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Spectroscopic Measurements in the Post-Hole Convolute on Sandia's Z-Machine

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Outline

- Introduce 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

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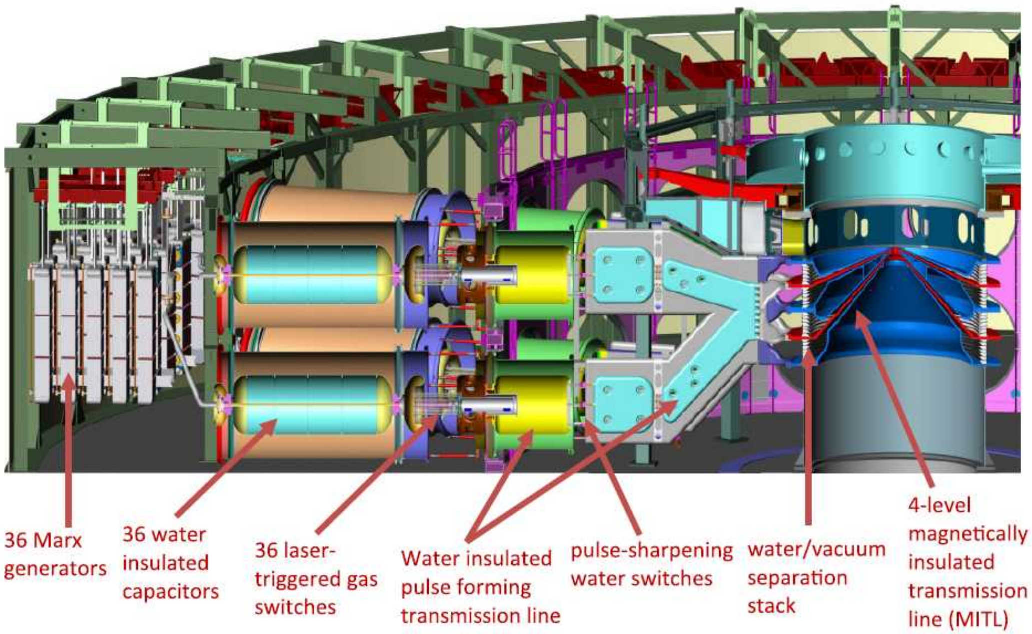
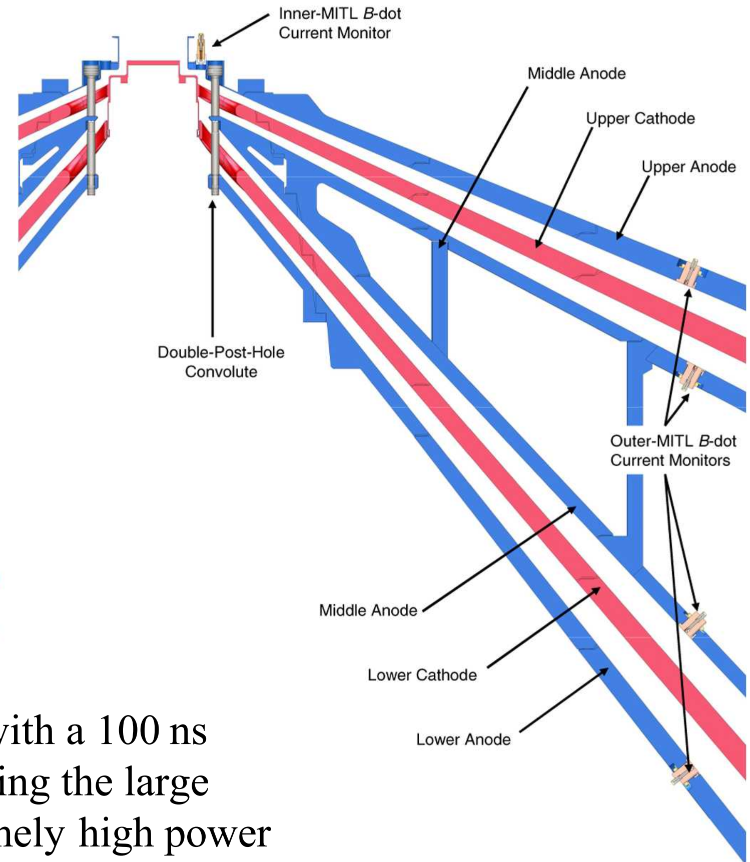
Z-Machine[1,2]





The Z-machine is nominally capable of delivering 27 MA with a 100 ns risetime to a load on the order of 1 cm in radius. Compressing the large amount of stored energy in space and time creates an extremely high power density, which can lead to unwanted plasma formation.

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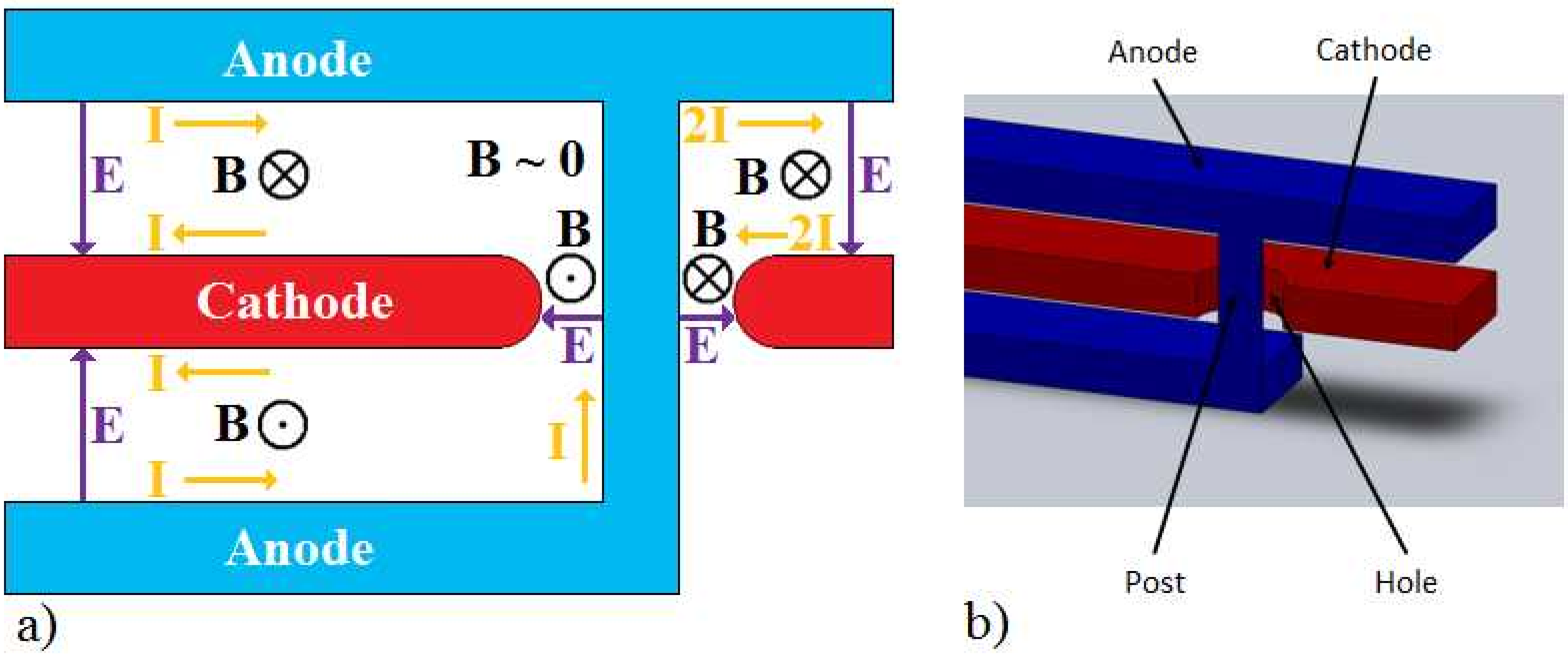
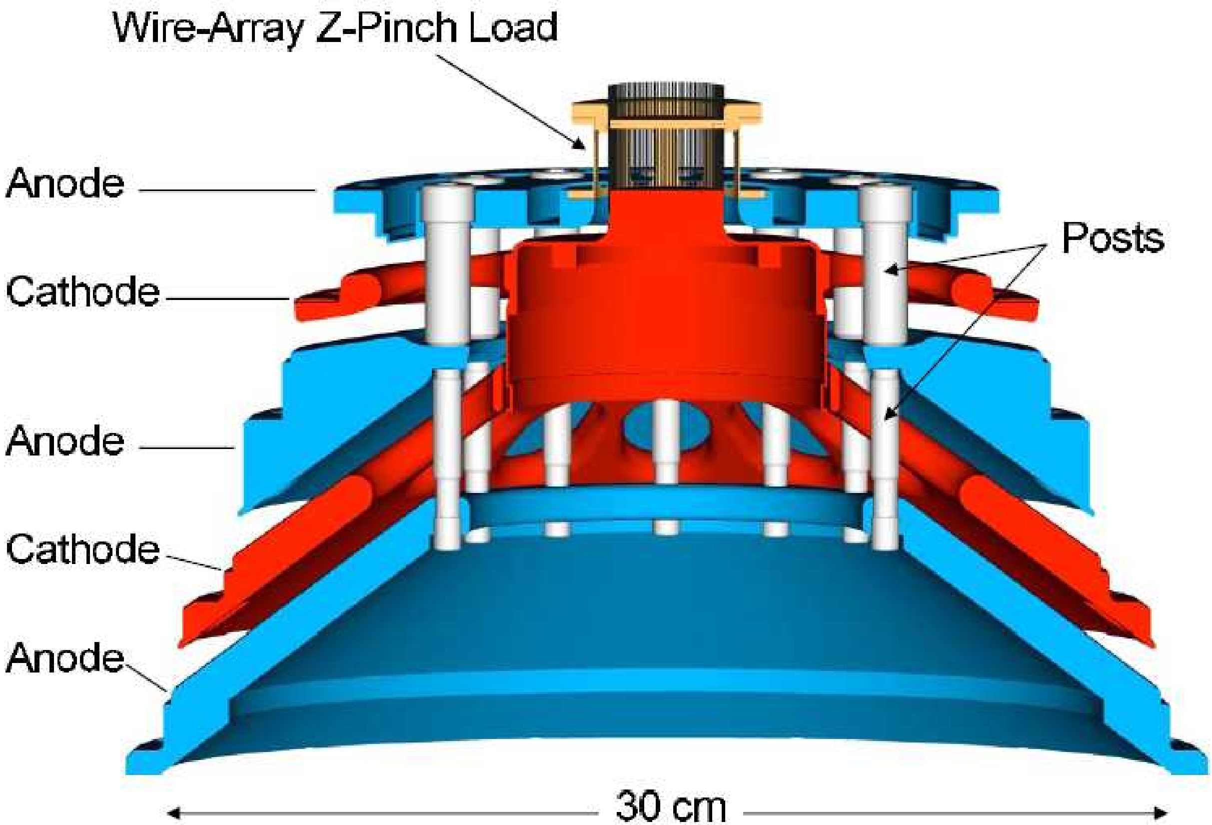
Post-Hole Convolutes[3]



The current flowing through the post is on the order of 1 MA, and voltages are on the order of 1 MV with anode-cathode gaps on the order of 1 cm. This creates a region of very high electric and magnetic fields. Combining the high fields with a complicated three dimensional geometry produces a dense plasma with complex motion.

Double Post-Hole Convolute[4]



The Z-Machine utilizes a double post-hole convolute to combine the current from 4 MITLs.
The convolute has a 12-fold azimuthal symmetry to reduce inductance and to increase azimuthal current symmetry at the load.

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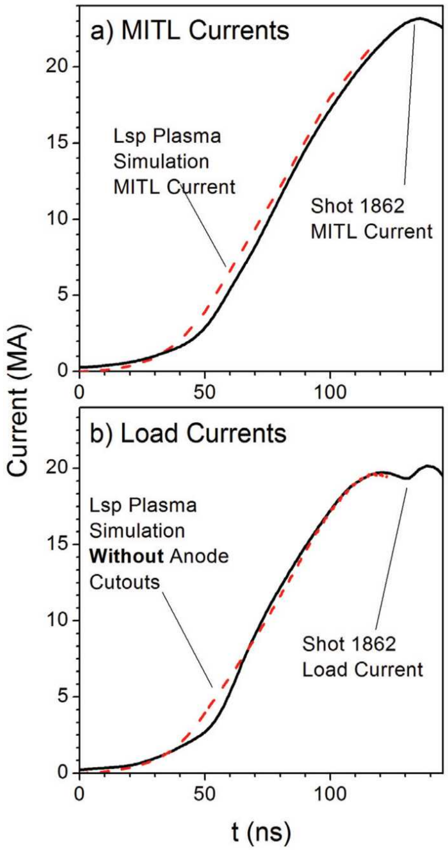
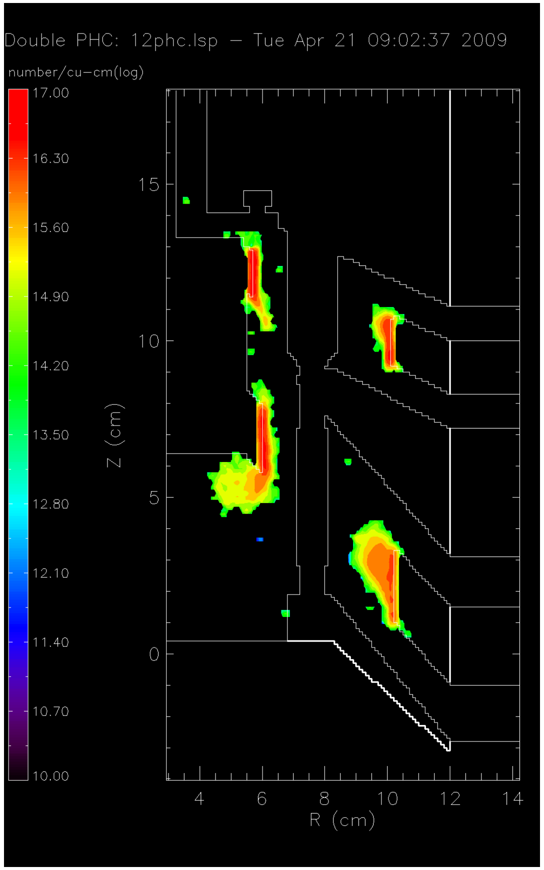
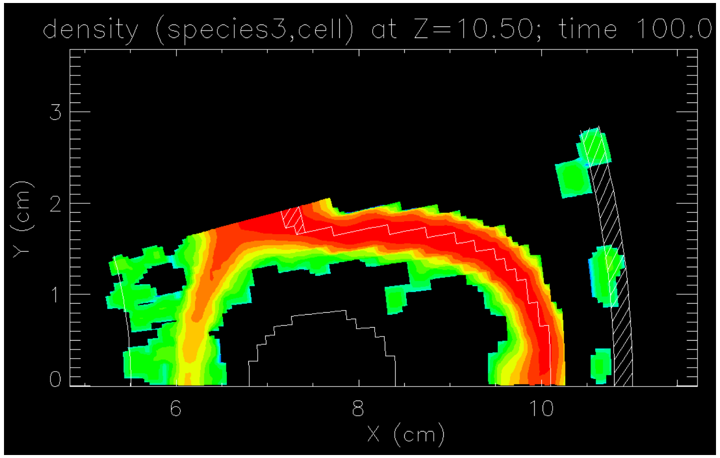
Post-Hole Convolute Simulations[5]







Current losses in the post-hole convolute region on Z can be several MA.

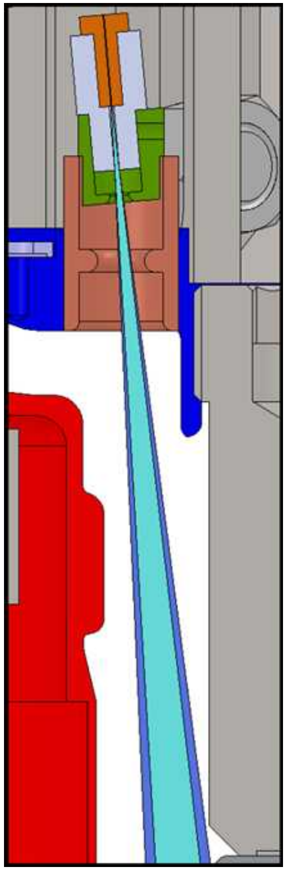
Simulations show that the current losses can be accurately modeled if plasma formation is allowed to occur at the electrode surfaces.

Experimental Setup

Streaked Visible Spectroscopy system consists of a 1 meter spectrometer coupled to a streak camera.

System is typically fielded with 2 Å spectral resolution and 2 ns temporal resolution.

System is fiber optically coupled to the diagnostic probe.



Probe is inserted into a vacant inner B-dot hole. Typically the hole is "on-post."

The body of the probe is electrically similar to that of a B-dot to avoid disturbing the system.

Probe limiting aperture produces a 3 degree full angle field of view to provide spatial resolution.

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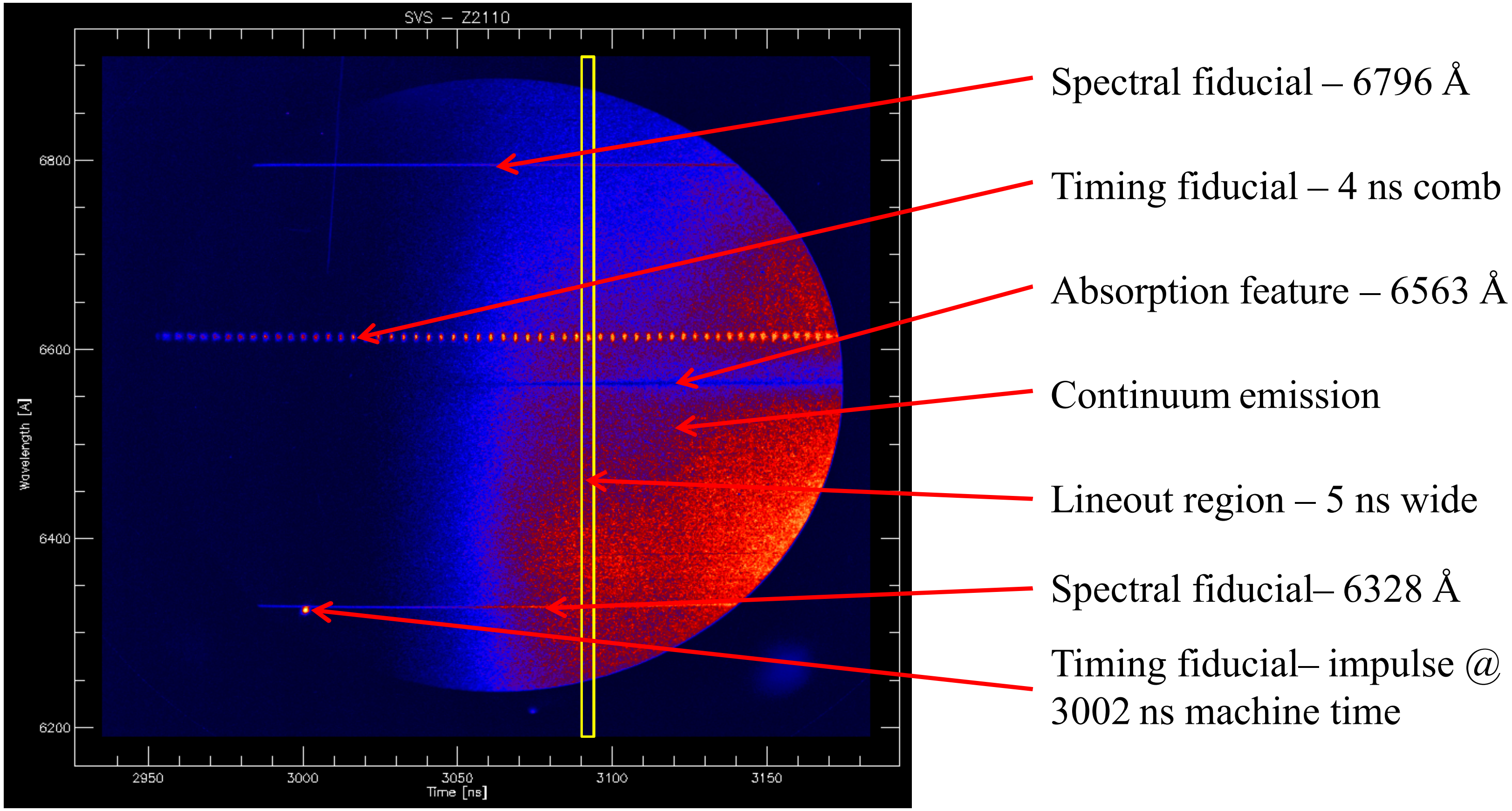
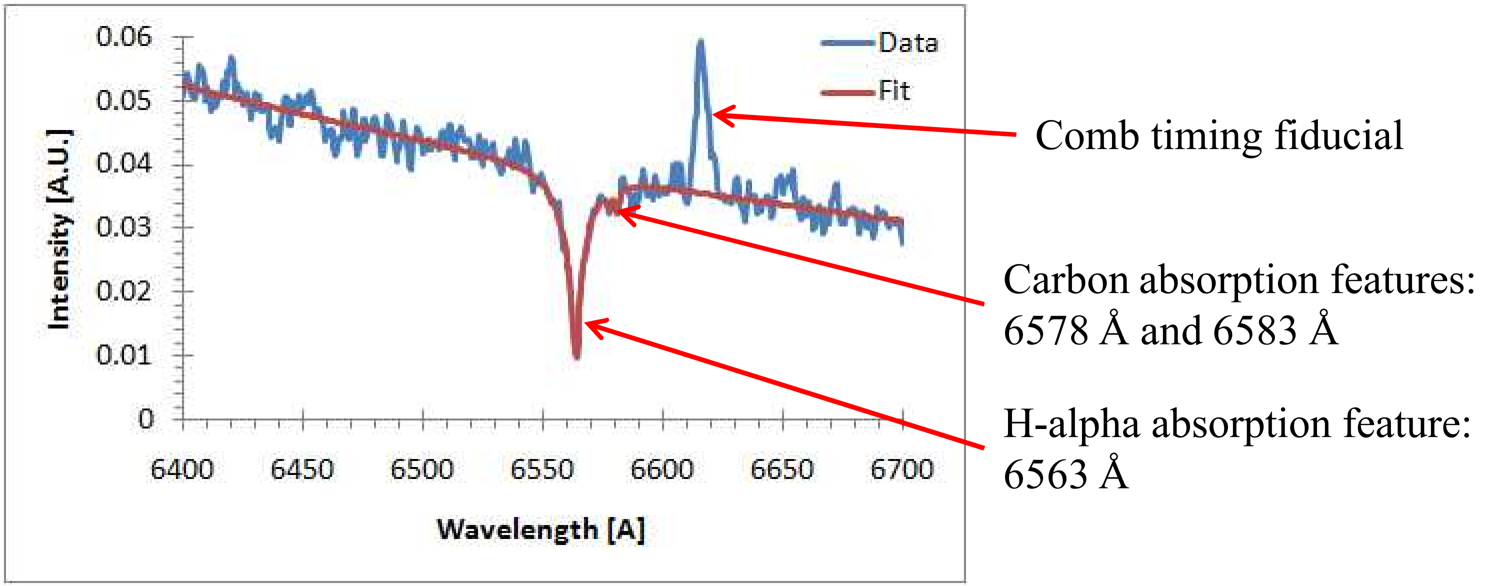
Sample Data

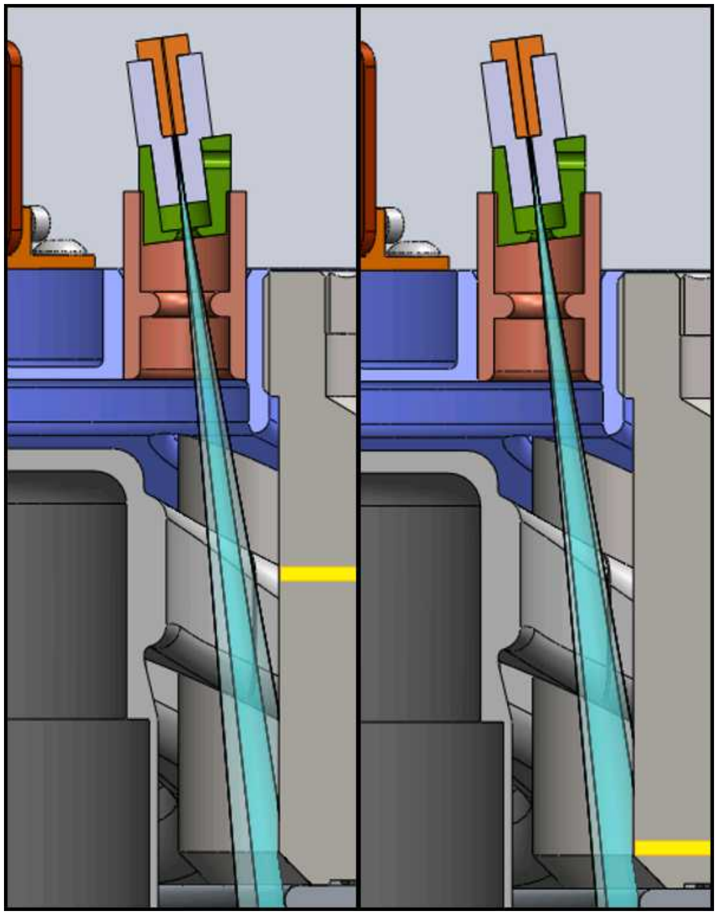

SVS – Z2110
6800
6600
6400
6200
Wavelength [A]
2950
3000
3050
3100
3150
Time [ns]
Spectral fiducial – 6796 Å
Timing fiducial – 4 ns comb
Absorption feature – 6563 Å
Continuum emission
Lineout region – 5 ns wide
Spectral fiducial– 6328 Å
Timing fiducial– impulse @ 3002 ns machine time

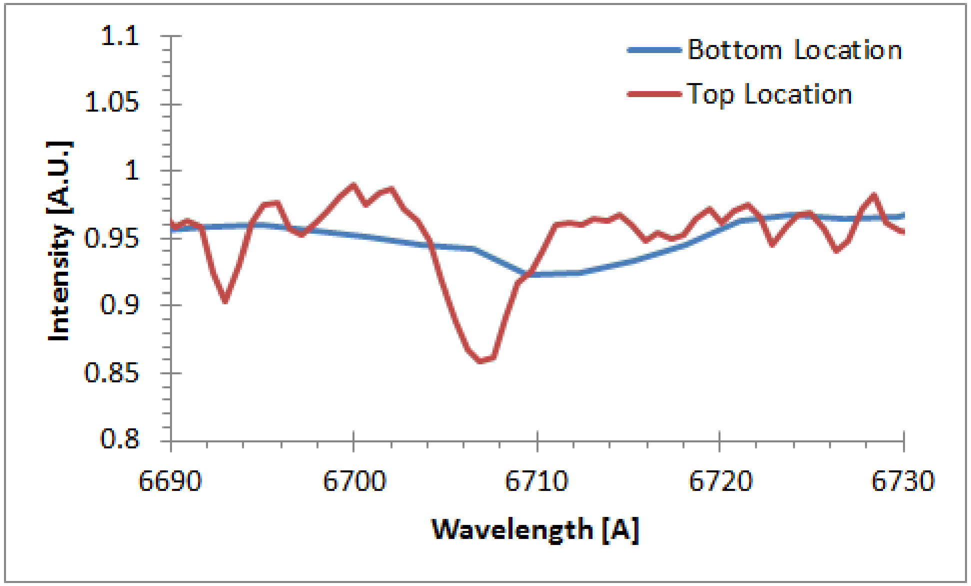
Sample Data



For the cases where the shape of the H-alpha feature was used to infer the density of the plasma, a linear fit to the continuum was combined with a fit to the absorption features in the spectrum. A least squares regression analysis was applied to optimize the fit.

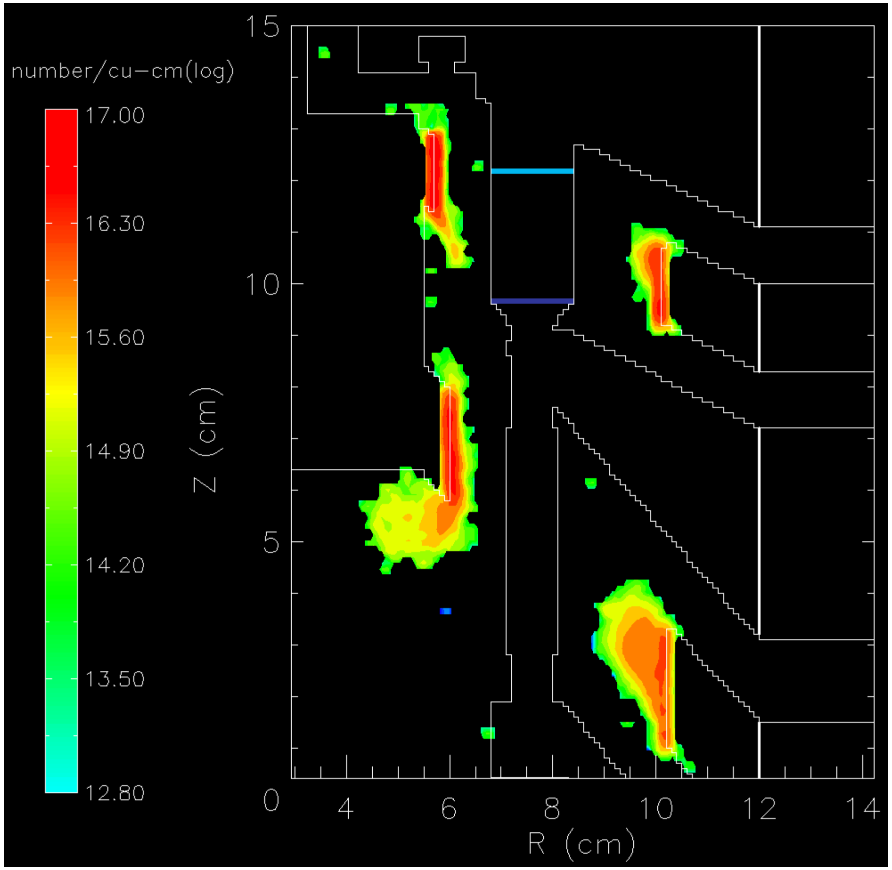
Dopant shots[3]





There is a distinct absorption peak at 6708 Å for the case with the dopant in the top location (the left view), while there is no feature observed for the case with the dopant at the bottom location.

Dopant shots[5]



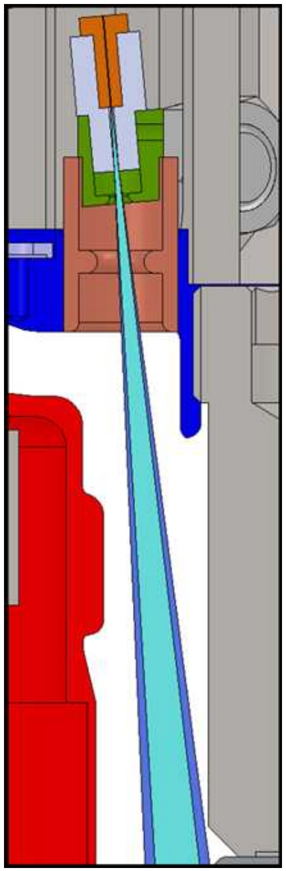
The initial top dopant location is shown in light blue and the initial bottom dopant location is shown in dark blue.

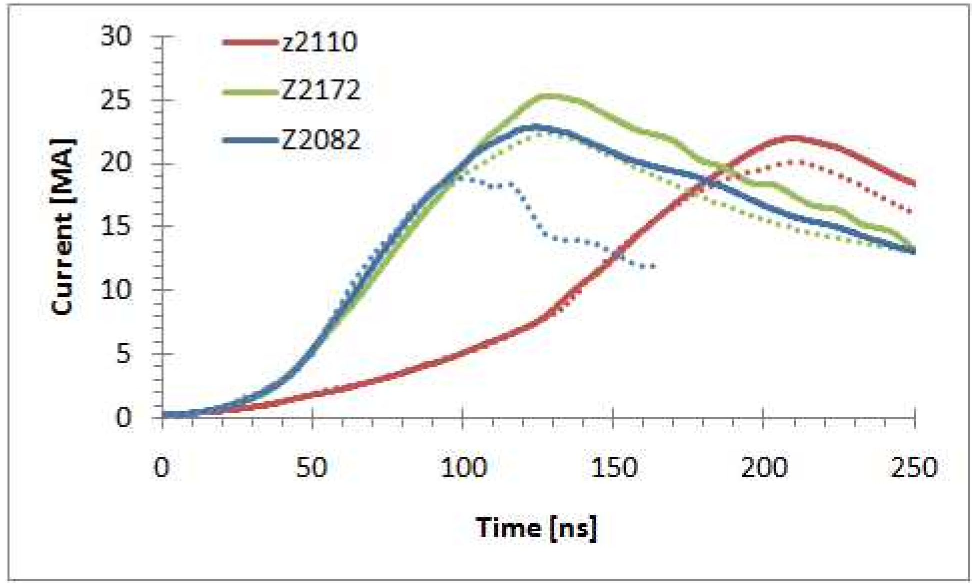
Li absorption feature was observed with the dopant in the top location and not with the dopant in the bottom location.

Confirms that observed continuum is located in the convolute.

Places bounds on the location of the backlighting plasma.

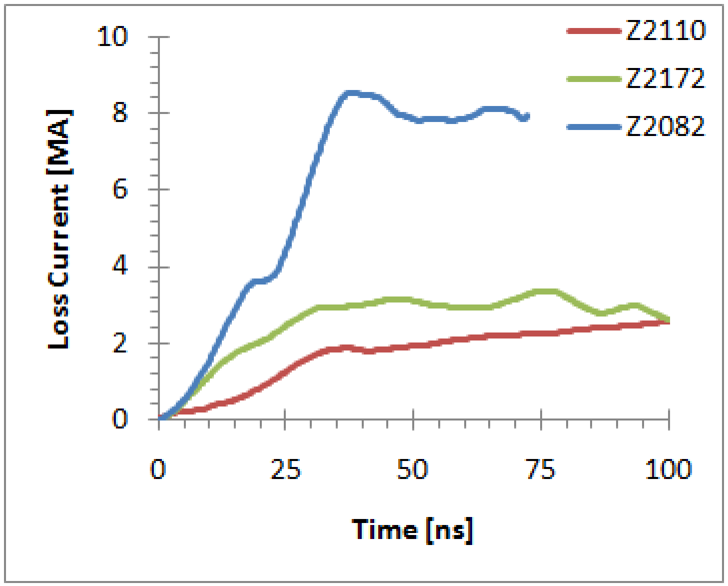
Plasma density versus load



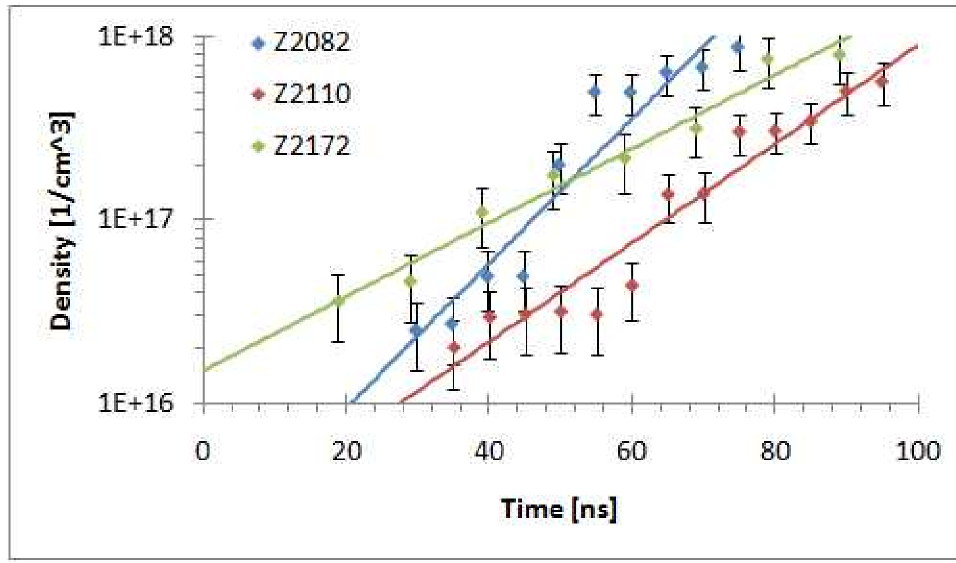


A comparison of the current for three shots with different loads. The solid lines show the MITL current and the dashed lines show the load current.

Plasma density versus load



A comparison of the loss current for the three shots with different loads. A time shift has been applied such that the loss currents all start at t = 0.



The inferred density based on the spectroscopic measurements with identical convolute views on three shots with different loads.

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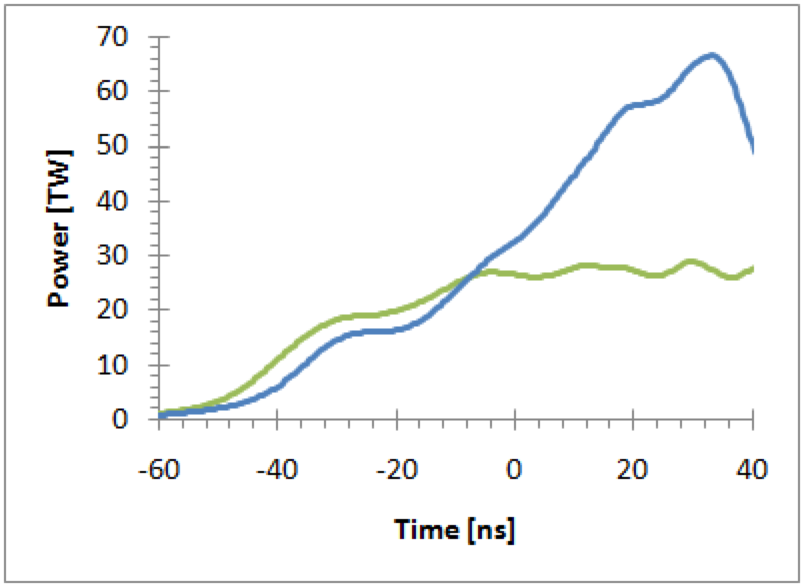
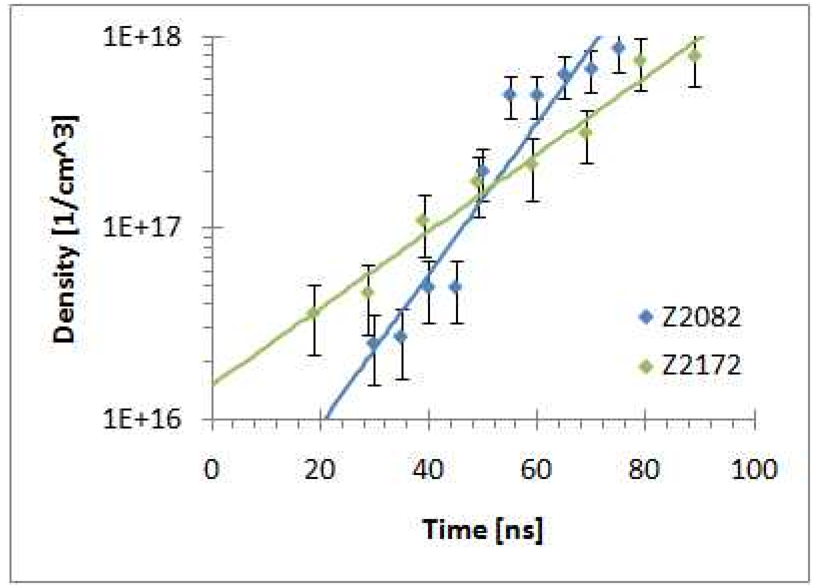
Plasma density versus load





Z2172 has greater initial inductance, but Z2082 has a larger L-dot. For approximately 40-50 ns, Z2172 has greater electrical power and higher plasma density than Z2082. Subsequently Z2082 overtakes Z2172 in both categories. Note that the electrical power is on a different time scale than the plasma density.

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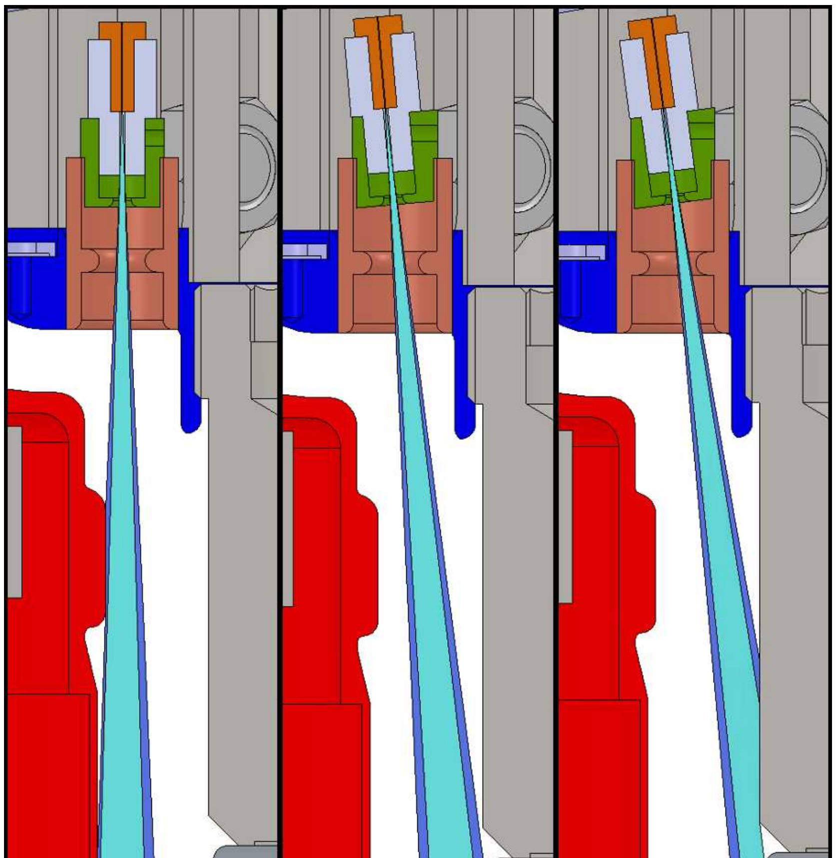
A-K Gap Closure[3]

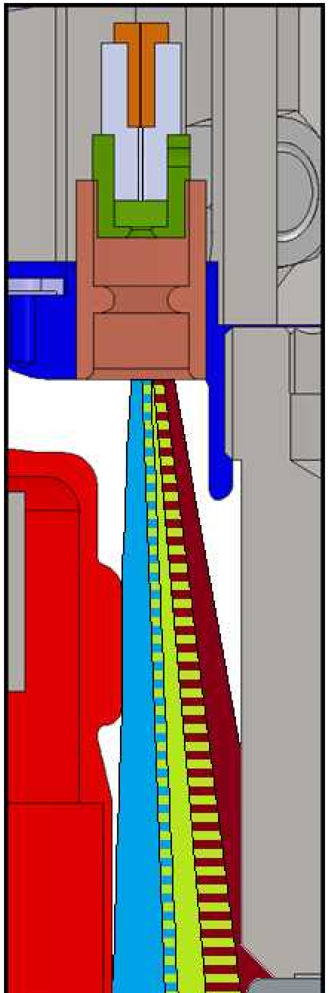


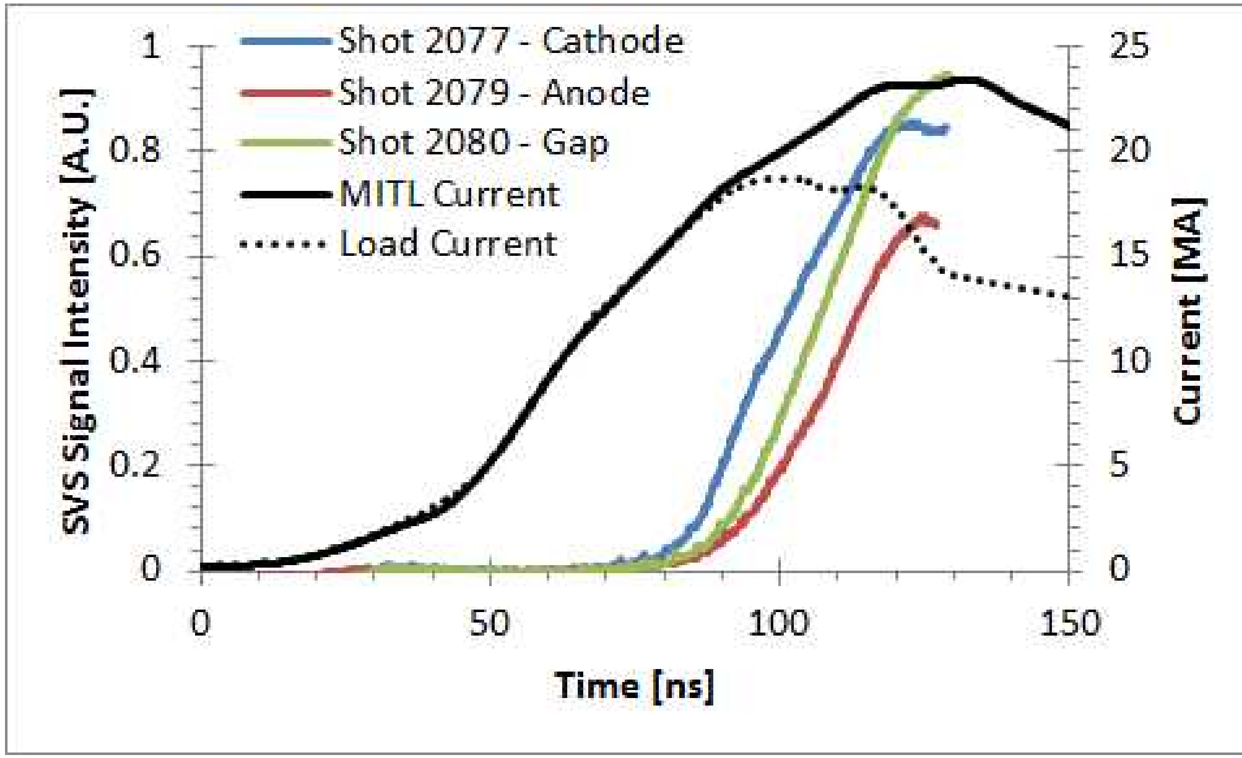
Goal is to examine the plasma motion in the anode-cathode gap.

Determine direction of plasma motion and estimate the velocity of the plasma.

Experimental setup:
- Three nominally identical shots
- Identical diagnostic settings
- Three different views of the convolute

A-K Gap Closure





Based on these measurements, the anode-cathode gap closure velocity could be as high as 40 cm/µs.

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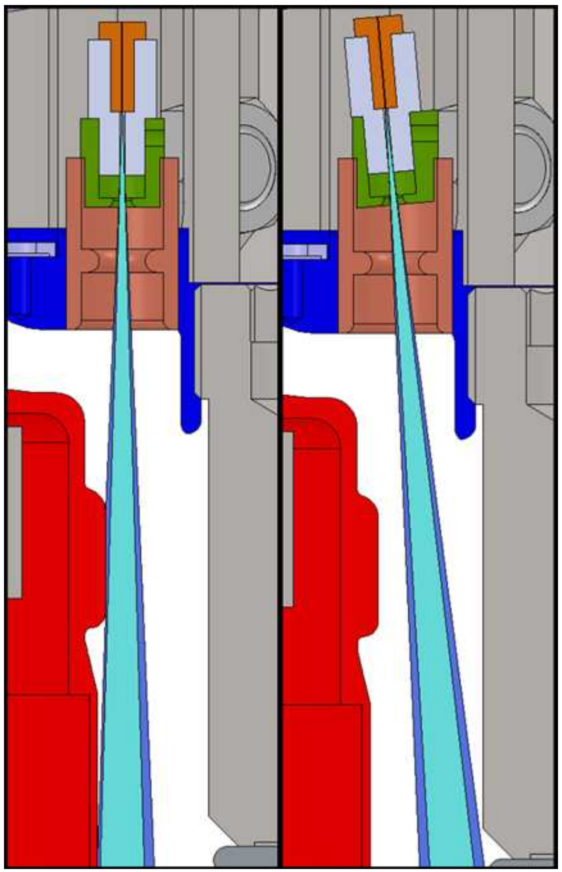
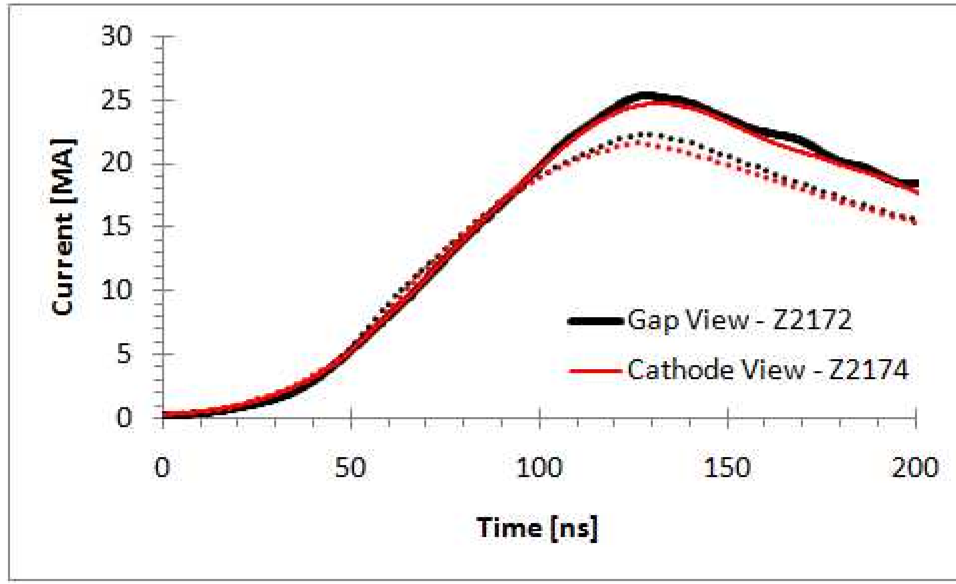
Plasma density vs position





A comparison of the current for two nominally identical shots. The solid lines show the MITL current and the dashed lines show the load current.

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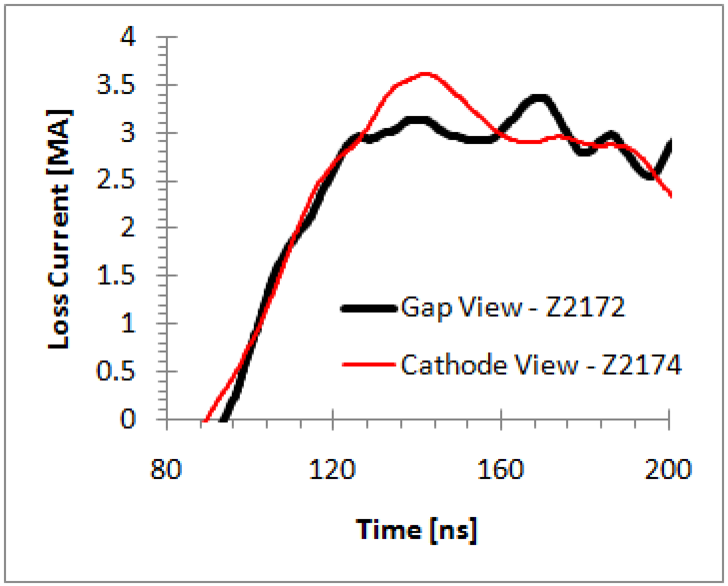
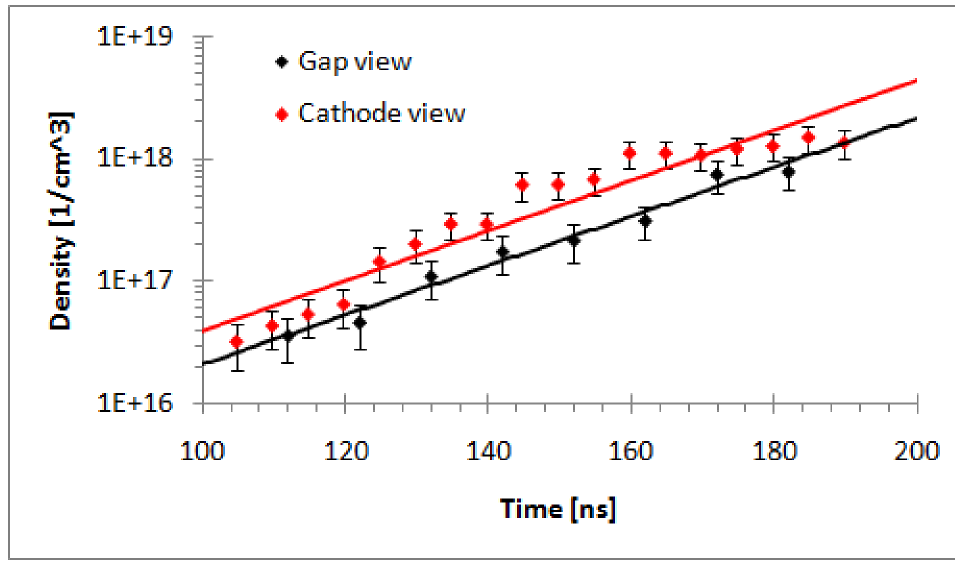
Plasma density vs position



A comparison of the loss current for the same two nominally identical shots.



The inferred density based on the spectroscopic measurements with two different convolute views on the same two nominally identical shots.

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

Summary

- Shots utilizing Li dopant show that observed plasma is within the convolute
  - Identified upper limit for axial position of continuum source
  - May have also set lower limit for axial position of continuum source
- Measured plasma densities up to 10^{18} cm^{-3}
- Showed strong dependence of plasma density on load dynamics
- Established that plasma crosses A-K gap from cathode to anode
  - Apparent closure velocity is 10s of cm/μs

References

[1] K. R. LeChien, W. A. Stygar, M. E. Savage, P. E. Wakeland, V. Anaya, D. S. Artery, M. J. Baremore, D. E. Bliss, R. Chavez, G. D. Coombs, J. P. Corley, P. A. Jones, A. K. Kipp, B. A. Lewis, J. A. Lott, J. J. Lynch, G. R. McKee, S. D. Ploor, K. R. Prestwich, S. A. Roznowski, D. C. Spencer, S. D. White, and J. R. Woodworth, "6.1-MV, 0.79-MA Laser-Triggered Gas Switch for Multimodule, Multiterawatt Pulsed-Power Accelerators," *Physical Review Special Topics -Accelerators and Beams, vol. 13, 2010, pp. 1-11.*

[2] D. V. Rose, D. R. Welch, C. L. Miller, R. E. Clark, E. A. Madrid, C. B. Mostrom, T. C. Wagoner, J. K. Moore, W. A. Stygar, J. E. Bailey, T. J. Nash, G. A. Rochau, and D. B.Sinars, "10^7-A Load-Current B-Dot Monitor: Simulations, Design, and Performance," *Physical Review Special Topics - Accelerators and Beams, vol. 13, 2010, pp. 1-9.*

[3] M.R. Gomez, Plasma Evolution and Current Loss in Post-Hole Convolutes, Ph.D. Dissertation, Defended Nov. 18, 2010; Final Submission Dec. 16, 2010.

[4] D. V. Rose, D. R. Welch, T. P. Hughes, R. E. Clark, and W. A. Stygar, "Plasma Evolution and Dynamics in High-Power Vacuum-Transmission-Line Post-Hole Convolutes," *Physical Review Special Topics – Accelerators and Beams, Vol. 11, 2008, pp. 1-10.*

[5] D. V. Rose, D. R. Welch, R. E. Clark, E. A. Madrid, C. L. Miller, C. Mostrom, W. A. Stygar, M. E. Cuneo, C. A. Jennings, B. Jones, D. J. Ampleford, and K. W. Struve, "ZR-Convolute Analysis and Modeling: Plasma Evolution and Dynamics Leading to Current Losses," Pulsed Power Conference Proceedings, vol. 17, 2009, pp.1153-1158.

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