Tokamak GOLEM for fusion education - chapter 13

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The GOLEM tokamak is the oldest operational tokamak worldwide. Currently it serves mainly as an educational device. GOLEMs most unique feature is its remote-control system [1]. This contribution is devoted to the current experimental projects of students.

Visible plasma tomography is being implemented using a newly installed pair of fast cameras Photron FASTCAM Mini UX50. The maximum frame rate is 102, 400 fps with resolution of 1280 by 24 pixels. They are positioned at the same toroidal section at perpendicular ports viewing the same poloidal cross section. Camera lens calibration by point fitting has been performed using a 3D scene made up of an optical breadboard and optical components of known geometries, as the absence of any well defined points visible in the tokamak chamber wouldn't allow for a direct calibration. For this calibration the CALCAM software was used [2]. Some preliminary results have already been produced using the Minimum Fisher Regularisation algorithm implemented in the Tomotok package shown in Fig 1. The accuracy of these is limited by uncertainties in camera positions. More precise measurement of the camera positions relative to the tokamak chamber is foreseen to improve reliability of the tomographic inversions.

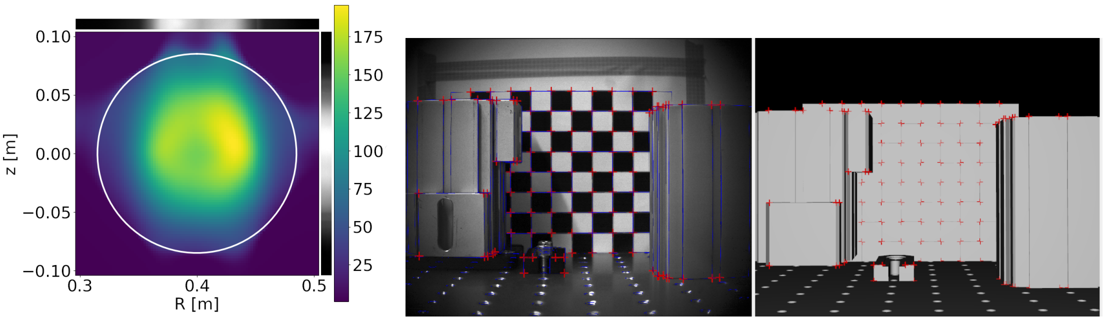

Figure 1: Left) Preliminary tomographic reconstruction. White line represents the vessel wall. Right) Camera lens calibration using Calcam software.

Measurement of the energy spectra of runaway electrons was performed. The peak pile-up was reduced using a small LYSO(Ce) scintillator (3x3x5mm) coupled to SiPM (silicon photomultiplier). The signal from scintillator detectors from discharge is shown in the left part of Fig 2. In the middle, in more detail. A pile-up effect is present in PMT and SiPM coupled scintillators (middle part of Fig 2). The individual HXR peaks in the LYSO(Ce) detector are identifiable. With a known peak function, it is possible to generate synthetic signal matching LYSO(Ce) measurements (right part of Fig 2). Thus, peak heights corrected from pile-up are obtained. HXR spectrum from original peak heights compared to the corrected one is shown in Fig 2, bottom right.

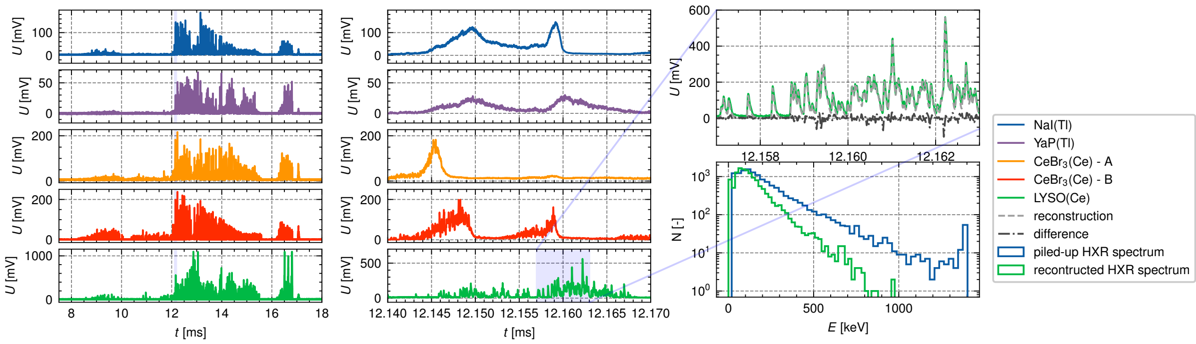

Figure 2: Left) Comparison of HXR signals from 5 scintillation detectors. Center) In more detail. Right) HXR signal reconstruction, and its spectrum.

Energetic spectra and Compton scattering reconstruction were measured using Timepix3 detectors equipped with 2 mm thick CdTe sensors. Detectors were placed 3 m from limiter and the temperature stabilization using active fans was performed. The energetic spectrum is shown in Fig 3. The display plane was placed 304 cm from the detector for the reconstruction of the Compton scattering, which approximately corresponds to the position of the limiter. The limiter is assumed to be the main source of x-rays. Results are shown in Fig 3 with resolution of 1 cm x 1 cm for a pixel. There is no evident source of the x-rays visible in the figure yet.

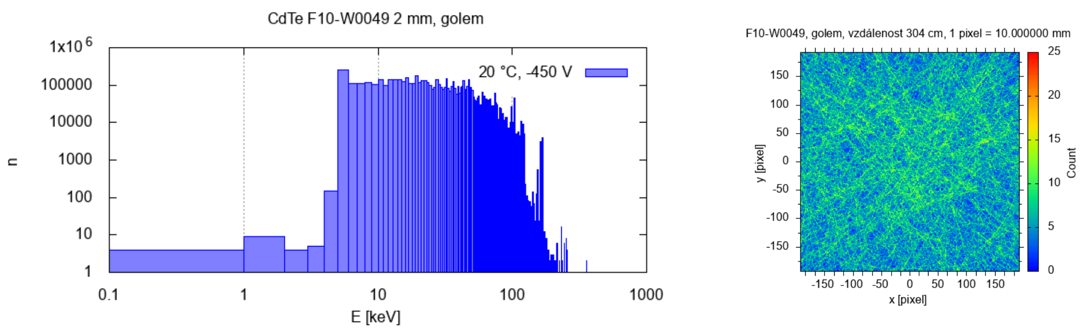

Figure 3: Left) Energy spectrum. Right) Compton scattering reconstruction.

Thanks to **an upgrade of stabilization windings**, which now have a more turns per coil, it is possible to generate a stronger magnetic field, that provides better control over the position of the plasma column during the discharges. The positive effect of stabilization is demonstrated in Fig 4, where the generated additional magnetic field resulted in the prevention of the plasma column shift towards the HFS and the upper wall of the chamber, thus extending the discharge duration by more than 5 ms. Until recently, the position of the plasma was obtained only from the Mirnov coils. However, during discharges with stabilization, the signals from these coils may be affected by the generated additional magnetic field. Therefore, new fast cameras have been installed to better determine the position of the plasma. A comparison of the calculated radial position from the cameras with the position obtained from the Mirnov coils for the discharge without stabilization depicted in Fig 4 shows a good agreement between the two methods.

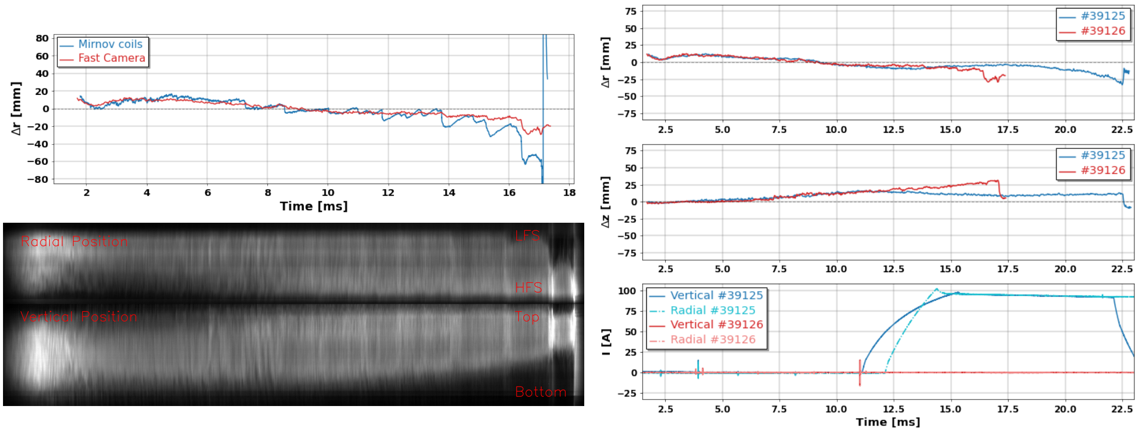

Figure 4: a) Comparison of the radial plasma position obtained from the fast camera (red) and from the Mirnov coils (blue), b) Plasma displacement taken by fast cameras, c) Radial plasma position, vertical plasma position and current driven in stabilization coils without stabilization (red) and with radial and vertical stabilization (blue).

The new motorized probe manipulator was calibrated and installed on the GOLEM tokamak. The manipulator allows both the radial and angular profiles measurements with possibility of fast remote control, which is significant benefit compared to the old manual manipulator, which was used before. The picture of the manipulator, including all the main components (two stepper motors, two controllers, and the probe holder) is shown in Fig 5. The manipulator was equipped with the double tunnel probe (DTP) and ion flows were measured. First, dependency of ion saturation current on the angle between probe and magnetic field was measured. The results correspond to experiments on other tokamaks [3], showing the maximum of flows along magnetic field and non-zero flows in direction perpendicular to the magnetic field. Second, both components of the Mach number were measured. The perpendicular component was measured for the first time on the GOLEM tokamak using equation $M_{\parallel} = K \ln(R_\alpha + M_\perp \cot\alpha)$ considering two different assumptions. First method assumes $M_{\parallel}$ constant through all angles, while second method lies in fitting R. Both the methods give similar results corresponding to the theory. Results of the second method are shown in Fig 5.

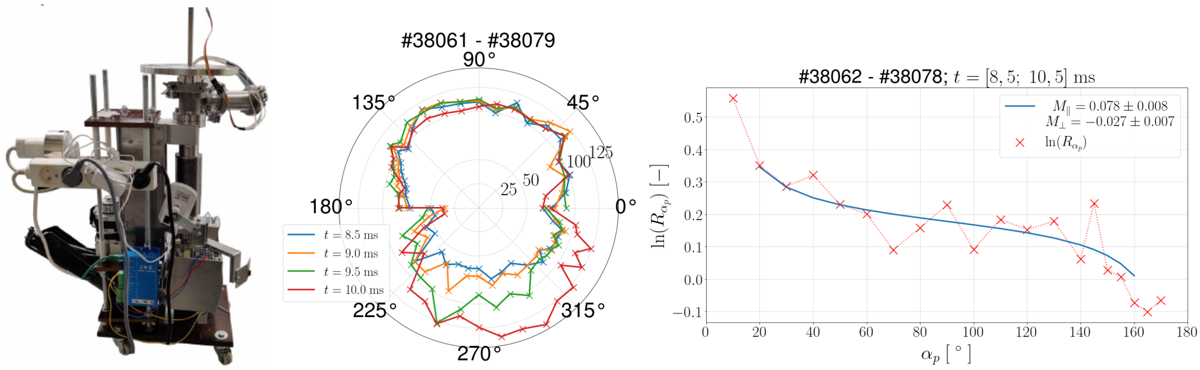

Figure 5: Left) New motorized manipulator. Center) Angular profile of I_{sat}. Right) Angular profile of current ratio R.

The double tunnel probe was used for the **fast electron temperature measurements**. The probe is calibrated on the ion current ratio between its two electrodes, tunnel and back-plate, using 2D3V PIC code PICCYL [4]. The current ratio is proportional to the electron temperature. The calibration itself is performed, and electron temperature is obtained. The results are validated against electron temperature measured by combined ball-pen and Langmuir probe, Fig 6. The very good agreement is observed for discharges with high enough density. Low density discharges cannot be calibrated because of the limit of PIC code.

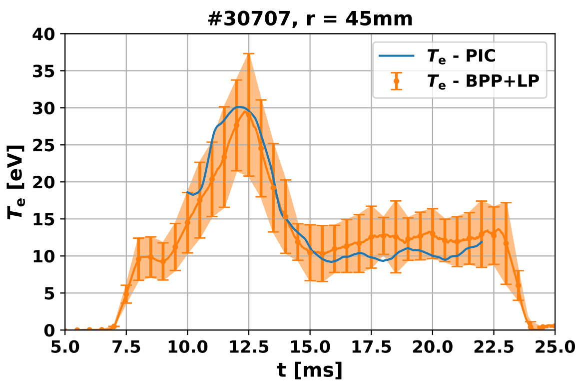

Figure 6: T_e comparison.

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