Implementing beam-beam CX-reactions in the ASCOT-code
and prediction of active NPA measurement

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Introduction

To extend the fast ion investigations on the ASDEX Upgrade tokamak (AUG), the possibility of a Neutral Particle Analyser (NPA) active measurement provided by a beam from the neutral injection (NBI) system is presently being explored. This should allow the fast ion signal to be dominated by the core fast ions neutralised in the NBI-neutral cloud instead of the neutrals originating from the edge. The new capabilities could be used to study the unpredicted fast ion redistribution affecting NBI current drive (CD) experiments [1].

In order to get an estimate of how much signal could be obtained from the beam-beam charge exchange (CX) reactions relative to neutralisation from cold neutral background, the Monte-Carlo orbit following code ASCOT [2] can now deal with three dimensional neutral density. The aim of this work is to quantitatively predict the neutral fluxes at the detector position and to determine if the new hardware would allow monitoring fast ion dynamics due to phenomena such as turbulent diffusion [3] and MHD instabilities [4, 5].

The NBI system produces a dense beam of energetic neutral gas. The fast NBI ions can interact with the fast neutral cloud via CX reaction and become neutral. Part of this flux manages to escape the plasma before further CX reactions or ionisation take place. Also of the neutrals that encounter multiple CX reactions, a certain fraction will escape from the plasma. The sum of these fluxes is measured by the neutral particle analysator (NPA) diagnostic.

The ASCOT code has synthetic NPA-diagnostic that allows to predict the NPA signal from a real experiment. The code uses accurate beam geometry to calculate the beam density: both the ionisation distribution and now also the neutral density.

In ASCOT the density distribution is utilised to calculate the CX-rate of the fast ions. The model takes into account the gyro-motion of fast ions and the strongly non-isotropic velocity distribution of the beam neutrals.

Neutral Beam geometry and possible detector locations in ASDEX Upgrade

There are two NBI boxes in AUG. The proposal is to utilize one of the boxes as the neutral source and the other as the ion source. This is particularly useful, when the maximum ion energy is higher for the ion source. The geometry is illustrated in Fig 1. Each box has four independent

sources. This work used source number 3 (60 keV) as the neutral source and sources 6, 7 and 8 (93 keV) as the ion sources. The NPA sightlines are vertically near the midplane and the angle with the magnetic fields is similar to the NBI beams, making the beam ions visible to the detector.

Simulations

The simulation used true-to-life plasma kinetic profiles and magnetic backgrounds (#19913). The beamlet based NBI model of ASCOT was used to calculate the 3D-neutral beam density and ionisation locations of an ensemble of test ions. The ions were followed while they slowed down by collisions to the background plasma. For each simulation time-step the code checked if the test particle passed through a part of 5D-phase space visible to the detector. The weighted sum of these contributions was the quantity of interest. The weight came from two components: The source strength of the NPA signal was calculated from the local neutral density (1D profile + 3D). The signal dissipation along the path from the neutralisation location to the detector was also computed.
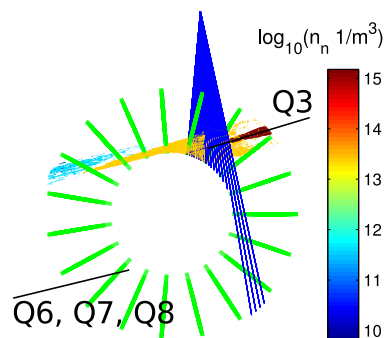

Figure 1: The geometry of the proposed active NPA and an example of the NBI beams. The 3D-neutral density isosurfaces are color-coded by density. The green lines depict the plasma size up to $\rho_{pol} = 1.1$. The black lines depict the NBI beams: 6, 7 and 8 produce ions with energies up to 93 keV and the bean number 3 reaches only 60 keV. The NPA sightlines are drawn in blue.

With one test-particle simulation one can study a large number of sightlines. They were arranged in a 20×20 array, hence producing a synthetic low-resolution "NPA-camera" with app. $10°$ vertical view and $15°$ horizontal view. A few frames of the camera results are illustrated in figure 2. Column (a) shows the simulated flux from a plasma without MHD activity and only Neo Classical transport. The other columns show how the newly calculated flux, divided point wise by the flux in column (a) figure, is affected by different physics.

For the most parts of the view, the 3D-neutral density does not dominate the measurements. Column (b) in Figure 2 shows how significant fraction of the sightlines are dominated by the flux from the 3D-neutral density. These studies are sensitive to the background neutral density, which was obtained from Monte Carlo neutral simulation with boundary conditions from measurements.

Both the magnetic islands and the turbulent diffusion increase the radial transport of particles. The islands do this near the resonant flux surface, while the effect of turbulence varies as a function of the test particle and local plasma parameters, as shown in [3].

The end result is complex local patches of increased or reduced flux (Fig. 2, columns (c) and (d)). These patterns are at least three dimensional since they change not only spatially but also in energy. In fact, the complex shape is likely to be caused by the different sightlines measuring fast ion density in different parts of the 5D-phase space. Unfortunately, simulation data was inadequeate to completely rule out the effect of Monte Carlo noise in columns (c) and (d).

Conclusions & Discussion

The MHD phenomena and turbulence were found to change the measured fluxes by a factor of up to five in certain orientations of the detector. However, these changes vary strongly and rapidly as a function of the detector orientation and observed energy. This means that finding an optimal detector orientation is highly non-trivial.

The neutral flux intensity varies by orders of magnitude, so a change in level by a factor of two is by no means guaranteed to show above the noise (in the simulation case the Monte Carlo
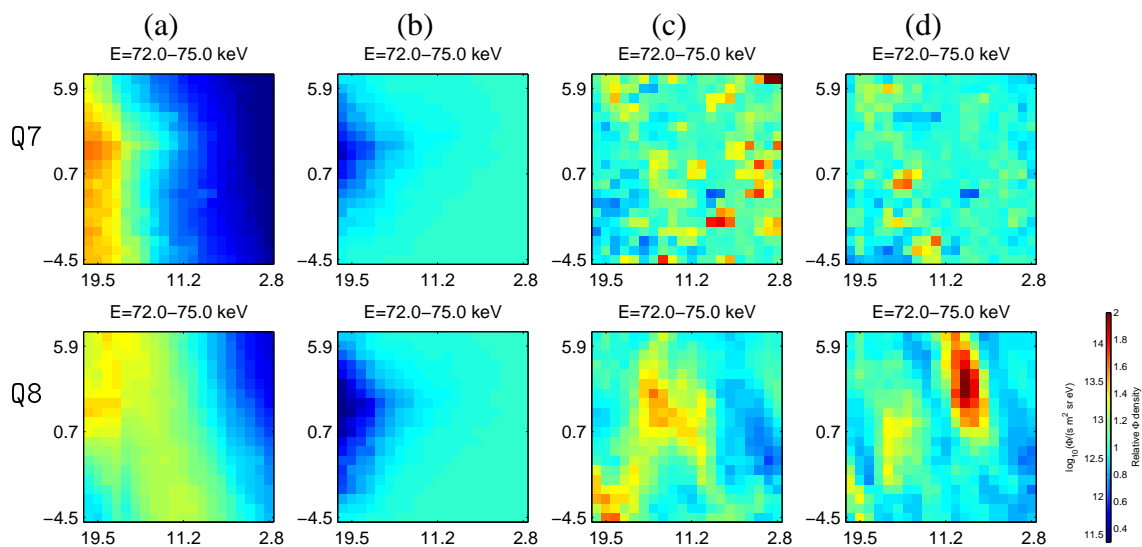

Figure 2: Simulation results from the tangential current drive beam 7 and the medium-tangential beam 8. The simulation for sourcebeam 7 used a small NPA aperture, resulting an angular resolution of 0.5° while for beam the resoution was 2.5° (effectively smoothing the picture). Column (a): Simulated neutral fluxes on 20×20 grid of different sightlines of the analysator. Column (b): The relative change in flux, when ignoring the neutral cloud from beam 3. Column (c): The relative change in flux, when the model for turbulent diffusion of fast ions is enabled. Column (d): The relative change in flux, when the model for magnetic islands is turned on.

noise, and in the physical case normal variations in the plasma). Hence this measurement would be better suited for applications where Fourier decomposition can be utilised. For example the modulation of the 3D-neutral beam or a rotating magnetic island would most likely be clearly detectable from the background by their characteristic frequency. The modulated signal could then be used to infer information about the core fast ion population.

Another possibility is to correlate the NPA signal with measurements from other fast ion measurements, such as fast ion loss detector (FILD), collective Thomson scattering and fast ion D_α measurements. In the case of MHD events, in particular, new information on the effect of various MHD modes on fast ion confinement could be obtained by correlating observations from lost ion diagnostics to measurements of confined fast ions given by active NPA.

There is an obvious improvement to the calculations performed in this work: the neutral beam halo is not yet included. From the three different beam ionisation reactions, (electron impact ionisation, ion impact ionisation and charge exchange), the CX creates new neutrals to the beam halo. These neutrals will contribute also to the neutral density within the plasma. Including this effect is currently being addressed. The core signal is expected to increase.

Once the beam halo is available, a broader selection of plasma parameters, especially densities, should be explored, to see how the parameters affect the observable fast-ion physics related fluxes.

References

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