# The effect of NTMs and TAEs on fast particles in ITER

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## Introduction

Fast particles, such as fusion-born alphas and energetic ions from external heating, are important in ITER for two primary reasons: 1) They are responsible for self-sustained heating and current drive. 2) They constitute a significant energy source in the plasma and, therefore, pose a potential risk to the material structures. In this work we study how magnetohydrodynamic (MHD) instabilities affect the fast particle distribution in a realistic ITER magnetic configuration including the toroidal field (TF) ripple, test blanket modules for tritium breeding (TBMs) and ferritic inserts (FIs).

The perturbations in the magnetic vector potential and scalar electric potential caused by the MHD modes were used to derive valid guiding-center equations of motion in a general coordinate system [1]. Using these equations, it is possible to trace particles with the MHD modes using any desired form of the magnetic field, while earlier methods were either restricted to use static MHD modes or axisymmetric magnetic fields.

The following ITER scenarios are considered: 1) Fusion alpha simulation in the presence of NTMs in the standard 15 MA H-mode scenario, 2) fusion alpha simulation in the presence of TAEs in the advanced reversed shear 9 MA scenario and 3) the same for NBIs. In all the cases, the effect of MHD modes on fast ion power loads to the wall and on plasma heating is studied. Moreover, in case of NBIs, the effect of MHD modes on the current driven by the beams is investigated.

## Standard 15 MA scenario, alpha particles

In this scenario we have simulated the effect of NTMs on fast particle distribution. The radial profile for the NTMs is shown in Figure 1(a). This profile is generated using a parametrization [2]

$$\alpha_{mn}(\psi_p) = c_0 \psi_p^{k_1/2}(1-\psi_p)^{k_2}, \tag{1}$$

with the parameters $k_1 = 4$ and $k_2 = 1$. The amplitude $c_0$ is scanned in this study. We have simulated 50 000 alpha particles, weighted by the local fusion rate, and recorded the total power to the wall as a function of the amplitude of NTMs. The particles are simulated until they thermalize or intersect first wall elements. The results are shown in Figure 1(b). As can be seen, the total power to the wall will increase as the amplitude of the perturbation is increased.

However, even with the largest perturbations the total power load is still in acceptable level. Moreover, the island width for the last two data points is already more than the limit for NTM suppression, i.e. roughly 15 cm. Hence, these are unacceptable large islands that should never exist in ITER. For the realistic island size, the total power to the wall is very close to MHD quiescent level.

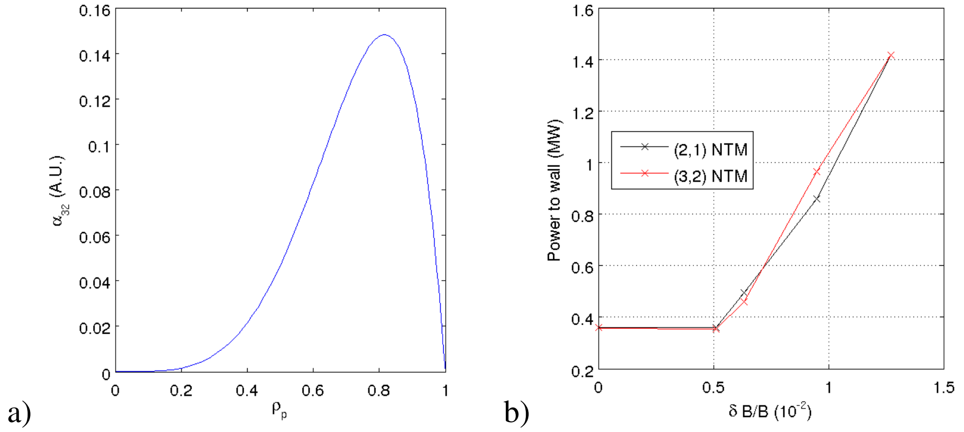

Figure 1: (a) The radial profile for (3,2) NTM. (b)The total alpha particle wall power load vs. perturbation amplitude for the (3,2) and (2,1) NTM. As the NTMs are expected to be mitigated in ITER, the relevant operation region will be within the first three bullets.

### Advanced 9 MA scenario, alpha particles

In the advanced reversed shear 9 MA scenario we have simulated the effect of TAEs on fast ion distribution. The eigenfunctions for the TAEs were calculated by LIGKA [3], and they are shown in Figure 2(a). The resulting perturbation in the magnetic field is shown in Figure 2(b). In the simulations, only the most unstable mode, i.e. n=5, was used. The frequency of the mode was $f = 51.5$ kHz and altogether 16 poloidal harmonics ranging from 10...16 were used. The particles are initialized to sample the mode period, i.e. each particle is born with a random phase with respect to the mode. This enables us to gather slowing down distributions. Altogether 200 000 fusion born alphas were weighted according to local fusion reaction rate and simulated until a thermal energy was reached or alphas intersected the first wall element. The alpha wall power load was found to stay close at the MHD-quiescent level even with the TAE perturbation applied. However, redistribution of alphas was found at the core plasma, at around $\rho = 0.4$. Relative difference in the alpha particle density raised up to 10%, as shown in Figure 3(b). The change in the alpha density also affected the power deposition from alphas to plasma. In figure 3(a), this is shown for electrons but similar redistribution was found also for ion species. Moreover, the velocity phase space was observed to undergo redistribution as shown in the

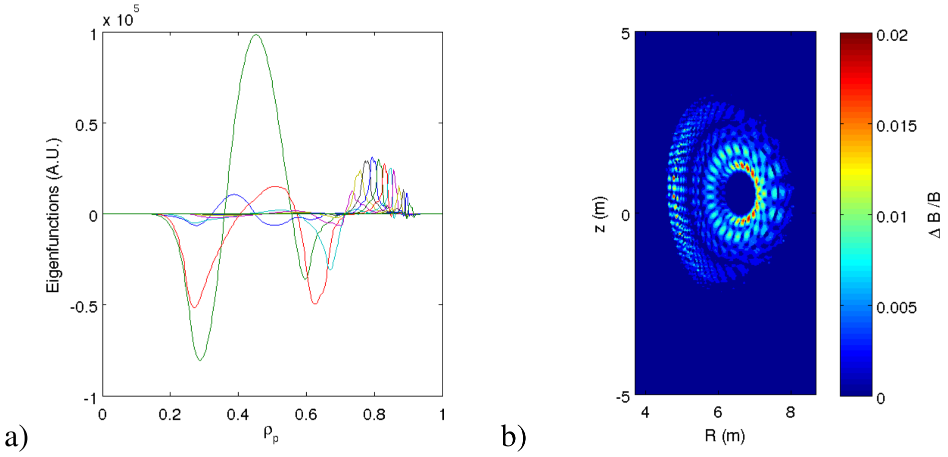

Figure 2: (a) The eigenfunctions as a function of $\rho_p$ for the most unstable TAE n=5 for the ITER 9 MA scenario, as calculated by LIGKA. Poloidal harmonics with $m = 10\ldots25$ are shown and used in the simulations. (b) The perturbation in the magnetic field at the zero toroidal angle with respect to the background magnetic field.

energy/pitch -histogram in Figure 4. The redistribution is from trapped particles to passing ones. This explains, at least partly, the red spot in the high field side of Figure 3(b) that is generated by these extra passing particles.

## Advanced 9 MA scenario, neutral beam particles

A beamlet based NBI model of ASCOT was used to generate 200 000 NBI particles with energy of 1 MeV. The deposition profile is shown in Figure 4(b). As can be seen, a major fraction, if not all, of these particles are in the passing orbits. The particles were simulated until they thermalized or intersected the first wall. Again the wall load stayed at the MHD quiescent level and a redistribution took place. The redistribution was very similar to that found for alpha particles, but the maximum relative change was found to be a bit higher, i.e. up to 20%. Also the neutral beam current drive, that is proportional to NBI density, undergoes a redistribution. In Figure 5, we show both the absolute level of the NBI driven current, with out the electron drag effect, and the relative change in the current density for case with TAE with respect to MHD quiescent case. At the peak of the current density, the redistribution causes roughly a 10% change in the driven current density.

## References

[1] E. Hirvijoki *et al.*, Comp. Phys. Comm. **183**, 2589 (2012)

[2] Q. Yu, Physics of Plasmas, **13**, 062310 (2006)

[3] P. Lauber *et al.*, Journal of Comp. Physics **226**, 447 (2007)

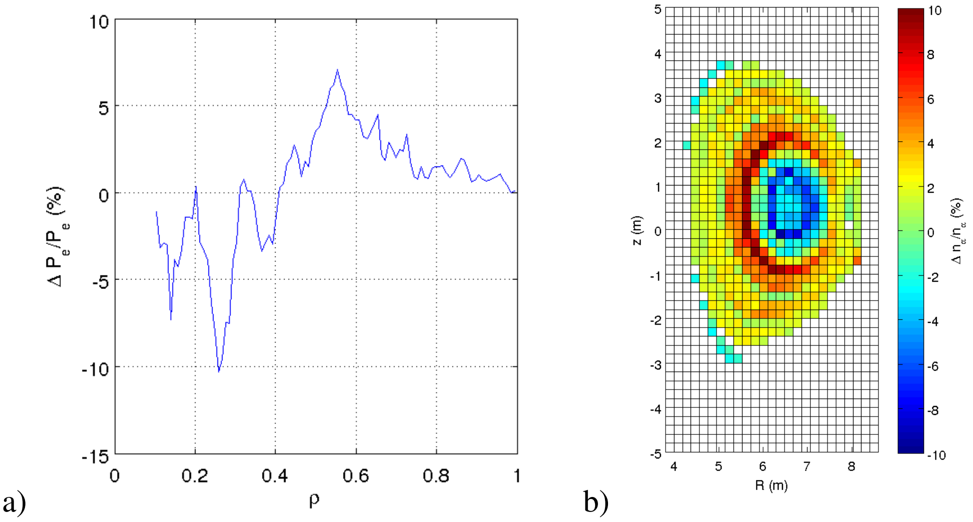

Figure 3: Relative change in the deposition from alpha particles to electrons (a) and density (b) with TAE with respect to with out TAE.

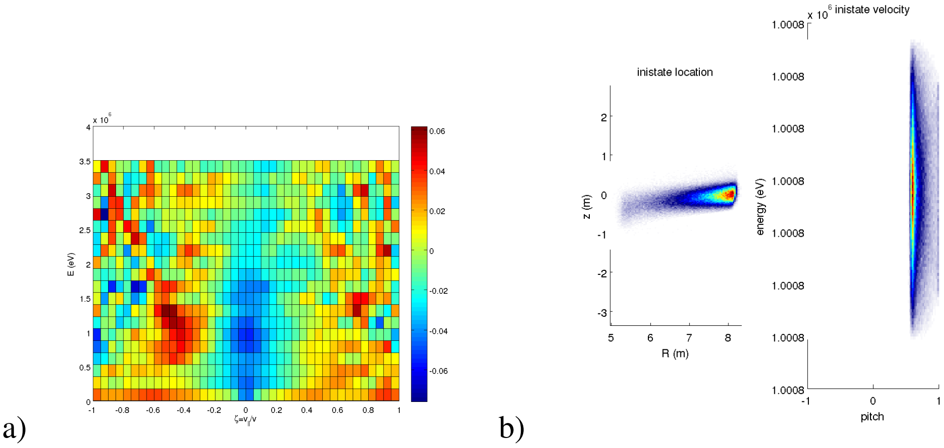

Figure 4: (a) Relative change in the histogram of particle pitch and energy with TAE with respect to with out TAE. (b) NBI deposition in poloidal plane and in velocity space.

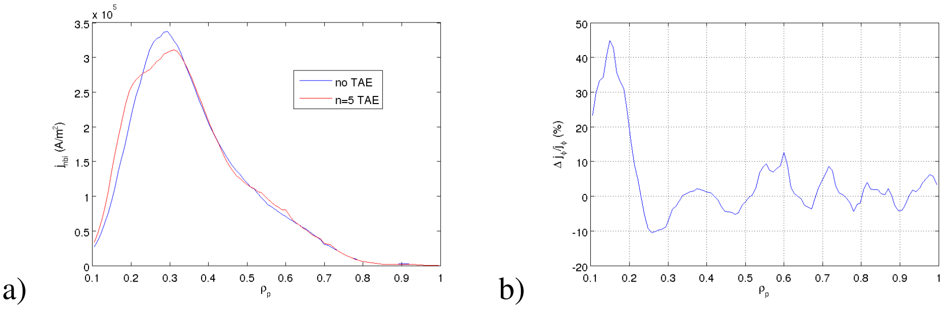

Figure 5: (a) A NBI particle driven current density (not including the electron drag effect) for the cases with and with out TAE. (b) The relative change in the current density for the case with TAE with respect to MHD quiescent case.