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DETERMINATION OF THE RADIAL ELECTRIC FIELD FROM PASSIVE HE II EMISSION

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1. Introduction

During high confinement or H-mode operation, edge turbulence is strongly suppressed in the edge region just inside the last closed flux surface (separatrix), which is known as edge transport barrier (ETB). The shear in the radial electric field in the pedestal region is considered as important component to reduce the instability drive and thus the turbulence level. A new method to determine the radial electric field at the plasma edge has been developed which is based on passive spectroscopy of the He II line at 468.57 nm. As this method relies only on passive radiation, no active components are necessary as in other diagnostic methods, e.g. heating beams for CX measurements [1] or microwaves for Doppler reflectometry [2]. The line integrated spectrally and temporally resolved data are modelled and the radial electric field is calculated by means of an integrated data analysis (IDA) approach applying Bayesian probability theory.

2. Experimental setup

At ASDEX Upgrade the optical head of the Lithium-beam diagnostic is used with 18 lines of sight (LOS) probing the plasma virtually poloidally. For a detailed description of the experimental setup see e.g. [3], [4]. The light is guided via fibre optics from the torus hall to two Czerny Turner spectrometers equipped with fast frame transfer CCD cameras. The spectra are recorded with a repetition time of 4 ms. Figure 1a shows for one LOS the temporal development of the central wavelength of the He II (4-3) transition at 468.57 nm while the plasma develops from L-mode ($t < 3.7$ s) via a few dithering cycles ($t=3.7$-4.0 s) into H-mode ($t > 4.0$s). The obvious correlation of the central wavelength with plasma state is related to a mainly poloidal velocity increase of the He^+ impurity ions. In figure 1b again the central wavelength is shown, but this time for a plasma which is swept radially by 2.5 cm (see included trace for the separatrix position). The radial dependence of the wavelength shift is well resolved, when the plasma is moved across the LOS, which first probes the SOL and then the falling branch inside the separatrix. Indicated in the plot is the position of the maximum poloidal velocity, which corresponds to the minimum in the E_r well. Already from this signal directly the maximal distance of the E_r minimum from the separatrix can be estimated to be < 1 cm.

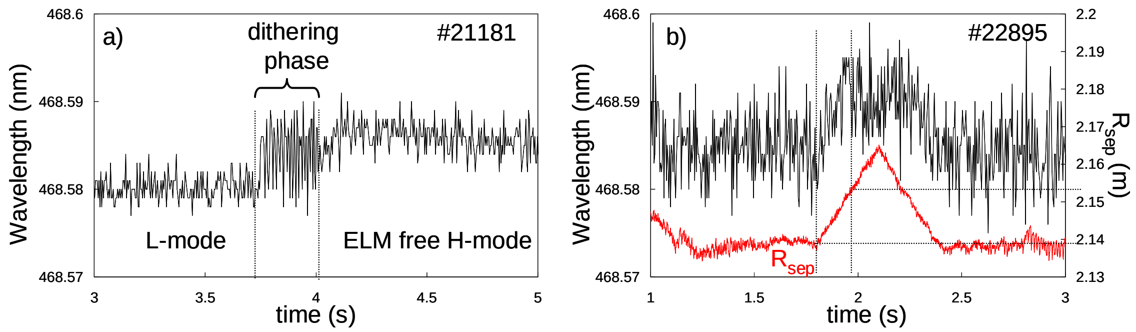

Figure 1: Central wavelength of the He II (4-3) transition of one LOS for a) an L to H-mode transition and b) for an ELMy H-mode during a radial shift of the plasma. The separatrix position is indicated in red (right axis).

3. Modeling and integrated data analysis

In order to extract information about the radial electric field from these data, an accurate assessment of the relevant atomic processes leading to the occupation of the He^+ (n=4) state was carried out. Charge exchange processes and recombination were found to be negligible. The major mechanism to populate the He^+ (n=4) state is given by electron impact excitation. Photon emission coefficients (PEC) were calculated with the ADAS (atomic data analysis structure) [5] program package. With the midplane profiles of He^+ density (n_{He+}), electron density (n_e) and electron temperature (T_e) as input a radial emission profile of the He II line can be computed.

The relevant forces which act on the emitting particles are the E x B force due to the radial electric field and the diamagnetic force due to the pressure gradient. The corresponding velocities, i.e. v_{ExB} and v_{dia}, as well as the toroidal velocity, v_{tor}, are taken into account for the calculation of the spectrally resolved He II profile. The modelled spectra are composed of 100 single spectra along each LOS, which are subsequently summed up to yield line integrated He II spectra. In the framework of Bayesian probability theory the posterior probability distribution function (pdf) is proportional to the likelihood pdf, describing the misfit between the modelled and measured data, and the prior pdfs, describing all additional information [6]. Several input parameters are unknown and need to be quantified simultaneously by prior distributions: i) the E_r profile, which will be the main result of the fit, was parameterized with a cubic spline polynomial. ii) in order to determine the diamagnetic velocity the pressure profile of He^+, i.e. the He^+ density profile and the He^+ temperature profile, need to be determined, as they are also not directly measured. Because the n_{He+} profile is directly related to the radial emission profile, a comparison to the measured intensities of all LOS determines its values inside the separatrix. In the SOL, where n_e and T_e are so small that even unphysically large n_{He+} value lead to a vanishing He II emission profile, restrictions are chosen using the results of the 1D transport code STRAHL. T_{He+} is linearly parameterized. iii) v_{tor} is measured via core CXRS up to ρ_{pol} =0.95 and is extrapolated to zero in the SOL. Estimates of the profiles of E_r, T_{He+} and n_{He+} and the corresponding errors are obtained by the maximum and width of the posterior pdf, respectively.

Figure 2 shows the flow diagram of the method, clearly distinguishing the known and unknown parameters which are part of the modelling. One of the major advantages of this method is the consistent calculation of uncertainties as all error sources and uncertainties in the measurements are part of the inputs to the calculations.

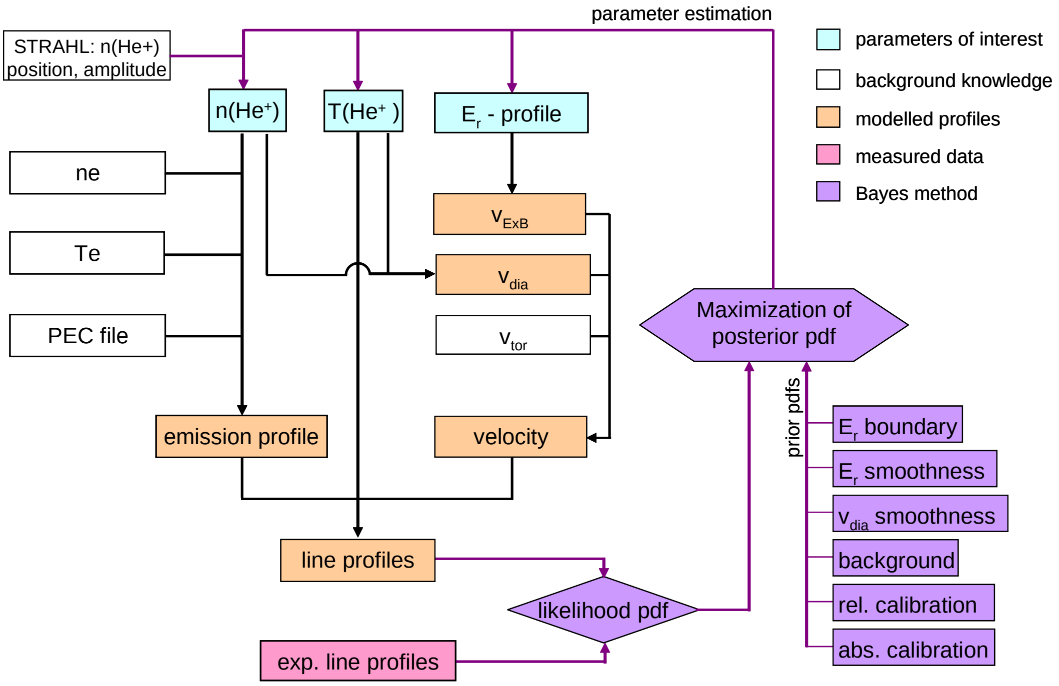

Figure 2: Flow diagram of the evaluation algorithm. Unknown profiles of n(He^+), T(He^+) and E_r are represented by parameters (e.g. splines), the parameters of which are adjusted until the calculated line profiles match the experimental line profiles.

4. Sensitivity analysis

Extensive sensitivity studies were carried out regarding the influence of the wavelength calibration, the choice of spline interpolations, the restrictions on the He^+ density profile, the diamagnetic velocity, the uncertainty in the toroidal velocity as well as the E_r boundary conditions. As an example figure 3a shows the resulting E_r profile of discharge #21181, t=5.s, for various choices of boundary conditions for the radial electric field, and figure 3b depicts the changes due to the uncertainty in the toroidal velocity. While the choice of E_r boundary conditions does not change the calculated value of the E_r well in the pedestal region, strong changes in the assumed toroidal velocity have a significant effect on the absolute values of E_r.

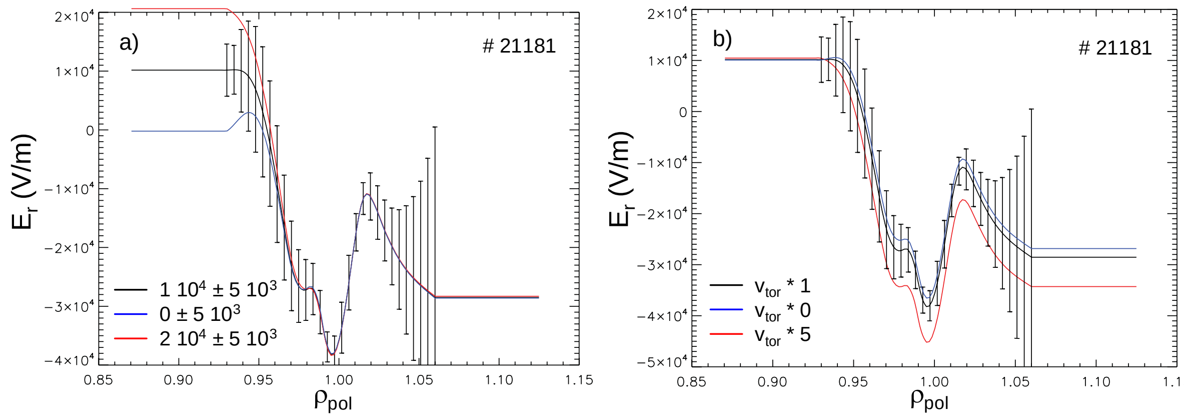

Figure 3: Effect of a) E_r boundary conditions at ρ_{pol} = 0.9 and b) variation in the toroidal velocity on the resulting E_r.

5. Results in L-mode and weak H-mode

Of enhanced interest is the change in E_r for the transition from L-mode into H-mode. For this purpose a discharge has been developed with a slow L-H transition with an extended dithering phase before the final jump into H-mode (see also figure 1). The corresponding E_r profiles are shown in figure 4. A considerable difference can be seen just inside the separatrix position, i.e. for $0.98 < \rho_{pol} < 1$. The depth of the well increases by a factor of 1.5 and the gradient on the low field side steepens. The error bars show that high accuracy can be achieved in the region with sufficient He II emission, namely at $0.95 < \rho_{pol} < 1.02$.

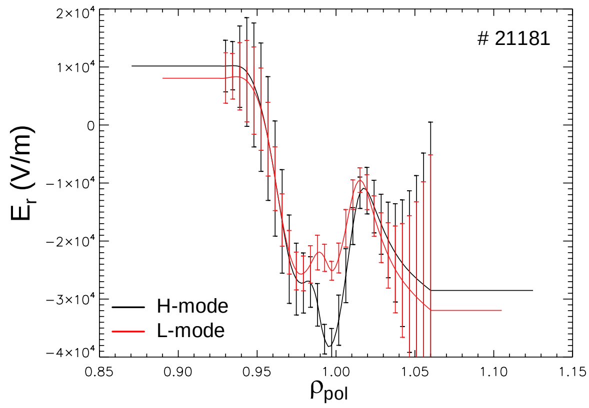

Figure 4: E_r profiles of L-mode (red) and H-mode (black).

Future work will include a detailed analysis of the respective $n_{e,i}$ and $T_{e,i}$ profiles in order to decide whether the E_r profiles are determined by neoclassical physics only or whether anomalous effects play a role for the depth and position of the radial electric field in the ETB region of H-mode discharges.

References:

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