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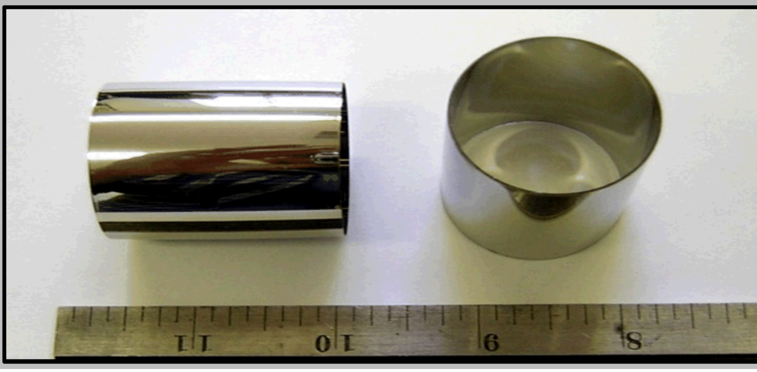

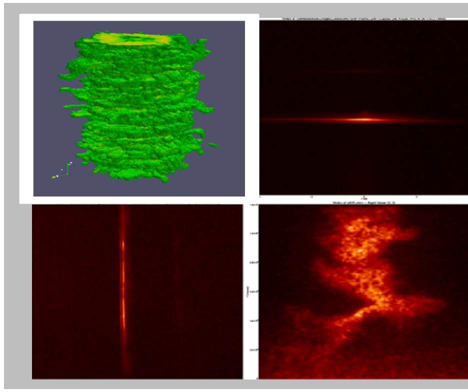

Wolter Imaging On Z

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ICF Diagnostics Workshop, October 5th 2015

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

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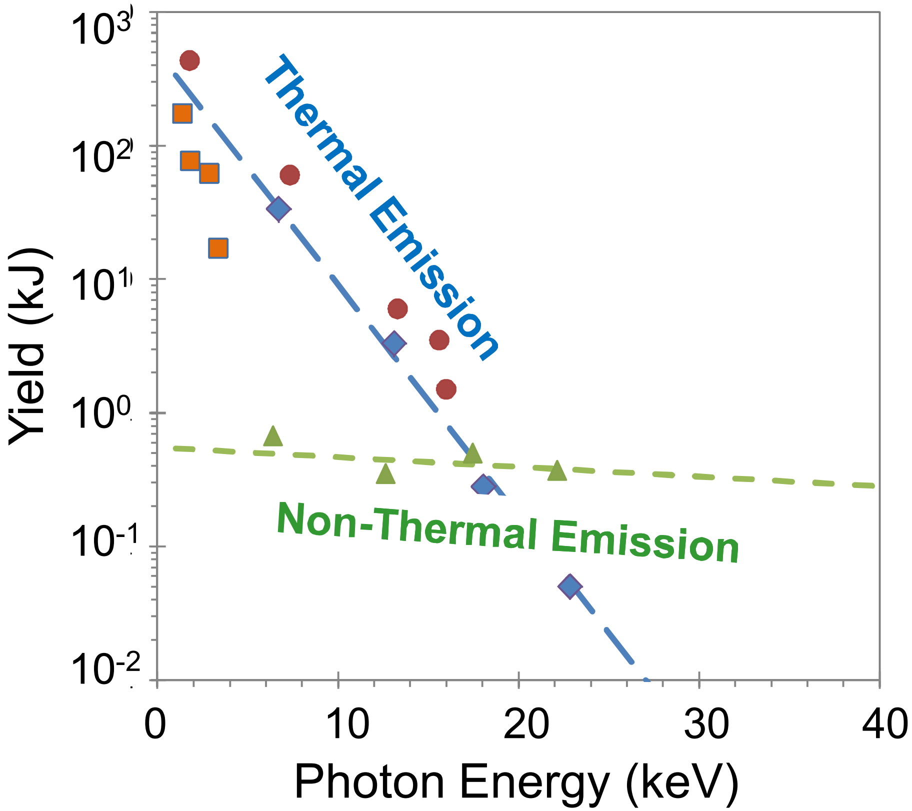
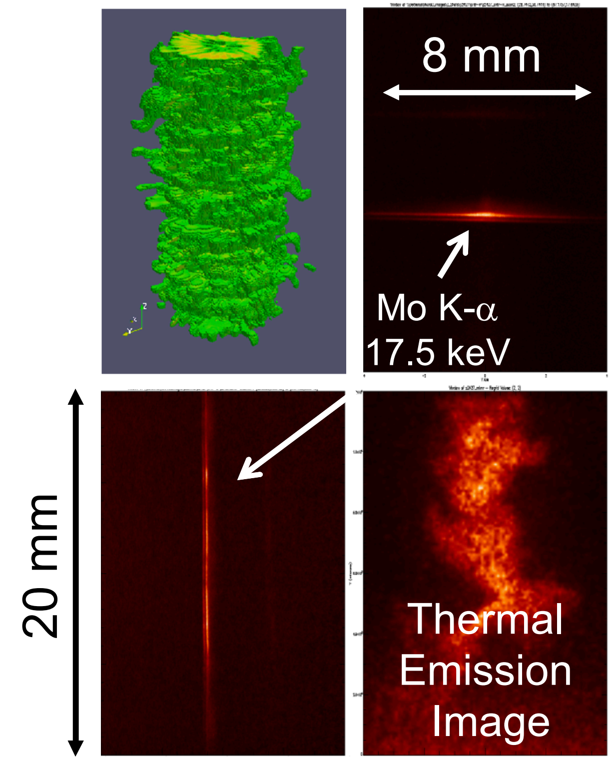
K-α emission from z pinches can provide >15 keV x-rays for Radiation Effects Science – Where do these x-rays originate?

Non-thermal processes (cold K-α) become more efficient at >15 keV



Spectra show cold K-α from a large area, but structure is complex

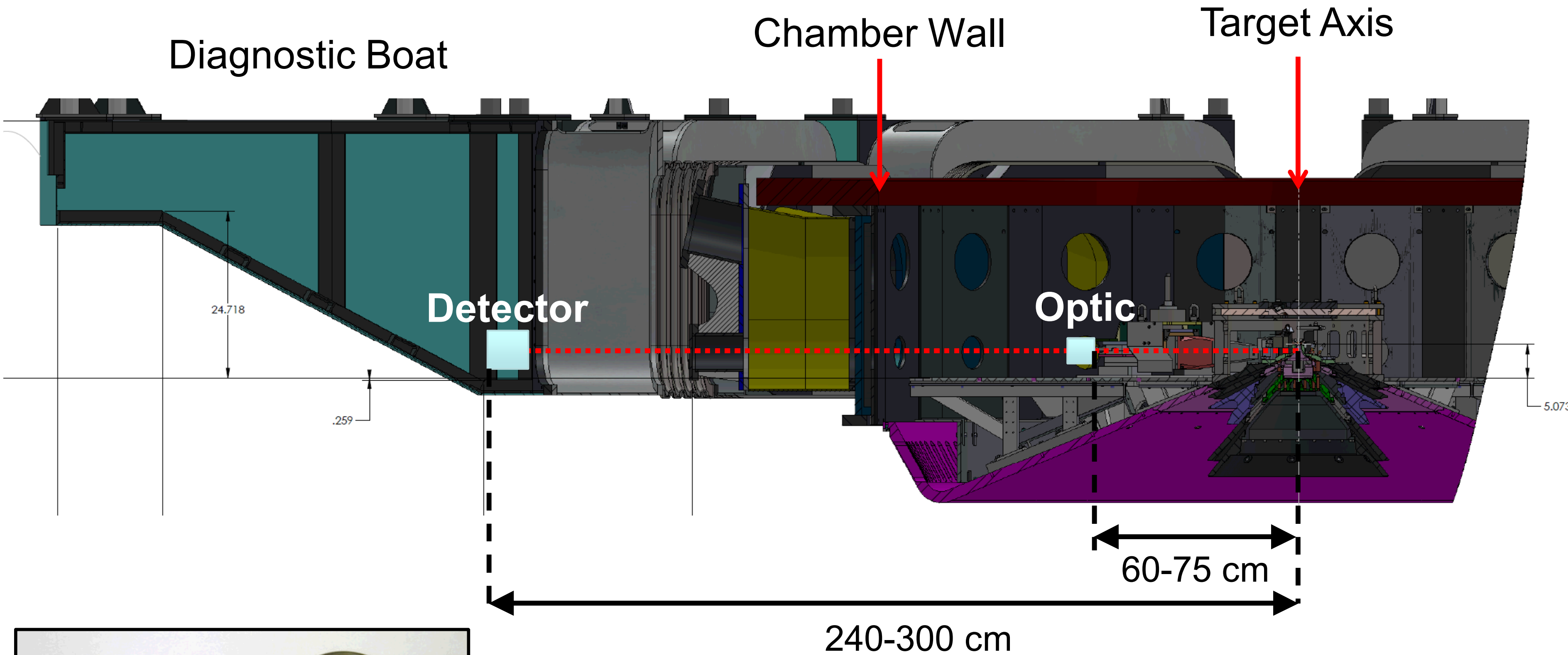


Monochromatic Kα imager needs

Need	Goals	Driver
Photon energies (Kα's)	Mo: 17.479 keV Ag: 22.163 keV W: 59.318 keV	Study K-shell radiators from Ag to W *Also: Off line-center? (L-shell state)* *He-α?*
Spectral window	~1 keV	Simultaneously view K-alpha 1 & 2 from cold and low-ionization states
Field of view	+/-12 mm	Collect all emission from 2 cm pinch. Kα emission comes from large diameter
Spatial resolution	0.1 mm desirable; 0.25 mm required	Resolve length-scale of structures emitting Kα (don't know what these are)
Time resolution	Time integrated OK initially ~1 ns in 3-5 years	Resolve evolution over pulse
Sensitivity	100 J from ~cm^3 source with good signal to noise	Able to record 100 J over full source area
Calibration	Relative response at image plane known to <10%	No need for absolute calibration

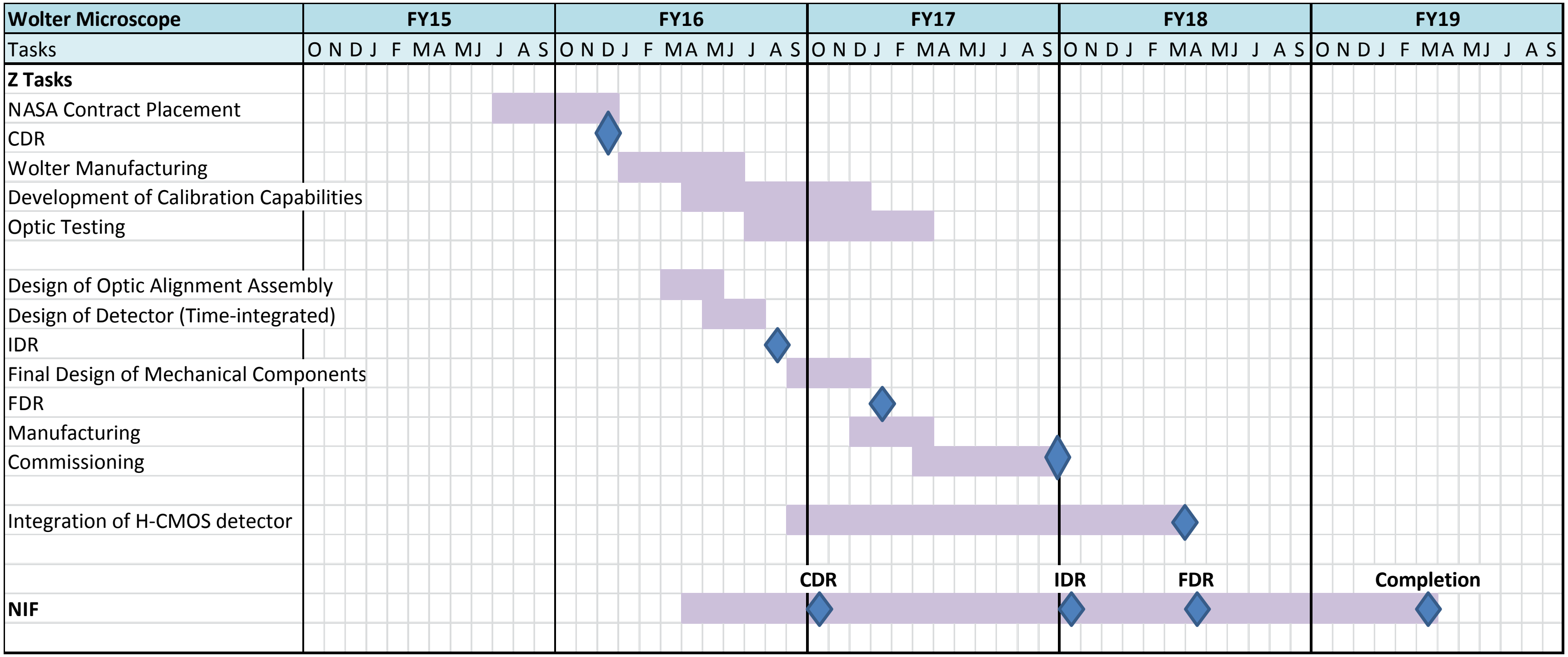
- Other considerations
  - Survivable (optic at >40 cm from source)
  - Hard x-ray background (1-inch W in LOS)
  - 0 degree view (detector <300 cm from source)

A mag = 3 Wolter microscope would go along a 0-degree port on the Z target chamber with the optic ~75 cm from the source



This is a geometry very similar to what has been previously demonstrated with multi-layer Wolters

The development roadmap has the first Wolter system fielded on Z in FY17 with time-resolved versions on Z and NIF in FY19



- Manufacture and test multi-layer Wolter optic for Z before beginning significant design for NIF
- hCMOS at 20-40 keV comes available in FY18-19

Why a Wolter?

- Requirement is for large FOV (so no kB)
- Can de-couple resolution from effective collection area
- Custom tailoring of x-ray spectral bands
- Comparison with a Pinhole:
  - For same magnification and detector plane:
    - ~2mm pinhole to maintain same number of photons on detector
      - Resolution insufficient
    - To maintain resolution, 400X decrease in signal
      - SNR insufficient
  - To maintain similar resolution and signal level on detector: 100-micron pinhole; detector 35 cm from load (pinhole 23 cm), assuming equivalent filter efficiency.
    - Detector survivability an issue, facility integration much more challenging, higher background

Parametric design space for SNL Wolter Optic

Case A1-A8 (Mo)
- M=3/4
- D= 2.54/2.92/3.05 m
- Mirror length (L_H)= 30/40 mm
- θ_i = 1.33°
- FoV ≈ ± 10 mm
- $\eta \approx 10^{-5}$

Case B1-B8 (Ag)
- M=3/4
- D= 2.54/2.92/3.05 m
- Mirror length (L_H)= 30/40 mm
- θ_i = 1.05°
- FoV ≈ ± 10 mm
- $\eta \approx 10^{-5}$

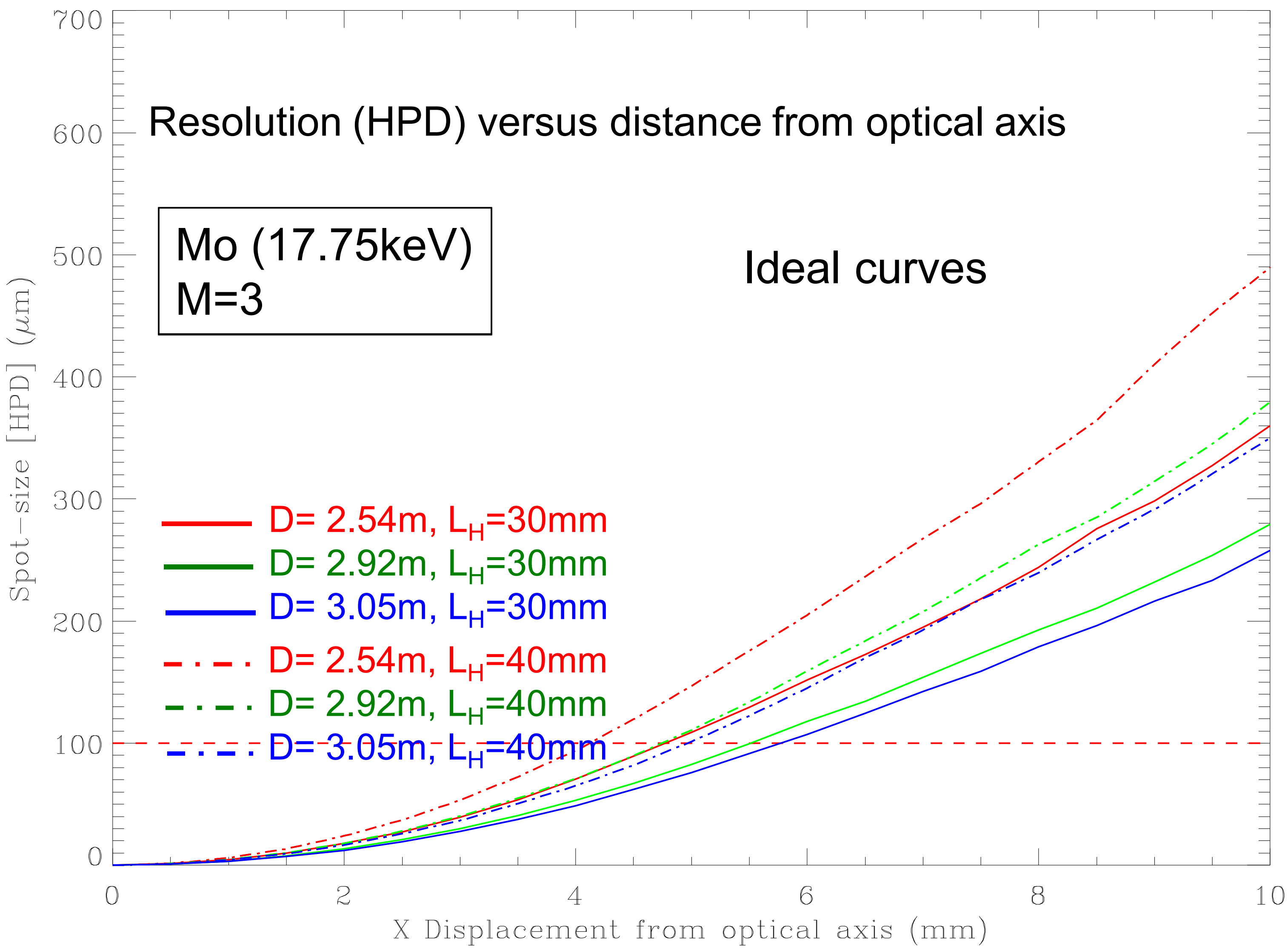
Case C1 (Mo)
- M=4
- D= 3.00 m
- Mirror length (L_H)= 20 mm
- θ_i = 0.47°

(Suzanne's parameters)

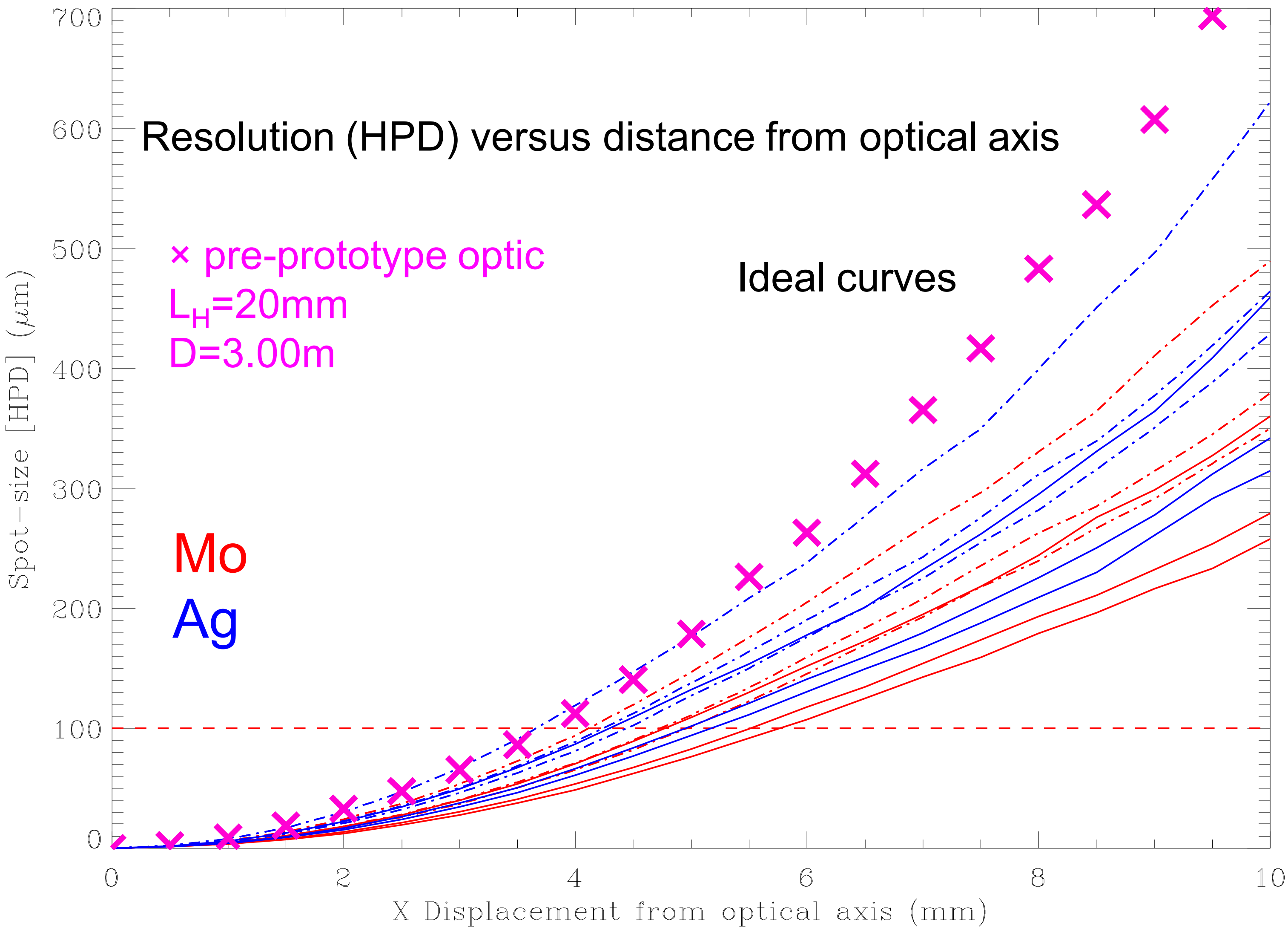
Parameters for case A and B are similar, but currently optimized for corresponding energy

Note: all curves are "ideal curves", i.e. no figure error, ML included

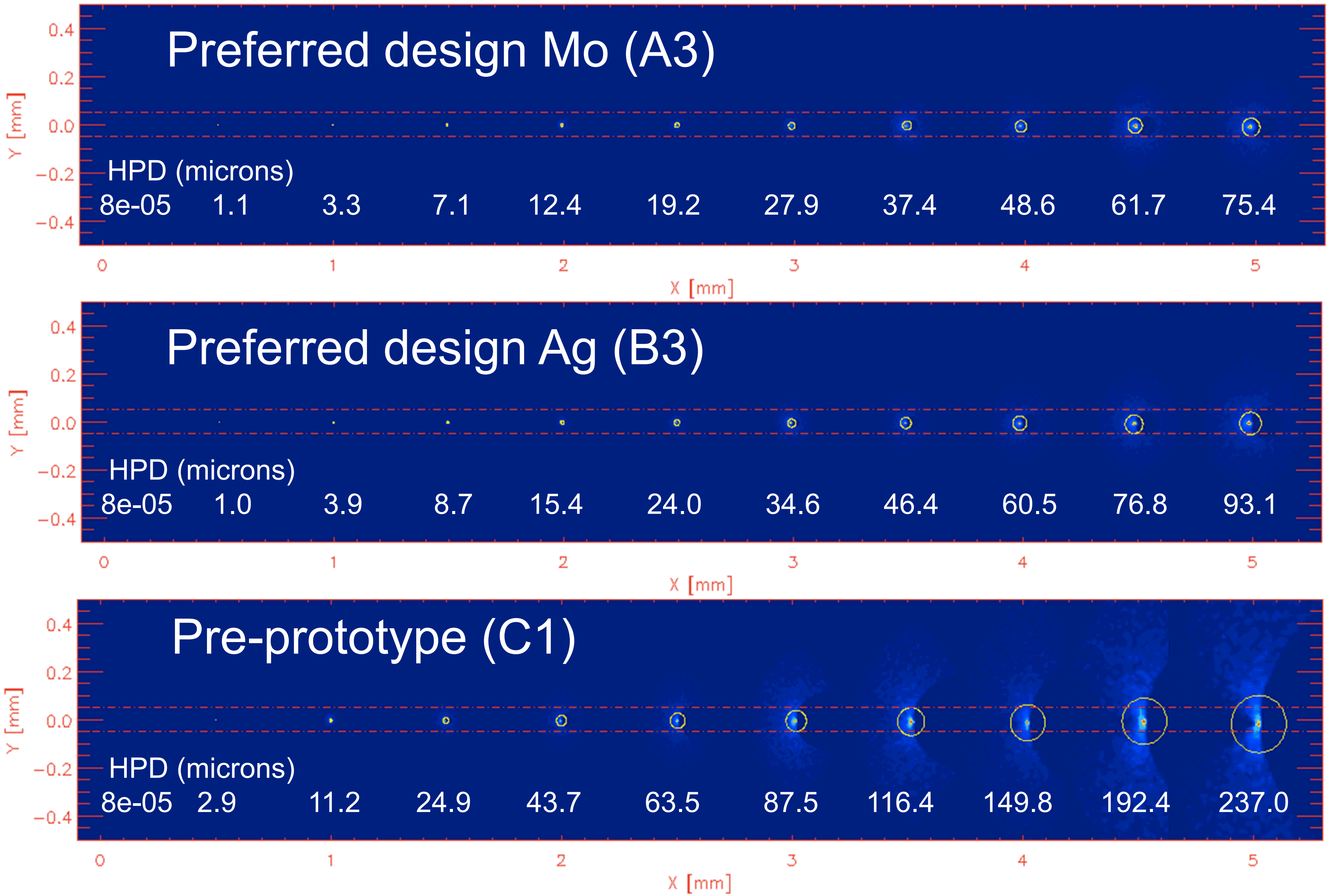
Resolution (object plane), mirror length



Resolution (object plane)



Resolution (object plane)

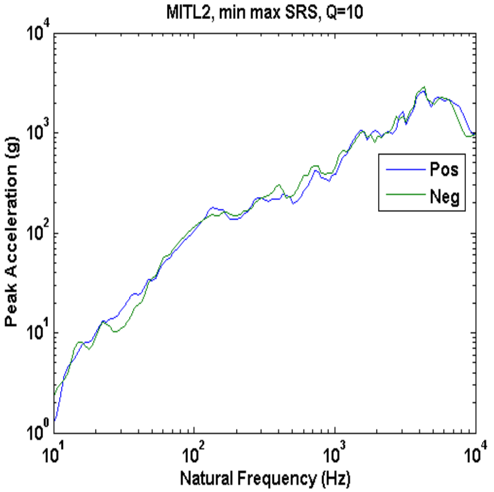


Wolter Optic calibration

- The calibrations are needed to determine throughput and resolution as functions of x-ray energy and off-axis angles
- Initial calibration at synchrotron light source (APS)
- Develop in-house calibration facilities (LLNL and SNL)
- X-ray source requirements: energy (15-100 keV), flux (~10^6 photons.sec^{-1}.mm^{-2}), and beam size (10s mm for SNL)
- High precision rotation and translation stages for Optics: three-axis rotations, (0.001°) and two-axis translations (~ 1μm)
- Hard x-ray imaging detectors: CCD-based hard x-ray imager

Shock and debris pose major challenges

- Wolter Multilayer Optic will sit ~76 cm from the pinch
  - Protecting from debris damage and soot deposition critical
  - Plan is to use heavy filtering and hermetic sealing of optic to protect it
    - 3 X 0.5 mm aluminized Kapton on front, 1X0.5 mm on back
    - Sintered filter on vent port
- Significant experience with other diagnostics (CRITR, TIPC) at similar or nearer locations using this methodology
- Promise shown with other protection schemes for large-format imagers (XRS3; UHD polymers)
- Strategy will be to protect the optic, but make the alignment stage low-cost, potentially disposable



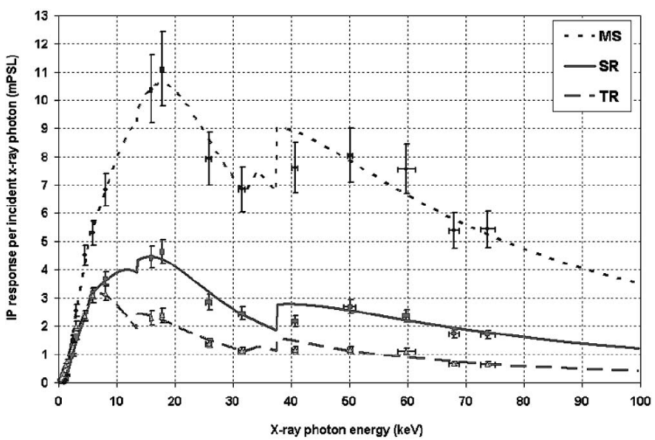
Optic Alignment Tolerance and Alignment Strategy

- Alignment requirement based on:
  - optic performance simulation
  - angular misalignment will be similar to thin lens
- R, Z, Theta of optic: +/- 1 mm acceptable
- Angular alignment +/- 2 miliradians

- Alignment logistics:
  - Retro-reflector on back of optic
  - Visible laser to define optical path, angular alignment of optic
- Motorize alignment to enable alignment from diagnostic boat and while under vacuum

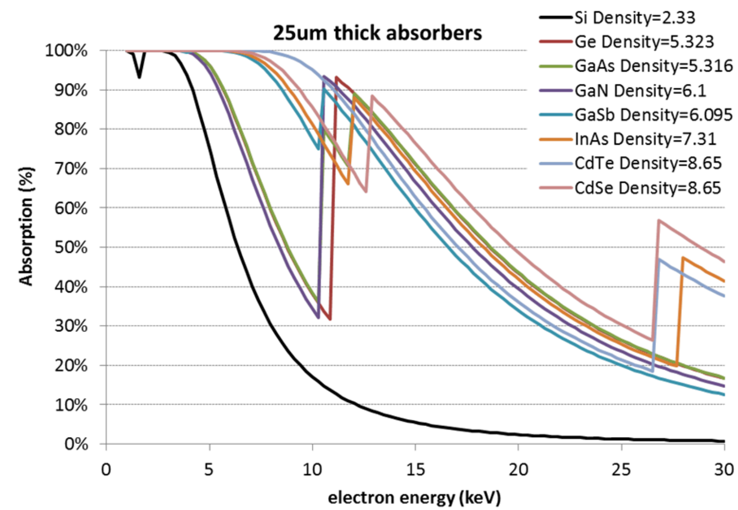
Detector

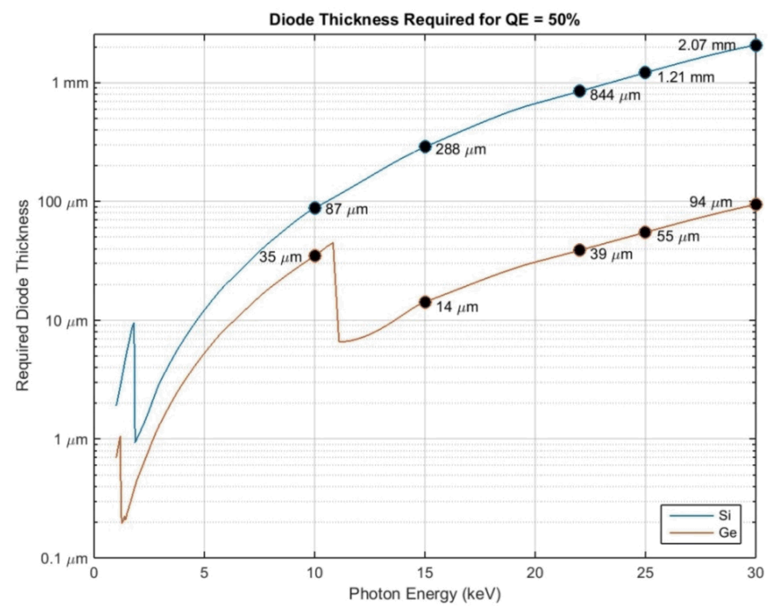
- Image Plate



Ref: RSI Vol 79, 113102 (2008)

- H-COMS:1- 2 ns gate time, 8-frame, FY18)
  - 3-D diode approach
  - High Z material, Ge or GaAs





Summary

- Initial studies show it's feasible to meet the science objectives for measuring cold k-alpha emission on Z with a Wolter microscope
  - Simulations of resolution (HPM) meet requirement
  - Estimated reflectivity and spectral window promising
  - Alignment tolerances achievable
- Implementation appears to be straightforward
  - Debris mitigation feasible
  - Alignment requirements do not require complex implementation
  - Time-integrated detector trivial (image plate), time-gated depends on hCMOS development of a high-energy (20-60 keV)sensor in FY18