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Predictions of neutral beam current drive in DEMO using BBNBI and ASCOT within the European Transport Simulator

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Introduction

Extensive predictive modelling is absolutely essential to avoid costly mistakes when designing future fusion devices. Modelling the entire burning plasma requires self-consistent treatment of a number of interconnected physics processes from magnetic equilibrium and auxiliary heating to radiation and transport of heat and particles. European Integrated Modelling (EU-IM) framework provides a platform for combining numerical tools that model the different physics processes in the plasma. It allows building complex integrated simulations (*workflows*) by connecting pre-compiled physics modules (*actors*) using standardized data structures known as *Consistent Physical Objects* (CPOs) [1].

Neutral beam injection (NBI) is used extensively in current fusion devices for, e.g., driving current and heating the plasma. It is also foreseen to be used in ITER and future fusion reactor, DEMO. In this work BBNBI [2] was used to model the injection and ionization of neutrals. The ionized particles were then followed using Monte Carlo code ASCOT [3] to model how they, e.g., heat the plasma and drive current. BBNBI and ASCOT were ran within one of the most advanced workflows developed on EU-IM framework, the European Transport Simulator (ETS) [4], to study neutral beam current drive (NBCD) in DEMO. In particular, the effect of horizontal and vertical tilting of the beam on NBCD and plasma heating was investigated. In addition to gaining valuable insight into the characteristics of NBI in DEMO, the objective of this work was to demonstrate that existing tools are capable of flexible and sophisticated modelling of NBI, for arbitrary injection geometries, as a part of an integrated transport simulation.

Neutral beam injection in DEMO

Simulations were carried out for two DEMO discharge scenarios; one with a *peaked* and the other with *flat* density profile. The temperature and density profiles of these discharges

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[*] See http://www.euro-fusionscipub.org/eu-im.

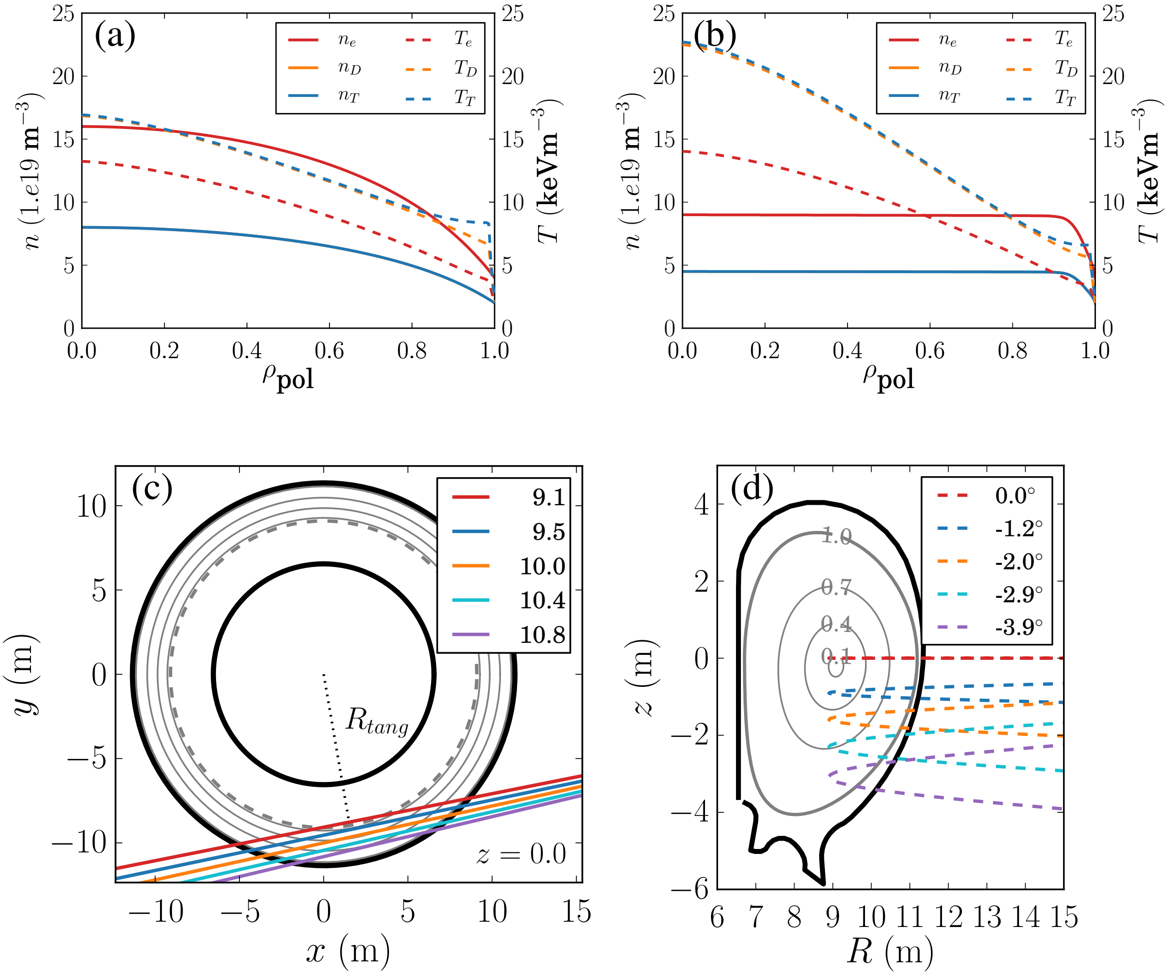

Figure 1: T and n profiles of the *peaked* (a) and *flat* (b) density DEMO discharge scenarios, and the beamlines of the scans performed by increasing the R_{tang} (c) and tilting the beam downwards (d). A set of magnetic flux surfaces (grey), including the magnetic axis (dashed) and the last closed flux surface (bold), are shown. In (c) and (d), the red beamline with $R_{\text{tang}} = 9.1$ m and $\theta_{\text{tilt}} = 0.0°$, is the reference case. Data courtesy of T. Franke, PPPT.

are presented in Fig. 1(a) and (b), respectively. In both scenarios, $n_{\text{D}} = n_{\text{T}}$, $I_{\text{p}} = 16$ MA, and $B_{\phi} = 6.791$ T. The magnetic equilibrium was calculated within the ETS using CHEASE [5] based on plasma boundary obtained from 2013 CREATE [6] simulations.

For the NB injector, a model of ITER injector was scaled up to DEMO dimensions and, for the reference case, horizontal injection was assumed. The study consisted of a scan of three beam energies; 0.75 MeV, 1.0 MeV, and 1.5 MeV. When tilting the beam, the beamlines were aimed so that corresponding horizontally and vertically tilted beams had their tangency point at about the same value of ρ_{pol} (see Fig. 1(c) and (d)).

The NBCD density profiles resulting from the beam scans are illustrated in Figs. 2(a)–(c) for the peaked density discharge and in Figs. 2(d)–(f) for the flat density discharge. The colors and line styles of the profiles in Fig. 2 correspond to those of the beamlines in Fig. 1. The shape

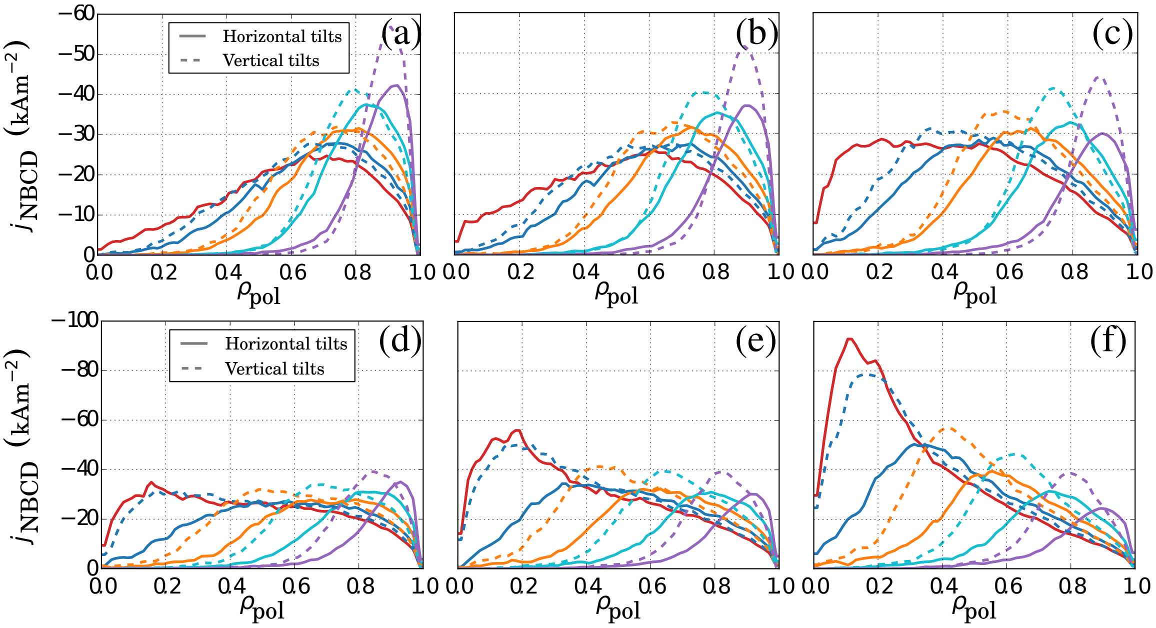

Figure 2: NBCD for vertical (solid) and horizontal (dashed) scans for the peaked (top) and flat density discharge (bottom). The beam energy was varied from 0.75 MeV (left) to 1.0 MeV (centre) and to 1.5 MeV (right). The red solid curve is the reference case, whereas the other colors are as indicated in Fig. 1.

of the driven current density depends strongly on the beam aiming and energy. Low energy beams barely reach the plasma core, whereas tilting the beam horizontally or vertically moves the profile further outwards. The power deposition from fast ions to the plasma (electrons and ions) follows the same trends as the driven current, with the exception of the very core where the fast ion current is strongly shielded.

Since the peaks of the resulting current density profiles are not at exactly the same locations in ρ_{pol}, the radially increasing volume differentials make quantitative visual comparisons between them difficult. Therefore, the integrated values of power deposition to the plasma ($P_{\mathrm{dep,tot}}$) and the driven current ($j_{\mathrm{NBCD,tot}}$) for all the beamlines are plotted in Fig. 3. It is noteworthy how tilting the beam vertically, while driving current deeper in the plasma where the electron shielding is larger, still produces higher total beam driven currents compared to horizontal tilting. That is, from the current drive perspective, tilting the beam vertically is the better of the two options.

The extreme tilts, drawn in purple in Fig. 1, have more beam shine-through and orbit losses than the others, resulting in significantly lower power deposition to the plasma (see Fig. 3(b) and (d)). For the peaked density plasma, the decrease of electron shielding towards the last closed flux surface counteracts the effect of increased shine-through and losses. Consequently, $j_{\mathrm{NBCD,tot}}$ does not decrease with increased tilting as strongly as the power deposition.

The results indicate that beams tangential at $\rho_{\mathrm{pol}} = 0.4$ (orange, $R_{\mathrm{tang}} = 10.0$ m, $\theta = 0.0^\circ$

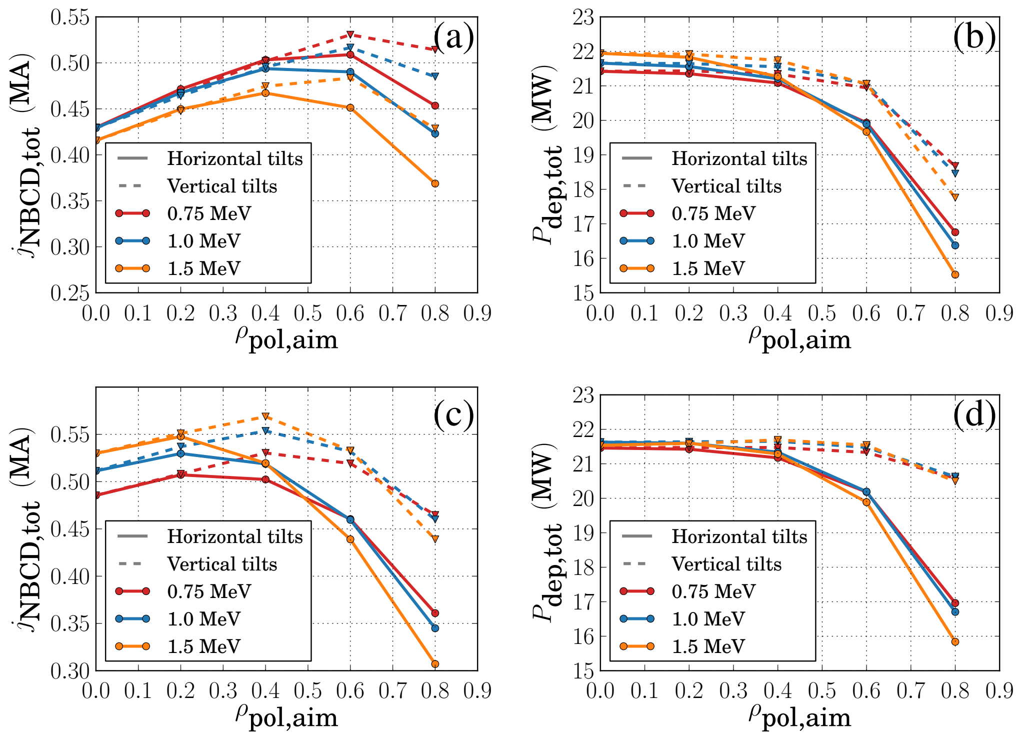

Figure 3: Total NBCD (left) and power deposition to plasma (right) in the peaked (top) and flat density (bottom) discharges as a function of flux surface ($\rho_{\mathrm{pol,aim}}$) at which the beam was aimed.

and $R_{\mathrm{tang}} = 9.1$ m, $\theta = -2.0°$) are a good compromise to maximise the total current drive with minimal penalty in deposited power in both scenarios. The desired current density profile shape and engineering constraints will eventually dictate how far out the beams should be tilted.

Summary

It was demonstrated that BBNBI and ASCOT are capable of flexible and sophisticated modelling of NBI as a part of an ETS simulation. The simulations showed that tilting the DEMO beam vertically results in a few per cent higher current drive than comparable horizontal tilts.

Disclaimer and Aknowledgements

The results presented here, obtained using the WPCD framework, present an integrated modelling exercise testing and verifying the consistency of dedicated physics actors and are not meant to address any decision making on the design and parameters of the DEMO NBI system. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement number 633053 and from Tekes – the Finnish Funding Agency for Innovation under the FinnFusion Consortium. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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