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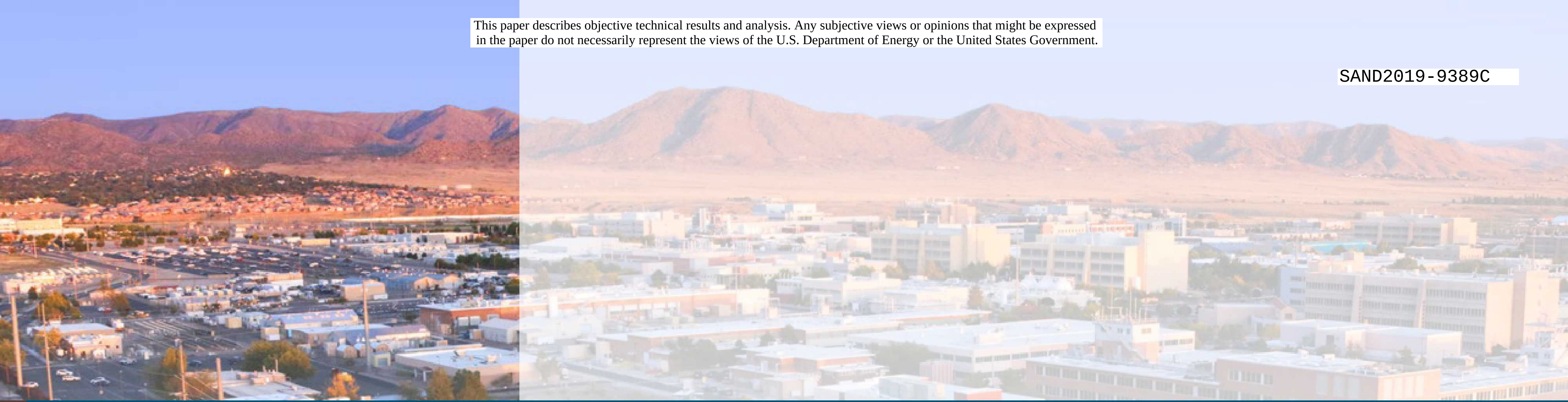

Diagnostic Efforts at Z

Z Fundamental Science Workshop

8/12/2019

Michael Jones

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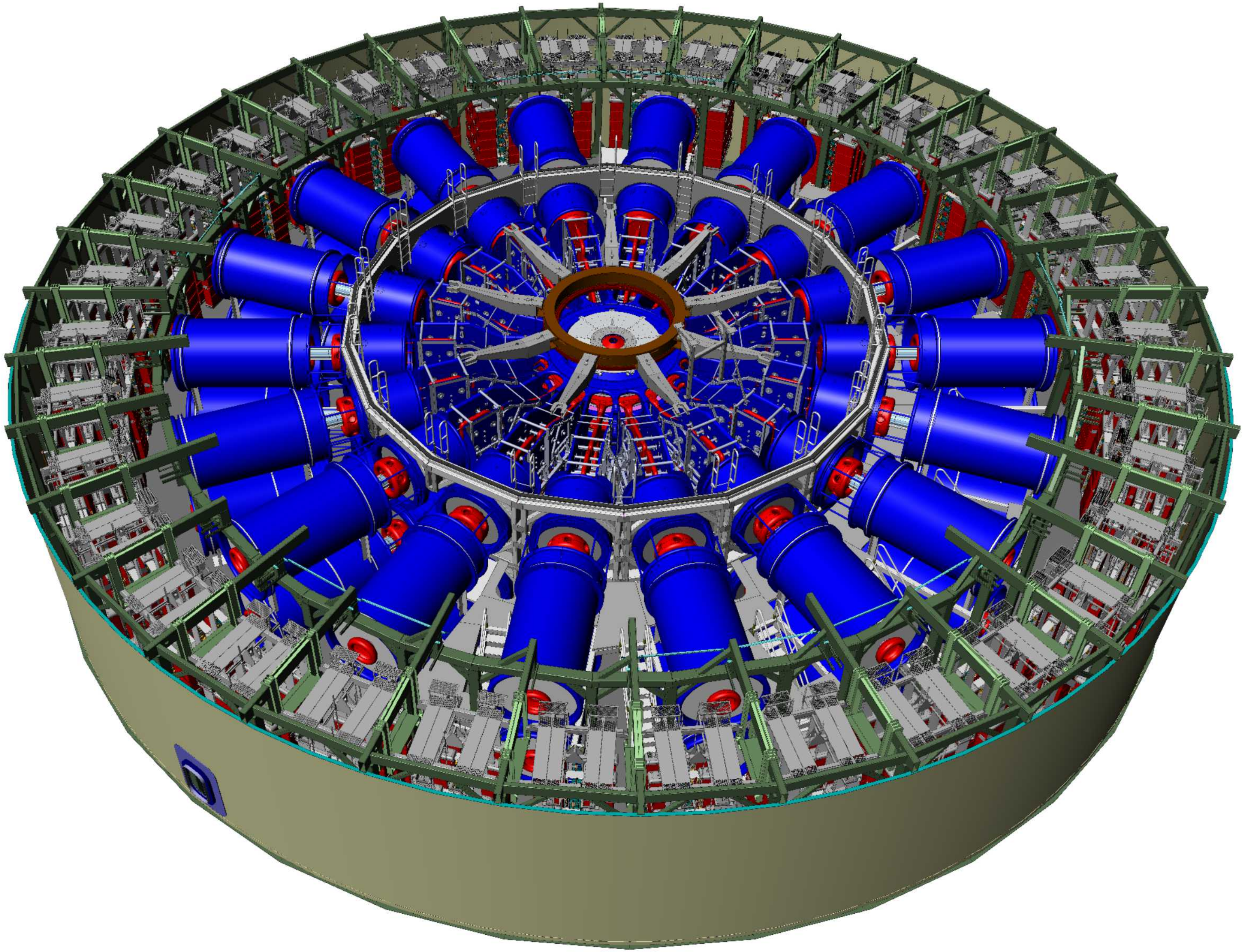
Agenda

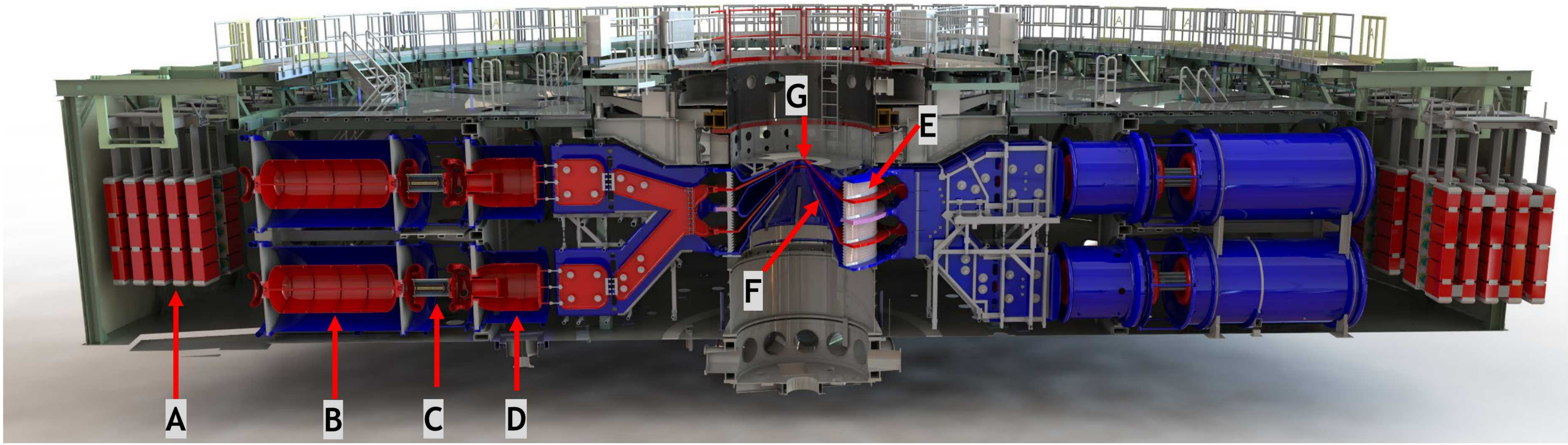
- Overview of Z and how it relates to Diagnostics
- Annual Z Diagnostic Workshop
- National Diagnostic Working Group
- Recent Diagnostic Development
- New Initiatives

Z Compresses Energy in Space and Time to Create Extreme States of Matter



- Over several minutes 36 Marx Banks are charged up to 95 kilovolts.
- This results in a stored energy around 25 million Joules
- This energy is directed inward from a distance of 16 meters to a ~1 cm radius.

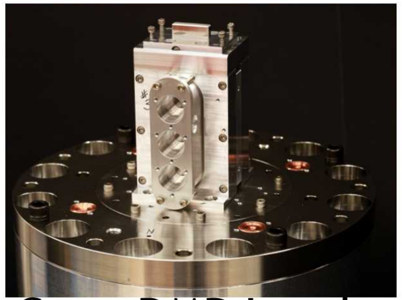
Z Compresses Energy in Space and Time to Create Extreme States of Matter



- As the energy travels towards the center there are several stages of pulse compression.
- The electrical pulse-length is compressed from 1.5us to 100ns
- X-ray outputs occur over a 3-10 ns timescale

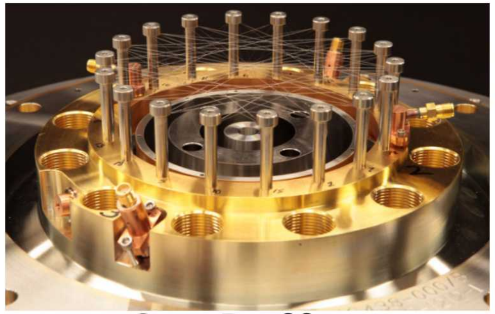
A	Marx Capacitors
B	Intermediate Storage Capacitors
C	Laser Trigger Gas Switches
D	Pulse Forming Lines
E	Insulator Stack
F	Magnetically Insulated Transmission Lines
G	Load

Z has a Diverse Portfolio of Experimental Platforms Supporting Multiple Experimental Campaigns

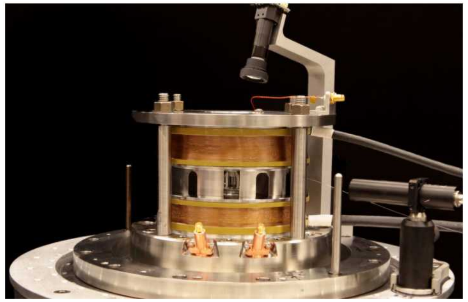


Coax DMP Load

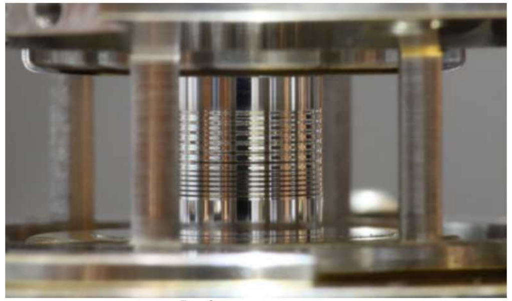
Wire Array



Gas Puff



MagLIF



Liner

Dynamic Materials Properties (DMP)

Fundamental Science (FS)

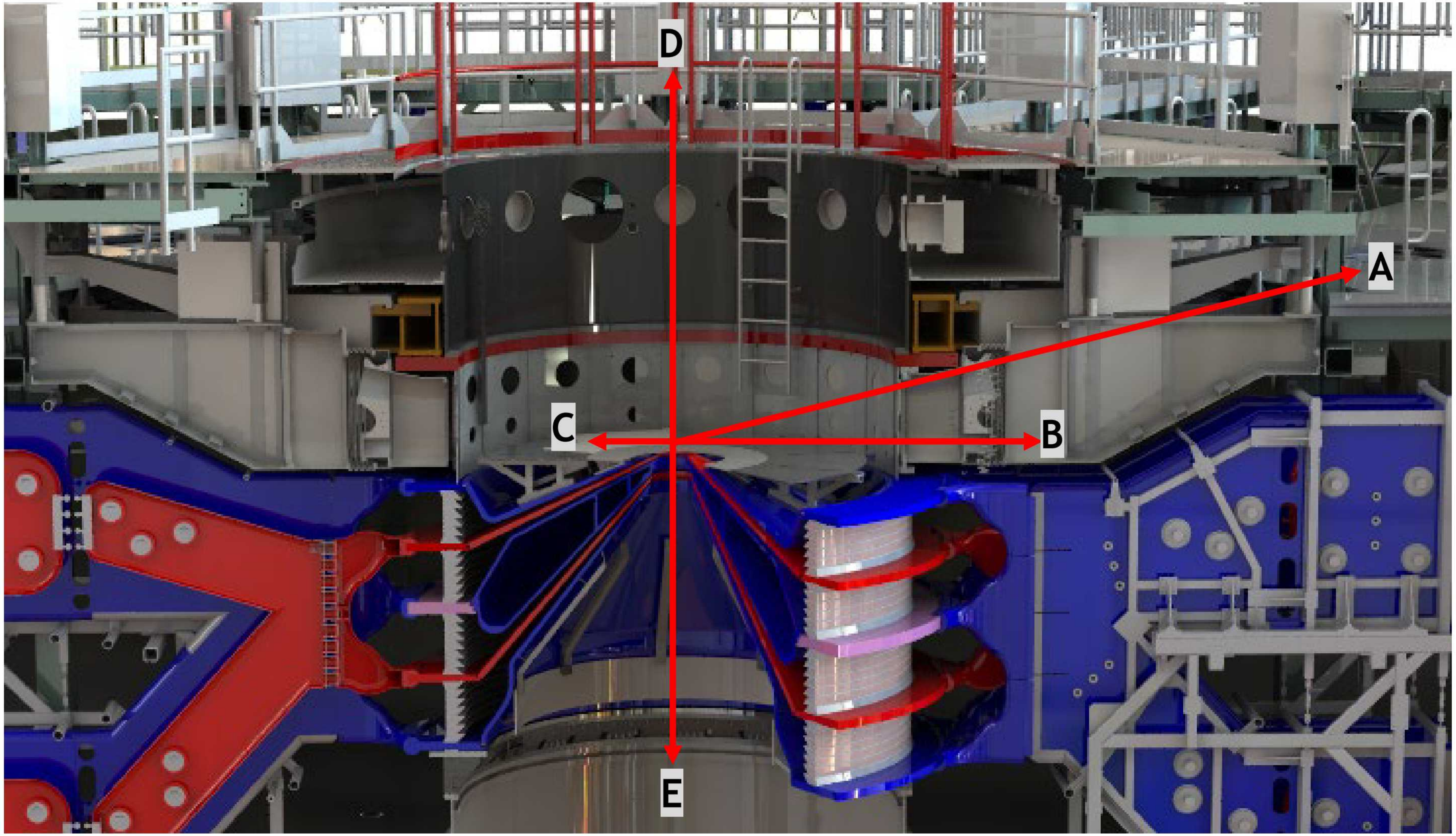
Radiation Effects Sciences (RES)

Secondary Assessment Tech (SAT)

Inertial Confinement Fusion (ICF)

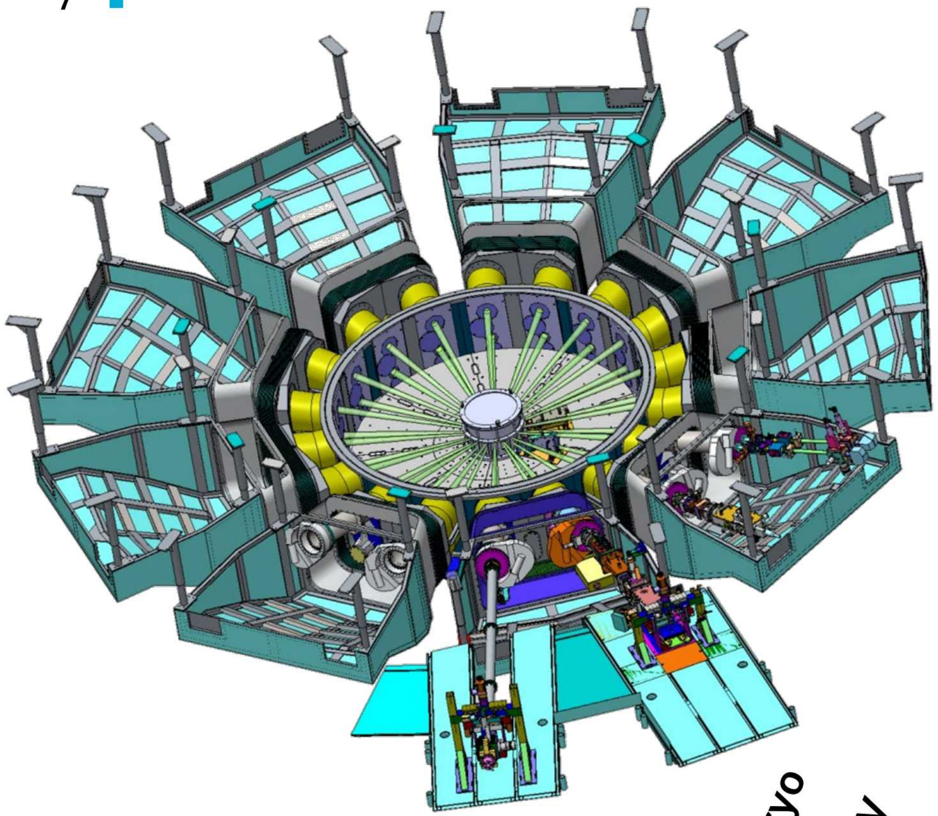
Primary Assessment Technology (PAT)

Diagnostic Access on Z is Limited by the Geometry of Pulsed Power Components

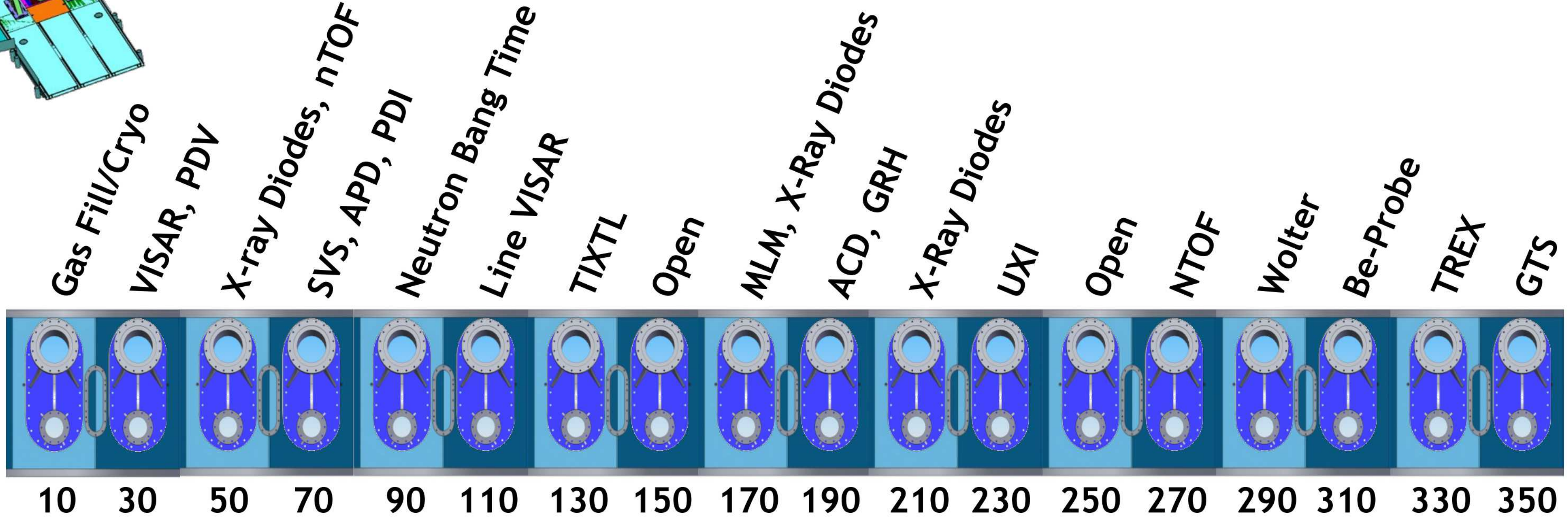


A	12° Line of Sight
B	0° Line of Sight
C	In Chamber
D	Top Axial
E	Bottom Axial

Radial Line of Sight Usage on the Z Facility

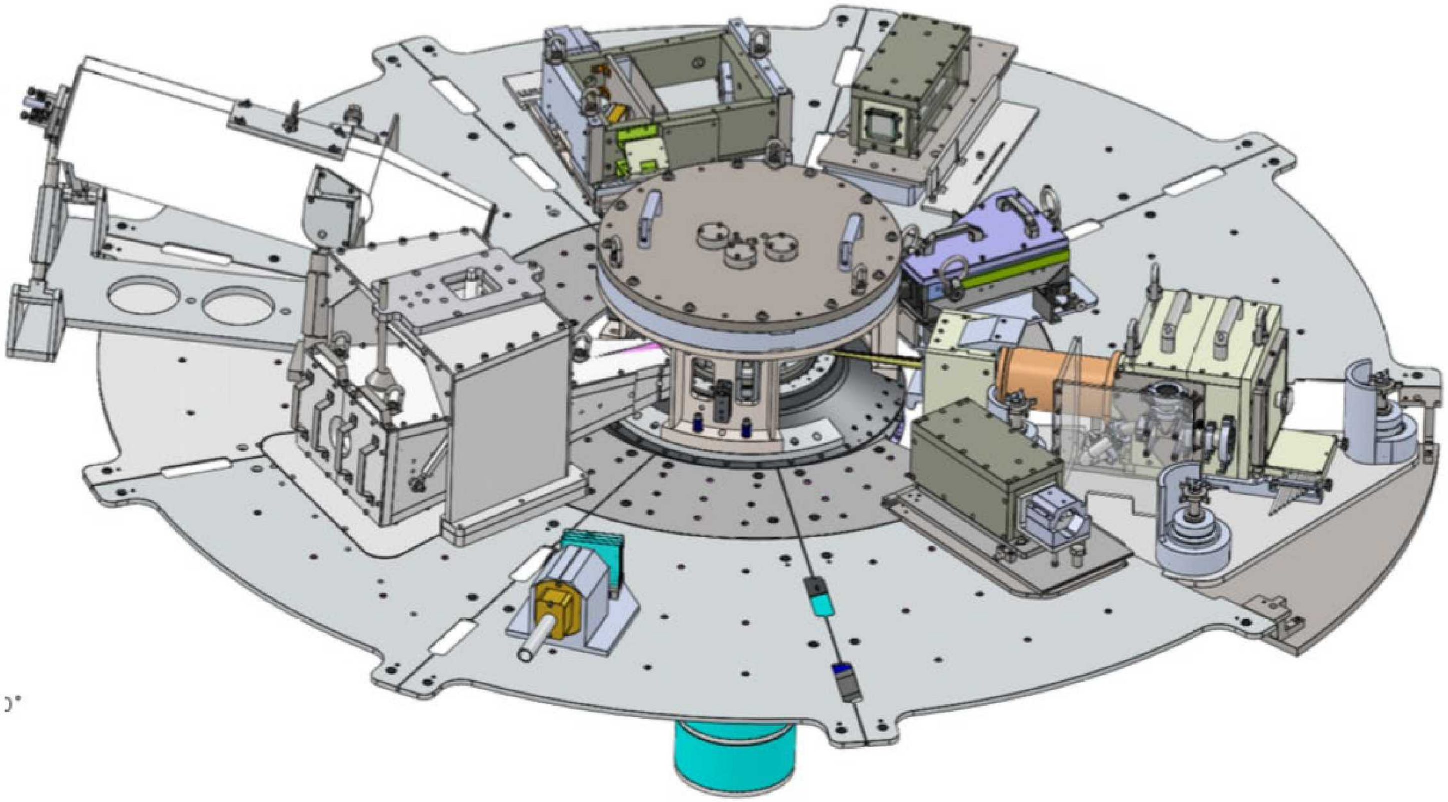


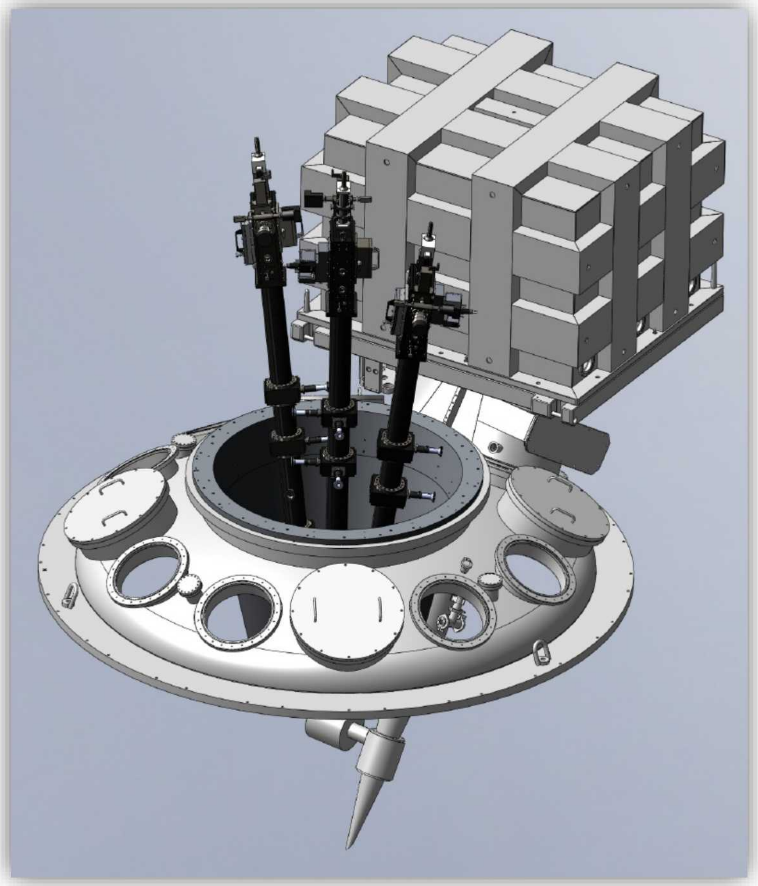
- There are 18 radial Lines of Sight, spaced every 20°.
- Most have a 12° and a 0° access port.
- 12° access is open at four of the LOS's. LOS10, LOS150, LOS250, and LOS350.
- 0° access is more widely available



Axial and Chamber Diagnostics

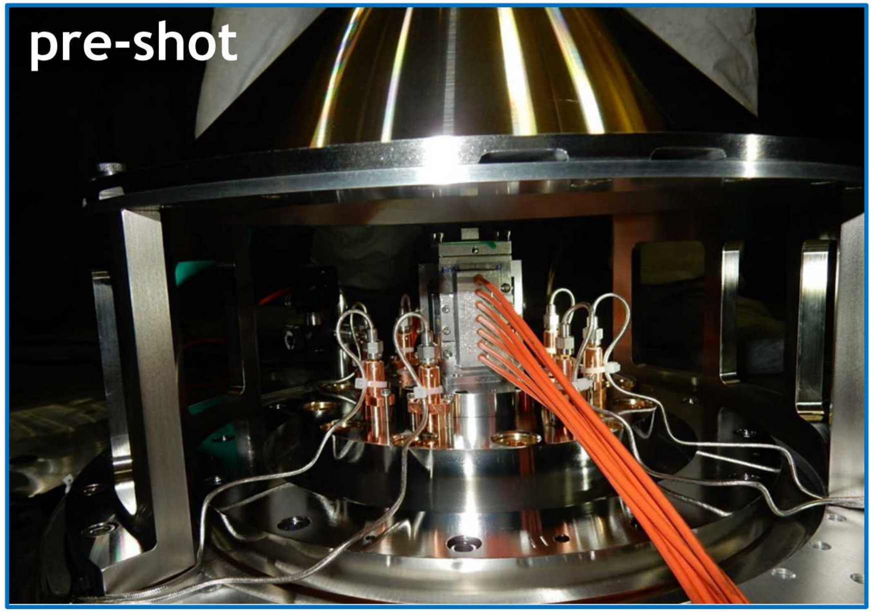
- For improved sensitivity, diagnostics can be fielded as close as ~10cm to the target. However, space is getting limited.
- A project will begin next year to stand up the capability for axial diagnostics to be used in parallel with x-ray backlighting using the off-axis FOA

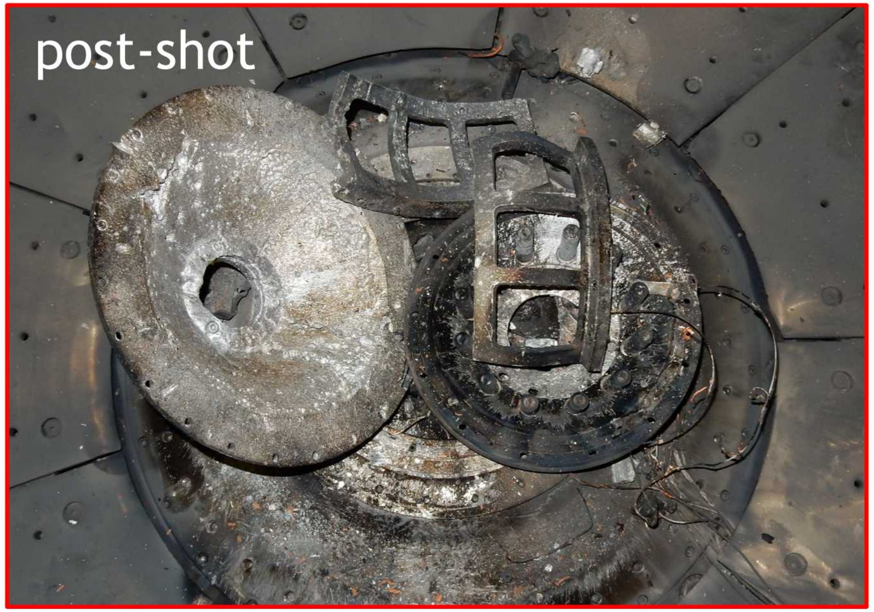




Environmental challenges must be considered when developing diagnostics for Z

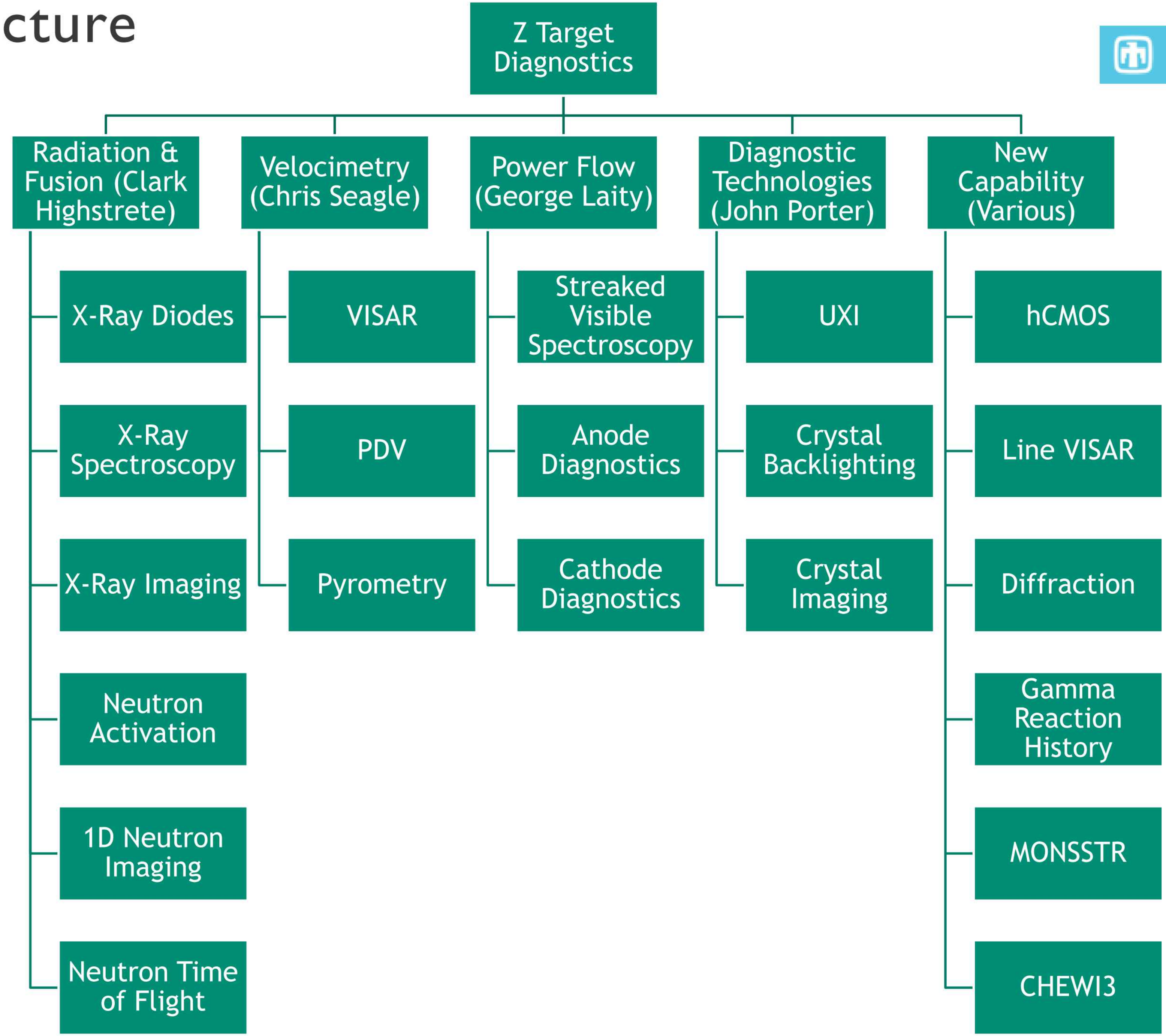
- Z can be a harsh environment to field diagnostic
- Diagnostics fielded within the chamber are exposed to significant amounts of debris, shock, EMP, radiation background, neutron background, and fiber darkening.
- This past year two new initiative have begun to address these issues
  - A new diagnostic area has been formed focused around Environmental measurements – mostly around Shock and Debris.
  - Our Center is collaborating with Sandia-CA and LLNL to develop a neutron scattering model of Z facility and surrounding area to facilitate neutron diagnostic accuracy, facility shielding models, and worker dose potential assessment.





Target Diagnostic Structure

- Target diagnostics are dispersed into five different areas
- There are two additional areas focused on pulsed power diagnostics and environmental diagnostics
- A complete list of diagnostics can be found in: *Summary Slides for Z Diagnostics: SAND2019-7354 O*



We have created summary slides for over 60 diagnostics that are currently utilized at Z

Exceptional service in the national interest

Sandia National Laboratories

SUMMARY SLIDES FOR Z DIAGNOSTICS

Contents

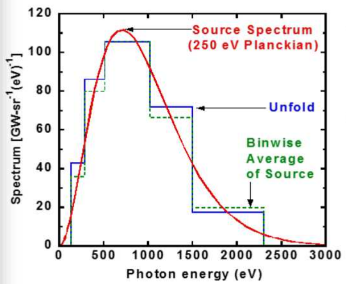
SAND2019-7354 O

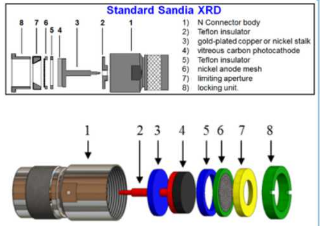
U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

FILTERED X-RAY DIODES

Activity	Radiation & Fusion
Diagnostic Scientist	Tim Webb
Primary POC	Tim Webb
Engineering POC	Decker Spencer

Overview:
Five Channel Filtered XRD System that consists of diamond polished vitreous carbon disk and one of the following filters:
Kimfol, Vanadium, Zinc, Beryllium Parylene, Beryllium Vanadium.





Specifications:

Spectral band(s)	Used for sub 2.5 keV radiation
Spatial resolution	NA
Temporal resolution	Recorded on 1GHz analog bandwidth digitizers.
Field of view	Can view entire length of emission that is visible through 12deg. Typically an aperture is used to define emission length.
Physical Location(s)	LOS50, 12°, xxx cm from source; LOS170, 0°, xxx cm from source; LOS210, 12°, xxx cm from source
Number of Channels	5 @ LOS50, 2 @ LOS170, 4 @ LOS210
Dynamic Range	

References:

X-ray power and yield measurements at the refurbished Z machine. M. Jones, RSI, **85**, 083501
Filtered x-ray diode diagnostics fielded on the Z accelerator for source power Measurements, G. A. Chandler, RSI, **70**, 561.

RADIATION & FUSION: X-RAY IMAGING

Diagnostic	Spectral band(s)	Spatial resolution	Temporal resolution	Field of view
High resolution continuum x-ray imager (HRCXI)	1st order = 3.1069 keV (Δ = 2 eV) 2nd order = 6.2137 keV (Δ = 4 eV) 3rd order = 9.3206 keV (Δ = 6 eV) 4th order = 12.4275 keV (Δ = 8 eV)	Mag ~5.8 15 µm x 15 µm	Time-integrated	3 mm wide and >10 mm tall
Time Gated High Energy Radiation pinhole camera (TiGHER PHC)	Minimum filter for debris mitigation 2 mm Kapton with additional filters possible Mag 3: 1 channel Mag 1: 3 channels	Mag 3: 31 µm (20 µm pinhole) Mag 1: 64 µm (20 µm pinhole)	Gen 2 MCP 0.15, 0.25, or 0.8 ns gates 8 frames	Mag 3: ~1 mm wide and ~12 mm tall Mag 1: ~3 mm wide and ~12 mm tall
Time Integrated Pinhole Camera (TIPC)	Minimum filter for debris mitigation 1.5 mm Kapton 5 channels with additional filters	Mag 0.375: 190 µm (50 µm pinhole)	Time-integrated	Several cm in both directions
Multilayer mirror pinhole cameras (MLM)	277 eV or 528 eV Can split frames between the two spectral bands	Mag 0.5: 320 µm (100 µm pinhole)	Two Gen 1 MCP 0.25 or 0.8 ns gates 6+8 = 14 frames	Several cm in both directions Views target at 13 degrees above horizontal
Filtered pinhole camera (MLMC)	Filter options available from 1 µm aluminized-Lexan (> 0.5 keV) to 30 mils Kapton (> 5 keV)	Mag 0.5: 180 µm (50 µm pinhole)	Gen 1 MCP 0.25 or 0.8 ns gates 8 frames	Several cm in both directions Views target at 13 degrees above horizontal
Z beamlet x-ray backlighting	6.151 keV or 7.242 keV or 1.865 keV Can field two different configs	Mag ~6: ~15 µm (limited by image plate)	1 ns long x-ray bursts recorded on image plate (2 separate LOS)	~10 mm wide and ~4 mm tall Frames are at +/- 3 degrees from horizontal
Axial pinhole imager (APE) and Side-on pinhole imager (SOPI)	Minimum filter for debris mitigation 3 mm polycarbonate 12 filtered channels per head SOPI = 2 heads, APE = 3 heads	Mag 10: 10-15 µm (10 µm pinhole)	Time-integrated	< 1 mm Many pinholes in array and need to avoid overlapping images
Final Optics Assembly pinhole camera (FOA PHC)	Soft x-ray, minimum filter 2 µm poly carbonate 3-4 channels with additional filters per head Multiple heads available	Mag 1: ~600 µm (300 µm pinhole)	Multi-frame ultrafast x-ray imager: 2-8 frames, 2 ns gate Image plate: time-integrated	~1 cm Views target at ~7.5 degrees from vertical
Mirrored Imager Plasma emission acquisition systems (MIPs)	Multilayer mirrors at 277 eV or 528 eV Can split frames between the two spectral bands	Mag 1: ~400 µm (200 µm pinhole)	2 Gen 1 MCP 0.15, 0.25, or 0.8 ns gates 8+8 = 16 frames	~8 mm Views target at ~9 degrees from vertical

For a copy of this slide deck please contact Marcus Knudson or Michael Jones: *Summary Slides for Z Diagnostics: SAND2019-7354 O*

Z Diagnostic Workshop

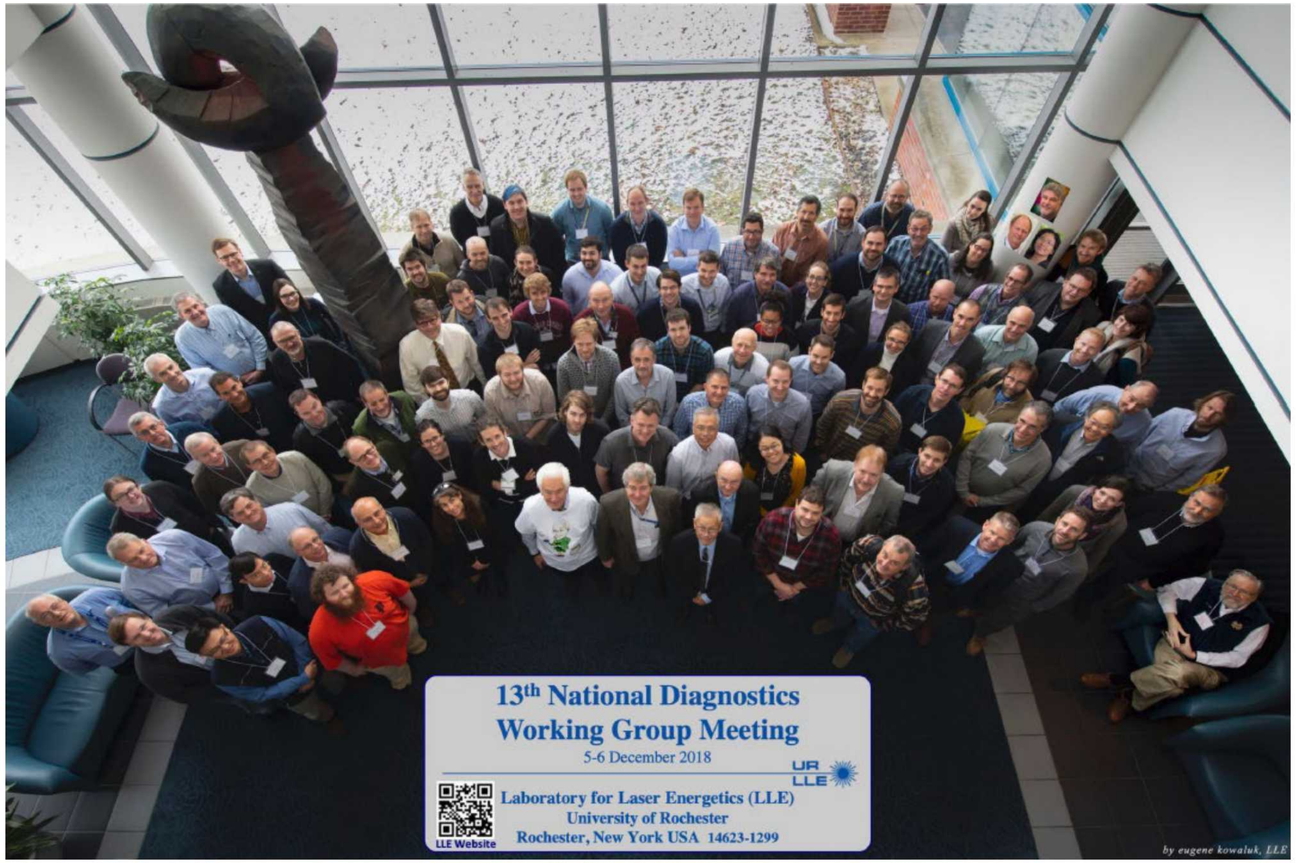
- A two day workshop was held on April 17th and 18th
- There was participation from many institutions: SNL, LLNL, LANL, LLE, NNSS, and UNM
- The primary focus this year was around our Radiation Sciences Programs
  - Program leads shared the direction and future measurement needs for their programs
  - Breakout sessions were held focused on: 1) an initiative to time-resolve target diagnostics at Z and 2) developing baseline requirements for DT based neutron diagnostics.
- Discussed challenges of fielding diagnostics at Z
  - EMP, Shock, Debris, …
- Expecting the 2020 Z diagnostic workshop to be held in the February timeframe.
  - Focusing on other programs – Material Science, Power flow, or Fundamental Science
  - If you have ideas or suggestions please send them to me

National Diagnostics Working Group Update

- The National Diagnostics Working Group (NDWG) is an active and productive community focused on transformational diagnostics for Z, NIF, and LLE.

- Workshops held in FY19

CEA/NNSA Meeting	Oct
VISAR Workshop	Nov
NDWG Annual Meeting	Dec
nTOF Workshop	Dec
hCMOS Workshop	Jan
Z Diag. Workshop	Apr
CEA/NNSA Meeting	May



- Workshops have attendees from each site and are used to share ideas, identify solutions, and develop action plans.

- In addition to these workshops, the NDWG leadership meets quarterly to plan these interactions, track progress on actions, and solve cross-laboratory issues.

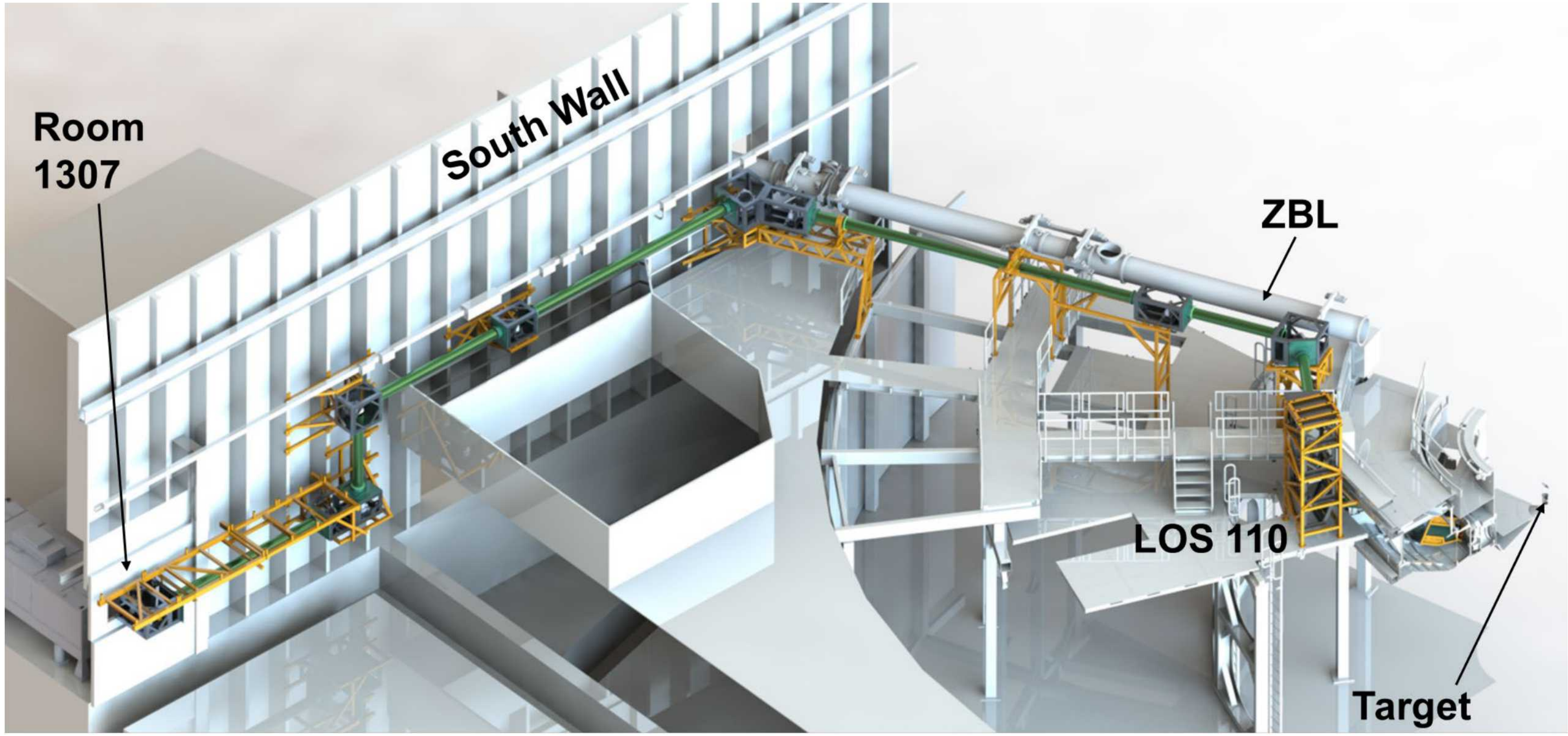
- The first phase of many efforts are now in operations at the 3 facilities providing new data. A few examples tied to Z:
  - High Resolution x-ray spectroscopy
  - Hard x-ray Imaging – Wolter on Z
  - hCMOS – seven instruments operating across the three labs
  - Line VISAR

Recent Diagnostic Development

➢ Line VISAR*	Clayton Myers and Dave Bliss
➢ X-Ray Diffraction using SCDI*	Tommy Ao, Marius Schollmeier
➢ Ultrafast X-ray Imager (UXI)*	Tony Colombo
➢ hCMOS / HE diodes	Marcos Sanchez, Liam Claus, Quinn Looker
➢ Wolter	Jeff Fein
➢ Aerogel Cherenkov Detector	H. Herrmann, Y. Kim, K. Yates (LANL), G. Chandler
➢ Pyrometry	Dan Dolan
➢ Calibration Sources*	Ming Wu and Pat Lake
➢ One Dimensional Imager of Neutrons (ODIN)	Mike Mangan
➢ Vacuum Power Flow Diagnostics*	George Laity
➢ Axial Pinhole imagEr (APE)	Tom Awe and LLNL
➢ Side-On Pinhole Imager (SOPI)	Tom Awe and LLNL
➢ Multi Crystal X-Ray Imaging	Eric Harding
➢ Neutron Activation	Mike Mangan
➢ CR39 Processing	Mike Mangan

A Line VISAR Diagnostic was recently installed and commissioned onto Z

This was a multi-year project and was extremely successful due to a strong collaboration between Lawrence Livermore National Laboratory and Sandia National Laboratories



The ZLV beam transport system (9 lenses, 12 mirrors) is 50 meters long

ZLV diagnostic requirements

Velocity interferometer

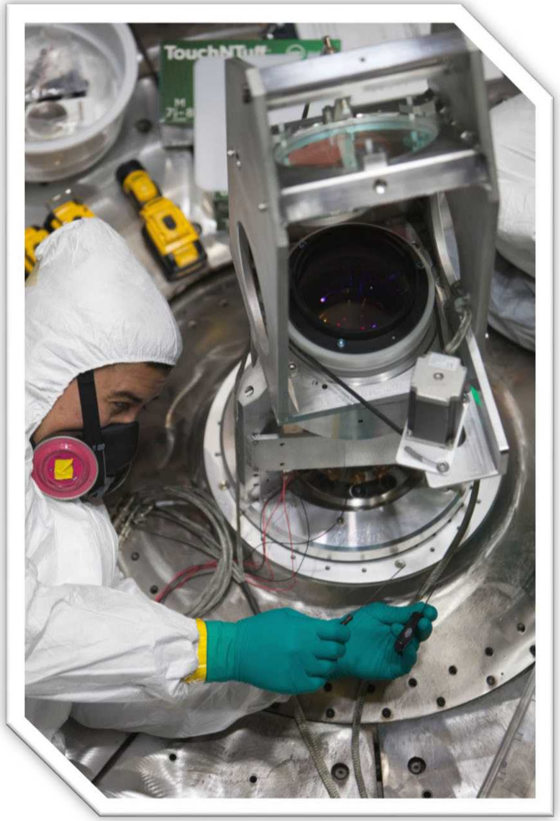
- Spatial resolution better than 10-20 μm
- Timing accuracy better than 20 ps
- 1, 2 and 4 mm FOV
- f/2 (!)
- Two interferometer legs for fringe ambiguities

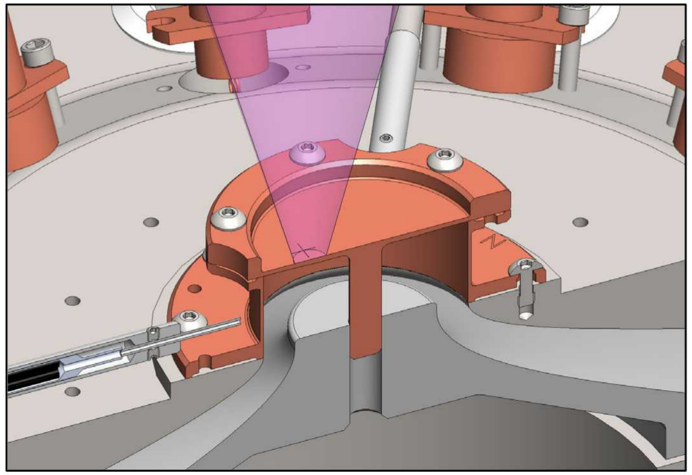
Gated Optical Imager (GOI)

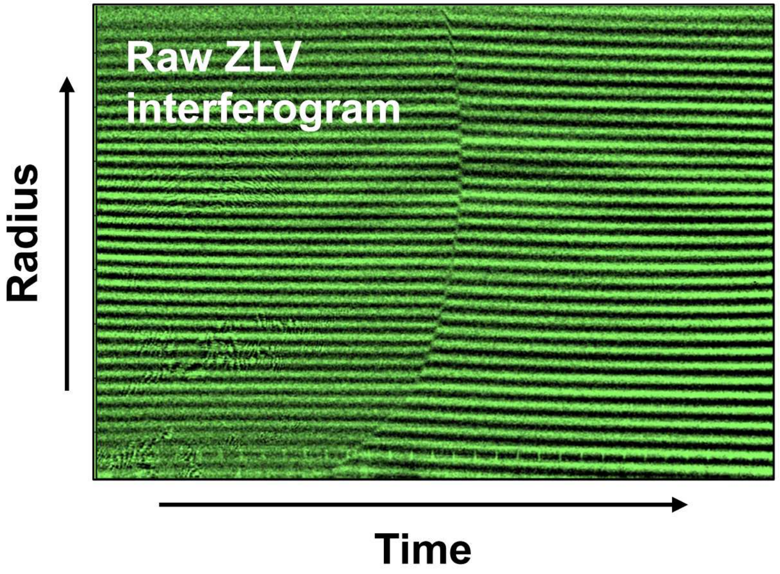
- Spatial resolution of ~100 μm
- Multiple images (8) to account for physics and facility jitter

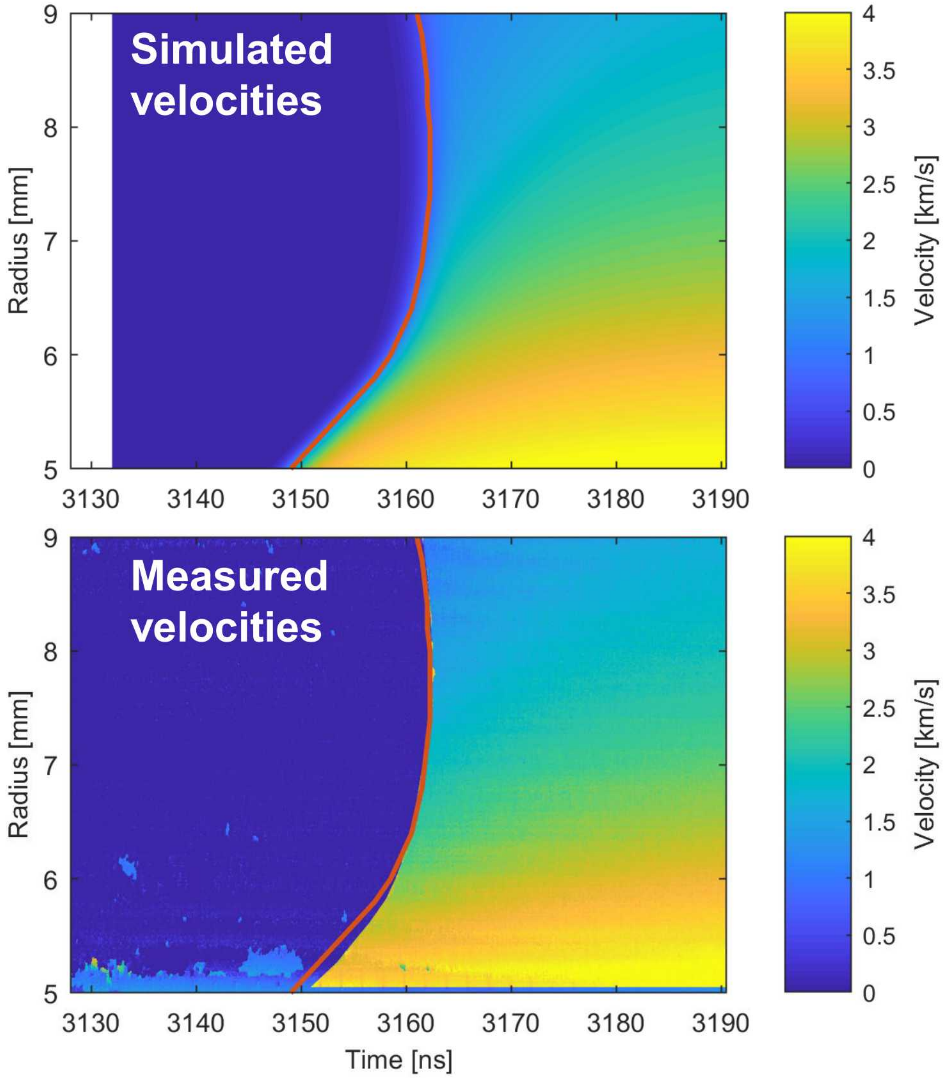
Z Line VISAR is a transformational diagnostic that provides the first spatially and temporally resolved load current measurements on Z

Measure the velocity history of a metal flyer to determine the magnetic drive pressure and therefore the load current







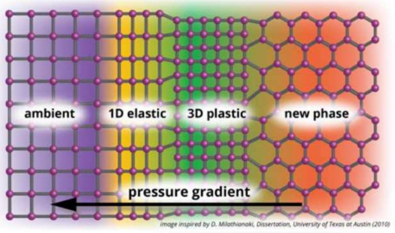


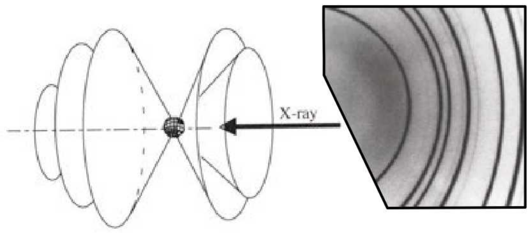
Lossless commissioning experiment (z3337) validates Z Line VISAR's capabilities

Development of x-ray diffraction (XRD) capability on Z

Scientific Objectives

- Characterize phase transformations of dynamically compressed matter
- Diagnose material lattice dynamics (kinetics)



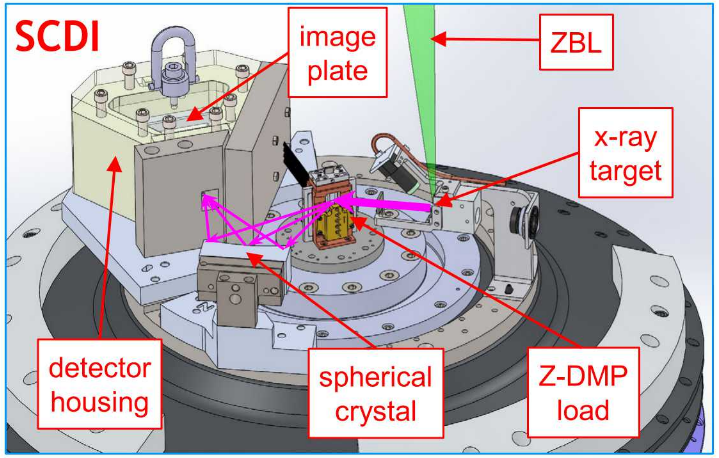


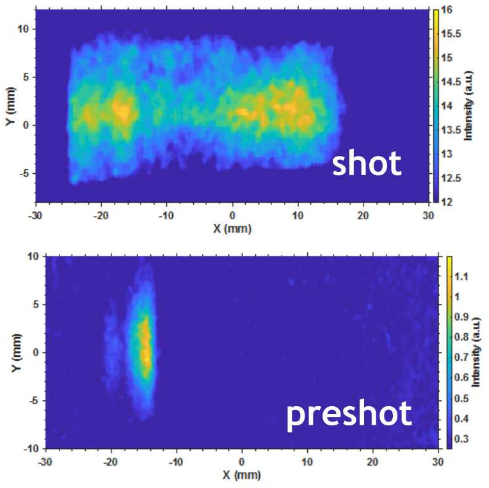
Experimental Approach

- Produce source x-rays with ZBL/ZPW laser
- Generate high-pressure state with Z-DMP load
- Detect diffracted x-ray pattern

Recent Progress

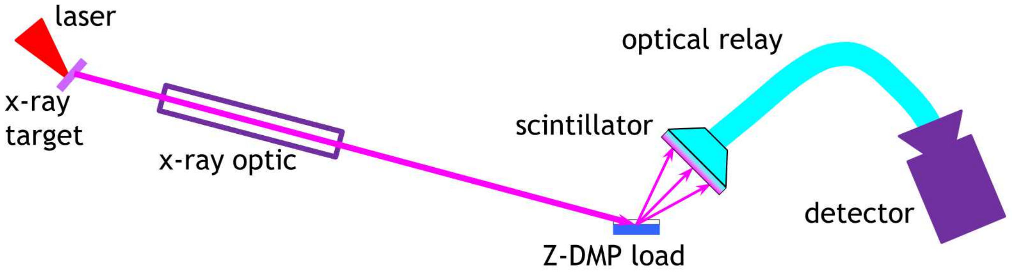
- Spherical crystal diffraction imager (SCDI) enabled 1st XRD measurements on Z
- Mitigation of load debris & x-ray background challenges





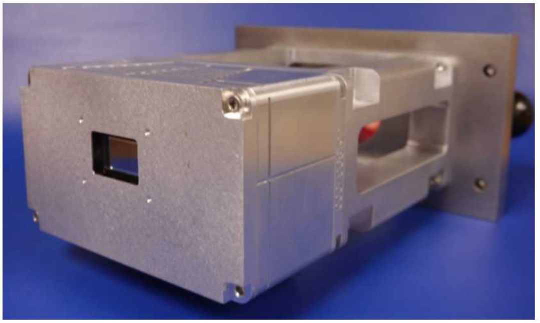
Future Developments

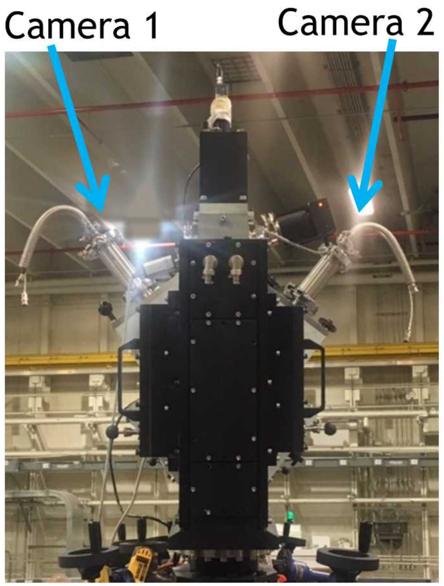
- Higher photon energy (15-20 keV) x-ray sources using ZPW
- Polycapillary x-ray optic to enhance x-ray flux
- Scintillator and optical relay to transfer XRD from Z-DMP load
- New detector schemes for time-resolved/gated XRD

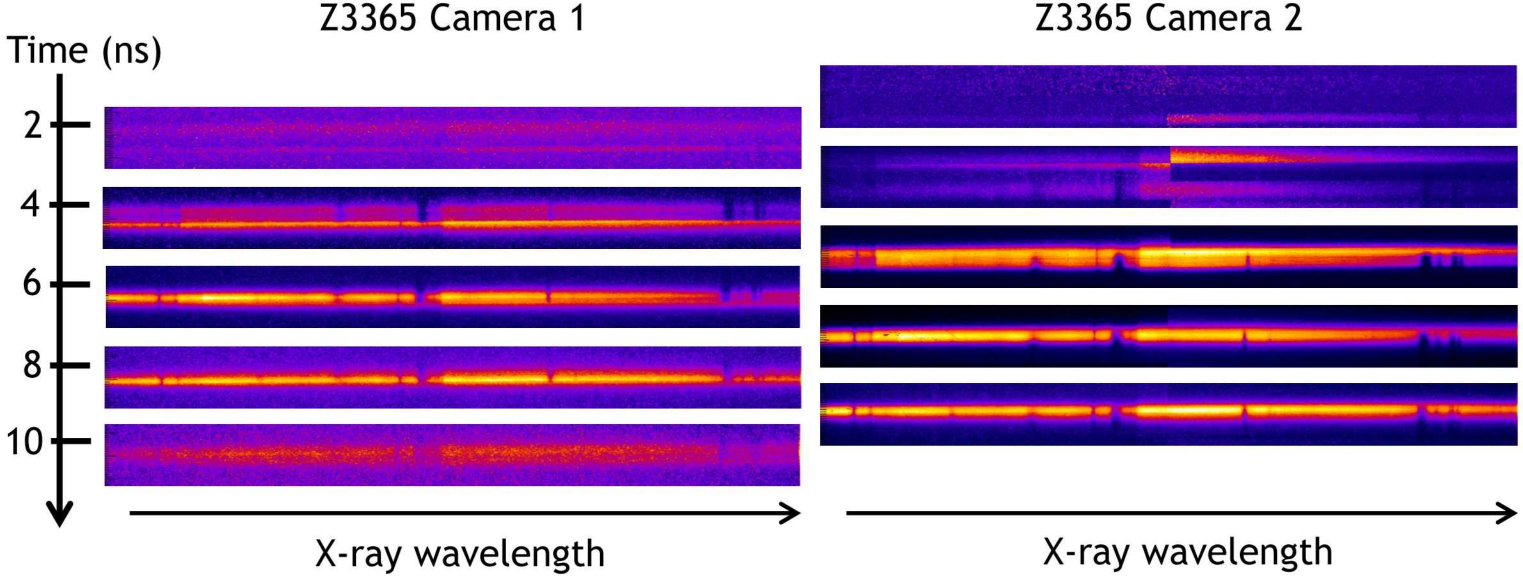


We have made recent progress with UXI in the Center Section, the Final Optical Assembly, and the Axial Package.

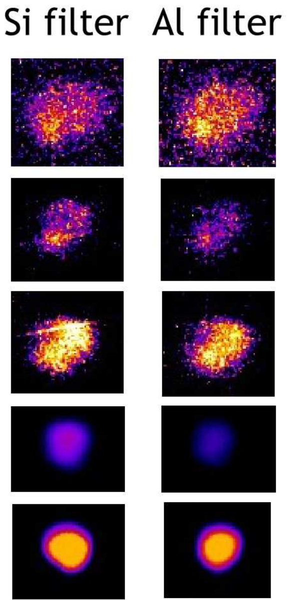
Opacity Spectrometer with 2 UXI Cameras in the Axial Package







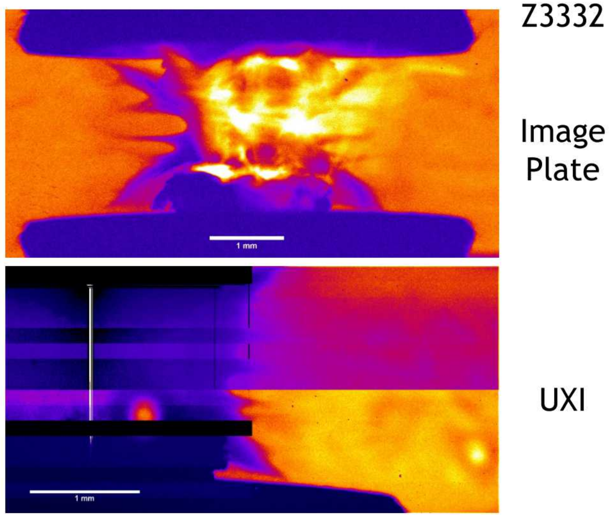
Axial Pinhole Camera In the Final Optical Assembly



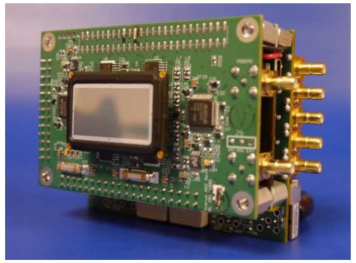
Time series of images from Z3371 MagLIF Preheat Te.

2 UXI cameras will be deployed on MagLIF Bz Scaling (October 2019).

Gated Backlighting in Z Center Section

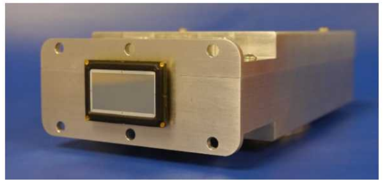


Recent electronics testing on Z3387 & Z3388



DE0_NANO a.k.a. “UXI 2.0”

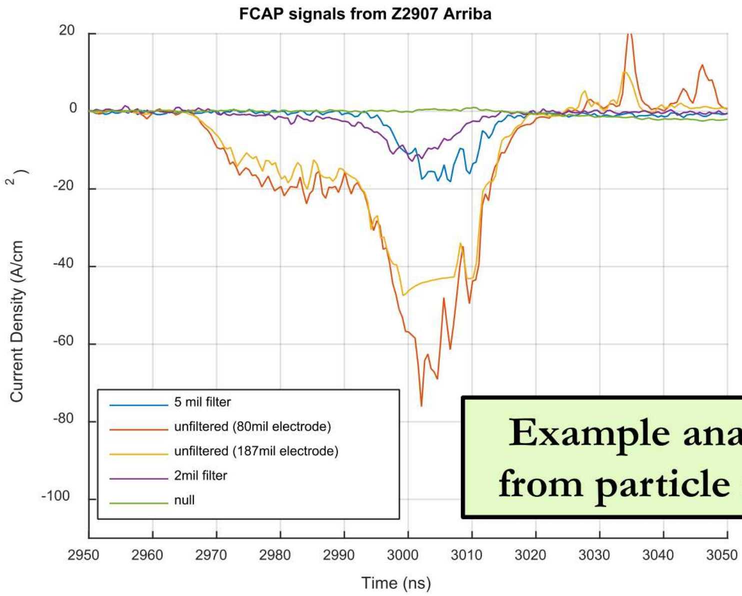
Successfully operated electronics (non-imaging) near/during stagnation.

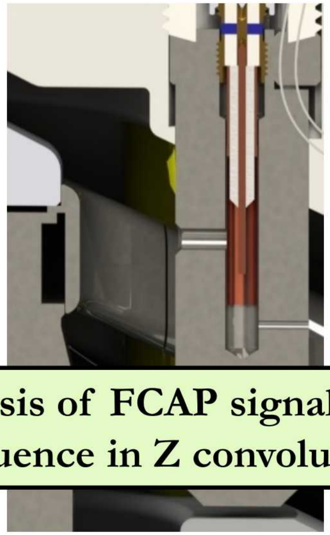


Z-System Board a.k.a. “UXI 3.0”

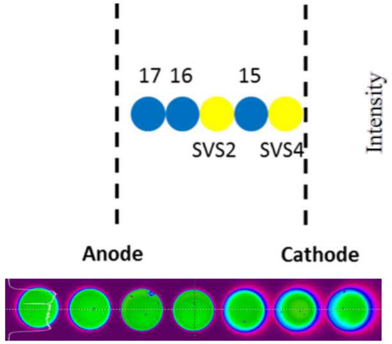
Passed first low-level tests of functionality.

Several diagnostics have been developed recently to explore the physics mechanisms of vacuum power flow on large pulsed power accelerators



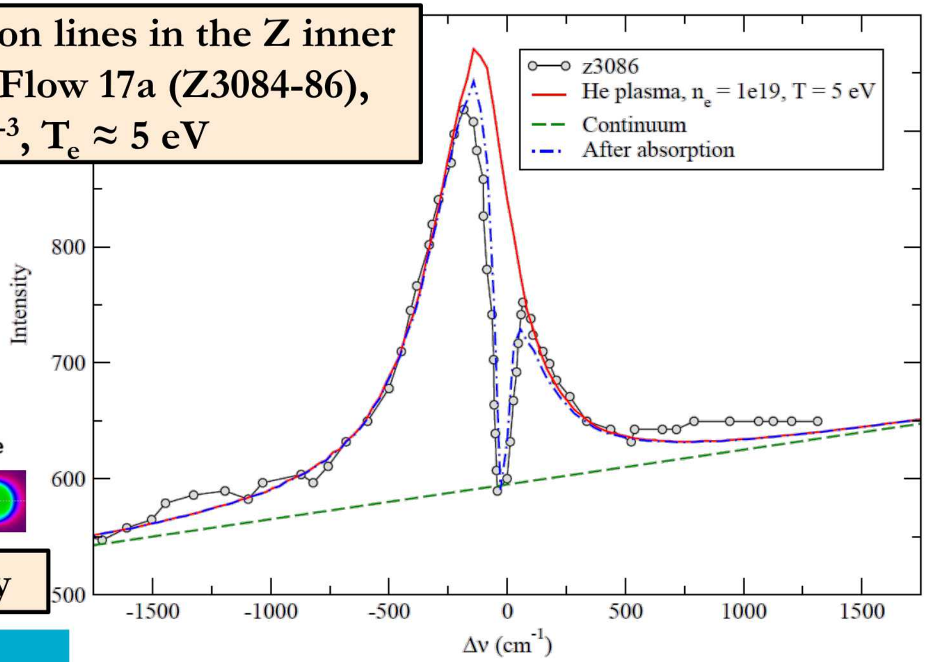


Example analysis of FCAP signals from particle fluence in Z convolute

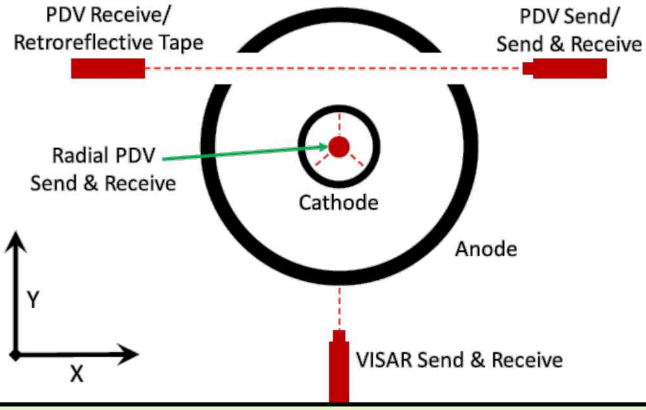


Chordal Fiber Array

Analysis of Mg emission lines in the Z inner MITL during Power Flow 17a (Z3084-86), $n_e \approx 10^{19}$ cm^{-3}, $T_e \approx 5$ eV



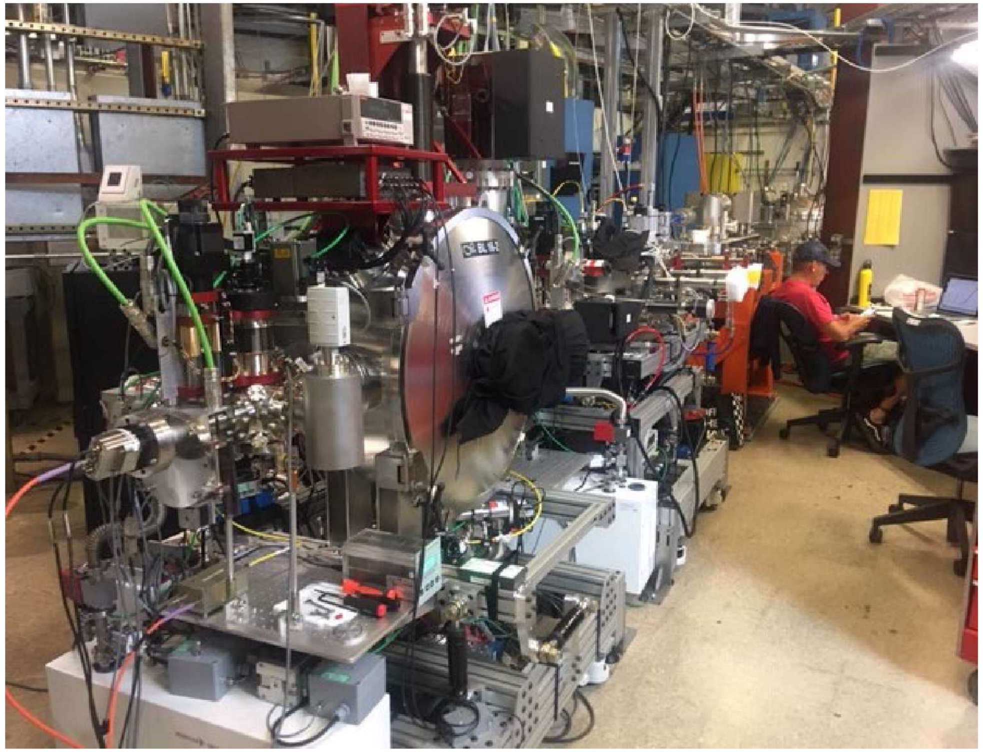
Power Flow Diagnostic	Physics Information Provided
PDV Chordal Interferometer	Plasma presence/timing in A-K MITL gaps
Streak Visible Spectroscopy (SVS)	Plasma density/temp, electric/magnetic fields
Avalanche Photo Diode (APD)	Plasma luminosity, electrode temp (pyrometry)
Faraday Cup Anode Post (FCAP)	Particle fluence in the Z convolute, loss current
Mini-XRD Probe	Electrode temperature (pyrometry)
Anode Post Magnetic Spectrometer	Particle energy spectrum in the Z convolute
Cathode Ion Detector for Z (CIDZ)	Positive ion fluence in the Z convolute



Example chordal PDV interferometry setup to explore inner MITL plasma, Dolan et al., J. Appl. Phys., (2018).

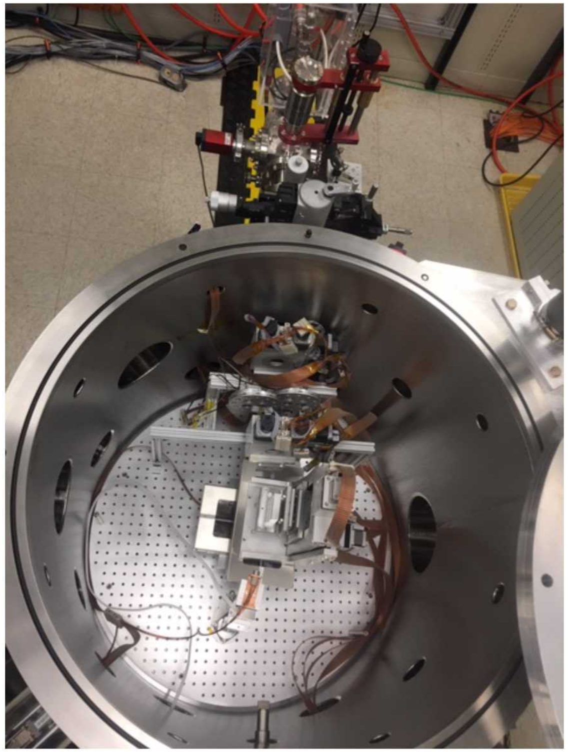
New X-ray Sources accessible for Calibrations and Experiments

SSRL 16.2 Beamline



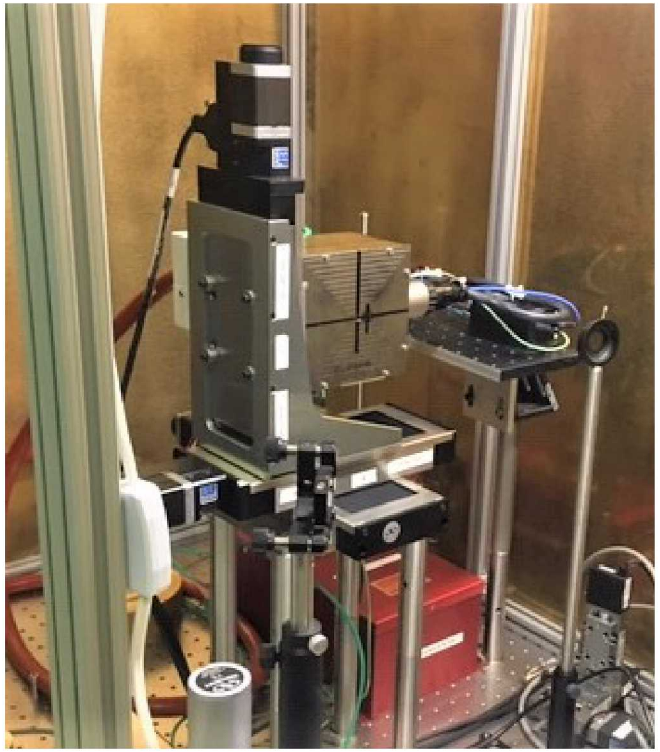
Energy Range: 50 – 2400 eV
Energy Resolution (E/ΔE): 1500 -2500
Beam Divergence: < 0.2 mrad (V), ~ 0.55 mrad (H)
Photon Flux: 10^8 – 10^{10} Photons/sec.

Henke Source (970/137)



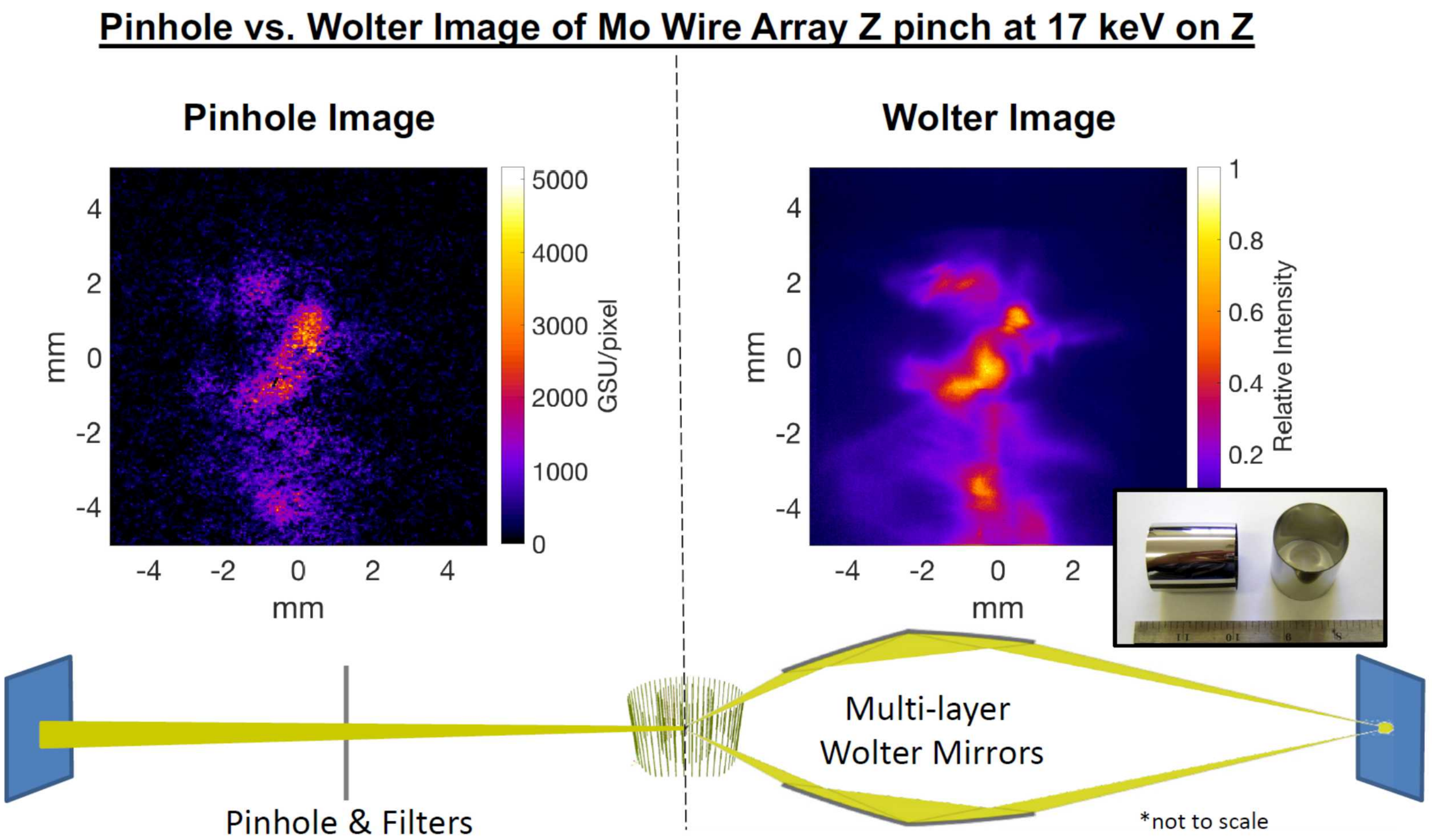
HV: 20 KV; Emission Current: 60 mA
Anodes: Al, Cu, Fe(SS),Mg, Mo, Ni, etc.
Two 12 slot filter Wheels; Two JJ Slits
Five axis sample stage
Amptek SSD Detector
Princeton Vacuum CCD

Microfocus X-ray Source (970/121)



Source Anodes: Mo, Nb, Ag, and W
Source Size: 10 -20 μm
Two 12 slot filter Wheels; Two JJ Slits
Five axis sample stage
Amptek SSD and CdTe Detectors
Princeton PIXIS XB and XF CCDs

Wolter optics are providing much improved spatial resolution at >17 keV photon energy



- The Wolter Imager has successfully imaged x-ray sources on the Z Machine in the 17-18 keV energy band, with development at ~22-keV
- Wolter has demonstrated a spatial resolution better than 150 microns with high signal/noise, significantly improving upon previous imaging capabilities
- Image processing techniques show potential to recover sub-resolution features in recorded images
- New fabrication techniques have been developed, capable of producing even higher-resolution optics

Successful collaboration between SNL, LLNL, Harvard-Smithsonian Center for Astrophysics, Universities Space Research Association, and NASA Marshall Space Flight Center.

New and Upcoming Initiatives

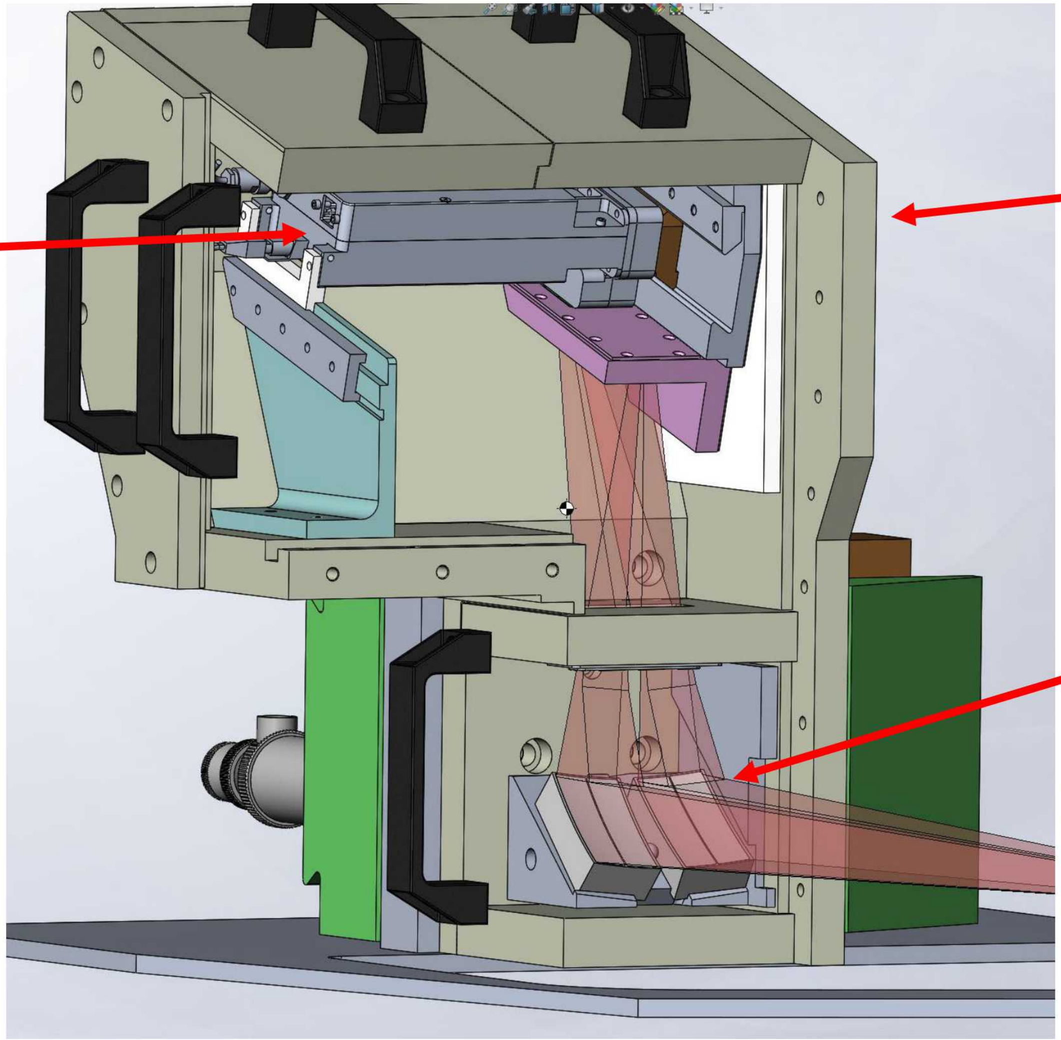
- Time-gated, spatially-resolving in-chamber spectrometer*
- Three Crystal Imager*
- Radial Line VISAR *
- 2D Neutron Imaging
- Fusion Reaction History
- Fast x-ray emission (Streak Cameras)
- Fast x-ray imaging (Pulse Dilation)
- X-ray diffraction (Higher Energy, Time Resolved)
- Wolter (Time Resolved)

We are designing a time-gated, spatially-resolving spectrometer with high-spectral resolution. Detector is an hCMOS sensor developed at Sandia.

MONSSTR

(Multiple Optic Novel Spherical-Crystal Spectrometer with Time Resolution)

hCMOS sensor and electronics.
Δt ~ 2 ns
Up to 8 frames using Icarus.

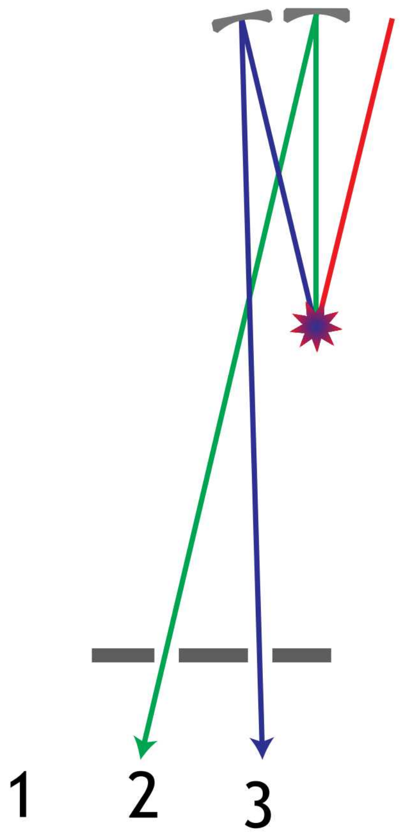


1" to 2" thick tungsten housing for hard x-ray shielding.

Two spherically bent crystals
E/ΔE > 1000
Δx~ 200 μm

A narrow band, three-crystal imager will enable measurement of T_e and n_e with a spatial resolution $\Delta x \sim 20\ \mu m$.

Three-crystal imager concept



3-channel crystal imager generates spectral images in 3 narrow bands.

Co K-shell spectra from z3078

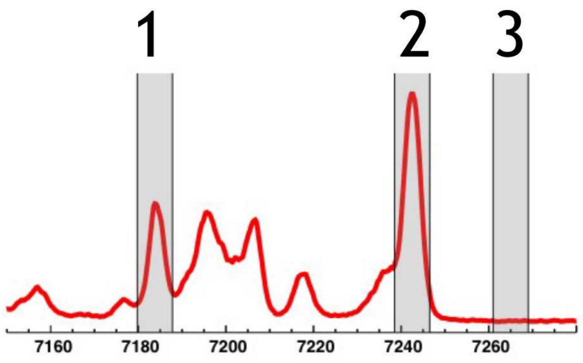
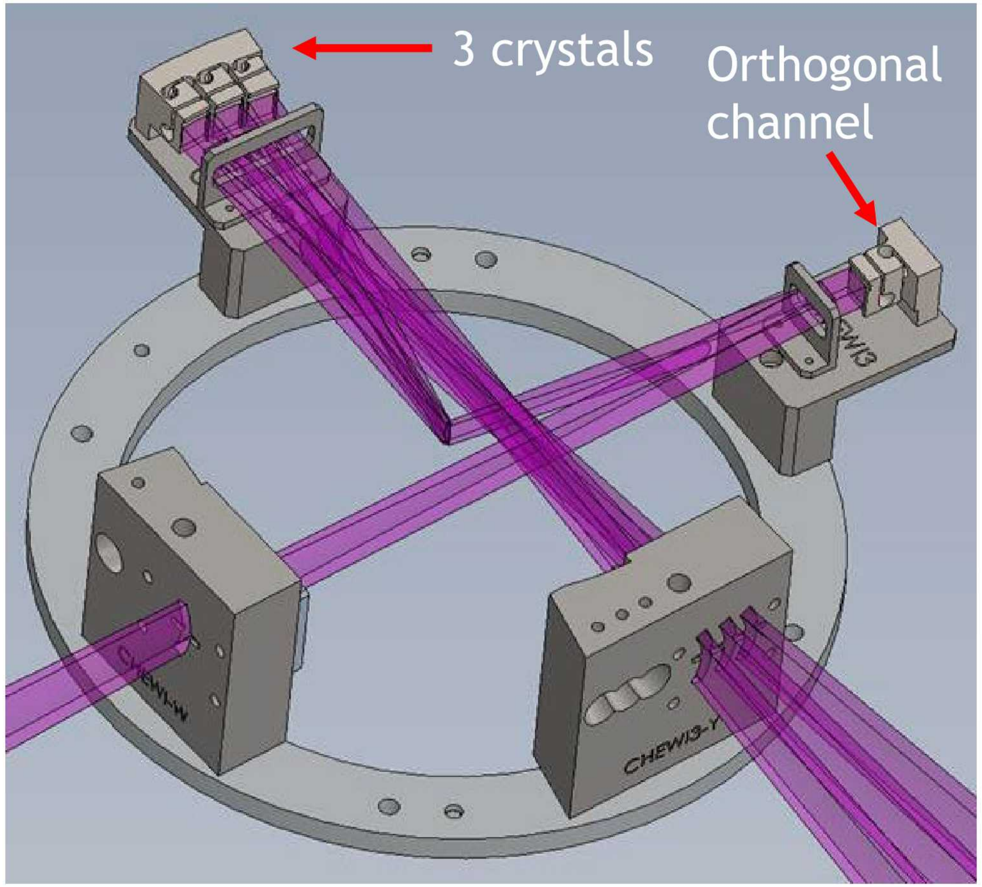


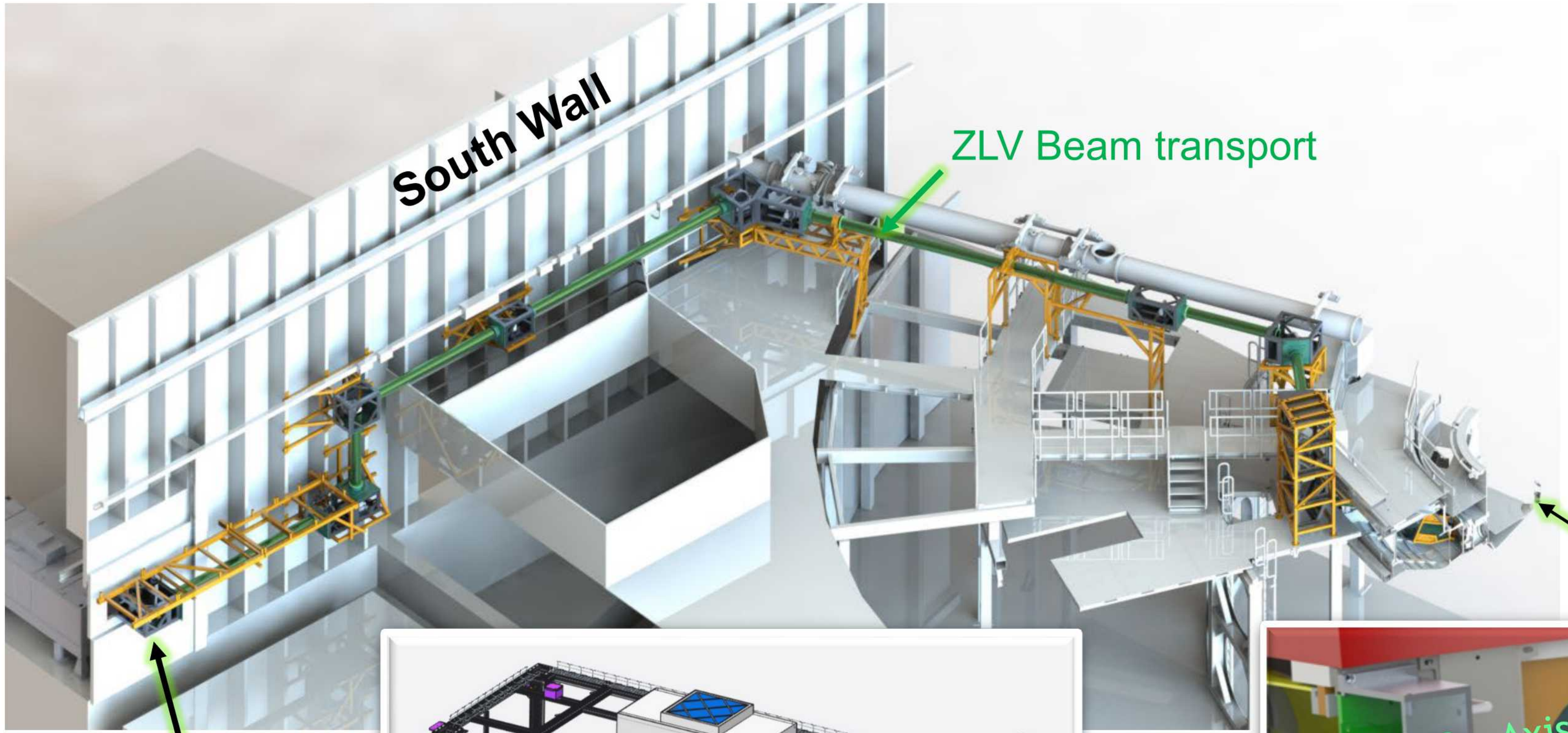
Image ratios can then give reveal variations in T_e or n_e depending on spectral lines.

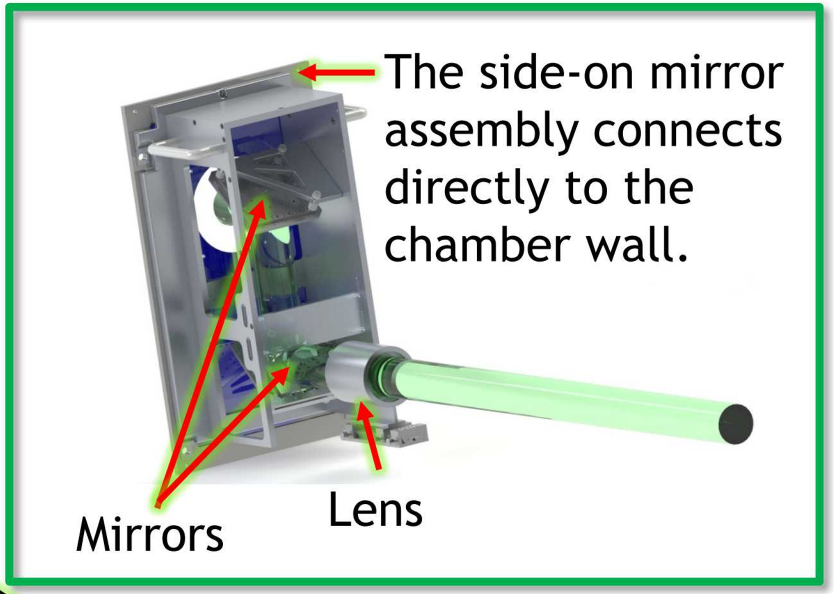
Three-crystal imager (a.k.a., CHEWI3)
Shown with an option orthogonal imaging channel.

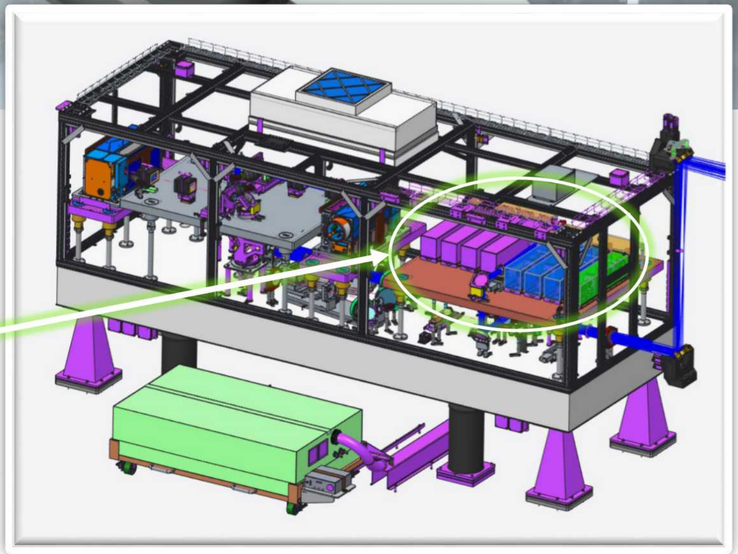


This will be fielded for the first time on Z in October 2019.

The 8 channel gated optical imager and beam transport optics that are part of the Z Line VISAR system are being utilized to create a self-emission imager to visualize loads (e.g. liners) and power flow surfaces.







Thanks