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Comparison of CTS Signals due to NBI heating and Alphas in ITER

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Introduction

Collective Thomson scattering (CTS) has, among other potentials, the capability to allow observation of confined fast ions in plasmas. The technique has been demonstrated at JET [1] and TEXTOR [2]. The proposed CTS system for ITER is designed to employ millimeter waves at 60 GHz emitted by 1 MW gyrotrons [3]. The spectral power density of scattered waves in this frequency range leaving the plasma can be measured and a number of plasma parameters can be inferred. With the proposed ITER CTS system it is possible to measure time-resolved fast ion velocity distributions in several measurement volumes simultaneously, which are given by overlaps of probe and receiver beams [3]. The resolved velocity direction in each volume is then given by the fluctuation wave vector $\mathbf{k}^\delta = \mathbf{k}^s - \mathbf{k}^i$ where $\mathbf{k}^s$ is the wave vector of the scattered radiation (receiver beam) and $\mathbf{k}^i$ is the wave vector of the incident radiation (probe beam).

The purpose of the present study is to assess the impact of auxiliary heating on the ability of the fast ion CTS diagnostic to measure confined fusion alpha dynamics in ITER. The question arises whether fusion alpha physics can be observed by CTS even under presence of 1 MeV beam deuterons in the case of neutral beam injection (NBI) or fast tritons or helium-3 in the multi MeV range in the case of ion cyclotron resonance heating (ICRH). It is conceivable that fast ions generated by these auxiliary heating schemes may overshadow the fusion alphas in the CTS signal. To answer this question, we determine the expected CTS signals originating from fusion alphas as well as from fast ions generated by auxiliary heating and compare their sizes. In the spectrum of the scattered radiation, these contributions lie in frequency bands beyond the bulk ion feature as for example shown in Figure 1 to be discussed below. If the calculated alpha con-

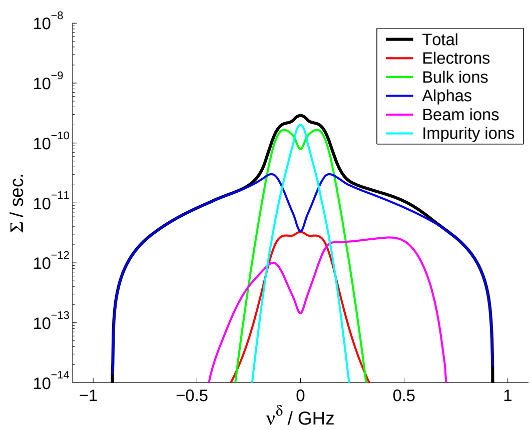

Figure 1: Scattering function for location in the NBI beam path, resolving near parallel velocities; scattering parameters: $R = 5.9m$, $Z = 0.58m$, $\phi = 6^o$, $\theta = 22^o$, $\psi = 176^o$

tribution is much larger than the other calculated contributions in these frequency ranges, then most of the measured signal will be due to alphas and will allow observation of alpha particle dynamics. This study focusses on the impact of NBI, whereas the impact of ICRH will be discussed elsewhere. The 1 MeV deuterons from NBI are of concern when it is desired to diagnose fusion alphas, since CTS cannot distinguish between an alpha and four deuterons moving at the same velocity. However, it can be noted that, with respect to dynamics, it is of no particular interest how the fast ions have been accelerated, i.e. by NBI or fusion reactions. If one neglects the difference in drag between alphas and deuterons, one finds that the motion of deuterons as well as alphas is determined by the Vlasov equation. Dynamics after the Vlasov equation depends on the charge-to-mass ratio, implying identical dynamics of deuterons and alphas on time scales smaller than the collision time. Here we calculate the theoretical scattering spectra for conceivable measuring volumes in ITER. Egedal *et al.* [4] performed such a study which is corroborated and extended here. The findings of the present study point favorably towards the ability of the fast ion CTS diagnostic to measure the fusion alphas without severe disturbance due to NBI heated fast ions, since the fusion alpha signal in the outer frequency bands is indeed much larger than other contributions for most cases.

Assumptions and Methods

To determine the theoretical spectrum of the scattered radiation, one must make several assumptions regarding the distribution functions of the species present in the plasma. The densities of the bulk ion species, impurities, and the electrons at the respective measurement location are assumed to be given by the standard steady-state ITER plasma equilibrium [8], also called scenario 4, and are assumed to have a Maxwellian distribution function. For the fusion alphas, we use an isotropic classical slowdown distribution since the anisotropy in the alphas is small [4]. The distribution functions of beam deuterons have been computed with the ASCOT code [5] and alternatively with the FPCOM code [6, 7] within an EFDA collaboration [8]. From the 1D projections of the distribution functions along $\mathbf{k}^\delta$ in typical ITER scattering volumes one can determine the scattering function [9, 10]. The equation of transfer for a CTS diagnostic can be expressed via an equation for the spectral power density:

$$\frac{\partial P^s}{\partial \omega^s} = P^i O_b (\lambda_0^i)^2 r_e^2 n_e \frac{1}{2\pi} \Sigma \tag{1}$$

Here, P^i and P^s are the incident and scattered power, respectively, ω^s is the frequency of the scattered radiation, O_b is the overlap of probe and receiver beam patterns [9], λ_0^i is the vacuum wavelength of the incident probe radiation, r_e the classical electron radius, n_e the electron density, and Σ the scattering function. The scattering function accounts for the spectral content in the microscopic fluctuations in the plasma and therewith also in the received scattered power density. The separate contributions of the electrons and several ion species (alpha, fast deuteron, bulk ions, impurities) to the scattering function can be found and compared, and the relative influence on the expected CTS signal can be determined for the entire spectrum. Therefore, we present the results in terms of the scattering function in this study. Typical scattering geometries are calculated by ray tracing: We describe the location by the standard ITER coordinates R and Z, neglecting the toroidal coordinate. The direction is given by the angle ϕ between the magnetic field vector **B** and the resolved fluctuation vector $\mathbf{k}^{\delta}$, the scattering angle θ between the probe and receiver beams, and the azimuth $\psi = \angle(\mathbf{k}^i \times \mathbf{B}, \mathbf{k}^i \times \mathbf{B})$.

Results and Discussion

The fast beam deuterons have a large velocity component parallel to the magnetic field and are therefore mostly a concern for the high field side CTS system which resolves dynamics parallel to the magnetic field. The scattering function for this case is shown in Figure 1 for a location in which beam ions have been found to have large contributions and which thus has the greatest relevance in the context of the present study. This volume is located at $R = 5.9m$ and $Z = 0.58m$ and has the angles $\phi = 6^o$, $\theta = 22^o$, and $\psi = 176^o$. The total signal in Figure 1 is the sum of the individual contributions of electrons and various ion species. The bulk ions consist of bulk tritium and bulk deuterium, whereas the beam deuteron contribution is marked separately. The plasma equilibria contain beryllium, argon, and helium-3 which are lumped as impurity ions in this graph. The beam ion signal has a significant contribution compared to the fusion alpha signal (though the contribution is still smaller than the alpha contribution) for frequency upshifts in the frequency band from +0.2 to +0.6 GHz. The results indicate that in this range it may be difficult to draw conclusions about the distribution function of the fusion alphas. However, the beam ions are highly anisotropic, and they influence the signal only for frequency upshifts in the present geometry, leading to the asymmetry of the beam ion feature in Figure 1. For frequency downshifts the beam ion contribution is several orders of magnitude smaller than the fusion alpha contribution and clearly negligible. The fusion alphas can therefore be

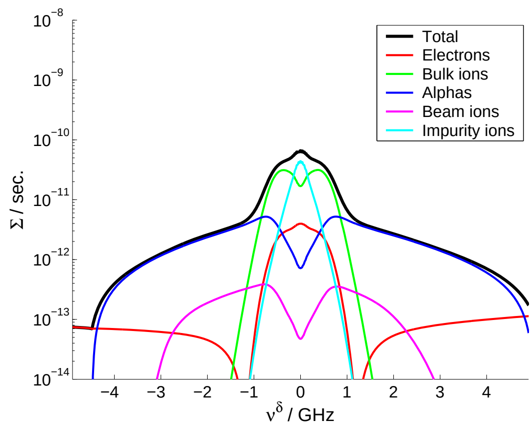

Figure 2: Scattering function for location in the NBI beam path, resolving near perpendicular velocities; scattering parameters: $R = 6.0m$, $Z = 0.62m$, $\phi = 101^o$, $\theta = 163^o$, $\psi = 7^o$

diagnosed, undisturbed by beam ions, for frequency downshifts, even at the location with the strongest beam ion CTS signal. The beam ion distribution functions displayed in this study have been computed with the ASCOT code [8]. These conclusions are also consistent with results obtained with beam ion distributions computed with the FPCOM code [8] and the earlier related study by Egedal *et al.* [4]. The beam ions also have a perpendicular velocity component due to the NBI geometry, and they are additionally subject to pitch angle scattering. Deuterons therefore leave a signature in the spectra calculated for the low field side CTS system which measures the near perpendicular velocity distribution. A spectrum with large beam contribution is plotted in Figure 2 with the same color code as in Figure 1. The geometry parameters are $R = 6.0m$, $Z = 0.62m$, $\phi = 101^o$, $\theta = 163^o$, and $\psi = 7^o$. The contribution to the CTS signal due to the beam ions is at least an order of magnitude smaller than the contribution due to fusion alphas for both upshifted and downshifted frequencies. Thus, the spectra of the perpendicular velocity of fusion alphas can be resolved in the entire frequency band for all spatial locations.

Acknowledgments

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