SAND2011-4060C

Sandia National Laboratories

Inverse Diode for Combination of Multiple Modules and Fusion Driver-Target Standoff

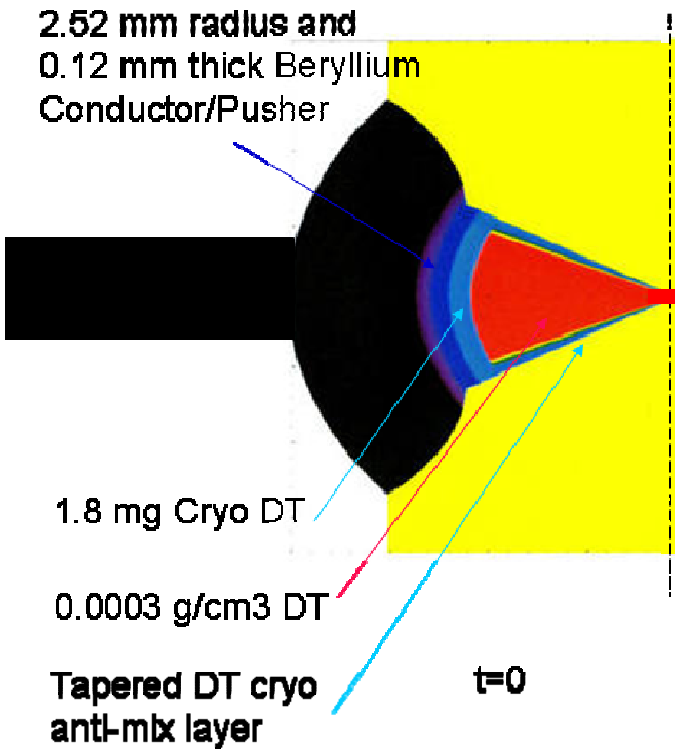
J. P. VanDevender[1,2],
D. B. Seidel[2], K. A. Mikkelson[2] , R. D. Thomas[2],
V. J. Harper-Slaboszewicz[2], L. X. Schneider[2], and B. P. Peyton[3]

[1]VanDevender Enterprises, [2]Sandia National Laboratories, [3]Ktech Corp.

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

Sandia National Laboratories

Quasi Spherical Direct Drive capsule offers 500 MJ yields with 85 MJ energy store and 45 MA at 1.6x10^{15} A/s.



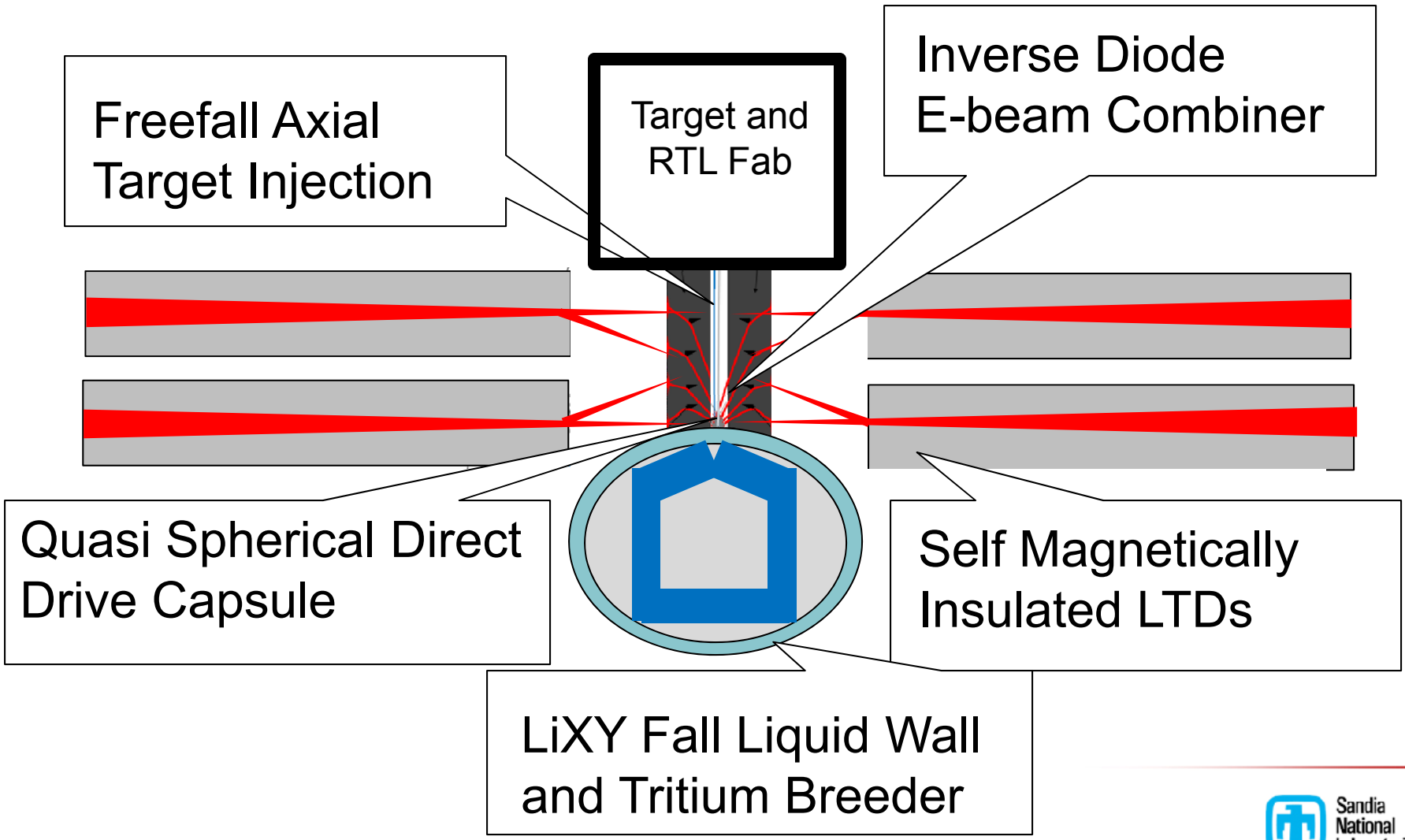
Many issues are mitigated with a higher dI/dt.

- **Uniform Initiation**
- **Less growth of Magnetic Rayleigh Taylor instability**
- **Lower driver energy**
- **Higher ηG**
- **Lower Cost of Electricity**

45 MA at 1.6x10^{15} A/s requires invention.

Sandia National Laboratories

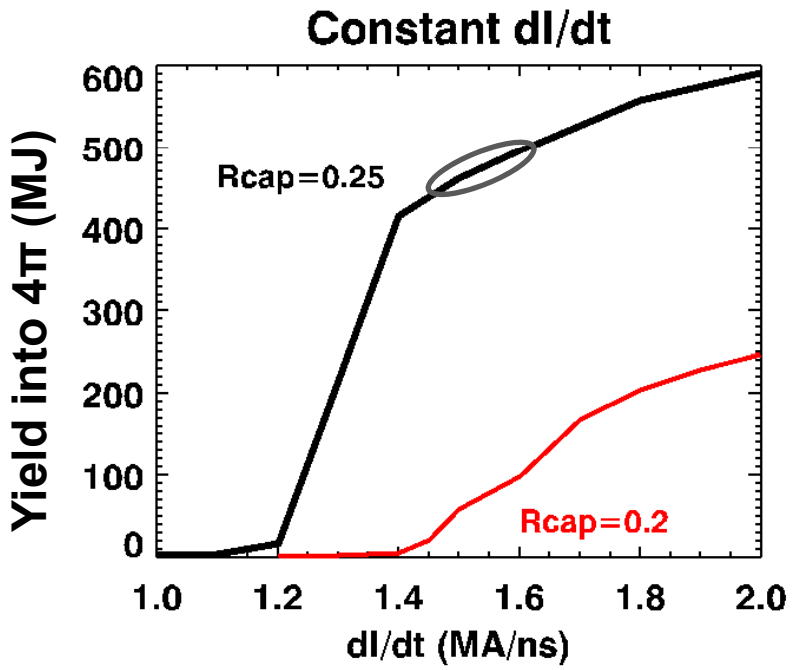
45 MA Inverse Diode couples fusion capsule to driver in Plasma Power Station (PPS).

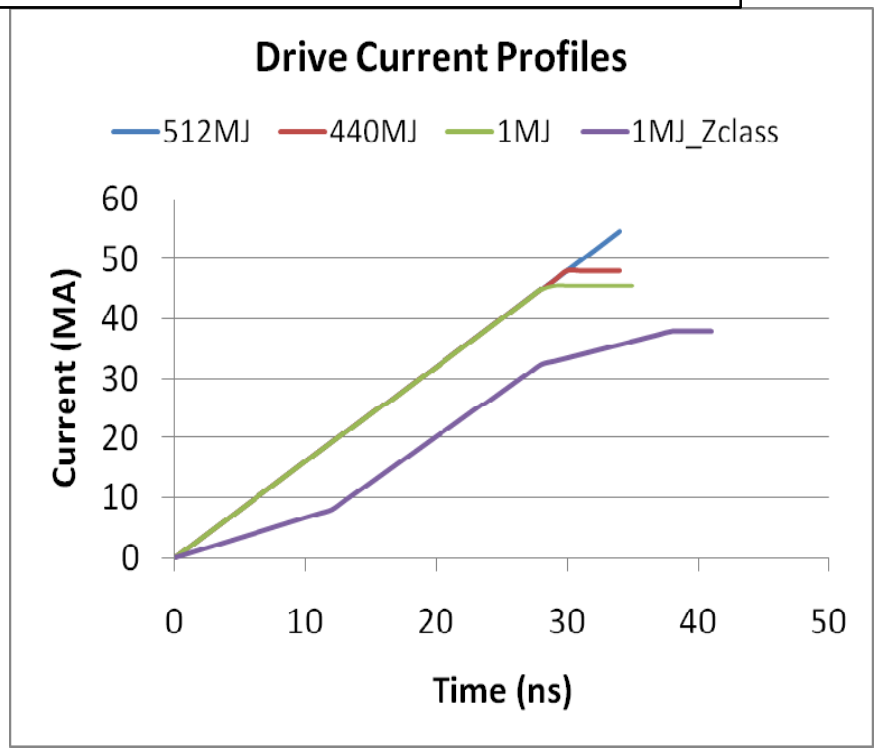


Sandia National Laboratories

Projected drive current is ~ 38 MA for ignition on Z-class driver and ~48 MA for high-gain on PPS.

Magnetic Rayleigh-Taylor instability
allows initial aspect ratio of $R_o/\delta = 21$.

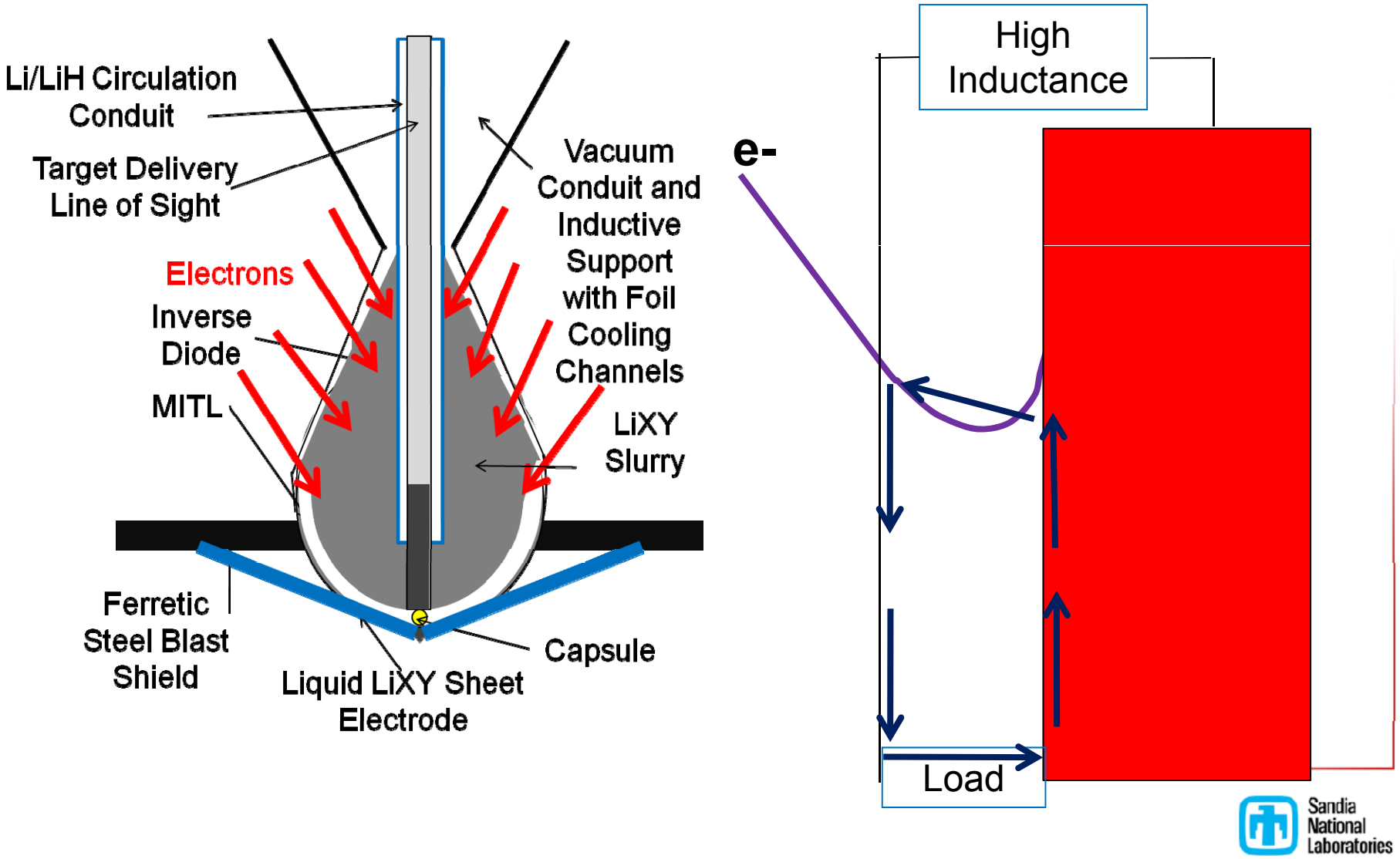




Producing $dI/dt = 1.5 \times 10^{15}$ A/s in a 2.5 mm radius capsule requires a new technology.

Sandia National Laboratories

Inverse Diode turns electron beam current into Magnetically Insulated Transmission Line Current.



The Inverse Diode uses electrostatic insulation to prevent electron losses in low B-field regions.

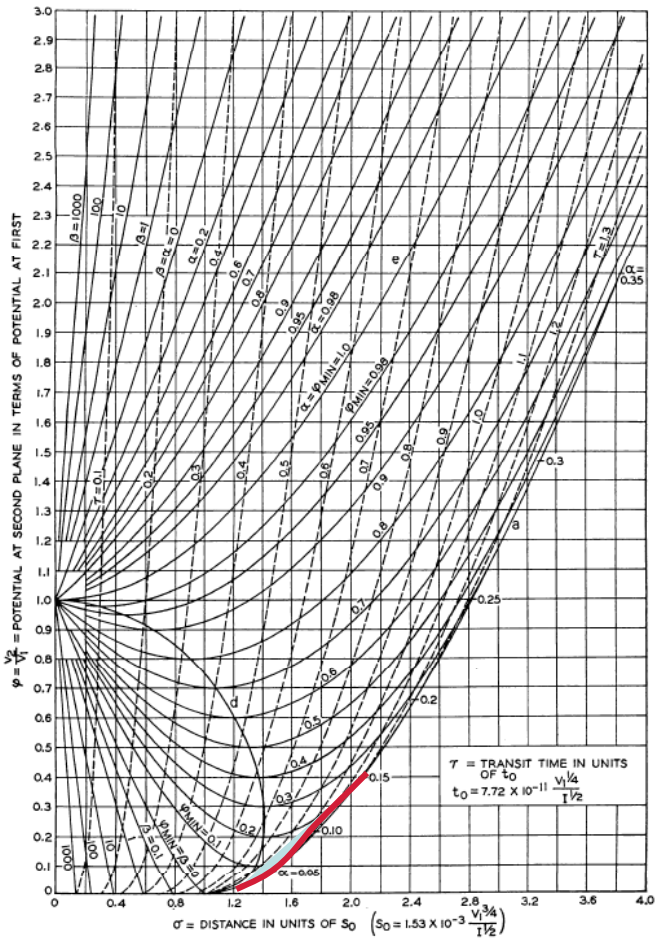


Fig. 3—Potential distributions of the C and D types. The solid lines are potential curves, the broken lines indicate the transit times.

On the Theory of Space Charge between Parallel Electrodes by C.E. Fay, A. LO. Samuel, and W. Shockley, Bell Systems Technical Journal, 17, Issue 1, pp 49-79 (1938) Table 3

- Let d_scl = space_charge-limited gap and
  d_max= the maximum inverse diode gap (near the axis).

- For electrostatic insulation:
  1.2 d_scl < d_max < 2.1 d_scl

With relativistic correction:

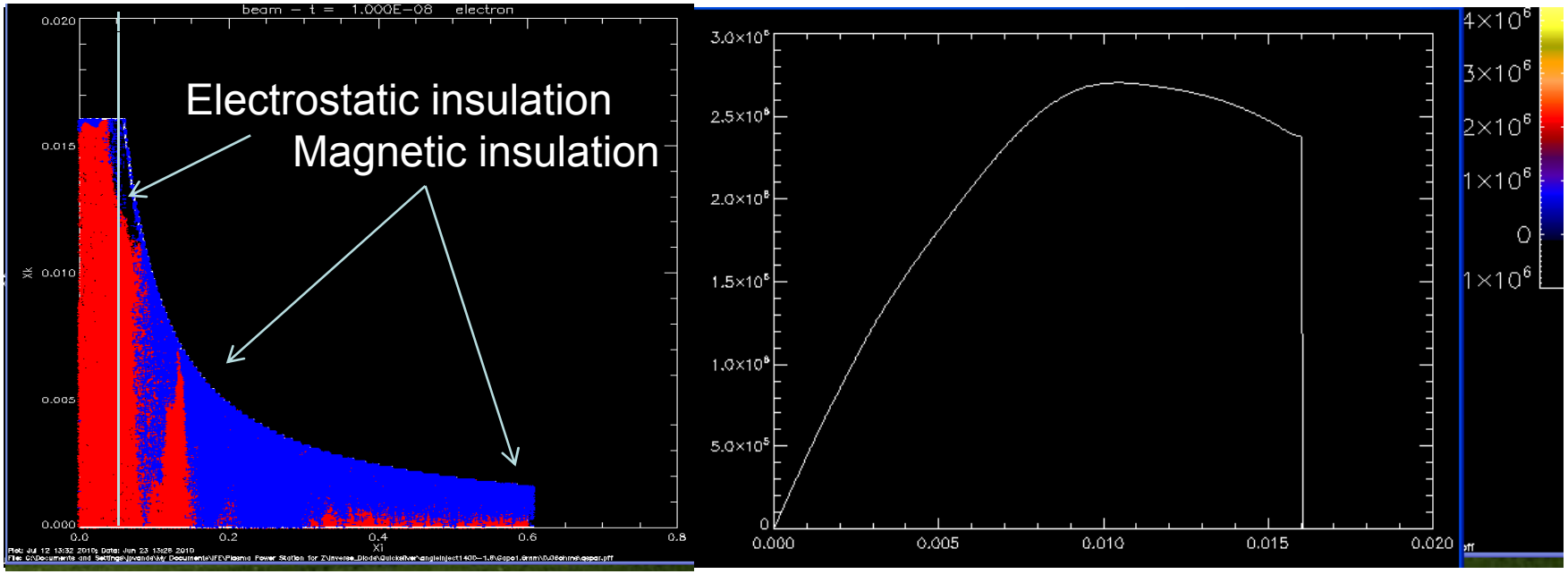
$$d\_scl = \sqrt{\left[(11.3/V^{0.187})*(2.32E\text{-}6*V^{1.5}/J)\right]}$$

Sandia National Laboratories

Space charge distribution prevents secondary electrons from neutralizing injected current.

Red: Injected electrons
Blue: Electrons emitted from cathode

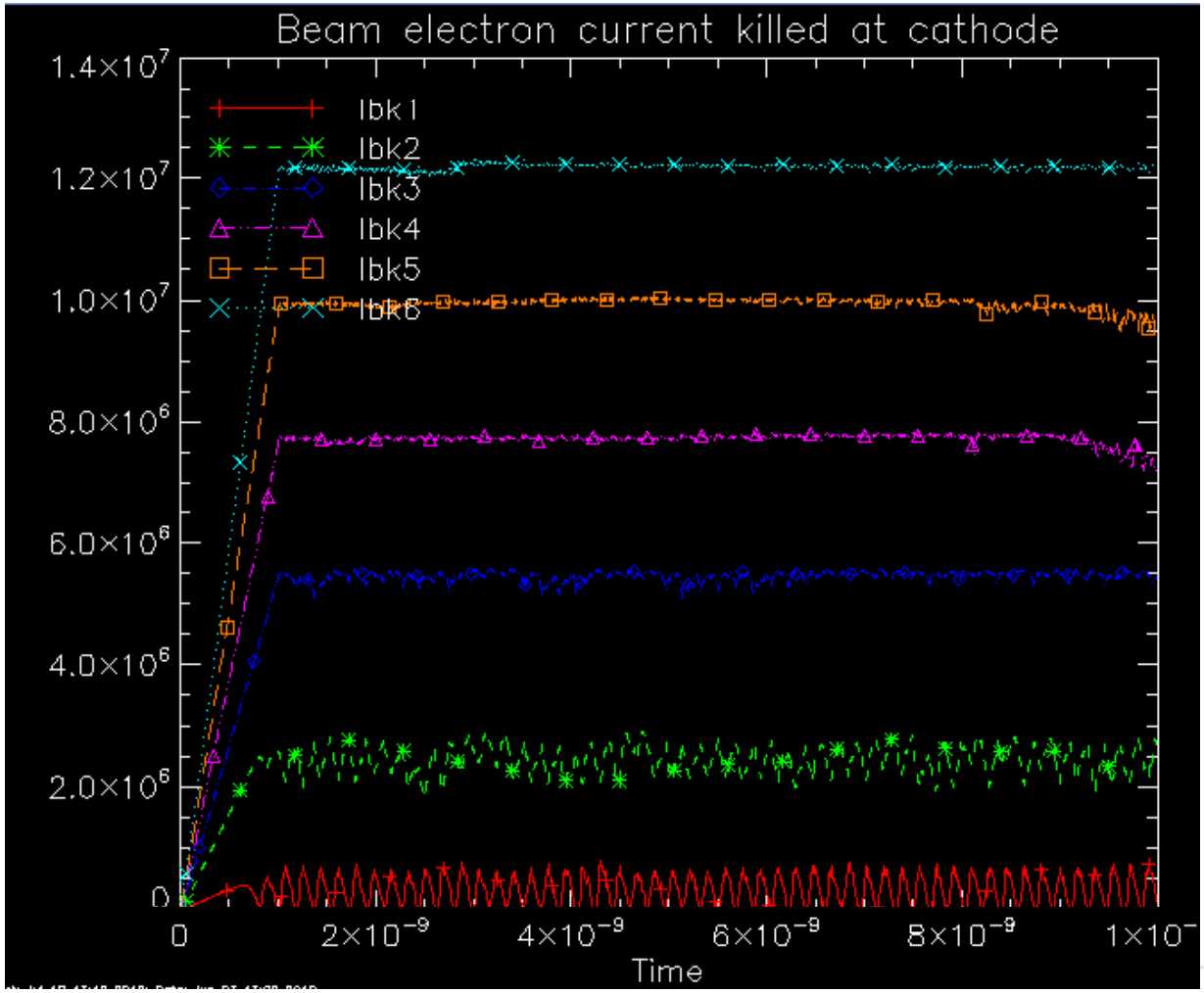
Potential distribution across AK gap at r=0.05 m shows E-field reversal at cathode.



40 MA at 4 MeV injected and 33 MA at 2 MV at load without optimization

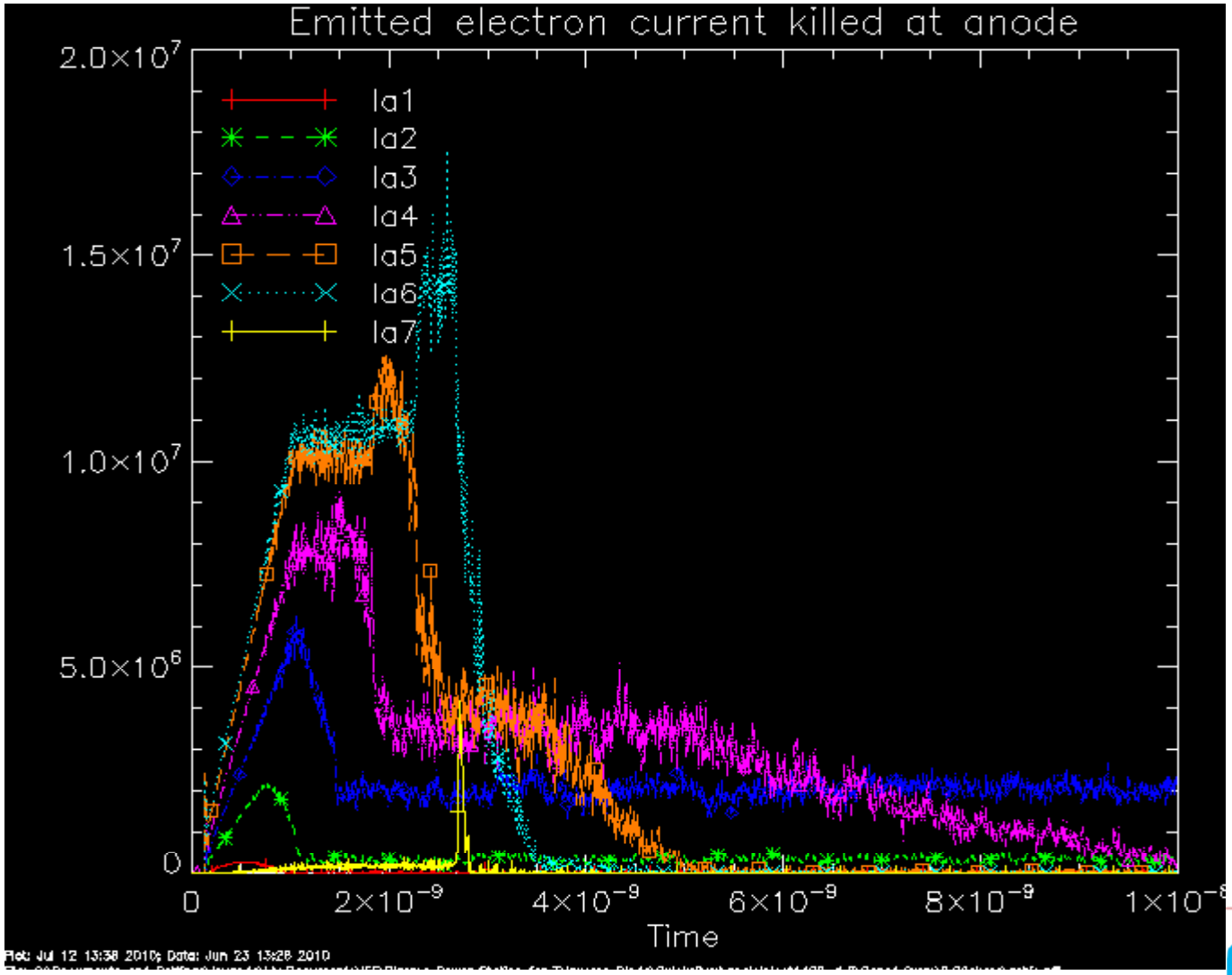
Sandia National Laboratories

Beam electron current captured at cathode shows well behaved flow and high efficiency.



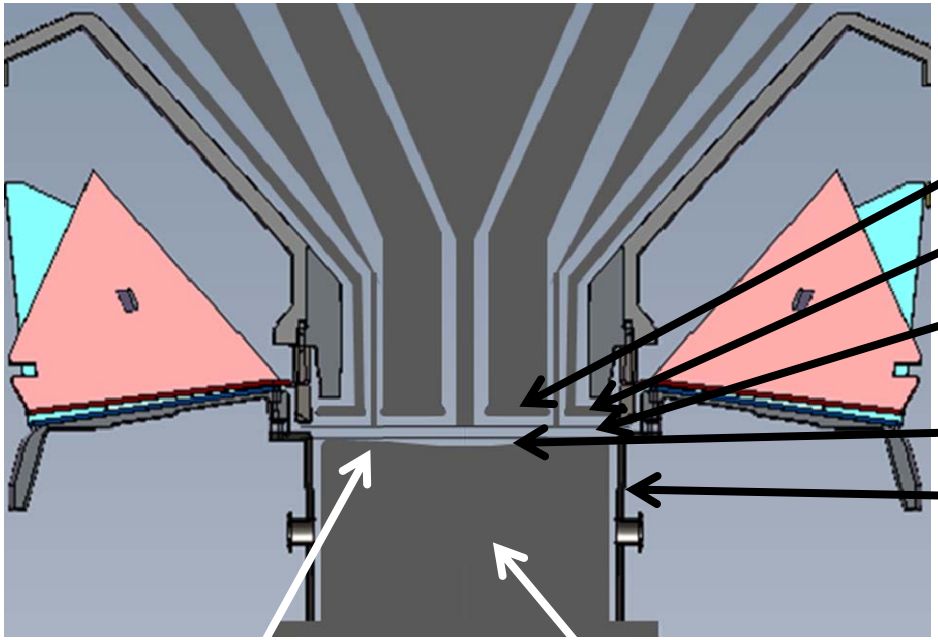
Sandia National Laboratories

Emitted electron loss in transition region is 3 MA.

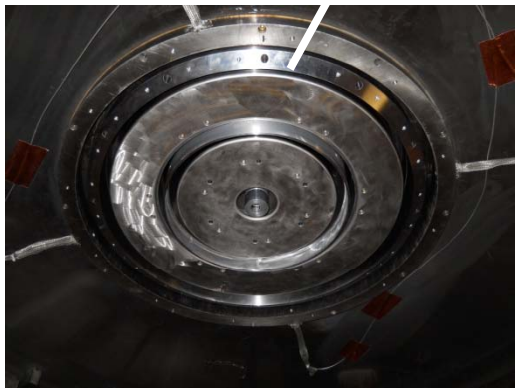


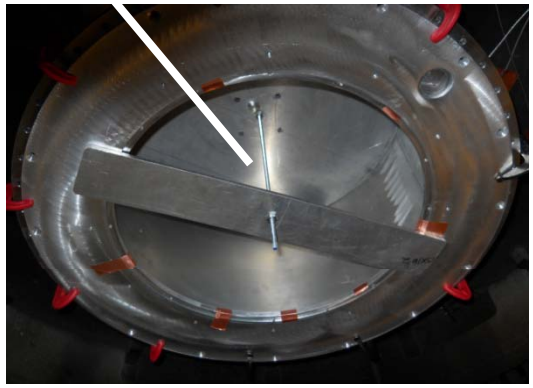
Sandia National Laboratories

Saturn experiment supports the feasibility of the Inverse Diode for the PPS—in some key parameters.



- Inner MITL Cathode
- Outer MITL Cathode
- Post Accelerating Gap (PAG)
- Inverse Diode Gap
- Voltage Monitoring Inductor

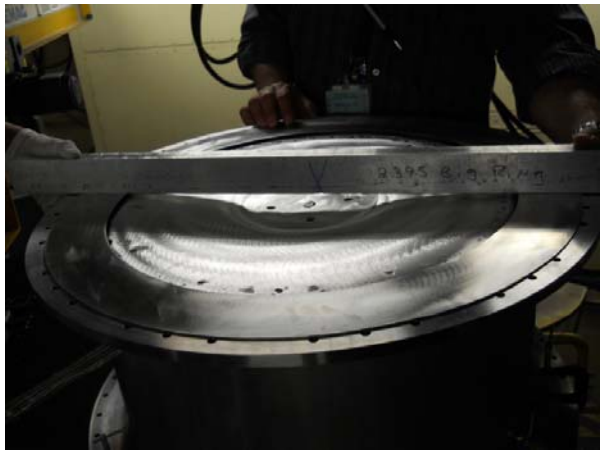


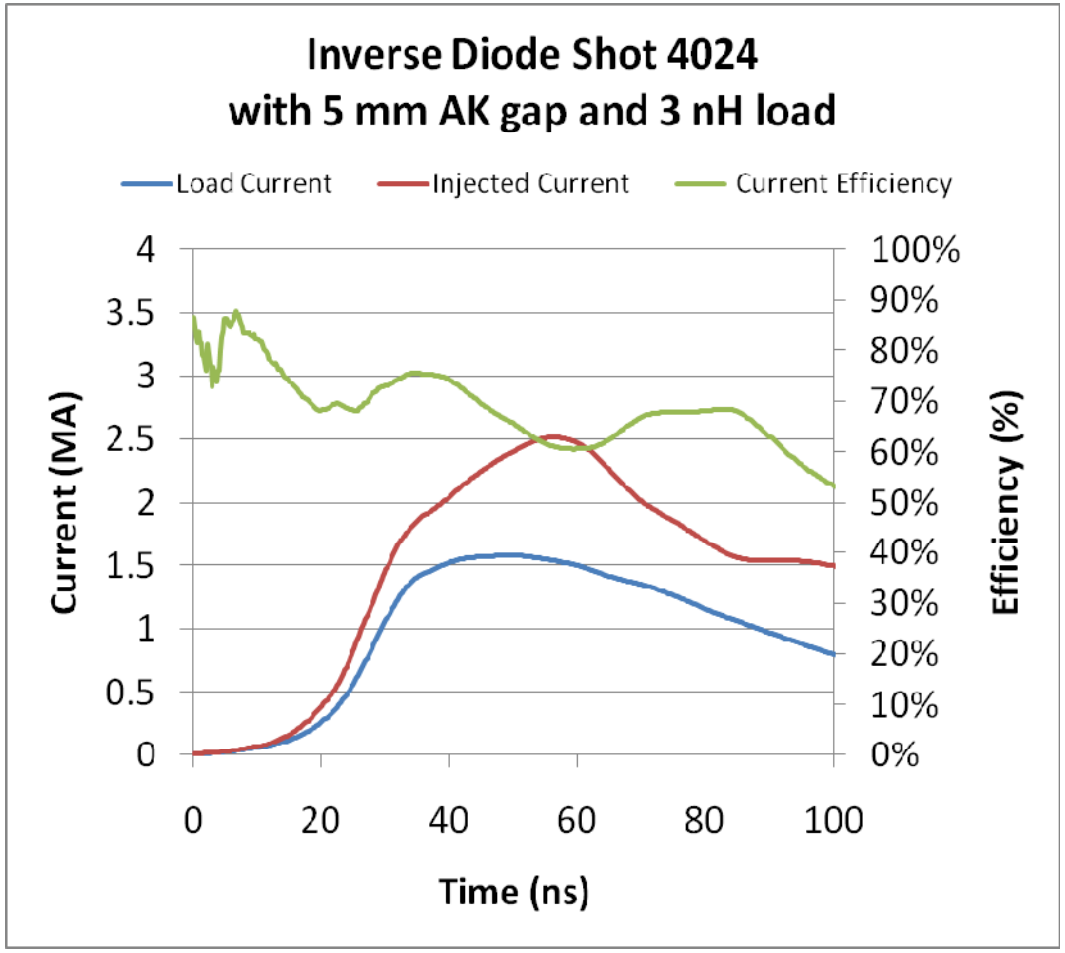


Saturn	PPS
2.2,2.7 MV	7 MV
2 kA/cm^2	0.56 kA/cm^2
2.5 MA	45 MA

Sandia National Laboratories

Unoptimized Inverse Diode had ~65% collection efficiency on Saturn.

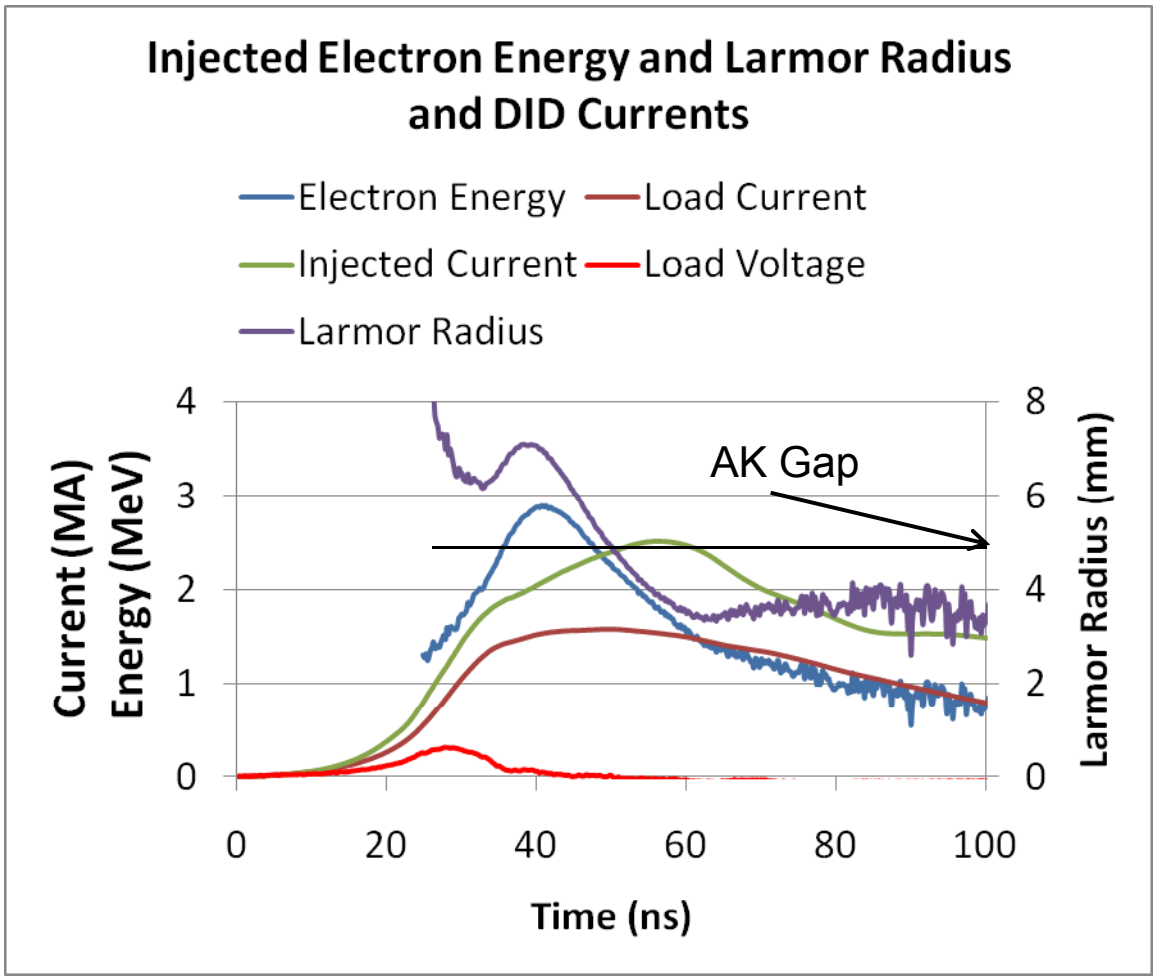




Electrostatic insulation works.
Otherwise efficiency = 0.

Sandia National Laboratories

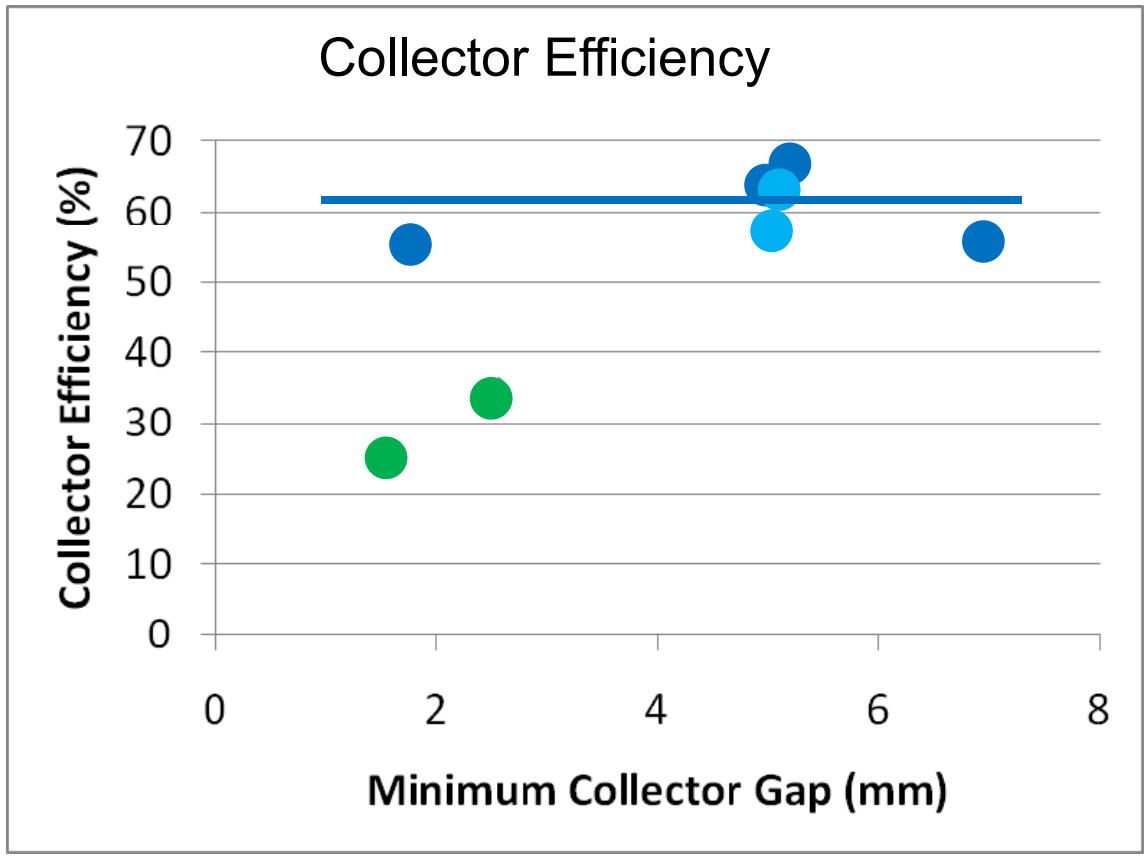
Difference between injected current and collected current can not be attributed to magnetic effects.



- The collector anode-cathode gap is 5 mm.
- Larmor radius increases after the load current has reached its peak.
- .Load voltage too low for electrostatic reflexing and too continuous for shorting.

Sandia National Laboratories

Beam divergence is a critical factor. Efficiency is not strongly dependent on AK gap for lower divergence beams.



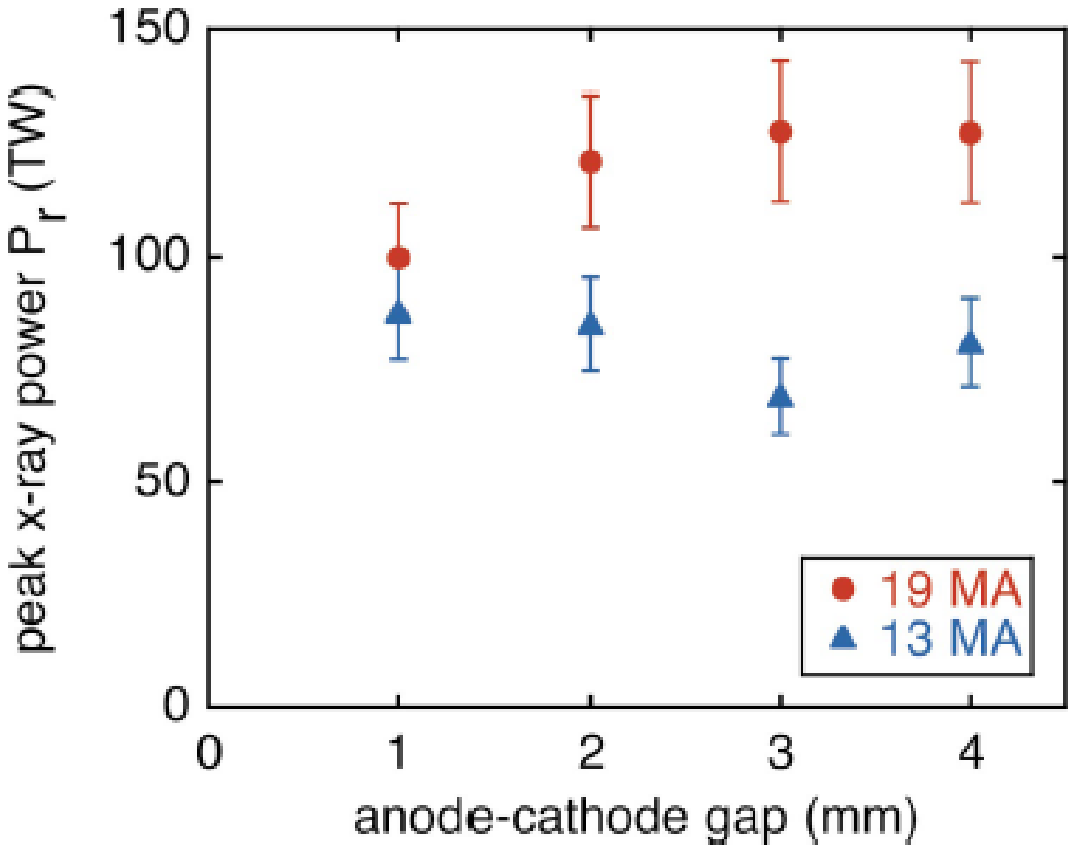
Roughened Stainless Steel

Grooved Stainless Steel

Roughened Stainless Steel with worn grooves

Sandia National Laboratories

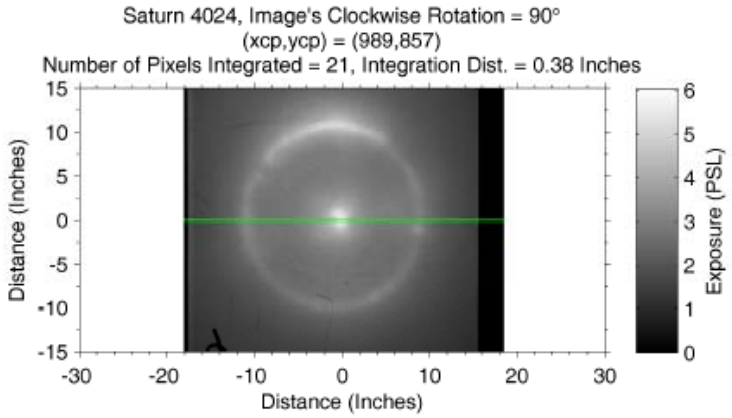
Stygar, et al (2004) find 1 mm MITLs stay open through peak power in 100 ns pulse.

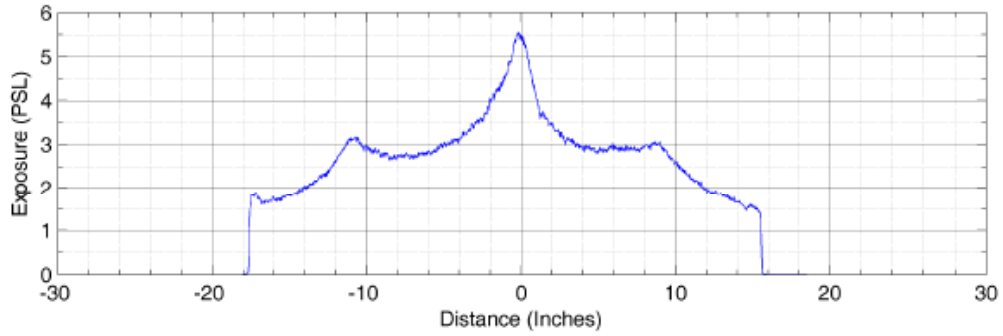


More data with large area MITLs are needed and can be obtained from a prototype PPS on Saturn.

Sandia National Laboratories

Bright spot is center is consistent with primary diode pinch at some time.





- Injector diode impedance shows 2 kA/cm2 of electrons does not create anode plasma.
- Make emission more uniform.
- Go to lower (560 A/cm^2) current density.

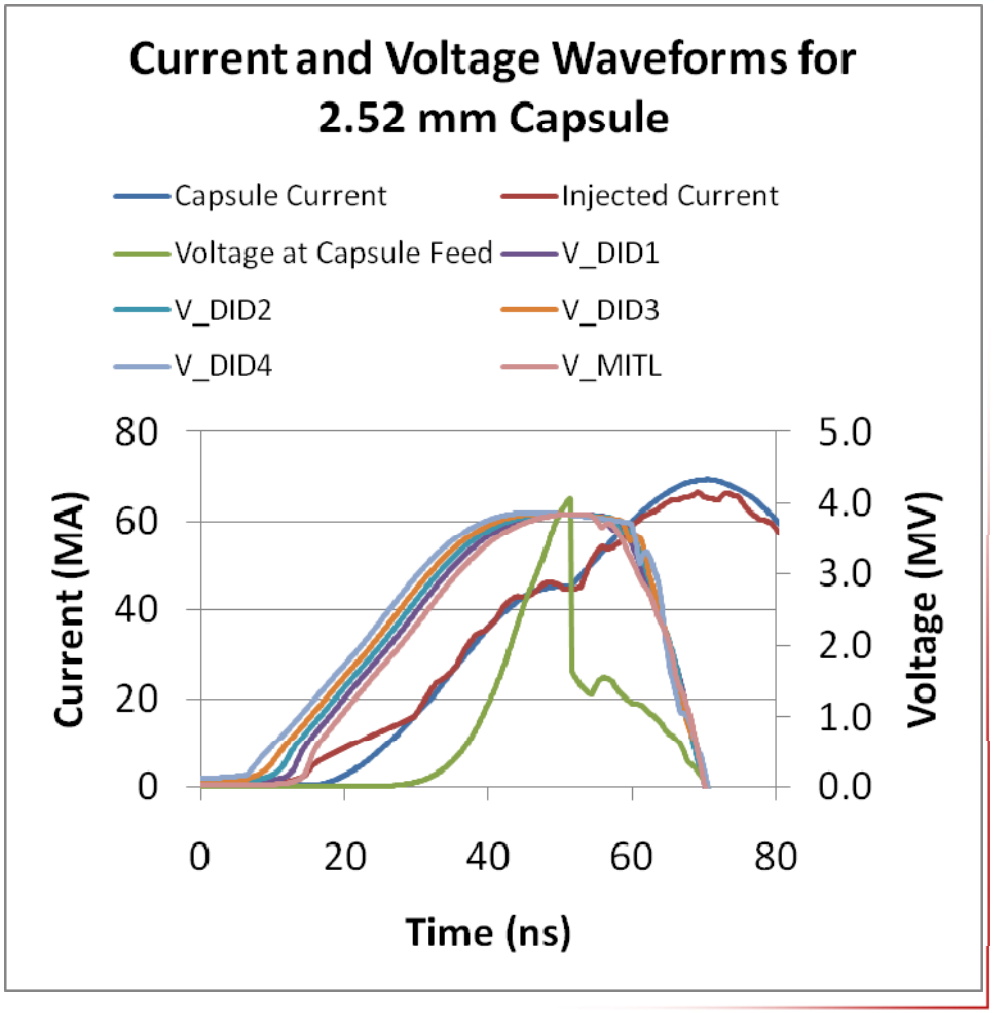
Poco graphite cathodes have been fabricated for July 2011 series.

Sandia National Laboratories

45 MA at 1.5x10^{15} A/s in QSDD capsule and 560 A/cm^2 Inverse Diode current density drives the design of the rest of the PPS.

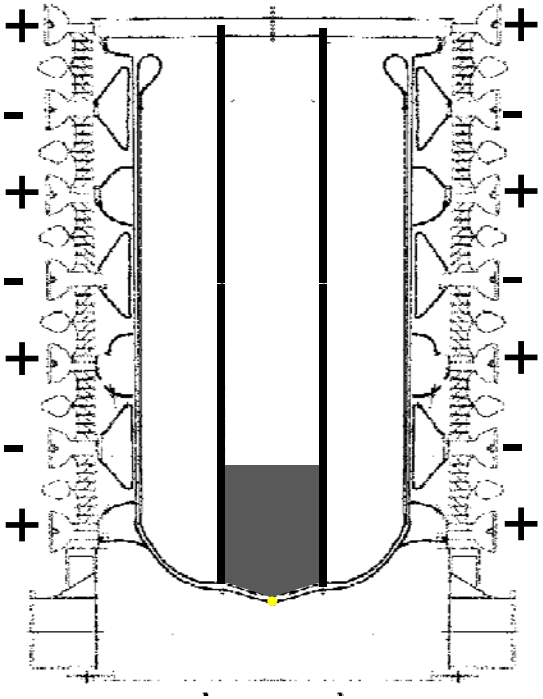
- Direct Inverse Diode
  - 1 meter radius
  - 560 A/cm^2 injected electrons
  - 1 mm to 2mm minimum AK gap for 7.5 to 15MeV injected electrons
- MITL and Capsule
  - 1mm to 2 mm AK gap
  - 2.5 to 3.5 mm QSDD capsule

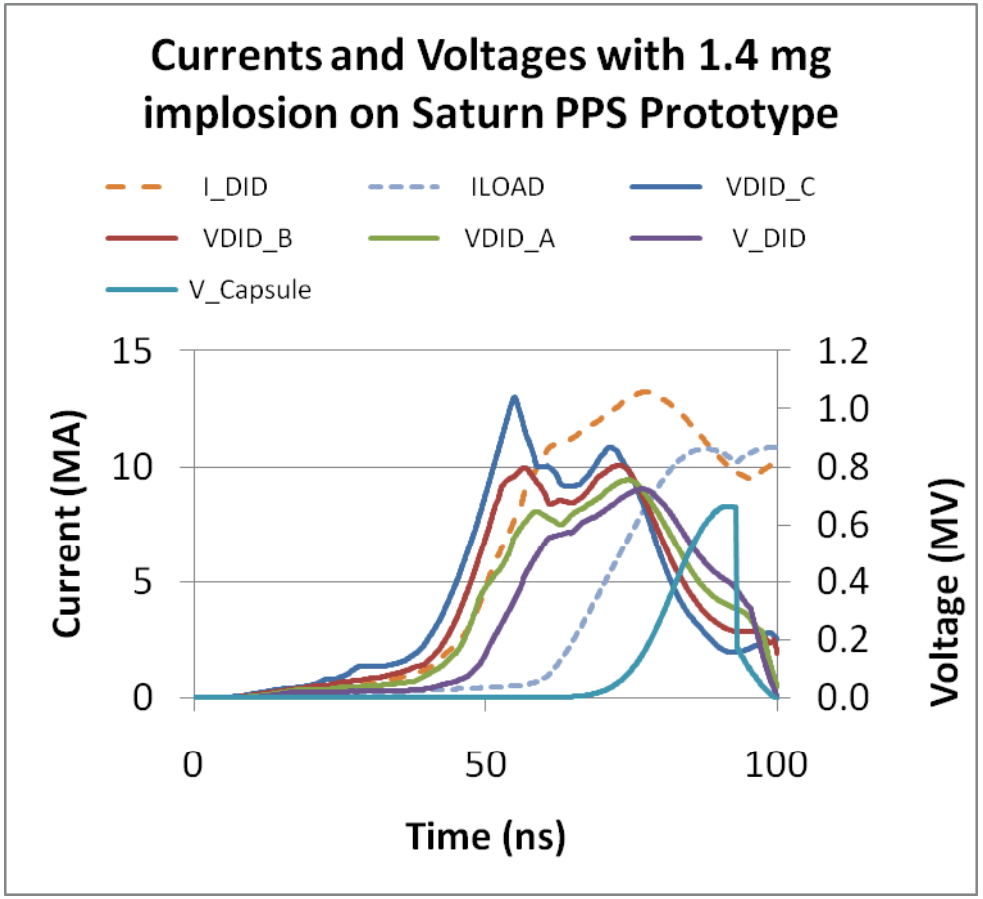
MITLs with 1 mm to 2 mm AK gaps must not short out.



Sandia National Laboratories

Saturn could prototype the PPS Inverse Diode, RTL, and QSDD Capsule.

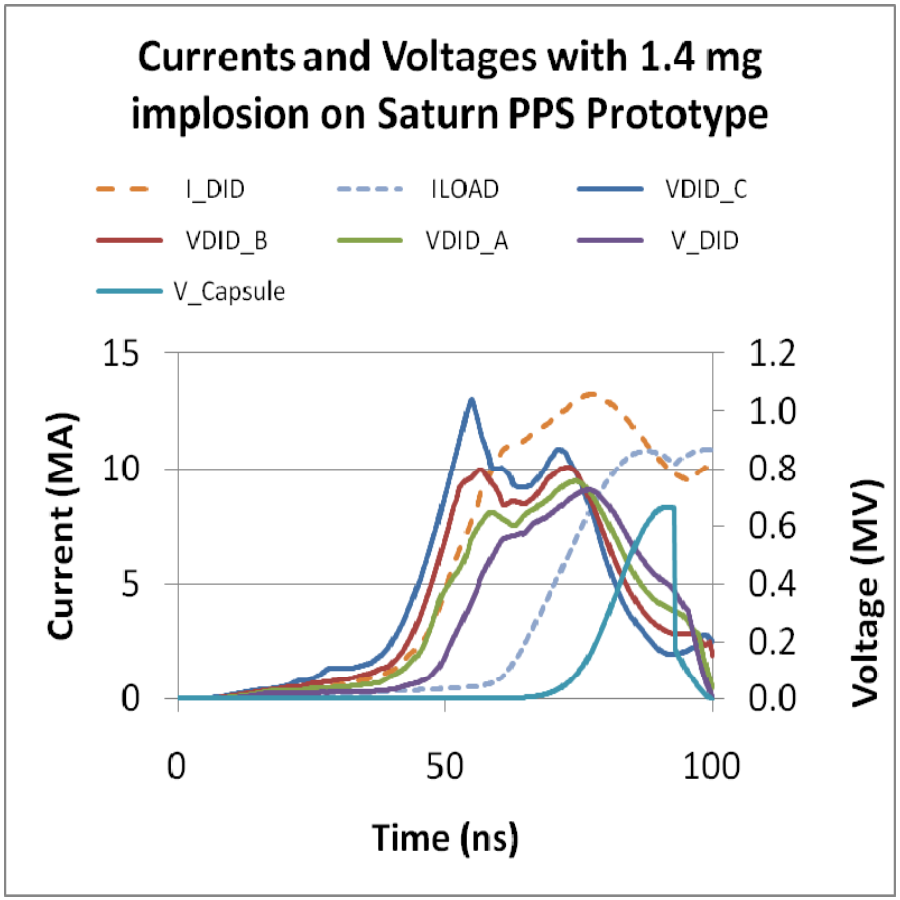


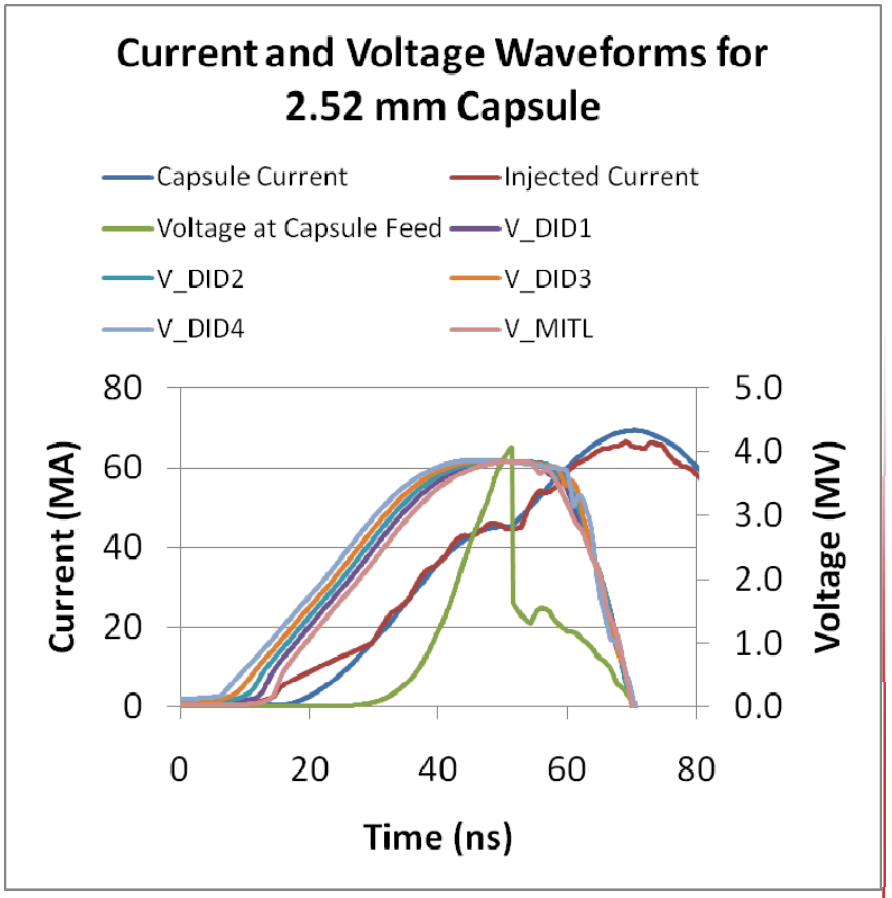


QSDD baseline with 17.5 mg mass has 4 cm/ μs velocity.
QSDD surrogate with 1.4 mg mass has 22 cm/μs velocity.

Sandia National Laboratories

Saturn should test the design codes for the Inverse Diode, RTL, MITL, and capsule.





Sandia National Laboratories

Conclusions

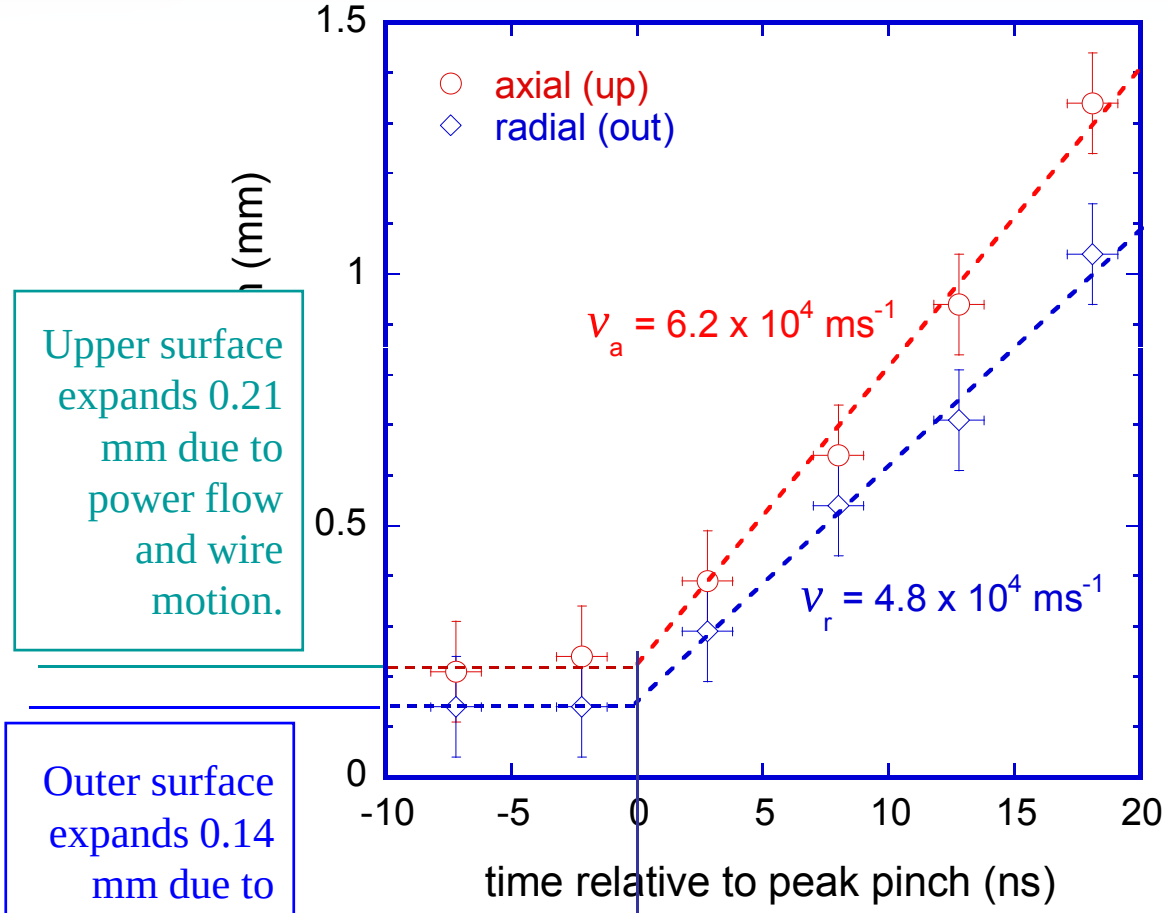
- High-current Direct Inverse Diode offers a new way to couple pulsed power to imploding plasma loads.
- Electrostatic and magnetic insulation mitigate counter streaming currents.
- Exploratory experiments on Saturn are encouraging but more work needs to be done to establish feasibility.
- Beam pinching must be avoided.
- Make electron emission more uniform .
- Use multiple beams at lower current density to avoid anode plasma and beam pinching.

Sandia National Laboratories

Backup Slides

Sandia National Laboratories

Plot of Cathode Expansion in the Radial and Axial Directions Versus Time



Upper surface expands 0.21 mm due to power flow and wire motion.

Outer surface expands 0.14 mm due to power flow.

A linear regression of the cathode position after peak pinch extrapolates to the power flow position!

Assuming that the anode expands with a similar radial velocity, 4.8×10^4 ms^{-1}, then the observed high density plasma would take ~40 ns after peak pinch to close the 4 mm gap.

Therefore a low density, low gradient plasma must be responsible for shorting the gap at earlier times. The high density plasma serves as a moving

Sandia National Laboratories