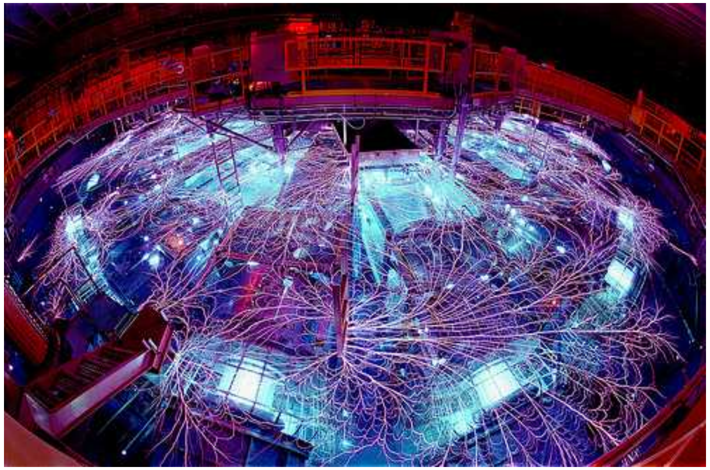
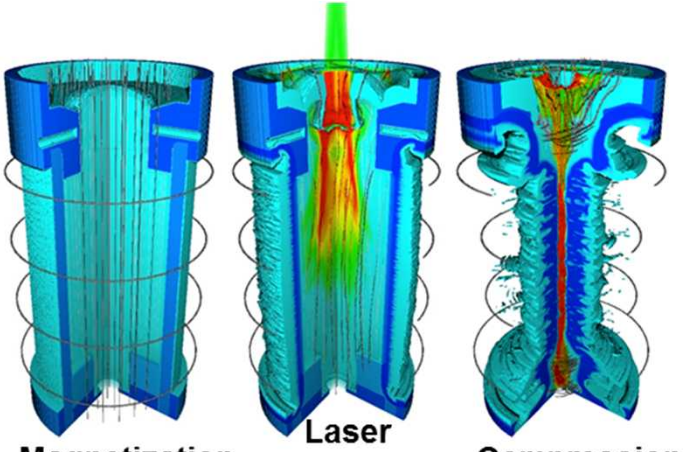
SAND2014-4742C

Exceptional service in the national interest

Sandia National Laboratories





Magnetic Field Measurements via Visible Spectroscopy on the Z Machine

M. R. Gomez, S. B. Hansen, K. J. Peterson, R. D. McBride, C. A. Jennings, D. E. Bliss, A. L. Carlson, D. C. Lamppa, D. G. Schroen, D. J. Ampleford, T. J. Awe, J. E. Bailey, A. J. Harvey-Thompson, B. Jones, P. F. Knapp, M. E. Cuneo, G. A. Rochau, and D. B. Sinars

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Magnetic fields are a critical parameter in experiments on the Z Machine

- Targets are imploded through the JxB force
  - Target performance often scales as B^2 or higher
  - Accurate simulations require knowledge of the magnetic field at the load
- Drive field is measured using B-dot monitors and VISAR
  - B-dot monitors are located > 6 cm from the load
    - Minimum fielding radius limited by loop diameter and voltage
    - Losses in the final A-K gap are not accounted for
  - VISAR monitors require iterative MHD simulations to unfold the current, which can be time consuming
- Magnetic flux compression plays a key role in magneto-inertial fusion concept being evaluated on Z

Magnetic fields can be measured spectroscopically through Zeeman splitting

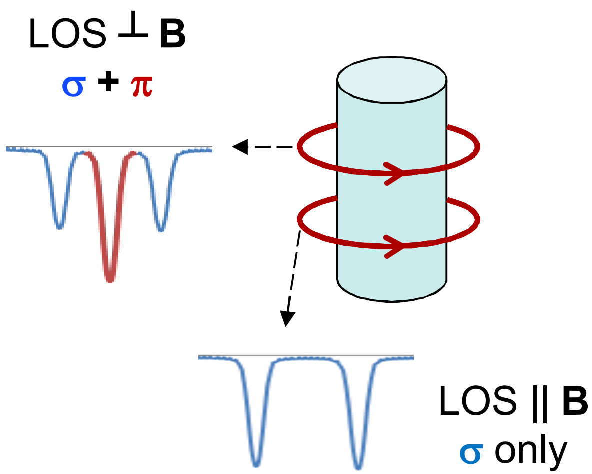
$$B = \frac{\mu_0 I}{2\pi r}$$

$$B[T] = \frac{200 * I[MA]}{r[mm]}$$

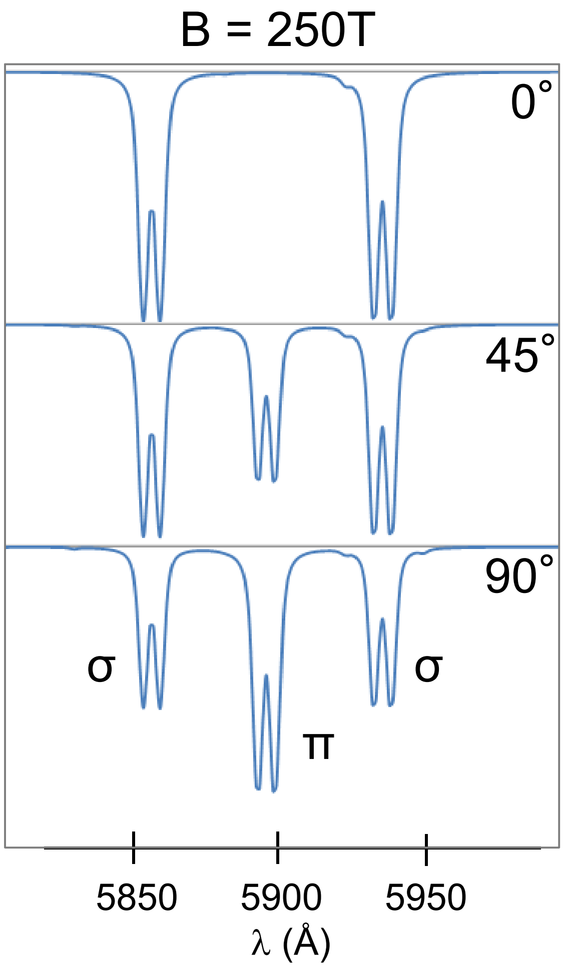
$$\Delta\lambda[\text{Å}] = 0.32 * B[T]$$

$$\Delta\lambda[\text{Å}] = \frac{64 * I[MA]}{r[mm]}$$

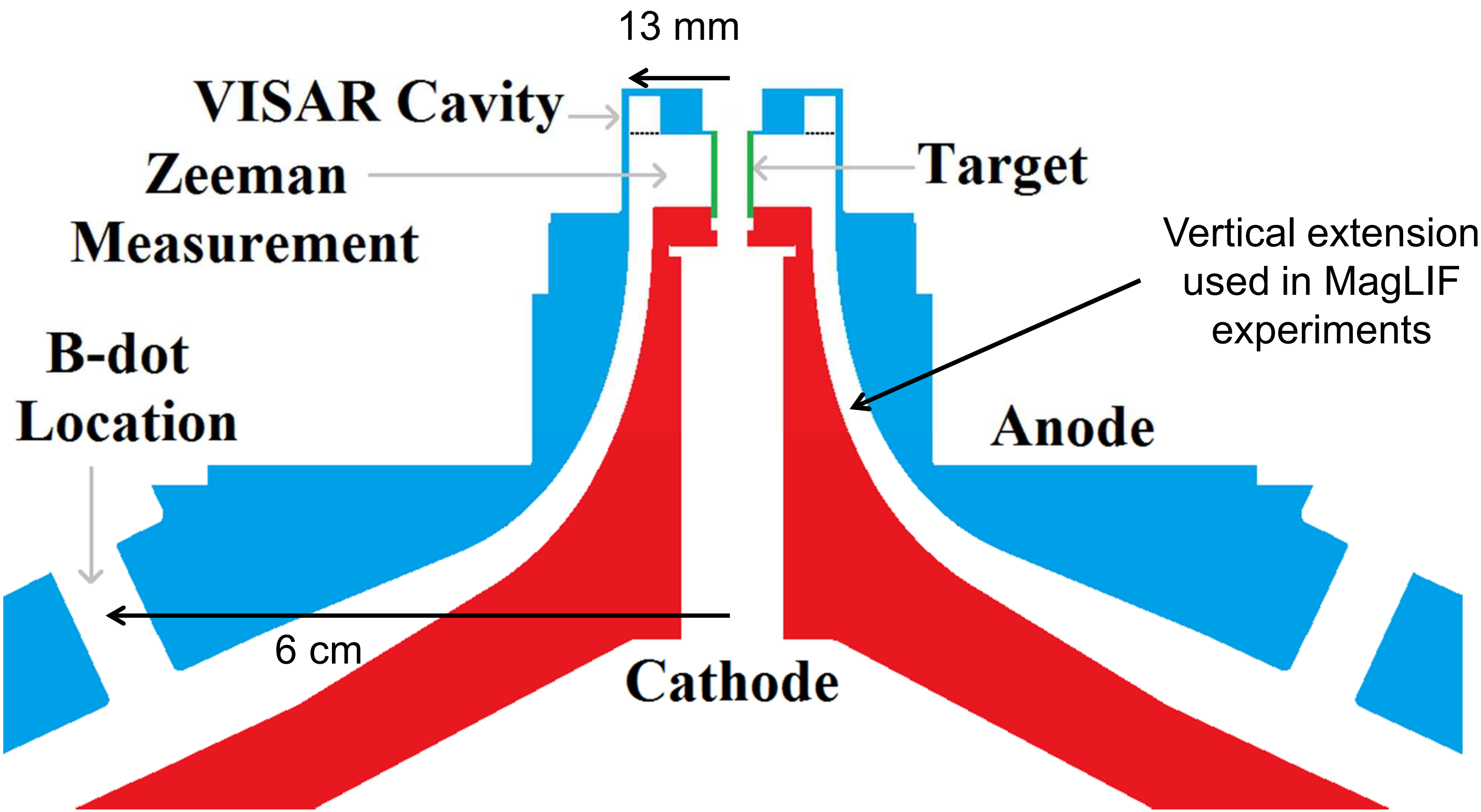
(for Sodium 3s-3p)



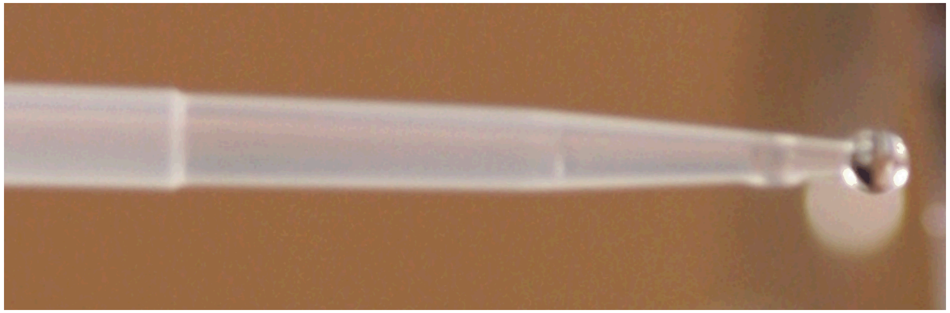
The relative strength of σ and π components indicates field direction



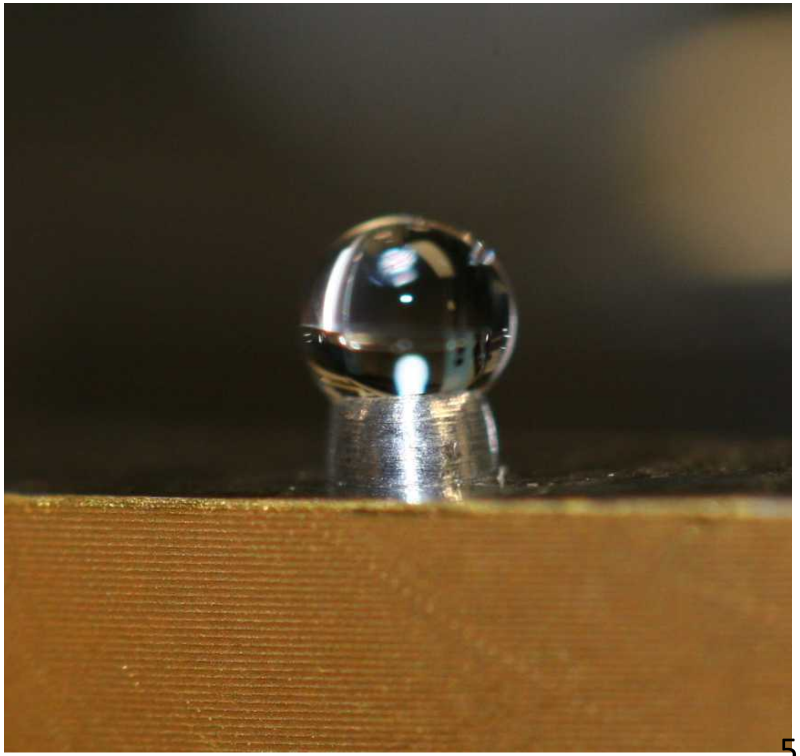
Load hardware geometry used in experiments on Z



Spectroscopic dopant is applied to target or return current can



- NaCl solution
- 1 mg/L
- 2 µL droplet
- Mass ~ 2 ng
- Localized to 2 mm diameter
- Surface tension holds drops in place
- Liquid evaporates in ~15 minutes leaving dopant film

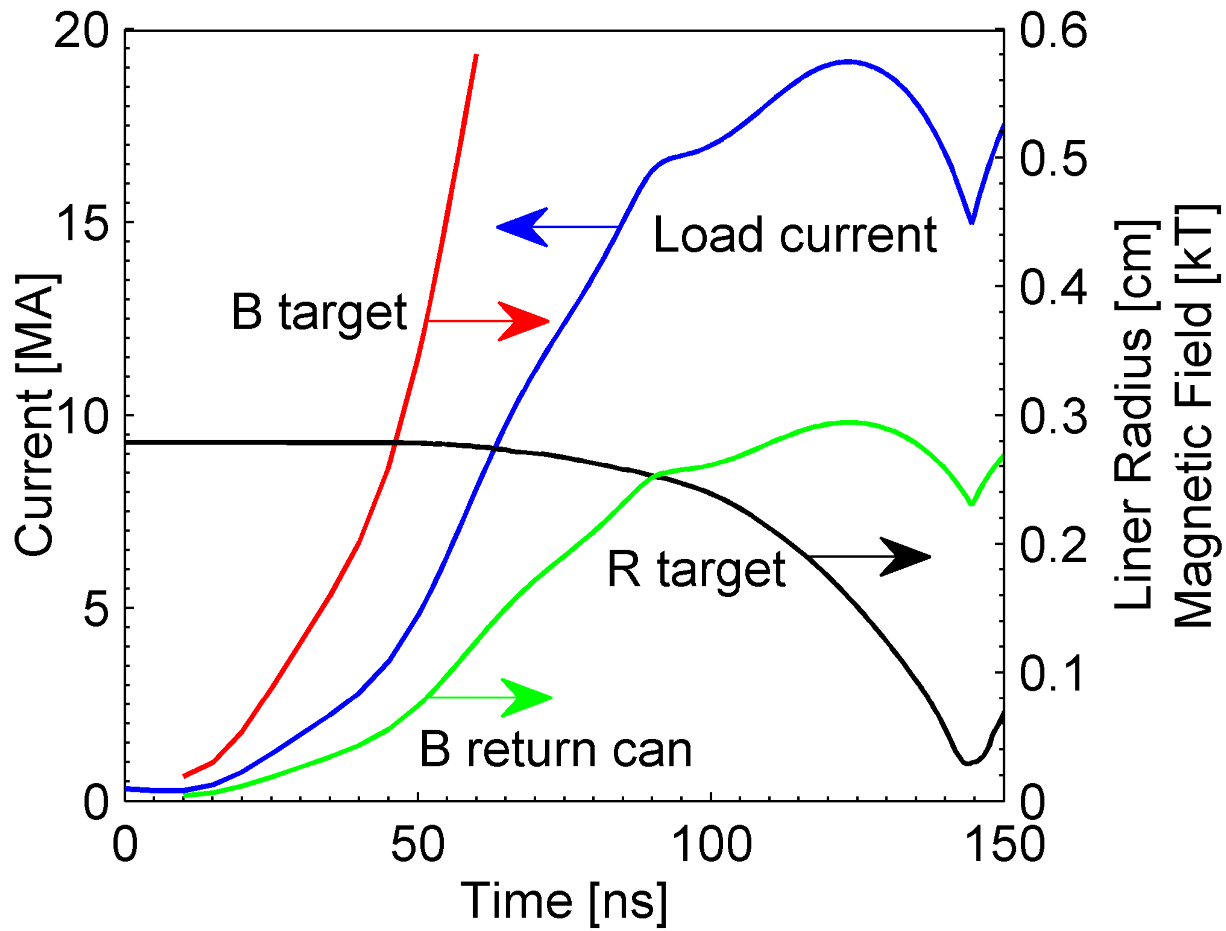


Expected range of magnetic fields accessed in drive field measurements

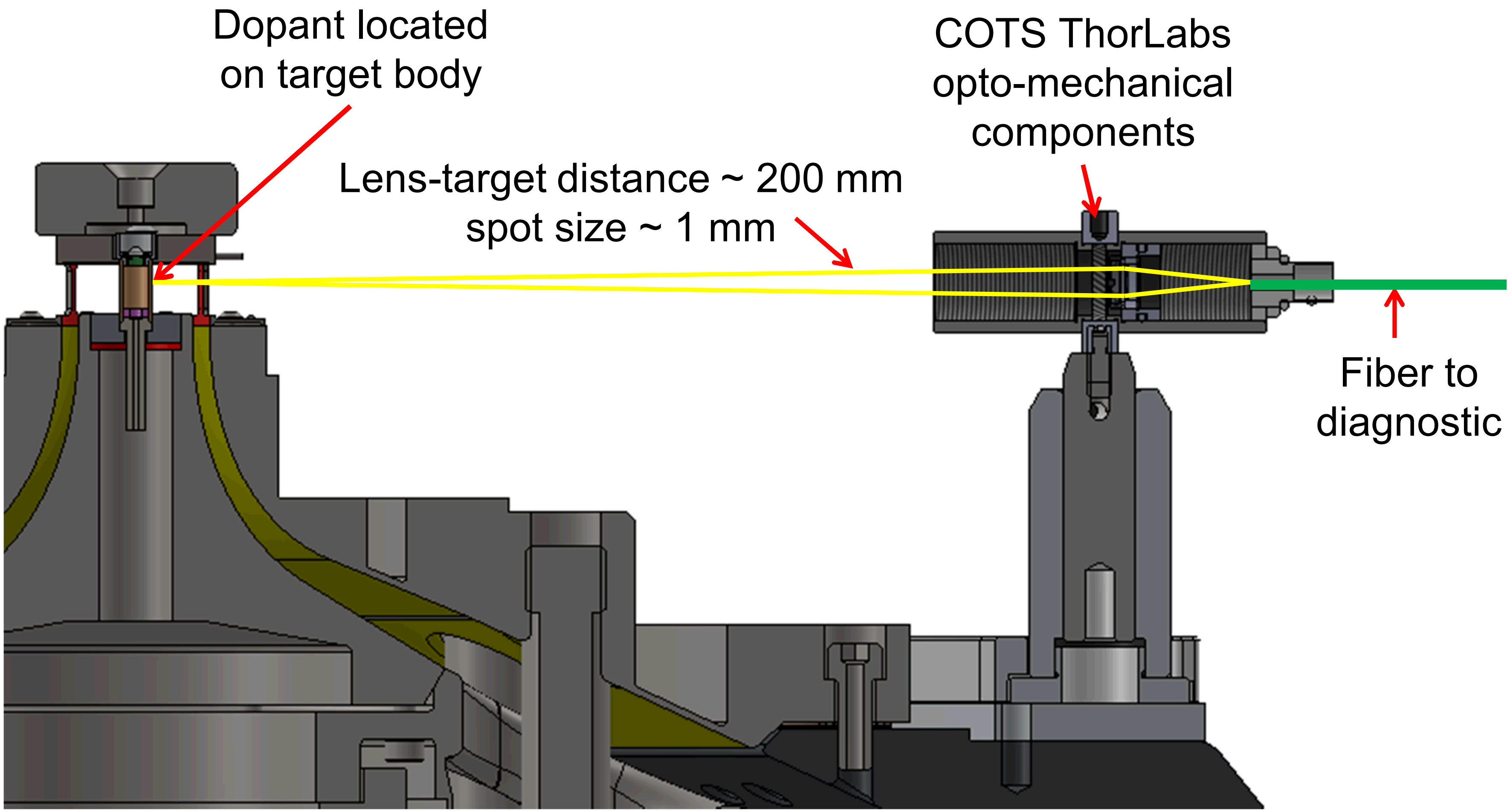
Magnetic fields up to 500 T can be accessed at the target surface before it begins to move.

Magnetic fields at the return can peak around 300 T.

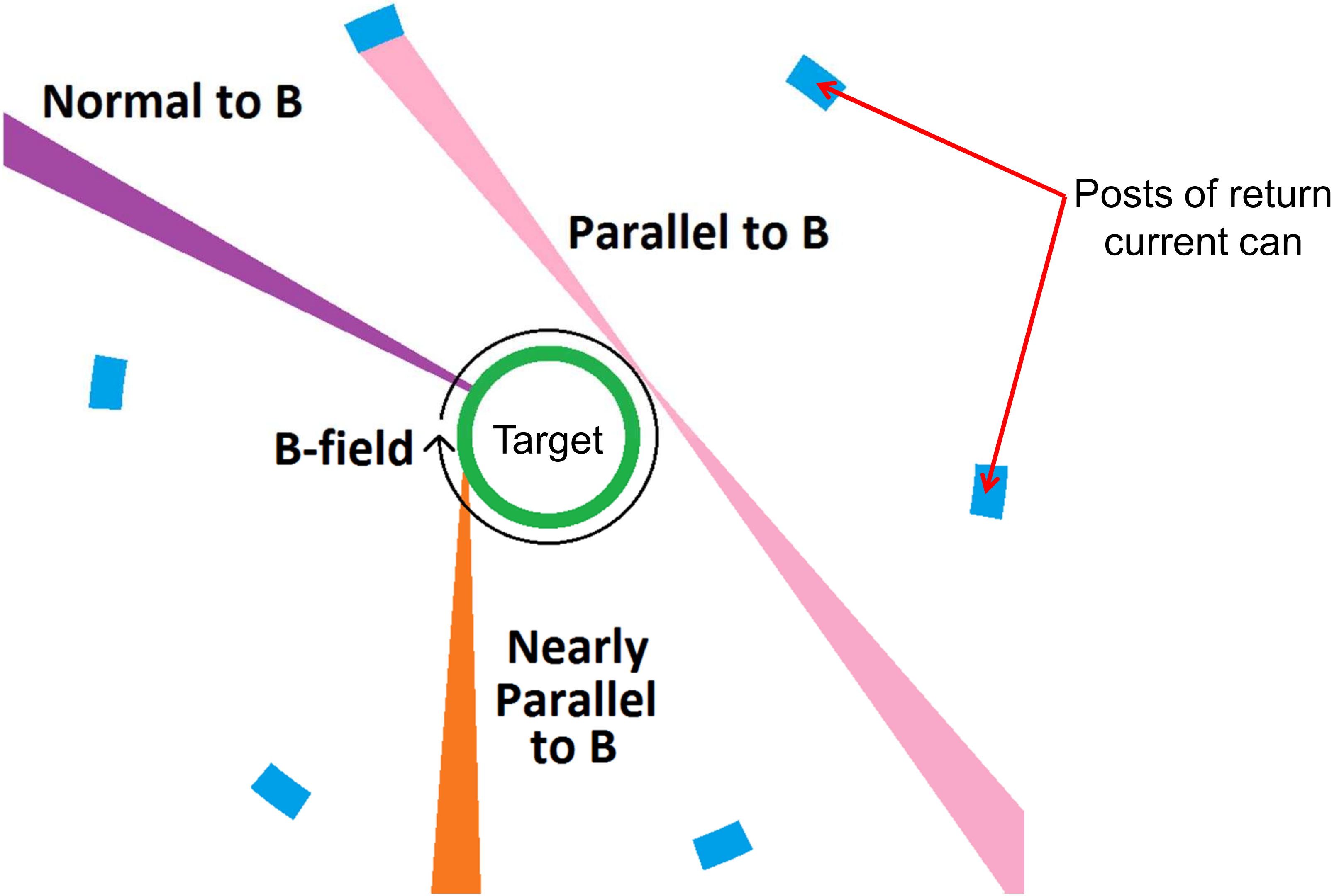
Losses between the return can and target are expected to be negligible



Visible spectroscopy probe setup



Visible spectroscopy probe setup

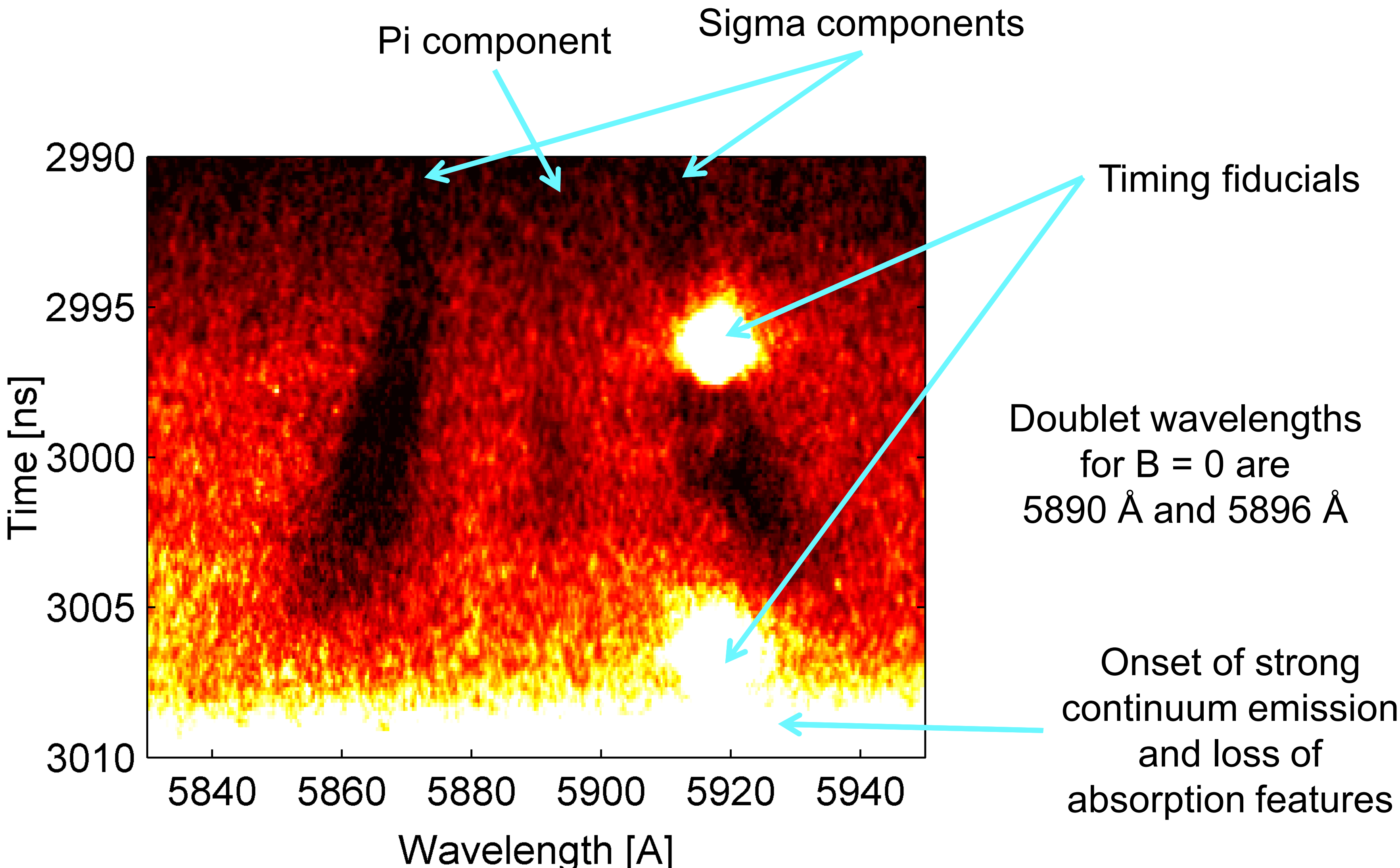


Streaked Visible Spectroscopy System

- McPherson Model 2061 scanning monochromator
  - 1 m focal length with astigmatism correcting mirror
  - 600 G/mm, 6563 Å blaze angle, 140 mm x 120 mm diffraction grating
  - Spectral resolution = 2.5 Å
  - Spectral range ≈ 600 Å

- NSTec L-CA 24 streak camera
  - 240 ns sweep duration
  - Temporal resolution ≈ 1 ns
  - Temporal accuracy ≈ 1 ns

Zeeman splitting in sodium doublet was observed

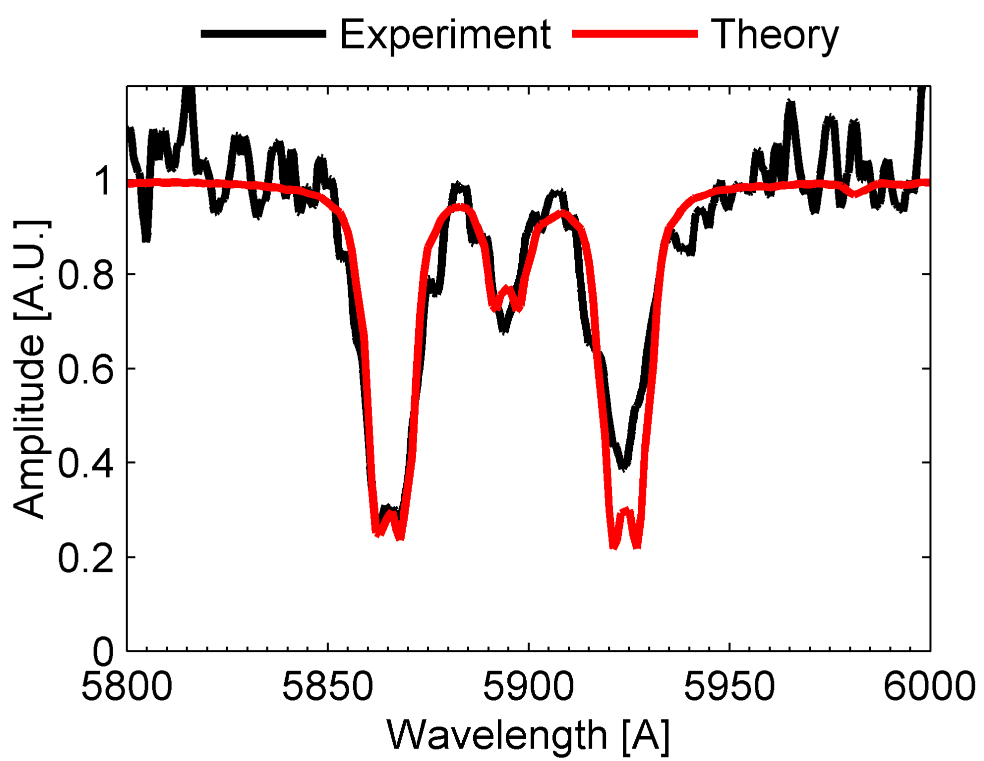


Doublet wavelengths for B = 0 are 5890 Å and 5896 Å

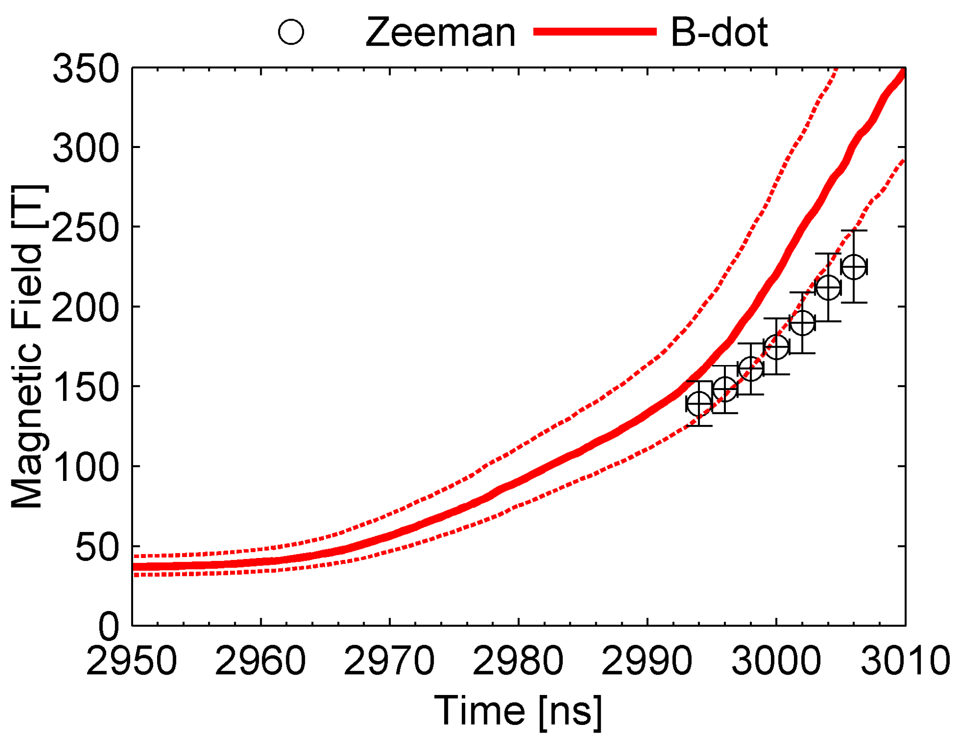
Theoretically calculated spectrum fit to data to determine magnetic field

Experimental lineout was corrected to flatten the continuum and normalized to unity

Theoretical spectrum assumes a magnetic field of 180 T, an angle of 25 degrees between the diagnostic line of sight and the magnetic field, and an electron density of 5e17/cm^3



Current inferred from B-dot used to estimate magnetic field at target



Magnetic field from B-dot measurement exceeds the field from the spectroscopic measurement for all times

Signals are within uncertainty in the measurements for the majority of the time but appear to deviate at late times.

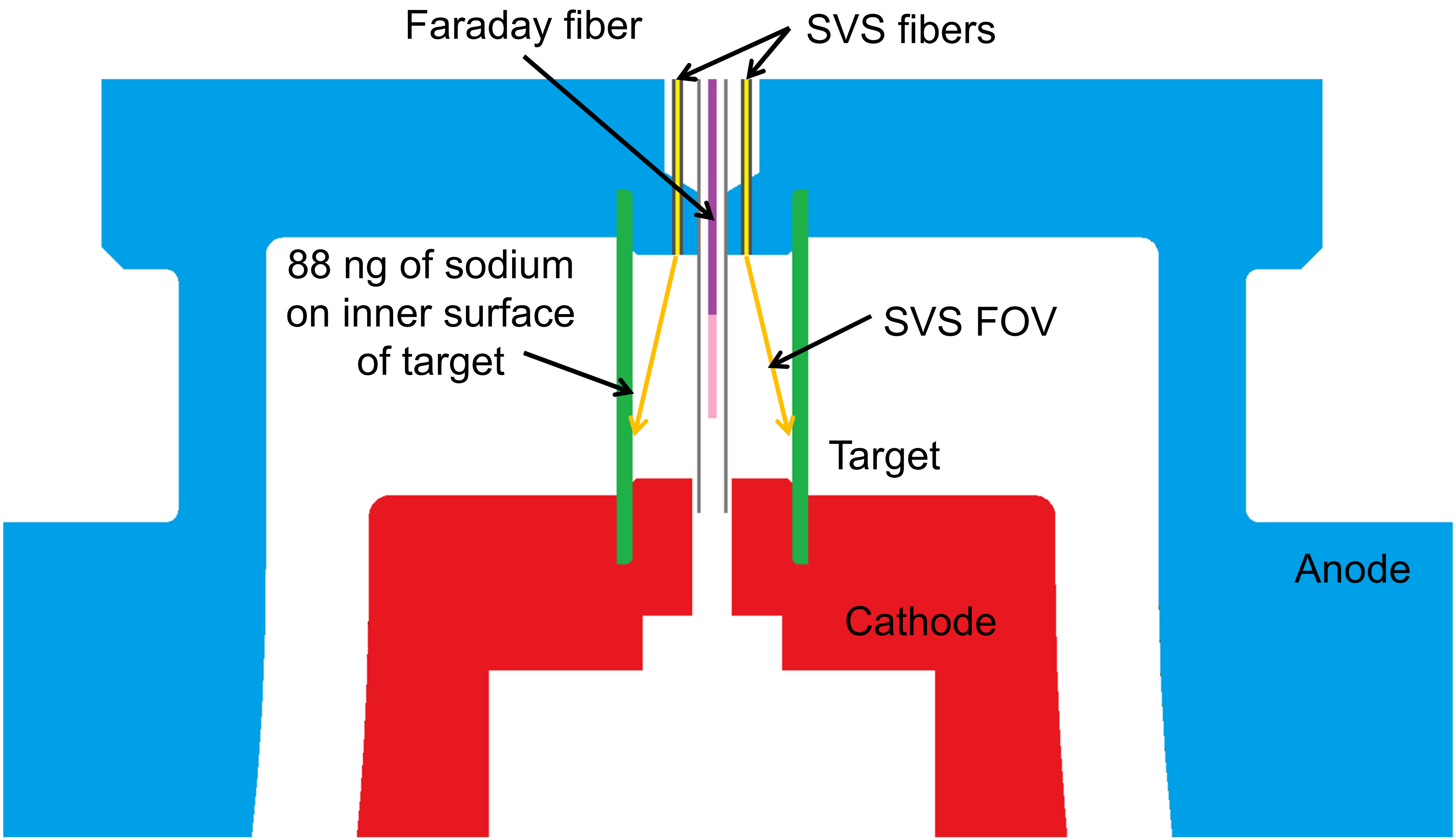
This may indicate current loss between the B-dot and the load

Summary of measurements of driving magnetic field at load

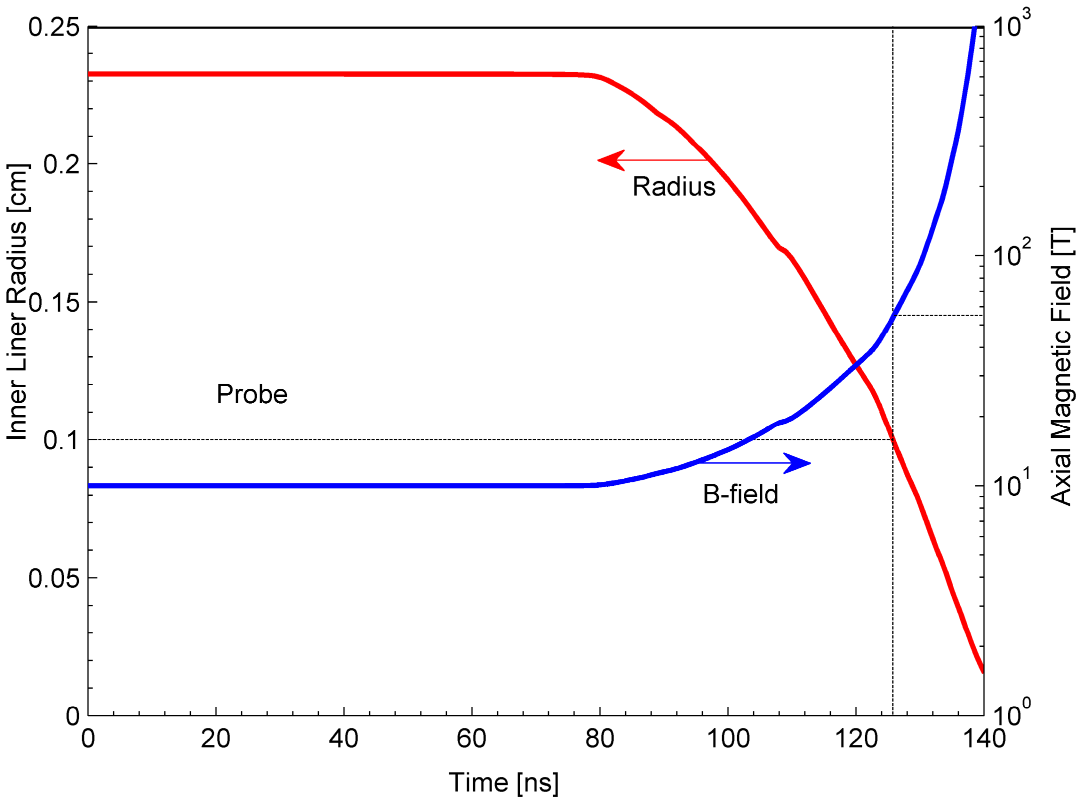
Sandia National Laboratories

- Magnetic field measurements of 150 to 225 T were made using Zeeman splitting of the sodium 3s-3p doublet
- Measurements suggest that some current could be lost between the inner-most B-dots and the load
- Above 225 T (current density ~ 2 MA/cm) the signal is lost
  - May be the result of sodium dopant ionizing
  - May be the result of plasma formation on lens of probe
- Assuming 225 T is a practical limit for the measurement, currents up to 15 MA could be measured at the surface of the return current can
  - Minimal losses are expected between the return can and the target

Target geometry for magnetic flux compression measurements



Expected range of magnetic fields for flux compression



$$B = B_0 * CR^2$$

$$B[T] = 0.54 * R[cm]^2$$

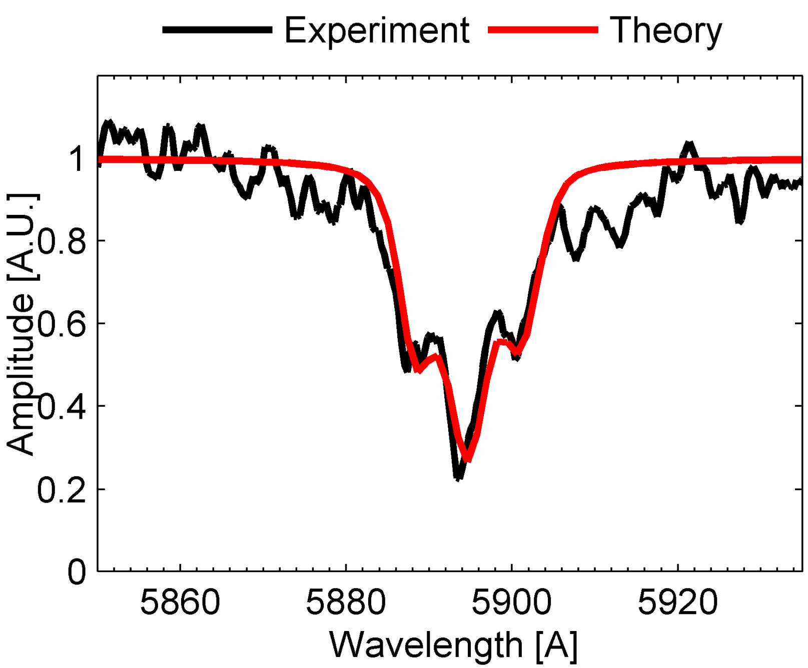
Probe is located at 1 mm

Maximum field reached prior to liner crossing 1 mm is 55 T

Probe located on axis with r = 0.1 mm could measure over 1 kT

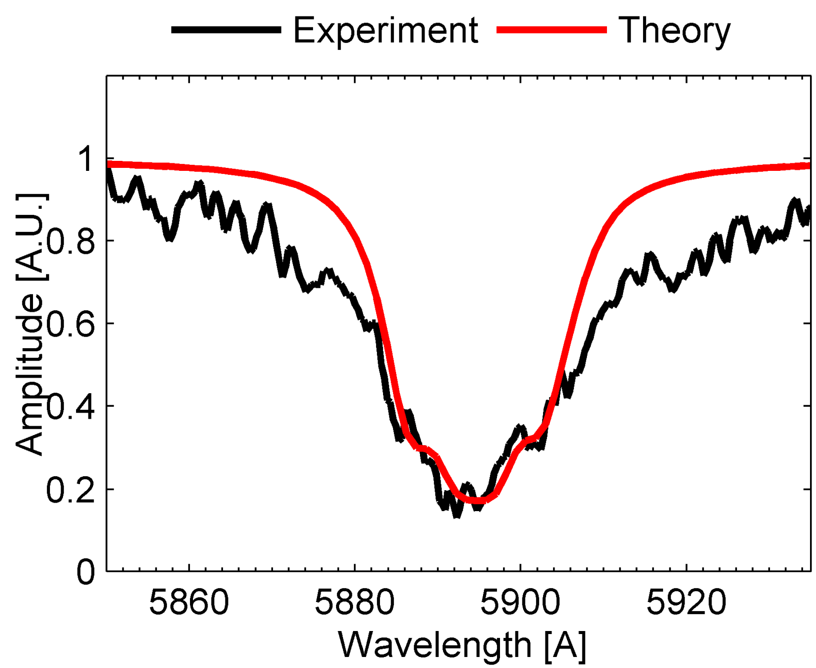
Spectrum shows Zeeman splitting initially followed by significant broadening

3065 ns



B = 20 T
Angle = 35 degrees
Density = 1e17

3070 ns



B = 30 T
Angle = 35 degrees
Density = 1e18

Summary of magnetic flux compression measurements

- Zeeman splitting of sodium was demonstrated in flux compression measurements
- Fields between 20 T and 30 T were measured before significant absorption signal broadening
- Glass tube on axis may be source of extra sodium signal (borosilicate glass is ~ 5% sodium)
  - Broadening approximately coincides with shock reaching tube
  - Glass replaced with quartz tube on recent experiment and no massive increase in sodium signal was observed
- Nearly at limit of measurement due to probe position (55 T)
  - Future measurements closer to axis could allow measurements in the range of 100-1000 T