Assessing the effect of TBMs and ELM mitigation coils on fast ion confinement in ITER

T. Koskela, O. Asunta, E. Hirvijoki, T. Kurki-Suonio, S. Äkäslompolo

Aalto University School of Science, Department of Applied Physics, Espoo, Finland

tuomas.koskela@aalto.fi

Introduction In order to mitigate ELMs in H-mode operation, the current plan is to equip ITER with 3 rows of 9 ELM mitigation coils. In this paper we use the orbit-following Monte Carlo code ASCOT [1] to assess the combined effect of ELM mitigation coils, TF ripple, Ferritic Inserts, and Test Blanket Modules on the confinement of Neutral Beam Injection (NBI) ions and α particles born in thermonuclear fusion reactions in ITER. We show that in cases where excessive losses are obtained, the magnetic background would not be able to support the edge plasma profiles assumed in the simulations and, thus, the edge fast ion source is over-estimated.

Simulations We consider two ITER reference operating scenarios: The 15 MA plasma current standard H-mode scenario, sometimes referred to as "scenario 2" and the 9 MA plasma current advanced steady-state scenario, sometimes referred to as "scenario 4". The temperature and density profiles used in this work are shown in figure 1, along with the q-profiles. The temperature and density profiles are used to evaluate the magnitude of coulomb collisions, as well as fast ion birth density profiles.

We assume a 2D equilibrium, onto which the density and temperature profiles are mapped. The equilibrium data have been imported from eqdsk files obtained from the ITER database,

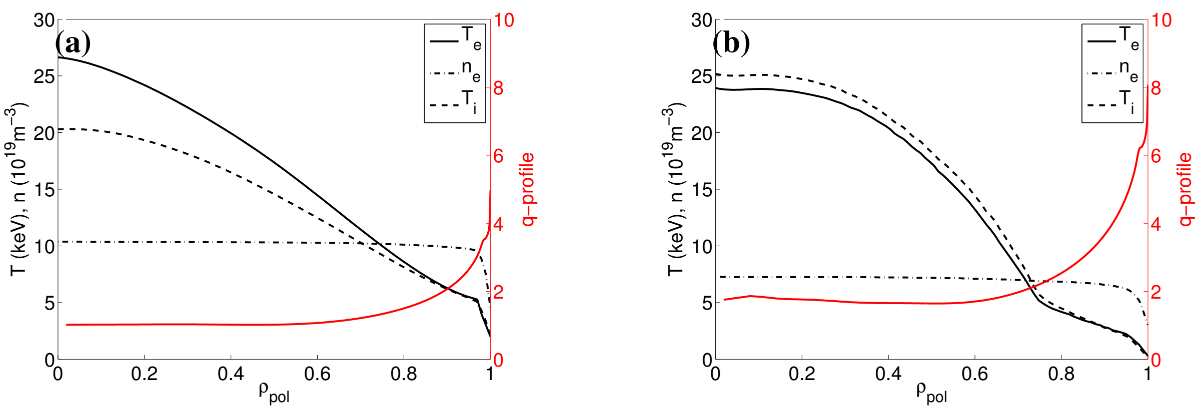

Figure 1: Temperature and density profiles (left axis) and q-profiles (right axis) for **(a)** 15MA ITER scenario and **(b)** 9MA ITER scenario.

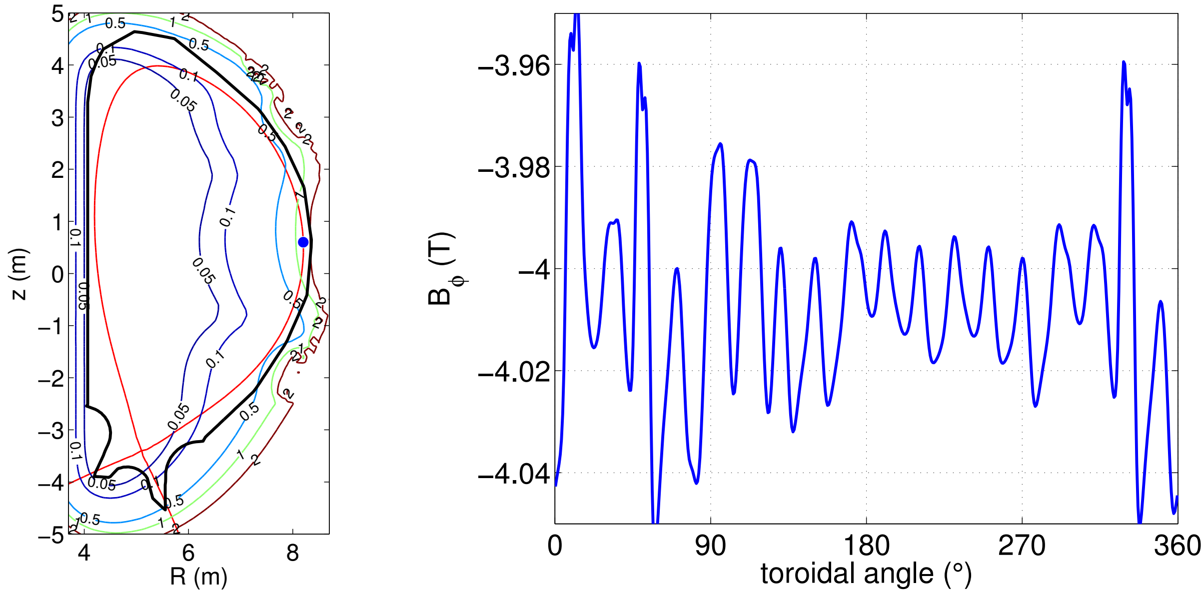

Figure 2: On the left: Ripple map with the combined effect of TF ripple, TBMs and ELM coils. On the right: Toroidal field strength with R and z coordinates fixed to the blue dot on the left hand side figure.

documents 478WJZ and 48M46L. The 3D perturbation fields are assumed to be small enough so that they may be added to the equilibrium field without causing significant errors in the background. The result of the addition process is presented in figure 2, which shows the TF ripple map and the toroidal profile of the field. The data for the TF ripple and TBM perturbation has been imported from the ITER database. The data sets can be found in documents 4LSDBC, 64KHJP, 64D8GV and 64PD6G. The ELM coil perturbation has been calculated from the ELM coil geometry, by numerically solving the Biot-Savart law [2]. We assume the coils to run 90 kAt current in a N = 4 cosine waveform, with the rows phase shifted as given in [3].

Two types of simulation results are presented: First, we investigate the structure of the magnetic field and present the results of field line tracing of the combined 3D magnetic fields. Field line tracing is a very lightweight tool to gain some insight on the confinement capability of the magnetic field. Second, we present the results of NBI and α particle slowing-down ASCOT simulations.

The results of field line tracing are presented in figures 3a-d in the form of Poincare plots where the Poincare surface is on the outer midplane. We have followed 100 field lines, starting at the outer midplane, distributed evenly in equilibrium ρ_{pol}, from $\rho_{pol} = 0.5$ to the assumed separatrix. We see that the field line structure changes significantly with the introduction of the ELM coils and, especially in the 15 MA scenario, the separatrix, ie., the last closed flux surface

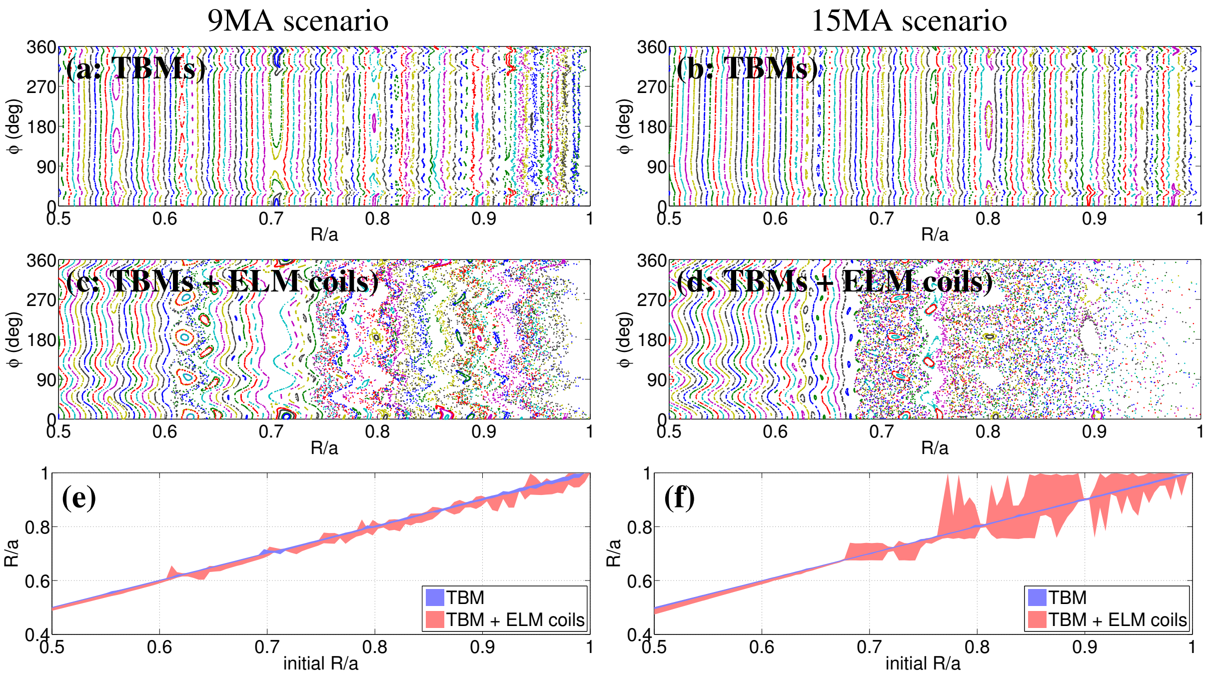

Figure 3: Poincare plots of the field lines from $R/a = 0.5$ to the separatrix. The 9MA scenario with TBMs only in **(a)** and with TBMs and ELM control coils in **(c)**. The 15MA scenario with TBMs only in **(b)** and with TBMS and ELM control coils in **(d)**. In **(e)** and **(f)**: the space in R/a in which the field lines move for **(a,c)** and **(b,d)**, respectively.

is shifted inwards. This is most clearly seen in figures 3e-f, since all field lines that reach the value 1 on the y-axis are in fact open field lines.

The particle tracing simulations show that the TBMs alone do not cause significant losses of fast ions. However, figure 4a shows that when the ELM coils are added to the model, losses increase significantly, especially in the 15MA scenario. This is due to the fast ions now being born on open field lines in the edge and flowing directly to the wall. Since the birth profiles in figure 4b have been calculated without taking the perturbation field into account, it is likely that the number of particles born in this region is overestimated. Therefore the loss fractions in figure 4a would still cause relatively small fast ion losses, were the 3D field structure taken into account in constructing the equilibrium.

Conclusions With the present method, either the fast ion source in the edge or the penetration of the perturbation field is overestimated. Both shortcomings lead to unrealistically large fast ion losses. Therefore the results given by the methods described in this paper are likely to overestimate the loss of fast ions. However, the simulation results indicate that even if 25% of the NBI power were lost to the ELM mitigation coil field, it would not lead to unacceptable peak

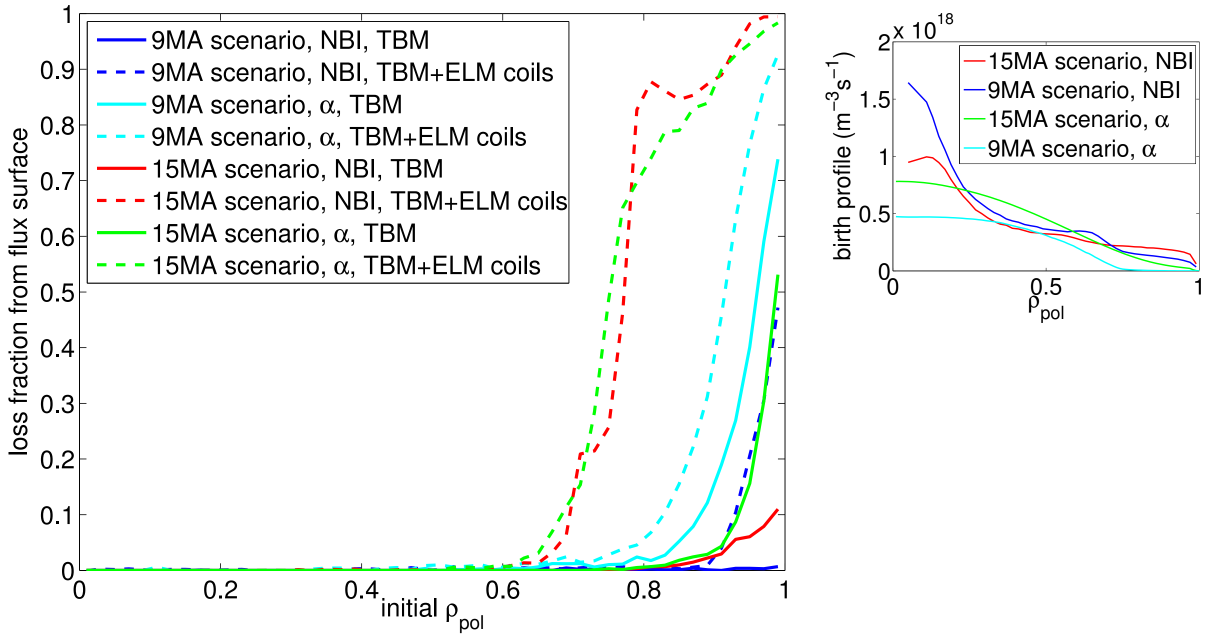

Figure 4: On the left: the fraction of fast ions born on a given flux surface interval which is lost. It should be kept in mind that each interval is scaled to the total amount of ions born in that interval. On the right: The birth rate of fast ions on a given flux surface.

power loads on the wall. To fully resolve the issue of the effect of ELM coils on fast ion losses, we feel that a 3D equilibrium solution is required, which takes into account both the effect of the perturbation field on the thermal plasma confinement and the effect of plasma shielding on the perturbation field.

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