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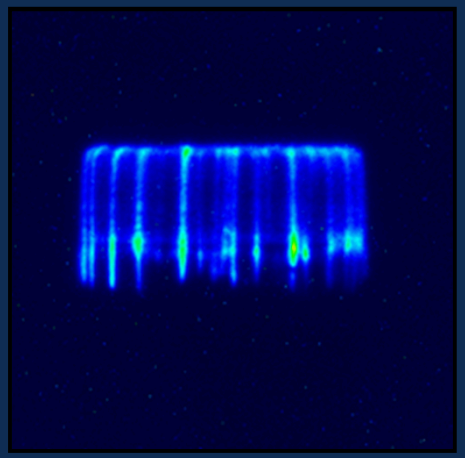

SCALING OF SMP DIODE PERFORMANCE WITH GEOMETRY AND VOLTAGE

M. L. Kiefer, M. D. Johnston, T. J. Webb, J. J. Leckbee, T. J. Renk, B. V. Oliver, M. G. Mazarakis, D. S. Nielsen, D. Ziska and P. W. Lake, N. L. Bennett, R. E. Gignac, C. C. Smith, D.W. Droemer, D. R. Welch

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Outline

- **Overview of the SMP diode and our development goals**
- **Plasma characteristics**
- **Dose and spot size trends**
- **Anode/cathode plasma velocities**
- **Premature impedance collapse**
- **Research and development plans**

We are evaluating and improving the SMP diode at the RITS-6 pulsed power accelerator

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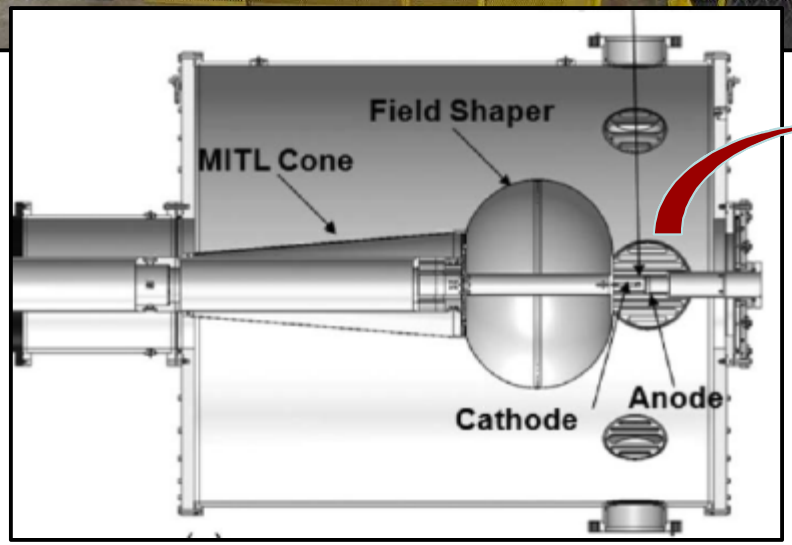
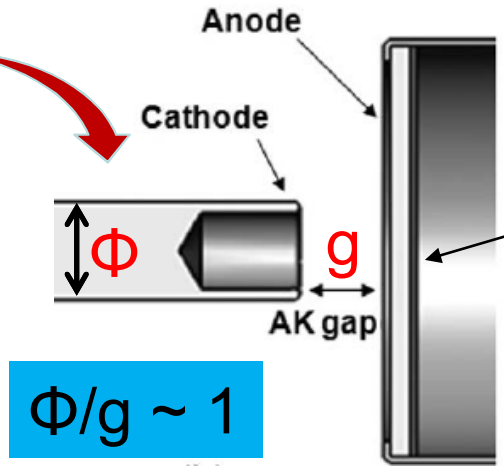
SMP Diode Parameters

- 3.5-7+ MV
- 150 kA (~15% ions)
- 50 Ω Impedance
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- > 350 Rads @ 1 meter
- < 3 mm focal spot size





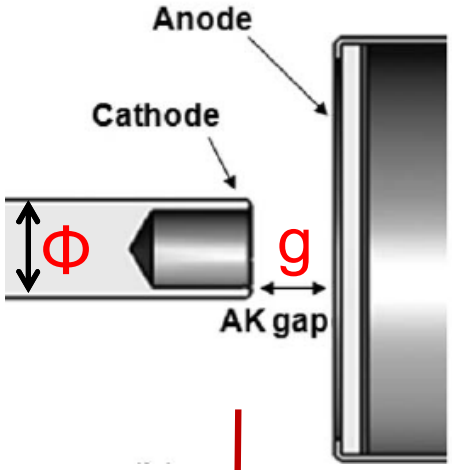
SMP Diode

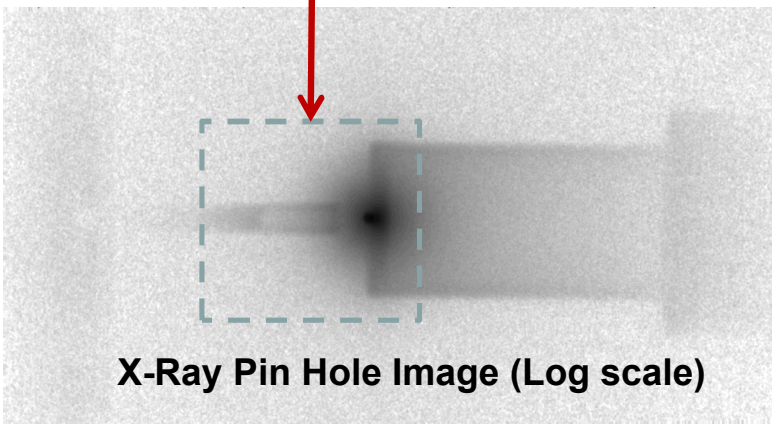
Bremsstrahlung Converter

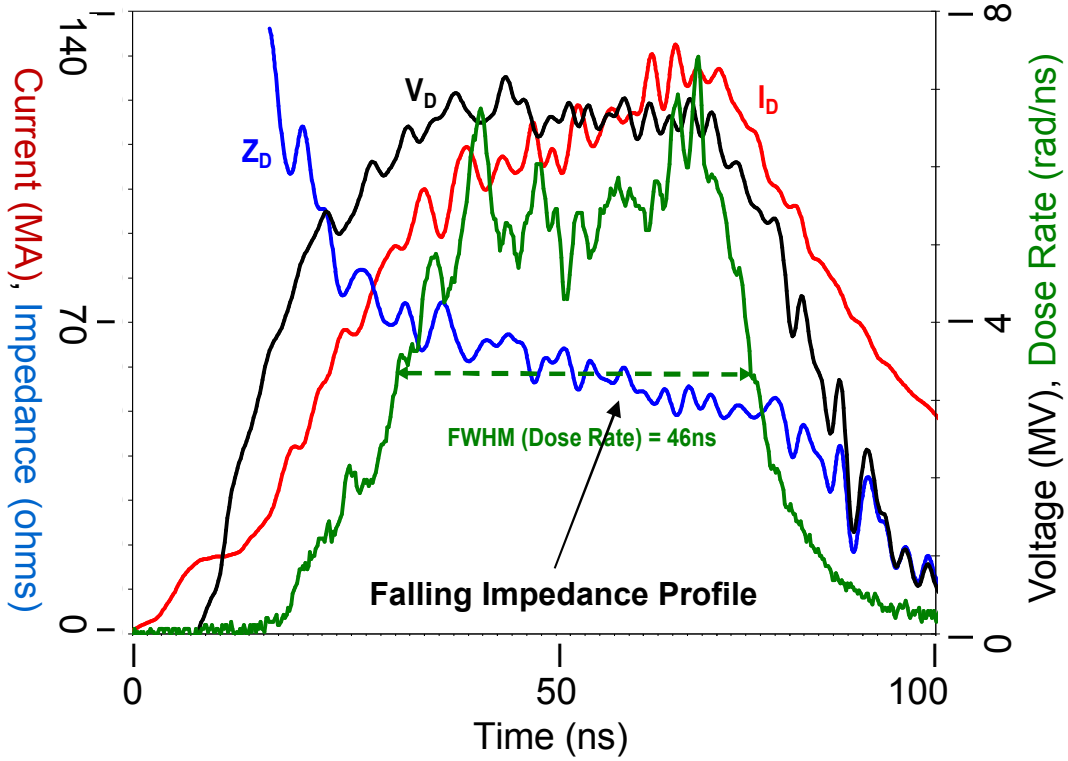
Φ/g ~ 1

AWE

A good shot has a radiation pulse of ≥ 45 ns




X-Ray Pin Hole Image (Log scale)



We seek to reduce the SMP x-ray spot size while maintaining adequate and reproducible x-ray dose

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- The SMP diode works well for "large" gaps, Φ/g ~ 1
  - < 3 mm spot
  - Stable electron focus - x-ray spot location is predictable and has little motion
  - Reproducible dose

- Trends:
  - Spot sizes smaller with rising voltage – weak trend
  - Spot sizes smaller with reduced cathode diameter

- With smaller cathodes and Φ/g ~ 1:
  - Lower impedance loads down accelerator, lowering dose
  - Focusing appears to be more unstable e.g. spot size variability/motion
  - E-beam pinch-in at converter grows steeper, reducing dose-rate or dose reproducibility
  - Premature impedance collapse occasionally, which may be related to all the above

Outline

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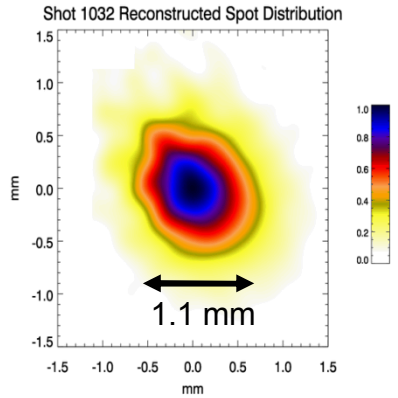
- Plasma characteristics
- Dose and spot size trends
- Anode/cathode plasma velocities
- Premature impedance collapse
- Research and development plans

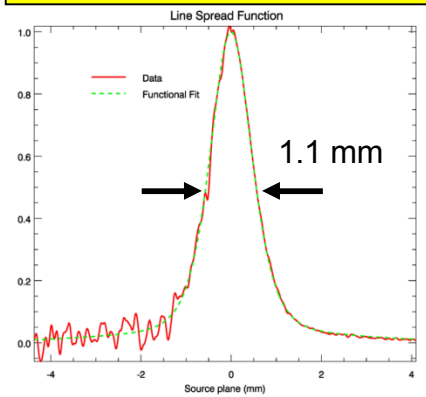
We are characterizing the behavior of the SMP diode

8.5 mm OD, 8 mm gap, 7 MV

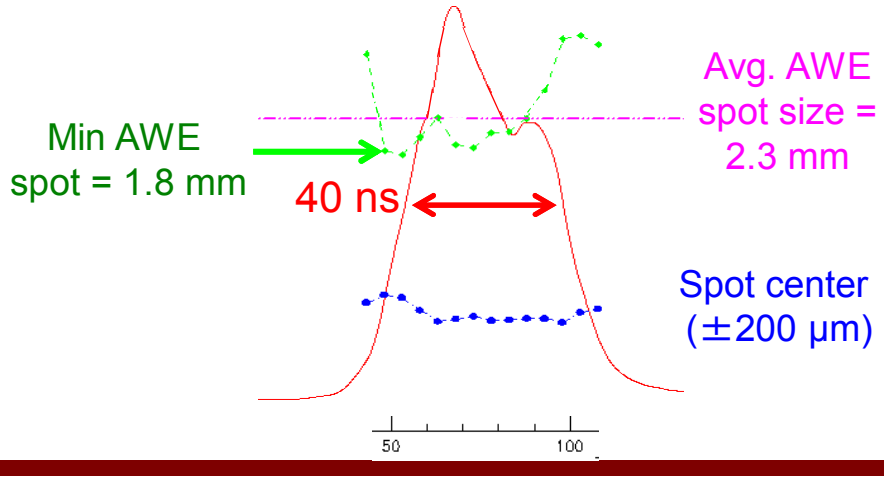
Source distribution



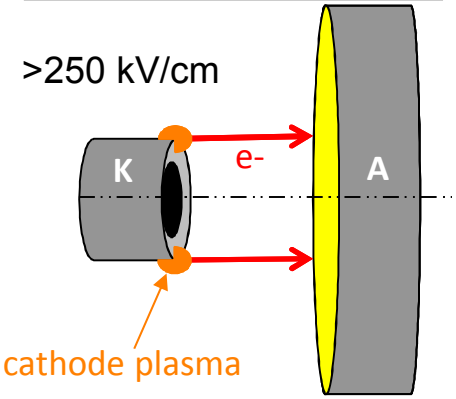
Line spread function



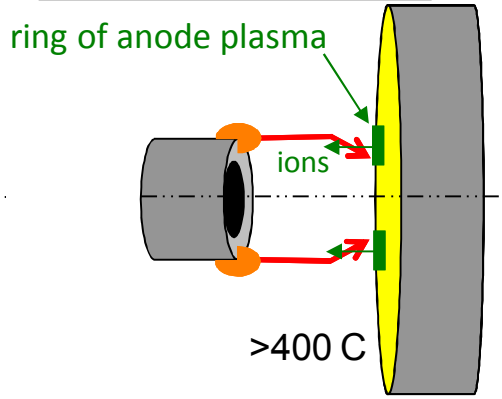
Time-resolved spot data



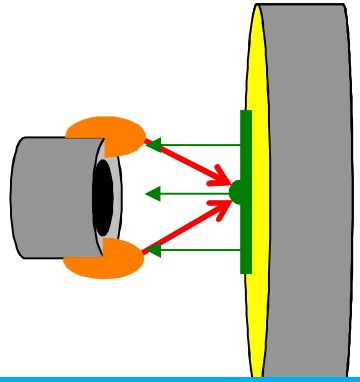
Cathode plasma forms (0-10 ns)



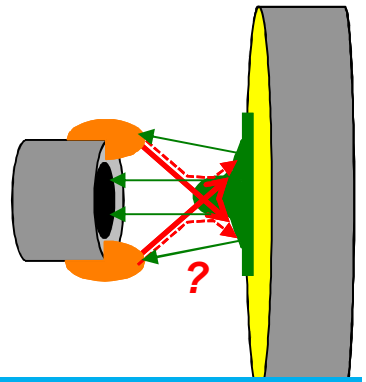
Anode plasma forms (10-20 ns)



A tight beam pinch (20-45 ns)

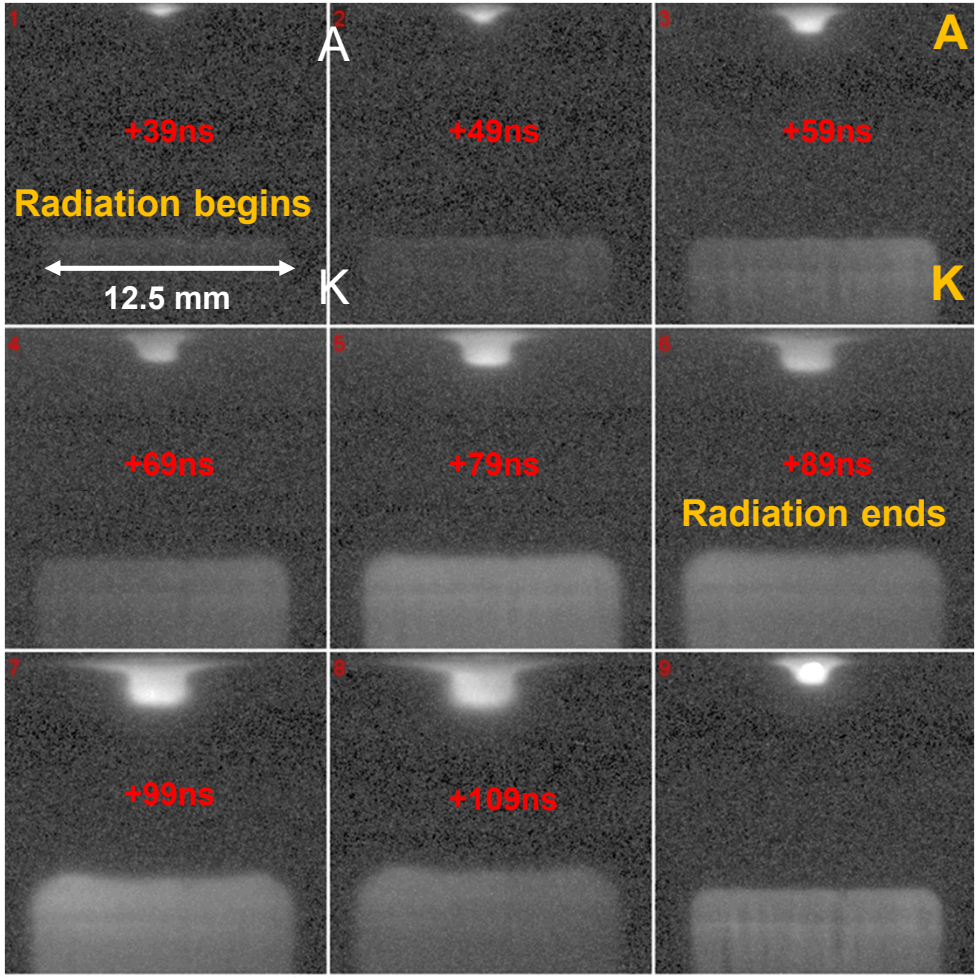


Pinch increases in size, pulse ends (45-70 ns)

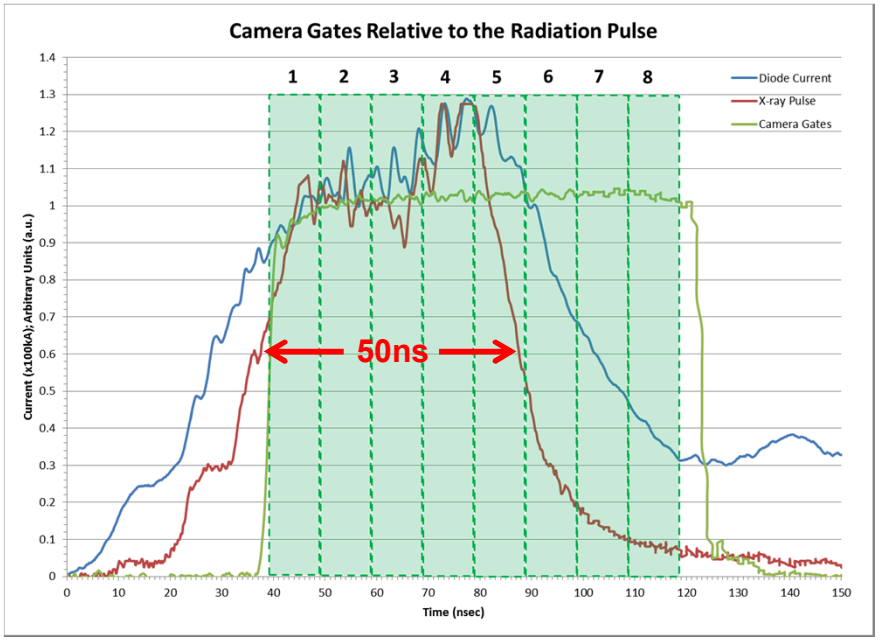


gap is f(t) due to expanding A/K plasmas

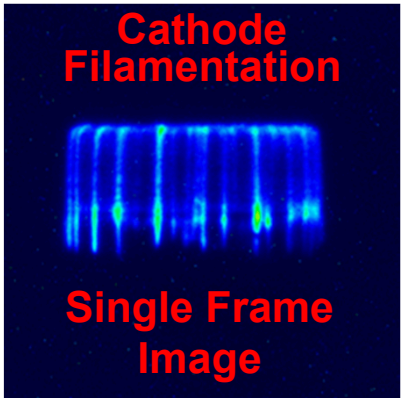
Optical emission and spectroscopy on RITS reveals plasma structure, apparent closure velocities



*10ns gates



FWHM of Radiation Pulse: 50ns



Filament formation on cathode:

- Non-uniform anode plasma
- Field fluctuations
- Thermal instability

Detailed visible emission spectroscopy and analysis reveals the density, composition, evolution, and structure of the anode plasma

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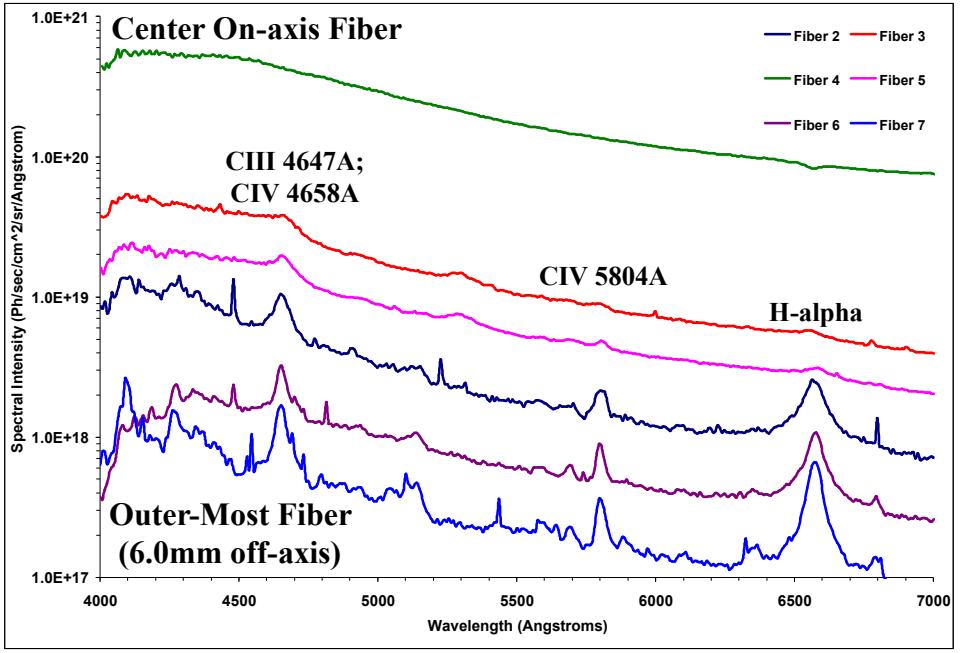
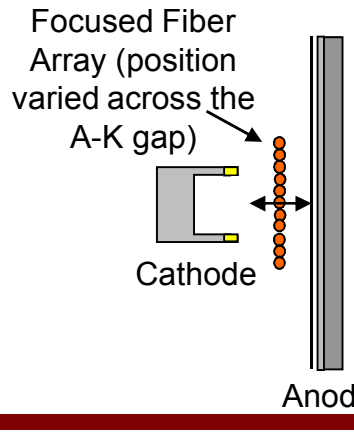
Johnston, Maron et al

- Spectra collected along the anode surface during the radiation pulse consist of carbon ion lines, hydrogen neutrals, and continua.
- Line of sight traverses plasmas with different properties.
- Plasma density decreases by a factor of ~35x from the center outward to 6mm.
- Asymmetries in plasma composition and density can be observed across the surface.
- Can these be correlated with electron beam focus and x-ray spot profile?



15ns Integration Time



Carbon Ion Lines Observed

- **CIII 4647A**
- **CIV 4658A**
- **CIV 5804A**

We are validating diode LSP simulations against extensive data sets

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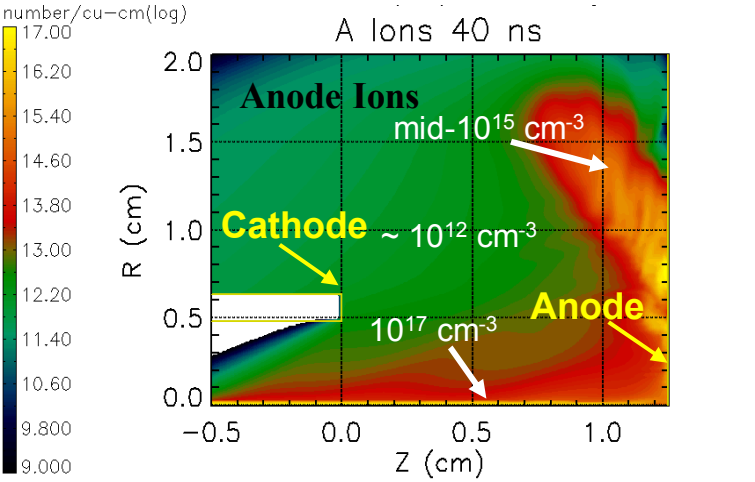
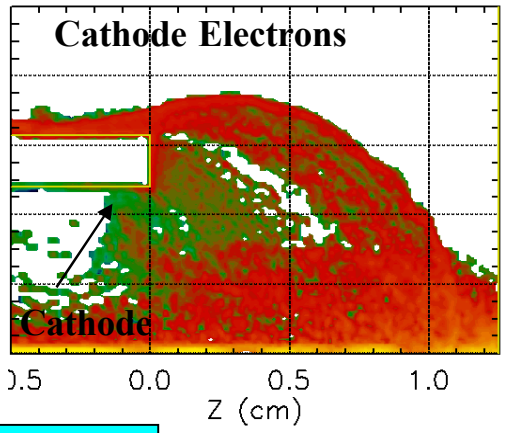
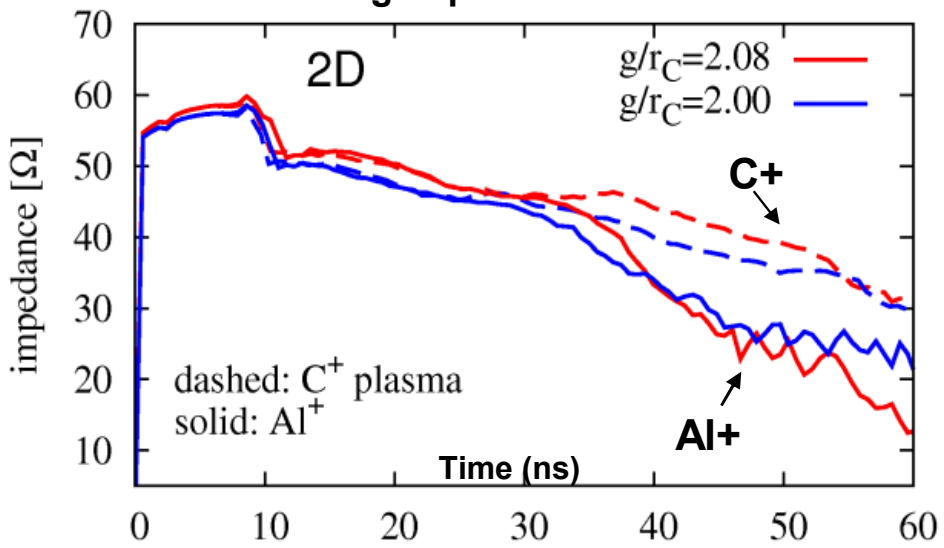
Simulations of Evolving Plasmas





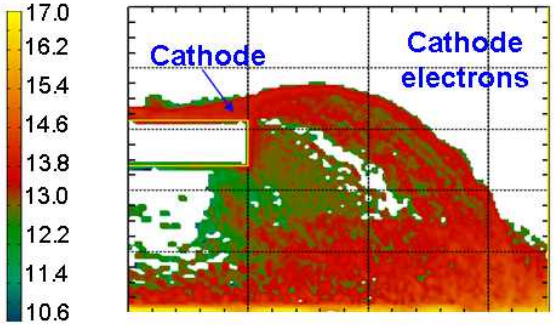
N. Bennett, et al

Falling Impedance Profiles

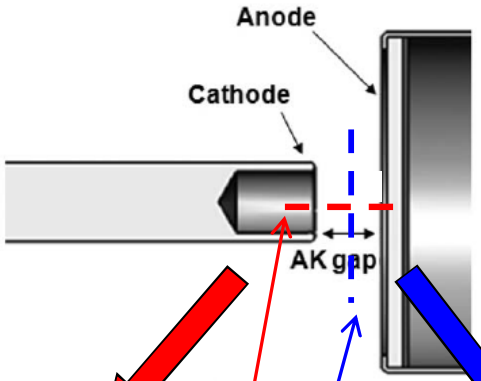


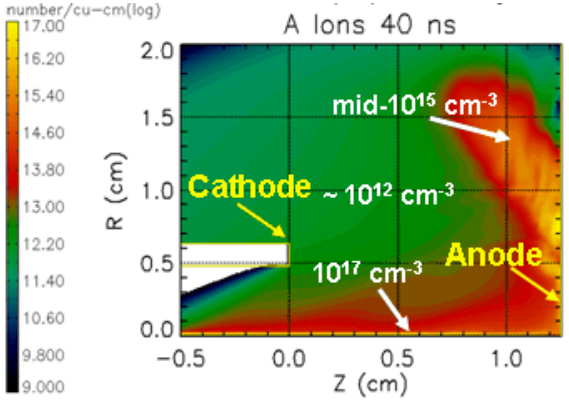
- LSP simulations predict:
  - Variations in plasma density of up to 5 orders of magnitude during a ~50ns radiation pulse
  - A falling impedance due to gap closure.
  - Gap closure occurs at a rate of ~10cm/μsec, dependent on species.

Streaked images of A-K gap plasmas

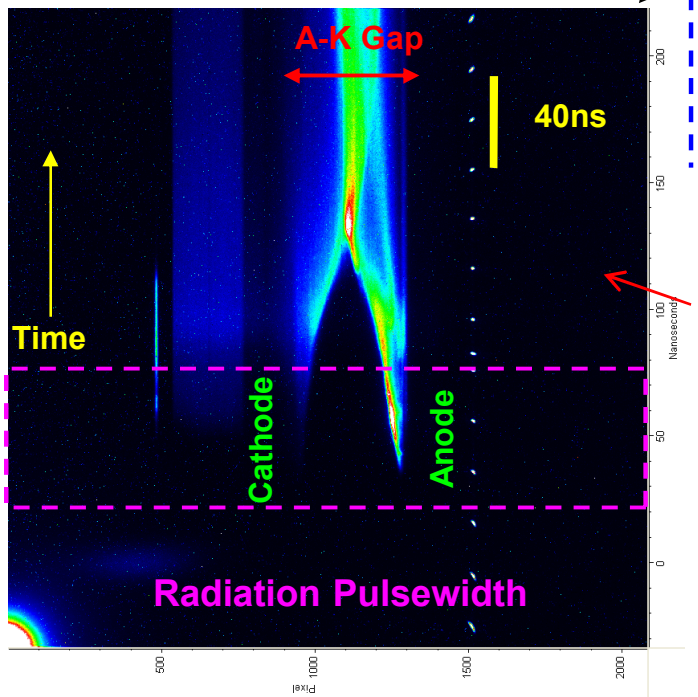


Hybrid particle-in-cell (PIC)/fluid simulations using LSP code





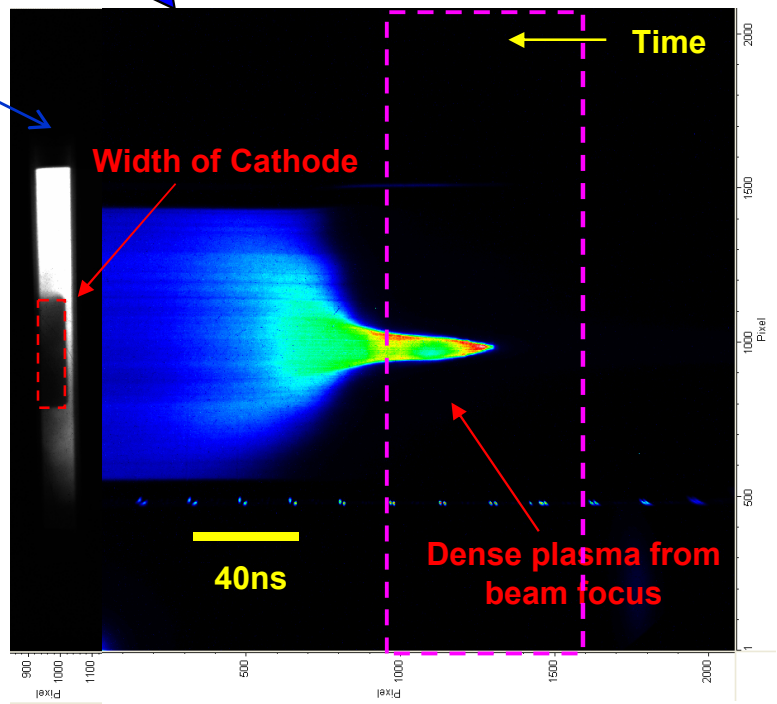
Axial Plasma Evolution



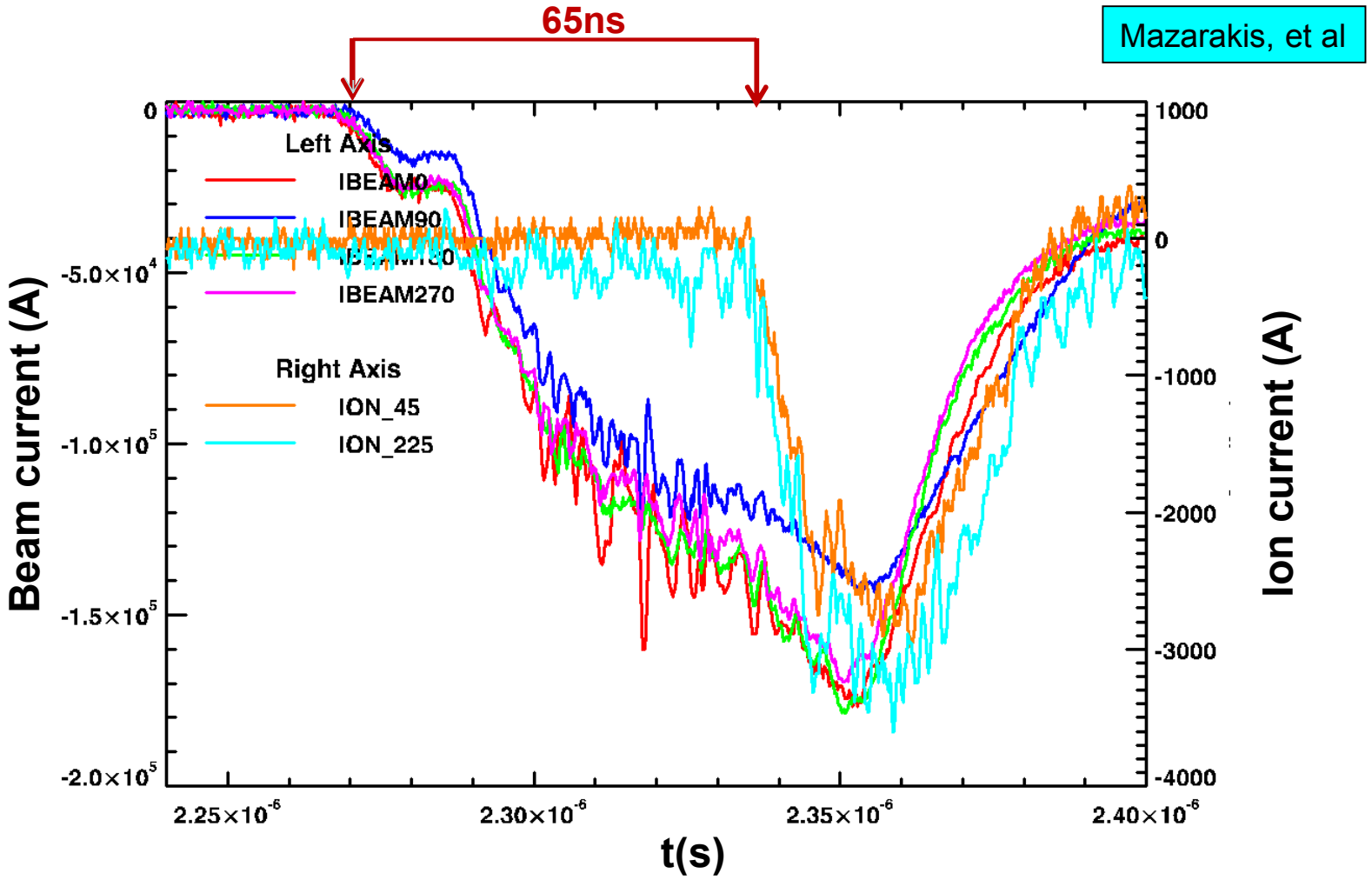
Vertical slit orientation across gap

Horizontal slit orientation spanning gap

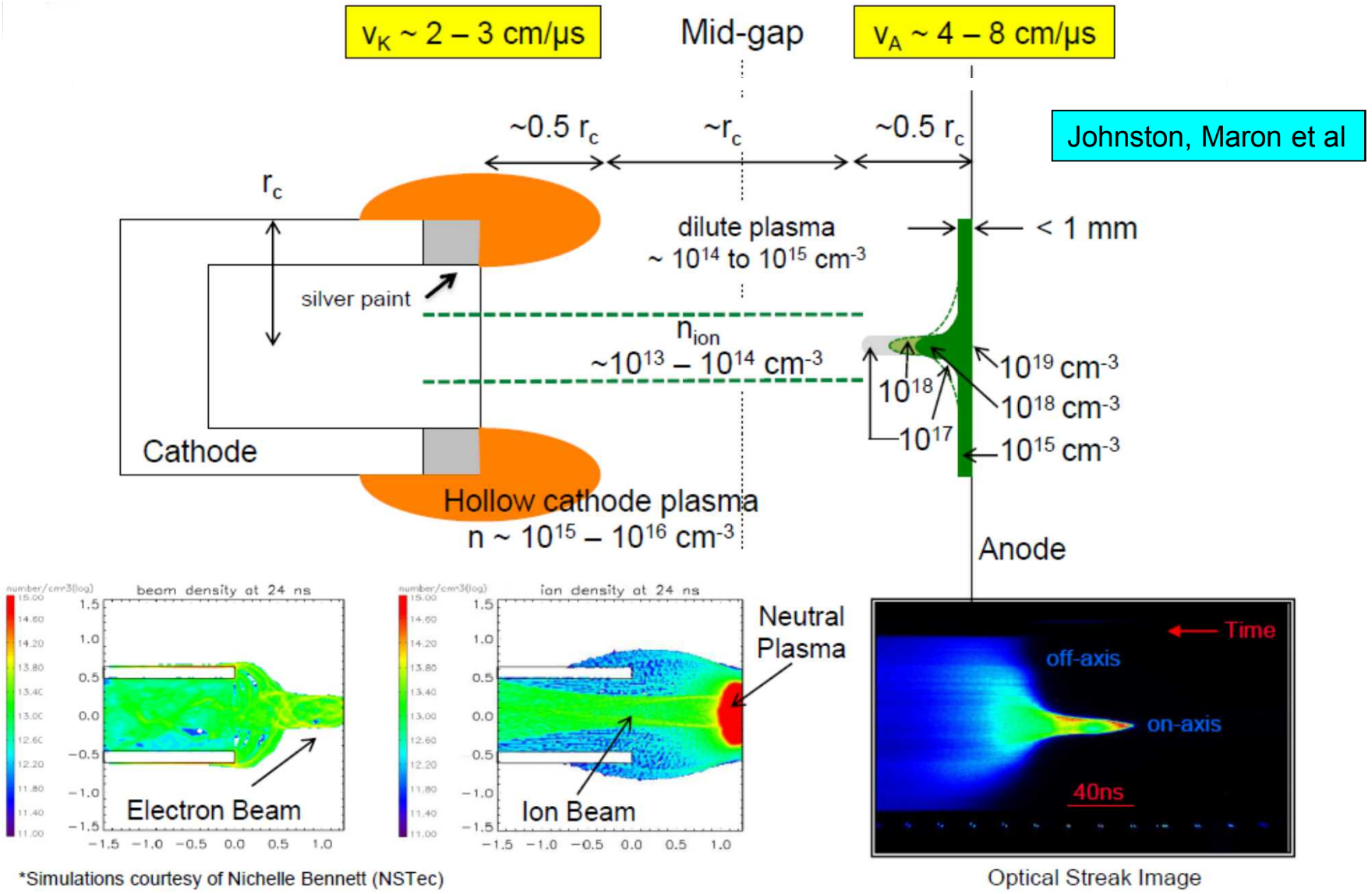
Radial Plasma Evolution



We are measuring the ion current into the cathode



The SMP diode encompasses a wide range of plasma characteristics



*Simulations courtesy of Nichelle Bennett (NSTec)

Outline

- Overview of the SMP diode and our development goals
- Plasma characteristics
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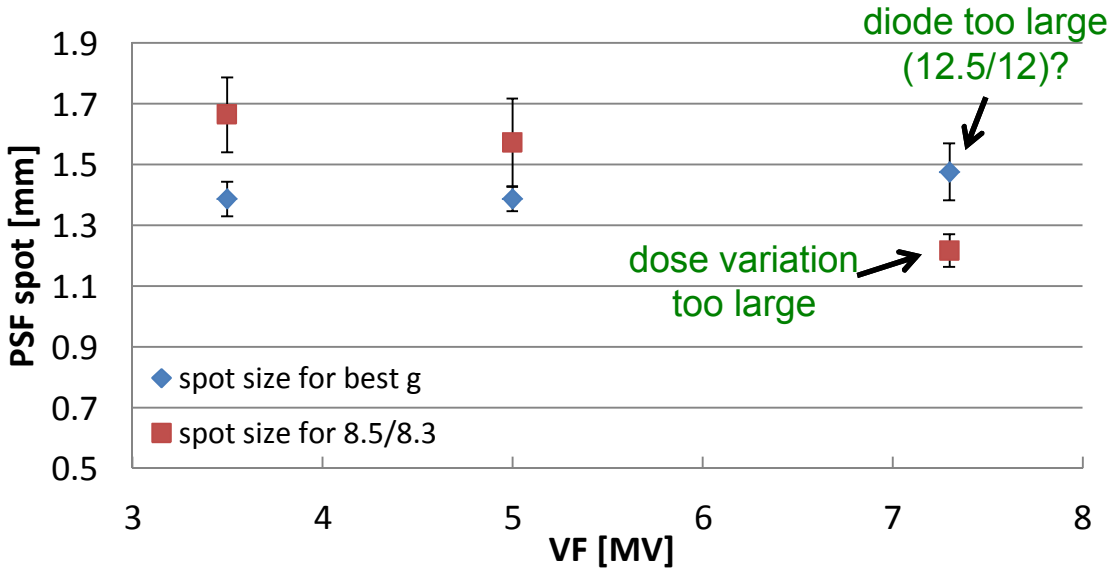
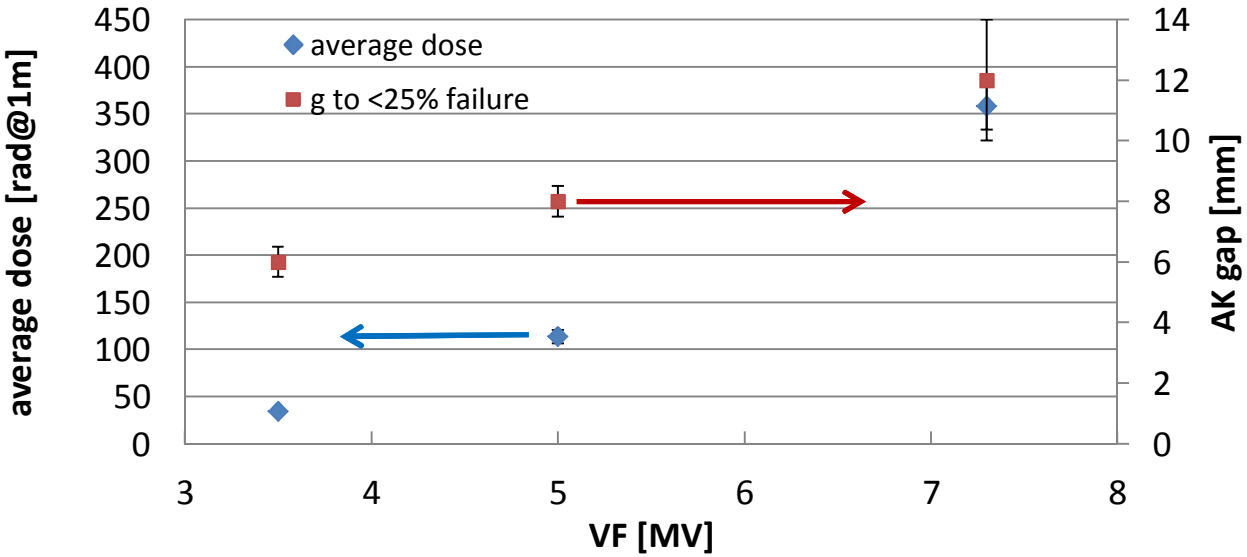
Dose and spot trends, small and large diodes

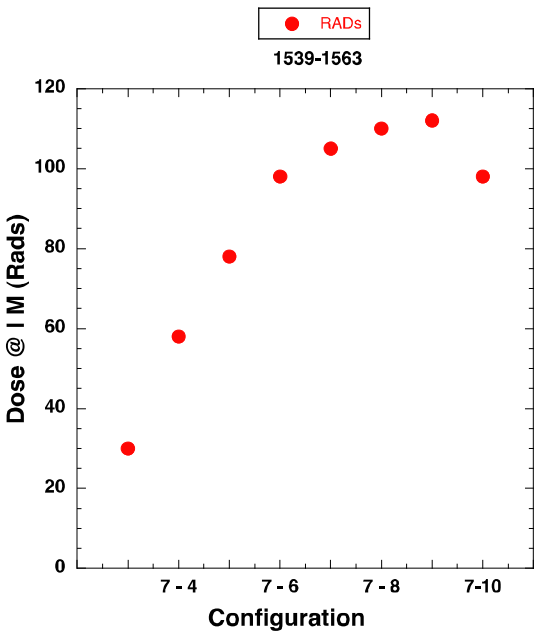


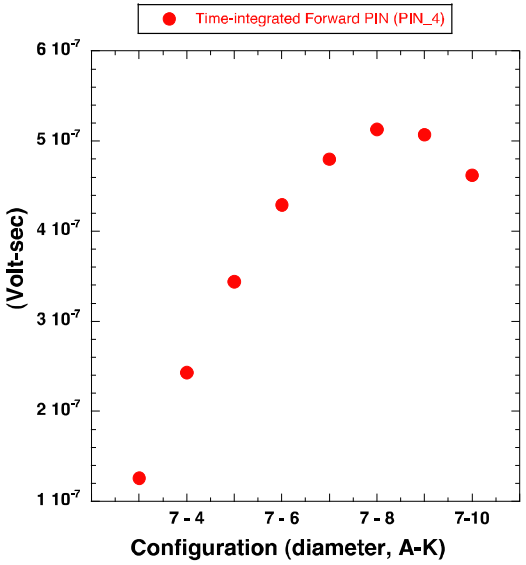
- Spot size is reduced with increasing V, for constant "size"
- As V increases, there is a diode size with a stable dose that at least maintains spot size

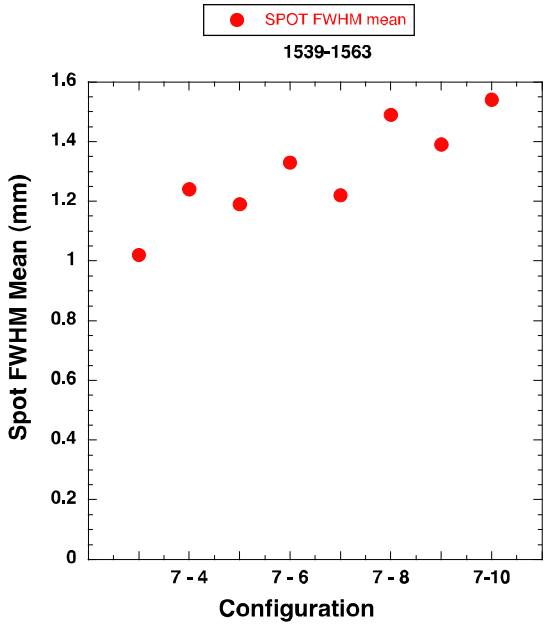


- Dose/Q ~ $V_d^{2.2}$

A-K gap scan at 4.5 MV with 7mm cathode diameter shows (soft) peak in x-ray dose at ~ 1-1 aspect ratio

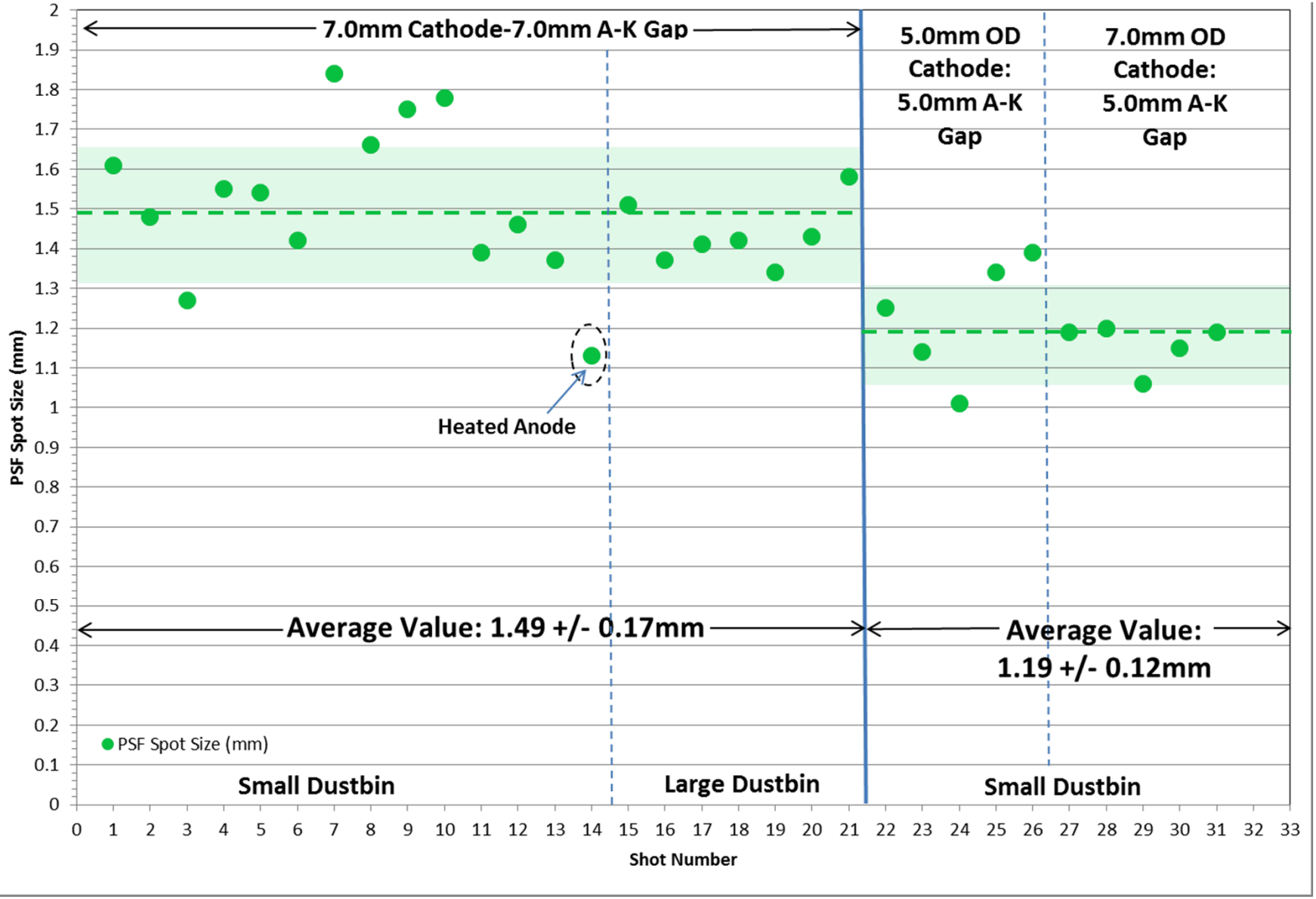




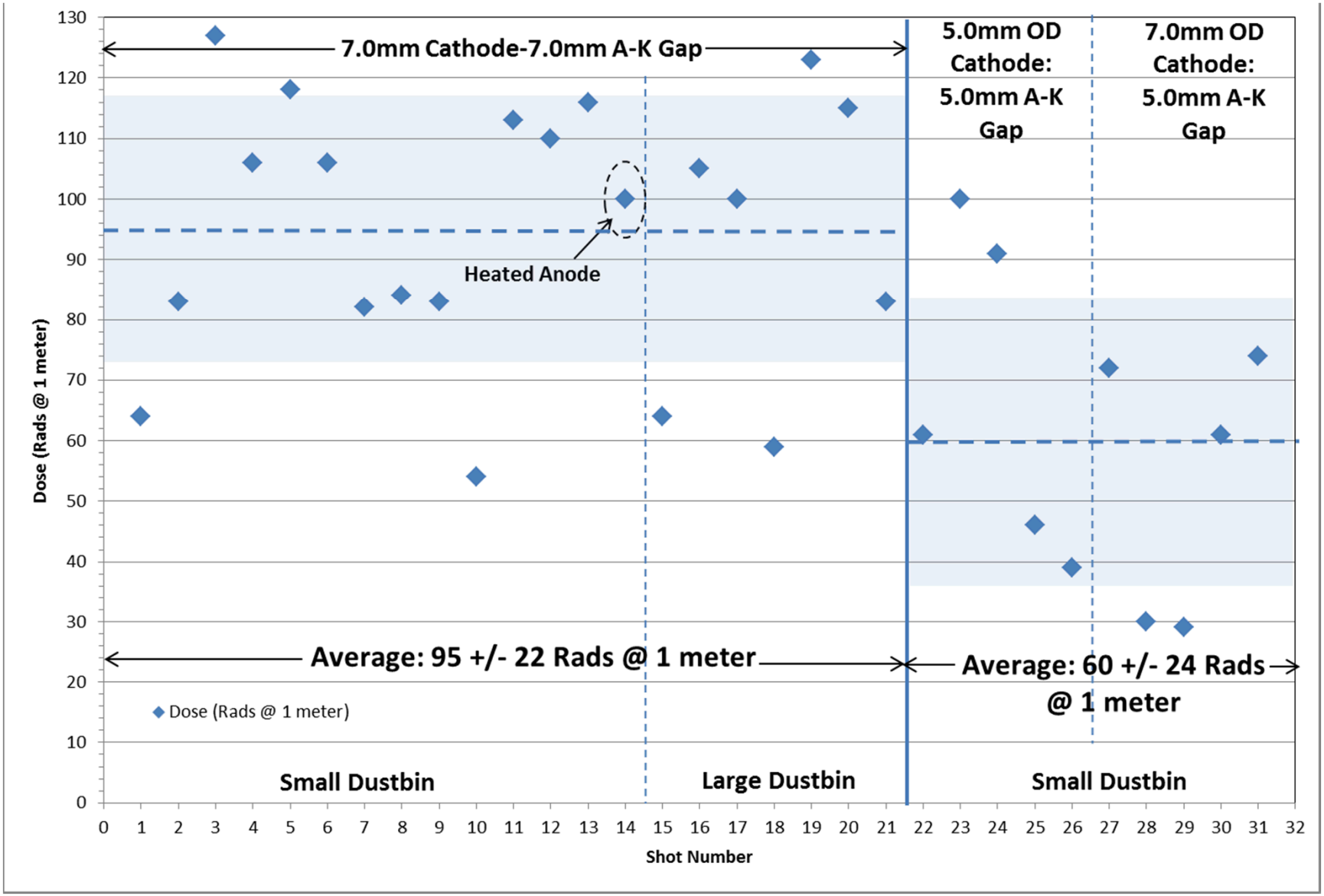


- Shots were taken from 3mm to 10mm A-K gap
- (LEFT) Dose @ 1meter (RADs)
- (CENTER) Time-integrated forward P-I-N (PIN_4)
- Dose drops at low A-K gap due to a) low impedance loading down diode, and b) premature Z-Collapse
- Dose drops at high end due to drop in diode current (high impedance)
- (RIGHT) Time-integrated spot size increases with A-K gap

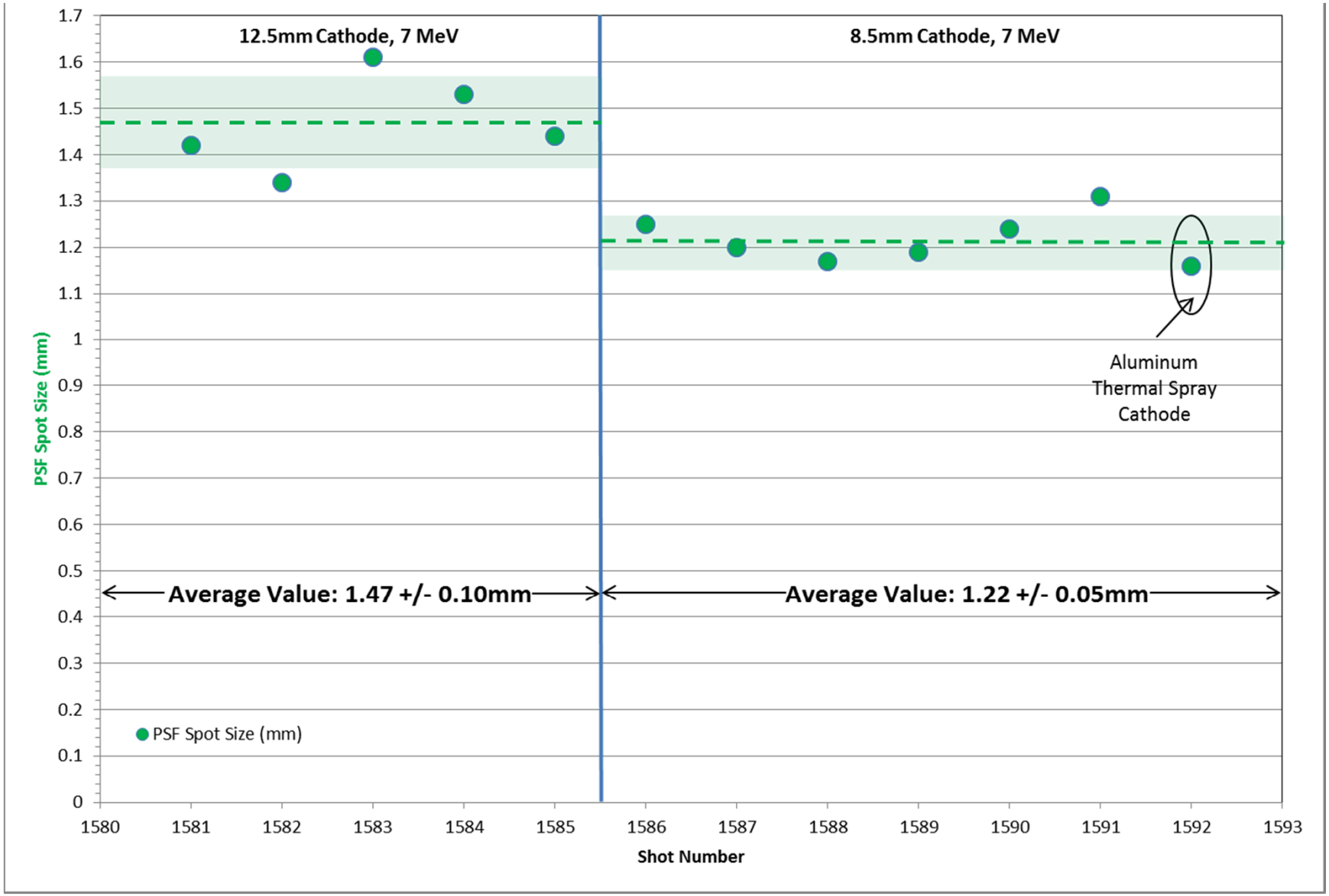
SMP spot size at 4.5 MV, various cathodes



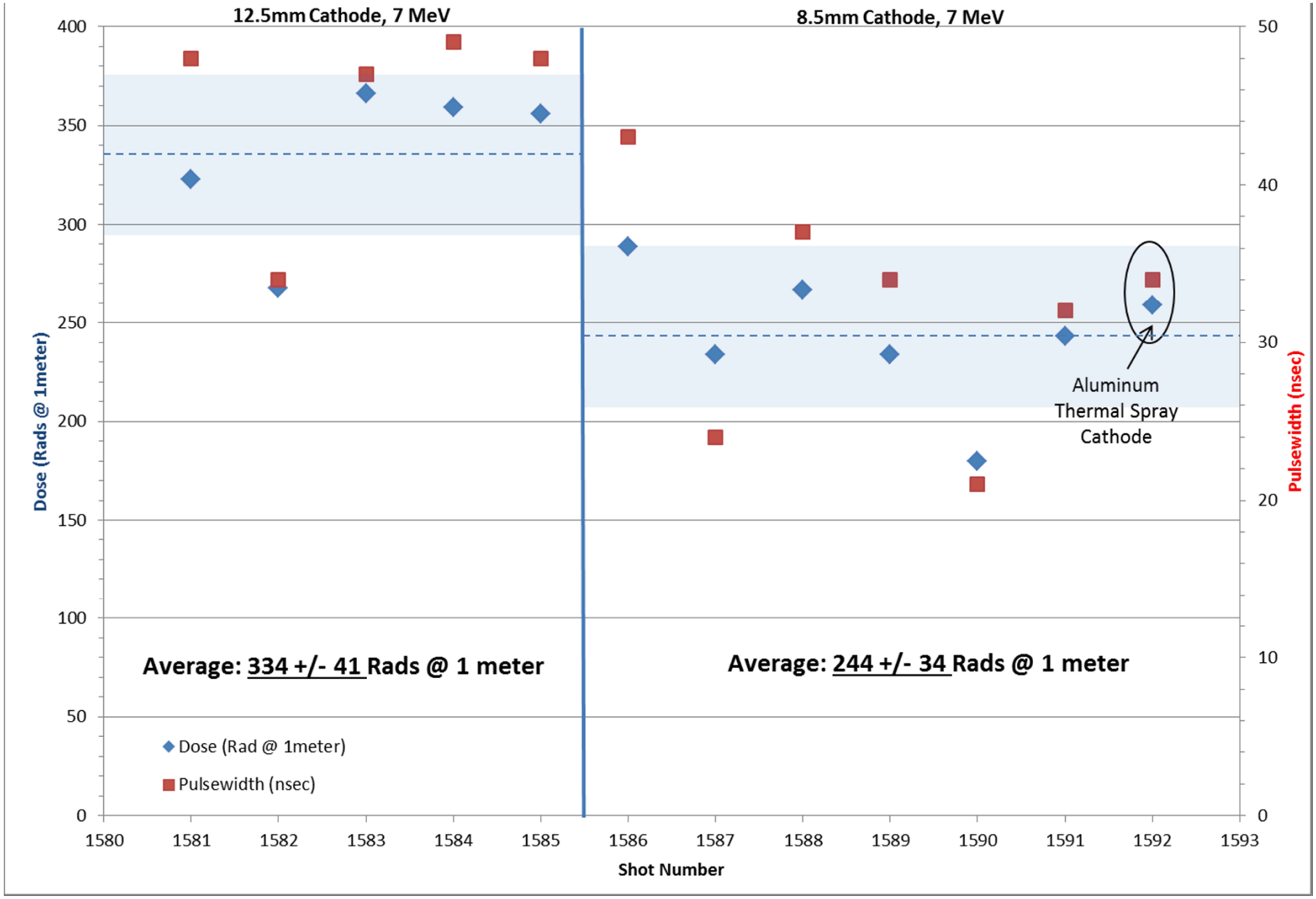
SMP Dose for 4.5 MV, 5 and 7 mm cathodes



SMP spot size at 7 MV, large/small K



SMP dose and pulsewidth at 7 MV, large/small K



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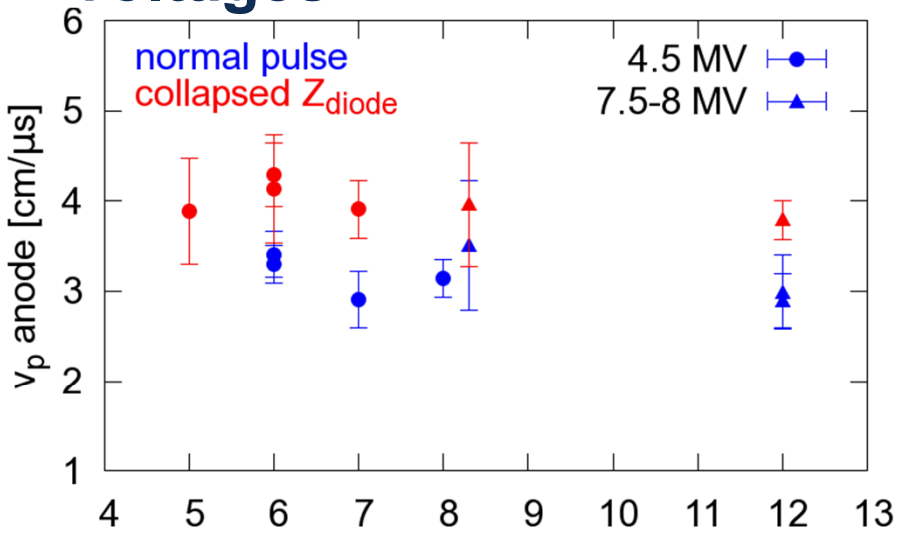
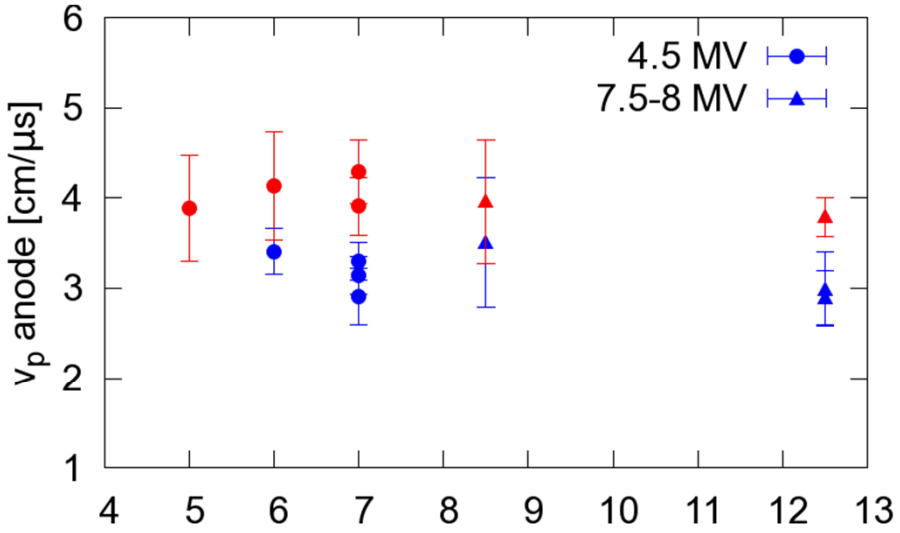
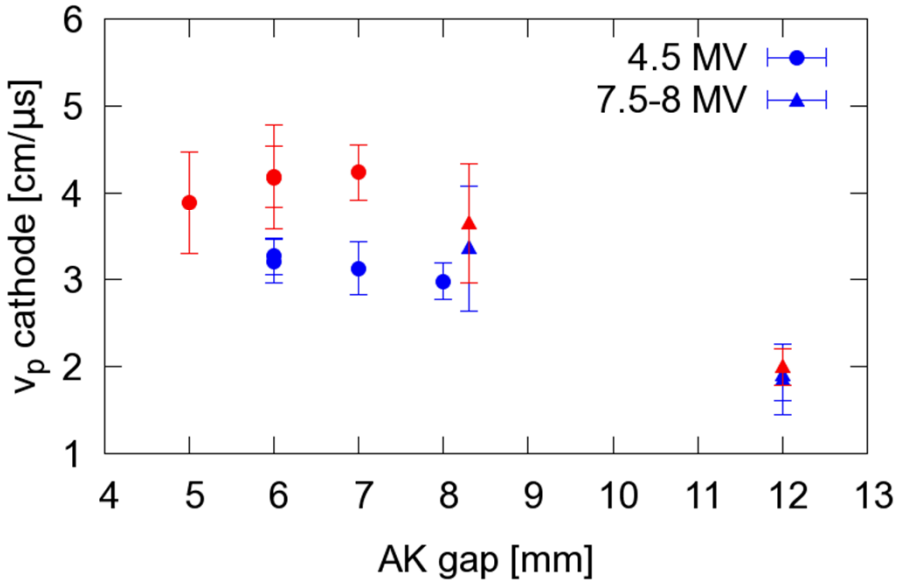
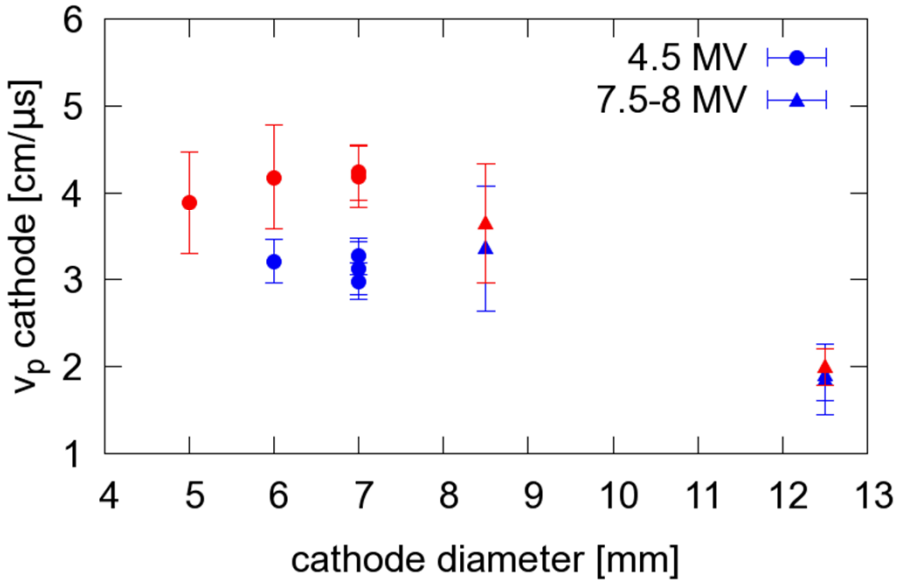
Anode and cathode plasma velocities at various voltages









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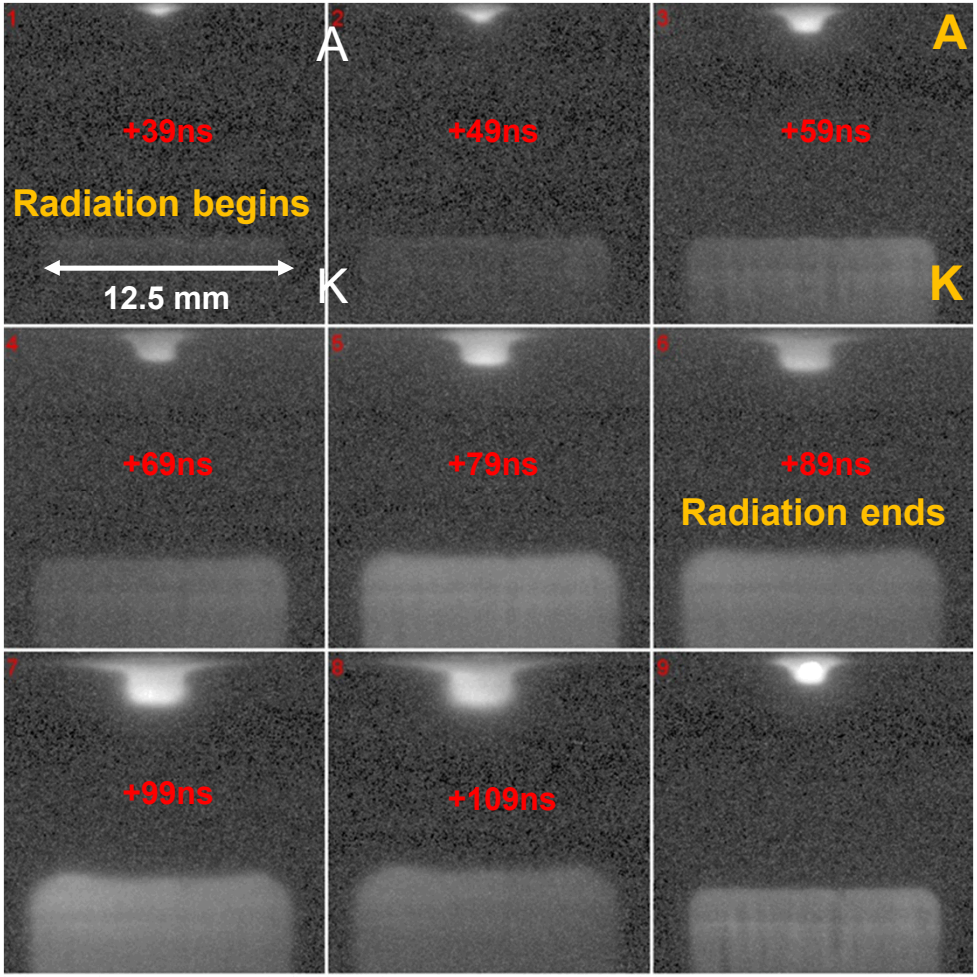
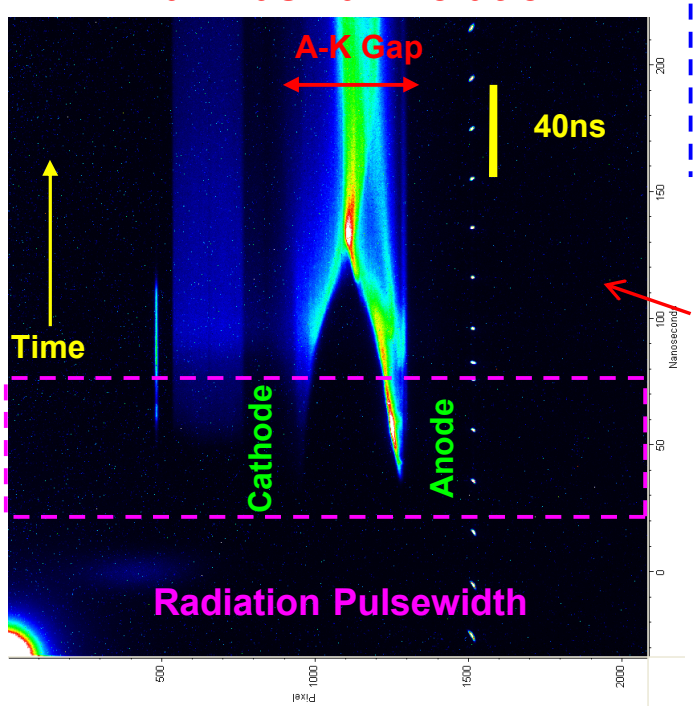
Impedance collapse not due to gap closure



*10ns gates

Axial Plasma Evolution



‘Premature’ Z-Collapse: Total and diode current increase rapidly, x-ray output (PIN diode) terminates before end of power pulse

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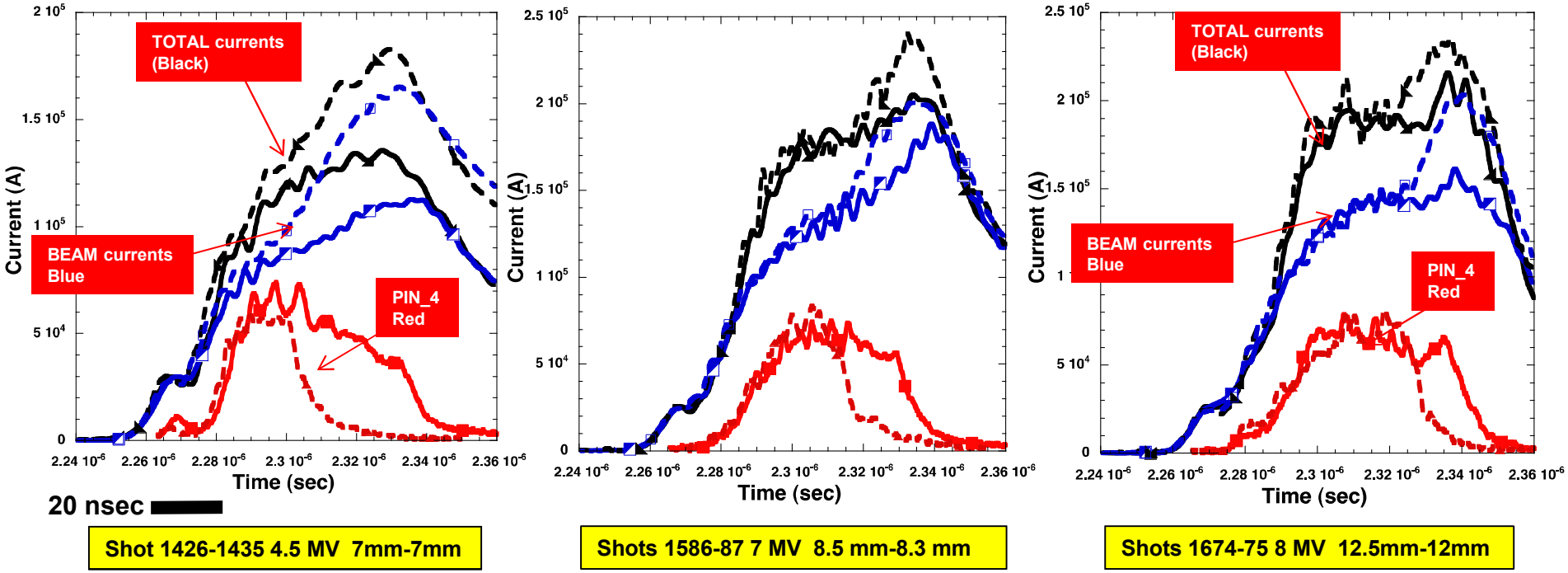


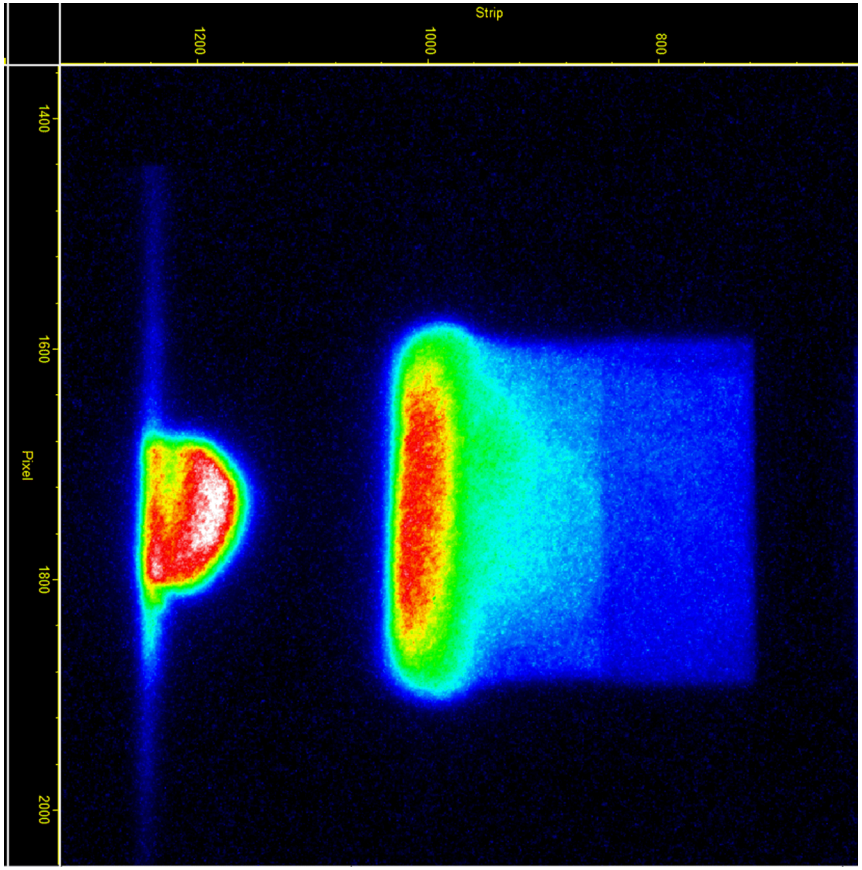
Shot 1426-1435 4.5 MV 7mm-7mm

Shots 1586-87 7 MV 8.5 mm-8.3 mm

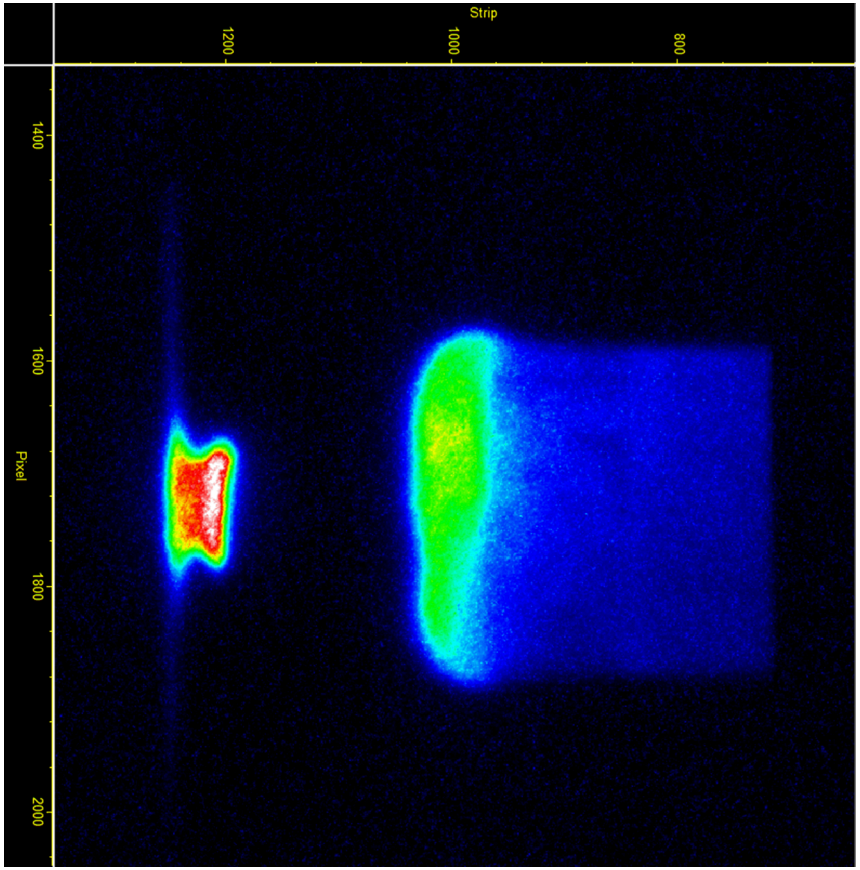
Shots 1674-75 8 MV 12.5mm-12mm

- Plots show Total and Beam current plus (scaled) Forward P-I-N (PIN_4) for three pairs of shots at different output voltages. When Beam current reaches inflection point on dotted curves, P-I-N signal collapses.
- 4.5 MV comparison shows increased Diode Current for all times. In other two shots, BEAM currents look very similar before one of them runs away.
- First two plots: indication of inflection point scaling with cathode Radius (cathode surface area), not cross-sectional Area

Anode plasma shape isn't necessarily an indicator



300 rad in 39 ns
1.15 mm spot



292 rad in 45 ns
1.25 mm spot

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We are executing an R&D program to further improve the SMP diode

- Is there a fundamental limit to beam spot size for a given geometry?
- Why does the electron beam pinch spot size grow in time?
- What governs the variation in the spot size, the spot axis, and the dose?
- What causes, sometimes, an early impedance collapse and termination of the pulse?

Plans:

- Higher voltage
- Cleaning – heating, RF discharge
- Cathode/anode geometry changes
- Cathode materials
- Advanced plasma measurements – map of the plasma density vs. time
- Reduce activation above 6 MV

Cathode with thermal-sprayed aluminum