Plasma Formation and the Correlation with Current Loss in Post-Hole Convolutes

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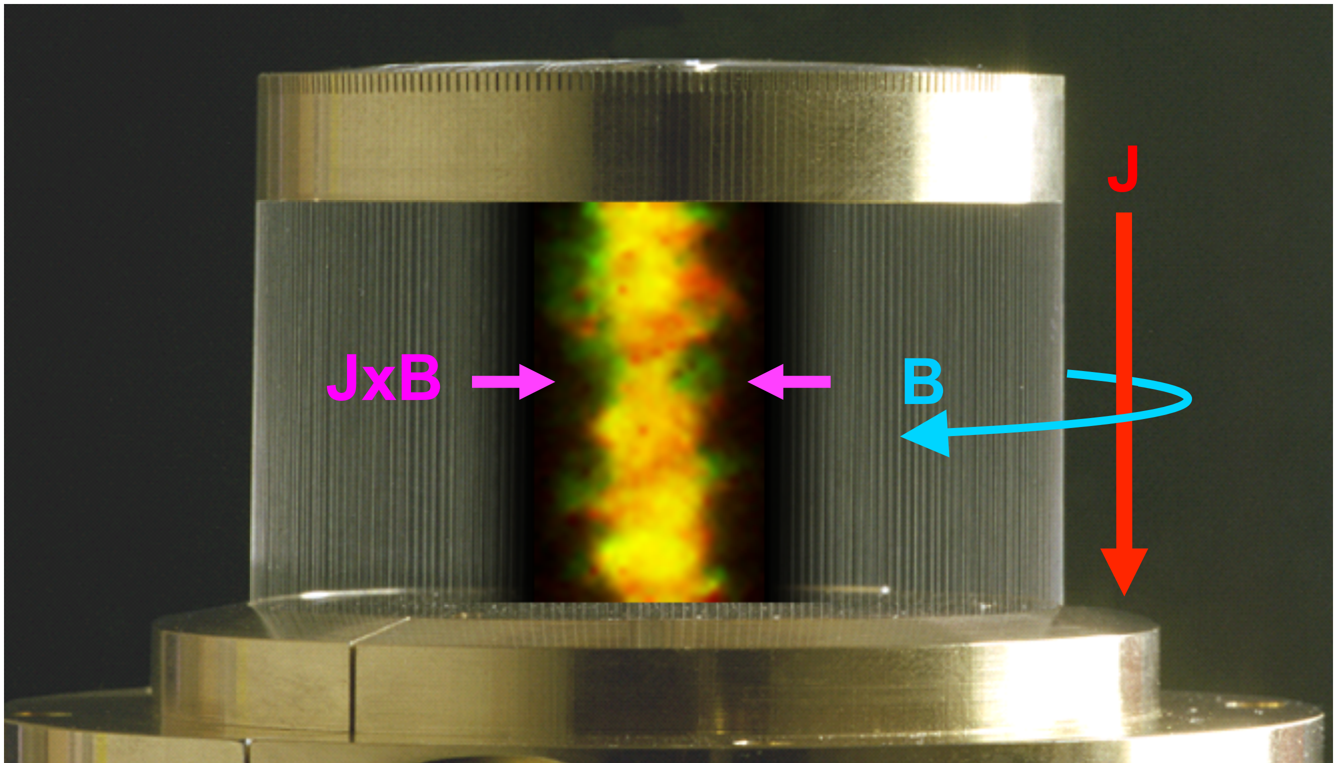
Outline

- Introduce Z-Pinches, the Z-Machine, and post-hole convolutes
- Diagnostic setup
- Example spectrum and basic analysis
- Experimental measurements
  - Axial plasma location
  - Plasma density as a function of load
  - Propagation of plasma across A-K gap
  - Plasma density as a function of location
- Summary and conclusions

Magnetically-driven z-pinch implosions are a very rich field of study

- **Wire array or gas puff x-ray sources**
  - Intense x-ray sources
    - up to 2 MJ x-rays as 200 eV Planckian
    - up to 80 – 300 kJ in K-shell radiation (several keV)
  - Applications to laboratory astrophysics
- **Magnetically-driven cylindrical liners**
  - Inertial fusion
  - Dynamic materials
  - Growth of the Magneto-Rayleigh-Taylor instability

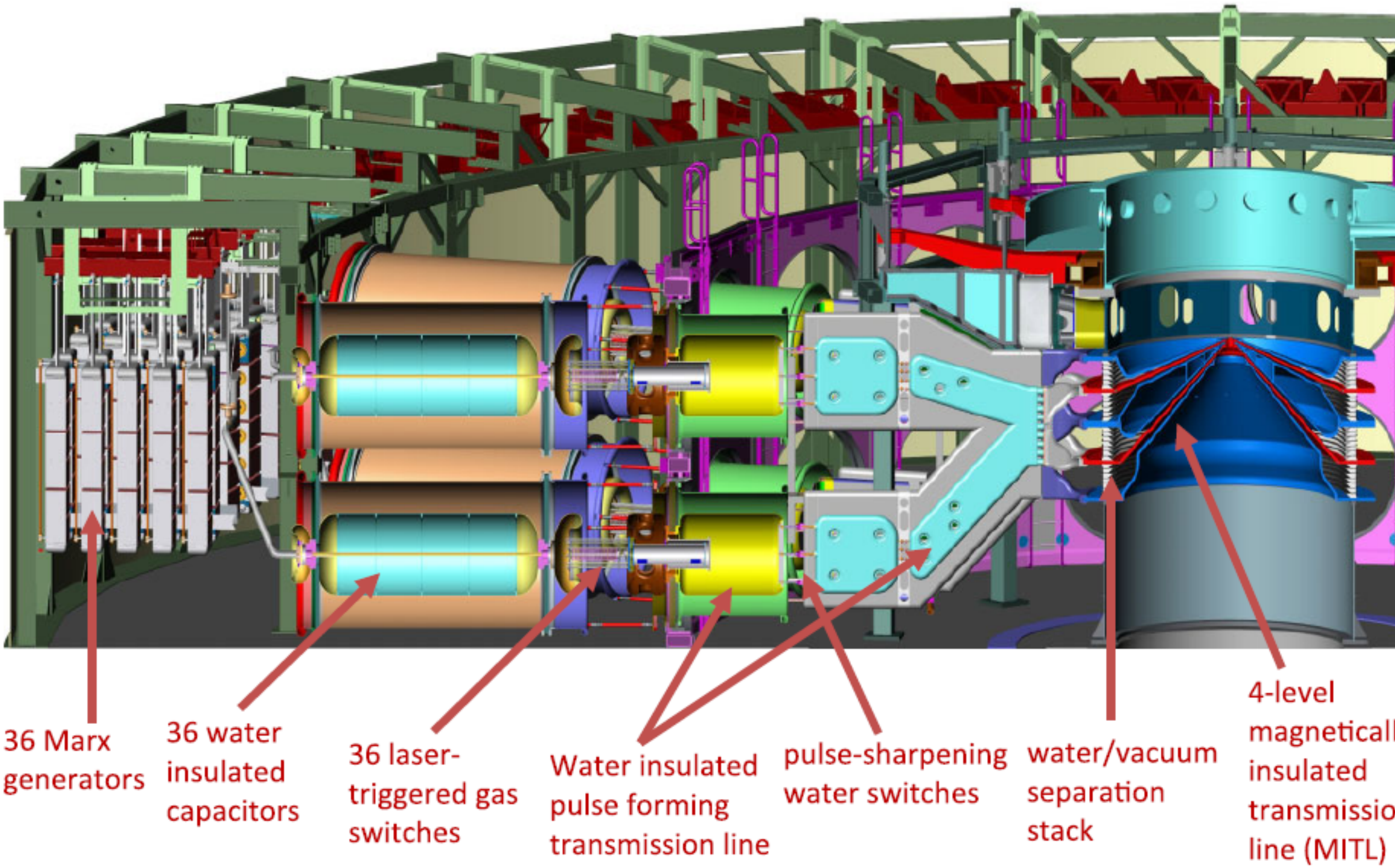
Magnetically driven implosions are efficient, powerful, x-ray sources from 0.1 to 10 keV



Power scales as current squared

20% current loss => 36% power reduction

The Z-Machine is the world's most powerful pulsed power driver, capable of delivering 25 MA with a 100 ns risetime [1]



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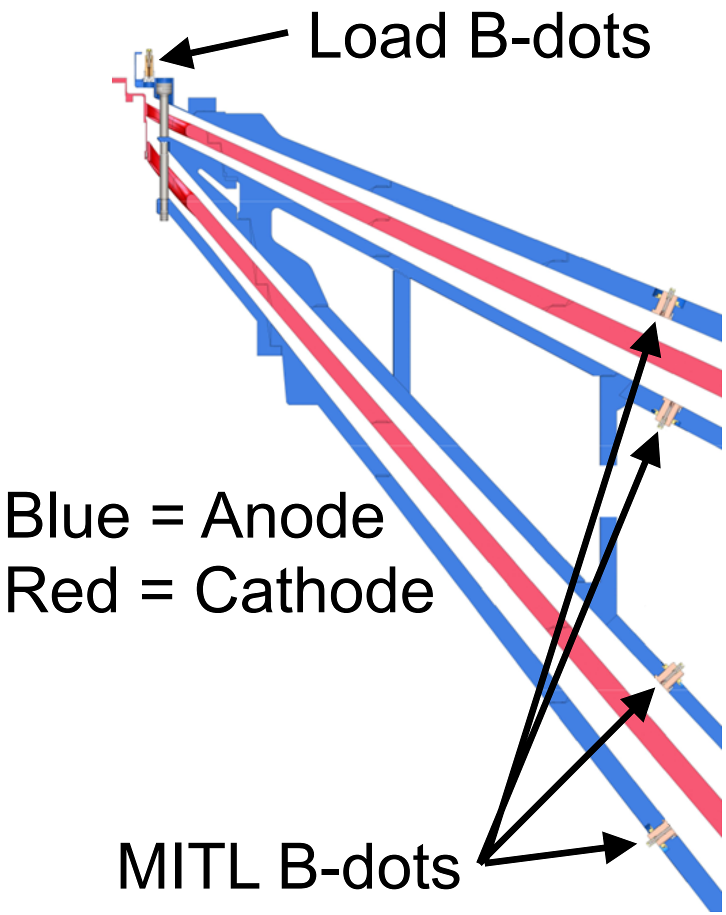
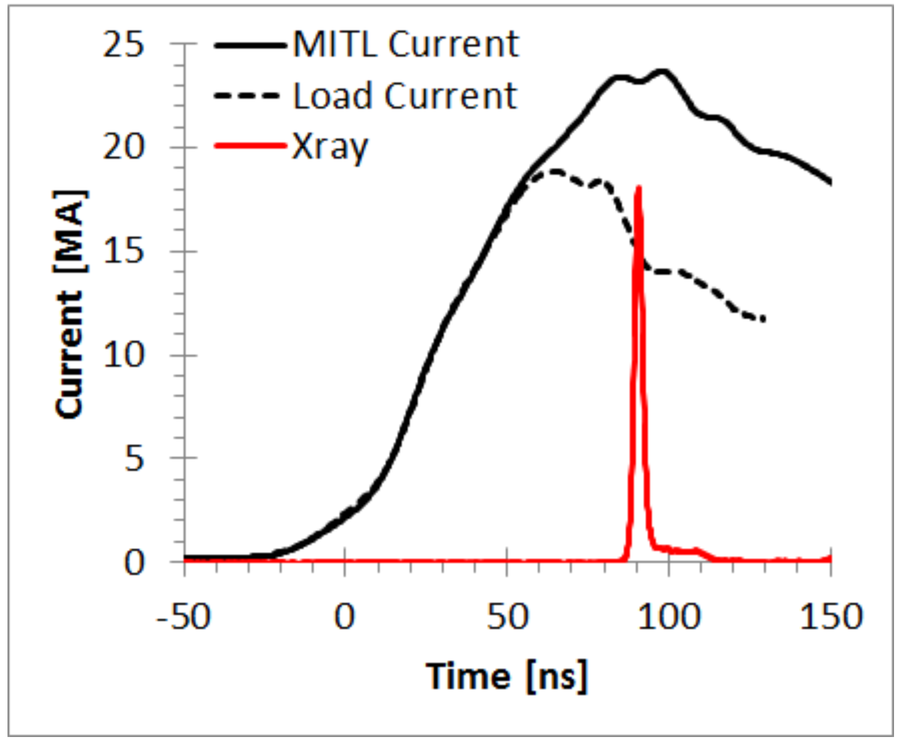
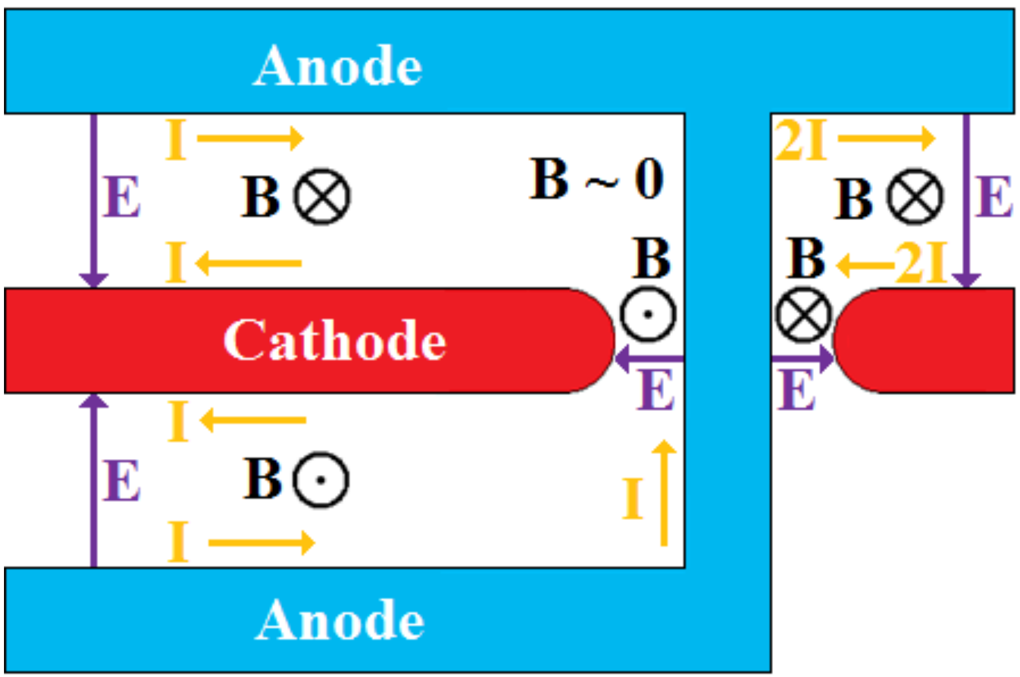
Up to 20% of the peak current is lost between the stack and the load[2]

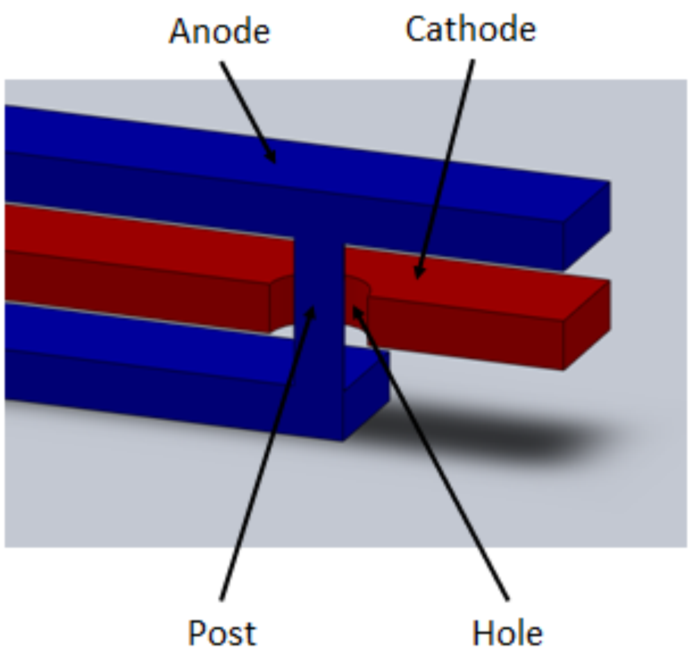




High-power post-hole convolutes have complex geometries and high electric and magnetic fields which produce interesting plasma[3]



a)



b)

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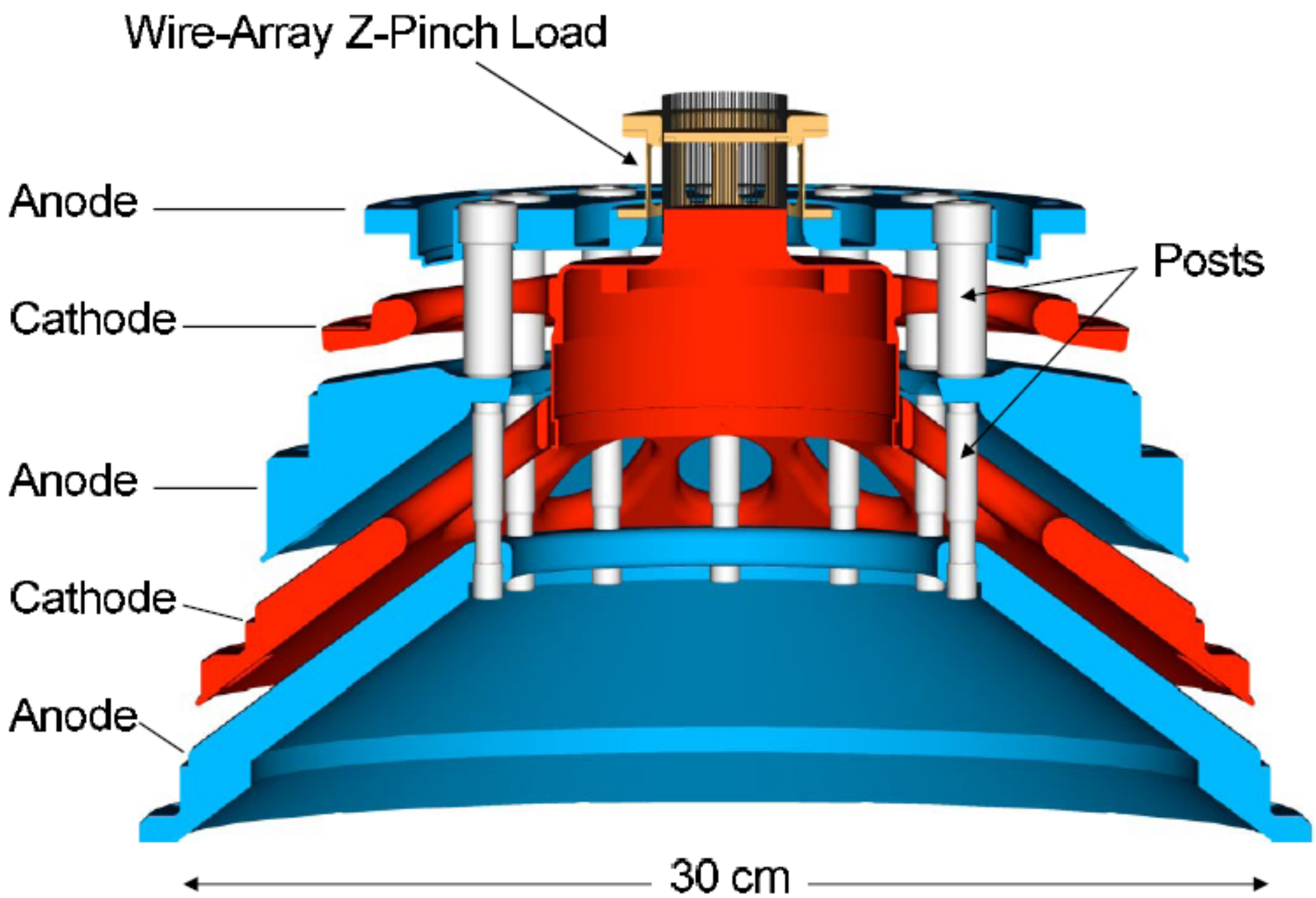
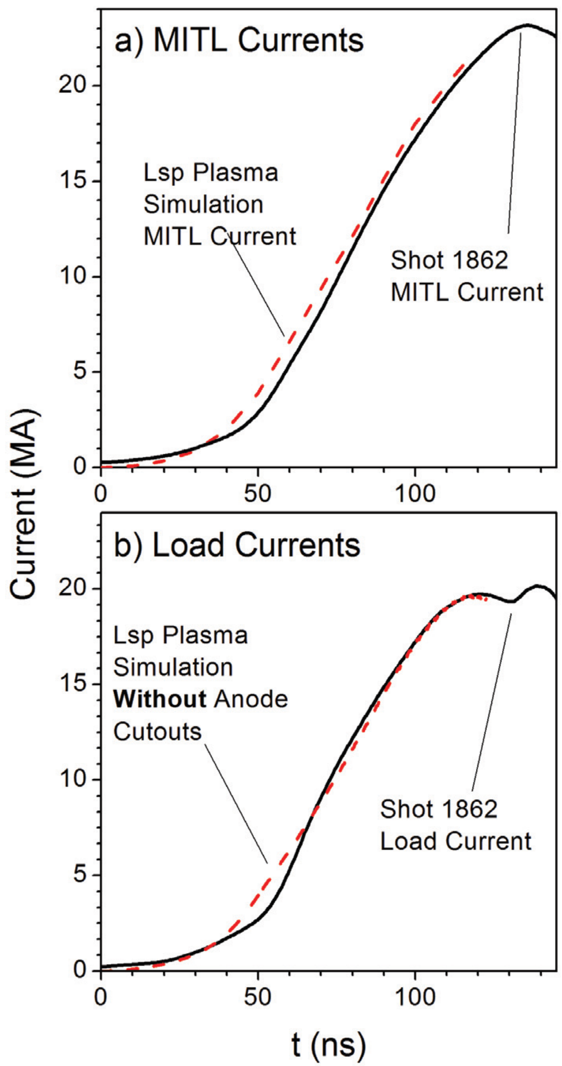
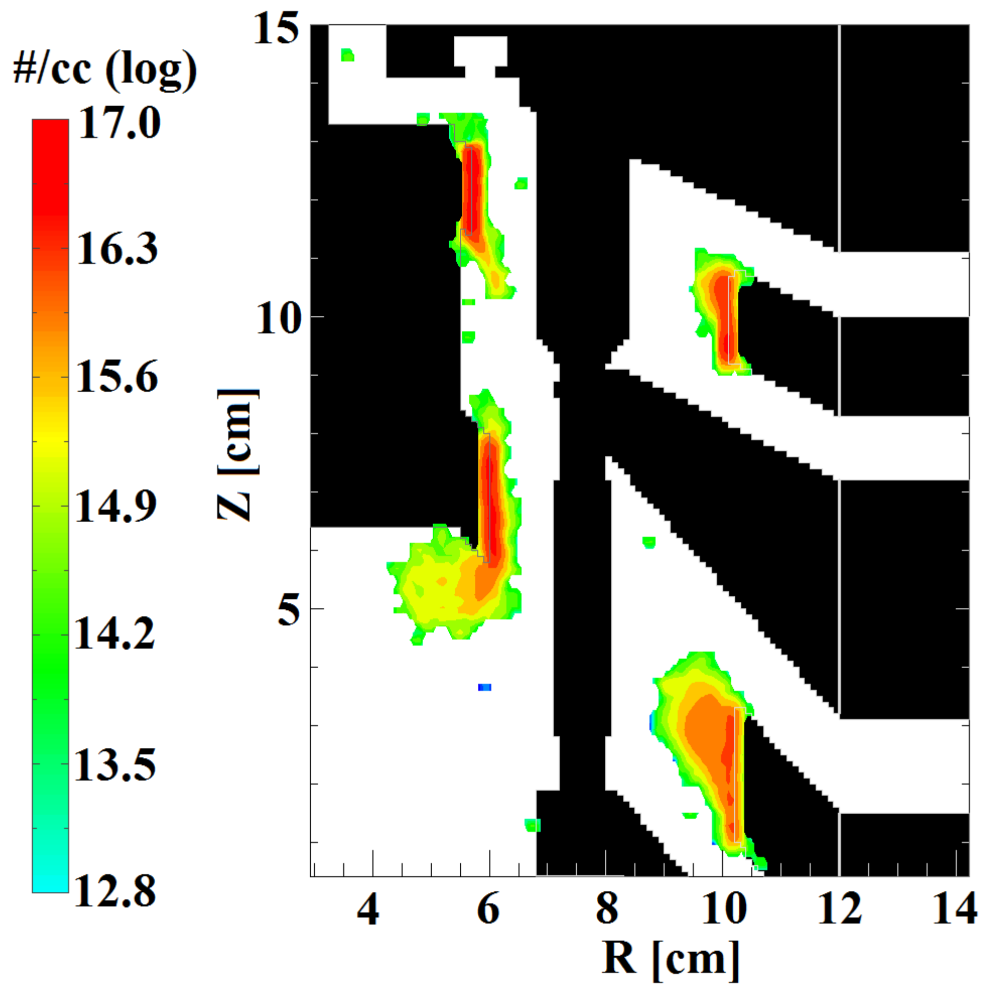
The Z-Machine uses a 12 fold azimuthal symmetry double post-hole convolute[4]



DPHC designed by Bill Stygar et al. It is the standard used for all 2200+ shots on Z.

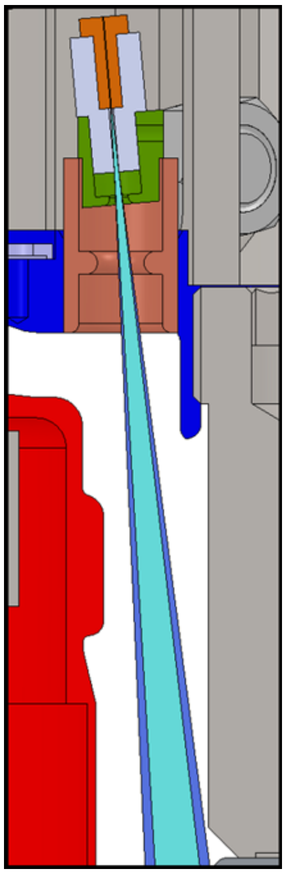
Post-Hole convolute simulations show that current loss can be explained by plasma formation in the convolute[5]





Simulations by Dave Rose et al.

The experimental probe replaces one of the inner B-dots and views just downstream of the convolute.



Streaked Visible Spectroscopy system

- 2 Å spectral resolution
- 2 ns temporal resolution
- Fiber optically coupled

Convolute Plasma Emission Diagnostic

- replaces one inner MITL B-dot
- “on-post”
- Limiting aperture provides coarse spatial resolution

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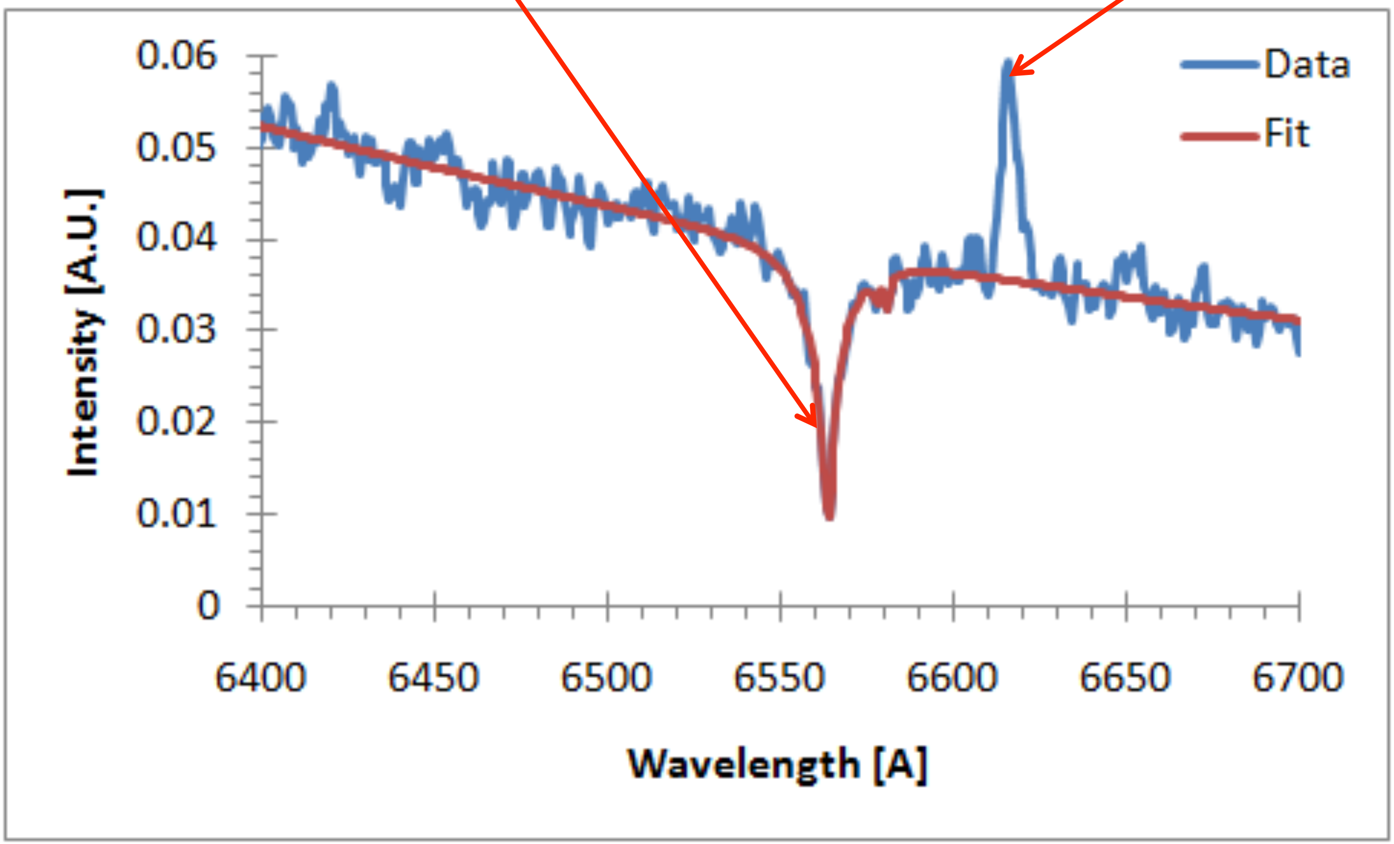
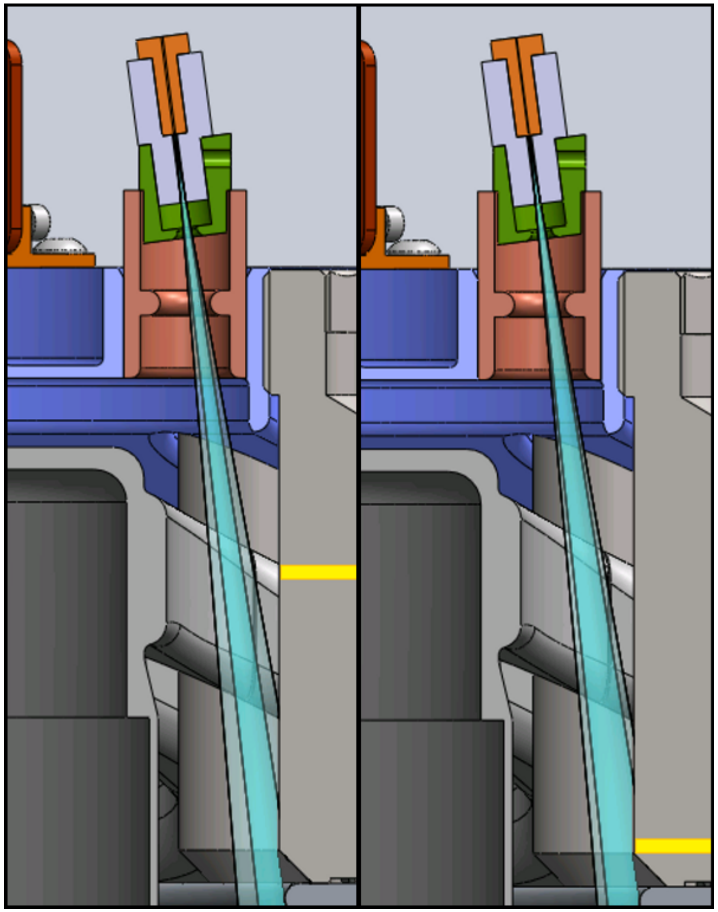
Stark broadening of the H-alpha absorption feature was used to determine the plasma density

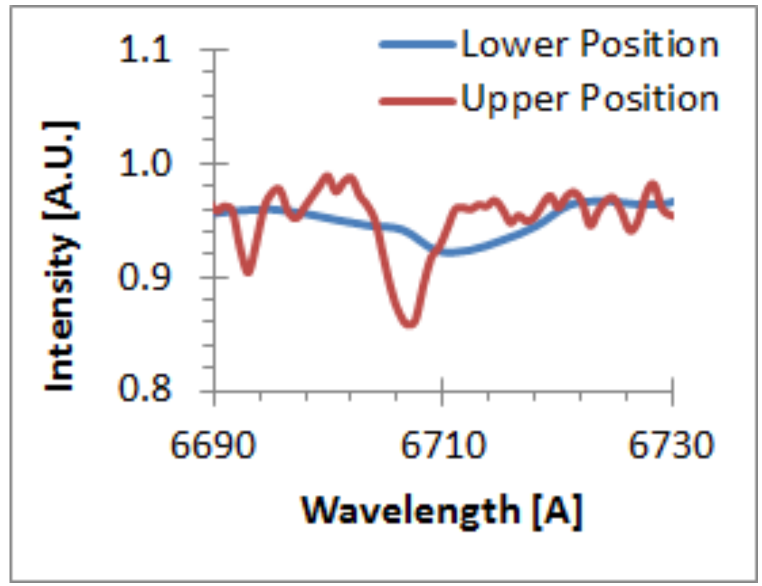
H-alpha absorption feature: 6563 Å

Timing fiducial

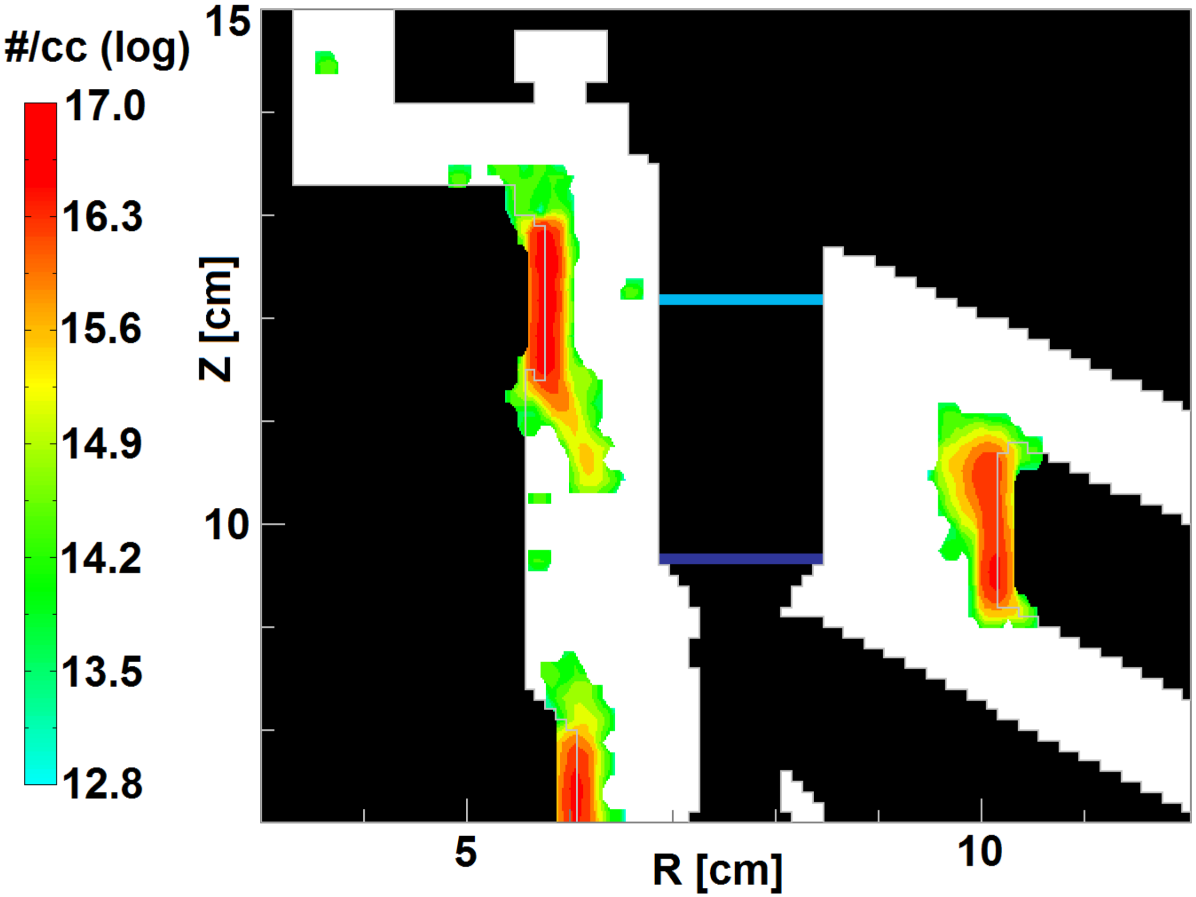


LiF dopant was used in the convolute to constrain the axial location of the continuum emitter[3]



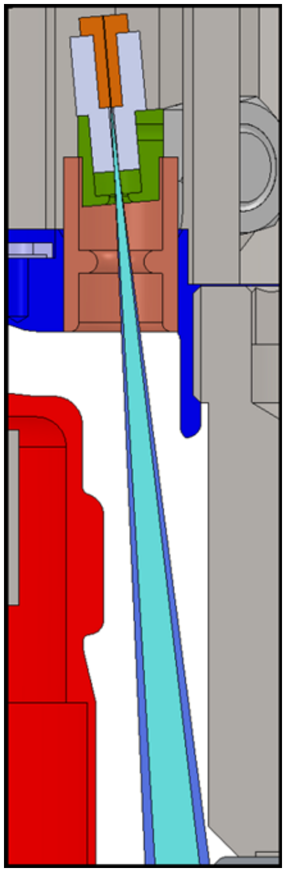


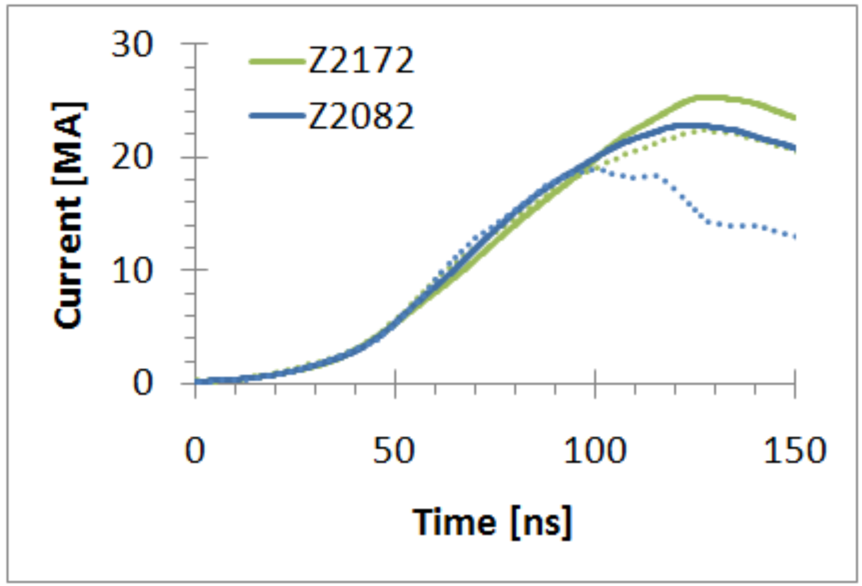
The experimental data indicate that the observed continuum emitter is located between the two dopant locations[5]



Simulations agree with experimental measurements to first order.

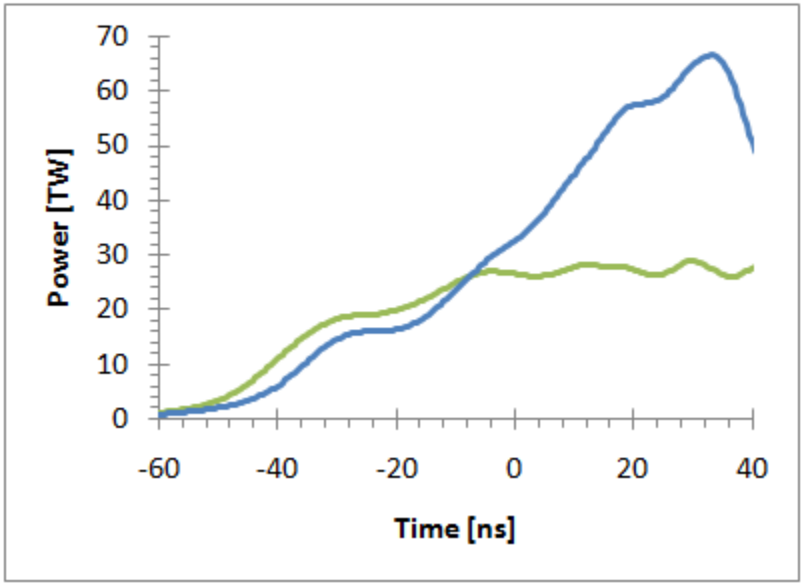
The plasma density as a function of time was investigated for two different load geometries.

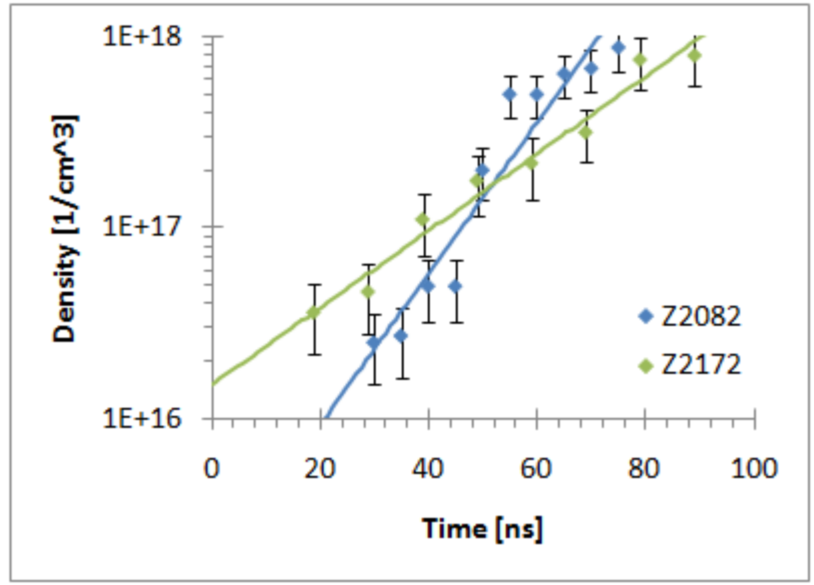




Z2172 – High initial L, Low L-dot
Z2082 – Low initial L, High L-dot

The energy transferred through the convolute affects the plasma forming in the region





This data indicates a closure velocity of 10-20 cm/μs.

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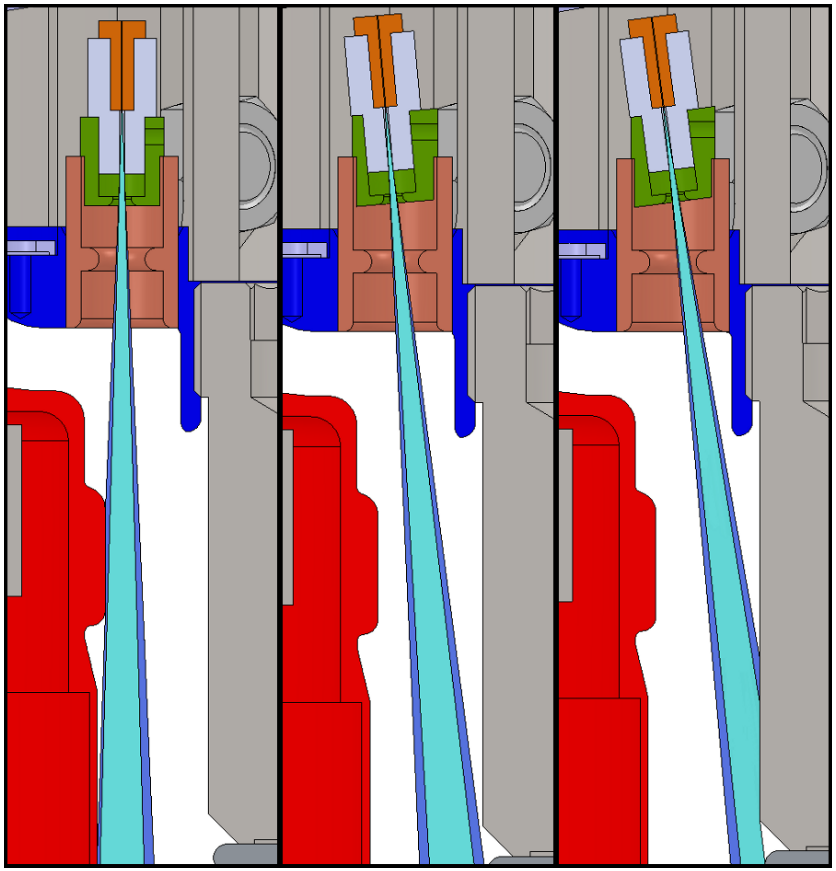
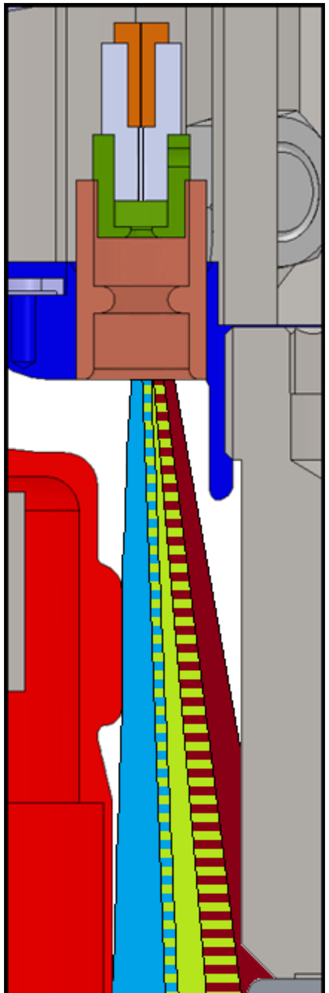
Experiments were conducted to directly measure the velocity of the continuum emitter[3]

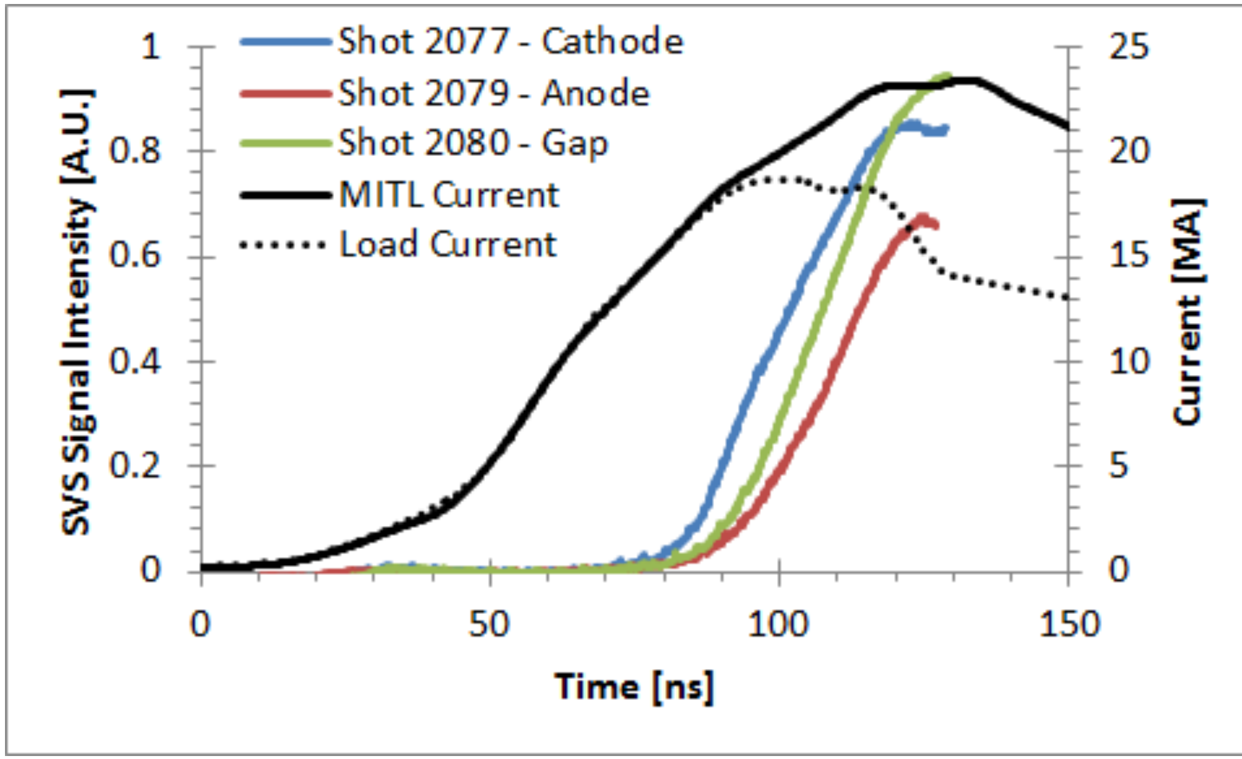


Experimental setup:

- Identical loads
- Identical diagnostic settings
- Different field of view

Emission source travels from cathode to anode at up to 40 cm/μs





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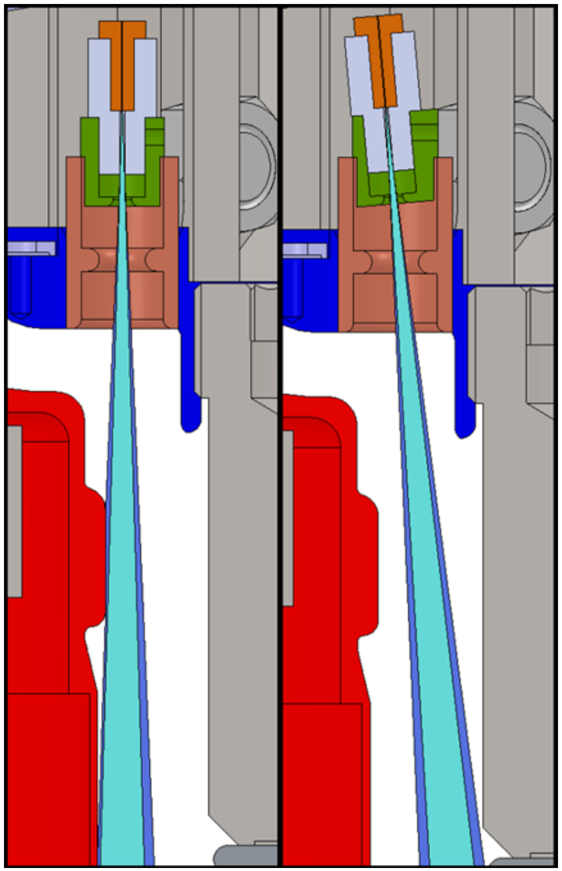
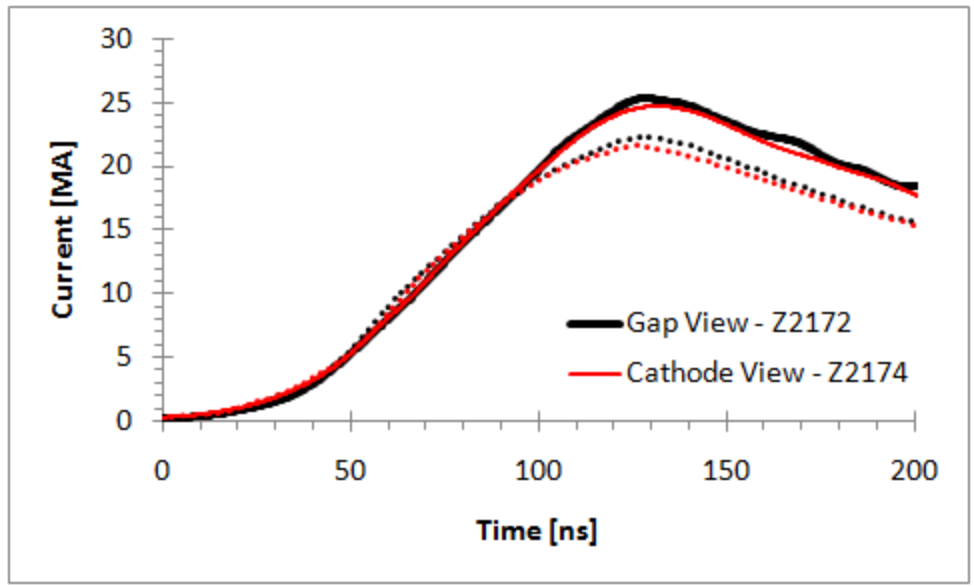
The plasma closure velocity was estimated based on plasma density measurements at several locations in the convolute





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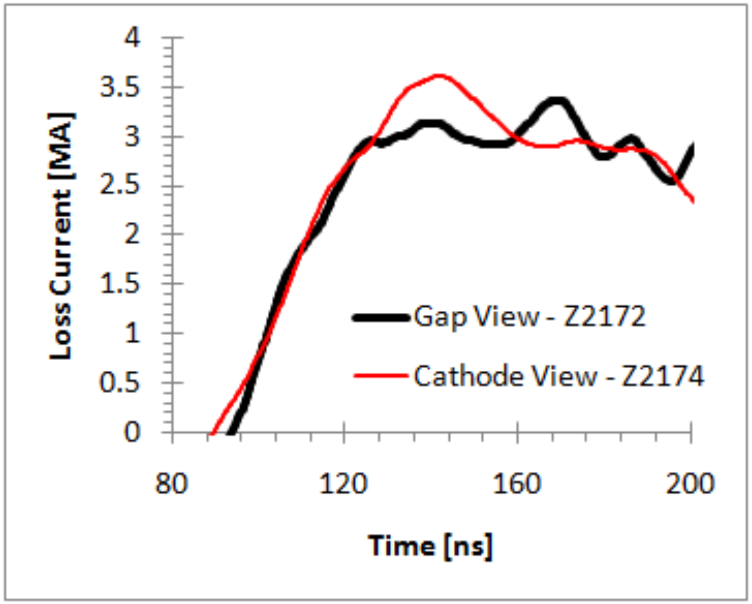
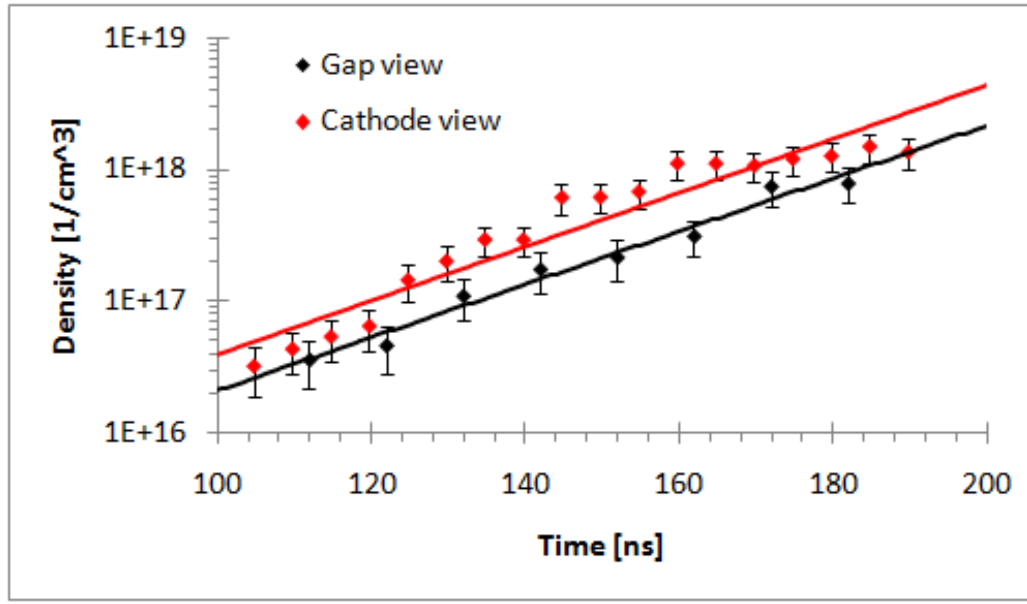
The plasma density inferred from the cathode view was greater than the gap view for all times.





The inferred gap closure velocity is ~ 20 cm/μs.

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Summary

- Li absorption features observed
  - Observed continuum emitter located in convolute
  - Set loose bounds on axial position
- Inferred plasma densities up to 10^{18} cm^{-3}
- Plasma density dependent on load impedance history
- Plasma crosses A-K gap from cathode to anode
  - Apparent closure velocity is 10s of cm/μs

Conclusions

- Post-hole convolutes are a critical component of high current pulsed power driver designs
- The losses in convolutes for certain loads have increased significantly as the power throughput of the convolute increased
- The plasma conditions/dynamics in the convolute are key to understanding the losses
- Experimental data are needed to confirm simulation results
- These experiments provide a basis to begin a study of the complex physics taking place in the convolute

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