Improved Edge Density Profile Measurements by the Li-Beam Diagnostic on ASDEX Upgrade

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Introduction

The edge density profile of a tokamak plasma shows a strong influence on the core plasma performance and is a key element for the particle and energy exhaust. Also a significant fraction of the scatter in confinement databases is thought to be caused by differences in the plasma edge and pedestal. Therefore the knowledge of edge density profiles with high accuracy from the scrape off layer (SOL) up to the pedestal top is necessary with high spatial resolution. For ELM resolved measurements or studies of L-H transitions a high time resolution is additionally required.

At ASDEX Upgrade the lithium impact excitation spectroscopy (LIXS) is successfully used for edge density measurements [1]. Also the Thomson scattering system delivers reliable edge density profiles. But due to the scatter of the data and the requirement of radial scans to reach a high spatial resolution this measurement is restricted to stationary phases. Because of the low intensity of the scattered light the Thomson measurement is not suitable in the SOL for $R > R_{sep} + 1\,\mathrm{cm}$. Therefore the Li-beam is necessary to determine edge density profiles during dynamic processes and in the SOL. Actual investigations like the influence of the pedestal on the gobal confinement, the comparison to edge density profiles of the Thomson scattering system require an improvement of the edge density measurement by the Li-beam. Therefore the acceleration voltage of the beam was enhanced from 35 kV to 60 kV (finally up to 100 kV) and the data evaluation software has been improved. The improvements of the edge density measurements and first results obtained with the improved Li-beam system will be presented in the following.

Experimental Setup and Density Profile Determination

The injector setup is based on the one developed by McCormick [2,3]. The injector source is a heated lithium aluminosilicate β-eucryptite. The Li-ions are extracted by applying an electric field (U_{ex}). After acceleration they are neutralized in a sodium gas chamber by charge exchange. The extracted current is limited by U_{ex}. The neutral lithium beam (diameter 10 mm) enters the plasma horizontally 33 cm above the torus midplane. The lithium atoms are excited and ionized by collisions with electrons. The line radiation 2p$\rightarrow$2s is detected by a 35 channel optics viewing from the top. The distance between two lines of sight (LOS) is 5 mm, the diameter of a LOS at the observation plane about 5 mm. Behind a bandpass filter the emitted light is detected by photomultipliers with a sampling rate of 5 kHz. Since the LOS are not perpendicular to the Li-beam the line emission is shifted to slightly shorter wavelengths. The Li-beam is chopped to determine the background radiation during the discharge. The detected emission profiles are averaged over typically 20 ms and fitted by a spline. The electron density profile is derived from the relative emission profile without absolute calibration of the diagnostic [4]. For the determination of the electron density profile the rate equations have to be solved. Therefore the LIXS is not a local measurement. The line radiation at a given radial position x depends on the whole (de)excitation and ionization history from the plasma edge to x. The density profile determination is stopped at the maximum of the emission profile, since the errors for the density are strongly increasing behind this point.

The density profile measurements of the Li-beam are compared to the edge measurements of the Thomson scattering system. To obtain reliable and spatially high resolved edge density profiles the plasma is swept radially in a stationary phase. The duration of the radial scan is typically about 0.5 s, the radial shift 40 mm. Six parallel, vertical laser beams are used to measure the density profile with a repetition rate of 20 Hz each. After mapping the data on a radial position relative to the separatrix the mean density profile is extracted using a box car Bayesian average [5] with 2 mm radial width or a median filter yielding a smooth density profile (see figure 1).

Comparison of Density Profiles determined by the Thomson Scattering and the Li-Beam Diagnostic

Detailed edge profile studies with the Thomson scattering system have been performed at ASDEX Upgrade. In H-mode discharges the edge density profiles determined from the Thomson scattering system by means of a radial sweep have very steep gradients at the separatrix. An example is shown in figure 1 for a discharge with $I_P = 1\,\mathrm{MA}$, $B_t = -2.5\,\mathrm{T}$, $\delta = 0.3$ and $\bar{n}_e = 9 \times 10^{19}\,\mathrm{m}^{-3}$. The light blue points are the Thomson data taken during a radial scan and mapped relative to the separatrix. The green points are the smoothed result using the Bayesian filter. Smoothing with a simple median filter (17 data points broad) shows a good agreement with the Bayesian filter. The yellow points in figure 1 are the density profiles of the Li-beam diagnostic determined by the present standard data analysis software during the same period. The acceleration voltage (U_{ac}) is 35 kV. This profile is significantly flatter than the profile measured by the Thomson scattering system. While the Thomson measurement delivers a density gradient ($\Delta n_e/\Delta R$) of $-3.6 \times 10^{21}\,\mathrm{m}^{-4}$ (Bayes) and $-4.5 \times 10^{21}\,\mathrm{m}^{-4}$ (median), the gradient of the Li-beam measurement yields $-2 \times 10^{21}\,\mathrm{m}^{-4}$. There are two reasons why the steep density gradients could not be reconstructed from the emission profile measurement. The average of the emission profiles contains ELM periods. This was a major problem when the walls of ASDEX Upgrade were conditioned by siliconization, as the emission profile of the Li-beam was strongly influenced by a silicon line during the ELM period. The inclusion of ELM periods in the averaged emission profile can increase the determined density in the SOL and decrease it inside the separatrix as shown in figure 2. Additionally the ELM phases increase the scatter of the measurement significantly. A further improvement is obtained by a new fitting routine for the emission profile. The cubic spline fit is replaced by an exponential spline fit and the smoothing in the increasing part of the emission profile has been reduced. Small structures in the emission profile can be decisive for the density profile reconstruction. In figure 3 the measured emission profile (black) and the fit using the exponential spline (red curve) are shown. The statistical errors of the measurement are very small since ELM phases are removed. The steep gradient zone close to the separatrix is related to the last increase of the emission profile gradient. In the SOL the electron density profile becomes flat.

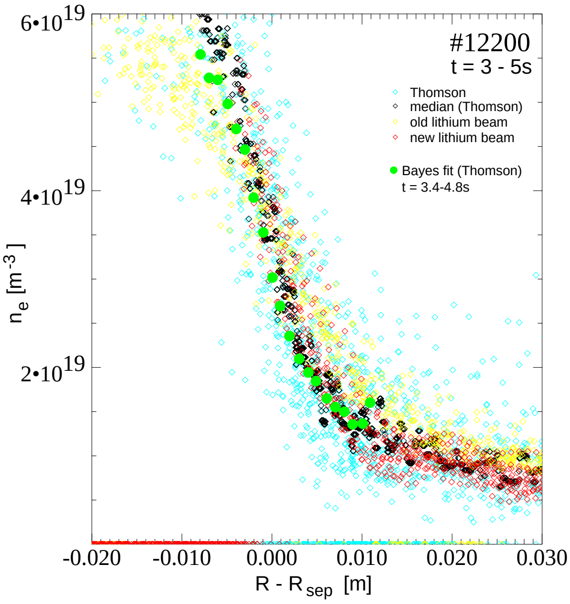

Figure 1: *Comparison of edge density profile measurements in a H-mode discharge using the Thomson scattering system and the Li-beam. For the Li-beam steeper profiles are obtained with the new data analysis software.*

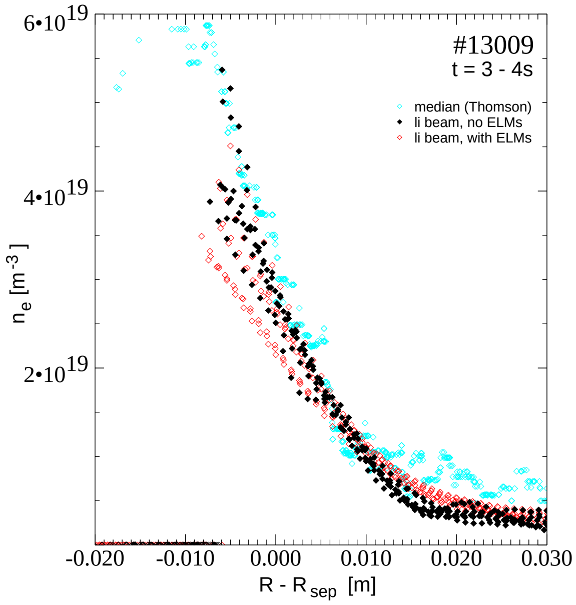

Figure 2: *Density profiles determined by the Li-beam profile. The emission profiles are averaged over* 20 *ms. For the black profiles ELM phases are excluded for averaging which leads to steeper profiles. For comparison the Thomson density profile is shown.*

Close to the flux surface which touches a limiter the density drops again. The present standard data analysis procedure tends to smooth the emission profile (figure 4) which causes the lower density gradient compared to the Thomson edge profiles.

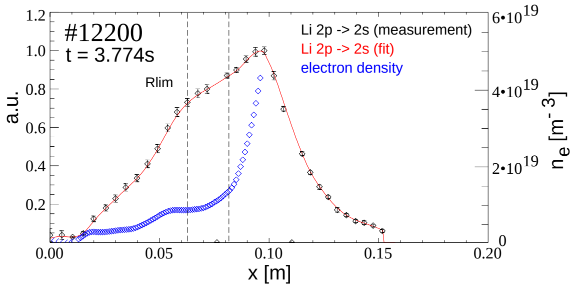

Figure 3: *Measured (black) and fitted (red) emission profile plotted over the Li beam coordinate. Blue, electron density profile determined from the fitted emission profile. The data evaluation is made with the new software. Rlim indicates the position of the first flux surface touching a limiter.*

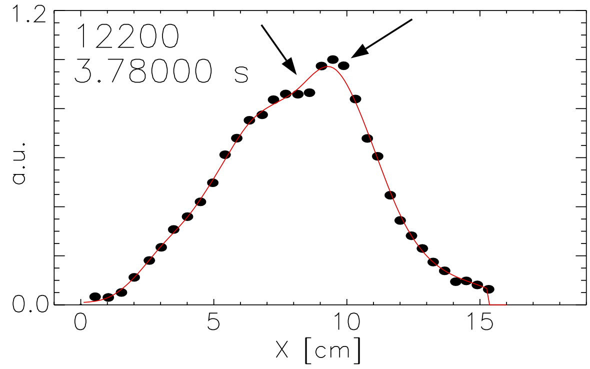

Figure 4: *Measured (black) and fitted (red) emission profile plotted over the Li beam coordinate. The results are determined by the old evaluation software.*

In figure 1 the red curves are the density profiles determined with the new data analysis software. The ELMs are removed in the averaged emission profiles and the fit of the emission profile is closer to the measured data. This leads to a good agreement of the density profiles determined by the Thomson scattering system and the Li-beam. The density gradient is $-4.0 \times 10^{21}\,\mathrm{m}^{-4}$ which is in between the result of the Bayesian and the median smoothed density of the Thomson scattering. The density profiles determined by the Li-beam diagnostic are shifted 1 cm towards the plasma centre. This shift of the Li-beam profiles turns out to be systematic. Since the separatrix position determined by the equilibrium reconstruction and the position calculated from Thomson measurements using an analytic edge model show good agreement [6, 7] this shift seems to indicate a slight misalignment of the Li-beam observation system.

Problems arise when the emission profile itself becomes very steep. In those cases the quality of the density profile evaluation is limited by the spatial resolution of the fibre optics. The results are then typically between the density profiles given by the present standard software and the ones measured by the Thomson scattering system. The limit is typically reached at high I_P and triangularity.

Enhanced Beam Voltage

U_{ac}, which is proportional to U_{ex}, has been enhanced from 35 kV to 60 kV. This causes an increment of the lithium ion current from $1.2 - 1.5$ mA to $2.4 - 3.5$ mA. The increased energy of the lithium atoms shifts the emission maximum about 1 cm towards the pedestal top (see figure 5) and the emission profile becomes broader due to the higher velocity of the excited atoms. The emission profiles are measured during an H-mode discharge with a line averaged density of $5.6 \times 10^{19}\,\mathrm{m}^{-3}$. The filters were optimized for the Doppler shift at 35 kV.

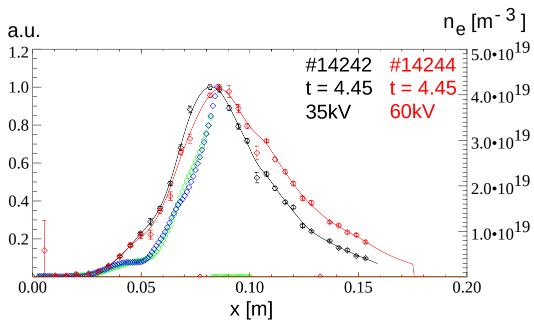

Figure 5: *Emission profiles for $U_{ac} = 35\,kV$ (black) and $U_{ac} = 60\,kV$ (red) in identical discharges. The according density profiles are green ($U_{ac} = 35\,kV$) and blue ($U_{ac} = 60\,kV$).*

Conclusion

The new data analysis software for the edge density profile measurements with the Li-beam allows to reconstruct very steep density profiles from the emission profile in agreement with the Thomson measurements. The removal of ELM activity in the averaged emission profiles reduces the scattering significantly. Together with the higher emission in the case of higher U_{ac} this allows to determine the density profiles with higher time resolution or better spatial resolution. The enhanced U_{ac} also increases the penetration depth of the Li-beam, so that the range of the density profile can be extended about 1 cm towards the pedestal top. For the future ELM coherent averaging of the emission profiles is planned which will enable ELM resolved edge density measurements. The possibility to reach a higher spatial resolution of the Li-beam measurement will be examined.

References

[1] S. Fiedler, IPP Report III/209 (1995), [2] K. McCormick, M. Kick, IPP Report III/82 (1983), [3] K. McCormick, et al., Fusion Engineering and Design, **34-35** (1997), p. 125, [4] J. Schweinzer et al., Plasma Phys. Controlled Fusion **34** (1992), p. 1173, [5] V. Dose et al., Maximum Entropy and Bayesian Methods, Kluwer Academic Publishers (1999), p. 47, [6] J. Neuhauser et al., ECA Vol. 23J (1999), p. 1521, [7] A. Kallenbach et al., these proceedings