ADAS application to low-field motional Stark effect diagnostics

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with the contributions from

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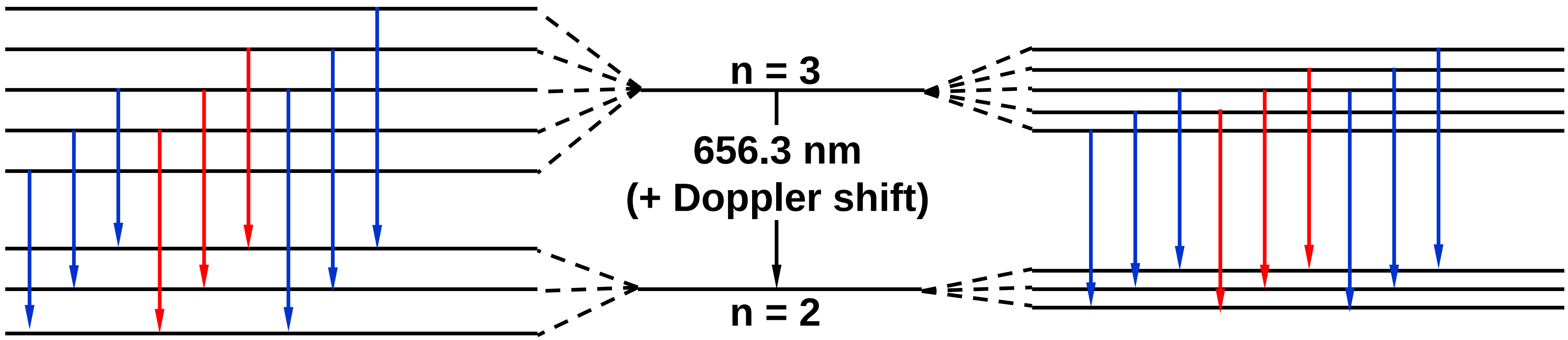
Motional Stark effect: Doppler-shifted polarized light gives local field information

Balmer alpha emission from energetic neutrals

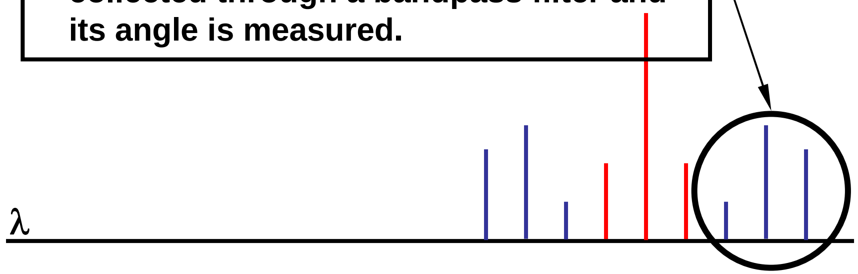


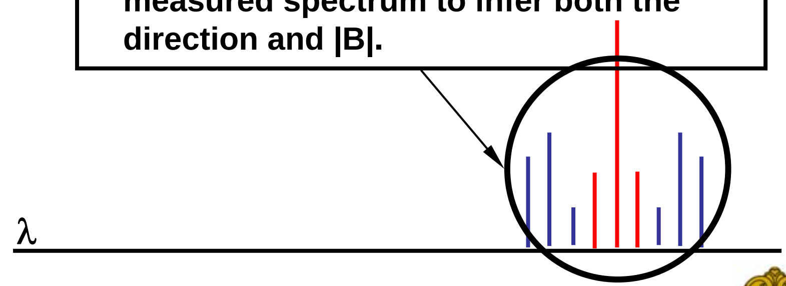
- Polarimetric approach: suitable for the devices with high fields (> 1 T).
- |B| usually known. Pitch angle unknown.
- One polarization component (σ or π) collected through a bandpass filter and its angle is measured.

polarization // E

polarization ⊥ E

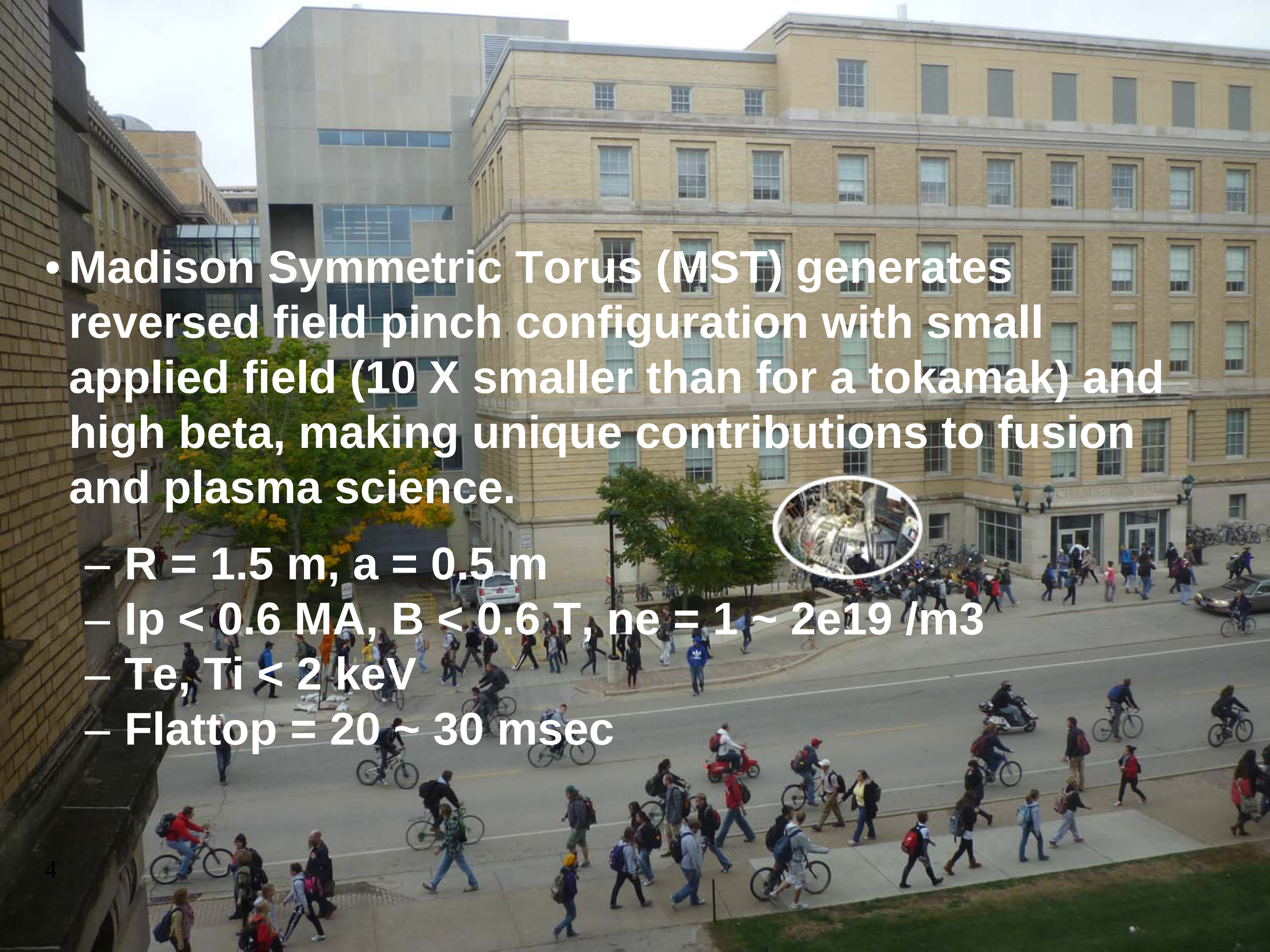
- Spectral approach: suitable for low-field device (like MST).
- Stark splitting too small to bandpass.
- An atomic model is used to fit the measured spectrum to infer both the direction and |B|.





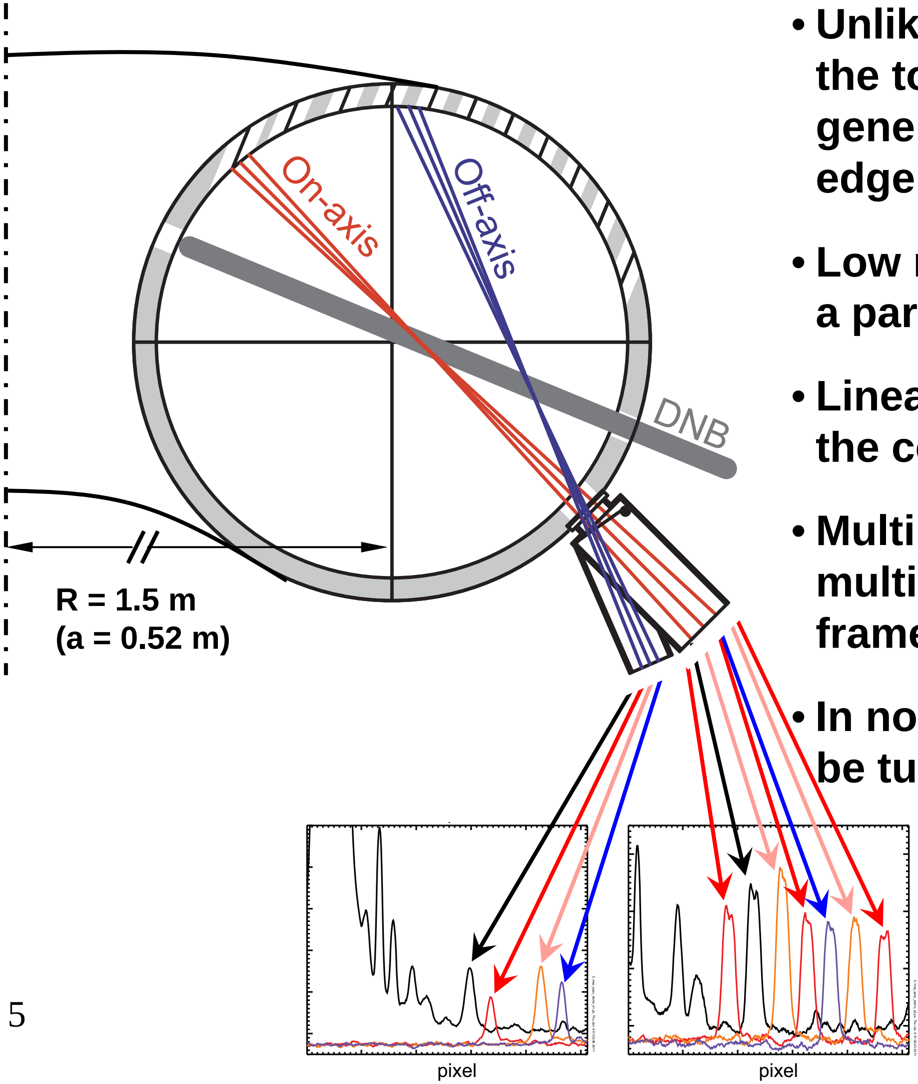
Outline

- MSE diagnostic at MST and its spectra
- Outline of the fitting scheme
- Density dependence of the upper state populations
- Summary and future/present work



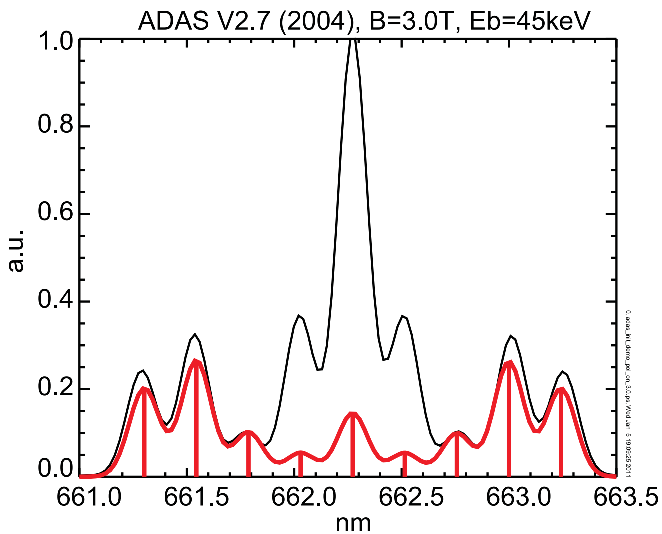
- Madison Symmetric Torus (MST) generates reversed field pinch configuration with small applied field (10 X smaller than for a tokamak) and high beta, making unique contributions to fusion and plasma science.
  - R = 1.5 m, a = 0.5 m
  - Ip < 0.6 MA, B < 0.6 T, ne = 1 ~ 2e19 /m3
  - Te, Ti < 2 keV
  - Flattop = 20 ~ 30 msec

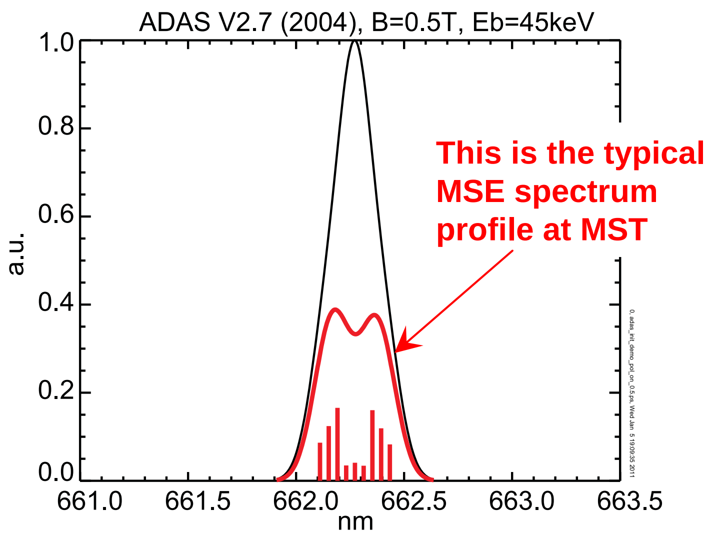
Low-field MSE spectra at MST is complex

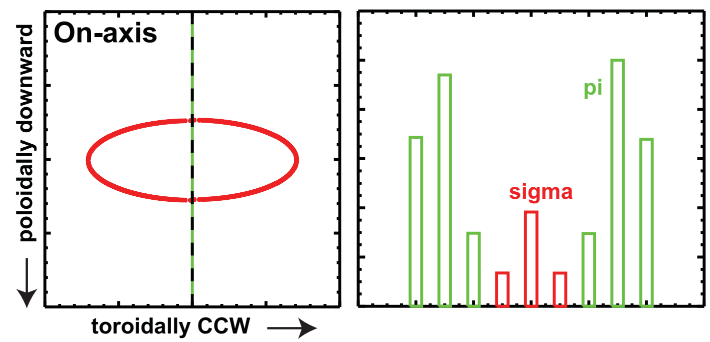


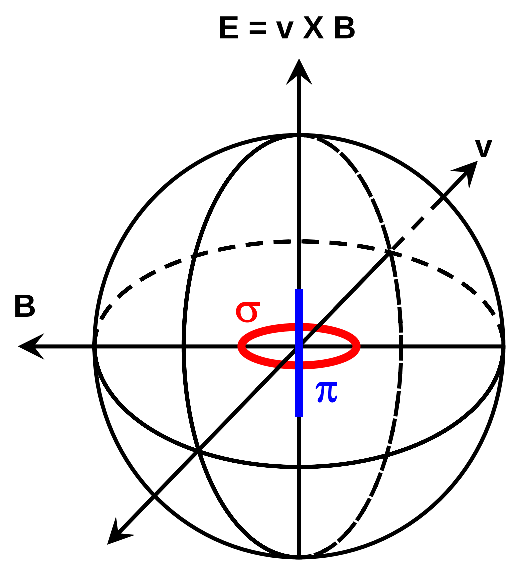
- Unlike tokamaks, |B| on axis is unknown since the toroidal field in this region is largely generated by poloidal current flowing in the edge, not by external TF coils.
- Low magnetic fields ($\leq$ 0.5 T) preclude selecting a particular Stark component in the signal.
- Linear polarizers are installed to exclude one of the components.
- Multiple views at each spatial location result in multiple groups of Stark multiplets within a CCD frame.
- In normal operations, some of the views need to be turned off.

Polarizers try to suppress one polarization component, but not perfectly

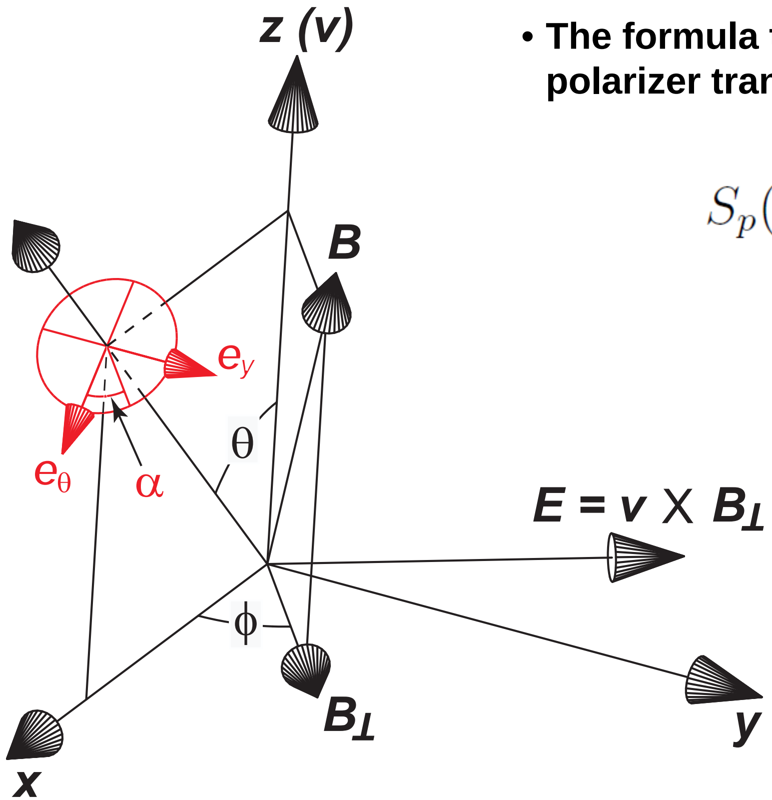








Stokes formulism for Stark multiplets relates geometric information with the intensities



- The formula to relate the intensity with the viewing angle (θ), polarizer transmission axis (α), and pitch angle (ϕ) [1]:

$$S_p(0) = \frac{1}{2}\left[I_0 + I_1\cos(2\alpha) + I_2\sin(2\alpha)\right]$$

$$\begin{bmatrix} I_0^\sigma \\ I_1^\sigma \\ I_2^\sigma \\ I_3^\sigma \end{bmatrix} = \begin{bmatrix} I^{(\sigma)np} + I_\perp^\sigma(1+\sin^2\theta\sin^2\phi) \\ I_\perp^\sigma(\cos^2\phi - \cos^2\theta\sin^2\phi) \\ I_\perp^\sigma\cos\theta\sin 2\phi \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} I_0^\pi \\ I_1^\pi \\ I_2^\pi \\ I_3^\pi \end{bmatrix} = \begin{bmatrix} I^{(\pi)np} + I_\perp^\pi(1-\sin^2\theta\sin^2\phi) \\ -I_\perp^\pi(\cos^2\phi - \cos^2\theta\sin^2\phi) \\ -I_\perp^\pi\cos\theta\sin 2\phi \\ 0 \end{bmatrix}$$

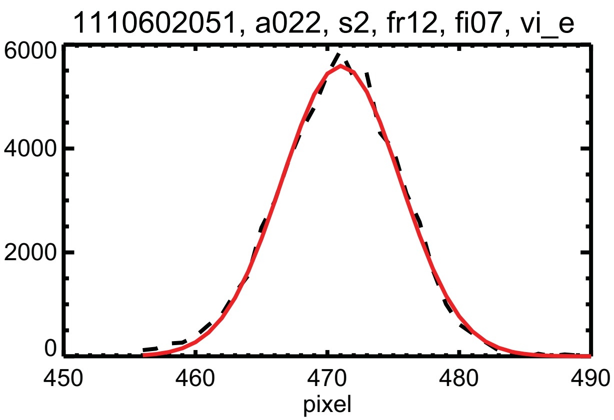
- $I_\perp$: Intensity of pure sigma & pi when viewed perpendicular to the Lorentz electric field E. ADAS comes in for this parameter.

[1] D. Voslamber, “Self-calibrating magnetic field diagnostics in beam emission spectroscopy”, Rev. Sci. Instrum. 66:4 (1995) 2892-2903

ADAS provides initial values for $I_{\perp}$'s

Beam-into-gas spectrum

Broadening (w_init)

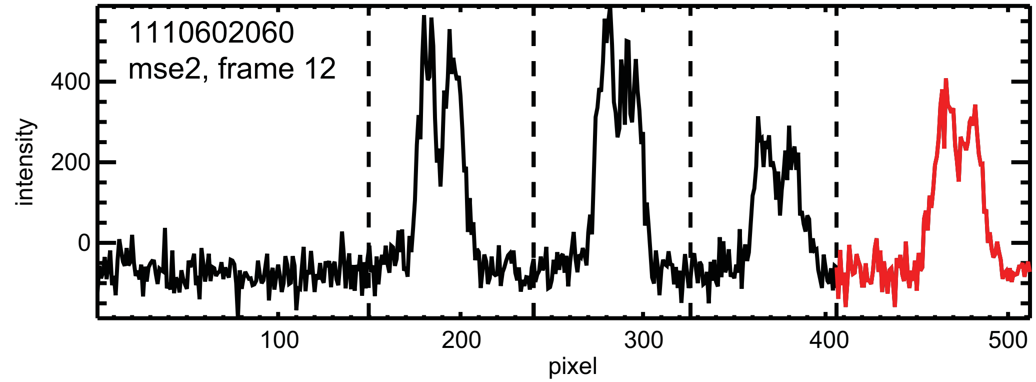


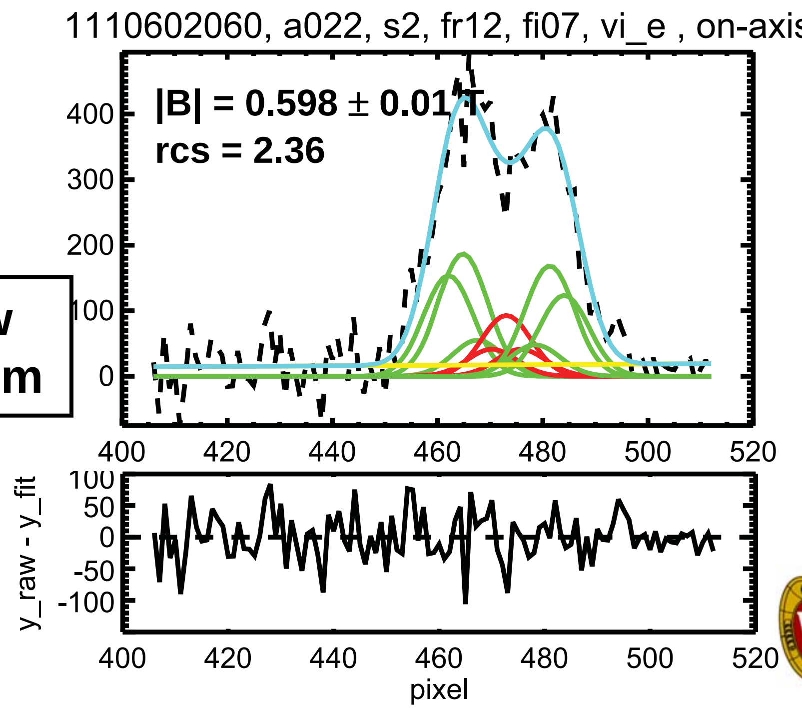
Plasma (ne, Te etc)

ADAS V3.1 (305)

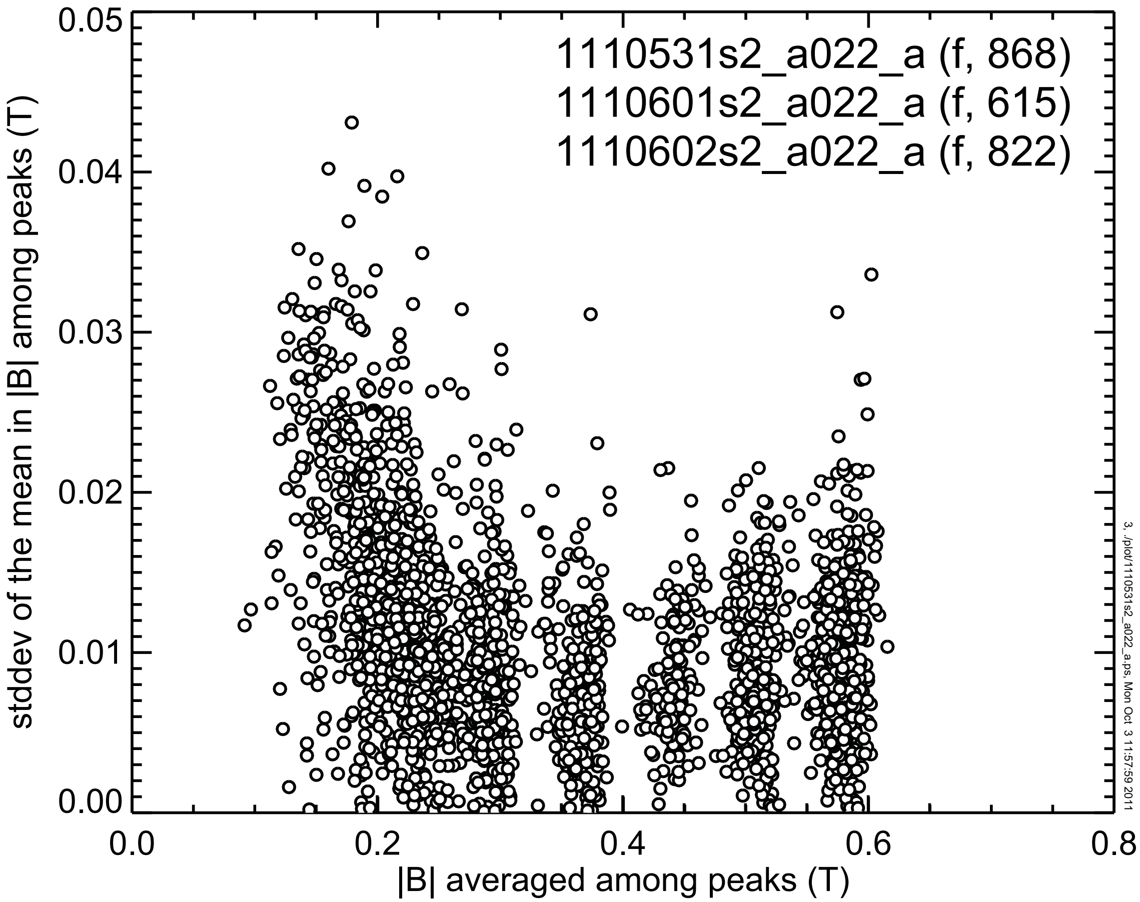
Intensity (i_perb_init)

Fit raw spectrum



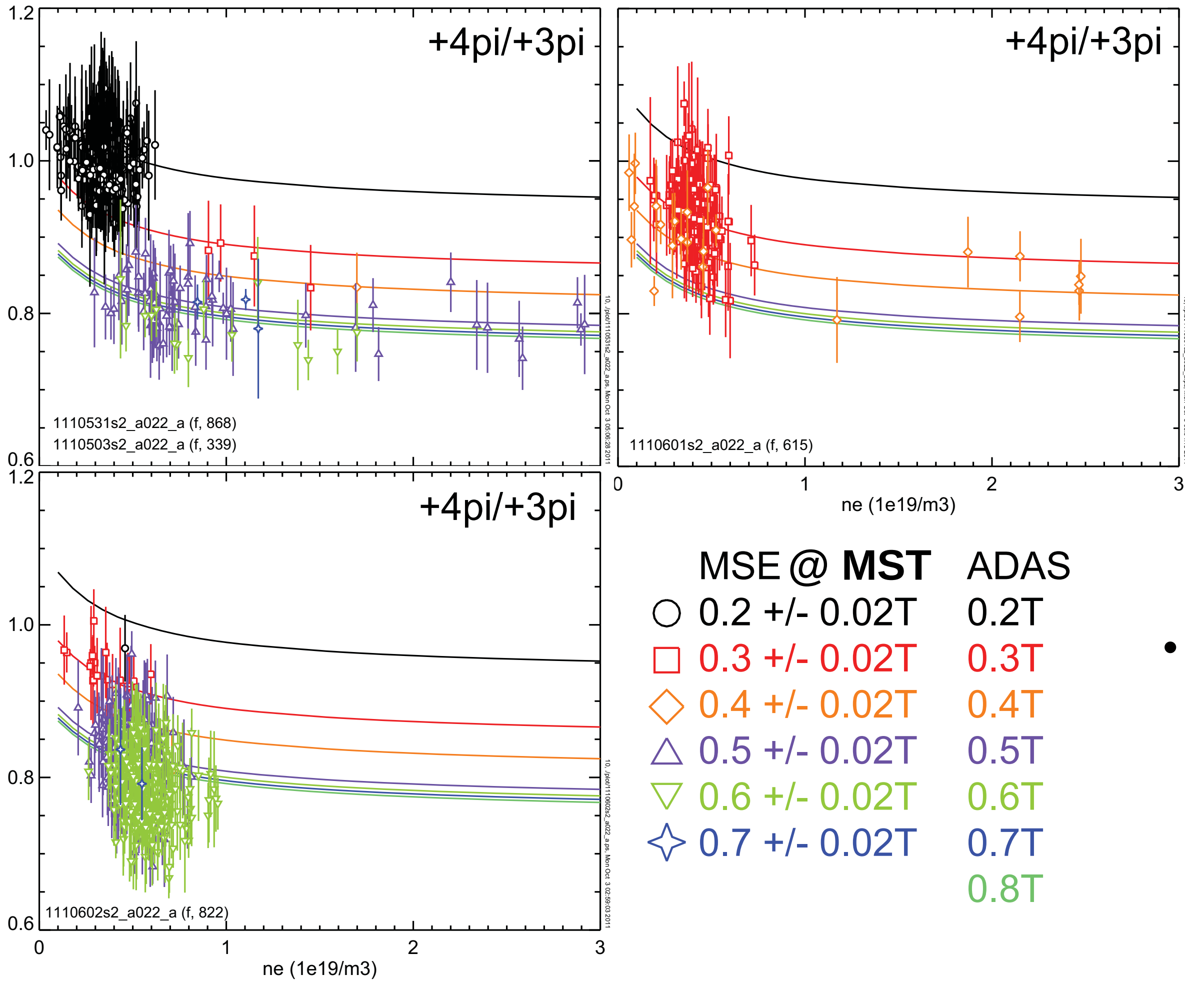


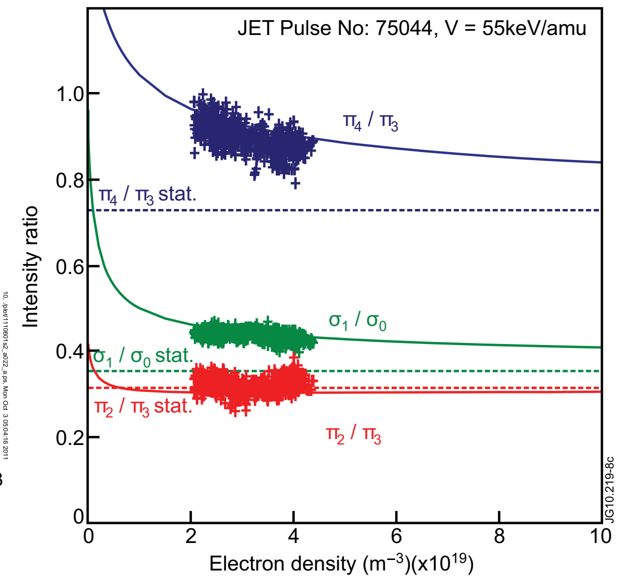
Measurements from multi chords for one time/space point improves the statistics



- **Upper bounds of the statistical uncertainties: 5 ~ 15 % for 0.6 ~ 0.2 T (roughly 600 kA ~ 200 kA)**

Both MSE and ADAS with low magnetic field implies ‘near’ statistical populations

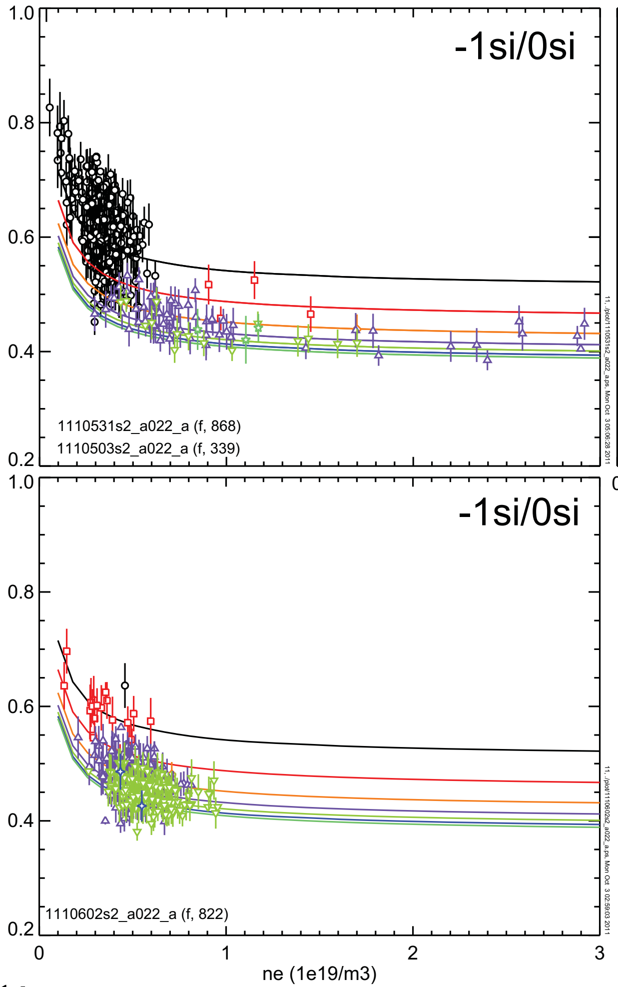




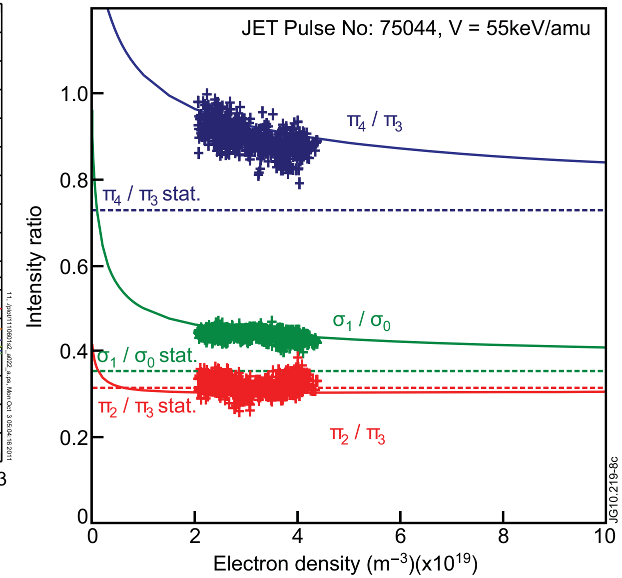
- **The most recent collisional radiative model (nkm-resolved)* confirms the deviation from a statistical population at ne < 2e19 /m3**

***E Delabie et al, Plasma Phys. Control. Fusion 52 (2010) 125008**
O Marchuk et al, J. Phys. B: At. Mol. Opt. Phys. 43 (2010) 011002

Deviations from statistical populations occur at lower densities



	MSE @ **MST**	ADAS
○	0.2 +/- 0.02T	0.2T
□	0.3 +/- 0.02T	0.3T
◇	0.4 +/- 0.02T	0.4T
△	0.5 +/- 0.02T	0.5T
▽	0.6 +/- 0.02T	0.6T
✧	0.7 +/- 0.02T	0.7T
		0.8T



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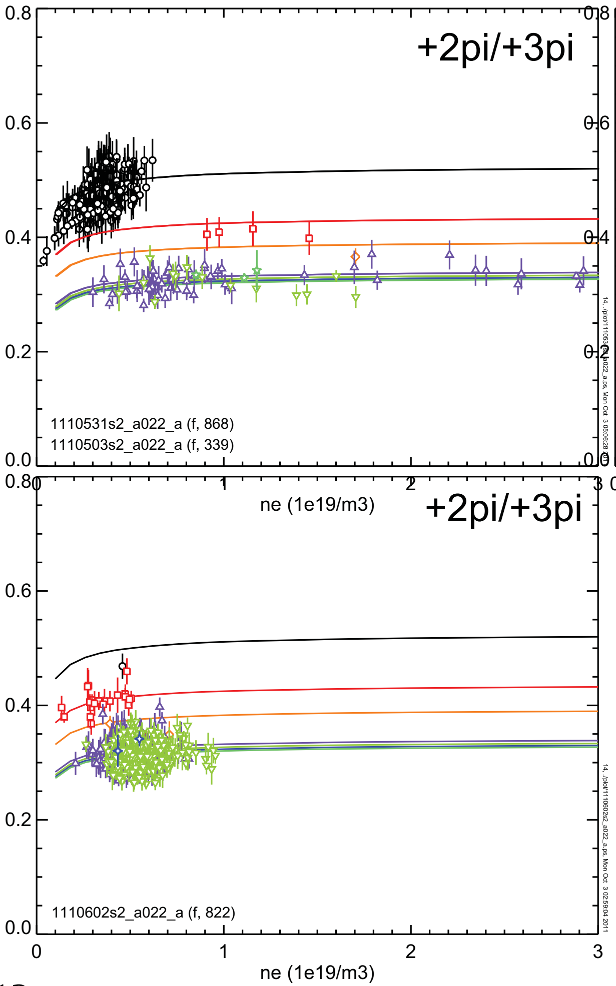
Sometimes, the density dependence is reversed



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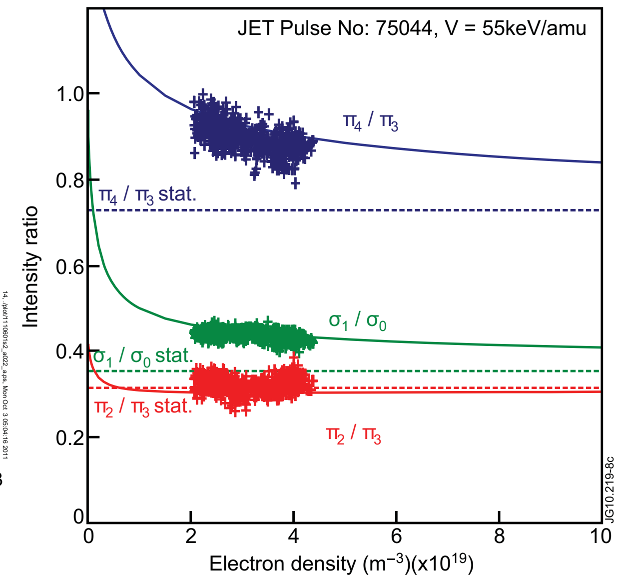
○ 0.2 +/- 0.02T	0.2T
□ 0.3 +/- 0.02T	0.3T
◇ 0.4 +/- 0.02T	0.4T
△ 0.5 +/- 0.02T	0.5T
▽ 0.6 +/- 0.02T	0.6T
✧ 0.7 +/- 0.02T	0.7T
	0.8T



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Summary

- The ADAS constraints with the Stokes formulism in the low-magnetic-field MSE spectrum fits can provide both the direction and magnitude of internal magnetic fields.

- Measurements from multi chords for one time/space point put the upper bound of the uncertainty (5 ~ 15 % for 0.2 ~ 0.6 T).

- Comparison of various Stark intensity ratios between the MST MSE spectrum fit and ADAS calculation shows qualitative agreement.
  - The upper state populations are close to statistical.
  - The deviation occurs below ne ≈ 0.5e19 /m3.

- This comparison implies that the density dependence of the upper state population with low fields is different from that with high fields.

Future / Present work

- Extend the analysis to the off-axis spectra.
  - We need to clarify some ambiguities in the MSE part of the ADAS module (geometry & polarizer effects etc)
- Compare / analyze the (low field) MSE data with other models (for example, NOMAD).
- Explore correlation of the uncertainty in |B| with other plasma / DNB parameters to further reduce the uncertainties.