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Evaluation of spot size and dose of the Self-Magnetic Pinch diode on the RITS-6 accelerator from 3-8 MV

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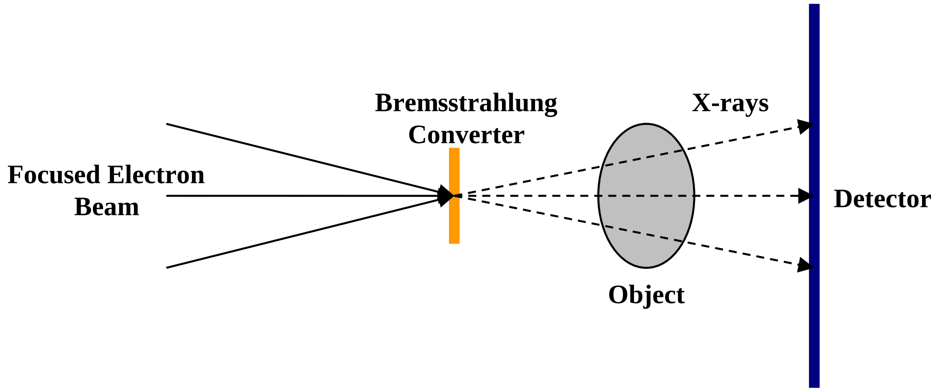
Abstract

The self-magnetic pinch (SMP) diode[1] is an intense radiographic source fielded on the Radiographic Integrated Test Stand (RITS-6) accelerator[2] at Sandia National Laboratories in Albuquerque, NM. The accelerator is an inductive voltage adder (IVA) that can operate from 2-10 MV with currents up to 160 kA (at 7 MV). The SMP diode consists of an annular cathode separated from a flat anode, holding the bremsstrahlung conversion target, by a vacuum gap. The resulting spot size or x-ray source distribution is characterized by the analysis of the radiograph of a thick "L" rolled edge with both time-resolved and time-integrated diagnostics. It has been found that the spot size and dose varies according to the diode geometry (cathode size and A-K gap) and diode materials but similar minimum spot sizes are achievable independent of voltage.

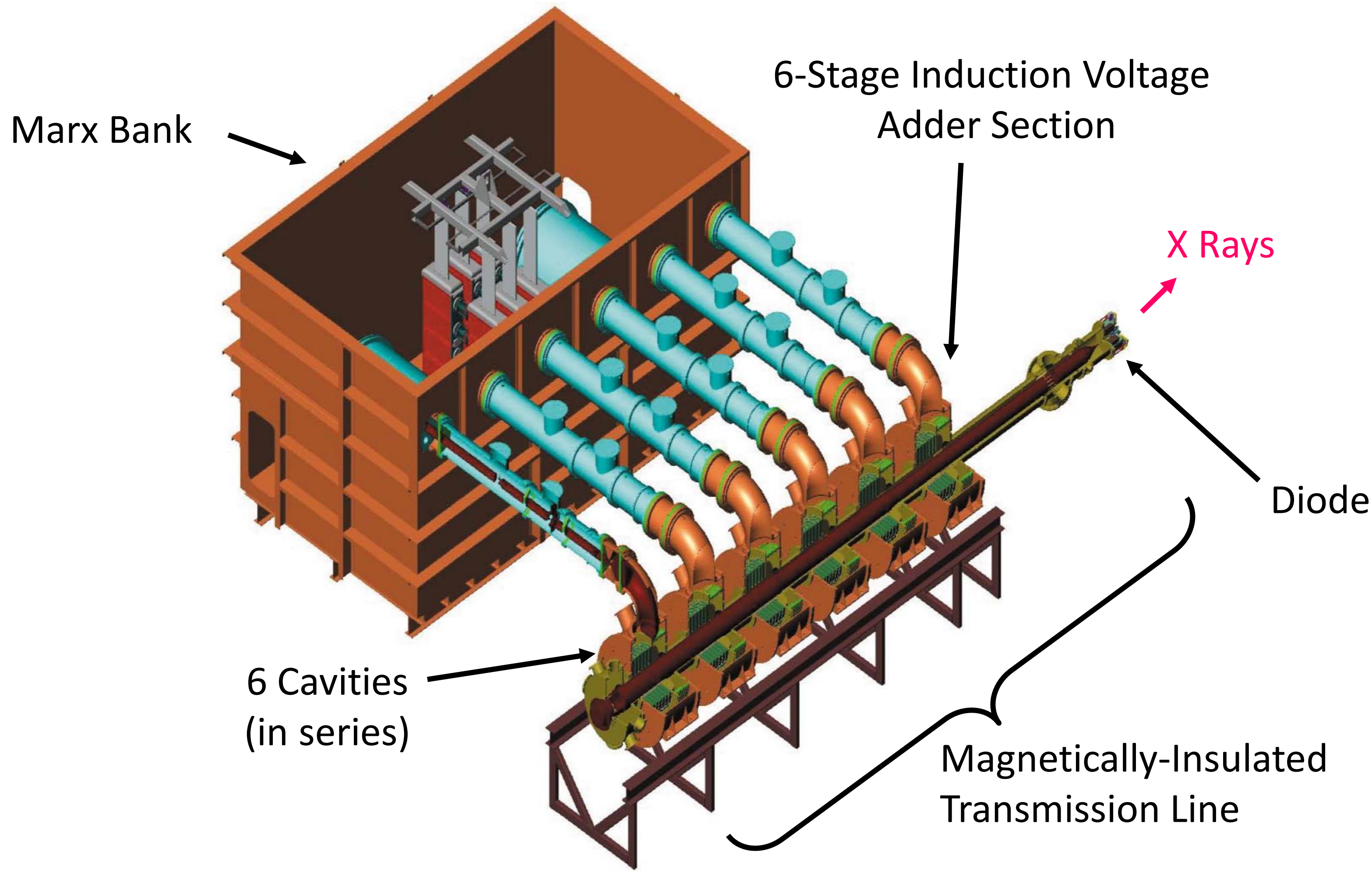
X-Ray Radiographic Source Properties



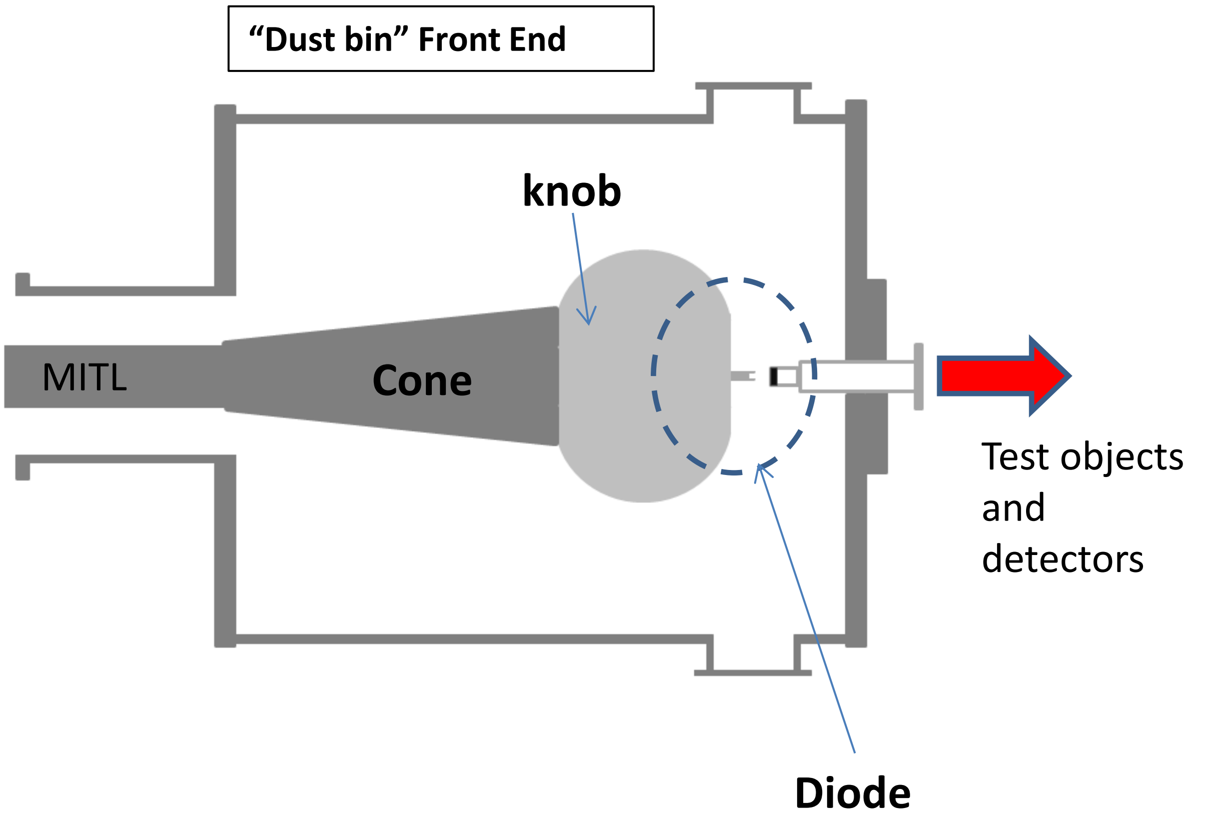
Radiographic Source Characteristics	Affect on radiograph or analysis
Dose	Signal-to-noise ratio (SNR)
Spot size	Resolution
Energy Spectrum	X-ray penetration and contrast
Flat field (beam uniformity)	Areal density reconstruction
Spot position	Spatial correlation of objects
Pulse width	*Degree of motion 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)

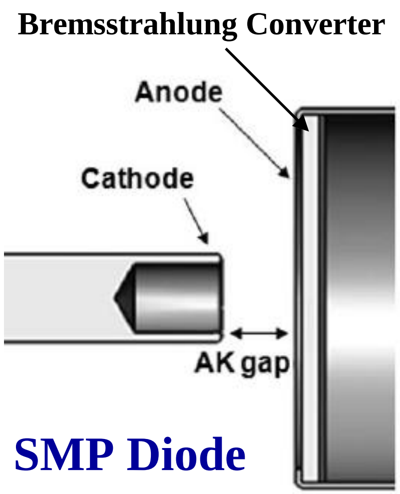


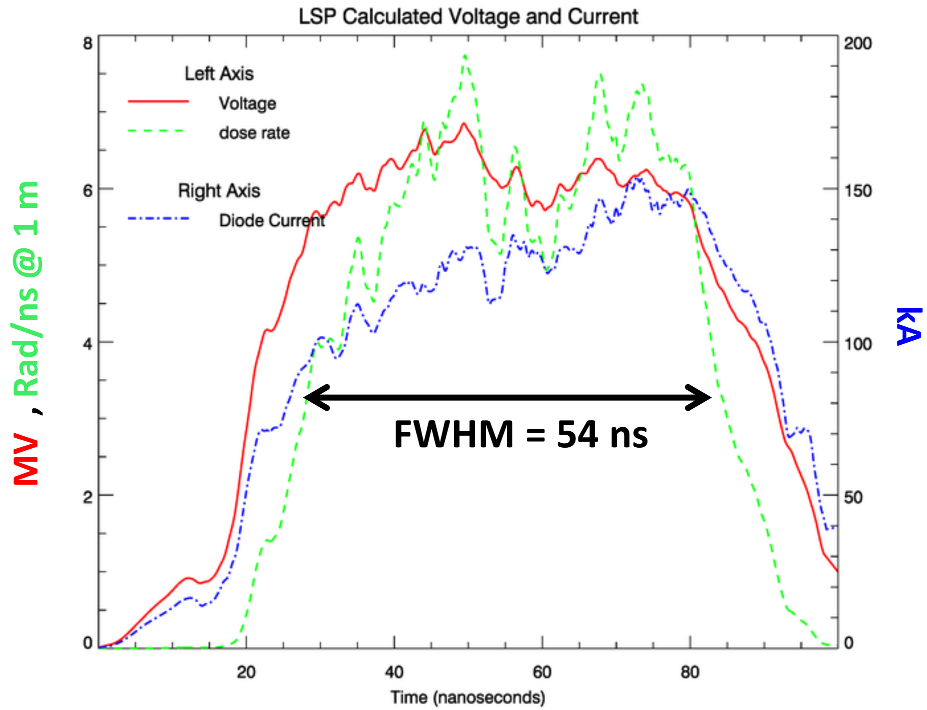
RITS-6 is a 8-12* MV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of flash x-ray radiography diode configurations (by my count around half-dozen different "diodes")

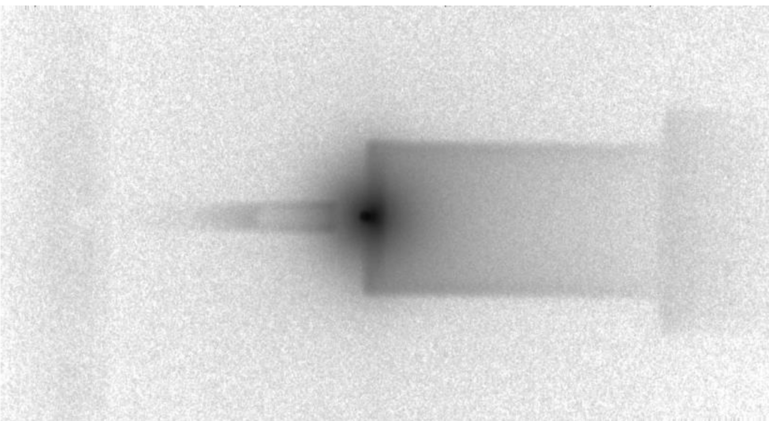


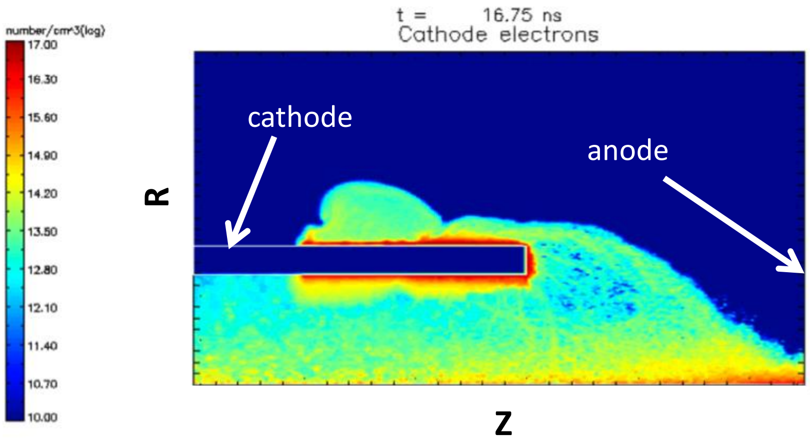
*Traditionally the maximum voltage is changed by changing the MITL inner conductor. Over the last six months we have operated the machine as low as 2 MV by different operating points on the Marx generator and PFLs.

The Self-Magnetic Pinch Diode



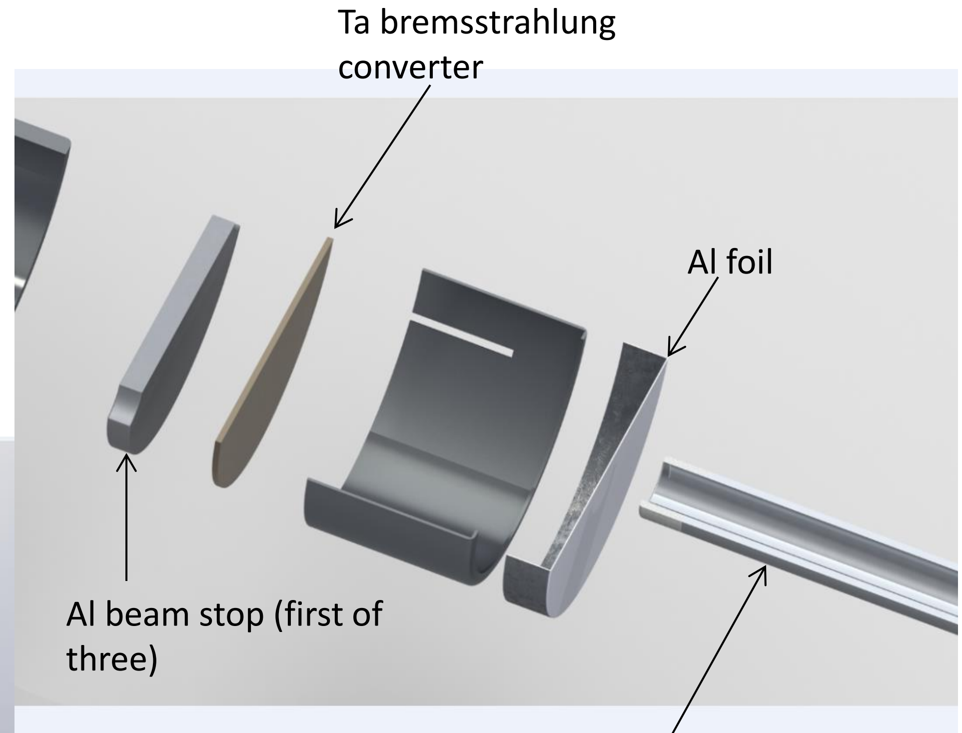


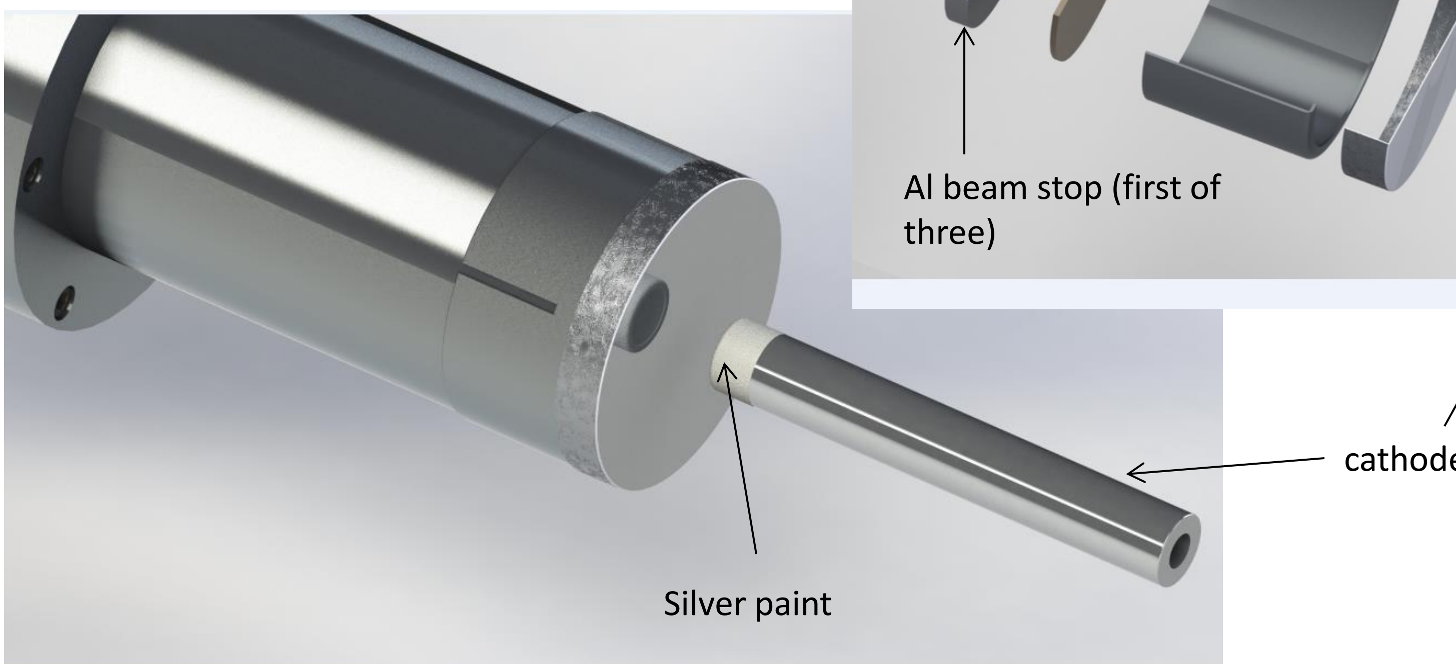




OUO

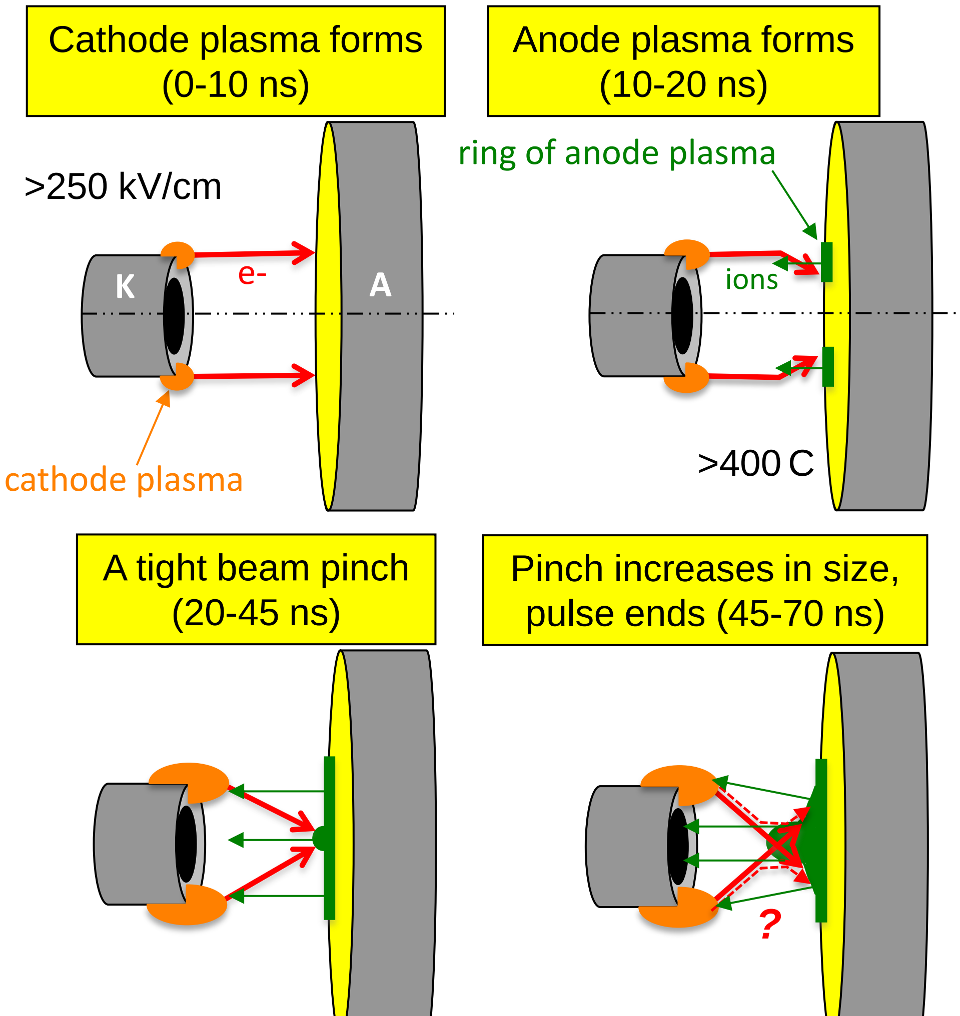
Nominal Diode Assembly



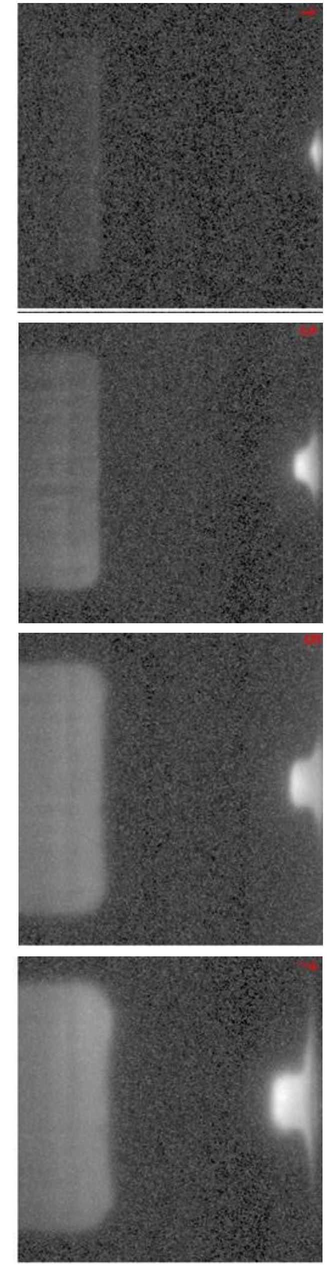


Thanks to Sean Simpson (SNL) for graphics.

Basic SMP beam dynamics

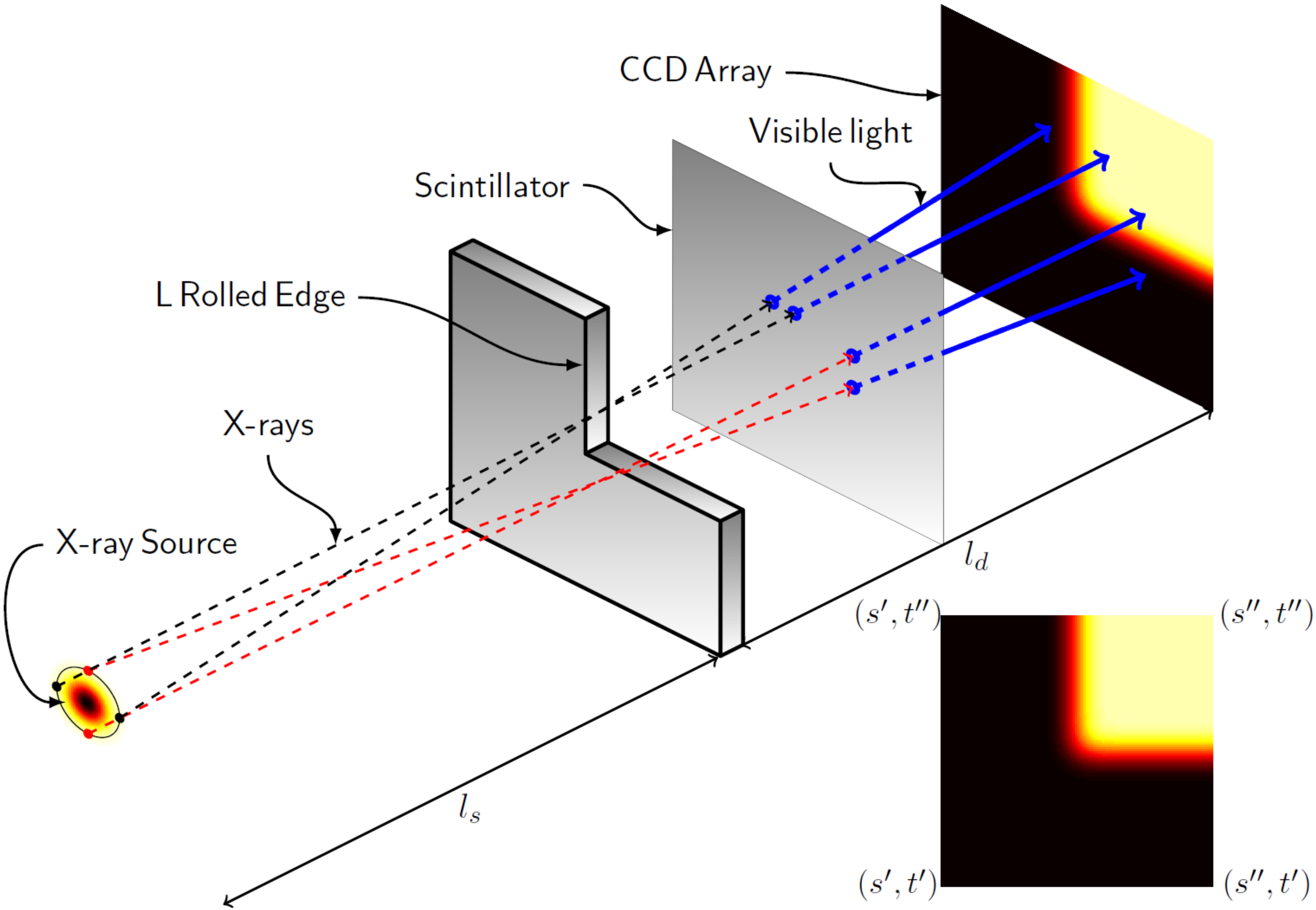


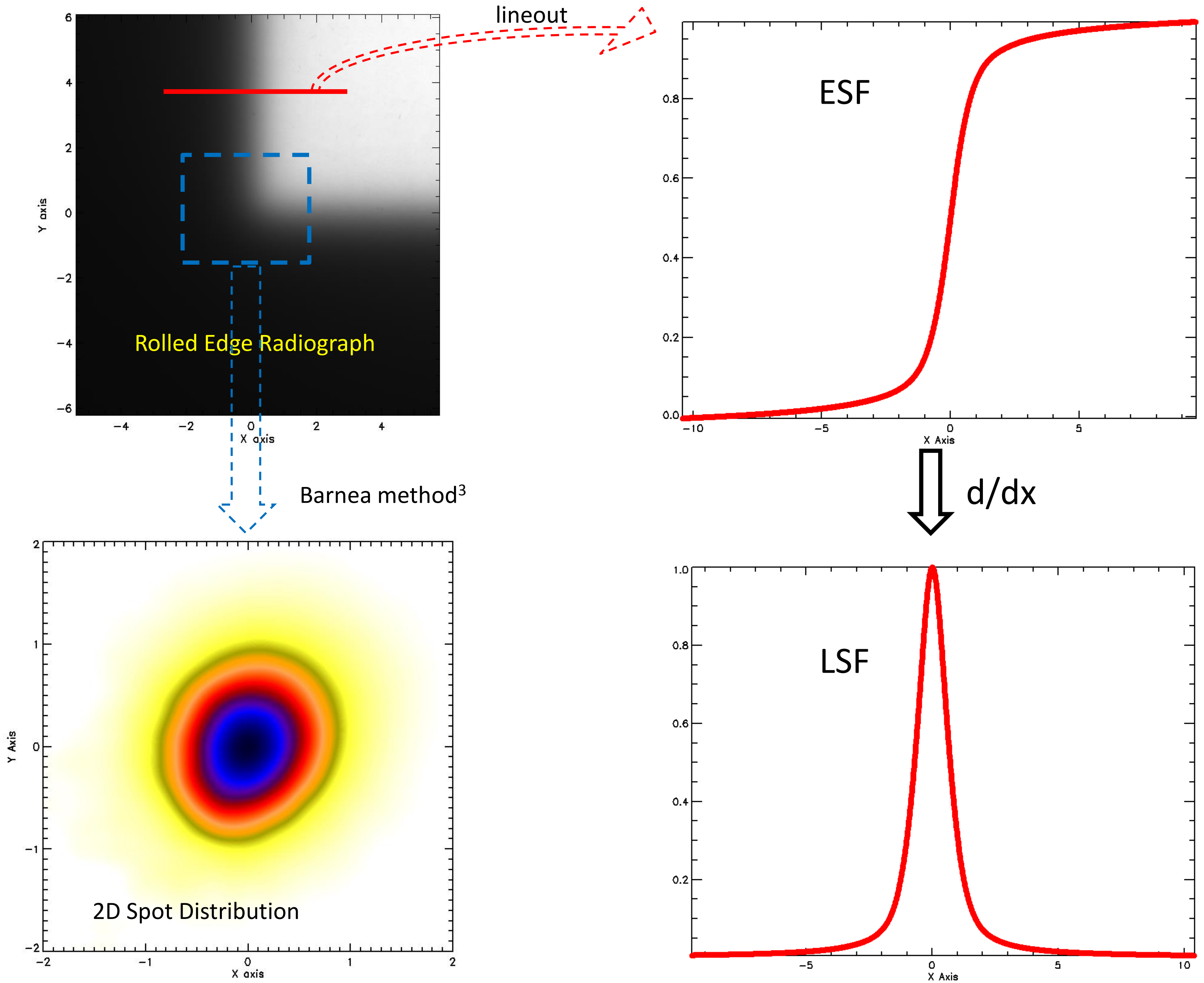
gap is f(t) due to expanding A/K plasmas



What we can change about the diode (not a complete list).

Diode Parameter	Comments / Results
In front of the foil	
Cathode diameter	Traditionally expected and measured smaller spots are possible through smaller cathodes
A-K gap	Affects impedance drop through plasma gap closure rate
Silver paint length	Some Ag paint is required but not clear if there is any change > 1-2 mm
Presence of Al foil	Smaller, more rapid pinch directly on conversion target
Higher-Z foil	Affects plasma formation due to different contaminants and heating rate
Shaped Anodes	Looking to affect pinch location and potentially raise impedance
Behind the foil	
Hard collimation	Attenuate beam radius beyond certain diameter; High potential for flatfield problems
Bulk Limited Targets	Good flatfield properties, dose depends on upstream pinch alignment
Rod-type Limited Targets	Benefits of hard collimation w/o flatfield variation, still sensitive to pinch location


CCD Array
Visible light
Scintillator
L Rolled Edge
X-rays
X-ray Source
l_d
l_s
(s', t'')
(s'', t'')
(s', t')
(s'', t')

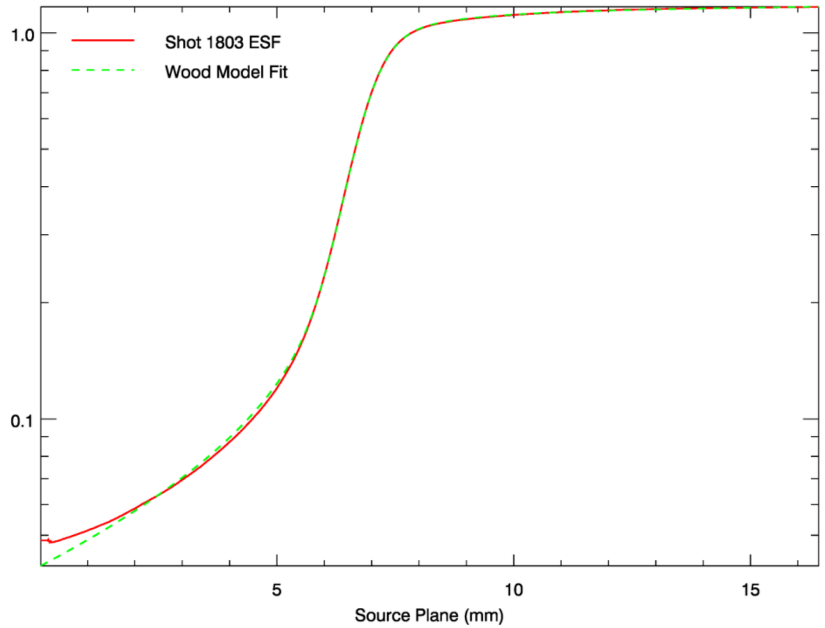

lineout
ESF
Rolled Edge Radiograph
Y axis
X axis
X Axis
d/dx
Barnea method[3]
LSF
2D Spot Distribution
Y Axis
X axis
X Axis

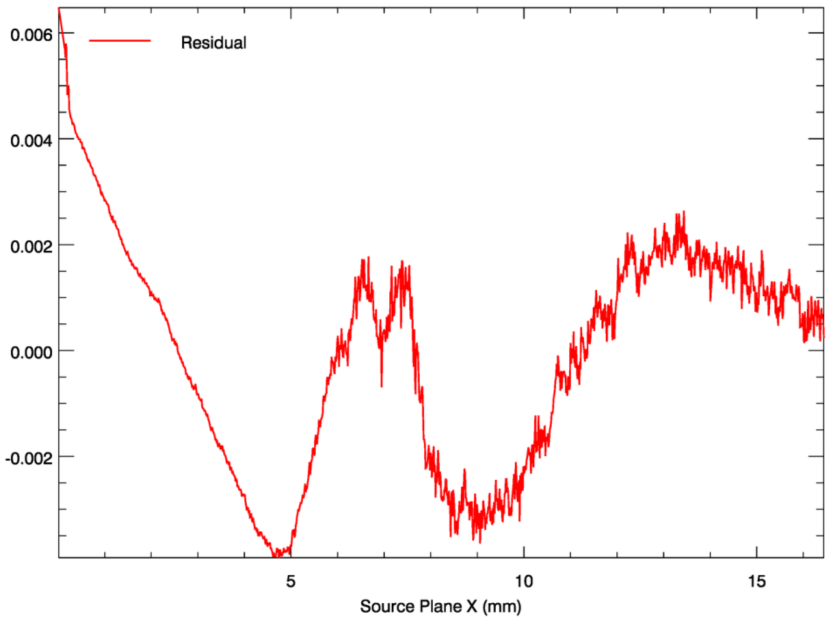
ESF model[4] allows easier computation of LSF and PSF

$$ESF(x) = \frac{A_0}{2}\left[1 + \mathrm{erf}\left(\frac{x - X_0}{A_1}\right)\right] + \frac{B_0}{\pi}\left[ATAN\left(\frac{x - X_0}{B_1}\right) + \frac{1}{2}\right] + \frac{C_0}{\pi}\left[ATAN\left(\frac{x - X_0}{C_1}\right) + \frac{1}{2}\right] + Y_0$$

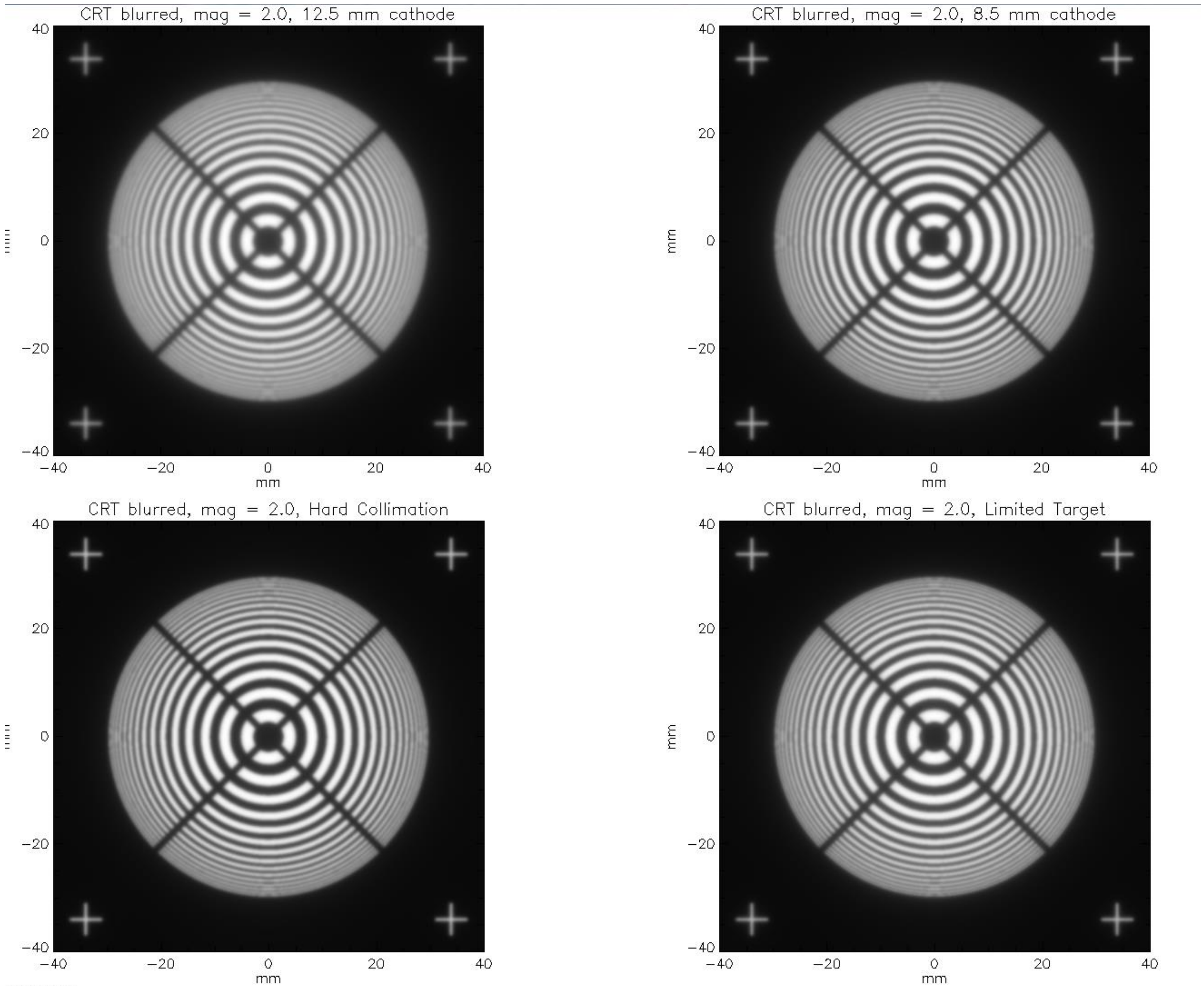
$$LSF(x) = \frac{A_0}{A_1\sqrt{\pi}} e^{\left(\frac{-(x-X_0)^2}{A_1{}^2}\right)} + \frac{B_0}{B_1\pi}\left[1 + \frac{(x-X_0)^2}{B_1{}^2}\right] + \frac{C_0}{C_1\pi}\left[1 + \frac{(x-X_0)^2}{C_1{}^2}\right]$$

$$PSF(r) = \frac{A_0}{A_1{}^2} e^{\left(\frac{-r^2}{A_1{}^2}\right)} + \frac{B_0 B_1}{2}\left[\frac{1}{\left(B_1{}^2 + r^2\right)^{3/2}}\right] + \frac{C_0 C_1}{2}\left[\frac{1}{\left(C_1{}^2 + r^2\right)^{3/2}}\right]$$

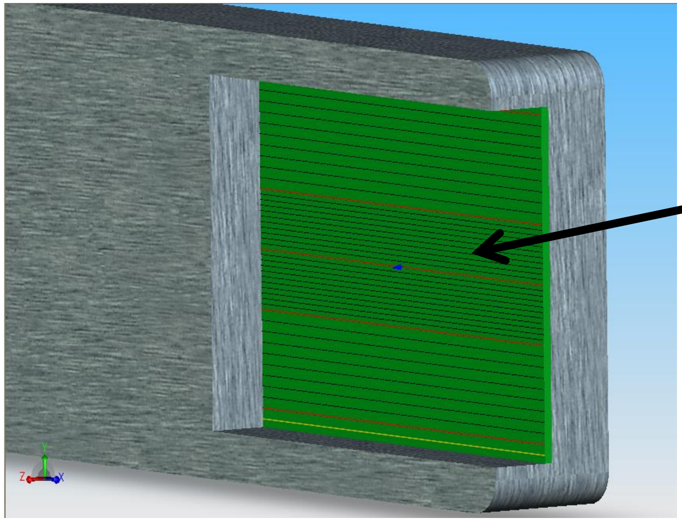




Full Spot Distribution Does Matter in Considering Object Resolution and Optimum Magnification

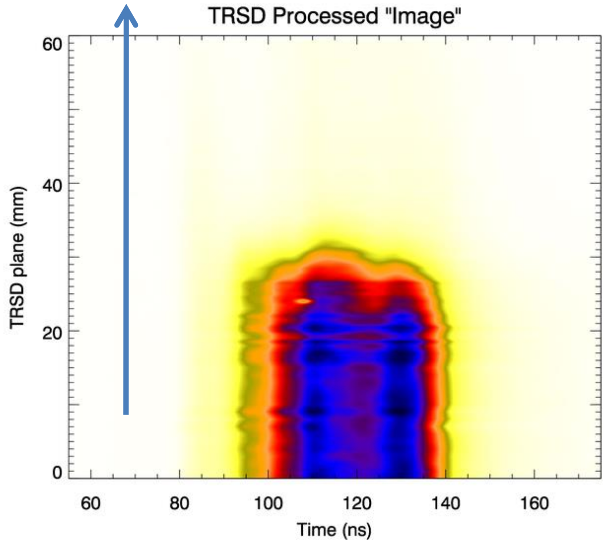


Time-Resolved Spot Diagnostic (TRSD)

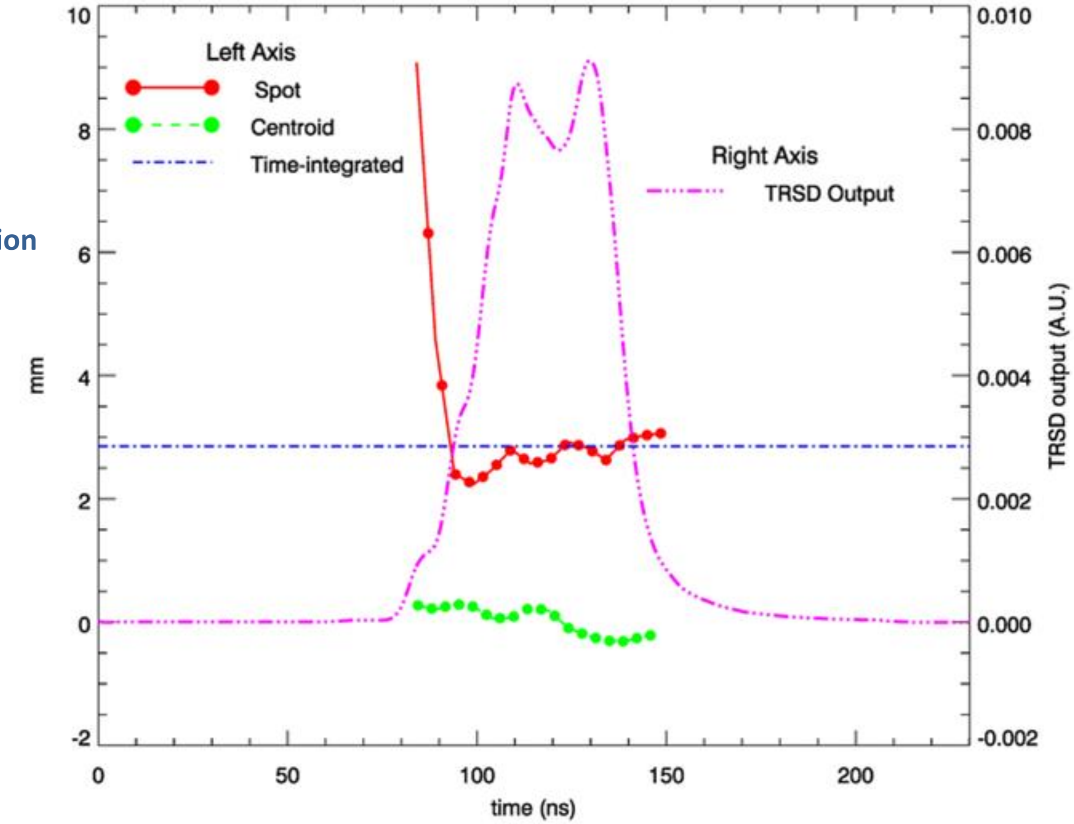


- Linear Array of 84 plastic scintillator fibers.
- Response time about 2.7 ns, light response of each fiber detected with streak camera.
- Can also give time-integrated spot size.

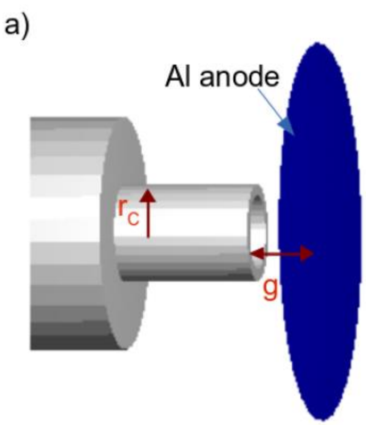
Vertical lineout gives instantaneous edge-spread function

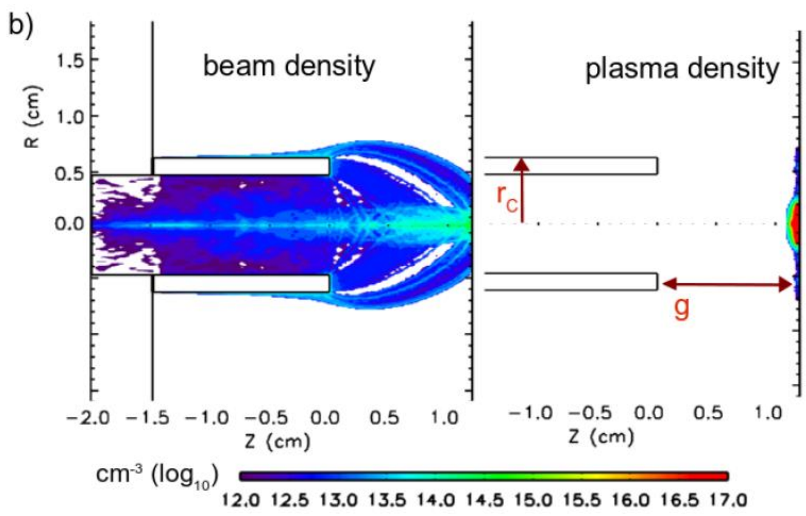


Horizontal lineout gives radiation pulse



LSP[5] is used to model SMP impedance and spot size

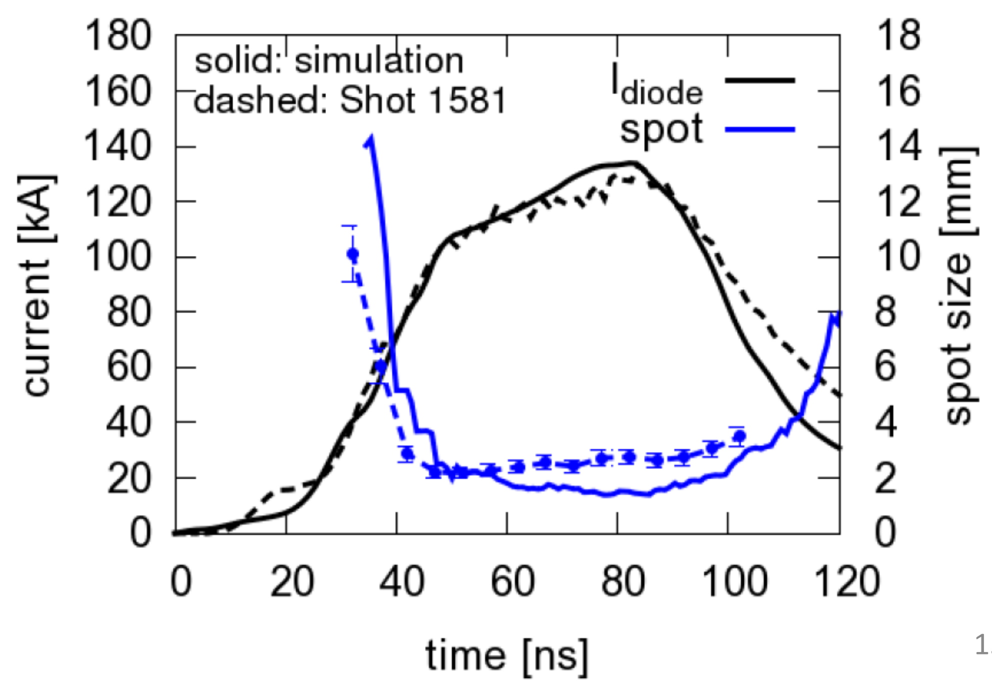




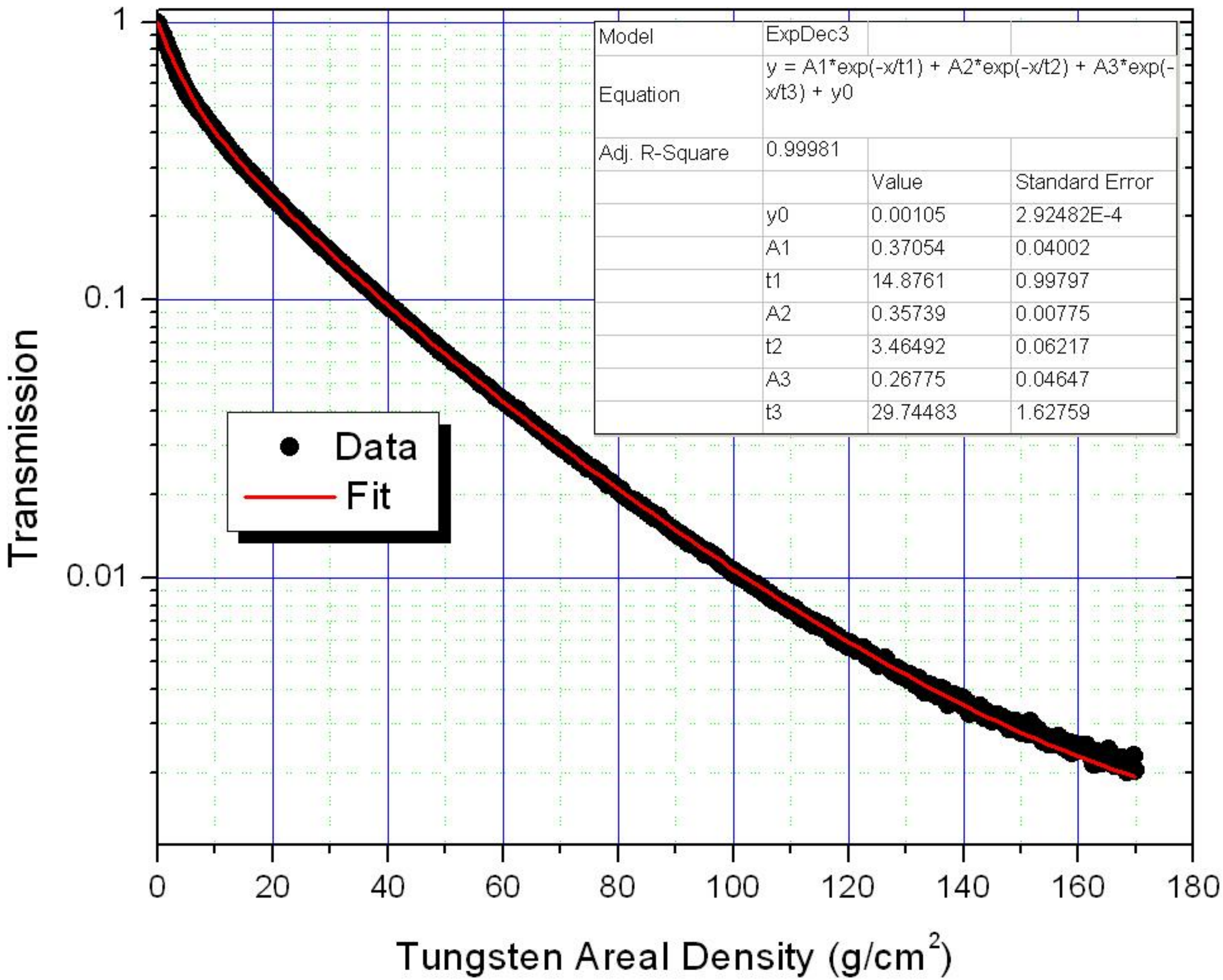
Includes anode plasmas which include surface mono-layer model:

$$\frac{dn(t)}{dt} = -\nu_{th} n(t)\ e^{-Q_a/(RT(t))} - \frac{J_e \sigma n(t)}{e}$$

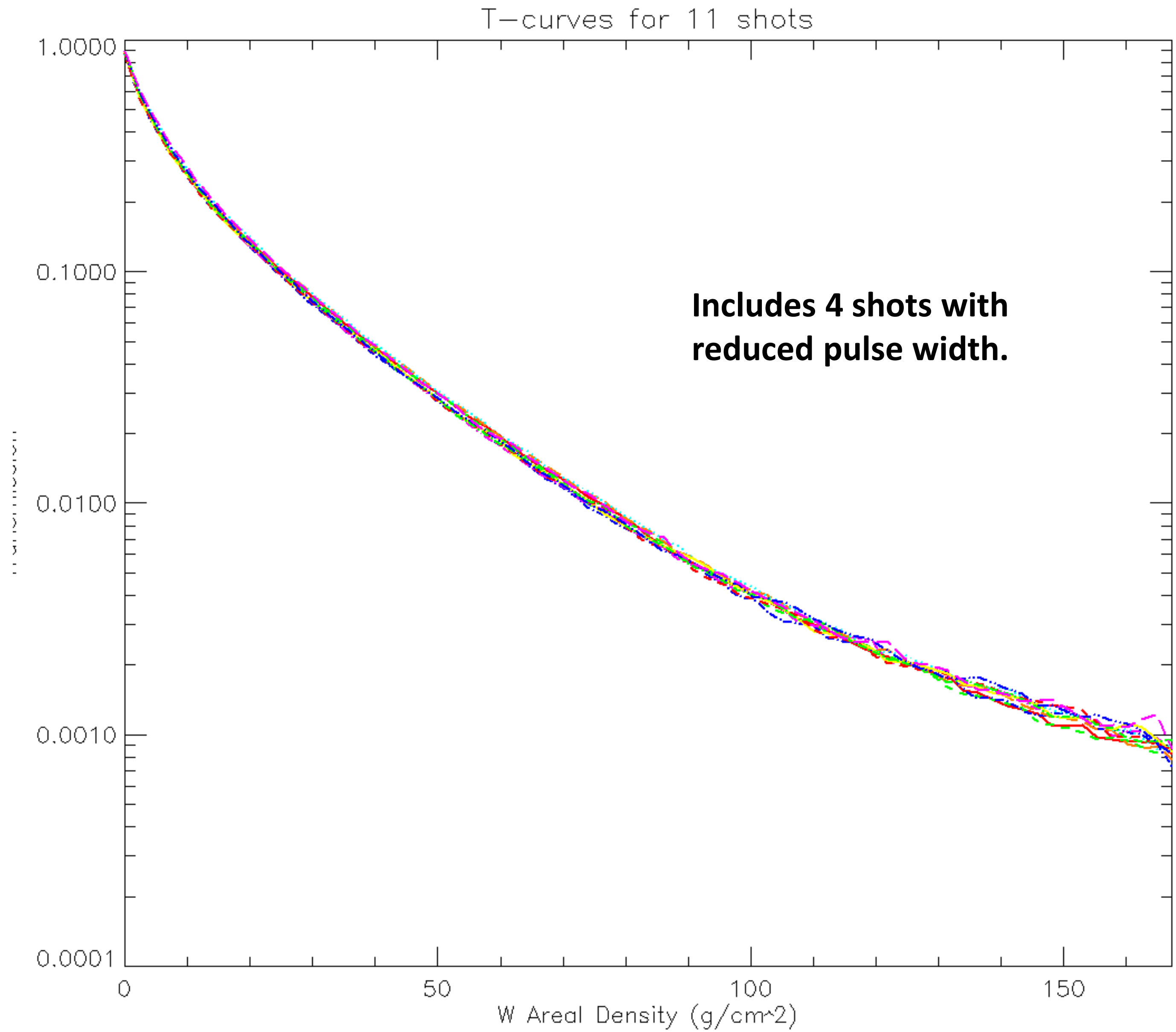
Currents and time-resolved spot size agree well.



Transfer Curve of SMP Diode at 7 MV



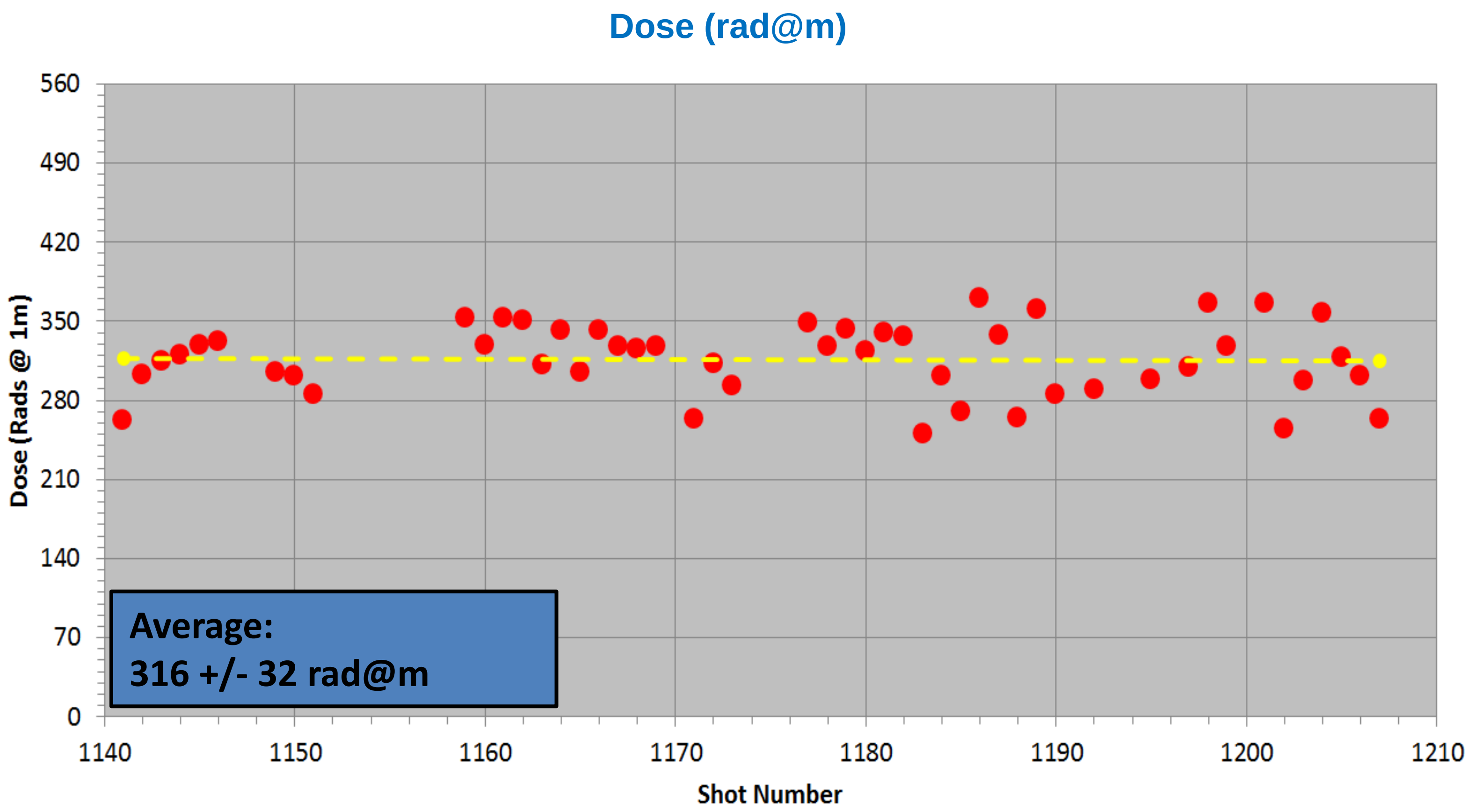
Example transmission curve data with RITS operating at 4.5 MV demonstrating spectral stability.



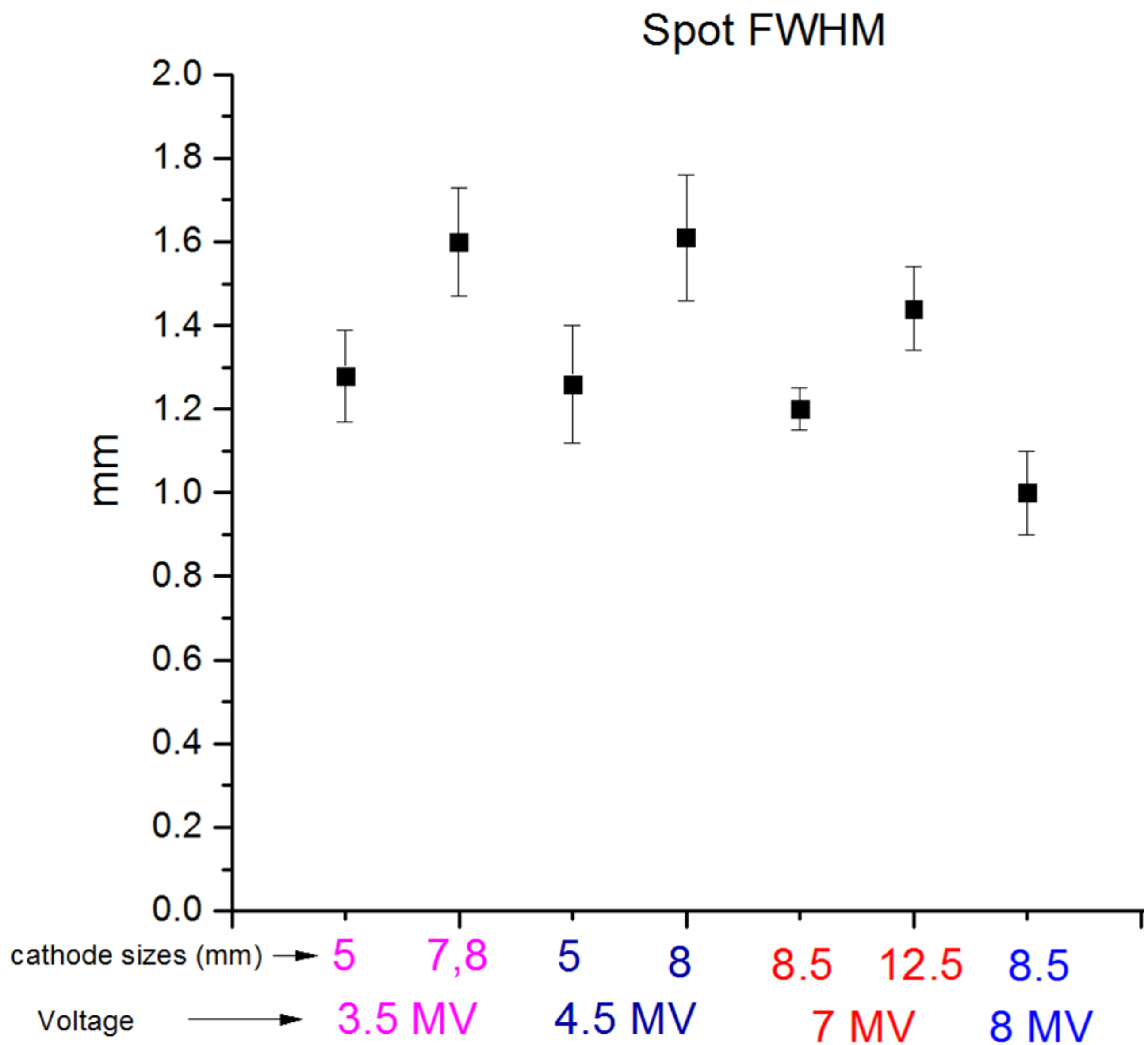
Operation of SMP Diode at Various Voltages

	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

Dose Reproducibility
End-point voltage ~7 MV

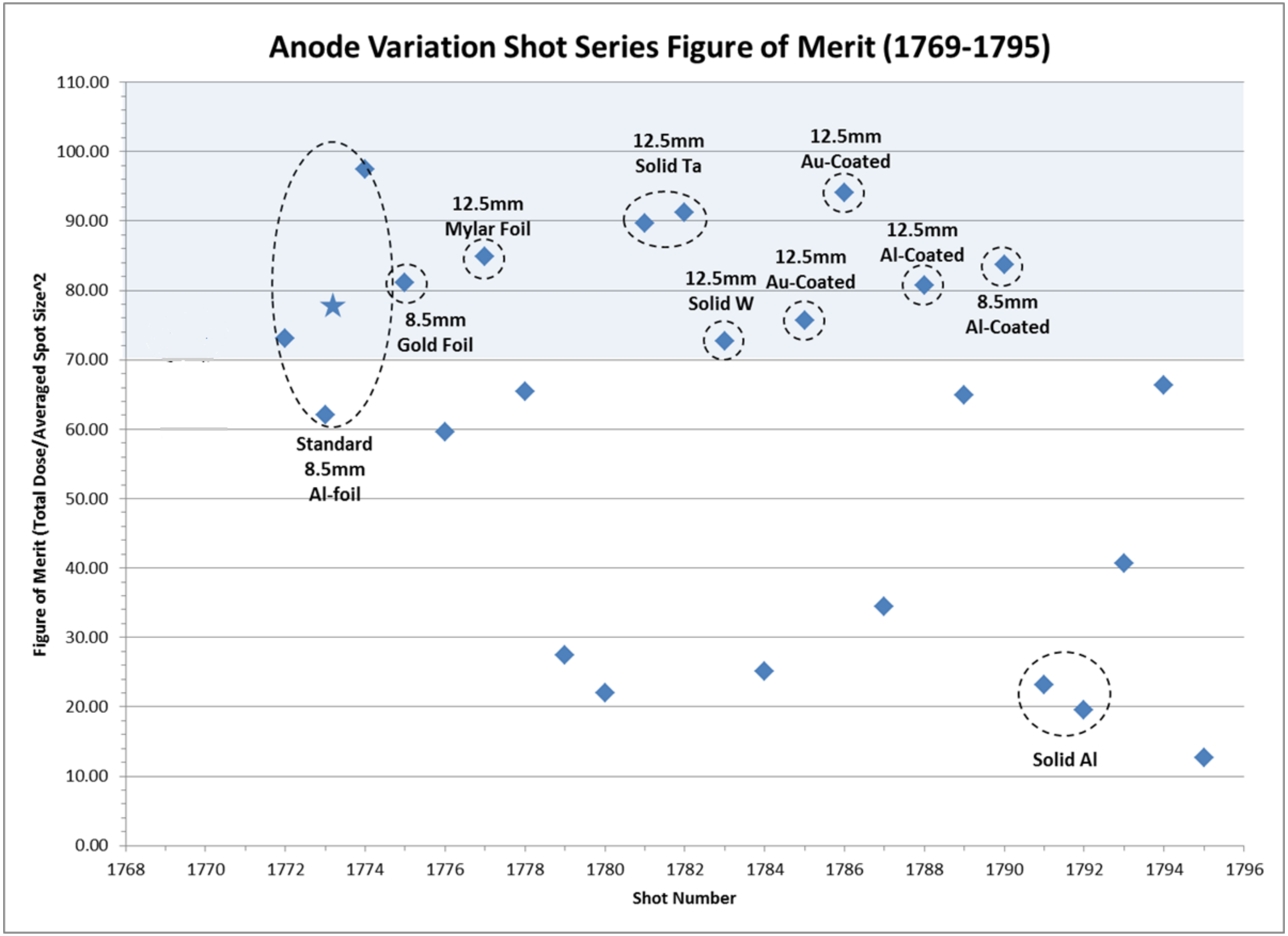


Points include “R&D” shots which are expected to be more variable.



Spot FWHM
mm
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
cathode sizes (mm)
5
7,8
5
8
8.5
12.5
8.5
Voltage
3.5 MV
4.5 MV
7 MV
8 MV

Anode Material Studies (7.8MV)



References

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