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Benchmarking the fully 3D ASCOT-code against experimental NPA data from ASDEX Upgrade

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Introduction

The Monte-Carlo Orbit-following code ASCOT [1] is benchmarked against neutral particle analyser (NPA) data from the ASDEX Upgrade tokamak. In 2005 several discharges were dedicated for comparisons of ASCOT-simulations to measurements. The NPA sightlines were varied from discharge to discharge. In each discharge six neutral beam injection sources were turned on in sequence. This work compares high energy neutral deuterium flux caused by re-neutralised fast ions. A preliminary comparison was presented in EPS 2006 [2]. The ASCOT code has been further developed since then. What follows is a current status of the comparison.

The ASCOT code

The ASCOT code follows charged test particles in a fully 3D magnetic field. The interaction with the background plasma is through Monte-Carlo collision operators. Thus, the full neo-classical physics of fast particles in a realistic tokamak can be modelled. The fields and plasma profiles are taken from experimental measurements.

ASCOT has been further developed since the previous report. The new fully three dimensional NPA model is the important reform regarding this work. In the new model the part of plasma seen by the NPA is a cone. Whenever a test particle spends even a fraction of a timestep within the cone, a further check of the velocity of the particle is performed. Neutral signal is accumulated, if the instantaneous velocity of the particle would carry it to the neutral particle analysator. (This models a neutralisation event, after which the fast neutral would fly ballistically into the detector.) The neutral source strength is calculated according to [3] and signal dissipation caused by re-ionisation in the plasma according to [4]. All the geometrical factors are considered, and the flux is given in the physical units $\mathrm{eV}^{-1}\cdot\mathrm{s}^{-1}\cdot\mathrm{ster}^{-1}\cdot\mathrm{m}^{-2}$.

Input from experimental measurements.

For the simulations we have used magnetic backgrounds and profiles of ASDEX Upgrade discharges #19913, #19915 and #19917. In each discharge six different NBI beams were on in sequence. All 18 cases were simulated. Figure 1 shows an example of the density and temperature profiles used in the simulations. It was assumed that the electron and ion temperatures are equal and that the main impurity is carbon. The neutral density profile was acquired from a Monte-Carlo simulation of the neutrals. For input, the calculation used H_α line emissions, neutral gas pressure, low-energy neutral flux and the ion temperature profile [5].

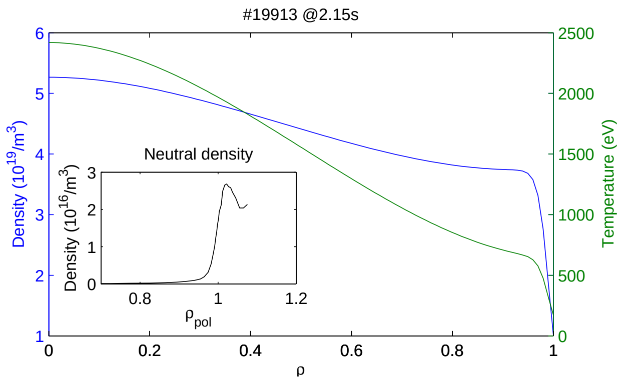


Figure 1: An example of the input plasma profiles. Note the one-dimensional neutral profile.

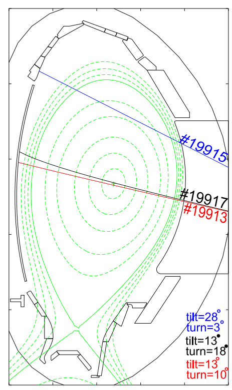


Figure 2: The NPA sightlines for the different discharges against the equilibrium for #19913 @2.15 s

The ASDEX Upgrade NPA can be tilted vertically as well as turned horizontally between discharges to measure different parts of the plasma. In #19913 and #19917 the tilt angle was 13° and the NPA sightline was practically radial at the core. In #19915 the analysator was looking at the very edge, above the midplane. This is illustrated in figure 2. The NPA settings were such that the particle pitch angle arcus cosine ranges from -0.3 in #19913 to -0.6 in #19917. In other words, the detected particles were predominantly on banana-orbits.

Results

Figure 3 shows how the measurements and simulations fit quantitatively together. Ideally there would be linear correlation, but in reality there is approximately an order of magnitude of scatter. In a more detailed inspection, the agreement in discharge #19913 is mostly as good as one can hope (Fig. 4a). In discharges #19915 and #19917 the simulations systematically over-estimate the flux by an order of magnitude or more (Fig. 4b). The disagreement between simulations and experiment is worst for the current-drive-beams (Fig. 4c).

Discussion

The NPA signal is very sensitive to background plasma through strong signal attenuation, and to the neutral density through the source strength. Therefore the measured flux varies by orders of magnitude between different energy channels and phases of a discharge. Hence, obtaining a reasonable congruence even on a log-log plot is an accomplishment. In nearly half of the measurements the simulation practically coincides with the measurement. The two primary candidates for error sources are the one-dimensional neutral density profiles and anomalous redistribution of fast ions, the latter of which could explain the poor agreement in the case of current drive beams.

The neutral density is assumed to vary only in radial direction, for which there is no physical basis. The measurements for the neutral density are performed in the same sector as the NPA measurements, but not exactly on the NPA sightlines. The neutral profile problem should cause

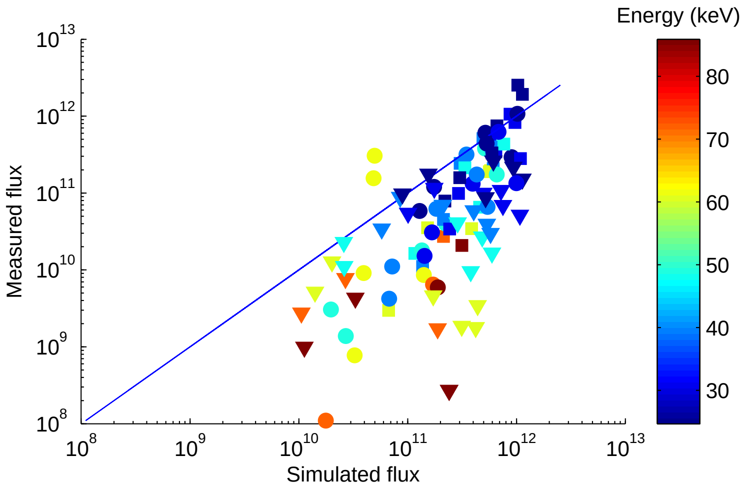
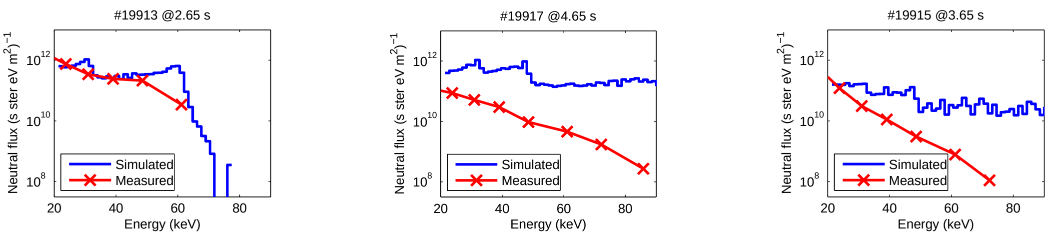


Figure 3: The measured fluxes versus the simulated fluxes. Squares denote points from #19913, circles from #19915 and triangles from #19917. The graph only shows datapoints where both simulations and measurements produced non-vanishing values.



(a) Excellent congruence when simulating a relatively radially launched 60 keV beam and radial sightline.

(b) Poor agreement of simulations of a 90 keV relatively tangential beam especially at high energies.

(c) The measured NPA signal from a 90 keV current-drive beam vanishes already below 80 keV.

Figure 4: Comparison of measured and simulated neutral fluxes. The step-structure clearly visible in the simulated spectra is due to the technical properties of the NBI beam: Some of the injected neutrals have $1/2$ or $1/3$ of the nominal energy, and hence start their slowing-down process from those energies.

similar errors to each simulation of a given discharge. This could explain why the results from #19913 are generally in much better agreement with measurements than the others: the sightline in #19913 lies closest to the neutral density measurement area. The sightlines in #19915 and #19917 are further from the measurement area.

The work can be extended by considering a physically motivated anomalous diffusion of fast ions in turbulent plasmas [6]. The 3D effects caused by ripple in the ASDEX Upgrade magnetic field will be considered in a future work. Further work includes comparison of the JET-ripple campaign NPA measurements to ASCOT simulations.

References

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