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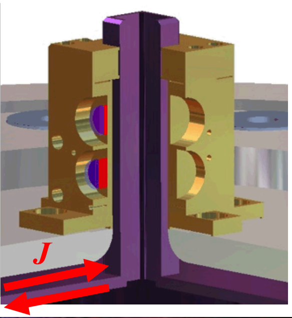

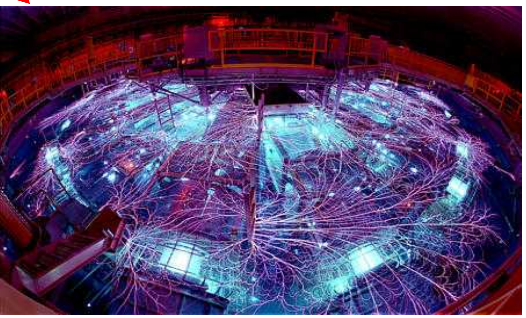

X-ray Thomson scattering of shocked carbon foams on the Z accelerator

T. Ao, E. C. Harding, J. E. Bailey, R. W. Lemke, M. P. Desjarlais, S. B. Hansen, I. C. Smith, J. Reneker, D. Romero, D. B. Sinars, G. A. Rochau, and J. F. Benage

Sandia National Laboratories, Albuquerque, NM

Sandia National Laboratories

Exceptional service in the national interest

19th Biennial Conference of the APS Topical Group on Shock Compression of Condensed Matter

Tampa, FL, June 14-19, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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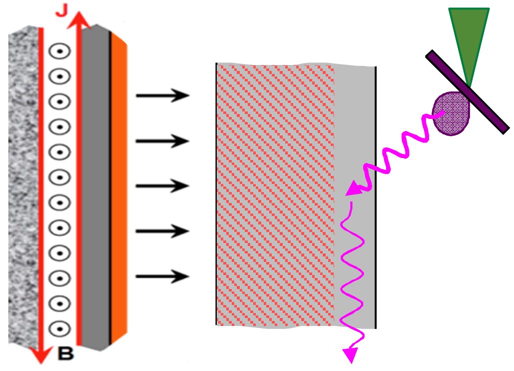
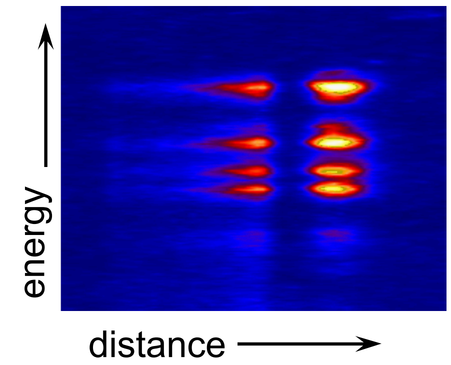
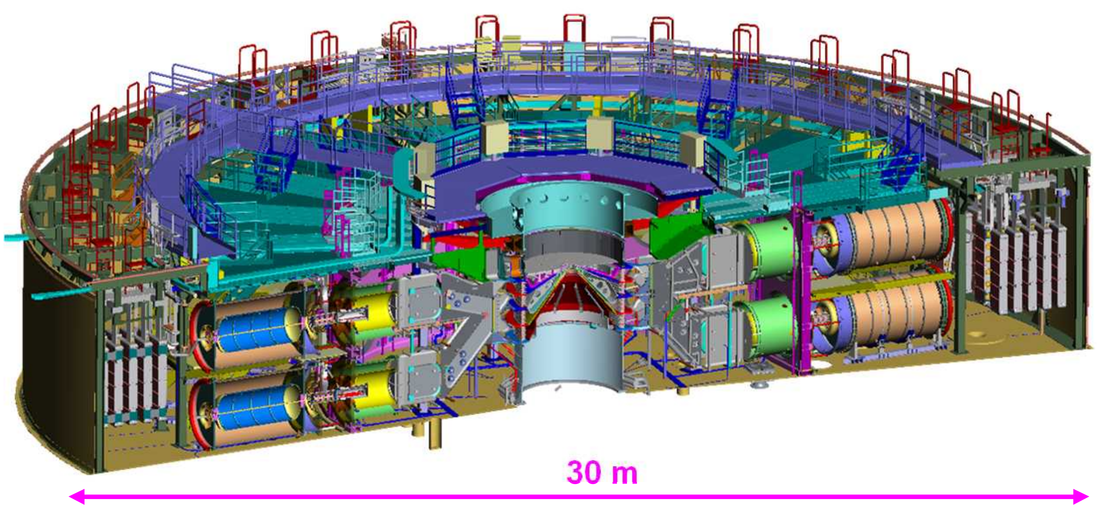
Combining x-ray Thomson scattering (XRTS) with Z's unique warm dense matter samples to provide benchmark quality data

- Z's warm dense matter samples are large, uniform, long-lived and precisely characterized
- XRTS expand diagnostic capabilities on Z beyond pressure and density measurements
- Importance of XRTS measurements with spatial resolution demonstrated on Z





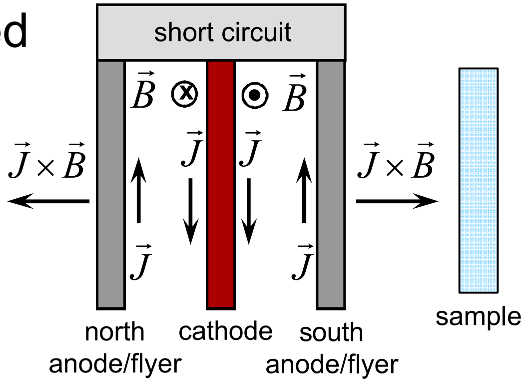


22 MJ stored energy
26 MA peak current
100–800 ns pulse lengths

M. K. Matzen, *et al.*, Phys. Plasmas. **12**, 055503 (2005)

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
  - Pressure and density well-characterized 1–2 %



- Large samples enable uniform shock states: spatially & temporally

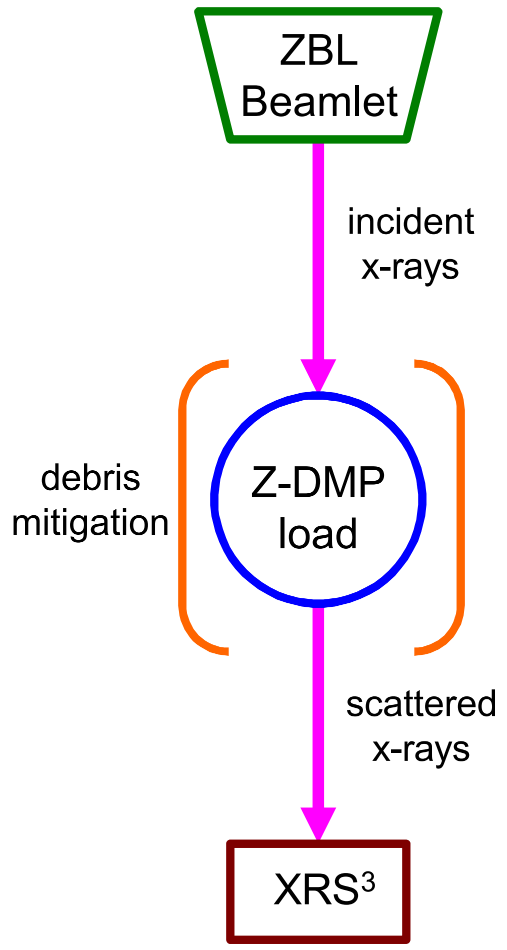
	dimension	Z	laser	Z / laser
Initial state	thickness	1–2 mm	0.25 mm	4–8
	diameter	5–10 mm	1 mm	5–10
WDM state	thickness	0.2–0.5 mm	0.050 mm	4–10
	scattering volume	4–40 mm^3	0.04 mm^3	100–1000
	duration	10–100 ns	0.1–1 ns	10–100

Large scattering volume and long steady-state duration provide enough scattered x-rays to be spatially resolved

R. W. Lemke, M. D. Knudson, D. E. Bliss, *et al.*, J. Appl. Phys. **98**, 073530 (2005)

3 key components to XRTS on Z-DMP experiments

- Produce quasi-monochromatic x-rays
  - ZBL Beamlet (2–4 kJ, 2–3.5 ns) irradiate metal foil
    ➔ Mn He-α (6.181 keV)
  - Synchronization of ZBL and Z: 1–2 ns
- 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 / film

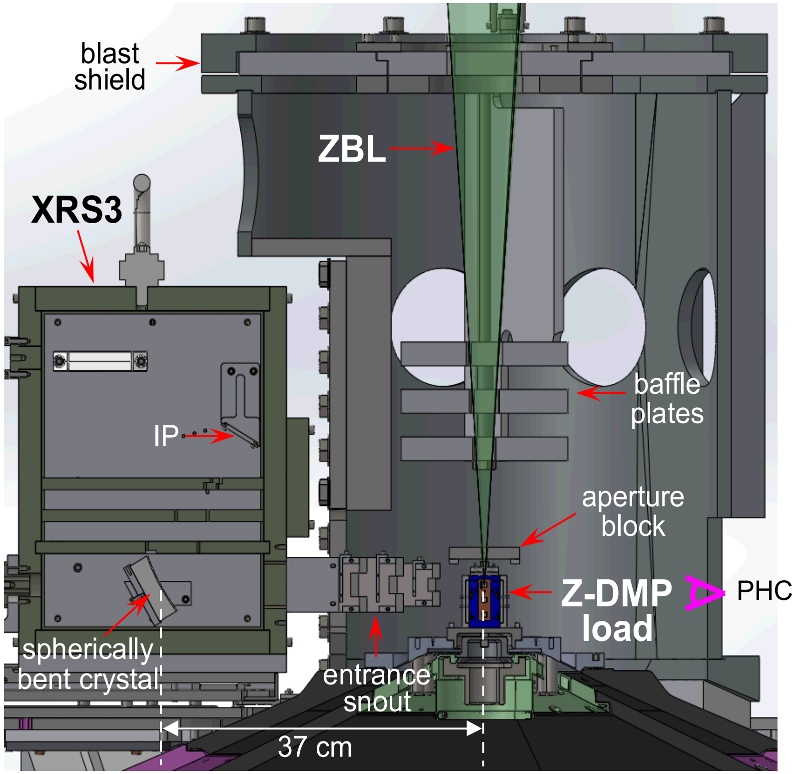


E .C. Harding, T. Ao, J. E. Bailey, *et al.*, Rev. Sci. Instrum. **86**, 043504 (2015)
T. Ao, E. C. Harding, J. E. Bailey, *et al.*, J. Quant. Spectrosc. Radiat. Transf. **144**, 92 (2014)

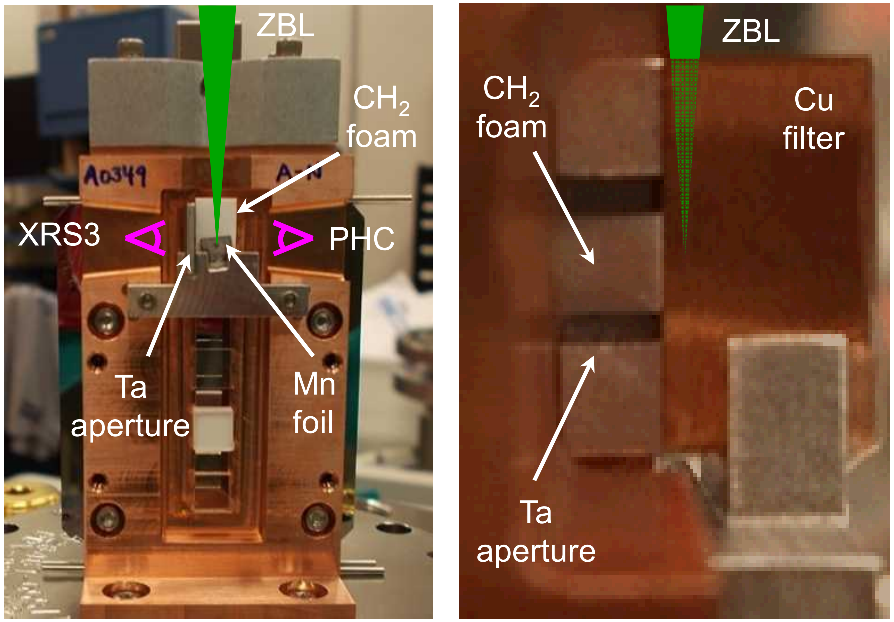
X-ray background and load debris posed challenges to Z-XRTS

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

Target chamber (cross–section view)



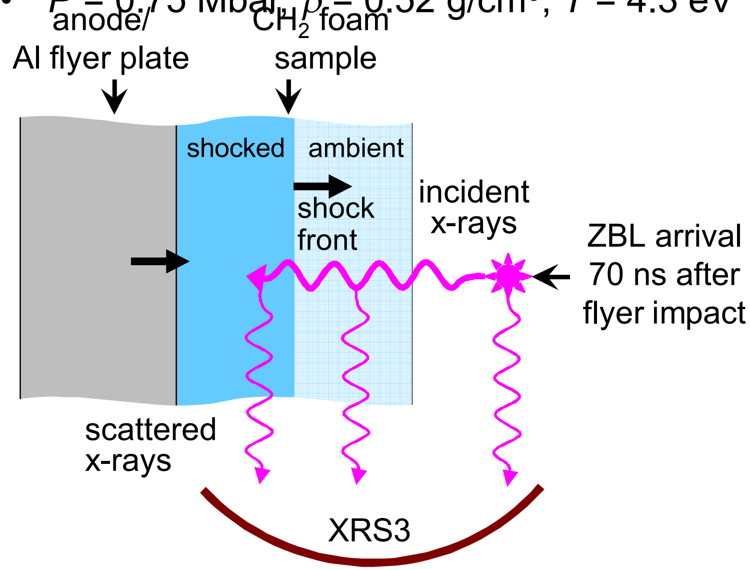
Z-DMP load

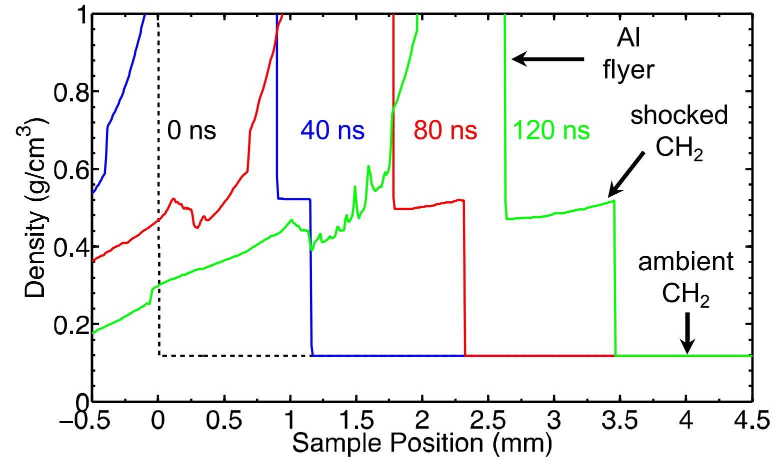


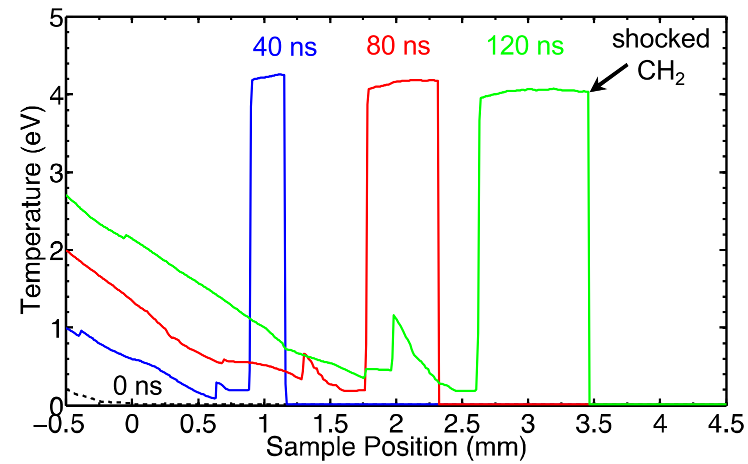
Back view Side (XRS3) view

Spatial resolution is essential for benchmark quality XRTS data

- ALEGRA calculations with Al flyer (25 km/s)
  - Ambient CH_2 foam
    - 7.5 mm x 5 mm x 2.5 mm, ρ_0 = 0.12 g/cm^3
  - Shocked CH_2 foam:
    - P = 0.75 Mbar, ρ = 0.52 g/cm^3, T = 4.3 eV



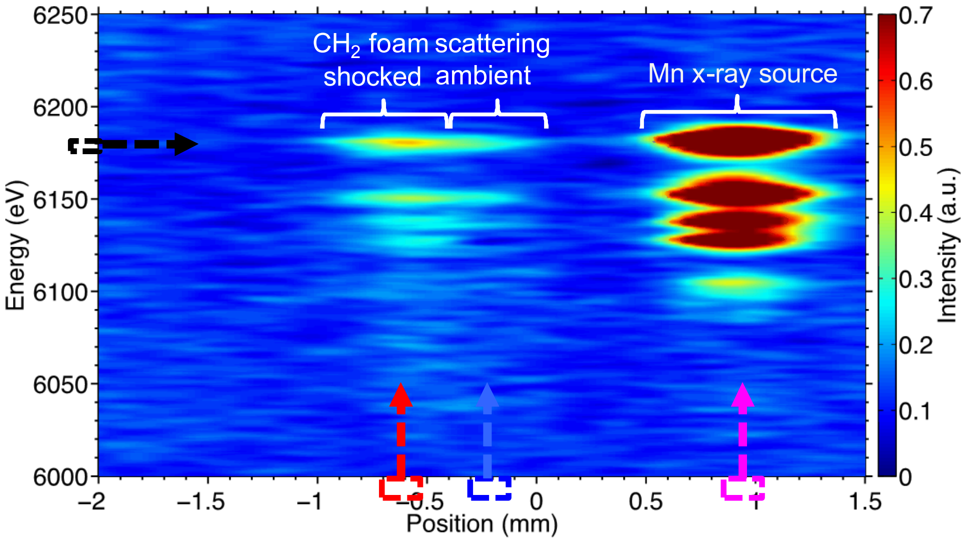


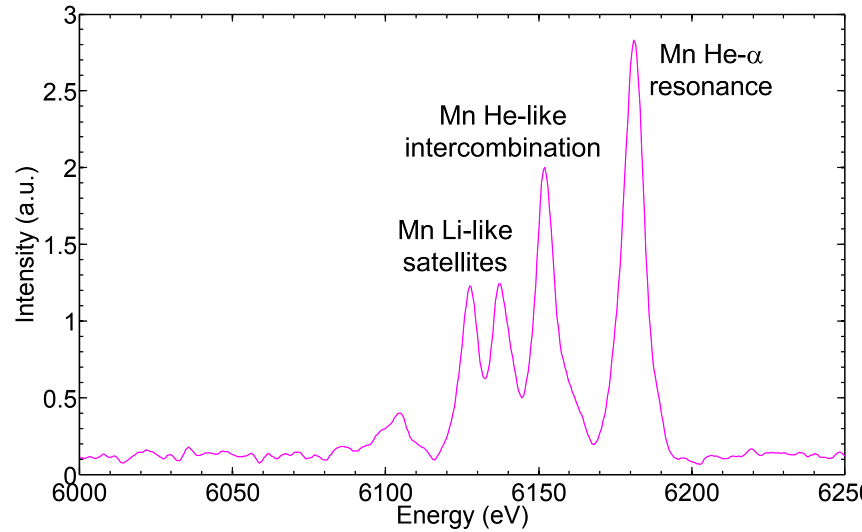


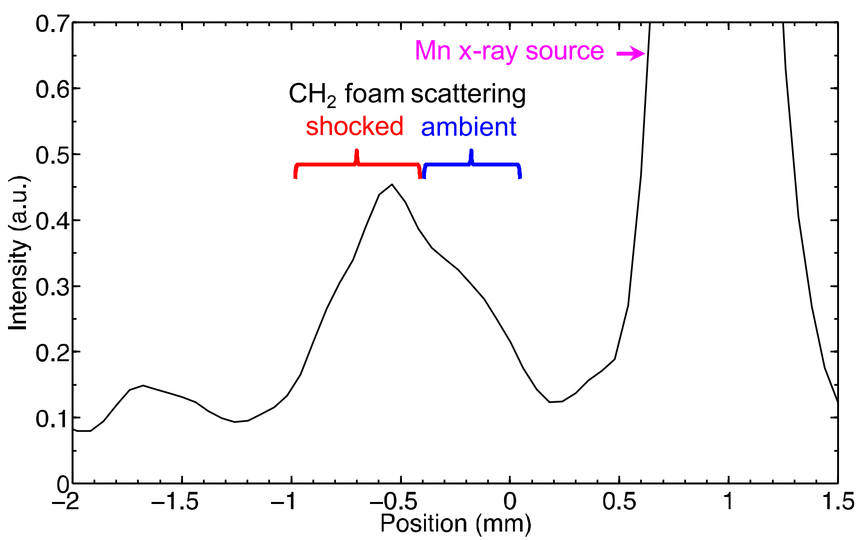
- Measure XRTS signal from ambient & shocked material, and x-ray source
  - VISAR: Al flyer impact velocity; CH_2 sample shock velocity, verify steady-state of WDM
  - XRS3: characterize Mn x-ray probe spectrum

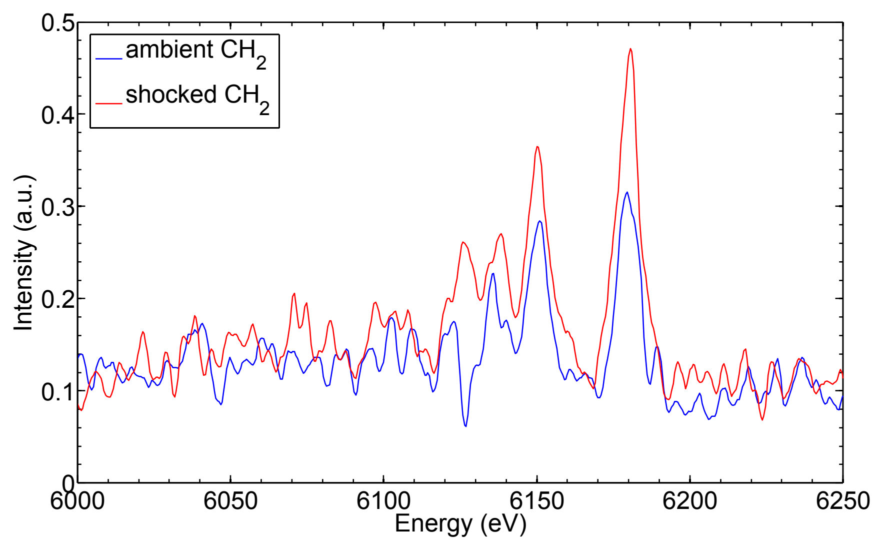
Z2661: Obtained 1st ever simultaneously recorded space-resolved scattering spectra from shocked & ambient states, and source

- Backward scattering (90°) of shocked CH_2 foam on image plate



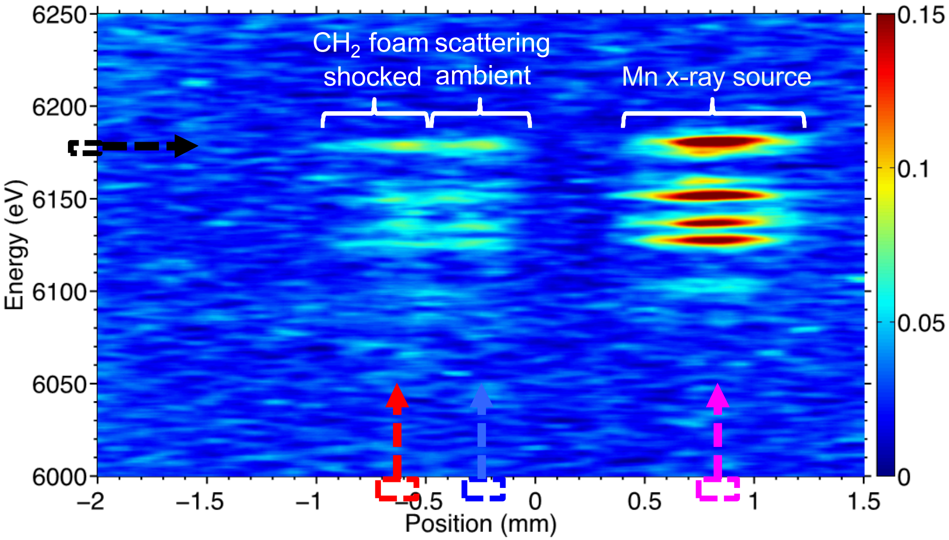


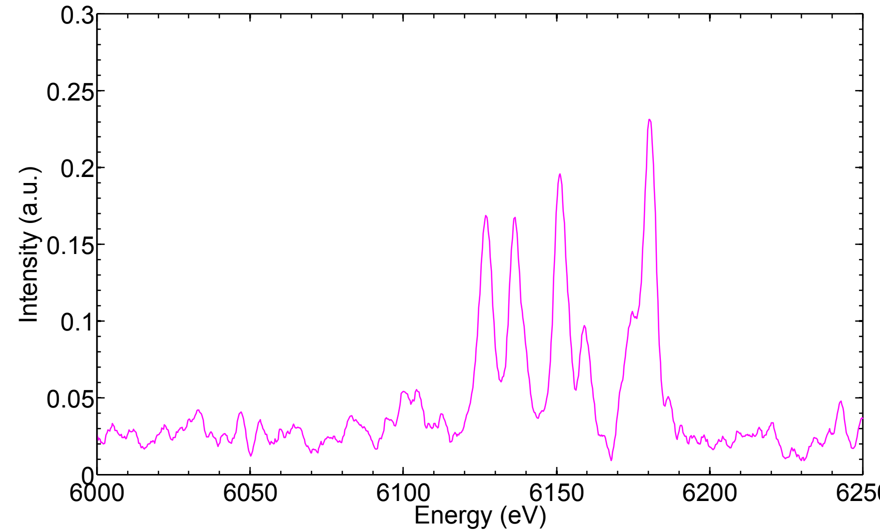


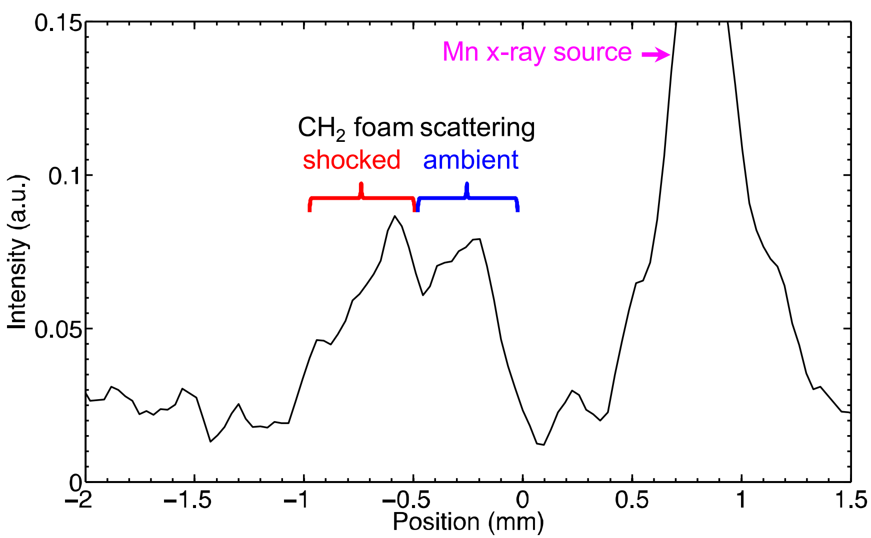


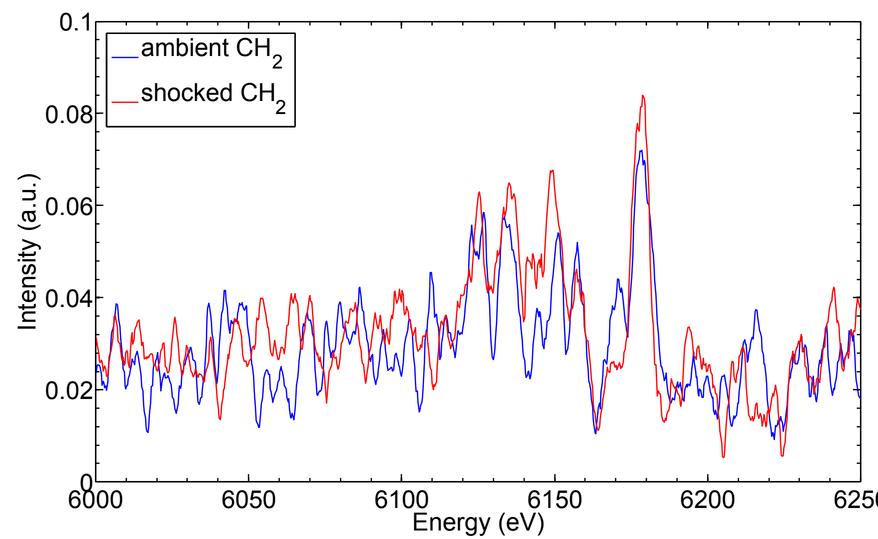
Z2704: Improved spectral and spatial resolution using film

- Backward scattering (90°) of shocked CH_2 foam on Agfa D8 film
- Reduced signal intensity



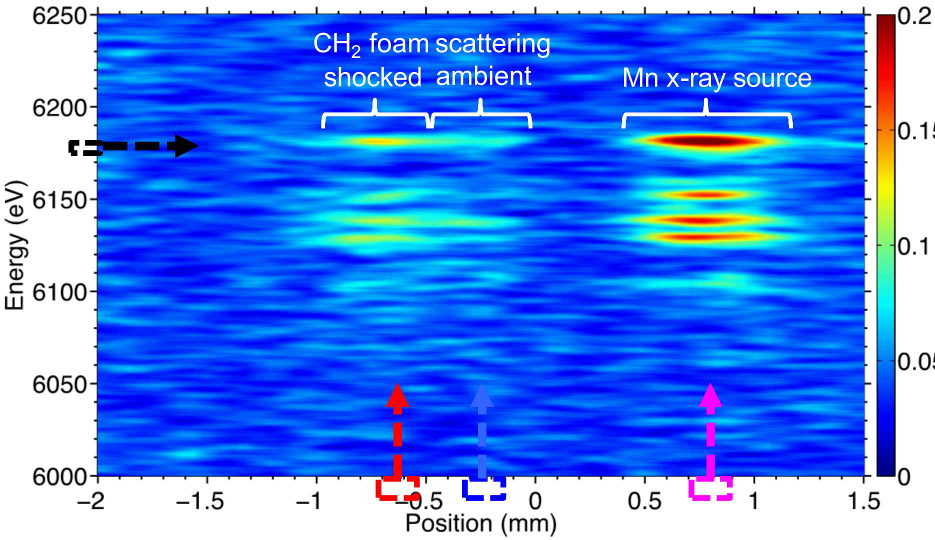


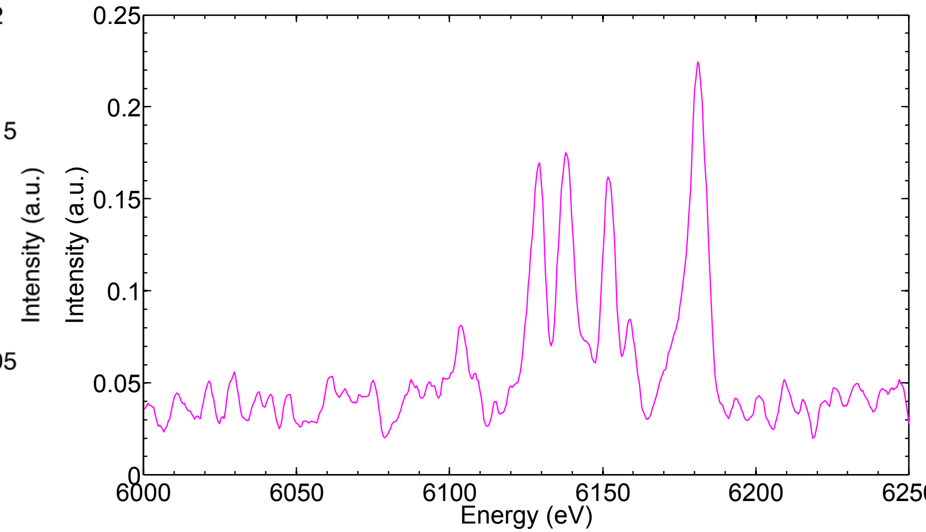


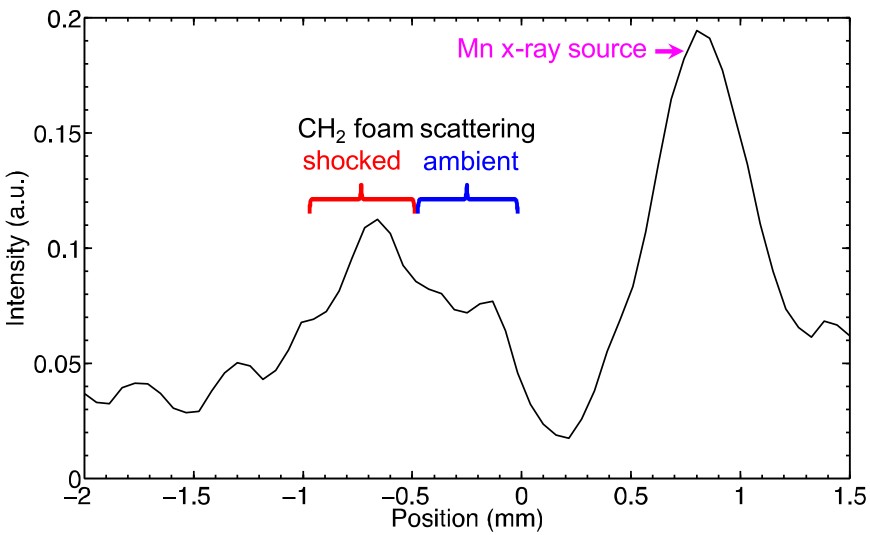


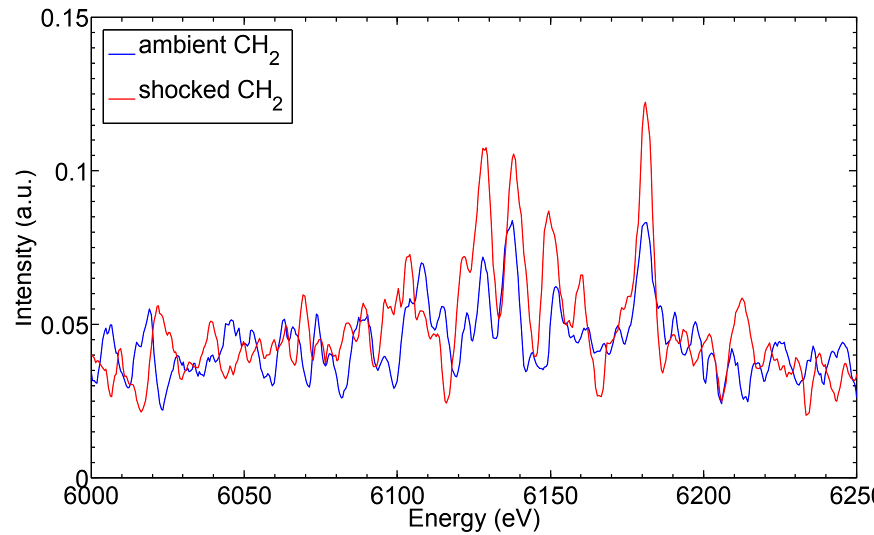
Z2750: Constrained scattering angle to reduce angular smearing

- Forward scattering (30°) of shocked CH_2 foam on image plate









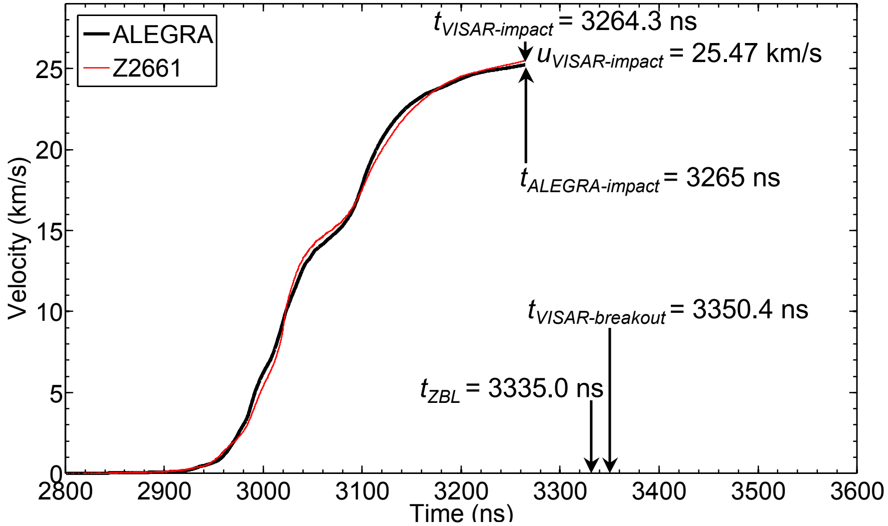
Summary

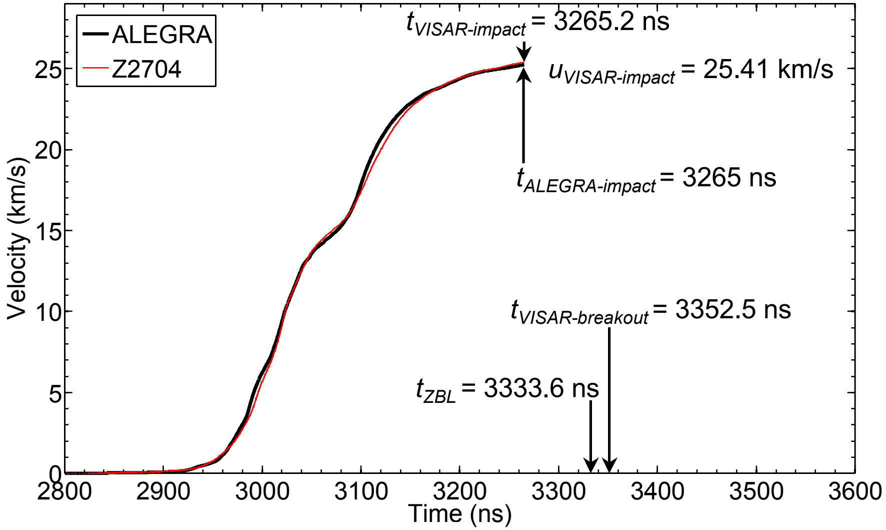
- Demonstrated spaced-resolved XRTS of shocked carbon foams
  - Simultaneous measurements of shocked and ambient states
  - In-situ x-ray source characterization
  - Backward and forward scattering
  - Image plate and film comparison

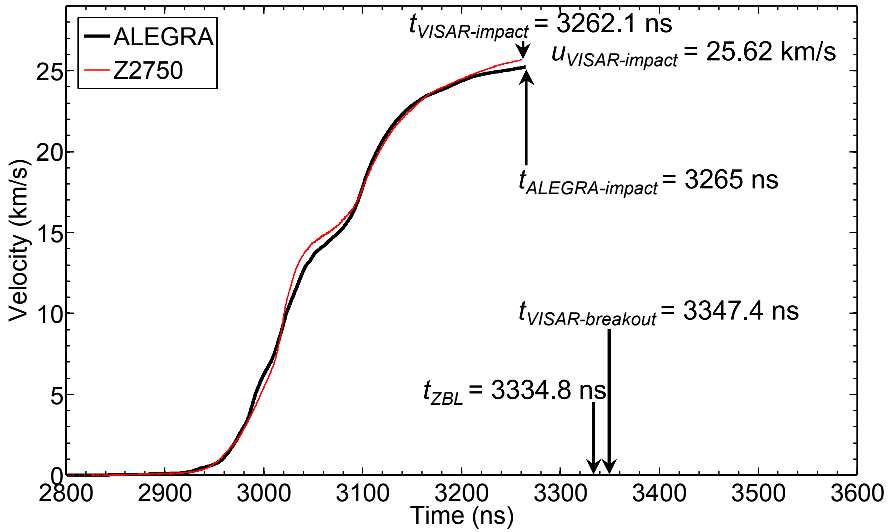
- On-going and future work
  - XRTS of ramp compressed Li samples on Z
    - H5.00004, 10:00 AM, Tues. June 16: L. Shulenburger
  - XRTS of shock compressed Be samples on Z
  - Higher energy x-ray probes
  - X-ray diffraction on Z

Extra slides

Reproducibility of flyer velocities, ZBL time of arrival, and shock break time of CH_2 foam (Z2661, Z2704, Z2750)







Preliminary Z-XRTS experiment measured high-resolution x-ray spectra of ambient CH_2 foam

- Current loss away from 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