SAND2011-8587C

System Radiographic Characterization of 7 MV Self-Magnetic Pinch Diode on RITS-6

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53rd Annual Meeting of the APS Division of Plasma Physics
November 18, 2011

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NNSA National Nuclear Security Administration

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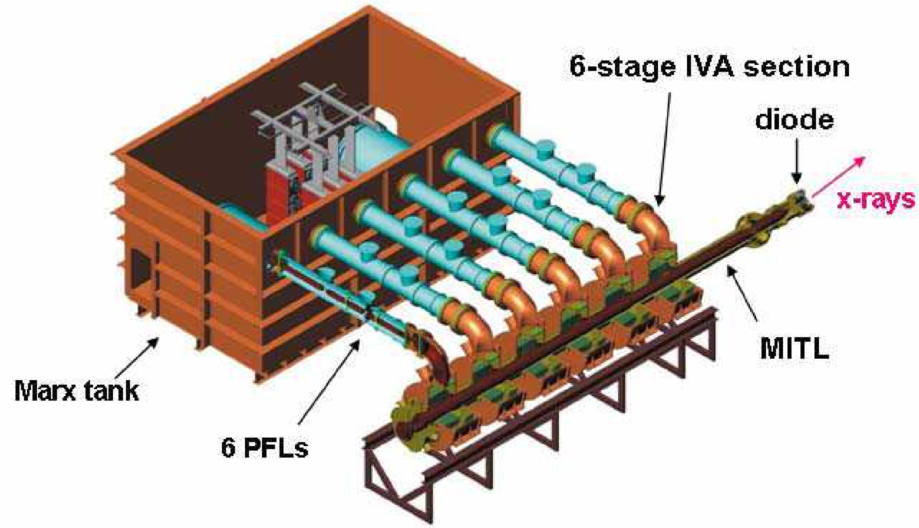
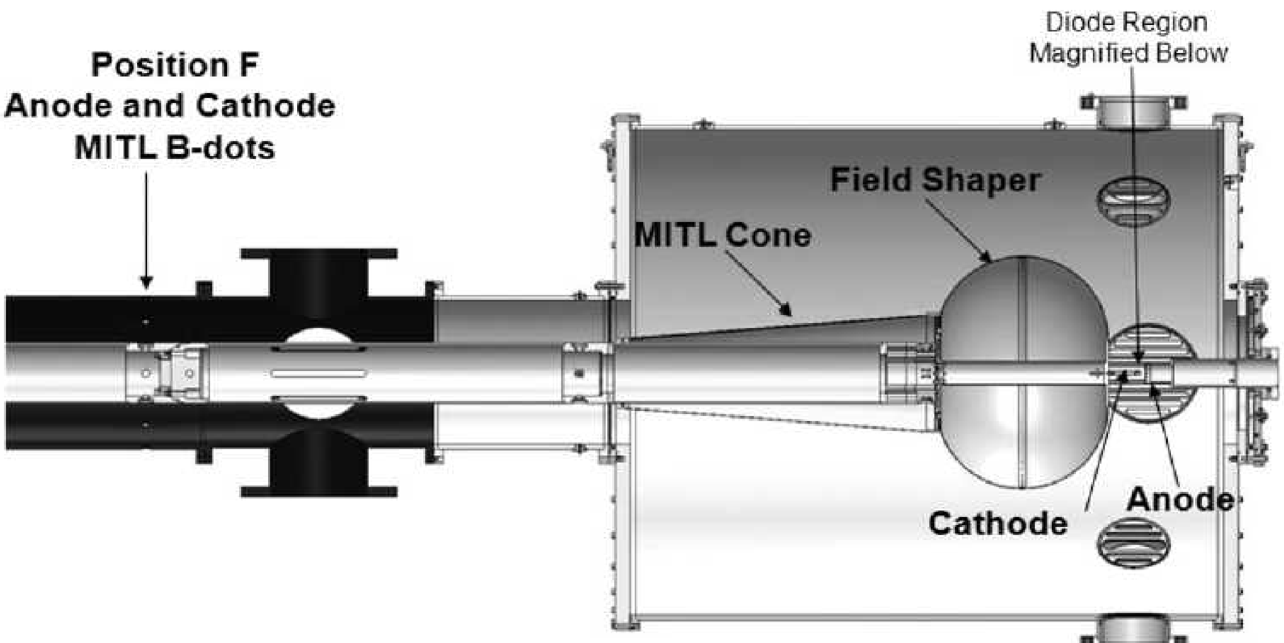
Abstract

The induction voltage adder RITS-6 is used as a test bed for research and development of sub-100 ns flash x-ray radiography of which the self-magnetic pinch (SMP) diode is an example. The x-ray source properties such as dose, source spatial distribution, and energy spectrum couple with the imaging detector sensitivity and blur to form the radiologic system performance which is also highly dependent on the imaging geometry. The system performance of some SMP diode configurations will be presented.

Radiographic Integrated Test Stand (RITS-6) at Sandia National Laboratories, Albuquerque, NM

Operating Parameters:
- 7.5 peak MITL voltage
- 180 kA total current
- 40 Ω operating MITL impedance

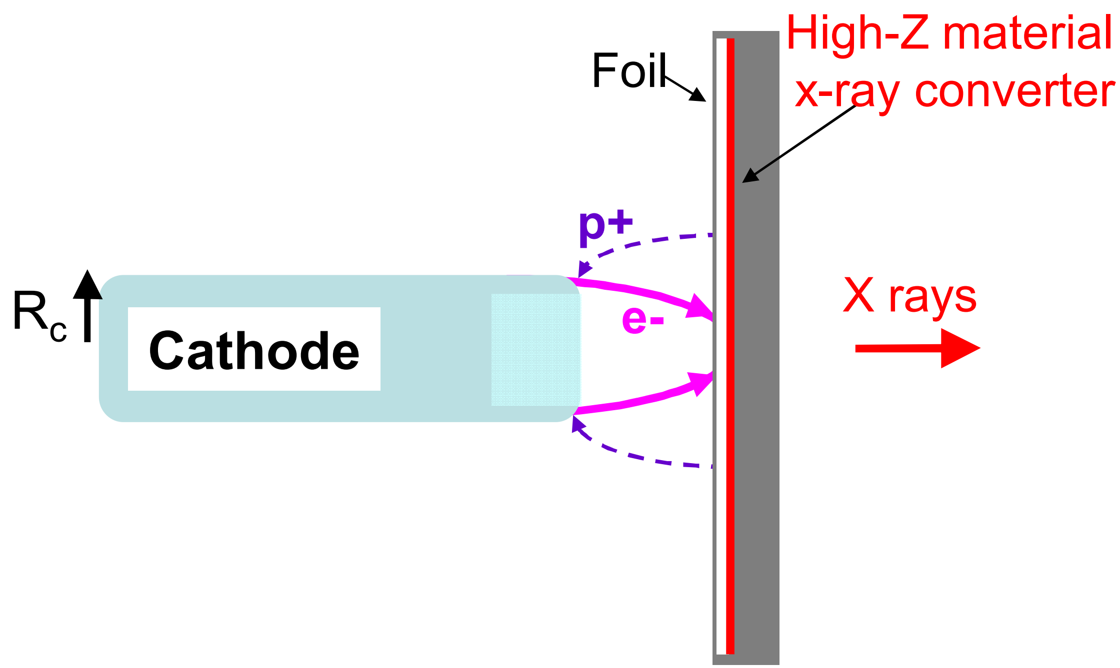




Self-Magnetic Pinch (SMP) Diode [1] – [3]

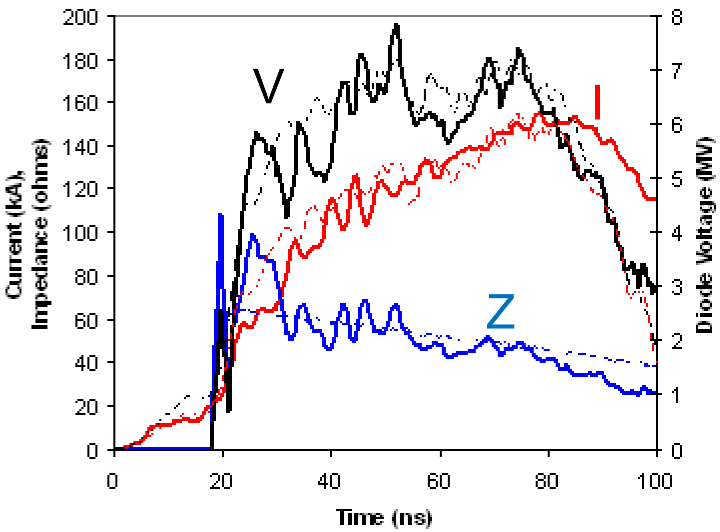
Diode Parameters

- 6-7.5 MV
- 150 kA (~15% ions)
- 50 Ω Impedance
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- Up to 350 Rads
- < 3 mm spot size

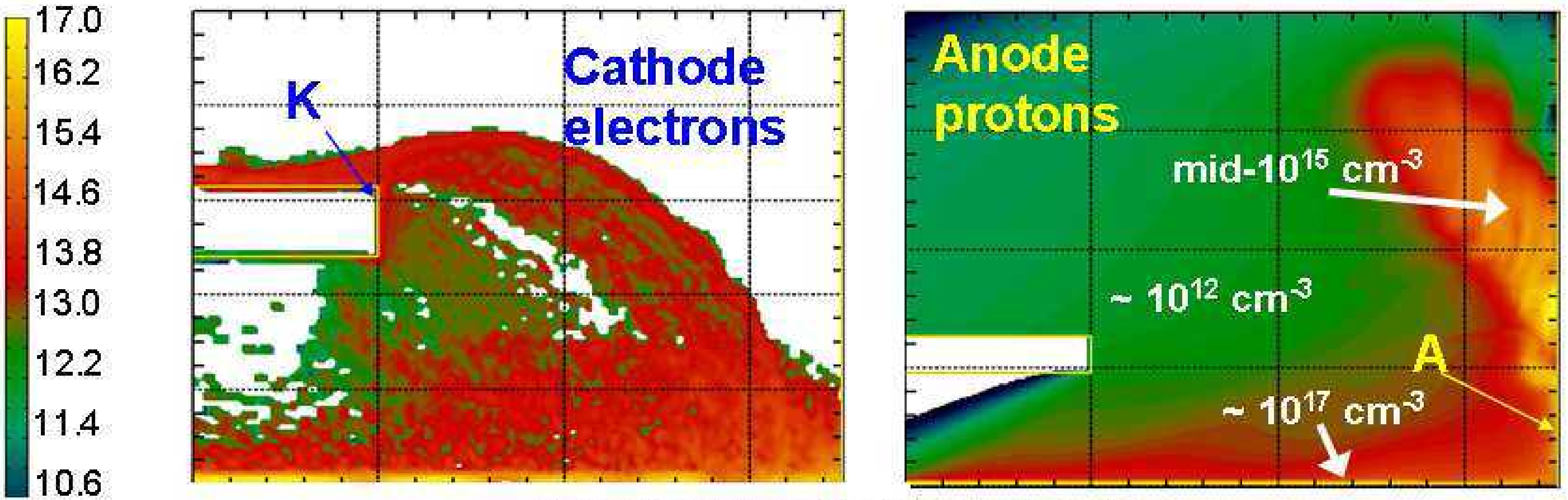


Early time pinch of electrons caused by charge neutralization by counter-streaming protons (few ns)

Impedance decreases with time with increasing ion current.



LSP [4] Simulations of Cathode and Anode Plasmas



Particle Density Plots @ 40 ns

Diagnostic Suite

Pulsed Power

- B-dot current monitors (MITL, diode, etc.)
- Voltage monitors in induction cell drivers (Marx, IS, PFLs)
- Voltage in MITL determined from theoretical formulas as long as load (diode) impedance ≥ MITL operating impedance
- Diode voltage estimated from radiographers equations and/or corrected MITL voltage

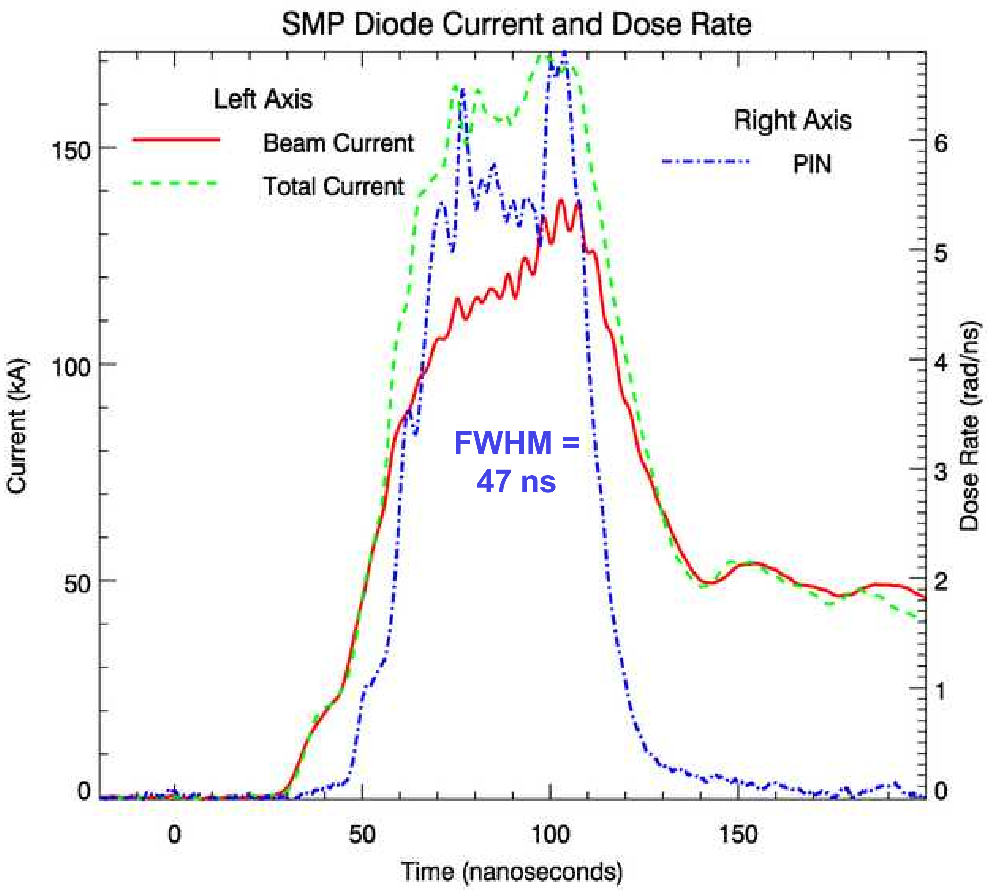
X-ray :

- Fuji image plates is primary imaging detector
- Gamma camera is under development
- Calibrated PIN diodes for dose rate
- Two axis rolled edge for spot measurement
- Two side-viewing 0.75 mm pin hole cameras
- Time Resolved Spot Diagnostic (TRSD)

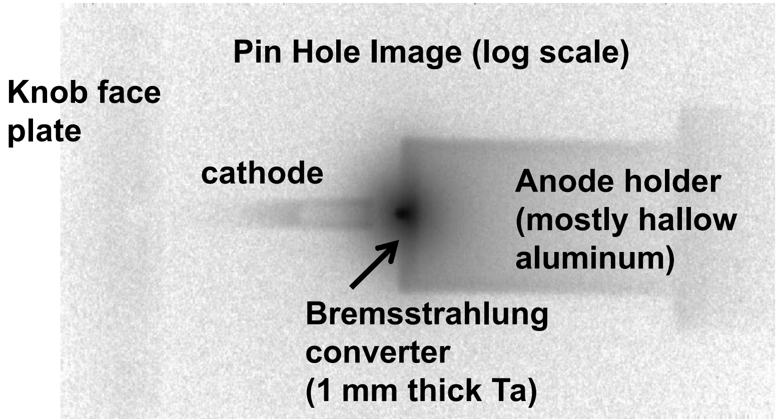
Optical / Plasma

- Visible / UV spectroscopy
- Optical imaging streak camera
- Optical fiber array
- ICCD cameras

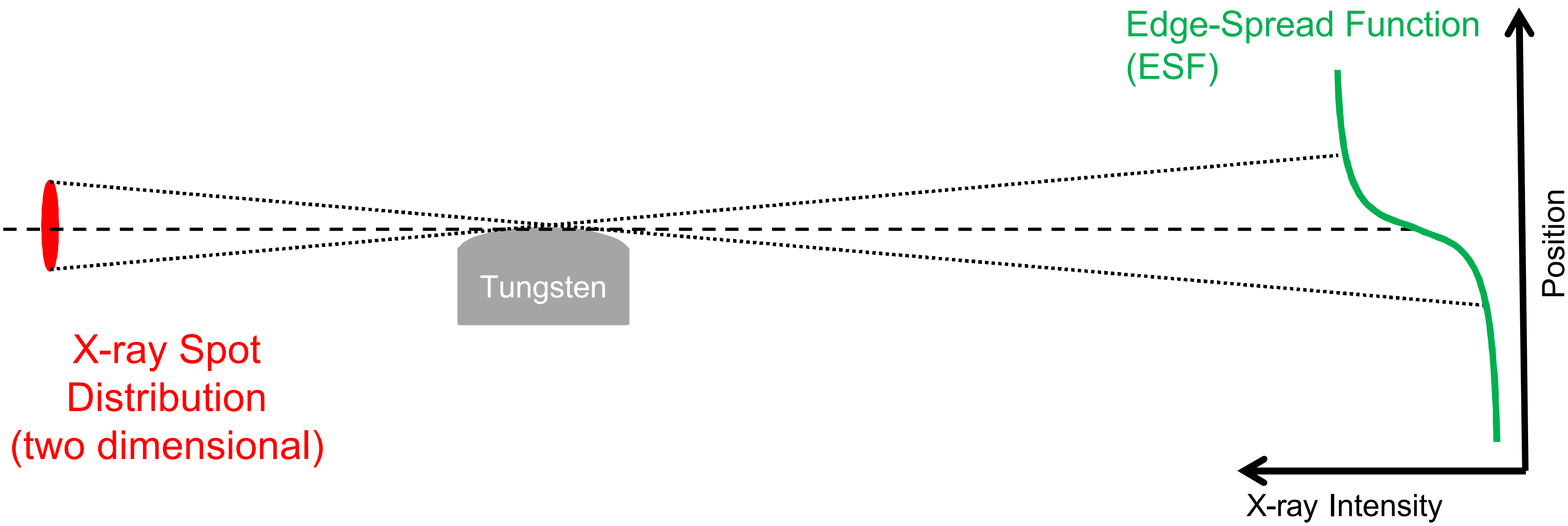
Standard Operating Characteristics



Difference between total and beam current is MITL flow



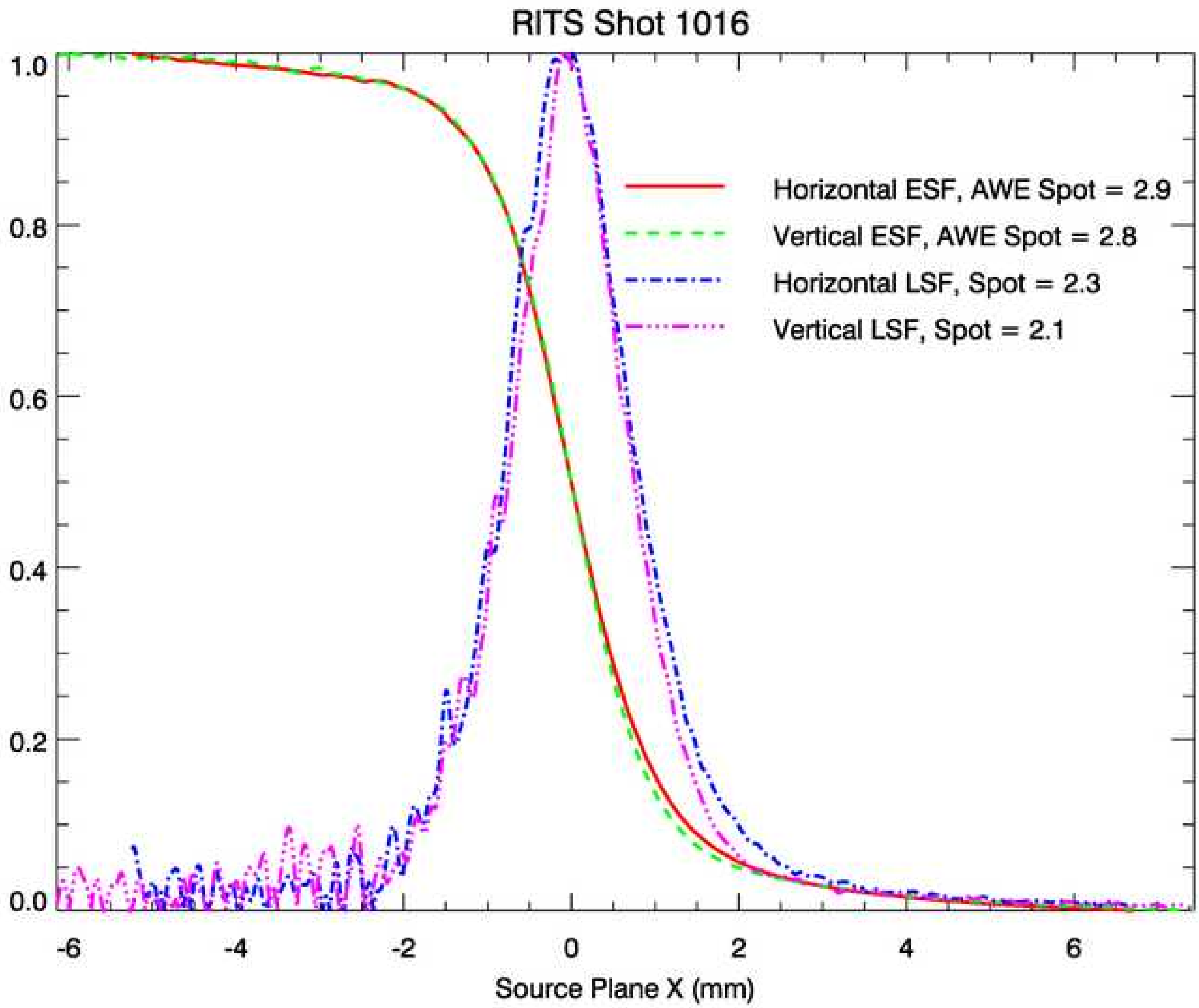
X-ray Spot Size – Rolled Edge Method

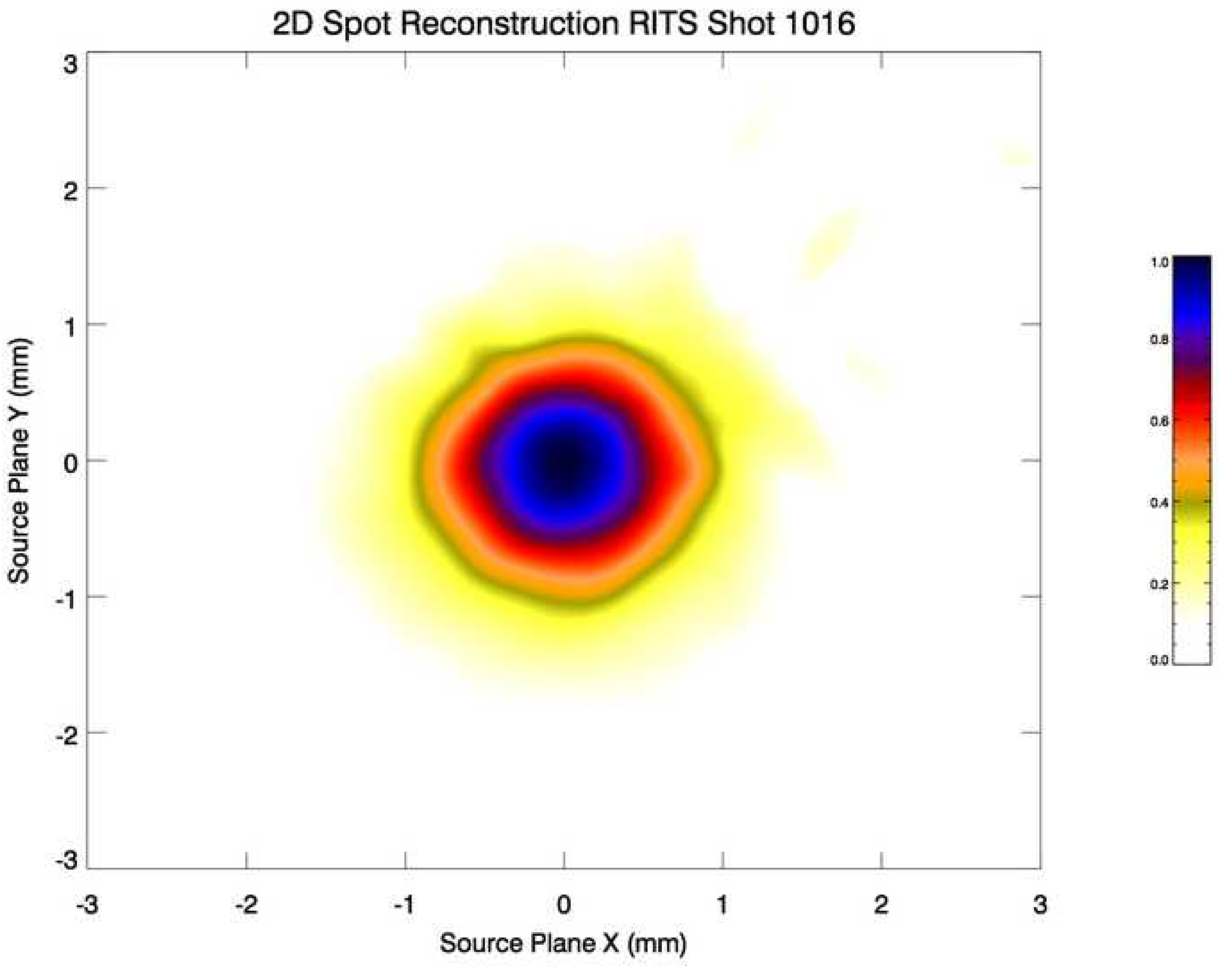


<u>Spot Sizes Metrics</u>

- ESF, AWE Definition [5]: 2.5 x (0.25 to 0.75 width)
- Line-Spread Function (LSF--spatial derivative of ESF): 1.4 x FWHM
- PSF (Abel-inversion of LSF assuming circular symmetry or measured directly with perpendicular rolled edges or apertures): FWHM

Typical Spot Sizes

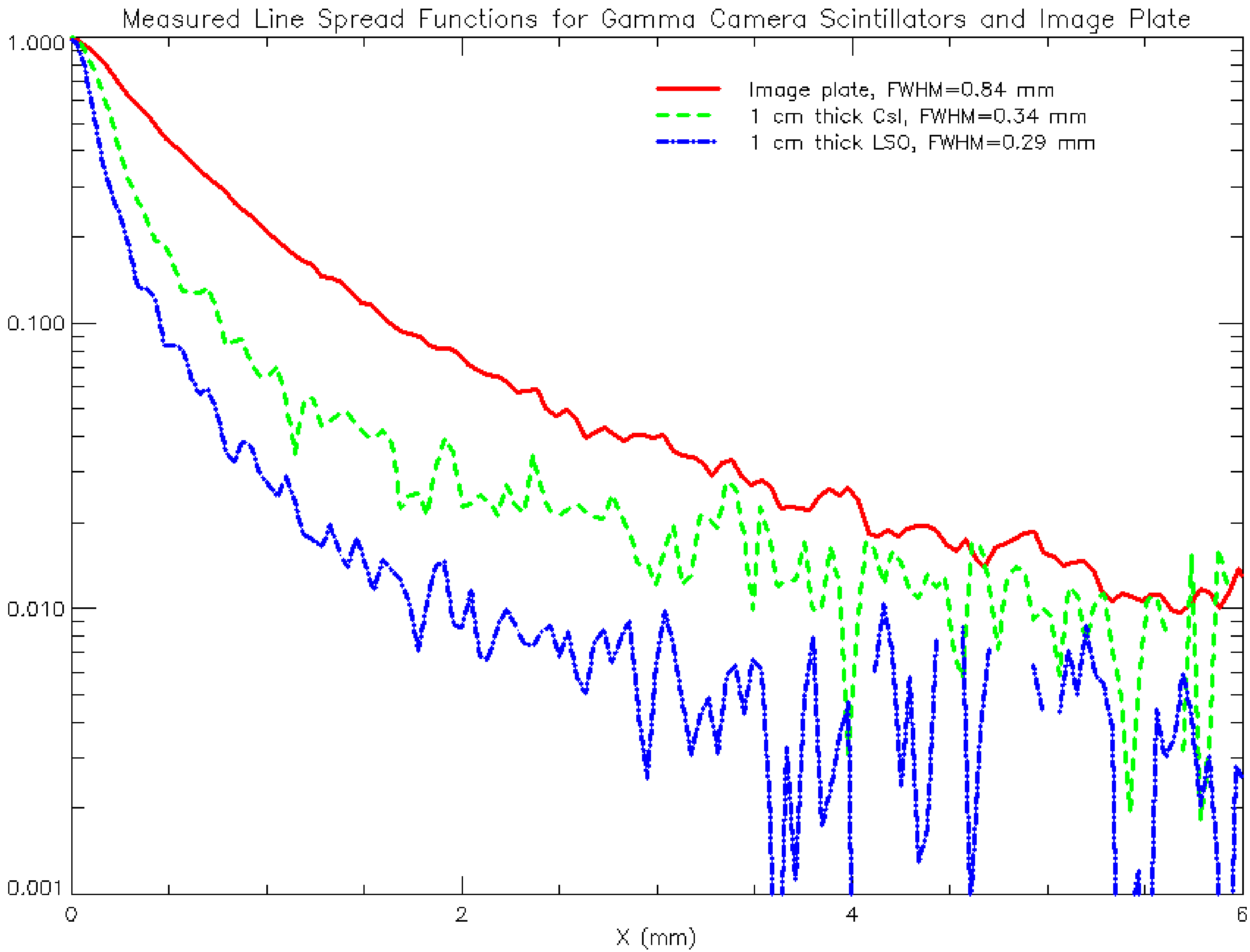




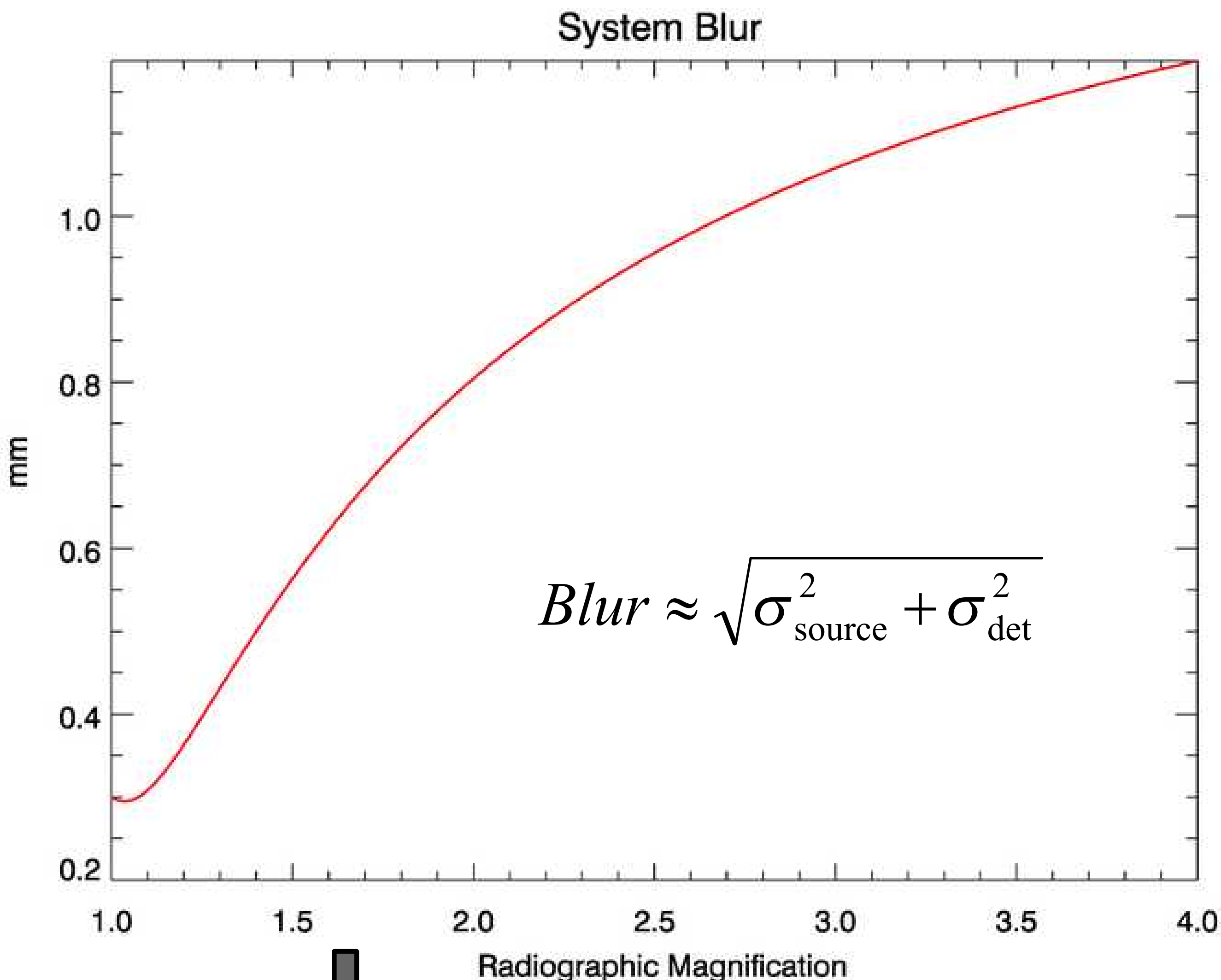
FWHM Average = 1.58 mm, stdev = 0.04 mm

Method: see ref. [6]

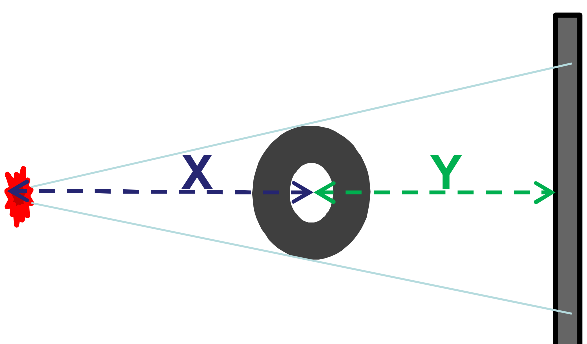
Detector Blur Functions



Obtained from rolled edge “contact” radiograph (spot blur negligible)



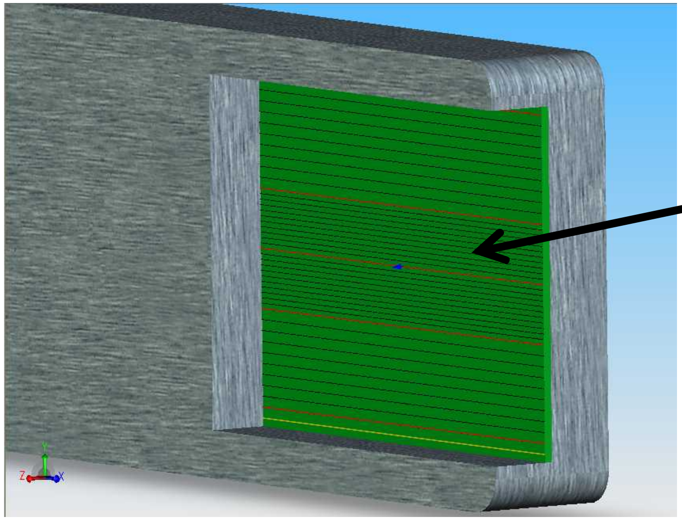
$$Blur \approx \sqrt{\sigma_{\text{source}}^2 + \sigma_{\text{det}}^2}$$



$$= \frac{X + Y}{X}$$

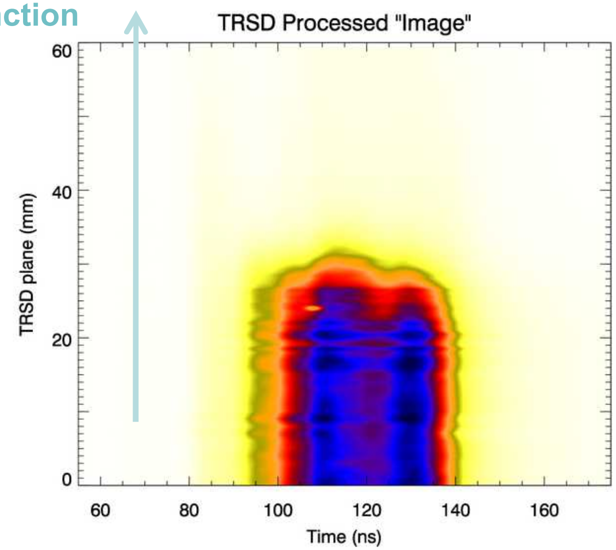
$\sigma \equiv \text{FWHM}$

Time-Resolved Spot Diagnostic (TRSD)

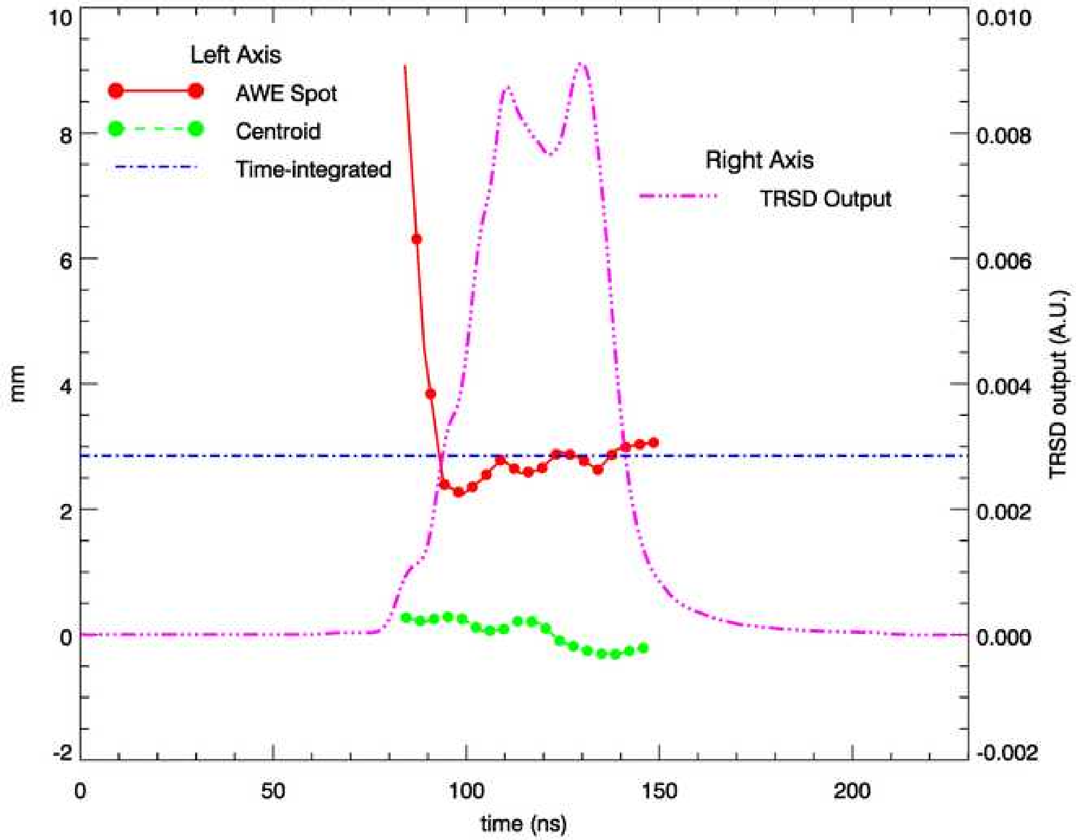


- Linear Array of 84 plastic scintillator fibers.
- Response time about 2.7 ns, light response of each fiber detected with streak camera.
- Can also give time-integrated spot size.

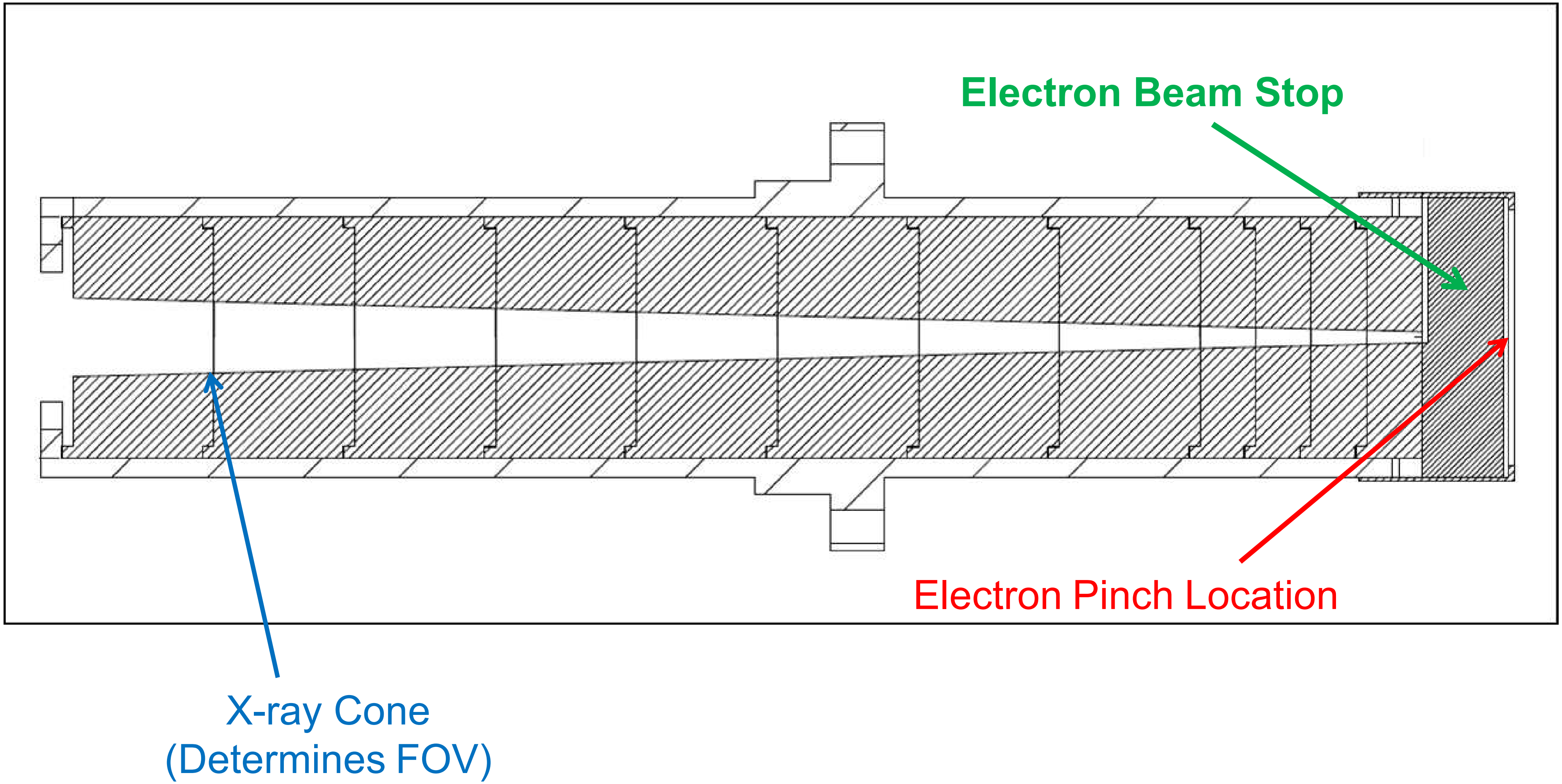
Vertical lineout gives instantaneous edge-spread function



Horizontal lineout gives radiation pulse

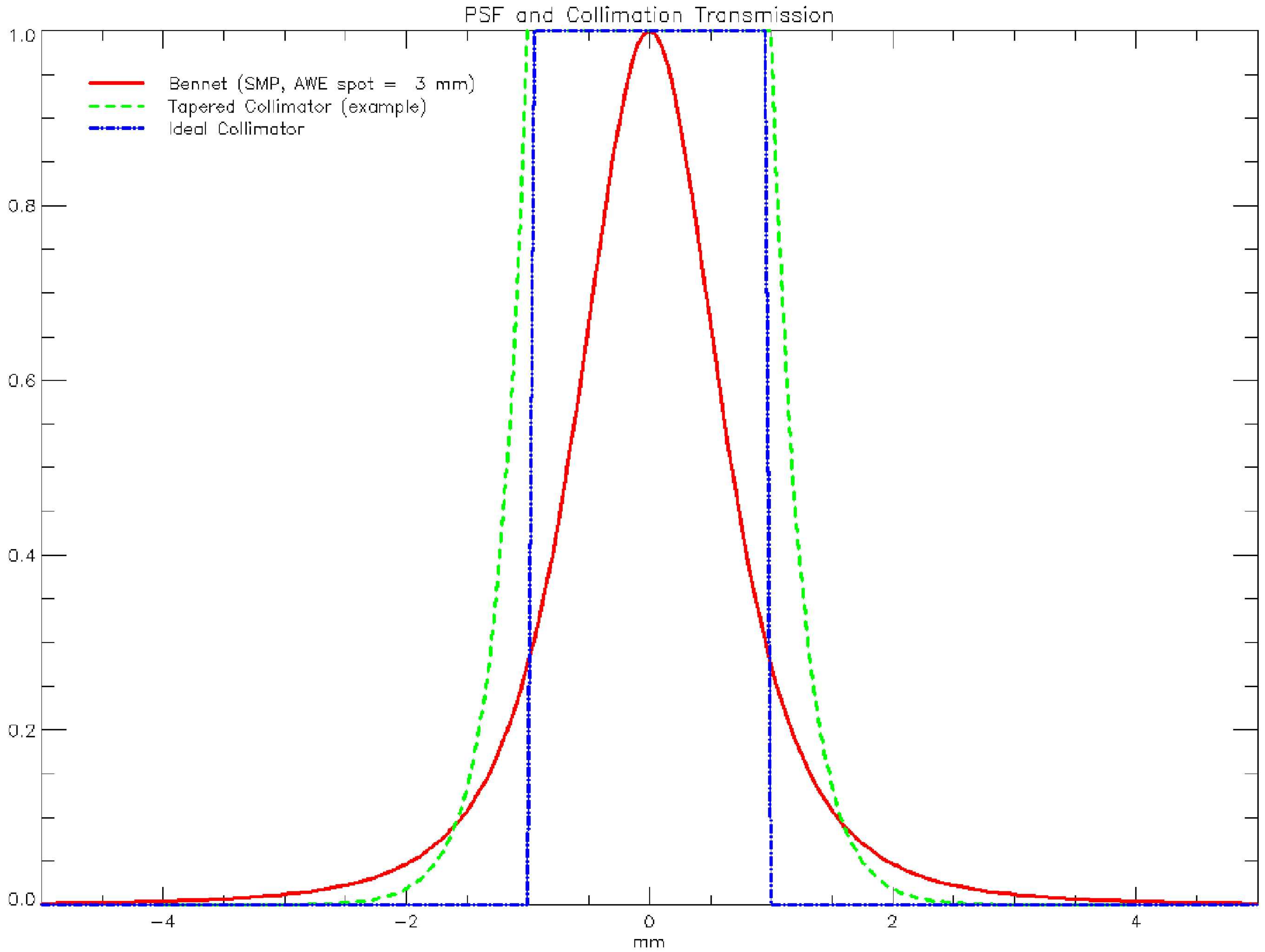


Stainless Steel Hard Collimator to Achieve Smaller Spot Size

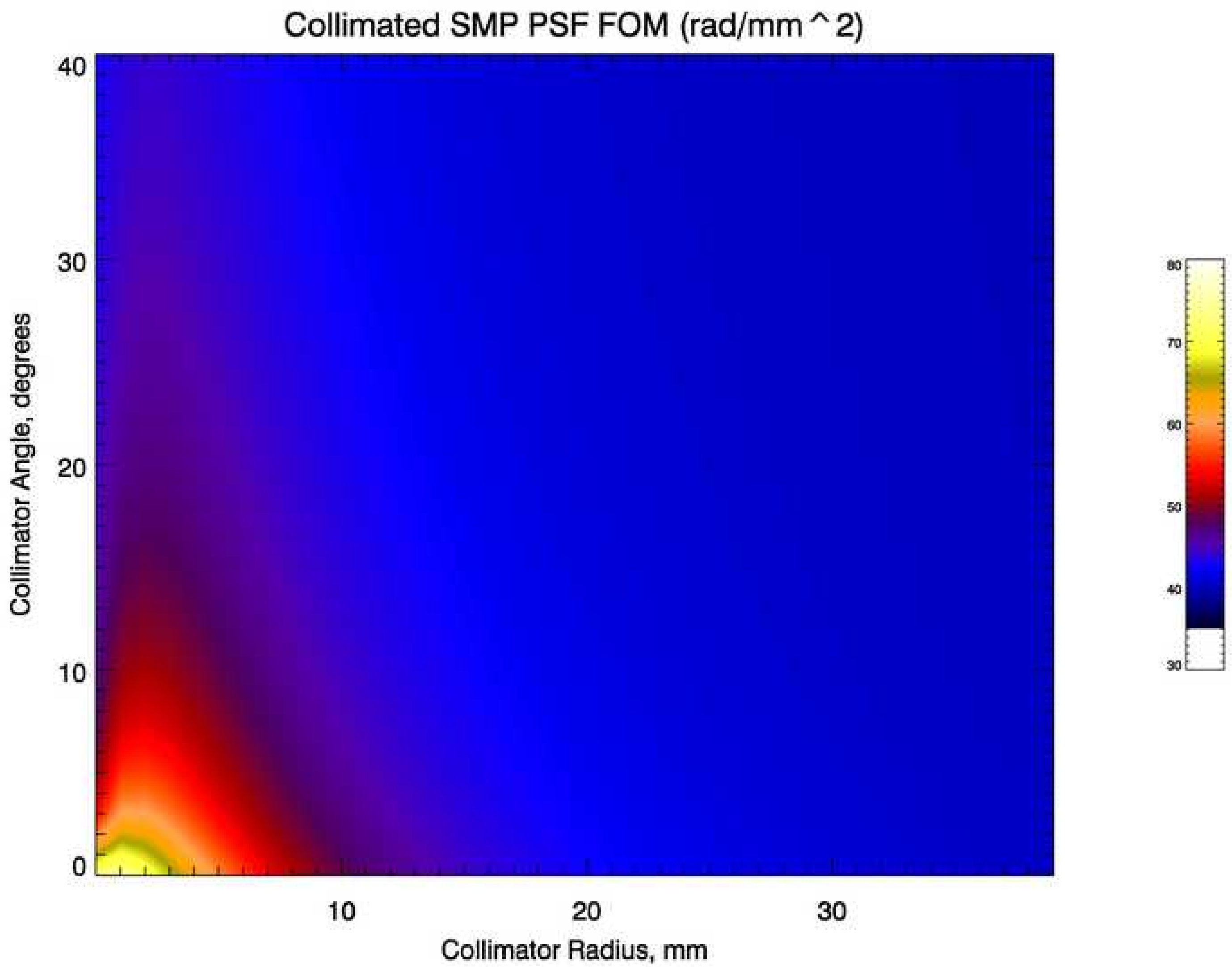


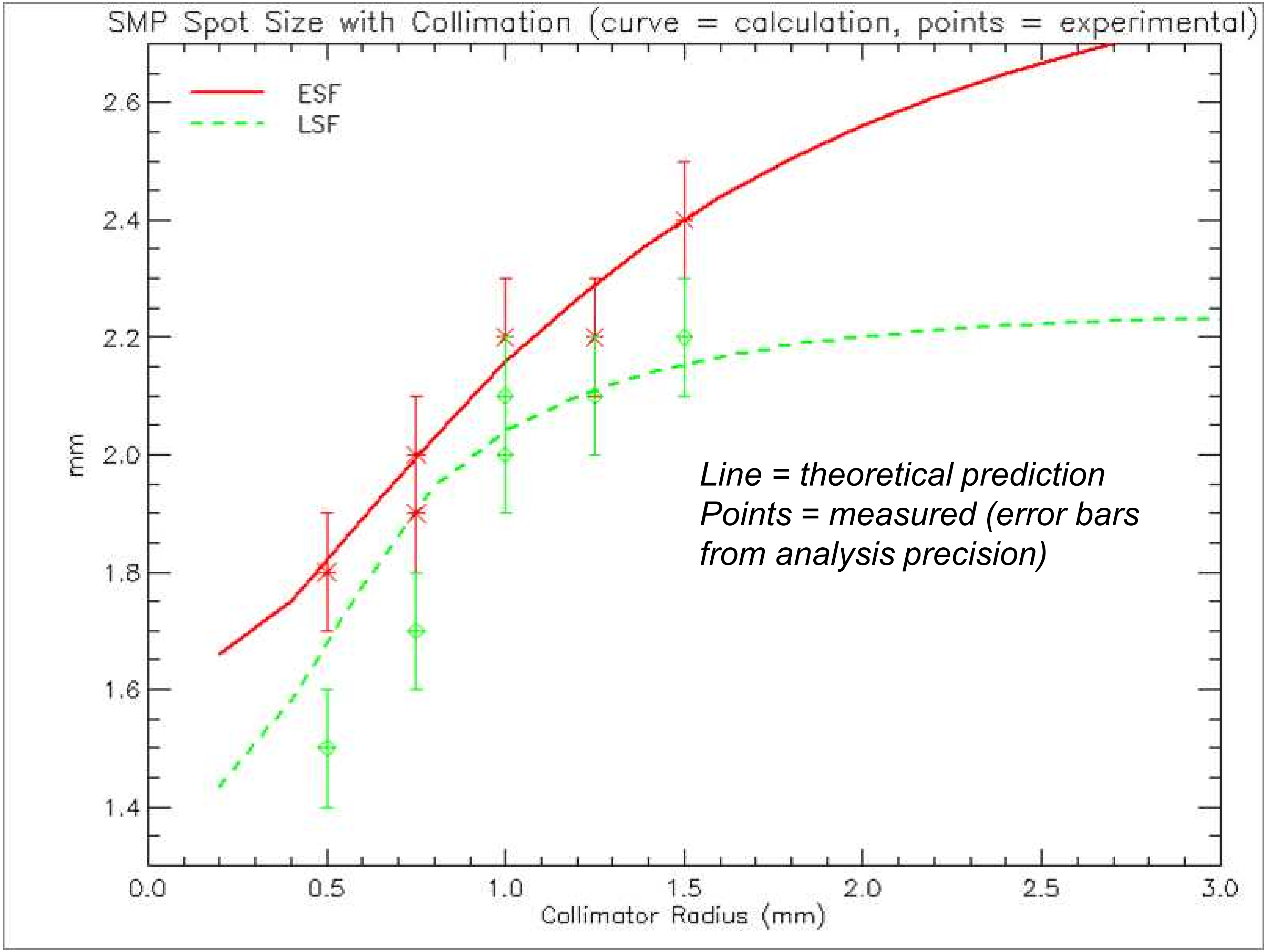
Drawing Not to Scale

Hard Collimation Truncates "Wings" of X-ray Source Distribution



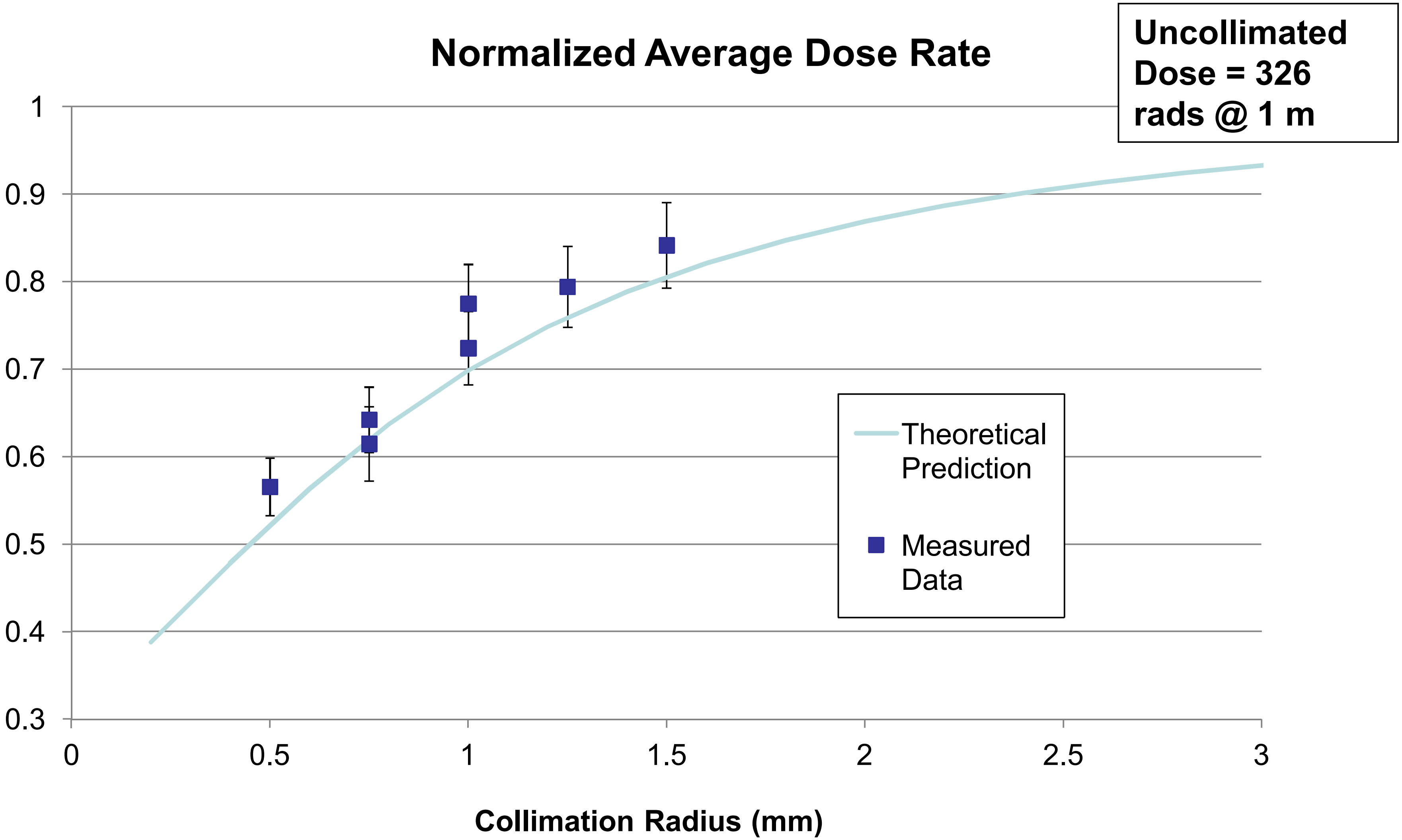
“Brightness” (dose/spot^2) Theoretical Calculation for Stainless Steel Hard Collimator





SMP Spot Size with Collimation (curve = calculation, points = experimental)
ESF
LSF
Line = theoretical prediction
Points = measured (error bars
from analysis precision)
mm
2.6
2.4
2.2
2.0
1.8
1.6
1.4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Collimator Radius (mm)

Dose as a function of collimator radius



Conclusion

The self-magnetic pinch diode is an x-ray source produced by a high-intensity electron beam incident on a thin high-atomic number bremsstrahlung converter. The beam focus is produced by charge neutralization of the beam by anode protons which causes the magnetic field to pinch the electron beam. Subsequent beam behavior is highly dependent on the anode plasma properties. Current and future work is being done to characterize this plasma (see Poster #29 by Mark Johnston).

The SMP source has been characterized on the RITS-6 accelerator with a peak voltage of 7.5 MV with a pulse width of around 45 ns with a dose of > 300 rads (CaF_2) @ 1 m distance. The FWHM of the PSF and LSF is approximately 1.6 mm. The total radiographic performance should include the effect of detector blur which is on the order of 0.3 mm depending on the detector material. However the system blur is dominated by the spot size when the magnification is greater than 1.2.

Hard Source collimation is effective in increasing the source brightness and measurements are in good agreement with theoretical predictions.

Future work will focus on increasing the effectiveness and reproducibility of the SMP diode in conjunction with higher density collimator materials as well as evaluating the dose requirements for transmission through thick objects, a problem which is highly coupled with the detection efficiency of the imaging system.

References

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