SAND2011-4107P

Experiments to Characterize a > 100 keV, High-Resolution X-ray Backlighter for Cylindrical Imploding Liners at the Z Machine

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Tim Webb[1], Bob Campbell[1], Dawn Flicker[1], Matthias Geissel[1], Ray Lemke[1], Craig Miller[2], and Bryan Oliver[1]

[1]Sandia National Laboratories, Albuquerque, NM

[2] Voss Scientific LLC, Albuquerque, NM

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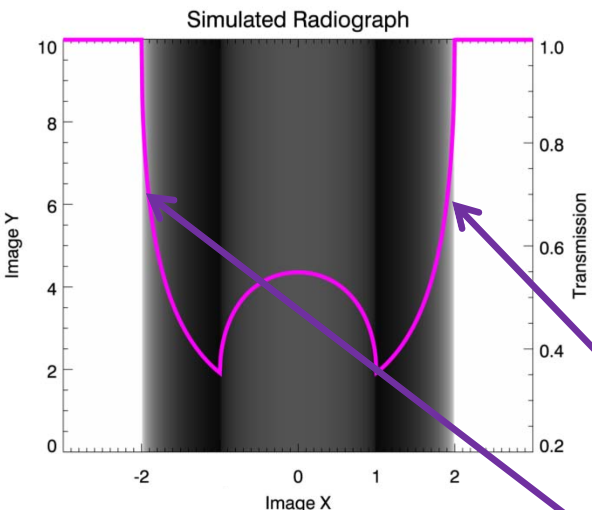
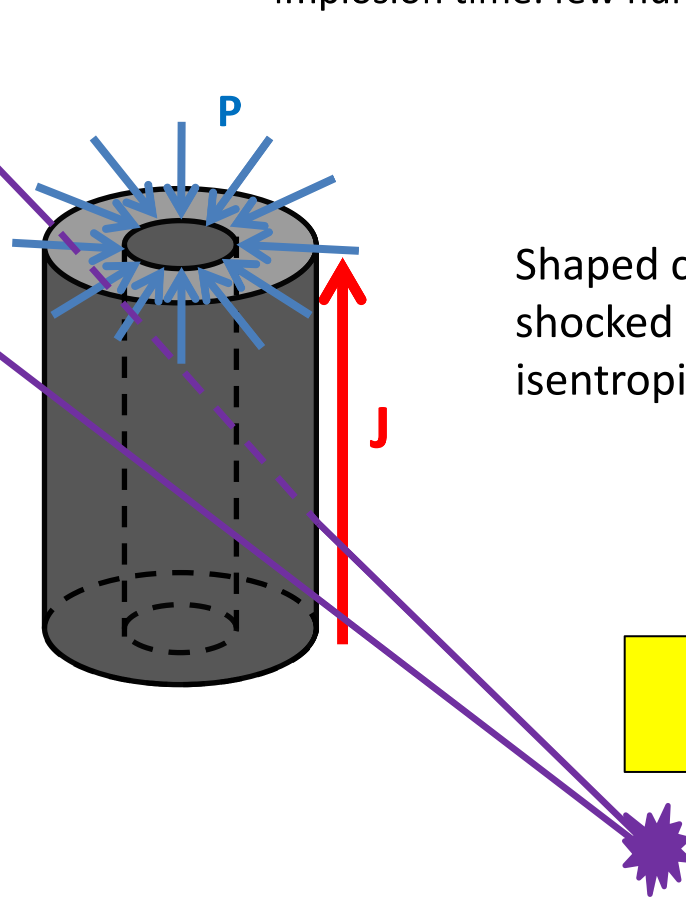
Motivation: Dynamic Material Studies Using Imploding Liners at the Z Machine



I ~ 20 MA
Implosion time: few hundred ns



Shaped current pulse to achieve shocked or unshocked (quasi-isentropic) compression.

$$P \propto \left(\frac{I}{R}\right)^2$$

$$R = 2.5\ mm$$

$$P \approx 10\ Mbar$$

X-ray backlighting (ps to ns)

Current capability: Z-Beamlet (< 10 keV)
Future capability: Z-PW (10's to hundreds of keV)

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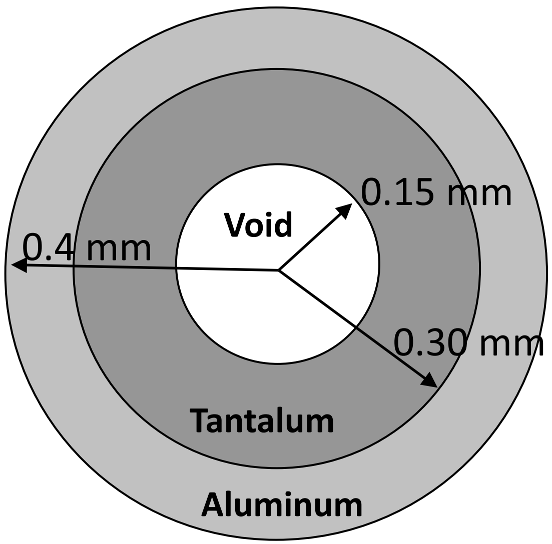
Project Goals

• Current capability -- **Z-Beamlet**. Few kJ over a few ns. < 10 keV x-rays, high resolution, mono-chromatic imaging with curved crystal imaging.
• New laser system -- **Z-PW**. Currently operating at 100 J at 0.5 ps (200 TW). K-shell or bremsstrahlung x-rays with point projection imaging.
• Future experiments envision nested imploding liners using mixture of high-Z and low-Z.

Example of liner configuration:



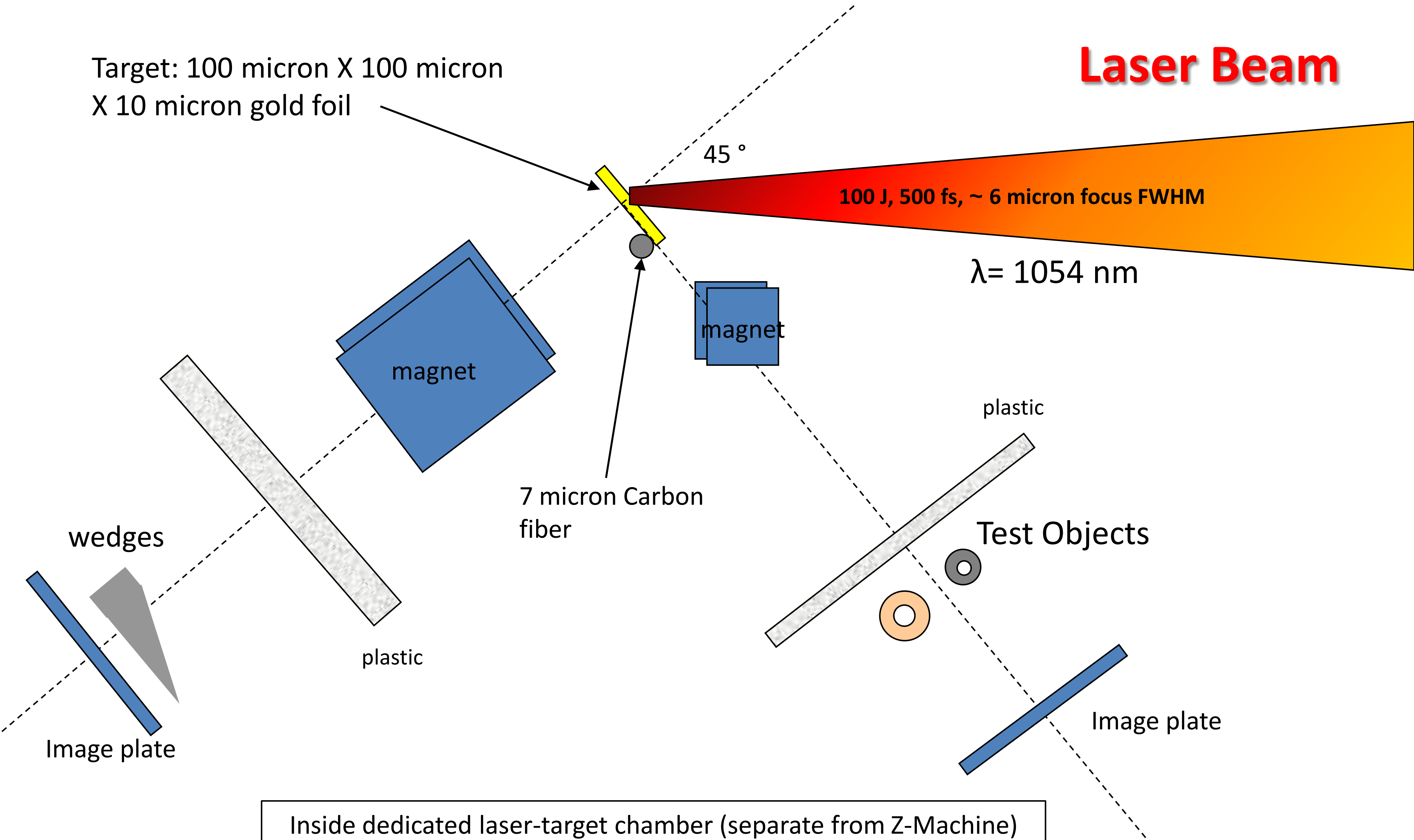
Copper (or other material) may be substituted for Tantalum.

• Develop high-energy penetration to view internal structure. Must have adequate transmission > 0.5 g/cm^2 Tantalum
• Resolution requirements: few tens of microns
• Dose requirements: few hundred mrads @ 1 m may be sufficient but depends on background on Z-machine which has yet to be determined.

Experimental Geometry

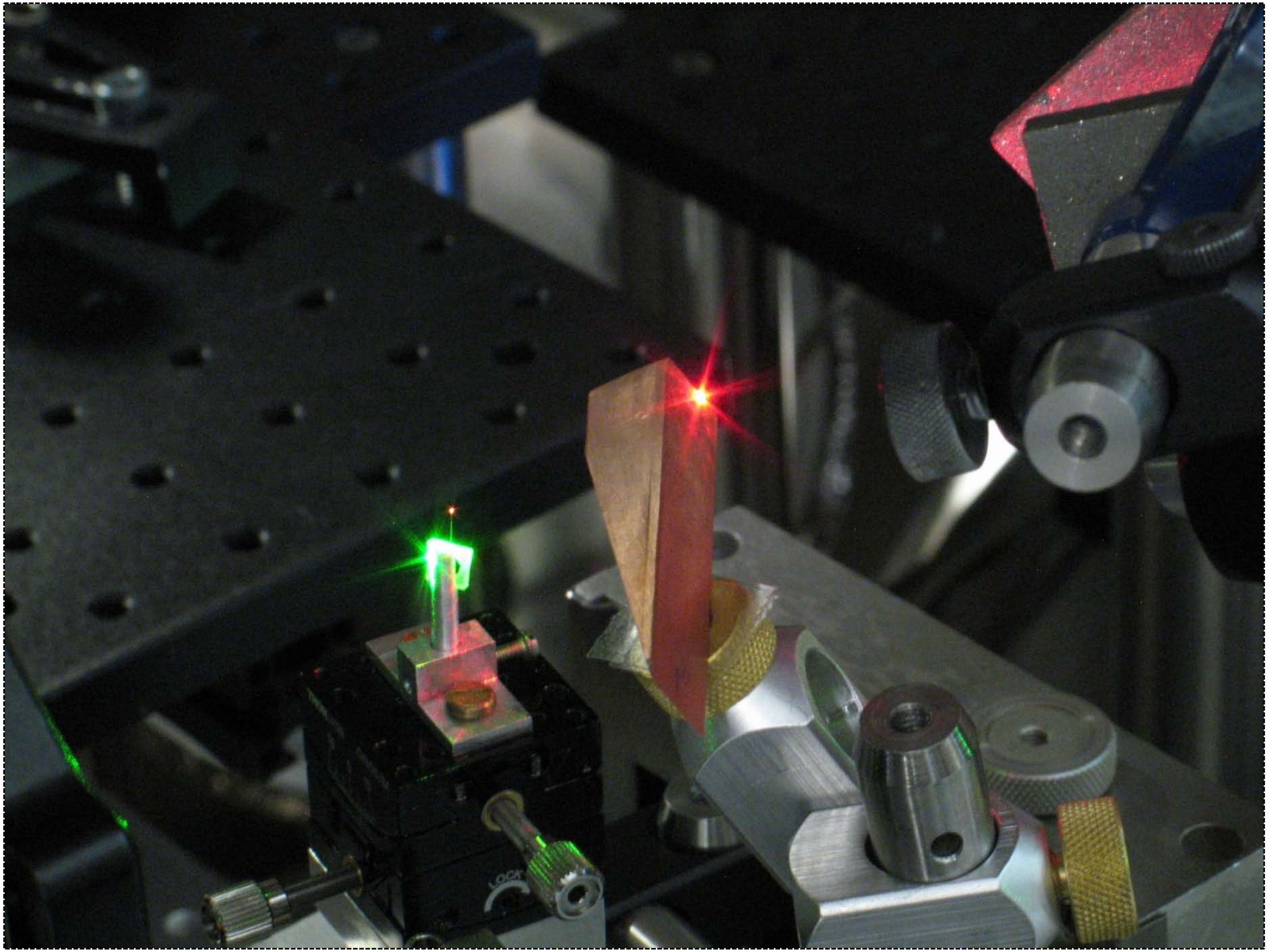
(not to scale)

Laser intensity: ~ 6 x 10^{20} W/cm^2



Inside dedicated laser-target chamber (separate from Z-Machine)

S-Polarization Setup: E-field is Vertical, Viewing Direction is Flag Side-On (minimum spot)
Laser beam comes in roughly from upper-right corner of image.



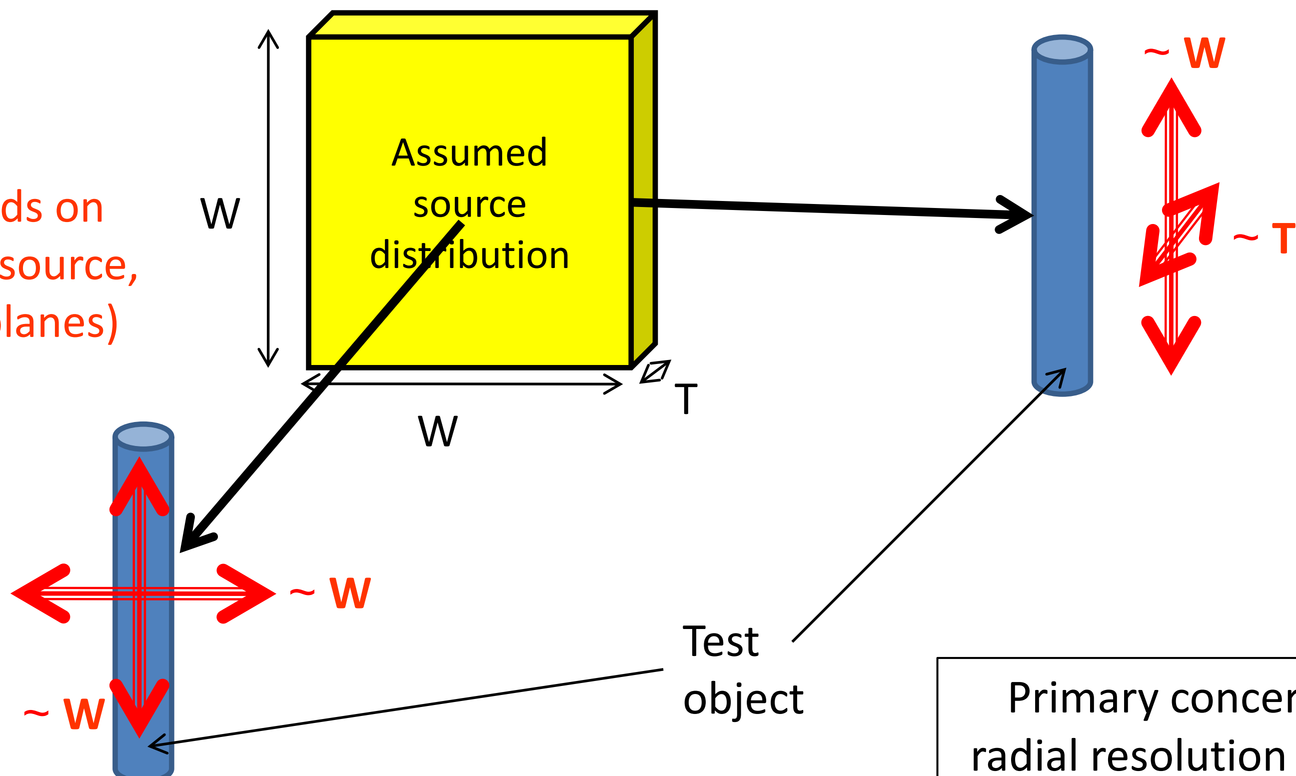
System Resolution

Total “blur” is the convolution of the source spot size and the blur within the detector.

$$Blur \approx \sqrt{\sigma_{\mathrm{source}}^{2} + \sigma_{\mathrm{det}}^{2}}$$

One must transform the blur factors to the plane of interest (object plane typically) via the radiographic magnifications. High magnification → source size dominates. Low magnification → detector blur dominates.

Source Blur
(exact value depends on relative distances of source, object, and image planes)

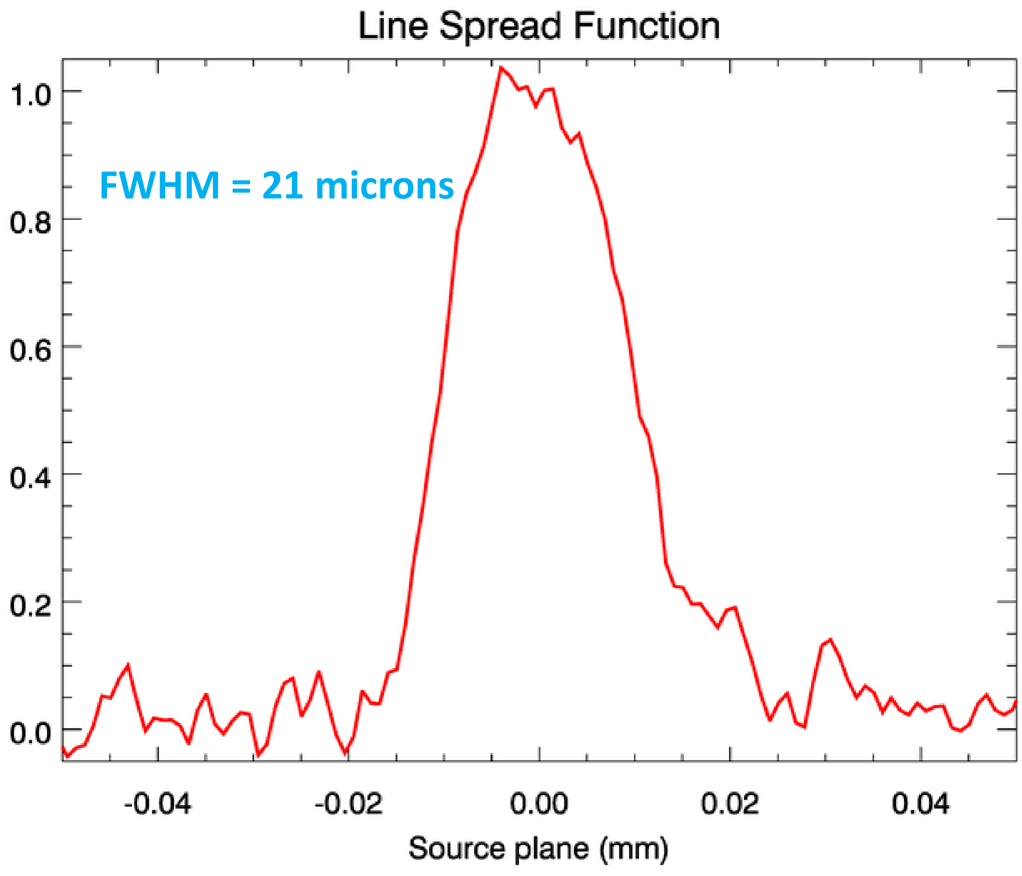


Measured Detector Resolution ~ 100 microns

Primary concern is radial resolution (~ T).

"Edge-On" Spot Distribution

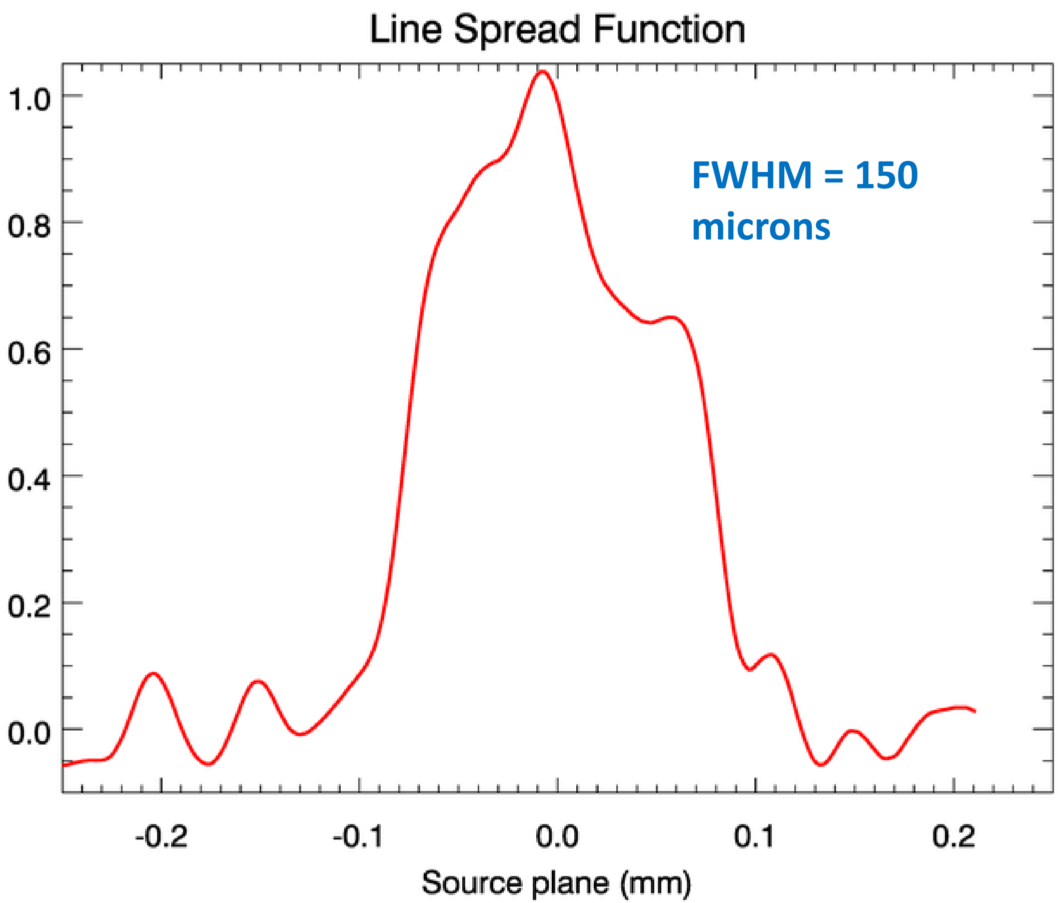
Edge is oriented parallel to the long edge of the foil, 90^0 from foil normal so that intensity gradient is sensitive mainly to x-ray source variations across the thickness of the foil.



There are several factors which would make the source size appear bigger than the foil thickness, most of them having to do with misalignments of the edge or foil. However spot sizes of ~20 microns or less are probably acceptable.

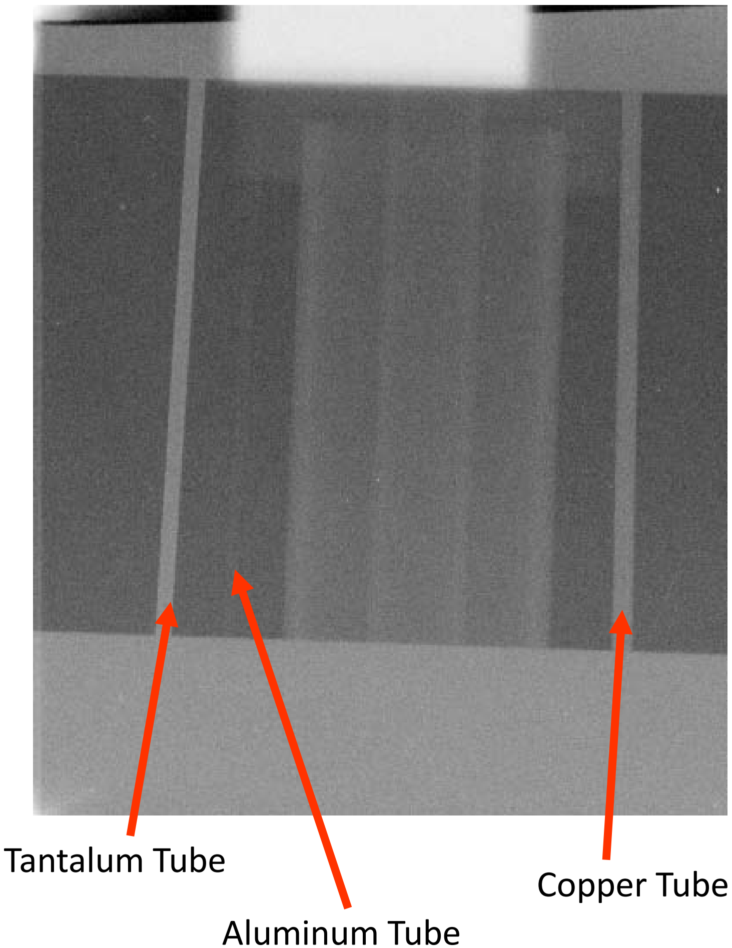
“Flag-Normal” Spot Distribution

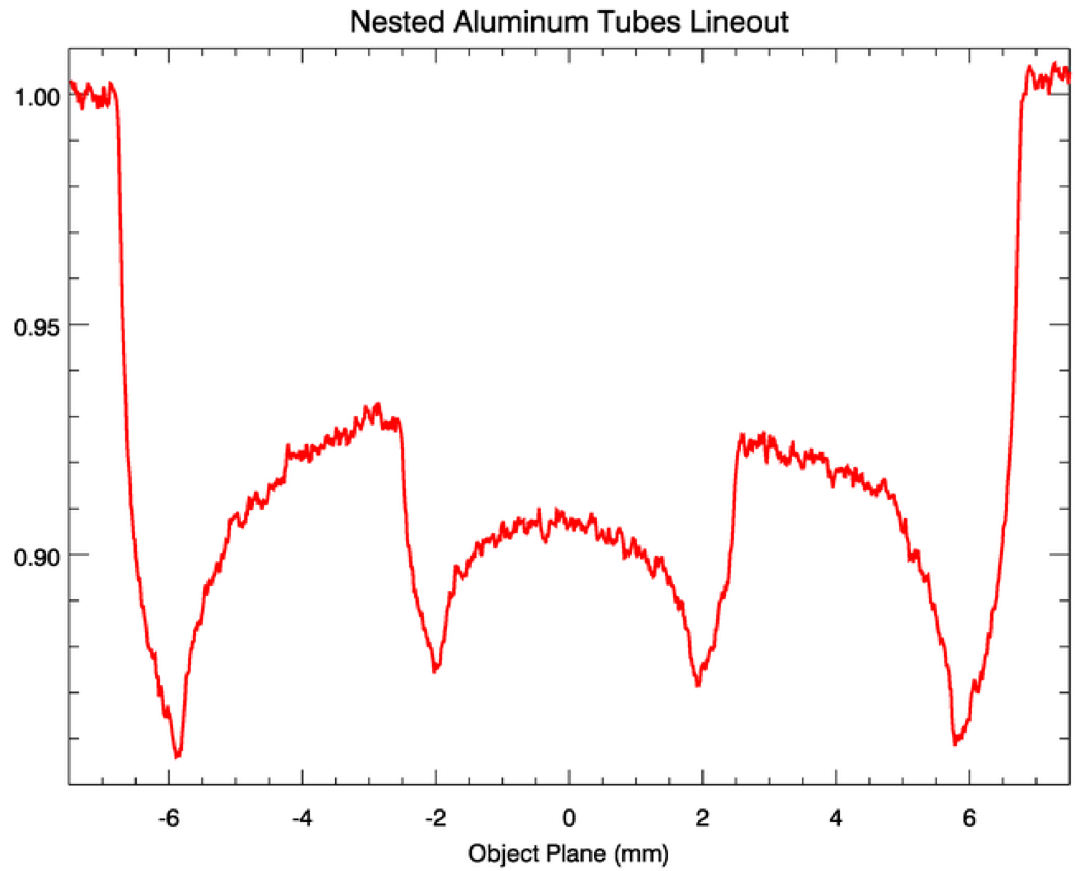
The spot size was also measured where the edge was placed in a direction approximately normal to the foil front surface. It was anticipated that the spot size would be about the size of the foil.



The foil width was actually about 130 microns. However the spot size was still somewhat larger. Asymmetry in the spot is obvious which suggests “hot spots” in the x-ray source.

Tube Radiographs

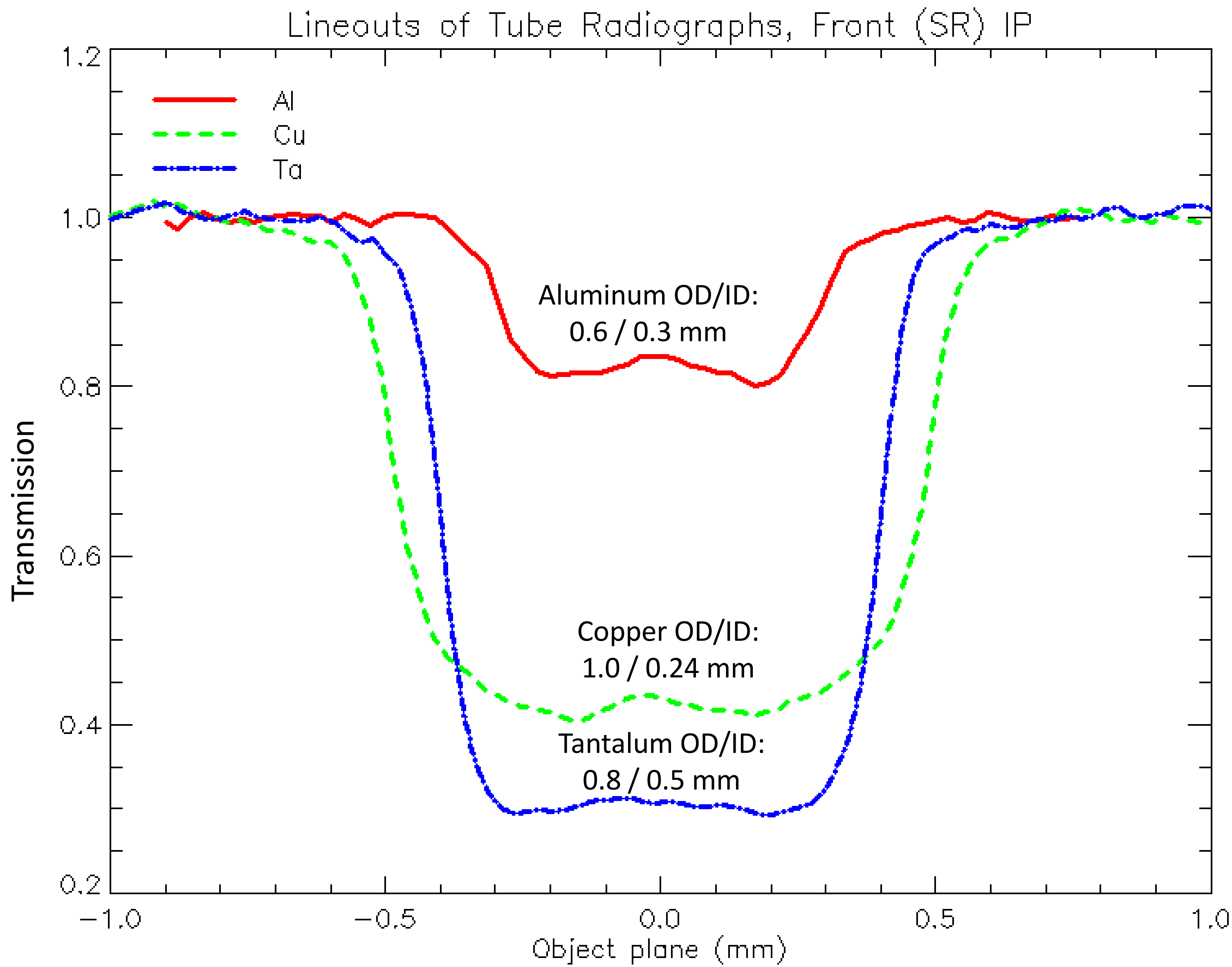


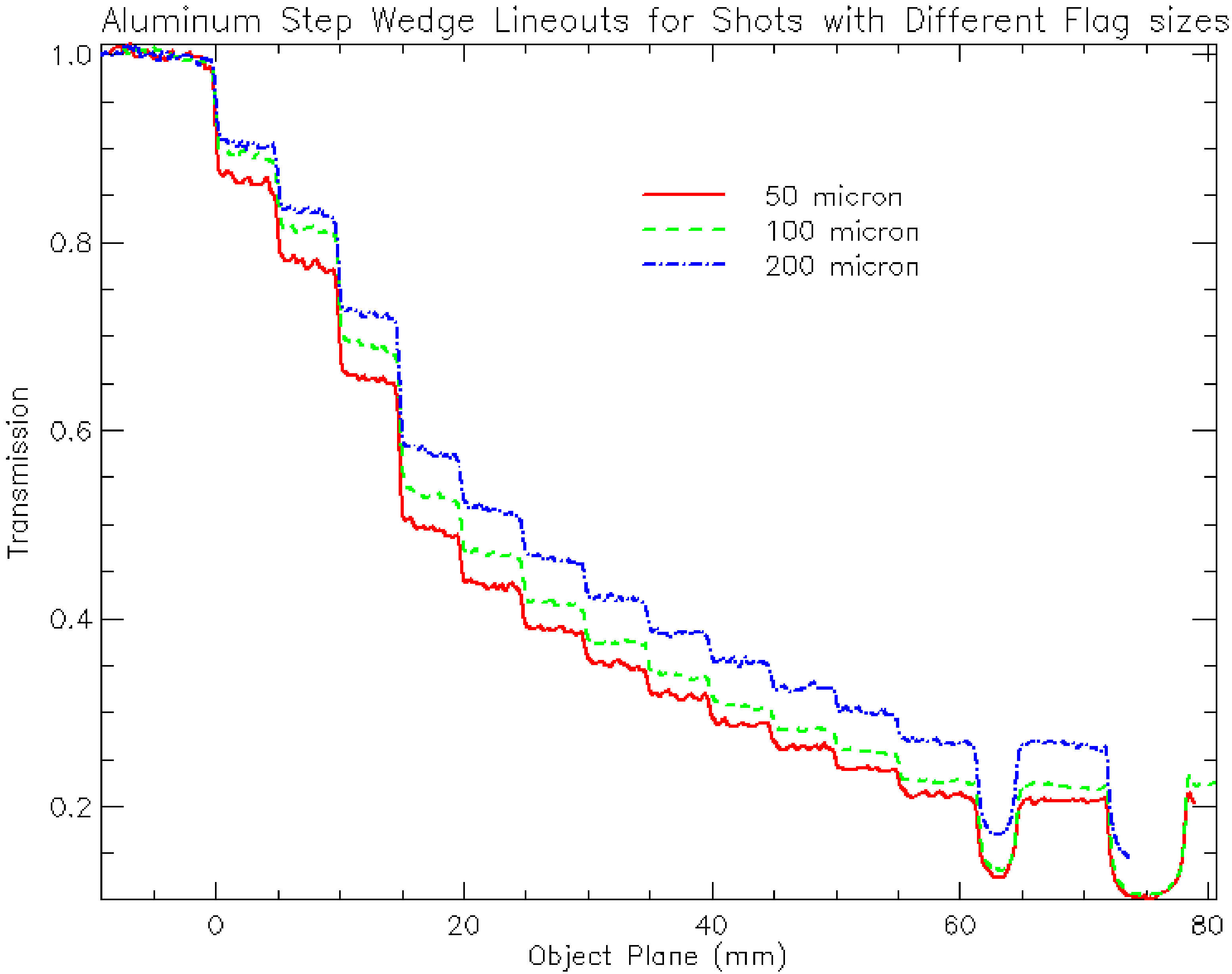


Nested Al tubes
ID1 (inner): 3.66 mm
OD1 (inner): 4.76 mm (3/16")

ID2 (outer): 10.92 mm
OD2 (outer): 12.7 mm (1/2")

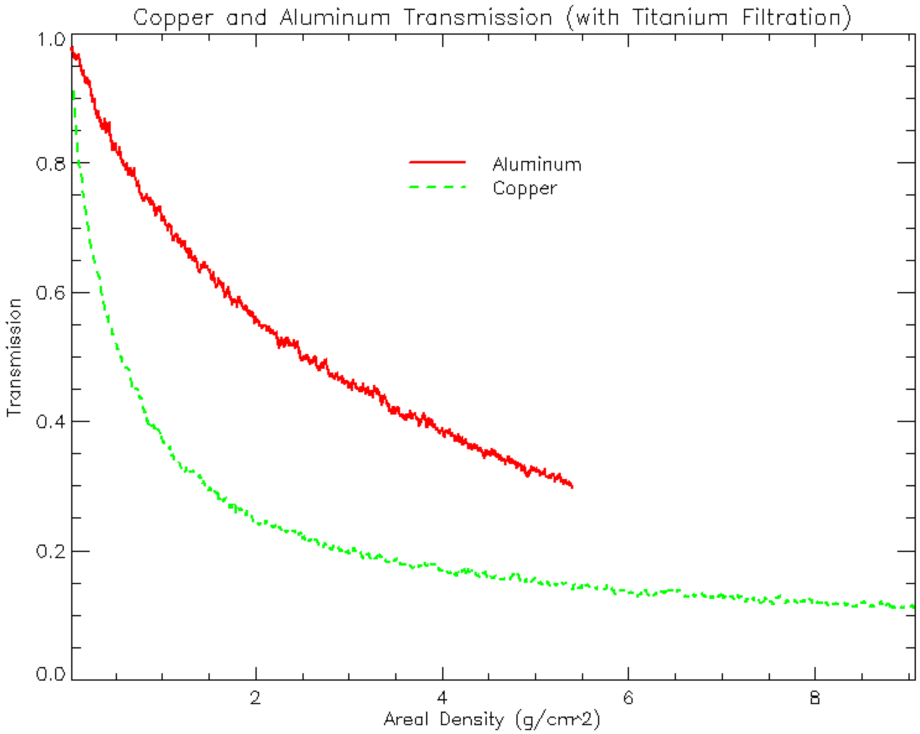
Tube Radiographs



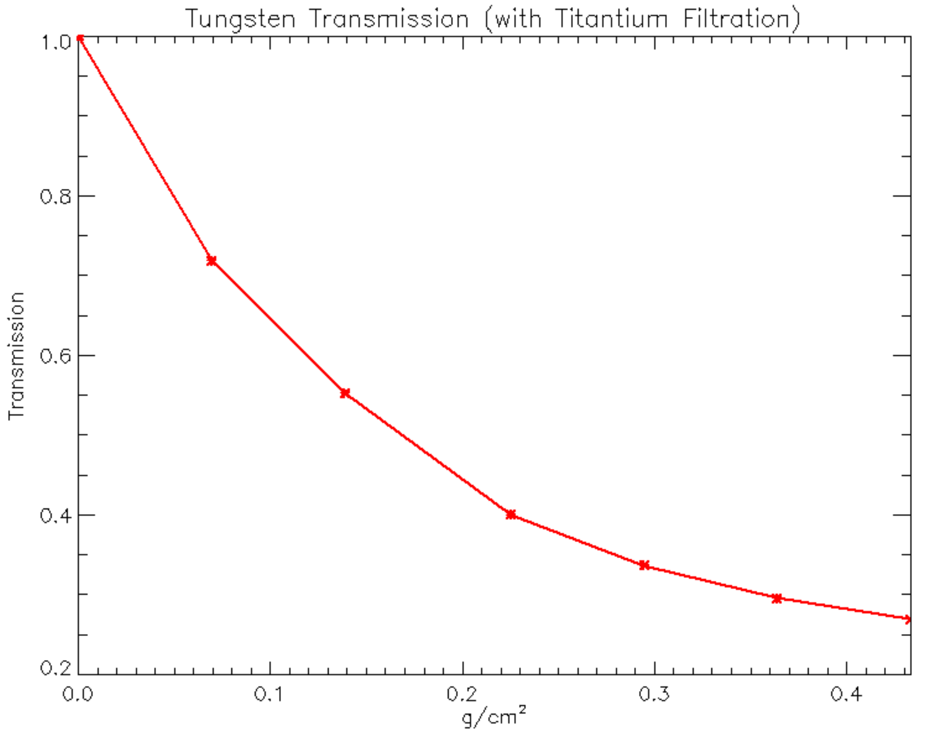


Striking difference: larger flag → harder spectrum

X-ray Transmission as a Function of Material



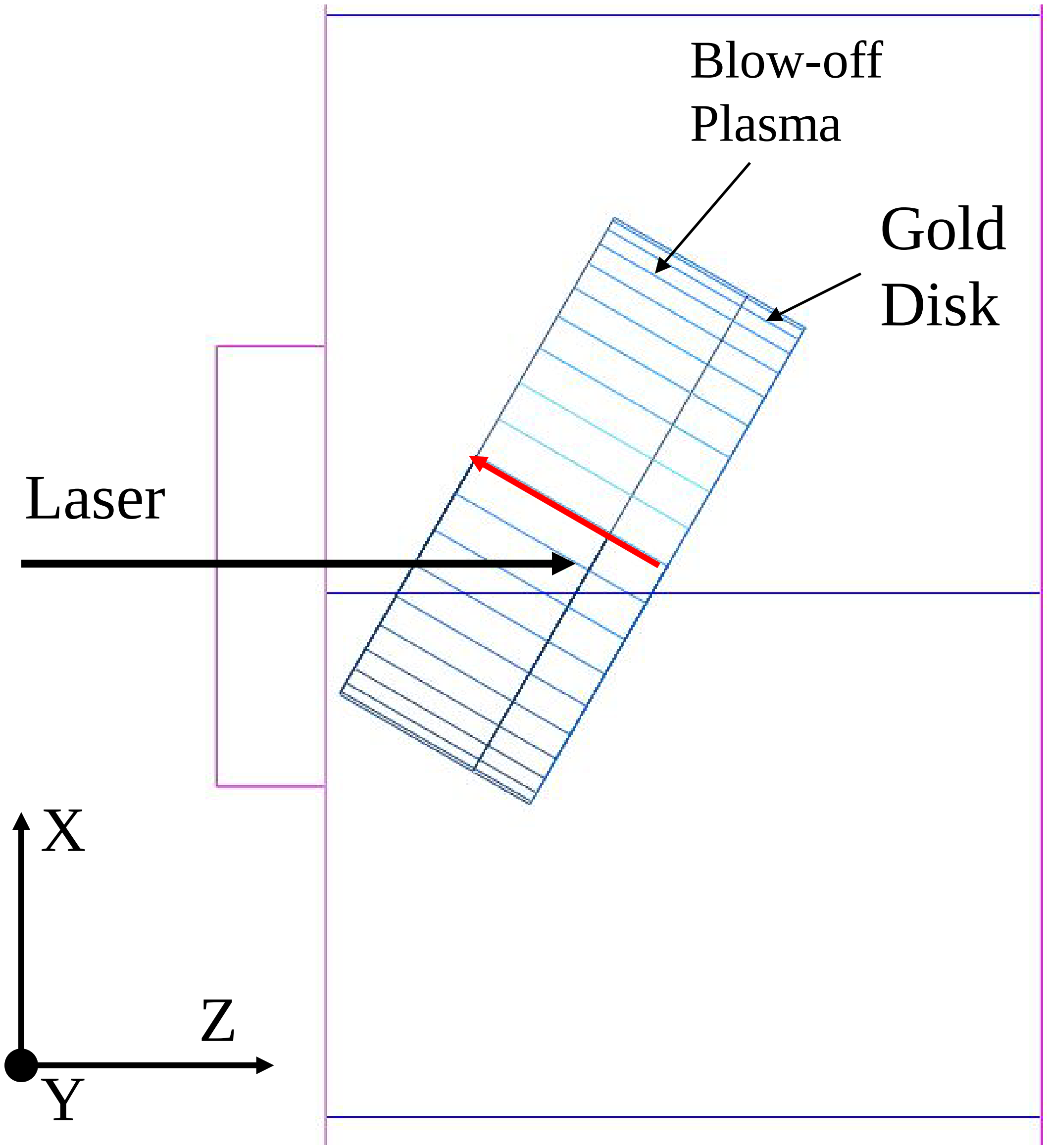
“Continuous” Wedge Data



Step Wedge Data

There is dependence on detector filtration as well.

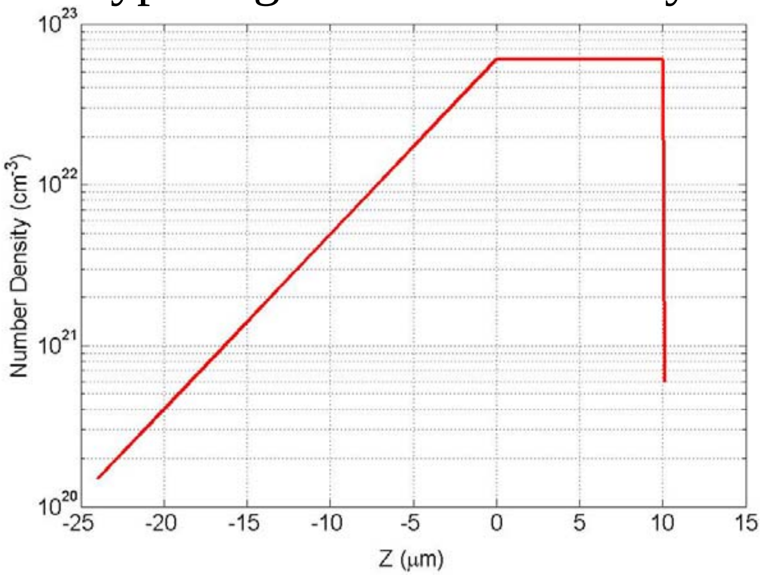
Particle-In-Cell Simulations of Laser-Plasma-Target Interactions



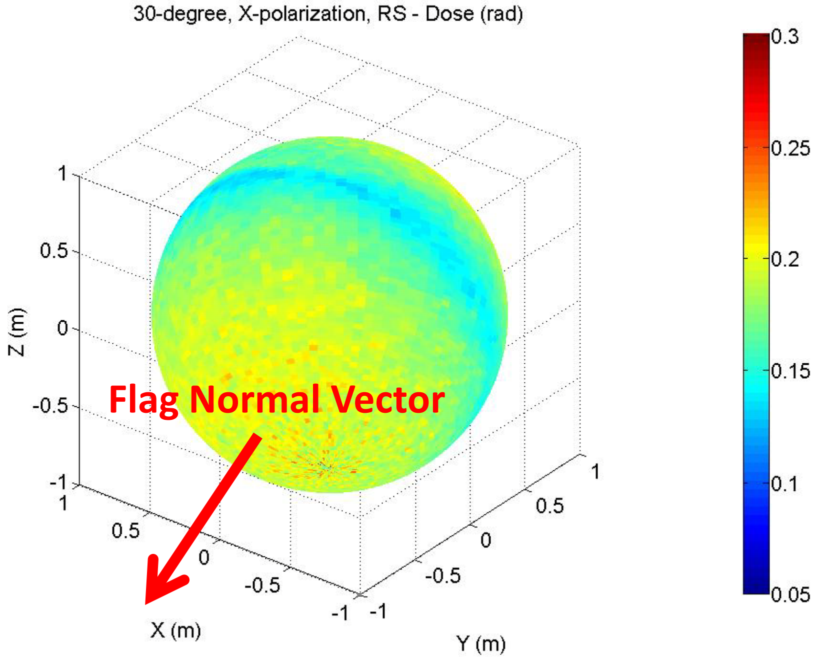
Fully 3D Cartesian Simulations with LSP

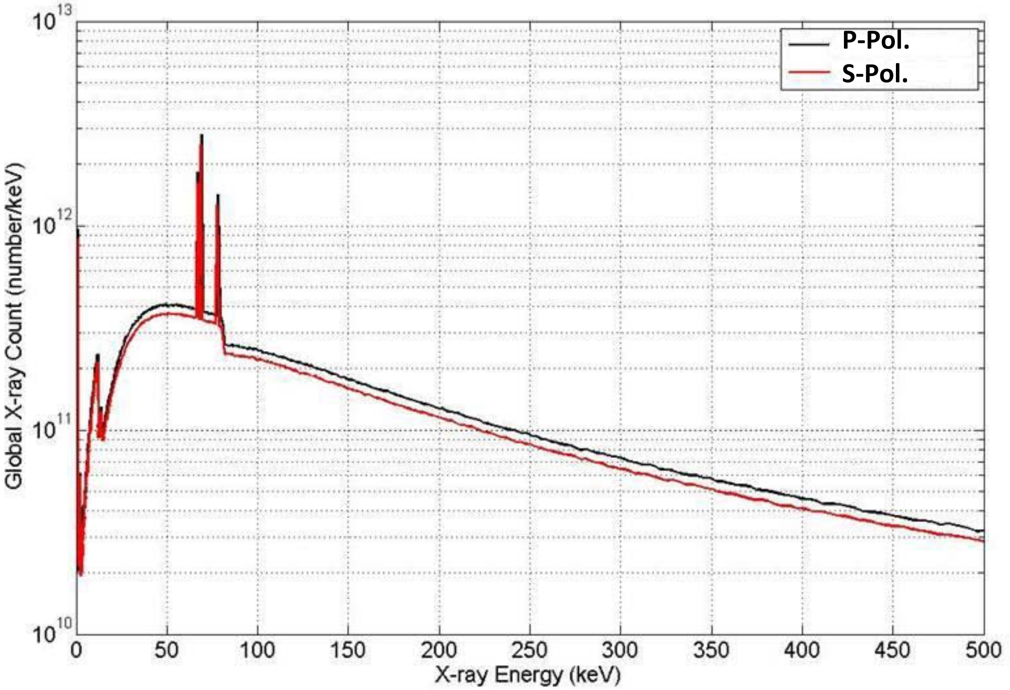
- Laser incident along Z-axis in positive direction
- X-polarized E-field → P-pol
- Y-polarized E-field → S-pol

- Typical gold number density:



LSP Calculation of Dose, Uniformity, and Photon Spectrum





- P-polarization uniformly 10% higher than S-polarization
- Energy conversion efficiency (laser energy to x-ray energy): ~5%.

Conclusion

Measured Source Characteristics:

- In one direction the minimum spot size appears to be about the foil thickness: **10 microns**.
- Doses on the order of **100 mrad @ 1 meter.**
- Penetration power*:

Tungsten:	**0.5 g/cm^2** maximum	
Copper:	8.0 g/cm^2 maximum	
Aluminum:	0.15 g/cm^2 minimum, >10 g/cm^2 maximum	

- 2% spatial x-ray dose uniformity over several centimeters.

Future Experiments:

- Laser focus, jitter, energy, and background dose as will be fielded in the Z-machine must be determined and x-ray source dose and spectrum must be measured again vis-à-vis the new laser parameters.
- Changing in source spectrum and dose by altering laser intensity (total energy is easiest).

Acknowledgements
(Sandia National Laboratories except where noted)

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Designer: Ray Lemke

Experimental: Matthias Geissel

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Z-Backlighter operations personnel: Mark Kimmel, Patrick Rambo, Marius Schollmeier, Jens Schwarz

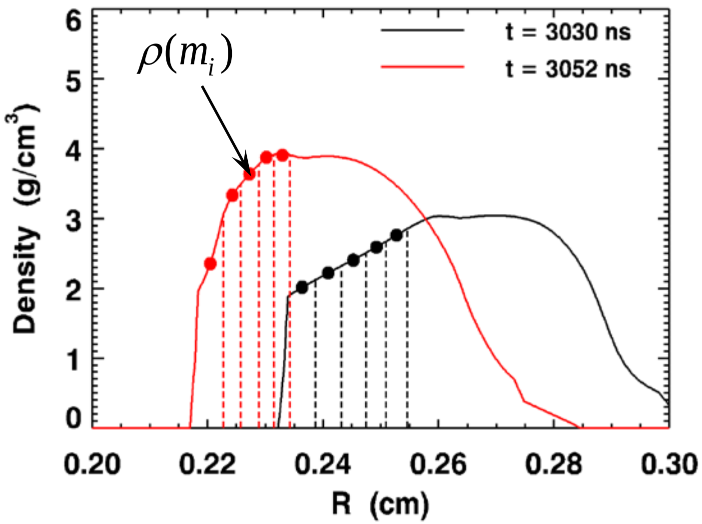
Laser target fabrication: Diana Schroen, Suzy Grine-Jones, Gary Smith (General Atomics)

Step wedge design: Kurt Tomlinson (GA)

Extra slides

Equation of State Measurements Unfolded from Abel-Inverted Radiographs

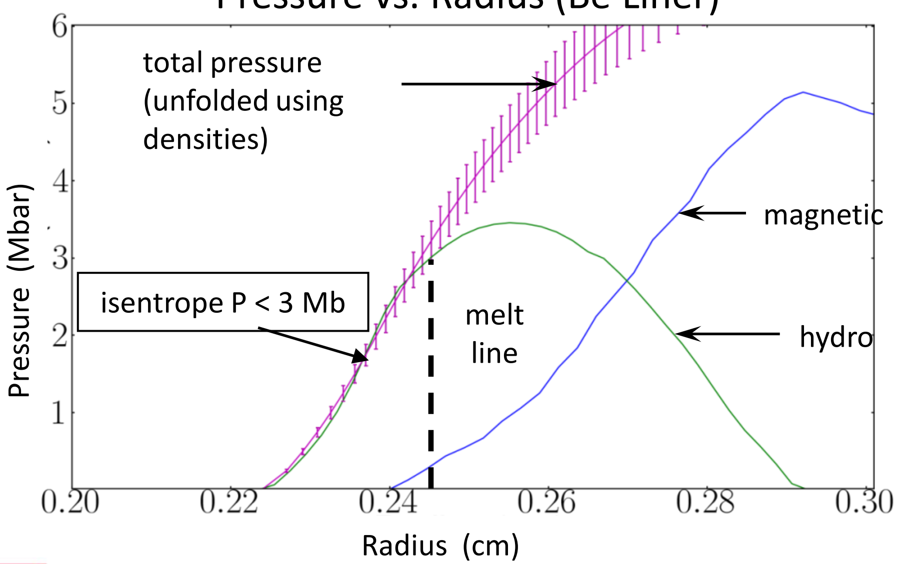
Liner Density vs. R (m_i = 10 mg)



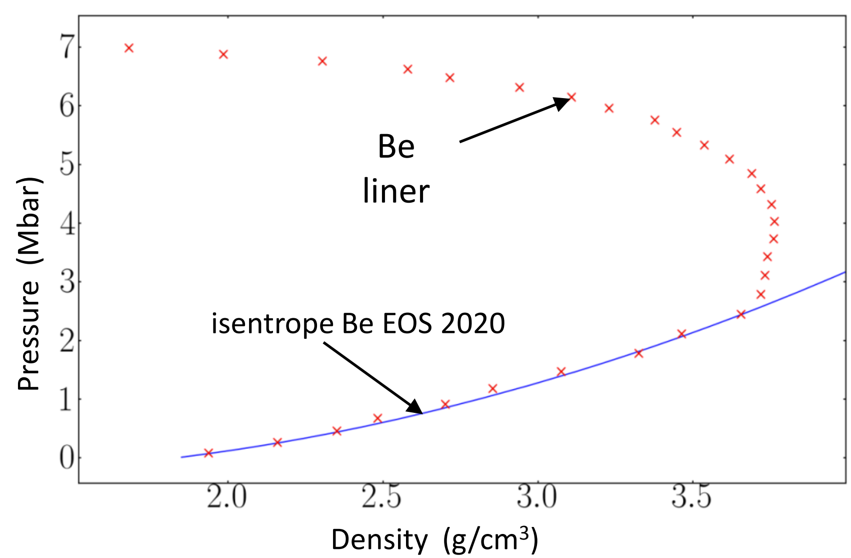
Multiple time-resolved radiographs allow determination of liner densities.

Total pressure and liner velocity calculated from Lagrangian hydro equations using Abel inverted liner densities.

Pressure vs. Radius (Be Liner)



Total Pressure (unfolded) vs. Density



Z Backlighter

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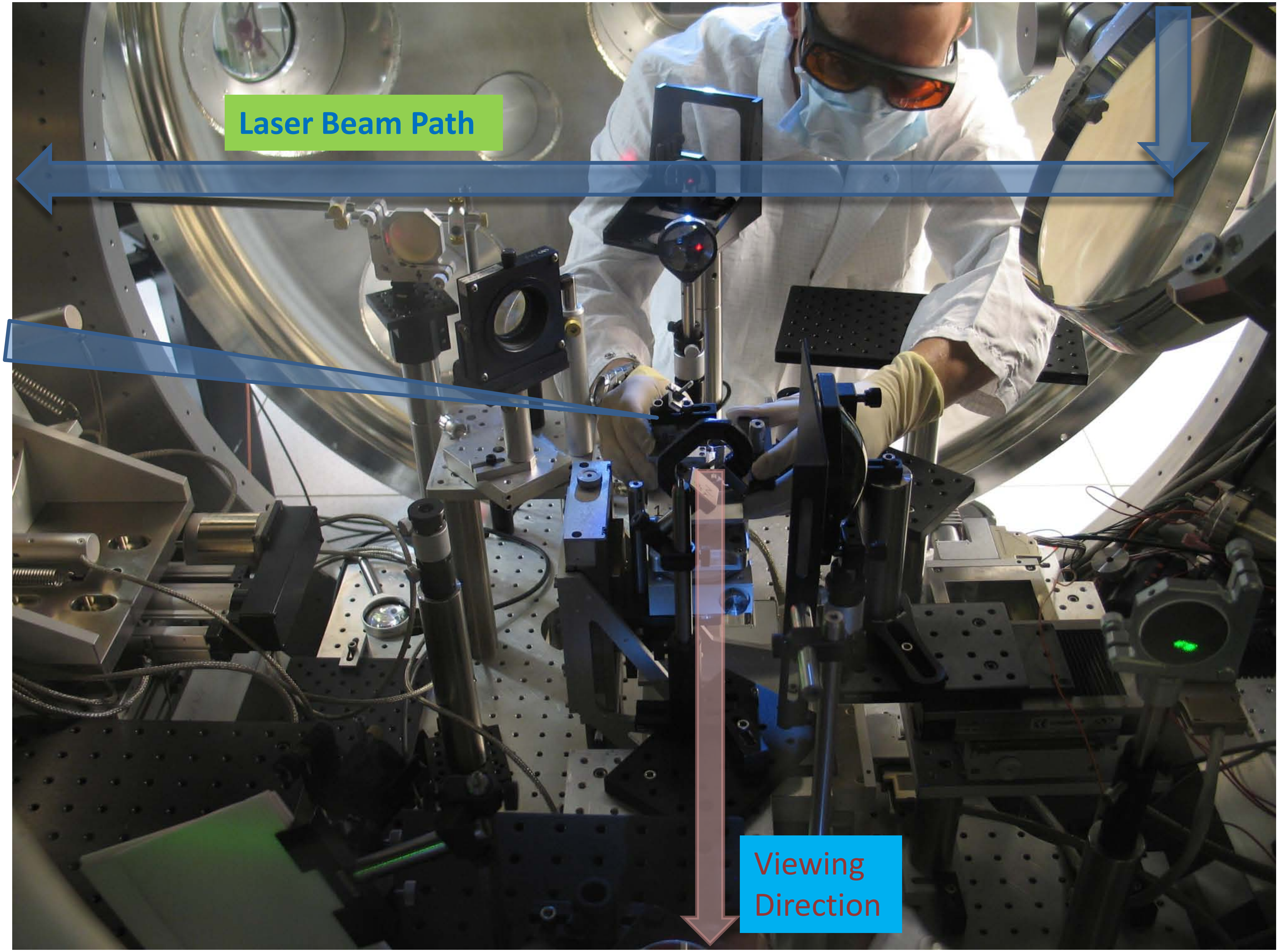
Radiographic Properties

Listed are some important radiographic properties measured. Results in RED will be summarized in this talk:

- X-ray source size
- X-ray source 2D distribution
- "Dose" or intensity measured at some distance
- Detector blur
- Transfer curve relating x-ray transmission to areal density (function of material)
- "Contamination" of beam due to charged particles which contributes to background
- Source reproducibility
- Beam flatness (uniformity over image area).

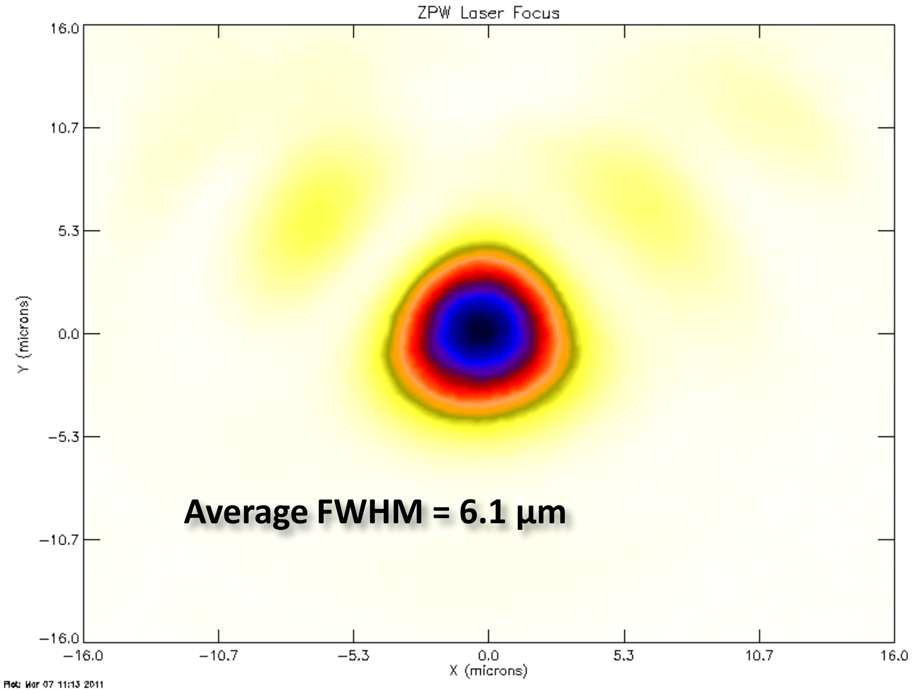
There is certainly potential to tailor the source to give properties we desire such as making the x-ray spectrum softer or harder via changing laser intensity. Spectrum hardening may be accomplished through filtering the beam.

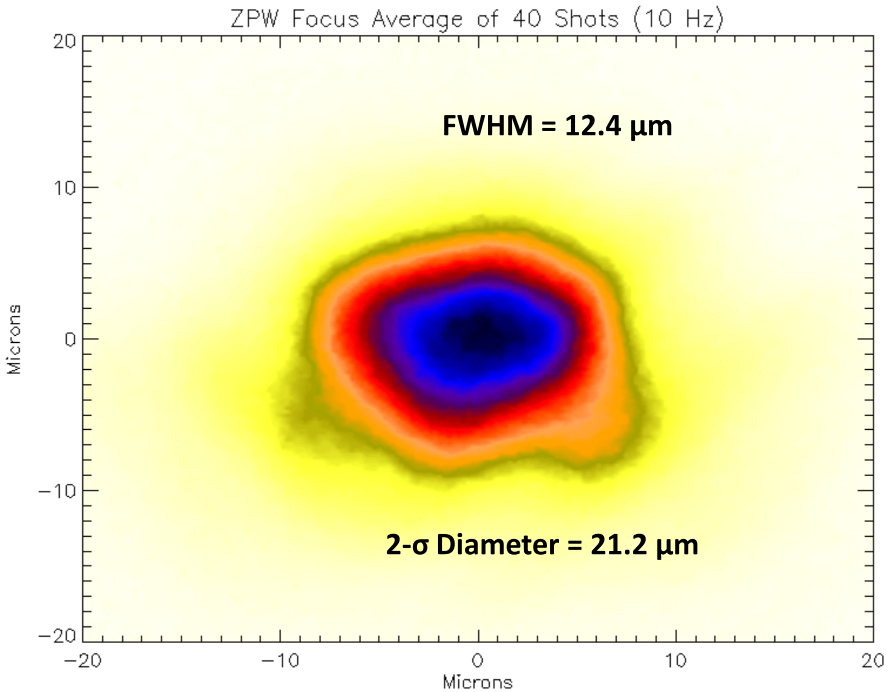
P-Polarization Set-up: Laser E-field is Vertical, Flag is tilted



Laser Focus Size and Spatial Jitter

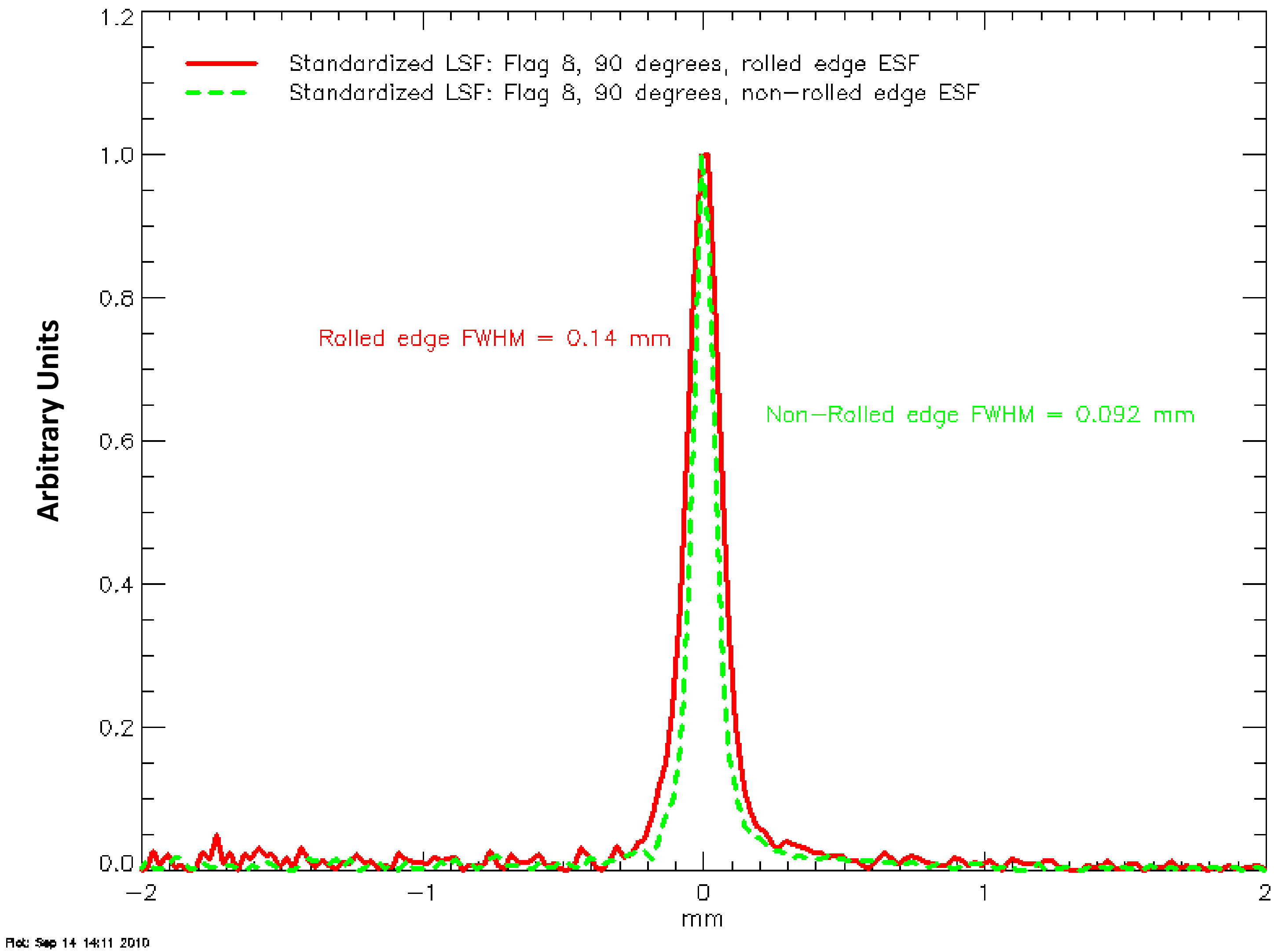
The laser intensity is determined from the laser focus size of course, but the minimum flag size (minimizes total x-ray source size) is determined from laser jitter.





These values are measured in a specialized target chamber. Transport to the Z-machine will likely result in larger values for the focus and jitter widths.

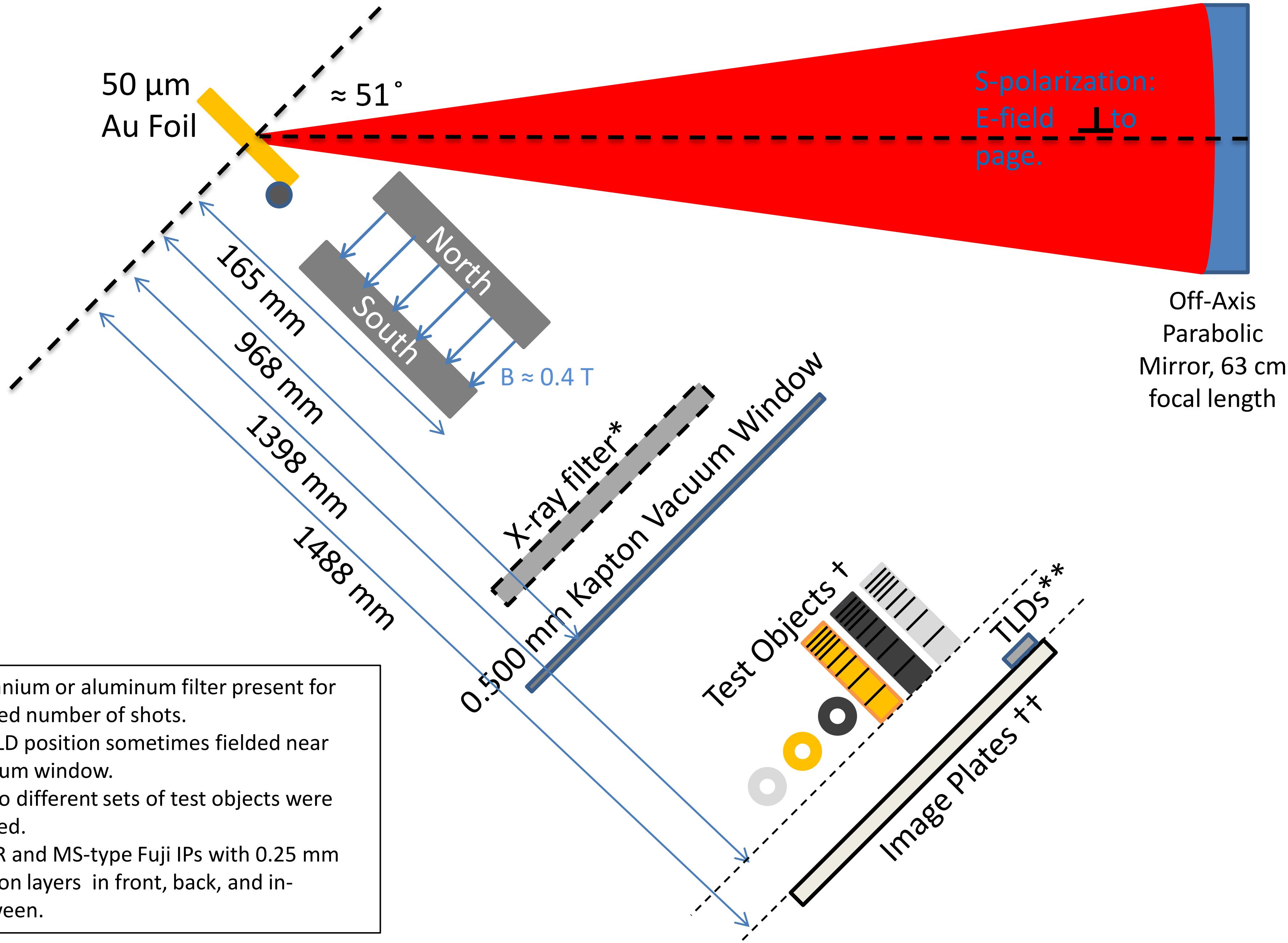
Detector Blur: FUJI SR-Type Image Plates*



Detector blur > Source blur → Large magnification ideal to maximize system resolution.

*Scan Sampling Resolution: 50 µm

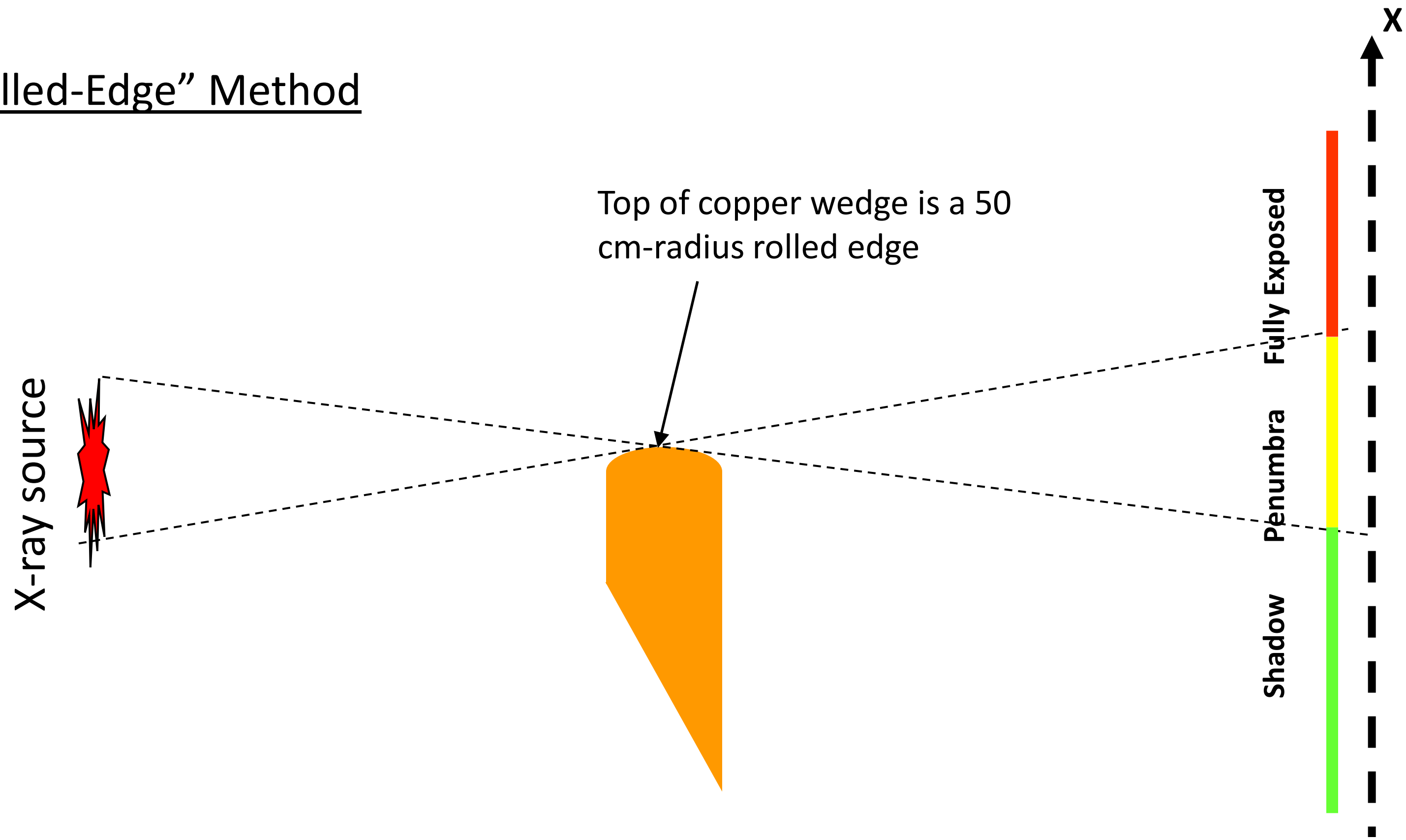
January 2011 Experimental Layout, TOP View



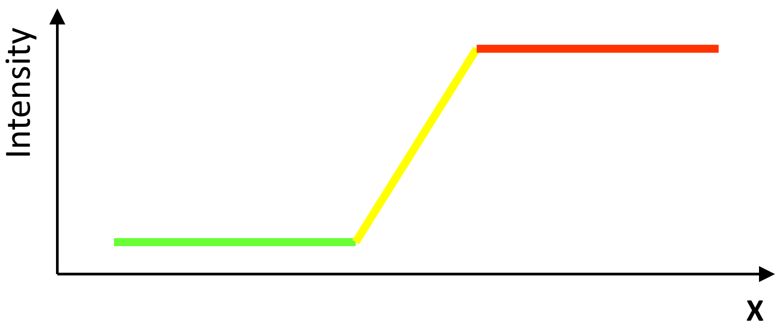
*Titanium or aluminum filter present for limited number of shots.
** TLD position sometimes fielded near vacuum window.
† Two different sets of test objects were fielded.
†† SR and MS-type Fuji IPs with 0.25 mm Kapton layers in front, back, and in-between.

Spot Size Measurements Technique

"Rolled-Edge" Method



Edge-Spread Function (ESF)



Line-spread function (LSF) = d/dx (ESF)

Width of ESF or LSF is a measure of effective spot size