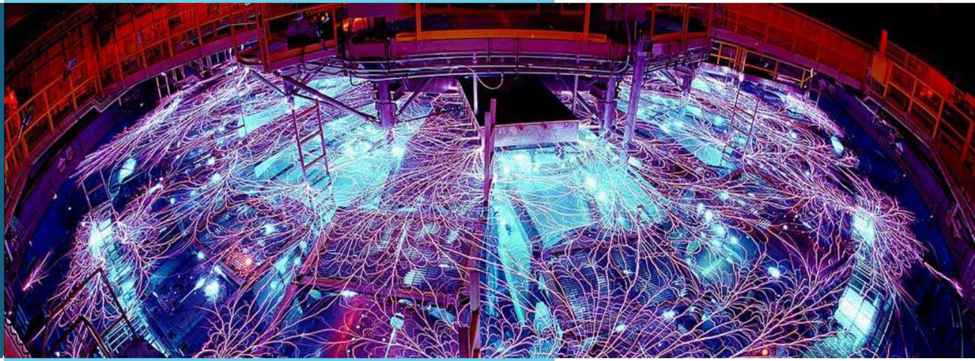
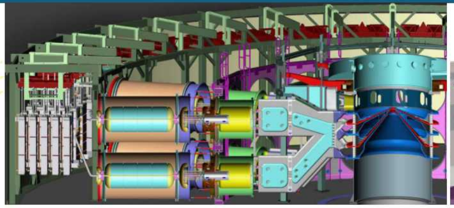
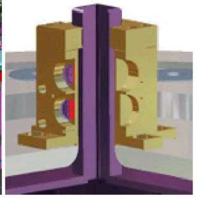
SAND2018-13537PE

Progress towards x-ray diffraction on dynamically-compressed matter on Z







PRESENTED BY

Marius Schollmeier for Tommy Ao, Sandia National Laboratories

National Diagnostic Working Group meeting
December 4-6, 2018

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Executive Summary

X-ray diffraction (XRD) on Z utilizing a 3-stage strategy

- 2017 - 2019 — 1st stage (near-term): Perform Z-XRD of compressed low-Z materials by leveraging spherical crystal imaging experience on Z
- 2016 - 2020 — 2nd stage (mid-term): Improvements to Z-XRD, such as increasing x-ray flux and photon energy, and implementing time-gating
- 2018 - >2020 — 3rd stage (long-term): Incorporate Z-XRD with containment system to diagnose compressed high-Z materials

Scientific Needs and Challenges

Purpose: diagnose material lattice dynamics during dynamic compression

What?

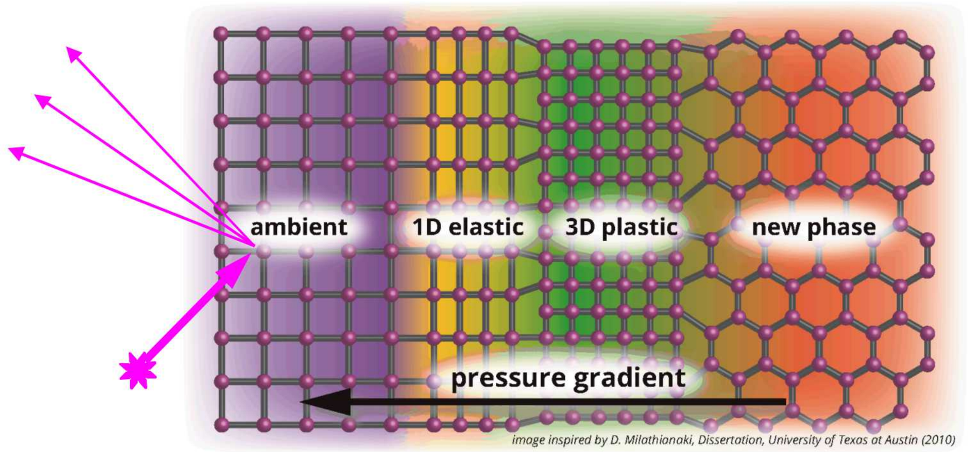
- Characterize phase transformations that occur in dynamically compressed condensed matter on ns time scales and nm spatial scales

Why?

- Such information enables to determinate how material behaves under extreme conditions
- For most materials, there are very few constraints on existing models for phase transitions under dynamic loading

How?

- Perform time-resolved, x-ray diffraction measurements on dynamically compressed, polycrystalline matter



Challenges of XRD on Z-DMP experiments

Target parameters

- Large and thick samples; high-Z samples
- Reflection geometry
- Containment targets: inserting x-rays & extracting diffracted x-rays

Destructive environment of Z-DMP load

- Retrieve data
- Prevent catastrophic vacuum breach
- Protect Z-Backlighter lasers

X-ray background

- High energy photons (up to 10 MeV) produced
- Sufficient signal-to-noise

Electromagnetic pulse (EMP)

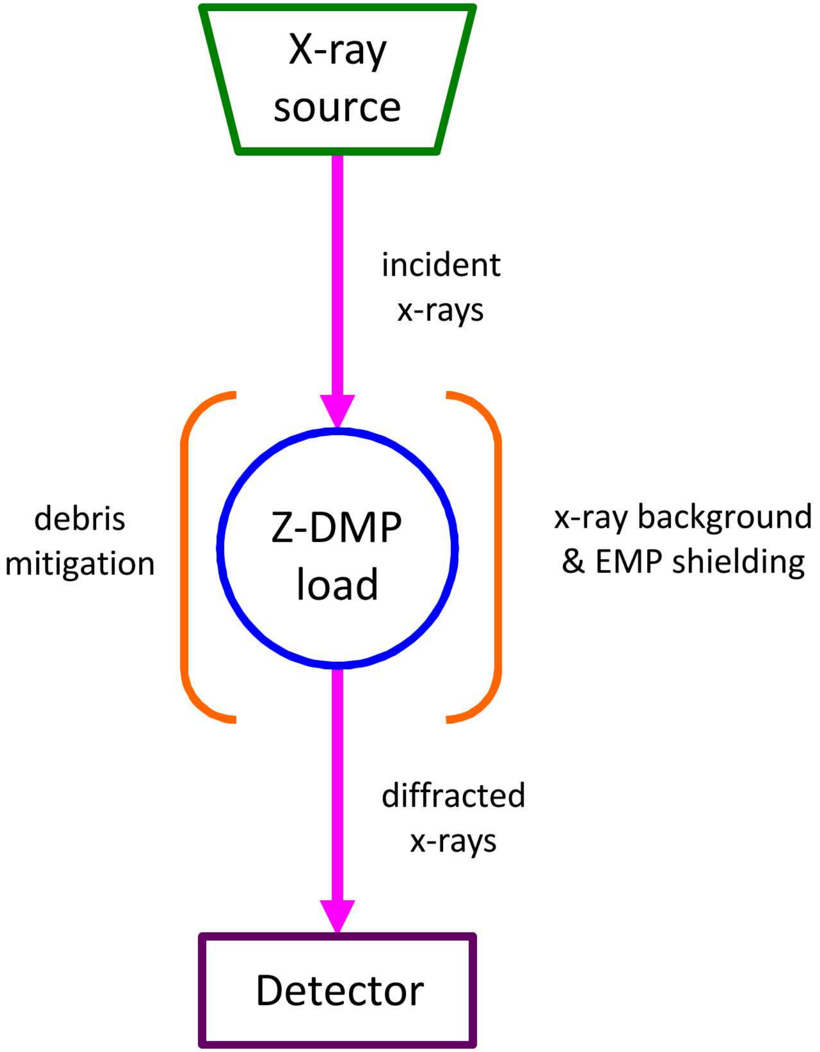
- Fry electronics

Three key components of x-ray diffraction (XRD) on Z-DMP experiments

Produce source x-rays
- Laser (ZBL/ZPW) irradiated metal foil

Generate high-pressure state
- Z-DMP load
- Debris mitigation
- X-ray background and EMP shielding

Detect diffracted x-rays
- Image plate
- Scintillator/phosphor
- Photodiode array
- CCD camera



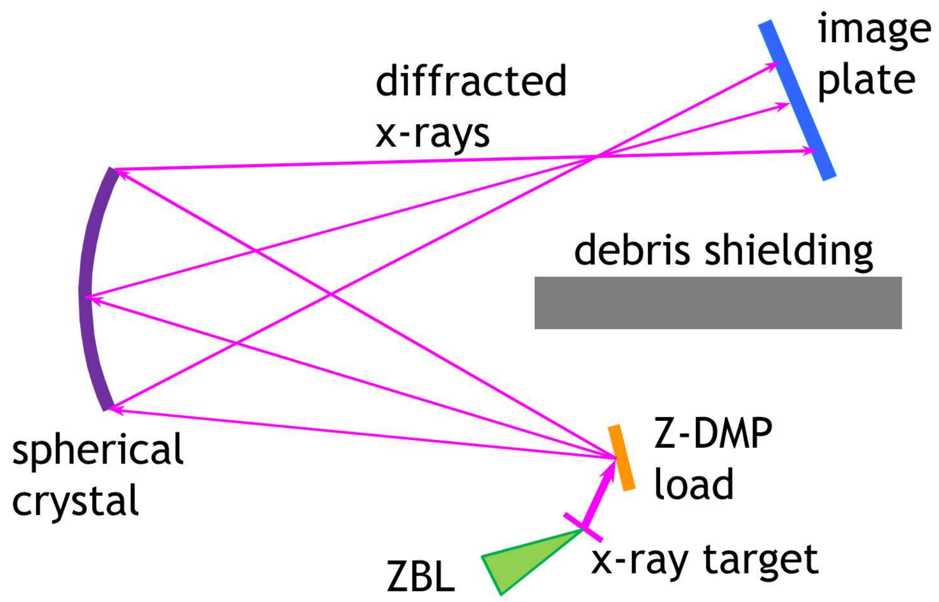
1st Stage (Near-term) Updates

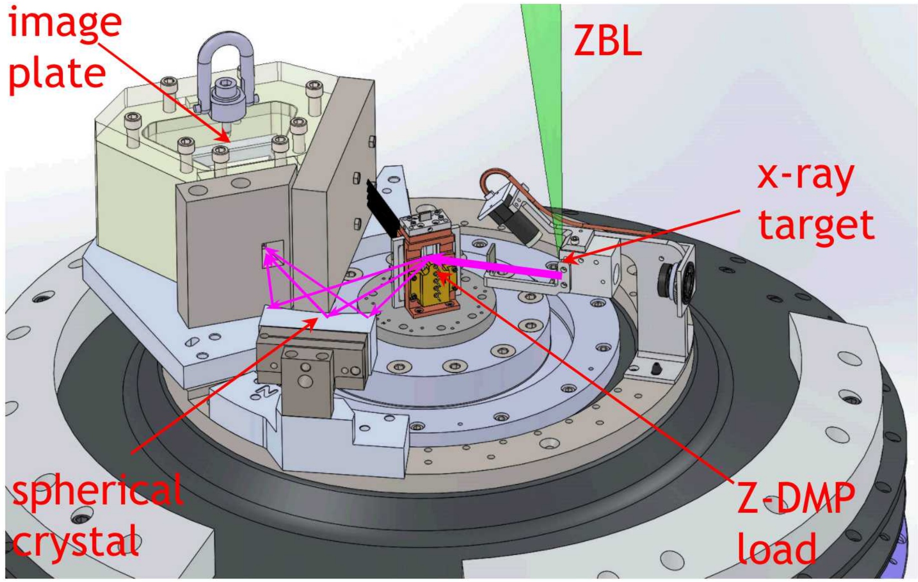
Perform Z-XRD of compressed low-Z material by leveraging spherical crystal imaging experience on Z

Commission spherical crystal diffraction imager (SCDI) diagnostic on Z

- Z-Beamlet (ZBL) laser ➡ 6 keV x-rays
- Spherical HOPG crystal ➡ collect diffracted x-rays
- Image plate ➡ record data

Obtain x-ray diffraction data to measure lattice compression & phase change

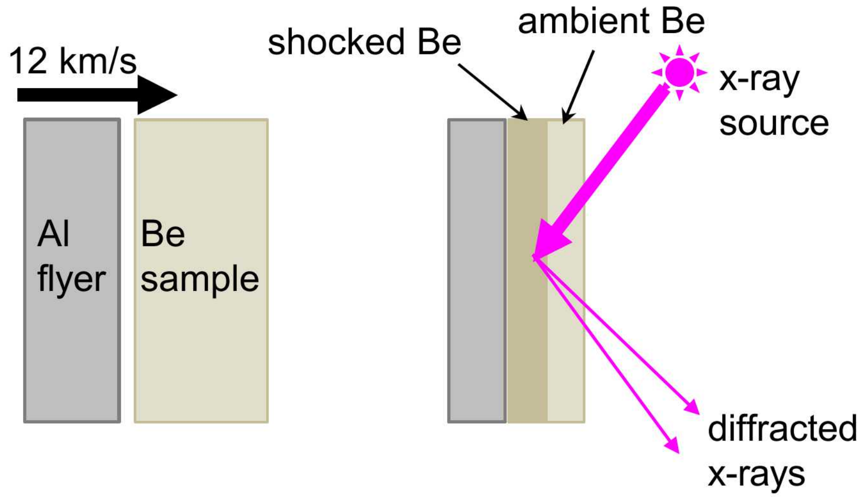


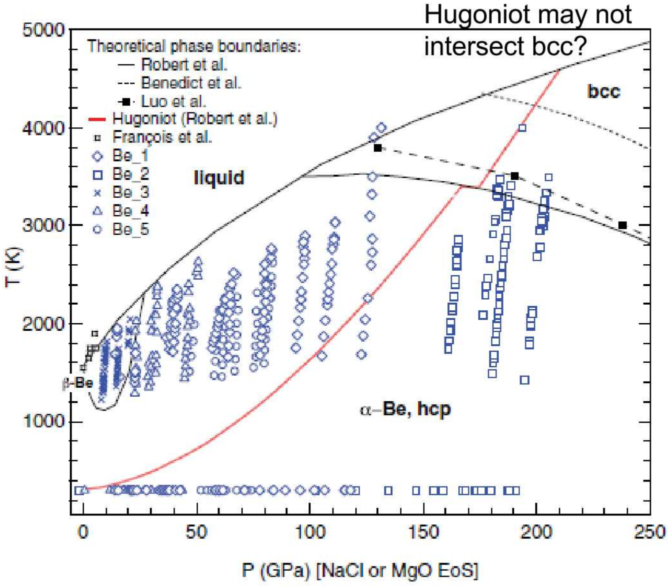


1st Z-XRD experiment: Beryllium shocked to 2 Mbar

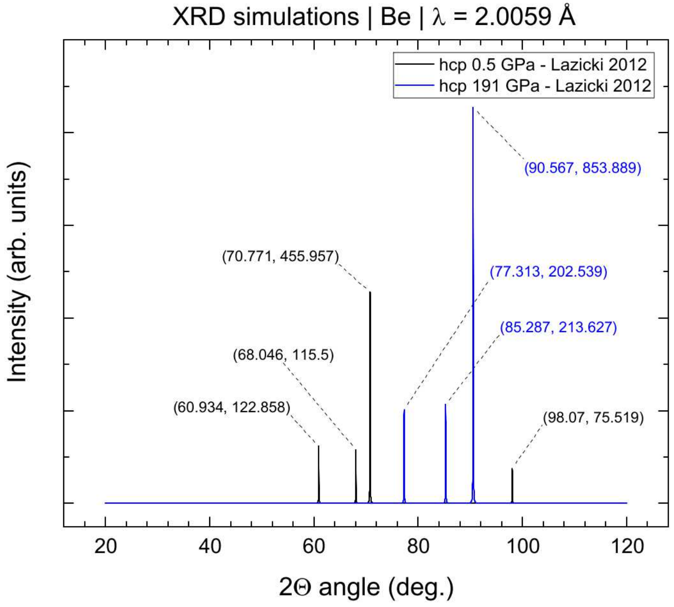
Beryllium has low mass attenuation coefficient
- Serves as own x-ray window
- Probe before free surface breakout

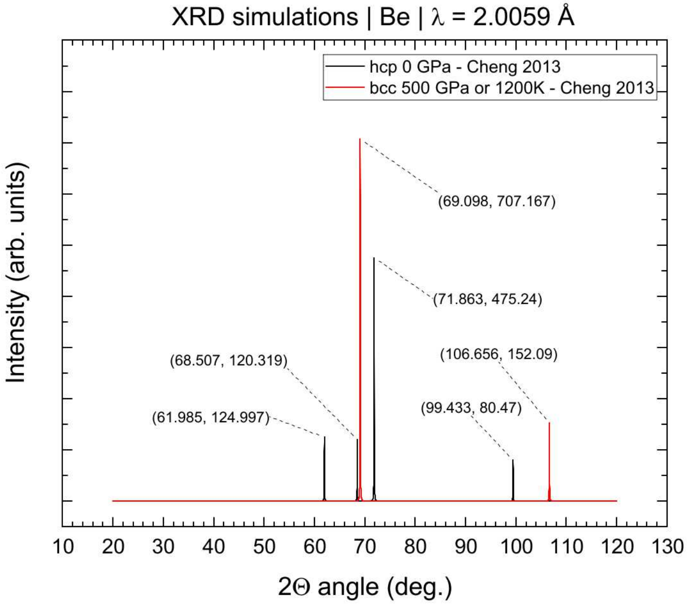
XRD probe shocked Beryllium state
- Measure compression of hcp lattice
- Attempt to observe possible bcc phase





A. Lazicki *et al.*, PRB **86**, 174118 (2012)

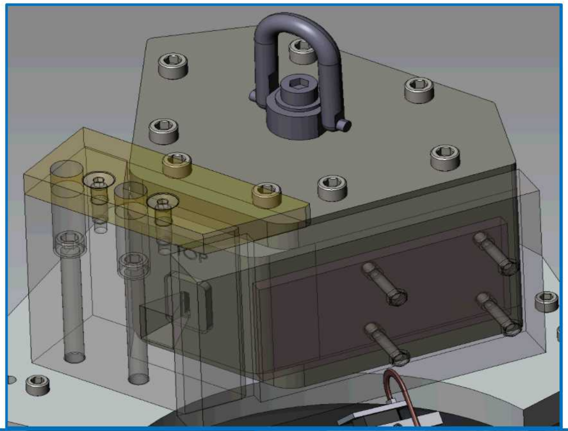


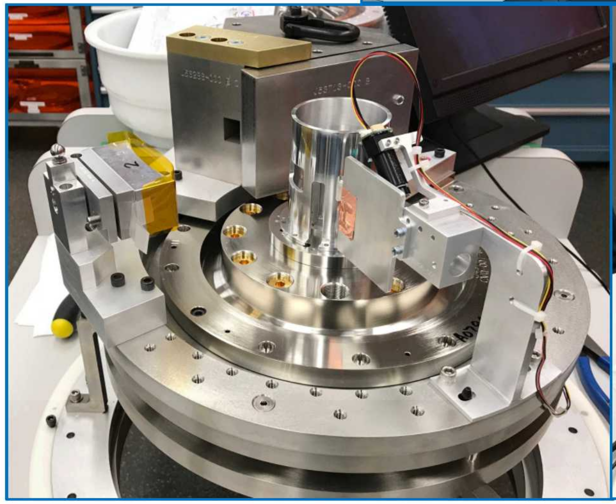


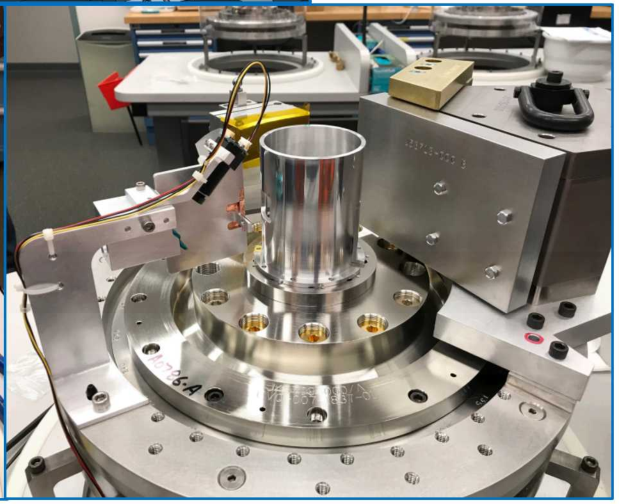
ZBL-3kJ only preshot, SCDI of ambient Be XRD

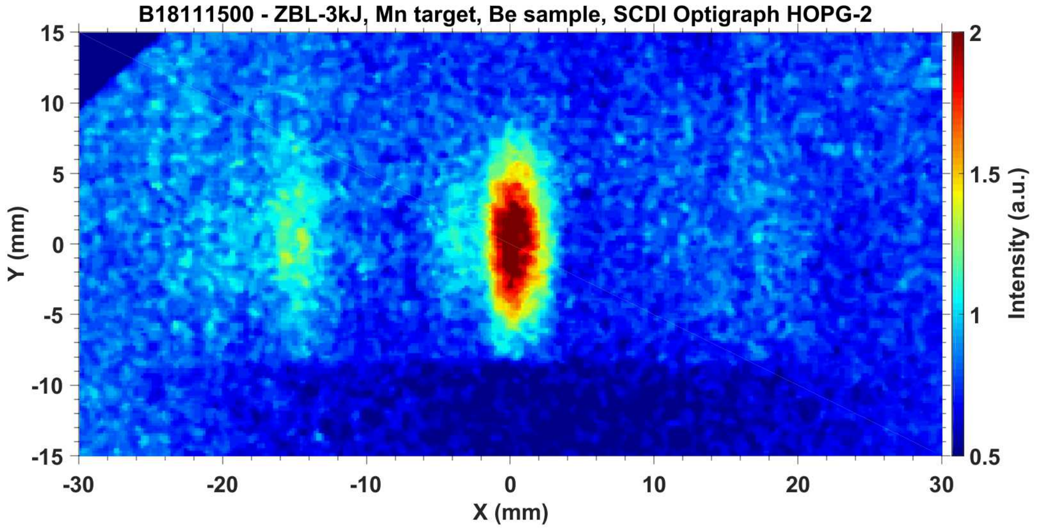
ZBL in Chama chamber

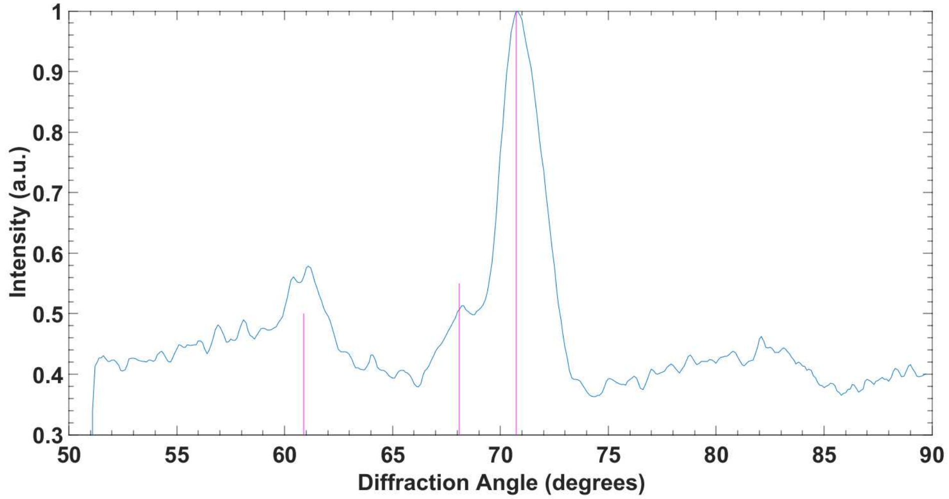
- Verified alignment with Z-DMP load
- ZBL generated 6.2 keV x-rays for XRD







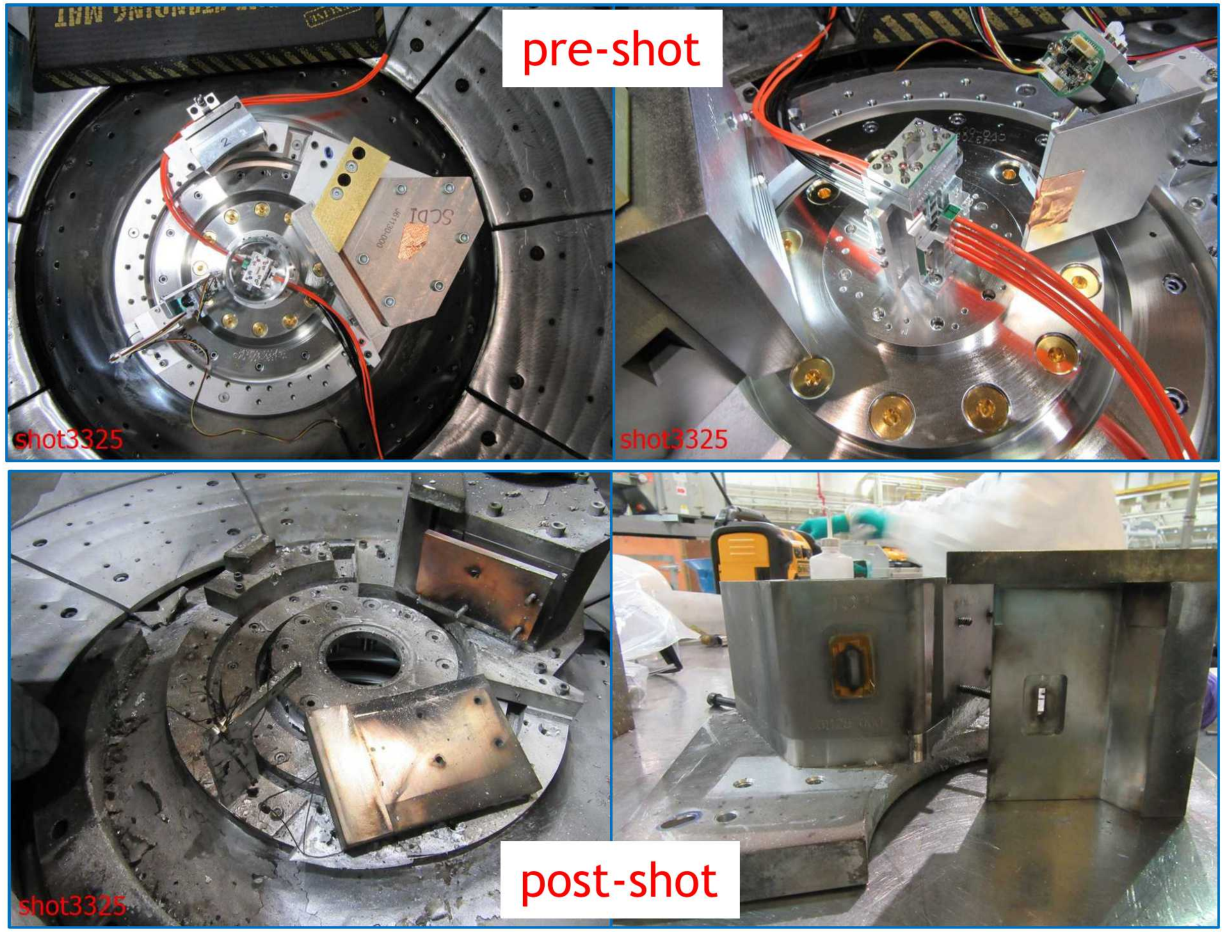


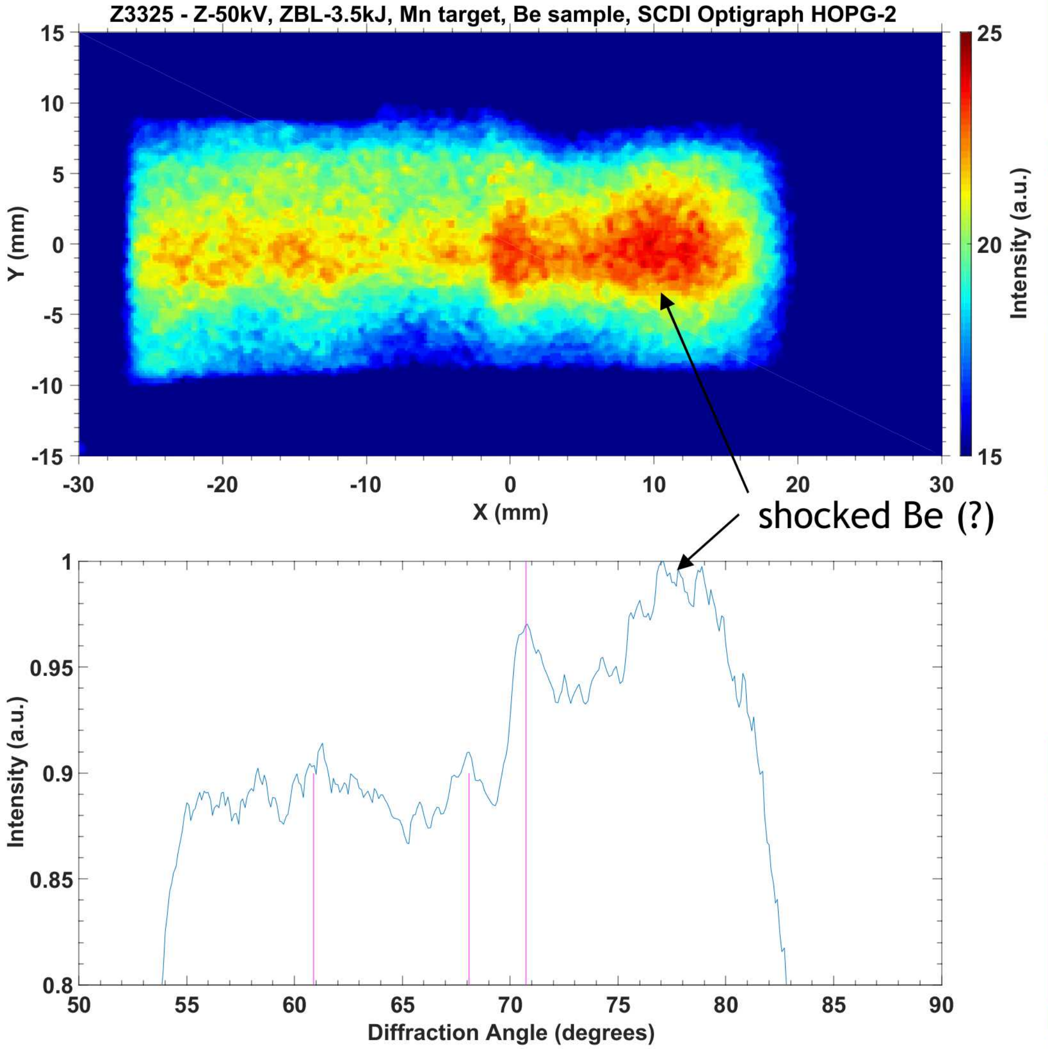


Z3325: Z-50kV, ZBL-3.5kJ, SCDI of shocked Be XRD

SCDI diagnostic commissioned on Z-DMP experiments

- Debris mitigated; high x-ray background
- Retrieved IP





Ongoing improvements to SCDI diagnostic

Reduce x-ray background

- Investigate possible x-ray sources: MITLs, DMP load, HOPG crystal
- Increase IP filtering
- Eliminate possible stray entrances
- Shutter crossover aperture

Time-gated x-ray detection

- Scintillator/phosphor
- Photodiode array
- CCD camera

Increase x-ray flux

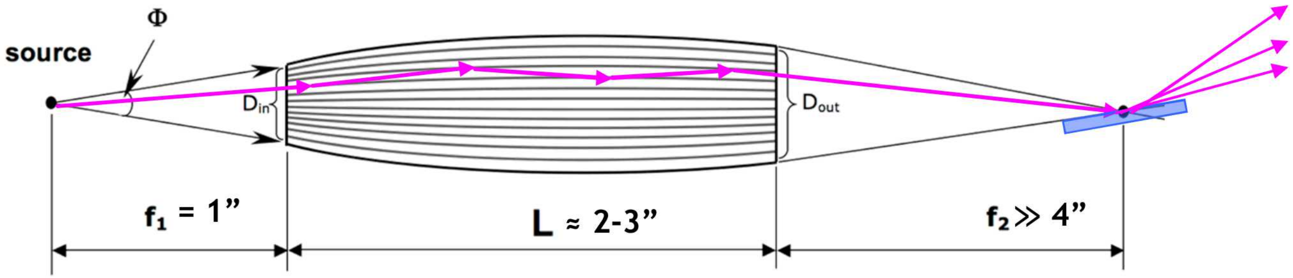
- Move x-ray source closer to DMP load
- X-ray polycapillary lens

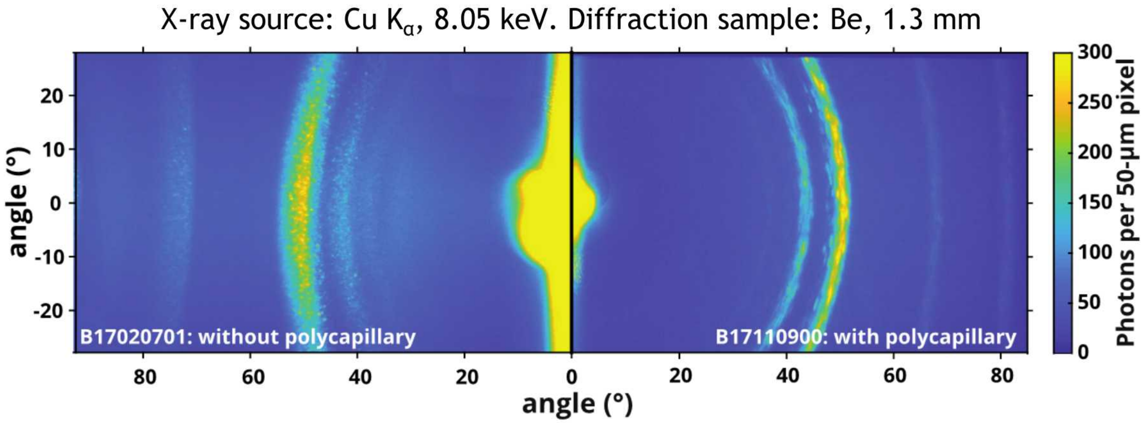
2^{nd} Stage (Mid-term) Updates

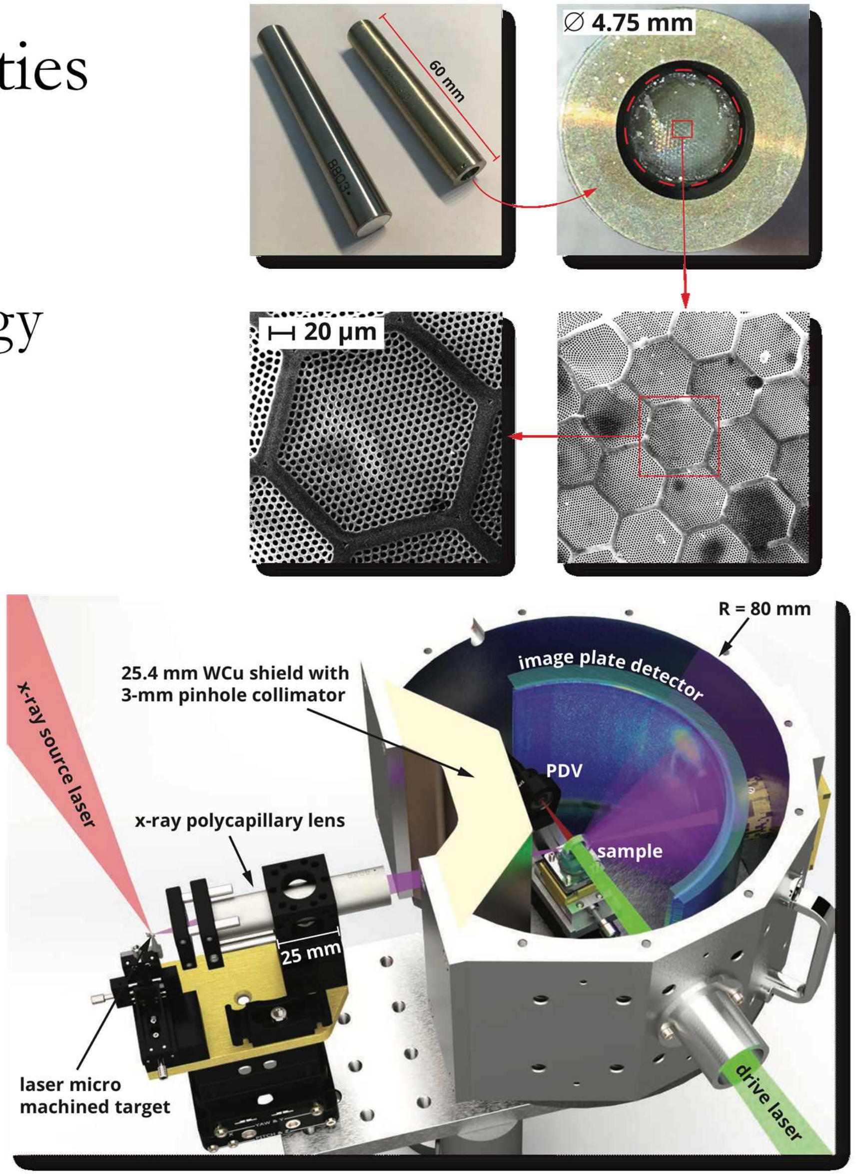
X-ray flux increased by 100-fold using x-ray polycapillary lens compared to pinhole collimator

Polycapillary x-ray focusing enhances capabilities of Z-XRD experiments

- Total external reflection fiber bundle
- $N_{photons\text{-}on\text{-}sample} = 10^9 - 10^{12} \rightarrow$ Enabling technology







M. Schollmeier, T. Ao et al., RSI 89, 10F102 (2018)

X-ray detection option 1: scintillator and imaging fiber

P47 phosphor x-ray-to-light converter

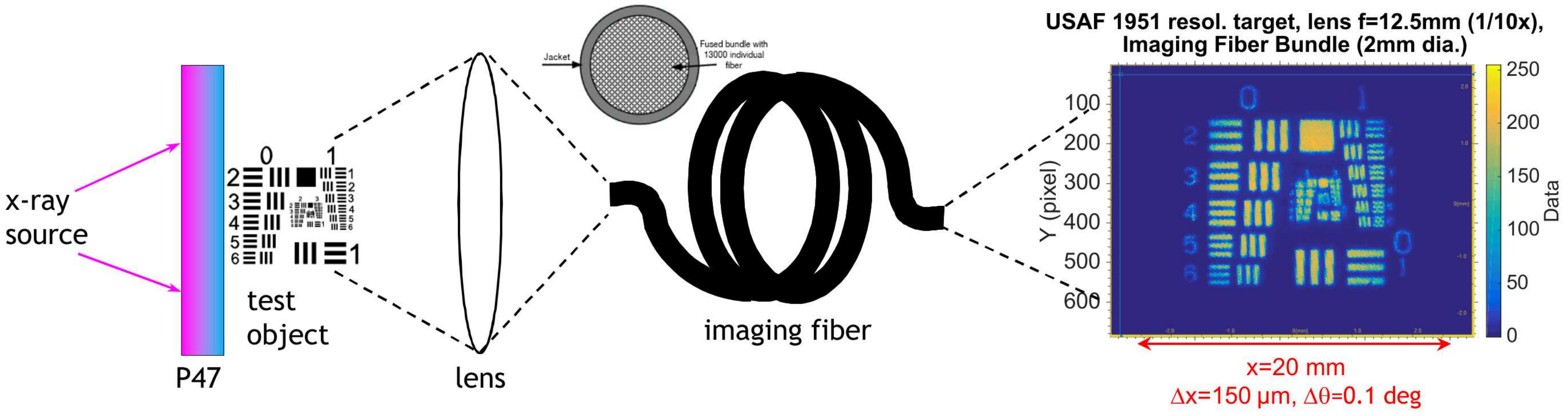
- 450 nm light, 50 ns decay

Polymer imaging fiber bundle

- 2 mm diameter, NA = 0.5, 13000 fiber cores, 15 μm diameter

Initial tests with Z-Beamlet laser show some promise, more work needed

- 6-8 keV x-rays
- Possible fiber darkening due to x-ray background



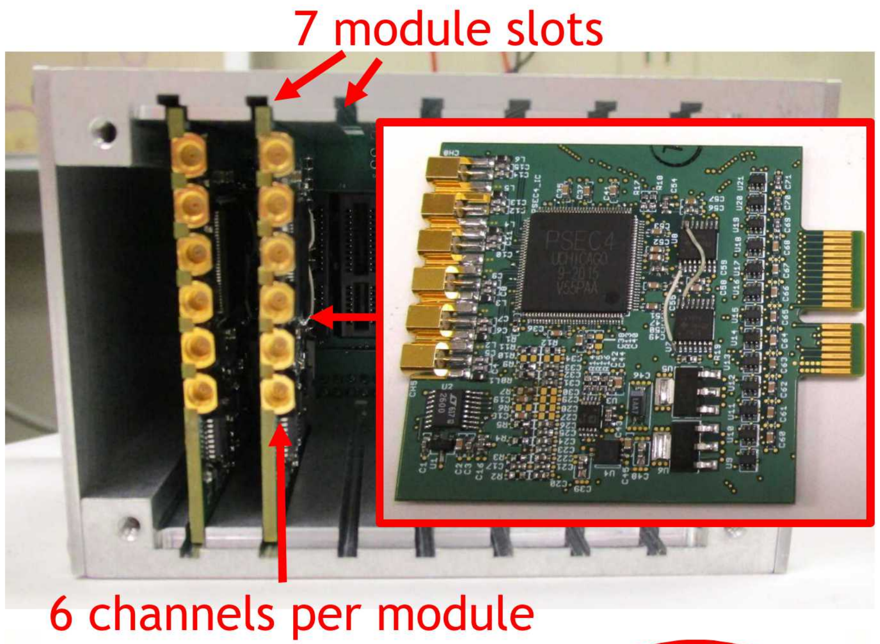
X-ray detection option 2: linear diode array (LDA)

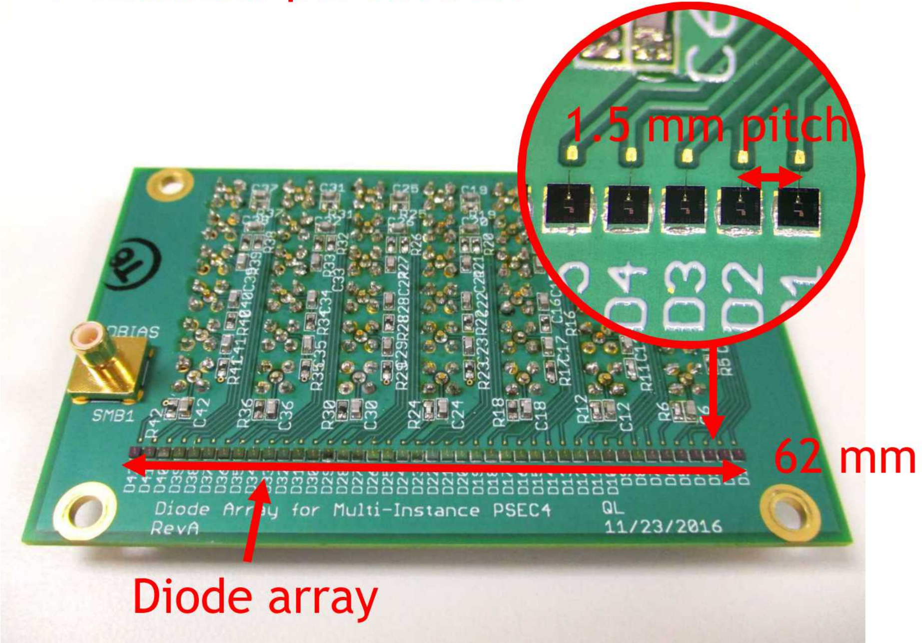
PSEC4 system:

- 24 to 42 channels per system
- Each channel 256 samples, 2 GHz bandwidth, ~8 to 15 GS/s
- USB interface

Diode Array Board

- attaches directly to PSEC4 inputs
- Onboard biasing circuit
- 42 detectors, 1.5 mm pitch, 0.25 mm active area
- Location/shape of diodes variable

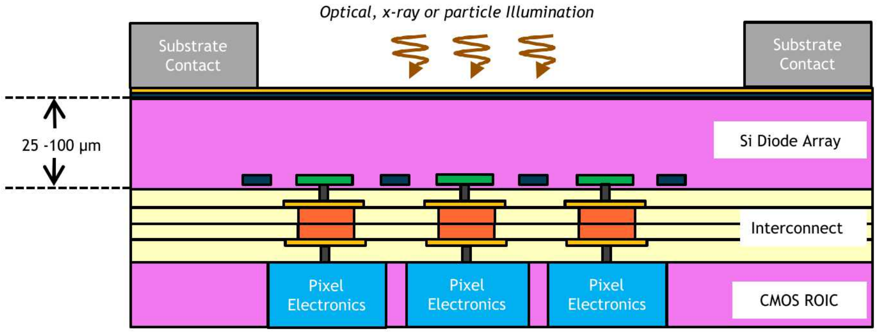




X-ray detection option 3: ultrafast x-ray imager (UXI)

Fast, time-gated, multi-frame, hCMOS camera

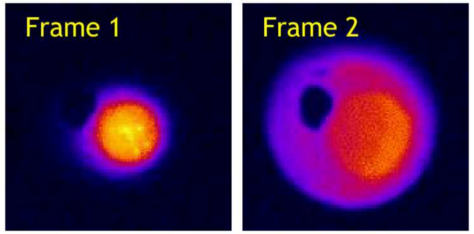
- Silicon detector: 25 μm thick ➞ 6 keV x-rays; 100 μm thick ➞ 13 keV, work needed for >15 keV x-rays
- 25 μm pixels, 448-512 x 1024 format
- 2-8 frames, 1.5 ns inter-frame times



CMOS Hybrid Image Sensor

Ongoing tests on Z machine

- E.g. X-ray emission from MagLIF gas cell

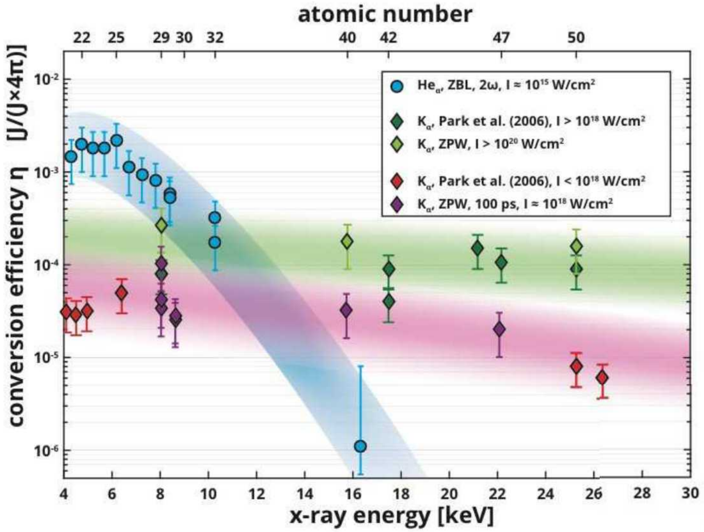


3rd Stage (Long-term) Updates

X-ray source developments

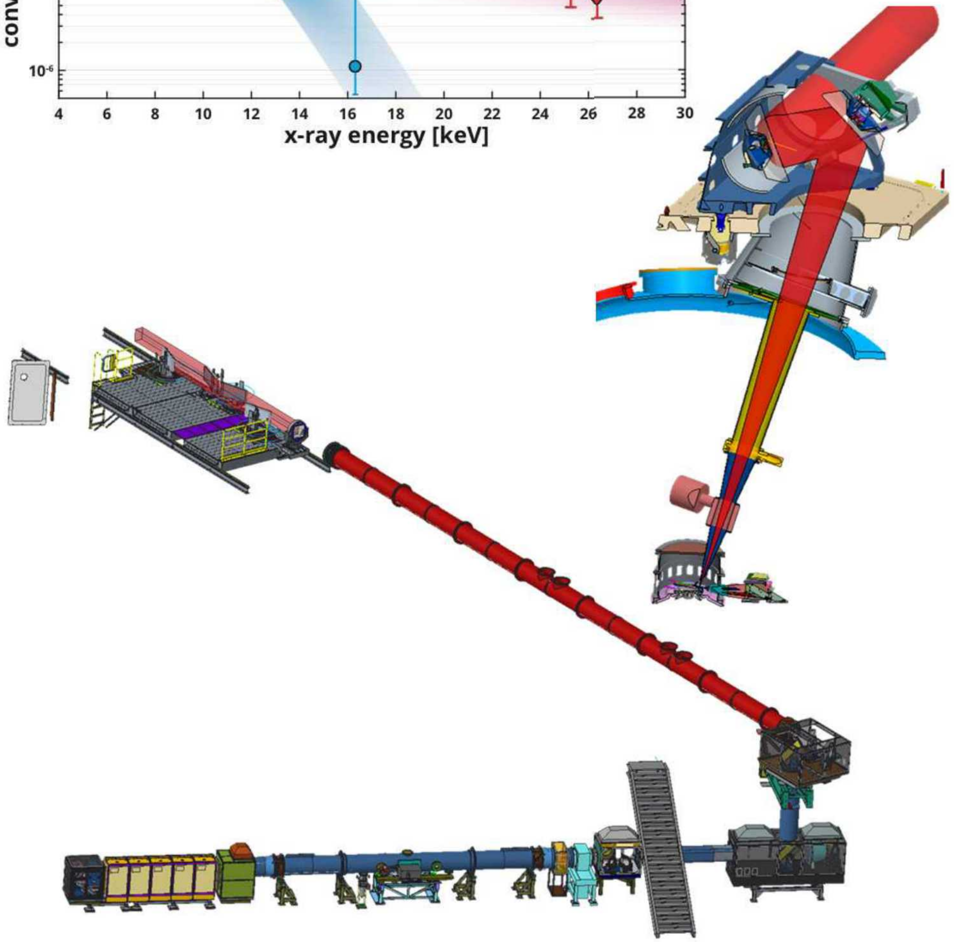
Z-Petawatt (ZPW) laser full-aperture upgrade

- Short-pulse: 1-2 kJ, 1054 nm, <0.2 ns
- High x-ray energies: 15-20 keV



Multi-pulse concept for ZPW

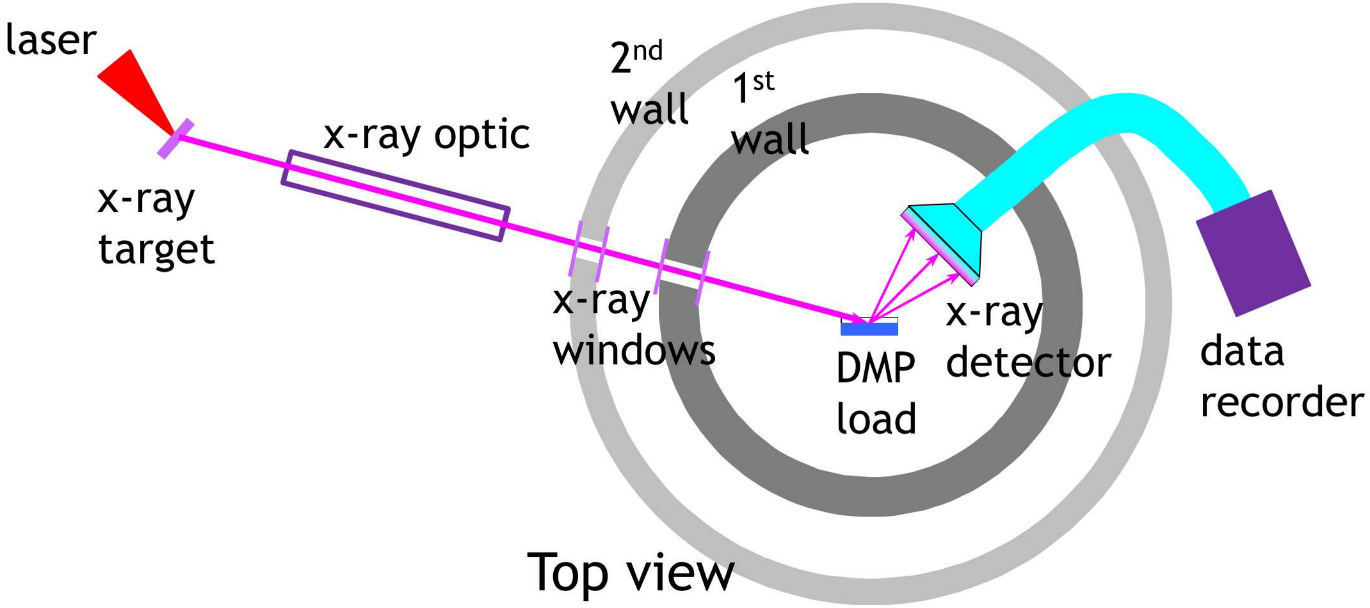
- Spatially split beam before injection into main amp section
- Full delay adjustment (≈2-20 ns)
- Separated far-field spots (2 targets)
- Similar to Z-Beamlet multi-frame backlighter



Conceptual design of high-Z containment experiment

High-level requirements

- Sufficiently high-energy (>15 keV) x-ray photons to diagnose high-Z materials
- Angular resolution to distinguish between diffraction lines
- Compatibility of input and output of x-rays with containment system on Z



Acknowledgements

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