Spectral measurement of |B| via Motional Stark Effect in the MST Reversed-Field Pinch

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ABSTRACT

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Using a 30 keV, 4 A diagnostic neutral H beam, we have made an initial measurement of the separation of the pi manifolds of the H-alpha Motional Stark Effect (MSE) spectrum in the MST Reversed-Field Pinch. The wavelength separation of approximately 0.2 nm is as expected for the B of about 0.5 T in the core of MST. The DINA beam is nearly monoenergetic and has low divergence, thus the Doppler-shifted Stark manifold is clearly separated from the background H-alpha, and beam-induced smearing of the Stark components is minimized. Since the magnitude of B in the core of MST provides an important constraint for equilibrium modeling, three refinements are planned to increase measurement accuracy. First, we will accurately model the expected H-alpha MSE spectrum for low magnetic fields, assuming statistical weighting of the Stark components. Second, using an existing fast spectrometer, we will attempt time-resolved simultaneous measurement of the smeared pi and sigma manifolds. Third, we will implement a new CCD spectrometer and viewing geometry to attempt direct time integrated measurement of the individual components of the Stark manifold.

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Introduction

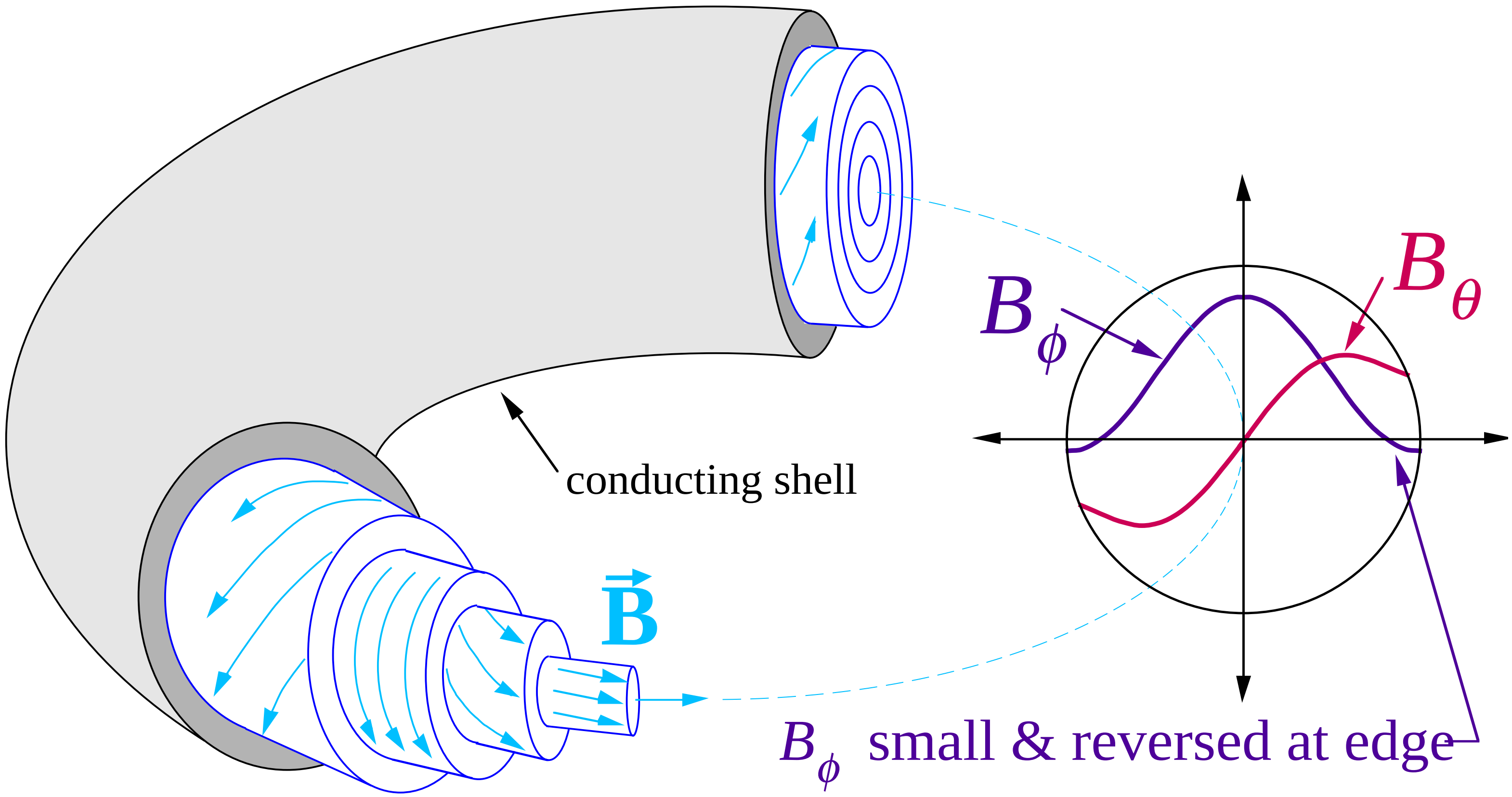
We have made measurements of |**B**| in the core of MST

- |**B**| in the core of MST provides an important constraint for equilibrium modeling

This is a direct measurement of the Stark spectrum

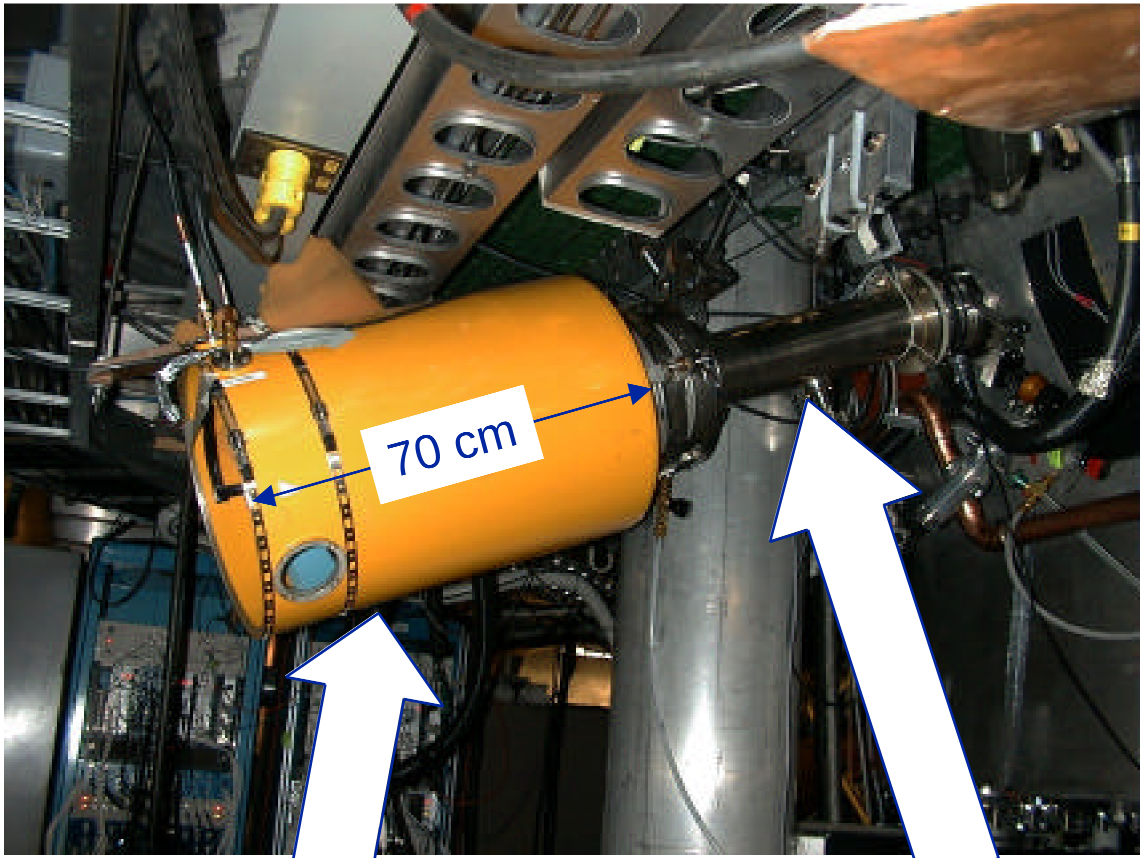
- polarimetry for measuring field line pitch is not suitable for low-field devices
- measure the separation of the π manifolds of the Hα Motional Stark Effect (MSE) spectrum

The RFP is a toroidally axisymmetric current-carrying plasma with toroidal field $B_\phi \approx$ poloidal field B_θ



- Self-generated currents drive plasma to relaxed state in which toroidal field is reversed at edge

DNB on MST - what it looks like



Ion Source

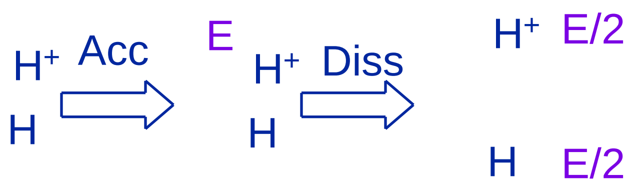
Neutralizer

Power Supply

Beam is mono-energetic (almost)

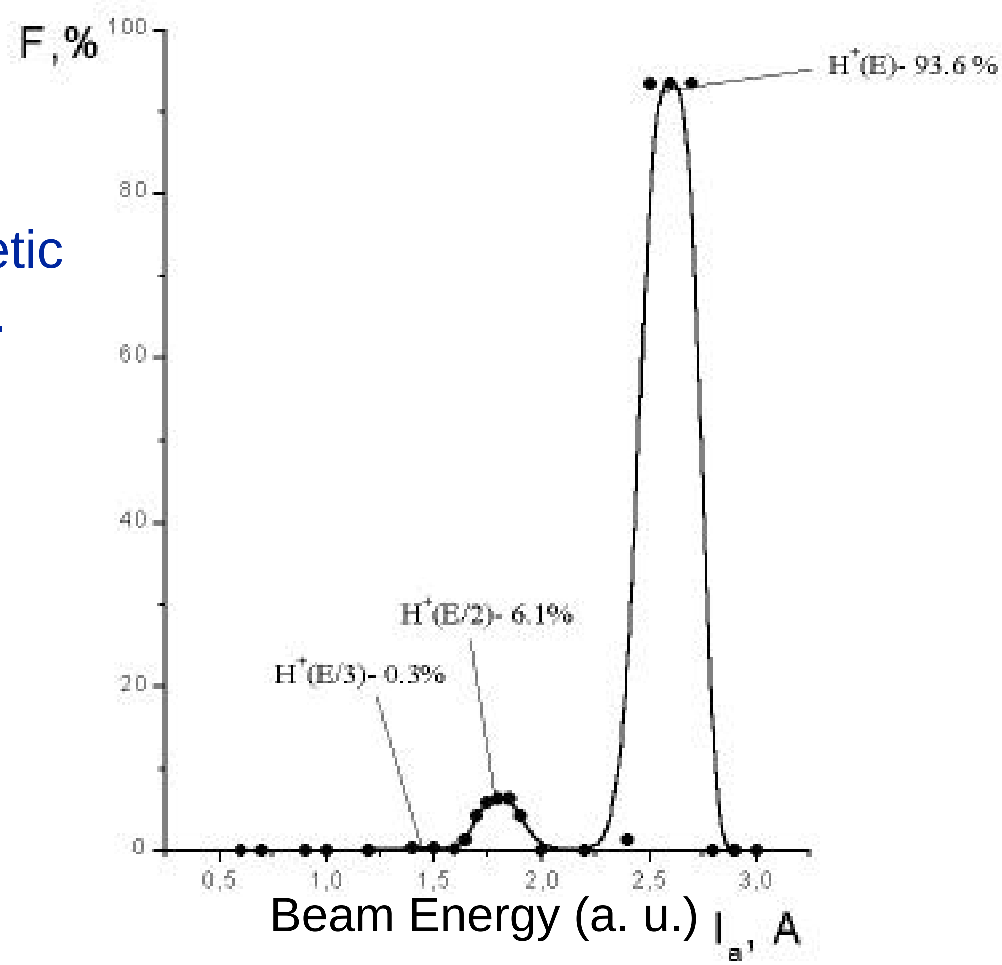
- Components with E/2 and E/3 present in hydrogen beams.

- Result of dissociation of energetic (E) molecular ions H_2^+ and H_3^+.



High density and and high temperature plasma ⇨ low concentration of H_2^+ and H_3^+

Beam mass-energy spectrum

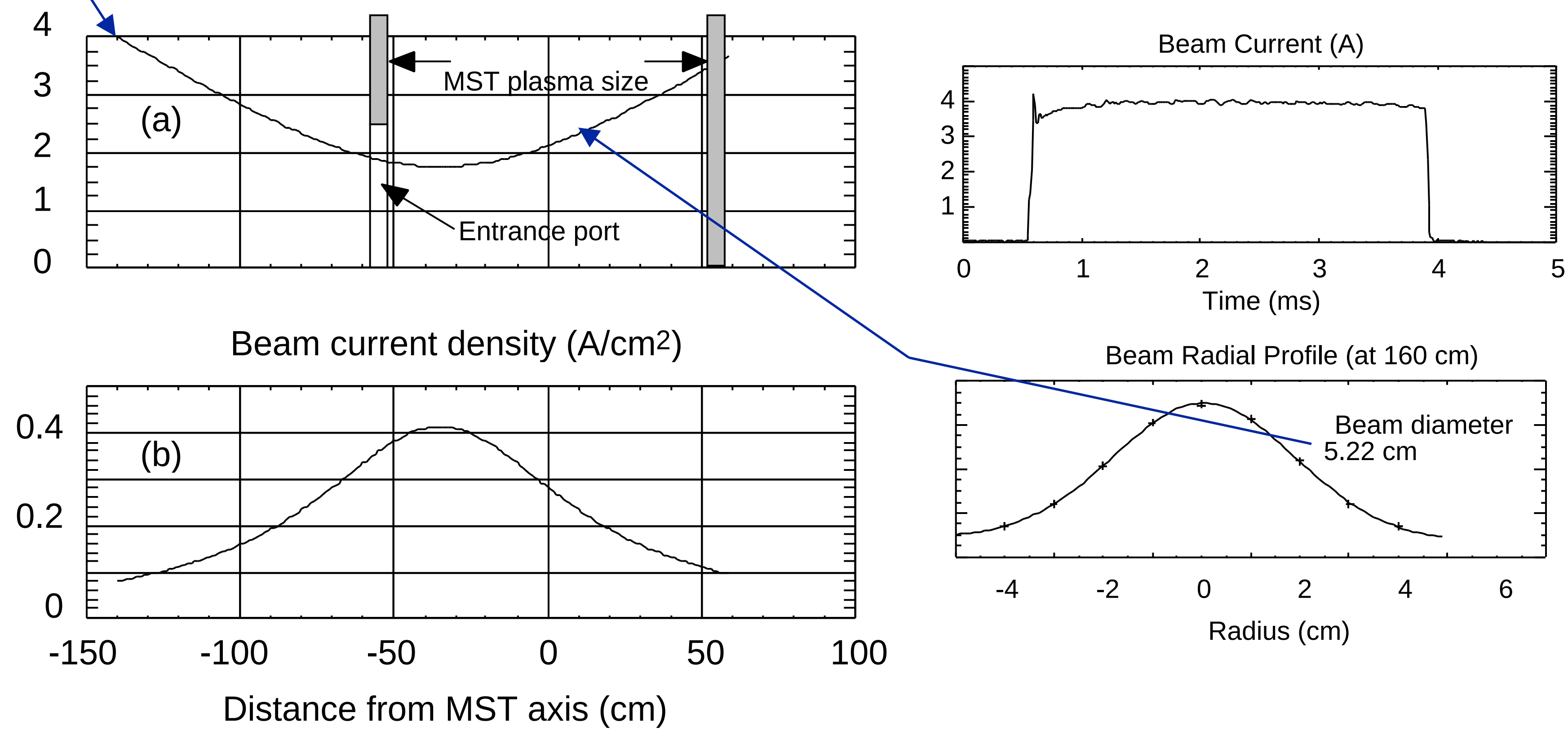


Beam is focused for higher intensity and to pass through small MST portholes

Small port size requires beam to be focused

Injector position

Waveform and Radial Profile
Hydrogen Beam
4A/30 keV



Stark Effect

- Investigated by Stark in 1913
- Breaking of the degeneracy of the energy levels of a hydrogen-like atom via the application of an electric field
- Results in the splitting of a given line, *e.g.*, Hα at 656.3 nm, into several lines whose wavelength separation in linearly proportional to the magnitude of the electric field

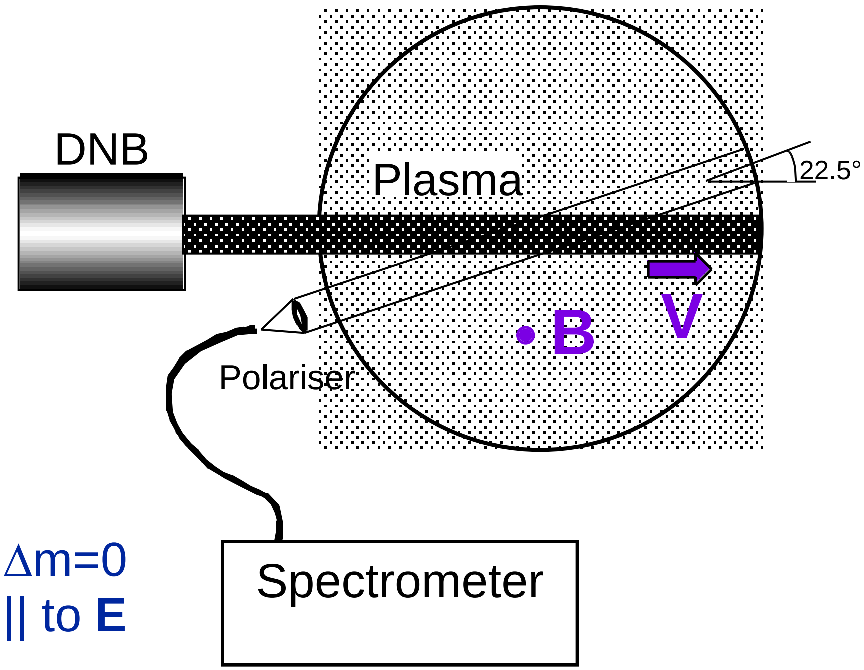
Motional Stark Effect

- An atom moving with a velocity **v** in a magnetic field **B** experiences an equivalent electric field $\mathbf{v} \times \mathbf{B}$ in its frame of reference
- When a beam of neutral hydrogen atoms is directed into a magnetically confined plasma, the atoms are excited and the resulting line emission is split as if the atoms were in an electric field $\mathbf{E} = \mathbf{v} \times \mathbf{B}$
- If the velocity of beam atoms is known, the magnetic field in the plasma can be determined.

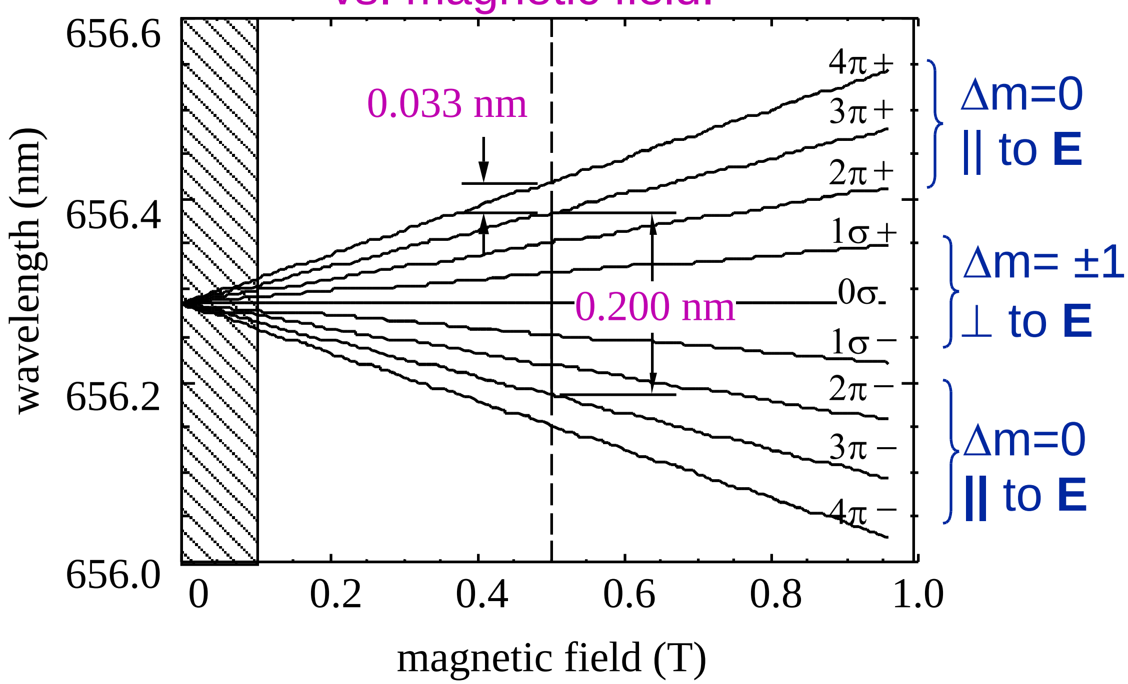
Principles of MSE

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.



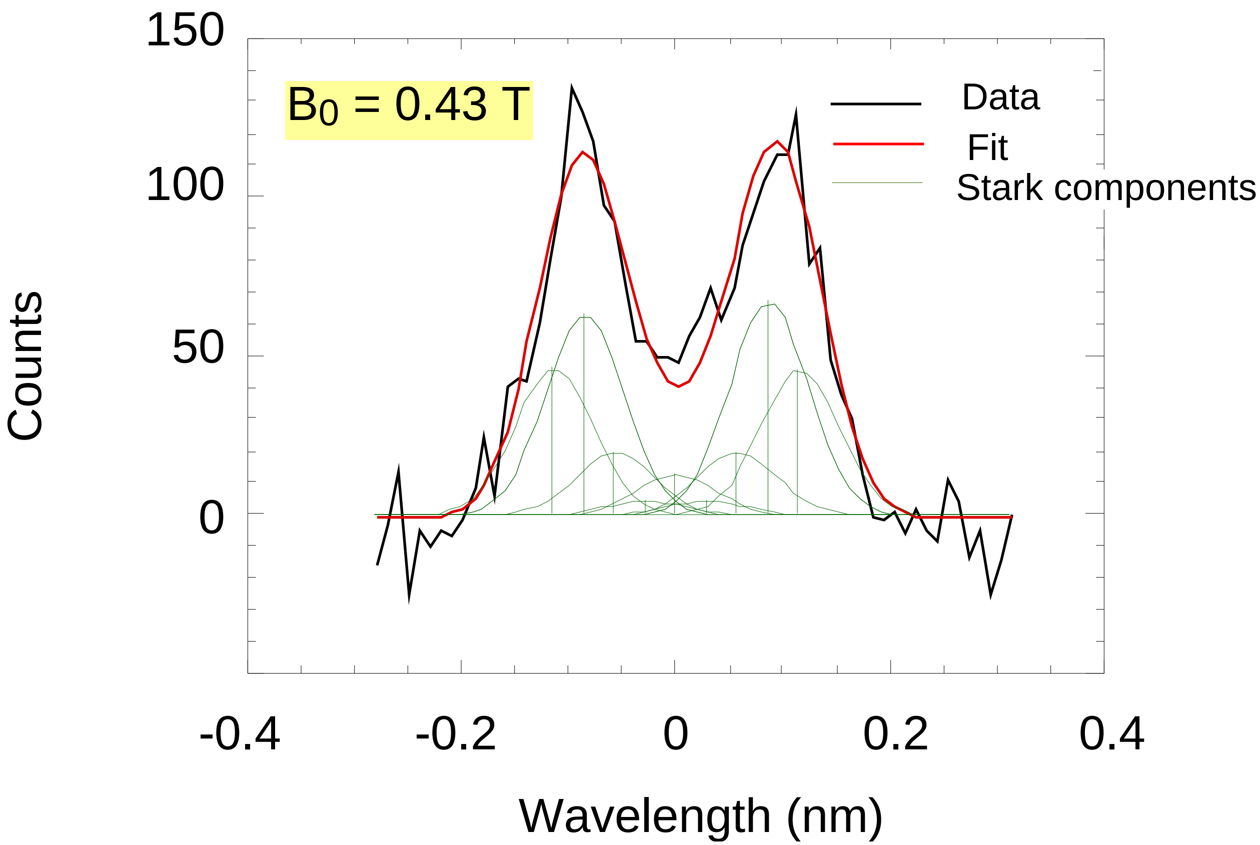
Nine Stark components are fitted

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

Fitted parameters

a_i and λ_i- amplitudes and wavelengths of Stark split lines

$\Delta\lambda$ –line smearing



Calculated values a_i

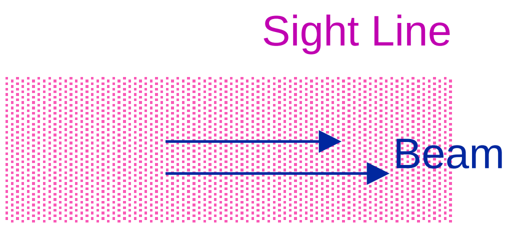
$\pi 4$	30.77%
$\pi 3$	42.13%
$\pi 2$	13.31%
$\sigma 1$	35.13%
$\sigma 0$	100%
$-\sigma 1$	35.22%
$-\pi 2$	13.25%
$-\pi 3$	44.81%
$-\pi 4$	30.42%

Line Smearing

Finite temperature effect $\exp(-\frac{mv^2}{2T}) \Rightarrow \exp(-\frac{\lambda^2}{2\lambda_T^2})$

$$\lambda_T[nm] = 3.26\times10^{-5}\lambda_0[nm]\sqrt{T[eV]} = 2.14\times10^{-2}\sqrt{T[eV]}$$

Non-mono-energetic beam



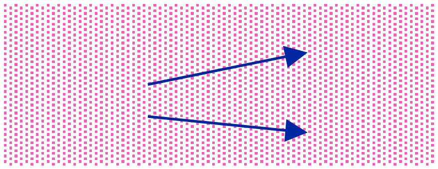
$T_{||} = \frac{\Delta\varepsilon_{||}^2}{2\varepsilon_0}$ =0.17 eV $\Delta\lambda_{||}[nm] = 8.1\times10^{-3}\cos(\vartheta)$

$\Delta\varepsilon_{||}$ =100 eV - beam energy spread

ε_0 = 30 keV - beam energy

$\vartheta = 22.5^\circ$ - angle between the beam and the sight line

Finite beam divergence $T_\perp$

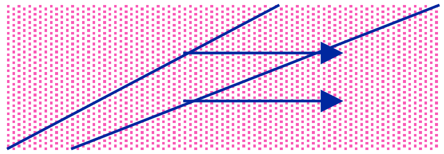


$T_\perp$ ≈ 30 eV and $\Delta\lambda_\perp[nm] = 0.126\times\sin(\vartheta) = 0.045nm$

Finite light collection solid angle

$T_{\perp coll} = 2\varepsilon_0\alpha_{coll}^2$ = 7.5 eV and $\Delta\lambda_{coll}[nm] = 5.9\times10^{-2}\sin(\vartheta)$ = .022nm

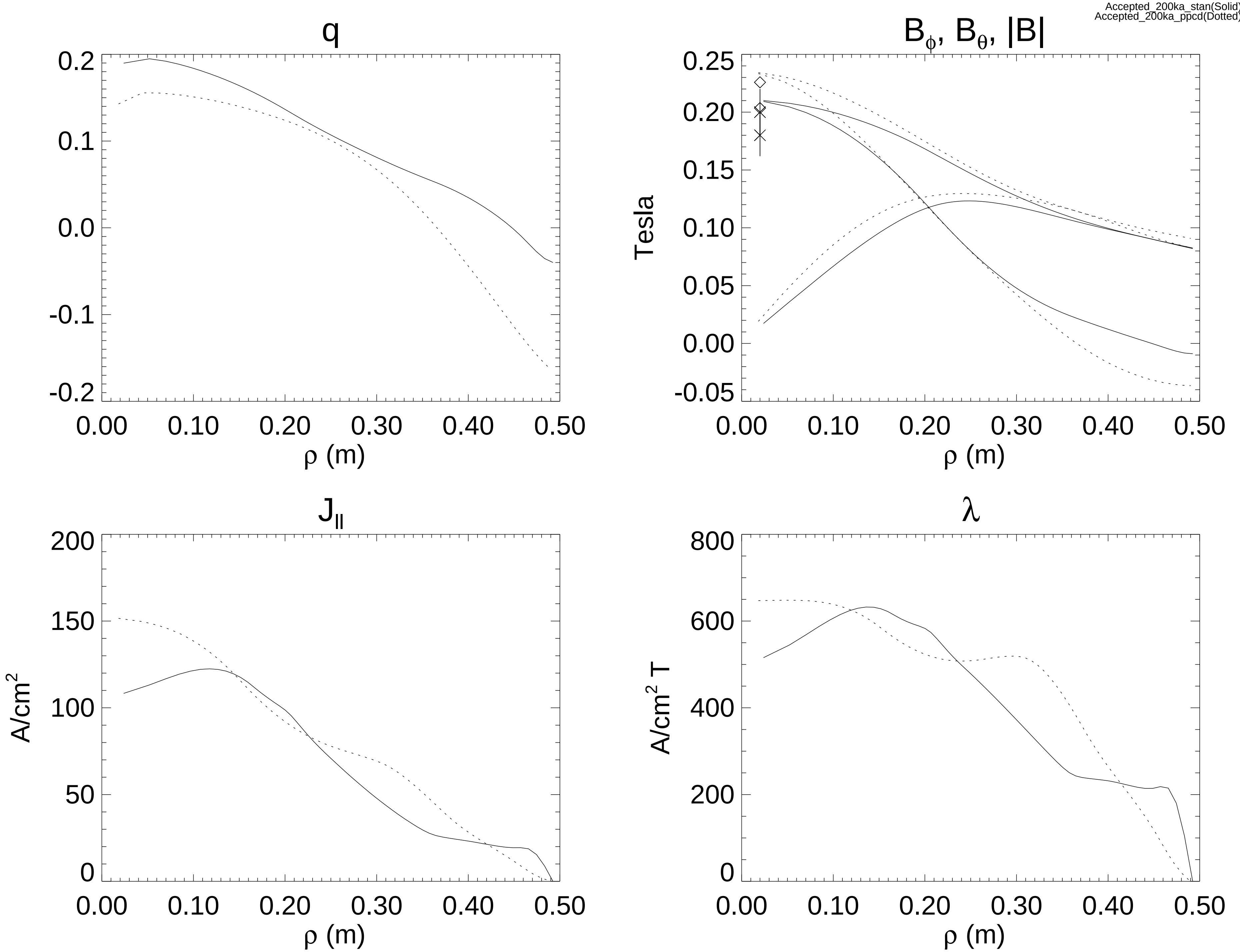
α_{coll} = .01 rad (determined by the viewing optics)

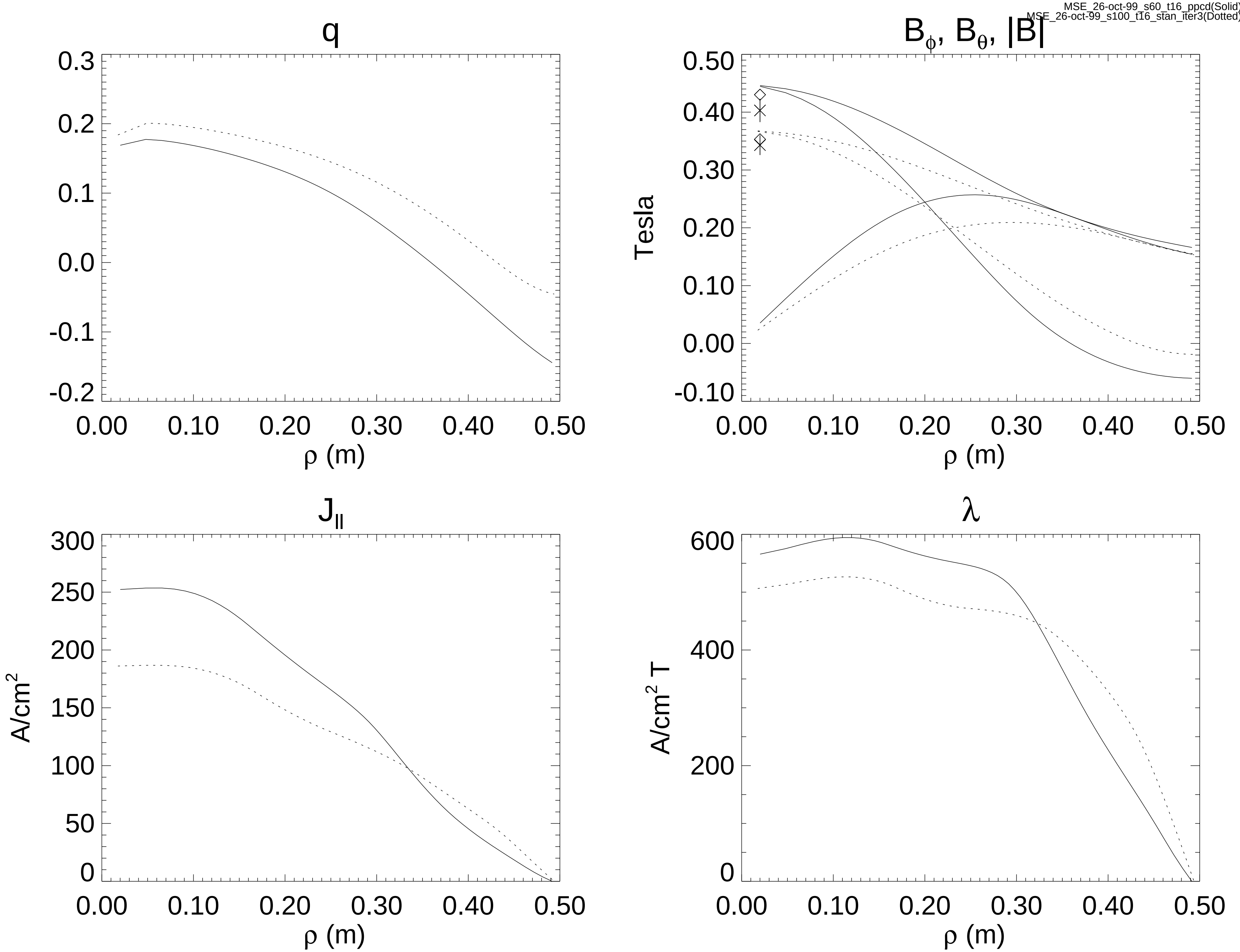


$$\Delta\lambda_{tot} = \sqrt{\Delta\lambda_{||}^2 + \Delta\lambda_\perp^2 + \Delta\lambda_{coll}^2} \approx 0.05nm$$

On axis measurement of |B| provides a strong contstraint for equilibrium modeling of q and $J_{||}$ profiles

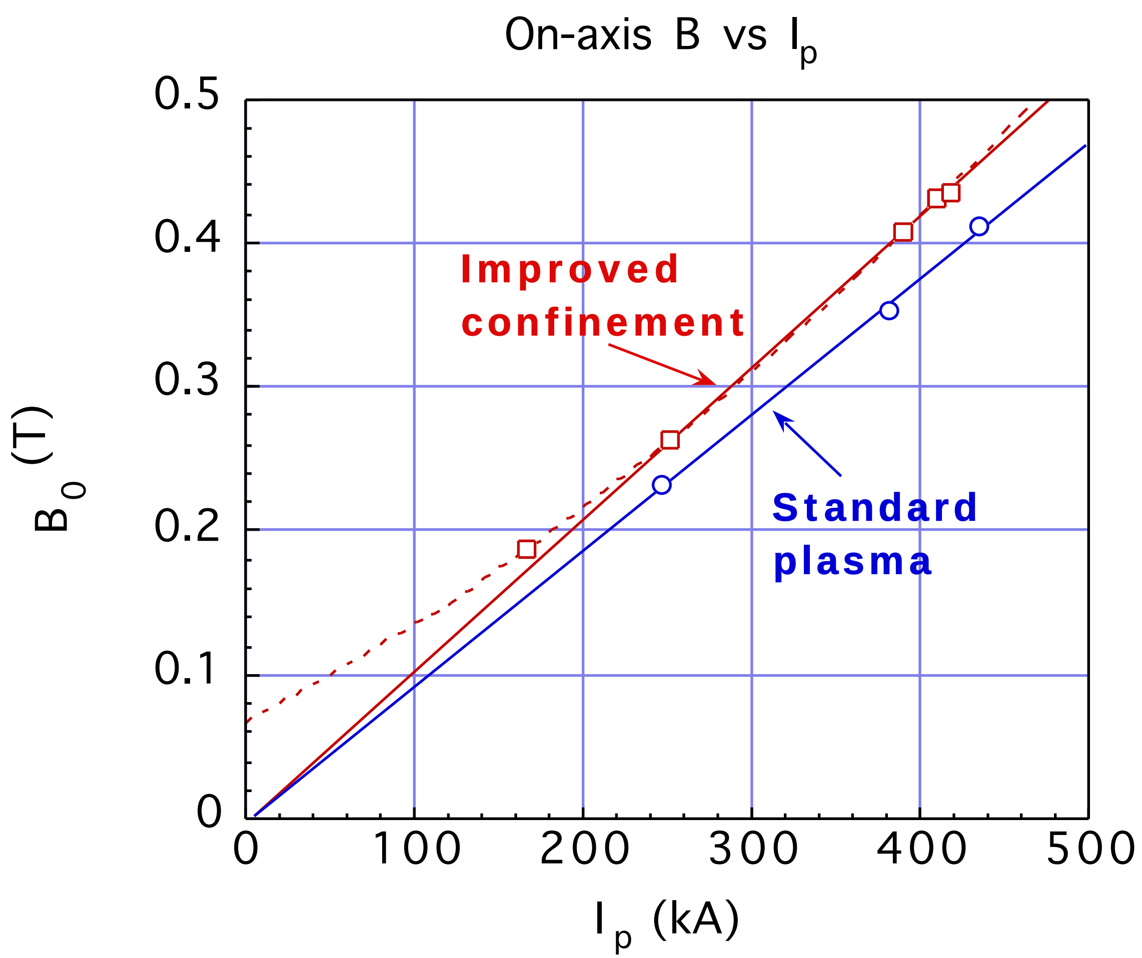
- important for differentiating standard (dotted lines) and improved confinement (solid lines) profiles


Accepted_200ka_stan(Solid)
Accepted_200ka_ppcd(Dotted)
q
B_ϕ, B_θ, |B|
Tesla
$J_{||}$
A/cm^2
λ
A/cm^2 T
ρ (m)
0.00 0.10 0.20 0.30 0.40 0.50


MSE_26-oct-99_s60_t16_ppcd(Solid)
MSE_26-oct-99_s100_t16_stan_iter3(Dotted)
q
0.3
0.2
0.1
0.0
-0.1
-0.2
0.00 0.10 0.20 0.30 0.40 0.50
ρ (m)
B_ϕ, B_θ, |B|
Tesla
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
0.00 0.10 0.20 0.30 0.40 0.50
ρ (m)
$J_{||}$
A/cm^2
300
250
200
150
100
50
0
0.00 0.10 0.20 0.30 0.40 0.50
ρ (m)
λ
A/cm^2 T
600
400
200
0
0.00 0.10 0.20 0.30 0.40 0.50
ρ (m)

On-axis magnetic field has been measured via MSE for the first time in an RFP

- Magnetic field as low as 0.16 T is measured.
- Improvements needed to increase accuracy and time resolution.



Summary

- Motional Stark Effect measurements of |**B**| have been accomplished in a low-field (< 0.5 T) magnetically-confined plasma.

- Good measurement sensitivity differentiates between standard and improved confinement profiles in MST.

Acknowledgement: J. K. Anderson supplied the MSTFIT equilibrium modeling results. This work was supported by the United States Department of Energy.

Planned Refinements

- We will more accurately model the expected H-alpha MSE spectrum for low magnetic fields, checking the assumption of statistical weighting of the Stark components.

- We will implement a new CCD spectrometer and FLC shutter to attempt time resolved measurement of the the Stark manifold.

- Using a fast spectrometer, we will attempt time-resolved simultaneous measurement of the smeared pi and sigma manifolds.