DOE/NV/25946--1802

SAND2014-4421C

Plasma Dynamics in the Self-Magnetic-Pinch Diode*

N. Bennett, M. D. Crain, R. Gignac, R. Obregon, C. C. Smith, F. Wilkins, and D. W. Droemer

National Security Technologies, LLC

Las Vegas, NV 89193 USA

D. R. Welch

Voss Scientific, LLC

Albuquerque, NM 87185 USA

M. D. Johnston, J. J. Leckbee, M. G. Mazarakis, D. Nielsen, T. J. Renk, T. Romero, T. J. Webb, D. Ziska, and M. L. Kiefer

Sandia National Laboratories

Albuquerque, NM 87185 USA

*This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.

Purpose

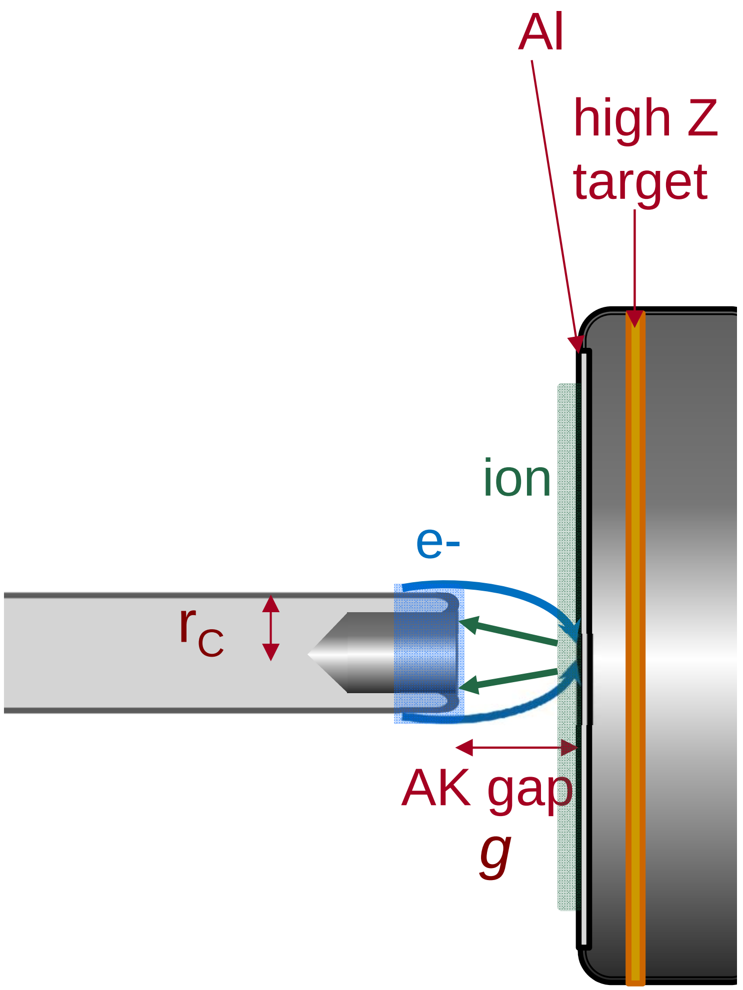
- The SMP diode is being developed by SNL, NSTec, NRL, AWE, …
- The measurement tools are catching up to the theoretical tools.
- Measurement and simulation provide corroborative evidence about the plasma formation and evolution.
- The results are well-described by the critical current theory.
- Evidence suggests:
  1) Surface plasmas are the reservoirs for particles in counter-streaming currents.
  2) The slower the plasma density builds on the anode surface (# monolayers), the faster it is depleted of ions.
  3) The diode current (impedance) can be calculated using I_{crit} with an effective AK gap, $g(t)$.
  4) The rate of change of $g(t)$, or v_{plasma}, is faster in some shots in a set with a fixed geometry and voltage.
  5) The relative number of fast v_{plasma} shots is a function of geometry and voltage. (see (2))

The Self-Magnetic-Pinch (SMP) diode operates in three impedance stages

- In all stages, the diode is modeled as current limited.[2]

$$I_{crit} = 8.5\alpha \frac{r_C}{g}(\gamma^2 - 1)^{1/2}$$

- High electric field stress causes explosive emission of plasma from the cathode. Electrons drawn from this plasma create the *monopolar* current.
- As the electron beam traverses the anode-cathode (AK) gap, it heats the anode, desorbing hydrocarbon contaminants and ablated foil material, forming an anode surface plasma.
- Ions are drawn from this plasma and counter-stream with the electrons to the cathode. (*bipolar* flow)
- This establishes a new equilibrium with a reduced impedance.
- The anode plasma expands into the AK gap, carrying the anode potential, which creates an effective gap: *g(t)*.



[2] Swanekamp, *et al*., IEEE Trans. Plasma Sci. **32**, 2004 (2004).

Modeling has provided insight into anode plasma dynamics

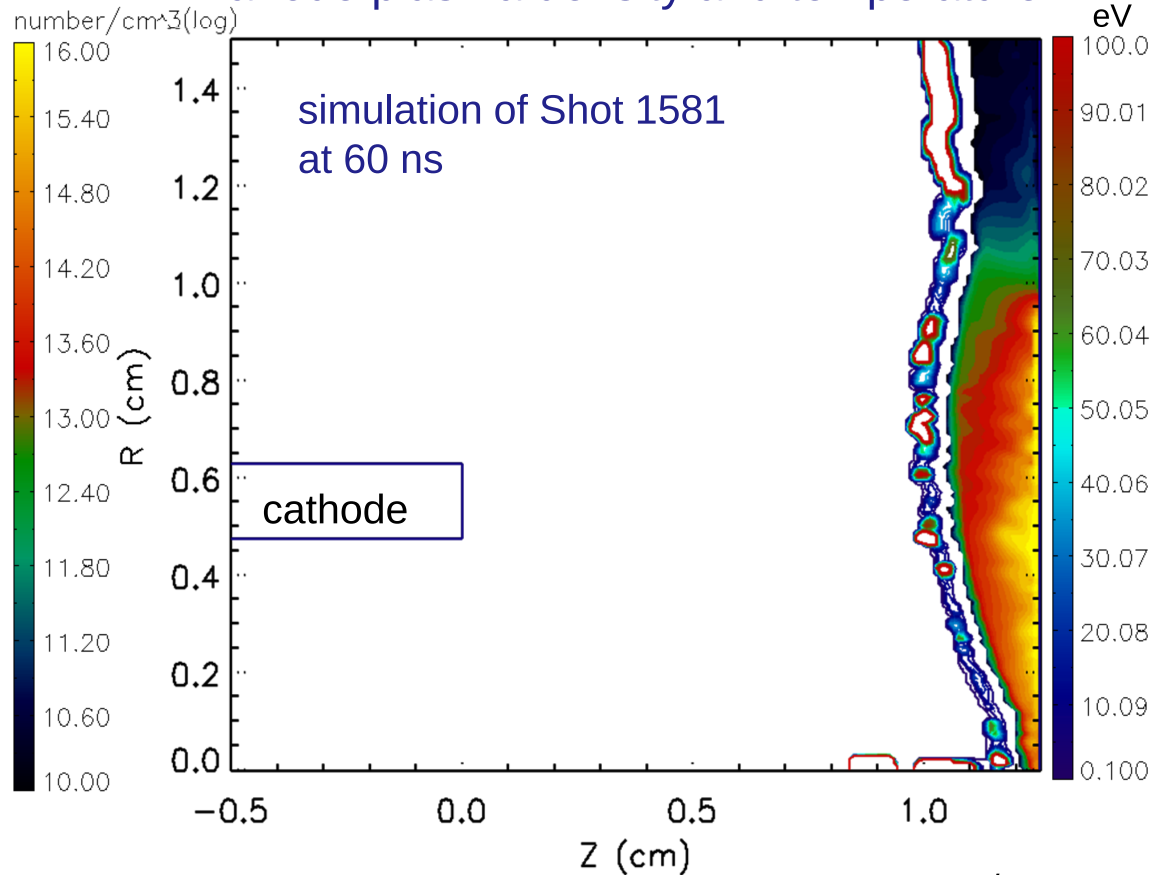
The anode plasma is generated with a hybrid particle-in-cell technique in 2D:

- The surface plasma is generated from thermal and stimulated desorption.
- Both emission rates linearly depend on the number of monolayers of contaminants.
- $\lesssim 10^{18}$ cm^{-3} plasma densities are modeled as inertial Eulerian fluids.
- $\sim 10^{13} - 10^{15}$ cm^{-3} densities in ion current are modeled as kinetic particles.
- Fluid particles transition to kinetic above a prescribed KE threshold (200 keV).

Plasma expansion creates an effective AK gap.

- I_{crit} with simulated $g(t)$ is consistent with measured beam currents.
- Expansion can be measured directly, too.

anode plasma density and temperature



$v_p = 3.33$ cm/μs
KE = 68 eV

Imaging diagnostics for electrode plasmas

Imaging streak and framing cameras share a telescoping lens system

NSTec Gen IV Streak Camera

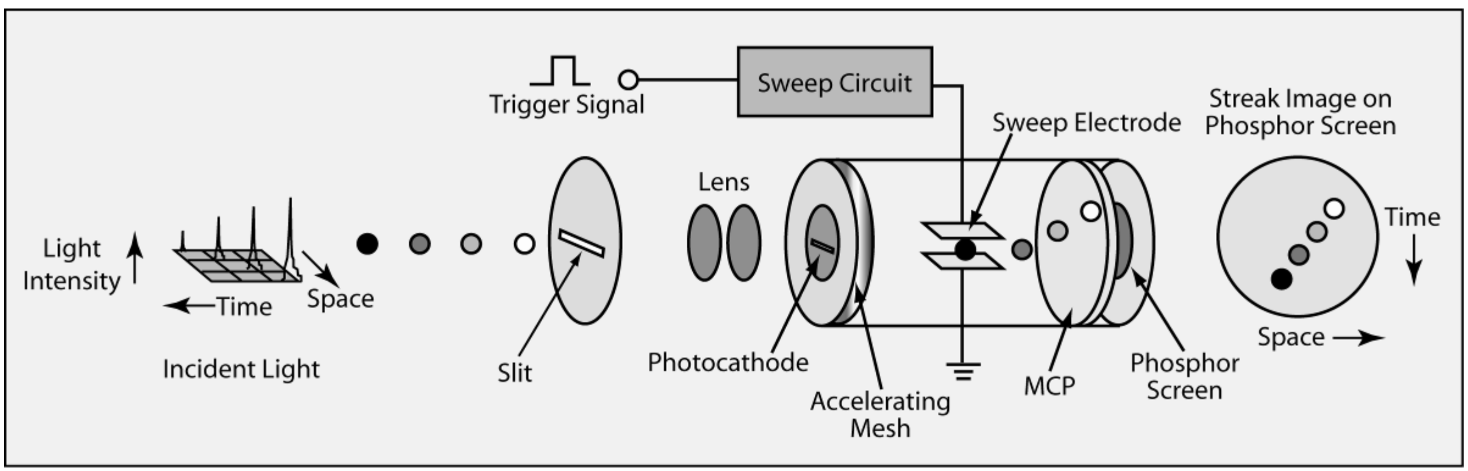
•Continuously Selectable Sweep Rates from 20ns to 500µs
•Photonis P510 Streak Tube
•6µm Fiber Faceplate
•35mm x 4mm Active Area Multi-alkali S-20 Photocathode
•60mm Aluminized P-22 Phosphor Screen
•Full remote control capability from external work station

Princeton Instruments Quad-Ro CCD

•24 µm pixels
•50mm chip

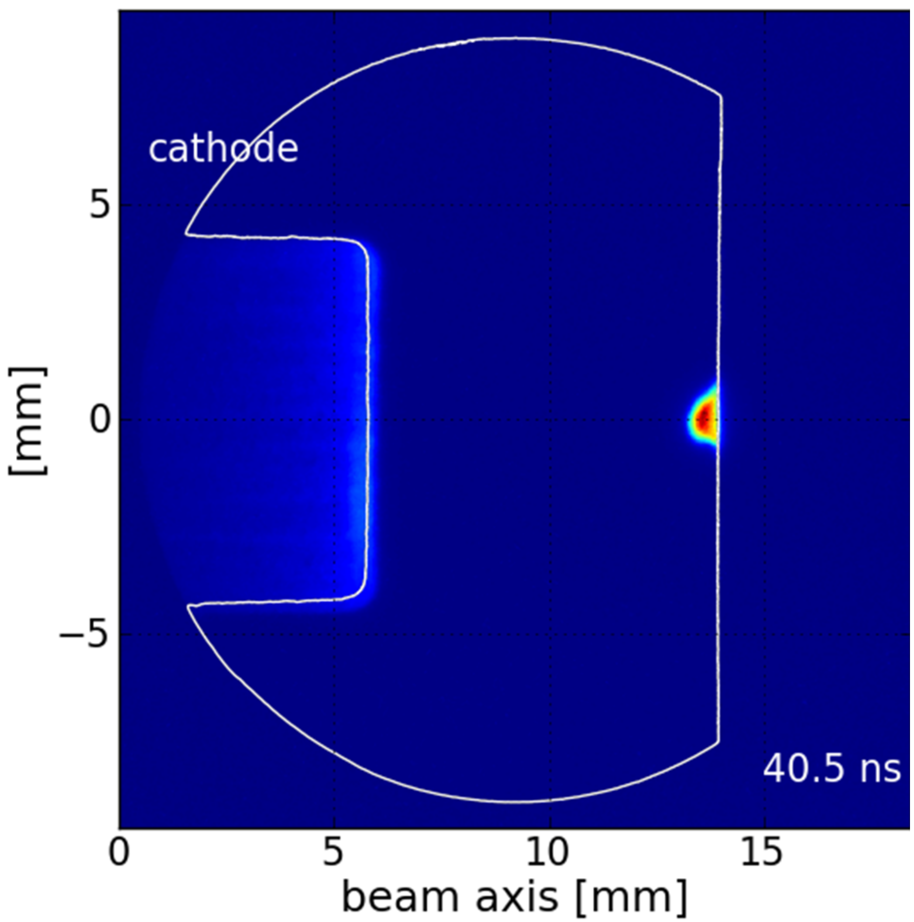
Princeton Instruments PI-Max ICCD Camera

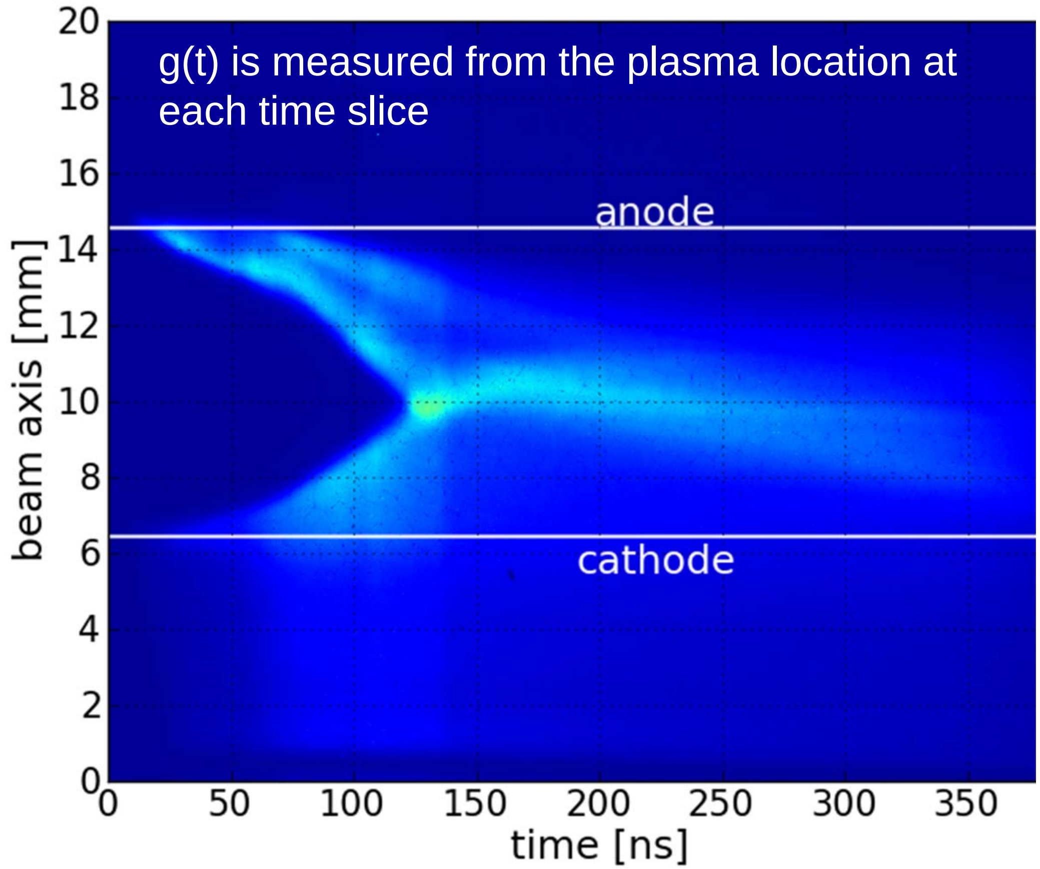
- Gen III filmless GaAsP photocathode (HBf)
- 25mm fiber-optic bonded 1:1 image intensifier
- P43 phosphor screen
- Front-Illuminated CCD
- 1340x1300 pixel array
- 20 µm pixel size
- < 7ns gating
- > 50% peak QE



Imaging diagnostics for electrode plasmas

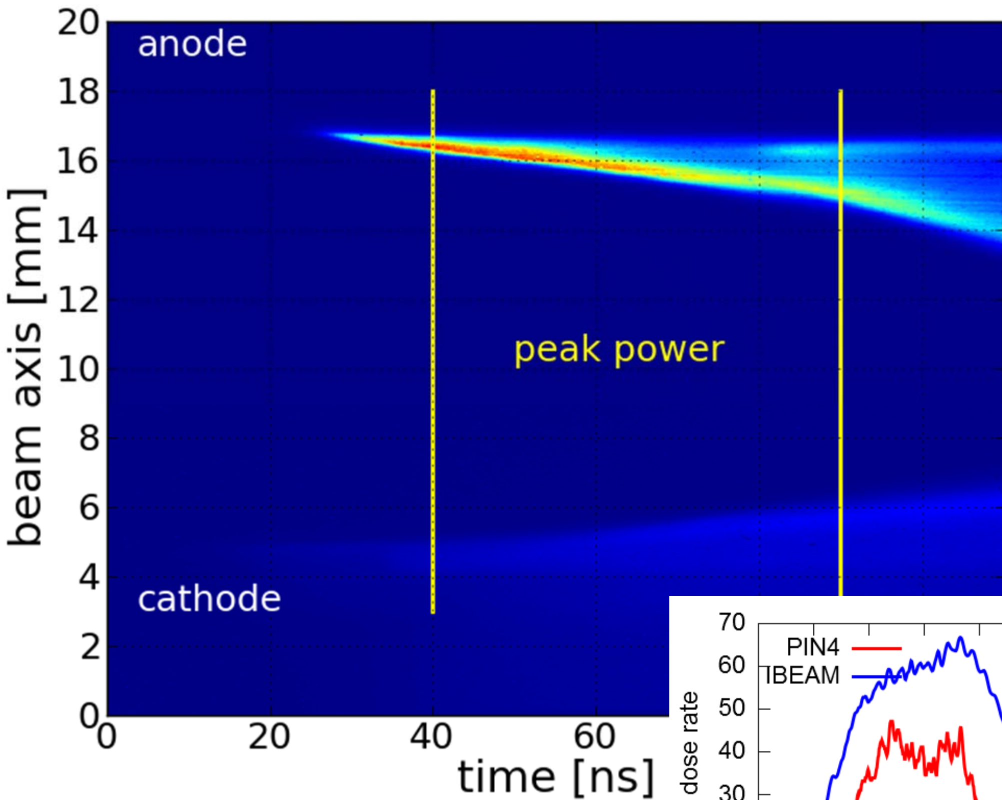
7.5 MV
framing and streak images from Shot 1670

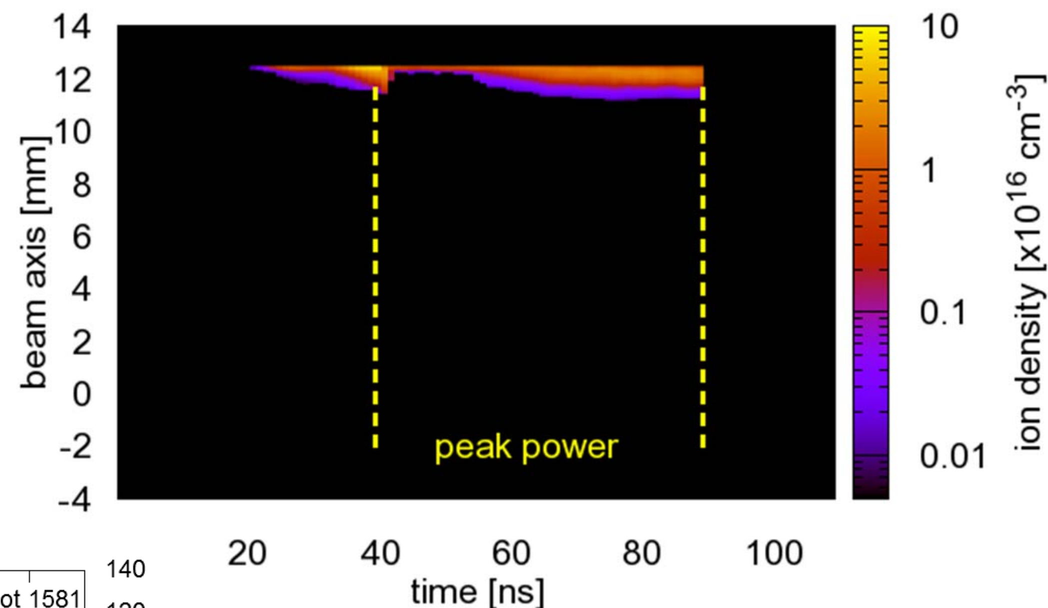


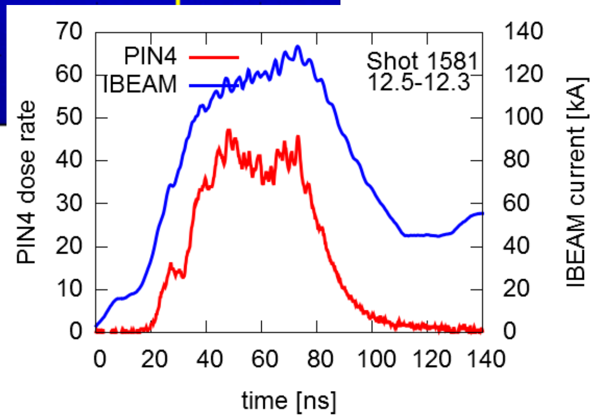


Streak image confirms plasma expansion from simulation

7.5 MV
Shot 1581



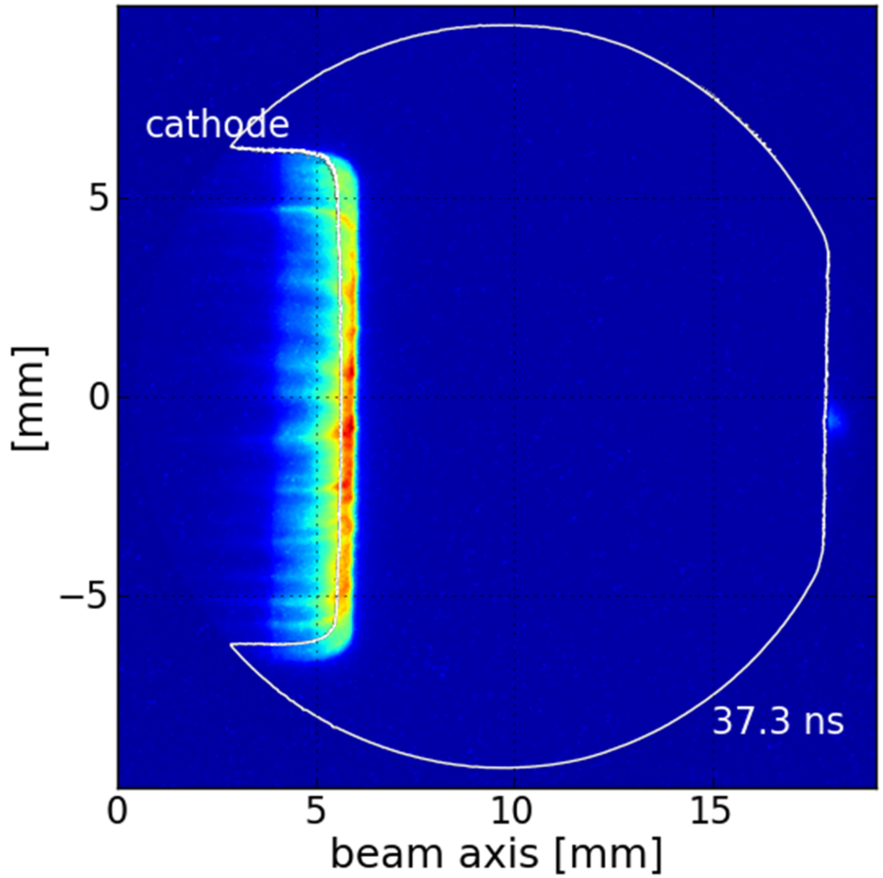


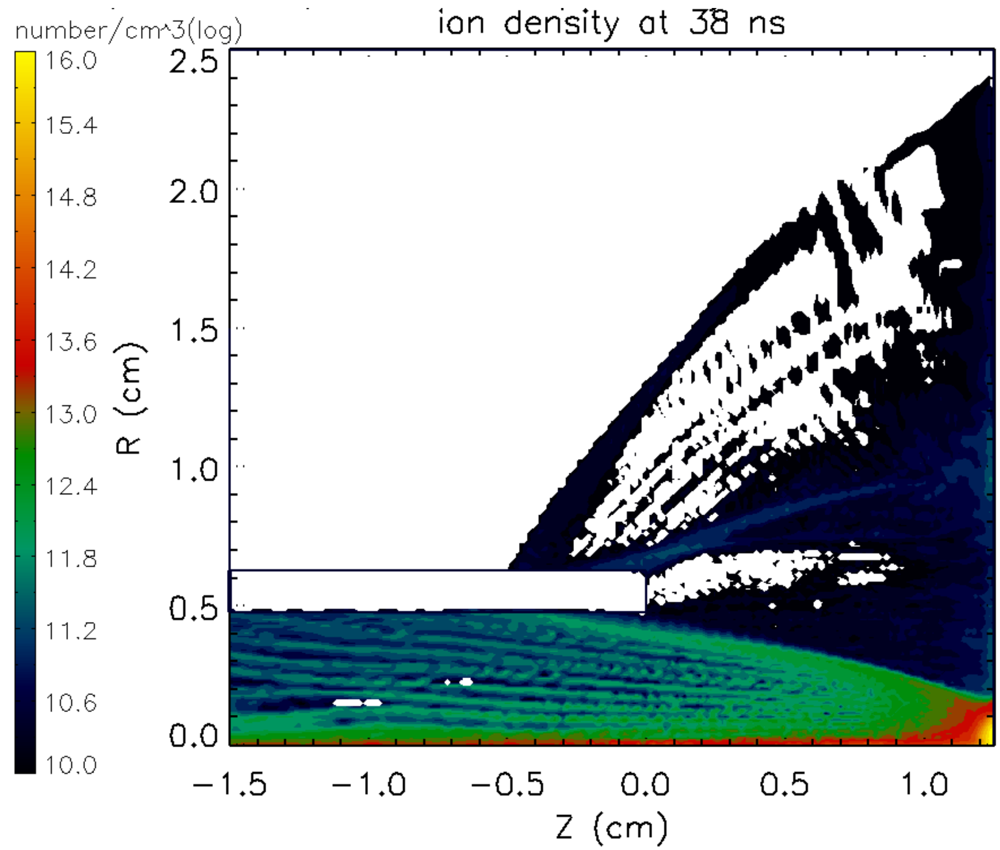


The pulse rise impacts the plasma desorption, increasing sensitivity to the number of monolayers.
This impacts the plasma distribution.

Framing image confirms plasma expansion from simulation

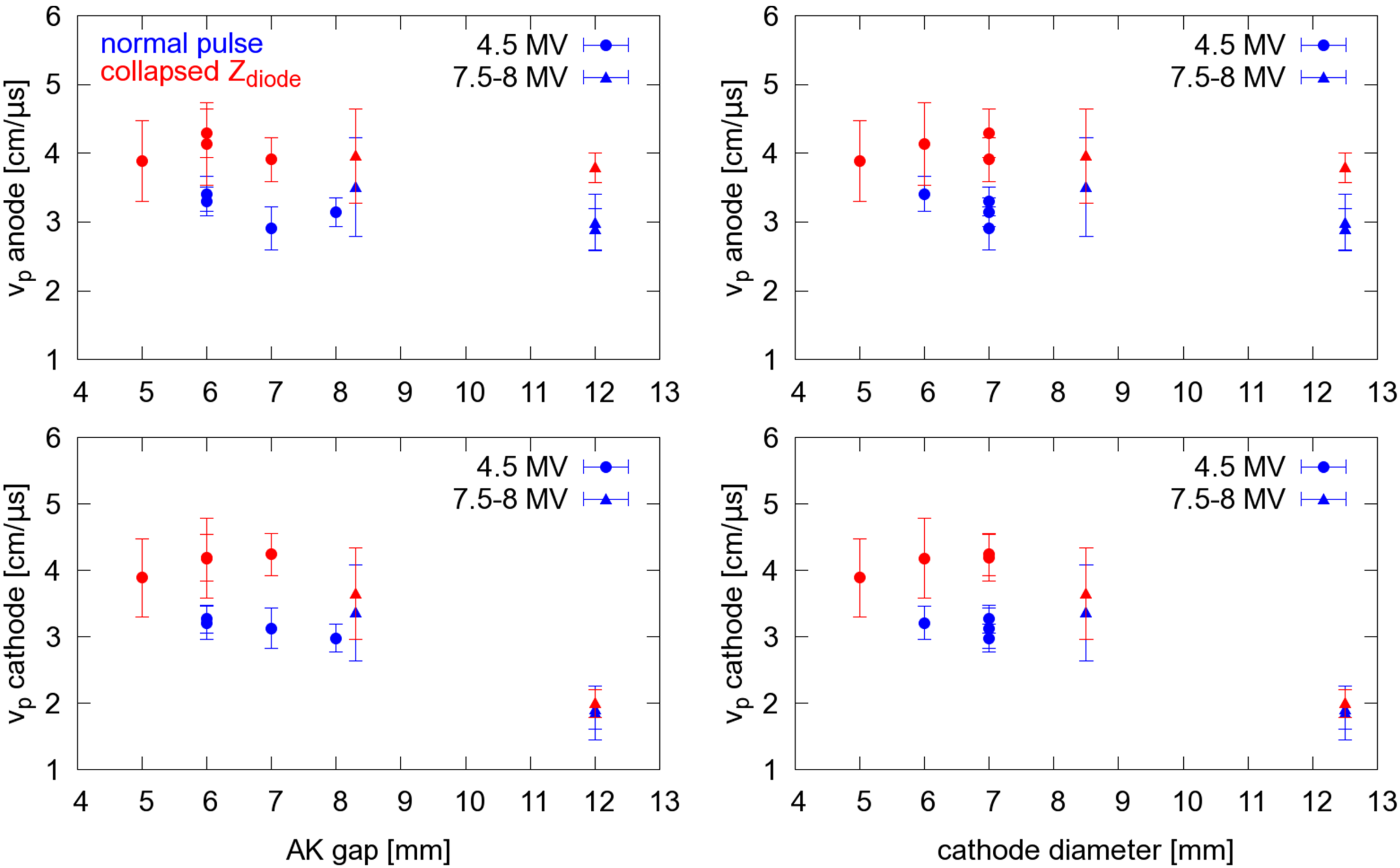
7.5 MV
Shot 1581





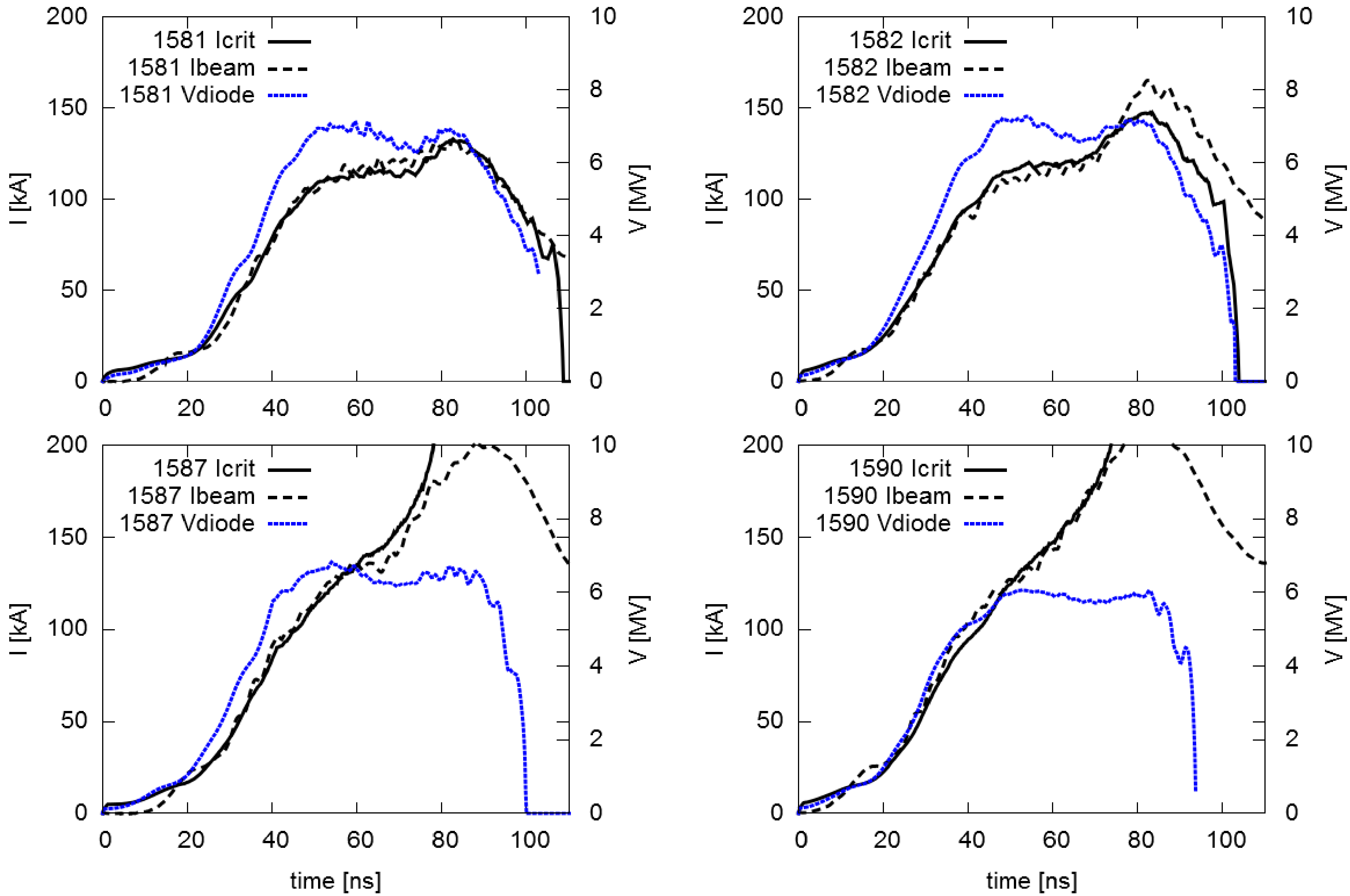
- The pulse rise impacts the surface heating/plasma desorption, increasing sensitivity to the number of monolayers.
- This impacts the plasma distribution and impedance.

plasma velocities



I_{crit} calculated using measured g(t) is a good match to I_{beam}

7.5 MV
r_C = 4.25 mm
g = 8.3 mm



Conclusions

- Plasma imaging, current measurements, and modeling have increased our understanding of plasma dynamics in the SMP diode:
  1. Surface plasmas are the reservoirs for particles in counter-streaming currents.
  2. An increase in the surface contaminants increases the desorbed plasma.
  3. Some mechanism causes greater v_{plasma}, and lower diode impedance, in some shots.
  4. The diode current (impedance) can be calculated using I_{crit} with an effective AK gap, $g(t)$.
  5. The relative number of fast v_{plasma} shots is a function of geometry and voltage.

- We are developing techniques to control surface contaminants.