Fast measurements of ion temperature in ELM filaments in the ASDEX Upgrade scrape-off layer

M. Komm[1], M. Kočan[2], D. Carralero[3], H.W. Müller[3], J. Stöckel[2] and the ASDEX Upgrade Team

[1] *Institute of Plasma Physics AS CR, v.v.i., Za Slovankou 3, 182 00 Prague 8, Czech Republic*

[2] *ITER Organization,13115 Saint-Paul-lez-Durance, France*

[3] *Max-Planck-Institut für Plasmaphysik, EURATOM Association, Boltzmannstr. 2, 85748 Garching, Germany*

Introduction

Interaction of plasma filaments with first wall elements during ELMs, and to lesser extent during inter-ELM periods, might be an issue for the first wall lifetime in future burning plasma reactors such as ITER. However, the understanding of the ELM filament transport in the scrape-off layer (SOL) is still incomplete. This is partly because important ELM filament parameters, such as the radial propagation speed or the electron temperature, are measured only sporadically. One of the key quantities, the ion temperature in ELM filaments T_i, is not measured at all on the filament time scale using existing techniques [1]. We present first T_i measurements in ELM filaments in ASDEX Upgrade (AUG), obtained from a new E×B analyzer.

E×B analyzer

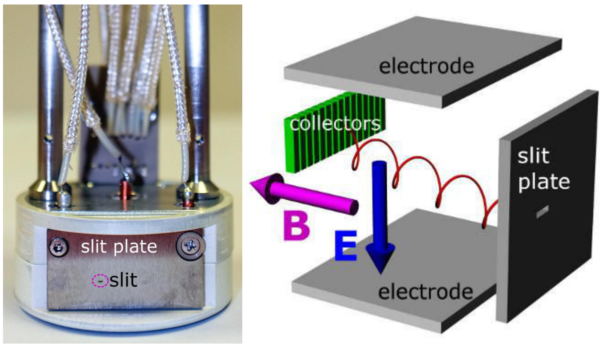

Figure 1: Photograph (left) and schematic view (right) of the E×B analyzer.

The E×B analyzer used in AUG is similar to the one used much earlier in DITE [2] and old ASDEX [3]. As shown in Fig. 1, the E×B analyzer consists of a negatively biased slit plate which reflects electrons back to the plasma and admits a fraction of the incident ion flux inside the analyzer. Inside the analyzer, two planar electrodes, biased to different constant voltages, create an electric E perpendicular to B, which leads to the dispersion of transmitted ions due to the E×B drift. The ions, displaced from the slit axis by Δ_x

$$\Delta_x = \frac{E}{B_{loc}} L \frac{1}{v_{||}}, \tag{1}$$

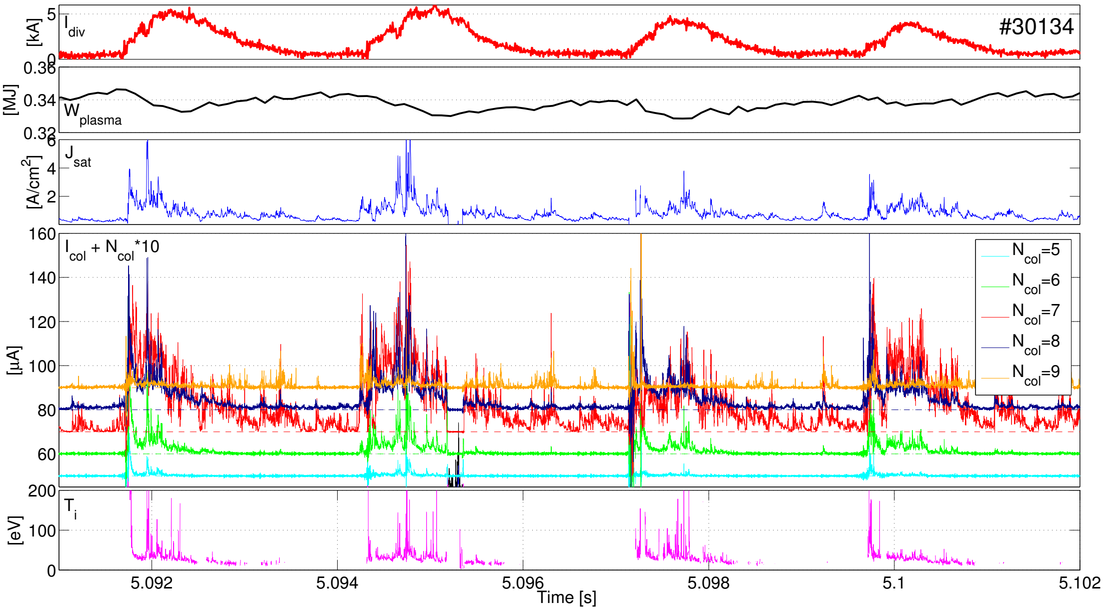

Figure 2: From top to bottom: Inner divertor shunt current, plasma energy, ion saturation current density, curents to E×B analyzer collectors and ion temperature measured by the E×B analyzer during small ELMs.

(where L = 30 mm is the length of the electrodes parallel-to-B, with B_{loc} the local magnetic field, E the electric field created by electrodes and $v_{||}$ is the parallel ion velocity), are measured by an array of 14 collectors (width = 1.25 mm) placed behind the electrodes. Since all bias voltages are kept constant, the parallel ion distribution function $f(v_{||})$ can thus be measured at high acquisition frequencies (2 MHz in present experiment) from the currents to collector.

Experimental setup and results

E×B analyzer measurements were obtained in lower single null H-mode discharge #30134 in hydrogen characterized by pedestal electron temperature T_{eped}=400 eV and density $n_{eped} = 4.5 \times 10^{19}\mathrm{m}^{-3}$, total heating power P_{total}=12 MW (dominated by the neutral beam heating) with the ion $\mathbf{B} \times \nabla B$ drift pointing downwards towards the active divertor. The E×B analyser was mounted on the horizontal reciprocating manipulator located 31 cm above the outer midplane. In this discharge the slit was biased to -200 V, E=60 kV/m and B_{loc}=1.9 T. During the reciprocation the probe was kept at the Δr_{sep}=45 mm for 100ms. The measurement during this time interval comprise a number of ELMs, which are likely Type III or resistive ELMs [4] and are dubbed here *small ELMs*, and a single Type I ELM. The time traces of the inner divertor shunt current I_{div} (ELM marker) and the total plasma energy content W_{plasma} during the probe reciprocation are shown in Fig. 2. Also plotted in Fig. 2 is the ion saturation current density J_{sat}=$I_{sat}/A_{orifice}$ (where I_{sat} is the ion current measured by the slit plate and $A_{orifice}$ is the collecting area, which

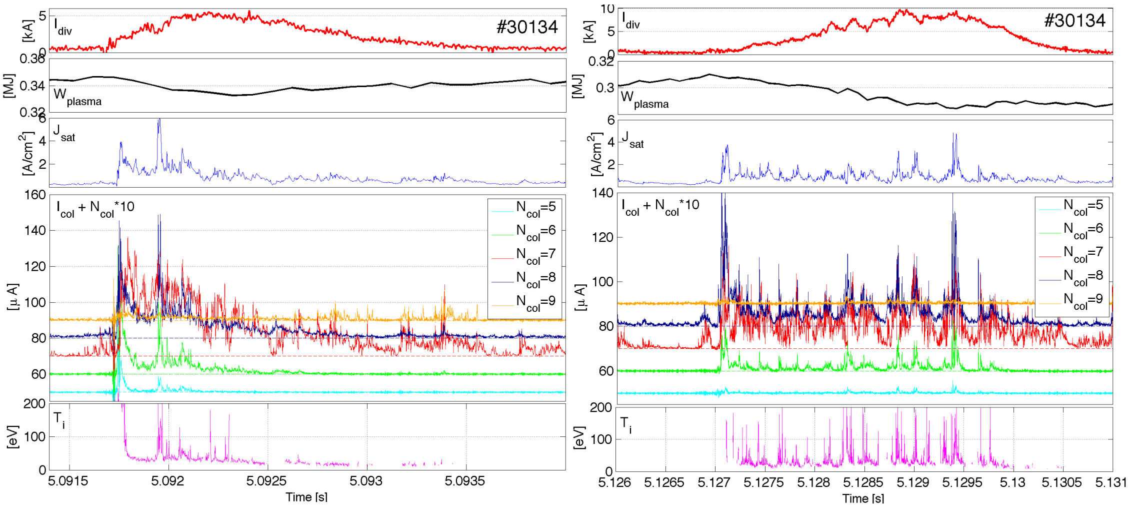

Figure 3: Comparison of signals during small (left) and Type I (right) ELM.

is assumed to be equal to the orifice in the probe graphite housing) as well as currents measured by the collectors $N_{col} = 5$, 6, 7, 8 and 9 (with the centre of the collector at Δ_x=1.3, 2.6, 3.8, 5.1 and 6.3 mm) which receive measurable currents.

The slit and collector currents measured during ELMs show a typical filamentary structure, which was observed in many other experiments. We have estimated T_i from currents to collectors 6 and 7, as

$$T_i = \frac{m_i E L}{2eB_{loc}} \left(\frac{1}{\Delta_x^2(7)} - \frac{1}{\Delta_x^2(6)} \right) / log \left(\frac{I_{col}(6)}{I_{col}(7)} \right) \tag{2}$$

The ion temperature was estimated from the portions of the measured time trace characterized by J_{sat}>0.7 A/cm^2. The ion temperature estimated from Eq. 2 was reduced by a factor 3 due to finite ion gyro-radius effect [2], obtained form Monte Carlo simulations of the ExB analyzer (details will be included in a future paper). The resulting T_i is plotted in Fig. 2. Large filaments of J_{sat} are correlated with bursts of T_i, with T_i up to 200 eV. During the Type I ELM, which lasts a factor 2 longer compared with small ELMs, T_i and J_{sat} in filaments remains constant throughout the ELM, at least for the Type I ELM captured in the present experiment. Similar J_{sat} and T_i in both, small and Type I ELMs suggests that filaments in both ELM types are characterized by a similar radial propagation speed v_r, consistent with observations in [6].

Modeling of filaments

A fluid model of the parallel ELM filament transport in the SOL [5] is used to estimate T_i in the filaments and compare with the probe measurements from Fig.2. Once the initial filament temperatures and density are specified in the model, their time evolution due to parallel transport to the nearest surface can be calculated. Current understanding of the ELM cycle is insufficient to provide theory-based estimates for the position at which any given ELM filament is ejected into the SOL.

We proceed under the assumption that ELM filaments detach at the separatrix with the ion and electron temperatures and electron density equal to the half of the pedestal top values. In the model, temporal and radial evolution of the ELM filament parameters are coupled through v_r. We assume radially constant v_r = 1000 m s^{-1}, corresponding to the most probable v_r in the far SOL of AUG [6] measured for a broad range of the main plasma parameters, albeit for Type I ELMs. However, observations from MAST indicate that v_r in Type I and Type III ELMs is similar [4]. To test the sensitivity of the predicted T_i on v_r, the simulations are reproduced also for v_r=500 m/s and 1500 m s^{-1}. The radial profiles of T_i obtained from the simulations are shown in Fig. 4. At the probe position T_i is in the range of 72-129eV which compares favourably with T_i measured in largest filaments.

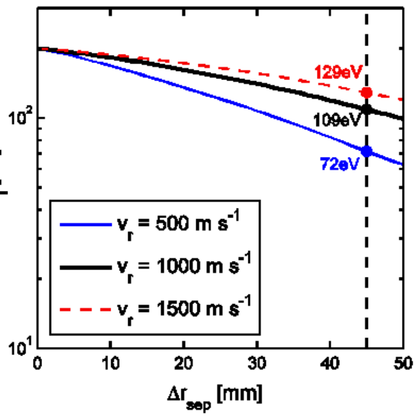

Figure 4: Radial evolution of the ELM filament T_i obtained from the parallel loss model. The filament is launched from the separatrix with radially constant v_r. Vertical dashed line indicates the position of the E×B analyser sensors.

Acknowledgements

We thank M. Dunne, A. Kirk, E. Wolfrum for useful discussions. This work was partly supported by MSMT Project #LM2011021 and by EFDA Fellowship programme.

References

[1] M. Kocan et al, J. Nucl. Mat. **415**, S1133-S1138 (2011)

[2] G. Matthews et al., J. Phys. D: Appl. Phys. **17**, 2243 (1984)

[3] P. Staib, J. Nucl. Mat. **93-94**, 351-356 (1980)

[4] A. Kirk et al., Plasma Phys. Control. Fusion **53**, 095008 (2011)

[5] W. Fundamenski et al Plasma Phys. Control. Fusion **48**, 109 (2006)

[6] A. Kirk et al. Plasma Phys. Control. Fusion **53**, 035003 (2011)