

# **ADAS application to low-field motional Stark effect diagnostics**

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with the contributions from

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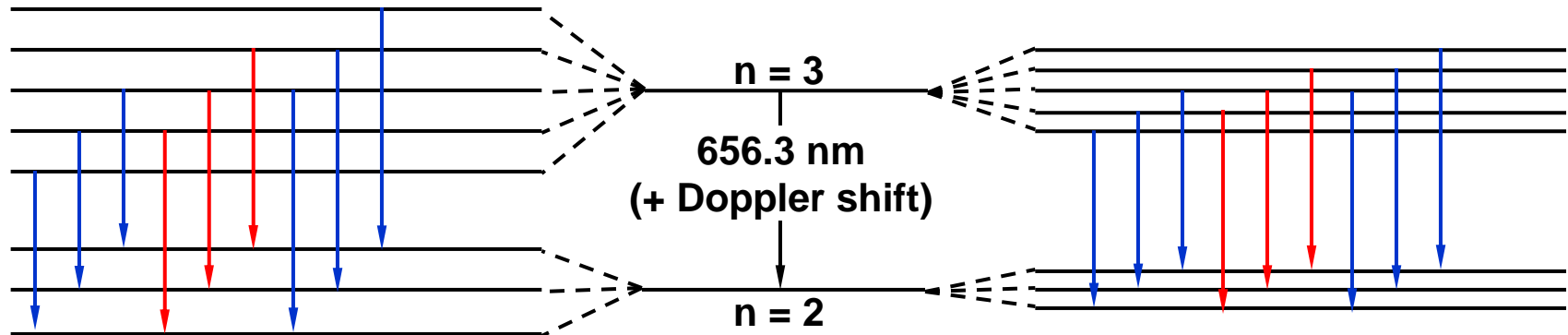


THE UNIVERSITY  
*of*  
**WISCONSIN**  
MADISON

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

## Balmer alpha emission from energetic neutrals

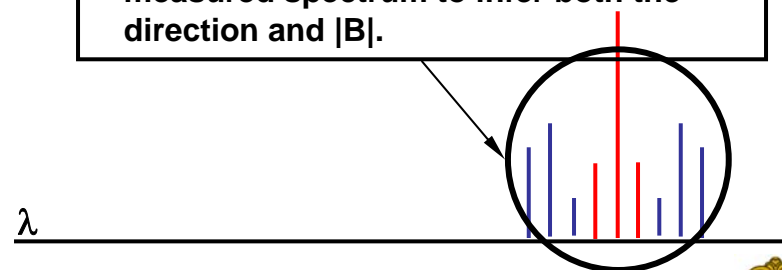
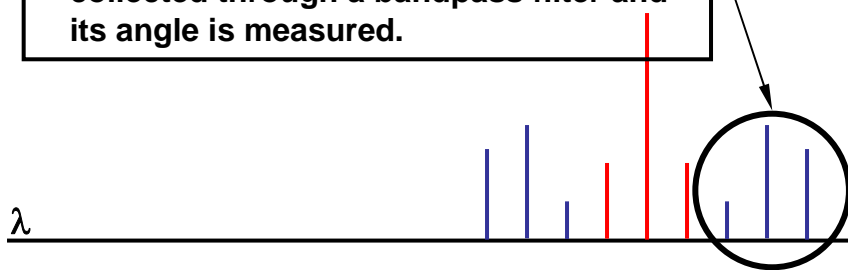


- Polarimetric approach: suitable for the devices with **high fields** ( $> 1$  T).
- $|B|$  usually known. Pitch angle unknown.
- One polarization component ( $\sigma$  or  $\pi$ ) collected through a bandpass filter and its angle is measured.

polarization // E

polarization  $\perp$  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.

–  $R = 1.5 \text{ m}$ ,  $a = 0.5 \text{ m}$

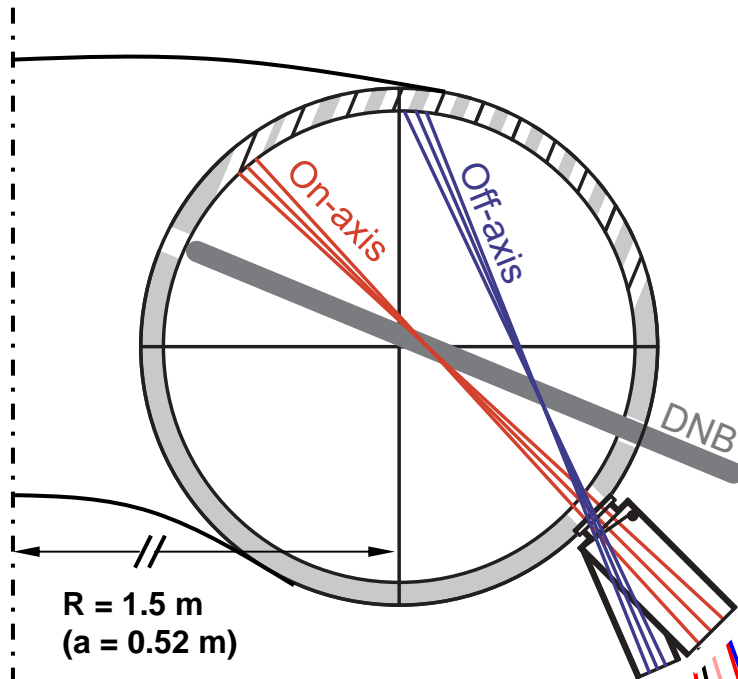
–  $I_p < 0.6 \text{ MA}$ ,  $B < 0.6 \text{ T}$ ,  $n_e = 1 \sim 2e^{19} / \text{m}^3$

–  $T_e, T_i < 2 \text{ keV}$

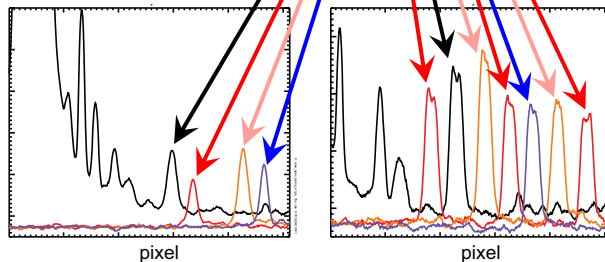
– Flatop = 20 ~ 30 msec



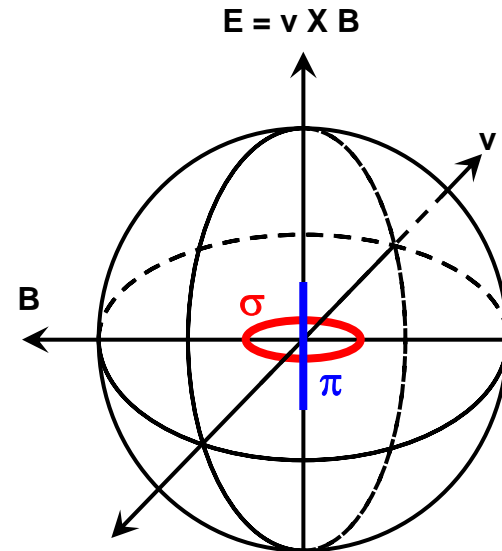
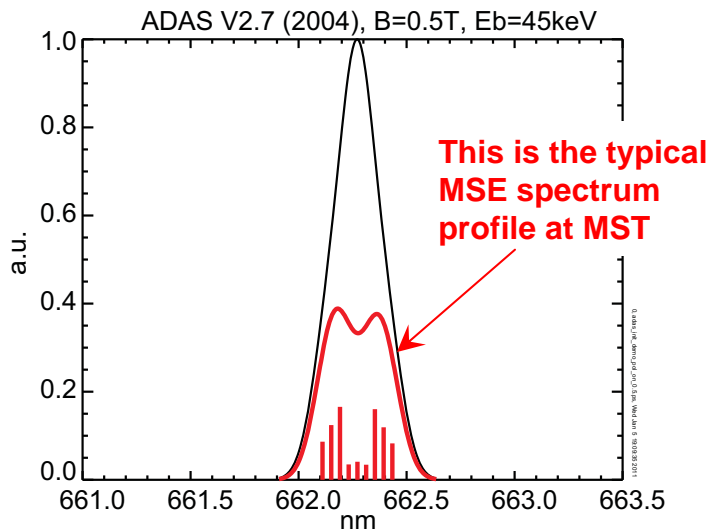
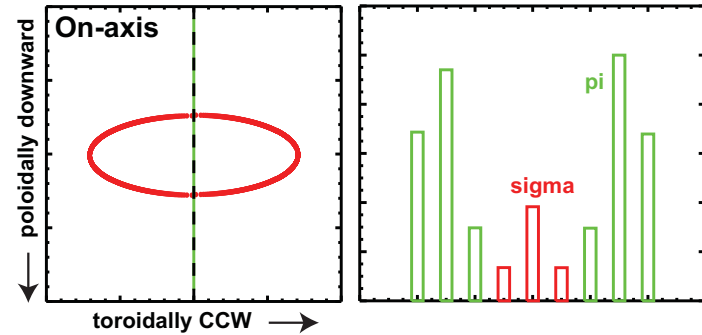
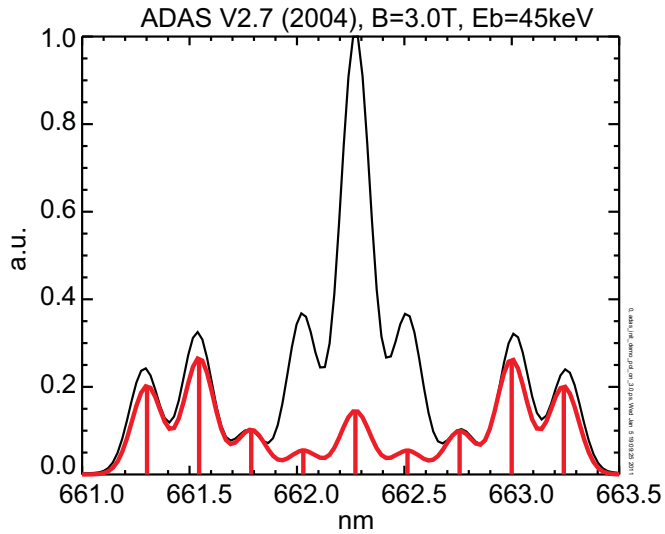
# Low-field MSE spectra at MST is complex



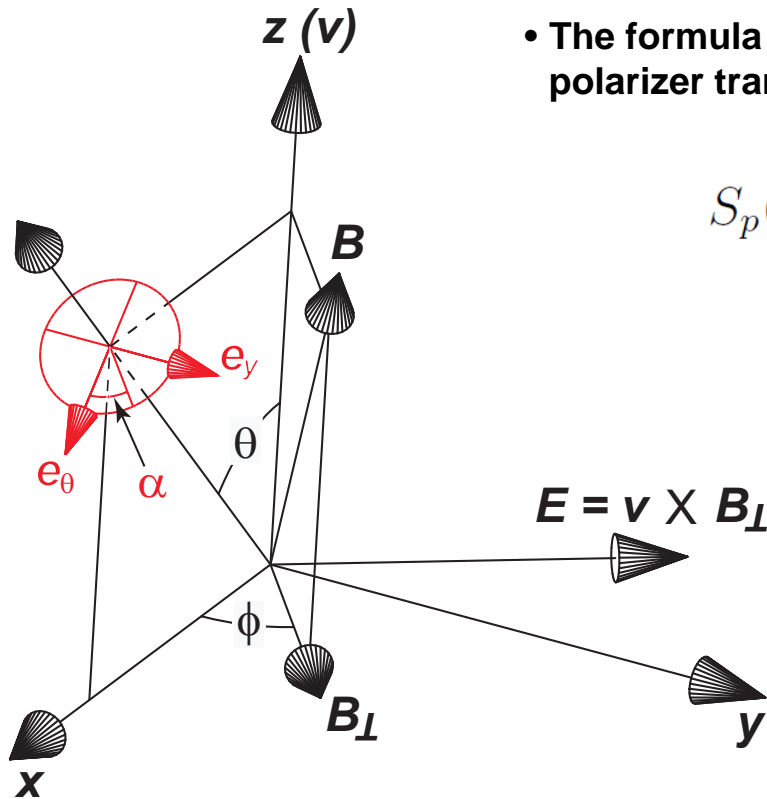
- Unlike tokamaks,  $|B|$  on axis is unknown since the toroidal field in this region is largely generated by poloidal current flowing in the edge, not by external TF coils.
- Low magnetic fields ( $\leq 0.5$  T) preclude selecting a particular Stark component in the signal.
- Linear polarizers are installed 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 ( $\theta$ ), polarizer transmission axis ( $\alpha$ ), and pitch angle ( $\phi$ ) [1]:

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

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

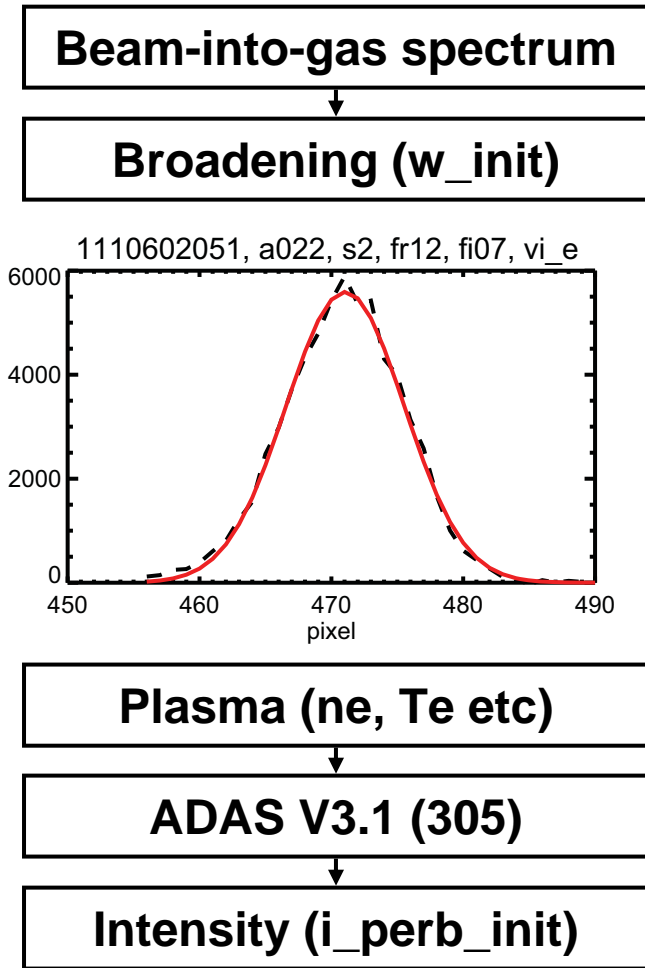
$$\begin{bmatrix} I_0^\pi \\ I_1^\pi \\ I_2^\pi \\ I_3^\pi \end{bmatrix} = \begin{bmatrix} I^{(\pi)np} + I_\perp^\pi (1 - \sin^2 \theta \sin^2 \phi) \\ -I_\perp^\pi (\cos^2 \phi - \cos^2 \theta \sin^2 \phi) \\ -I_\perp^\pi \cos \theta \sin 2\phi \\ 0 \end{bmatrix}$$

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

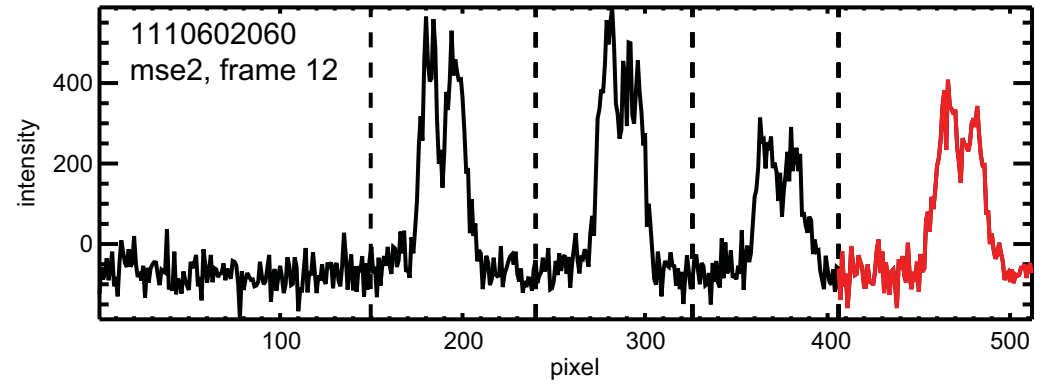
[1] D. Voslamber, "Self-calibrating magnetic field diagnostics in beam emission spectroscopy", Rev. Sci. Instrum. 66:4 (1995) 2892-2903



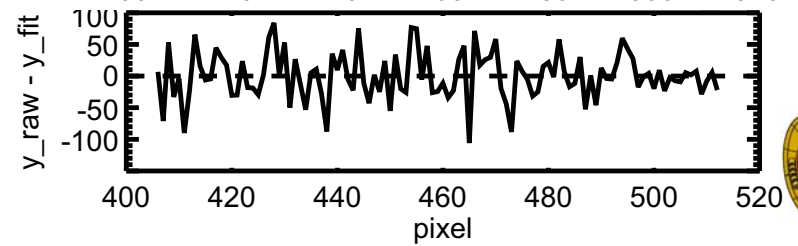
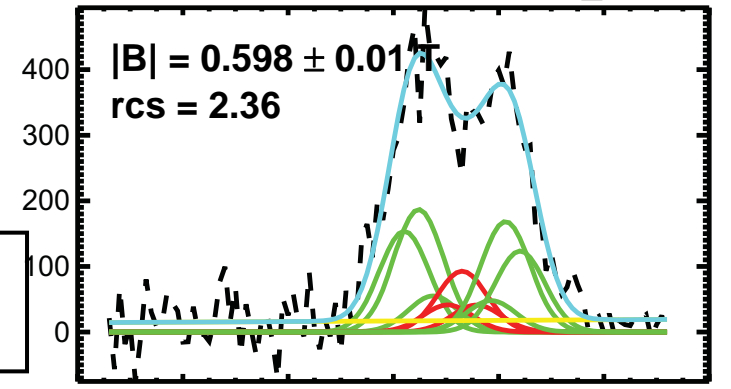
# ADAS provides initial values for $I_{\perp}$ 's



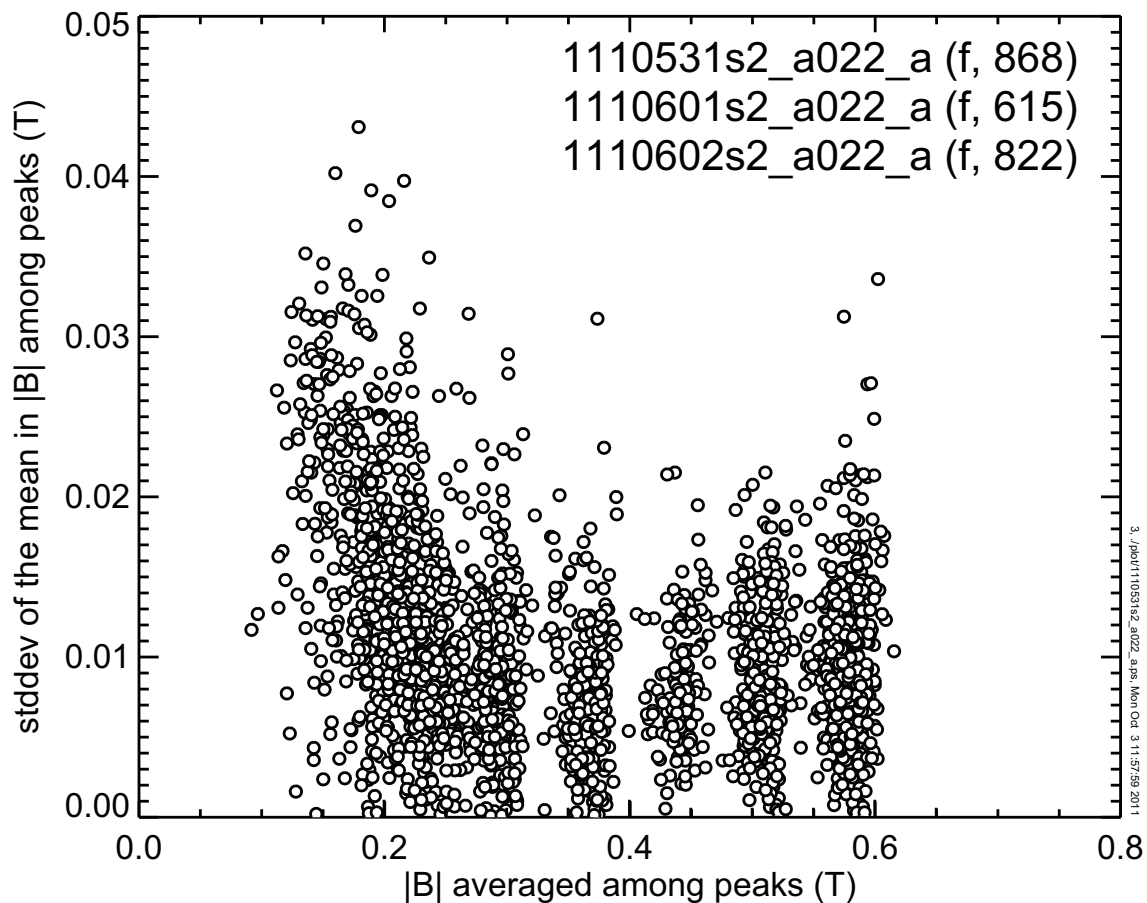
**Fit raw spectrum**



1110602060, a022, s2, fr12, fi07, vi\_e , on-axis



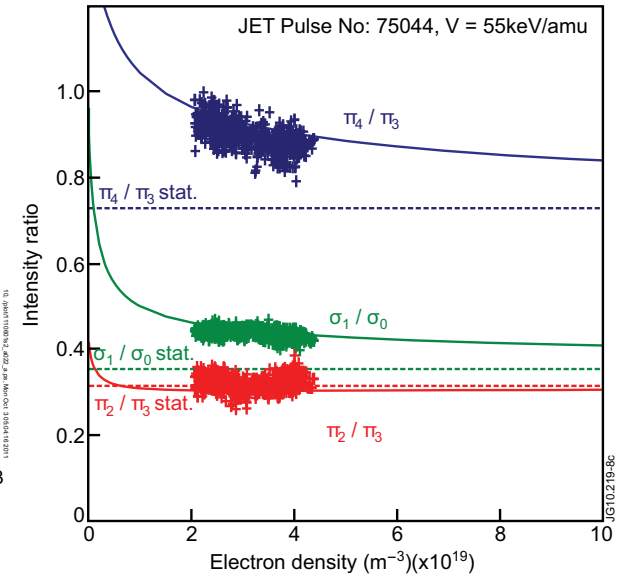
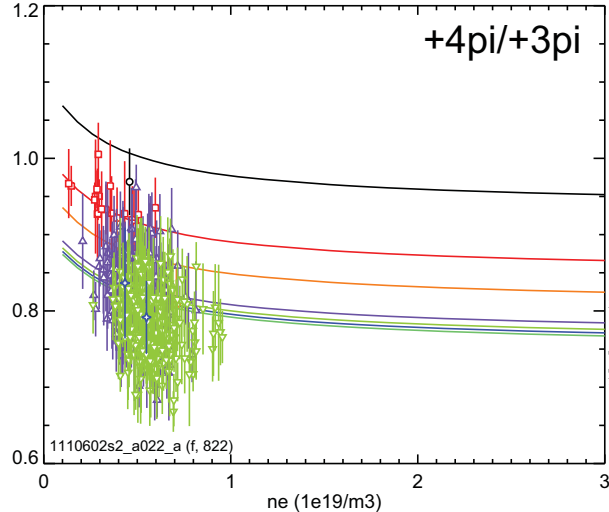
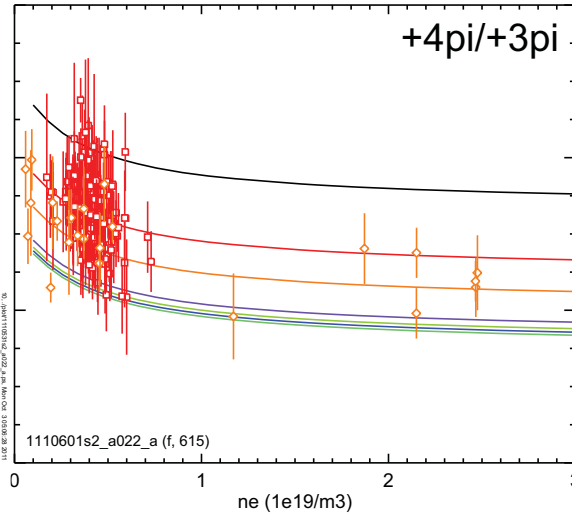
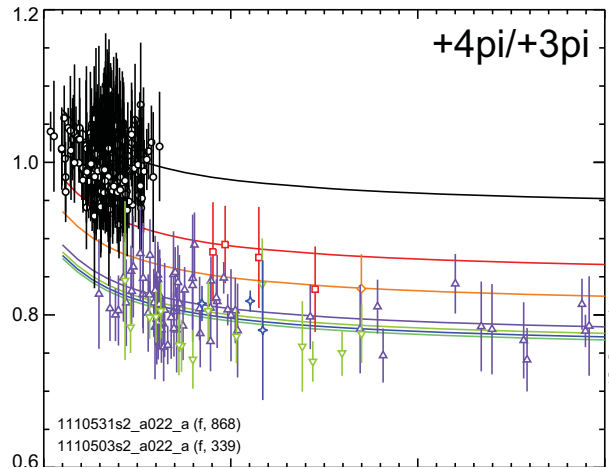
# Measurements from multi chords for one time/space point improves the statistics



- 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

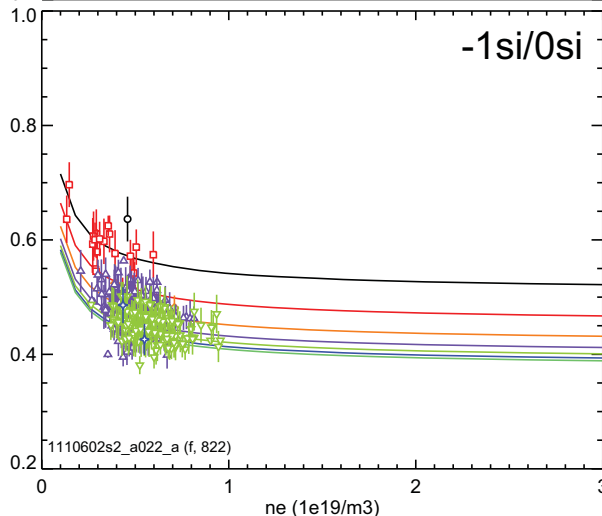
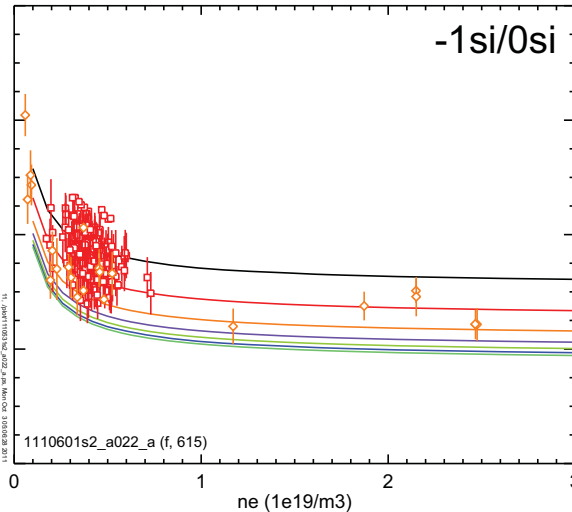
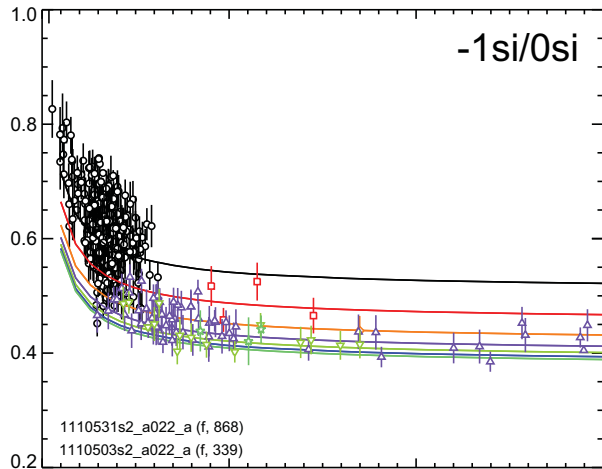


MSE @ MST	ADAS
○ 0.2 +/- 0.02T	0.2T
□ 0.3 +/- 0.02T	0.3T
◇ 0.4 +/- 0.02T	0.4T
△ 0.5 +/- 0.02T	0.5T
▽ 0.6 +/- 0.02T	0.6T
☆ 0.7 +/- 0.02T	0.7T
	0.8T

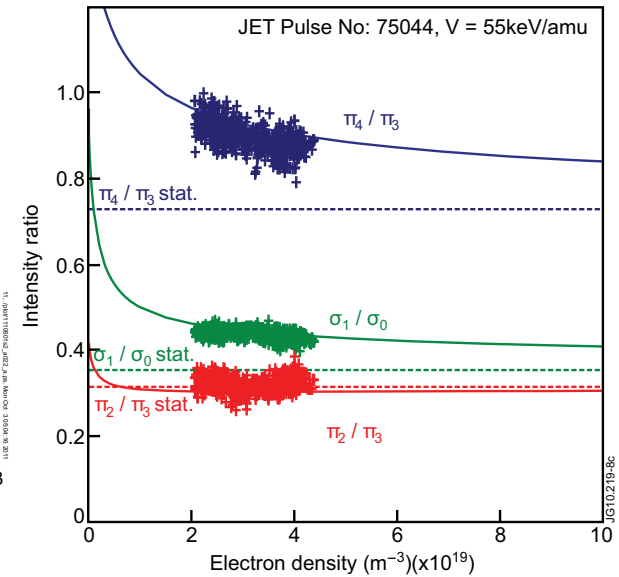
- The most recent collisional radiative model (nkm-resolved)\* confirms the deviation from a statistical population at  $ne < 2e19 / m^3$



# Deviations from statistical populations occur at lower densities



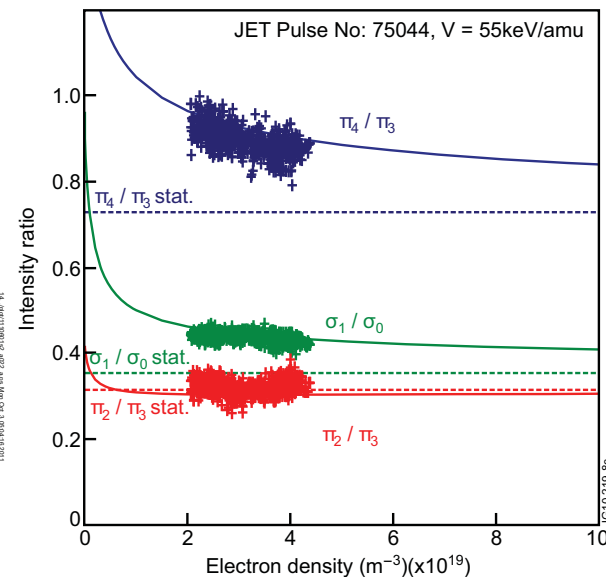
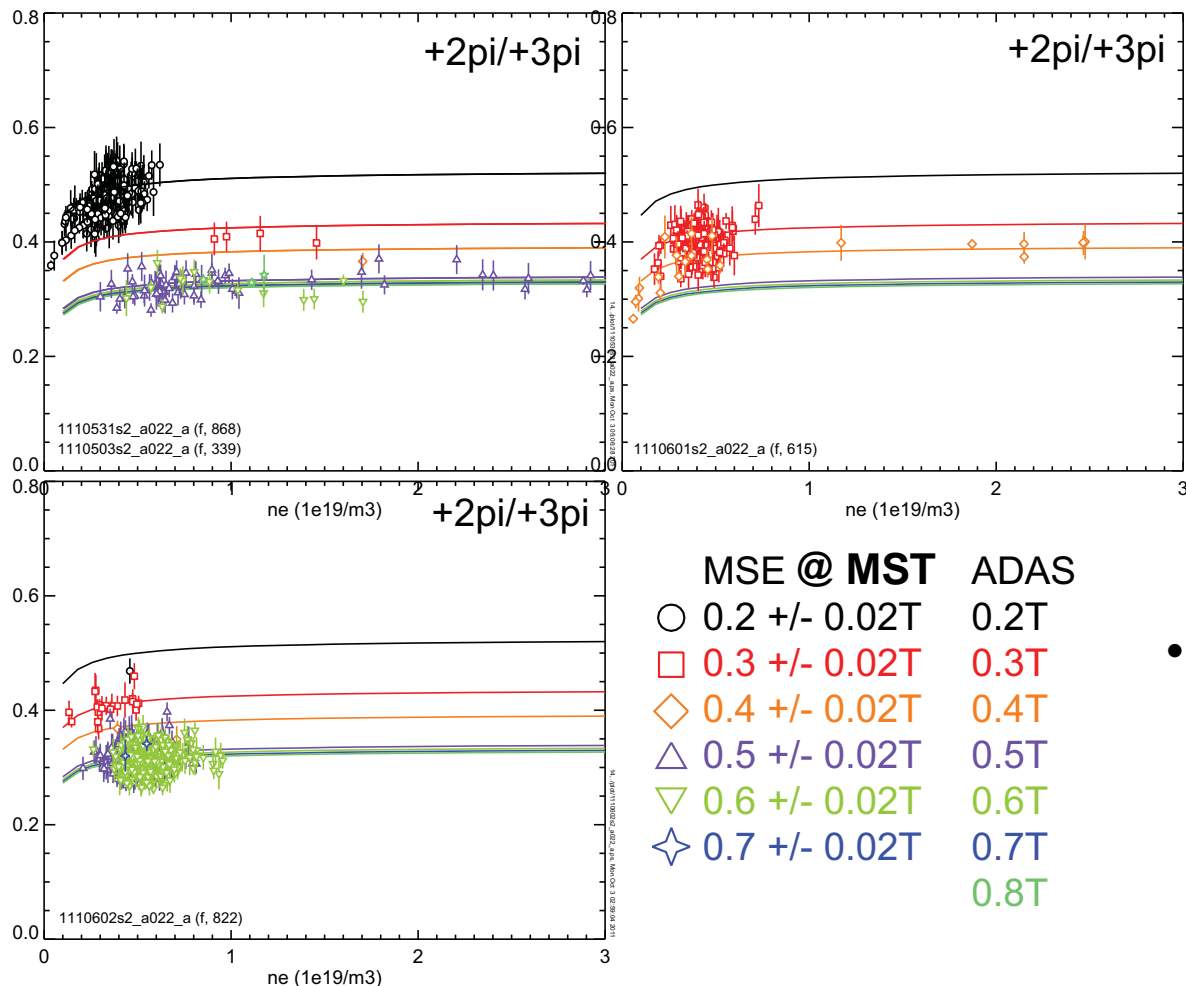
MSE @ MST	ADAS
○ 0.2 +/- 0.02T	0.2T
□ 0.3 +/- 0.02T	0.3T
◇ 0.4 +/- 0.02T	0.4T
△ 0.5 +/- 0.02T	0.5T
▽ 0.6 +/- 0.02T	0.6T
☆ 0.7 +/- 0.02T	0.7T
	0.8T



- The most recent collisional radiative model (nkm-resolved)\* confirms the deviation from a statistical population at  $ne < 2e19 / m^3$



# Sometimes, the density dependence is reversed



- The most recent collisional radiative model (nkm-resolved)\* confirms the deviation from a statistical population at  $ne < 2e19 / m^3$



# Summary



- **The ADAS constraints with the Stokes formalism 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  $n_e \approx 0.5e19 /m^3$ .**
- **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.**

