Direct determination of background neutral density profiles from neutral particle analyzers

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Introduction

Good knowledge of the background neutral density, n_0, is important to understand the plasma transport because n_0 is responsible for charge-exchange losses and for plasma fuelling. Here we present a method to determine n_0 profiles directly from measured fluxes of thermal passive neutrals towards the walls and then detected by neutral particle analyzers. Results of the presented method are compared with n_0 profiles derived from modelling tool KN1D.

Neutral flux escaping plasma

Neutral particle analyzers (NPAs) measure energy spectra of the flux Γ of neutral hydrogen and deuterium atoms escaping the plasma with energies ranging from hundreds of eV up to hundreds of keV [1]. These neutrals are formed by charge-exchange (CX) collisions between background neutrals and plasma ions (thermal Γ_{th} or fast Γ_{fi} ions). The formed neutral flux is attenuated by re-ionizing collisions with plasma particles.

Γ can be expressed as a line integration of neutral emissivity function along NPA view-line, Eq. (1).

$$\Gamma(E_n) = A\int_0^L <\sigma v>_{CX}\, n_0 n_i(E_n, pitch, l)\left(\int_0^l \frac{1}{\lambda_{att}}dx\right)dl = emissivity(E_n, pitch, l)dl \quad (1)$$

where E_n is the measured energy, A is a geometrical factor including NPA surface and opening angle, L is the length of the NPA view-line, $<\sigma v>_{CX}$ is the CX collision rate, $n_i(E_n, pitch, l)$ is the density of ions with NPA velocity vectors directed towards the NPA, λ_{att} describes the re-ionization rate of the formed neutral flux and l is NPA view-line.

As shown in Eq. (1), Γ can be expressed as the line integral of the emissivity function. The emissivity profiles are energy-dependent and their maximum moves towards the plasma core for higher energies as illustrated in Fig. 1. This energy-dependence allows us to extract radial information about n_0.

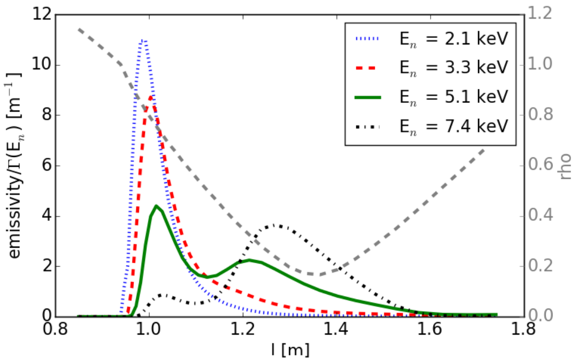

Figure 1: *Neutral emissivity of passive signal for different energies E_n in thermal range of Γ normed by $\Gamma(E_n)$. The emissivities of higher energies are located deeper in the plasma than lower ones. NPA is located at position l = 0 m.*

The parameter $n_i(E_n, pitch, l)$ in Eq. (1) for Γ_{th} depends on the local ion temperature T_i, where the CX collisions occur. Since detailed information on T_i profiles has become available in recent years due to the further development of CXRS, a direct investigation of n_0 from measured Γ_{th} has become possible. Here, we use a least square fit to minimize the difference between our model function [Eq. (1)] and measured Γ_{th}, by varying the n_0 function parameters.

Results

The presented method was developed and benchmarked with ASDEX-Upgrade (AUG) data. AUG is equipped with two NPAs with different view-lines and each of them can be set to measure different energies, either thermal Γ_{th} or fast ions Γ_{fi} [2]. Here we show results for a time point before and after an ELM in discharge #32065. The discharge can be characterized a toroidal field of -2.5 T, a plasma current of 600 kA, core temperatures in the range of 2 keV and a central density of $4 \times 10^{19}\,\mathrm{m}^{-3}$. One NPA is used to determine n_0 from Γ_{th} and a second one to investigate Γ_{fi}. Fig. 2 compares fitted n_0 profiles with results of KN1D simulation [3]. KN1D is a 1D kinetic neutral transport algorithm using the edge pressure measured by a pressure gauge as input. The points in Fig. 2 are derived directly from the measured Γ_{th} with the assumption of a locally constant n_0. The rho error bars give us an estimation about susceptible radial area of the fitted n_0.

The fitted n_0 profiles are used as inputs for the FIDASIM code [4], which is a Monte Carlo code simulating thermal Γ_{th} and super-thermal Γ_{fi} separately. Simulated and measured Γ_{th} and Γ_{fi} are compared in Fig. 3 and 4 respectively. Fig. 5 shows the TRANSP [5] fast ion density profiles n_{fi} before and after the ELM which are the inputs for Γ_{fi} FIDASIM simulations along the NPA view-line. The difference of n_{fi} and FIDASIM emissivities of Γ_{fi} are also shown in Fig. 5.

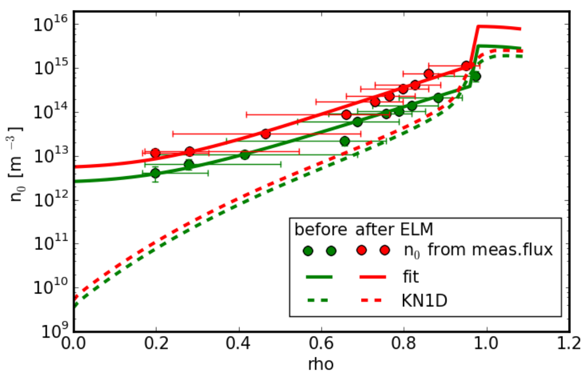

Figure 2: *Background neutral density profiles before (green) and after (red) ELM crash derived from NPA data (solid lines and points) and predicted by KN1D (dashed lines) simulations.*

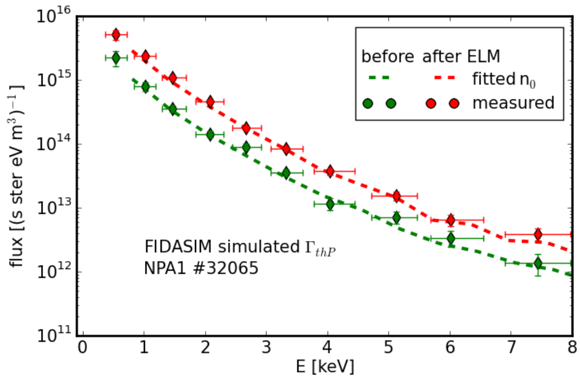

Figure 3: *Measured thermal part of passive neutral flux (diamonds) before (green) and after (red) ELM. FIDASIM simulations using fitted n_0 (dashed lines) as inputs.*

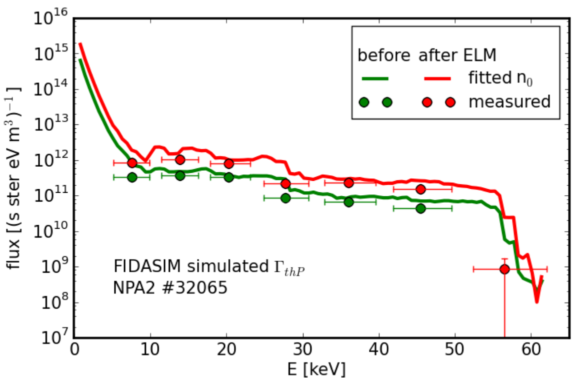

Figure 4: *Measured fast-ion part of passive neutral Γ (dotes) before (green) and after (red) ELM. FIDASIM simulated fluxes using fitted n_0 and TRANSP fast ion distributions (solid lines) as inputs.*

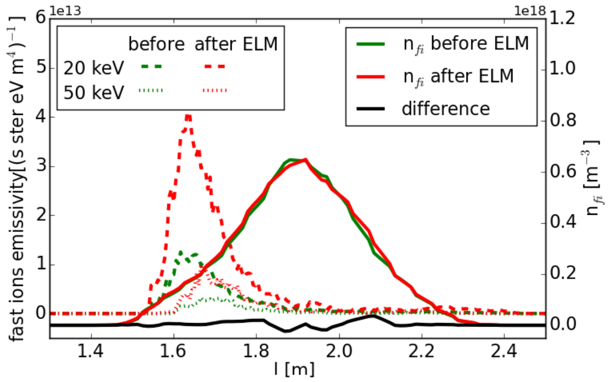

Figure 5: *Fast ion density profiles before (green solid line) and after (red solid line) ELM, their difference (black solid line) and FIDASIM emissivities for two energies E_n 20 keV (dashed lines) and 50 keV (dotted lines).*

The increase of n_0 after ELM is probably caused by higher thermal flux hitting chamber wall during ELM causing higher gas desorption. This trend is observed by both methods (Fig. 2).

However, the effect is weaker in the case of KN1D results.

The change of the measured Γ_{fi} is driven by an increase of the n_0 profile, which is about five times higher after the ELM. Good agreement is observed between the predicted and measured change of Γ_{fi} in presence of an ELM crash (plotted in Fig. 4). The TRANSP predicted fast ion density, as shown in Fig. 5, does not change during the ELM since MHD-induced losses are not considered. The good agreement with the neo-classical TRANSP simulation thus suggests that the ELM does not strongly influence fast ions in the observed part of the phase space. In addition, if a strong fast ion redistribution or loss was present, the shape of Γ_{fi} would be different and not almost the same as is observed.

Conclusion

We developed a method to determine the background neutral density profile n_0 directly from measured neutral fluxes. The method was benchmarked with FIDASIM simulations. It was shown that in an ELM cycle the difference in Γ_{fi} before and after an ELM is mainly caused by an increase of the neutral background density and not by the ELM influencing the fast ion distribution. FIDASIM simulated Γ showed, that fitted n_0 is accurate. Developed method will be later applied also for data measured by NPAs on the TCV and COMPASS tokamak.

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