SAND2015-3750C

A pulsed-power diode design for possible multipulse capability*

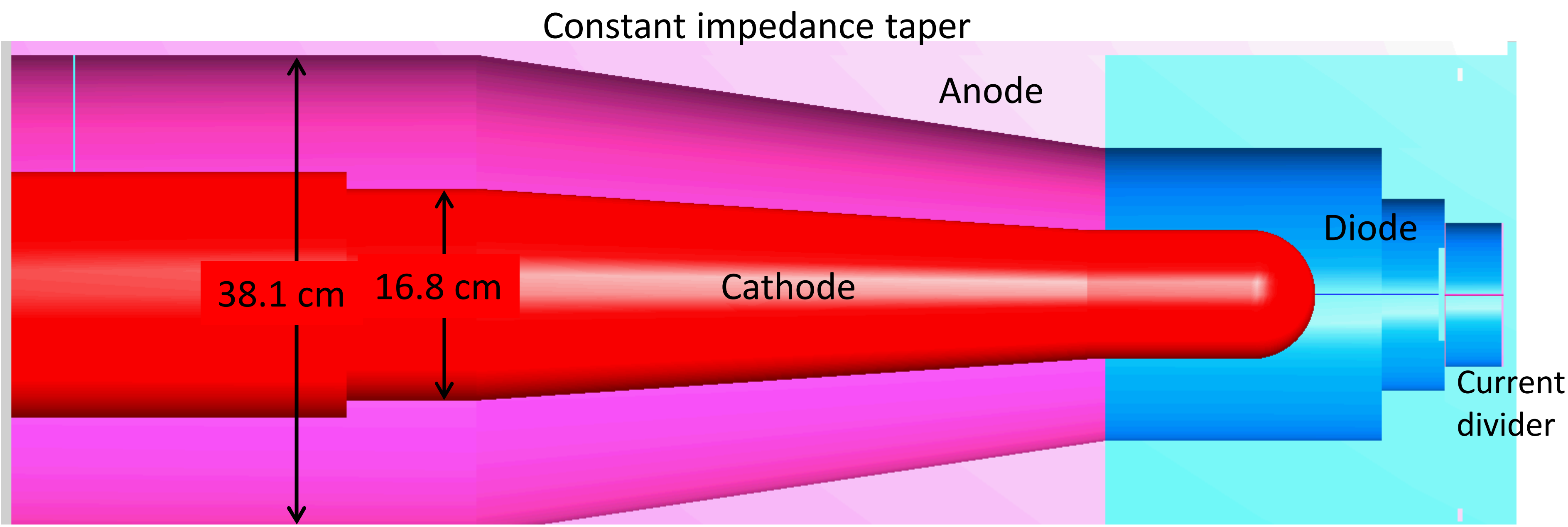
Steve Swanekamp, Steve Richardson, Justin Angus, Ian Rittersdorf, Joe Schumer, Gerry Cooperstein, Dave Hinshelwood, and Bruce Weber

*Work supported by US DOE through Sandia National Laboratories
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

We are exploring advanced radiographic diode designs

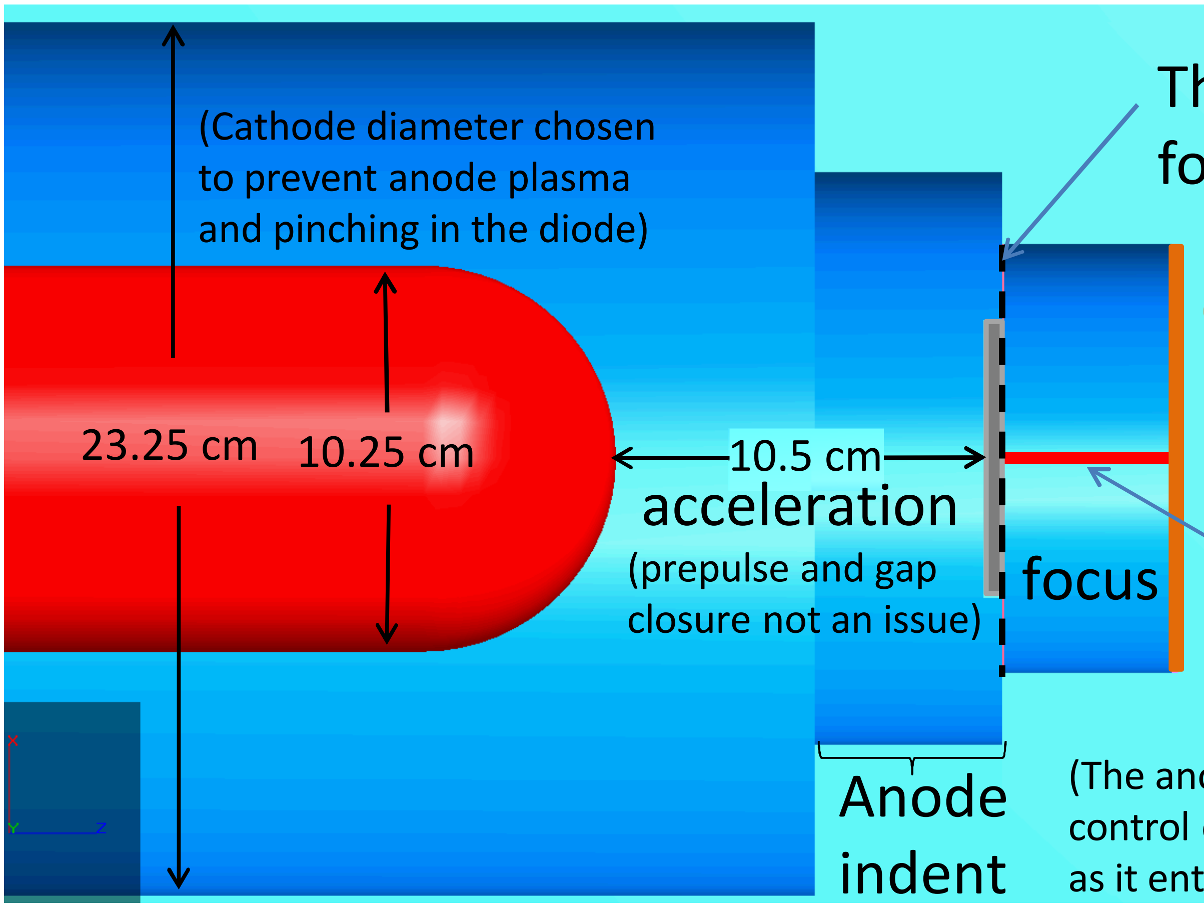
- Idea: Separate the IVA from the focusing geometry
- Simulations show that an inductive current divider offers control over the electron beam exiting an IVA
  - Bonus: A preferred axis-of-symmetry defines the pinch location
  - Bonus: All the IVA current participates in the pinch
  - Bonus: No dustbin or knob reduces the IVA footprint
  - Bonus: It *may* be possible to fire multiple shots on the same line-of-sight

The analysis is performed for the Mercury IVA



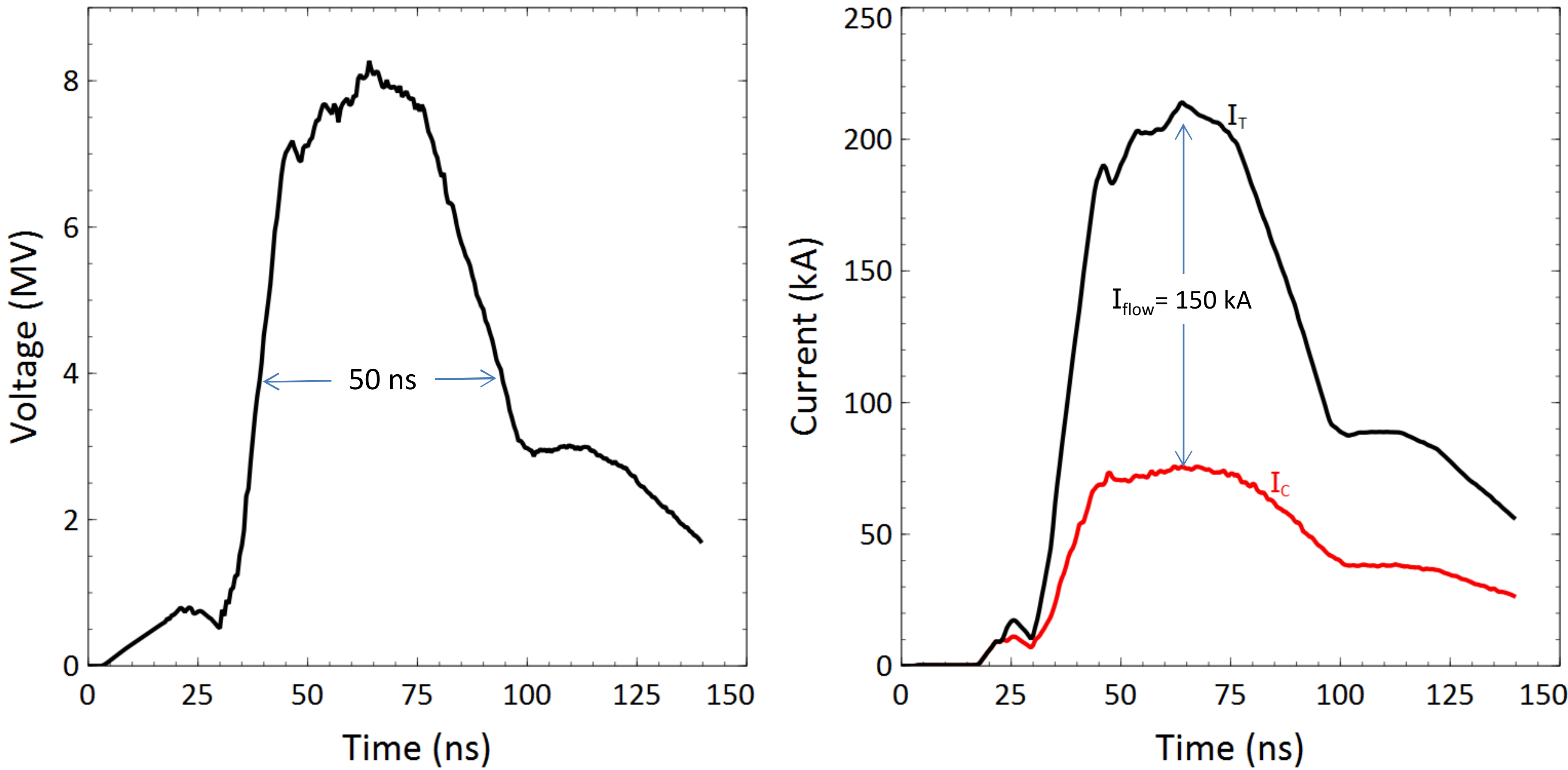
- Z_{vac}=49 Ω
- Z_{SL}=8MV/200 kA = 40 Ω
- No dustbin or knob and as much of the 200 kA current as possible is used

The idea is to extract the beam and focus it after it has been accelerated



*T.W.L. Sanford, J. W. Poukey, T.P. Wright, J. Bailey, C.E. Heath, R. Mock. P.W. Spence, J. Fockler, and H. Kishi, *Impedance of an annular cathode indented-anode electron diode terminating a coaxial magnetically insulated transmission line*, J. Appl. Phys. **63**, 681 (1988).

These are the voltage and current waveforms used in Mercury simulations



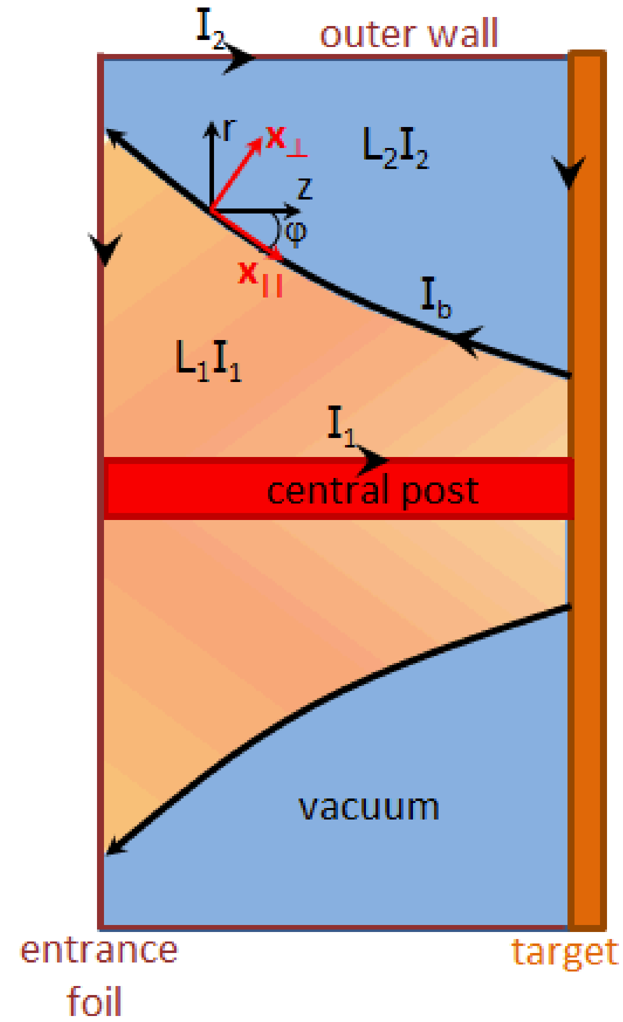
The focusing section is an inductive current divider

- Magnetic flux must remain zero at all times inside the current divider (flux is conserved)

$$L_1 I_1 = L_2 I_2$$

$$I_1 = \frac{L_2}{L_1 + L_2} I_b$$

- The boundary currents I_1 and I_2 can be changed by adjusting the inductance in the return current path



A beam envelope equation applicable to a hollow cylindrical beam

- The leading term for the average orbit is proportional to $(I_2 - I_1)/r_0$

$$\frac{dr_0}{ds} = \sin(\theta), \frac{dz_0}{ds} = \cos(\theta)$$

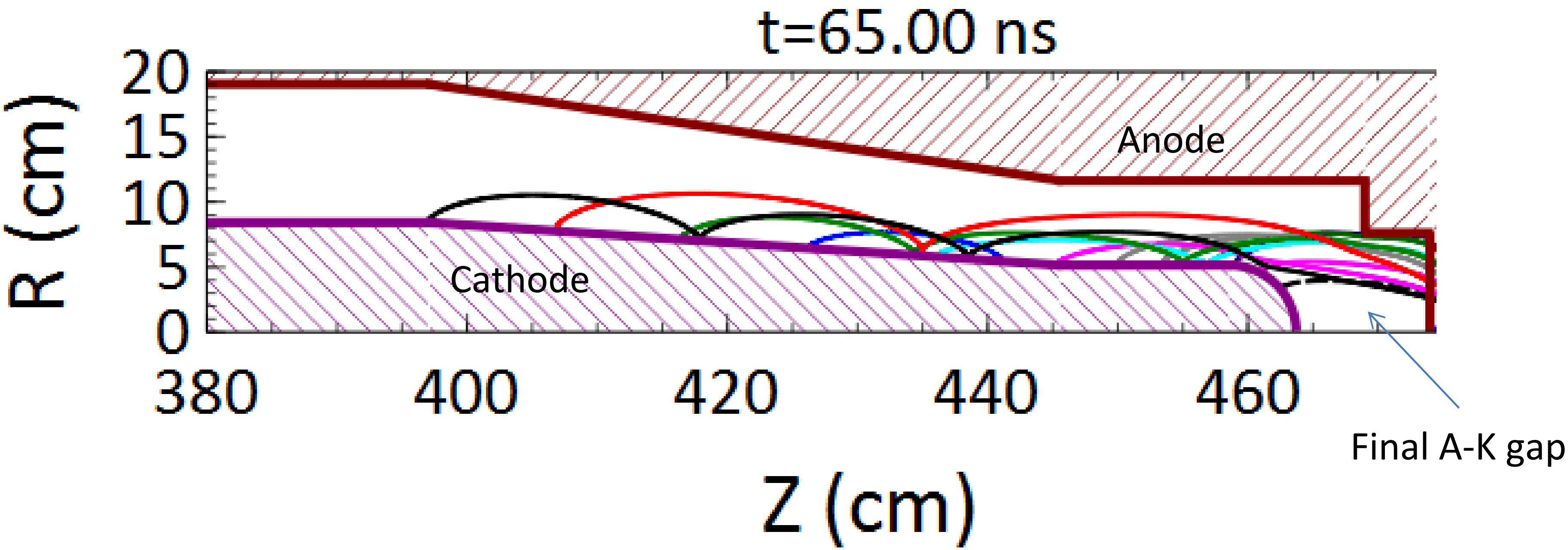
$$\frac{d\theta}{ds} = \frac{\langle F_\perp \rangle}{\gamma_0 mc^2 \beta_0^2} \cong -\frac{(f_i - 1/\gamma_0^2)}{\gamma_0 \beta^3 I_A}\left[\frac{(I_2 - I_1)}{r_0} - \frac{X_b \cos(\theta_0)}{\sqrt{3} r_0^2} I_b\right]$$

- The leading term for the RMS envelope is proportional to I_b

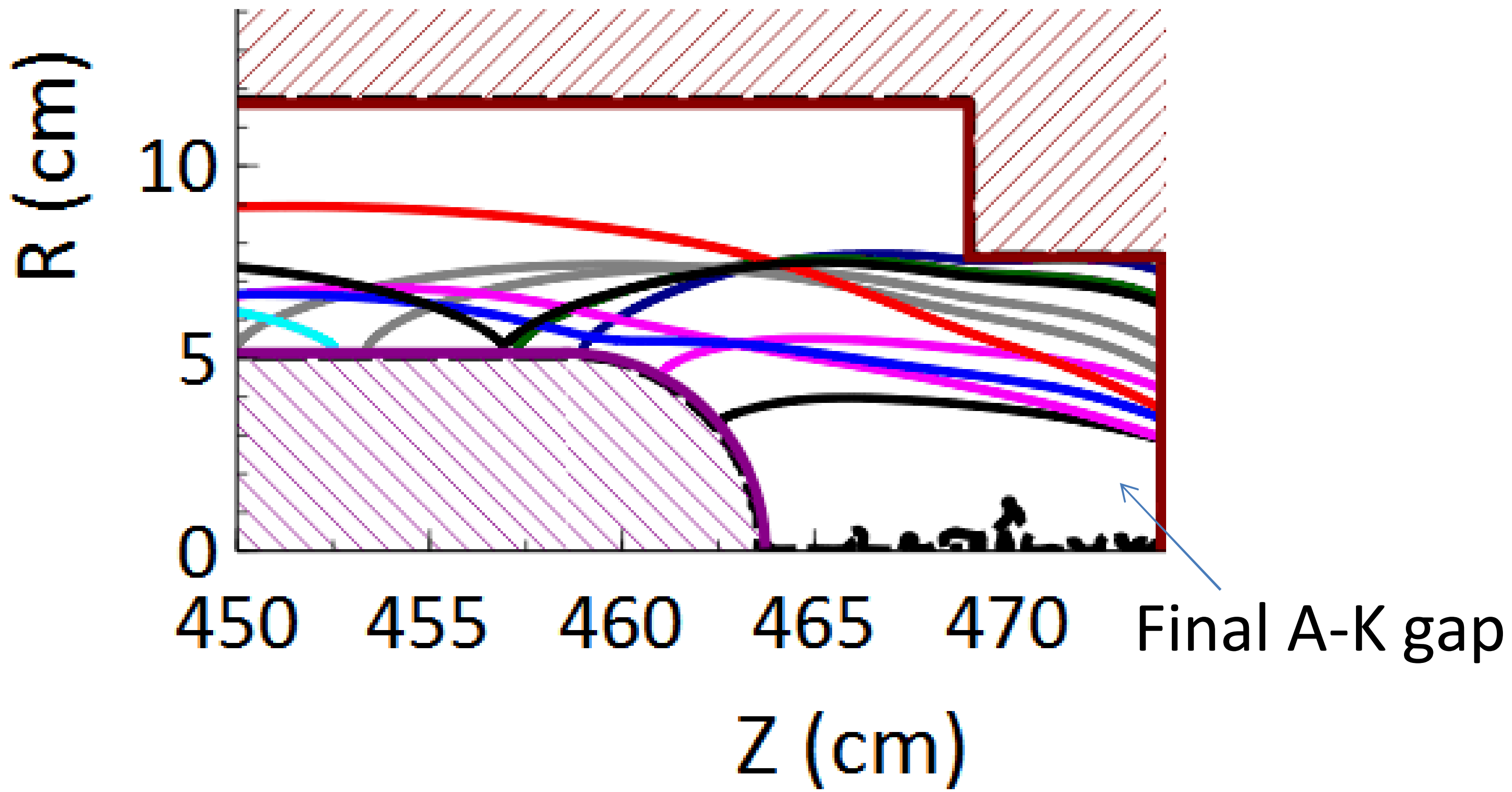
$$\frac{d^2 X_b}{ds^2} + \frac{U}{X_b} = \frac{\varepsilon^2}{X_b^3}$$

$$U \equiv \frac{\langle x_\perp F_\perp \rangle}{\gamma_0 mc^2 \beta_0^2} \cong (f_i - 1/\gamma_0^2)\frac{I_b}{\gamma_0 \beta^3 I_A}\left[\frac{X_b}{\sqrt{3} r_0}\left(1 - \frac{\sqrt{3} X_b \cos(\theta_0)}{r_0}\frac{(I_2 - I_1)}{I_b}\right)\right]$$

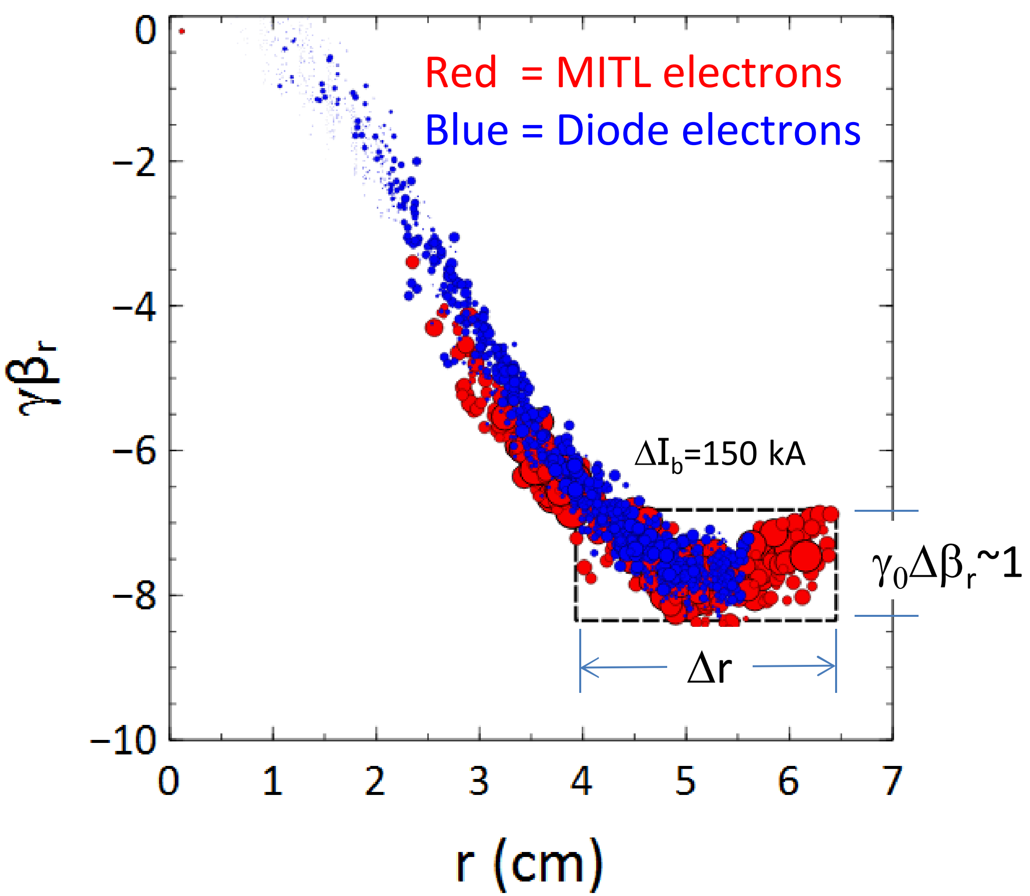
LSP simulations indicate that the emittance decreases as the electrons are accelerated across the final A-K gap



LSP simulations indicate that the emittance decreases as the electrons are accelerated across the final A-K gap



The beam emittance can be estimated from the transverse phasespace



- About 150 kA flows between r=4 cm and r=6 cm
- The transverse (unnormalized) emittance of the beam can be estimated from the phasespace

$$\varepsilon^2 = \langle\Delta r^2\rangle (kT_\perp/\gamma_0 mc^2)$$

- The average $\langle\Delta r^2\rangle$ ~ 1.0 cm^2
- The average transverse temperature (γ_0=16)

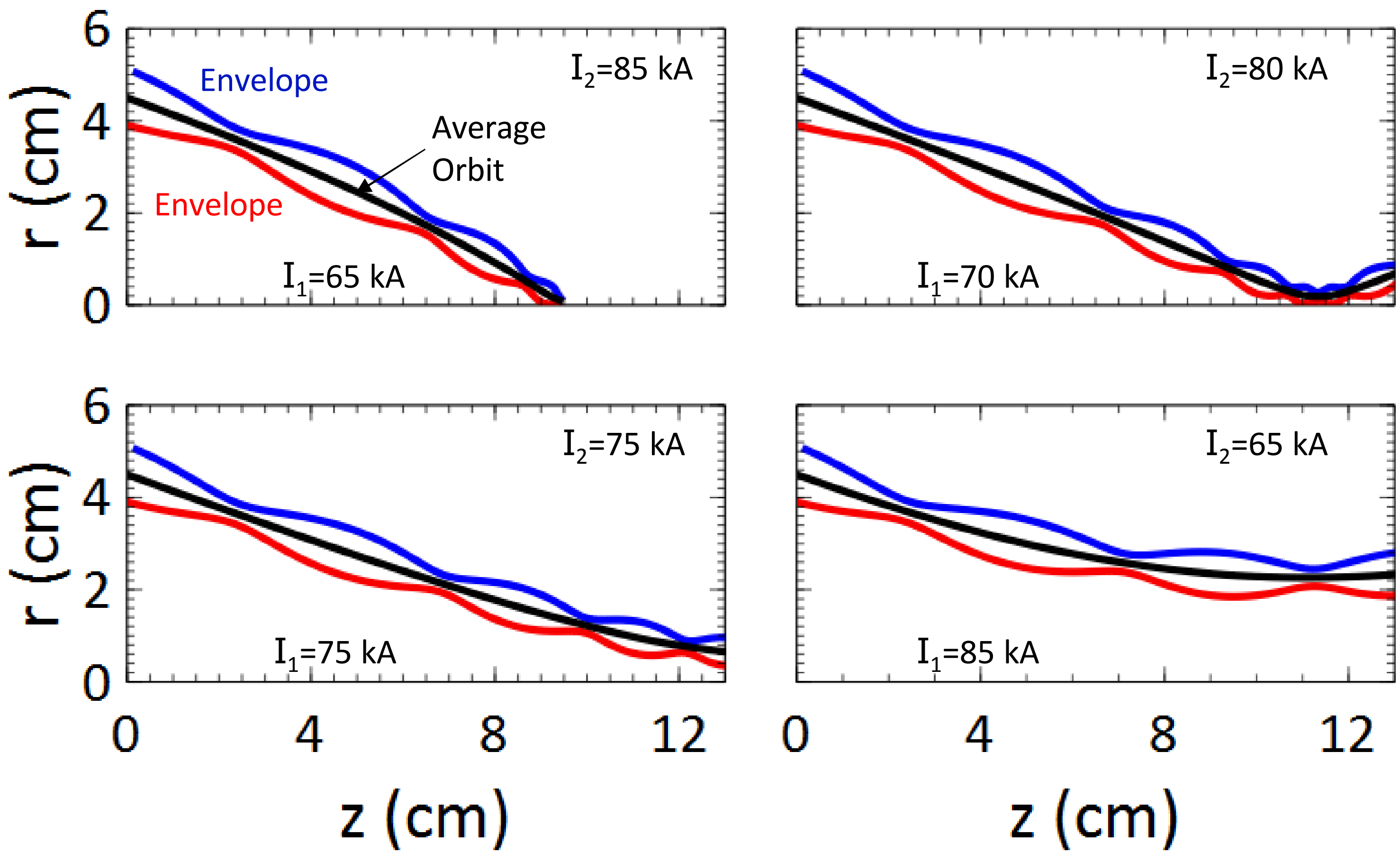
  $\Delta(\gamma_0\beta_r)$ ~1.0 ➔ $\Delta(V_\perp/c)=1.0/\gamma_0$

  $kT_\perp = 1/2\, mc^2 \langle\Delta(V_\perp/c)^2\rangle$~ 1 keV

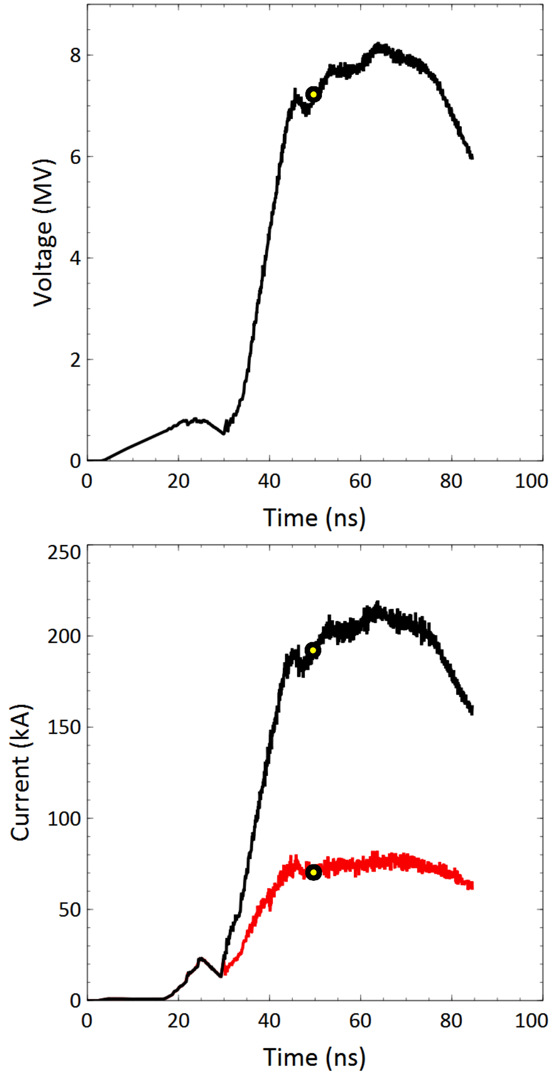
- $\varepsilon = 1.1\times10^{-2}$ cm-rad

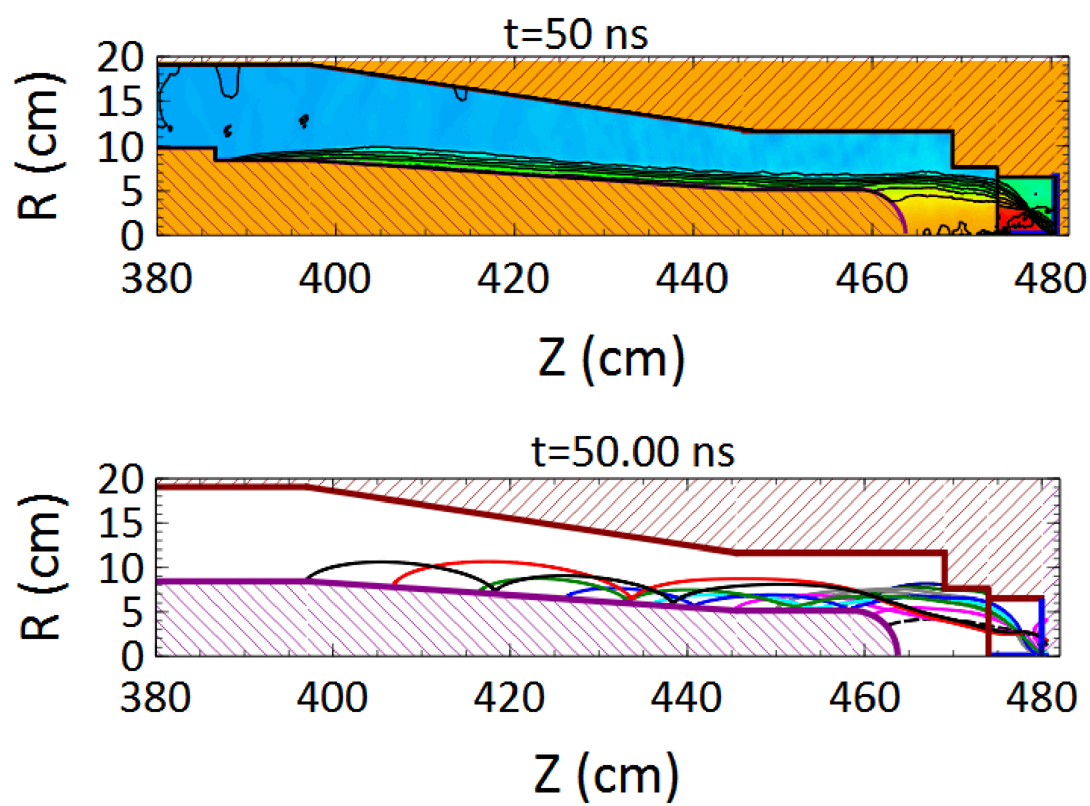
The envelope analysis shows that it is possible to focus the beam from an IVA

I_b=150 kA, ε=200 mm-mrad
f_i=1.0, width ~ 2.0 cm

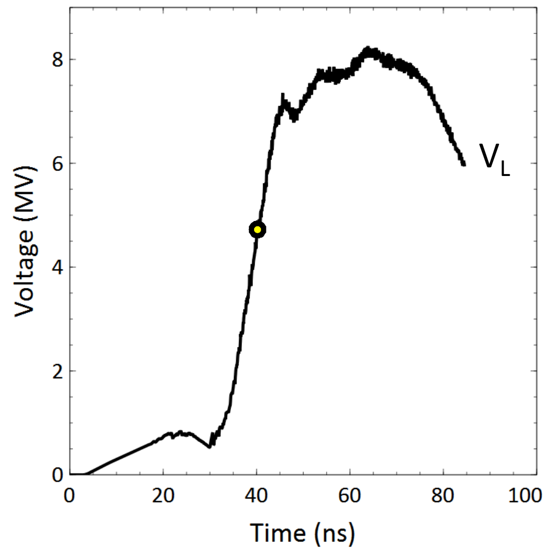


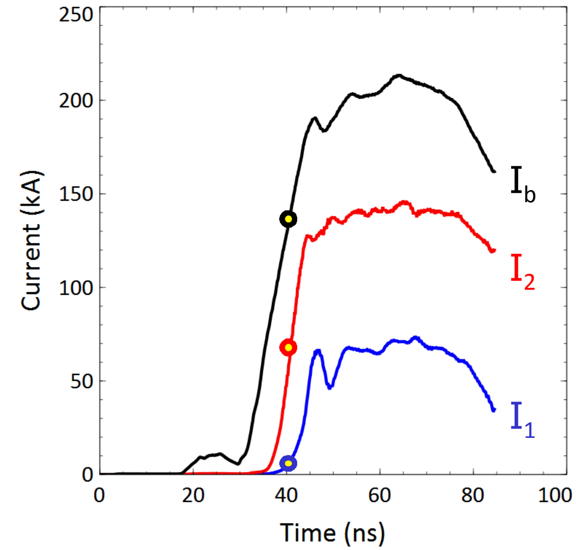
MITL voltage, currents, and particle trajectories for a Mercury-like simulation with 2-mm diameter rod

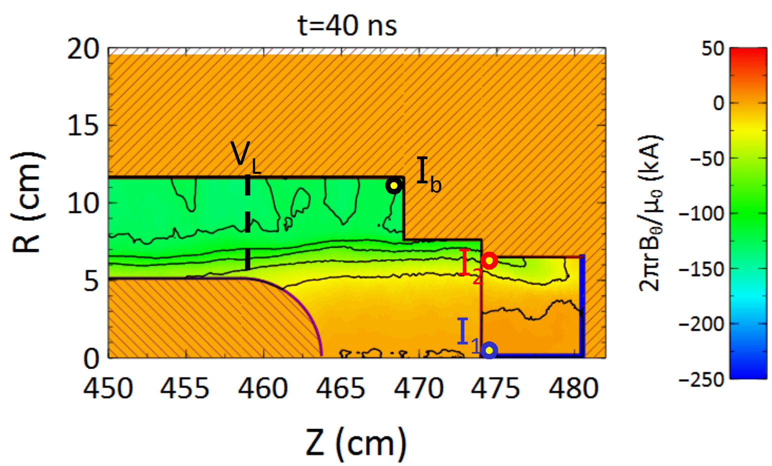


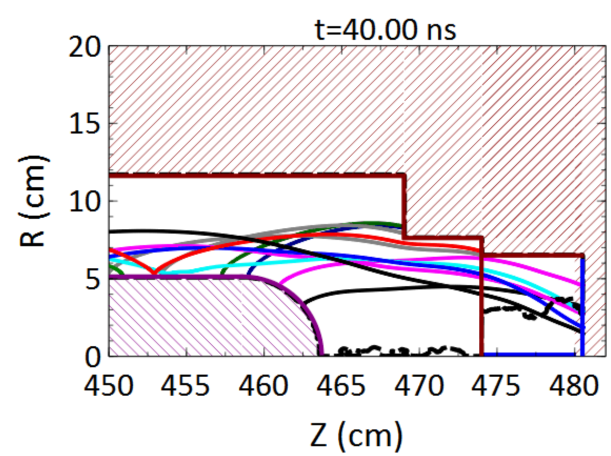


MITL voltage, currents, and particle trajectories for a Mercury-like simulation with 2-mm diameter rod

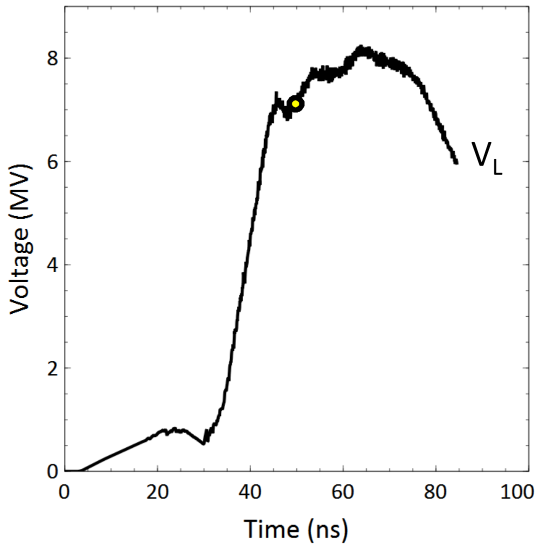


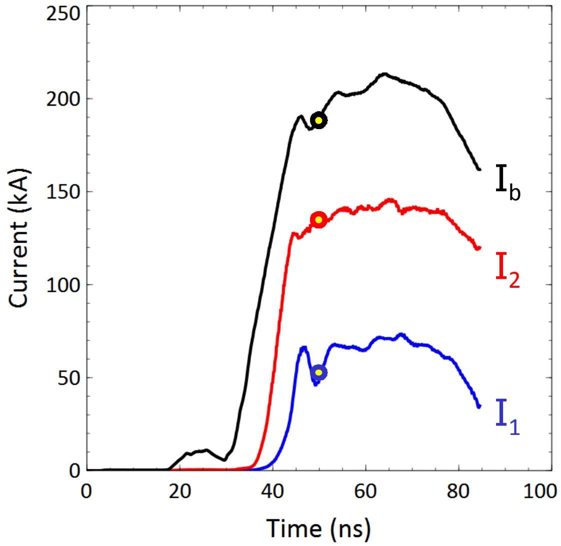


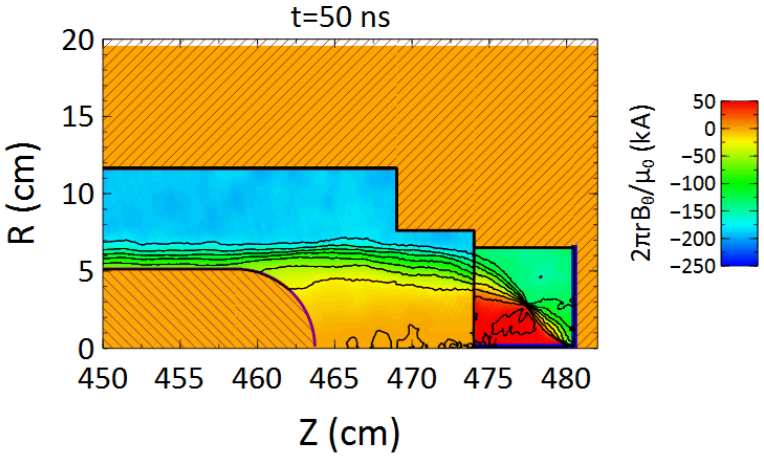


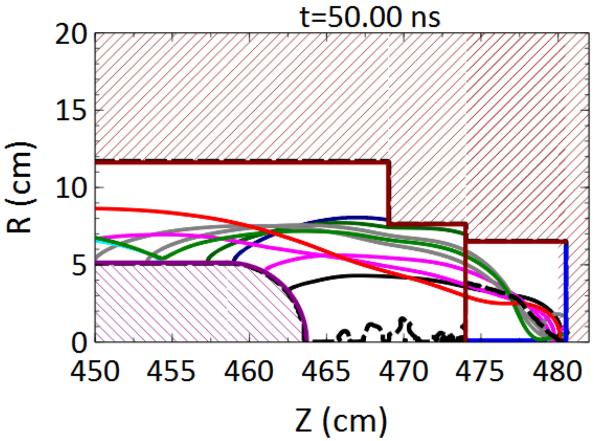


MITL voltage, currents, and particle trajectories for a Mercury-like simulation with 2-mm diameter rod

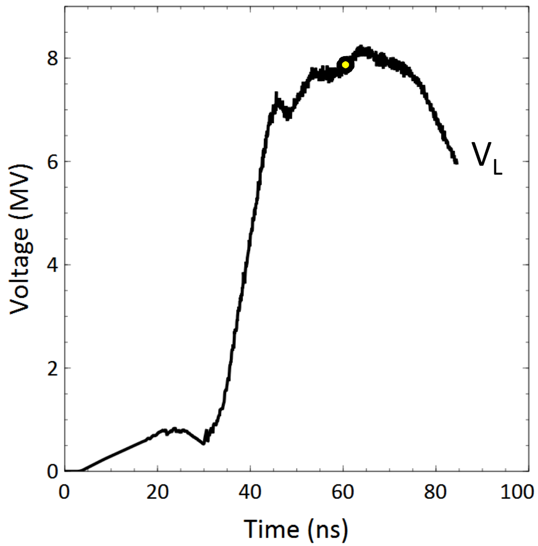


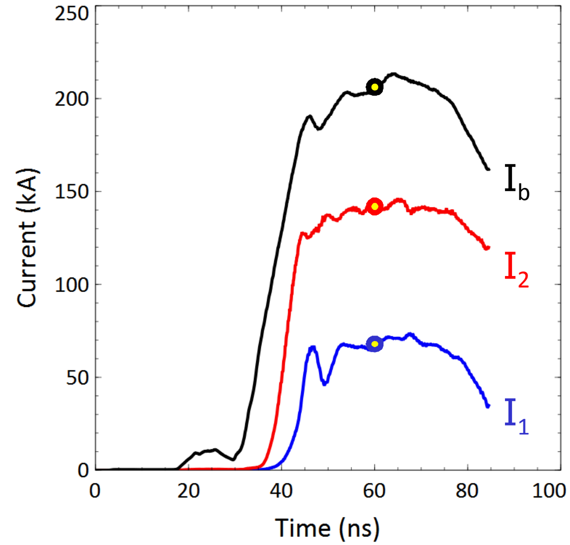


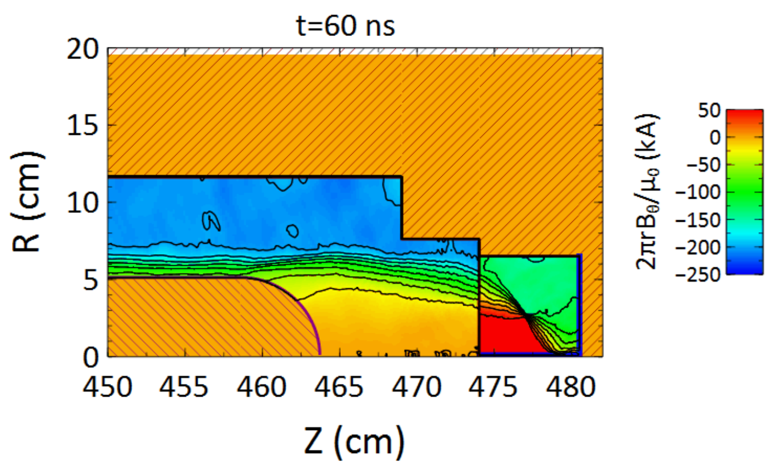


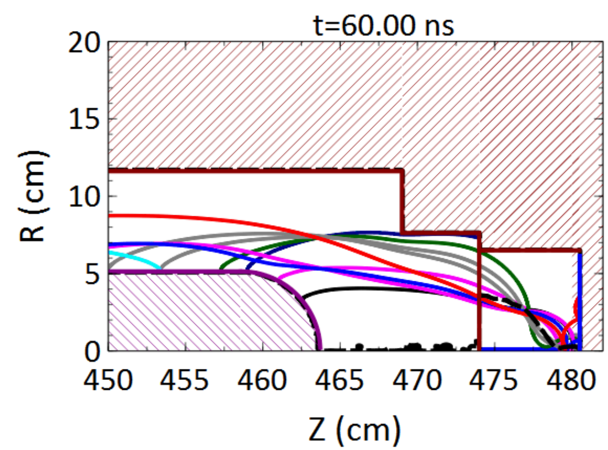


MITL voltage, currents, and particle trajectories for a Mercury-like simulation with 2-mm diameter rod

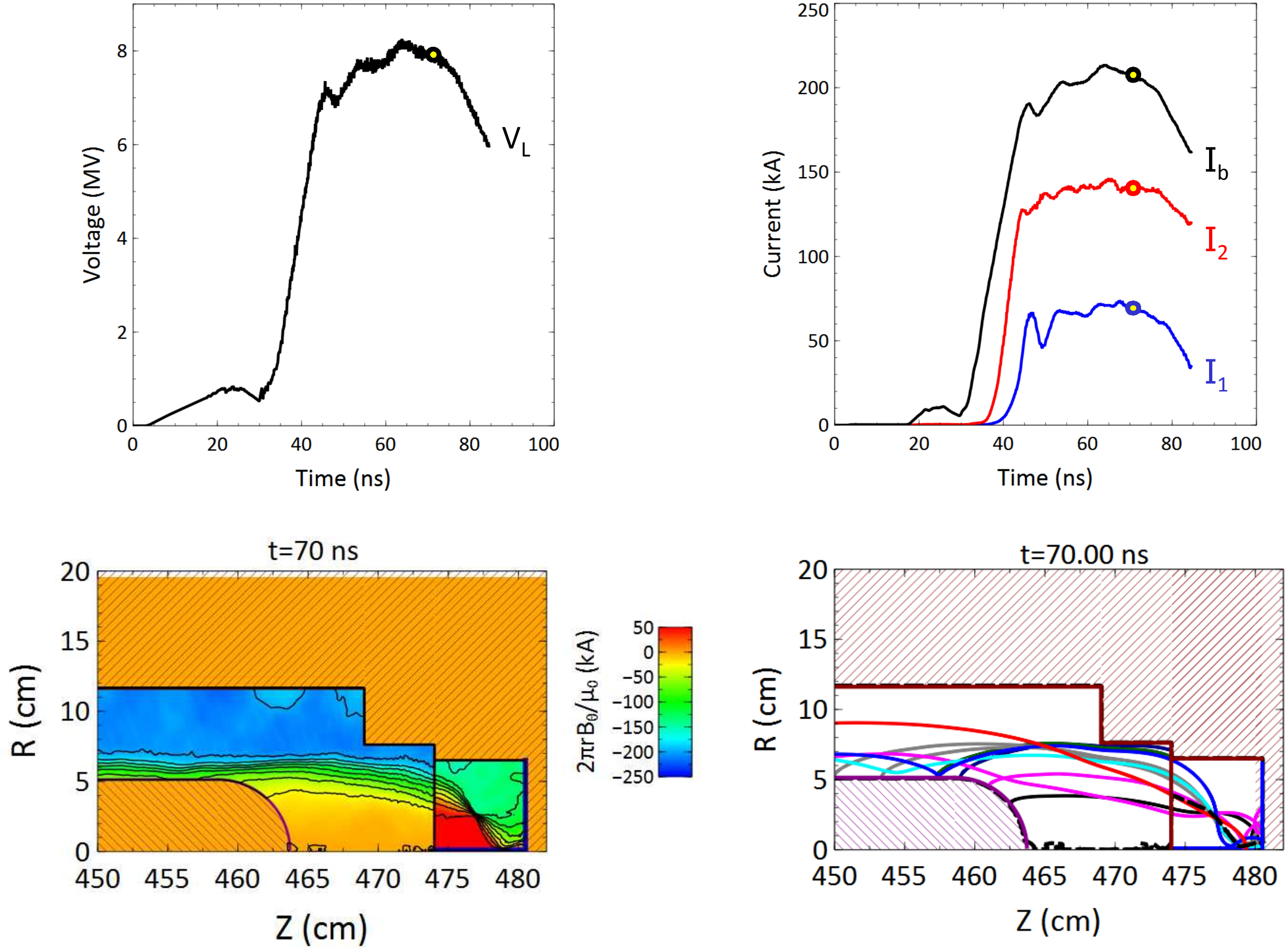




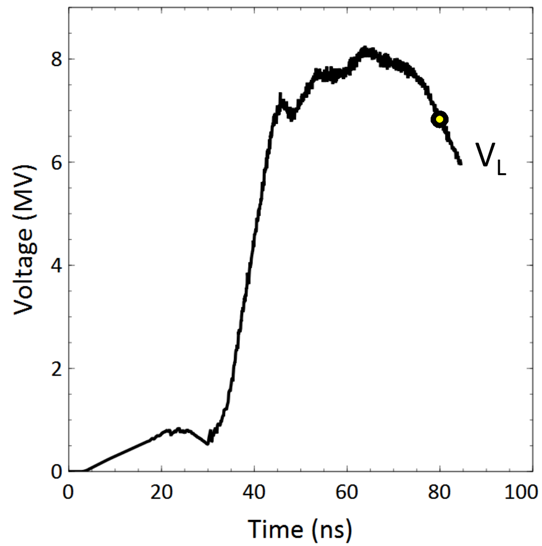


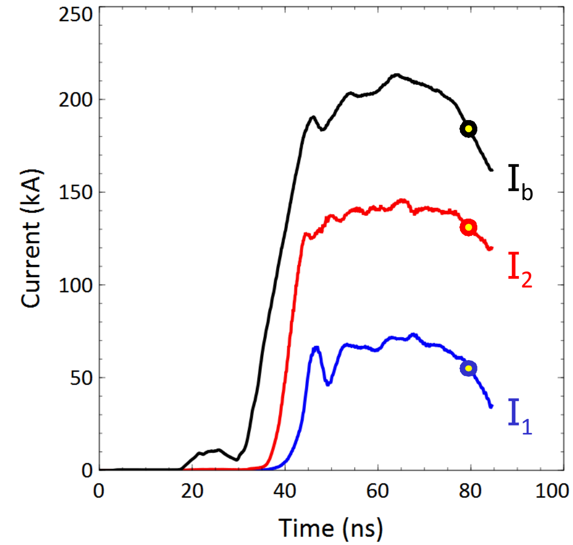


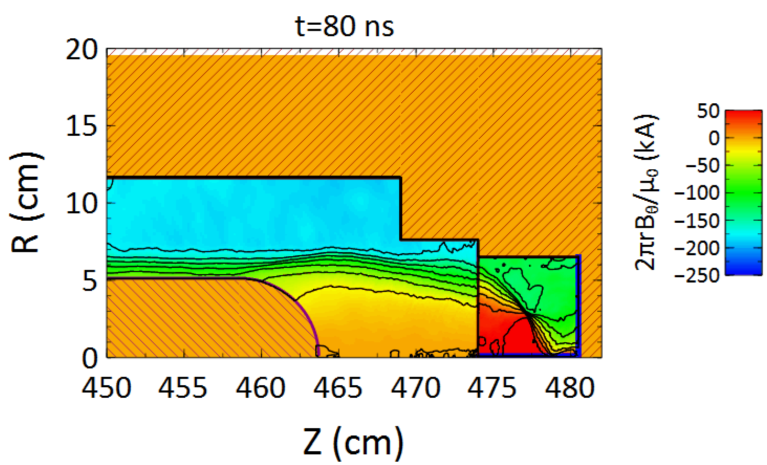
MITL voltage, currents, and particle trajectories for a Mercury-like simulation with 2-mm diameter rod

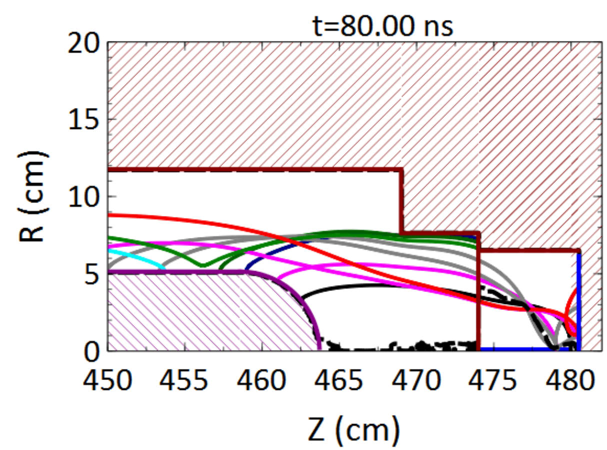


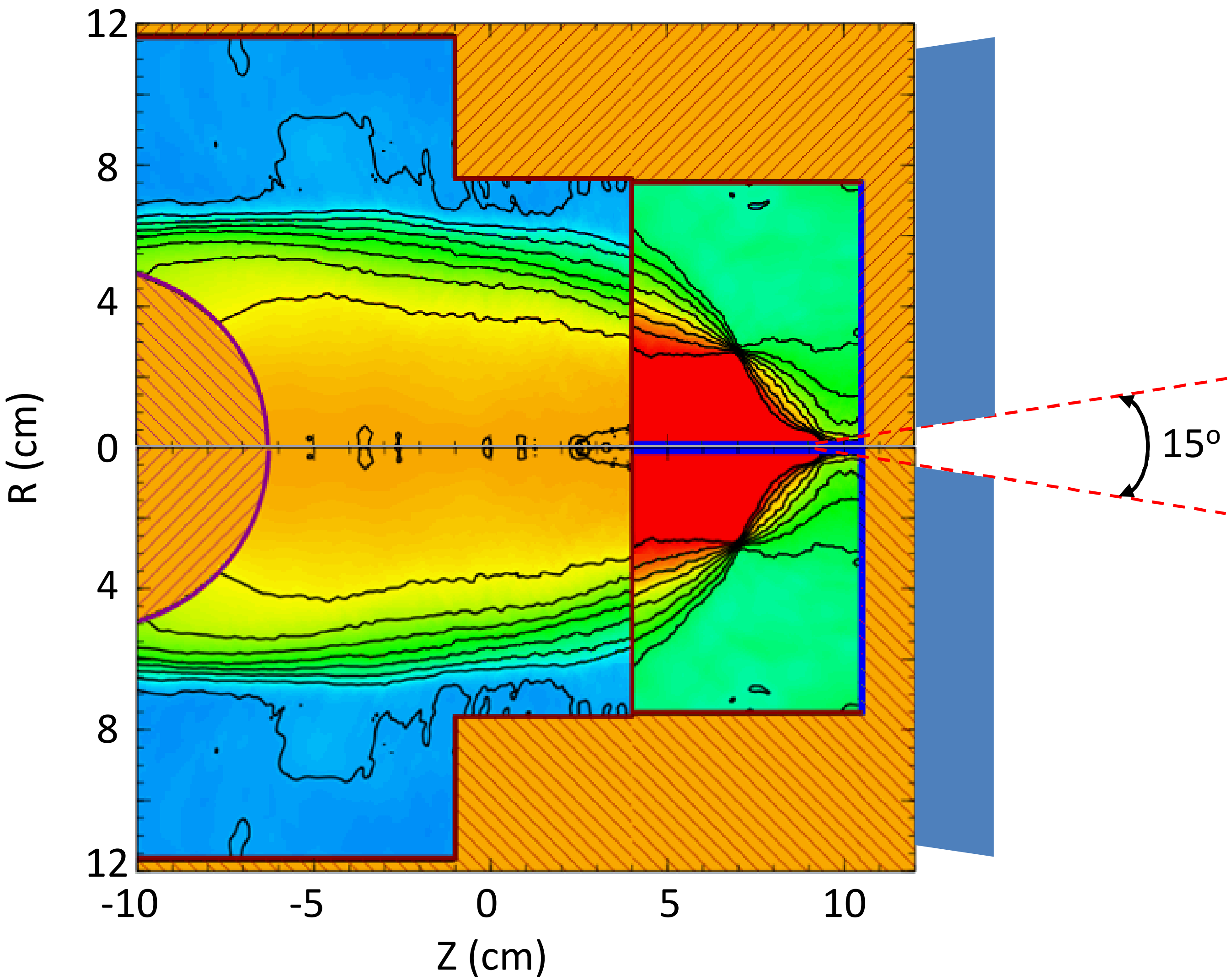
MITL voltage, currents, and particle trajectories for a Mercury-like simulation with 2-mm diameter rod









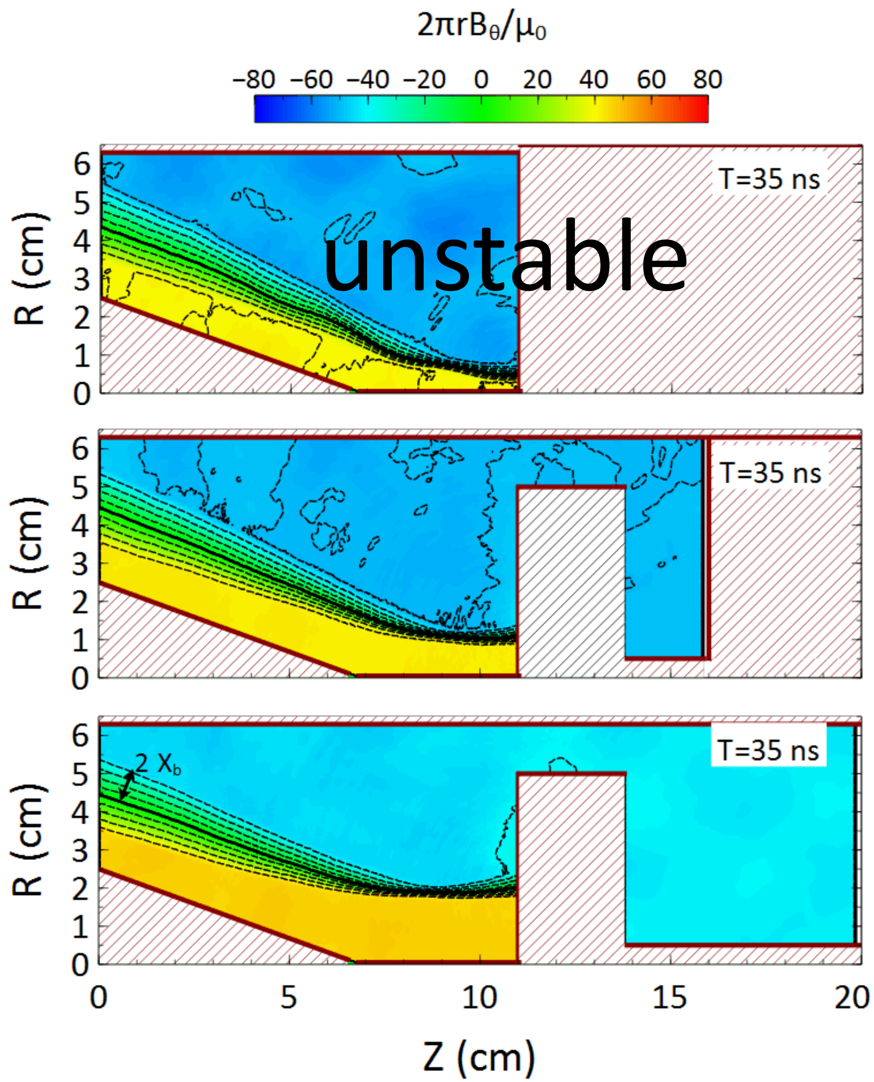

12
8
4
0
4
8
12
R (cm)
-10
-5
0
5
10
Z (cm)
15o

Conclusion

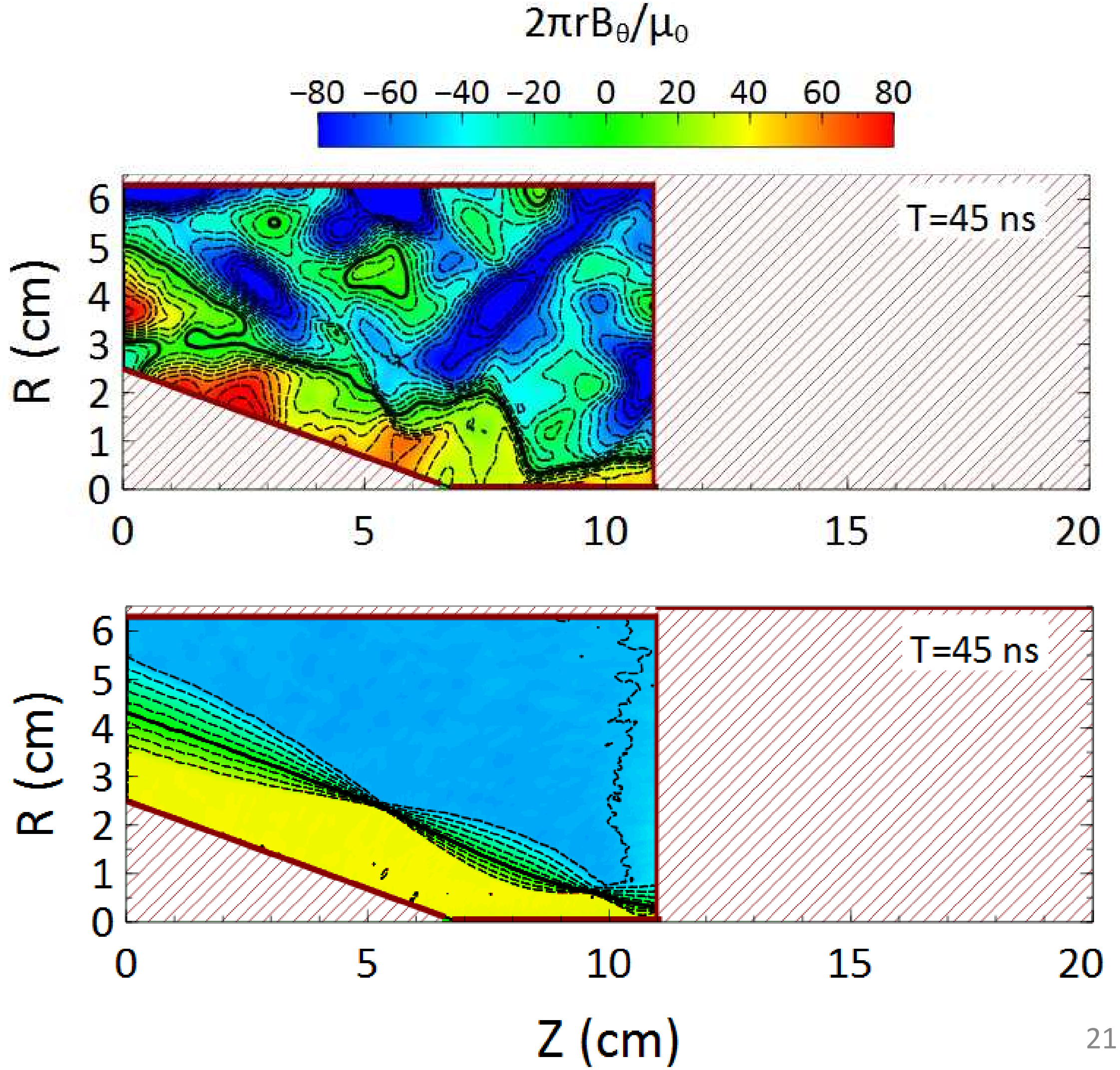
- Simulations show that changing the return-current inductance can focus the electron beam exiting an IVA
  - Bonus: A preferred axis-of-symmetry defines the pinch location (3D simulations planned)
  - Bonus: All the IVA current participates in the pinch
  - Bonus: No dustbin or knob reduces the IVA footprint
  - Bonus: It *may* be possible to fire multiple shots on the same line-of-sight
- More experimental and computational research is required to see if this idea has merit

Changing the inductance in the return current offers control over the beam

LSP simulations
Electrons only



Changing the inductance in the return current offers control over the beam



LSP simulations
electrons only

Unstable ☹
due to interaction of beam with strong E_r near rod

LSP simulations
with ion emission
from converter

Stable ☺
The presence of positive space-charge stabilizes the beam