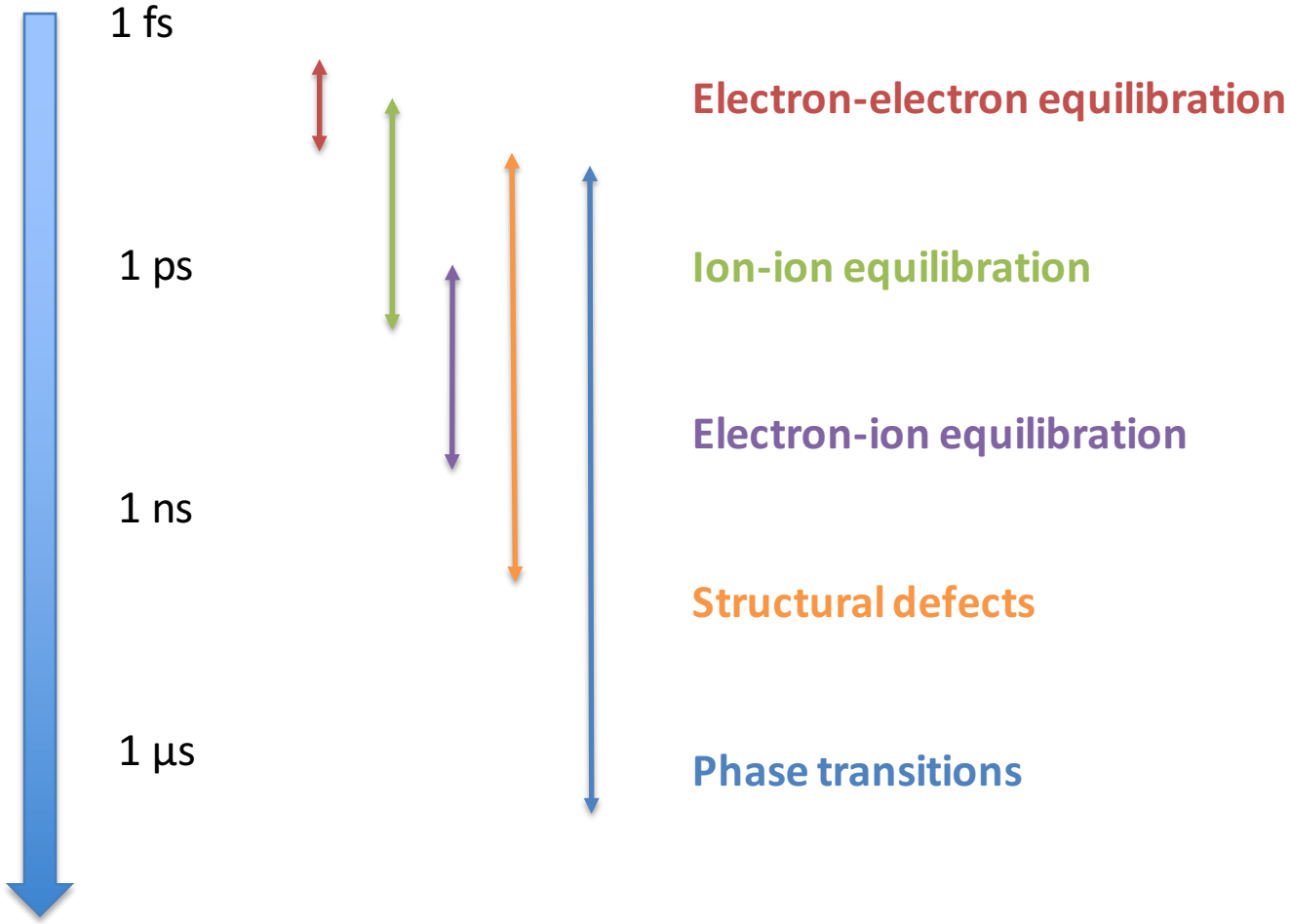
impacts

Laboratory experiments

Motivation | Time scales



What do we need?

- Equation of State
- Energy absorption rates
- Relaxation rates
- Response functions

Underlying physics

- Strong interactions (ions)
- Bound states / ionization balance
- Quantum degeneracy
- Structure

Measurements are usually not "theory-free"

- "Over-diagnose" experiments
- Homogeneous samples
- High temporal resolution
- Cover broad parameter space

Driver:

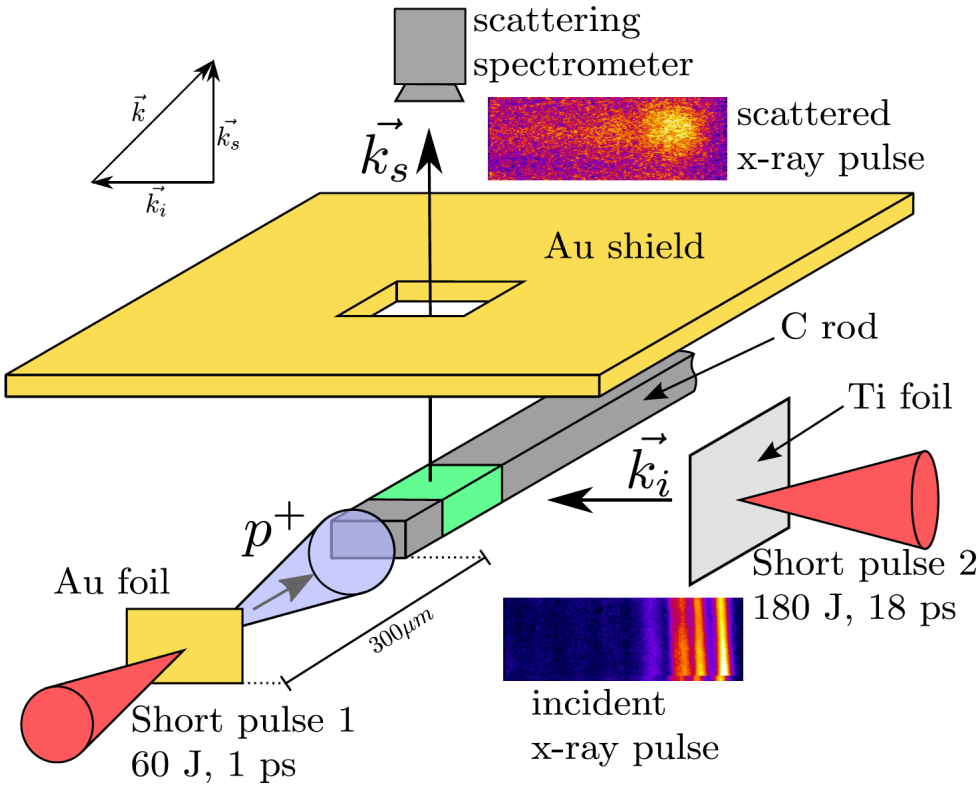
- Isochoric heating with electrons
- Isochoric heating with ions
- Isochoric heating with X-rays
- ”Micro-shocks” (I/c at 10^{19} W/cm^2 ~ Gbar)

Diagnostics:

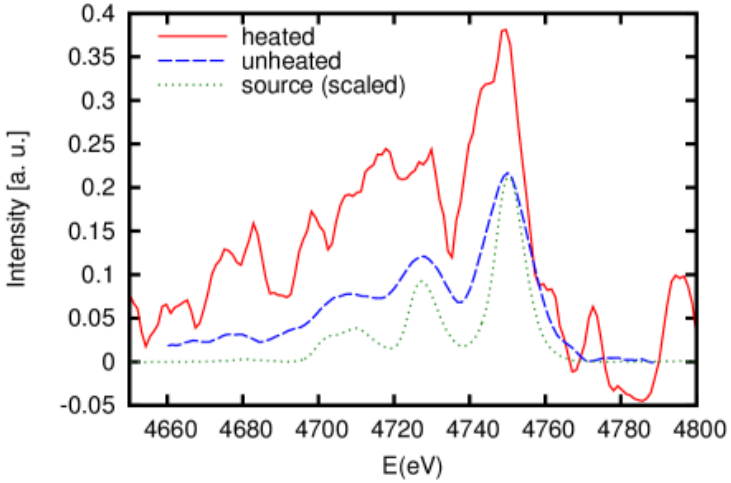
- X-ray sources (line emission, betatron, high harmonics, …)
- Particle sources (electrons, ions, neutrons, …)

--> Radiography, scattering, absorption, stopping power, …

WDM research | Example

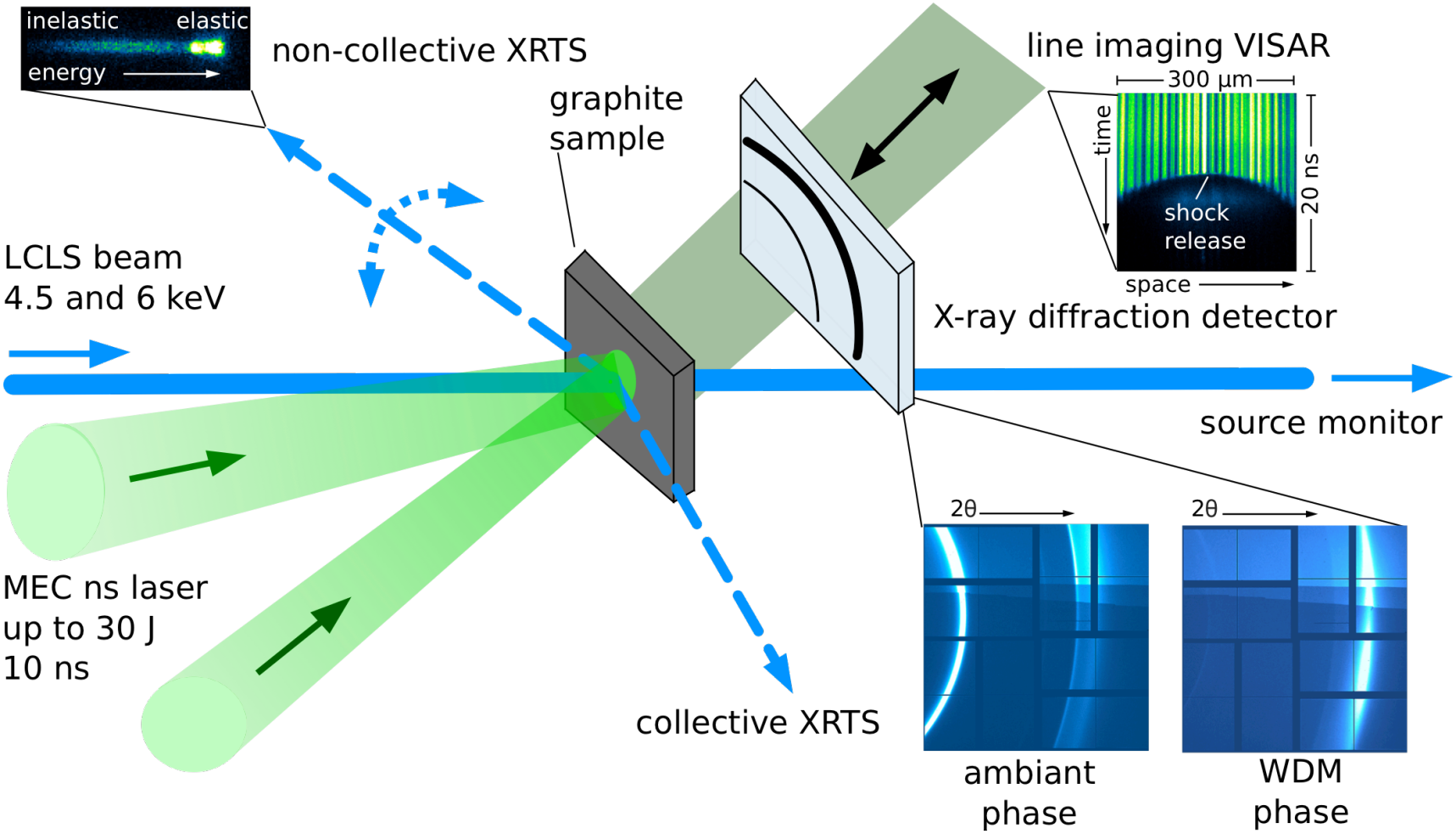


A. Pelka et al., PRL 105, 265701 (2010)

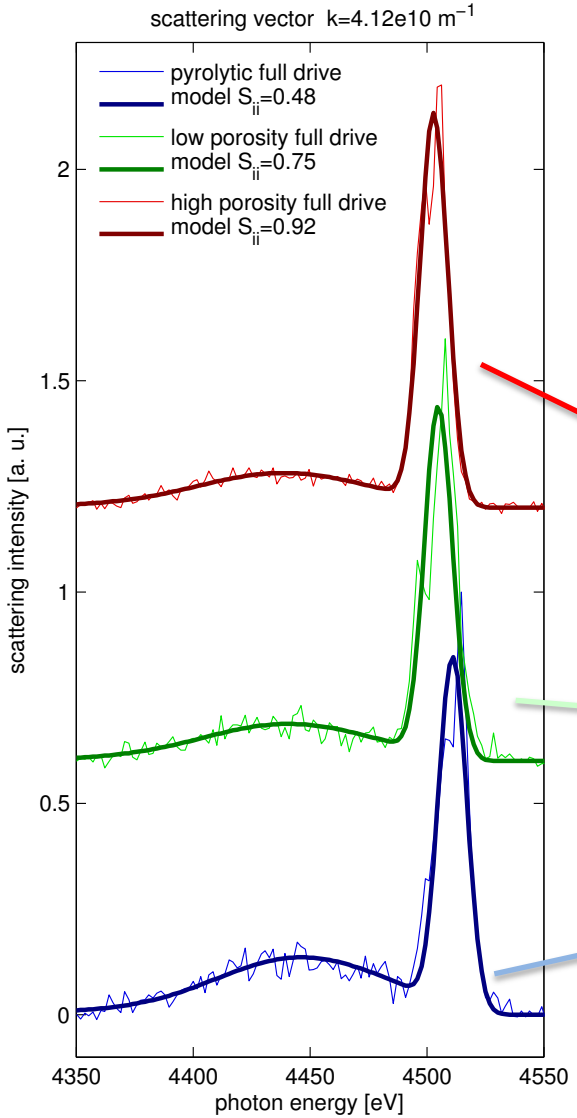


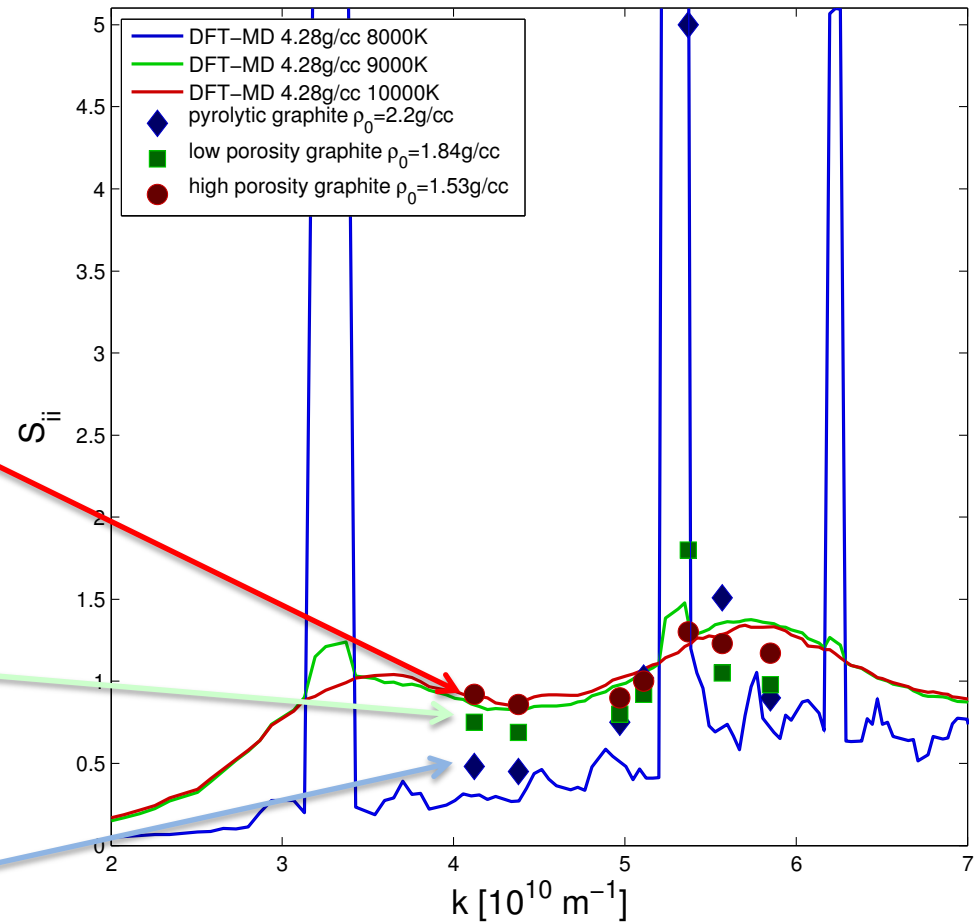
- Complex targets
- Background due to short pulse laser
- Hard to add additional diagnostics
- Fluctuations in laser performance

LCLS experiment | Setup



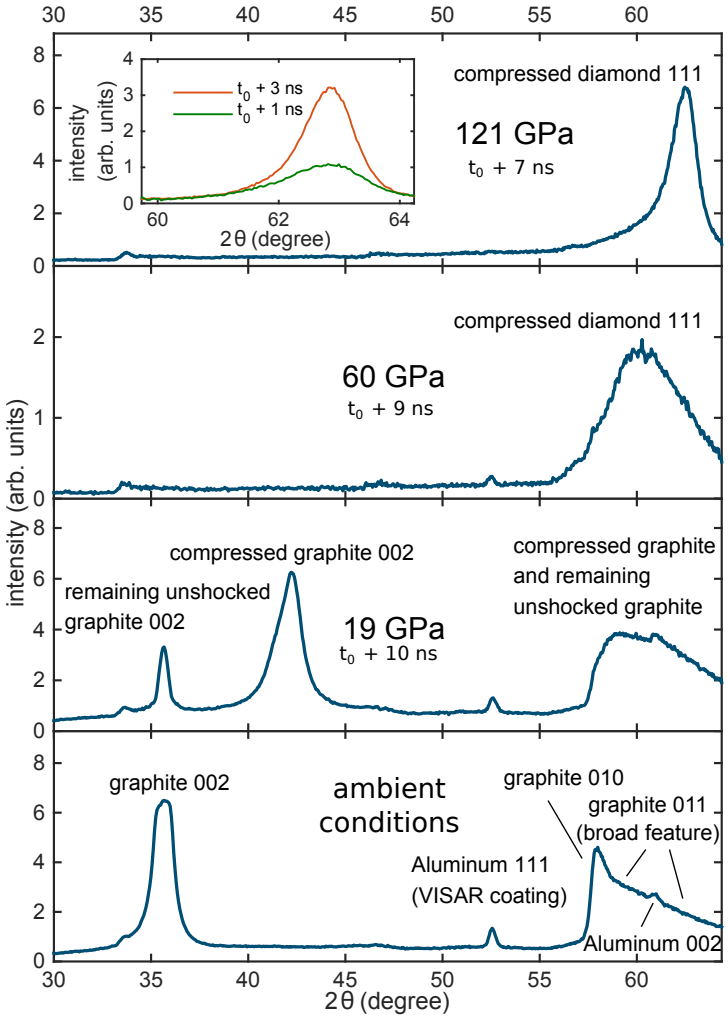
LCLS experiment | Solid and liquid structure at ~180 GPa

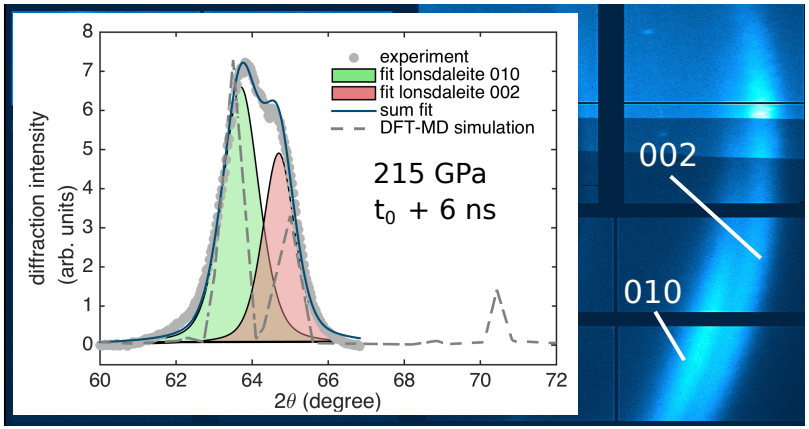




- High porosity samples → liquid
- Low porosity samples → liquid (but cooler)
- Pyrolytic graphite → solid, close to melting

LCLS experiment | X-ray Diffraction: ns-formation of diamond

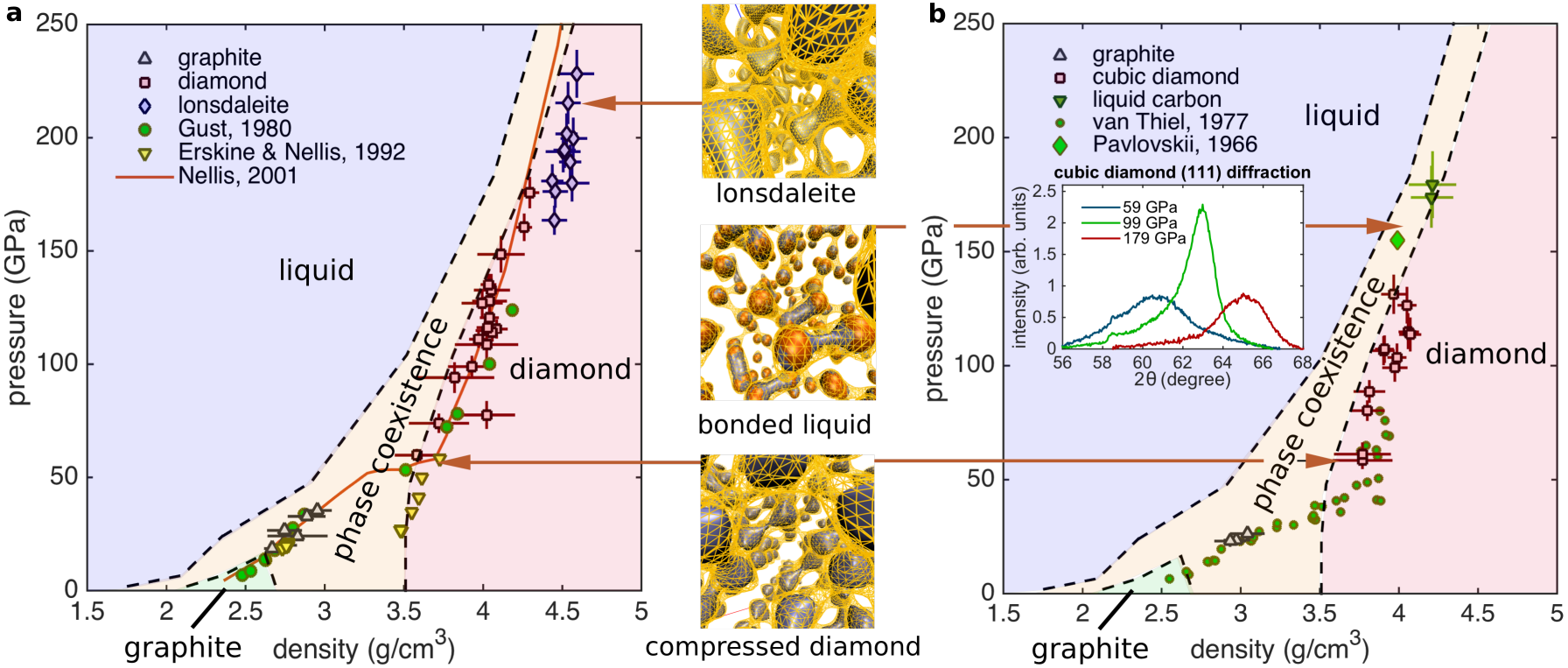




- First direct in-situ observation of the shock-induced transition from graphite to diamond.
- Pyrolytic graphite compressed above ~170 GPa: formation of lonsdaleite structure.

D. Kraus et al., submitted

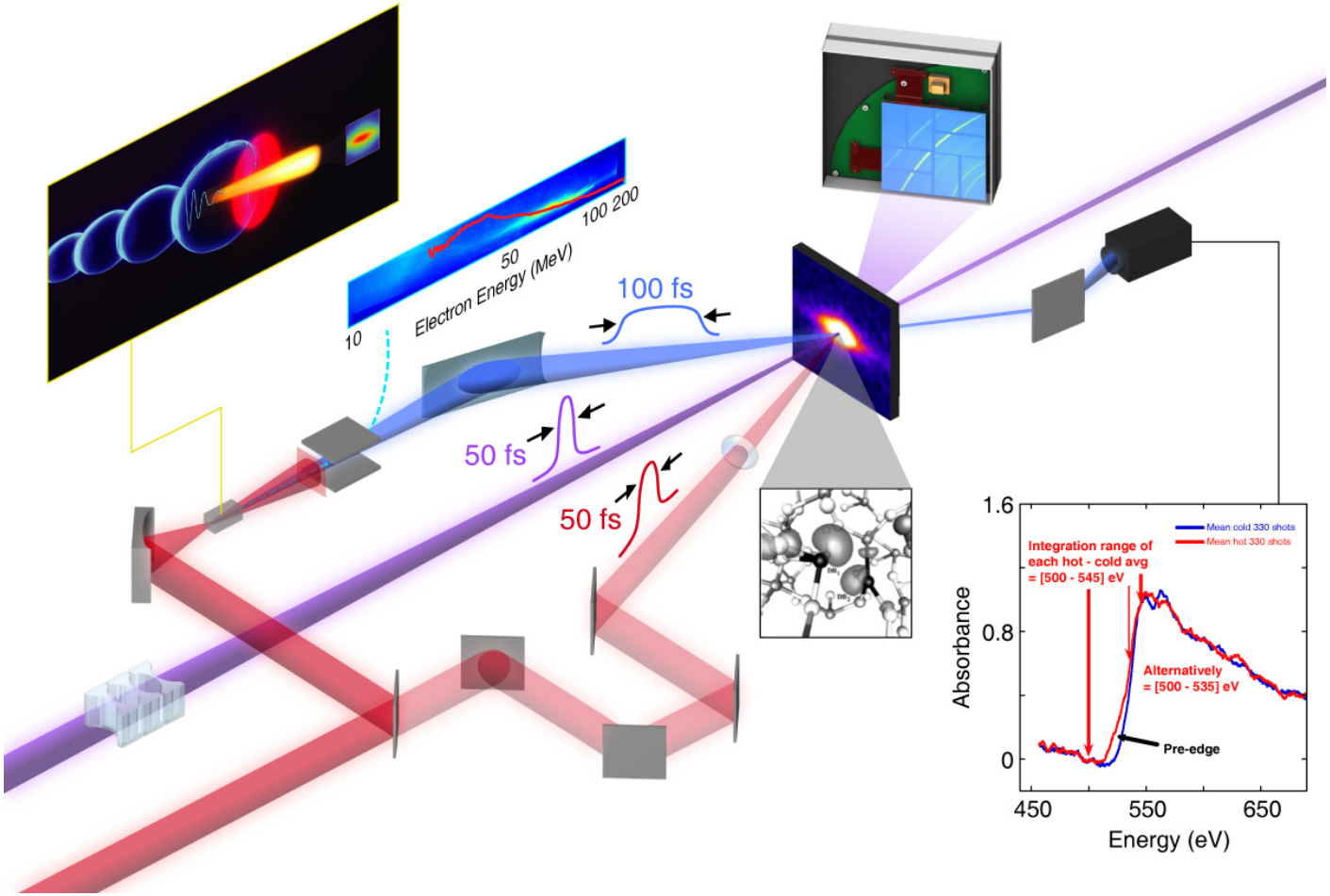
LCLS experiment | X-ray diffraction from porous samples



Isochoric heating using shorts pulse lasers can access different parameter regimes!

D. Kraus et al., submitted

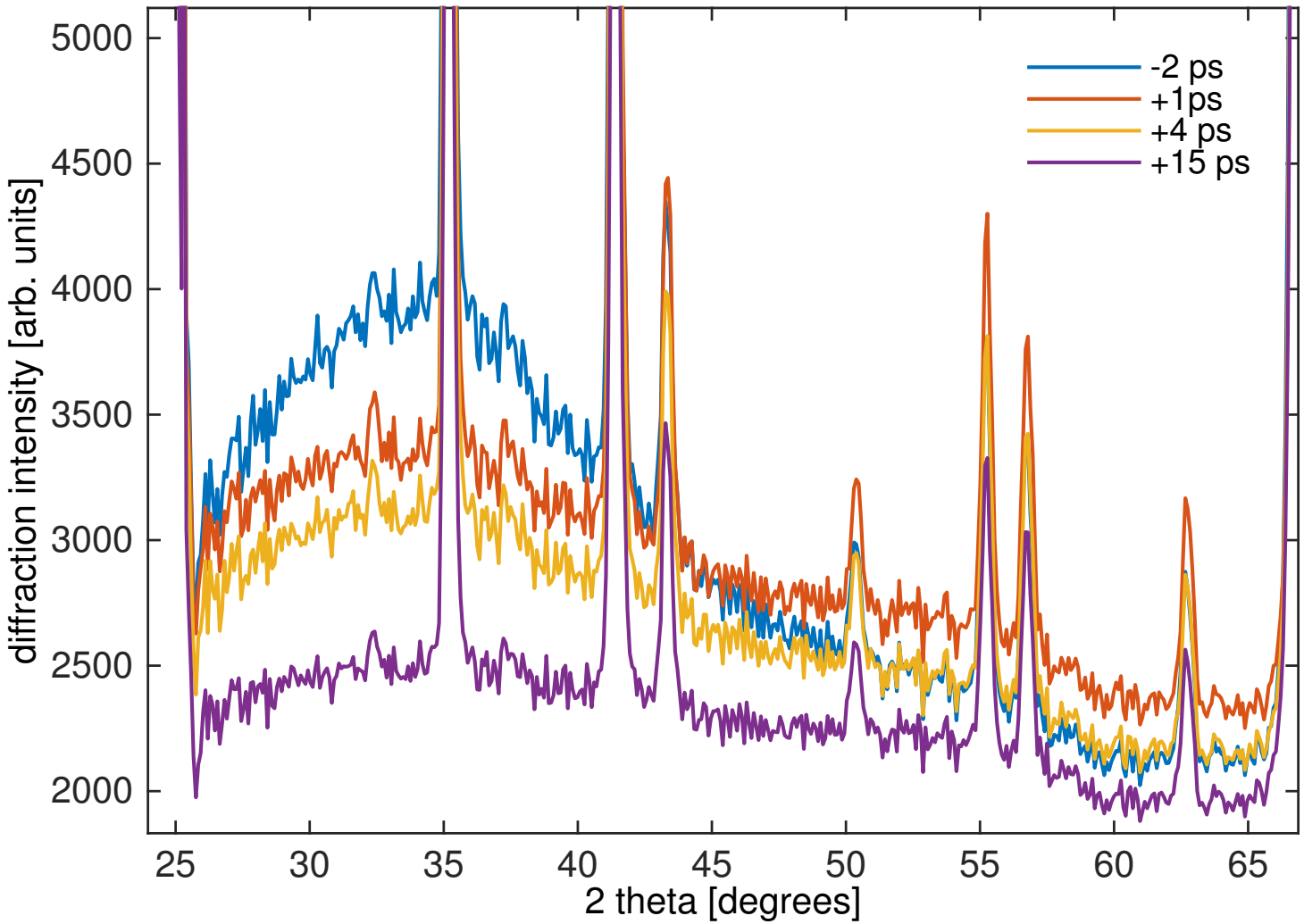
LCLS experiment | Diffraction + Absorption



Spectrally resolved X-ray scattering was also anticipated, but no space left in target chamber

B. Barbrel, UC Berkeley
F. Albert, LLNL
W. Schumaker, SLAC
…

LCLS experiment | Diffraction + Absorption



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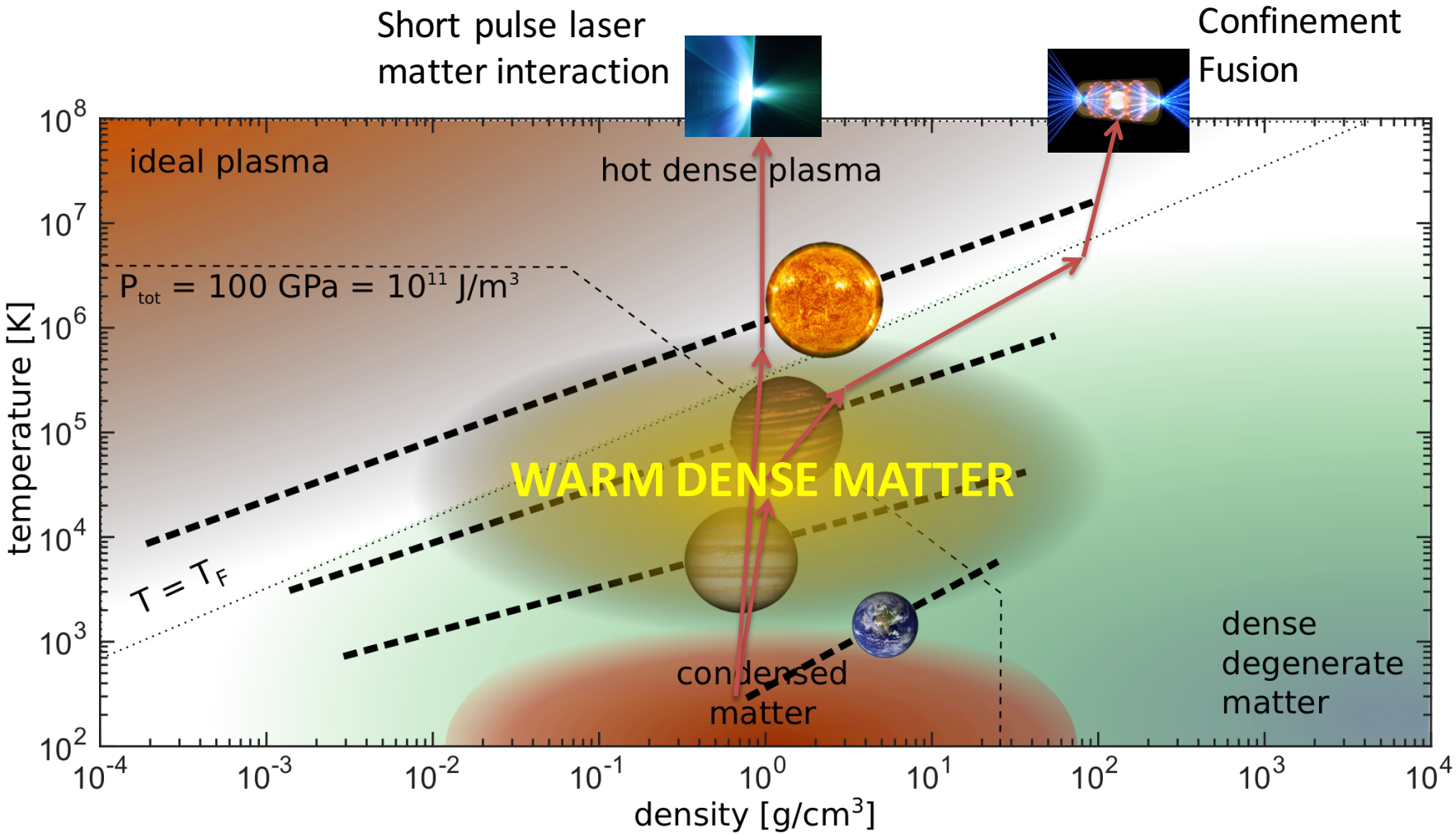
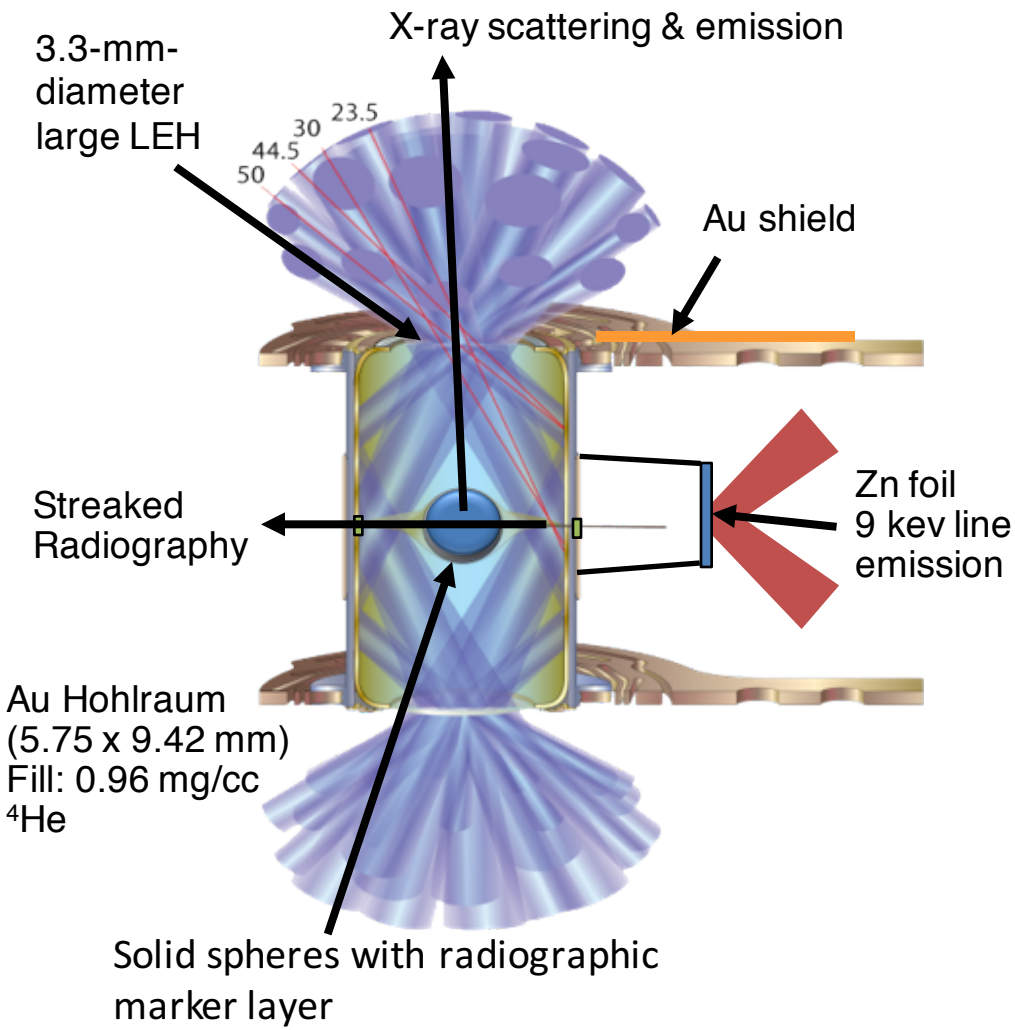
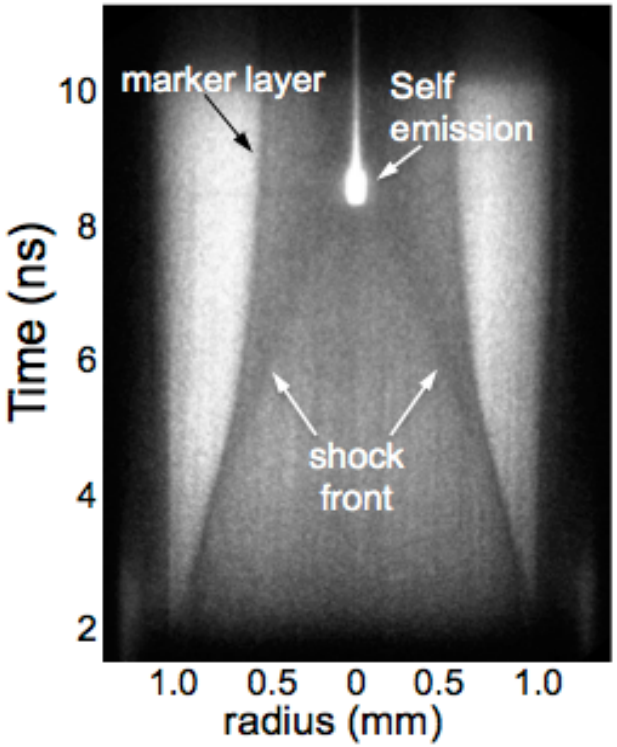


NIF experiments | Gbar fundamental science platform

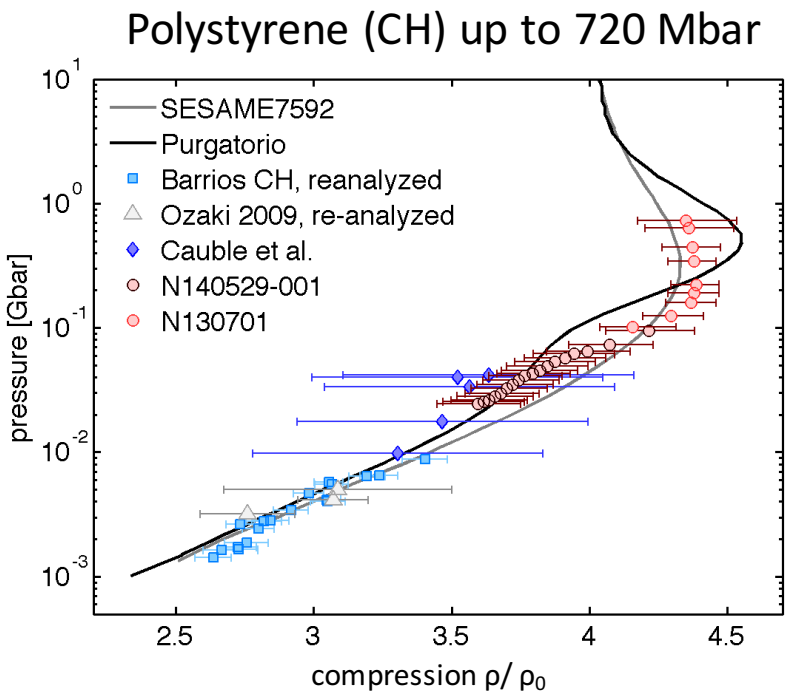


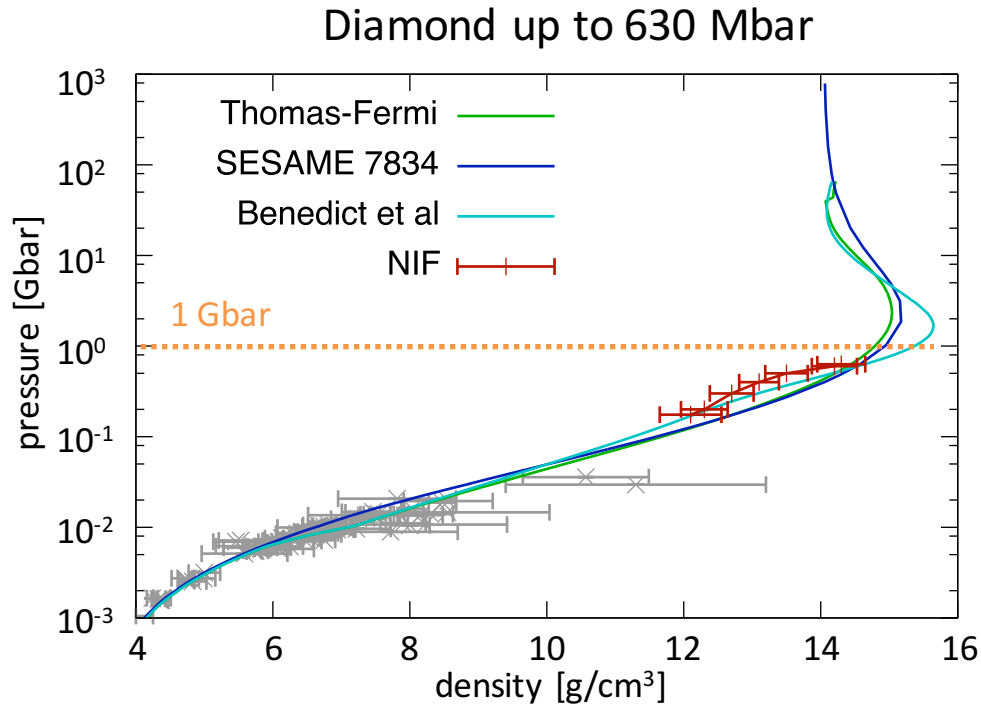
Main diagnostic:
Streaked Radiography



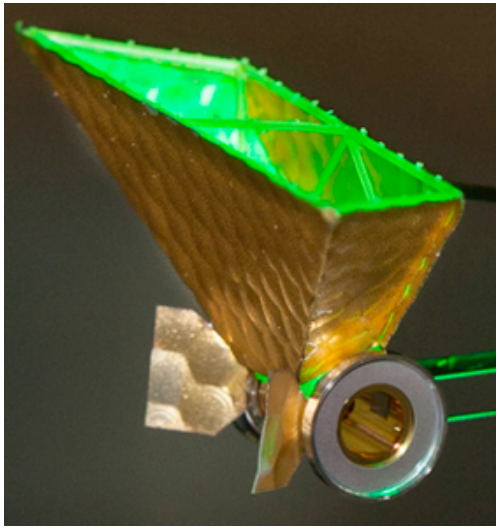
A. L. Kritcher et al., HEDP (2014).
T. Doeppner et al., J. Phys. Conf. (2014).
T. Doeppner et al., RSI (2014).
B. Bachman et al., RSI (2014).
D. Kraus et al., RSI (2014).
D. A. Chapman et al., PoP (2014).

NIF experiments | Measurements approaching 1 Gbar



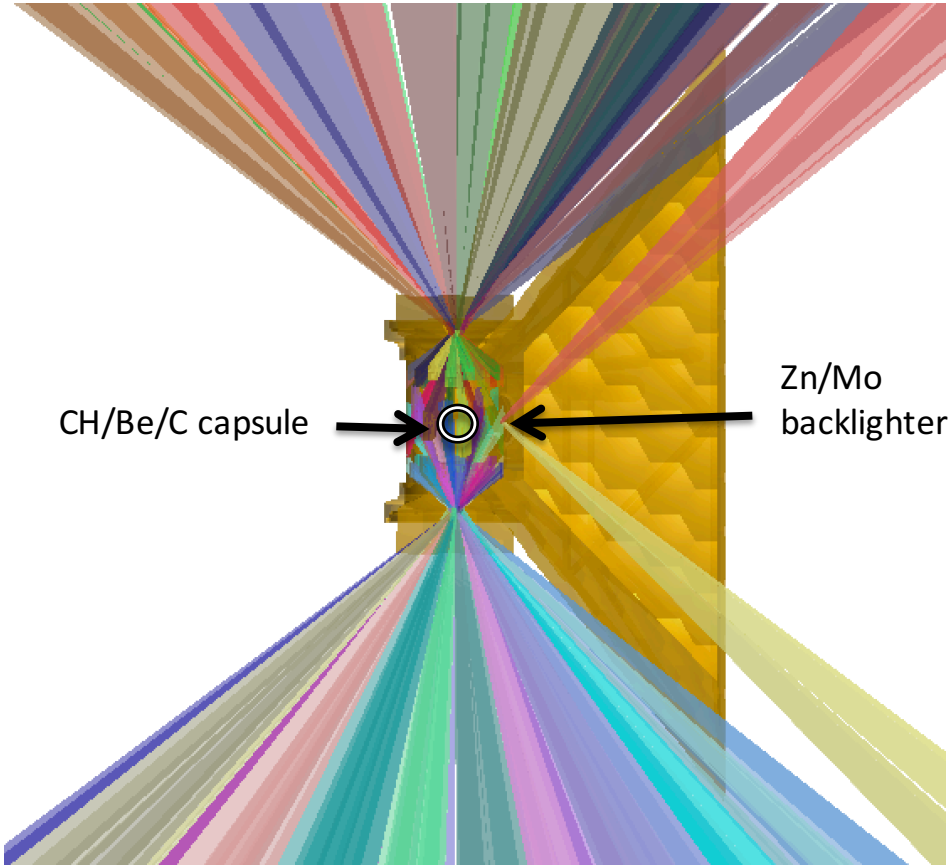


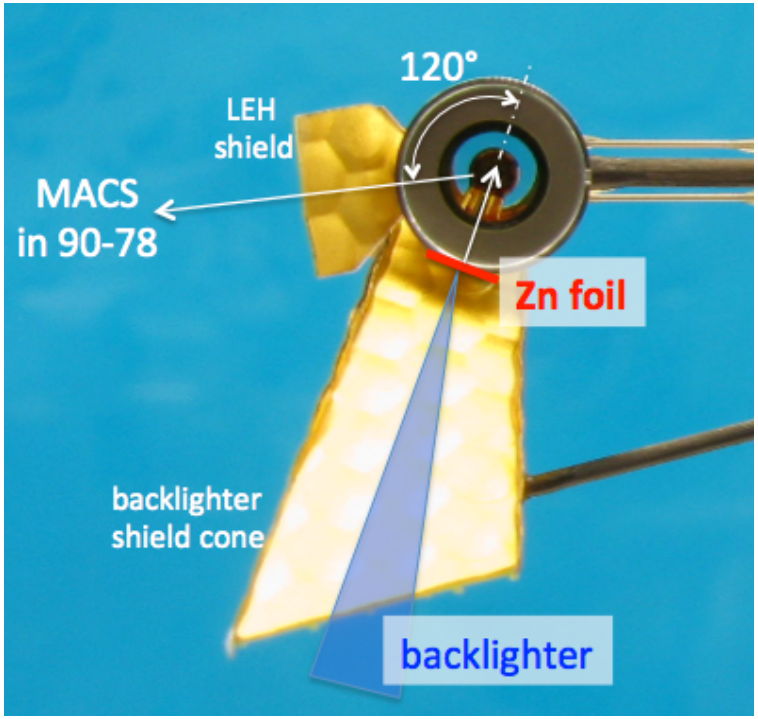
T. Doeppner et al., *Absolute Equation-of-State Measurements for Polystyrene from 25 - 100 Mbar*, in preparation.
A. L. Kritcher et al., *Hugoniot measurement at near Gbar pressures at the NIF*, in preparation.
D. C. Swift et al., *Equation of state measurement of diamond up to 630 Mbar*, in preparation.
B. Bachmann et al., *Probing hotspot conditions in spherically compressed matter*, in preparation.
D. Kraus et al., *Increased K-shell ionization of carbon in imploding CH spheres on the NIF*, submitted.



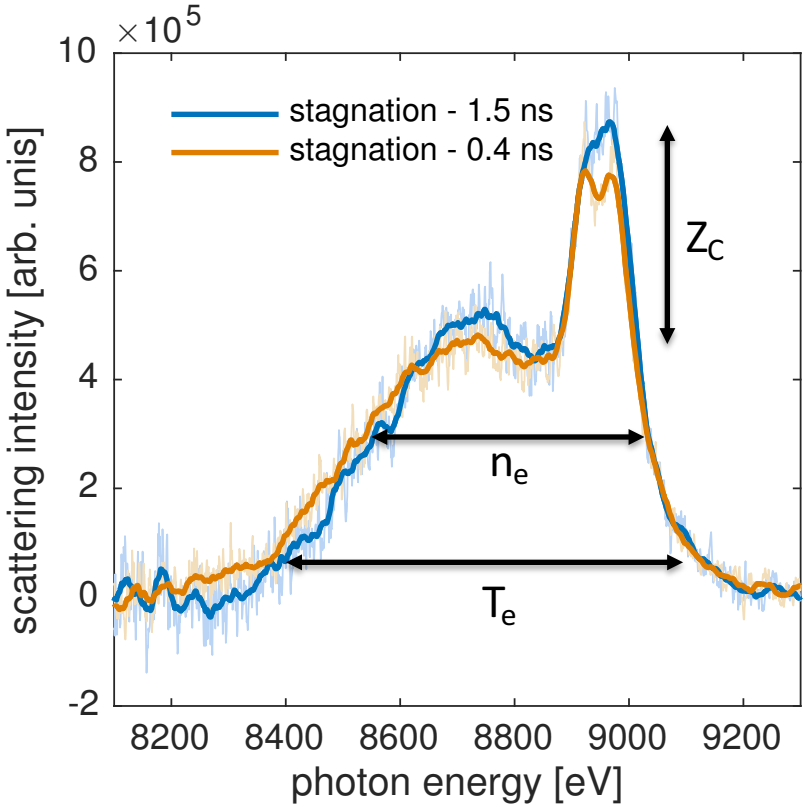
XRTS target design:

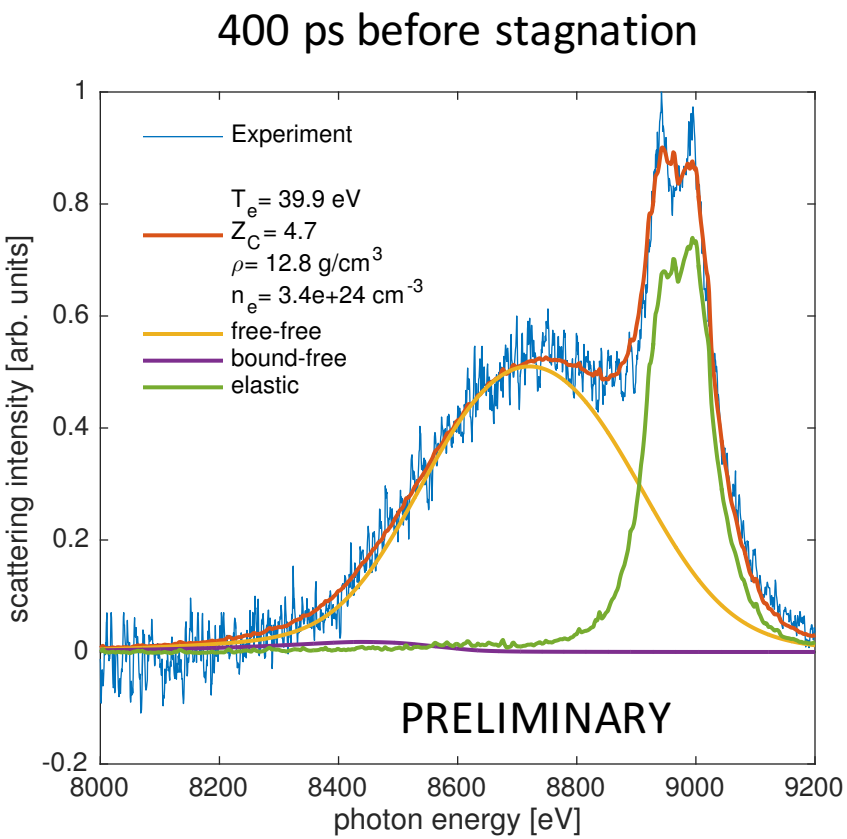
View from spectrometer



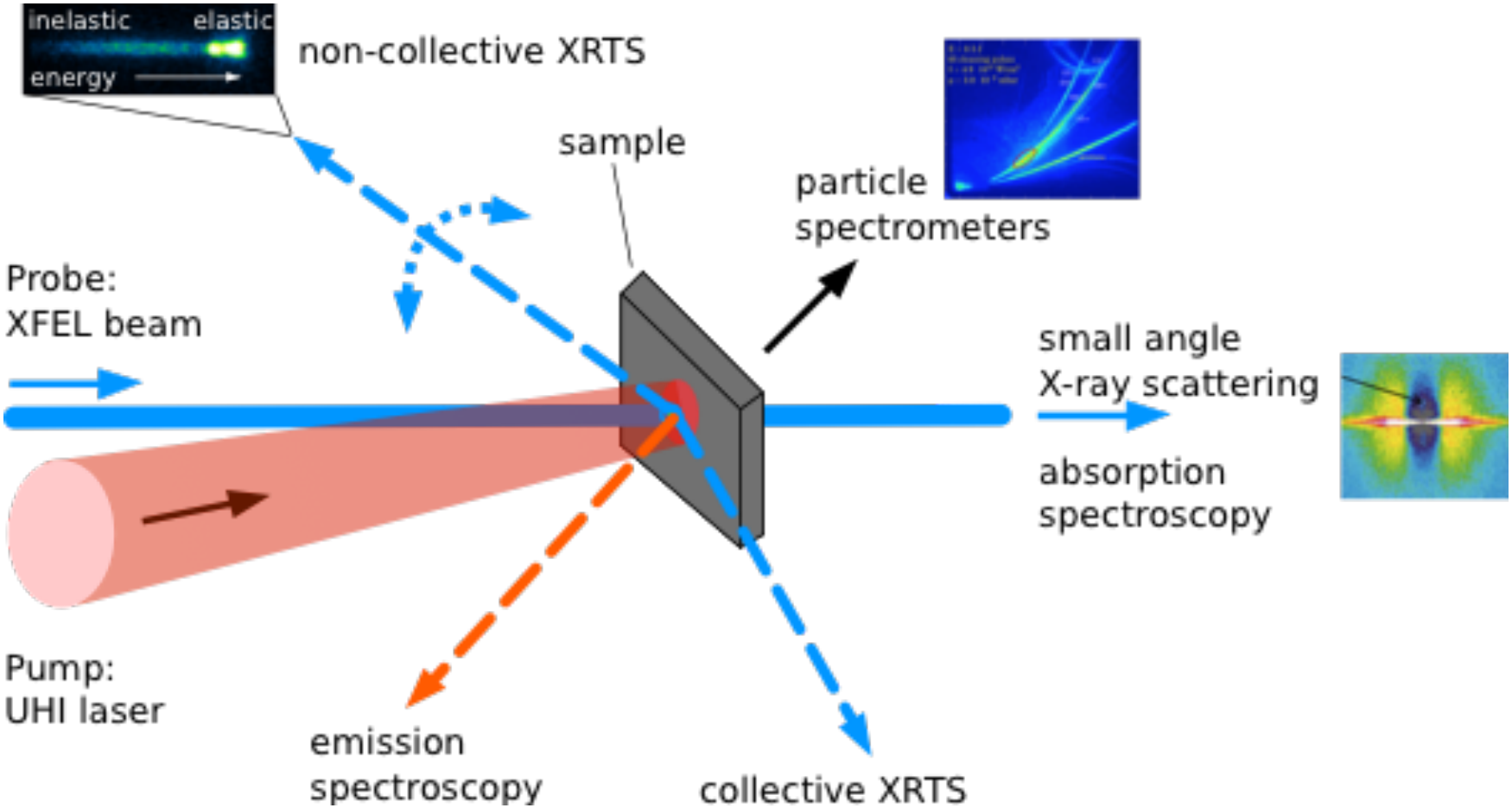


High quality spectra | Three-parameter fits





Summary | Anticipated future experiments

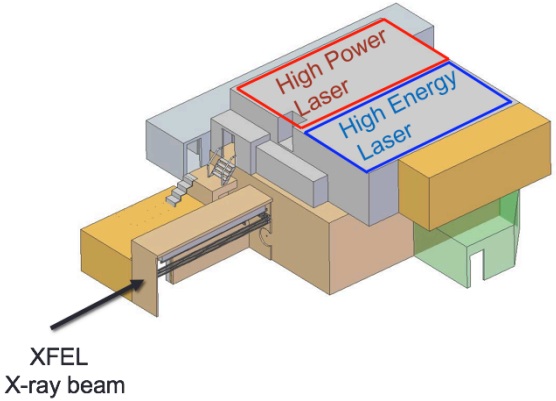


High repetition rate experimental techniques

- Target delivery
- Diagnostics development
- Radiation Shielding
- EMP Shielding
- Bright and stable broad band X-ray sources
- Stable and well characterized ion beams with high conversion efficiency
- Data acquisition, storage and online analysis

Outlook | Advertisment

High Energy Density at European XFEL – Helmholtz International Beamline for Extreme Fields



Job openings: now: postdoc & laser engineers

more soon

Thanks