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The Role of Plasma Evolution in the Operation of a Self Magnetically Pinched Diode

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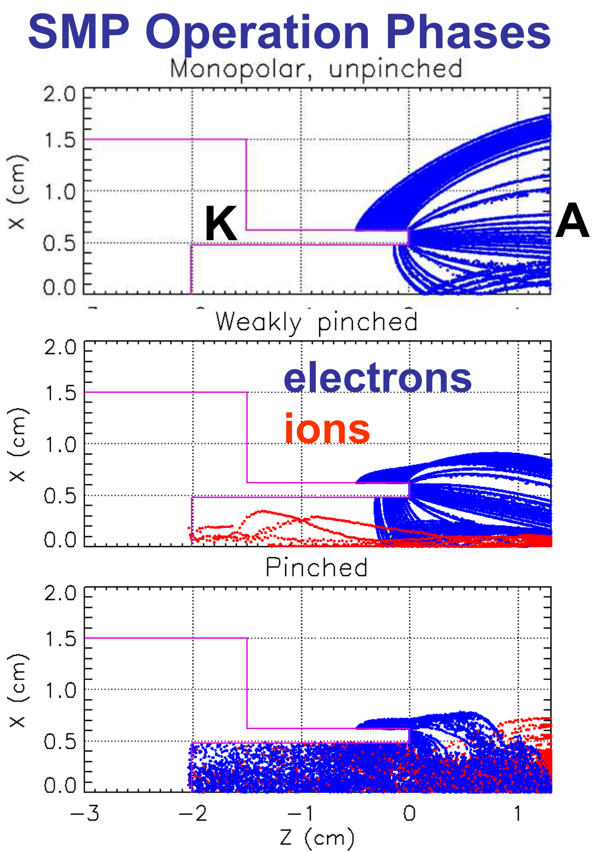
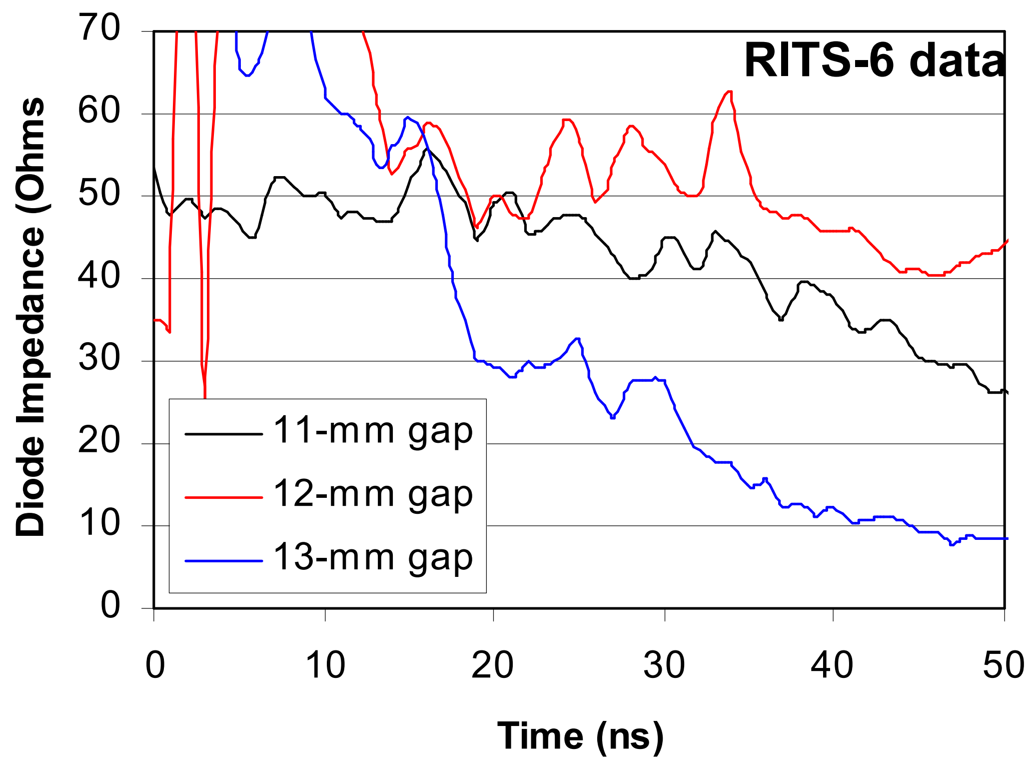
SMP data exhibit narrow AK gap operational window for annular cathodes

- **Cathode, anode design for Self Magnetically Pinched (SMP) diode suggests complex plasma evolution**
- **RITS-6 data at 6 MV, 150 kA for longer AK gaps, impedance initially higher, then rapid impedance loss**
  - **12 mm gap impedance holds up longest**

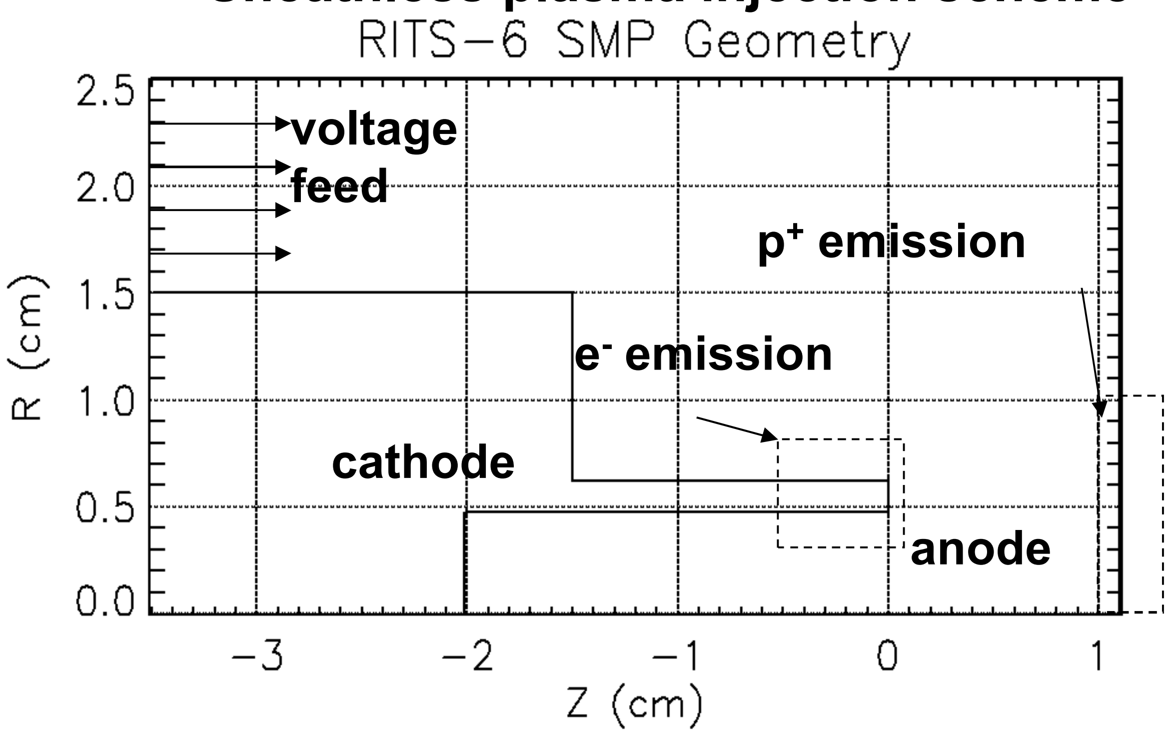




See poster 3P52, S. Portillo for details

LSP sim. using new plasma models

- We examine the plasma evolution of a RITS-6 6 MV, 150 kA, diode with 9--15-mm AK gaps
- LSP simulations* presented are:
  - 2D implicit electromagnetic
  - Fully kinetic using up to 5 million particles
  - Δx = 30 μm in gap, $c\Delta t$ = 15 μm
  - Sheathless plasma injection scheme



Neutrals transition into electron-ion pairs in 1-2 cells

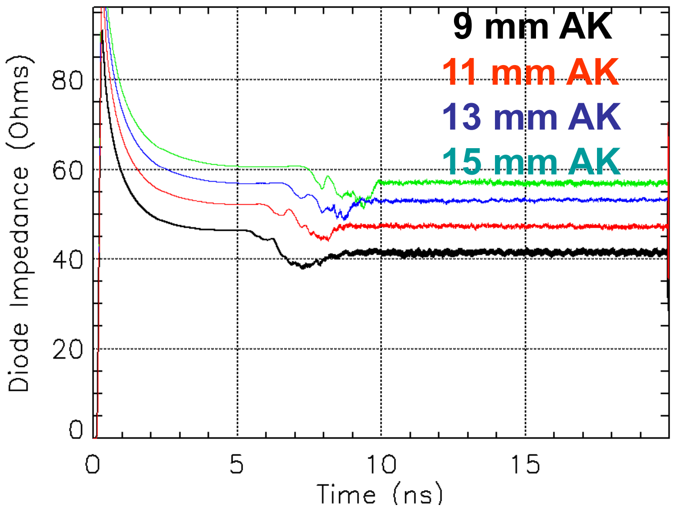
Plasma emitted via constant flux and/or stimulated method

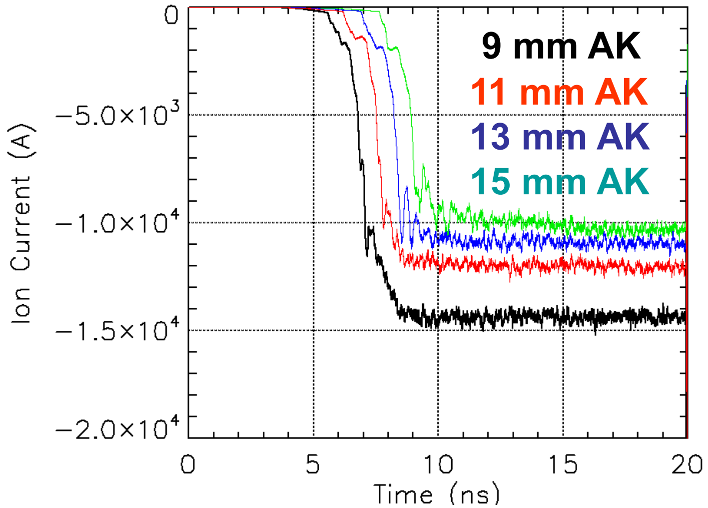
Constant flux method initiated by turn on of local SCL emission

*D. R. Welch, et al., Phys. Plasmas **13**, 063105 (2006)

Bipolar diode sim. shows decreasing impedance, proton current with AK gap

Anode proton emission with 400 k temperature rise threshold (ΔT)





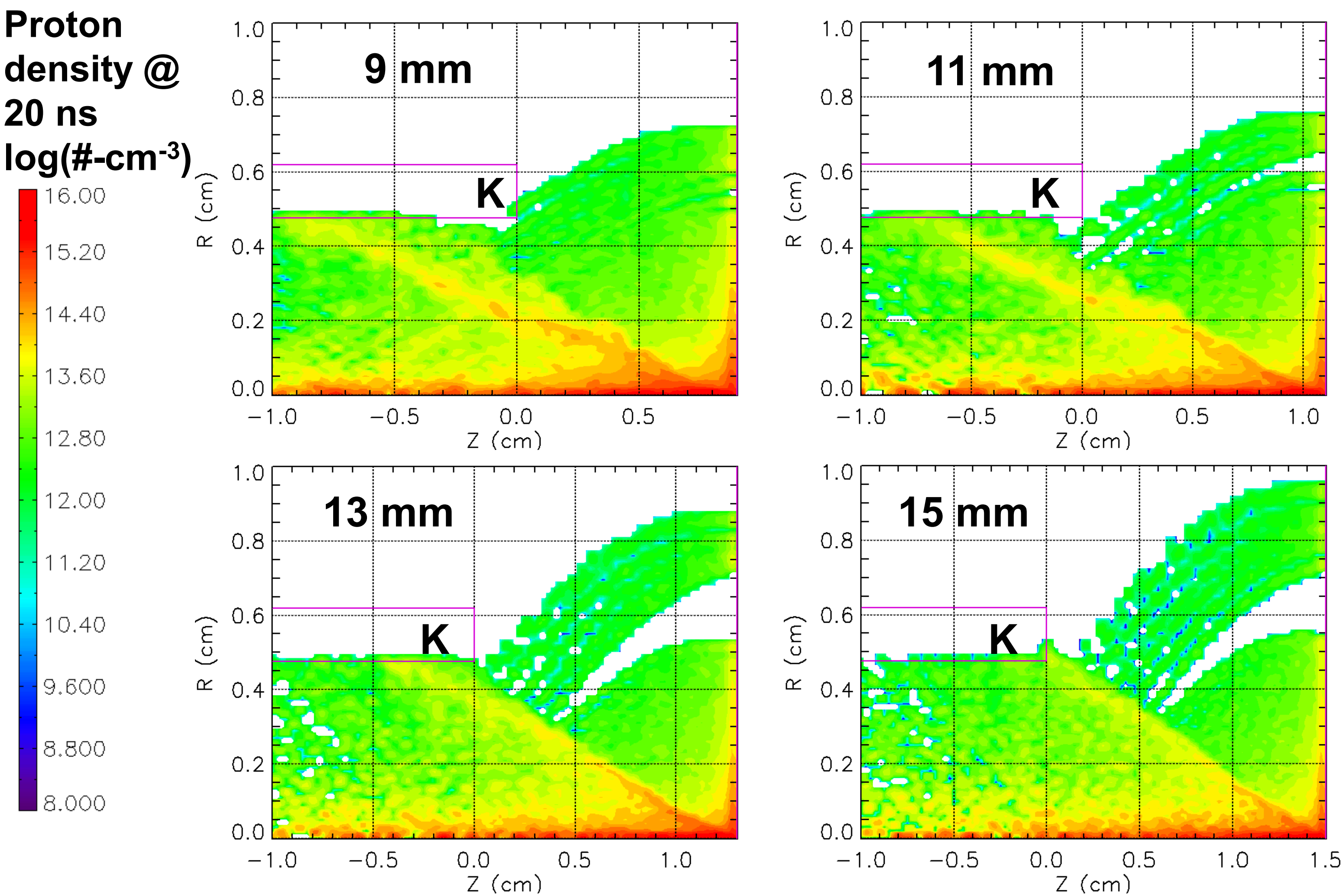
Diode Z = 41-57 Ohm, steady

Z falls with gap

Ion currents 10-14 kA

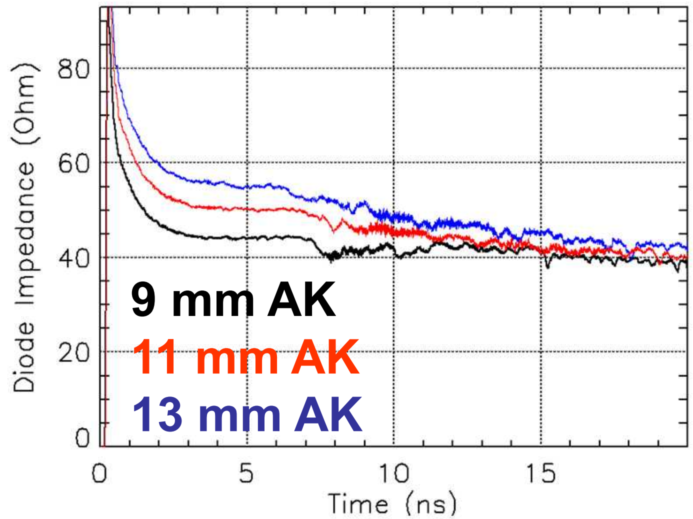
10% for all gaps

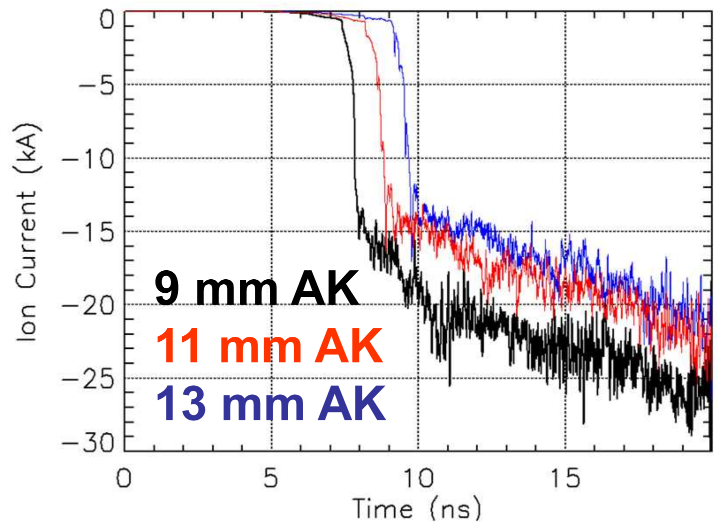
Protons strike K face for 9,15 mm gaps



Protons largely miss K face for 11, 13 cm gaps
Heavier ions require larger ΔT emission threshold

Constant plasma injection rate shows improved Z, I_{ion} with increasing AK gap





¼ ML/ns plasma injection once SCL emission begins on surfaces

Diode starts Z ~ 45-55 Ω, with 6 MV voltage

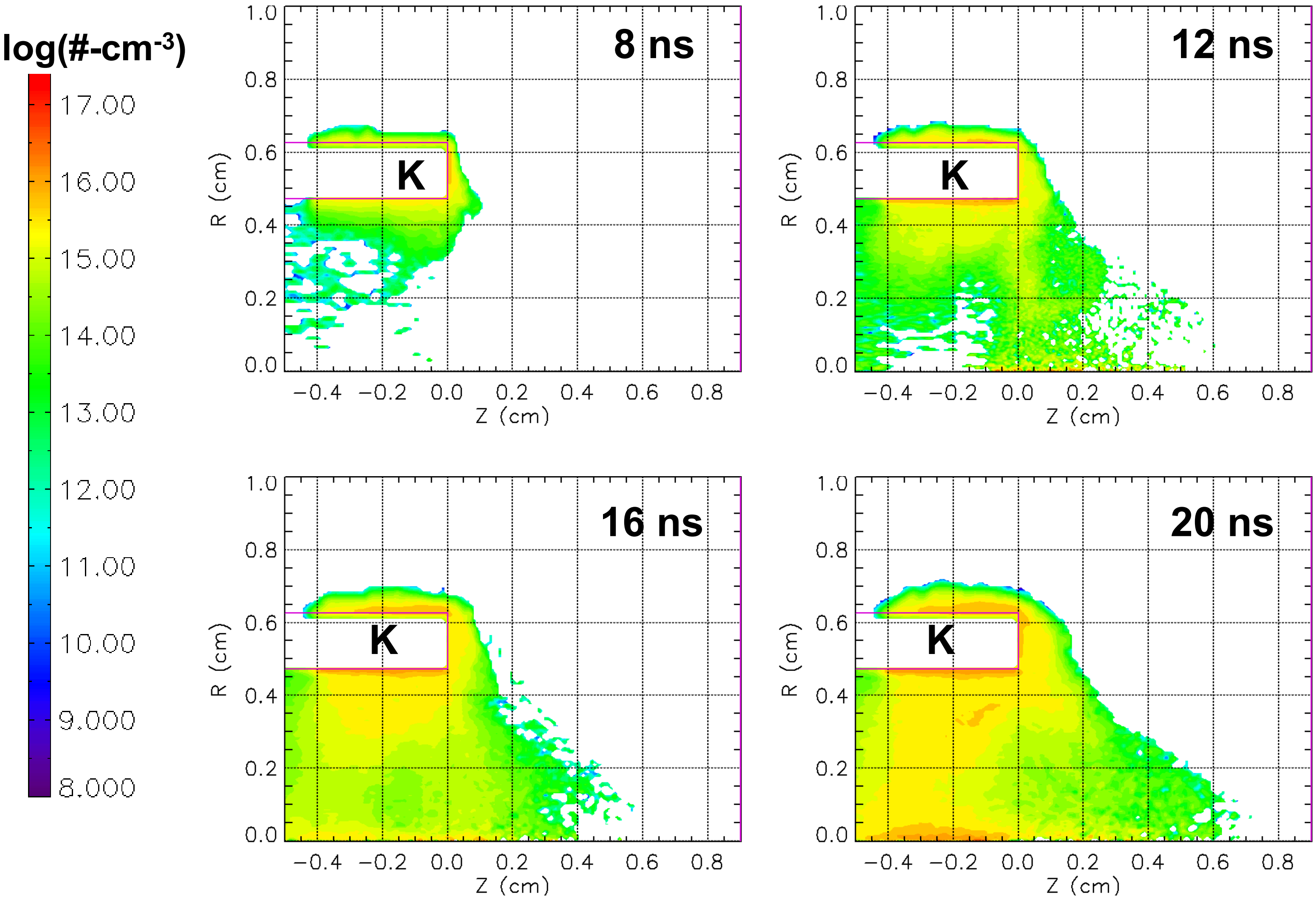
Ion currents rise to 20-27 kA by 20 ns

Z falls at roughly 0.3-0.5 Ω/ns

Constant rate plasma injection sim. exhibit *good* Z fall, do not show AK gap stability window

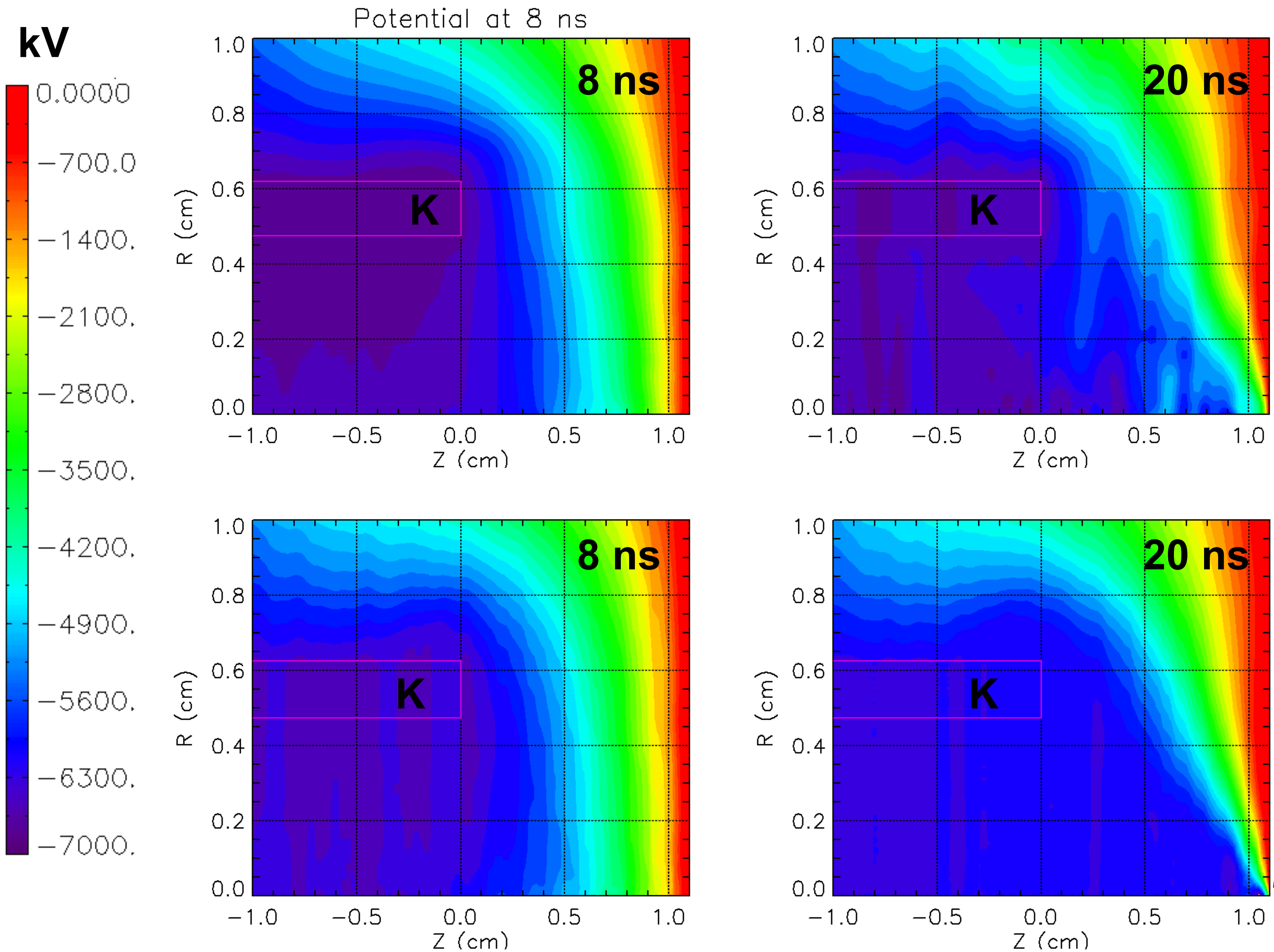
1 ML = 10^{15} cm^{-2}

K plasma evolves towards anode mainly at small radius



Cathode ion density shown for 9 mm gap

Potential sheath shrinks near axis



Bipolar only

Plasma injection

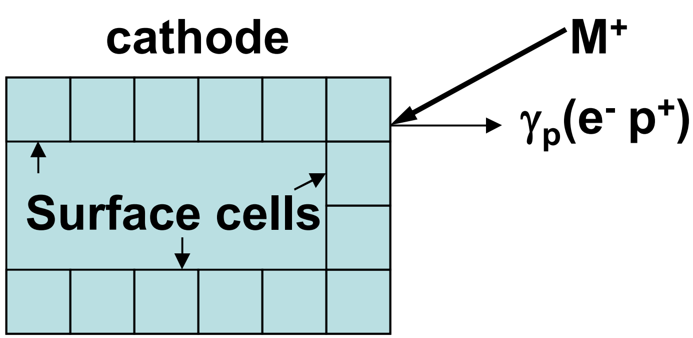
Tiny effective gap which enhances ion current

E ~50 MV/cm

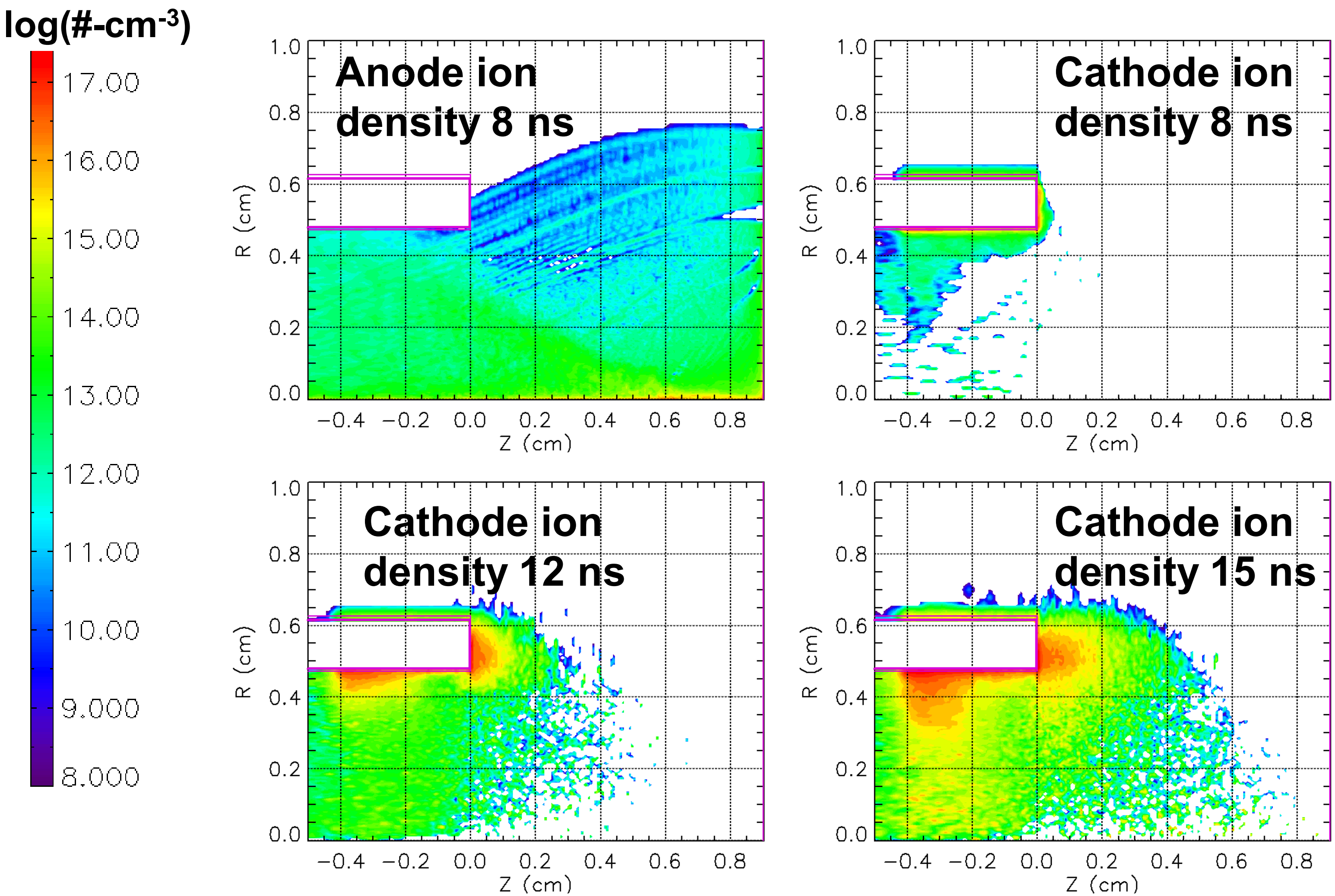
11-mm gap

High energy ions on surfaces liberate 1000's neutrals, 100's of electrons

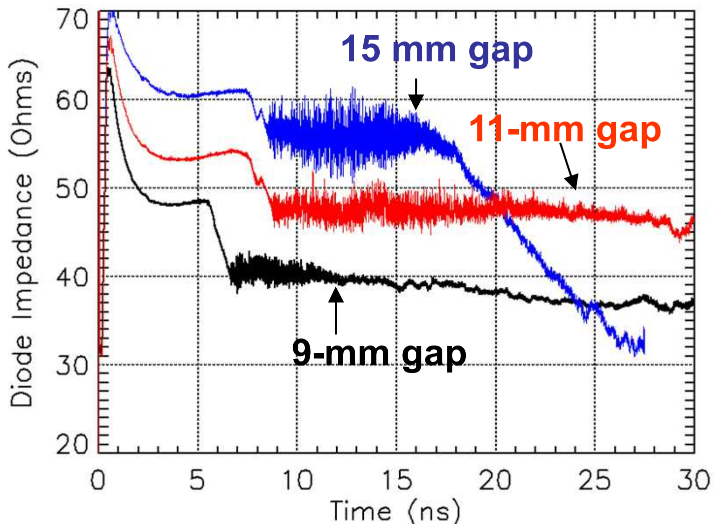
- Secondary yield fraction γ largely proportional to dE/dx – higher mass ions produce more secondaries
- Neutrals liberated on cathode surface will quickly ionize
- In coupled LSP simulations, we inject 100-1000 e-ion pairs per ion strike (γ_p) off same surfaces as emission
- The constant plasma flux after emission is reduced to 0.1 ML/ns

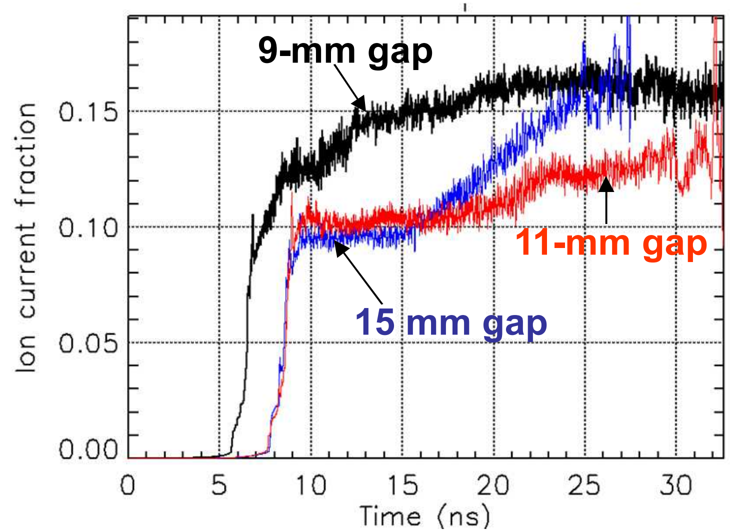


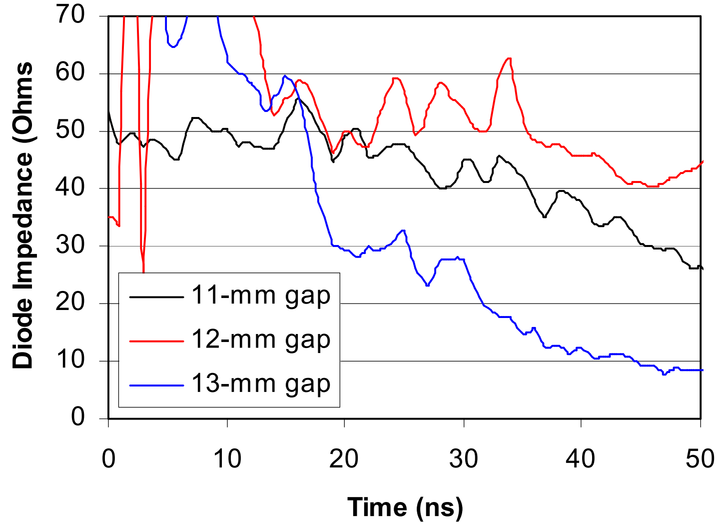
Extreme example - 9 mm AK gap with γ_p= 1000 has rapid Z fall



See operation AK gap window with full plasma model $\gamma_p = 100$







RITS 6 data

- Large gap has flat Z for 15 ns, then crashes
- Small gap starts low Z and falls immediately
- Just right gaps hang in for > 30 ns
- Ion current fraction ramps from 0.1--0.16 as Z falls

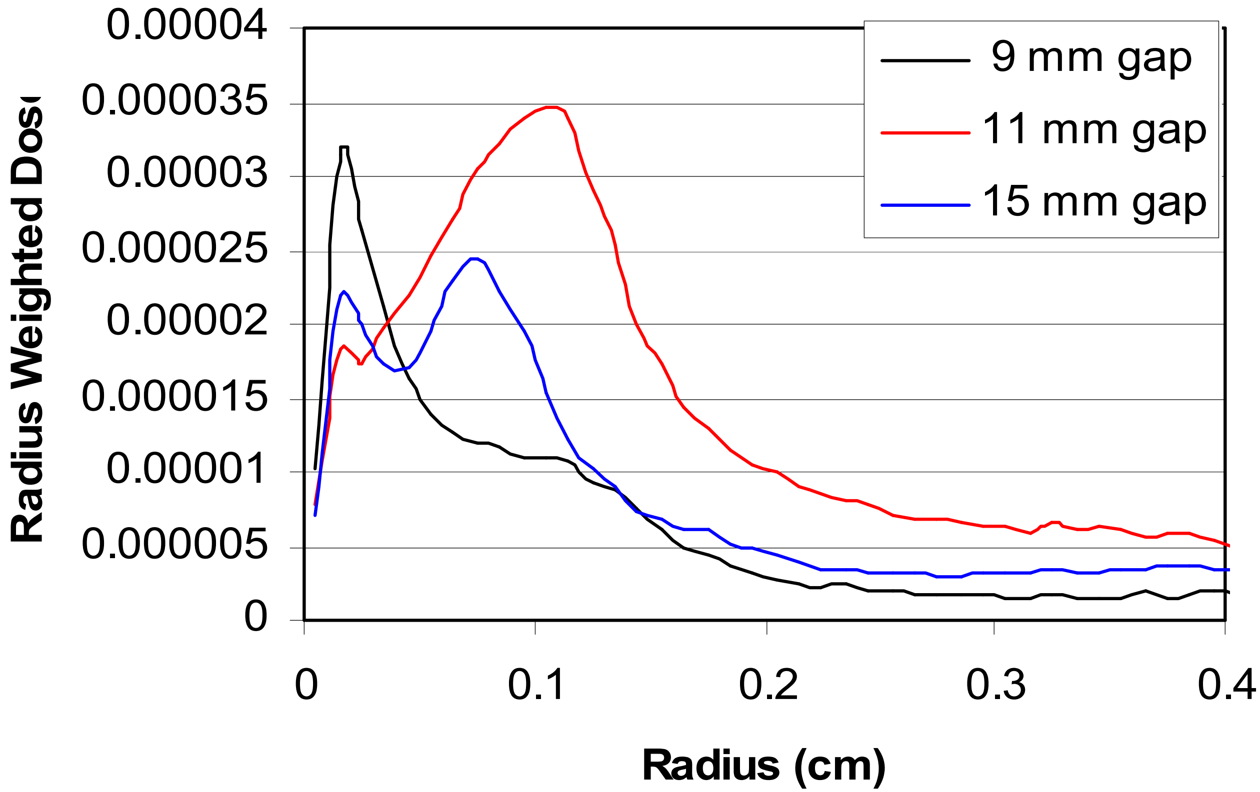
Anode ion impact on cathode face largely determines Z stability

- **Electron heating of surface provides ion source**
- **Hollow cathodes can effectively decouple enhanced plasma production from gap**
- **Small AK gaps are susceptible to large radius anode ions which strike early in time**
- **Larger AK gap susceptible to small radius ions; show later but more rapid Z fall**
- **AK gap operational window calculated – *consistent* with RITS6 data**
- **Anode, cathode heating might widen AK gap operational window, improve reliability**

Backup slides

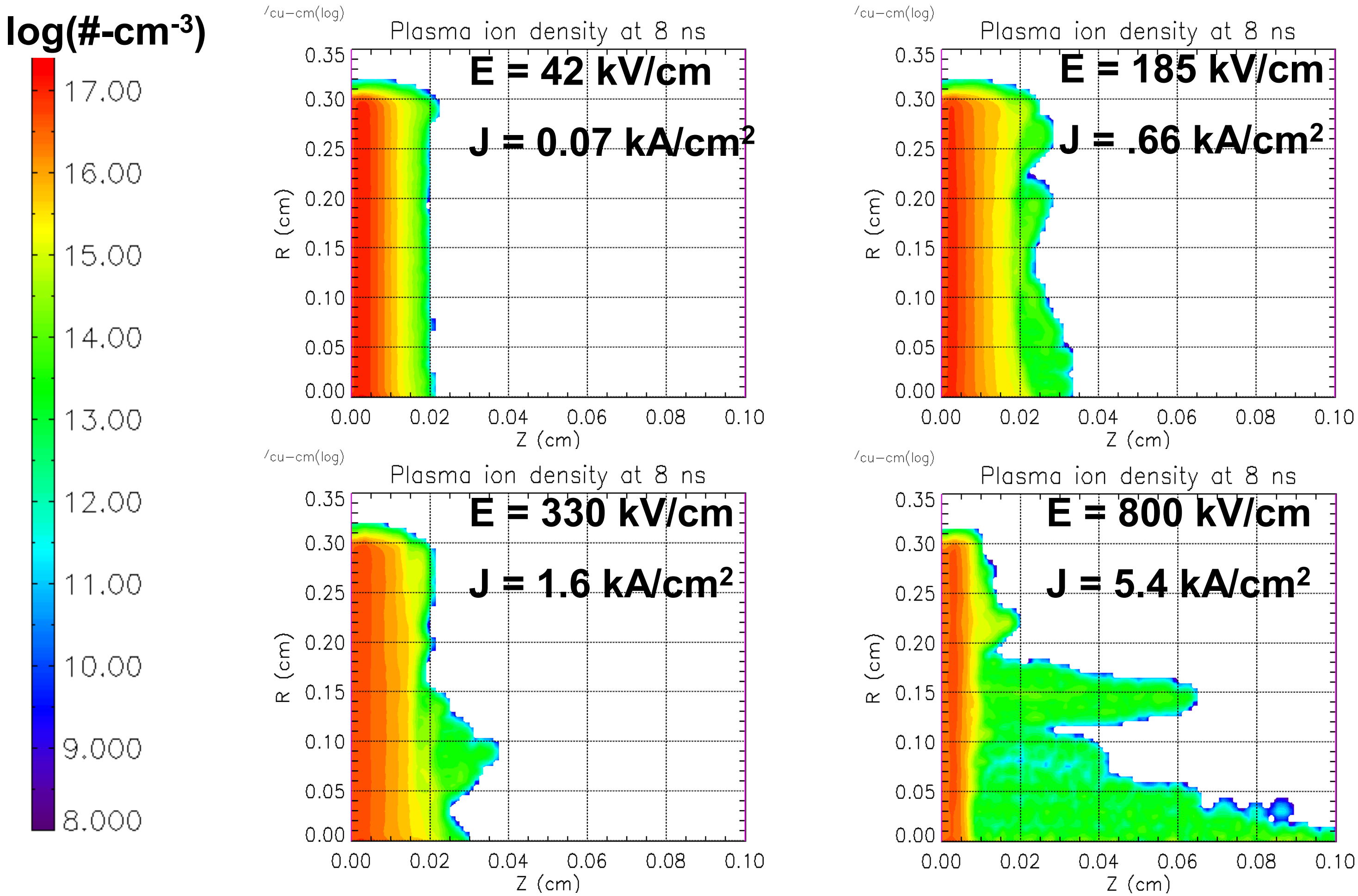
Time integrated dose, assuming constant beam angle, highest for 11 mm gap

- Dose obtain from Q*$V^{2.2}$ scaling
- 20-30% of dose is at large radius from early unpinched beam
- 9, 11 and 15 mm gap had dose (r < 4 mm) of .28, 1, .36 relative dose after 25 ns



K plasma can develop nonuniformities and jetting above critical current density

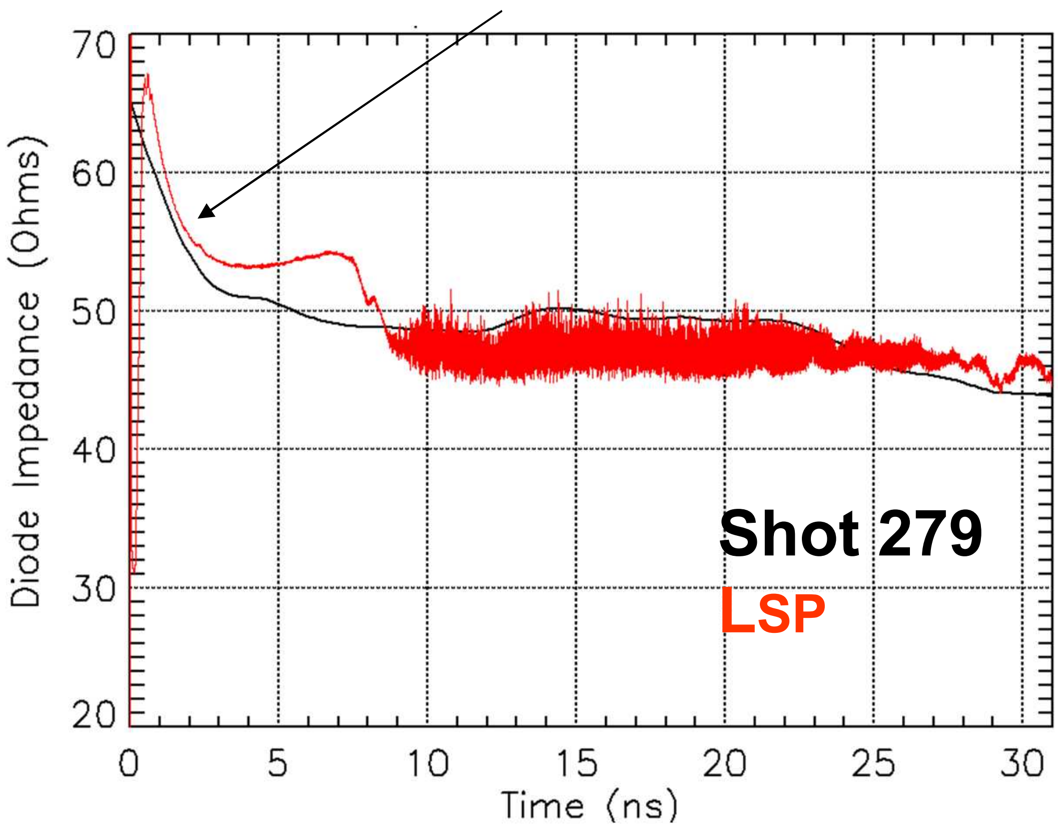
4 kA/cm² plasma flux



Paraxial current density 4 kA/cm²

Simulation of 11-mm AK RITS6 shot 279*

- **Simulation with stimulated plasma emission yield γ_p =100 largely follows impedance behavior of 11-mm shot on RITS6**
- **Time shifted to match initial Z fall**



***RITS6 data courtesy of Sal**

Impedance fall sensitive to γ_p