The 1st IAEA Research Coordination Meeting on
Data for Atomic Processes of Neutral Beams in Fusion Plasmas
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Experimental validation of atomic data for motional Stark effect diagnostics

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NFRI UST KSTAR

Scope of the project

Experimental validation of atomic data for motional Stark effect diagnostics

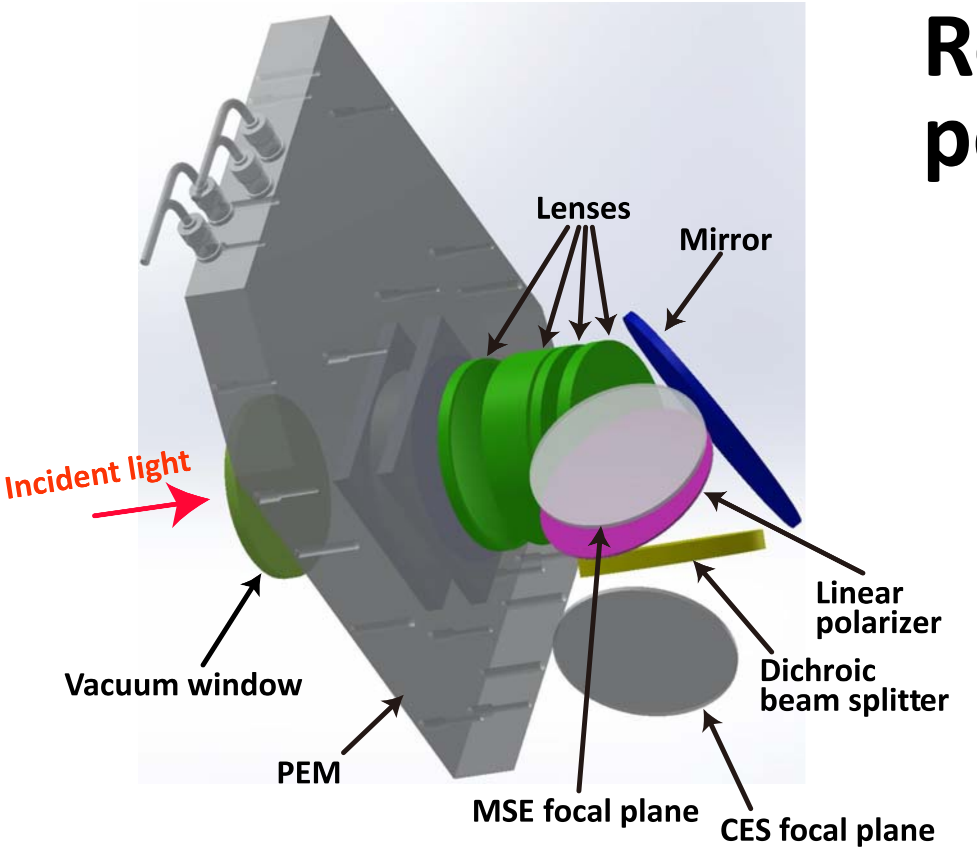
- High-precision measurements of beam-emission spectra from KSTAR discharges
- Development of a spectra analysis tool with a modulated interface for atomic data

Issues to address

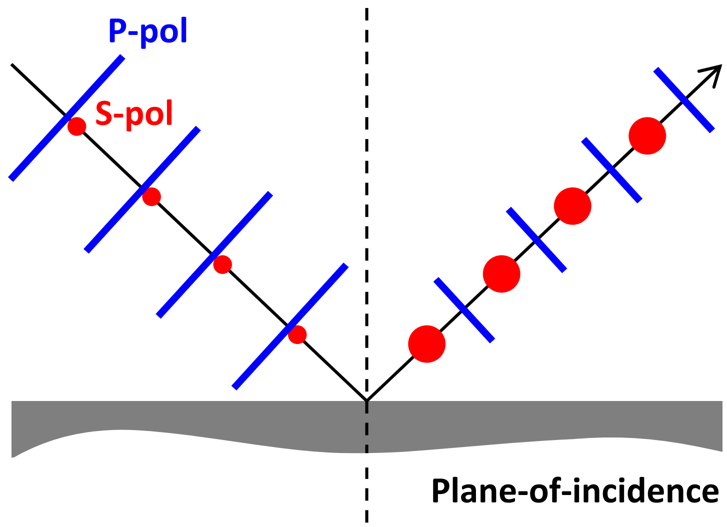
Calculated spectra are not always reproduce experimental observations.

… especially, when we are dealing with polarized light.

Issues to address #1



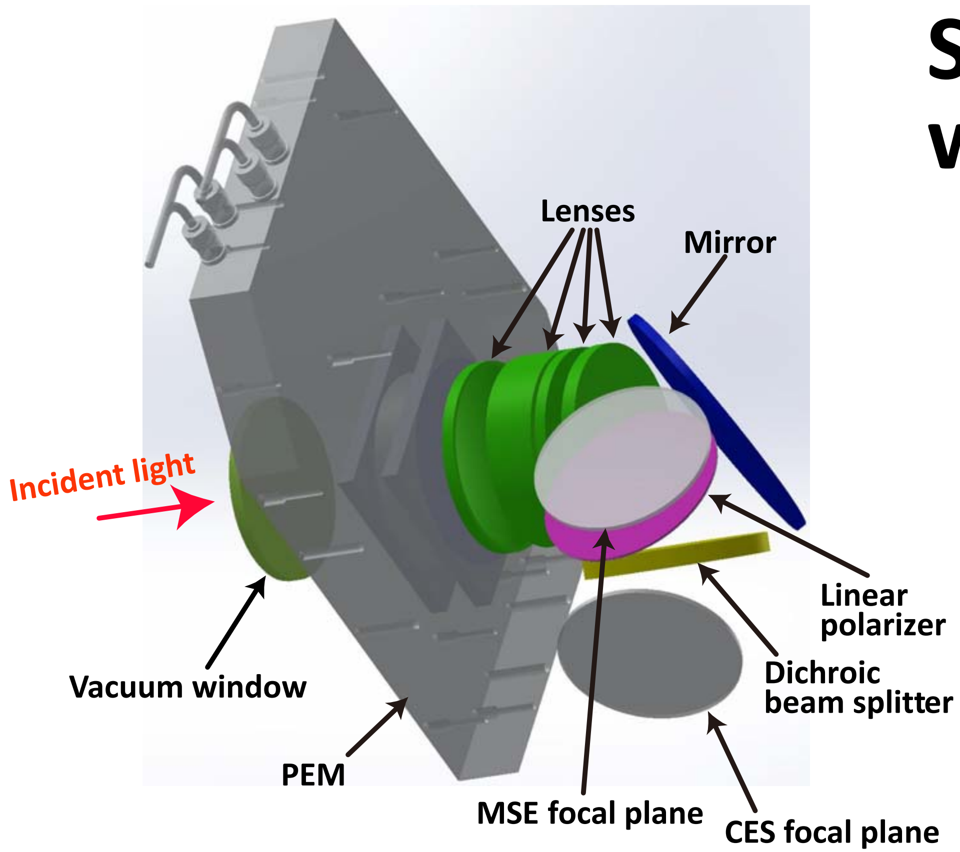
Reflections on mirrors distort polarization properties.



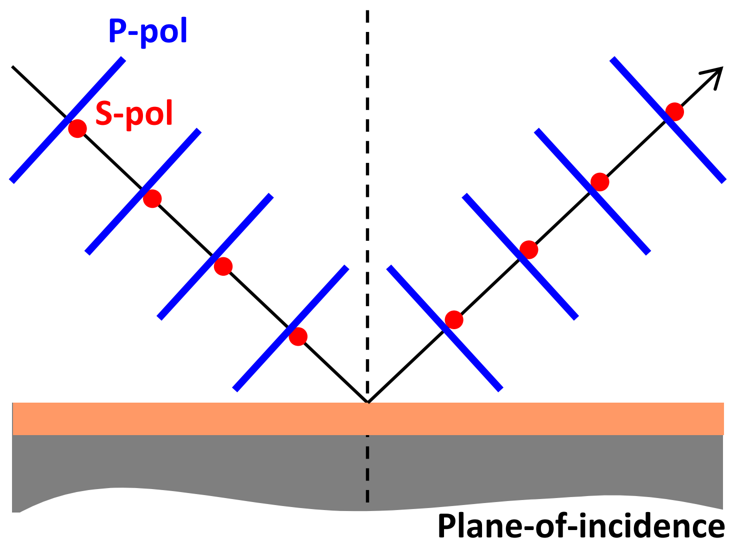
Normal reflective surface

Lee et al, Fusion Eng. Des. (In press)

Issues to address #1



Specialized dielectric coating works for present tokamaks…



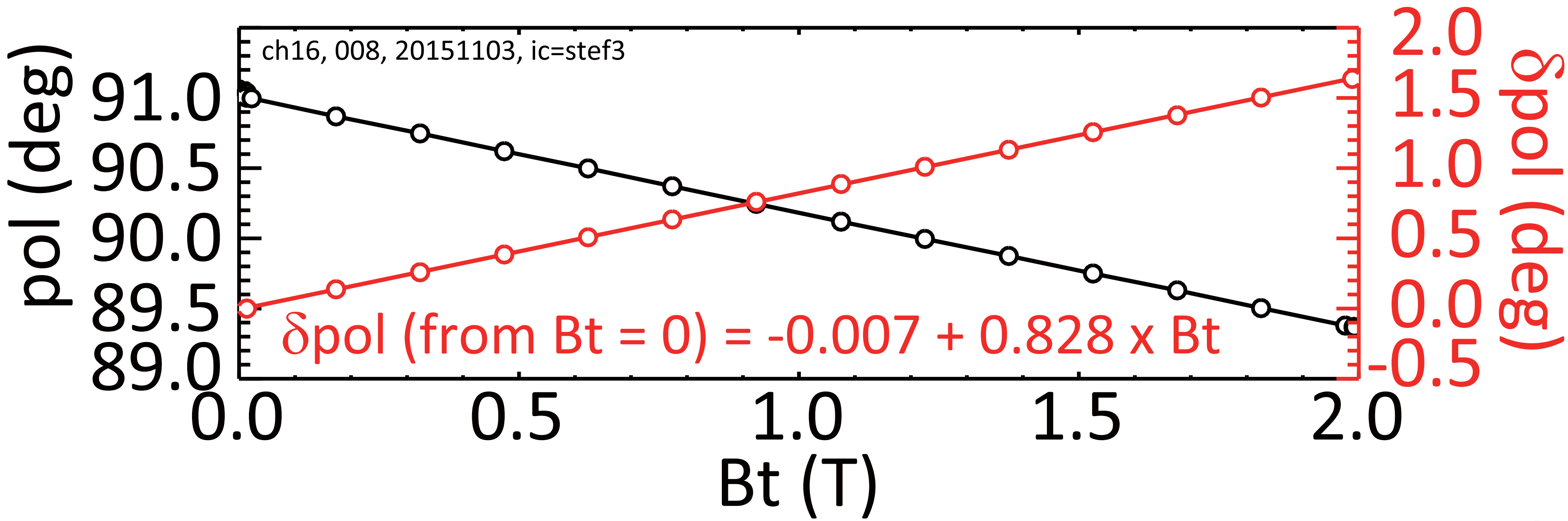
(Multi-layer) dielectric-coated surface

Lee et al, Fusion Eng. Des. (In press)

But not for ITER …

Issues to address #2

Faraday effect rotates the polarization angle.

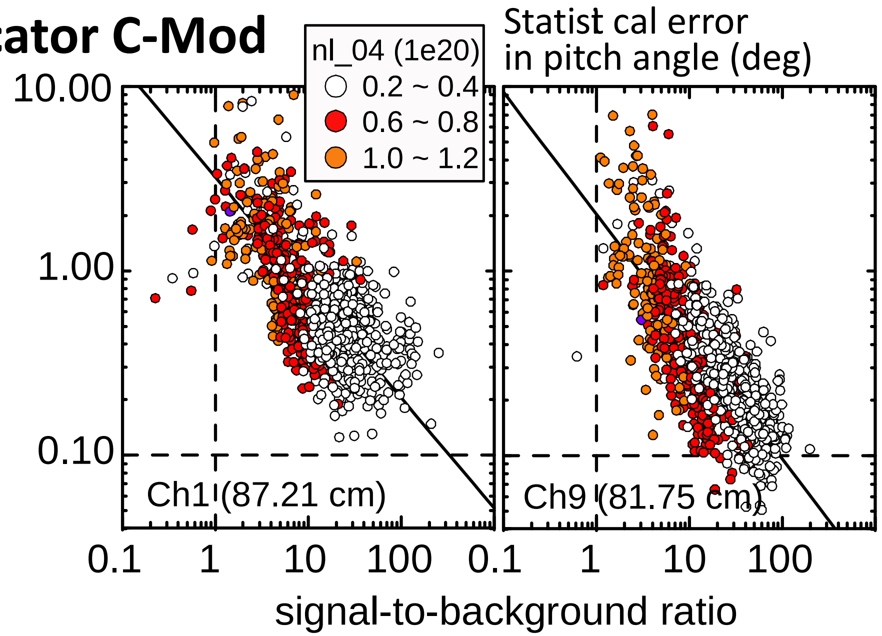


Ko et al, Rev. Sci. Instrum. 88, 063505 (2017)

Issues to address #3

Background polarized light does exist in a tokamak.

Alcator C-Mod



Ko, PhD Dissertation, MIT (2006)

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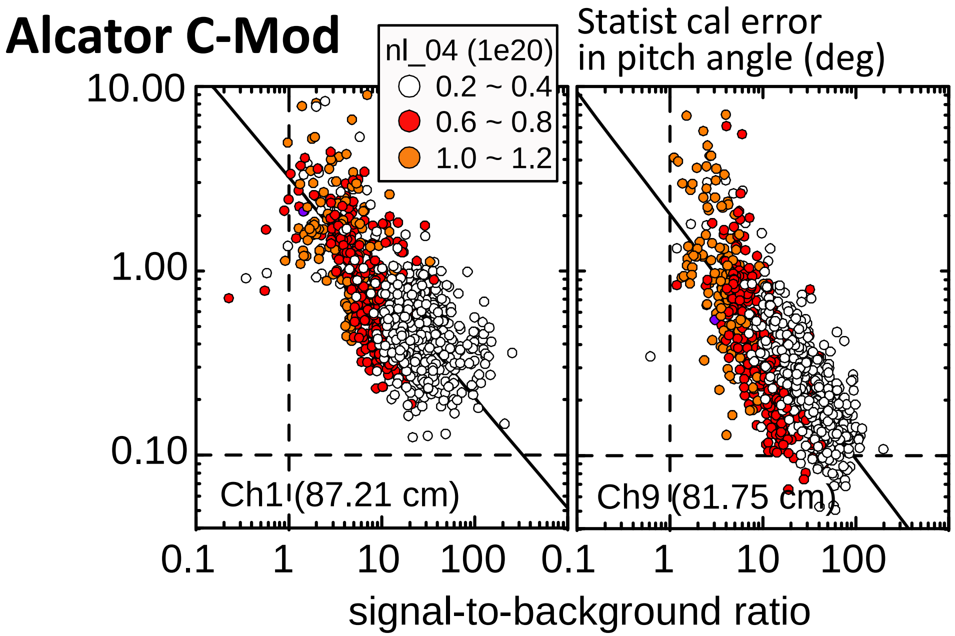
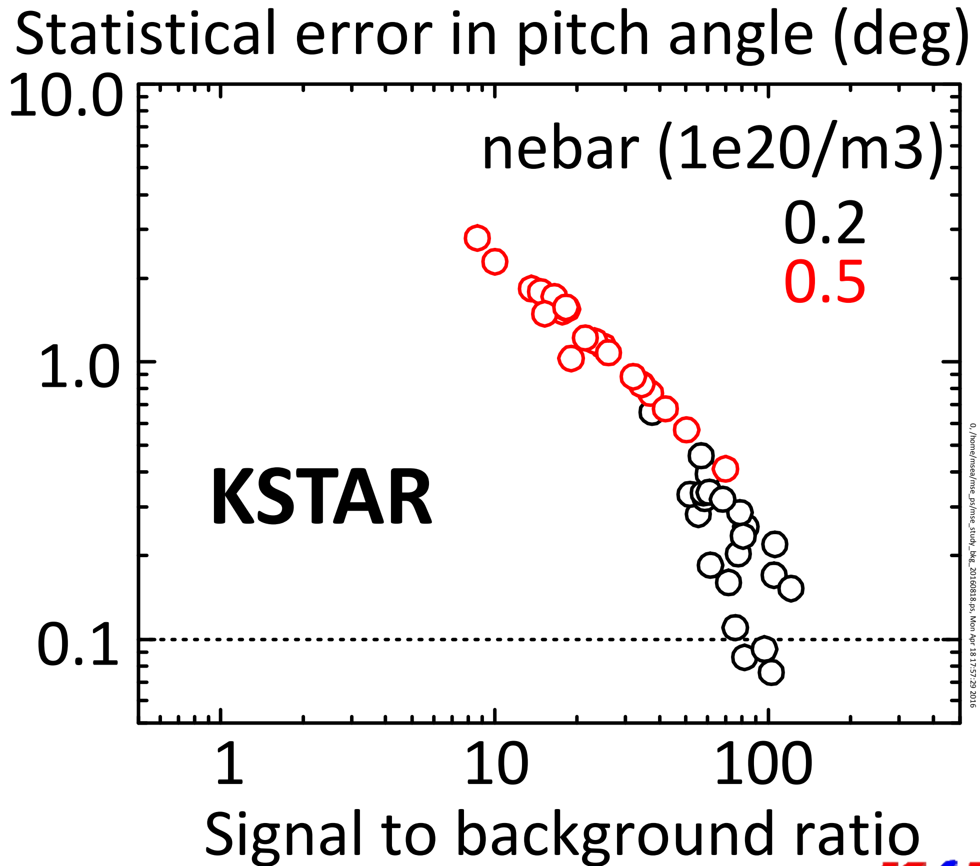
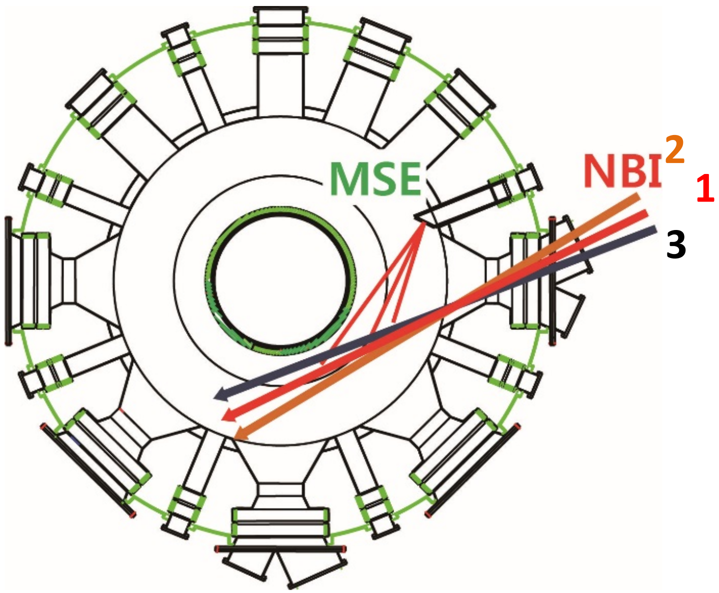


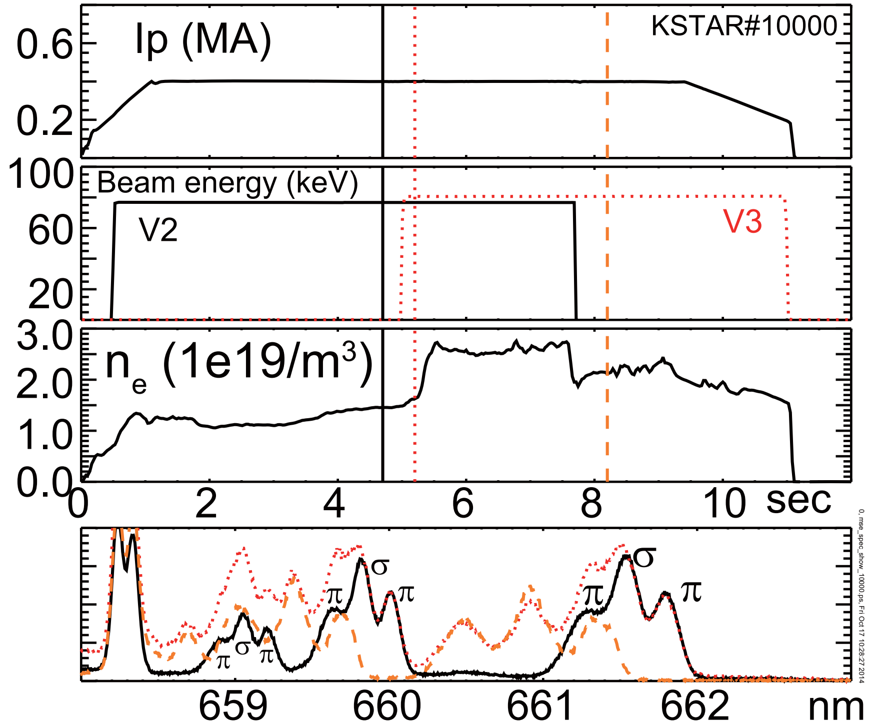
Ko, PhD Dissertation, MIT (2006)



Issues to address #4

Practically, multiple ion sources are used in NBI heating





Ko et al, J. Inst. 8, P1009 (2015)

Issues to address #4

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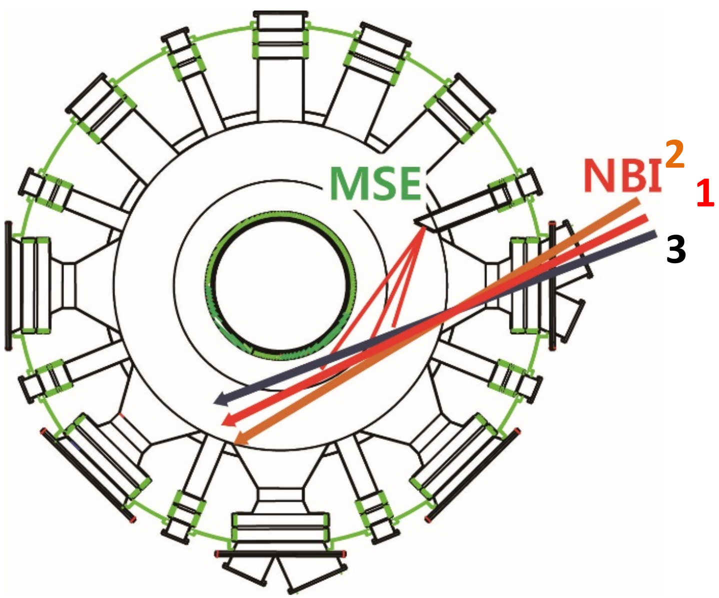
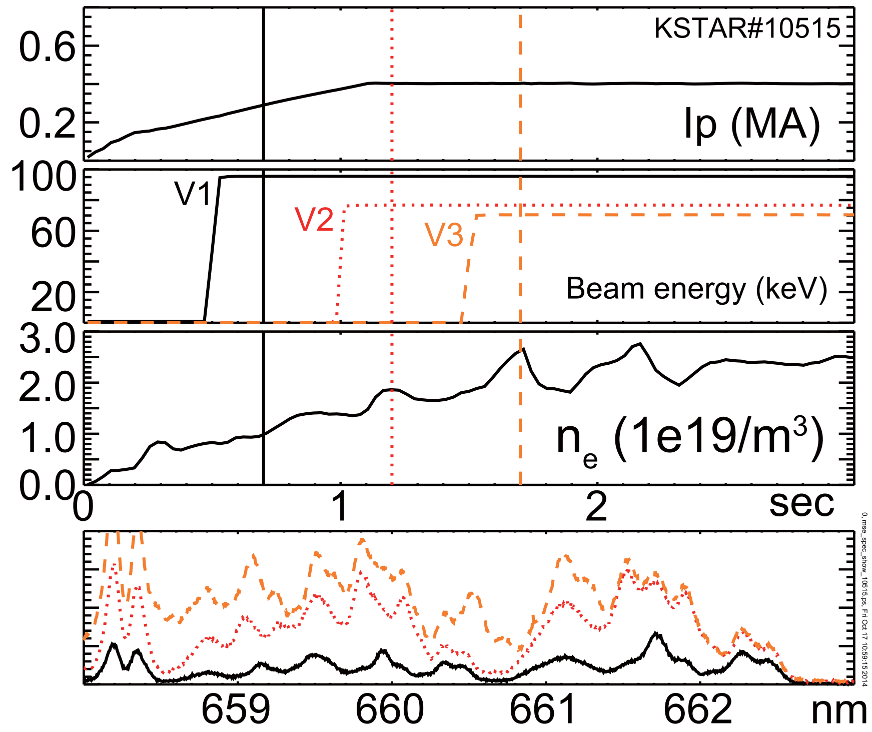
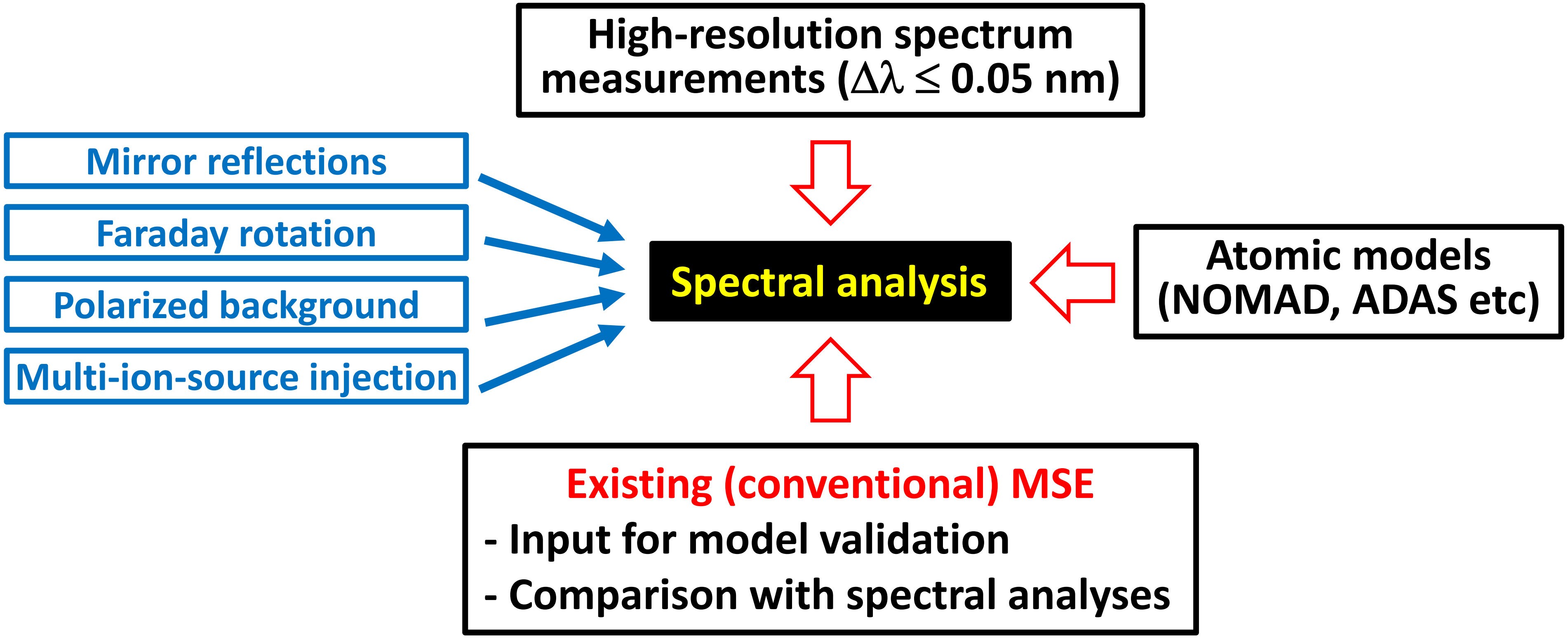


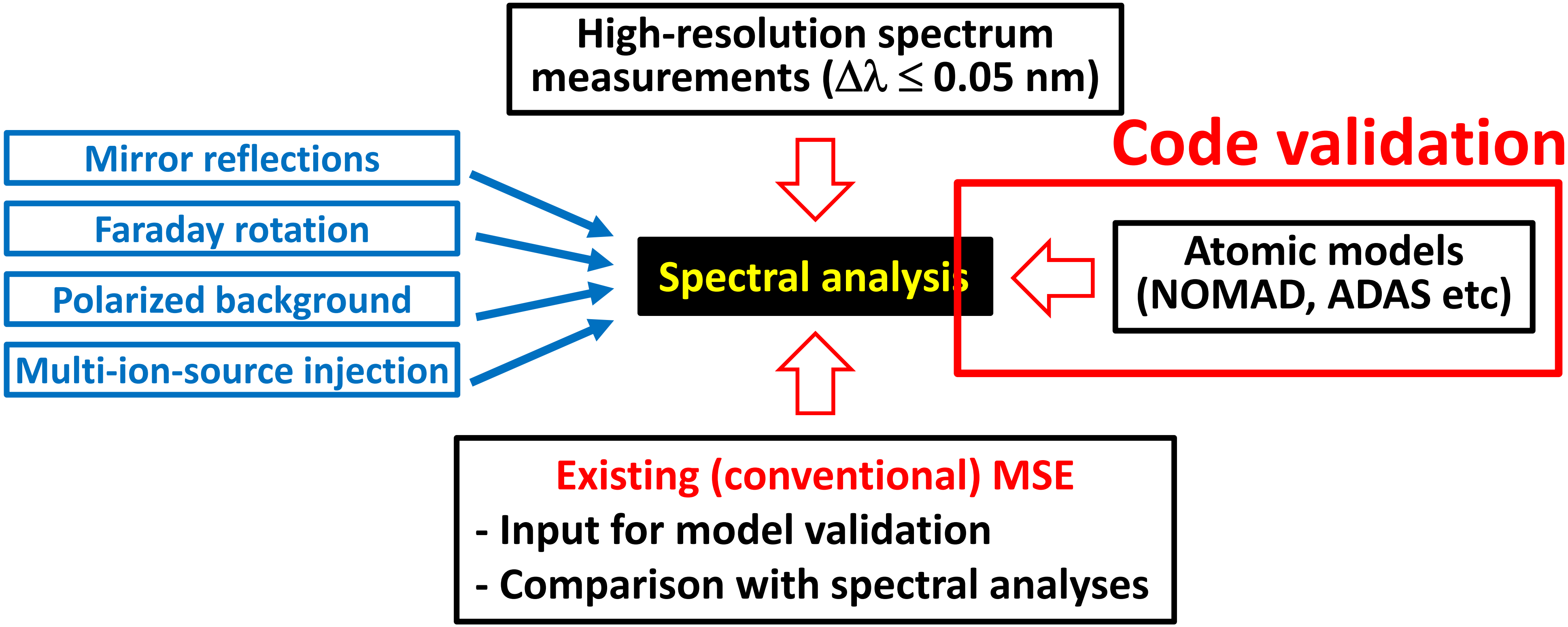


Ko et al, J. Inst. 8, P1009 (2015)

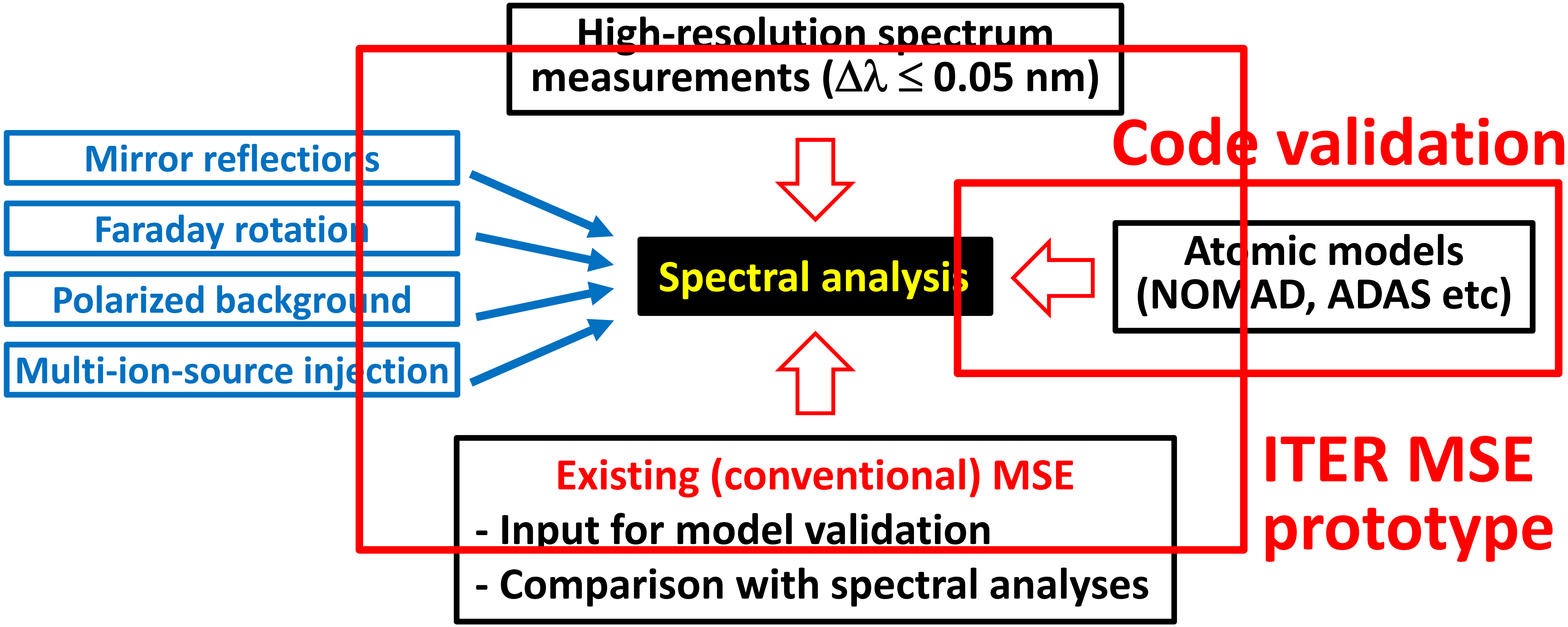
Outline of the activities



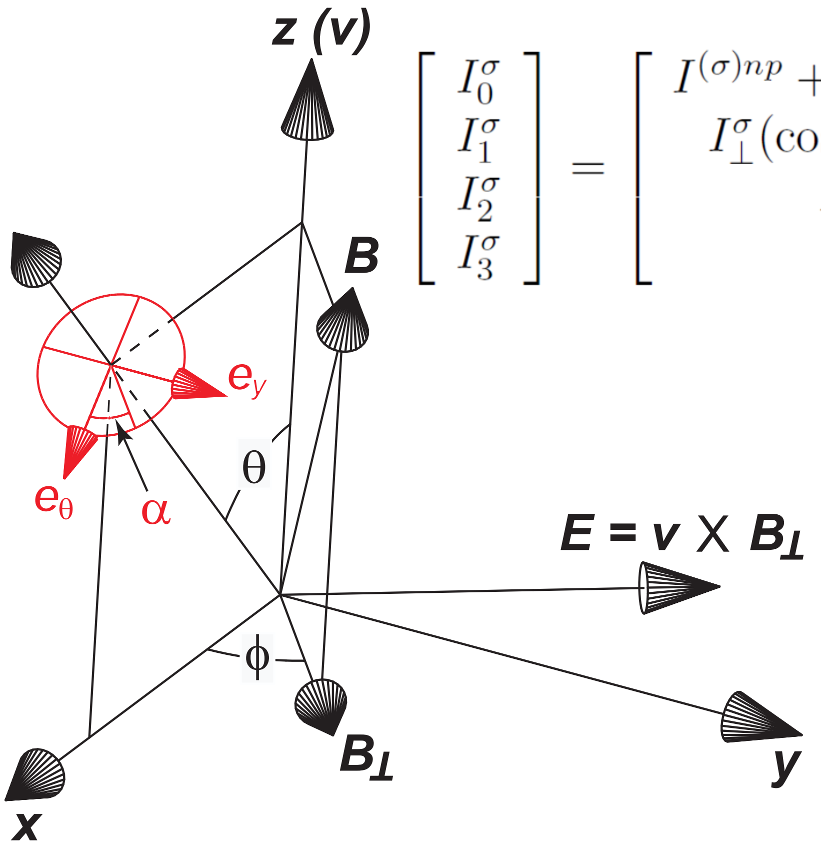
Outline of the activities



Outline of the activities



How the known pitch angles help the code validation?



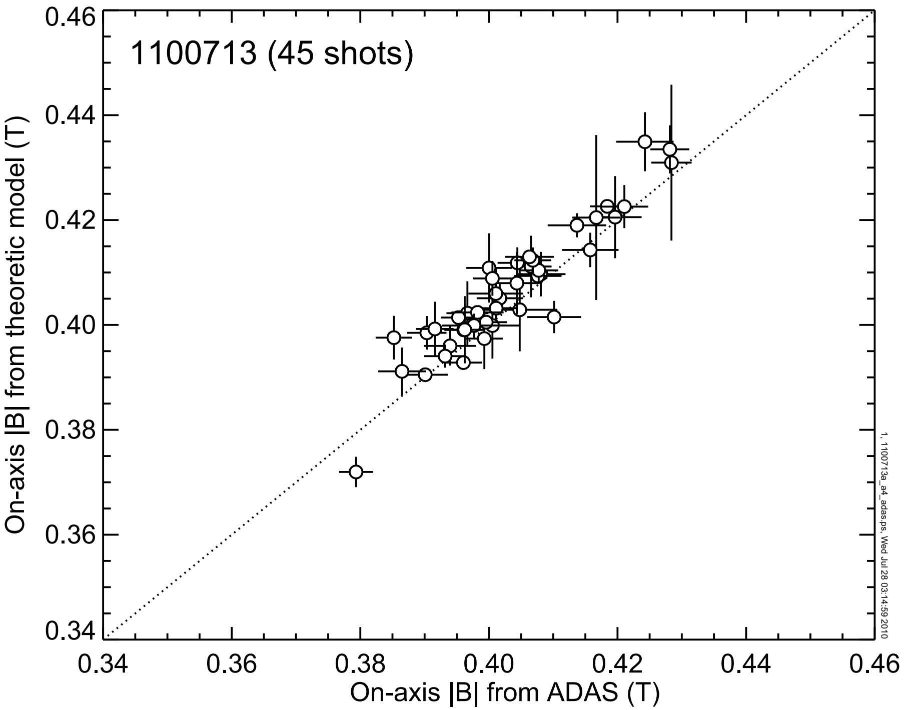
$$\begin{bmatrix} I_0^\sigma \\ I_1^\sigma \\ I_2^\sigma \\ I_3^\sigma \end{bmatrix} = \begin{bmatrix} I^{(\sigma)np} + I_\perp^\sigma(1+\sin^2\theta\sin^2\phi) \\ I_\perp^\sigma(\cos^2\phi - \cos^2\theta\sin^2\phi) \\ I_\perp^\sigma\cos\theta\sin 2\phi \\ 0 \end{bmatrix}, \begin{bmatrix} I_0^\pi \\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

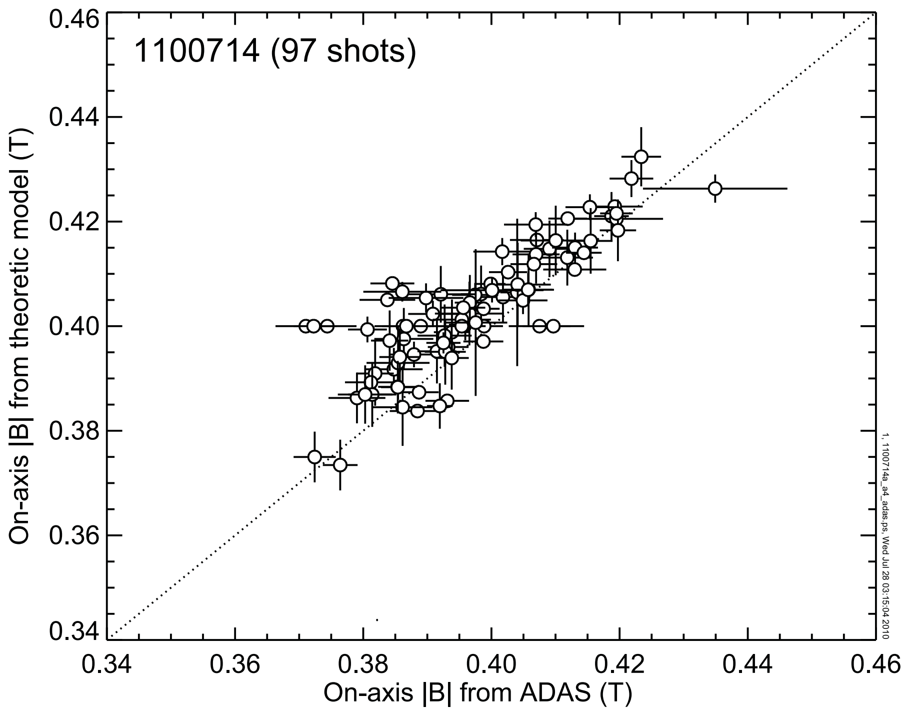
$$S_p(0) = \frac{1}{2}\left[I_0 + I_1\cos(2\alpha) + I_2\sin(2\alpha)\right]$$

$I_\perp$: Intensity of pure sigma & pi when viewed perpendicular to the Lorentz electric field E.

Voslamber, Rev. Sci. Instrum. 66, 2892 (1995)
Ko et al, Rev. Sci. Instrum. 81, 10D702 (2010)

Using ADAS for $I_\perp$'s can reduce the systematic error

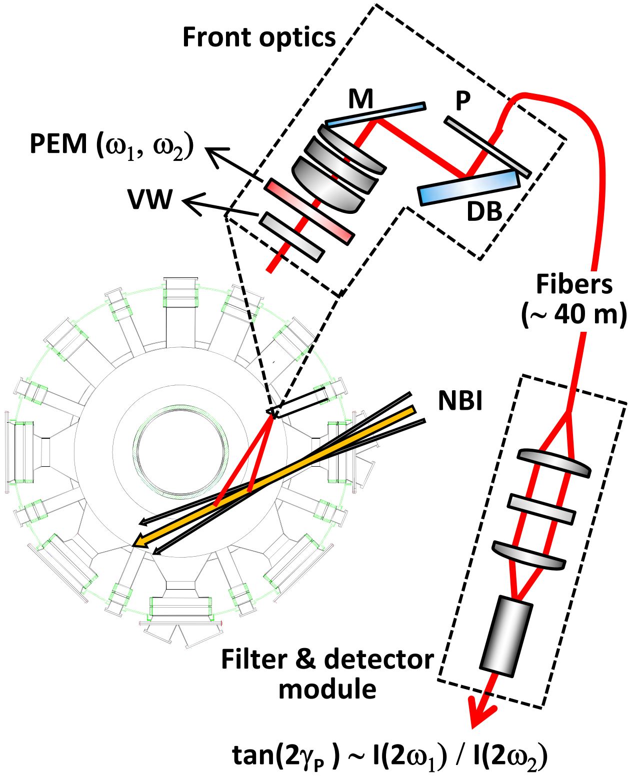




2 ~ 3 % of systematic error can be reduced over the range of typical MST operating conditions, when compared with the analytic model* which tends to overestimate |B|.

**W. Mandl et al. Plasma Phys. Controlled Fusion 35, 1373 (1993)*
Ko et al, Rev. Sci. Instrum. 83, 10D513 (2012)

Reliable inputs possible from the existing KSTAR MSE



- Operational since 2015
- Conventional polarimetric (photo-elastic modulation) method
- 25 channels with radial resolutions < 2 cm with ~ 10 msec interval
- Most of the systematic errors (Faraday, mirror reflections, geometric projections) have been calibrated.

Ko et al, Rev. Sci. Instrum. 88, 063505 (2017)
Ko et al, Fusion Eng. Des. 109-111 (2016) 742-746
Chung et al, Rev. Sci. Instrum. 87, 11E503 (2016)
Chung et al, Rev. Sci. Instrum. 85, 11D827 (2014)

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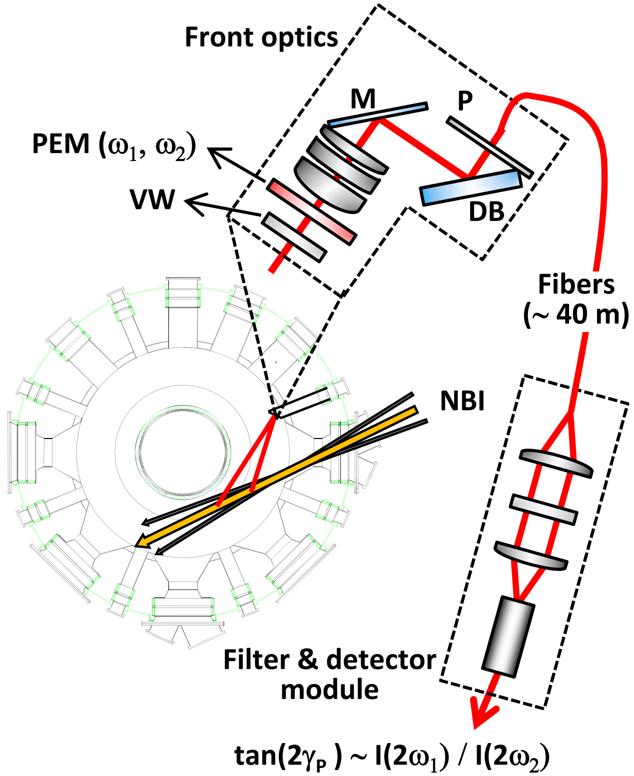

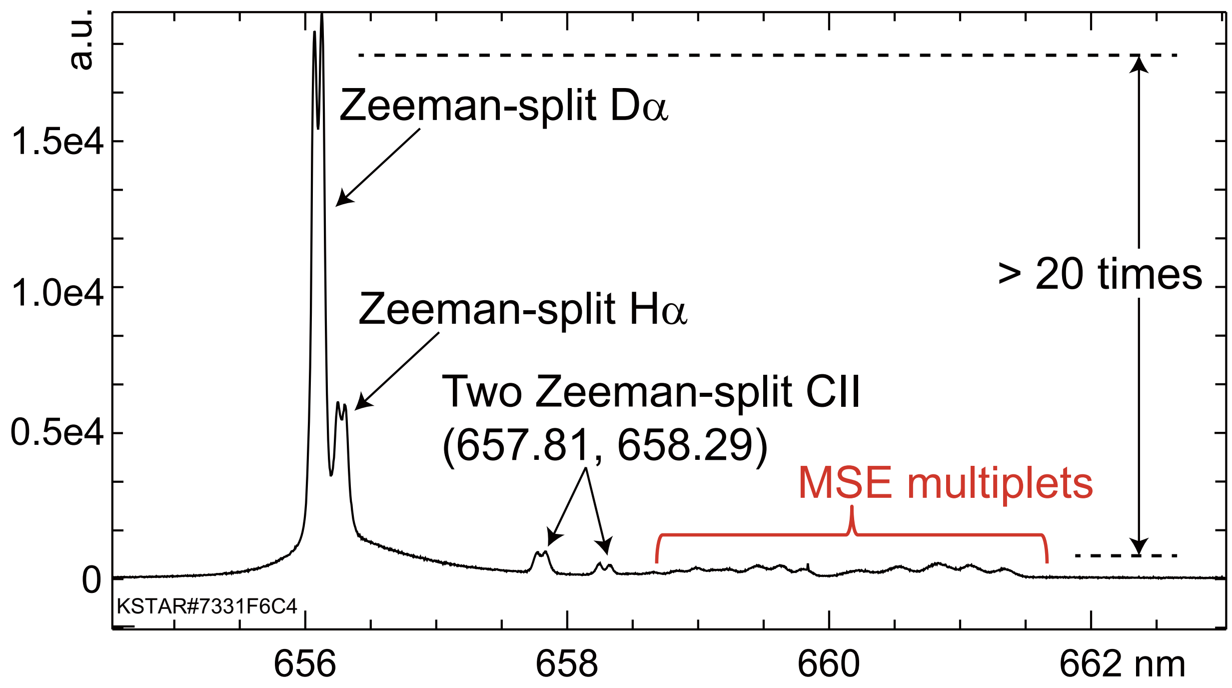

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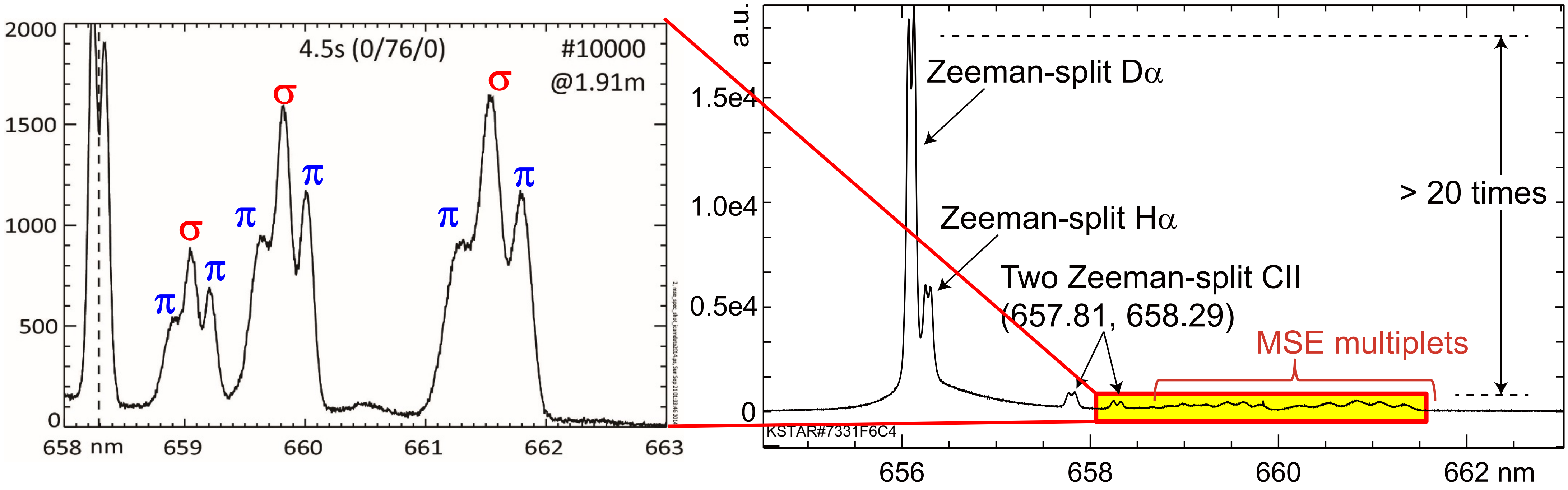

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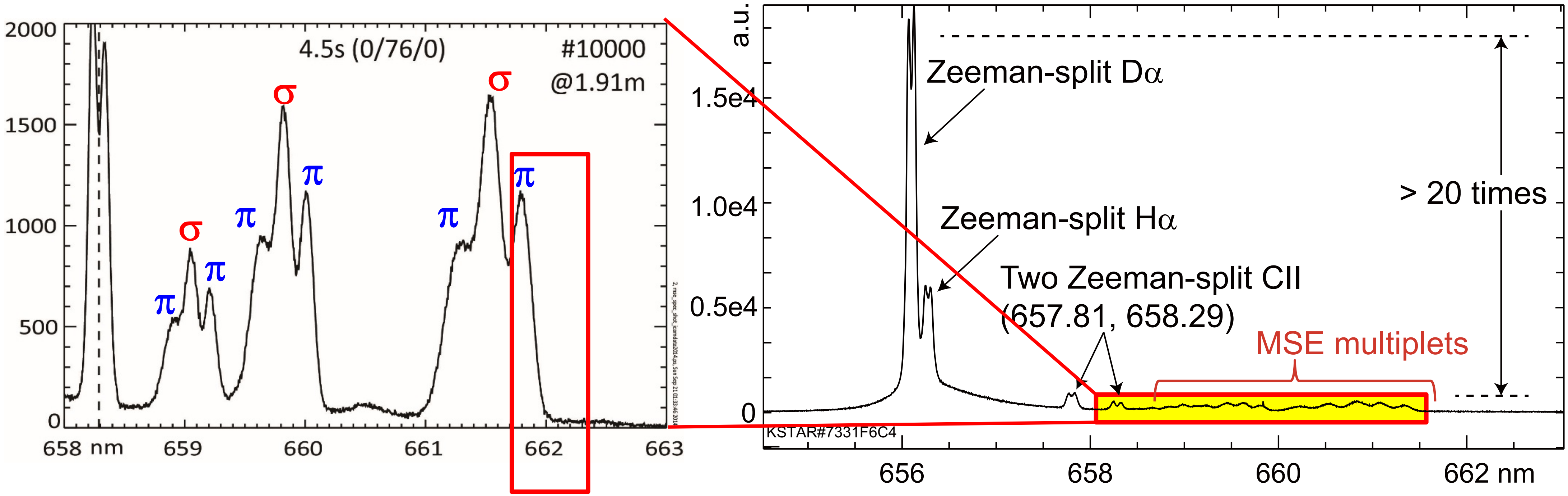
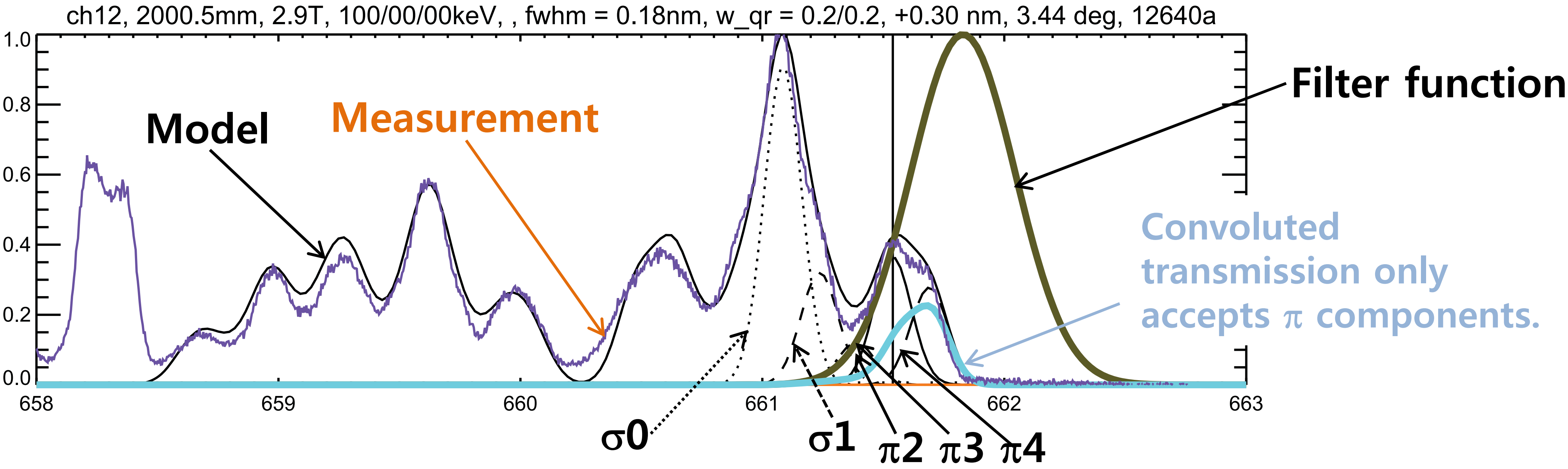


Spectral region for photo-elastic modulation
- Narrow bandpass filter is used

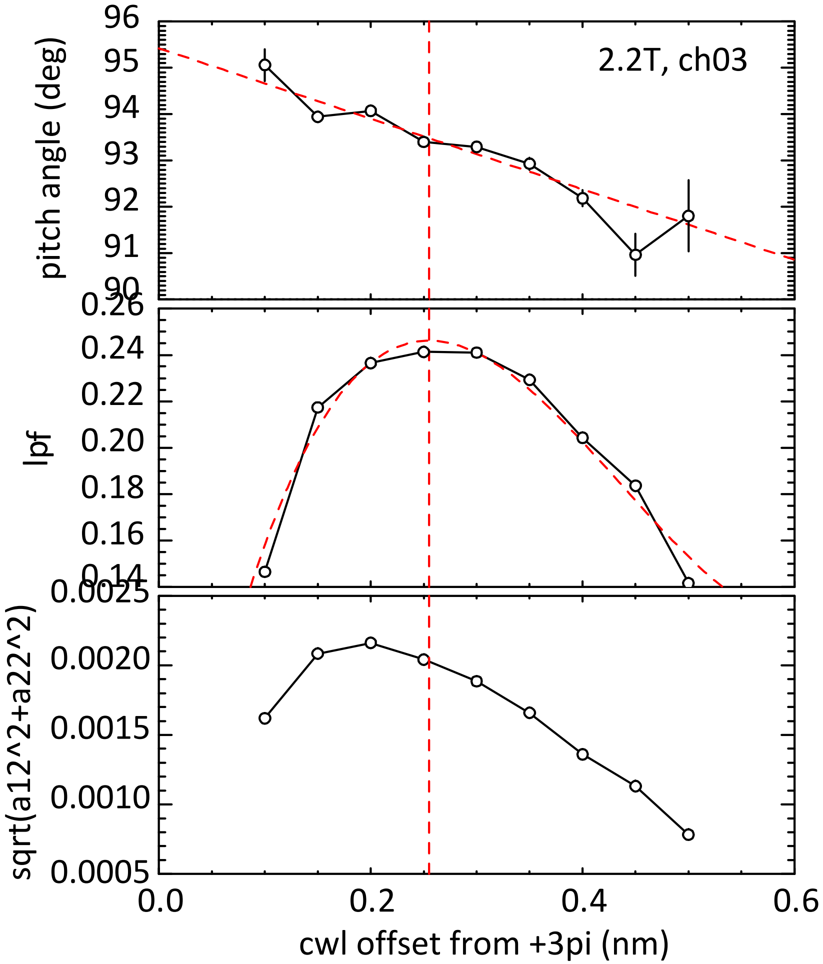
Very simple spectral analysis already helping bandpass filter calibrations

- **Filter tuning: 0.2 - 0.4 nm red-shift from +3pi**



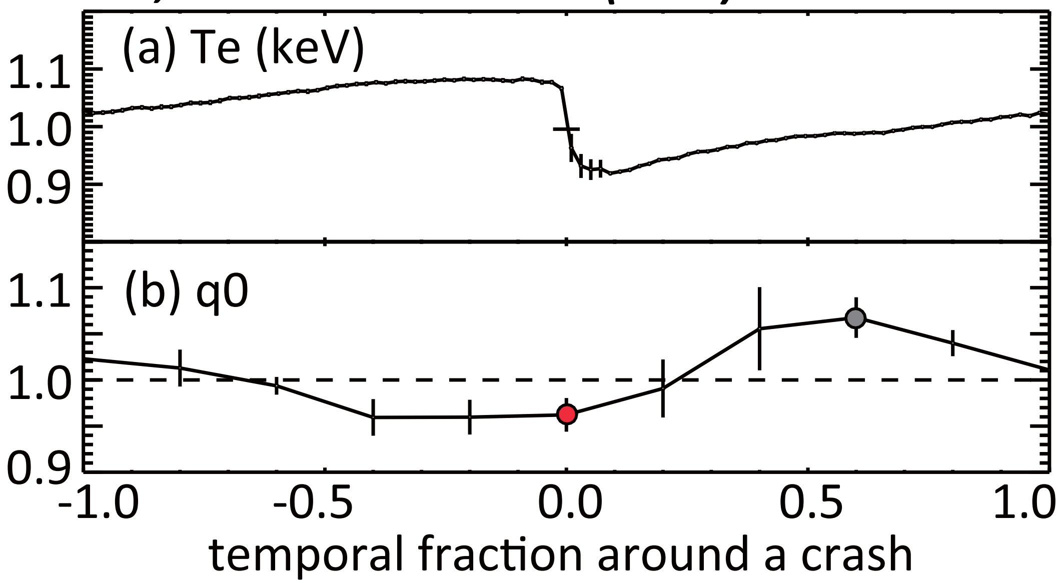
Very simple spectral analysis already helping bandpass filter calibrations

- **Quantitative analysis on lpf, cpf etc enables precise determination of the optimized amount of filter offset.**
- **Recently, this calibration has been performed from beam-into-gas injection tests (independent of the regular plasma run time).**



Direct derivation of q from pitch angle – q0 correlated with sawtooth events

Ko, Rev. Sci. Instrum. 87 (2016) 11E541



$$q = -\frac{\kappa a^2}{2R_0(R_X - R_0)\tan\gamma}\left\{\left[1 - \frac{4(R_X - R_0)}{a^2}(R - R_X)\right]^{-1/2} - 1\right\}$$

$$q_0 = -\frac{\kappa}{R_X}\left(\frac{\partial}{\partial R}\tan\gamma\right)^{-1}_{R=R_X}$$

R. Giannella et al, Rev. Sci. Instrum. 75 (2004) 4247-4250
C. Petty et al, Plasma Phys. Control. Fusion 47 (2005) 1077-1100

- **q_0 evolving around 1**
- **q_0 < 1 occurs before the sawtooth crash (confirming the internal kink) and the current build-up (q_0 > 1) is slow after the crash.**

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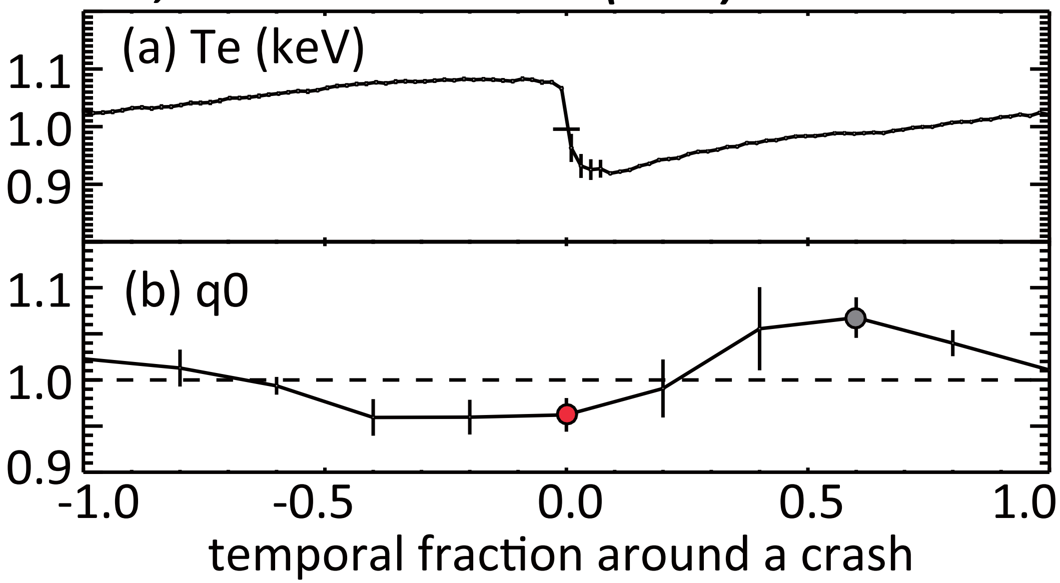
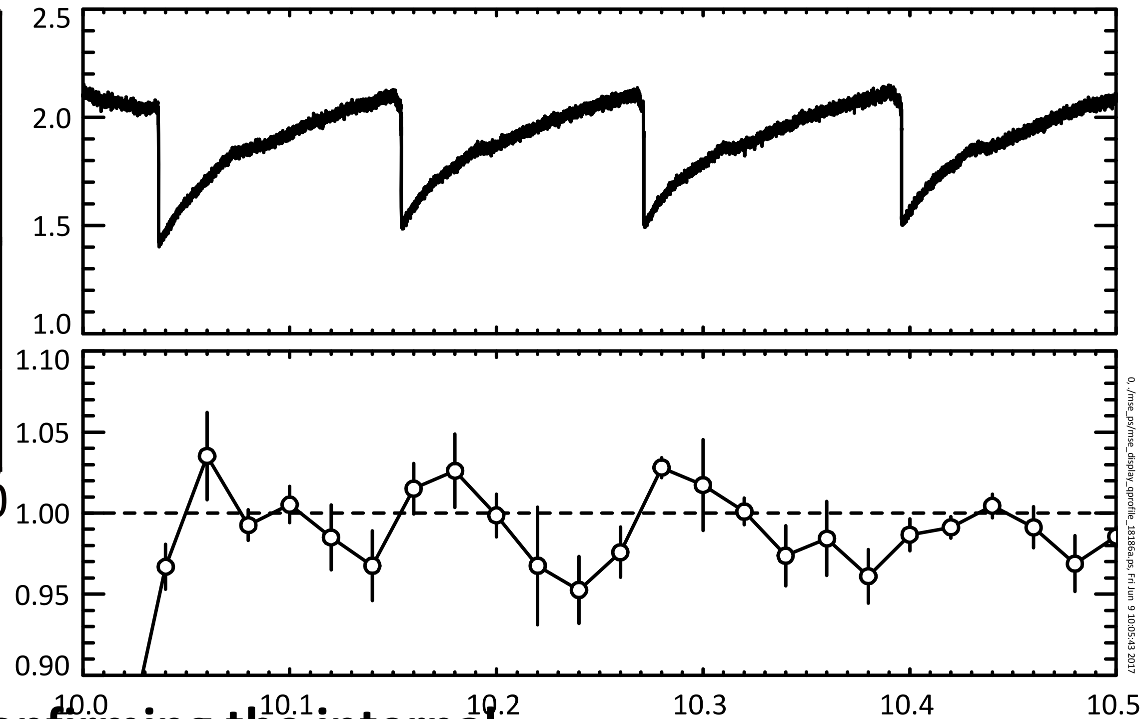


Shot #18186 (Tue 23 May 2017)



- **q_0 evolving around 1**
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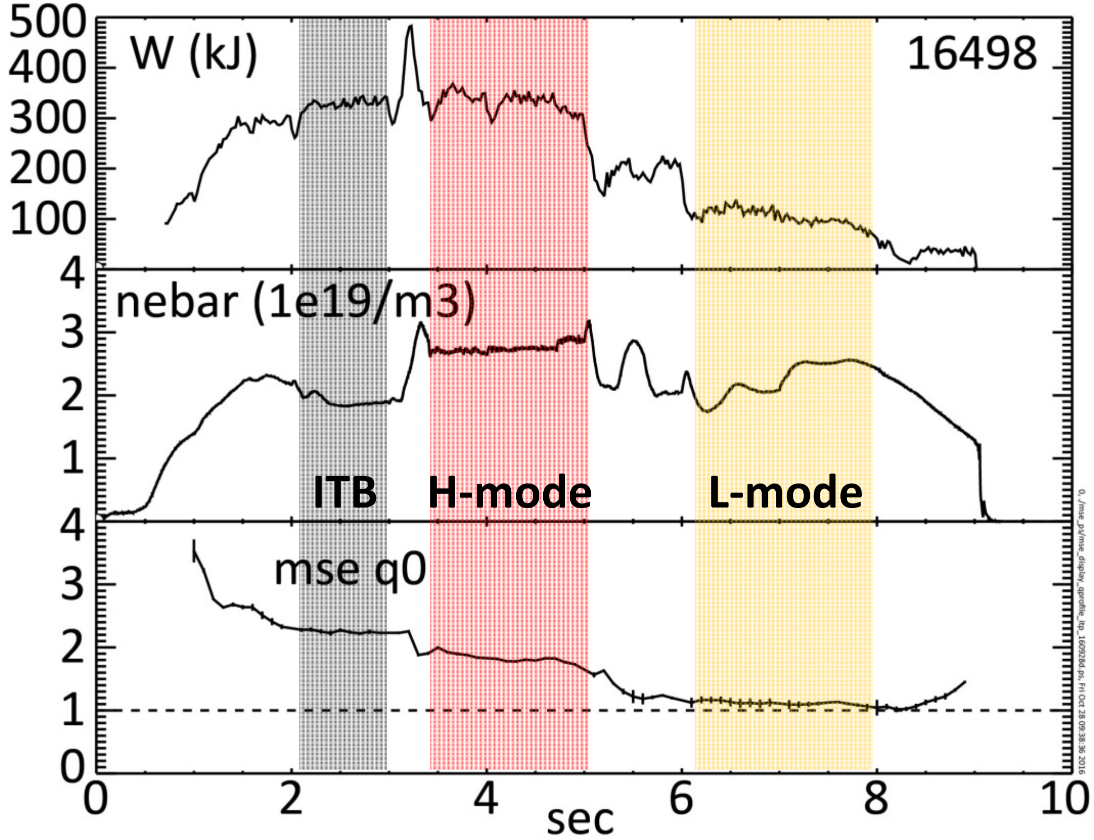
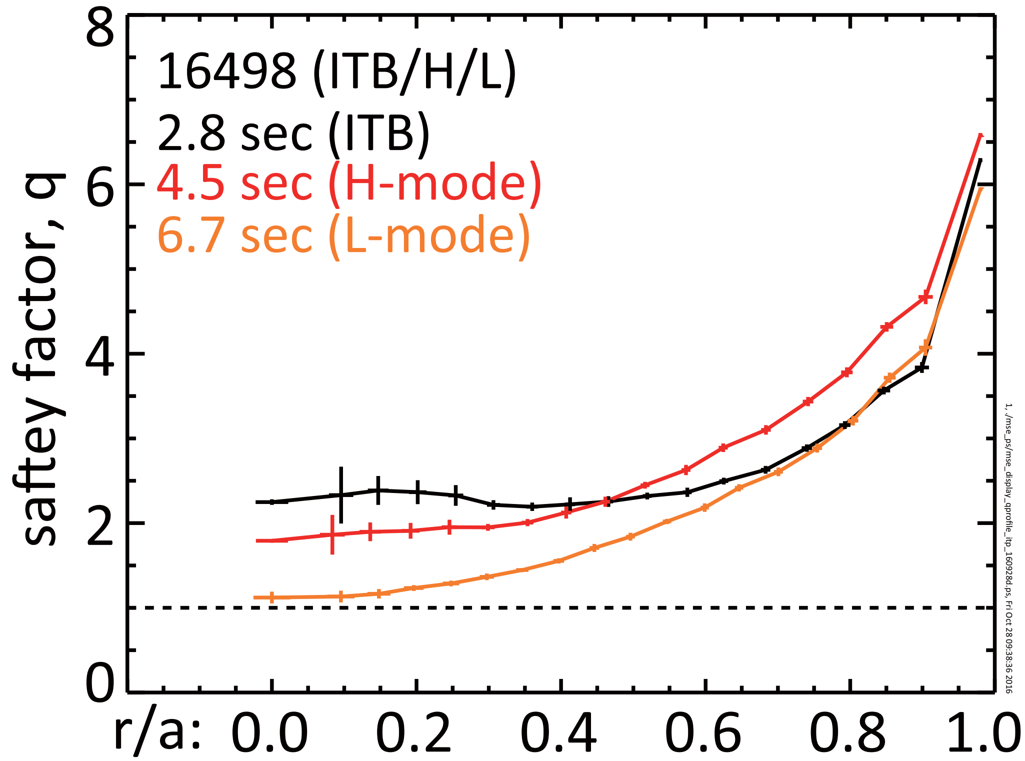
Flat (or near-hollow) q profiles with $q_0 \geq 1.5$ during steady ITB formation.





Inferred directly from MSE data using analytic models

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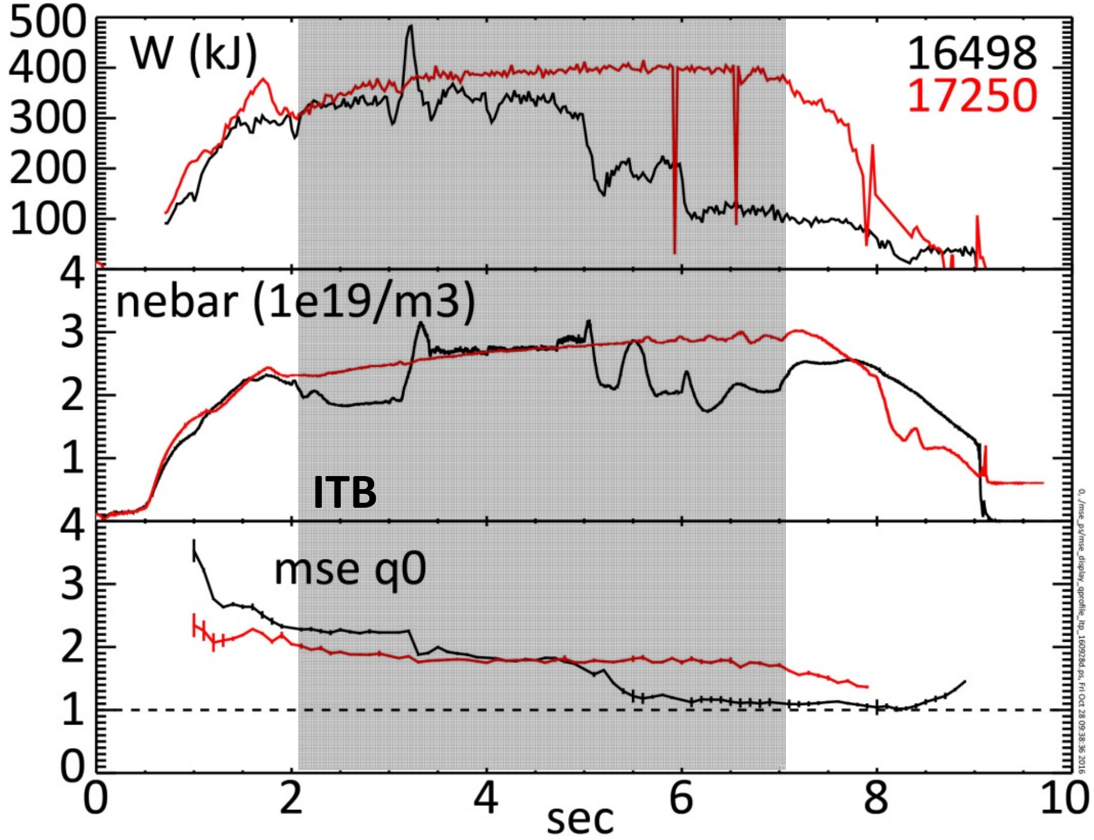

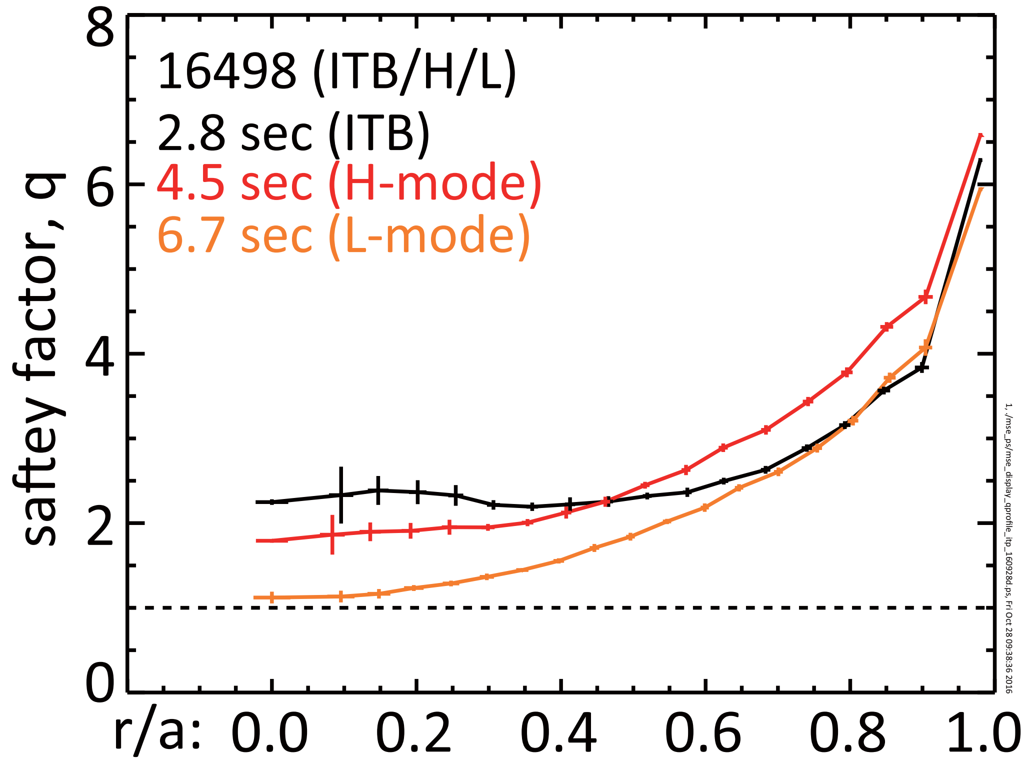

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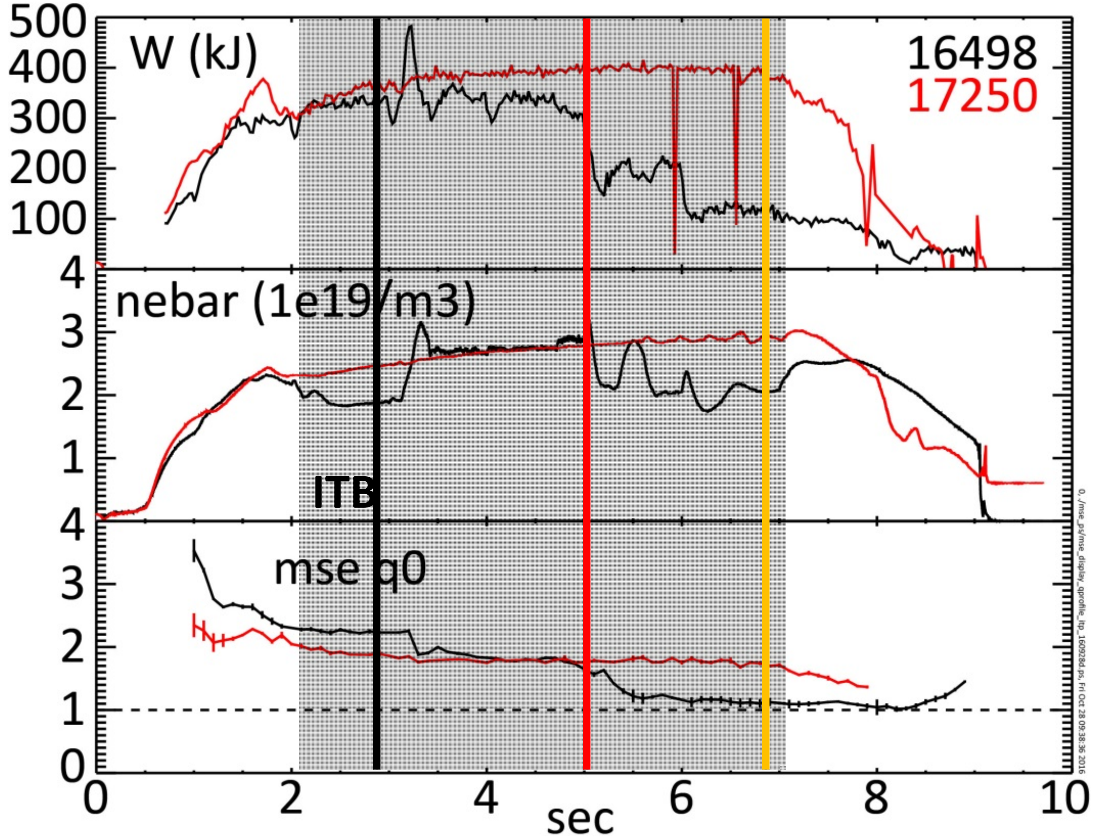

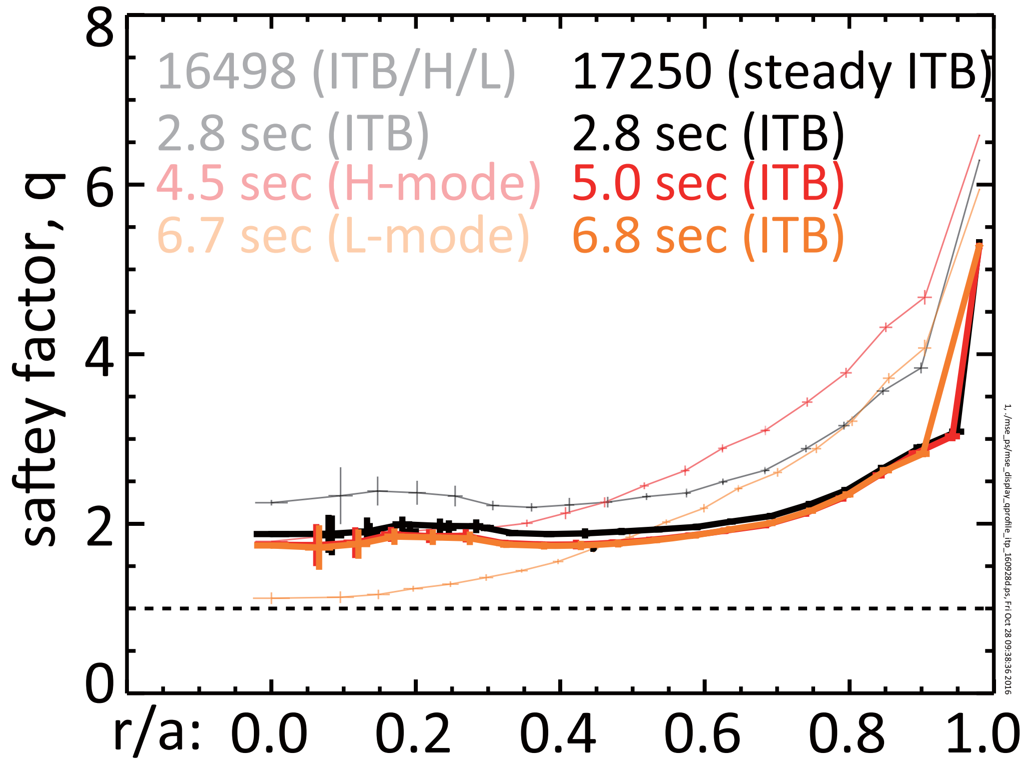

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Ko et al, Rev. Sci. Instrum. 88, 063505 (2017)

NFRI KSTAR

Time line for work plan

Year 1 (2017)

- Construction of self-calibrated high-precision ($\Delta\lambda \leq 0.05$ nm) spectral diagnostic
- Development of a single-ion-source-injection fitting routine and interface for existing atomic data and modeling packages (such as NOMAD, ADAS etc)

Year 2 (2018)

- Introduction of the polarization-distortion effects to the spectral analysis suite
- Systematic comparison with the PEM-base MSE

Year 3 (2019)

- Evaluation and assessment of the atomic data used in the spectral analyses
- Optimization of the spectral analysis suite for ITER application