Determination of plasma sheath current distributions by comparison of Zeeman spectroscopy with B-dot measurements in laser ablation Z-pinch experiments

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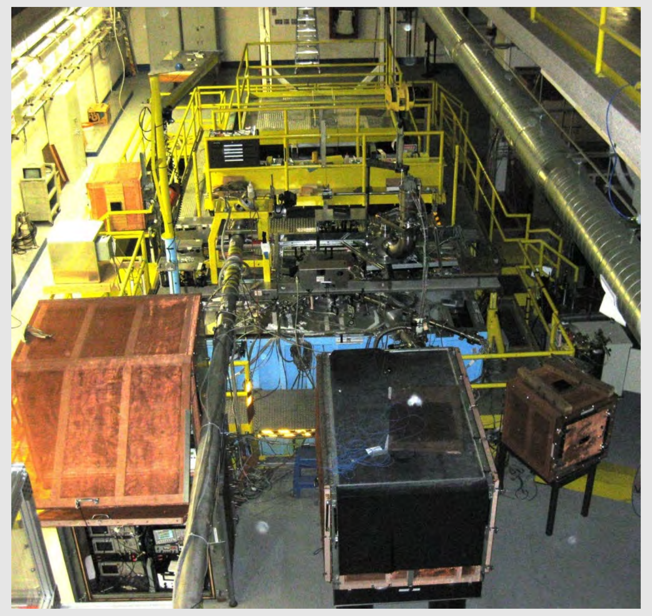
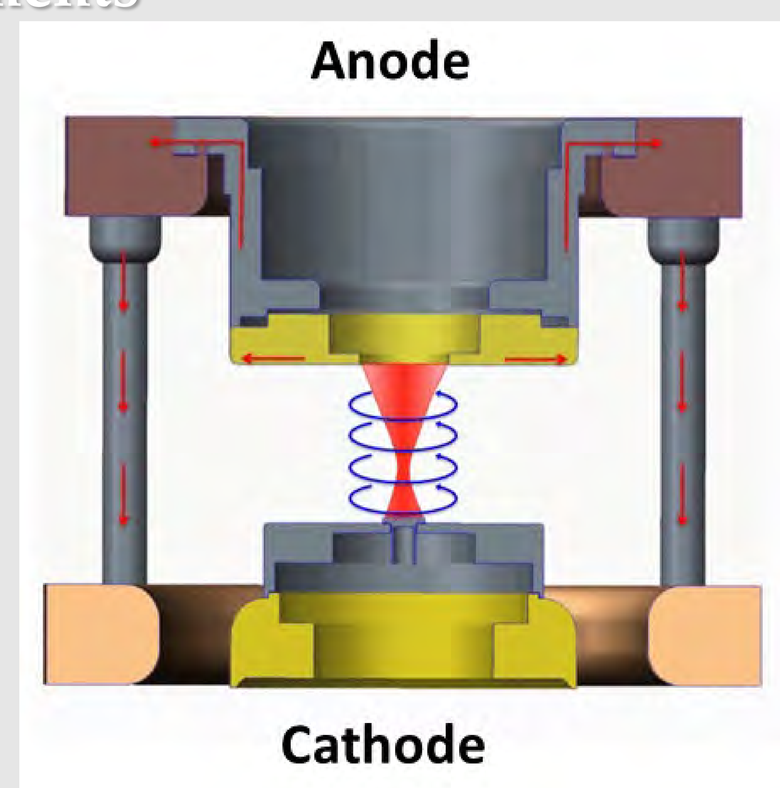
Introduction and Motivation



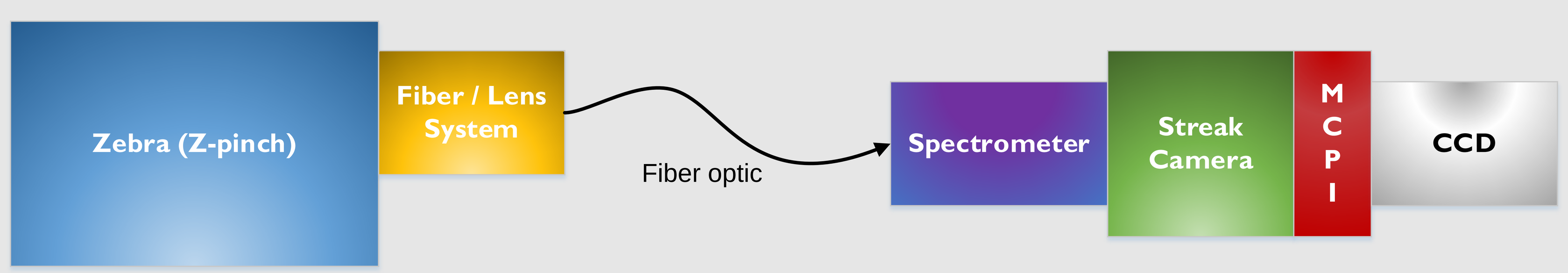
In plasma pinch experiments, measurements of current distributions and losses across the anode-cathode gap are needed to ensure uniform and repeatable implosions. Traditional B-dots diagnostics measure current a considerable distance away from the plasma source and provide little detailed information on the current distribution across the plasma sheath near the pinch. In the experiments presented here, visible spectroscopic techniques were used to measure magnetically induced Zeeman splitting. Ionic plasma species were chosen such that the Zeeman splitting of different fine structure doublets split non-uniformly with increasing magnetic field strength in the plasma. This differential splitting enables measurements of non-directional B-field strengths in the plasma across a wide range of conditions. More specifically, the optical emission of Al III, C IV, and O VI doublets, $^2P_{3/2}$ to $^2S_{1/2}$ and $^2P_{1/2}$ to $^2S_{1/2}$ transitions were measured and used to determine the Zeeman broadening. We have applied this technique to diagnose time- and space-resolved B-field strengths in laser ablation Z-pinch experiments (LAZE). Experiments were conducted at the Nevada Terawatt Facility (NTF) using the TW-class Leopard laser and the 1 MA Zebra Z-pinch. The currents inferred from Zeeman spectroscopy measurements were compared to those determined from the B-dot diagnostics.

Experimental Setup for Laser Ablation Z-pinch Experiments

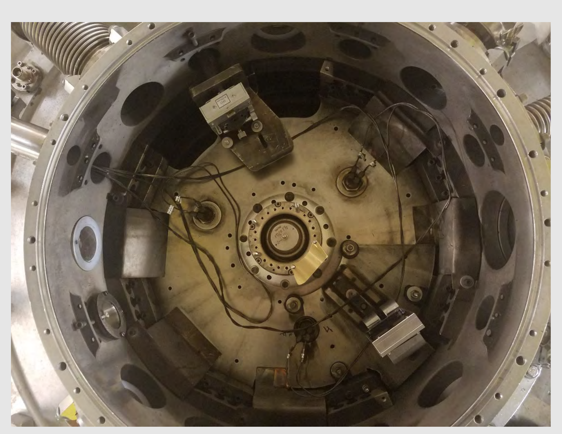
- A Terawatt class laser is used to ablate a target. Material spreads across the A-K gap and 1 MA from pulse-power generator (Zebra) pulse through the plasma sheath creating a JXB force that pinches the target material
  - Laser ablation targets used were polyethylene, aluminum oxide, and titanium deuteride
- Light is collected from plasma sheath through an off axis parabola collimator and routed via fiber to a streaked spectrometer
- Spectra Pro Model 2750
  - 150 gr*/mm, 1800 gr/mm, 2400 gr/mm (*grooves/mm)
- Streak Camera: NSTec L-CA-24
  - Sweep window of 480 ns



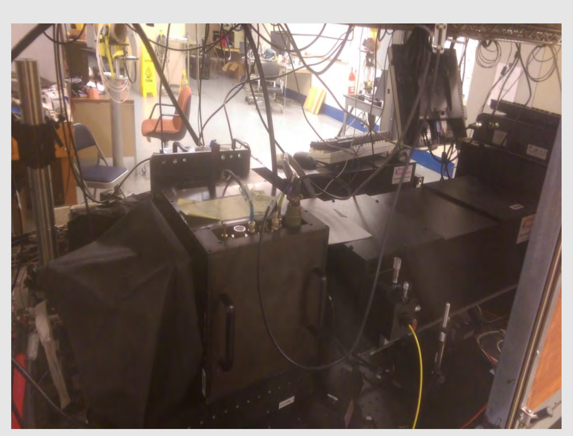
Laser Ablation Z-pinch Experiment illustration



Al_2O_3 target for LAZE campaign



Zebra Chamber, load placed at center of chamber



Streaked spectrometer system

Spectroscopy Data and Results for LAZE

Data from experiment is examined below. I series of lineout from streaked spectrum data, for Aluminum, Carbon and Aluminum Oxide are used to identify magnetic fields in the plasma.

Background image subtraction was done to improve the image/spectral quality
- Savitzky-Golay filter was applied to smooth the data and improve the signal to noise
- Simulation using a Zeeman spectral modeling code is used to analyze the data
  - The code incorporates both Doppler and collision broadening effects.

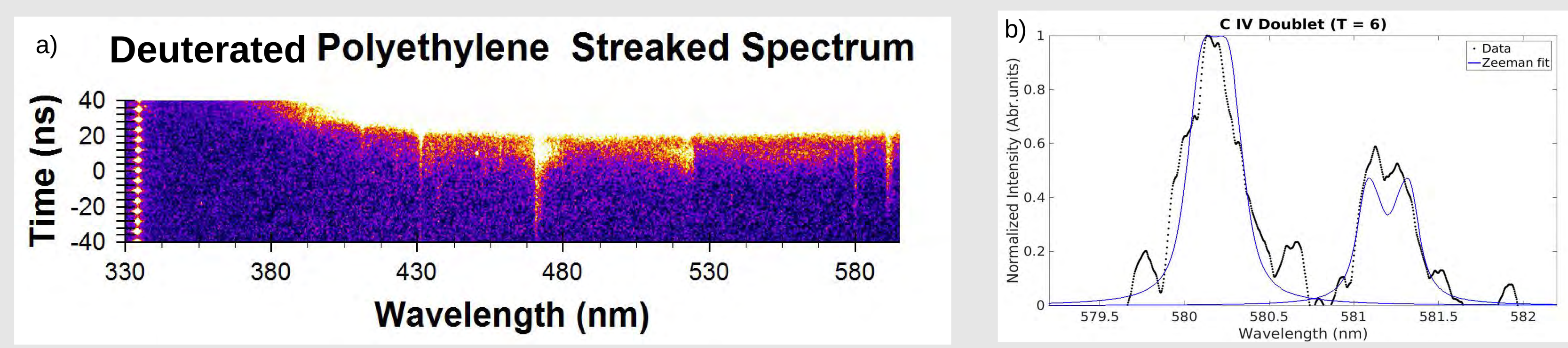


Figure 1: a) Streak spectrum of deuterated polyethylene and b) lineout of Streak spectrum of deuterated polyethylene

Streaked spectrum of deuterated polyethylene from LAZE is shown in **Figure 1.**
- The lower graph is of the C IV doublet
  - T_{ion} ~ 10 eV & N_e ~ 1e17 cm^{-3}
  - At t = 0 the magnetic field inferred from the simulation is B = 6 T.

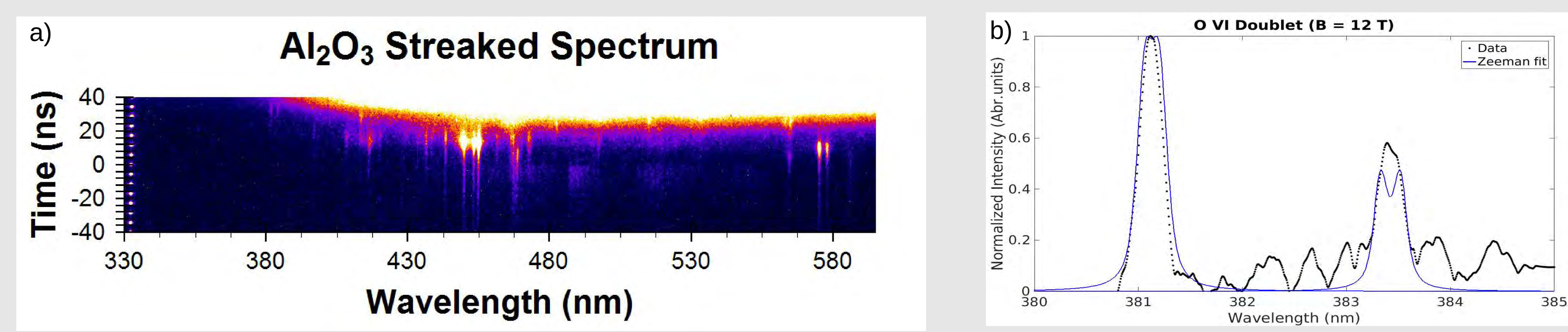


Figure 2: a) Streak spectrum of aluminum oxide and b) lineout of Streak spectrum of aluminum oxide

Streaked spectrum of aluminum oxide from LAZE as seen in **Figure 2**
- Top graph is a lineout separated O VI doublet.
- Zeeman spectral modeling code is applied
  - T_{ion} ~ 50 eV & N_e ~ 1e17 cm^{-3}
  - At t = 0 the magnetic field inferred from the simulation is B = 12 T
- The emission spectra is taken ~ 20 ns after Al III emission ends

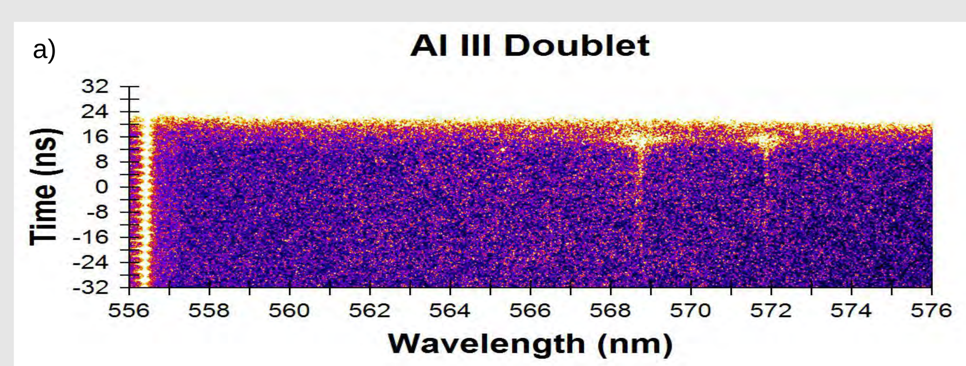
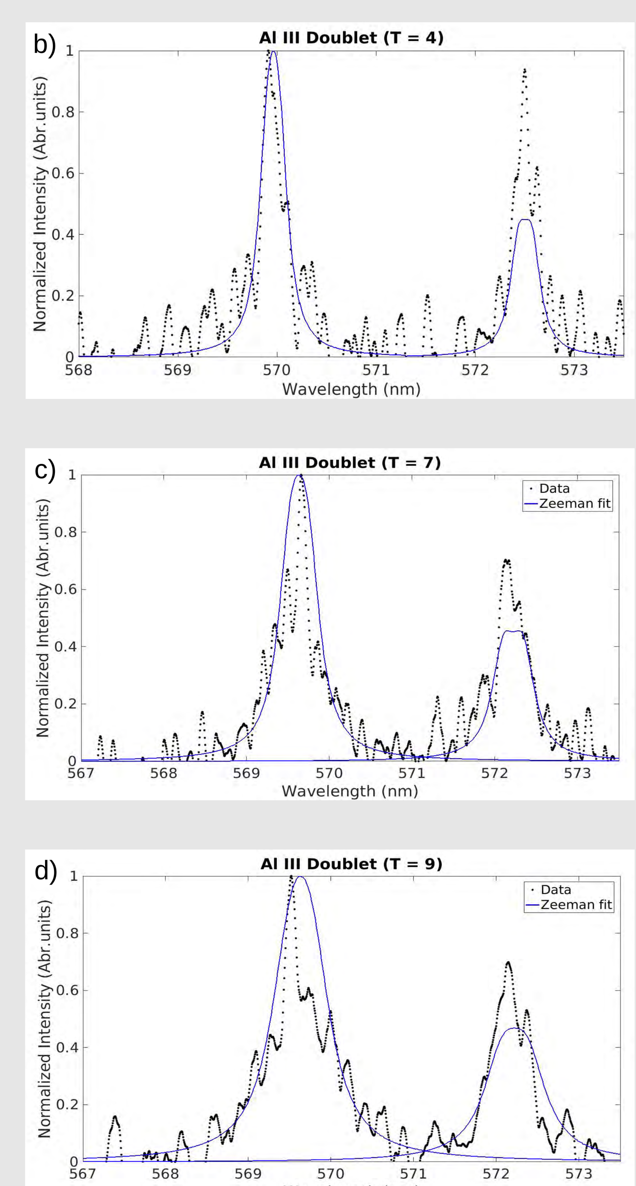


Figure 3: a) Streak spectrum of Al III doublet, b) lineout of Streak spectrum of Al III doublet at t = 0 ns, c) lineout of Streak spectrum of Al III doublet at t = 4 ns, and d) lineout of Streak spectrum of Al III doublet at t = 8 ns,



Al III Doublet shown in **Figure 3 a)** is an image taken from the streak spectrometer system using the high resolution grating

- **Figure 3 b), c), and d)** to the right are lineout separated by 4 ns of the Al III doublet.

- Zeeman spectral modeling code is applied

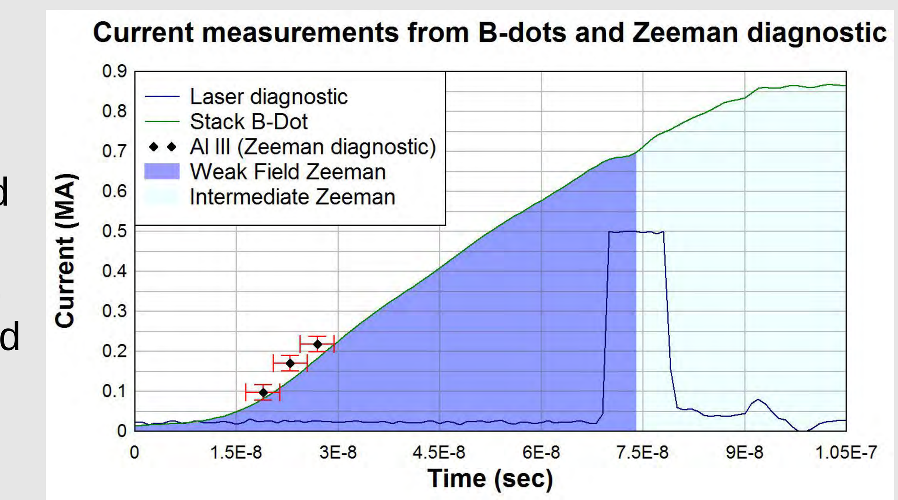
  - T_{ion} ~ 10 eV
  - N_e ~ 5e16 - 4e17 cm^{-3}
  - At t = 0, t = 4 and t = 8 ns the magnetic field inferred from the simulation is B = 4, B = 7 and B = 9 T, respectively

Comparison of current measurements

B-dots (traditional current diagnostic for pulse power applications).
- Current measurements reflect data taken from anode plate and stack b -dots

$$B[T] = 200\ \frac{I[MA]}{R\ [mm]} \quad \text{or} \quad B[T]\frac{R[mm]}{2000} = I[MA] \quad \textit{eq. 1}$$

Data taken from Zeeman diagnostic magnetic field measurements for Al III doublet
- Current for Al III doublet is calculated using eq. 1
- Plot along side B-dot measurements
- Both weak field and intermediate field Zeeman limits are shown
  - Our Zeeman line emission code works for all limits.



Conclusion and Future Work

Streaked spectra of Al III, C VI and O VI have been captured for laser ablation Z-pinch experiments at the NTF.
- New optical probe designs were incorporated into experiments. These provided higher spatial resolution capability than previous experiments.
- Simulation using Zeeman spectral modeling code has been conducted and applied to streaked spectral data.
- High resolution spectra were captured for Aluminum and Carbon.
- Low resolution spectra were captured for Oxygen

Future work will be conducted at the NTF in order to continue diagnosing laser ablation Z-pinch experiments.
- Continue high resolution acquisition of Al III, C IV, and O VI targets
  - Expand research to incorporate other potential useful transitions
- Continue development of Zeeman spectral modeling code.
  - Incorporate instrumental resolution and least square minimization error analysis

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Poster Information

This poster was prepared for and presented at the APS Division of Plasma Physics conference in October 2017 in Milwaukee, WI, by Eric Dutra. dutraec@nv.doe.gov. This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program. DOE/NV/25946--3394. This work was supported by the University of Nevada, Reno, under the U.S. DOE/ NNSA Cooperative Agreement No. DE-NA0002075.