SAND2020-7851PE

Diagnostic Efforts at Z

SAND # TBD

Z Fundamental Science Workshop

8/3/2020

Michael Jones on behalf of the Z Diagnostic Team

Diagnostic Structure

- There was a reorganization of diagnostics in early 2020
  - Radiation and Fusion Diagnostics moved from the Z Operations Group to the Radiation & Fusion Experiments Group.
  - Department was also split into two departments.
- Target diagnostics are organized into five different areas.
- There are two additional areas focused on:
  - Pulsed power diagnostics
  - Environmental diagnostics

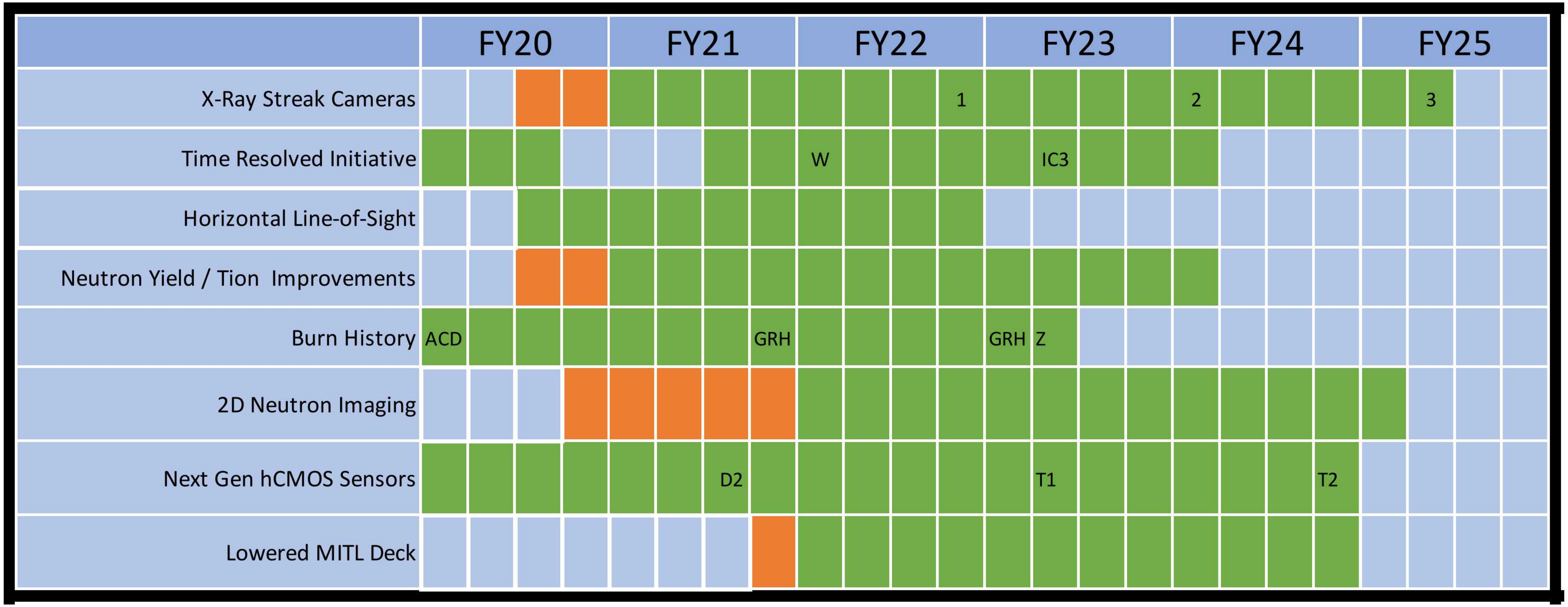
Radiation & Fusion Experiments — Greg Rochau (→ X-Ray Diagnostics, Fusion Diagnostics, Diagnostic Technologies)

HED Material Physics — Thomas Mattson (→ Velocimetry)

Pulsed Power Accelerator S&T — Mike Cuneo (→ Power flow)

X-Ray Diagnostics	Fusion Diagnostics	Diagnostic Technologies	Velocimetry	Power flow	Electrical
Michael Jones	Dave Ampleford	John Porter	Chris Seagle	George Laity	Mark Kiefer
XRDs PCDs Bolometers TEP / SiDs / GaAs TIXTLs TREX CRITR TiGHER / TRIXCI MLM WALLE Crystal Imaging Crystal Backlighting XRS3 MONSSTR TIPC APE SOPI Wolter Film MCPs Image Plate	nTOFs Activation Sample ODIN Be Probe GRH MCVD CR39	UXI in: - backlighting - MONSSTR - Axial Spectrometer FOA Pinhole Camera GaAs diodes	VISAR PDV Pyrometry Diffraction	SVS FCAPs Mini-XRDs APDs CIDz Line VISAR	B-dots V-dots IDTLs

Stagnation Diagnostic Roadmap (Abbreviated)



Orange boxes indicate planning / scoping exercises

Subject to change depending on resources – could speed up or slow down.

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

- Organizational Structure of Diagnostics
- List of Z Diagnostics by Area
- Summary Slides for each Diagnostic Instrument
- Summary Slides for Enabling Capabilities

SAND2019-7354 O

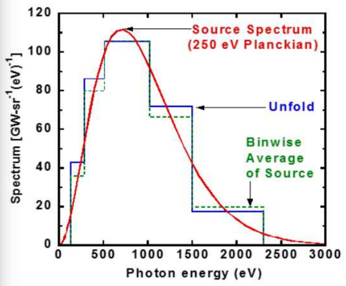
U.S. DEPARTMENT OF ENERGY NNSA

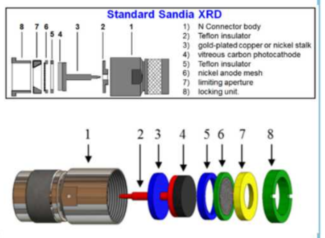
Will be updated in 2021!

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 multi day workshop is tentatively planned for the spring of 2021

- Would like participation from many institutions: SNL, LLNL, LANL, LLE, NNSS, and our university partners

- The primary focus last year was around our stagnation diagnostics
  - 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.

- Next year the focus of the 2021 workshop is still under discussion.
  - Potential Topics – high resolution X-ray imaging & spectroscopy, future uses of the hCMOS / UXI in Z measurements, alternative methods to measure nuclear burn history & T_{ion}.
  - If you have ideas or suggestions please send them to me

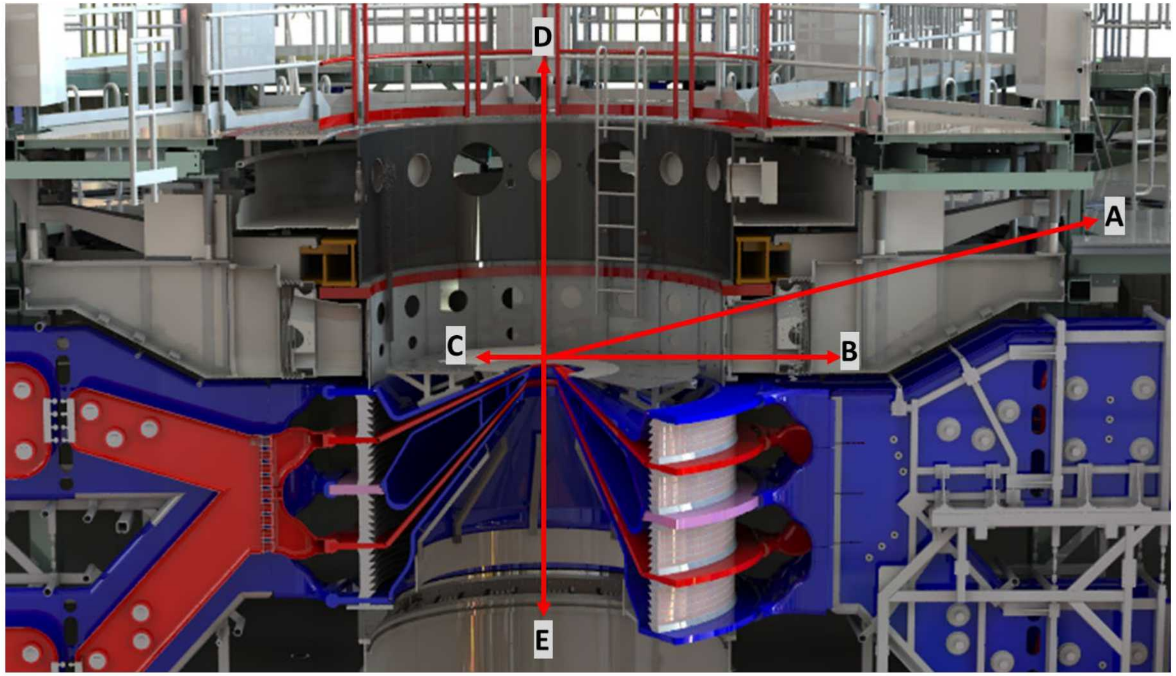
National Diagnostics Working Group Update

- The National Diagnostics Working Group (NDWG) is an active and productive community focused on transformational diagnostics for Z, NIF, and LLE.
- Workshops 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.
- In December 2019 the 14th National Diagnostics Working Group Meeting Occurred at LLNL. There were 6 breakout sessions focused on:
  - >15 keV GHz photon detection
  - High Resolution Imaging
  - Passive detectors
  - Burn Widths
  - Hot spot velocity
  - Magnetic field characterization

Enabling / Crosscutting Capabilities for Z

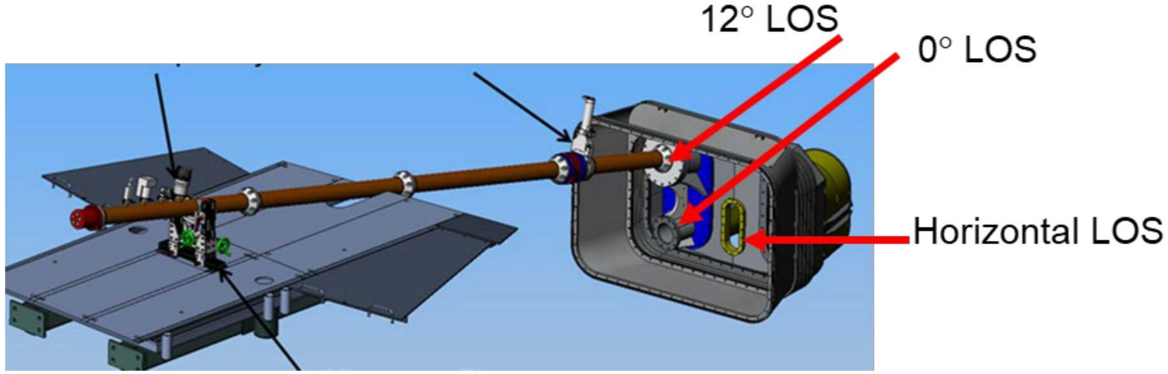
- Upgrading our shielded enclosures on the mezzanine
  - Replacing all single walled shielded enclosures with double-walled ETS-Lindgren enclosures.
  - This will double the rack space available in the Z Highbay
- Upgrading Digitizers for X-ray and Nuclear Diagnostics
  - The majority of our digitizers operate at 500MHz with 8-bit resolution.
  - Upgrading to 1-8 GHz with 12-bit resolution.
- Upgrading cable runs to improve the fidelity of electrical measurements
  - Over the past year the teams have made great progress in improving
- Started work to enable a new horizontal Line of Sight (more details on next slide)

Why a Horizontal Line of Sight



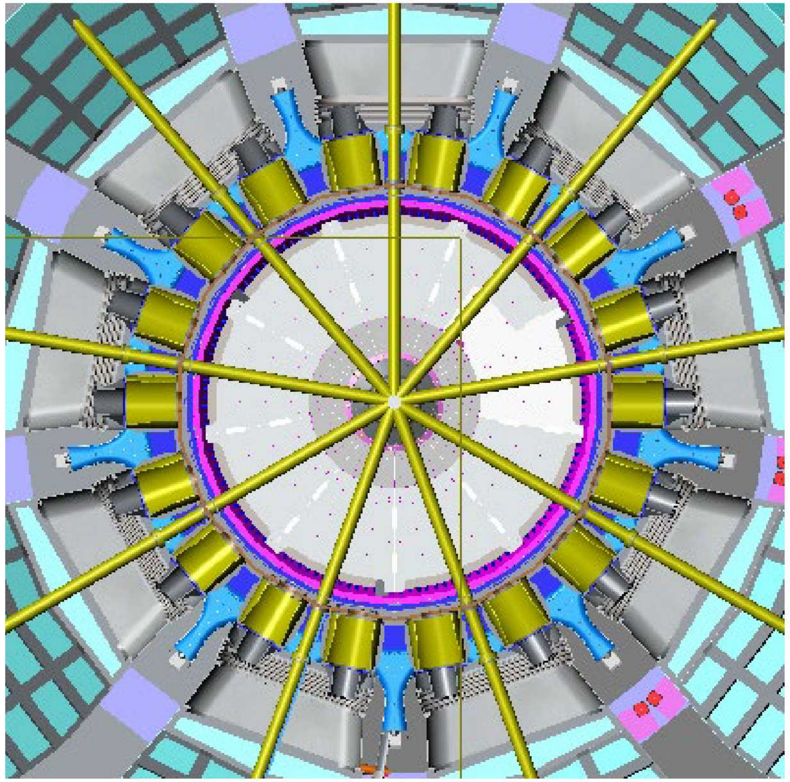
A	B	C	D	E
12° LOS	0° LOS	In-Chamber	Top Axial	Bottom Axial

- The pulsed power geometry limits how far away our diagnostics can be placed while maintaining a normal view to the target (0°)
- During the upgrade of the Z Machine there were plans to implement horizontal LOS's but were de-funded. Fortunately, infrastructure was left in the LOS spool and LOS weldment.



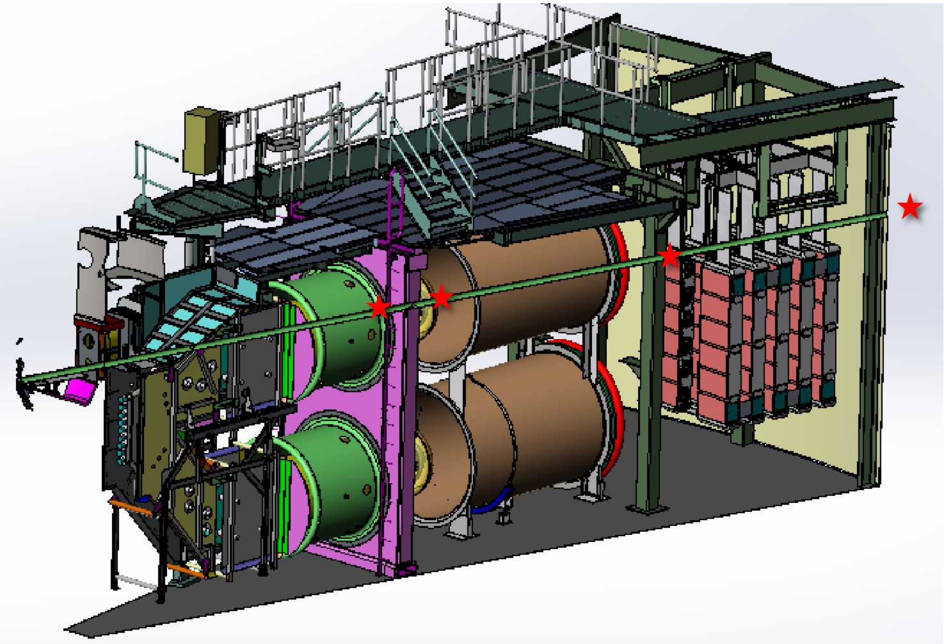
- By traveling through the water and oil sections, the neutron environment is cleaner. (less scattering & more collimation)

Implementing a Horizontal Line of Sight



- There are nine potential locations for horizontal LOS's
- Starts at LOS20 and then every 40°

- Initial use of a horizontal LOS would be for activation samples and nTOFs.



- Detectors could be potentially placed at the stars.
- Longer term this could be used for neutron imaging and far-field x-ray power and energy measurements
- In FY21 we expect to have the first phase completed.

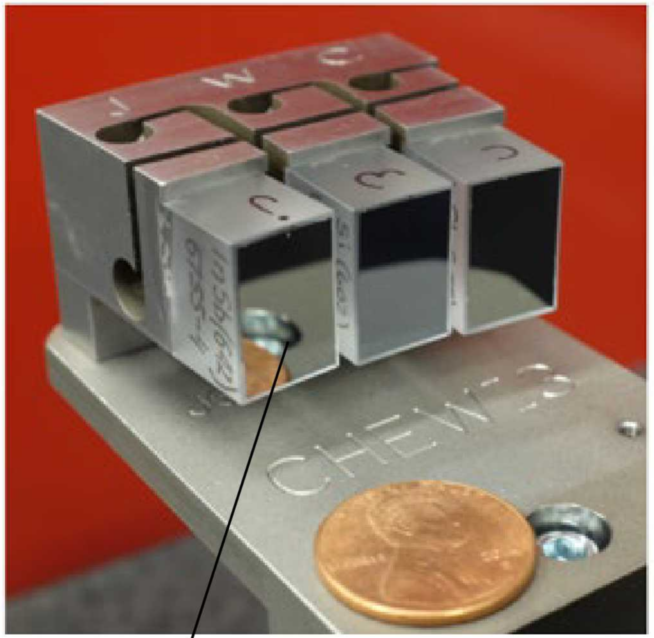
Recent Diagnostic Development

➢Multi Crystal X-Ray Imaging	Eric Harding
➢Orthogonal X-Ray Imaging	Eric Harding
➢MONSSTR	Eric Harding
➢Fast x-ray emission (Streak Cameras)	Jeff Fein
➢X-Ray Diffraction*	Tommy Ao, Marius Schollmeier
➢High Energy Diodes	Quinn Looker
➢Ultrafast X-ray Imager (UXI)	Tony Colombo
➢hCMOS	Marcos Sanchez
➢ACD	K. Yates
➢GRH	K. Yates
➢Neutron Imaging	Mike Mangan
➢Facility Neutron Modeling	Mike Mangan,

A new three-crystal imager is being developed to measure temperature gradients in MagLIF targets with a 20 μm spatial resolution.

MagLIF Mix19 (z3479)

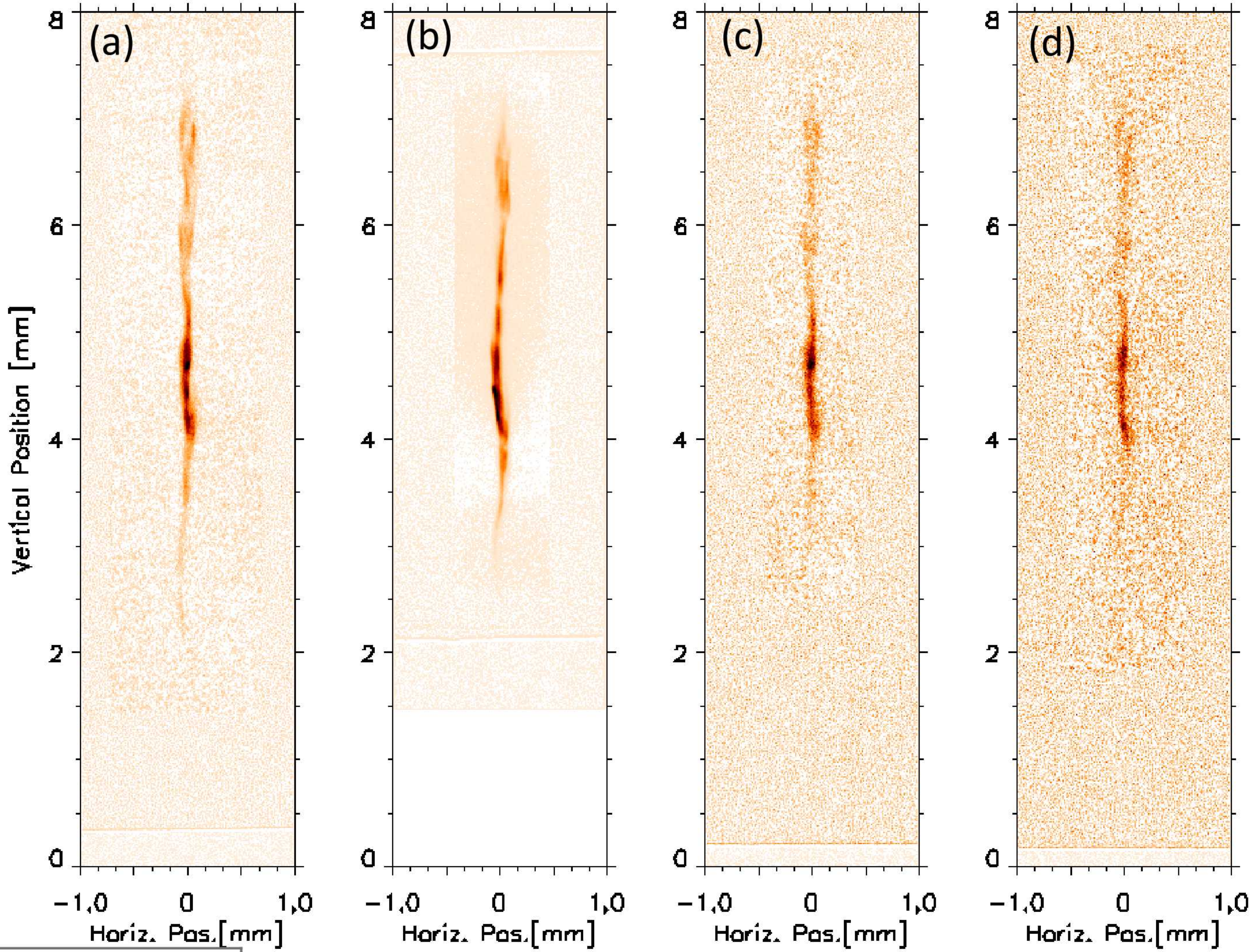
3-Channel Crystal Imager (CHEWI3)



Orthogonal Channel

Spherical x-ray mirrors generate three separate narrow band images.

A fourth channel provides an orthogonal line-of-sight using a single crystal. This is image (b) on the right.



On July 10th (2020), we successfully recorded time-resolved data with the new MONSSTR x-ray spectrometer.[1]

Commissioning of the MONSSTR x-ray spectrometer

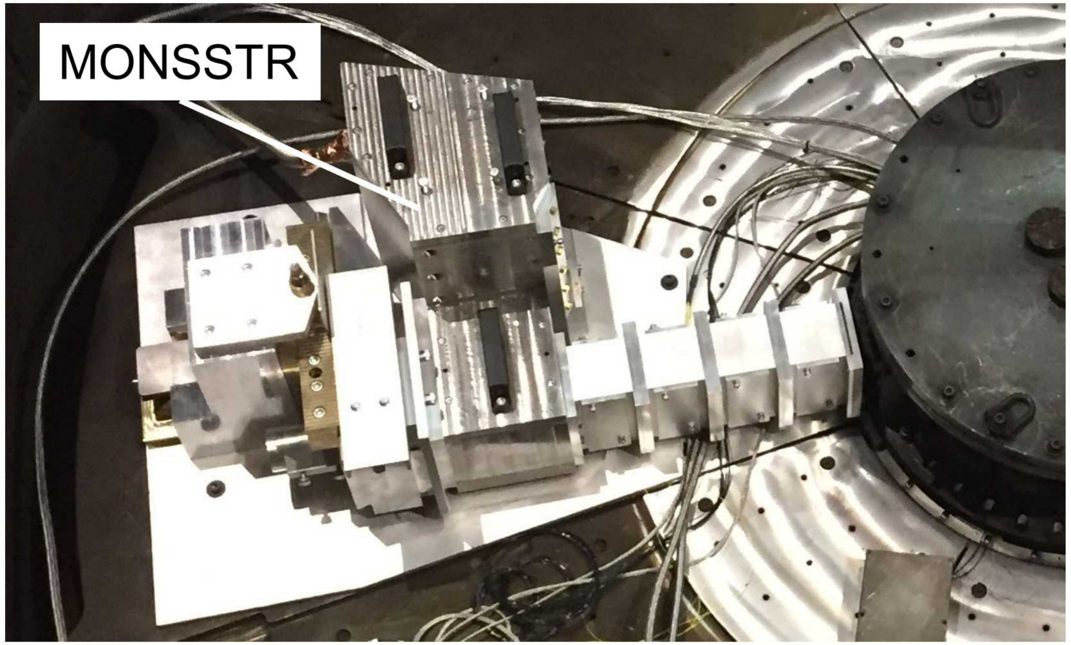


Figure 1. The MONSSTR is shown here inside the Z center section, ready for the downline shot.

Eric Harding, Paul Gard, Tony Colombo, Andy Maurer, Aaron Edens, Dan Folker,, Jeff Kellogg, Quinn Looker, and Michael Jones.

[1]***M**ulit-**O**ptic **N**ovel **S**pherical-crystal **S**pectrometer with **T**ime **R**esolution*

MONSSTR x-ray data from z3504 as recorded on an hCMOS detector.

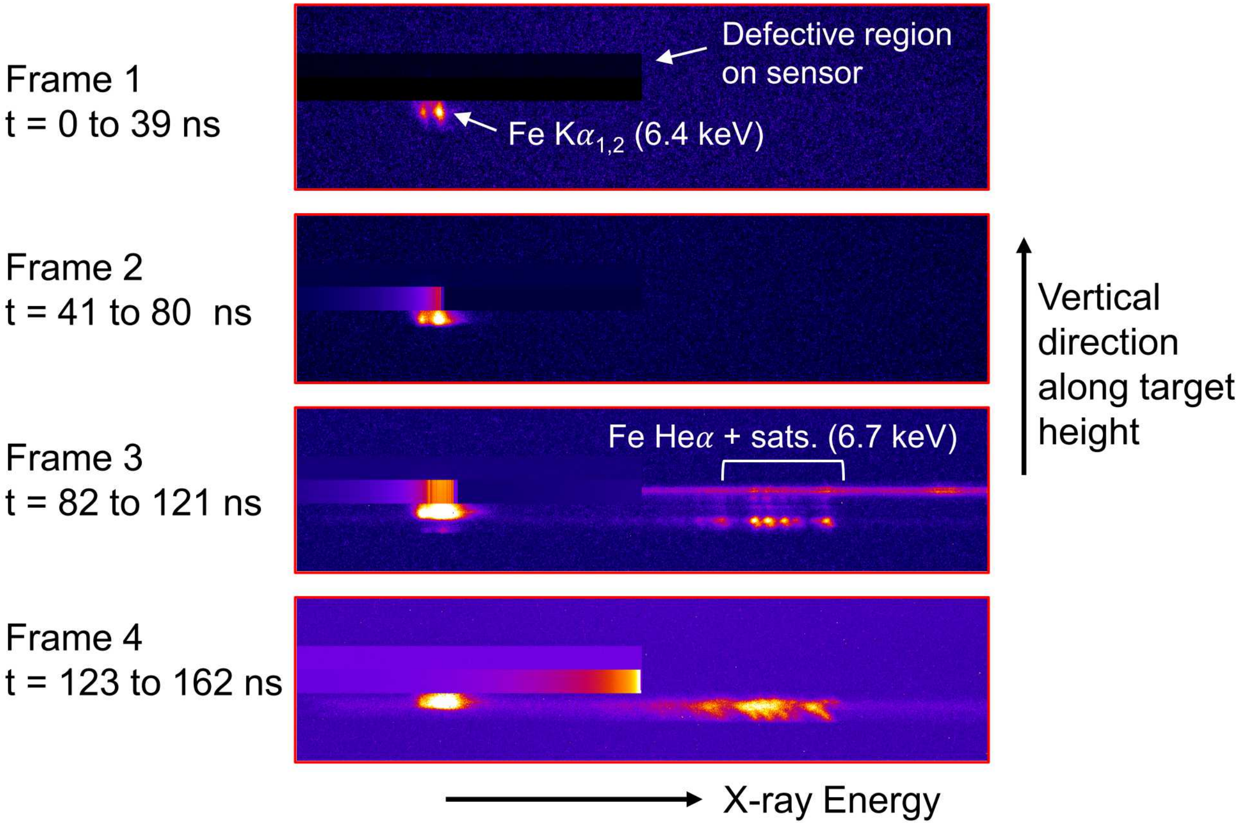
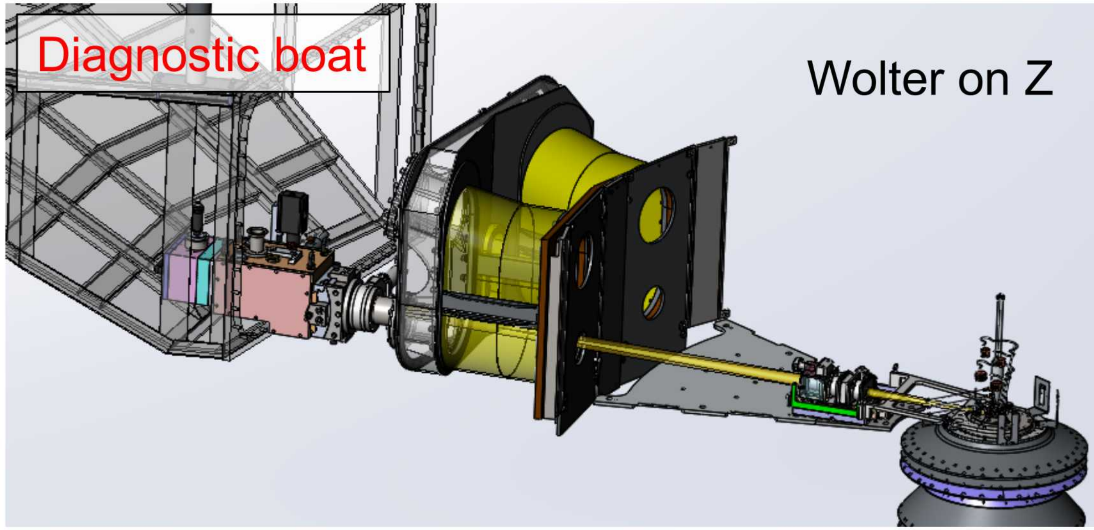


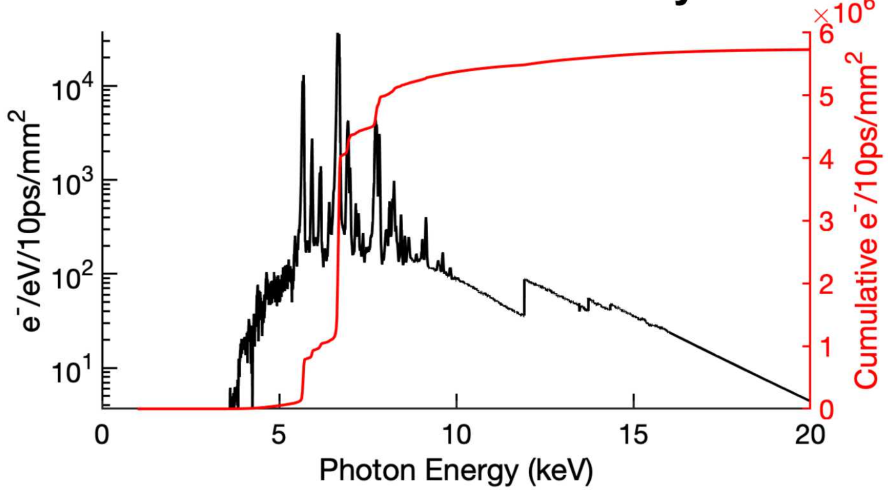
Figure 2. Here we show 4 separate frames of Fe spectral data from a MagLIF target. The data was recorded on an Icarus hCMOS detector with an exposure time of 39 ns per frame.

With LLNL, we are beginning development of an x-ray streak camera capability on Z, with future goals of streaked spectroscopy and 1D imaging

- Will enable high-resolution burn histories for ICF, temporally resolved temperature measurements, 1D implosion dynamics
- Photometrics indicate sufficient signal for a variety of applications when placing the photocathode ~3 meters from the source (e.g. in a Z diagnostic boat)
- First implementation will field multiple filter channels, “0D”
- We plan to integrate existing technologies (DISC[1] on NIF, Z Wolter alignment system, etc.) to minimize timeline



Photocathode signals from stainless steel wire array:



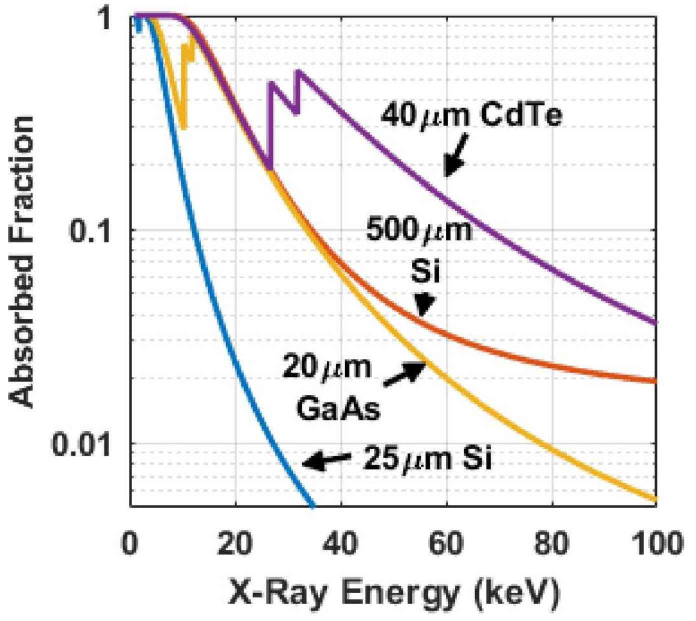
Photometrics summary for various platforms:

	SS Wire Array	MagLIF	Opacity
Electrons in Si sensor per 13-um x 13-um pixel	7.0E+06	1.1E+05	9.3E+05

1. Opachich, Y. P., *RSI*, *83*(12).

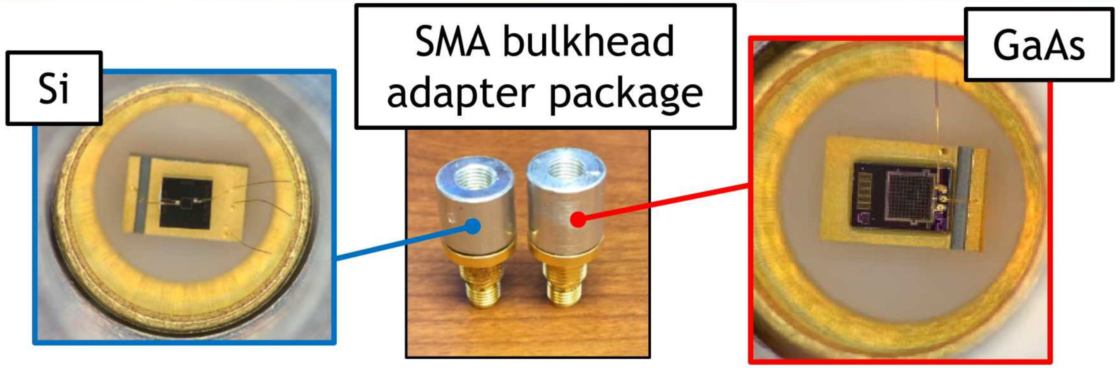
High-Z Semiconductor Detectors Enhance Hard X-Ray Detection Efficiency While Preserving Fast Temporal Response

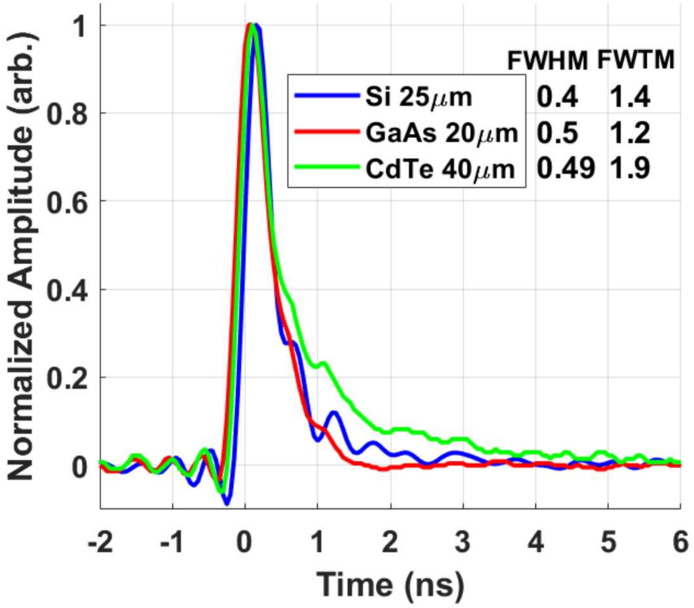
Higher atomic number absorber increases x-ray absorption without need for larger detector size



Q. Looker et al., *RSI* vol. 90, 113505 (2019)

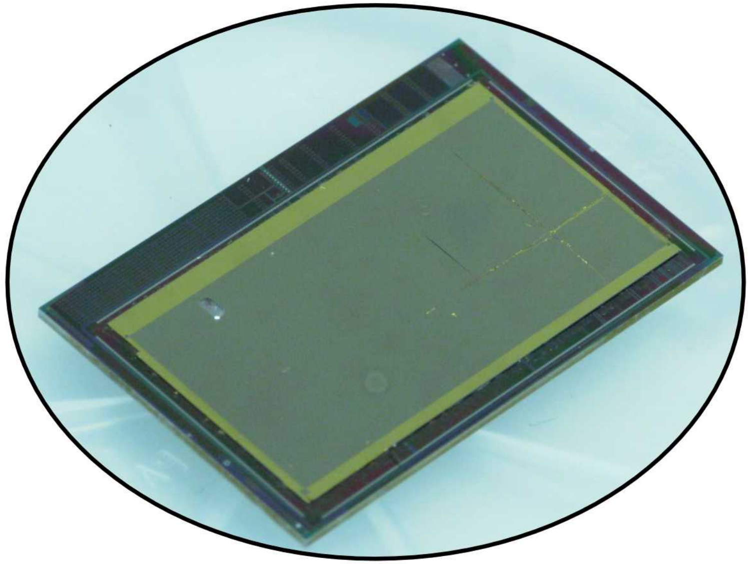
Current-mode detectors with sub-ns temporal impulse response





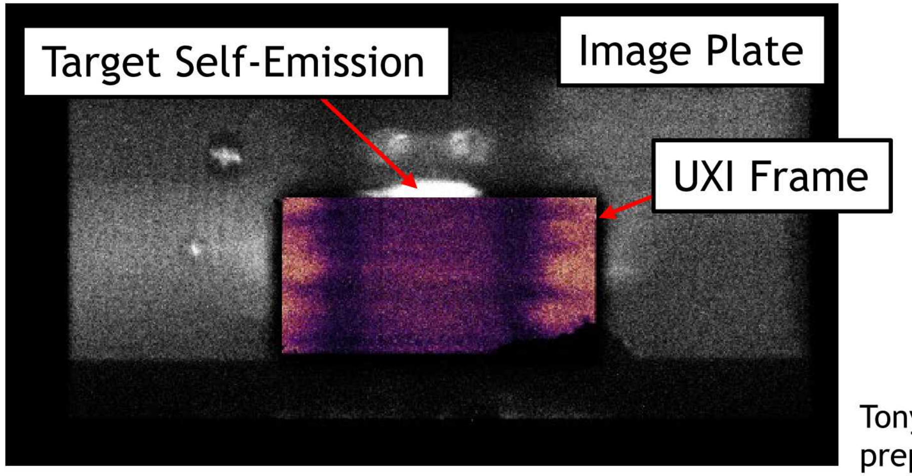
Q. Looker et al., *RSI* vol. 91, 023509 (2020)

GaAs pixel arrays for hCMOS under development



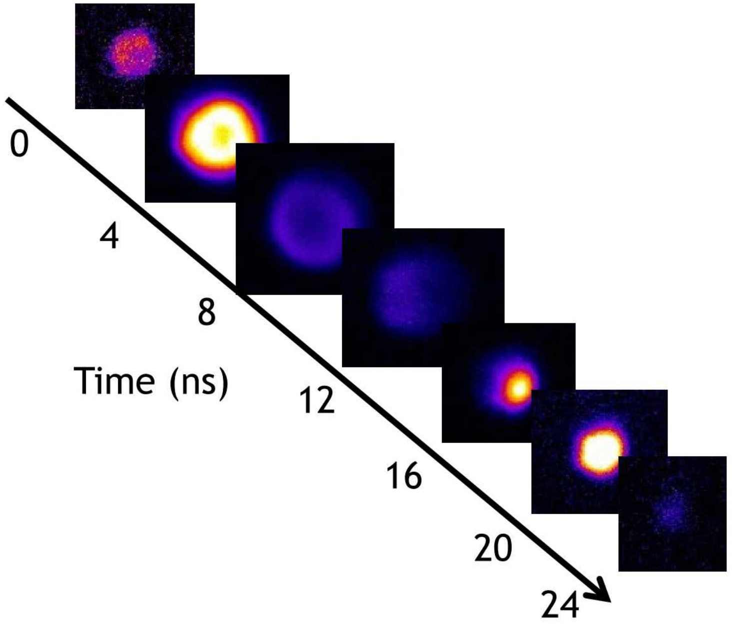
The Ultrafast X-Ray Imager Brings Nanosecond-Scale, Time-Resolved Imaging to Applications at Z

Time Gated Backlighting



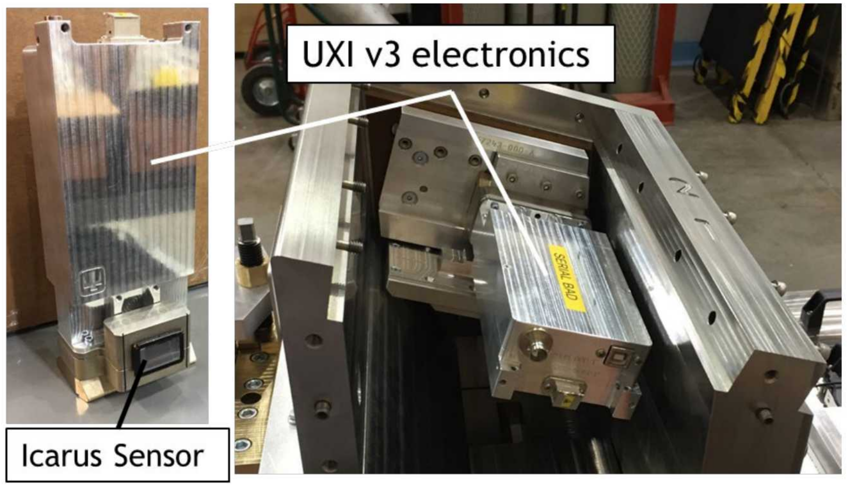
Tony Colombo, lead diagnostic scientist for the UXI, is preparing to install the camera into the center of Z.

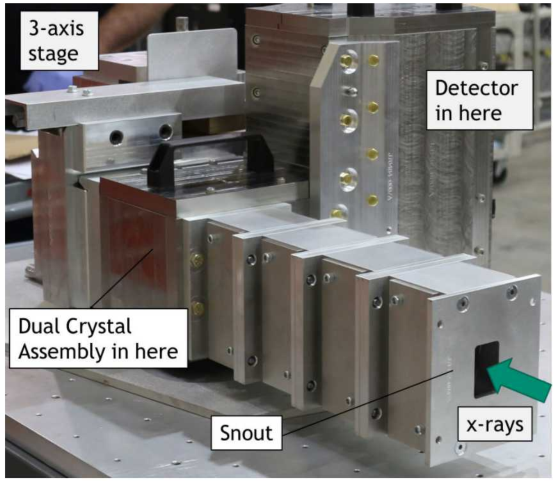
X-Ray Imaging



Pinhole Imaging of MagLIF Laser Entrance Window X-Ray Emission

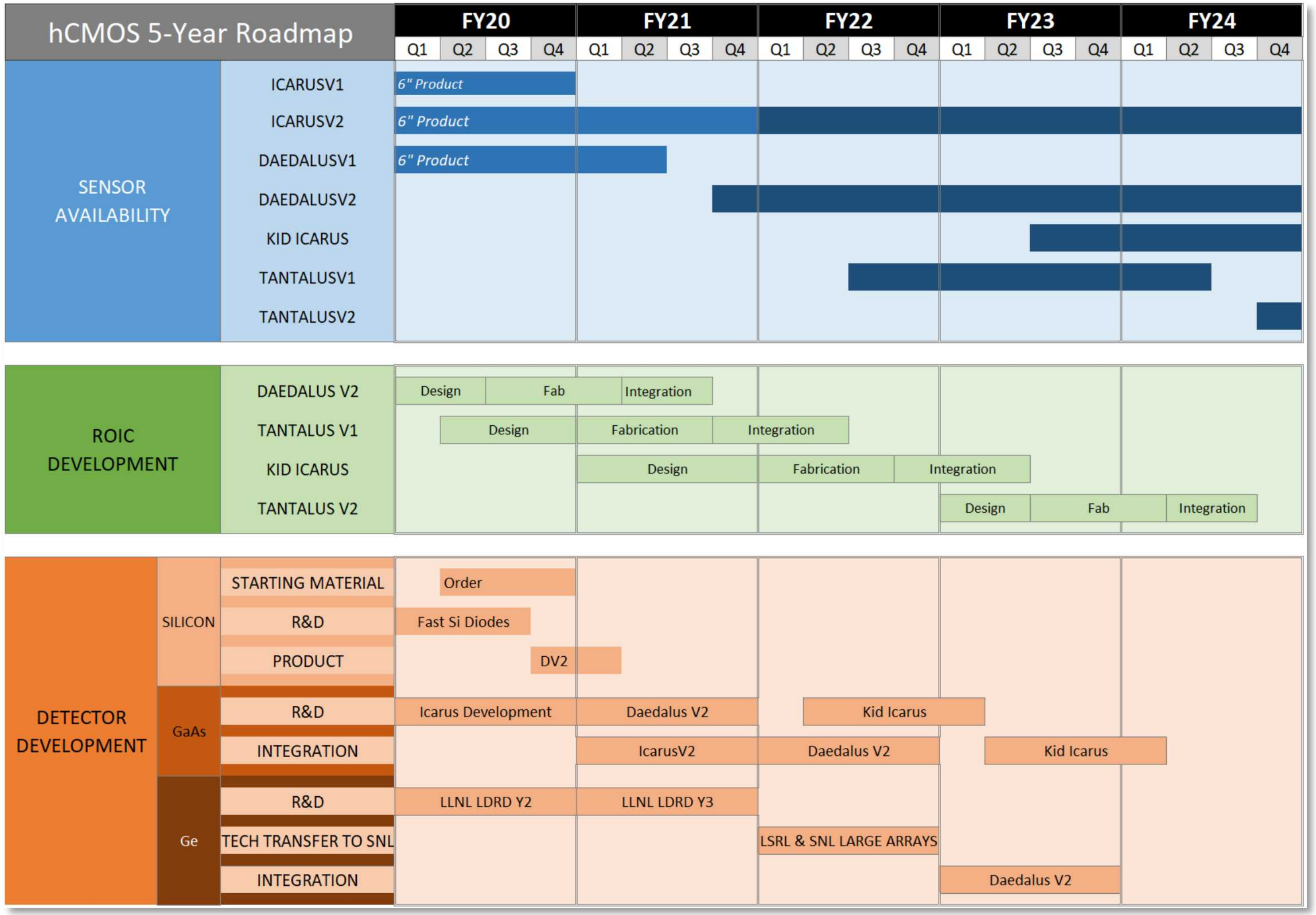
Time-resolved spectroscopy (New Application in MONSSTR!)





For more information on UXI in Z please contact Tony Colombo.

The hCMOS effort has established a 5-year roadmap in order to support diagnostic needs at Z-machine and other facilities



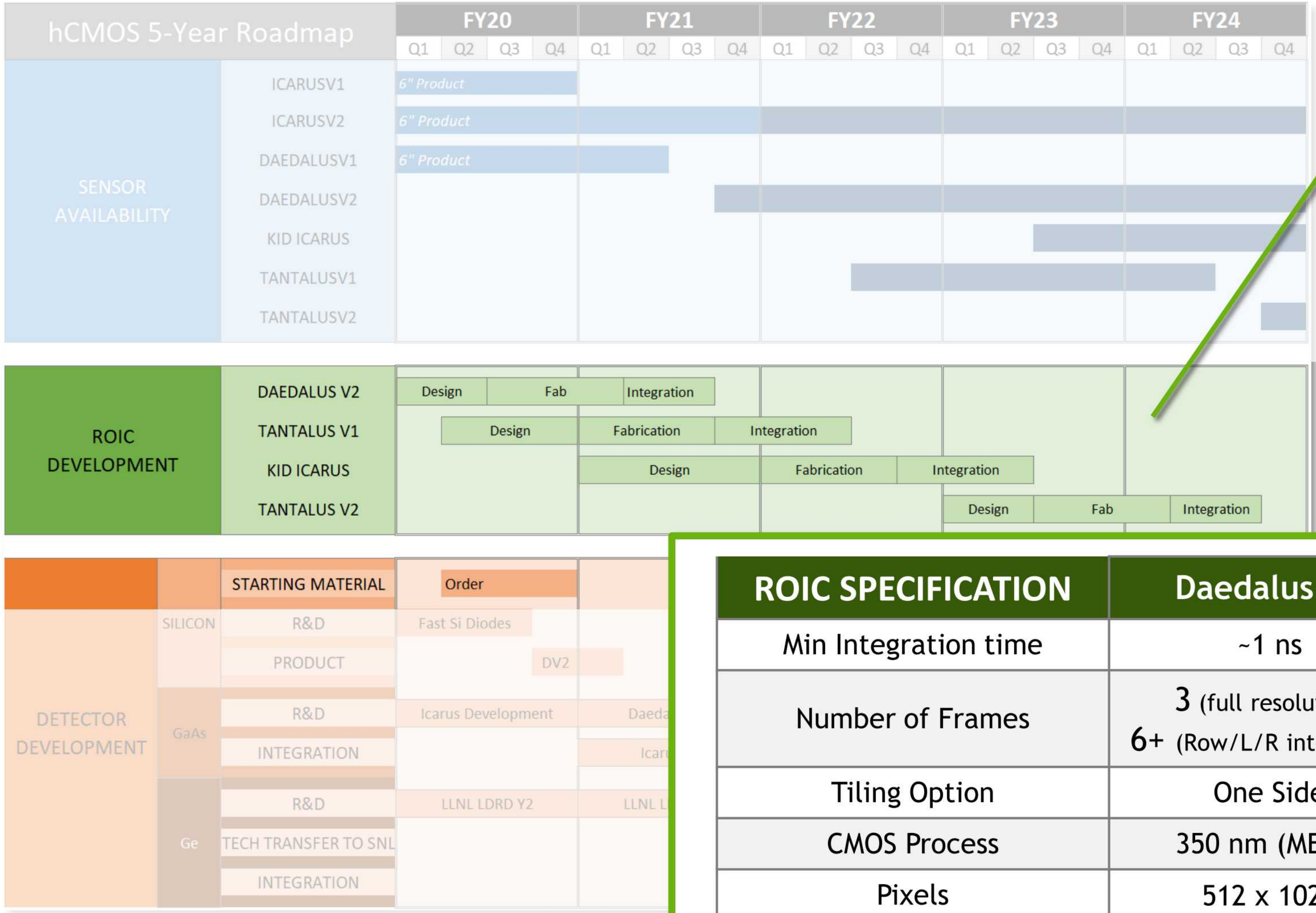
The hCMOS effort has established a 5-year roadmap in order to support diagnostic needs at Z-machine and other facilities

Sensor Availability

Users can incorporate the information shown in the roadmap in their diagnostic development plans

MESA fabricated sensors (Icarus and Daedalus) will be needed for the foreseeable future to support existing/planned diagnostics

The hCMOS effort has established a 5-year roadmap in order to support diagnostic needs at Z-machine and other facilities



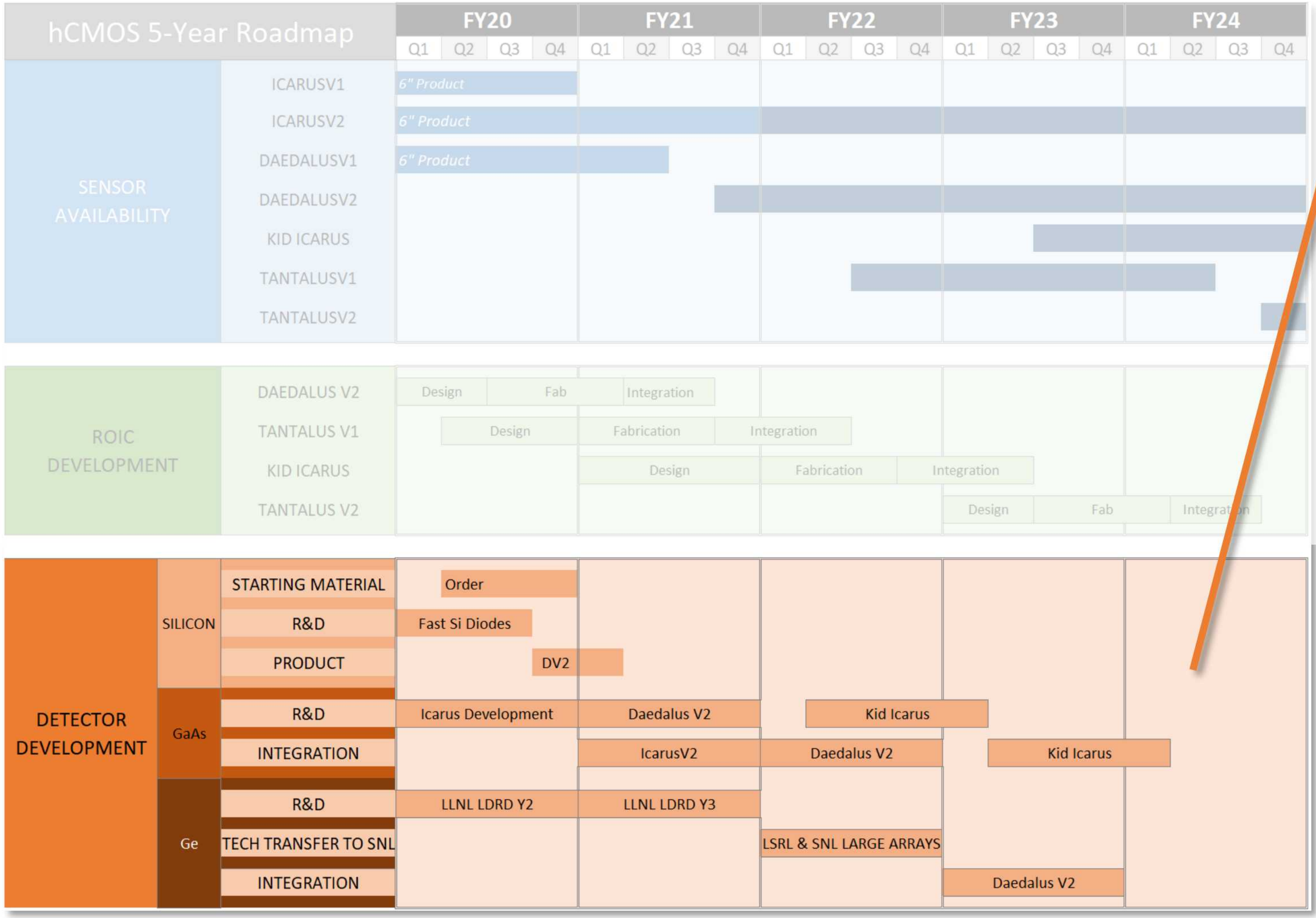
ROIC Development

ROICs will be fabricated at MESA as well as commercial foundries

- Commercial Foundry
  - ROICs will be designed to provide faster shutter times and more frames
- MESA
  - ROICs will support high radiation environments

ROIC SPECIFICATION	Daedalus V2	Tantalus V1/V2	Kid Icarus
Min Integration time	~1 ns	500 ps	~1.5 ns
Number of Frames	3 (full resolution) 6+ (Row/L/R interlacing)	4-6 (full resolution)	4 (full resolution) 8 (L/R interlaced)
Tiling Option	One Side	No	**No**
CMOS Process	350 nm (MESA)	130 nm (Jazz)	350 nm (MESA)
Pixels	512 x 1024	512 x 1024	256 x 512
Capacitor Full Well	1.5 million e^-	0.5 - 5 million e^-	0.5 million e^-

The hCMOS effort has established a 5-year roadmap in order to support diagnostic needs at Z-machine and other facilities



Detector Development

Silicon Detectors

- The ROIC shutter times are no longer the limiting factor for fast integration times, efforts in progress to increase speeds of existing silicon photo diodes
- There are needs to increase the sensitivity of Si detectors, leveraging JPL Delta-Doping

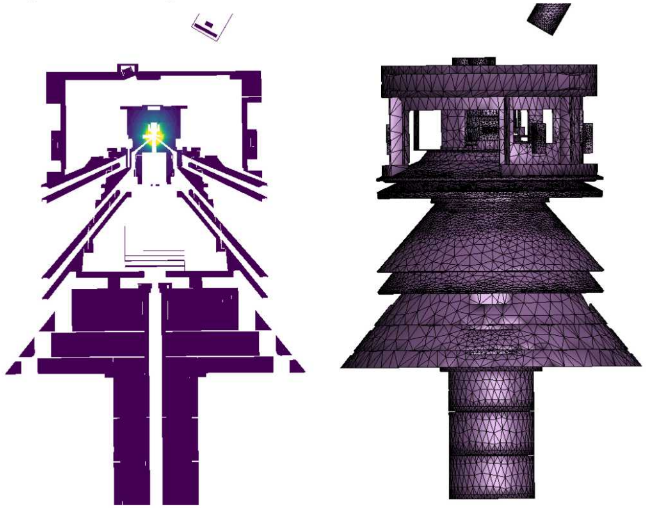
III-V Detectors

- Large need for sensitivity at 10-30keV X-ray
- GaAs detector work in progress at SNL
- Ge detector work in progress at LLNL
- Will require new pixel architectures (Tantalus) to handle large current values

Neutron Development Activities on Z

Neutron Transport Modeling

- Importing solid models into Attila

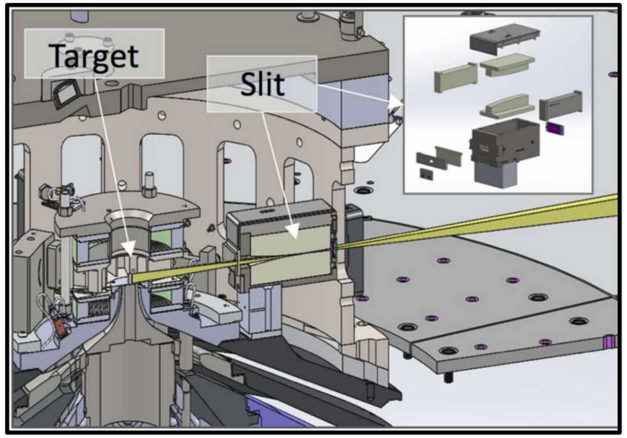


- To improve the fidelity of neutron yield measurements
- **SNL-CA & LLNL** developing large scale facility models for personnel dose modeling, understanding backgrounds for diagnostics, shielding

See Mike Mangan (1683) for more information

Imaging

- One-dimensional neutron imaging is in routine operation
- Recently developed capability to etch and scan CR39, which is the detector in this system – ODIN.



- Collaborating with LLNL, LANL to develop next generation of imagers for Z

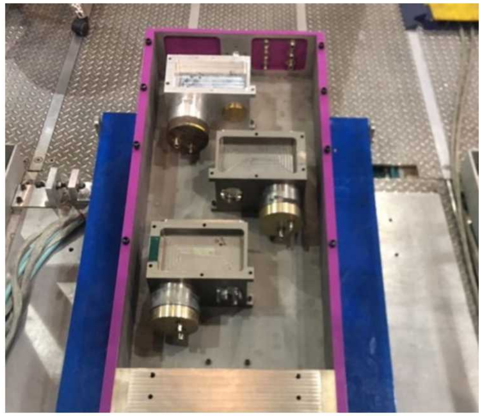
See Mike Mangan(1683) for more information

Burn History

Typically x-ray time-history is used as a surrogate for burn history on Z.

Multiple diagnostics are being developed to directly measure the fusion burn history.

- Gamma reaction history and Aerogel Cherenkov detector (in collaboration with LANL)
- CVD diamonds (in collaboration with LLNL



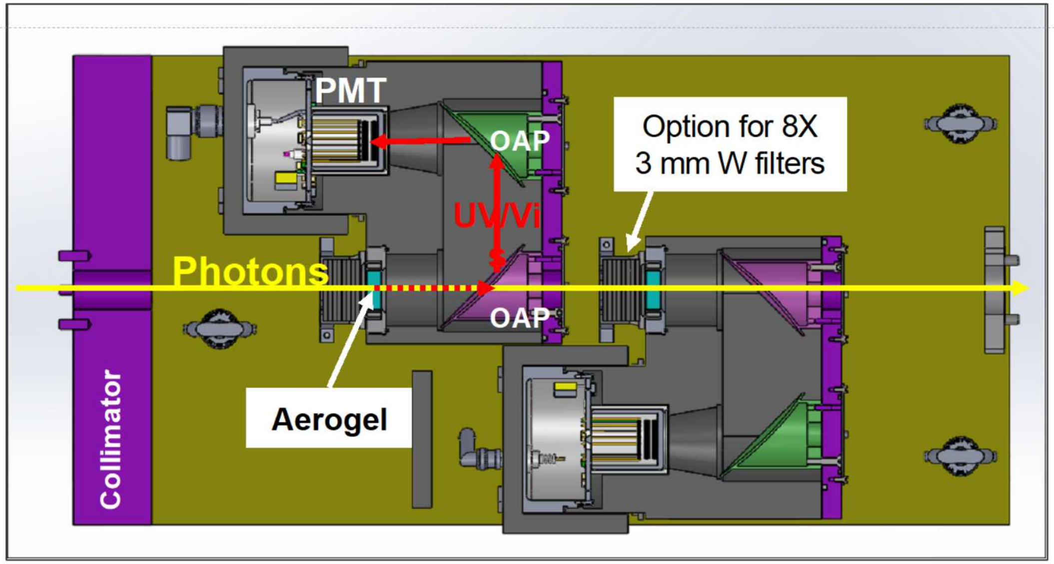
See Gordon Chandler (1683) for more information

Introduction of trace tritium into Z enables direct measurement of the nuclear burn history via gamma ray detection

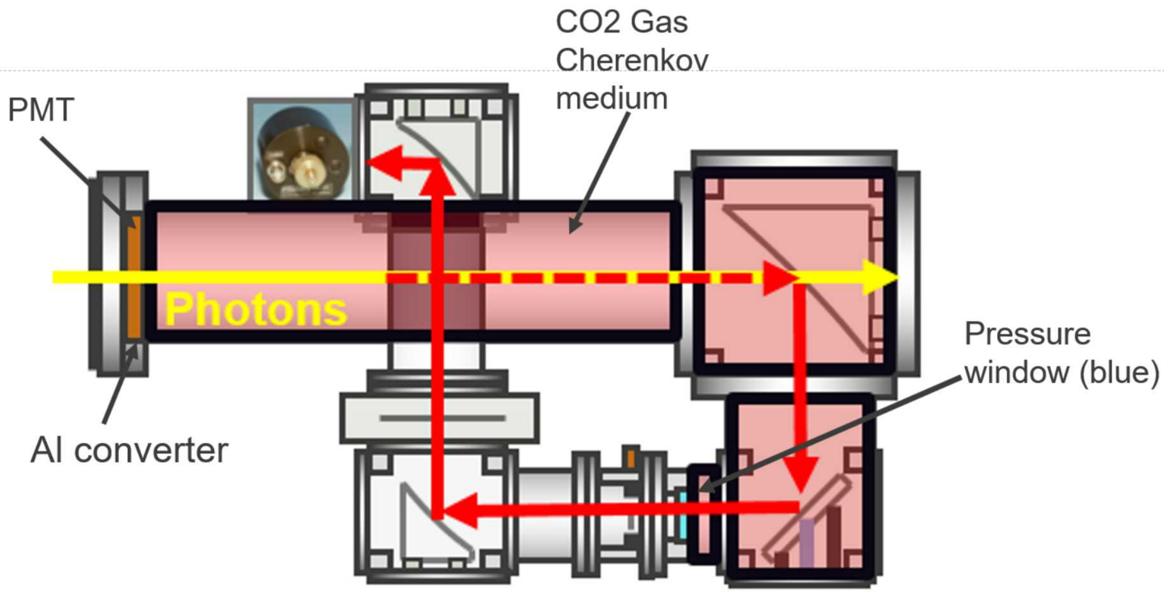
Cherenkov Detectors on Z will provide time-resolved x-ray and gamma detection in photon energy range >0.3 MeV

Cherenkov Detector steps:

- High-energy photons are Compton scattered to create high-energy electrons
- Relativistic electrons pass through Cherenkov medium → emits VIS/UV photons
- VIS/UV photons are relayed to PMTs

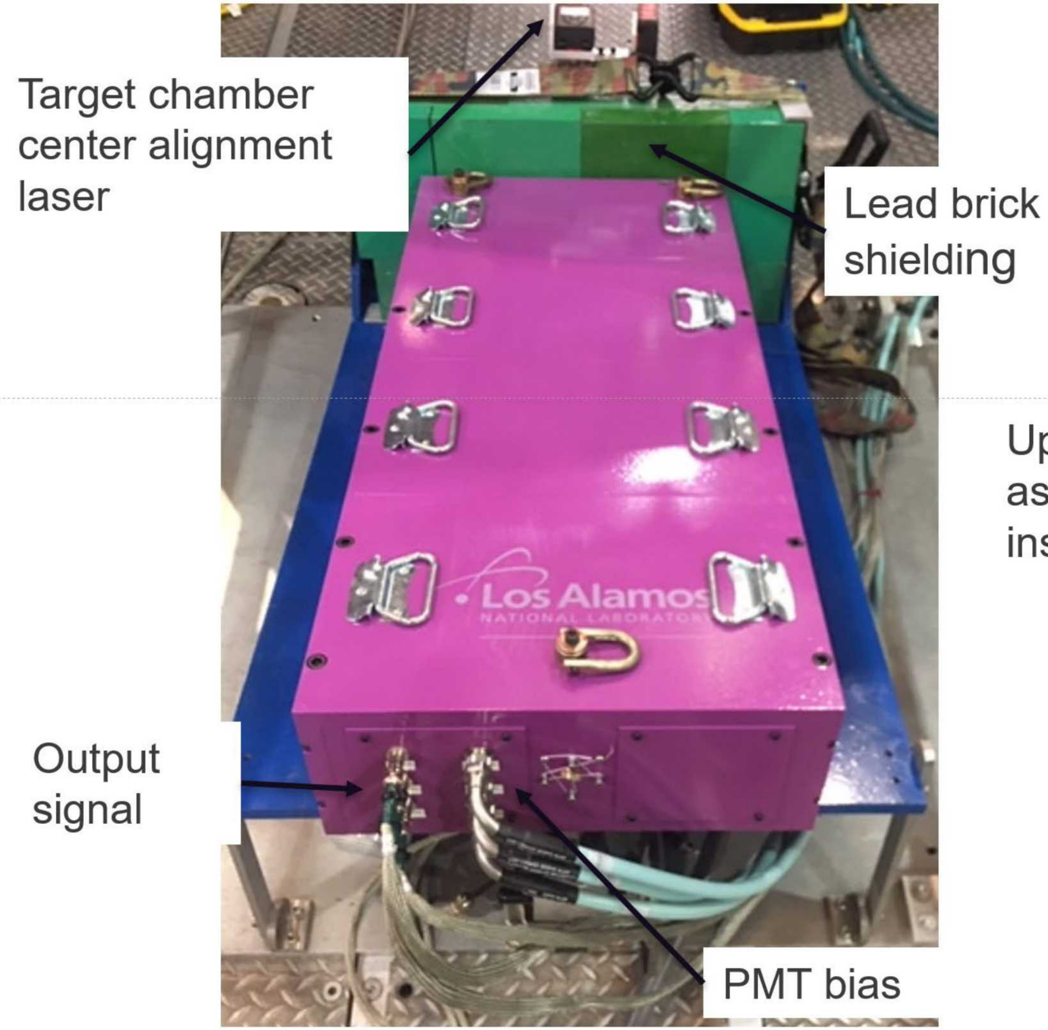


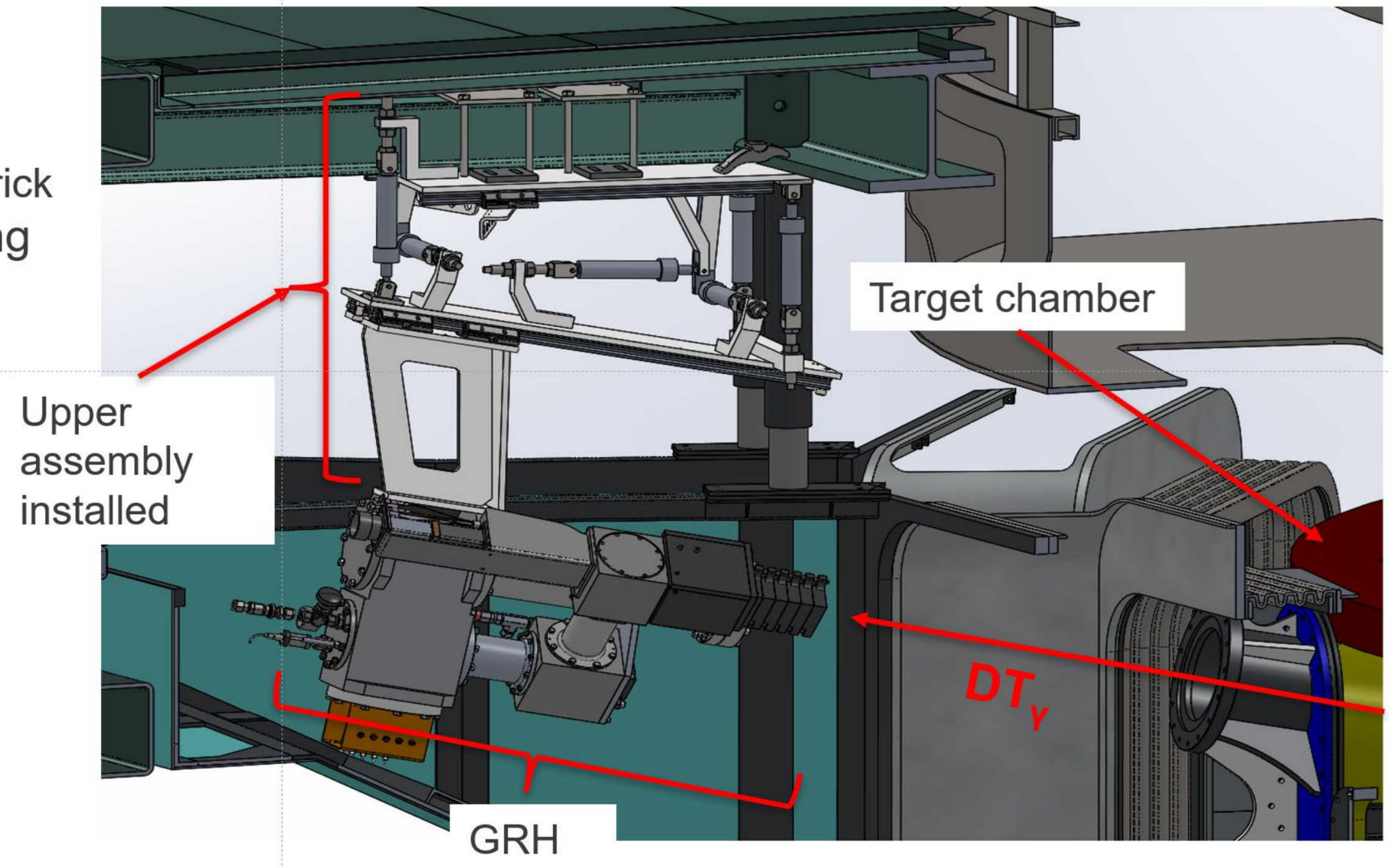
ACD: 2 module configuration (0.3-6.0 MeV)
→recently upgraded to 3 modules



GRH in LLE OMEGA configuration
(>3.0 MeV)

ACD is currently installed with the GRH installation planned for the week of August 3, 2020 → Data collection week of August 17



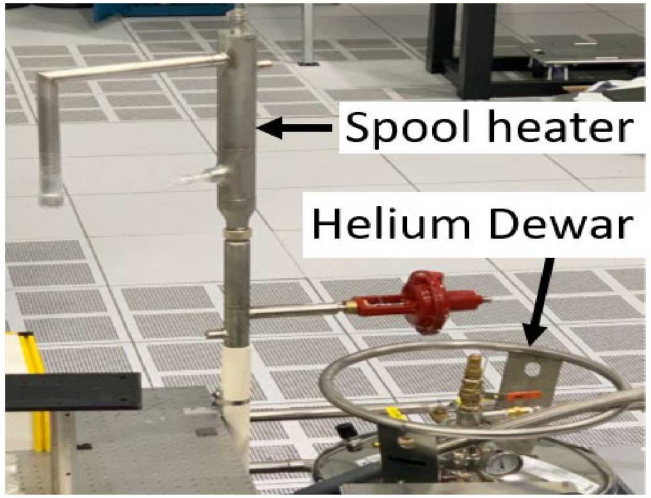


Experimental Systems

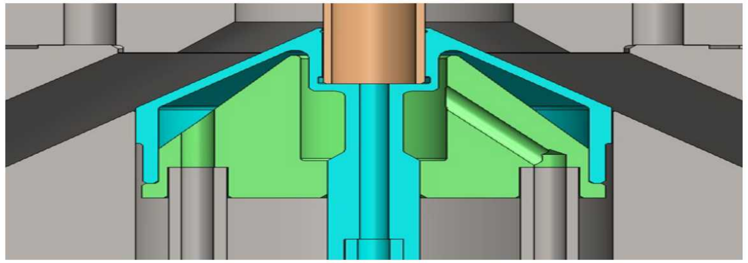
➢Advance Fuel Configurations	Tom Awe
➢Advanced Cryo Cooling Techniques	Allen Crabtree
➢Tritium on Z Roadmap	Michael Jones
➢Gas Fill Capabilities*	Allen Crabtree
➢Applied B on Z (ABZ)*	Derek Lamppa

Focused efforts to improve cryogenic target capabilities at Z

High pressure Dewar w/ spool heater
- Compact cryostat for cathode cooling
- Eliminate in chamber heaters
- Extended cooling times by ~3X

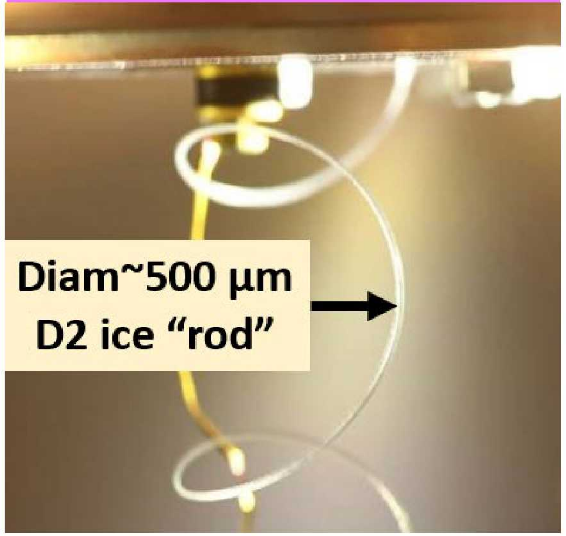


Liquid helium is vaporized and heated to a desired setpoint temperature at the Dewar

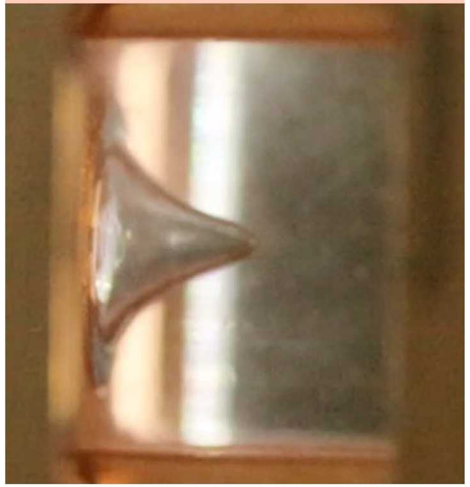


Advanced Fuel configurations
- Extruded deuterium fibers
- Gettered ice layers and fills
  - Kr-doped ice is goal

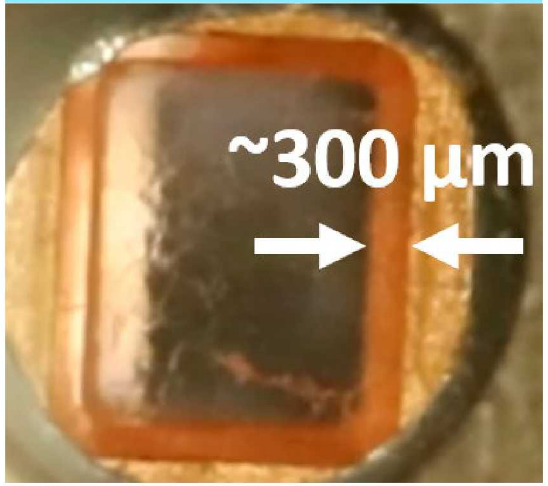
First test of deuterium screw extruder—helix likely due to crude/rough nozzle



½"-scale cell filling with uniform gettered ice



Thin shells of D2 ice



To realize the full potential of tritium in Z experiments we need to be vectoring towards ~10 experiments per year at higher target inventories.

Tritium Multi-Year Capabilities

1-3 Year Outlook	3-5 Year Outlook	5-10 Year	
100 mCi	200 mCi	500 mCi	Target Inventory (Chamber)
0.5 - 2 Ci	2 - 5 Ci	10 Ci	Target Inventory (UCV)
< 1E15	<1E16	<1E17	Facility Yield
1-3	2-5	10-12	Experiments / year

- 2 Planned shots left this calendar year

Thanks