SAND2013-4635C

Radiographic Characteristics of the Self-Magnetic Pinch Diode at RITS-6 and URSA-Minor

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IEEE Pulsed Power and Plasma Science Conference
San Francisco, CA
June 18, 2013

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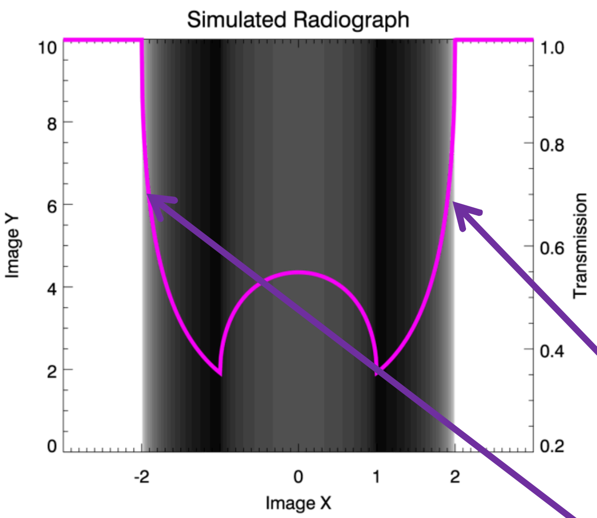
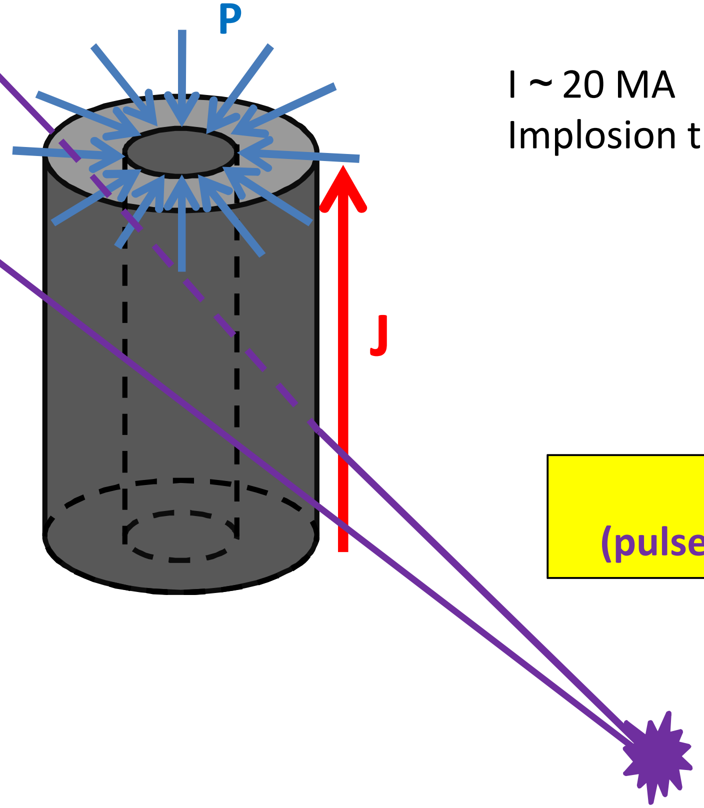
Abstract

The self-magnetic pinch (SMP) diode[1] is an intense flash x-ray radiographic source being developed at Sandia National Laboratories. The diode is capable of less than 3 mm spots and greater than 300 rads measured at 1 meter depending on the diode voltage. The diode is most commonly fielded on the Radiographic Integrated Test Stand (RITS-6), a 7.5 MV, 185 kA inductive voltage adder (IVA) accelerator and has also been tested on the URSA-Minor accelerator, an IVA based on the linear transformer driver (LTD) pulsed power generator at 0.9 and 2 MV. Various test objects including step wedges and resolution targets are used to study the spatial resolution and spectral characteristics of the radiographic system which of necessity include the x-ray source, shielding, and the detector system. These properties can be used to make general predictions of radiographic performance.

Why do radiography?
Example: imploding cylindrical shell



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



I ~ 20 MA
Implosion time: few hundred ns

Unfolded Densities and location of inner surface gives implosion velocity and information about material EOS.

X-ray backlighting (pulse width << implosion time)

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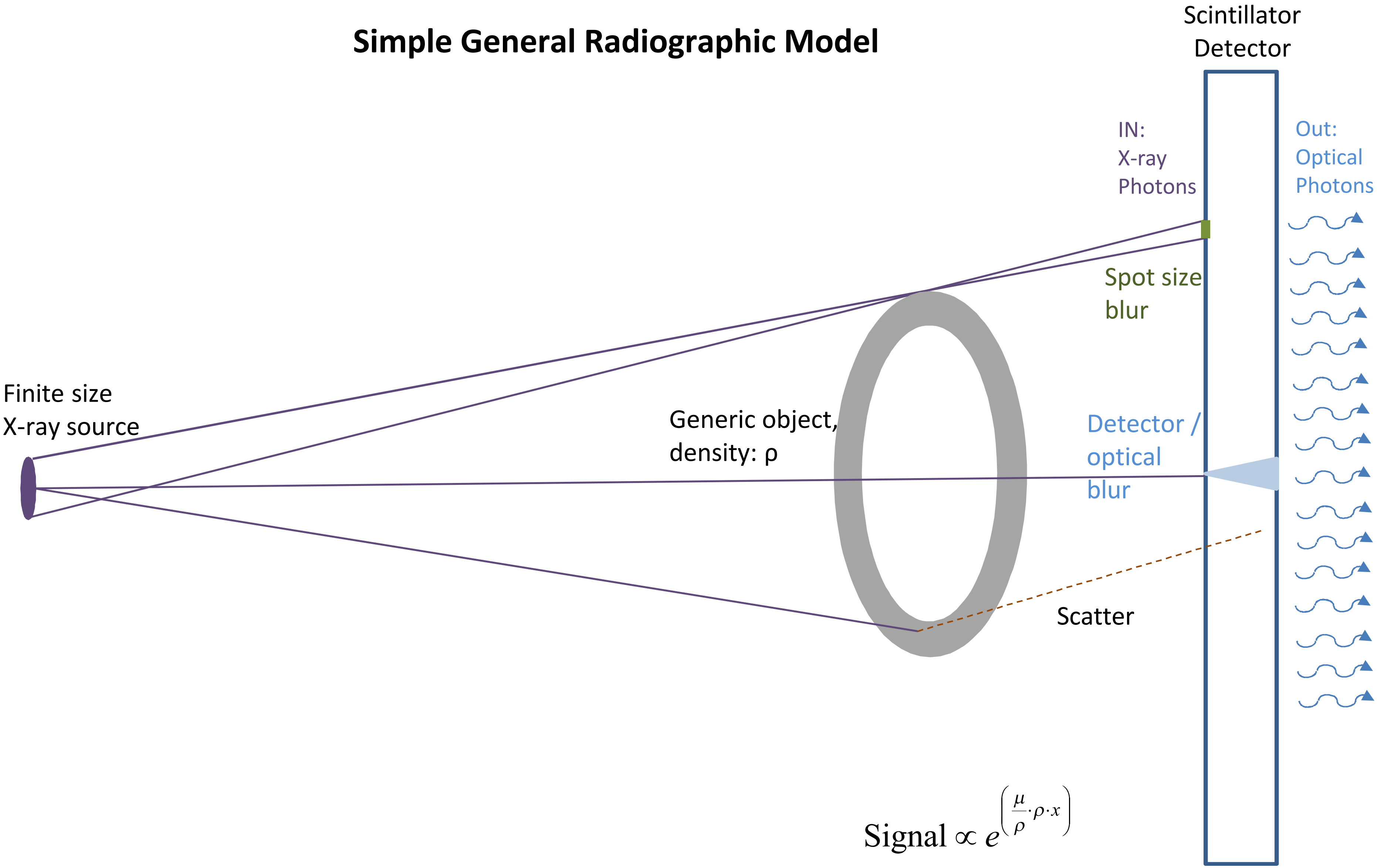
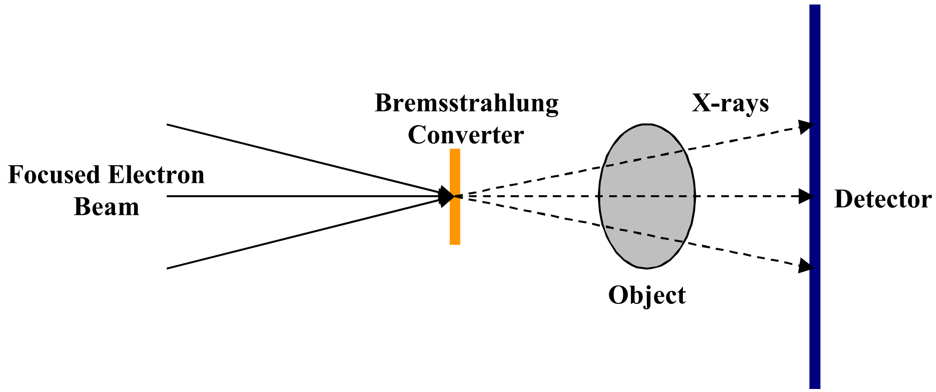
Simple General Radiographic Model



$$\text{Signal} \propto e^{\left(\frac{\mu}{\rho}\cdot\rho\cdot x\right)}$$

"*μ/ρ*" is property of x-ray spectrum and *x* is local line-of-sight material thickness

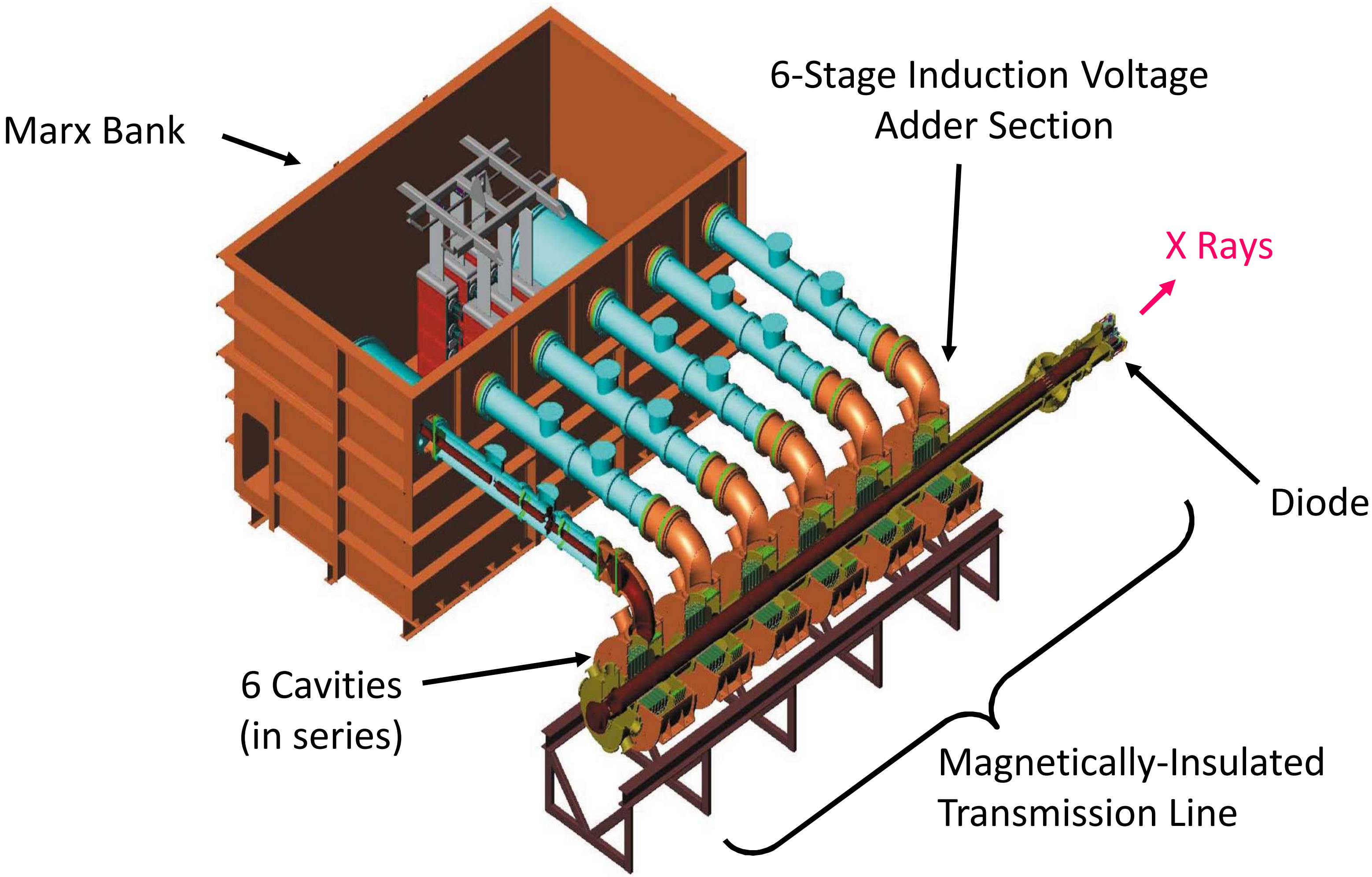
X-Ray Radiographic Source Properties



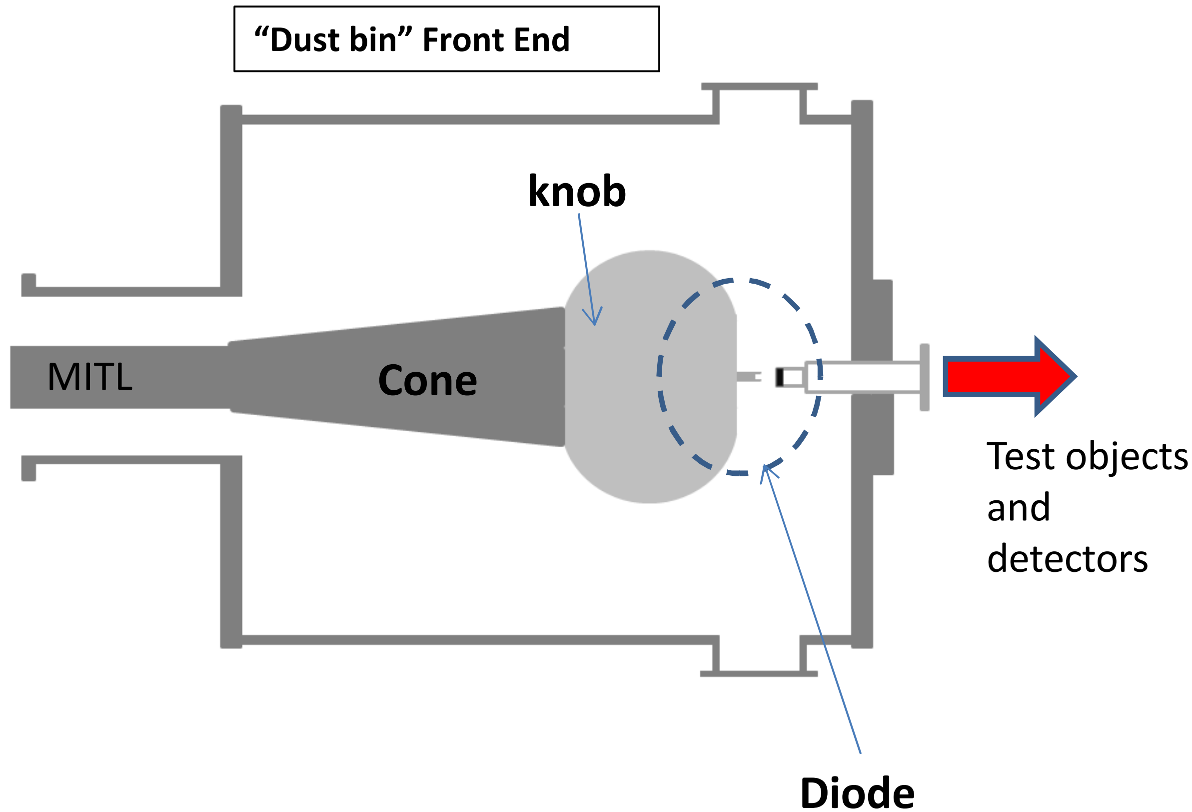
Radiographic Source Characteristics	Affect on radiograph or analysis
Dose	Signal-to-noise ratio (SNR)
Spot size	Resolution
Energy Spectrum	X-ray penetration and contrast
Flat field (beam uniformity)	Areal density reconstruction
Spot position	Spatial correlation of objects
Pulse width	*Degree of motion blur in dynamic objects*
Multi-pulse	*Time evolution of dynamic objects*
Multi-axis	*Three dimensional features of object(s)*

SMP diode research has been conducted on the RITS-6[2] pulsed-power accelerator

Radiographic Integrated Test Stand (RITS-6)

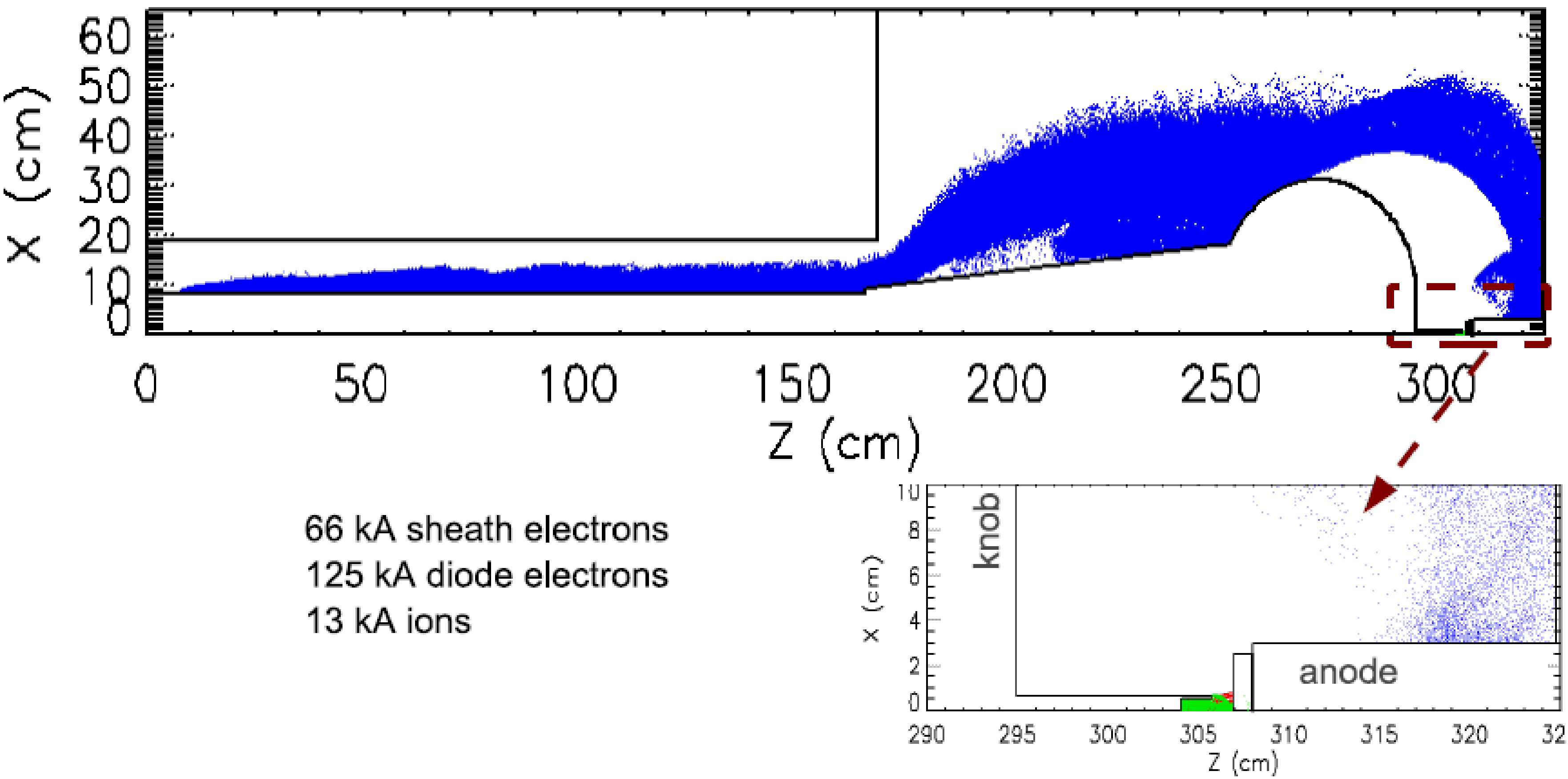


RITS-6 is a 8-12* MV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of flash x-ray radiography diode configurations (by my count around half-dozen different "diodes")



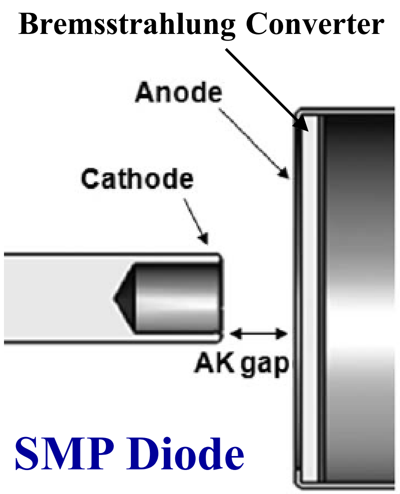
*Traditionally the maximum voltage is changed by changing the MITL inner conductor. Over the last six months we have operated the machine as low as 2 MV by different operating points on the Marx generator and PFLs.

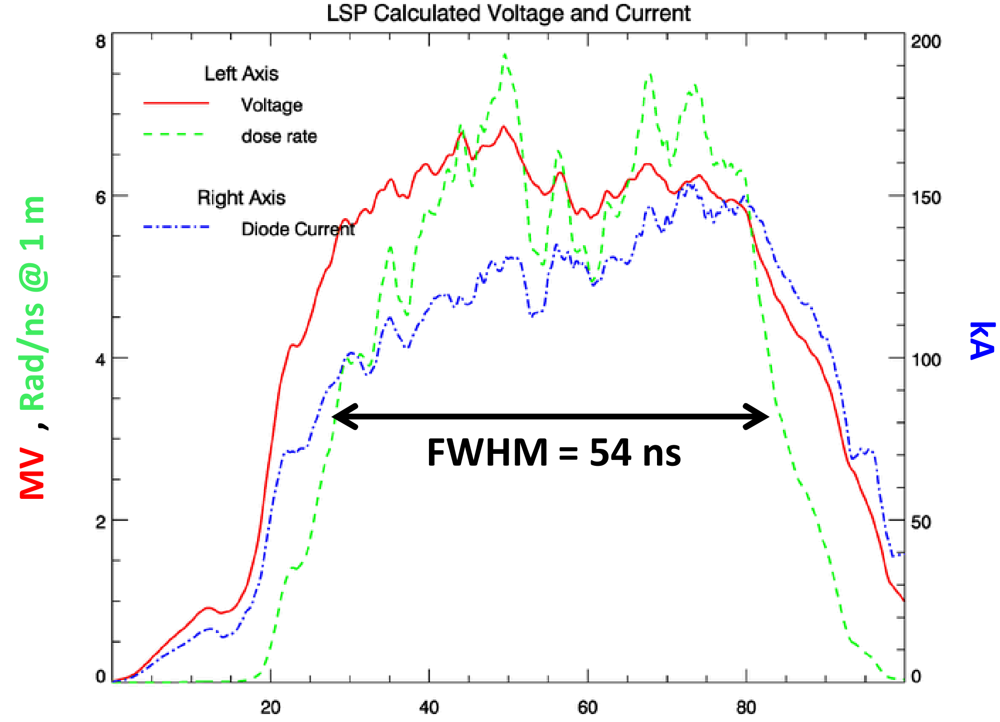
Particle-In-Cell Simulations of Electron Flow in Dustin Region[3, 4]

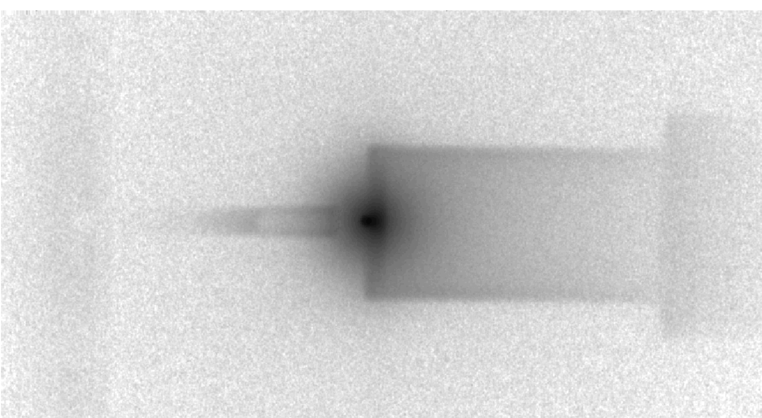


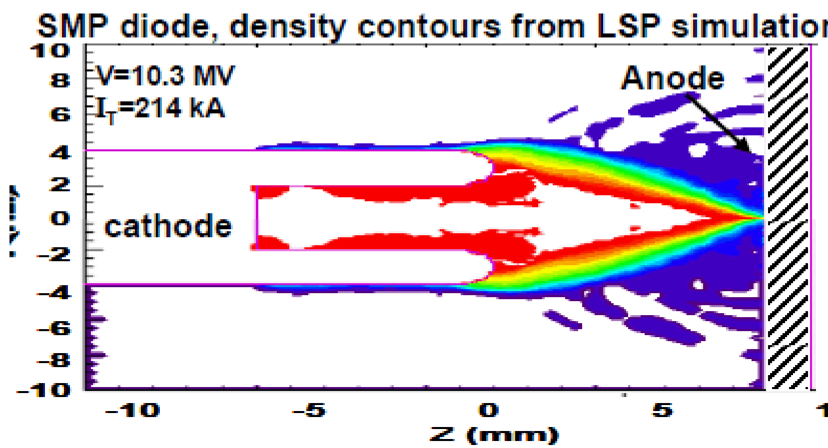
Electron "flow" is generally a nuisance which must be shielded out; it can affect diode operation however.

The Self-Magnetic Pinch Diode

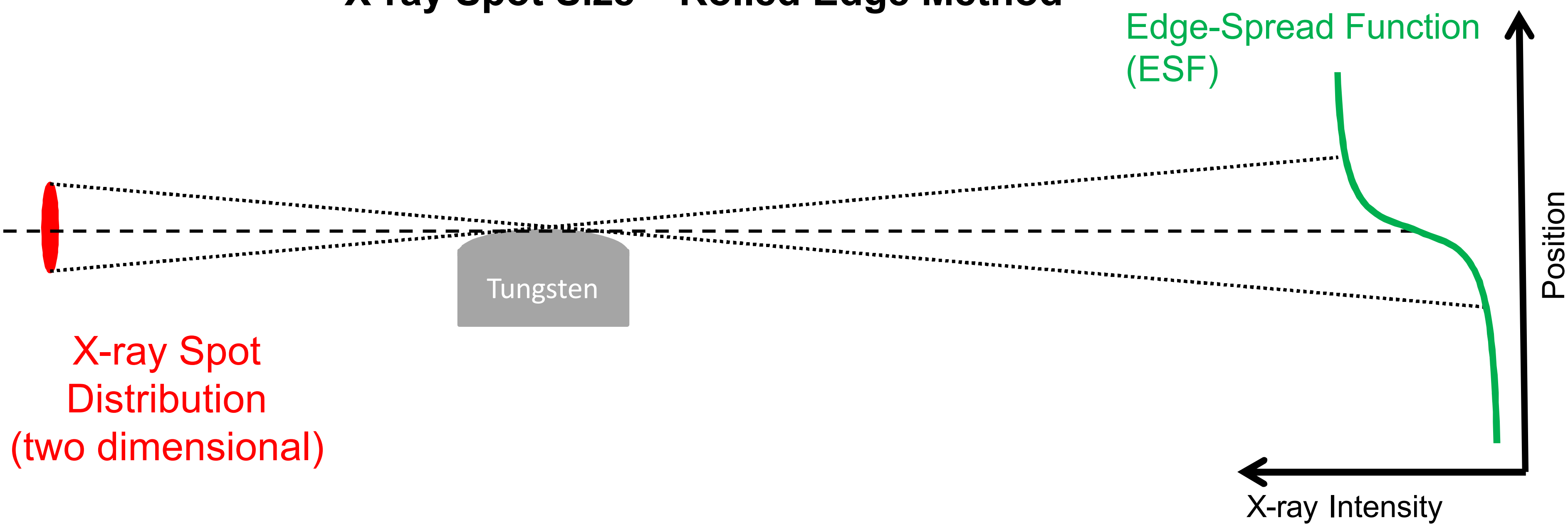








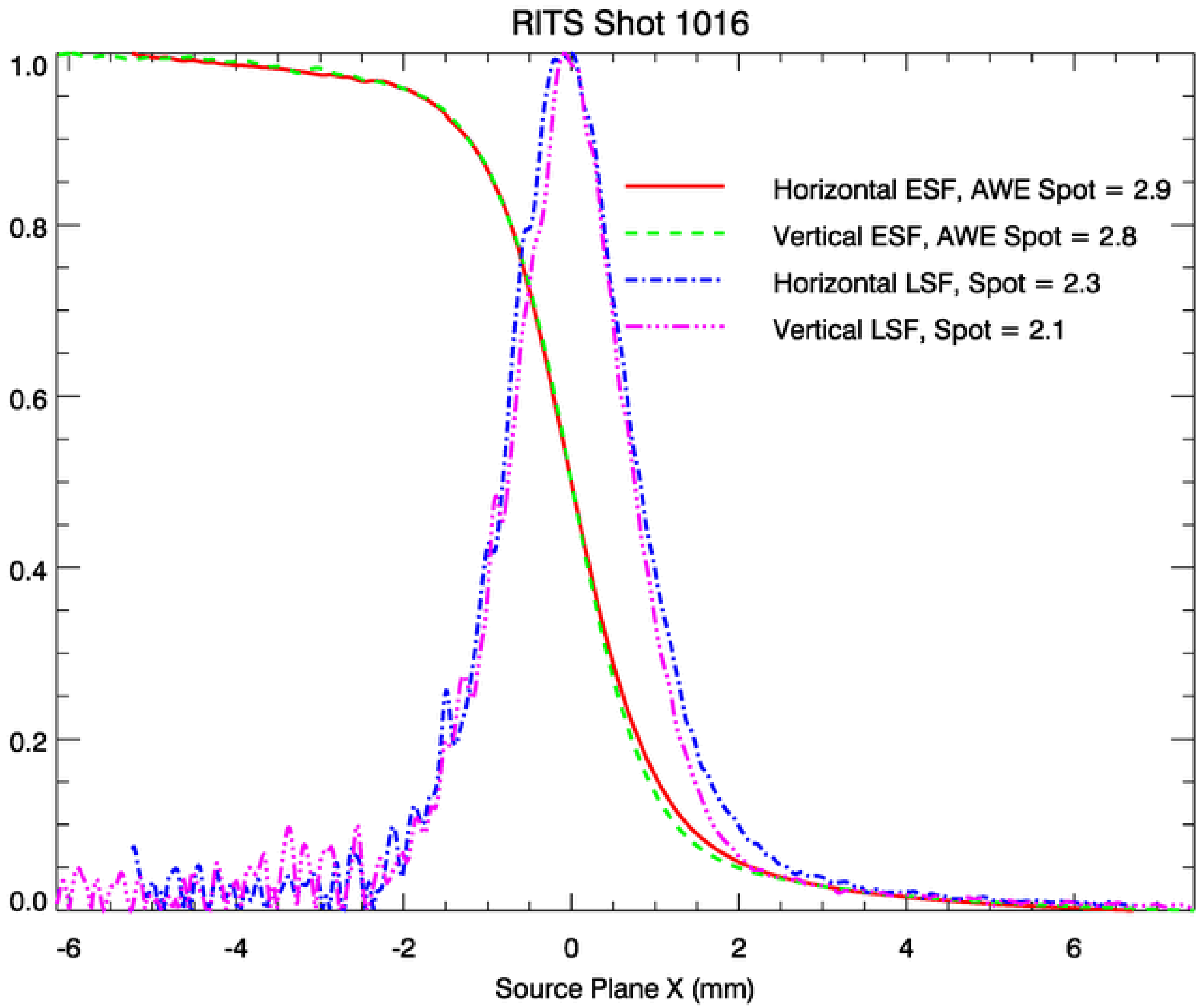
X-ray Spot Size – Rolled Edge Method

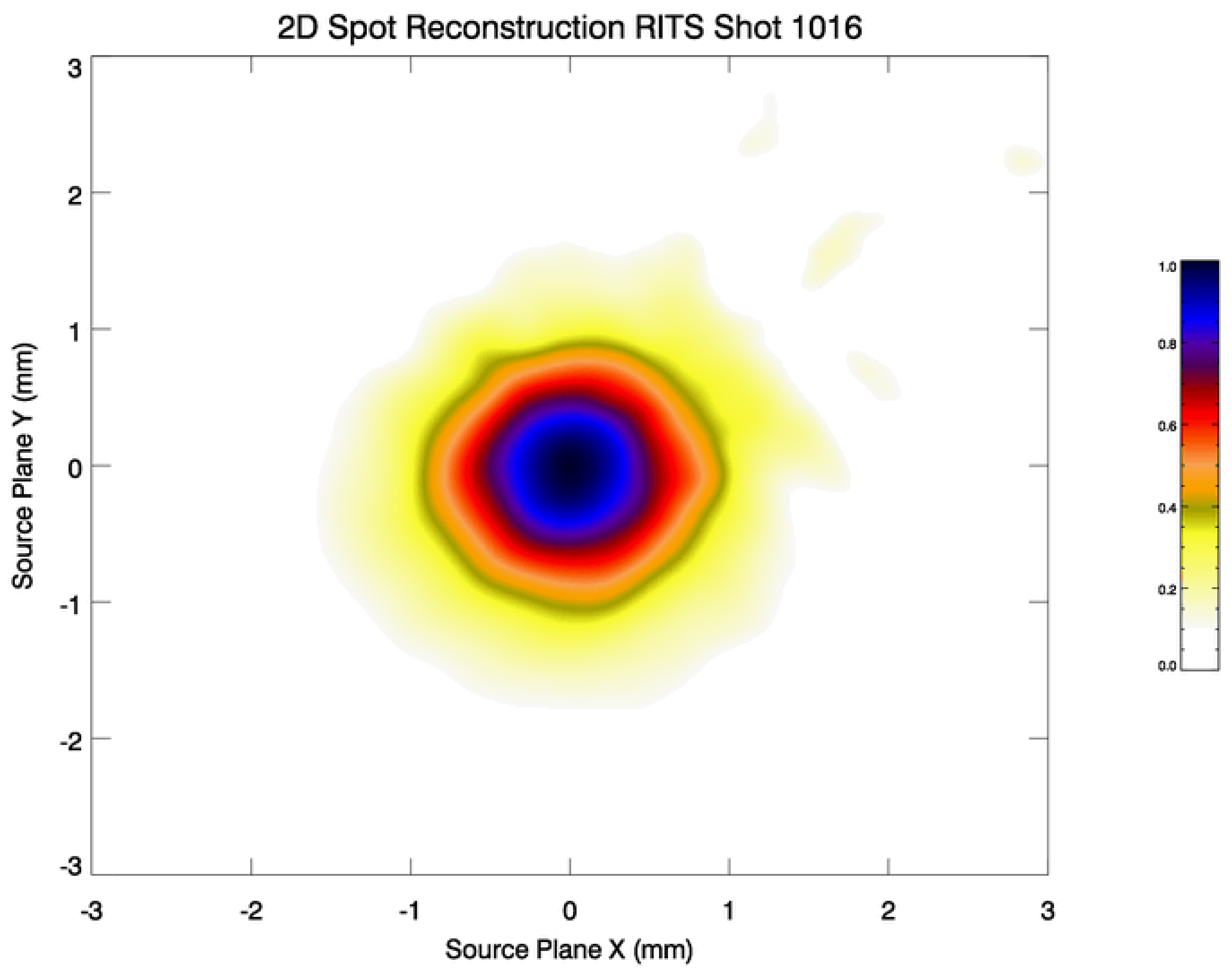


Spot Sizes Metrics

- ESF, AWE Definition: 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

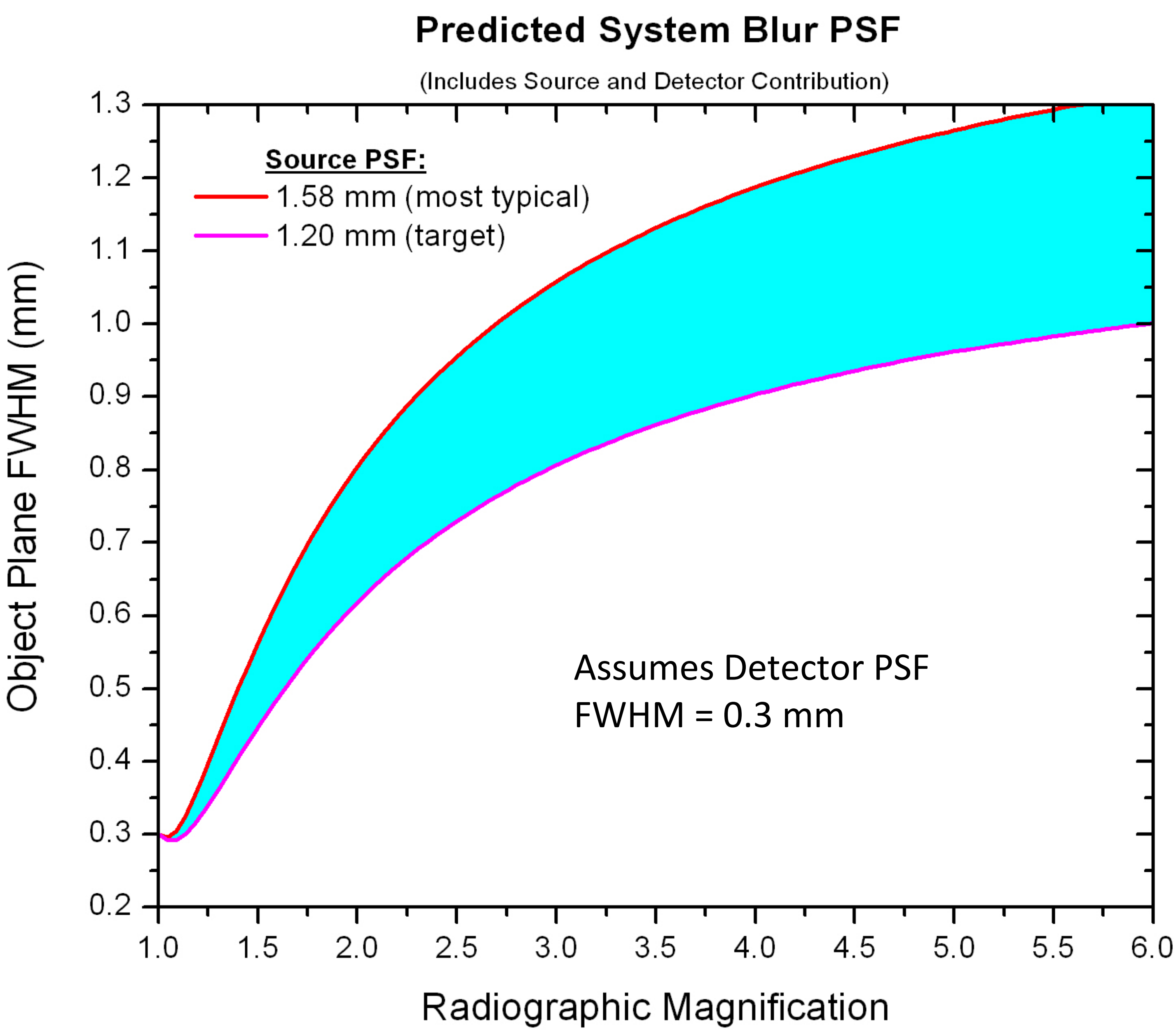
Typical Spot Sizes



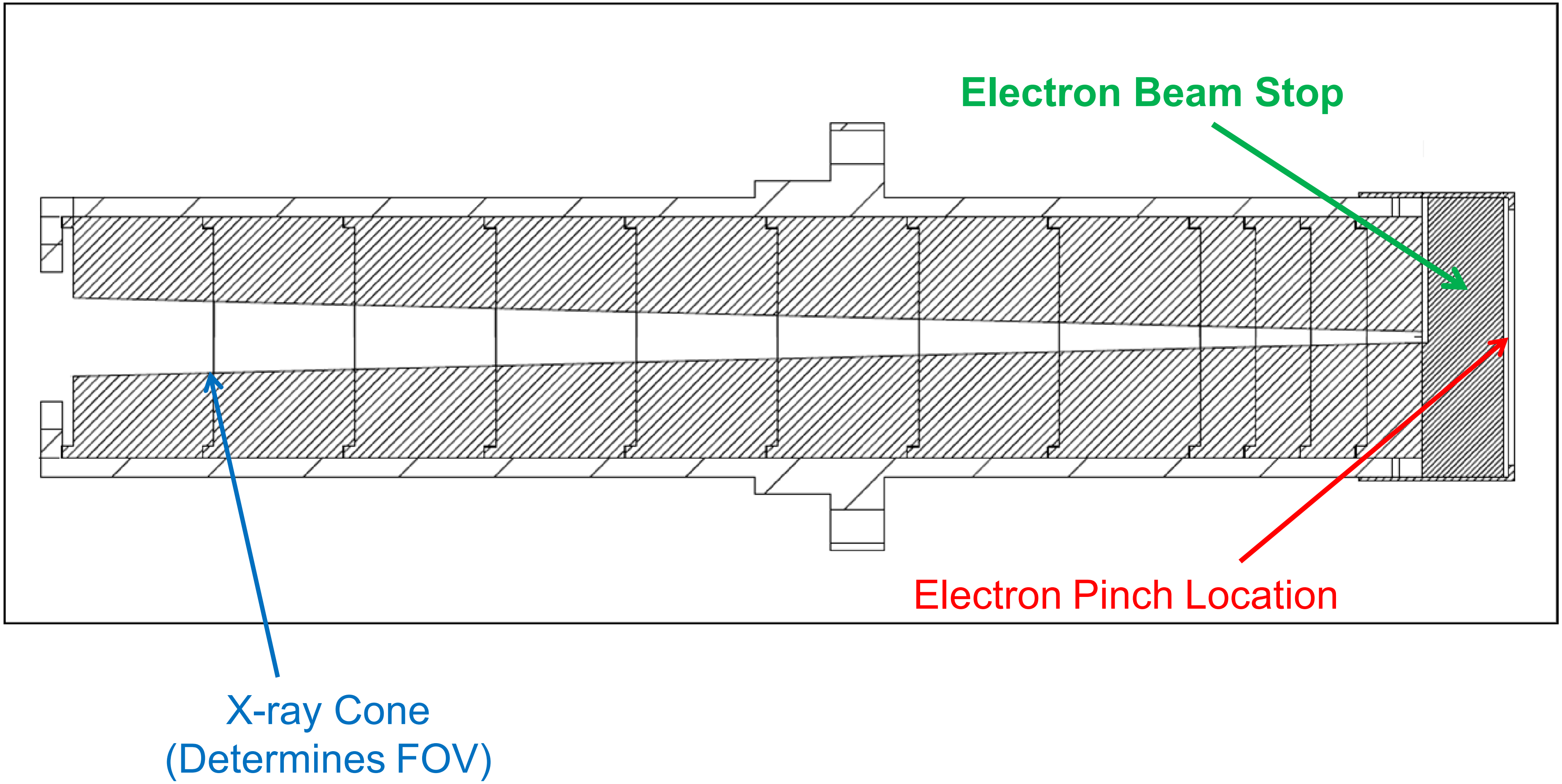


FWHM Average = 1.58 mm, σ = 0.04 mm

Reconstruction method: Ref. 5

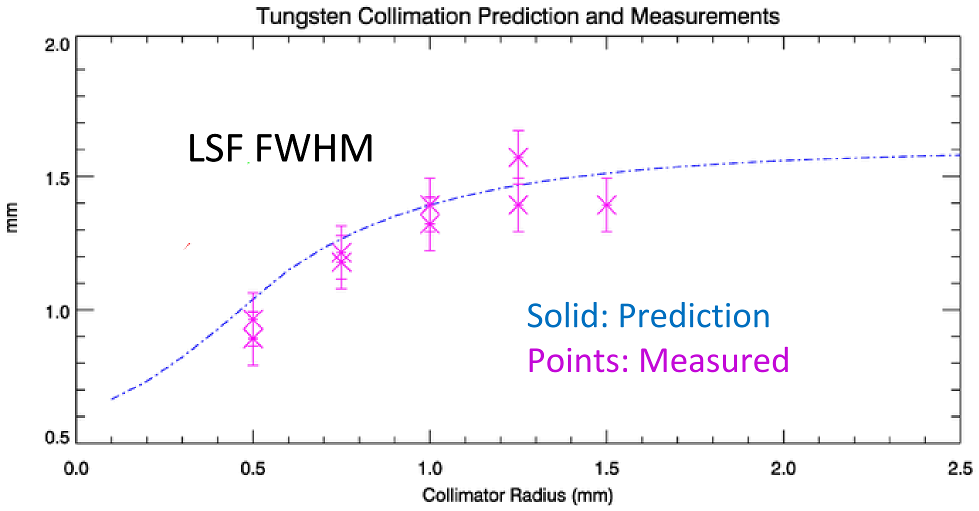

Predicted System Blur PSF
(Includes Source and Detector Contribution)
Source PSF:
1.58 mm (most typical)
1.20 mm (target)
Assumes Detector PSF
FWHM = 0.3 mm
Object Plane FWHM (mm)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Radiographic Magnification

Stainless Steel Hard Collimator to Achieve Smaller Spot Size



Drawing Not to Scale

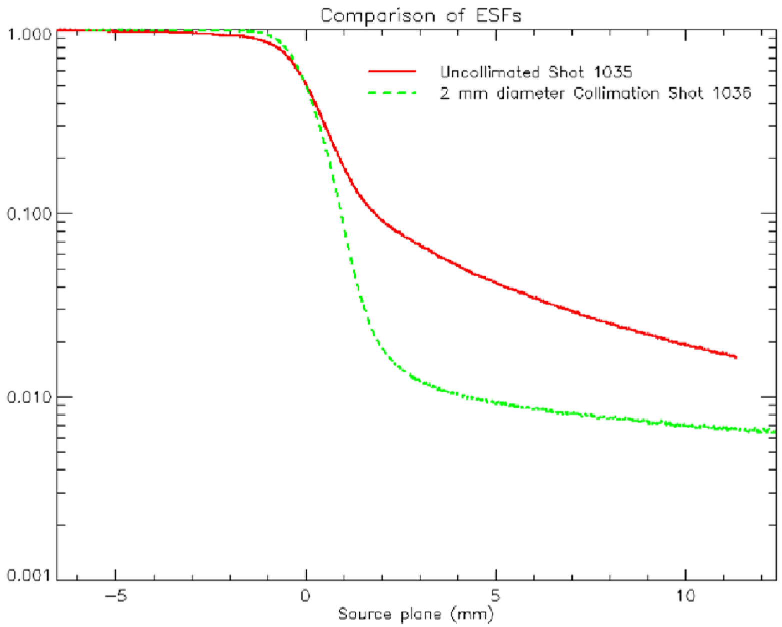
Hard collimation reduces spot size and increases image contrast

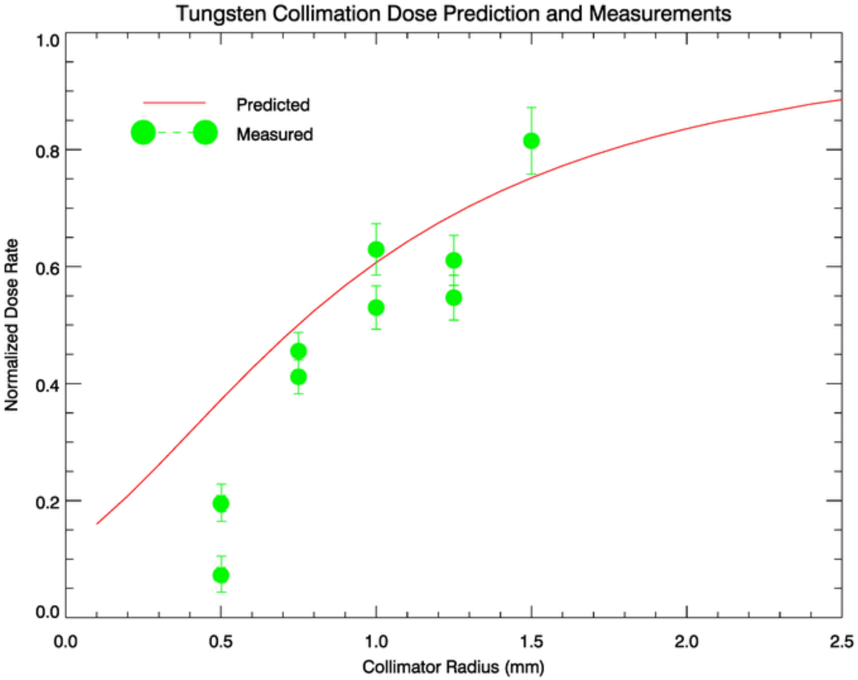


- Spot size agrees with theoretical expectation
- Increased edge dynamic range due to elimination of PSF tails.
- Increased dose / dose rate loss especially at smaller collimator diameter since it is more difficult to hit collimator center directly.

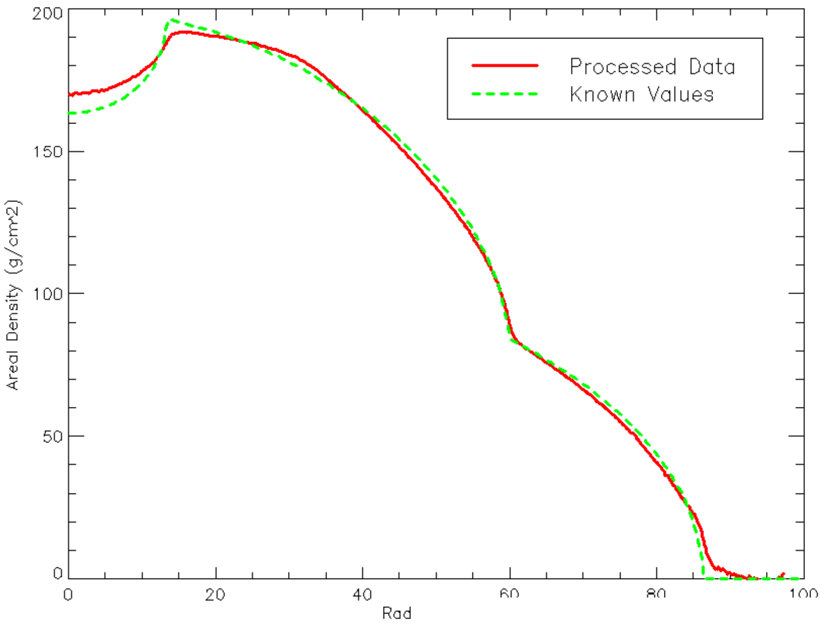
Also…

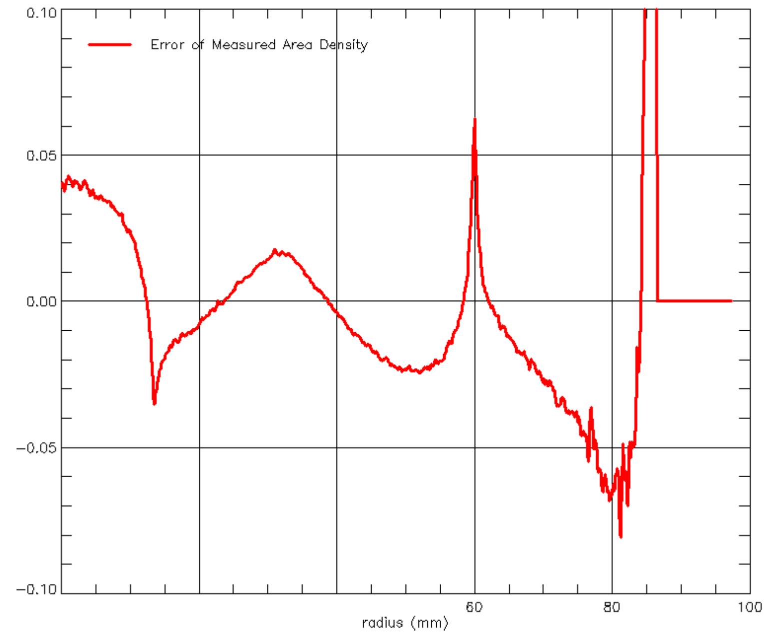
- Gradient introduced to flatfield profile if spot is misaligned to collimator.

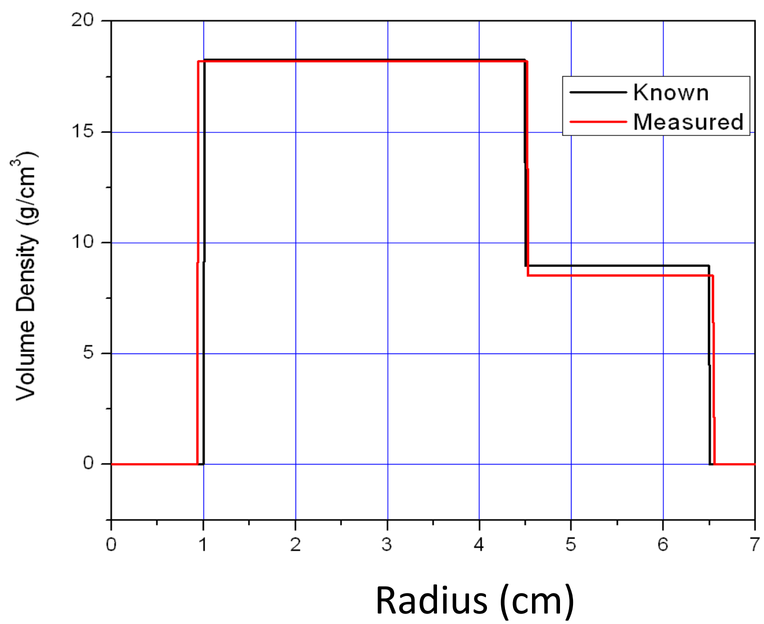




Density Unfolds

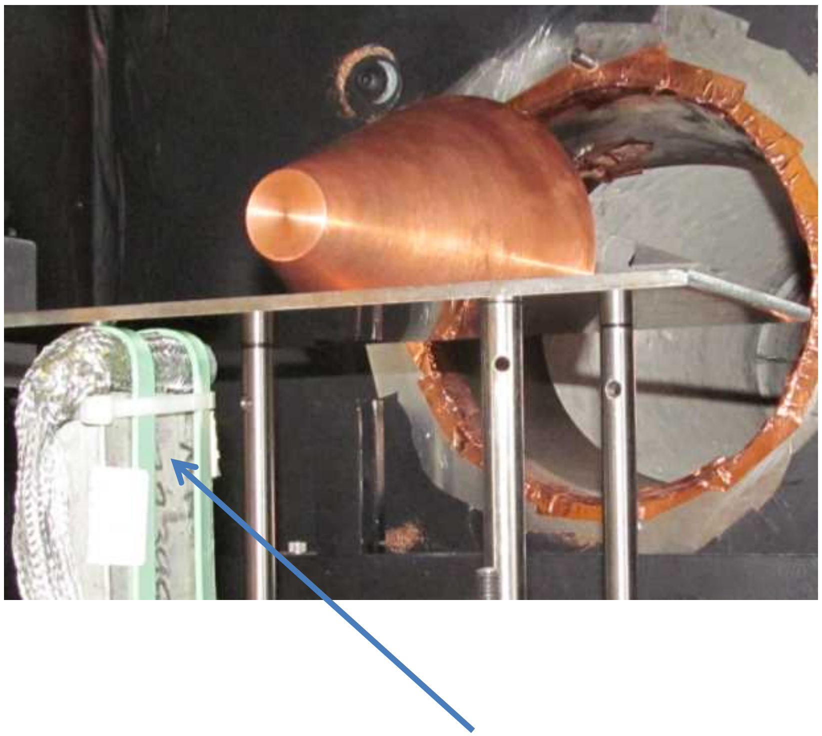




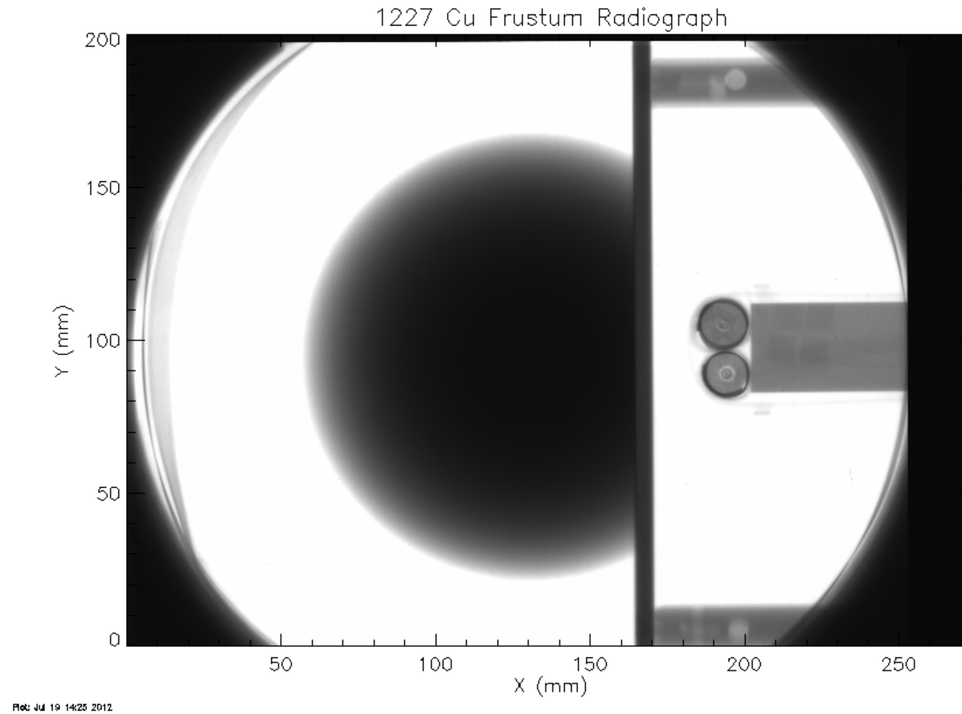


Source blur not accounted for in analysis, results in larger errors at edges.

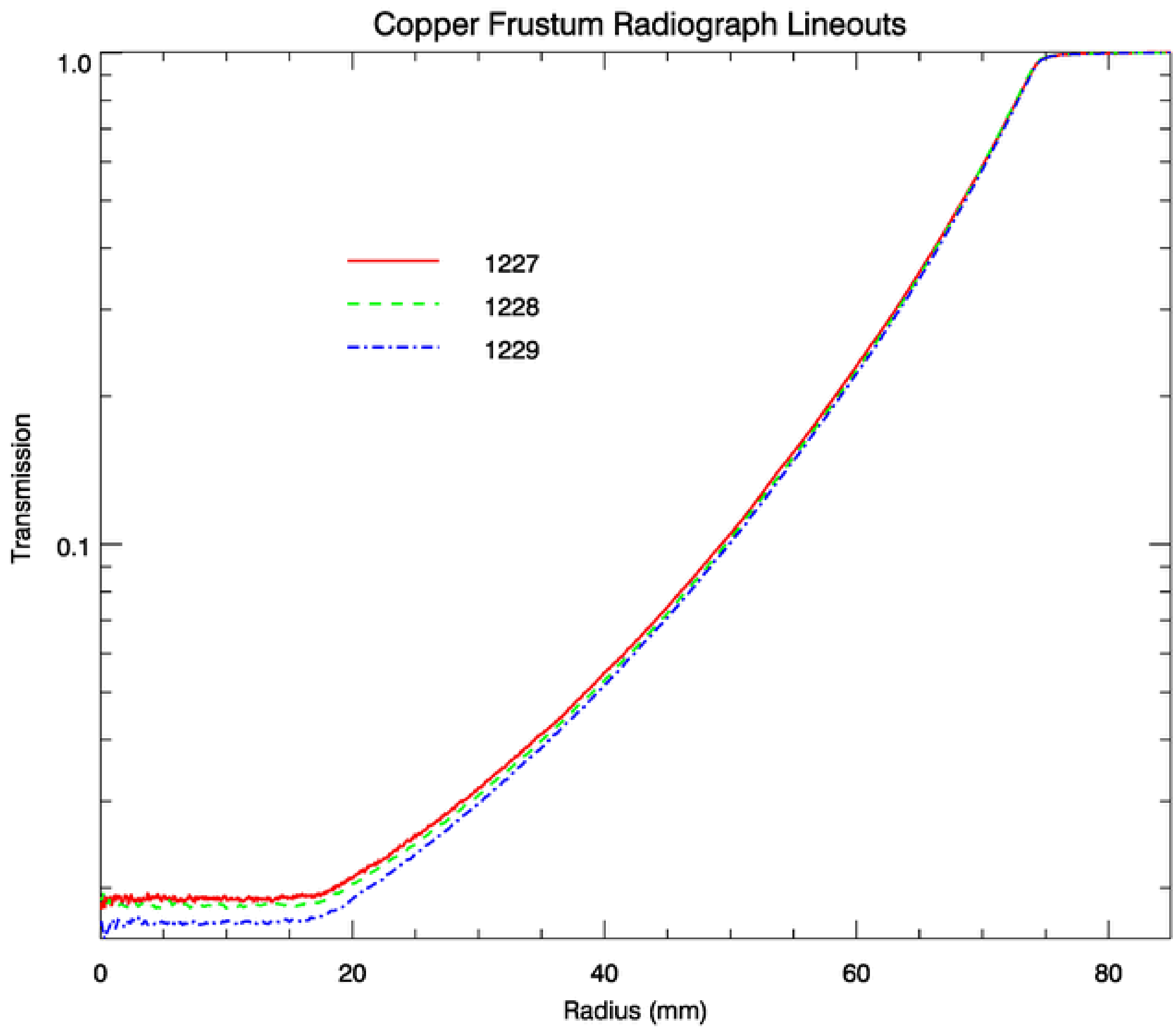
Spectral Variability: Transmission Function Measured with Repeated Shots on Copper Frustum (low magnification)



PIN diodes and TLDs

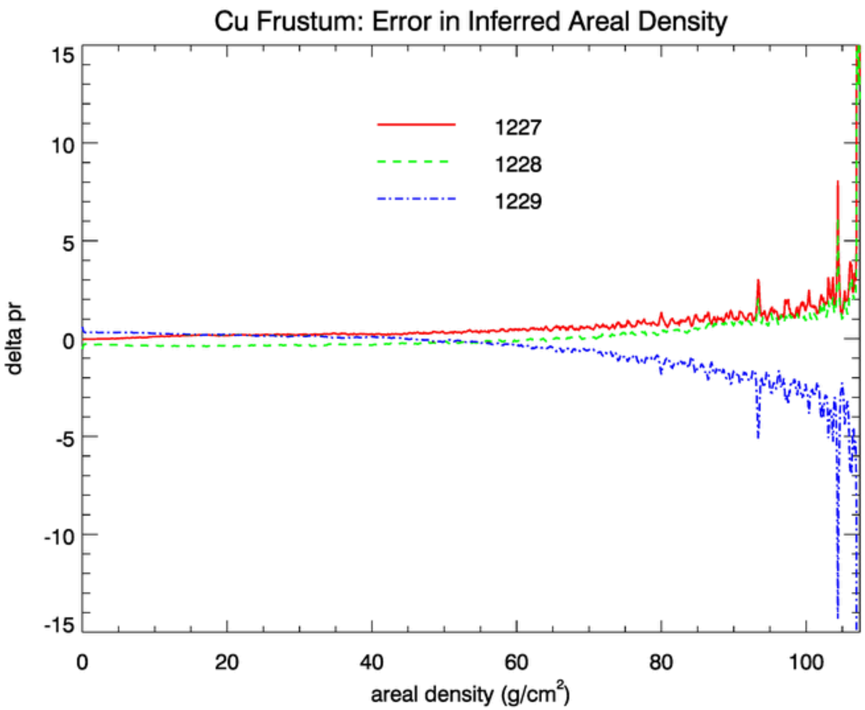


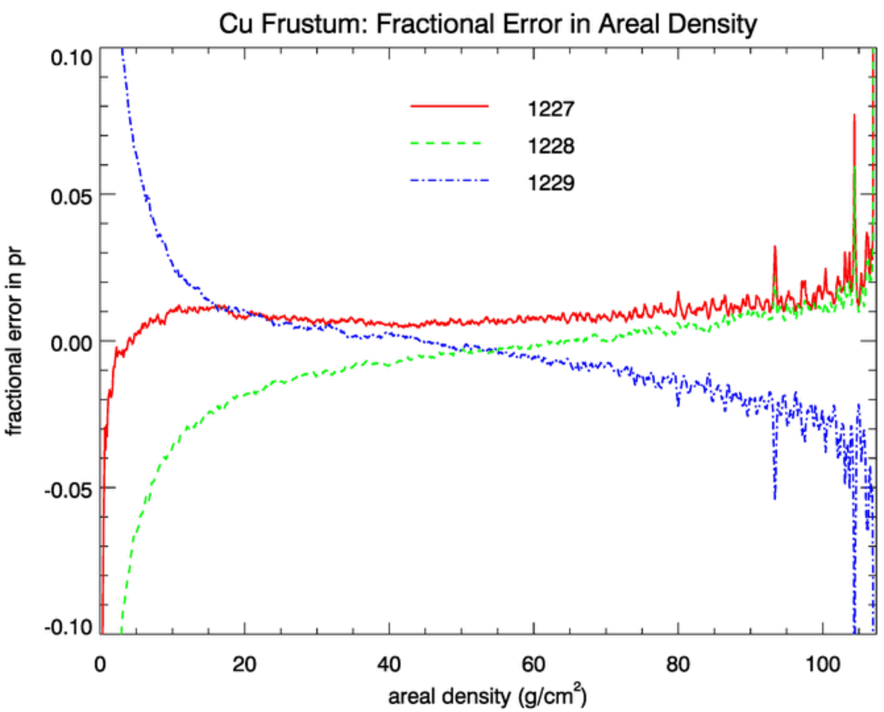
(Image rotated 90°)



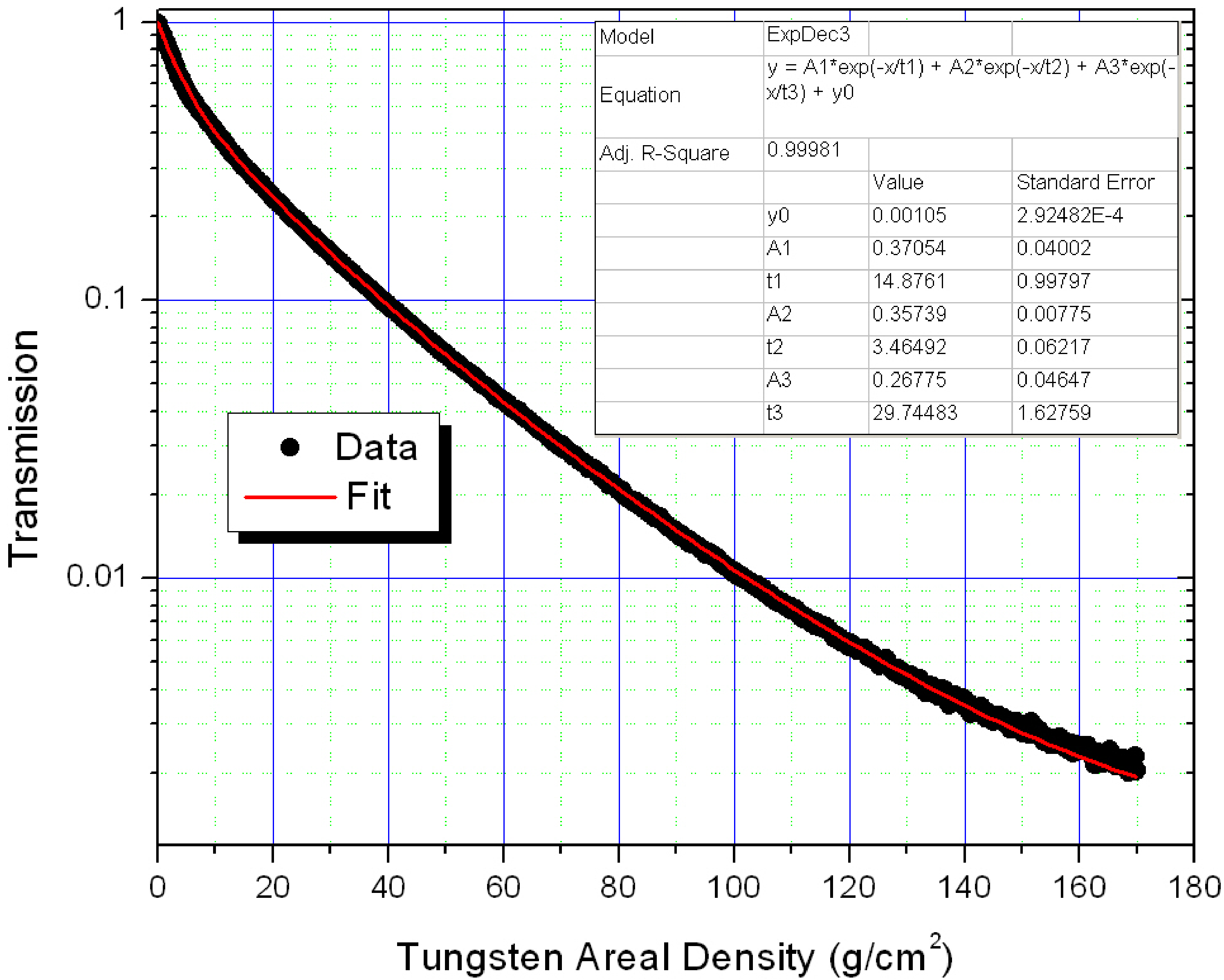
Copper Frustum Radiograph Lineouts
1.0
0.1
Transmission
1227
1228
1229
0
20
40
60
80
Radius (mm)

Taking the differences of the “measured” transmission curves from the average and dividing by the derivative gives an estimate of the “error” of the inferred areal density.





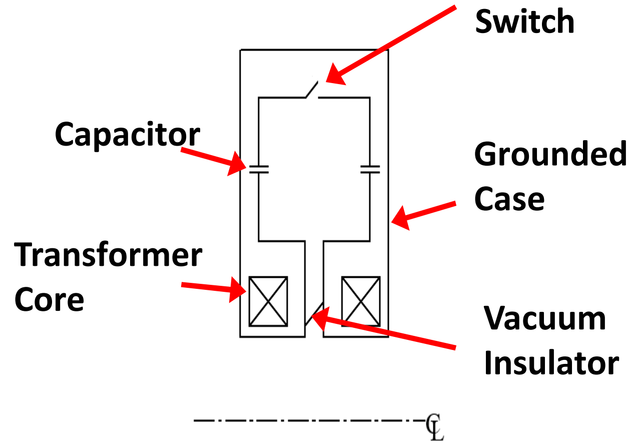
Transfer Curve of SMP Diode at 7 MV

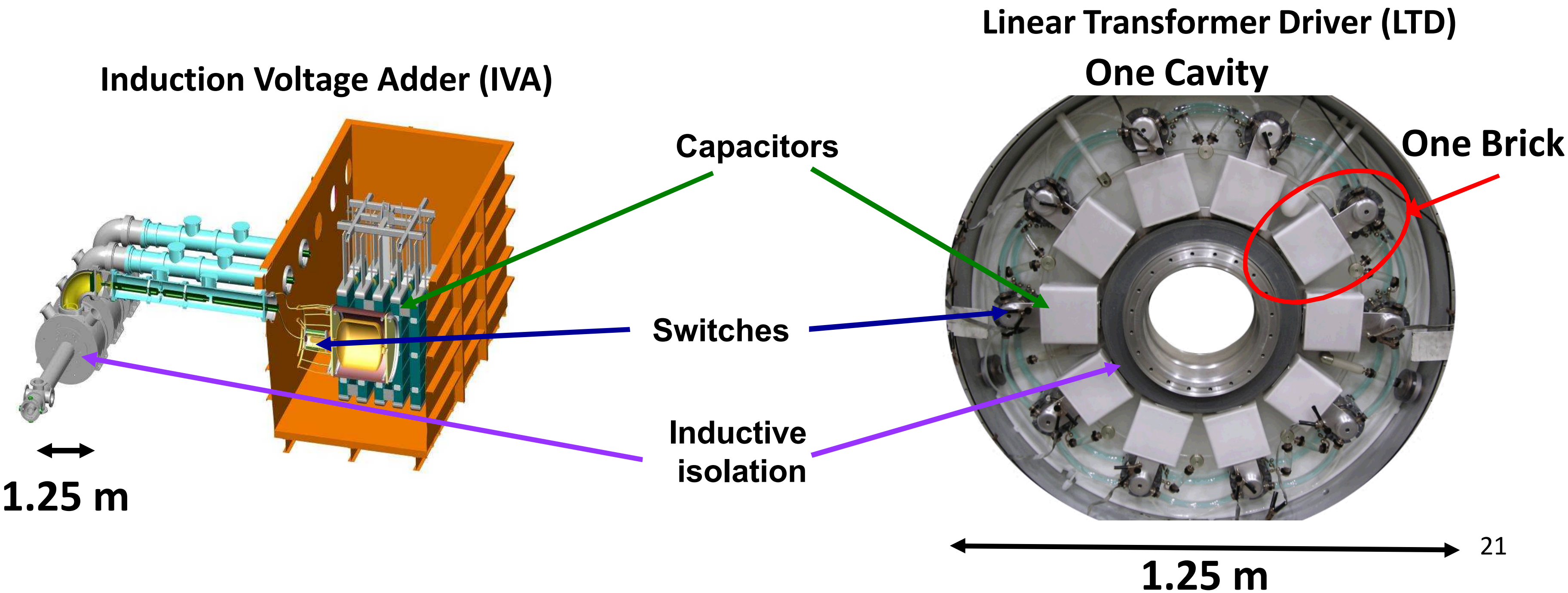


Model	ExpDec3		
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2) + A3*exp(-x/t3) + y0		
Adj. R-Square	0.99981		
		Value	Standard Error
	y0	0.00105	2.92482E-4
	A1	0.37054	0.04002
	t1	14.8761	0.99797
	A2	0.35739	0.00775
	t2	3.46492	0.06217
	A3	0.26775	0.04647
	t3	29.74483	1.62759

An LTD is a compact IVA with energy storage inside adder cavities

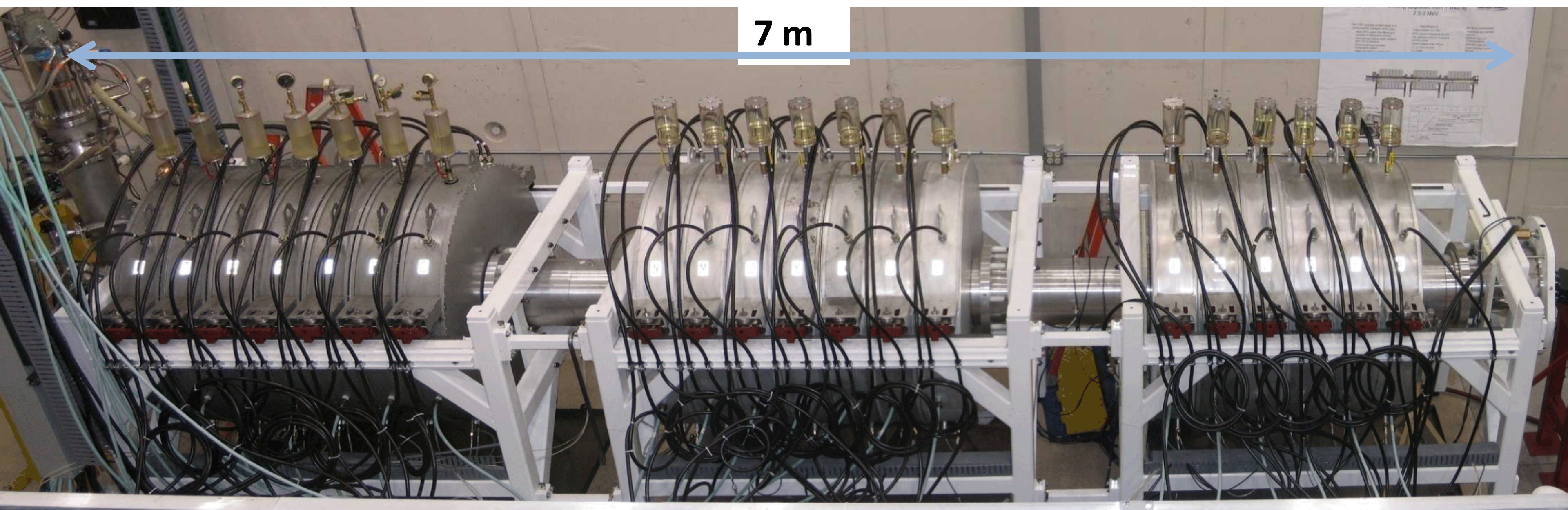
- The basic building block is a low inductance RLC circuit
- Eliminates the requirement for pulse compression stages typical of IVA accelerators
- Smaller footprint than comparable IVA





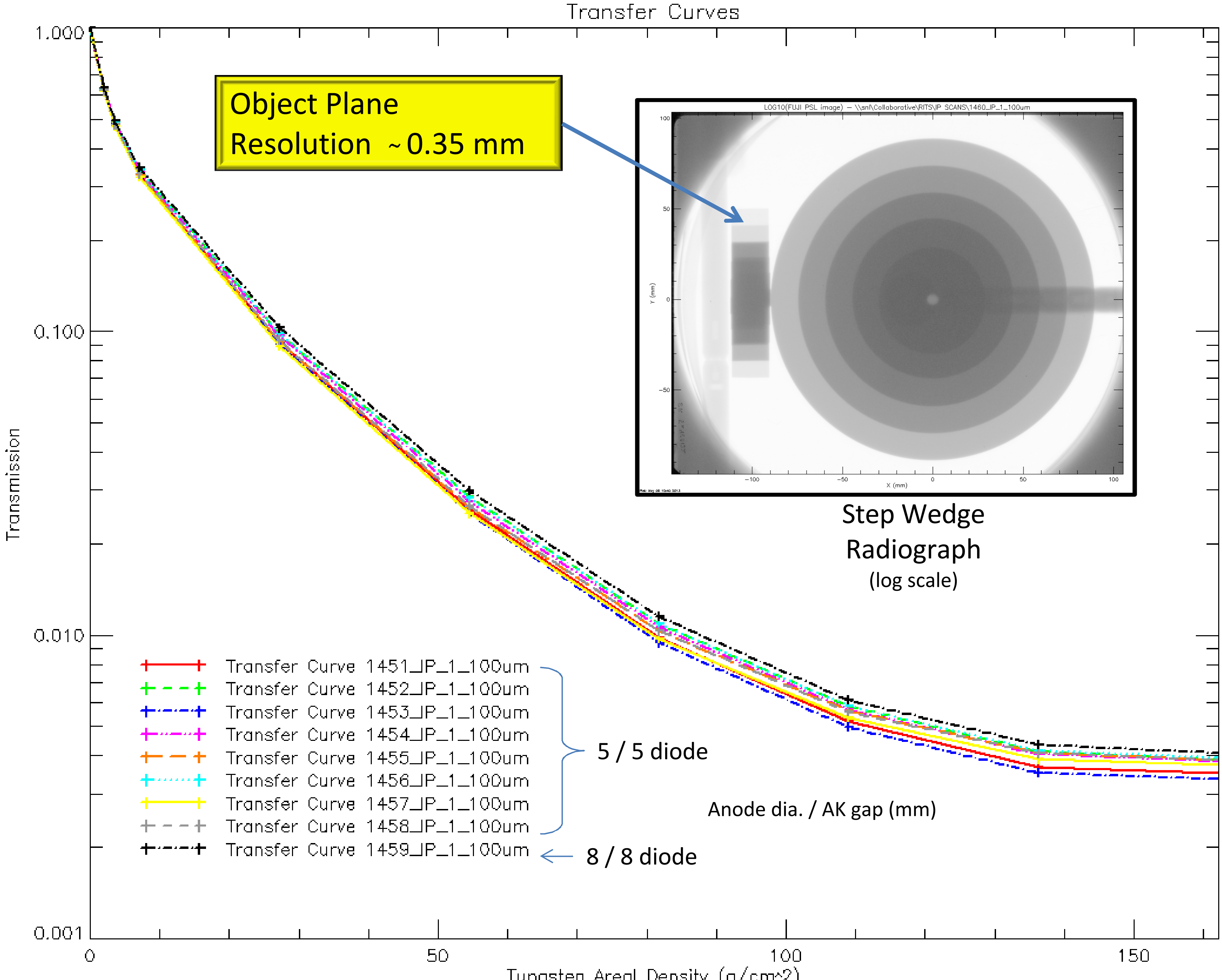
Ursa Minor[6] is a 2.5 MeV LTD for electron beam diode research

- Based on the 1 MV system developed by the Institute for High Current Electronics (Tomsk, Russia)
- Upgraded from 7 to 21-Cavities and commissioned in 2011
- Cavities coupled to load with a magnetically insulated transmission line (MITL)
- 10 parallel bricks in each cavity
- Total of 210 switches and 420 capacitors



Operation of SMP Diode at Various Voltages

	Spot size	rads @ 1 m	FWHM (ns)
LTDR: 0.8 MV	0.7 mm	2.4	40
Ursa Minor: 2 MV	0.95	16	54
RITS: 3-3.5 MV	1.3	30	43
RITS: 4.7 MV	1.3	100	45
RITS: 7 MV	1.6	350	45


Transfer Curves
1.000
0.100
0.010
0.001
Transmission
0
50
100
150
Tungsten Areal Density (g/cm^2)
Object Plane
Resolution ~0.35 mm
Step Wedge
Radiograph
(log scale)
Transfer Curve 1451_IP_1_100um
Transfer Curve 1452_IP_1_100um
Transfer Curve 1453_IP_1_100um
Transfer Curve 1454_IP_1_100um
Transfer Curve 1455_IP_1_100um
Transfer Curve 1456_IP_1_100um
Transfer Curve 1457_IP_1_100um
Transfer Curve 1458_IP_1_100um
Transfer Curve 1459_IP_1_100um
5 / 5 diode
8 / 8 diode
Anode dia. / AK gap (mm)

References

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