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Measurement of Electron Temperature and Density of Intermittent Plasma Objects by Thomson Scattering in ASDEX Upgrade

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1. Introduction

Turbulent transport into and across the scrape-off layer [1] has been observed years ago with fast cameras, e.g. in the ASDEX tokamak [2] or in other experiments [3]. Fast events at the plasma edge may play an important role for the radial transport [4]. The increased computer power makes it possible to use more complex transport codes, but it is necessary to obtain reasonable data of measured electron temperature T_e and density n_e of fast events. Gas puff imaging yields information about the size, velocity and the product of $T_e{}^{\alpha} n_e{}^{\beta}$ [5] of fast moving plasma blobs. Langmuir probes determine separately T_e and n_e, but only in regions far away of the separatrix to prevent perturbation of the plasma [6]. The Thomson scattering diagnostic allows to measure T_e and n_e at the same location and time without any mapping ambiguity. Using the improved vertical Thomson scattering (VTS) system [7] at ASDEX Upgrade, measurements of fast events can be performed with a variable time delay between the lasers, with a minimum time delay of 100 ns.

In this paper we present the improved VTS system, especially the new data acquisition system, and present examples of measuring T_e and n_e of fast events both inside and outside the separatrix.

2. The vertical Thomson scattering system VTS

The location of the scattering volumes for edge measurements are shown in figure 1 together with the equilibrium flux surfaces of shot #15859, from which measurement results of fast events are shown in this paper. The spatial channels j=1..8 measure in the edge layer in front of the antenna guard limiter, but the line of sight of channel j=1 is vignetted from parts of the port, channel j=9 is very close to the limiter shadow, and the channels j=10..16 fall into the limiter shadow. Hence, in practice only the channels j=2..8 are used. The right part of figure 1 shows the scattering volumes of the spatial channel j=2, demonstrating the high radial resolution of 2.7 mm between the lasers L1..6. Normally, the 6 lasers run equally spaced in time and measurements are performed every 8.3 ms (6 x 20 Hz). However, for the detection of fast events it is more appropriate using laser bursts with all six lasers close together (repetition rate of 20 Hz). After improvements, the existing data acquisition system (LeCroy, CAMAC) allows a minimum time delay between subsequent lasers of 10 microseconds, but with the new data acquisition system (Acqiris, Digitizer) a minimum time delay of 100 ns is possible. The VTS system uses for each spatial channel four spectral channels with avalanche diodes as light detectors. The transmission of the detectors of the spatial channel j=2 as function of the wavelength λ of the light is shown in figure 2 (right part, top). This function is obtained using as light source an optical parametric oscillator (OPO) - Nd:YAG laser system with tunable wavelength. The spectral filter characteristic is designed for measuring both low and high temperatures. The expected signals as function of T_e are shown in figure 2 (right part, bottom). For temperatures below 30 eV signals are expected in the spectral filters k=1 and 2, for higher temperatures the filters k=3 and 4 should obtain also signals. T_e and n_e are determined directly from the scattering signal using a maximum likelihood method without calculating ratios between the signals [8].

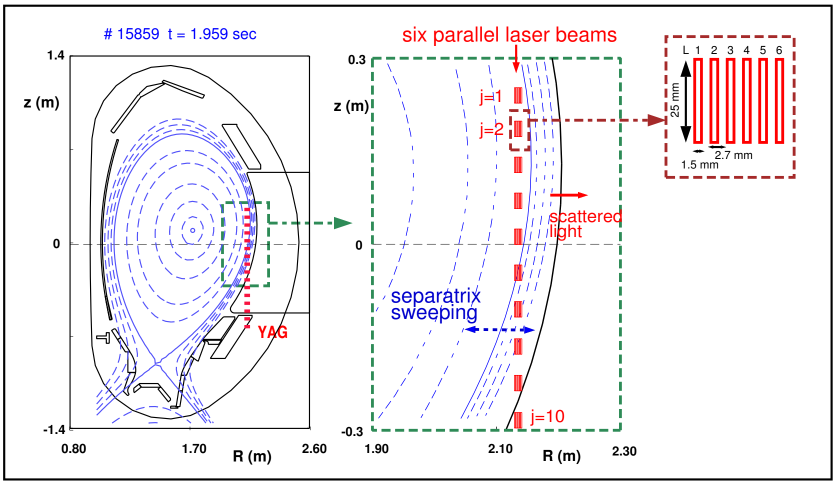

Figure 1: Poloidal cross section of ASDEX Upgrade (left part) together with equilibrium flux surfaces of shot #15859. The location of the scattering volumes of the VTS system are shown in more detail in the middle and right part.

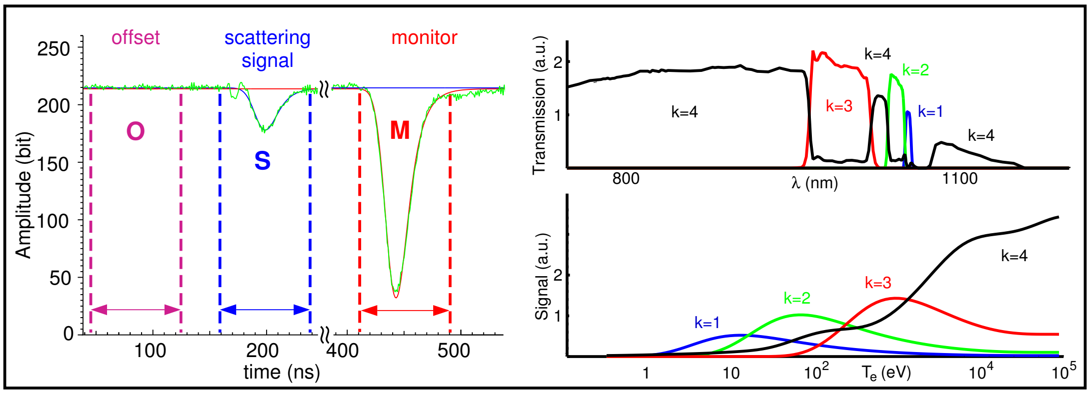

Figure 2: Scattering and monitor signal of a spectral channel k=4 and corresponding pulse fitting of the new data acquisition system (left part). Transmission of the spectral channels (right part, top) of spatial channel j=2 and expected signals as function of T_e (right part, bottom).

The new data acquisition system consists of Acqiris Digitizers [9] with 64 channels (16 spatial channels x 4 spectral channels) which record the signal shapes like an oscilloscope with 8 bit resolution and variable measuring range (100 mV- 5 V) and store the data on-line into the memory of a workstation. Figure 2 (left part) shows the scattering signal S and the monitor signal M which corresponds to the laser energy and the sensitivity of the detectors. The signal shapes are fitted to a reference pulse obtained from the convolution of a laser pulse and the transfer function of the detector; the values for signal and monitor are determined from the fitted slopes. The time delay between monitor and signal is fixed and well known. For this reason a lock-in technique can be used. The existing CAMAC system integrates the scattering signals while a gate pulse is applied to obtain the signal S and the offset O and uses the difference S-O as a measure of the scattering signal. In the existing system 5 consecutive time points of a single laser are used to determine the variance of the signal. With the new system the variance of the signal can be determined from the signal slopes and the background for every time point separately. The new system clearly improves the signal-to-noise ratio of T_e and n_e. Furthermore, the new system is suitable to perform measurements of single events or fast events.

3. Detection of fast events

The new VTS system allows to perform snap shots of fast events using the burst mode. For the following measurements the burst mode with a time delay of 500 ns between subsequent lasers is used. The radial spacing between two lasers of 2.7 mm yields a maximum radial velocity of 5400 m/s to obtain a correlation between two adjacent scattering volumes for a small moving plasma blob (radial size smaller than 2 mm). Larger blobs could have higher radial velocities and we would still obtain correlations. The temperature and density values are averaged over 25 mm height of the scattering volumes. The vertical spacing between two spatial channels is about 60 mm and there is a gap of 35 mm not covered by the optics (figure 1). Hence a plasma structure should have a vertical size of at least 35 mm to obtain a correlation between adjacent spatial channels j.

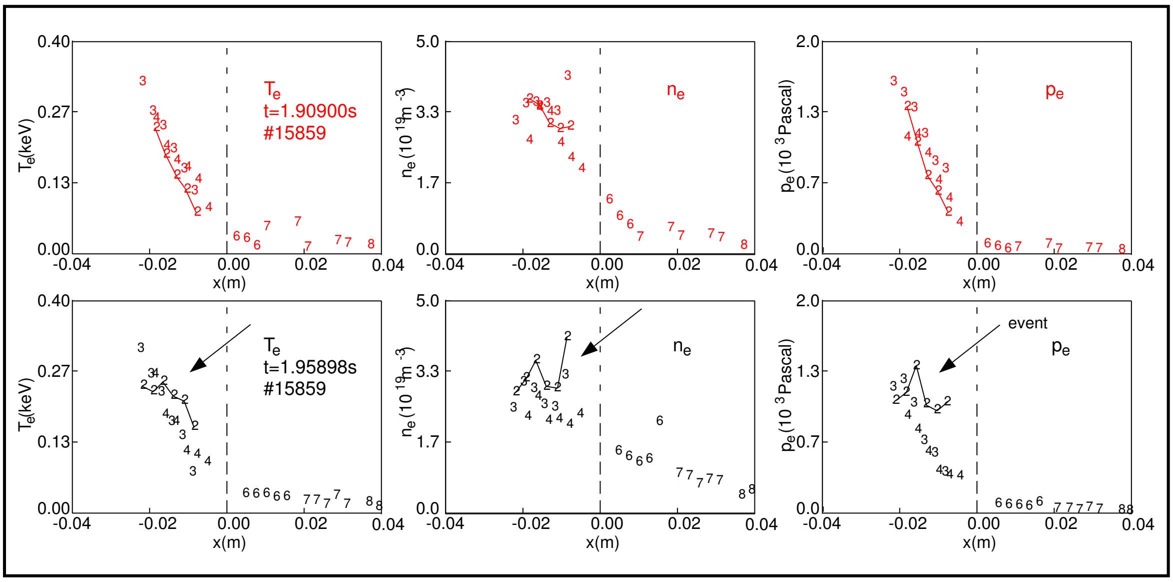

Figure 3: Detection of an event inside the separatrix: 50 ms before (top part) and during (bottom part) an event, profiles as function of distance $x = R - R_{sep}$ from the nominal separatrix position $x = 0$ (determined by equilibrium reconstruction from magnetic measurements). The numbers correspond to the spatial channels j, top part 1 ms after local maximum in D_α, bottom part during an ELM.

In figure 3 the spatial channels j=1..5 are close to the separatrix position $x = 0$ and the spatial channels j=6..8 are outside the separatrix. In the top part of figure 3 the spatial channels j=2..4 have a steep gradient in temperature T_e and pressure p_e. To mark channel j=2 the measurement results of the lasers are connected by a line. The next laser burst 50 ms later measures also a steep gradient in the spatial channels j=3,4. The channel j=2 shows a totally different behaviour compared to the other channels. Five lasers measure nearly the same temperature and pressure. This event could be small blob moving with a high velocity up to 10^4 m/s or a larger structure not or slowly moving. This question can be resolved by a correlation to other diagnostics or between several laser bursts close together (e.g. 3 bursts of 2 pairs of lasers).

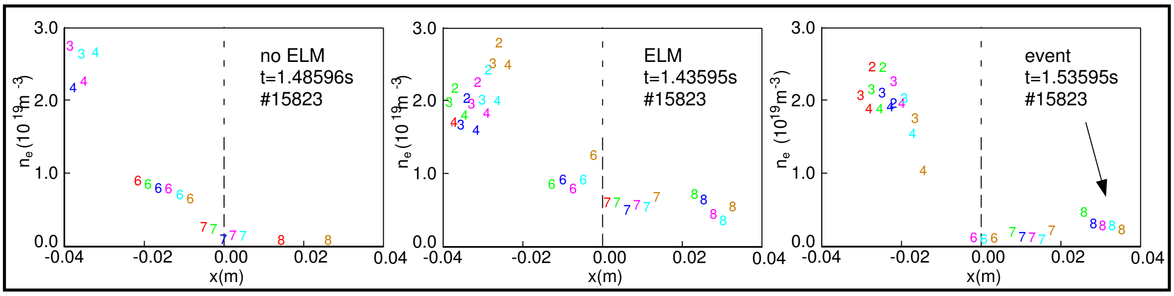

Figure 4: Detection of an event in the scrape-off layer of spatial channel j=8, 2 ms after local maximum in D_α, profiles as function of distance $x = R - R_{sep}$ from the nominal separatrix position $x = 0$. The numbers correspond to the spatial channels j, the colours to the lasers. The time evolution shown of the density profile around the time 1.43595s inside the separatrix is due to the relaxation of the plasma during an ELM.

Figure 4 shows the possibility to detect events in the scrape-off layer (SOL). The left part shows a measurement without an event and low density in the SOL. 50 ms later, shown in the middle part of figure 4, the SOL has a higher density during an ELM. Another 50 ms later, shown in the right part, the next laser burst measures in the SOL a low density in the spatial channels j=6,7, but detects a density rise in spatial channel j=8. This clearly shows the possibility to measure a localized event in the SOL.

4. Conclusion

The new Thomson scattering diagnostic at ASDEX Upgrade allows to measure the electron temperature and density of fast events, e.g. possible fast moving intermittent plasma blobs. Measurements inside the steep gradient zone close to the separatrix and in the scrape-off layer outside the separatrix can be performed. It is still unresolved which kind of structure we detect, e.g. fast or slow moving blobs or other structures. Correlations to other diagnostics or to other laser bursts have to be performed.

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