Effect of internal magnetic islands on confined fast ions in ASDEX-Upgrade and Wendelstein 7-X

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We present numerical simulations investigating the transport of fast ions in the confined region induced by magnetic islands. How fast ions react to magnetic instabilities is a crucial topic for future fusion reactors, as changes to the alpha particle distribution may negatively impact performance or damage the first wall by fast ions losses. We have upgraded the BEAMS3D [2] Monte-Carlo code at ASDEX Upgrade (AUG) and validated it against experimental measurements [1] using the fast-ion D-α (FIDA) diagnostic and the FIDASIM code [3]. The framework of using the fast ion distribution simulated by BEAMS3D to predict the FIDA spectra and fast ion profiles is now applied to simulate the effects of three-dimensional magnetic islands on the fast ions.

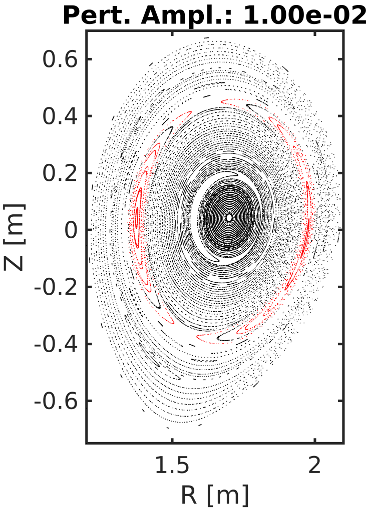

Figure 1: Poincaré plot of the AUG magnetic field with added (2,1) perturbation.

Previous studies in tokamaks have mostly focused on the calculation of (collisionless) fast ion losses caused by perturbed magnetic fields [7, 8, 9], as these offer clear experimental evidence and are straightforward to model numerically. Modeling the confined fast ions, taking into account slowing down and pitch angle scattering processes to assess changes to the fast ion distribution in the confined plasma has not received similar attention [5]. Established tokamak codes like NUBEAM assume axisymmetry, making them unsuitable for studying such three-dimensional perturbations. BEAMS3D is a Monte-Carlo code that can simulate the neutral beam deposition and steady-state fast ion distribution in both axisymmetric and 3D fields. Recent validation of BEAMS3D using FIDASIM has provided a robust framework for accurate simulations [1]. To study the effect of topological changes in the magnetic field, a new

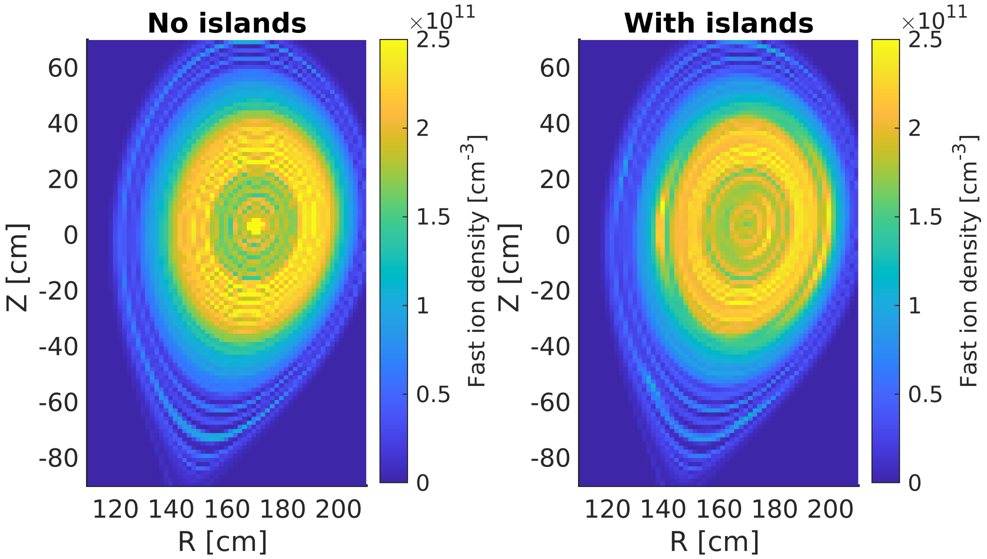

Figure 2: Fast ion density at the toroidal position of NBI location, phase space: energies between 30 and 50 keV and pitch values from -1 to -0.8. The (2,1) island structure is visible in the right plot

formulation of the equation of motion based on the Hamiltonian principle in [6] has been implemented, ensuring precise energy conservation especially in regions with large currents such as the tokamak core region.

For our study at AUG, we calculated the magnetic perturbation visible in Fig. 1 in the same way as outlined in [8], starting from an axisymmetric experimental EQDSK equilibrium. We focus here on conditions where off-axis NBI was injected. In these conditions, the birth pitch value ($v_{||}/v$) of the NBI particles ranges from -0.6 to -0.85, meaning the NBI generates counter-passing particles. The effect of magnetic islands on the fast ion density is large in cases with counter-passing particles and beam deposition predominantly at the island location, as shown in 2. Here, we show part of the fast ion distribution, namely at the toroidal position of NBI injection location while integrating in phase space over energies between 30 and 50 keV and pitch values from -1 to -0.8. This region of phase space is where the AUG FIDA system is mostly sensitive, as is visible from the weight function [10] of one FIDA line of sight in Fig. 3. A high value of the weight function corresponds to high sensitivity to a particular phase space region.

Figure 3: Weight function (phase space sensitivity) of a toroidal line of sight of the FIDA diagnostic and the extents of the slice of phase space used in Fig. 2. The white contours show the fast ion distribution distribution averaged over the measurement volume.

Simulating FIDA spectra for these conditions, we find that comparing the FIDA/BES profiles