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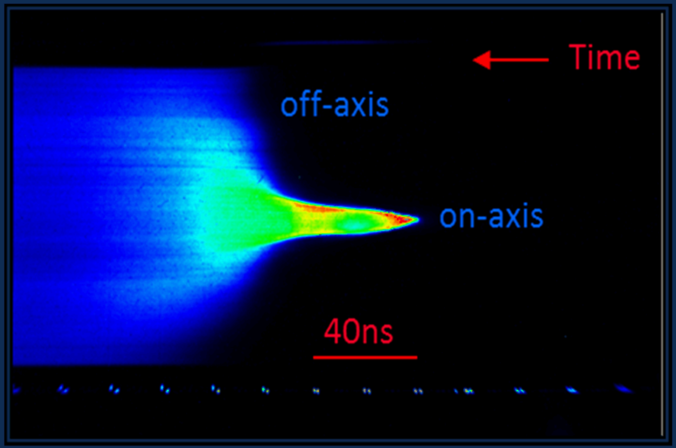

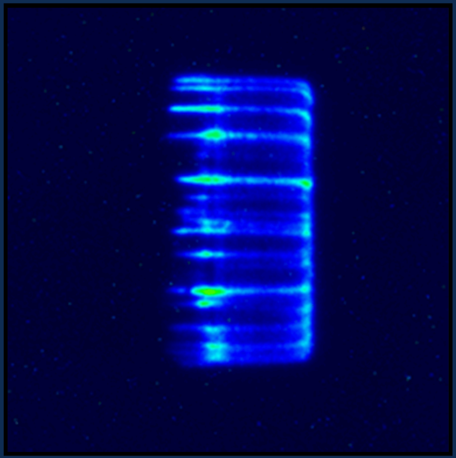

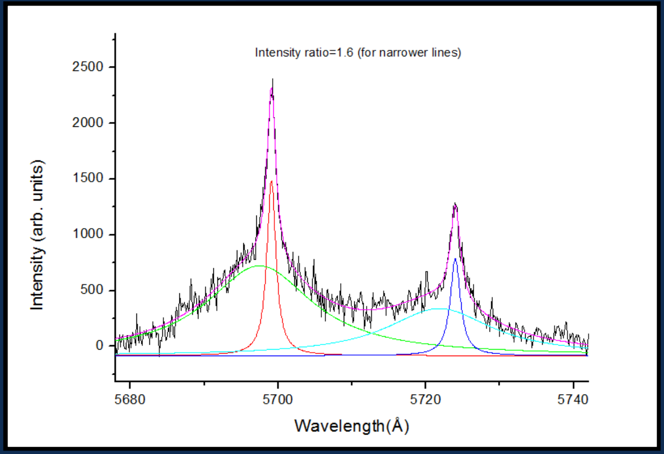

ELECTRIC AND MAGNETIC FIELD MEASUREMENTS IN HIGH ENERGY ELECTRON BEAM DIODE PLASMAS USING OPTICAL SPECTROSCOPY*

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Abstract

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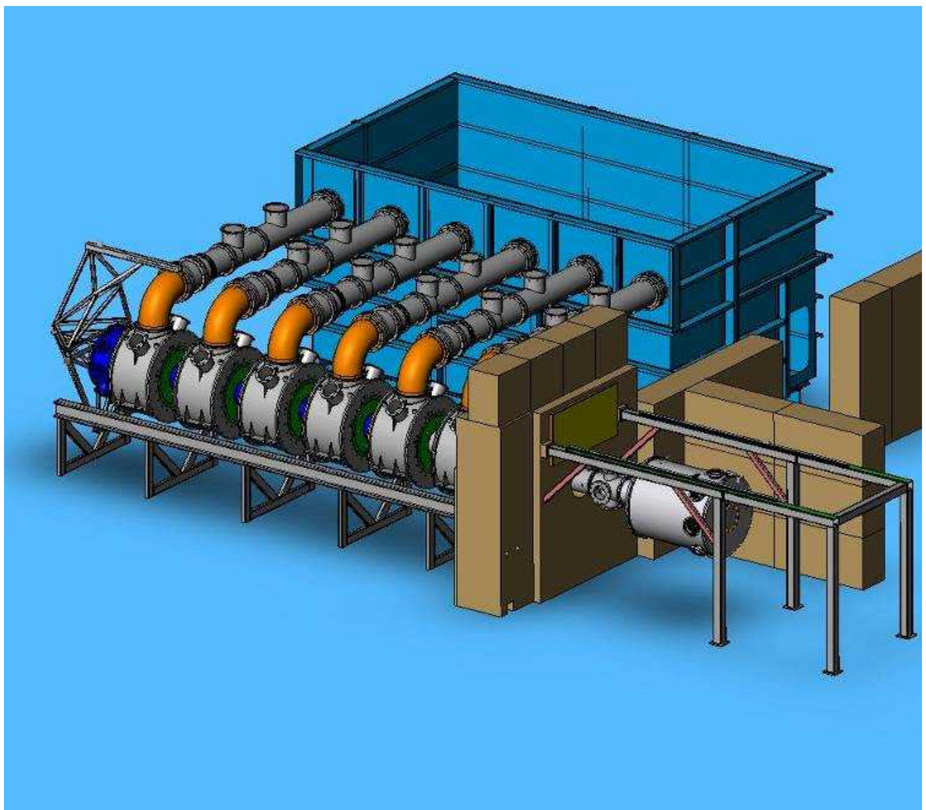
The RITS accelerator (5-11MV, 100-200kA) at Sandia National Laboratories is being used to evaluate the Self-Magnetic Pinch (SMP) diode as a potential flash x-ray radiography source. This diode consists of a small, hollowed metal cathode and a planar, high atomic mass anode, with a small vacuum gap of approximately one centimeter. The electron beam is focused, due to its self-field, to a few millimeters at the target, generating bremsstrahlung x-rays. During this process, plasmas form on the electrode surfaces and propagate into the vacuum gap, with velocities of 1-10 cm's/microseconds. These plasmas are measured spectroscopically using a Czerny-Turner spectrometer with a gated, ICCD detector, and input optical fiber array. Local magnetic and electric fields of several Tesla and several MV/cm were measured through Zeeman splitting and Stark shifting of spectral lines. Specific transitions susceptible to quantum magnetic and electric field effects were utilized through the application of dopants. Data was analyzed using detailed, time-dependent, collisional-radiative (CR) and radiation transport modeling.
Recent results will be presented.

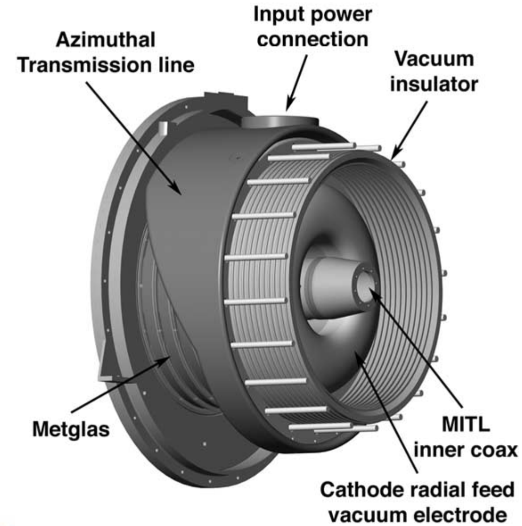
Outline

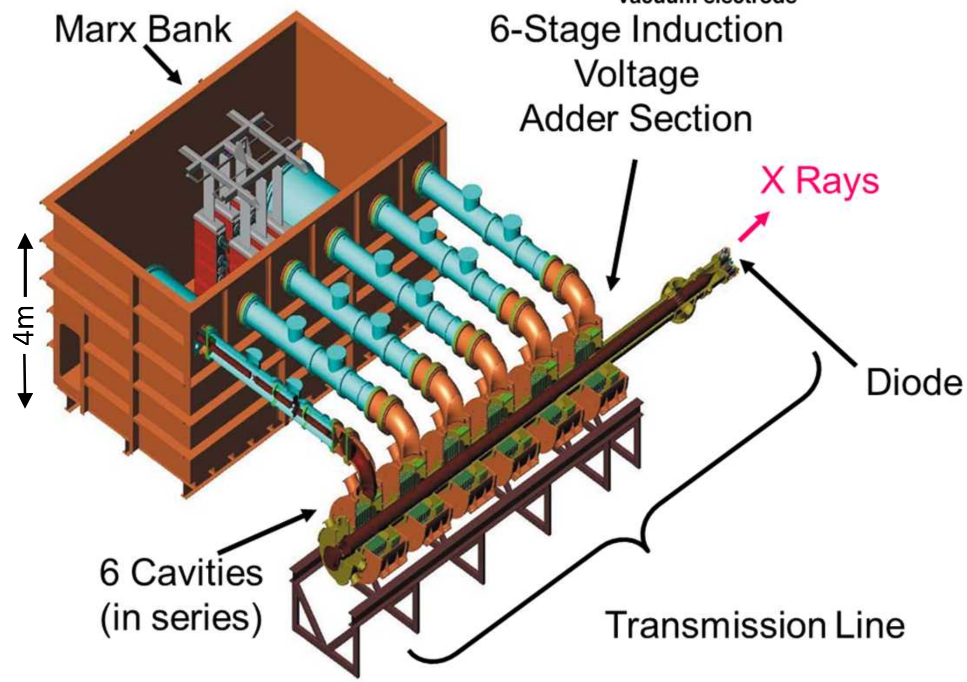
- RITS-6 Accelerator at Sandia National Laboratories (SNL)
- Self-Magnetic Pinch (SMP) E-beam Diode
- Plasma Diagnostics
- Zeeman Splitting Measurements (B-field)
- Stark Shift Measurements (E-field)
- Summary and Conclusions
- Future Work

RITS-6 Pulsed-Power Accelerator at Sandia National Laboratories (SNL)

RITS-6 is a 8-11 MeV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of electron beam diodes.[1]

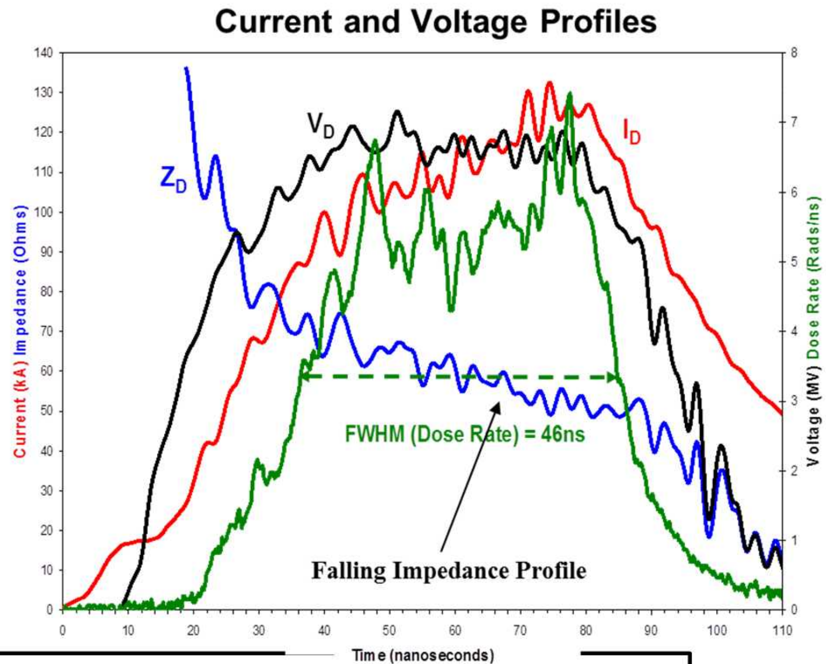






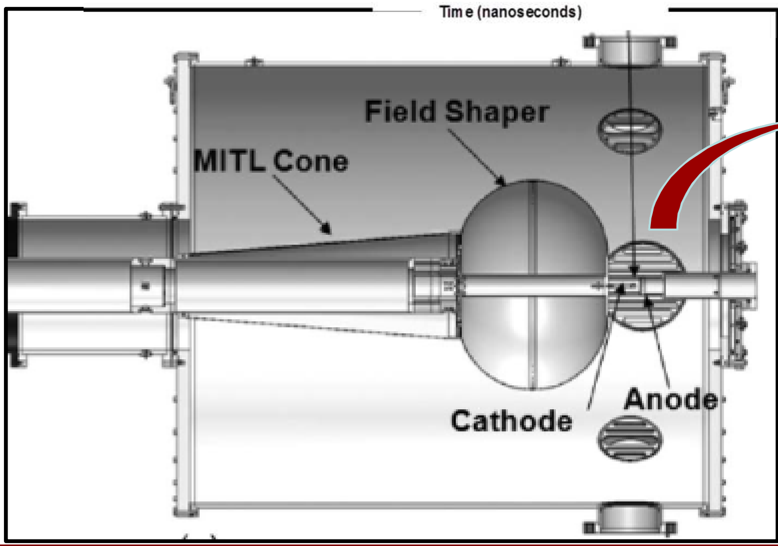
[1] D. Johnson, et al., *Proc. 15th IEEE Int. Pulsed Power Conf.* (IEEE, Jun. 13-17, 2005) p. 314–317.

Characteristics of the SMP Diode as Fielded on the RITS-6 Accelerator

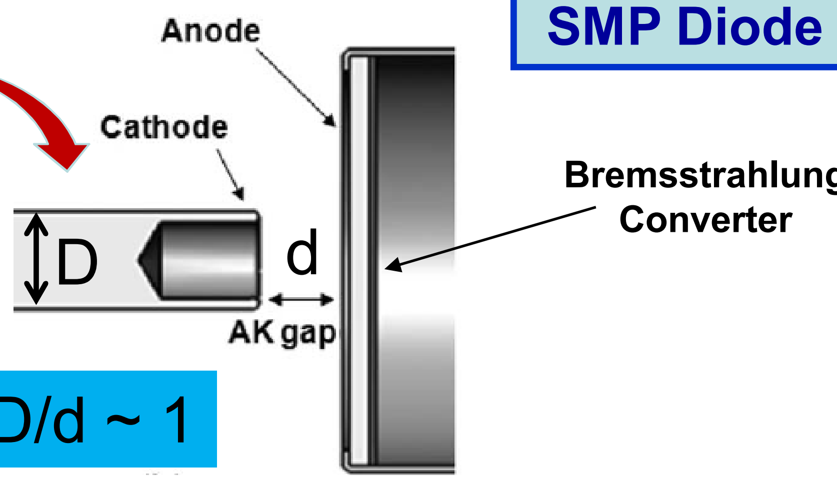


<u>SMP Diode Parameters</u>[2]

- 6-8.5 MV
- 150 kA (~15% ions)
- 50 Ω Impedance
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- > 350 Rads @ 1 meter
- < 3 mm focal spot size



SMP Diode

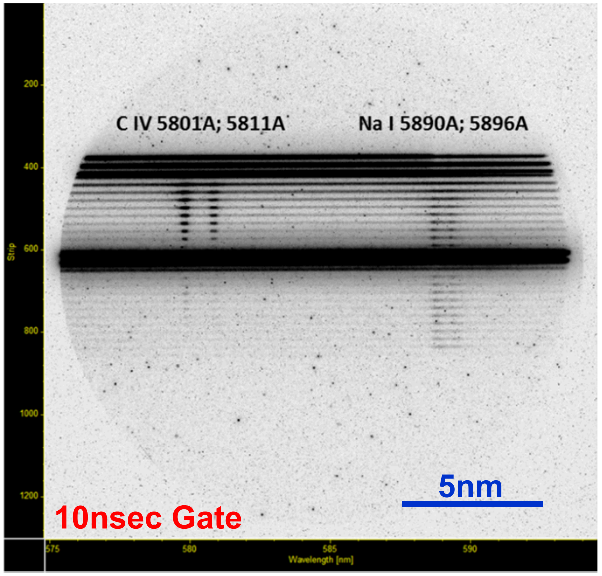


D/d ~ 1

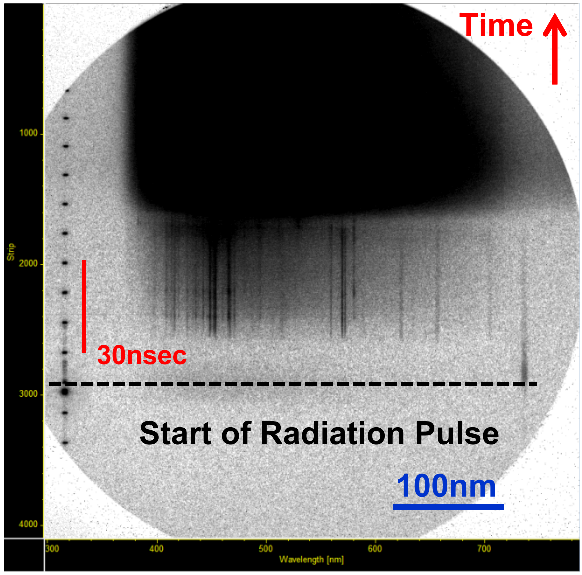
[2] K. Hahn, N. Bruner, M. D. Johnston, B.V. Oliver, et. al., IEEE Trans. Plasma Sci. 38 (2010) 2652-62.

Plasma Measurements Taken on the SMP Diode

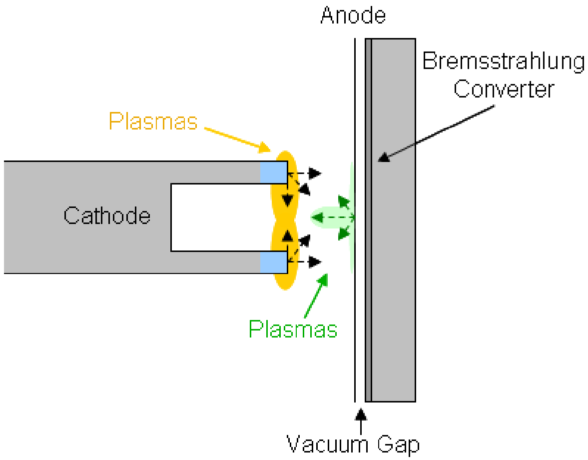
- Multi-Fiber Gated spectra
- Streaked spectra
- Avalanche Photodiodes

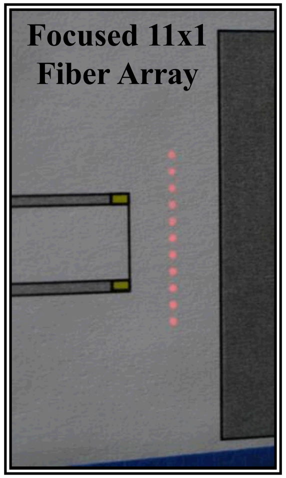


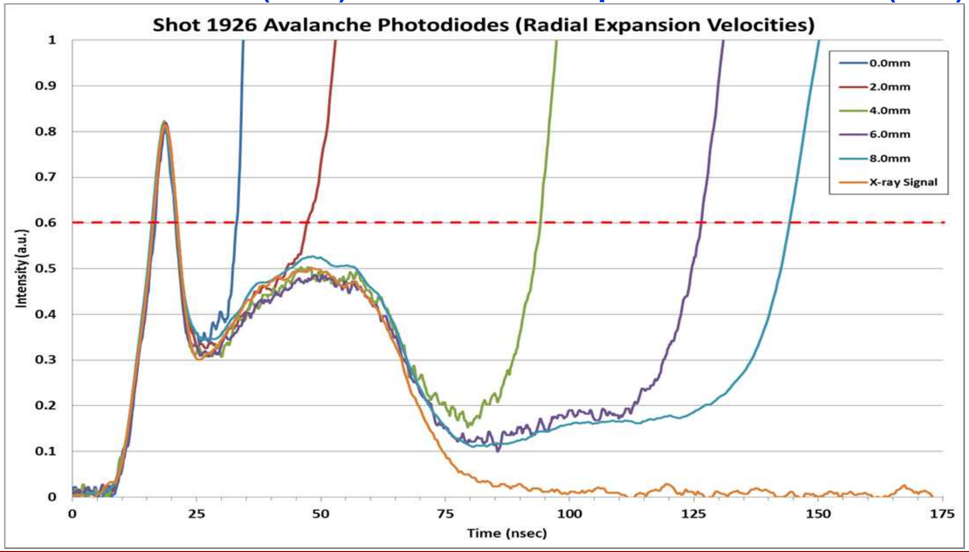
High Spectral Resolution (0.5A)



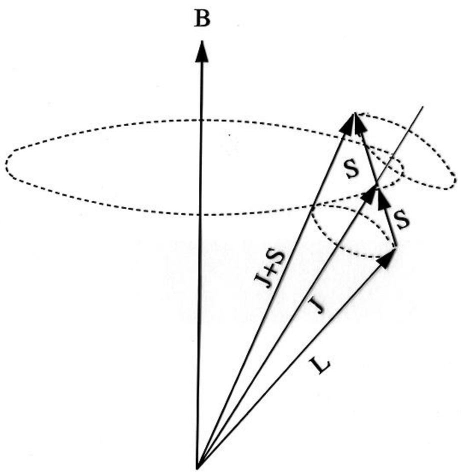
Lower Spectral Resolution (10A)

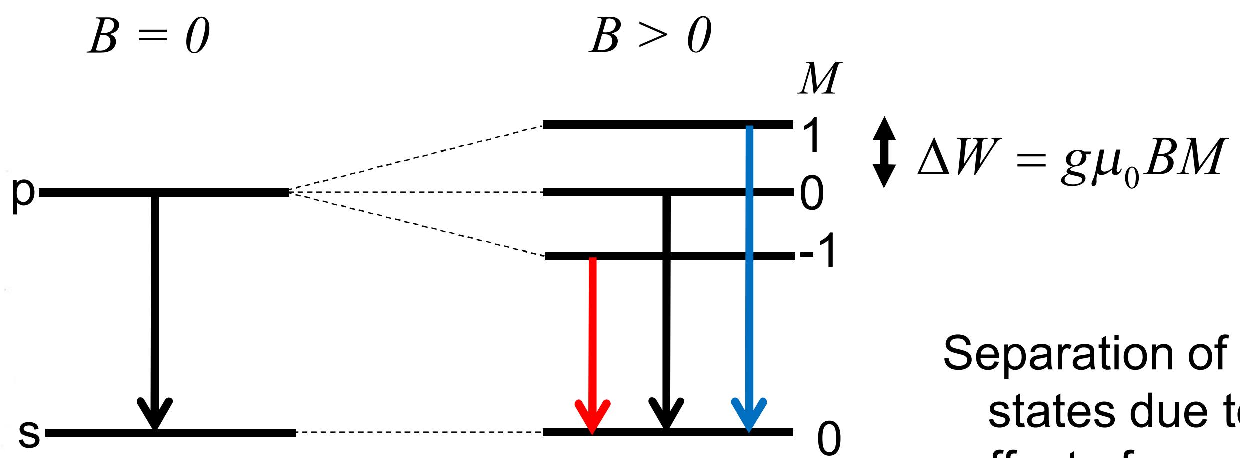




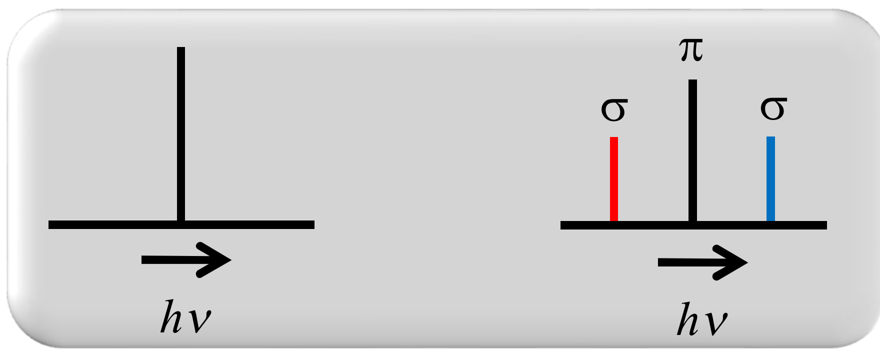


Zeeman Splitting is a Useful Technique for Magnetic Field Measurements in Plasmas





Observed



Separation of energy states due to the effect of an applied B-field on the magnetic moment of an atom or ion.

$$h\Delta\nu = \mu_0 B\left(g_u M_u - g_l M_l\right), \begin{bmatrix} \Delta M = 0, \ \pi \\ \Delta M = \pm 1, \ \sigma \end{bmatrix}$$

Zeeman Splitting of Carbon and Aluminum Lines (Single Array)

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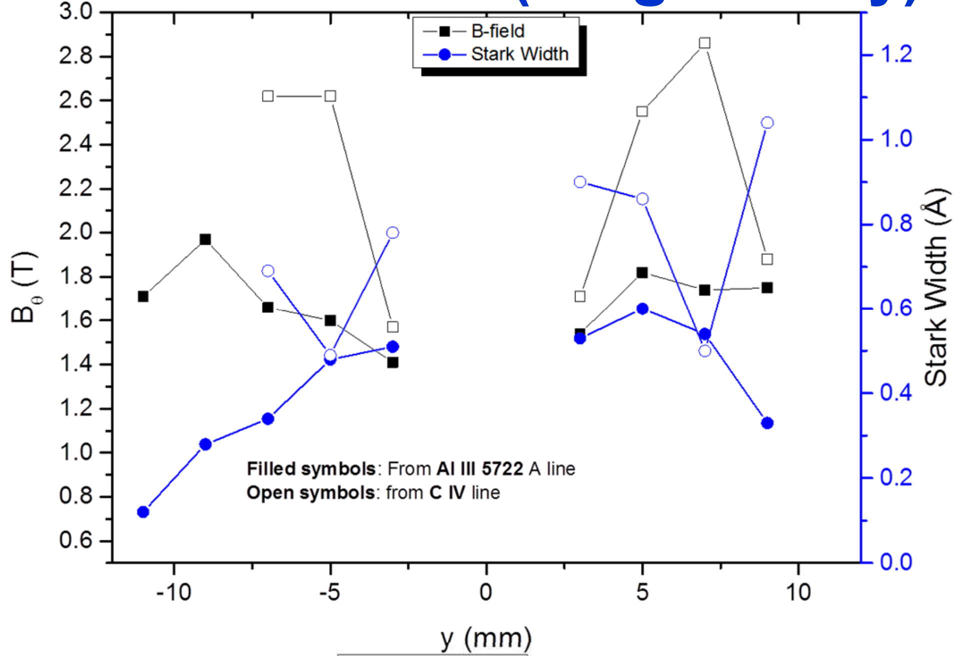
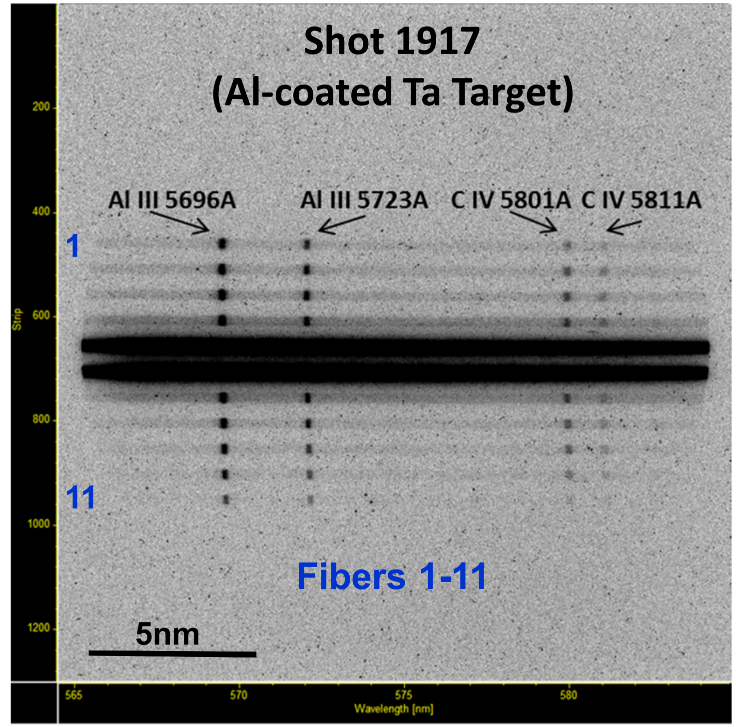
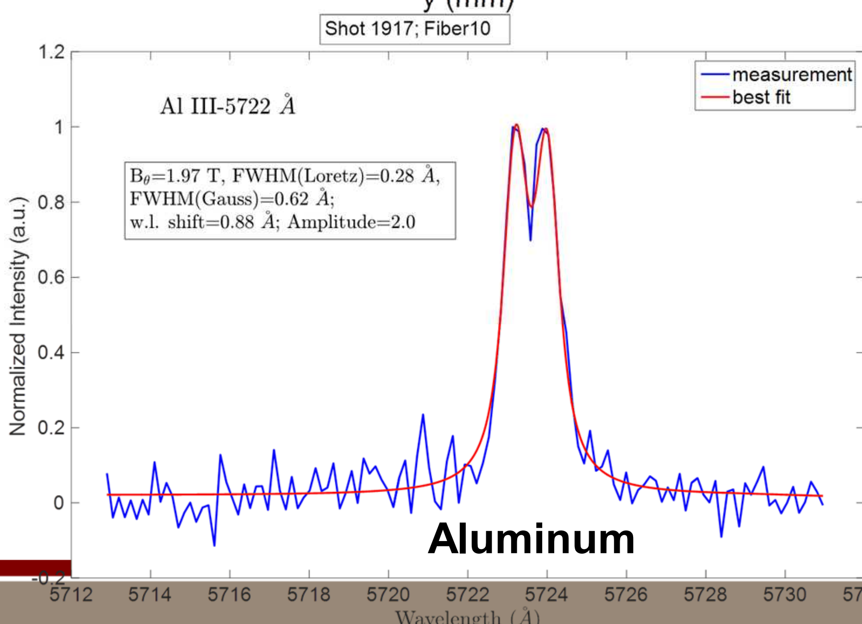
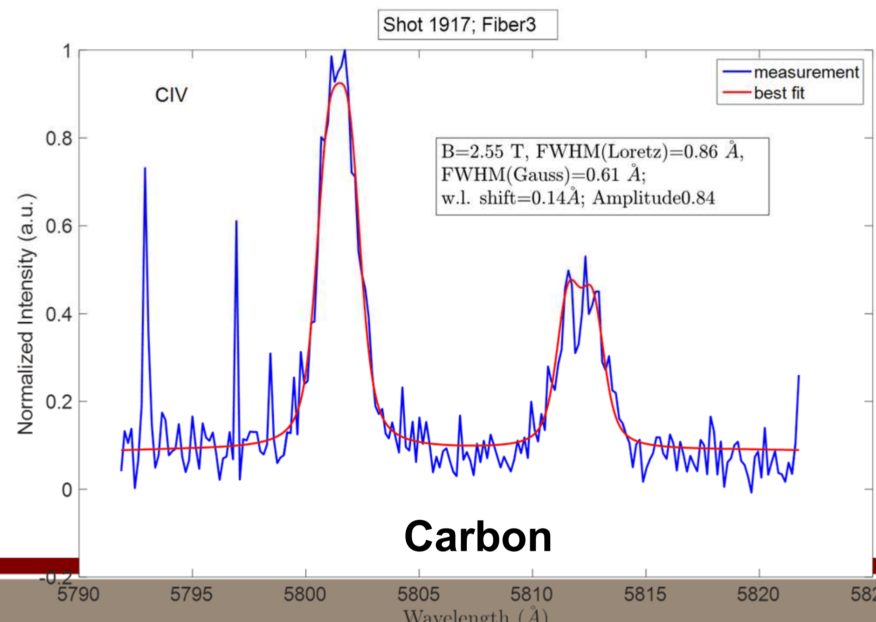
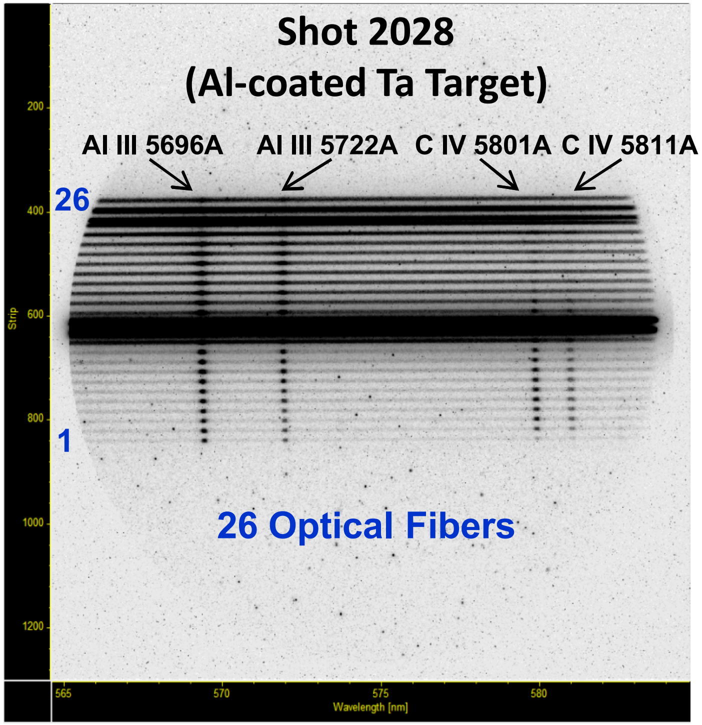


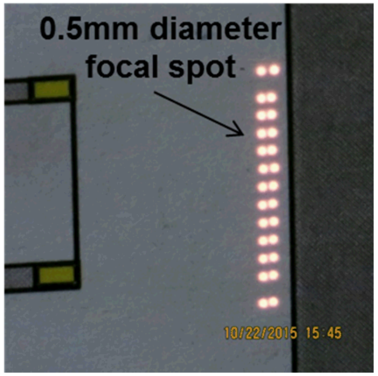


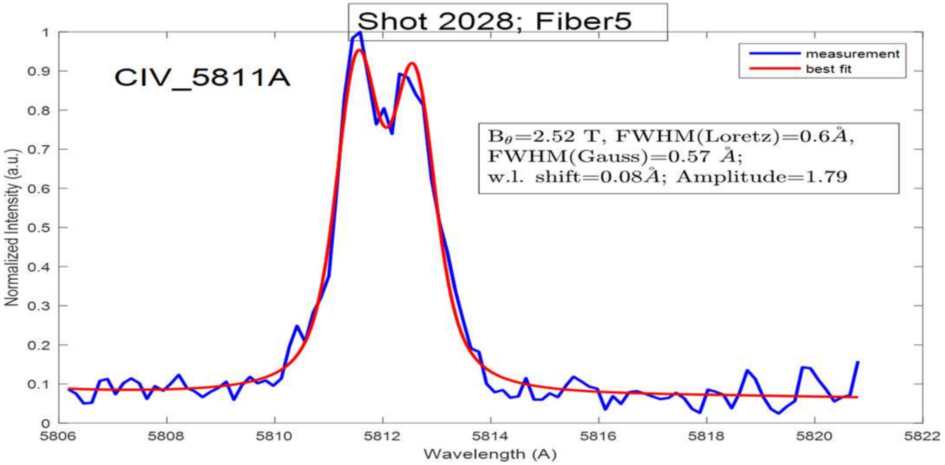


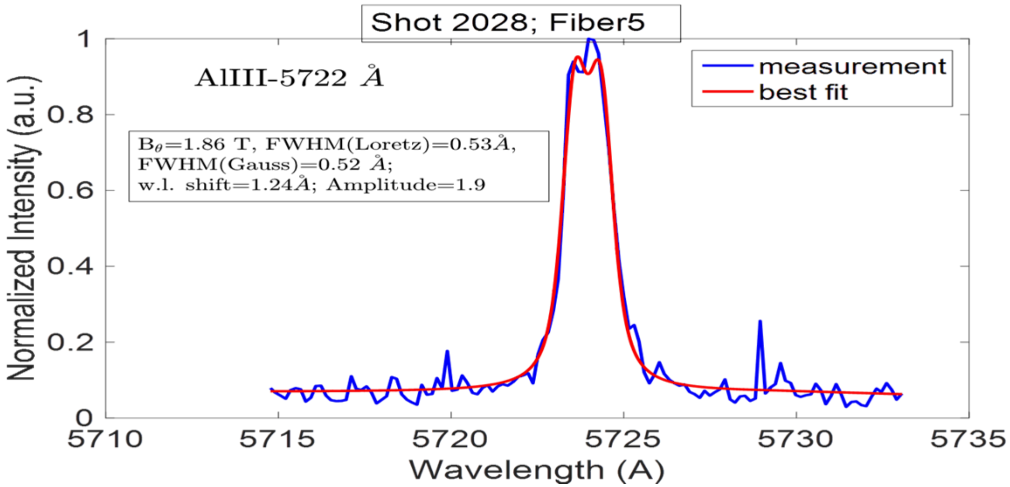


Aluminum and Carbon Line Analysis using Double Fiber Array

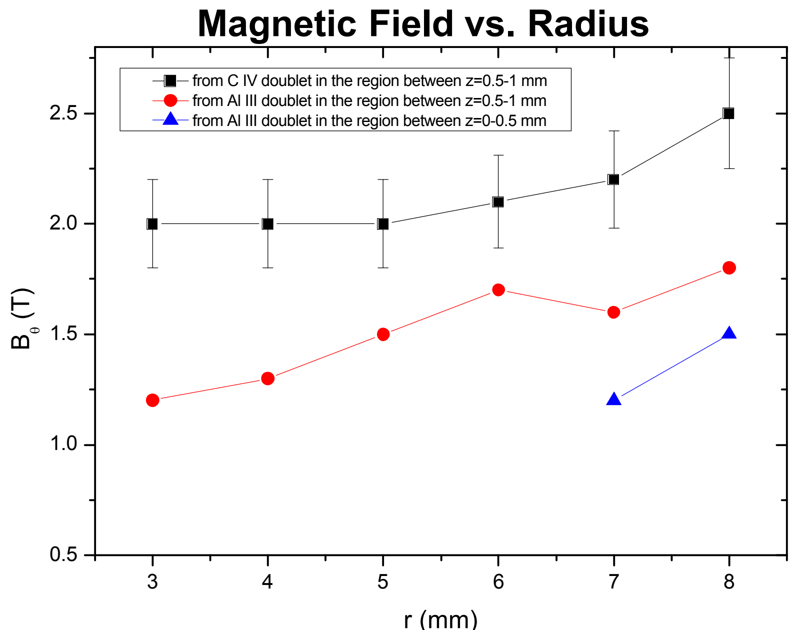


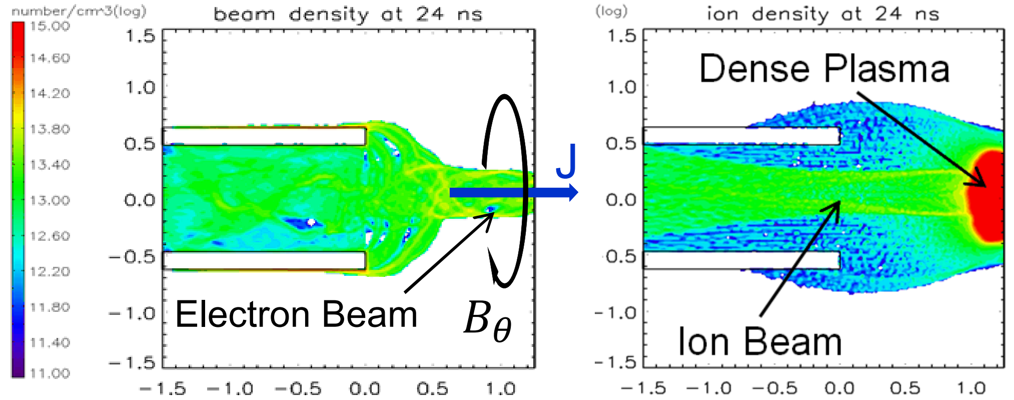


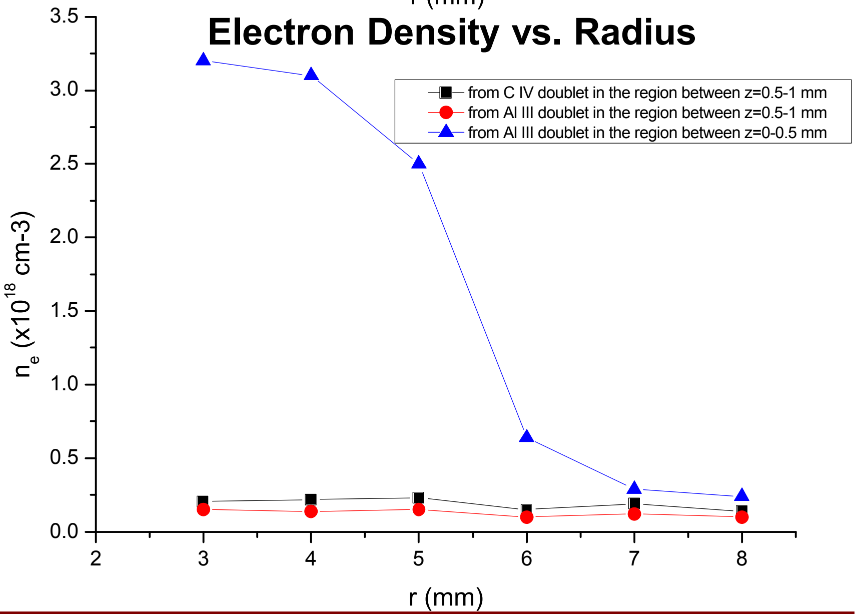


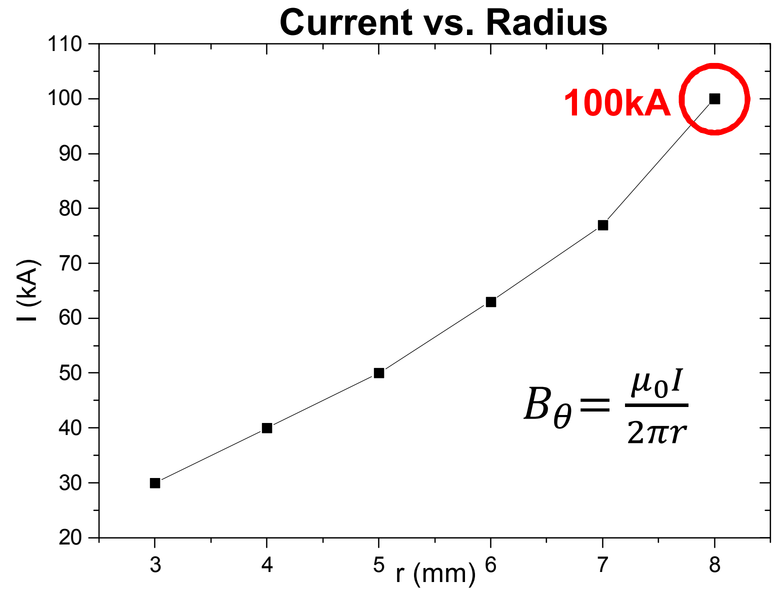


Zeeman Splitting Data Analyses and Conclusions









Measurements indicate an enclosed current of 100kA within an 8mm radius. B-dot measurements near the diode region give a total current of 120kA. The additional 20kA may reside outside of the 8mm radius or could be shielded by dense plasma near the electrode surface.

***LSP Simulations courtesy of Nichelle Bennett (NSTec)**

Quadratic Stark Shift is a Useful Technique for Electric Field Measurements in Plasmas

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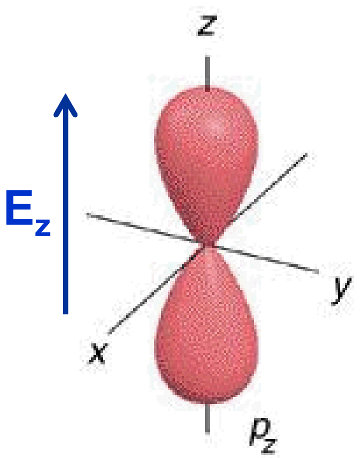
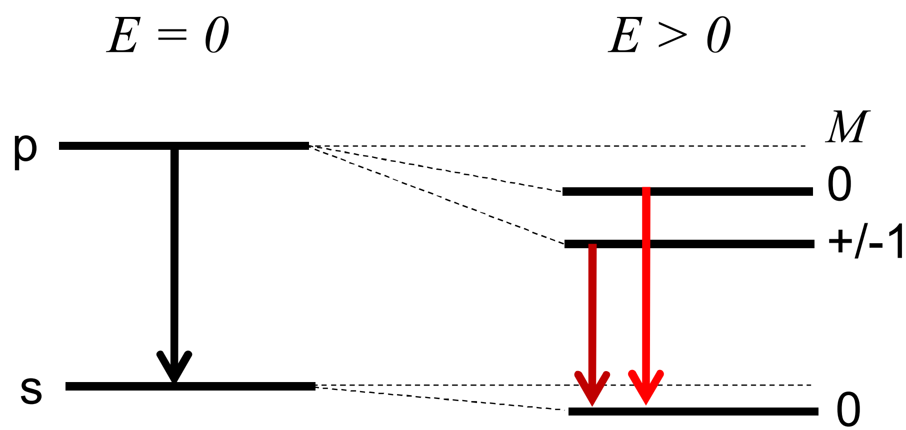


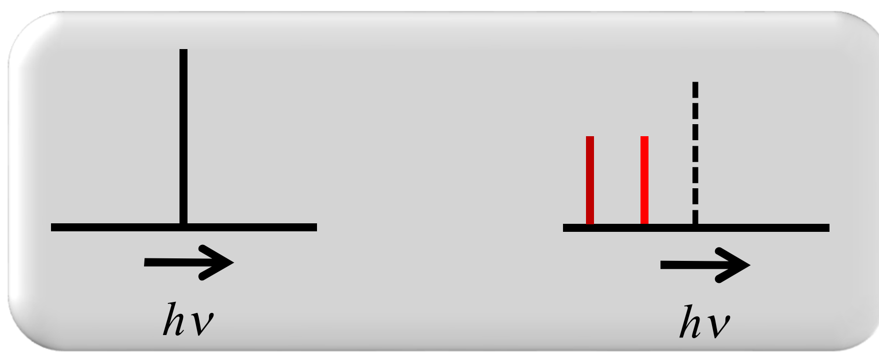


$$\Delta W = -\frac{1}{2}\alpha|E|^2$$

$$\alpha \propto M^2$$

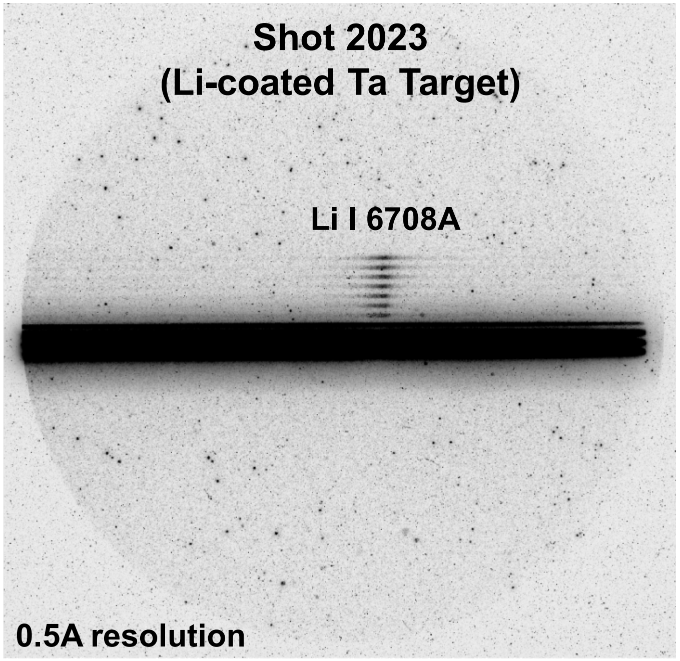
Separation of energy states due to an external E-field inducing a dipole moment in an atom or ion.

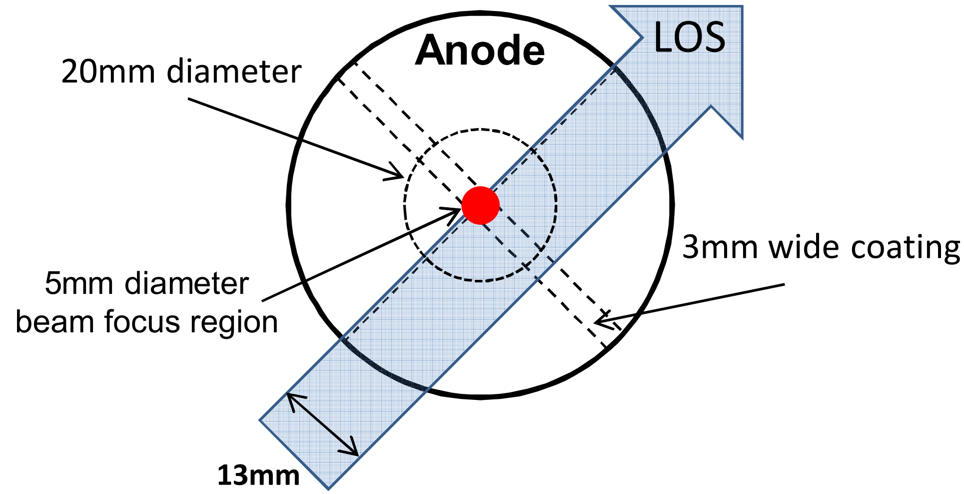
Observed

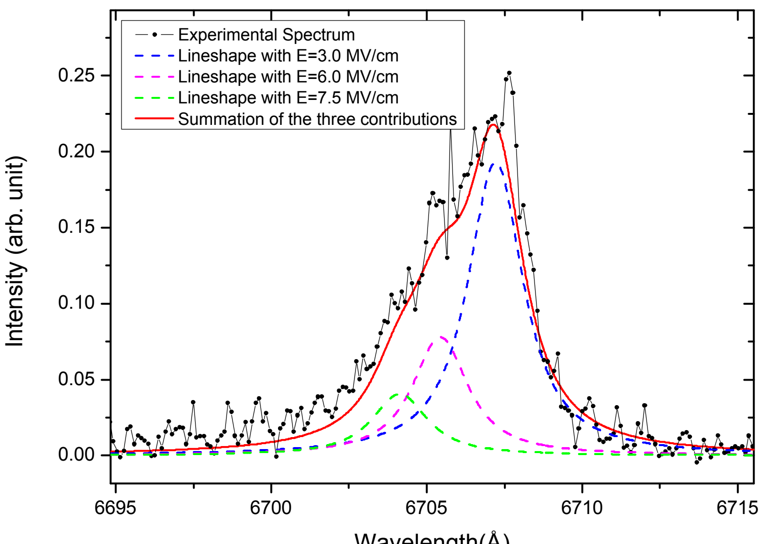


$$h\Delta\nu = h\nu_0 - (\Delta W_u - \Delta W_l)$$

Electric Field Measurements on SMP Diode

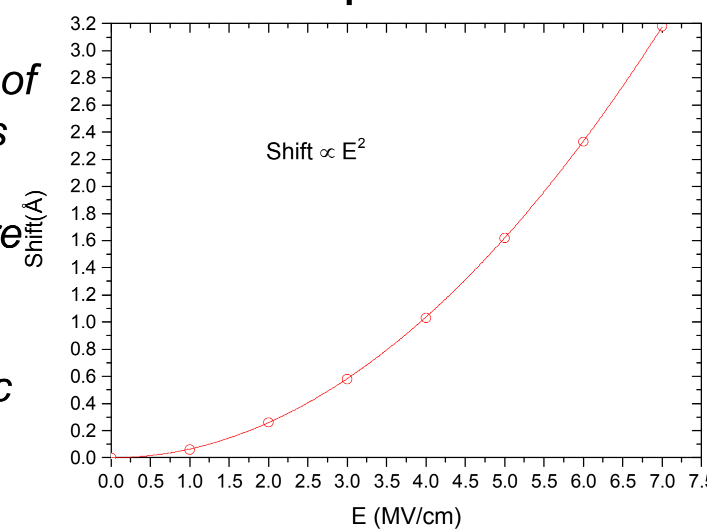






Large electric fields (MV/cm) cause a shift of the line-center towards shorter wavelengths. Since these spectra are integrated across multiple field lines, the result is an asymmetric line profile skewed towards the blue.

Li I 2s-2p Stark Shifts*



*** Y. Maron et. al.**

Summary and Conclusions

- Measurements of local magnetic and electric fields in the SMP diode have been performed. Changes in the magnetic fields have been determined over very small (0.5mm) spatial extents.

- Measurements of the magnetic field provide information regarding local current distributions in the diode and give indication of return current flow through the plasma.

- A new technique,[3] developed at the Weizmann Institute, to measure Zeeman splitting of spectral lines has been employed at SNL on the SMP diode.

- Measurements like these are needed to increase the fundamental physical understanding of plasmas and fields in high power diodes. Until now only global B-fields have been inferred from current probe measurements.

- Present and future understanding and design of high power diodes relies heavily on kinetic PIC and hybrid (PIC/fluid) simulation models.

Experimental measurements <u>are necessary</u> to validate the models.

[3] R. Doron, et al., *High Energy Density Phys.*, <u>10</u>, p. 56-60 (2014).

Future Work

- Continue to develop advanced techniques of spectral analyses. Techniques which include effects due to opacities, impurities, signal to noise, field orientations, line emission, absorption, and continua.

- Map magnetic fields and currents further into the A-K gap. Requires greater signal to noise and/or plasma injection scheme.

- Implement a streaked spectroscopy system at high resolution to record the time evolution of fields in a single shot.

- Further explore Stark shifts to measure E-fields in the diode as a function of time and space.

- Extend these methods to other pulsed-power platforms such as the Z Machine.