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Sandia National Laboratories

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Diagnostics at the Z Facility:
Current and Planned Diagnostic Capabilities

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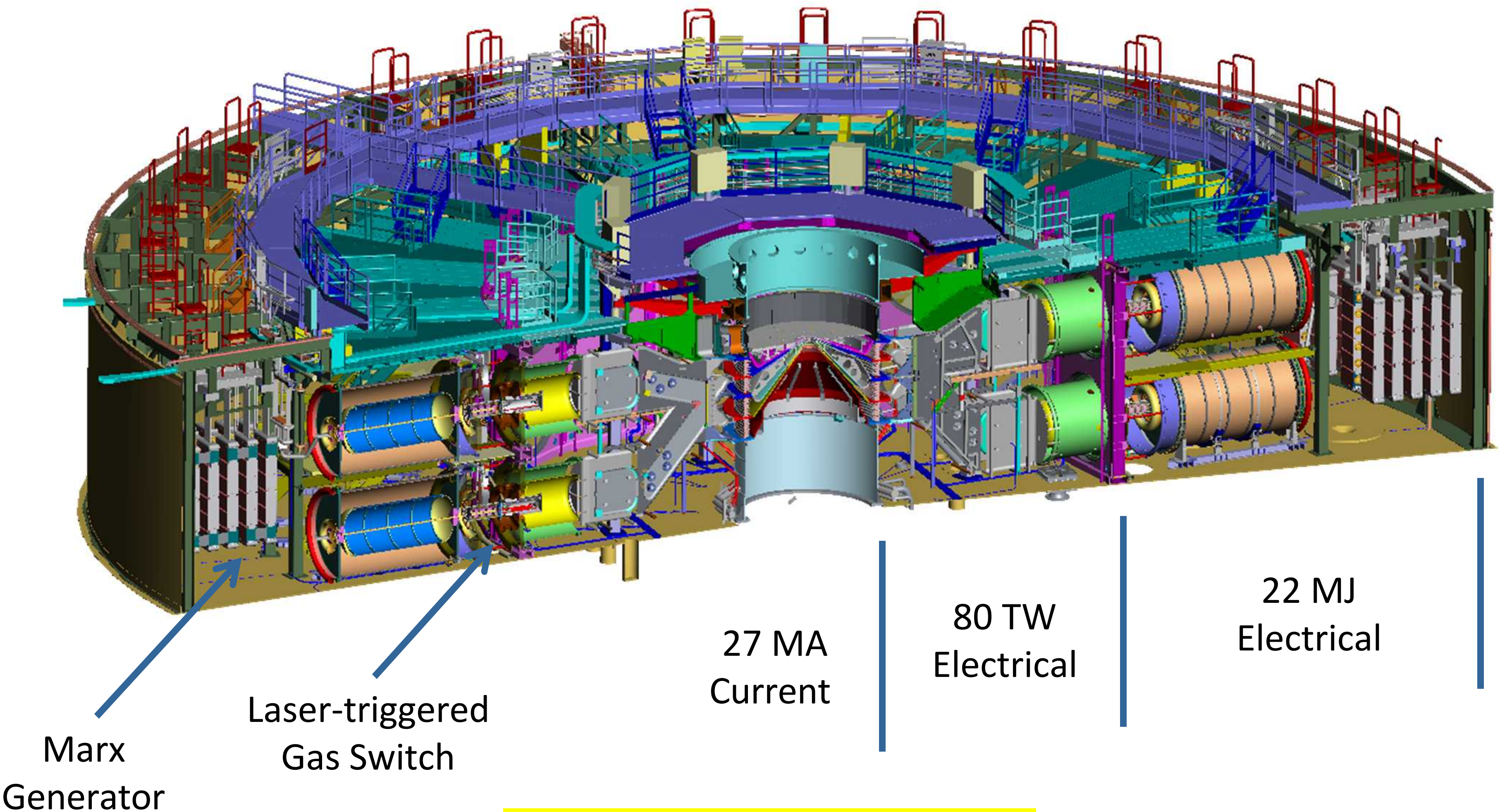
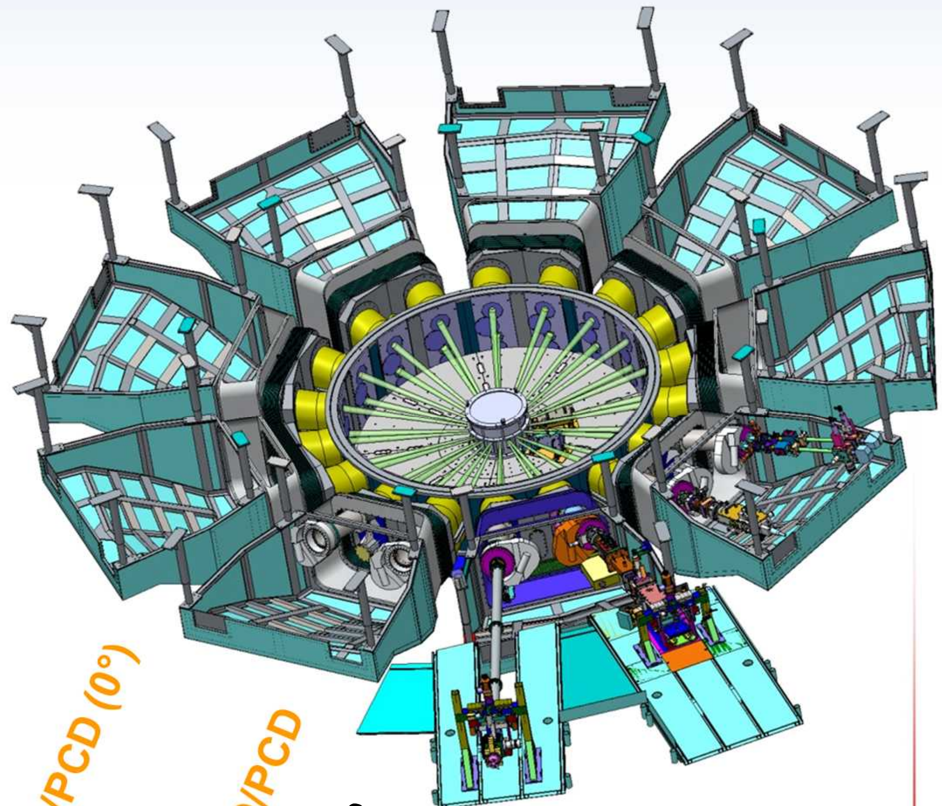
The Z facility at Sandia National Laboratories is the world's most powerful pulsed power machine.

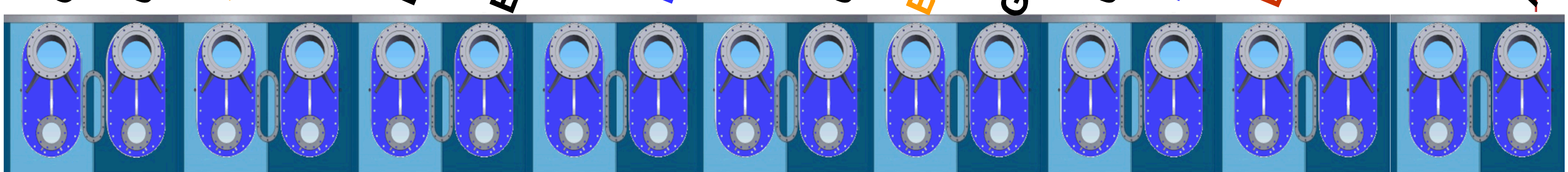


Operating Range: 11-27 MA

Radial LOS overview of the Z facility

- 18 Radial line of sights access ports at ~12º
- 18 line of sight access ports at ~0º
- Chamber diagnostics:
  - CRITR
  - TiGHER
  - SVS
  - DAHX
  - Neutron Activation(In and Cu)
  - Radiation effects cassettes
  - VISAR
  - PSBO
  - Monochromatic Backlighter
  - TIPC
  - APE
  - APC



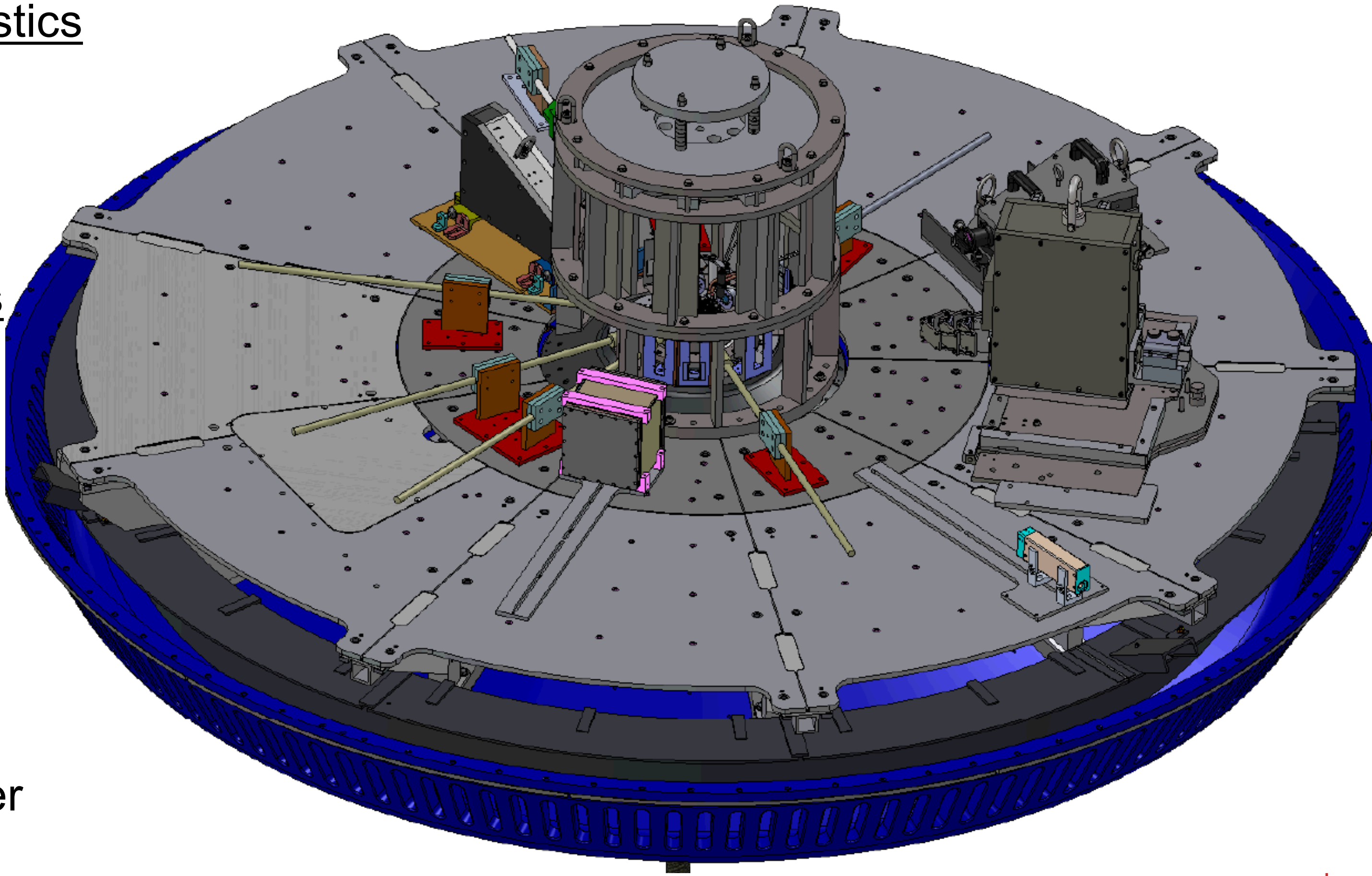


In-chamber diagnostics provide opportunities for improved access and sensitivity

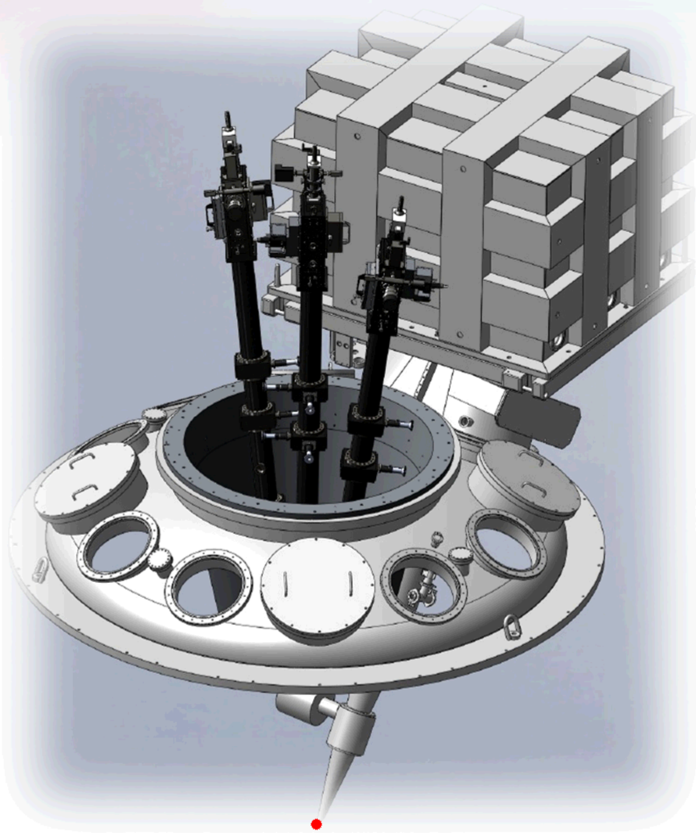
<u>Fiber-Based Diagnostics</u>
- VISAR
- PDV
- SVS

<u>X-ray Spectrometers</u>
- CRITR-AR
- CRITR-RR
- XRS3
- TiGHER
- DAHX

<u>X-ray Imagers</u>
- Monochromatic Crystal Backlighter
- Spherical Imager
- TIPC
- APC
- APE

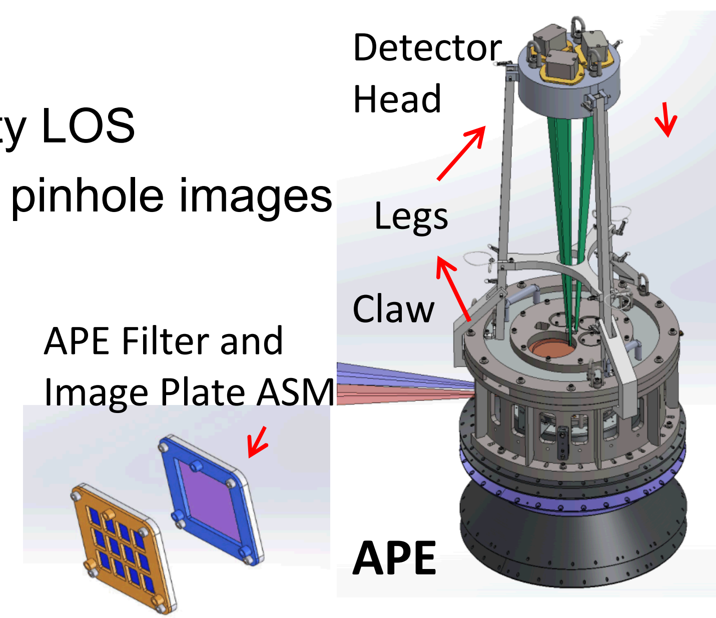


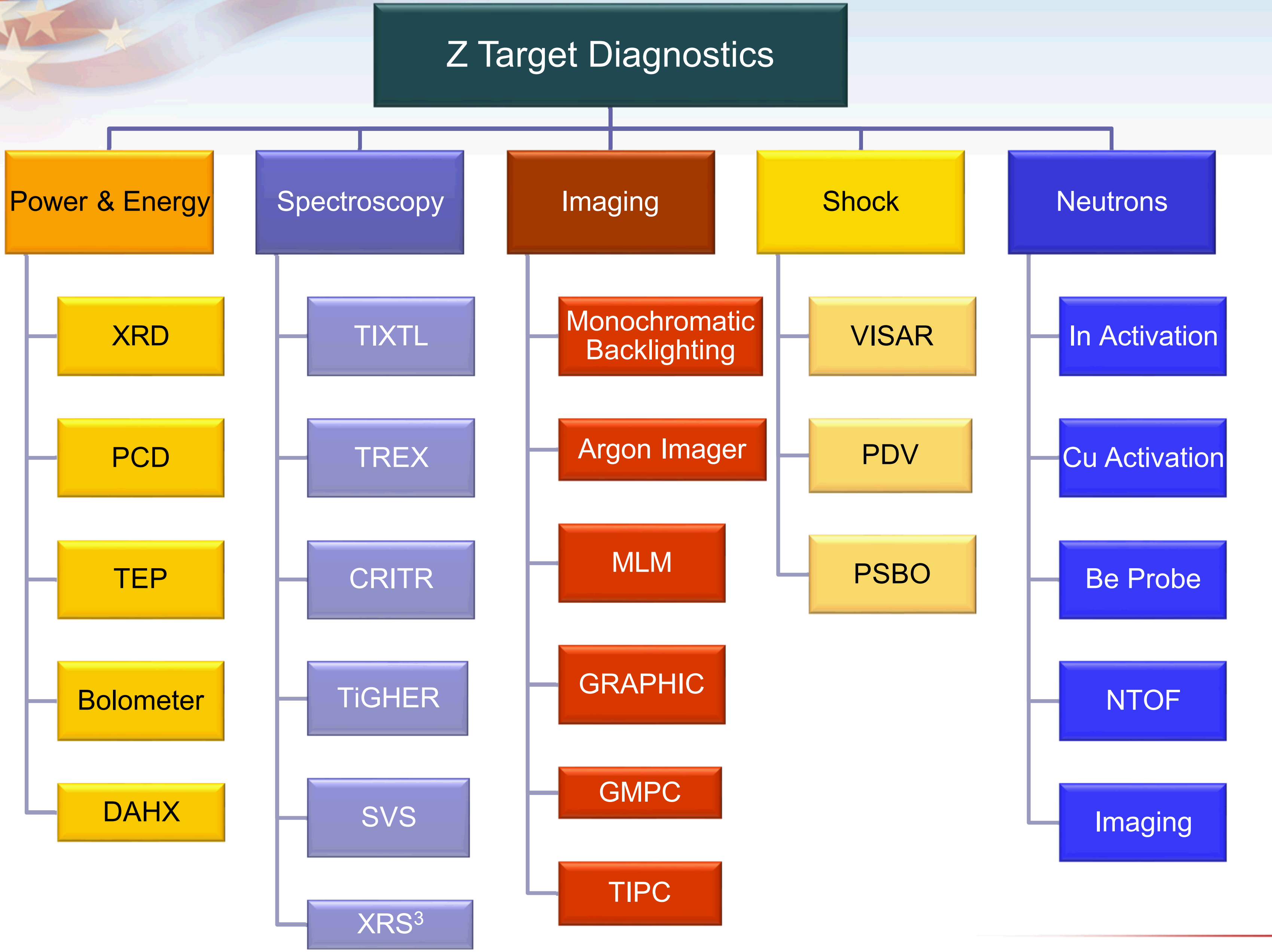
Axial LOS overview of the Z facility



- 3 Axial LOS:
  - –0°: PODD (ECP,CCP, MIP, GMPC)
  - – 9° E: PODD (ECP,CCP, MIP, GMPC)
  - –9° W: PODD (ECP,CCP, MIP, GMPC)

- 1 Close Proximity LOS
  - –3 sets of 12 pinhole images





* Overview of of each diagnostic is available in the backup slides

Where to go to find out more

- Overview of all current capabilities available on the ZFSP website
  - Will be updated and uploaded by 8/15.
  - Includes 1-slide overview, and SNL contact for the capability
- Capability development:
  - Z diagnostics has dedicated design team
  - Partners with the science community to define and prioritize development activities
  - Can work with the PI community to identify a need
    - Small modifications to existing capabilities takes 2-3 months; new systems 1-3 years, depending on extent of development and R&D needed.

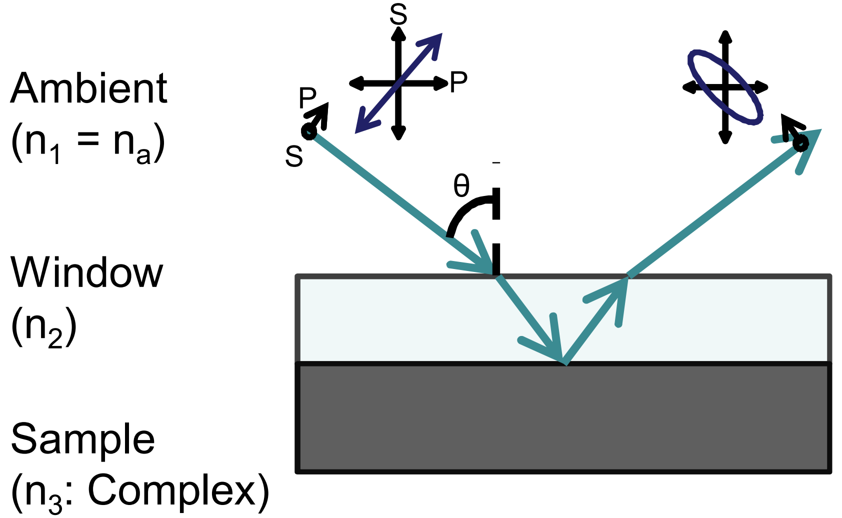
Development of an ellipsometry capability

Ellipsometry development on Z (S. Grant)

- Collaborative development between university partner and Z
- We intend to use this diagnostic as part of a ZFS proposals to study the transport properties of iron and iron alloys at P-T conditions similar to the Earth's core.
- This will be measuring the AC optical conductivity, but we will be trying to relate our measurement to the DC thermal conductivity, which is a value of high importance to the geoscience community.

Ellipsometry uses a polarized laser to probe material dielectric properties

- The polarization state of light interacting with a material interface changes based on the dielectric properties of the material
- By tracking the change in polarization, time-resolved dielectric information can be determined



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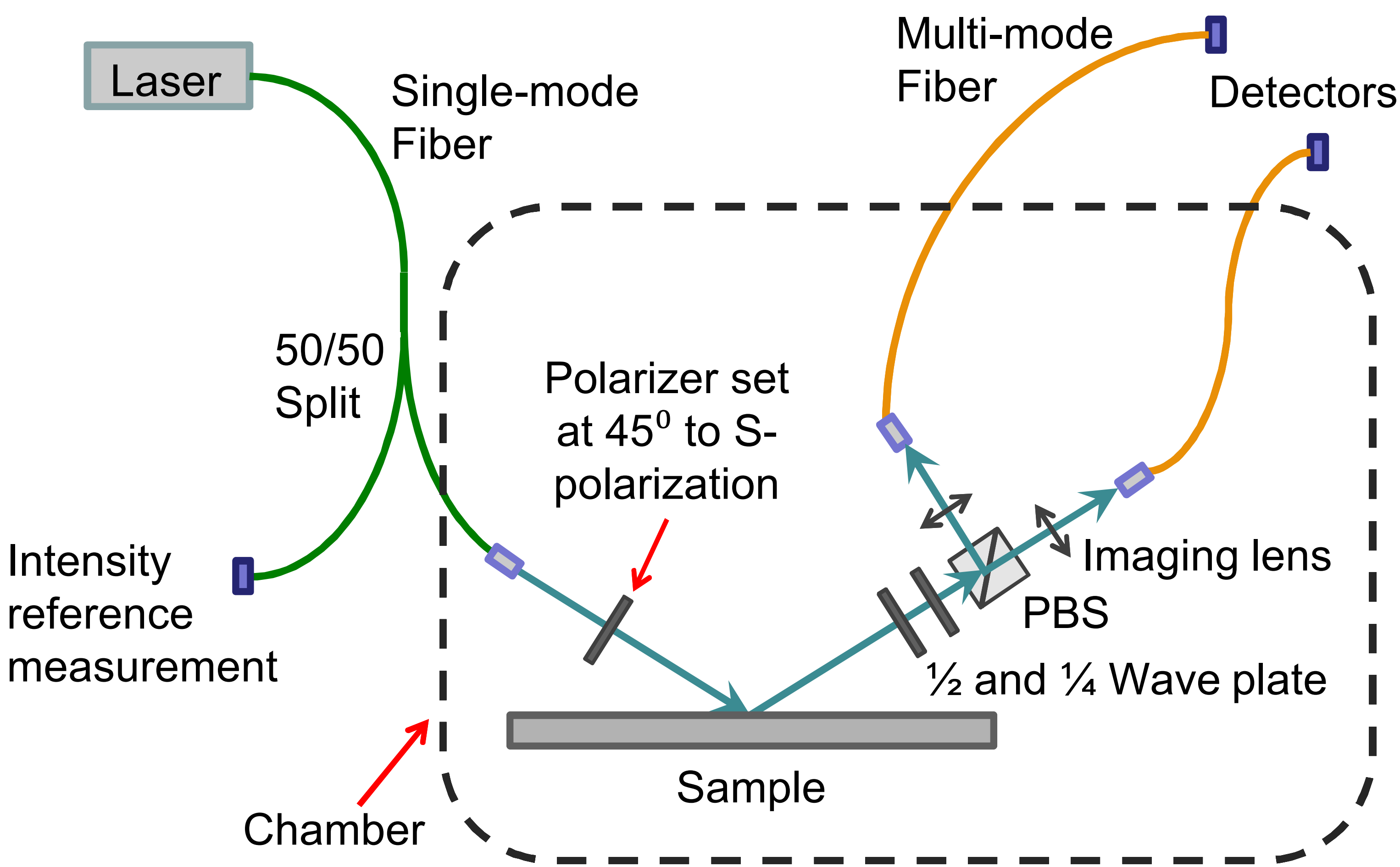
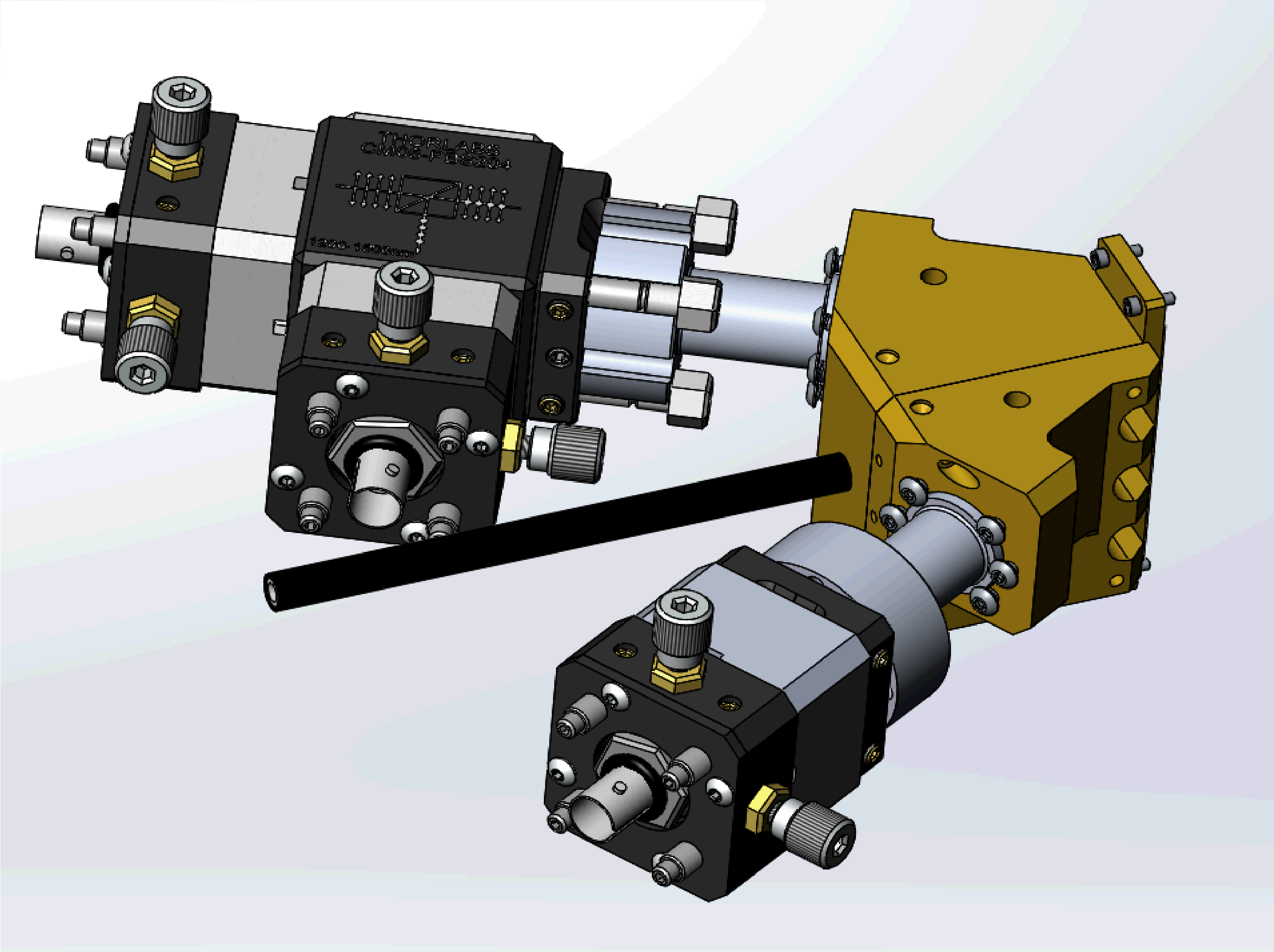
The basic design is a fiber/open-beam hybrid

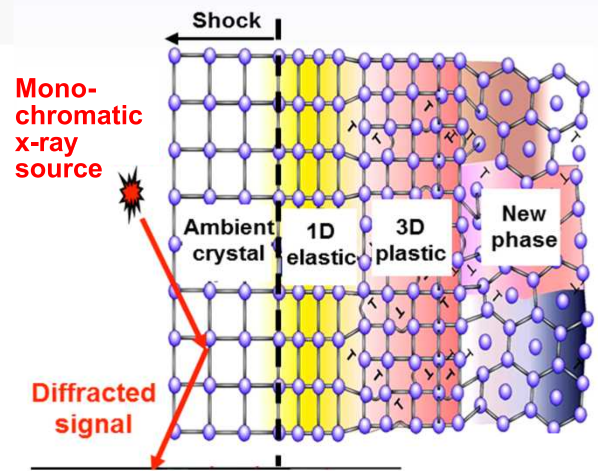


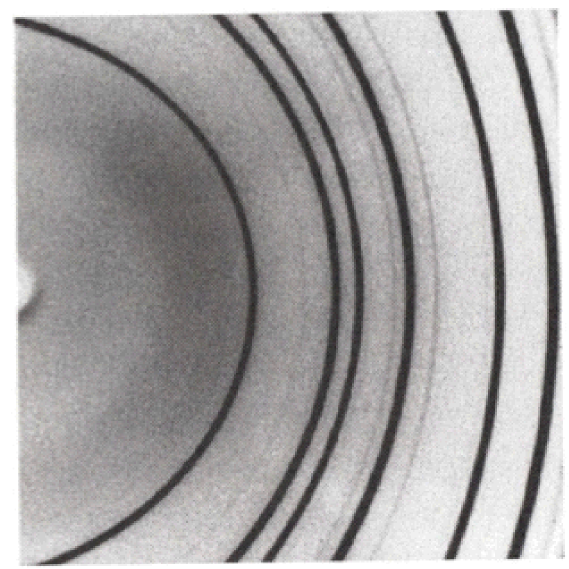
Ellipsometry load design for Z



X-ray diffraction (XRD) to diagnose material lattice dynamics during shock/ramp compression (T. Ao)

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





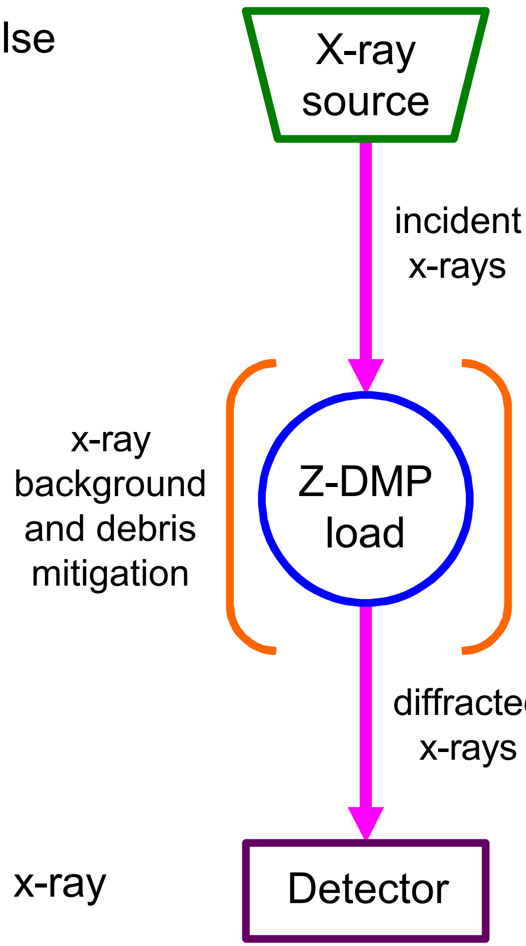
Powder x-ray diffraction pattern

Three key components of Z-XRD on Dynamic Material Properties (DMP) experiments

- Produce source x-rays
  - High energy (>10 keV), short duration (< 1ns), multi-pulse x-rays using Z-PetaWatt (ZPW)
  - Penetrate into thick and high Z targets
  - Temporally resolve phase transformations

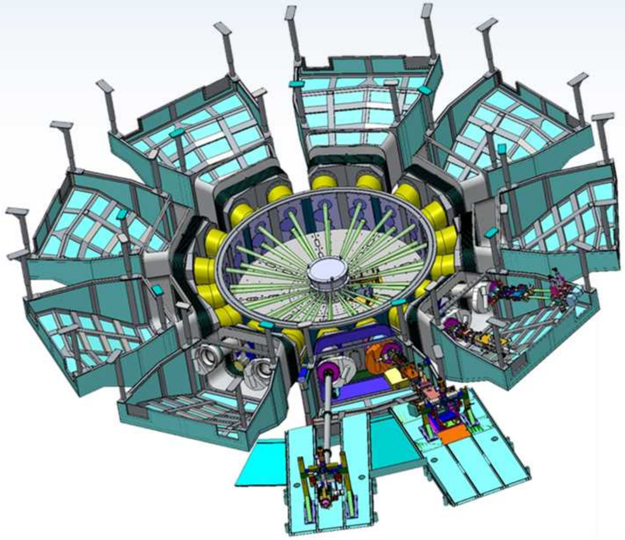
- Generate high-pressure state
  - Z-DMP load: shock, ramp, shock-ramp
  - Debris and x-ray background mitigation

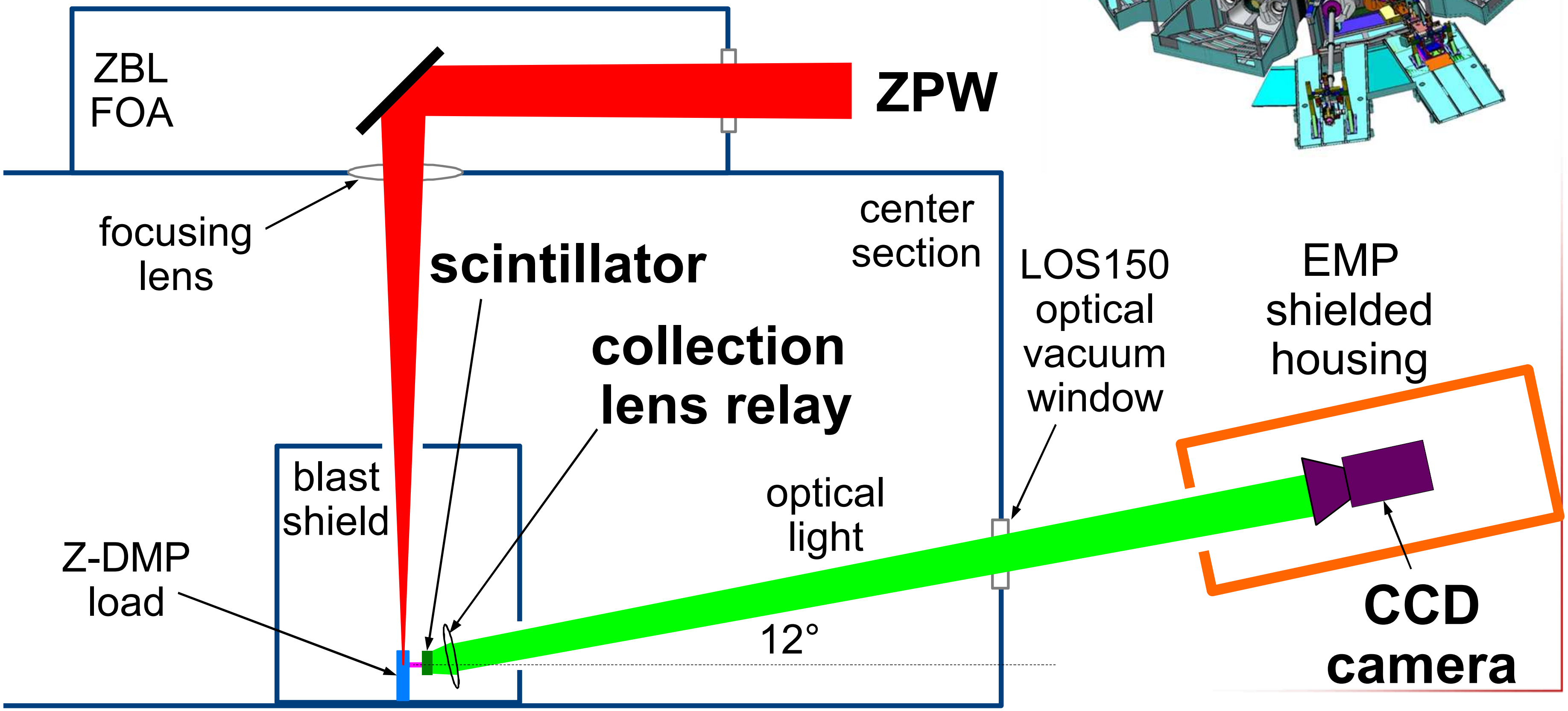
- Detect diffracted x-rays
  - Scintillator near load converts x-rays to optical light
  - Transport light out of load region
  - Record light on optical CCD camera away from debris, x-ray background and EMP field



Z-XRD diagnostic made up of scintillator/optical relay/CCD camera

- Radial line-of-sight (LOS) 150
  - Currently only used to field Neutron Imager
  - Implementation of proposed XRD diagnostic leveraging Neutron Imager work





Progress on diagnostic understanding of Stagnation & Burn on the MAGLIF platform

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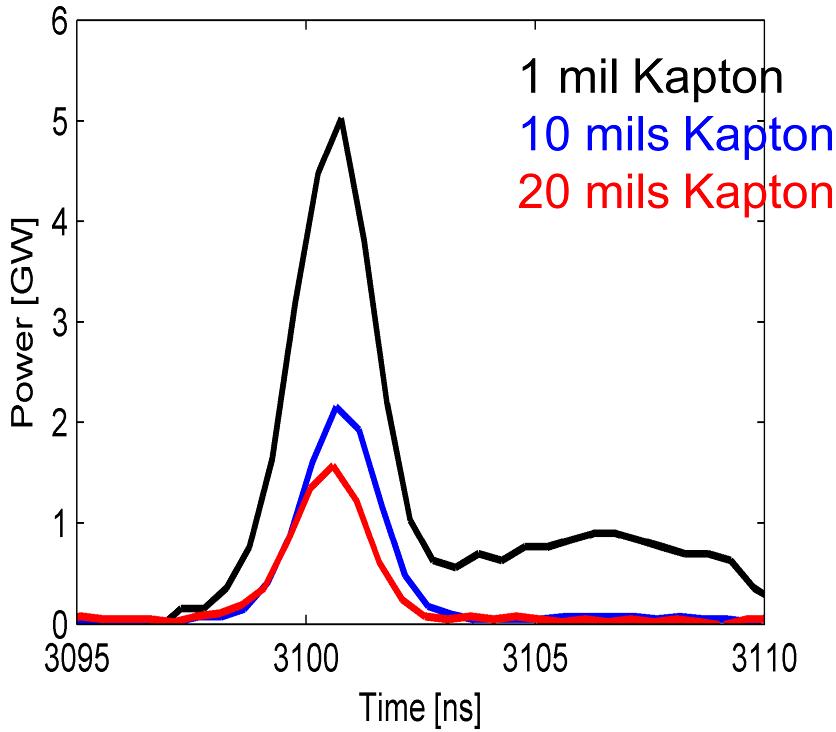
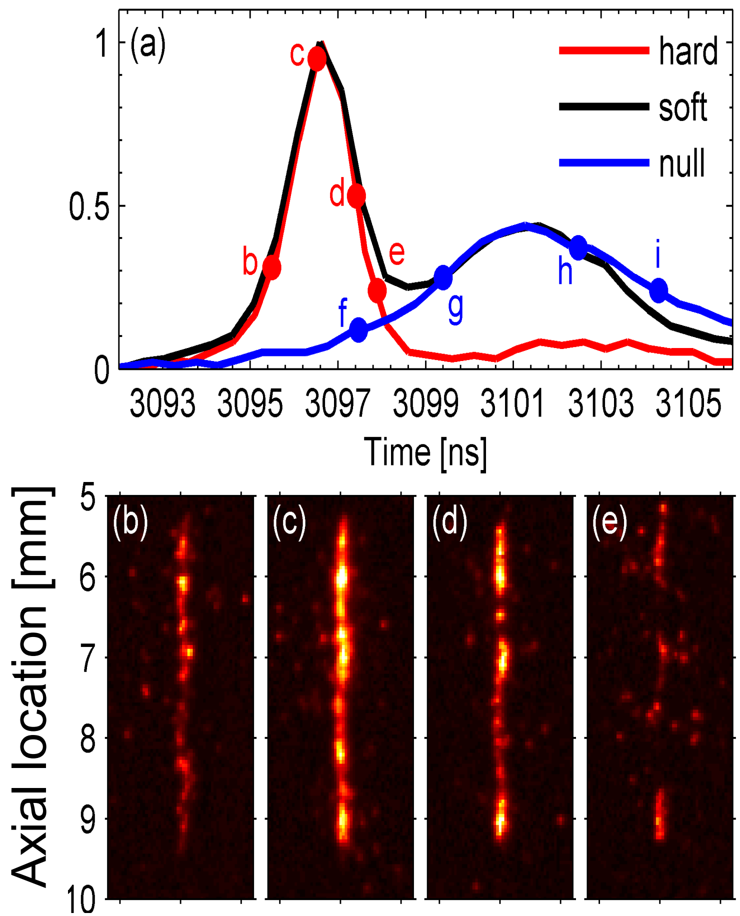
X-ray diode traces tell us that stagnation emission lasts about 2 ns



- PCD traces indicate x-ray emission at stagnation is ~10 J
- Requirements for a new diagnostic:
  - ~0.1 ns resolution
  - Coverage for 8 ns
    - Approximately 2 ns of emission and +/-3 ns of jitter
  - Sensitive enough to measure a source with ~10 GW spread over a 10 mm height and 0.2 mm width

The MLMc images tell us that the emission is relatively simultaneous over the target height



- Emission timing from narrow column matches the PCD emission timing
- The 13 degree angle of the MLMc LOS limits the field of view to the bottom half of the target
- Requirements for a new diagnostic:
  - 0 degree line of sight

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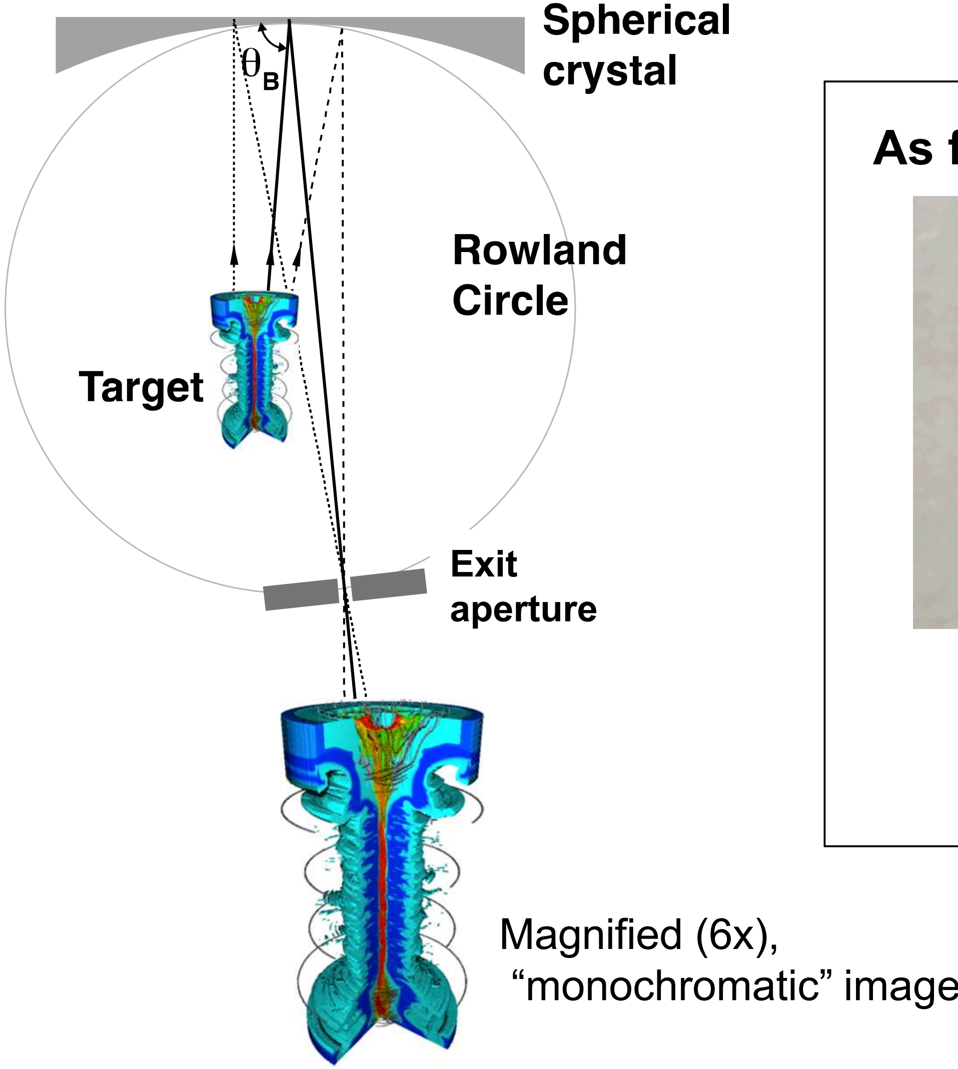
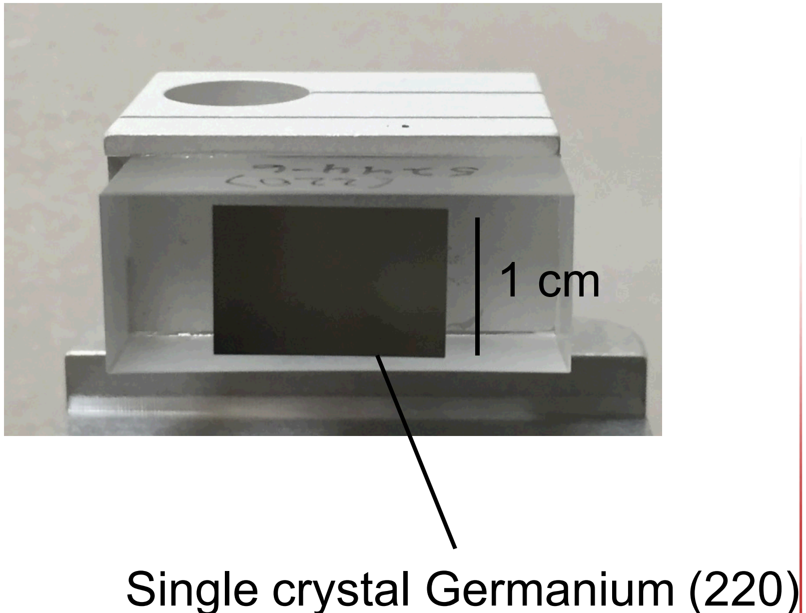
We use spherically bent crystal optics to image the x-ray, self-emission from our MagLIF targets.

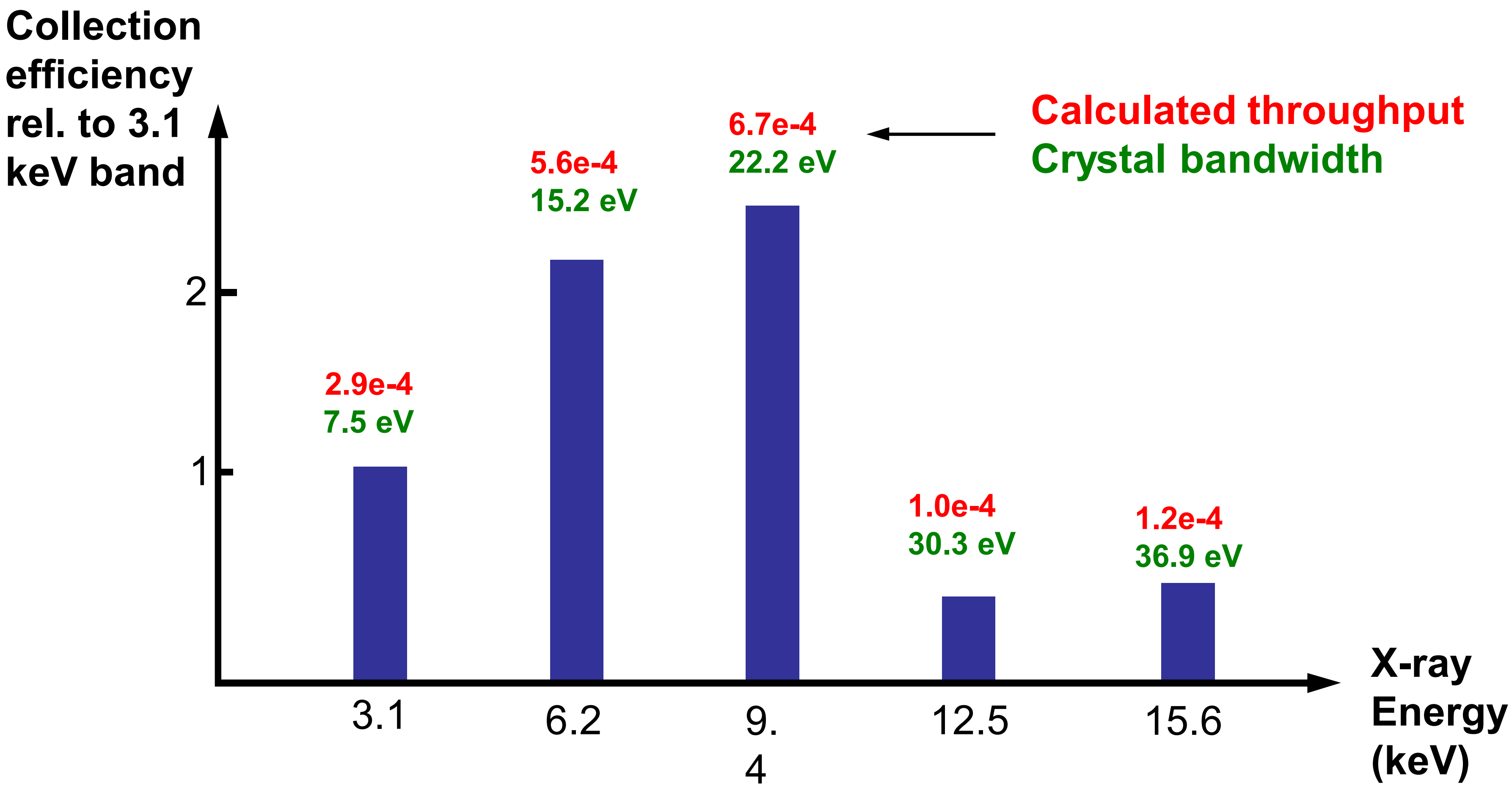
Diagnostic setup



As fielded, spherically bent crystal



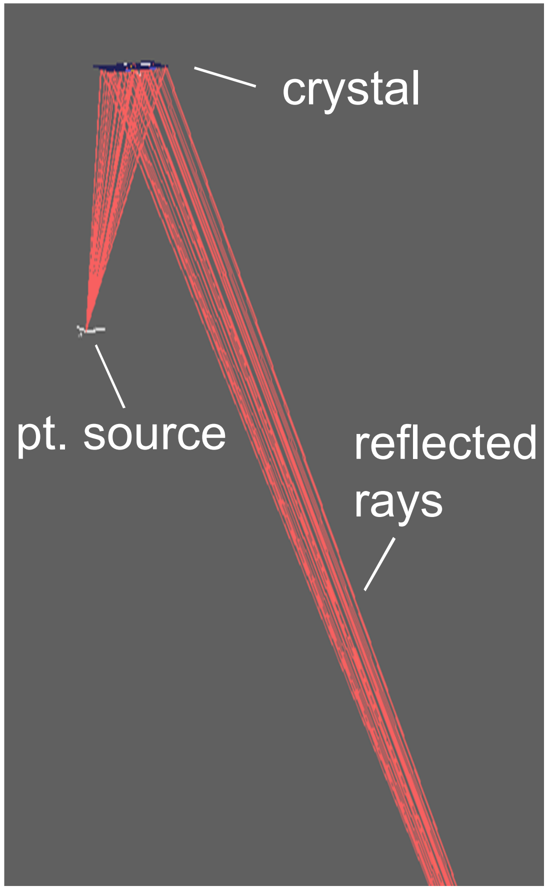
The image is a superposition of multiple x-ray energies. The absolute sensitivity to each of these energies was estimated.*



*The throughput estimates include filtering and the image plate response.
Reflectivity curves are calculated using the XOP software routines (M. Sanchez del Rio, SPIE 2011)

The spatial resolution is limited by astigmatic nature of the off-axis imaging. The resolution was estimated using the SHADOW* ray tracing code.

Ray Tracing w/SHADOW



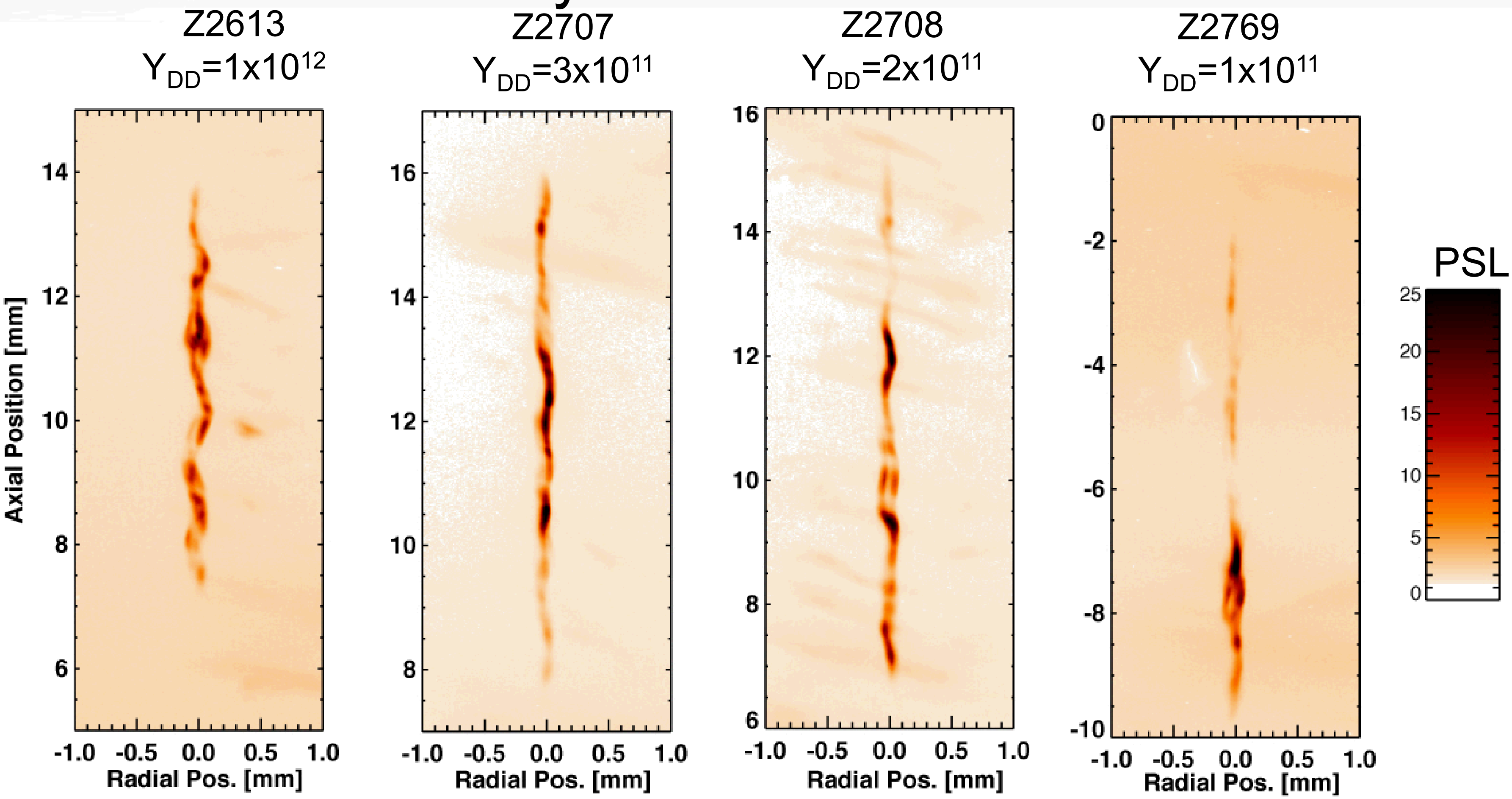
*M. Sanchez del Rio, SPIE 2011

Spatial Resolution Estimates

	Ar emission (δE = 1.3 eV)	Continuum emission
Vertical resolution	84 μm	84 μm
Horizontal resolution	16 μm	60 μm

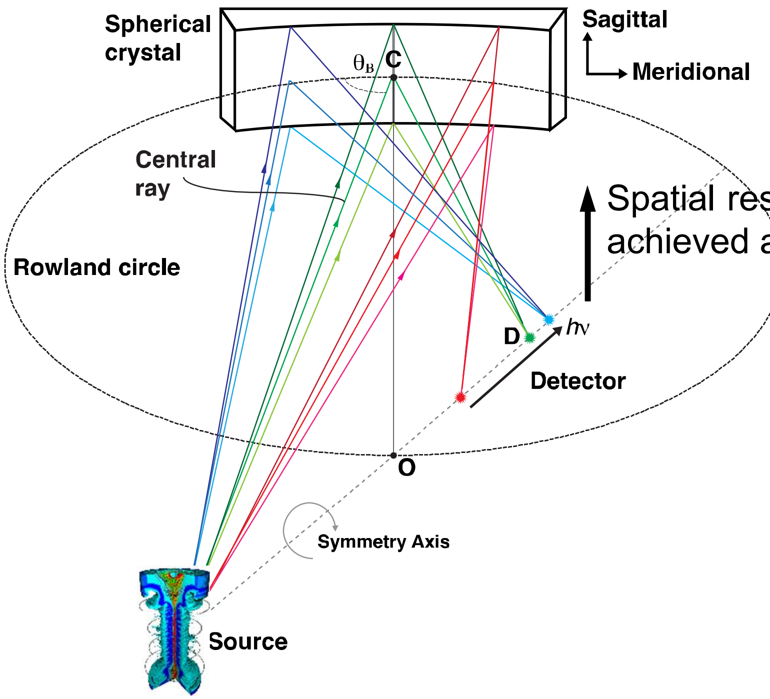
- **Continuum emission**: resolution improves in both directions with a smaller crystal.
- **Line emission:** Vertical resolution will primarily improve with a smaller crystal.

The continuum emission generated during the liner stagnation shows complex structure and non-uniformity in the vertical direction.



The average, radial width is ~100 μm, which is approaching the diagnostic limit of 60 μm.

Spherical crystal spectrometer[1]



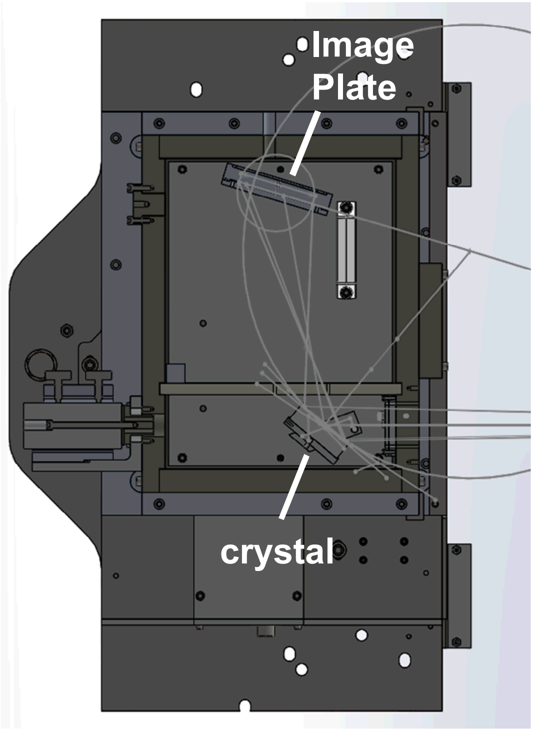
[1]E.C.Harding et. al., RSI (2015)
D. Sinars et. al. JSQRT (2006)
FSSR used on dynamic hohlraum capsule implosions

To resolve the Fe emission generated at stagnation we use a spherically-bent crystal spectrometer.

The existing XRS^3 spectrometer was optimized for the detection of the weak He-like Fe emission, while maintaining high-spectral resolution.

Spectrometer setup for He-like Fe emission

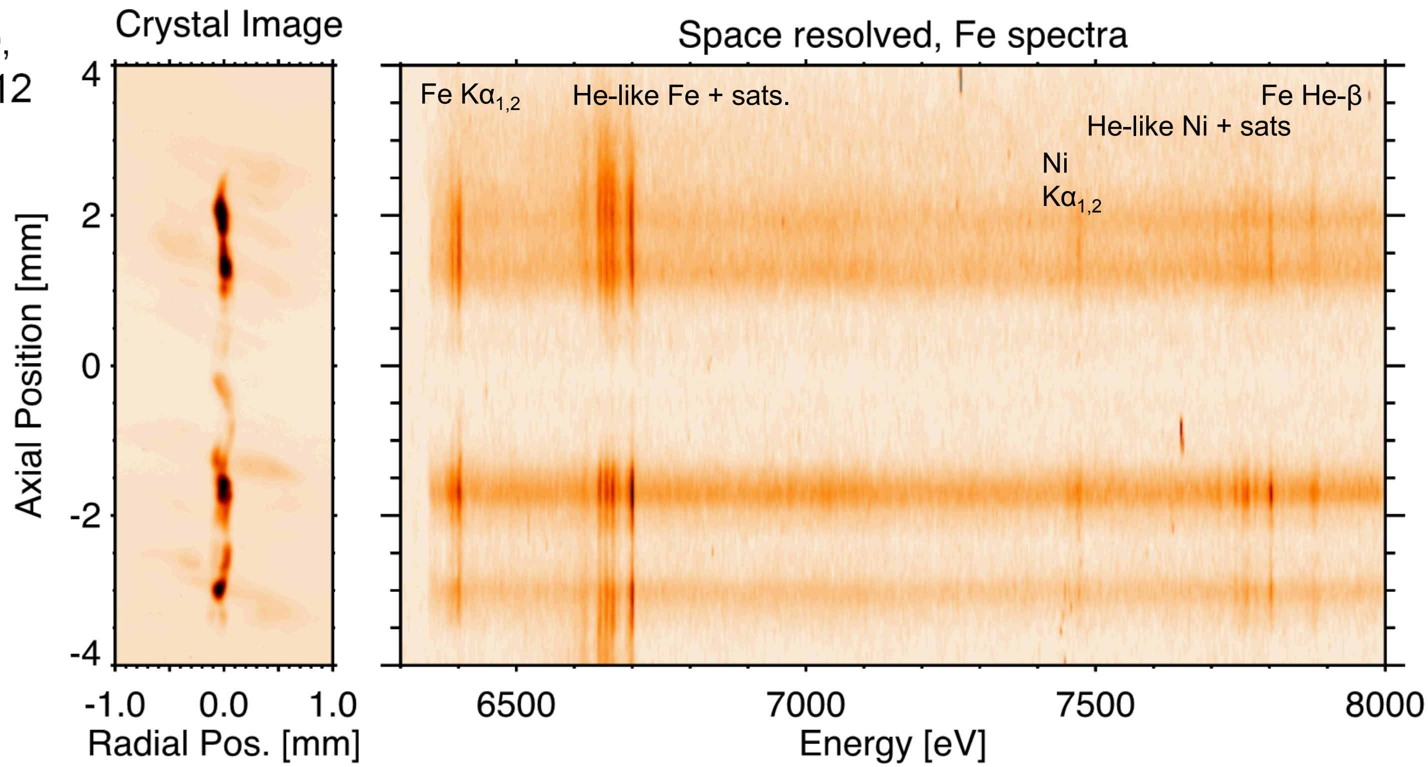
Crystal	Q20-23 (2d = 2.749 Å)
Source-to-crystal	800 mm
Crystal-to-detector	256.92 mm
Crystal Radius	250 mm
Center Bragg Angle	40°
Crystal size[1]	60 x 36 mm
Spectral Range[2]	6328 - 7977 eV
Spatial Mag. (M_{sag})	0.30x
Spectral Resolution[3]	2 eV
Spatial Resolution[3]	210 µm
Throughput	1.9e-7 steradians



[1]This is a tiled crystal consisting of 2 strips, each one is 60 x 18 mm
[2]Detector length must be 85 mm to capture entire spectral range.
[3]Limited by the Image Plate resolution of 63 microns.

We believe we are observing He-like Fe emission from stagnation. The He-like Fe lines allow us to infer T_e and n_e for several axial locations.

Shot z2850, Y_{DD} = 3.1e12



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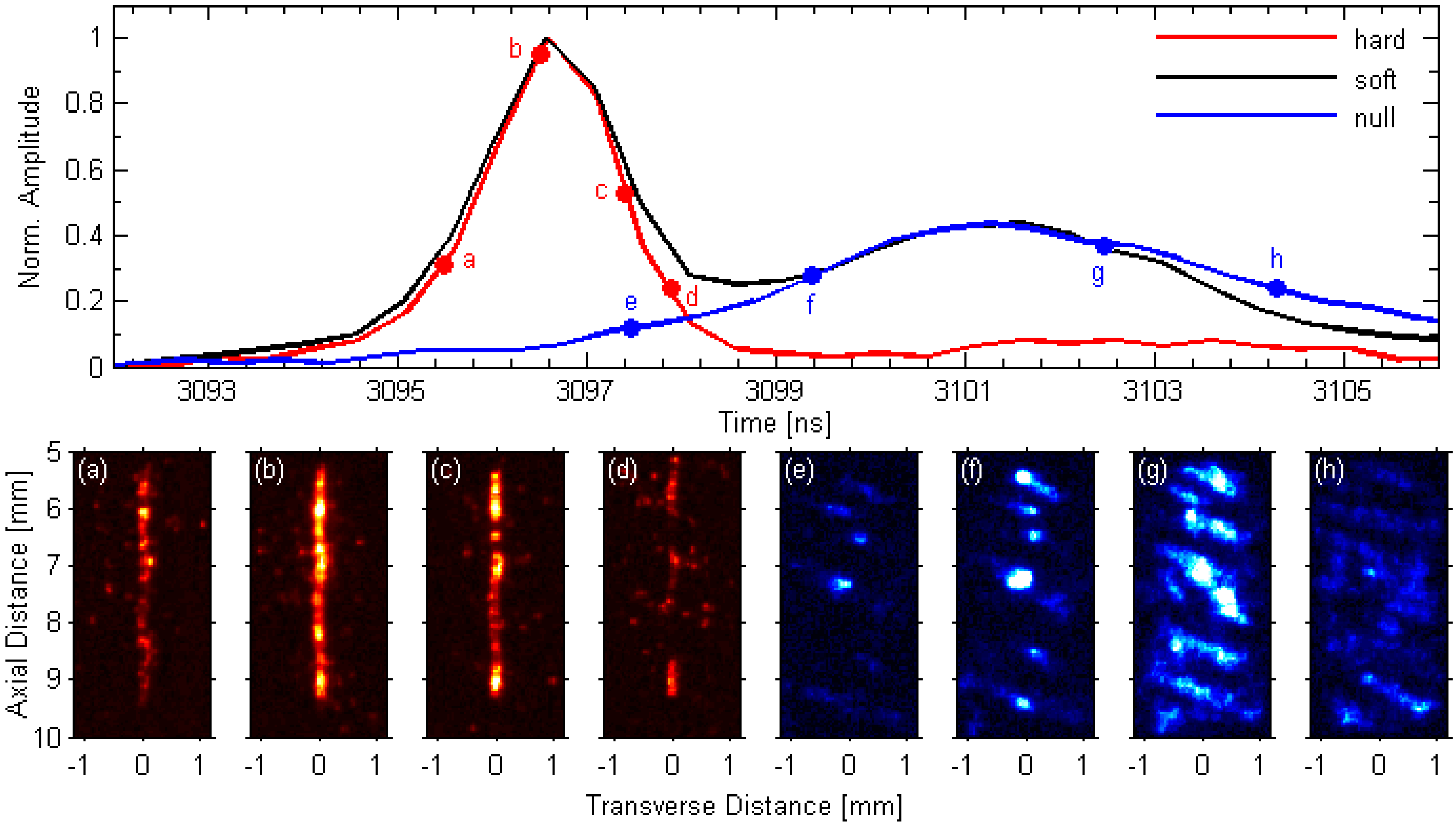
We have had some success with a time-resolved filtered x-ray pinhole camera



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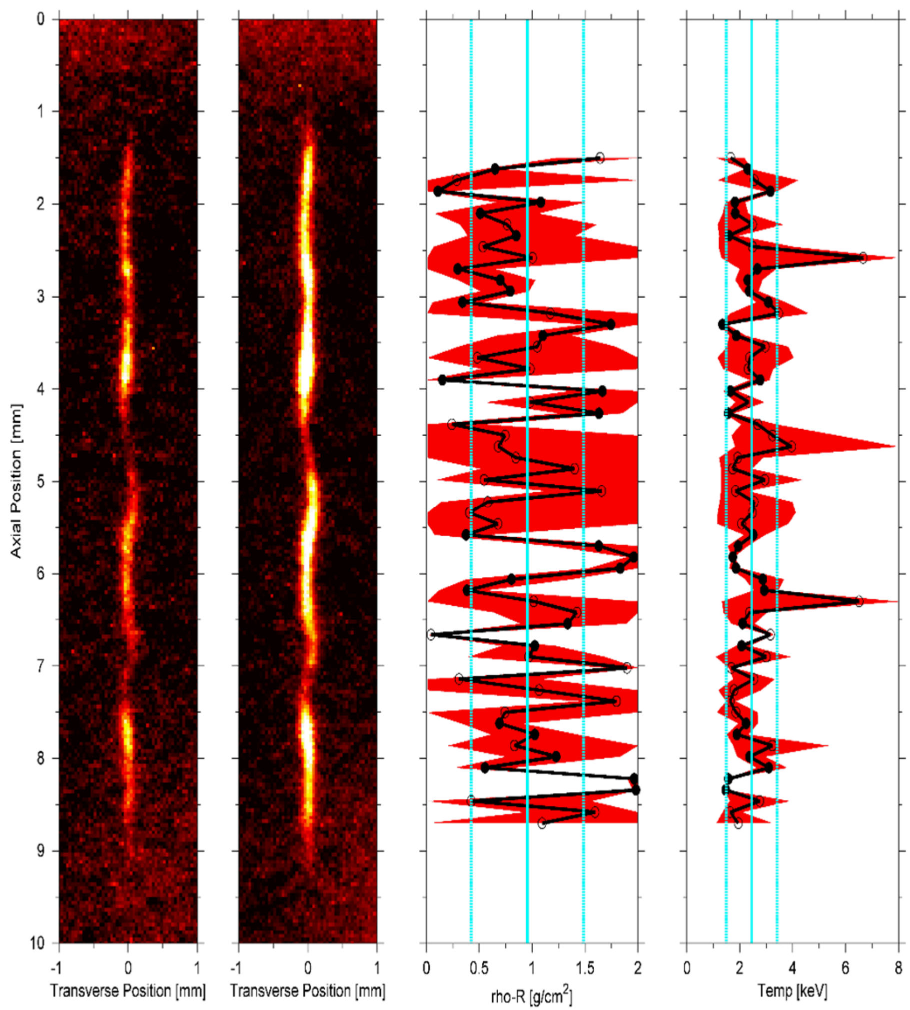
The TIPC images tell us that the majority of emission is less than 12 keV photons



- Estimates of electron temperature are approximately 3 keV
- Estimates of liner opacity are equivalent to approximately 1 g/cm^2 cold Be
  - Cuts out emission below approximately 6 keV
- Requirements for a new diagnostic:
  - Sensitive in the 6-12 keV photon range
    - Limits the filtration on the front end of the diagnostic to approximately 1.5 mm Kapton

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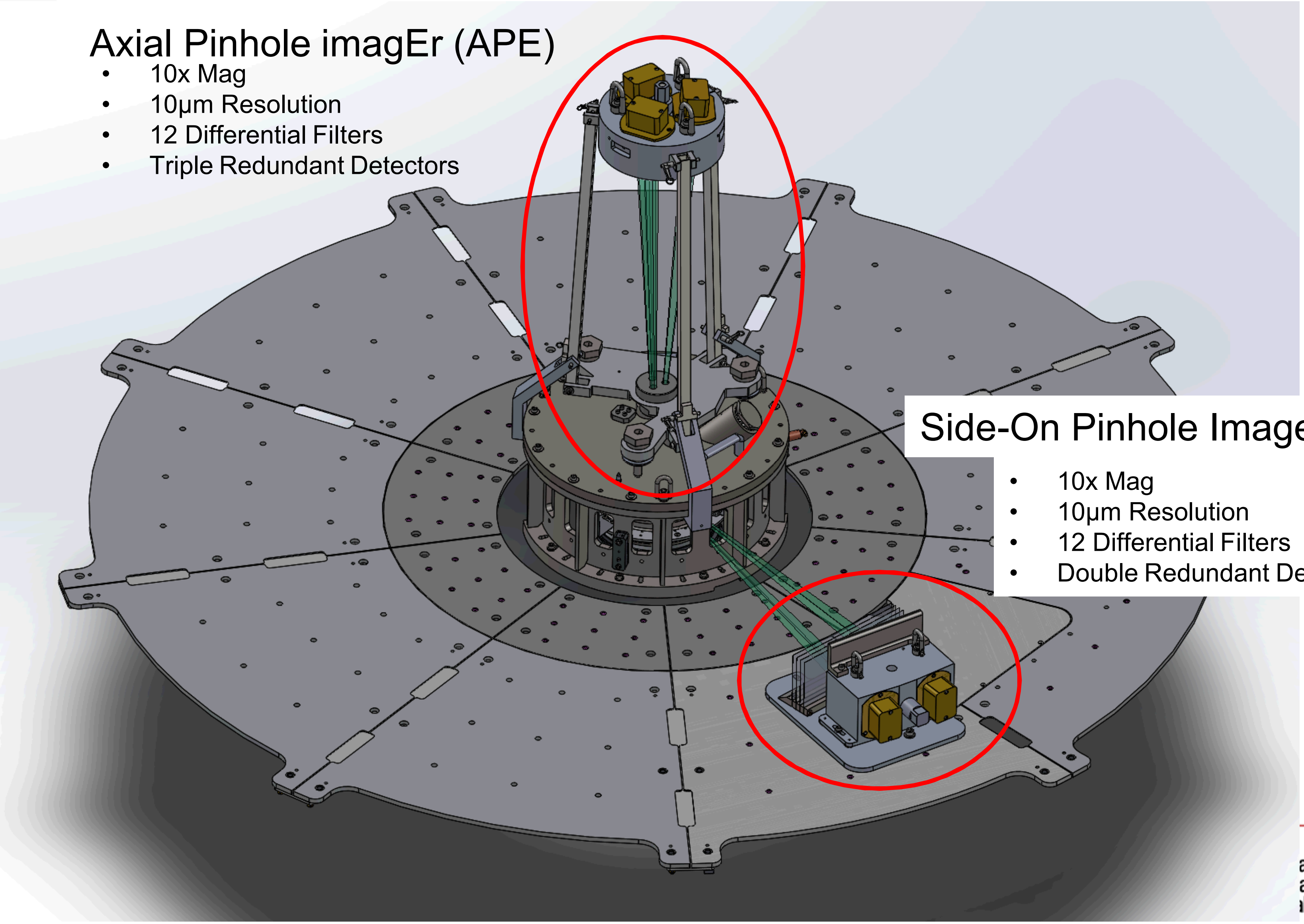
APE and SOPI

Axial Pinhole imagEr (APE)

- 10x Mag
- 10µm Resolution
- 12 Differential Filters
- Triple Redundant Detectors



Side-On Pinhole Imager (SOP

- 10x Mag
- 10µm Resolution
- 12 Differential Filters
- Double Redundant Detectors

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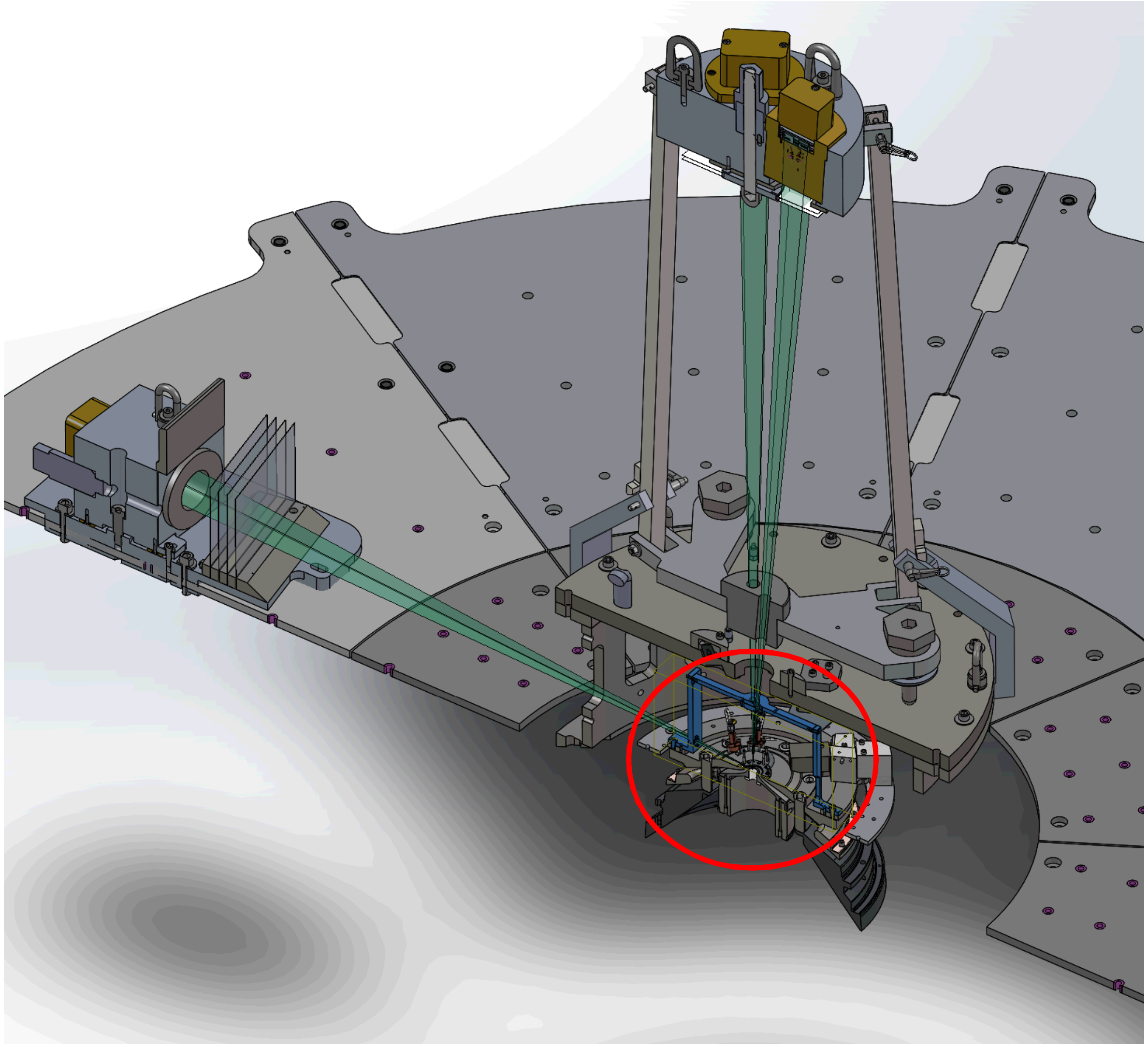
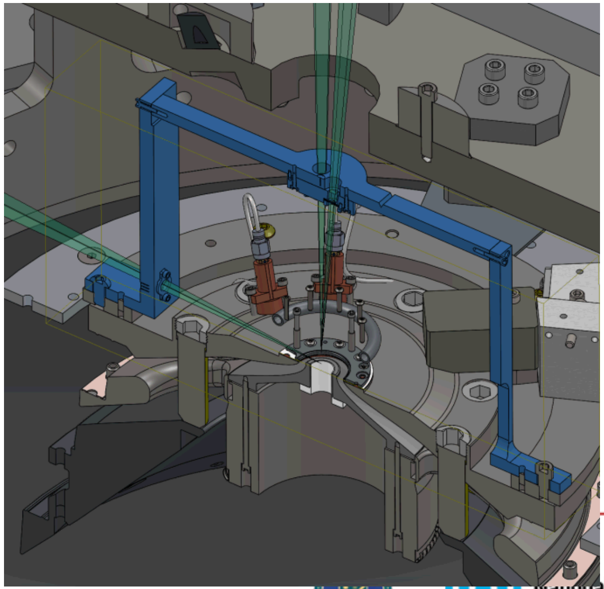
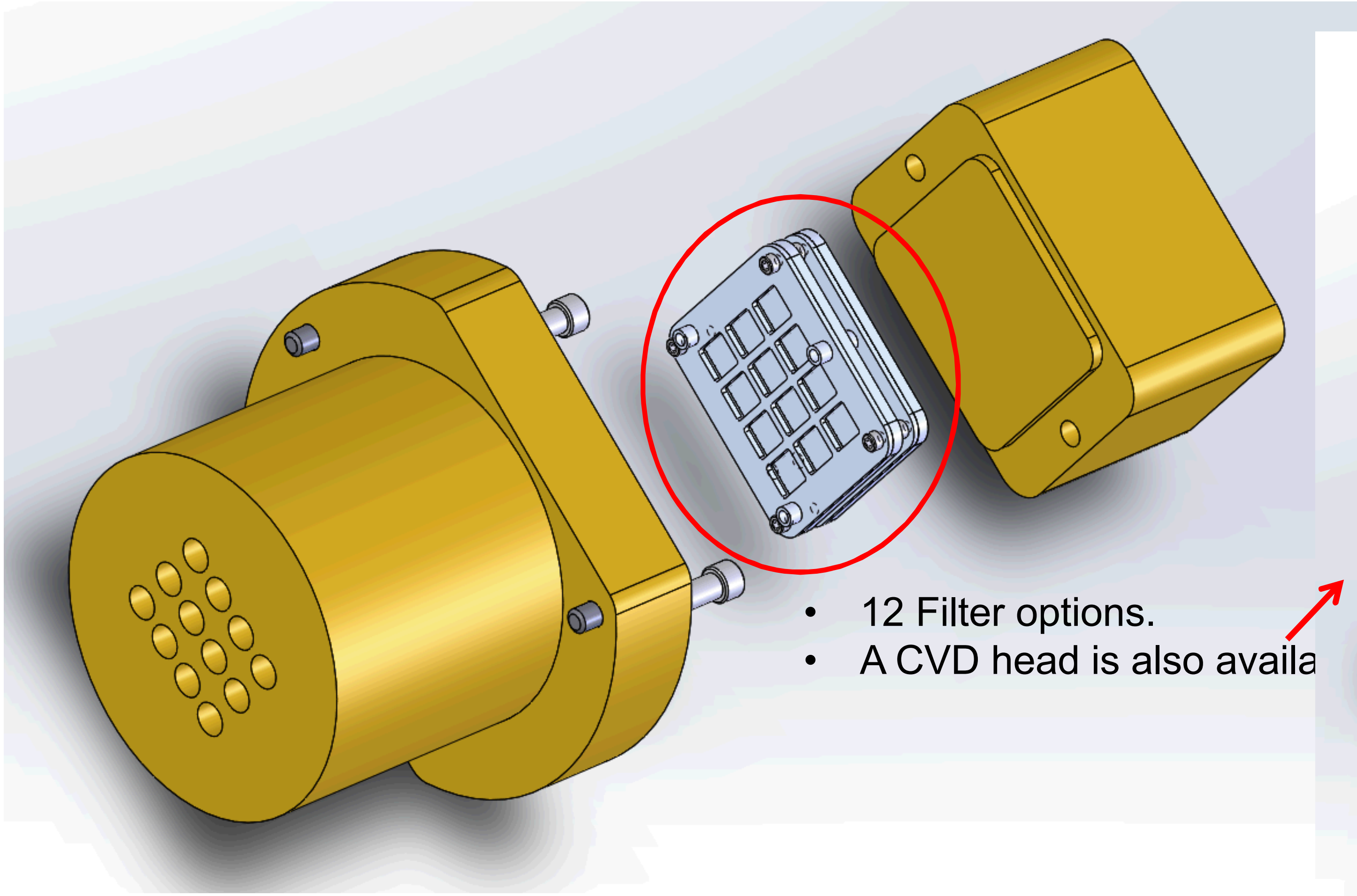
Load mounted apertures.



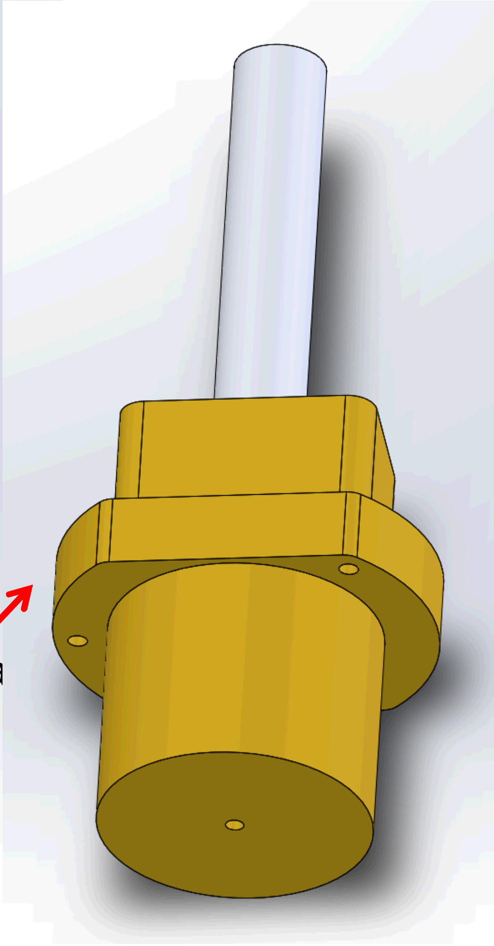
Apertures mounted 10cm from the load.



Detector



- 12 Filter options.
- A CVD head is also availa



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Time-resolved x-ray imaging diagnostic requirements

- Sensitive enough to measure ~1-10 GW x-ray powers distributed over 10 mm axial height and 0.1 mm diameter in the > 5 keV photon energy range
  - ~ 10 J radiated over 2 ns, escapes from liner (~1 g/cm^2 Be)
- Able to resolve 10-50 μm scale transverse spatial structure
- Able to spatially resolve 0.5-1 mm scale axial spatial structure
- Temporal resolution of approximately 0.25 ns
  - 1 order of magnitude less than the x-ray pulse duration
- Sufficient number of frames and interframe spacing to cover at least +/-2 ns for machine jitter plus 2 ns pulse width
  - 6 ns coverage with 0.5 ns spacing requires 12+ frames

We plan to develop a high-resolution version of the filtered x-ray pinhole camera

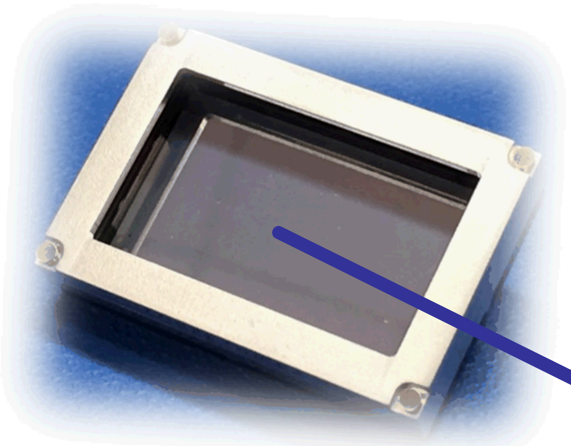
- Change MCP stripline geometry
  - Different MCP that is currently in use on Z
  - Allows for approximately 3x magnification (change from 0.5x)
- Use 15 μm pinholes (change from 50 μm)
  - In the geometric limit for photons above 5 keV
  - 3x mag => 20 μm resolution
  - 60 μm spot at the image is well matched to 50 μm MCP camera pixel size
- Sensitivity calculation
  - ½x mag to 3x mag drops signal per pixel by 36x
  - Moving pinholes from 3546 mm to 170 mm increases signal by 435x
  - Decreasing pinhole size from 50 μm to 15 μm drops signal by 11x
  - Approximately 10% more sensitive than existing diagnostic
- Temporal resolution and coverage
  - Same as existing diagnostic, 8 frames, 0.25 ns gate

TiGHER M=3 Pinhole Imager

Alternative: SLOS spherical crystal imager

We have developed the fastest multi-frame digital x-ray camera in the world, enabling high speed imaging along a single line-of-sight.

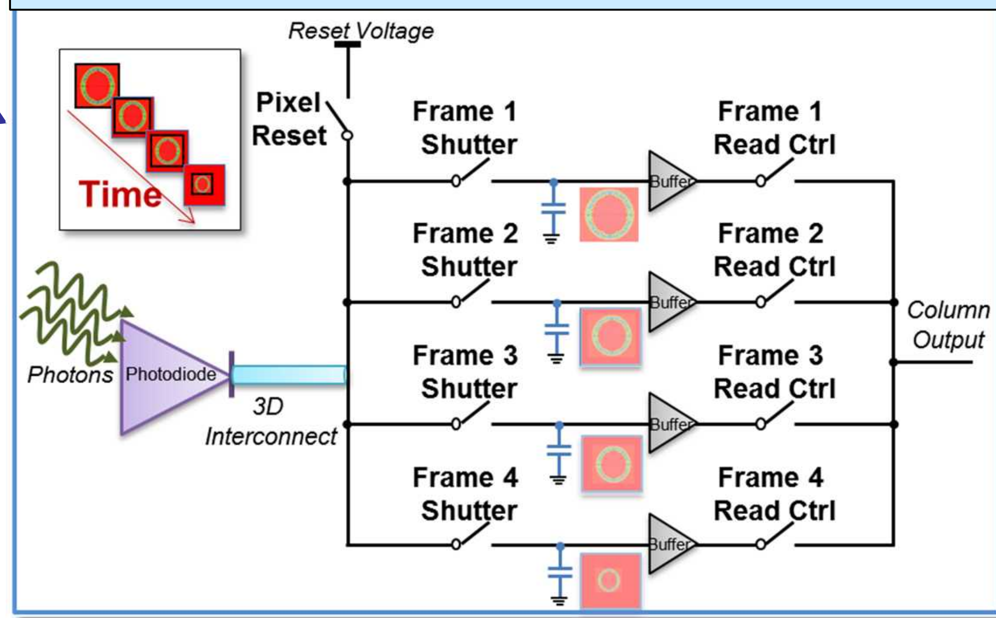
hybrid CMOS (hCMOS) camera



- >0.5 Megapixels, each 25 um x 25 um
- Sensitive to visible, >2 keV e$^-$, and 0.7-10 keV x-rays
- 1.5ns gate times
- 4 frames (full resolution)

designed and built in collaboration with the MESA facility

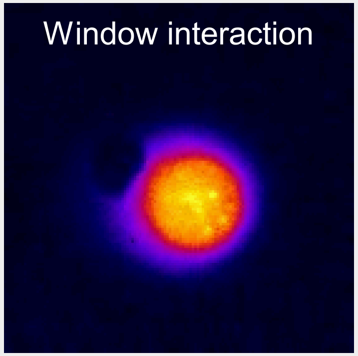
Each of the 512 x 1024 Pixels Has
This Four Sample, Hold & Read-Out Circuit

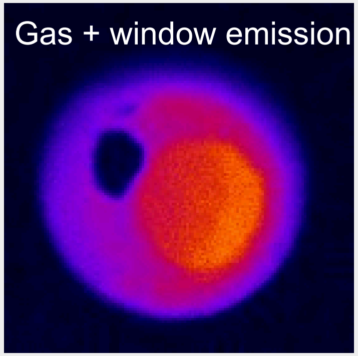


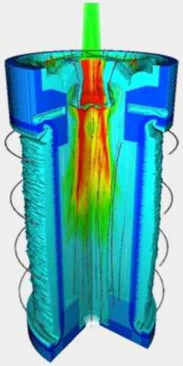
hCMOS imagers have been used on Z for laser preheat shots, and testing is underway for gated opacity measurements

MagLIF laser preheat on Z*

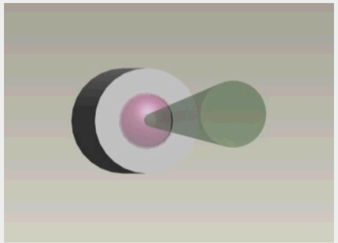
9 ns gate separated by 10 ns







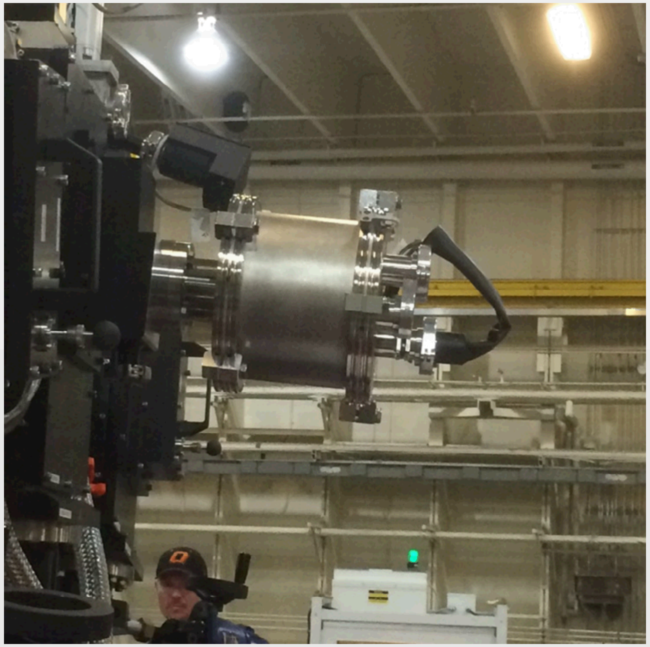
Camera View of LEH



Use during integrated MagLIF shots planned for early FY17

hCMOS testing for gated opacity

hCMOS assembly on an axial elliptical crystal spectrometer



Initial measurements planned this summer

*Porter (SNL) et al.

SLOS imaging is key to the US national diagnostic strategy and will transform capability across ICF and the Science Campaigns

FY14	FY15	FY16	FY17	FY18	FY19

2 Fm,

2-8 Fm (interlaced)

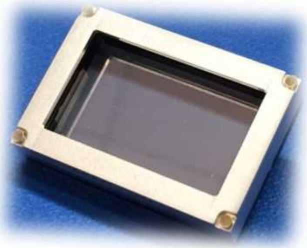
4 Fm Low-E, e-

3-12 Fm (interlaced)

20-40 keV 3-12 Fm (interlaced)

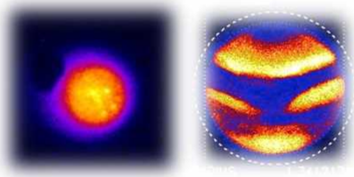
8 Fm, <1 ns (130 nm)

Key Direct Sensor Applications

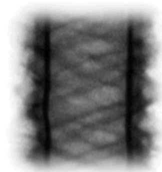


1-2 ns

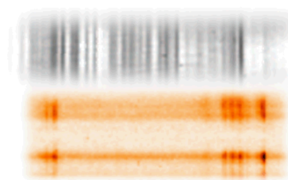
LEH imaging (Z & NIF)



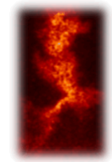
Backlighting (Z)



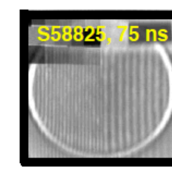
Spectroscopy (Z)



K-α Imaging (Z)

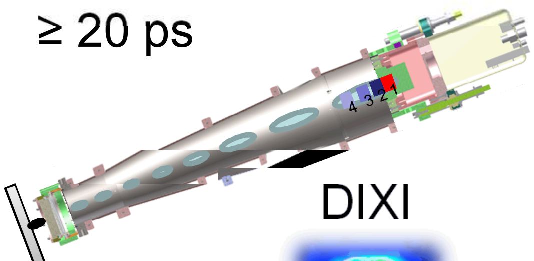


Strength (NIF)

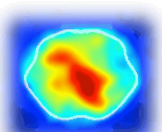


Key Pulse-Dilation Applications

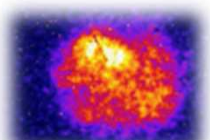
≥ 20 ps



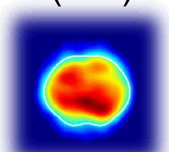
DIXI



SLOS-1
Pinhole
(Omega)

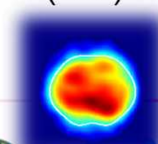


SLOS-2
Crystal Imaging
(NIF)

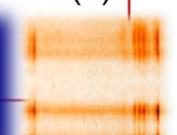


SLOS-3

Wolter (NIF)



Spectra (Z)



GENERAL ATOMICS

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