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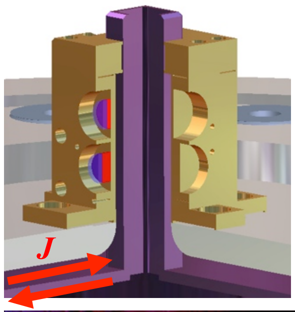

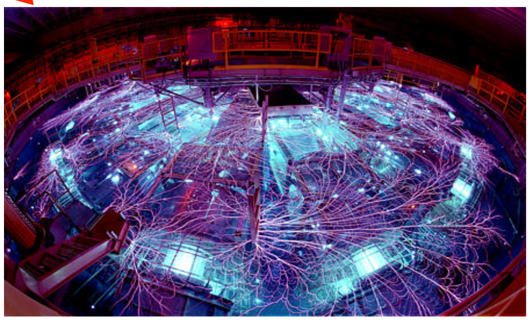

X-ray Thomson scattering of warm dense matter on the Z-accelerator

T. Ao,[1] E. C. Harding,[1] J. E. Bailey,[1]
M. P. Desjarlais,[1] S. B. Hansen,[1] R. W. Lemke,[1] L. P. Mix,[1]
D. B. Sinars,[1] G. A. Rochau,[1] M. Geissel,[1] I. C. Smith,[1] G. Gregori[2]

[1]Sandia National Laboratories, Albuquerque, NM
[2]University of Oxford, Oxford, UK

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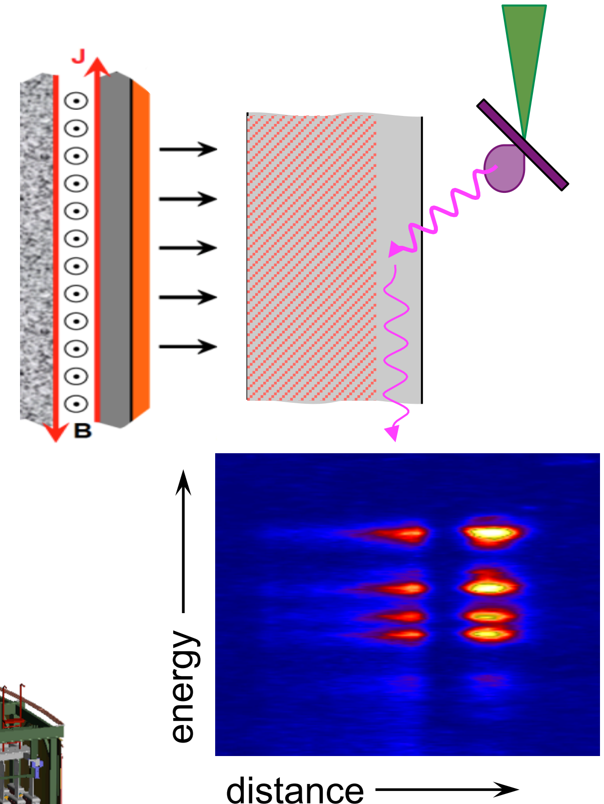
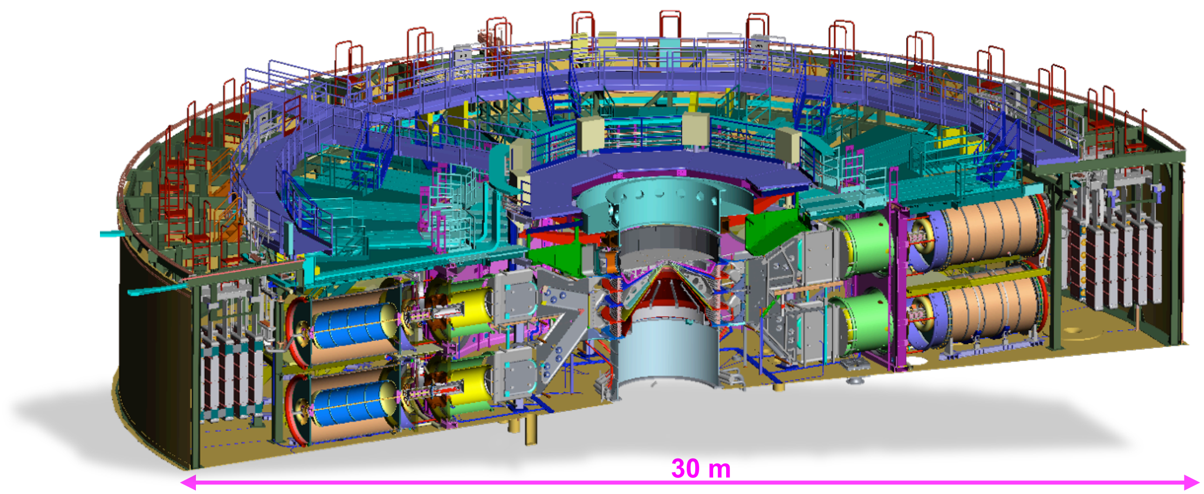
Combining x-ray Thomson scattering with Z's unique warm dense matter samples will provide benchmark quality data

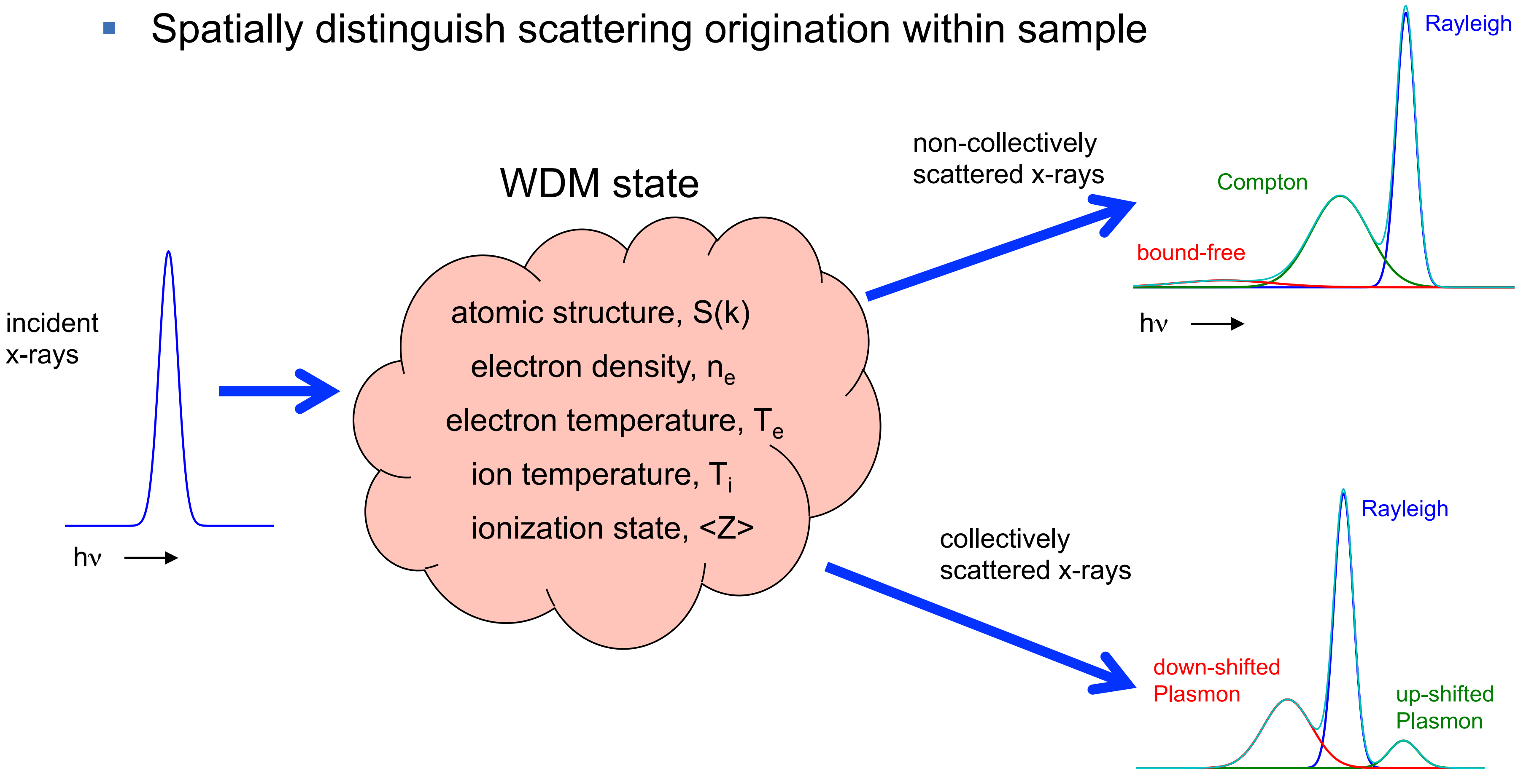
- Z's warm dense matter samples are large, uniform, long-lived and precisely characterized
- X-ray Thomson scattering will expand diagnostic capabilities on Z beyond pressure and density measurements
- We have demonstrated XRTS measurements with spatial resolution on Z





X-ray Thomson scattering (XRTS) is a powerful diagnostic to infer n_e, T, <Z>, and phase information

- Extract information about sample from scattered x-rays
  - Spectrally resolve elastic and inelastic features
  - Spatially distinguish scattering origination within sample



S. H. Glenzer and R. Redmer, Rev. Mod. Phys. **81**, 1625 (2009).

Z is a unique platform for accurate and precise warm dense matter research

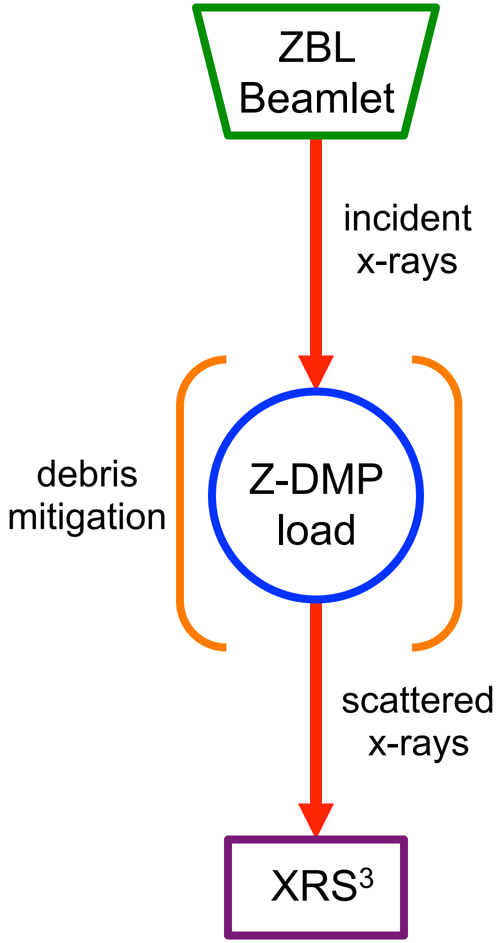
- Z-Dynamic Materials Properties (Z-DMP) experiments
  - Shock-compressed state experimentally determined from flyer's impact velocity (~ 40 km/s, 10 Mbar, several eV)
  - Pressure and density characterized ~ 1-2 %
- No x-ray or hot-electron preheat of sample
- Large samples enable uniform shock state: spatially & temporally
  - Promotes more accurate and precise measurements

	dimension	Z	laser	Z/laser
Initial state	size	1 mm x 10 mm	0.25 mm x 1 mm	4 x 10
WDM state	thickness	200 – 400 um	50 um	8 – 16
	scattering volume	8 – 15 mm^3	0.04 mm^3	750 - 1500
	duration	10 – 100 ns	0.1-1 ns	10 - 100

R. W. Lemke, *et al.*, J. Appl. Phys. **98**, 073530 (2005).

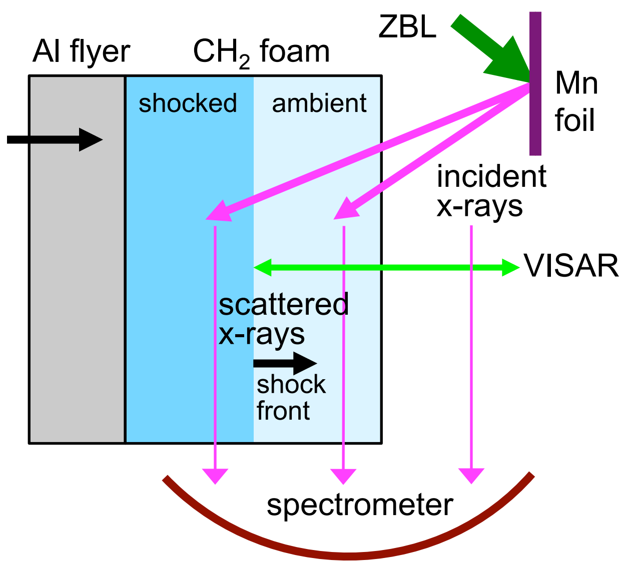
3 key components to XRTS on Z-DMP experiments

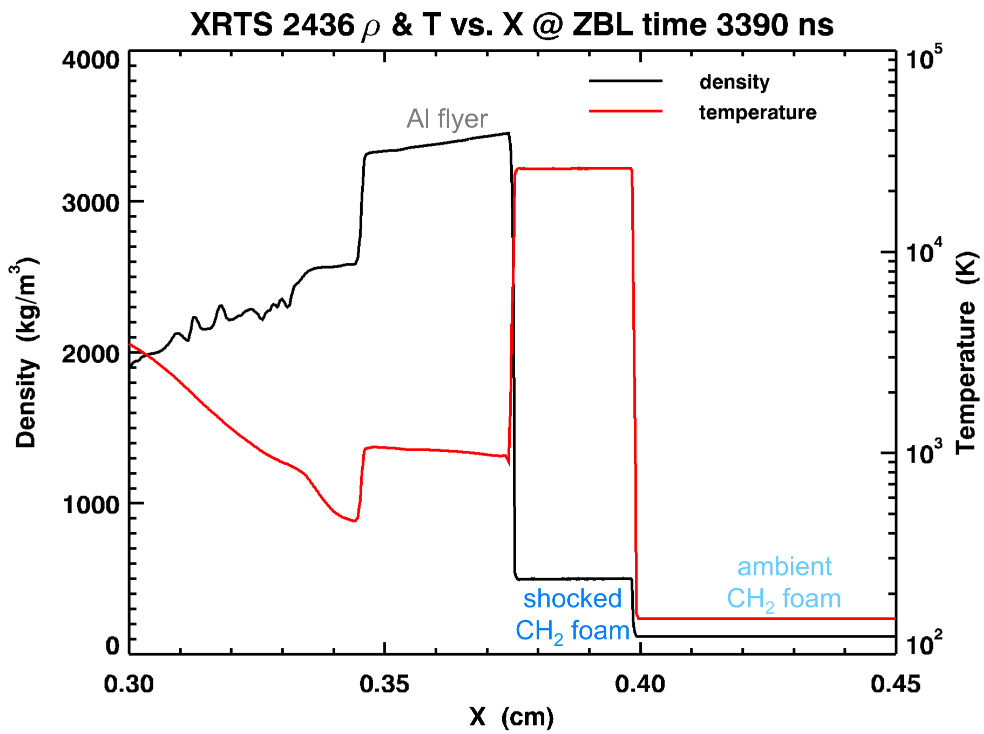
- Produce quasi-monochromatic x-rays
  - ZBL Beamlet (2 kJ, 2 ns) irradiate metal foil
    ➔ Mn-He-α (6.181 keV)
- Generate WDM state
  - Z-DMP load using magnetically launched flyer to shock compress sample ➔ coaxial load
  - Debris mitigation to protect ZBL
- Detect scattered x-rays
  - X-ray scattering spherical spectrometer (XRS^3), resolve scattered x-rays spectrally and spatially using spherically bent crystal ➔ Ge 422
  - Record x-rays ➔ image plate



Spatial resolution is essential for benchmark quality XRTS data

- ALEGRA calculations with Al flyer (16.7 km/s)
  - 0.4 Mbar, 2.5 eV in CH_2 foam target
  - Large spatial extent: 270 μm
  - Long time duration: 90 ns



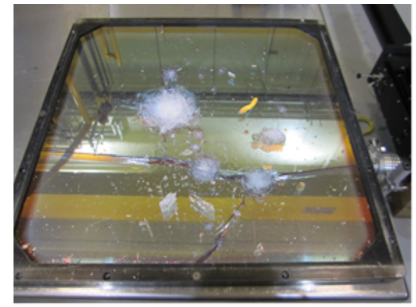


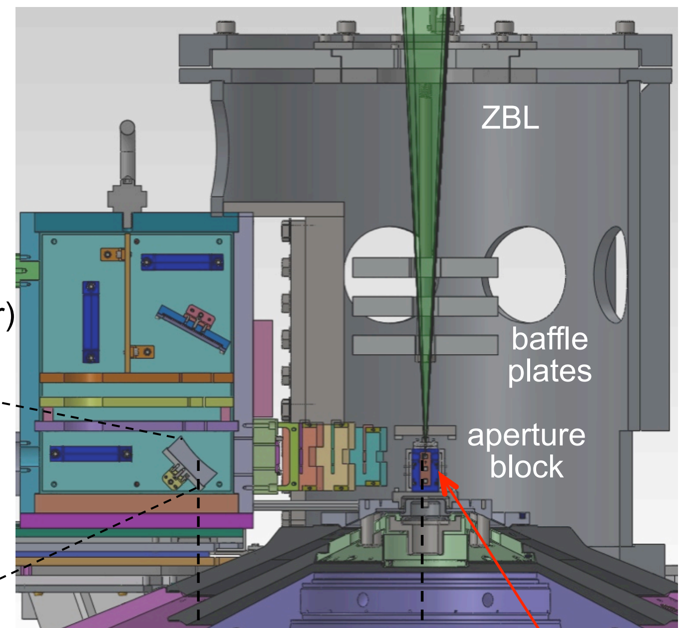
- Measure XRTS signal from ambient & shocked material, and x-ray source
  - Verify uniformity of WDM state
  - Characterize x-ray probe spectrum

X-ray background and load debris pose challenges for Z-XRTS experiments

- X-ray background
  - Photons with energies up to 10 MeV are produced in both power feed section and load region
  - Sufficient signal-to-noise
- Debris mitigation
  - Protect ZBL final optics assembly (FOA)
  - Prevent catastrophic vacuum breach
  - Retrieve XRTS data
  - Protect spherically bent crystal

FOA glass shield

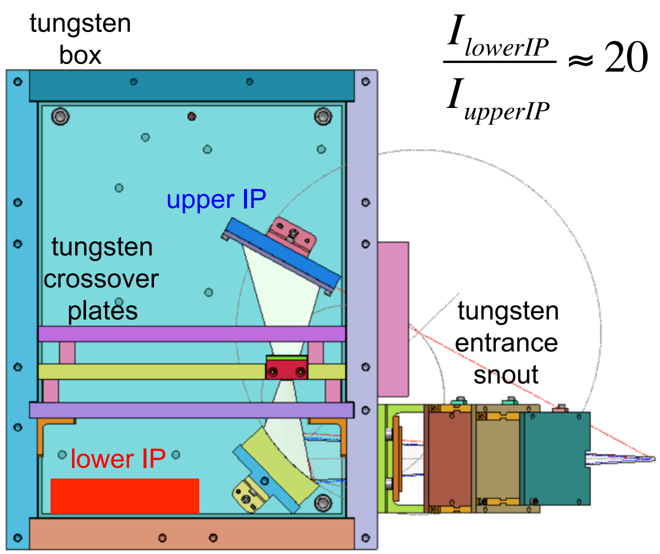




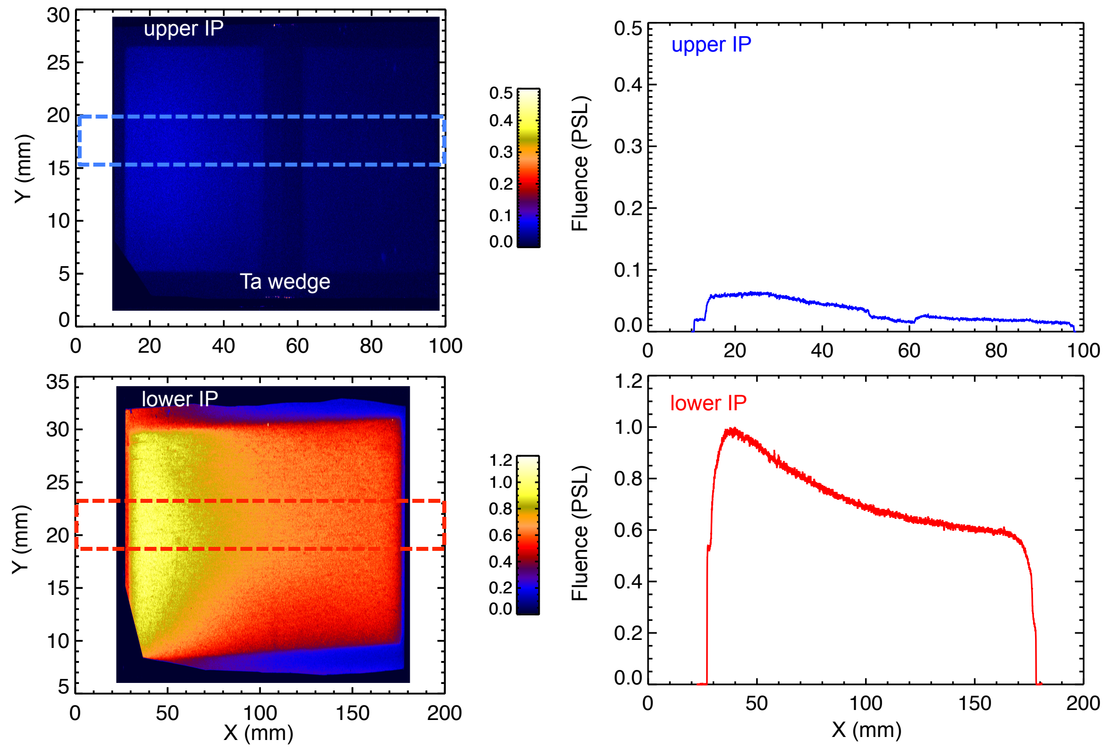
spherical crystal

Low x-ray background of Z-DMP experiments make XRTS viable

- Z-pinch radiation producing experiments
  - Strong x-ray background > 25 PSL (photostimulated luminesce)
- Ride-along tests on Z-DMP experiments
  - Lower x-ray background < 1 PSL
  - External and internal tungsten shielding reduced x-ray background ~ 0.05 PSL

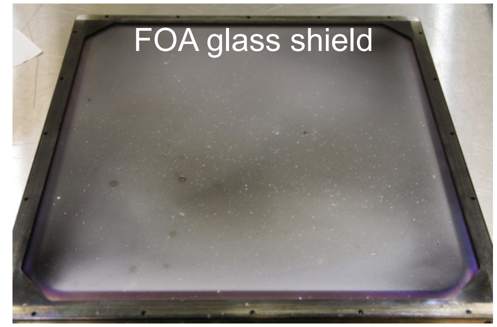


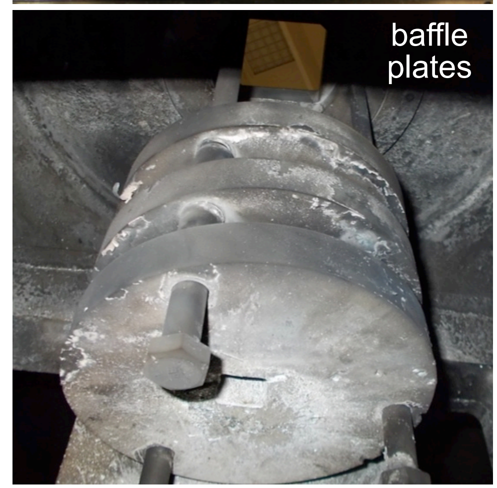
$$\frac{I_{lowerIP}}{I_{upperIP}} \approx 20$$

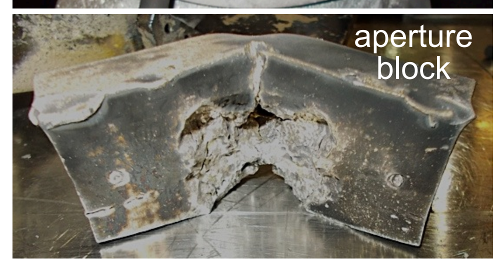


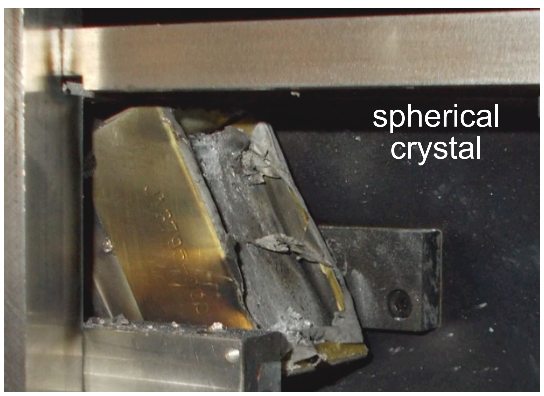
Debris mitigation strategy has been successful

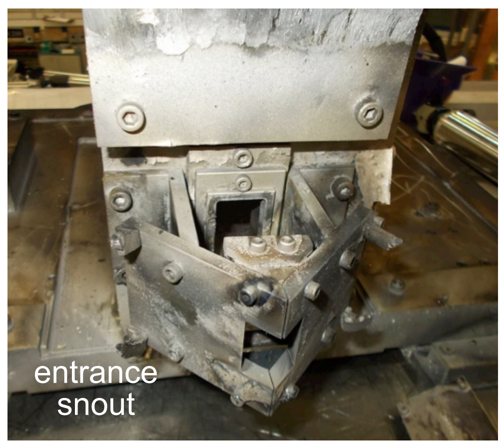
- Hypervelocity penetration depth,[1] $y_{depth} = 0.266\rho_{proj}^{0.595} d_{proj}^{1.05} v_{proj}^{0.995} (\cos\theta)^{0.496}$
  - Increase FOA glass shield thickness
  - Decrease projectile density, size, and velocity
- Aperture block and baffle plates limited axial debris
  - Mostly liquid, some small solid fragments
  - ZBL FOA protected
- XRTS data retrieved from XRS[3]
  - Crystal still damaged







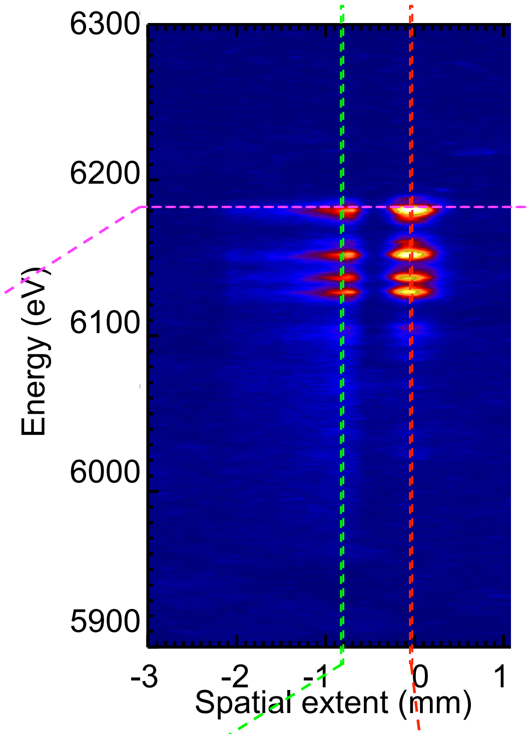


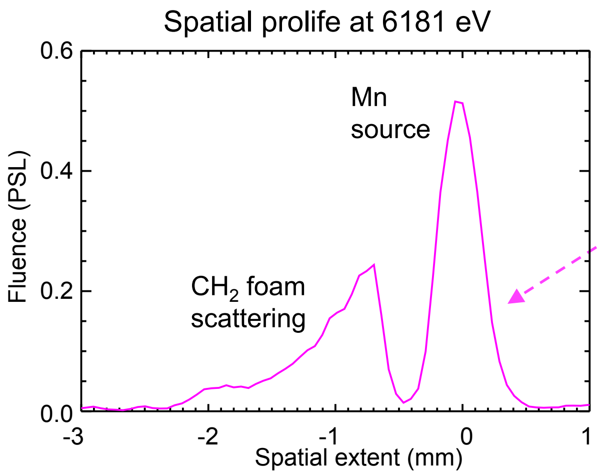


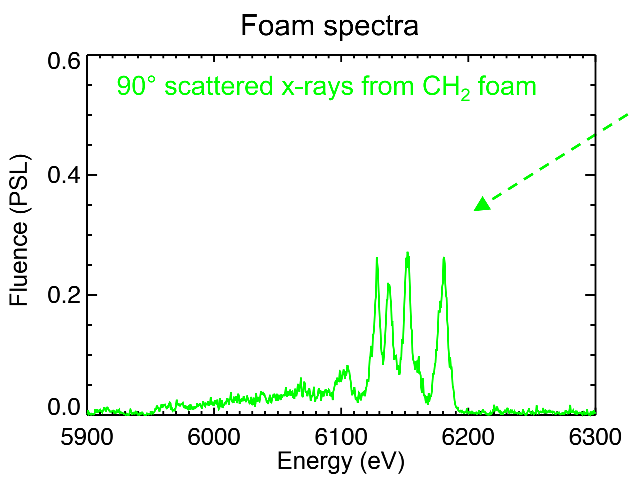
[1]R. R. Burt and E. L. Christiansen, Int. J. Impact Engineering **29**, 153 (2003).

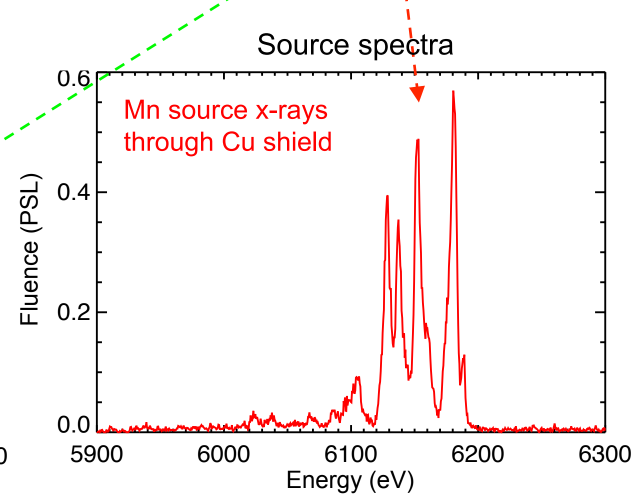
First integrated Z-XRTS experiment measured high-resolution x-ray spectra

- Current loss near load reduced flyer velocity to only 9 km/s
  - ZBL generated x-rays 190 ns early relative to shock arrival in CH_2 foam
  - Scattering from ambient CH_2 foam





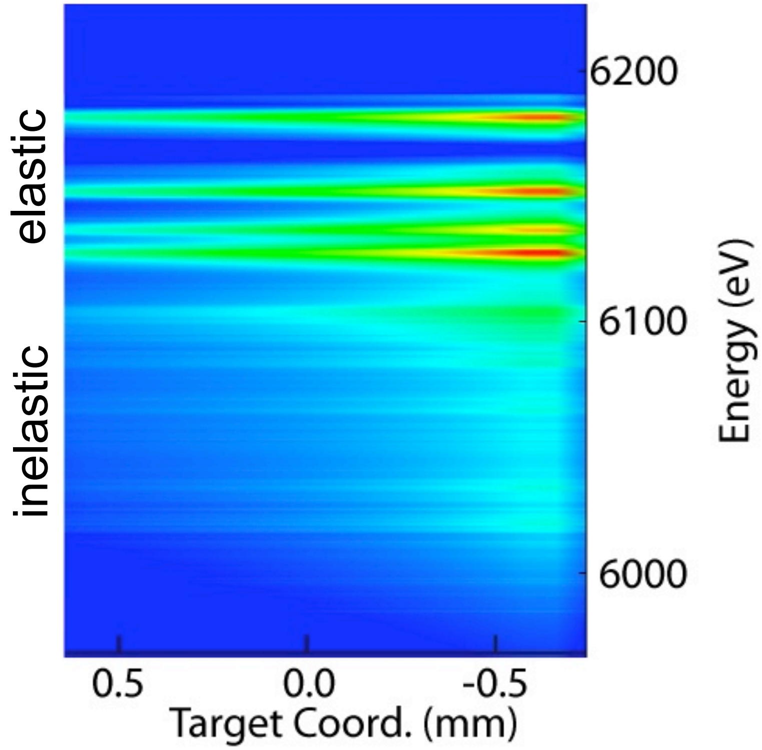




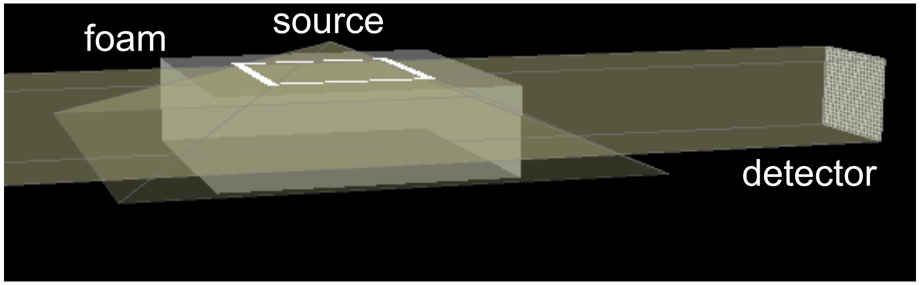
Ambient scattering data useful for validating predictions of XRTS code

- Gregori's XRTS code[1] was combined with SPECT3D in order to model scattering from 3D, non-homogenous plasmas.[2]

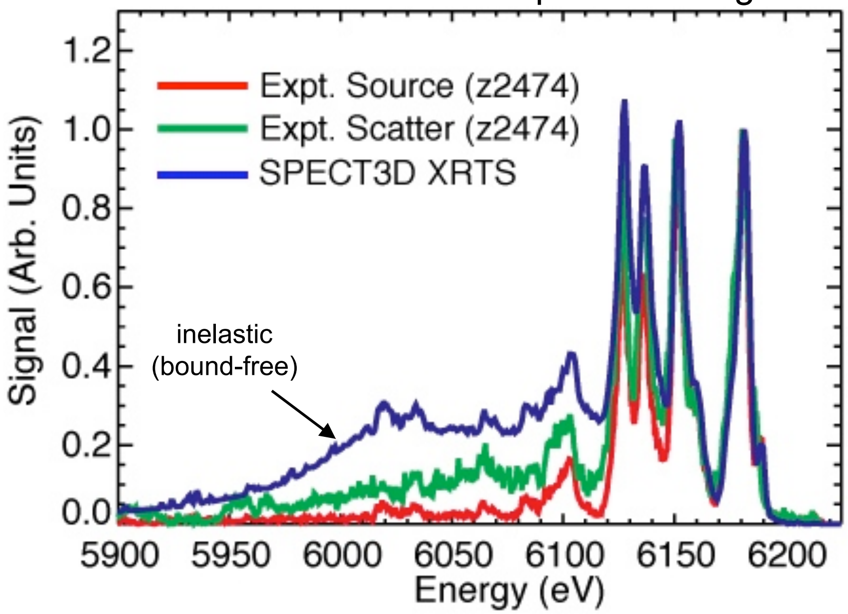
Simulated CH_2 scattering spectra



SPECT3D geometry



Simulated vs. Expt. Scattering



[1]G. Gregori *et al.*, PRE **67**, (2003)

[2]I. Golovkin *et al.*, HEDP *(submitted)*

Combining x-ray Thomson scattering with Z's unique warm dense matter samples will provide benchmark quality data

- We have demonstrated XRTS measurements with spatial resolution on Z on ambient sample

- Future work
  - XRTS of shocked CH_2 foams, Be and LiD targets
  - Higher energy x-ray probe (Ni-He-α, 7.804 keV)
  - Spherical crystal debris mitigation