Time-resolved Motional Stark Effect Measurements of |B| on the MST RFP

D. J. Den Hartog, D. Craig, and G. Fiksel

Department of Physics, University of Wisconsin—Madison

Abstract

‰ A spectral motional Stark effect (MSE) diagnostic is now in regular operation on the MST RFP. This is the first time MSE has been applied to measure the magnitude of the magnetic field in the core of a low-field (0.2 to 0.5 T) magnetic confinement device, an accomplishment made possible by a high quality diagnostic neutral beam and a carefully designed beam emission collection and detection system. Measurement of the core magnetic field provides a strong constraint for equilibrium reconstruction in MST. The diagnostic neutral hydrogen beam is short pulse (3 ms), intense (4 A and 0.4 A/cm^2), mono-energetic, and low-divergence. MSE measurements are made by recording the Doppler-shifted H-alpha Stark spectrum emitted by the beam with an imaging spectrometer and CCD camera. Signal-to-noise is sufficient to allow single-shot exposures of less than 100 μs using a ferroelectric liquid crystal shutter. An array of shutters will provide seven sequential exposures during a single neutral beam pulse to measure the evolution of on-axis magnetic field during fast equilibrium changes such as sawtooth crashes.

Introduction

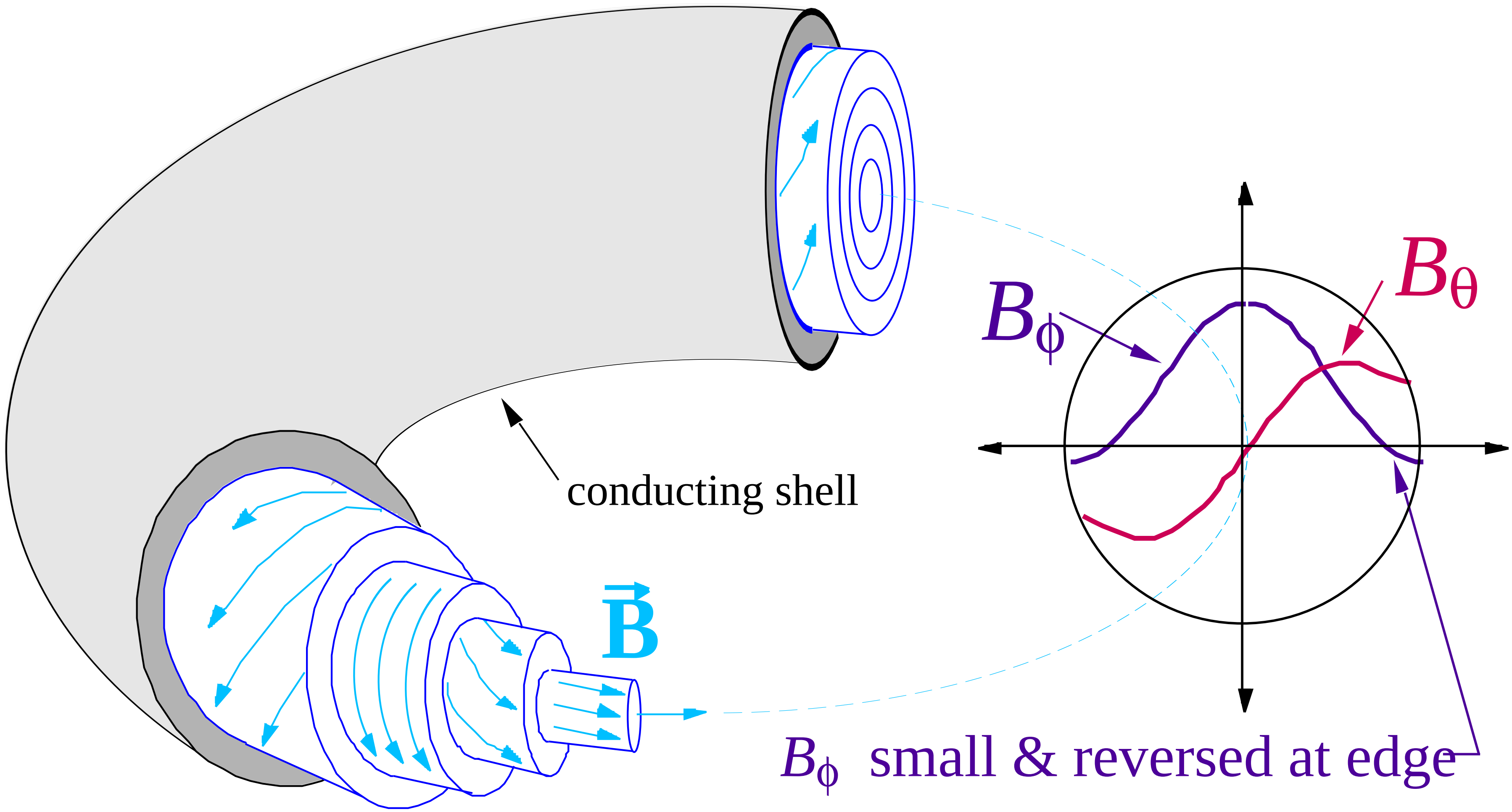
‰ Motional Stark effect (MSE) is now in regular operation on the MST reversed-field pinch (RFP) to measure |**B**| in the core of a low-field (≤ 0.5 T) magnetic confinement device.

‰ MST is a large RFP (R = 1.5 m, a = 0.52 m) operated at moderate current ($Ip \leq$ 500 kA), with n_e typically 1–2 $\times 10^{19}$ m^{-3} and T_e, $T_i \leq$ 1 keV

Outline

- Introduction to the Reversed-Field Pinch and MST
- Spectral MSE
  - Diagnostic neutral beam for MSE and CHERS
  - MSE measurements
  - Next step for MSE diagnostic

The RFP is a toroidal magnetic confinement device with toroidal field $B_\phi \approx$ poloidal field B_θ



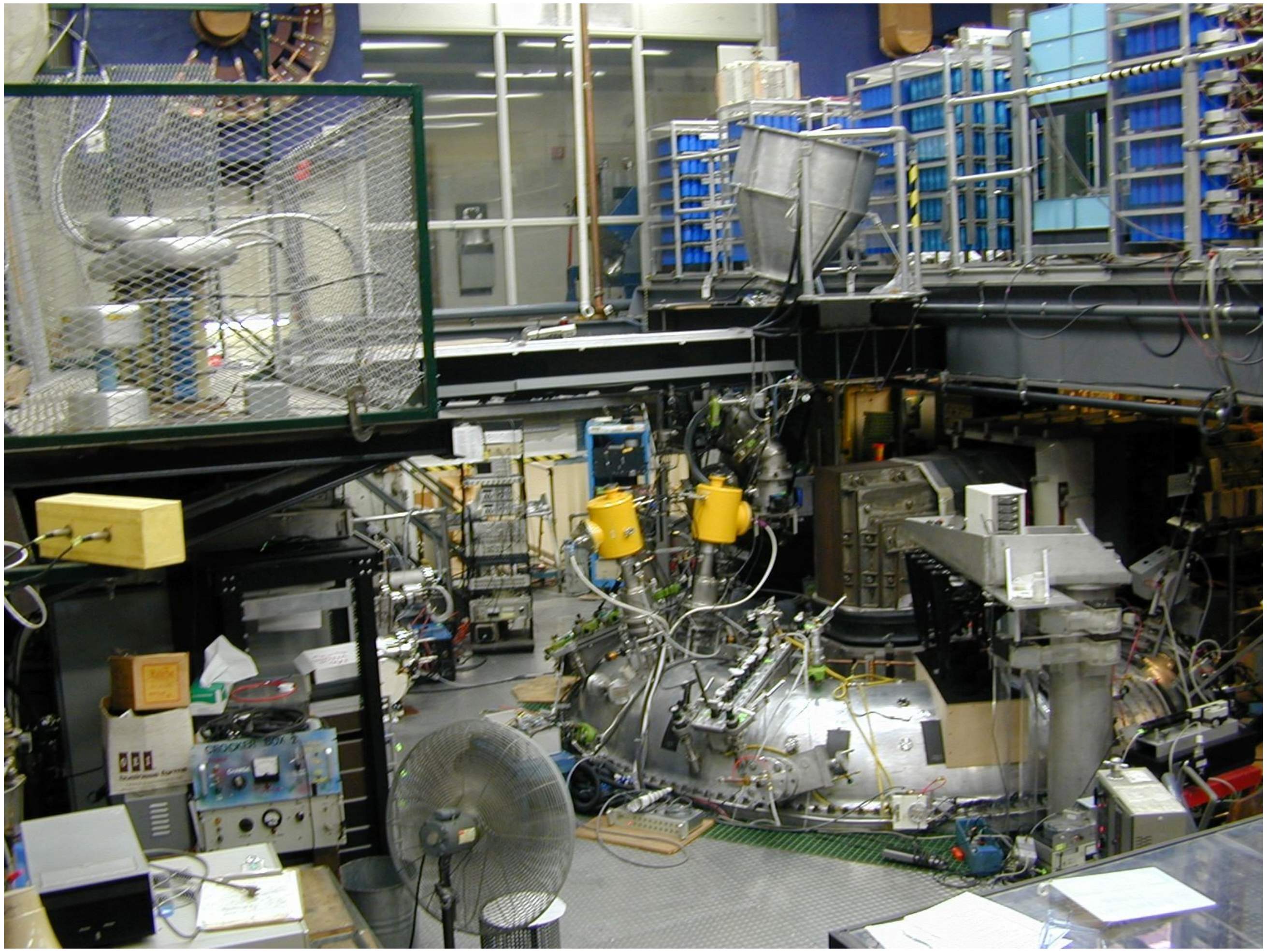
Self-generated currents drive plasma to a relaxed state in which toroidal field reverses direction at edge

MST (Madison Symmetric Torus)

R = 1.5 m
a = 0.52 m

$Ip \leq$ 500 kA
$|\mathbf{B}| \leq$ 0.5 T

$n_e = 10^{19}$ m^{-3}
$T_e \leq$ 1 keV

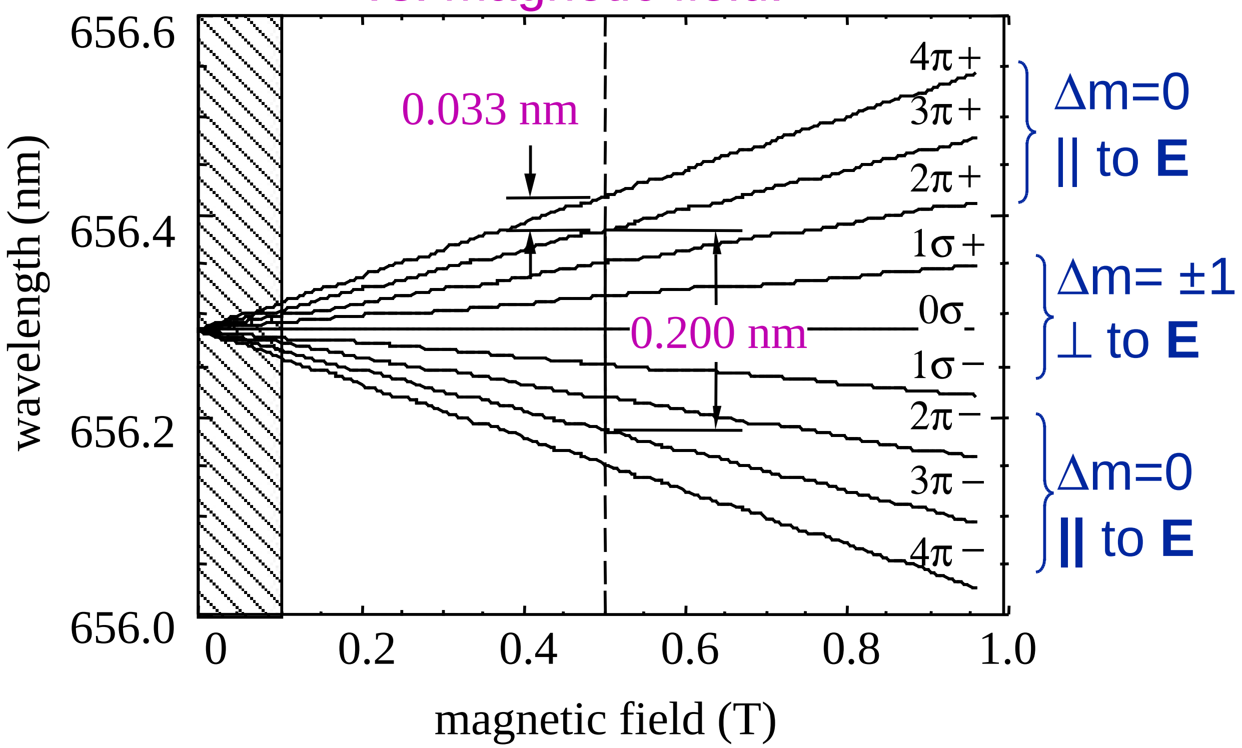


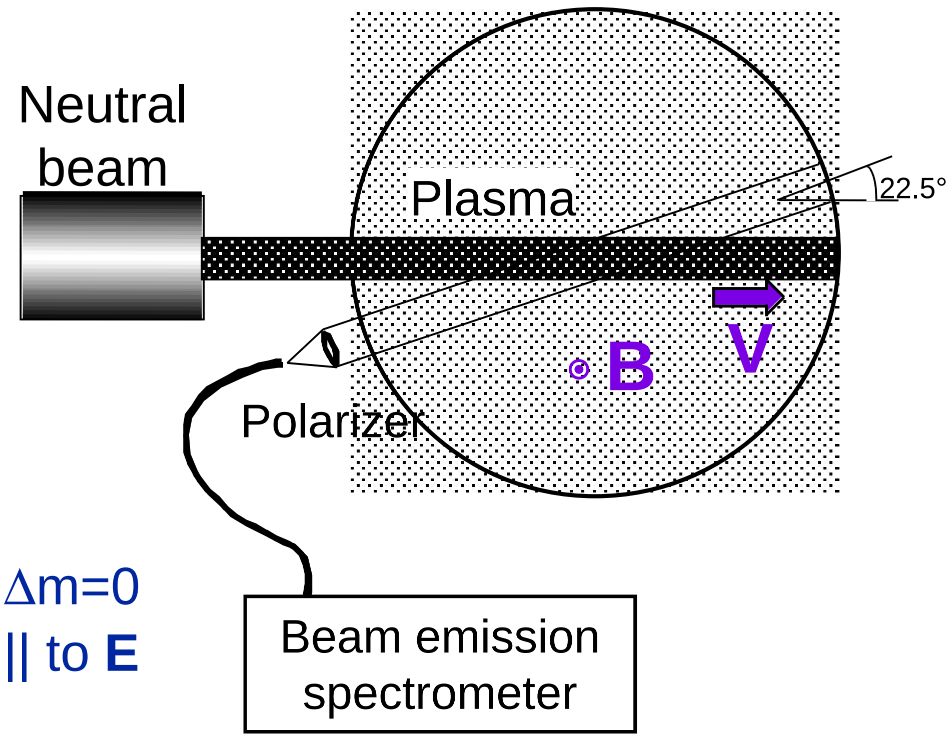
Principles of MSE measurement

What is measured:

Linear Stark effect - splitting of hydrogen beam emission line (H_α, 656.3 nm) due to **vxB** electric field.

Separation of Stark manifold components for 30 keV H beam vs. magnetic field.



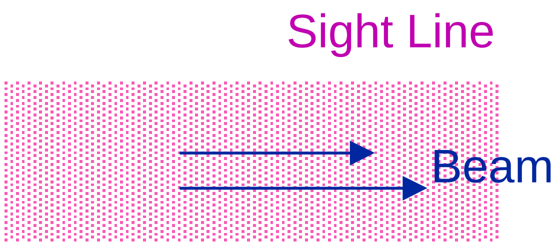


B can be extracted from the Stark splitting because the beam **v** is accurately known

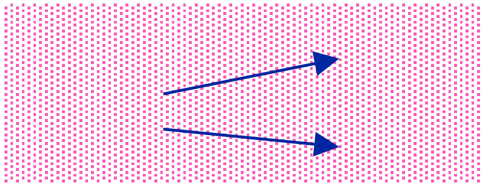
Must have high quality neutral beam and good collection optics to resolve Stark spectrum

The first order line smearing mechanisms are

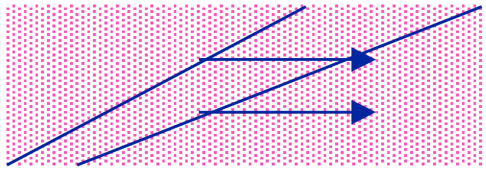
Non-mono-energetic beam ($T_{||}$)



Finite beam divergence ($T_{\perp}$)



Finite collection solid angle



On MST, low beam temperatures and carefully designed optics result in a total line smearing of FWHM ≈ 0.1 nm

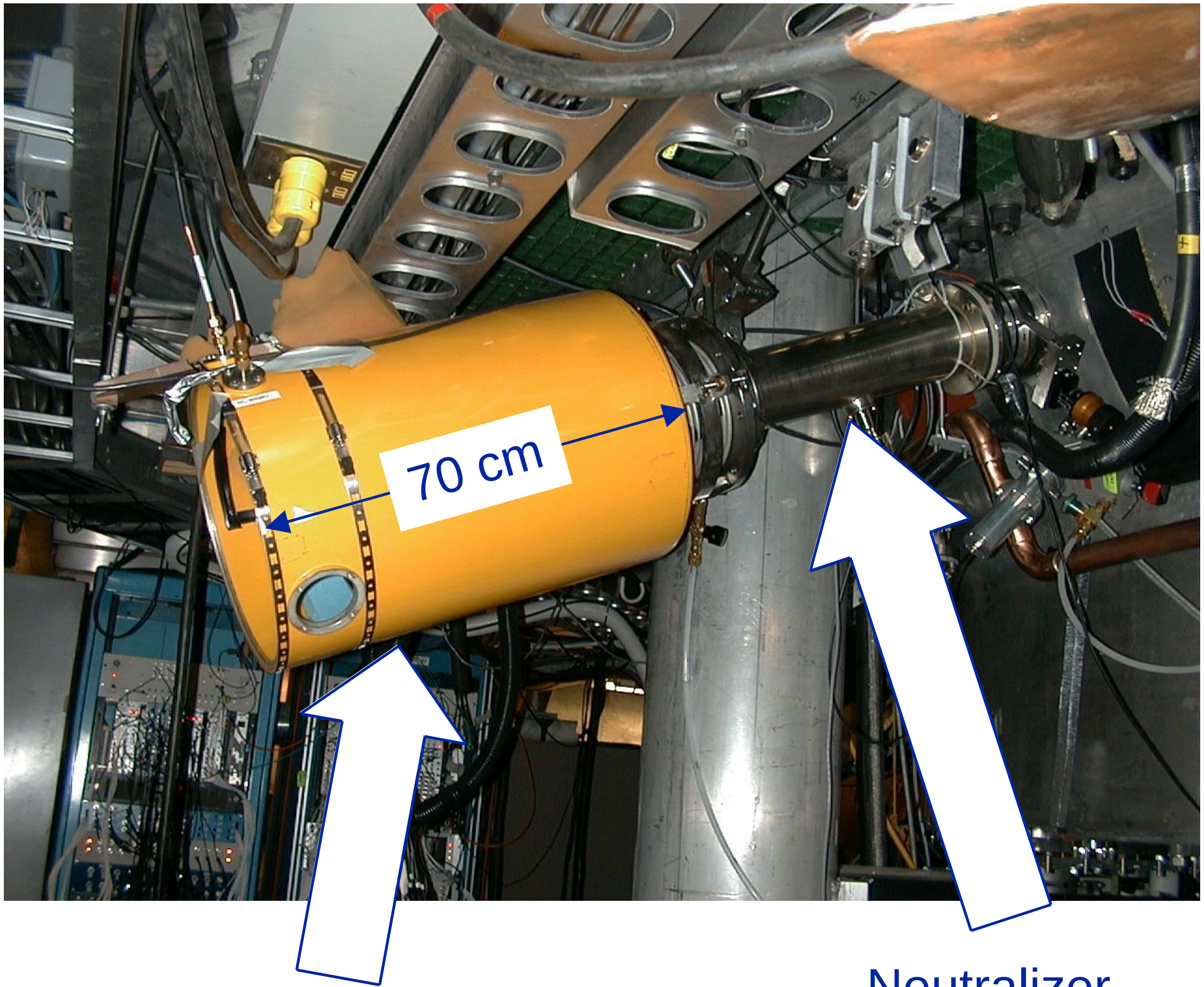
MST diagnostic neutral beam

Beam energy	30 keV
Equivalent beam current	4 A
Duration (power supply limited)	3 ms
Beam diameter	4 -5 cm
Beam current density (max)	0.4 A/cm^2

- High beam current and current density crucial for MSE
  - Result in sufficient beam emission to overcome Poisson noise

- Beam designed and built at the Budker Instititute in Novosibirsk, Russia

Diagnostic Neutral Beam on MST



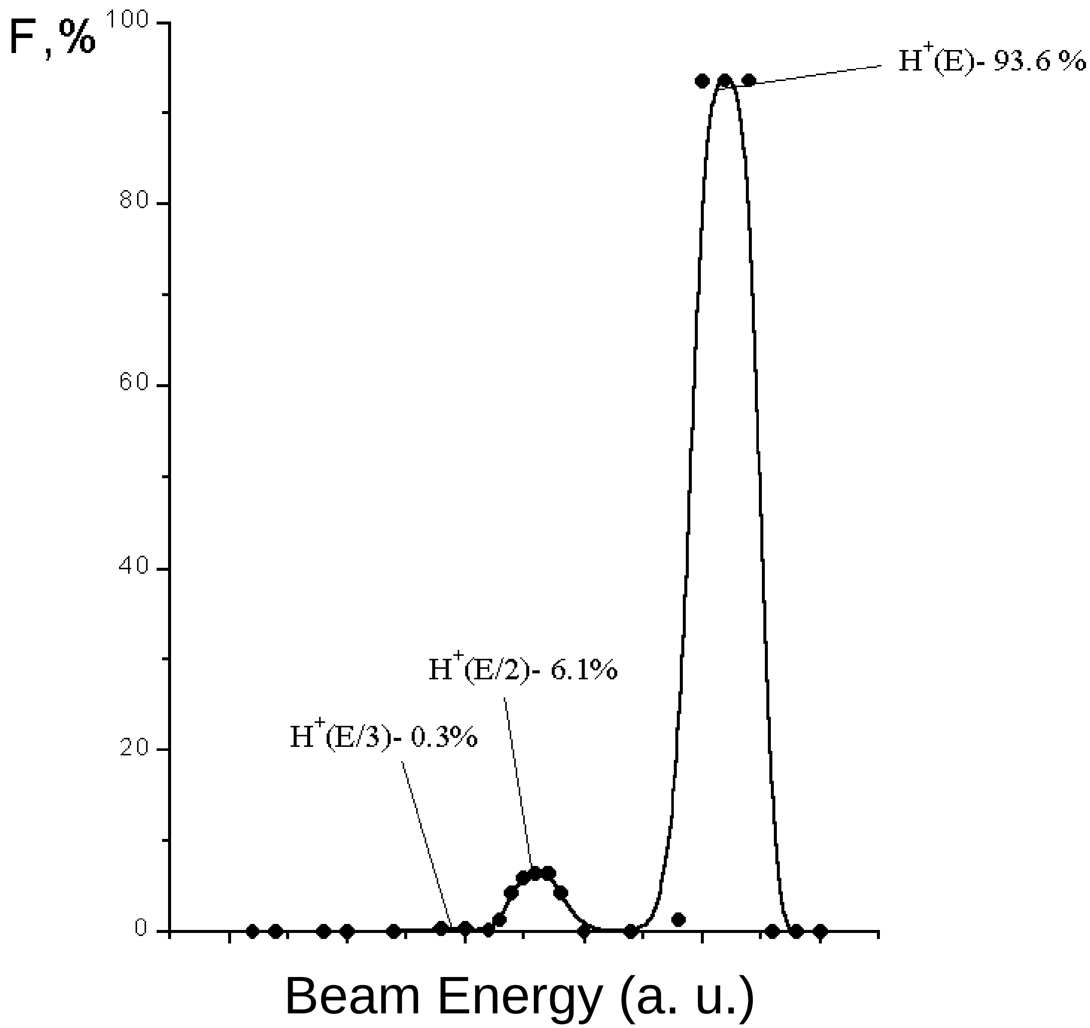
Ion Source

Neutralizer

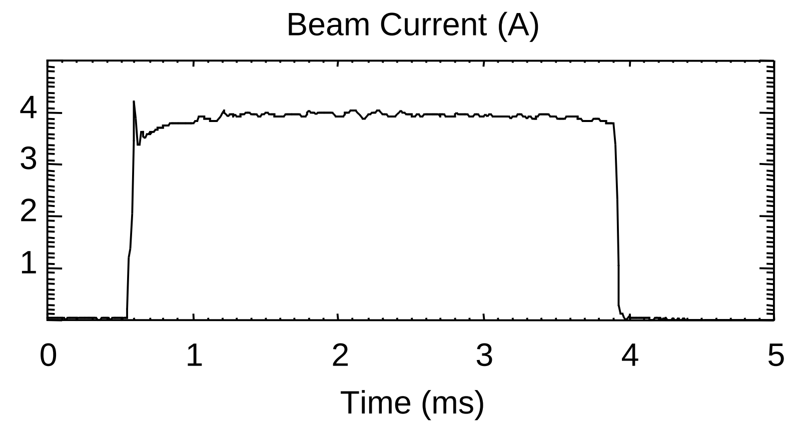
Power Supply

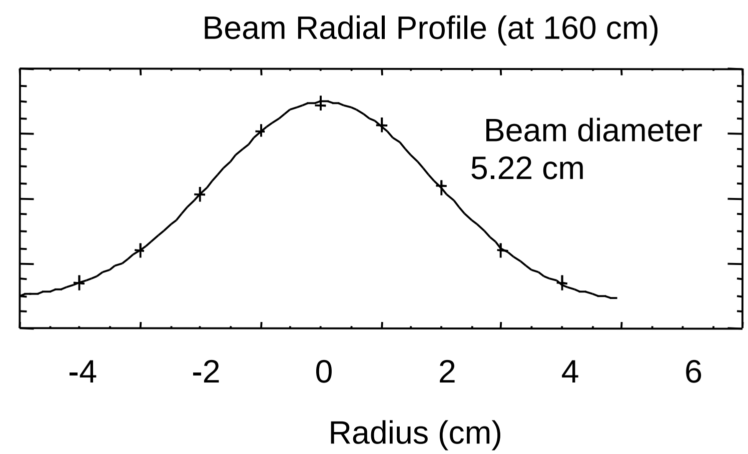
Beam has excellent operational characteristics

94% primary energy component



Stable waveform and smooth radial profile



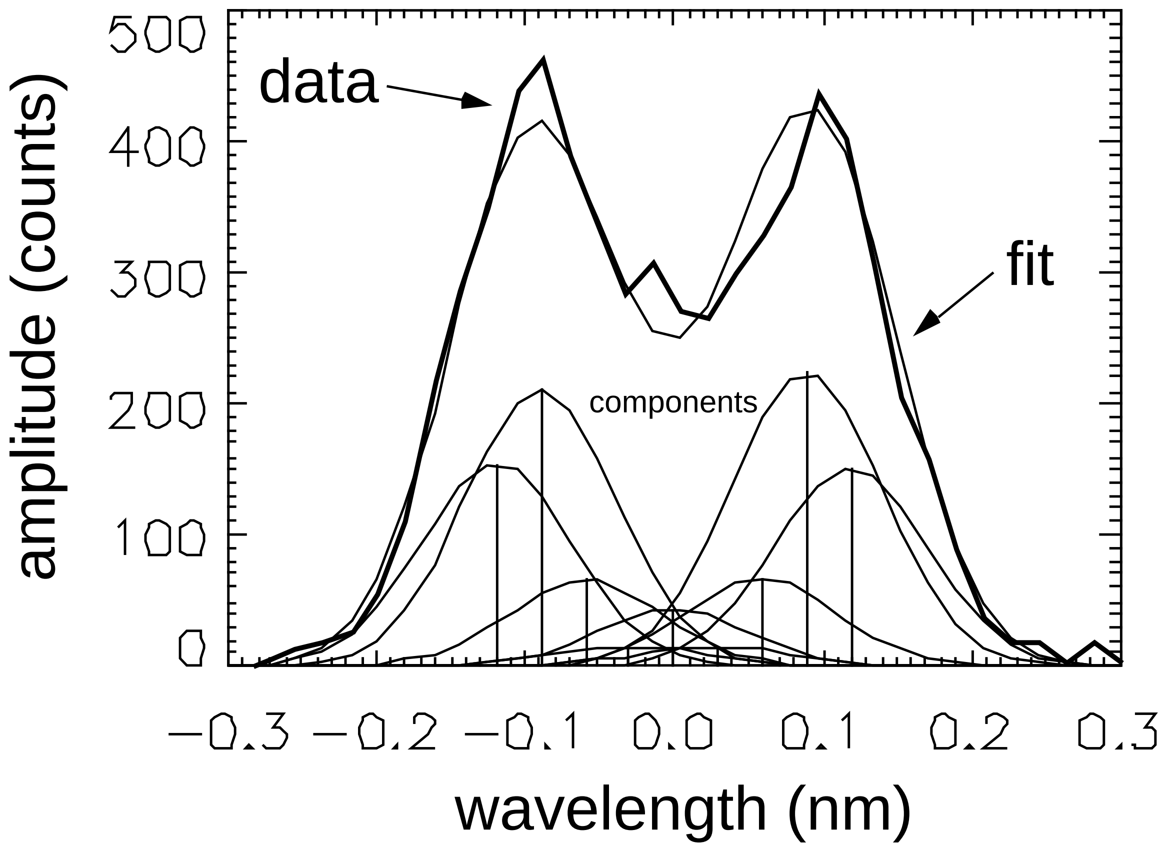


Nine Stark components are fit

$S = c\Sigma a_i \exp\{-(\lambda-\lambda_i)^2/2\Delta\lambda^2\}$

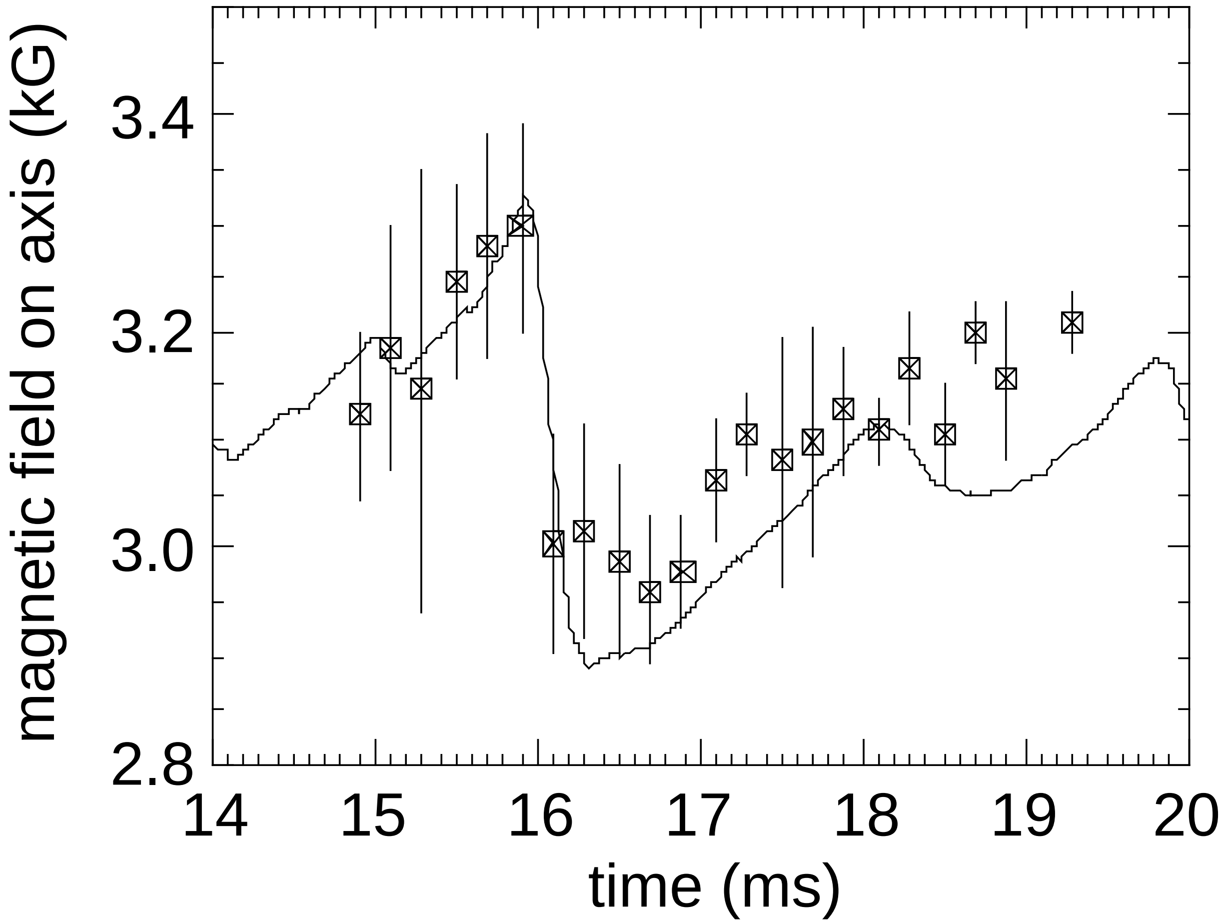
Fitted parameters

a_i and λ_i- amplitudes and wavelengths of Stark split lines
$\Delta\lambda$ –line smearing



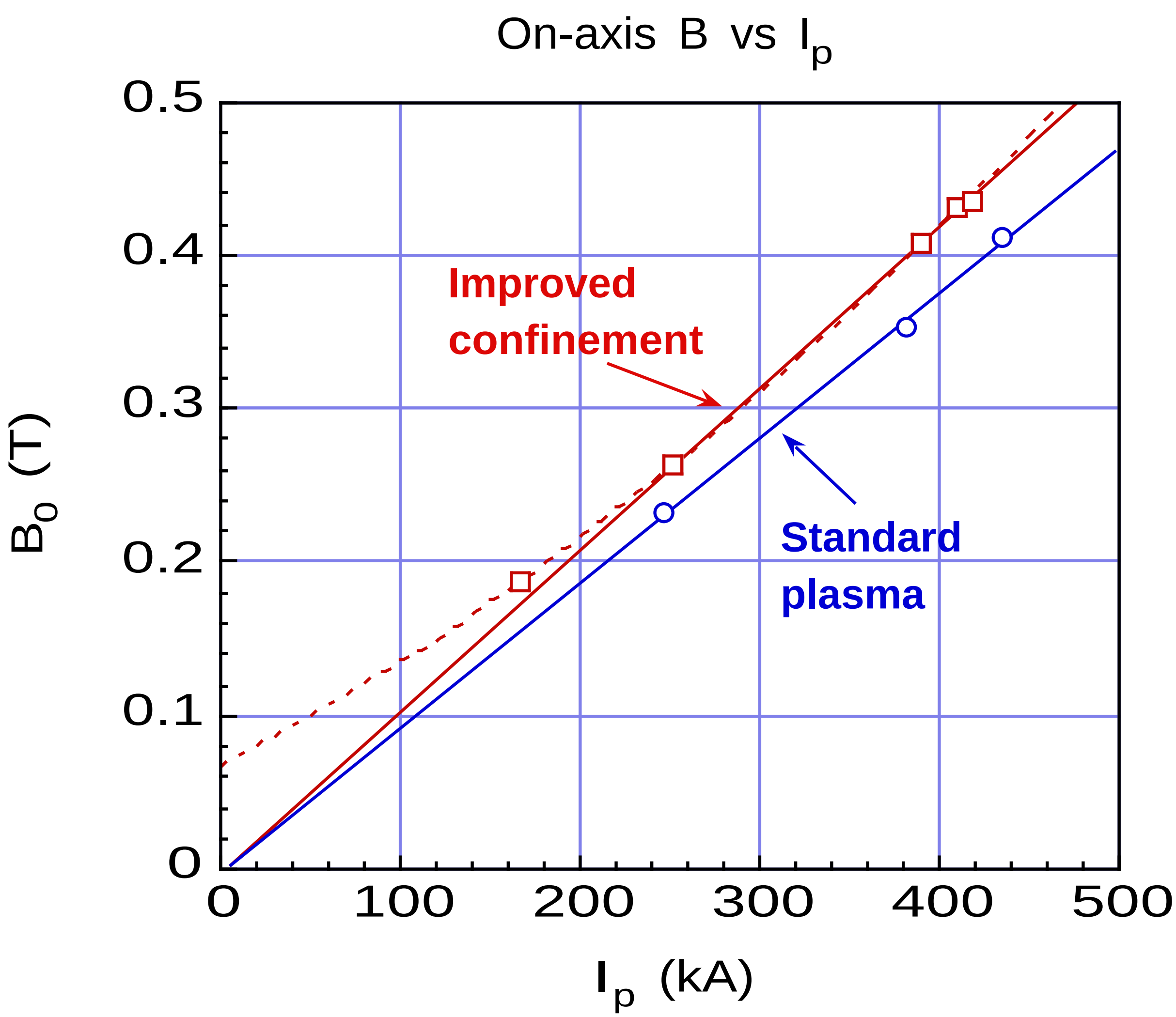
On-axis |**B**| through a sawtooth crash

- Data points from spectral MSE diagnostic
- Solid line from equilibrium modeling

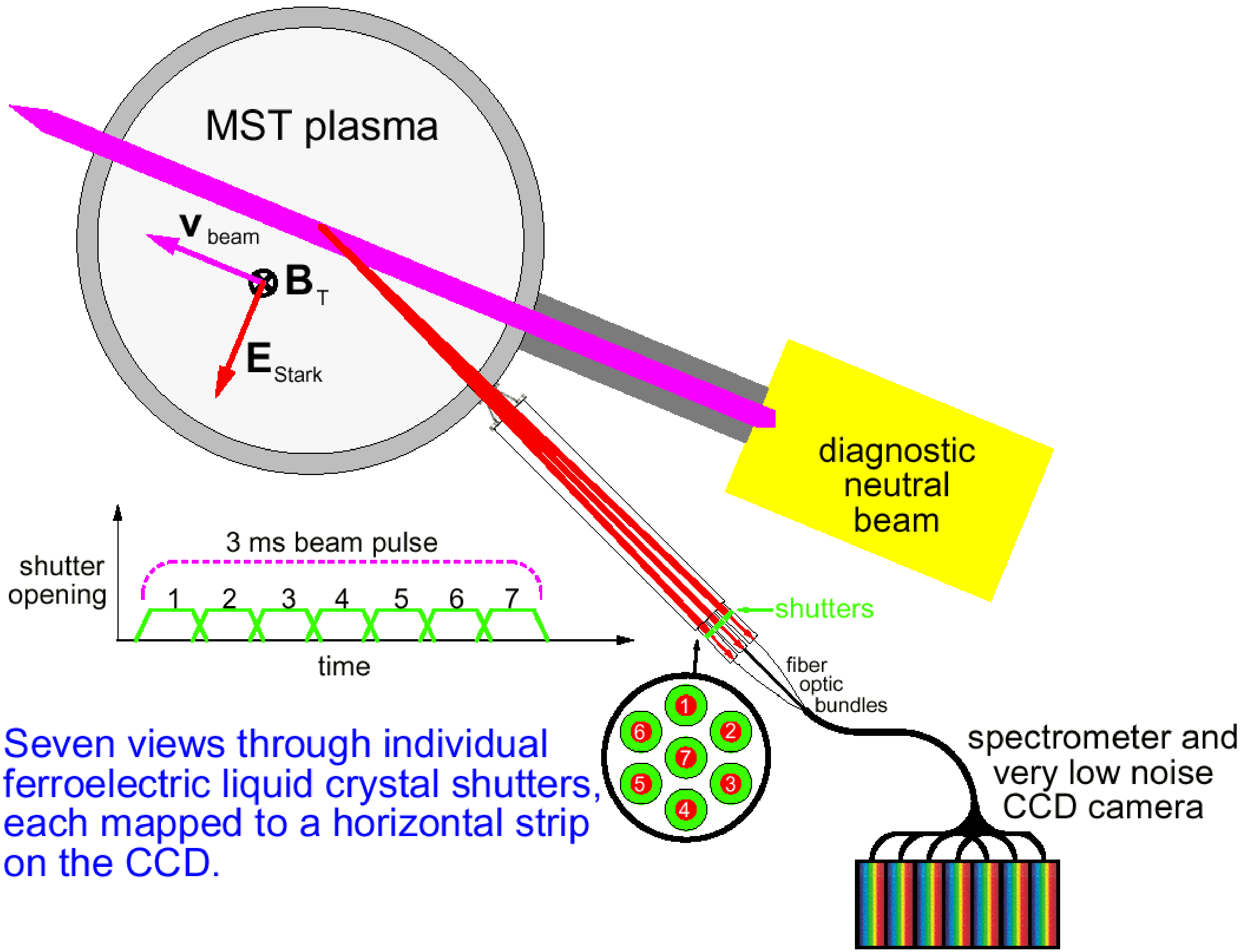


First-time measurements of on-axis |**B**| in an RFP

- Magnetic field below 0.2 T is measured
- On-axis |**B**| provides a strong contraint for equilibrium reconstruction
    - Important for differentiating standard and improved confinement discharges



Next step on MST: time resolution



Seven views through individual ferroelectric liquid crystal shutters, each mapped to a horizontal strip on the CCD.

MSE analysis questions remain

- Levels are statistically mixed, but data show slight difference in π^+ and π^- amplitude from expected
- Need to calculate effect of fine structure on Stark spectrum
  - Important below 0.2 T

Acknowledgements

‰ MST research group

‰ This research is funded by the U. S. Department of Energy