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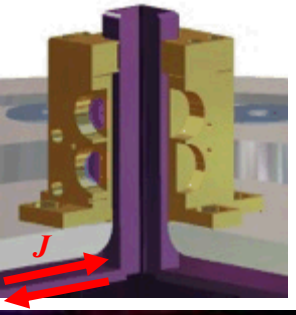

X-ray diffraction on Z

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Sandia National Laboratories

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National ICF Diagnostics Working Group Meeting
Lawrence Livermore National Laboratory, CA, September 9-11, 2014

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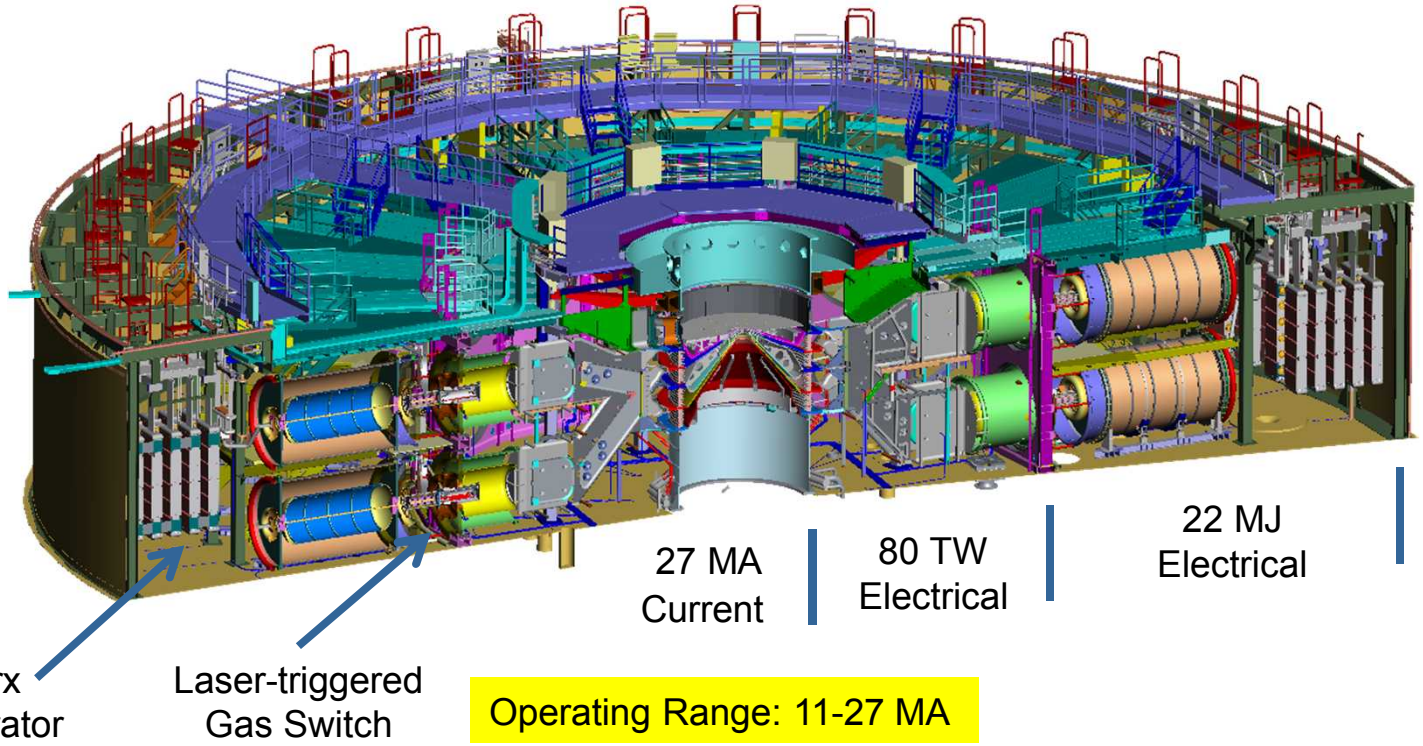
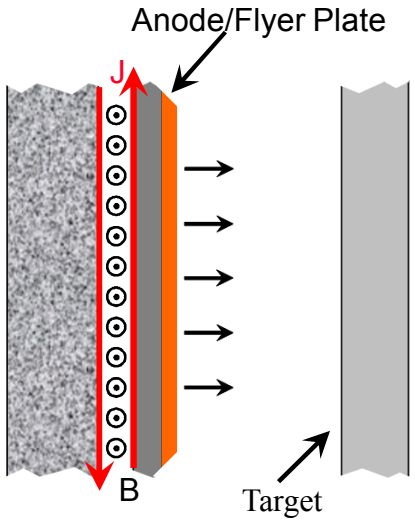
Combining x-ray diffraction with Z's unique high energy density samples will provide benchmark quality data

- Z's high energy density matter samples are large, uniform, long-lived and precisely characterized
- X-ray diffraction will expand diagnostic capabilities on Z beyond pressure and density measurements

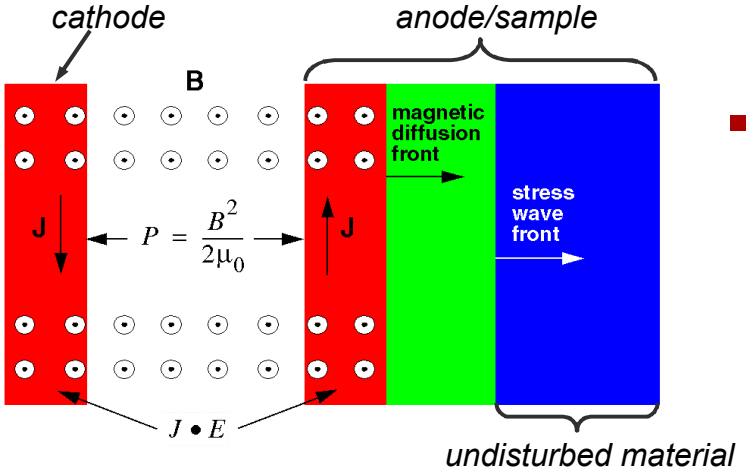


Z is a unique platform for equation-of-state studies

- Dynamic material properties (DMP) experiments



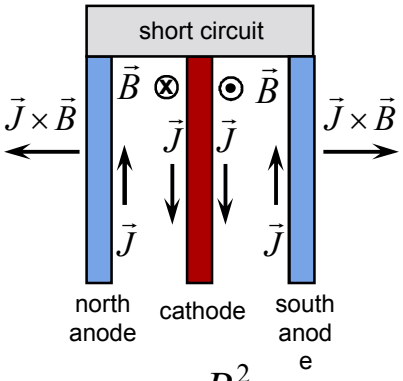
- Magnetically launched flyer plates
  - ~ 40 km/s, 10 Mbar, several eV
  - Shock-compressed state experimentally determined from flyer's impact velocity
  - Pressure and density characterized ~ 1-2 %



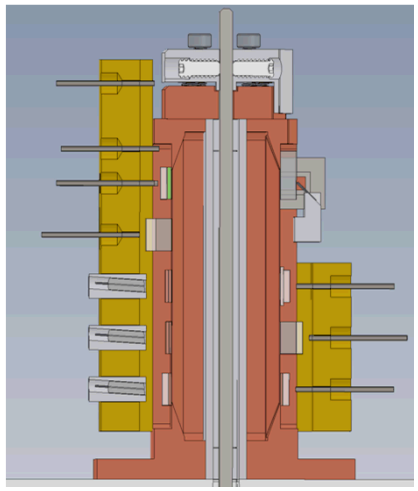
- Shockless (ramp) compression
  - Continuous compression to ~ 5 Mbar
  - Strain rates ~ 10^6-10^7 /s

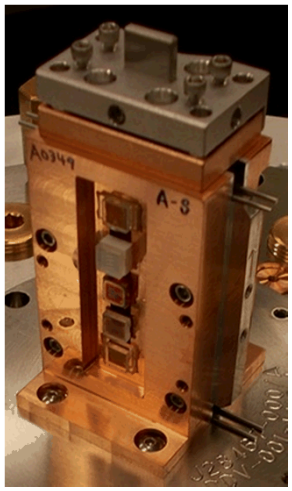
Z-DMP planar experiments

- Coaxial load[1]
  - Cathode stalk surrounded by anode panels
  - Dual pressures possible on north and south panels
  - Enclosed magnetic fields
  - More sample locations
  - Optimal for (flyer plate) shock compression

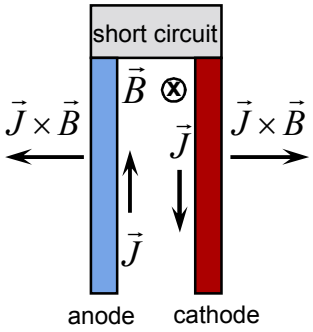


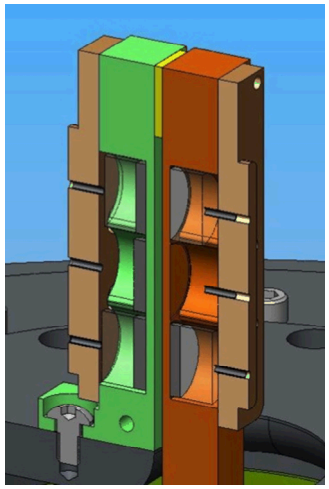
$$P = \frac{B^2}{2\mu_0}$$





- Stripline load[2]
  - Identical pressure on both cathode and anode panels
  - Higher current density and pressure
  - Open magnetic fields
  - Optimal for high-pressure ramp compression



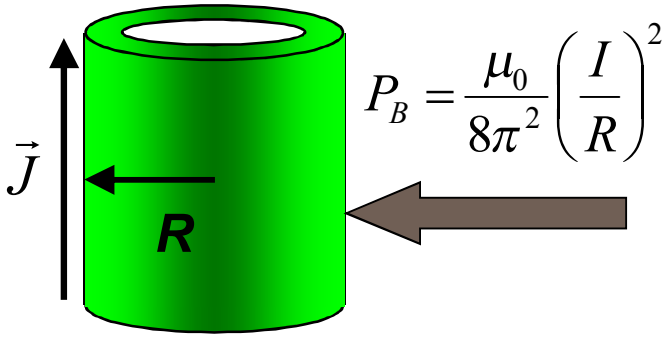


[1]M. D. Knudson *et al.*, J. Appl. Phys. **94**, 4420 (2003)

[2]R. W. Lemke *et al.*, Int. J. Impact Eng. **38**, 480 (2011)

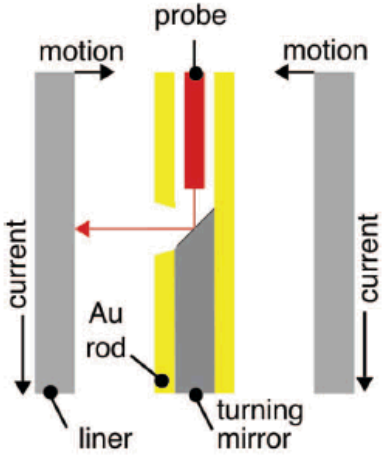
Z-DMP cylindrical experiments

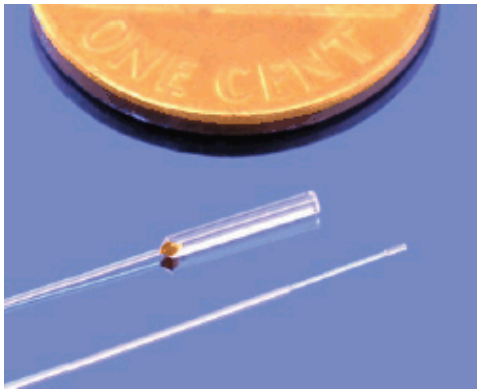
- Cylindrical implosion reaches extreme pressure states[1]
  - Current pulse shaping creates ramp-wave compression
  - Quasi-isentropic compression to 20 Mbar



$I = 20$ MA
$R = 1$ mm
$P_B \approx 64$ Mbar

- Diagnostics are challenging
  - Limited space
  - Miniature probes
  - Velocities well beyond 10 km/s

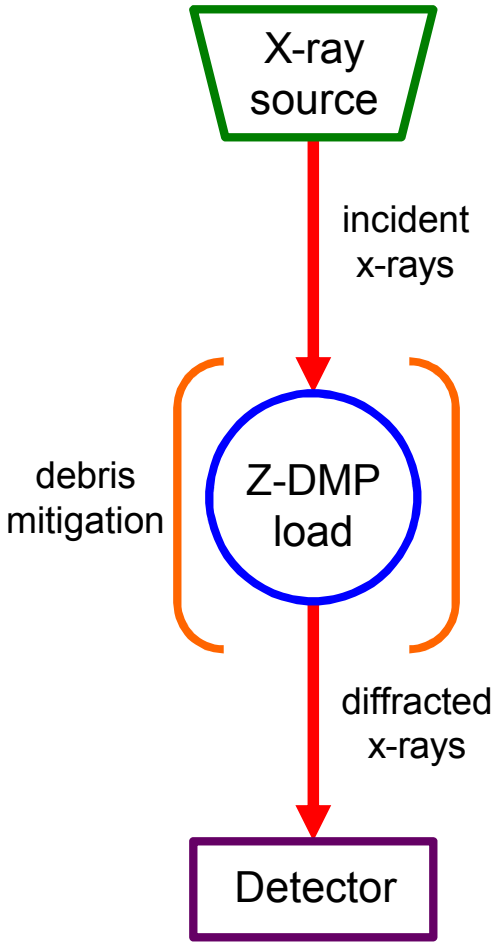




[1]R. W. Lemke *et al.*, AIP Conf. Proc. **1426**, 47 (2012)

3 key components to x-ray diffraction on Z-DMP experiments

- Produce source x-rays
  - Z-Beamlet laser irradiate metal foil
  - X-pinch
- Generate high-pressure state
  - Z-DMP load
  - Debris mitigation
- Detect diffracted x-rays
  - Film
  - Image plate
  - Streak camera
  - CCD



Challenges of x-ray diffraction on Z

- Destructive environment of Z-DMP load
  - Prevent catastrophic vacuum breach
  - Protect ZBL
  - Retrieve data
- X-ray background
  - High energy photons (up to 10 MeV) produced in both power feed section and load region
  - Sufficient signal-to-noise
- Electromagnetic pulse (EMP)
  - Fry electronics

Addressing challenges of Z-XRD

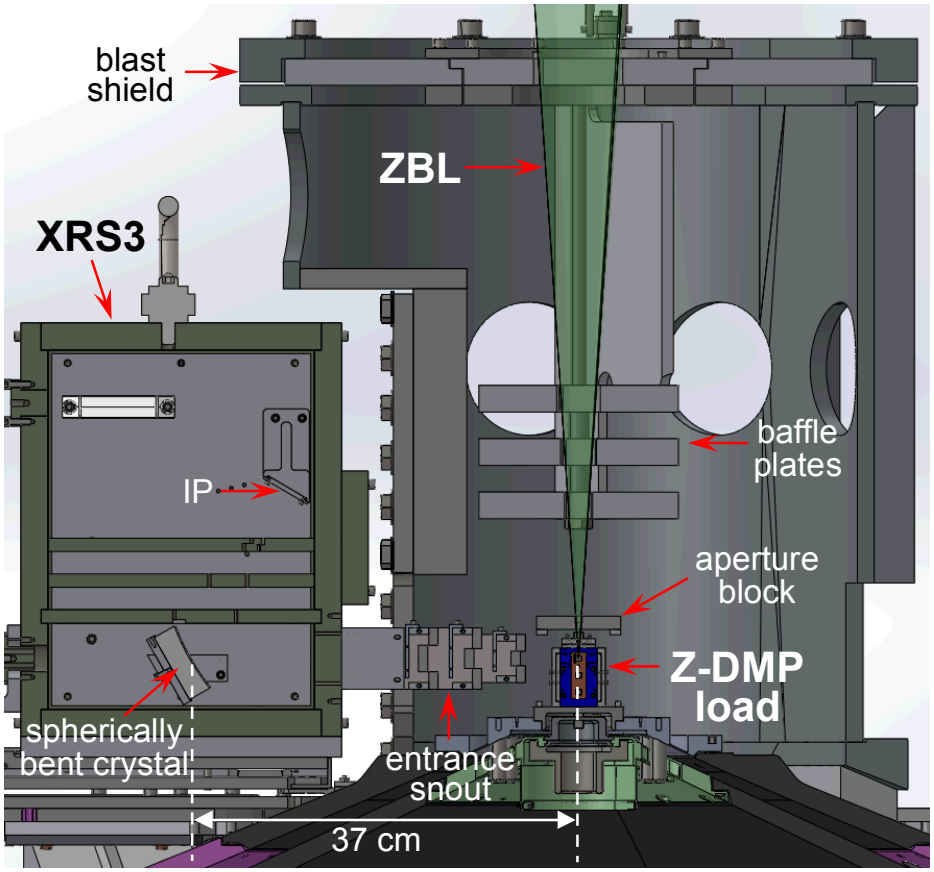
- Placing image plate, film, x-ray CCD, and x-ray streak camera near load
  - Robust x-ray and EMP shielding
  - Advanced debris mitigation

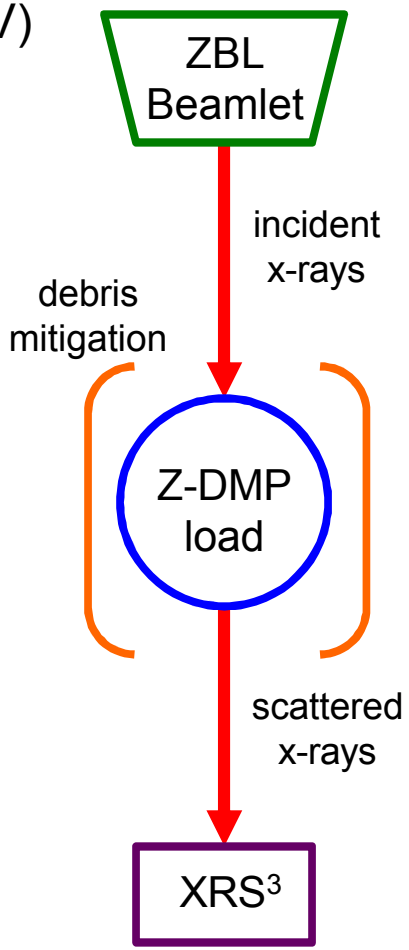
- Convert diffracted x-rays into visible photons
  - X-ray phosphor near load
  - Transport light out of load region (fiber or open optics relay)

- Leverage previous work done to implement x-ray Thomson scattering (XRTS) on Z

X-ray Thomson scattering on Z

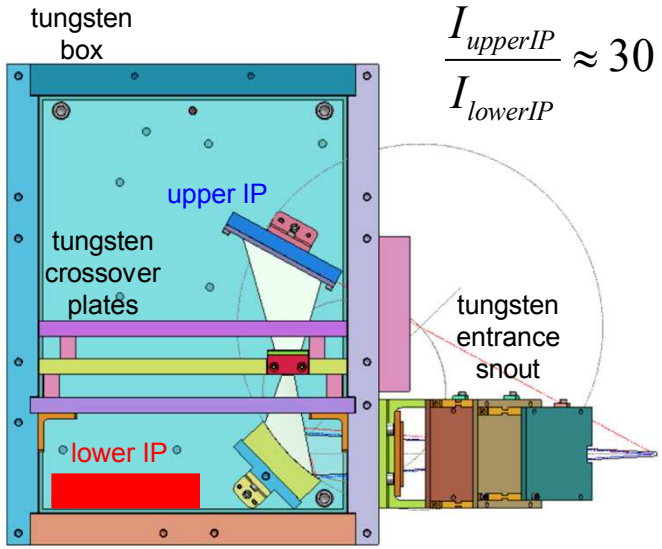
- 3 key components to XRTS on Z-DMP experiments[1]
  - ZBL produce quasi-monochromatic x-rays (6.181 keV)
  - Z-DMP load generate warm dense matter state
  - Detect x-rays with spectrometer (XRS3)



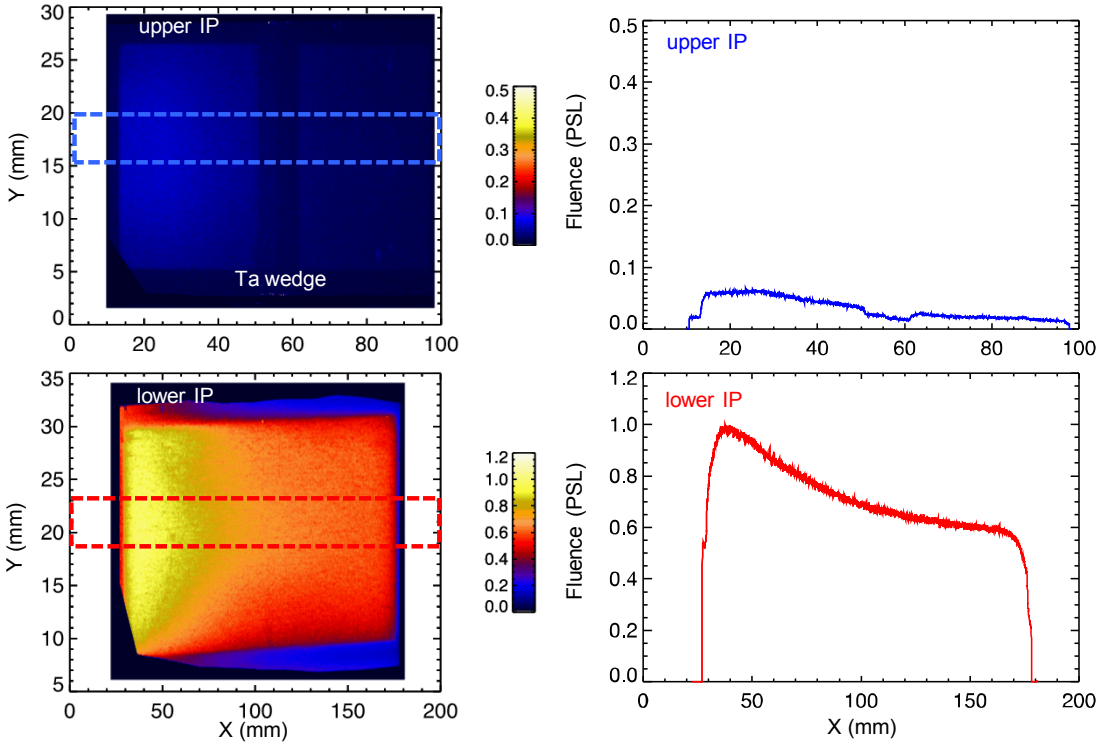


Low x-ray background of Z-DMP experiments make XRTS viable

- Z-pinch radiation producing experiments
  - Strong x-ray background (> 25 PSL)
- Ride-along tests on Z-DMP experiments
  - Lower x-ray background (~ 1 PSL)
  - External and internal tungsten shielding reduced x-ray background ~ 0.03 PSL

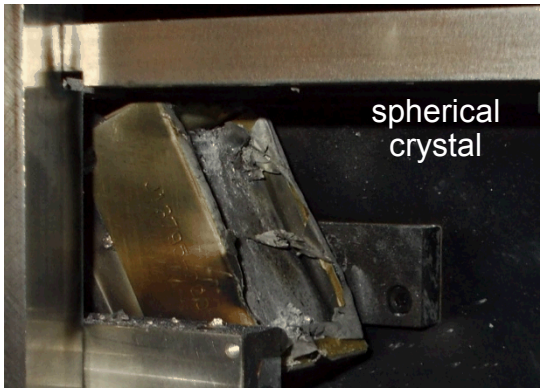


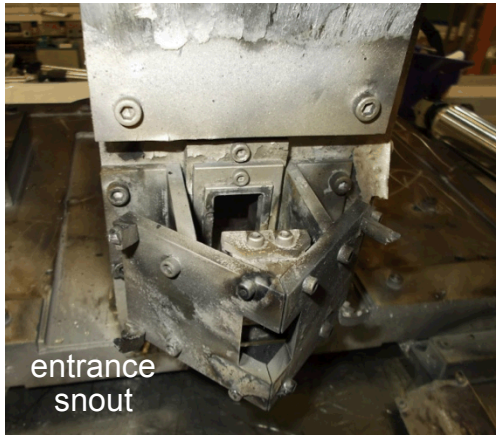
$$\frac{I_{upperIP}}{I_{lowerIP}} \approx 30$$

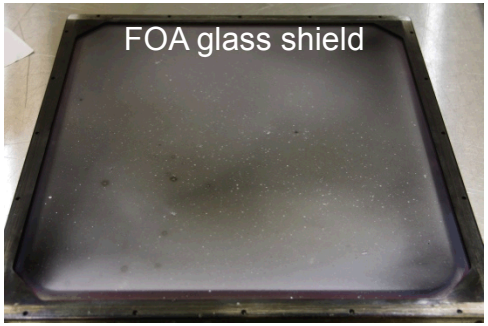


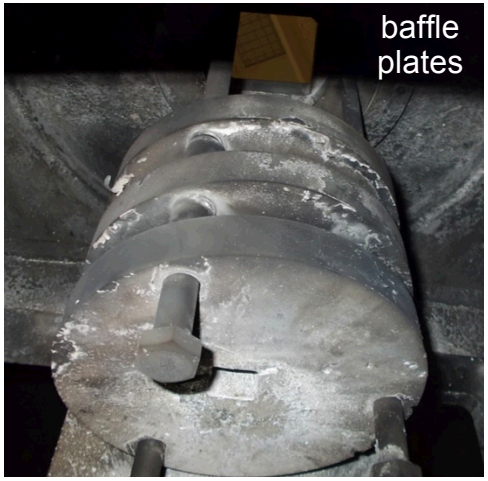
Debris mitigation strategy has been successful

- 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





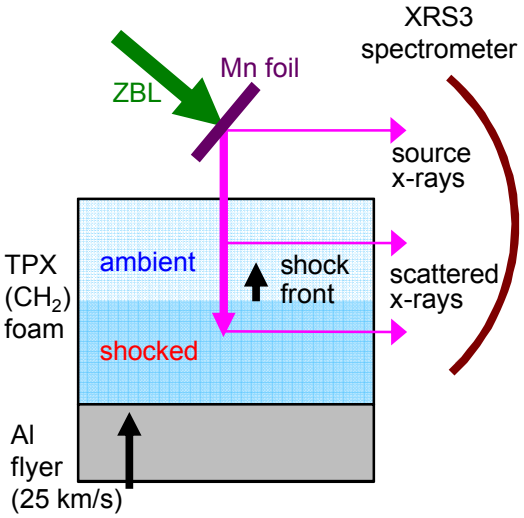


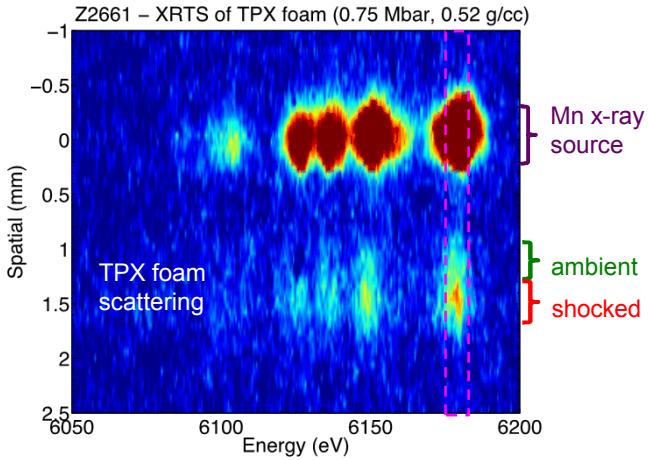


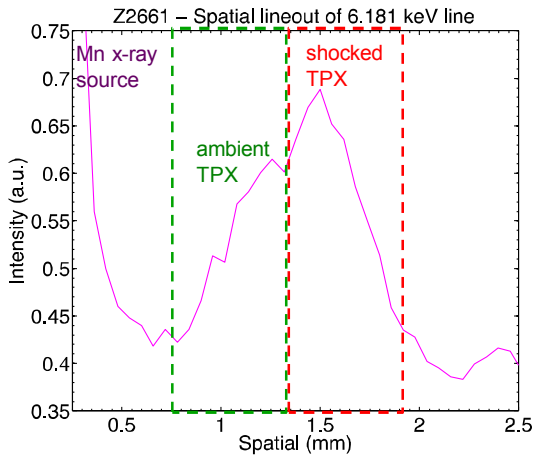
[1]R. R. Burt and E. L. Christiansen, Int. J. Impact Engineering **29**, 153 (2003).

XRTS capability successfully implemented on Z

- First time x-ray source and scattering simultaneously measured
  - Scattering volume is huge compared to laser experiments (~ 1000 ×)
  - Shock state is uniform (~ 1-2 %); long steady-state duration (~ 100 ns)





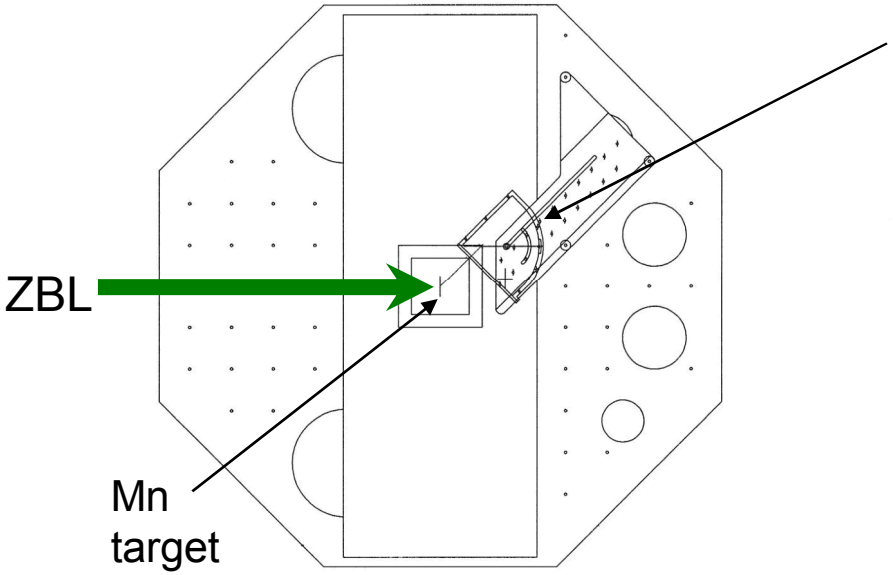


- Spatially-resolved x-ray scattering measurement enables novel and decisive extraction of data
  - In-situ comparison of shock state with ambient material
  - Direct measurement of x-ray probe source spectrum
- High-spectral resolution reveals subtle spectral features

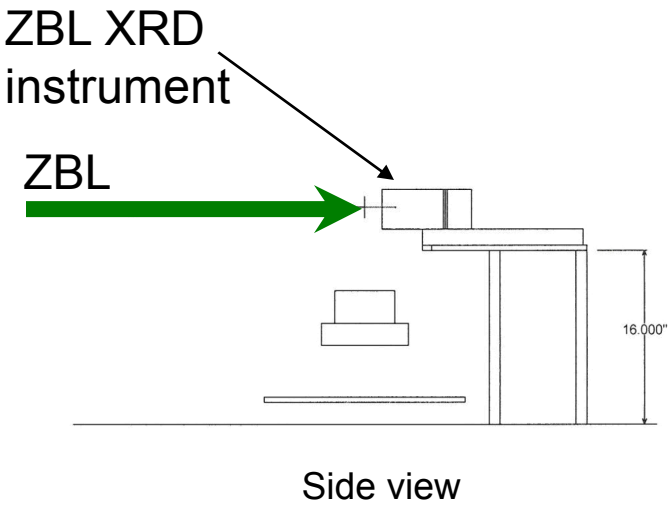
Activities to develop Z-XRD

- ZBL target chamber
  - X-ray source development
  - Ambient material x-ray diffraction
- Z-DMP experimental ridealongs
  - X-ray background
  - Characterization of debris field
- DICE facility
  - X-ray diffraction of compressed samples using DXD Supersaver x-ray source
    - Gas gun: shock loading
    - Veloce small pulser: ramp loading
  - X-ray phosphor and fiber relay testing

ZBL target chamber initial x-ray diffraction test

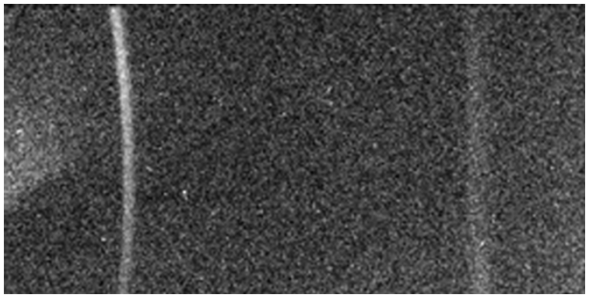


Top view



Side view

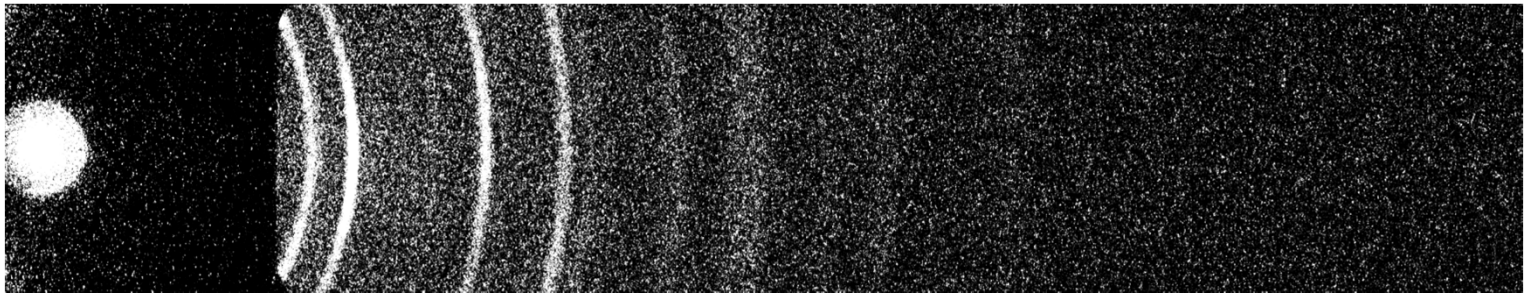
- Preliminary x-ray diffraction results with ZBL
  - Mn-He-α (6.181 keV)
  - Ambient Fe sample



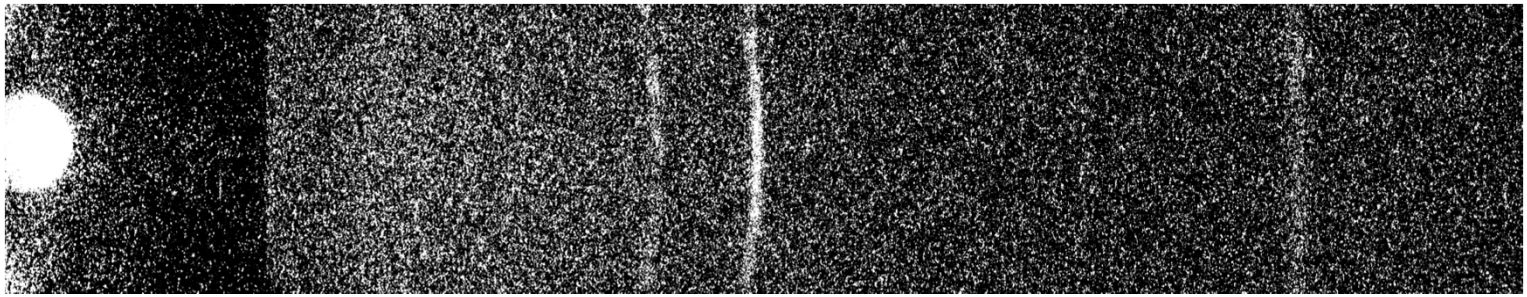
Fe 110 Fe 200

XRD patterns from fcc aluminum using DXD Supersaver x-ray source and ZBL XRD instrument

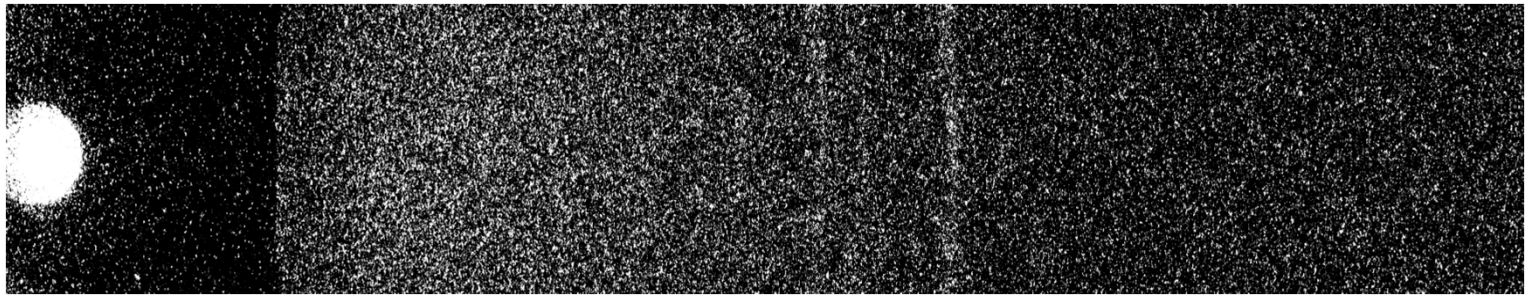
Mo Anode
17.4 keV



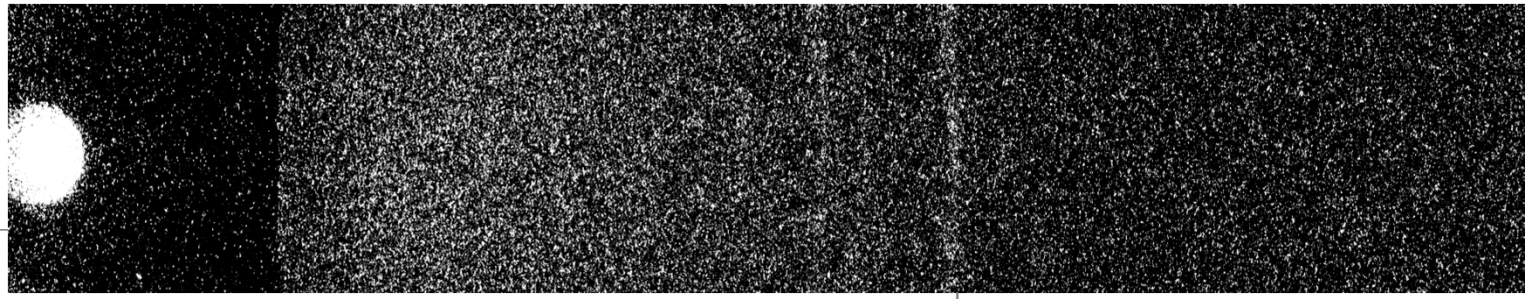
Cu Anode
8.0 keV

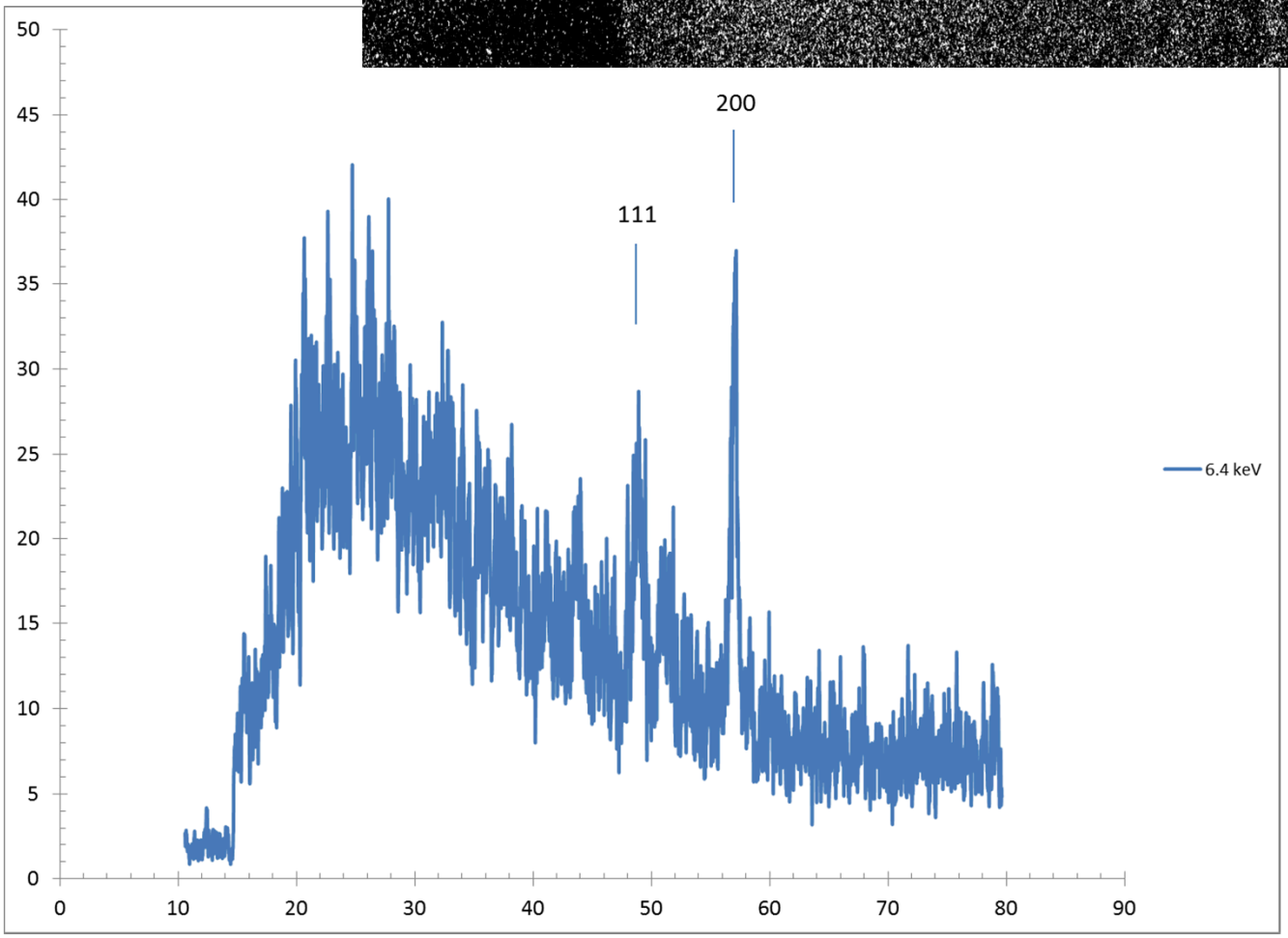


Fe Anode
6.4 keV

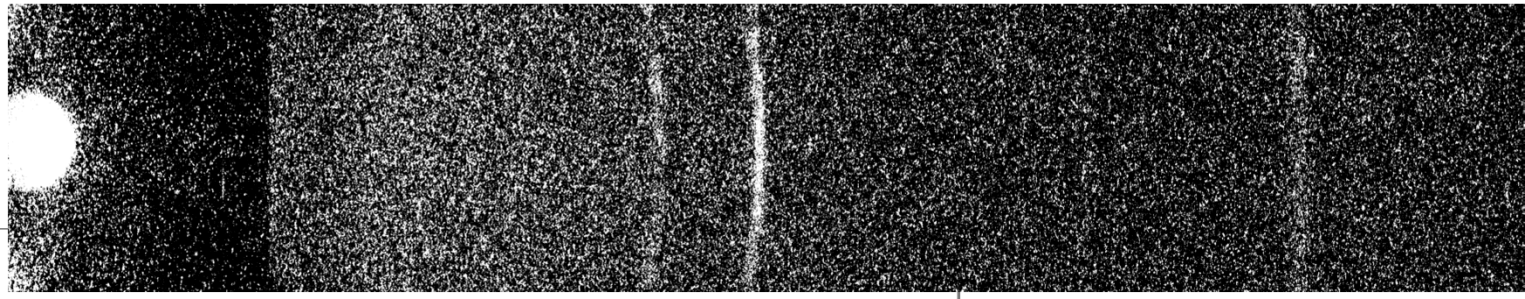


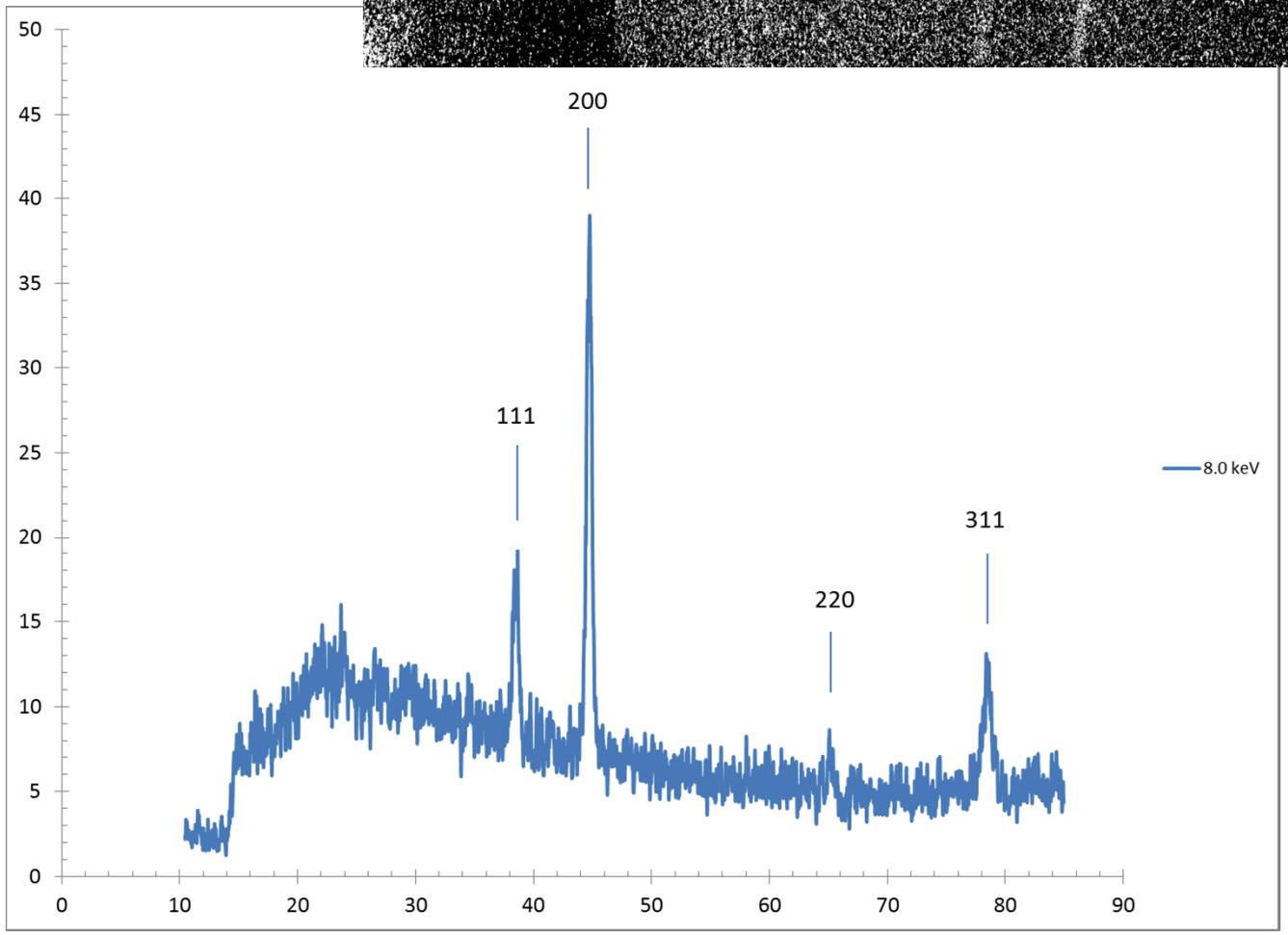
Aluminum XRD Debye ring integration at 6.4 keV



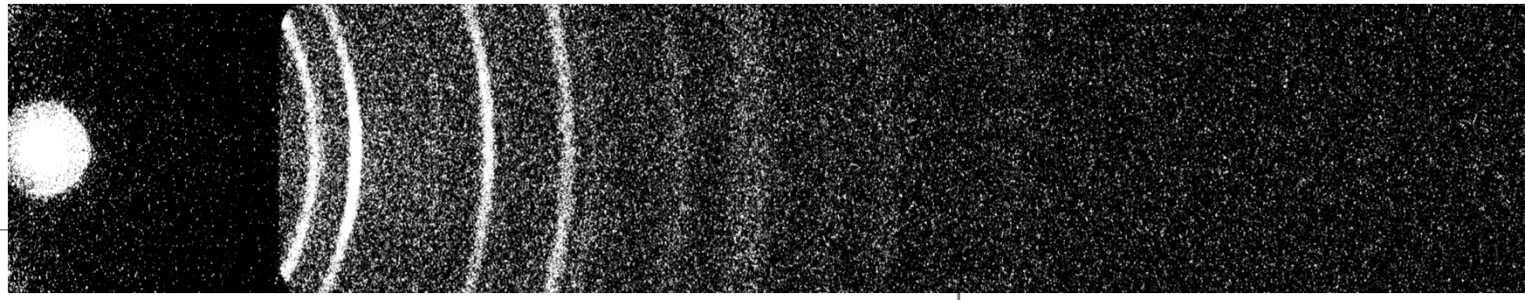


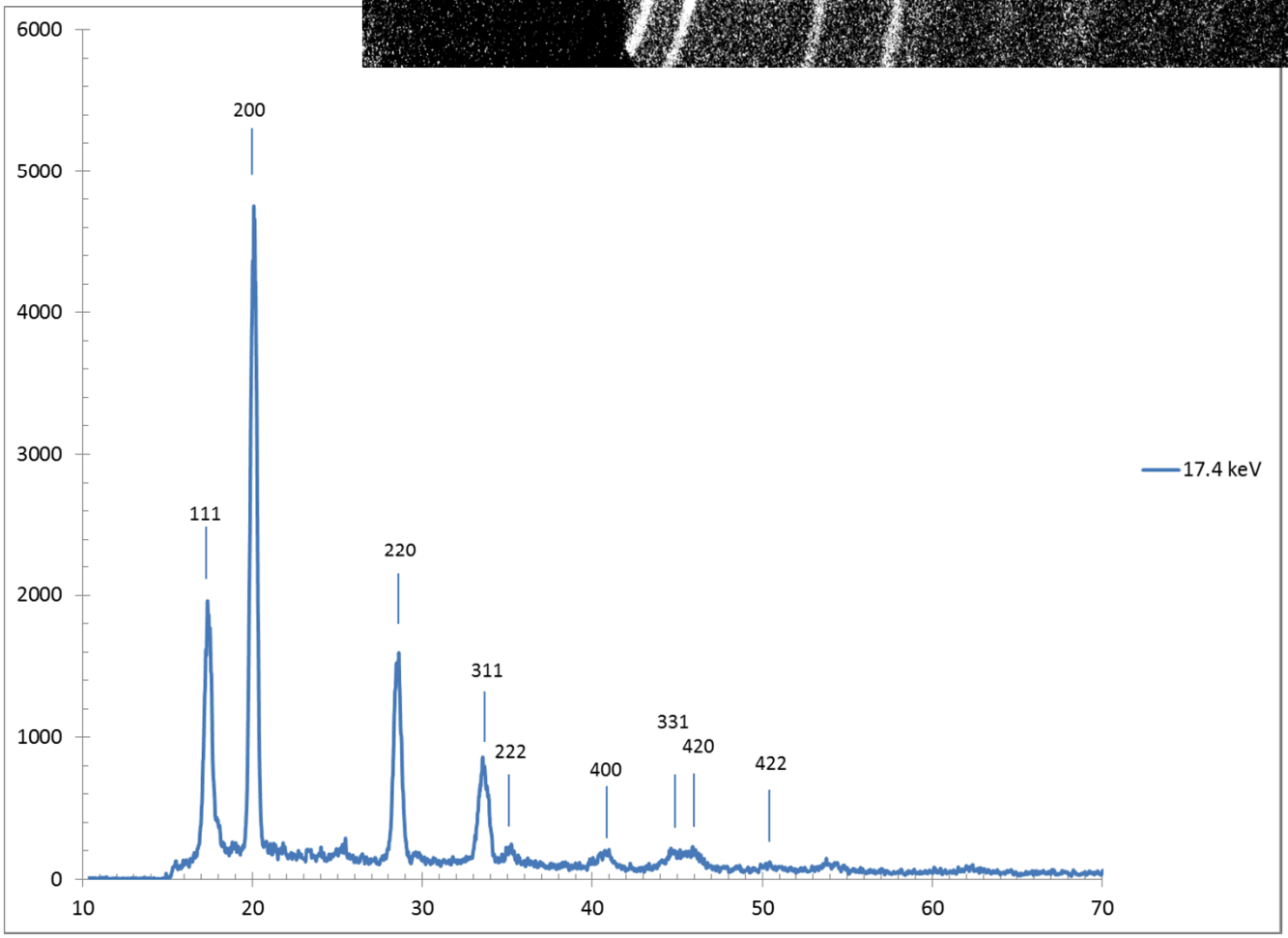
Aluminum XRD Debye ring integration at 8.0 keV





Aluminum XRD Debye ring integration at 17.4 keV





Future concepts for Z-XRD

- Time-resolved x-ray diffraction
  - Multi-frame ZBL x-ray sources
- X-pinch x-ray source
  - Separate small pulser to drive x-pinch
  - X-pinch load in parallel with Z-DMP load
  - Multiple x-pinches
- Containment targets
  - Inserting incident x-rays
  - Extracting diffracted x-rays