

Development of a dual vertical Thomson scattering diagnostic system on EAST

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Presented by Yan Li



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- 02** Theoretical Foundation of Dual-System Thomson Scattering Diagnostic
- 03** Dual Thomson Scattering system principles and design
- 04** Dual system test results and data analysis
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Introduction of a traditional TS System

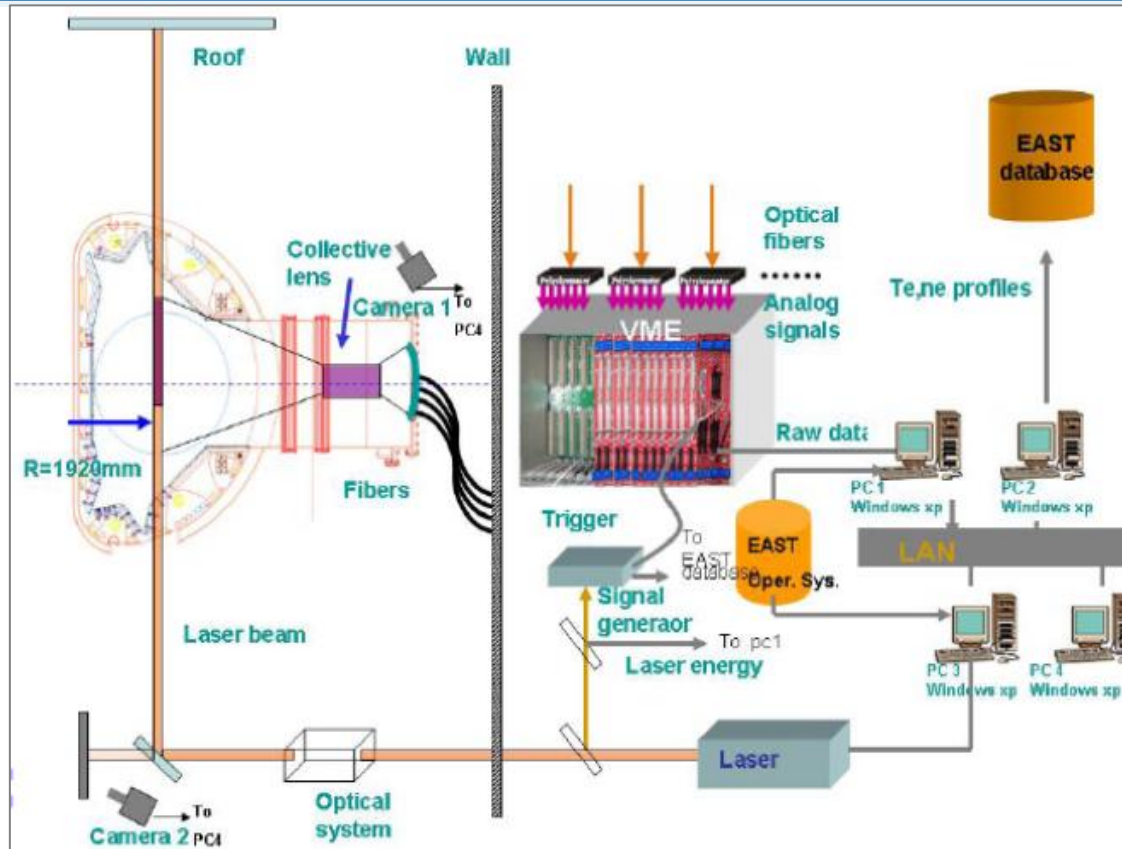
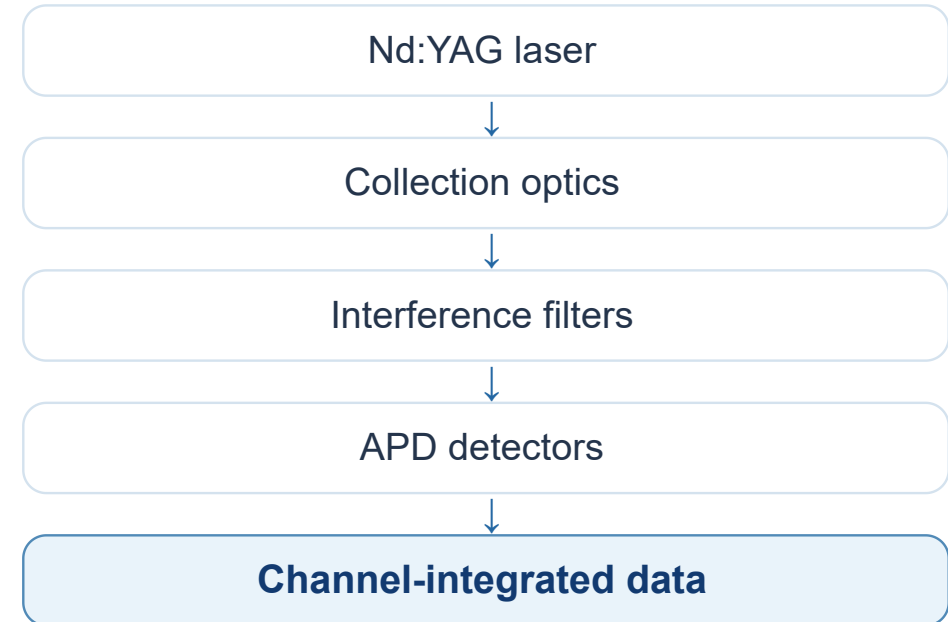


Figure 1. Schematic diagram of the traditional TS system in EAST.

Traditional TS · 1064 nm



- **Advantages:** wide dynamic range($n_e > 0.5 \times 10^{19} \text{m}^{-3}$, $T_e > 100 \text{eV}$), high temporal resolution(**50-100Hz**, **5kHz**), and high system stability(absolute error, $T_e < 10\%$, $n_e < 15\%$);
- **Challenges:** complex system architecture, limited spectral resolution, and measurement uncertainties at extremely high temperatures ($> 10 \text{ keV}$) and extremely low temperatures ($< 50 \text{ eV}$).

Introduction of a tangential TVTS System

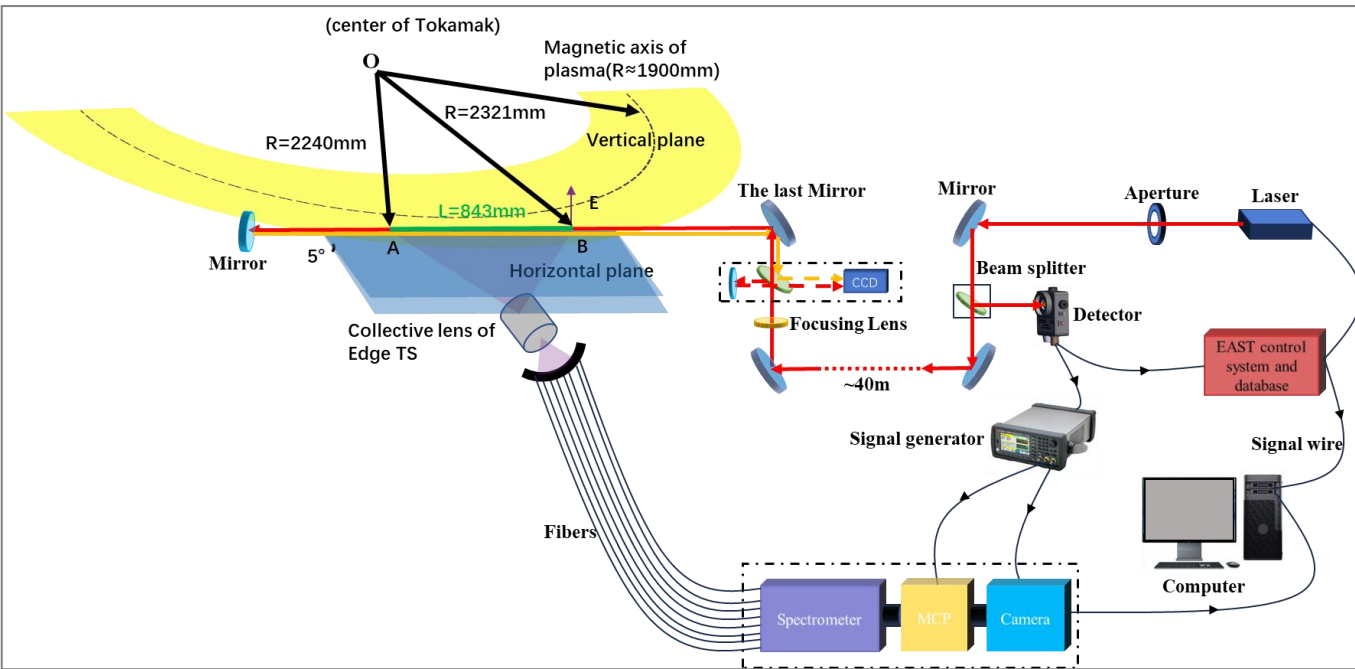
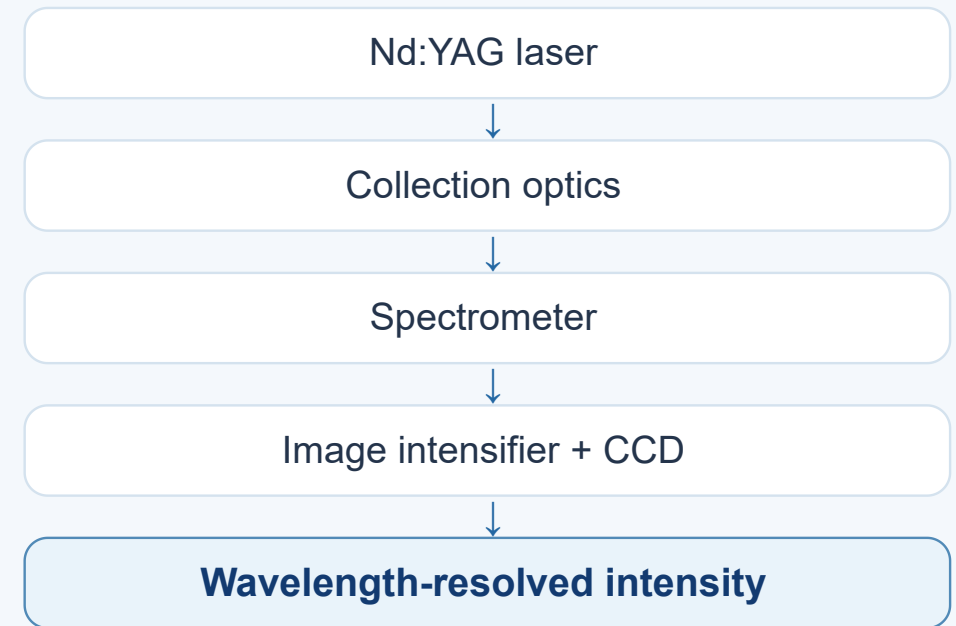


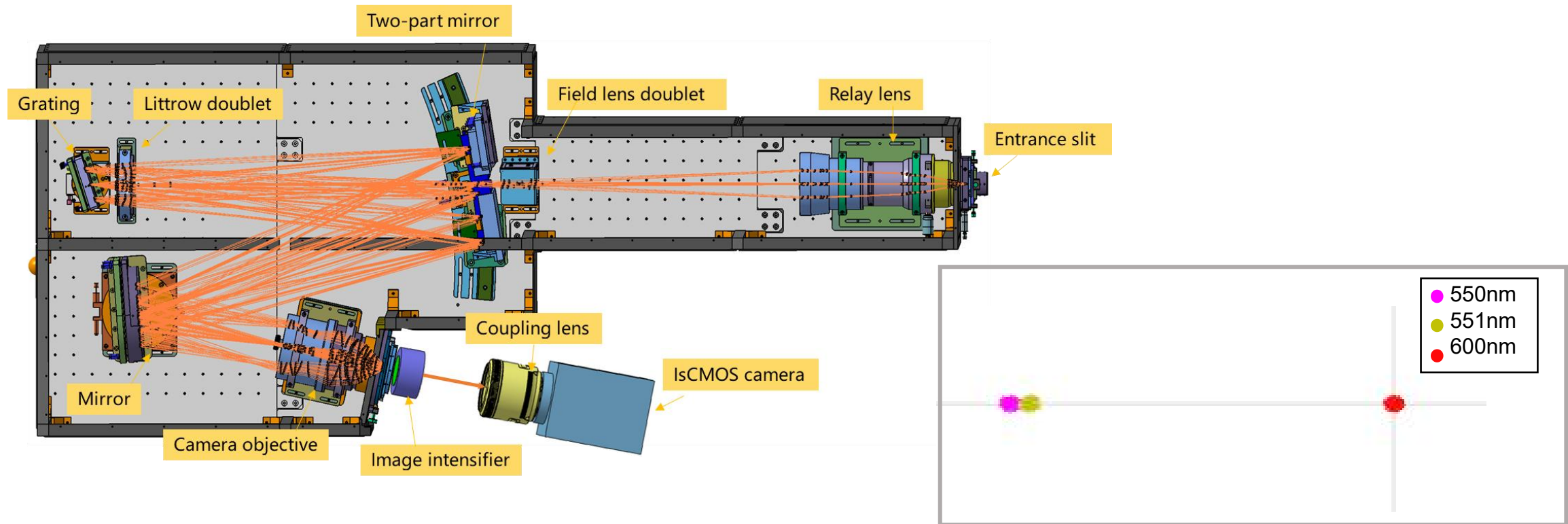
Figure 2. Schematic diagram of the tangential TVTS system in EAST.

Tangential TVTS System · 532 nm



- **Advantages:** high spatial resolution and high measurement accuracy (direct acquisition of the scattering spectrum shape);
- **Challenges:** wide spectral bandwidth, low signal intensity and high stray light levels.

Introduction of a tangential TVTS System



➤ Spectrometer system characteristics:

- ✓ Modified **Littrow structure**
- ✓ **High entrance slit: 70mm(support 100 channels)**
- ✓ Spectral resolution: 6nm @1.5mm
- ✓ Notch bandwidth ~ 6nm, OD>4@532nm

➤ Spectrometer resolution < 1 nm

For fixed T_e and scattering angle, $S(\epsilon, \theta)$ has the same normalized shape.

For a given scattering angle, the shape of the normalized scattering spectrum is determined by the electron temperature and the relative wavelength shift

- $\epsilon = \lambda_s / \lambda_i - 1$

λ_i and λ_s are the incident and scattered light wavelength, respectively

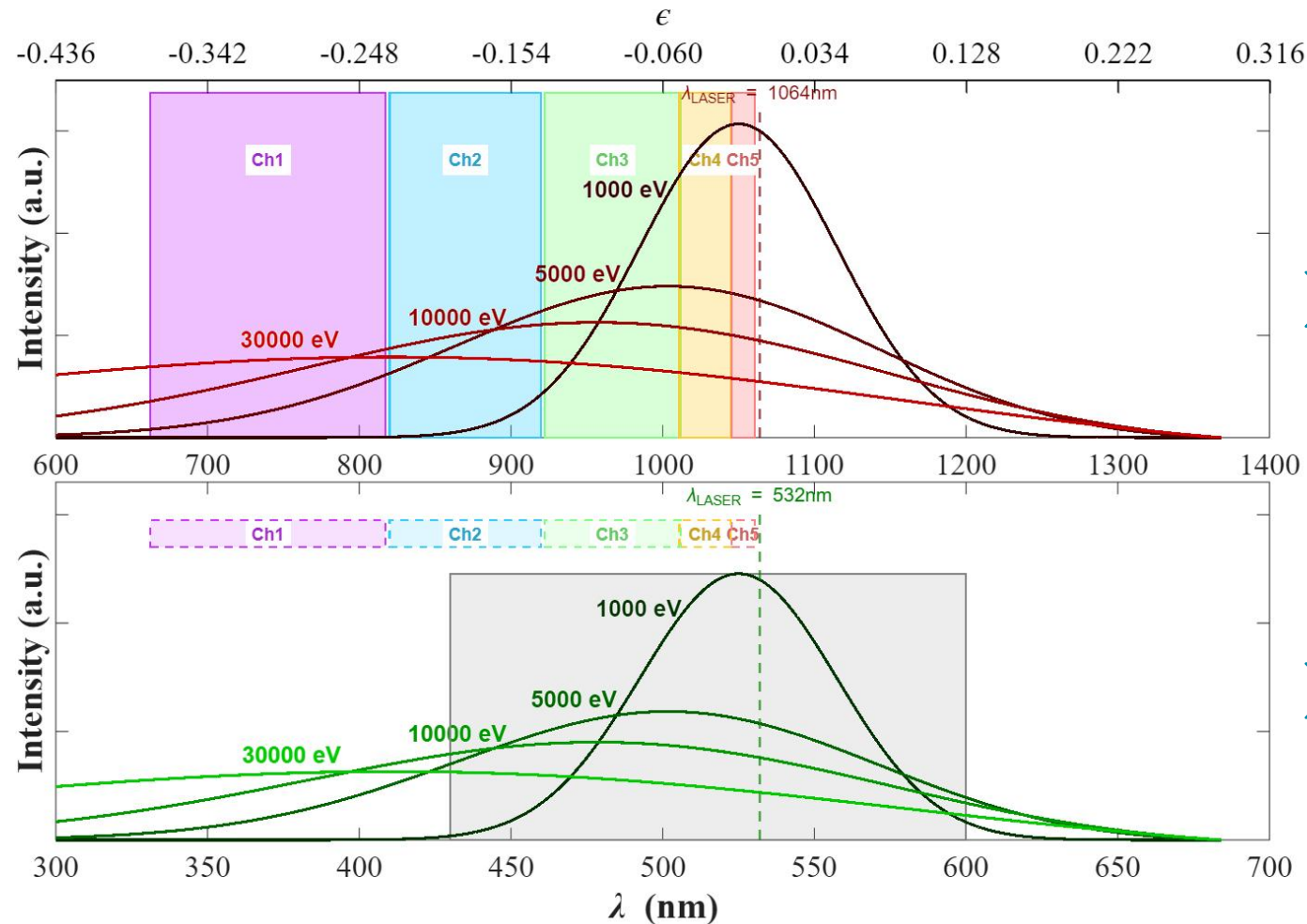
Equation (1) · Traditional TS filter signal

$$I_{\text{chi}} = K \int_{\epsilon_{\text{min,chi}}}^{\epsilon_{\text{max,chi}}} S(\epsilon, \theta) \cdot f_{\text{chi}}(\epsilon) d\epsilon$$

Equation (2) · TVTS corresponding spectral band

$$I_{\text{chi}}^{\text{TV}} = K^{\text{TV}} \int_{\epsilon_{\text{min,chi}}}^{\epsilon_{\text{max,chi}}} S(\epsilon) \cdot f(\epsilon) d\epsilon$$

K and K^{TV} represent distinct calibration factors and $f(\epsilon)$ represents the transmission efficiency of the i -th filter.



Traditional TS system: The signal ratio between channels ($I_1/I_2, I_1/I_3, \dots, I_{n-1}/I_n$) correlates with the electron temperature.

TVTS system: The system collects signal in the wavelength range from 430 nm to 600 nm.

Figure 3. Theoretical relativistic Thomson scattering spectra at incident wavelengths of 1064 nm and 532 nm, along with collection band and filter channel correspondence between the EAST traditional TS system and the TVTS system.

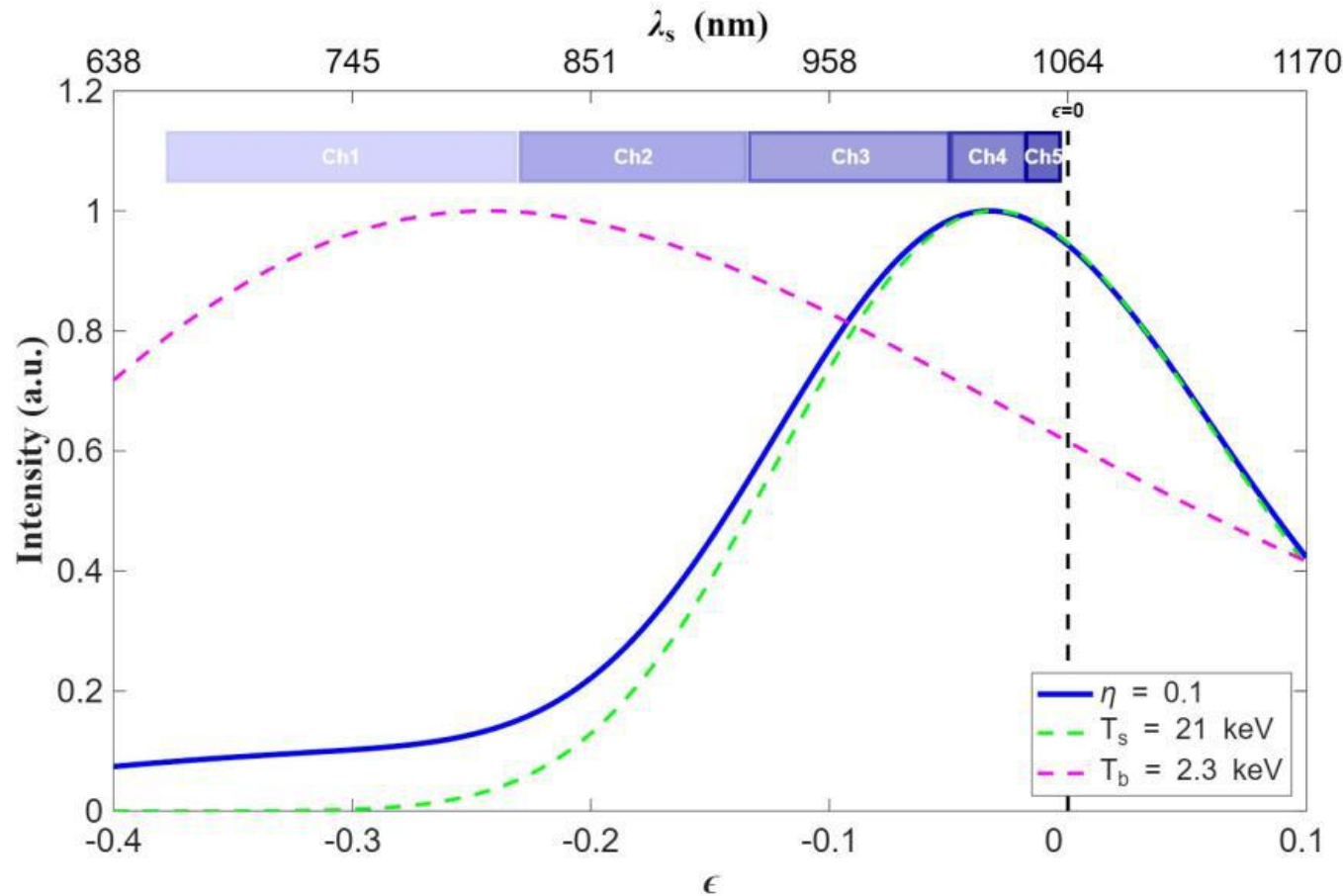


Figure 4. The scattering form factors based on bi-Maxwellian distribution functions. The lower X-axis displays normalized coordinates. The upper x-axis represents the scattering wavelengths corresponding to incident wavelengths of 1064 nm laser light.

Note: The bi-Maxwellian model is a simplified analysis tool, not a definitive representation of the real electron velocity distribution in EAST plasma. Its applicability to experimental results remains to be verified in future studies.

bi-Maxwellian electron velocity distribution model

$$f_B(\mathbf{v}) = (1 - \eta)f_M(\mathbf{v}, T_b) + \eta f_M(\mathbf{v}, T_s)$$

Bulk: 2.3 keV

Tail: 21 keV

Tail fraction: 10%

- Channel-ratio deviations may expose a suprathermal contribution.

Dual Thomson Scattering system principles and design

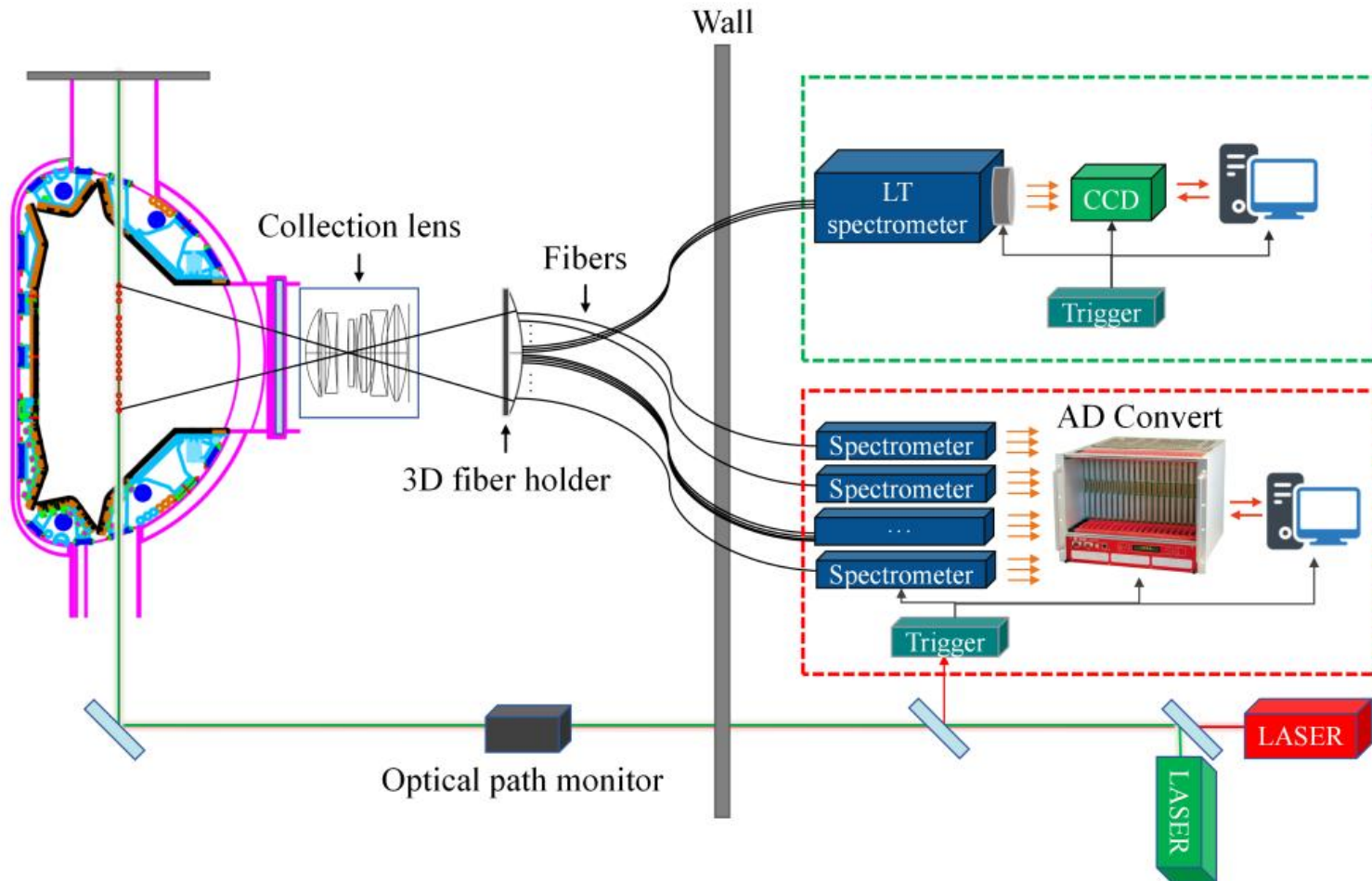


Figure 5. Overall schematic of the dual vertical TS system on EAST.

Laser & transmission

- two Nd:YAG incident beams
- beam combining technique
- ~45 m shared transport path

Optical collection system

- same collection lens at the L port
- same fiber

Synchronous triggering and time sequence design

- nanosecond timing control

Spectroscopic detection system

- different detection system

Combine a traditional TS system with a TVTS system on the EAST tokamak

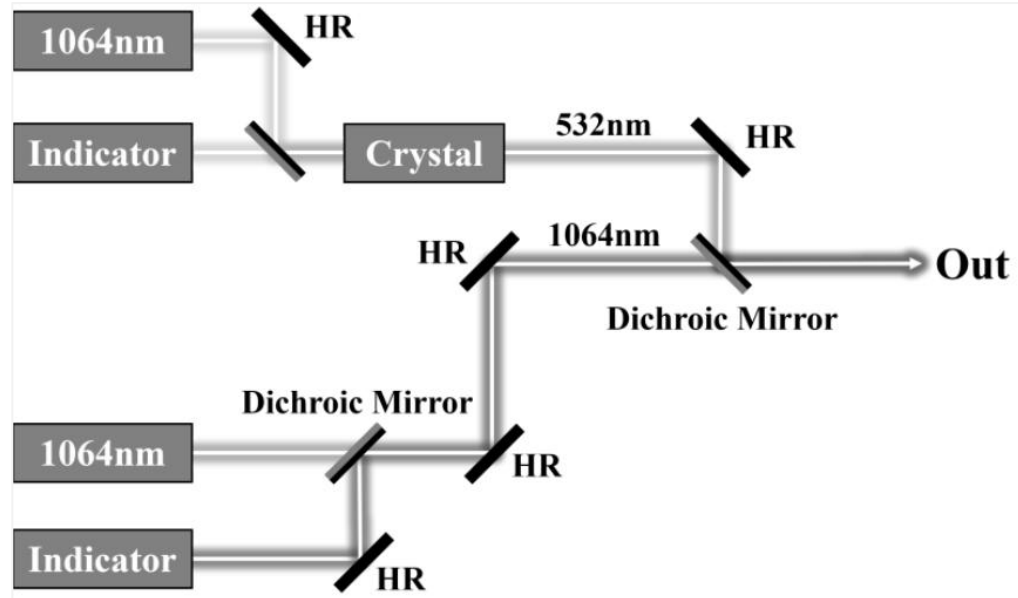


Figure 6. Optical configurations for laser wavelength combining.

- Dichroic: high reflectivity at 532 nm and high transmission at 1064 nm.

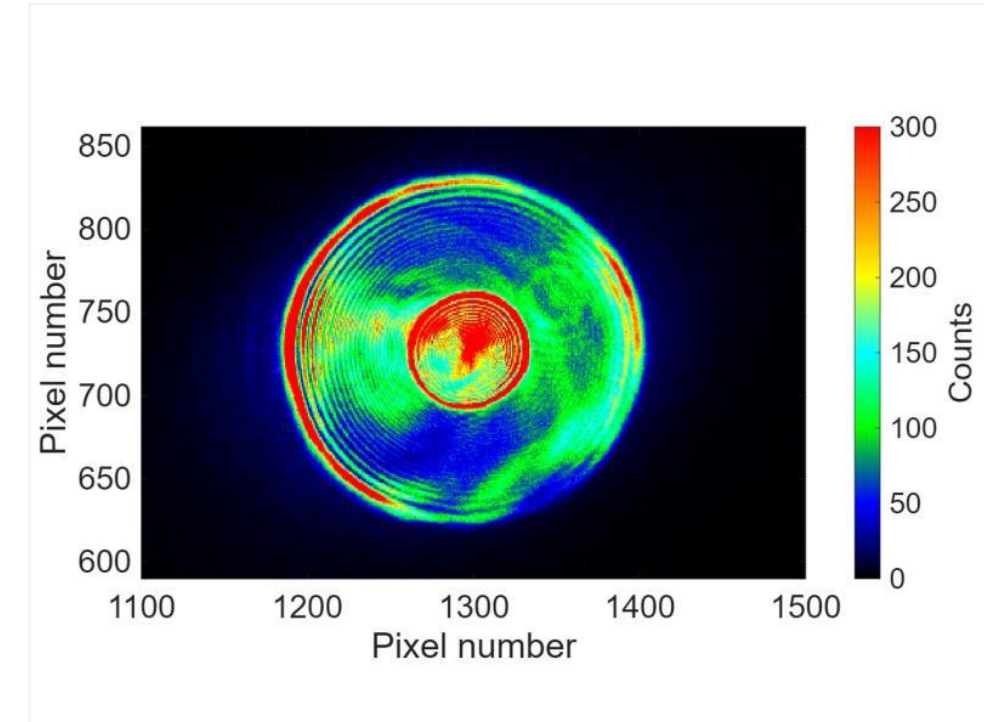


Figure 7. Beam-monitor result after combining (original measurement).

✓ **Laser beam combining system:** Realize different wavelength laser beam combining.

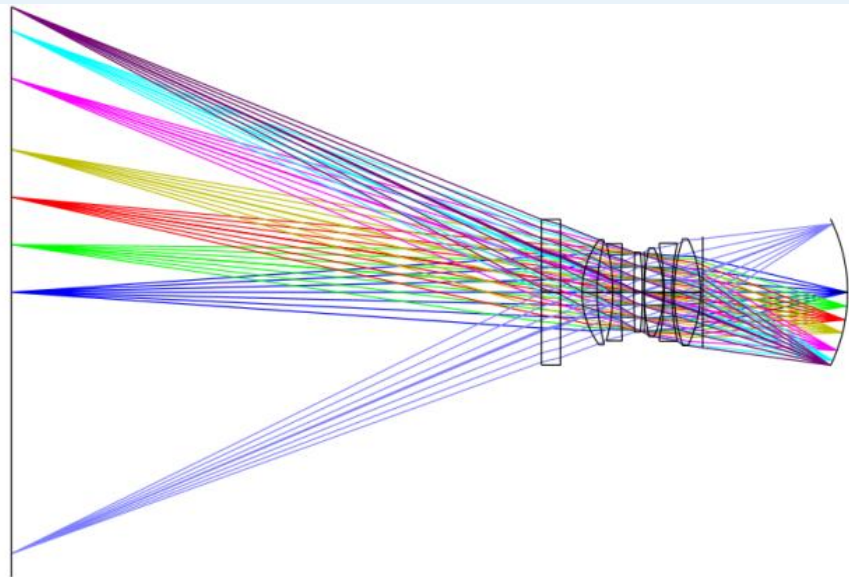


Figure 8. The optical schematic of the collection lens, configuring seven fields of view to cover object surface dimensions of $\pm 600\text{mm}$.

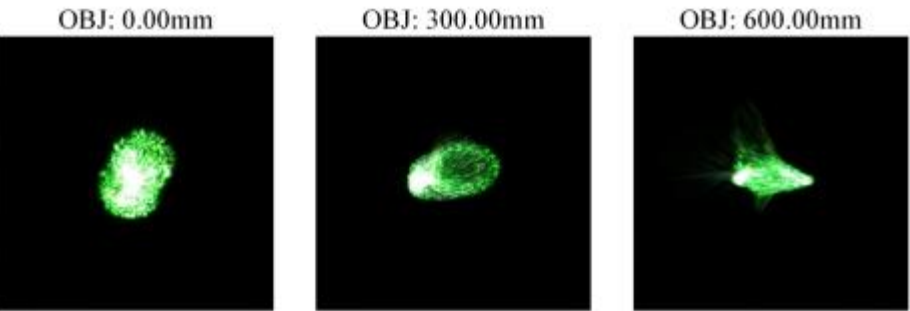


Figure 9. The actual spot diagram of the collection lens, each CCD pixel is $1.4 \times 1.4\mu\text{m}$. The brightness of the image background depends on the camera's exposure time.

Table 1. Parameters of the collecting lens.

Parameters	Collecting lens
Working band	420nm-1100nm
Number	6
Lens type	1 aspherical + 5 spherical
Including field of view	$\pm 600\text{mm}$
Magnification	0.295
Transmission	$\sim 78\%$
Numerical aperture on the image-side axis	0.22
Fiber	1.5mm

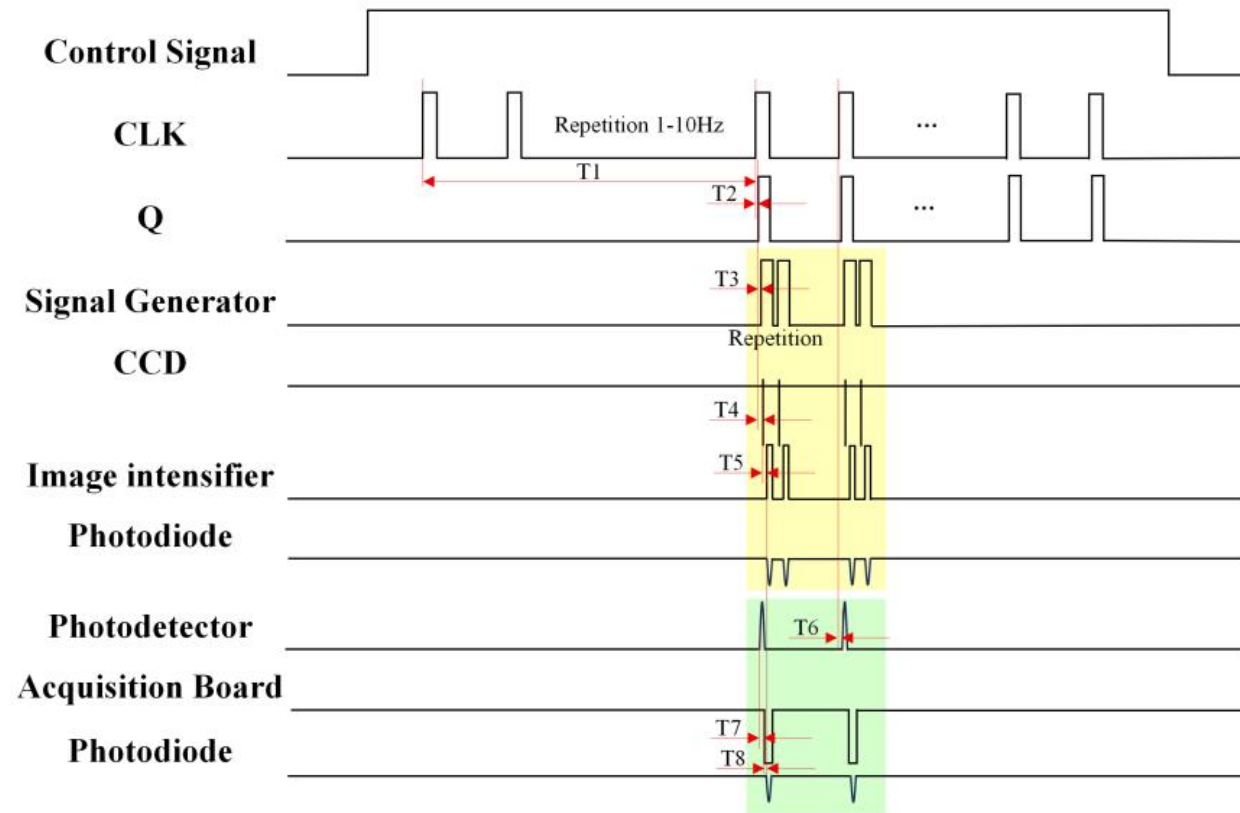


Figure 10. Schematic diagram of the dual system timing sequence

T1: laser warm-up time

T2: time delay for the laser flash lamp and Q-switch

T3: signal generator delay time

T4: CCD's own delay time and the system setup delay

T5: image intensifier's delay to precisely align the photocathode's activation time with the arrival time of scattered photons

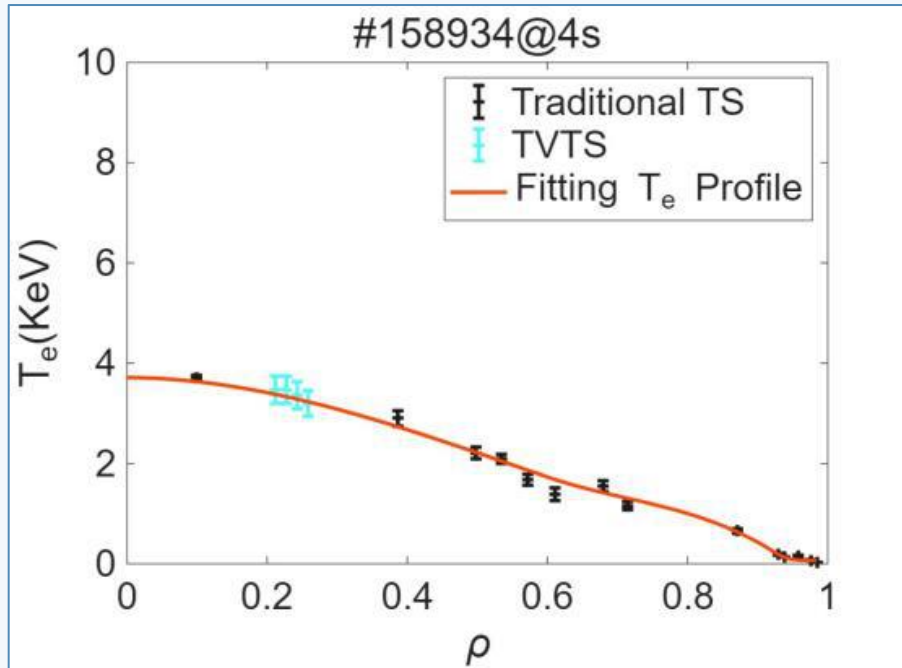
T6: delay in a traditional TS system

T7: system's relative acquisition time

T8: time difference between data acquisition in the two systems

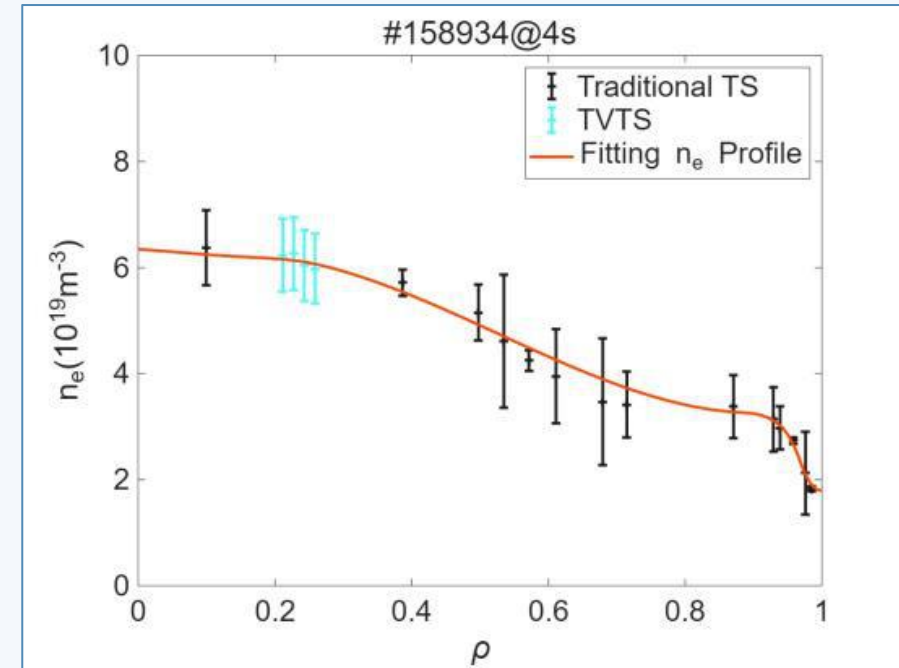
Traditional TS points and TVTS points follow a consistent trend.

Te profile of shot number 158934 at 4s



$$\frac{\sigma_{Te}}{Te} = \sqrt{\left(\frac{\sigma_{\lambda}}{\lambda}\right)^2 + \left(\frac{\sigma_{\theta_{laser}}}{\theta_{laser}}\right)^2 + \left(\frac{\sigma_{P_{signal}}}{P_{signal}}\right)^2 + \left(\frac{\sigma_{\Gamma}}{\Gamma}\right)^2} = \pm 8\%$$

ne profile of shot number 158934 at 4s



$$\frac{\sigma_{ne}}{ne} = \sqrt{\left(\frac{\sigma_{\theta_{laser}}}{\theta_{laser}}\right)^2 + \left(\frac{\sigma_{P_{signal}}}{P_{signal}}\right)^2 + \left(\frac{\sigma_P}{P}\right)^2 + \left(\frac{\sigma_{\sigma_{RM}}}{\sigma_{RM}}\right)^2} = \pm 11\%$$

Figure 12. (a) The core Te profile and (b) ne profile of shot number 158934 at 4s. The blue points are achieved by the vertical TVTS system, the black points are obtained by the traditional TS system installed on EAST and the red lines are the fitting profile of Te and ne.

Note: Measurements used a temporary fiber arrangement.

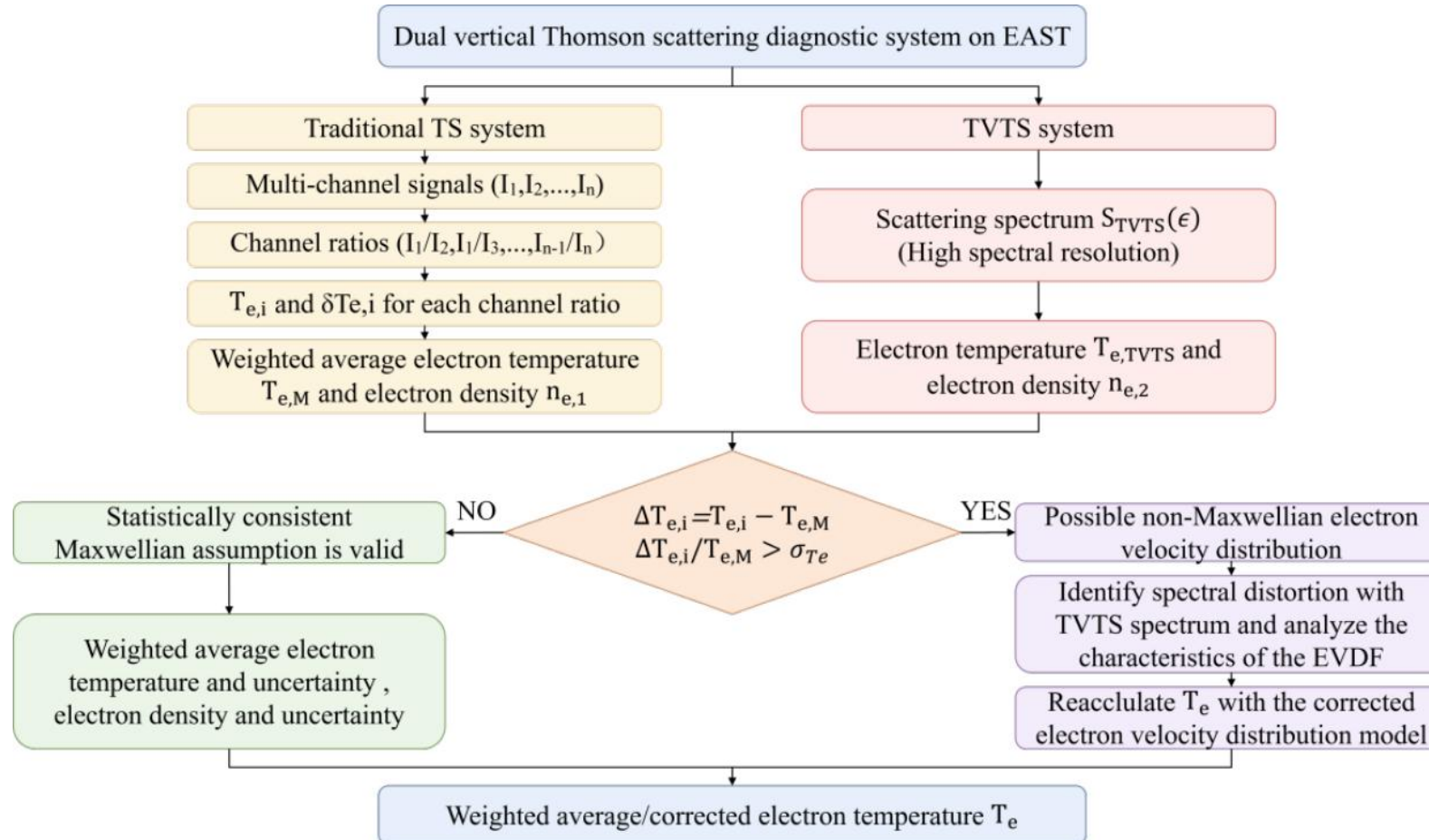


Figure 13. The overall analytical workflow of the dual Thomson scattering diagnostic system.

Next plan

- Complete same-location optical signal sharing.
- Study bi-Maxwellian and kappa EVDF models.
- LHCD/ECRH suprathermal electron simulations and experiments
- Quantify Te bias and validate corrections with measured spectra.

Thank you for your attention!

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