Calculations of the "knock-on" ion distribution function for NPA diagnostics in ITER

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Introduction

Detection of high-energy particles by neutral particle analyzer (NPA) is considered as the basic diagnostic method of measuring the DT fuel ratio in the ITER core plasma [1]. At the same time principal possibility of such measurement is based on the detection of high-energy deuterium and tritium produced in result of close collisions of fast ions including fusion alpha particles, NBI and ICRF heated ions with thermal D and T ions.

NPA in ITER will register neutrals within a narrow viewing angle centered around zero parallel velocity. Therefore, the correct calculation of the expected signal requires detail knowledge of knock-on distribution function in velocity space. In case of alpha particle produced knock-ons, the angular distribution should be isotropic due to the apparent isotropy of the source. For knock-ons produced in close collisions with NBI ions characterized by strongly anisotropic distribution the accurate calculation of knock-on distribution function is possible only numerically. In the present report we perform these calculations using the algorithms for evaluation of the NBI distribution function [2].

Algorithm and calculations

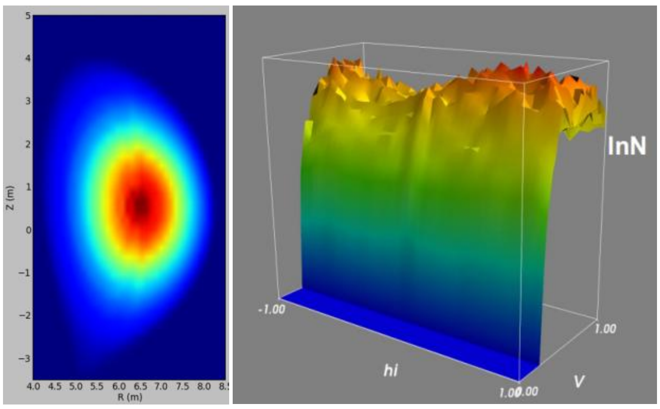

Fig.1. The stationary distribution function of α – particles.
Left: (R-Z), right: (V- χ).

Calculations are performed for «knock-on» ions produced by α-particles and heating beam. The algorithm of calculation is as follows:

1. The stationary distribution function of α-particles and beam particles are calculated by code DRIFT [3];
2. The «knock-on» ions source function (Q) is calculated;
3. The trajectory of «knock-on» ions is integrated and the stationary distribution function of these particles is calculated (again by DRIFT).

4. Calculations of the fast neutral fluxes into NPA.

Initial positions and velocity vectors for nock-ons were randomly sampled in accordance with source function [4] valid for both isotropic (alphas) and non isotropic (NBI) distributions of fast ions, f_{fast}:

$$Q_z = \frac{8\gamma^2 n_z}{v}\int_{\gamma\vartheta}^{vo}\frac{d\sigma}{d\Omega}v_\alpha^2 dv_\alpha\int_{\cos(\psi+\theta)}^{\cos(\psi-\theta)}\frac{f_{fast}(v_\alpha,\chi)d\chi}{\left(\left((\sin\theta)^2-\chi^2\right)\vartheta_\alpha^2+2\gamma\chi v_\alpha\cos\theta-\gamma^2\vartheta^2\right)^{1/2}}$$

Here n_z , z=D,T is the thermal ion density. Cross section σ in the present report was taken for Coulomb collisions only. For angle definitions see [4]. The lower energy limit for sampling the nock-on source was taken E_{min}=200keV (the lower limit for HENPA [1])

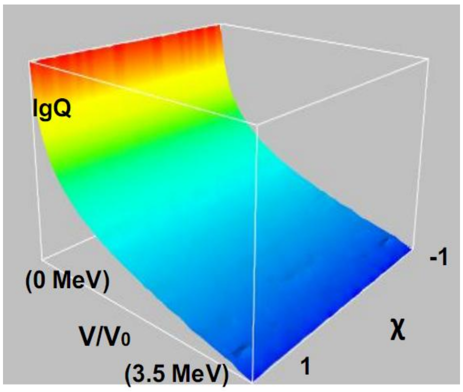

Fig.2. «Knock-on» ion source (derived from α –particles).

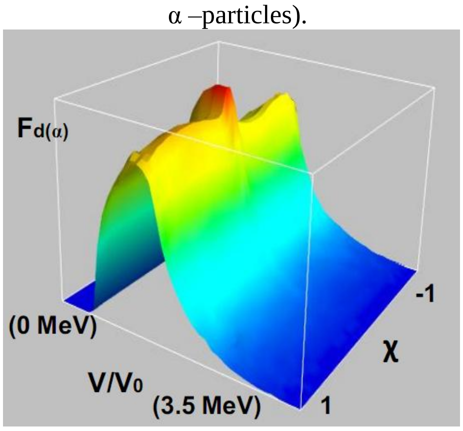

Fig.3. The stationary distribution function of knock-ons from α – particles (for D).

The stationary distribution function for «knock-on» ions produced by α-particles was calculated (Fig.1), it is isotropic (Fig.1, right plot). For this stationary distribution function we obtained the «knock-on» ion source function (Fig.2) and the stationary distribution function of knock-ons from α – particles (for deuterium). (Fig.3). As it was expected from theoretical calculations [4], the source function is isotropic and decreases drastically (as $1/(v^5)$). Therefore, the discussed method of calculation is correct and can be used for calculations of «knock-on» ion (produced by the heating beam) stationary distribution. The stationary distribution of the ITER heating beam ions was calculated as in [2] taking into account realistic injection geometry (Fig.4). Then calculated anisotropic distribution function was used in evaluation of the «knock-on» anisotropic source

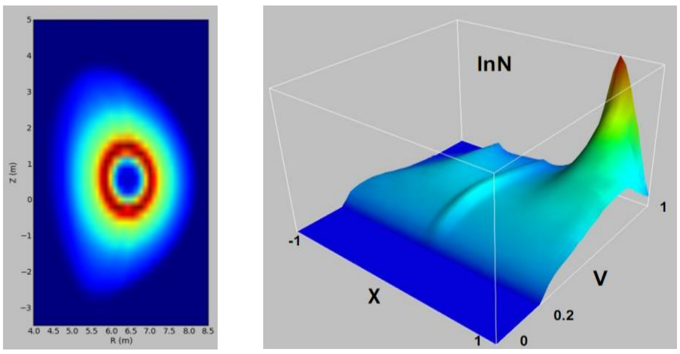

Fig.4. The stationary distribution function of the HB particles. Left: (R-Z), right: (V- χ).

(Fig.5 and Fig.6). It should be noted that the difference in the number of particles from χ = (-1) to χ = 1 is large (Fig.5). The anisotropy of the nock-on source is clear seen at the Fig.6, where integration over the range 200KeV < E < 1MeV has

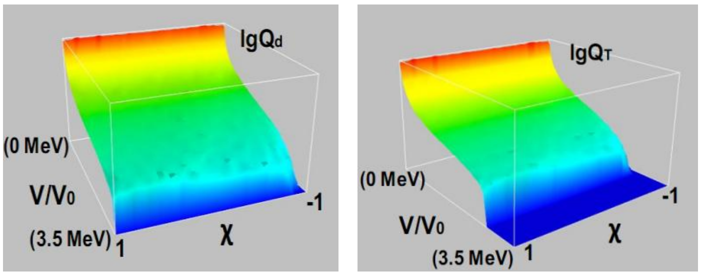

Fig.5. Knock-on source function for the heating beam ions. Left: for D, right: for T.

been performed. For lower energies the source is isotropic (as we see in Fig.5). After that we obtained the stationary distribution function of knock-ons from heating beam (for deuterium: Fig.7 and Fig.8, right plot; for tritium: Fig.8, left plot).

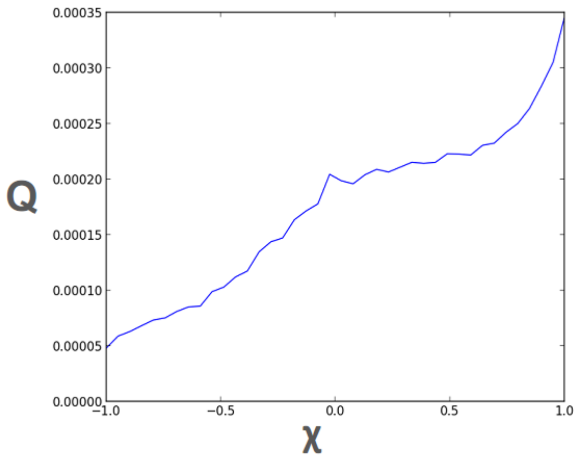

Fig.6. «Knock-on» ion anisotropic source.

To calculate the NPA signal the nock-on distribution function multiplied by the probability of neutralizing and by the probability for a fast atom to pass through the plasma (the transparency of the plasma) (see Fig.9) should be integrated within NPA viewing angle [2]. Result of these integration are shown at the (Fig.10), we see that α – particles knock-on contribution is comparable with heating beam knock-on contribution.

Therefore, both alpha and heating beam sources should be considered to analyze NPA signal. However, for registered atoms with energies above 0.5MeV the contribution from alpha produced nock-ons dominates and influence of the heating beam can be neglected.

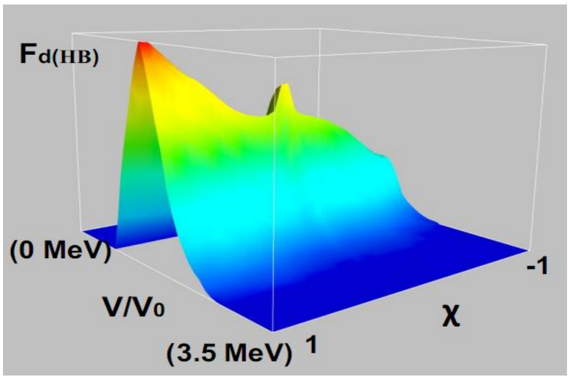

Fig.7. The stationary distribution function of knock-ons from the HB (for D).

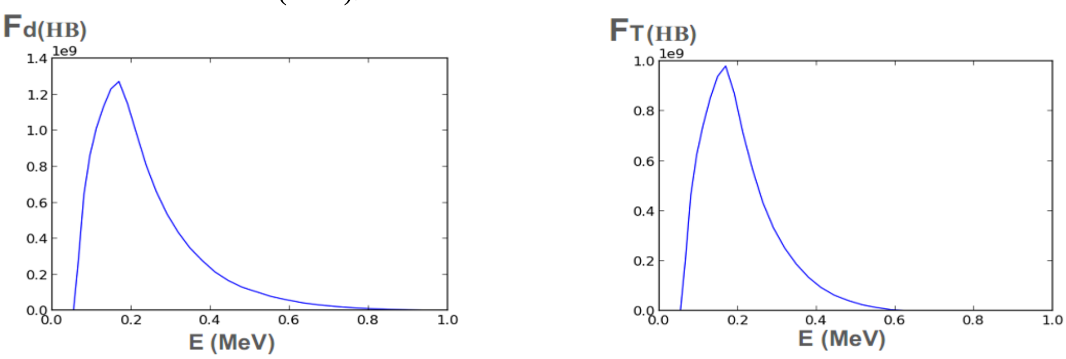

Fig.8. The stationary distribution function of knock-ons from the HB. Left: for D, right: for T.

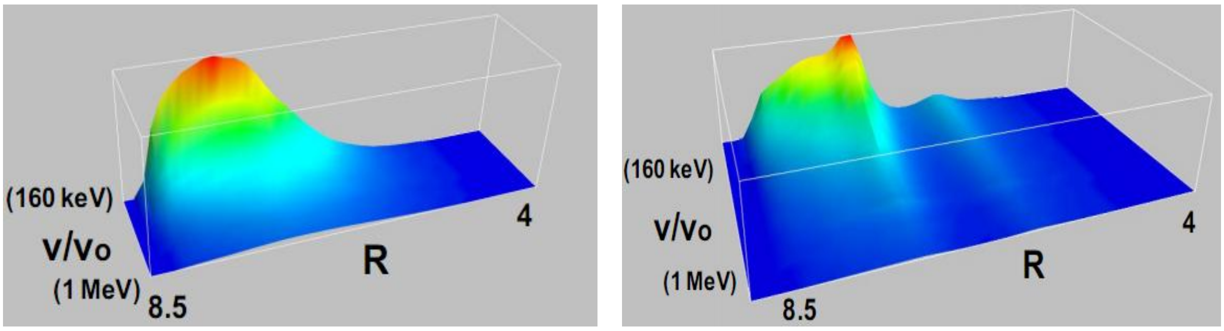

Fig.9. (E, R) distribution of «knock-on» ions multiplied by plasma transparency inside the NPA viewing angle. Left: produced by α - particles, right: produced by HB.

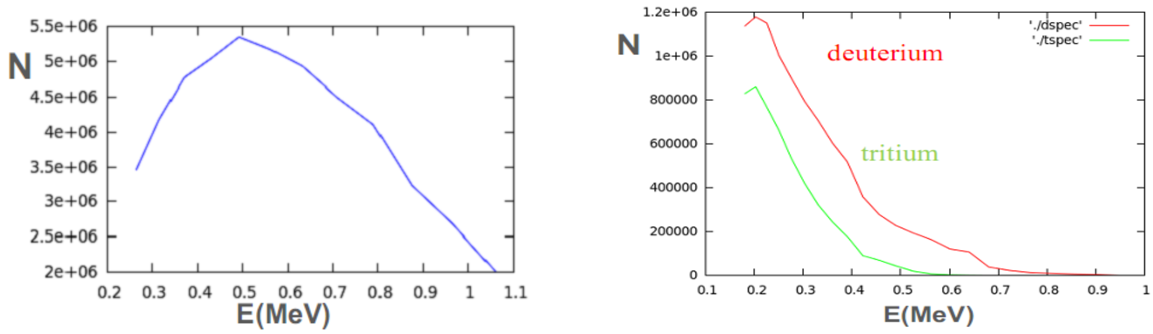

Fig.10. Knock-on spectra.
Left: produced by α - particles, right: produced by HB (for deuterium and tritium).

Conclusions

1. Method of knock–ons distribution functions (produced by isotropic and anisotropic source) calculation was developed.
2. The expected spectra of the deuterium and tritium knock-ons produced by alphas and heating beam (detected by NPA diagnostics) were restored.
3. Presumably, both alpha and heating beam produced nock-ons should be considered to analyze NPA signal.

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