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TOKAMAK GOLEM FOR FUSION EDUCATION - CHAPTER 17: MAGNETIC ISLANDS, DIAMAGNETIC MEASUREMENT, SPECTROSCOPY, TRANSPORT BARRIER, ION TEMPERATURE MEASUREMENT

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H=High school B=BSc M=MSc P=PhD PD=PostDoc

INTRODUCTION

This poster presents current **student projects carried out at the GOLEM tokamak**, operated at the Czech Technical University in Prague (CTU). This is the second part of two contributions on this topic.

GOLEM tokamak:

- **World's oldest operational tokamak**: $R = 0.4\,\mathrm{m}$, $a = 0.085\,\mathrm{m}$, $B_t < 0.8\,\mathrm{T}$, $I_p < 16\,\mathrm{kA}$
- **Remote-control interface**: students worldwide perform plasma experiments hands-on
- Subject of high-school projects and Bachelor's/Master's theses; **part of** the basic physics **curriculum**
- **Diagnostics testing bed**

Fig. 1: Geographic distribution of GOLEM remote operation sessions.

NN-BASED MAGNETIC ISLAND DETECTION

Objective: Automate magnetic island detection to study correlations with runaway electrons.
Method: Neural network utilizing Mirnov coil cross-correlation.
Data: 2D matrices from 0.3 ms windows, processed iteratively with every coil as a reference.
Input: Fed directly into the NN as raw matrices to preserve numerical fidelity.
Challenge: Establish empirical thresholds to distinguish true islands from transient edge MHD events.

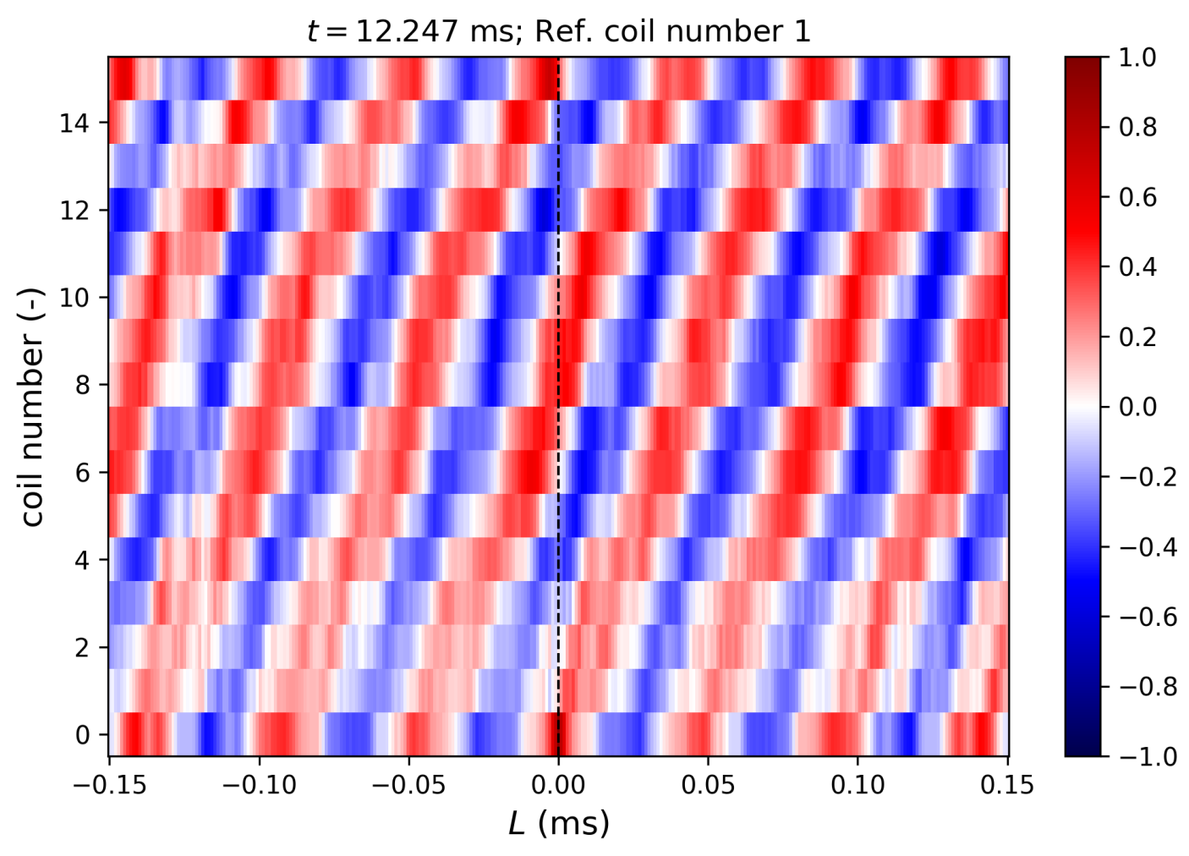
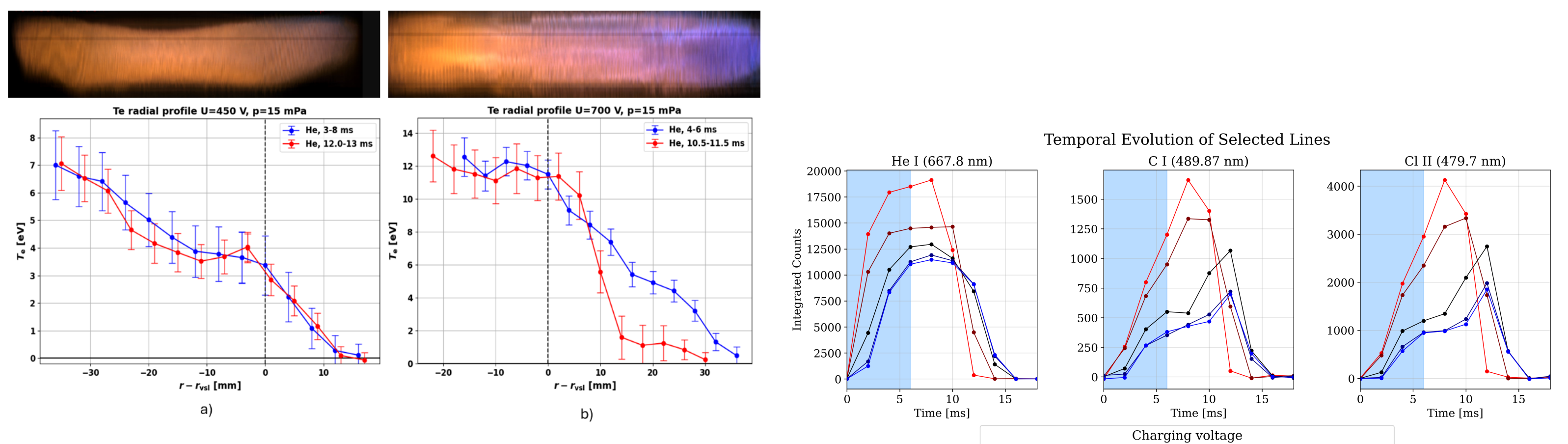


Fig. 2: Cross-correlation of Mirnov coil signals.

SPECTROSCOPIC STUDY OF TRANSPORT BARRIER

- Steep T_e radial gradients in He discharges persist on GOLEM after hardware upgrades, possibly indicating a transport barrier
- Color transition observed above ∼550 V and below ∼50 mPa; linked to impurity ionization state changes
- Cl I/Cl II and other impurity lines dominate high-energy phase spectra
- Three discharge phases identified: impurity accumulation → accumulation plateau → emission decrease
- He II line present only at low/intermediate pressures, indicating sufficient electron temperature for ionization
- Higher pressure suppresses temperature gradient formation via increased collisionality and electron cooling
- Removing chlorine contamination could extend the high-energy phase and improve confinement study conditions



(a) Comparison of T_e radial profiles at two different plasma currents. Upper fast-camera images show the temporal evolution of the plasma radiation (vertical view.)

(b) Temporal evolution of selected lines of main working gas and impurities, indicating the three discharge phases. Transition is not observed for voltages below 550 V.

Fig. 3: (left) Radial temperature profiles. (right) Temporal spectral line intensity.

NEW FAST SPECTROSCOPY DIAGNOSTIC

- Optical apparatus consisting of beam-splitters, dichroic mirrors, and spectral filters with radial LoS
- Measurement of multiple emission line (He, Cl, O, C, ...) intensities at 10 kHz, aiming for 100 kHz
- Future application: analysis of fast transients in transport barrier formation, impurity studies
- Highly modular, allowing for easy modification of monitored spectral lines

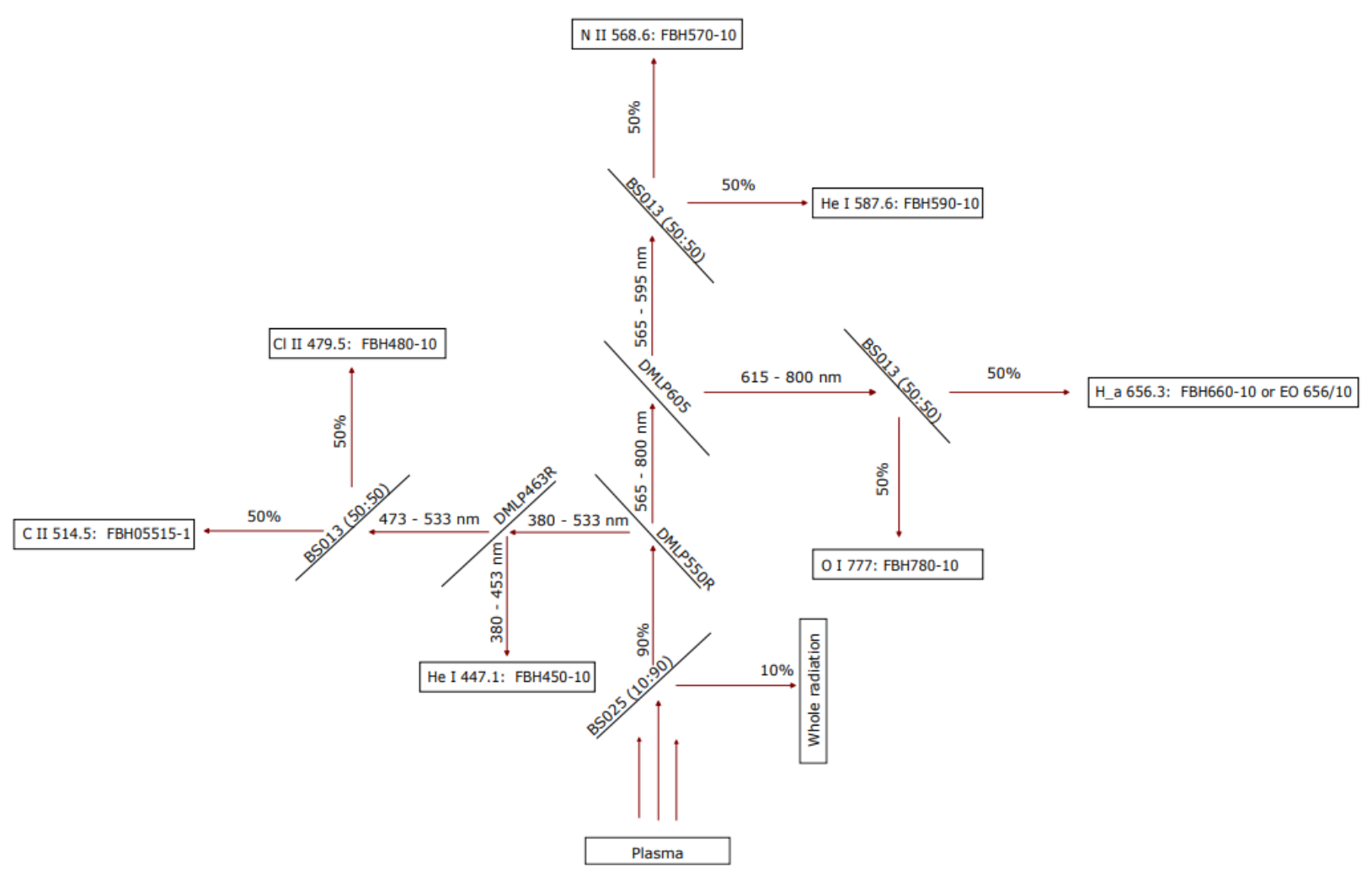
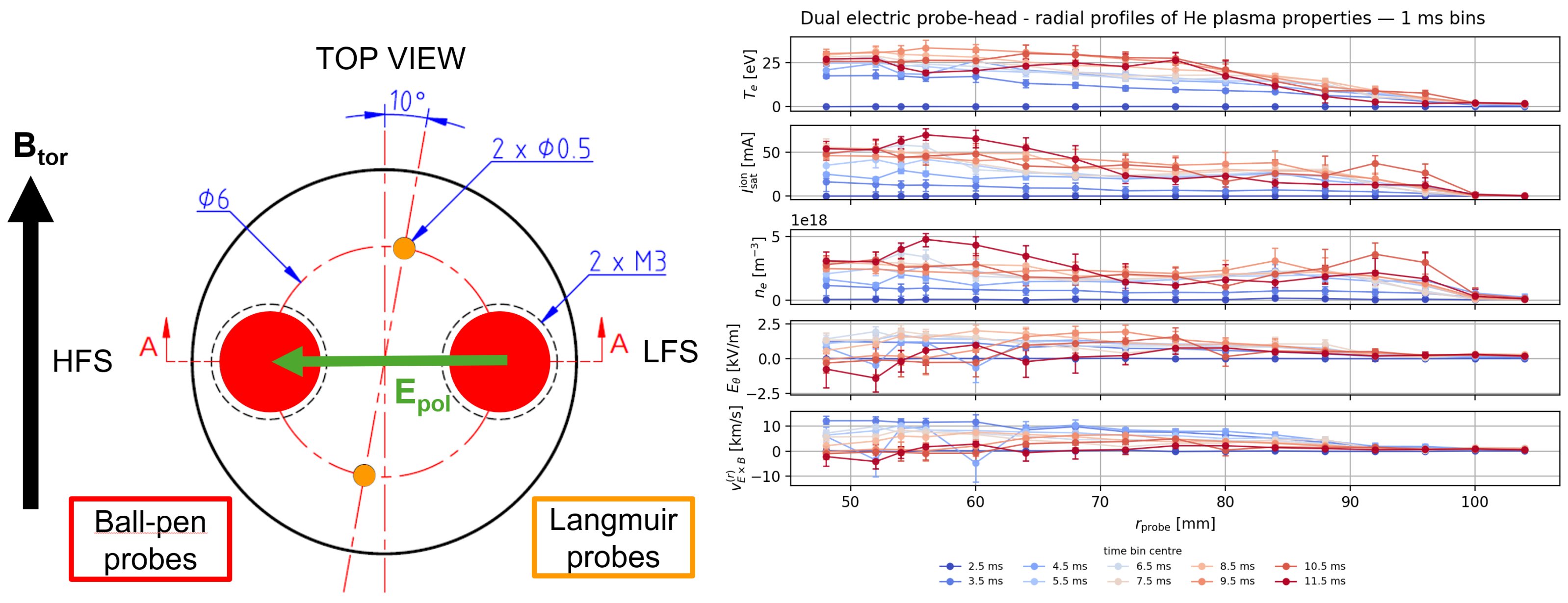


Fig. 4: A schematic of the optical apparatus.

ELECTRIC PROBES

- **dual probe-head** (2x Langmuir, 2x ball-pen probes), see Figure 6a left → enables simultaneous I_{sat}^{+}, floating and voltage-swept measurements.
- **Main purpose:** transport barrier studies [1] and fast (up to 100 kHz) T_i studies [2].
- **Operation:** successfully measuring radial profiles of plasma properties, including radial drift velocity $v_{\mathrm{ExB}}^{(r)}$ Figure 6b.



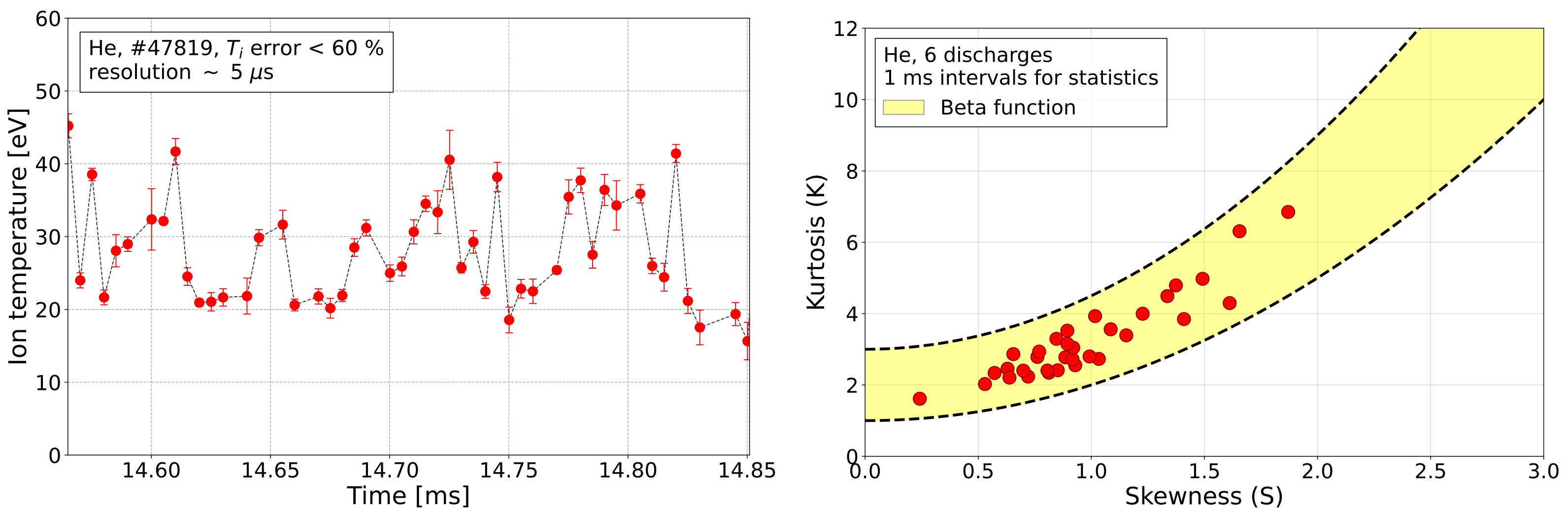
(a) Dual probe-head scheme

(b) Radial profiles of He plasma properties 53189 - 53207

Fig. 5: (left) Dual probe-head scheme. (right) Plasma properties profiles.

ULTRAFAST ION TEMPERATURE MEASUREMENT

- Ion temperature measured with an ultrafast temporal resolution of 5-10 s in He plasma using a fast swept ball-pen probe [[3], [4]].
- Data analysis was performed using a universal Python program successfully applied across other fusion devices (ASDEX Upgrade, COMPASS) and currently being tested on W7X.
- Statistical analysis of Ti time evolutions reveals characteristic distributions with pronounced high-temperature tails → positive skewness and high kurtosis [[4],[5]].
- Ti fluctuations follow a general parabolic relationship ($K = aS^2 + b$) bounded by a beta function → in agreement with general statistical behaviour of scrape-off layer turbulence.



(a) Measured time evolution of ion temperature.

(b) Parabolic dependance of skewness and kurtosis.

Fig. 6: (left) Ion temperature evolution. (right) Skewness and kurtosis.

A NEW DIAMAGNETIC DIAGNOSTIC

- Diamagnetic diagnostic on GOLEM uses flux loops, a compensation coil, an in-vessel Rogowski coil, and a Python-based analysis framework for automated processing.
- The weak diamagnetic signal requires dedicated compensation using flux loops, Mirnov coils, and a compensation coil.
- Hardware upgrades in data acquisition have already reduced noise, but remaining noise still limits reliable energy estimates.
- Ongoing work focuses on further noise reduction, optimization of compensation methods, and validation with the new Rogowski coil.

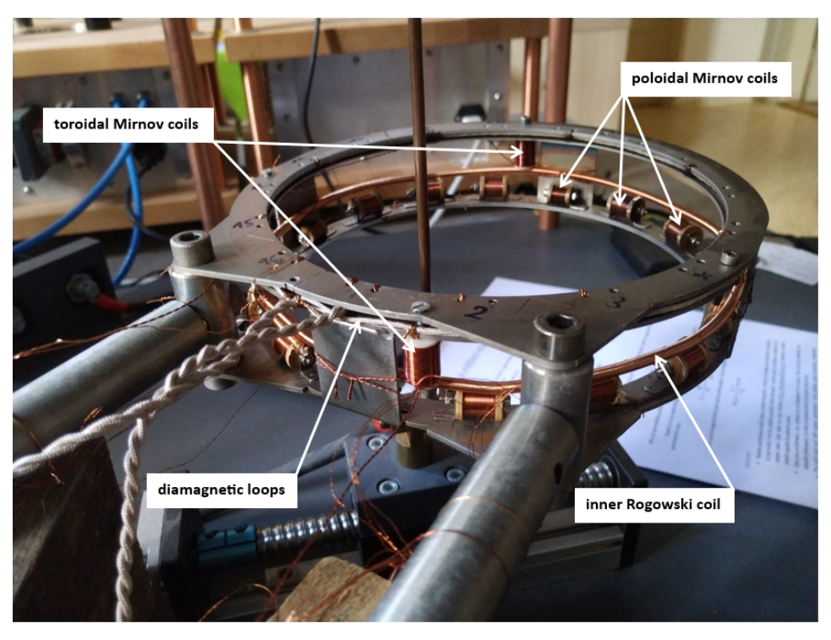


Fig. 7: Diamagnetic ring.

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