RABBIT: A high-fidelity code to simulate the NBI fast-ion distribution in real-time

M. Weiland[1,*], R. Bilato[1], R. Dux[1], A. Lebschy[1], E. Fable[1], F. Felici[2], R. Fischer[1], O. Kudlacek[1], B. Sieglin[1], M. A. van Zeeland[3], the ASDEX Upgrade[1] and Eurofusion MST1 teams

[1]*Max-Planck-Institut für Plasmaphysik, Garching, Germany*
[2]*École Polytechnique Fédérale de Lausanne, Switzerland*
[3]*General Atomics, San Diego, California, USA*

Knowledge of the fast-ion distribution arising from neutral beam injection (NBI) is important for transport analysis and magnetic equilibrium reconstruction. For sophisticated plasma control, which will be essential for the success of future fusion devices, it is very beneficial to know this distribution function already in real-time during the discharge. Then, the relevant quantities (e.g. heating profiles, current-drive etc.) can be controlled directly and fed to real-time transport and equilibrium codes to improve their estimates of kinetic and current density profiles. Beyond real-time applications, such fast models are essential for optimization problems, e.g. reactor design studies, discharge planning and inbetween shot analysis.

Several sophisticated models exist, that can calculate this beam ion distribution in good agreement with experimental data, such as the Monte-Carlo code NUBEAM [1]. The high accuracy of these codes has, however, to be paid with relatively intensive numerical efforts, which compromises their use in real-time applications. In this contribution, we review the RABBIT code [2]. RABBIT currently takes $\approx$15 ms per time step, which has already been demonstrated in real-time experiments and is faster than NUBEAM by roughly a factor of 1000. The approximations needed to arrive at this goal are discussed. A simplified beam geometry is used for calculating the beam attenuation. The collisions are treated by an analytic solution of the time-dependent Fokker-Planck equation in the uniform-plasma limit. A correction for finite orbit width effects is included by a bounce average of the source term over the first fast-ion orbit. Here, the fast computation time is made possible by calculating only very few orbits ($\approx$ 20) and using an optimized interpolation technique afterwards. Benchmarks have been carried out with the more accurate but also much slower NUBEAM code, indicating a good agreement.

A recent extension of the code is the calculation of the NBI torque input. This is challenging, because only the collisional torque is given as a moment of the distribution function. In addition, the $j \times B$ torque must be taken into account for which we have developed a calculation in the framework of the RABBIT orbit-averaging technique. This is used in ASTRA [3] for momentum transport studies.

In real-time, RABBIT is now run routinely at ASDEX Upgrade and experiments to demonstrate the newly gained capabilities, such as direct control of ion heating or current-drive, are carried out. This will allow more advanced discharge designs and is an important step towards the control capabilities needed for future fusion devices.

References

[1] A. Pankin et al., Computer Physics Communications Vol. 159, No. 3 157-184, 2004.
[2] M. Weiland et al., Nuclear Fusion, 58 082032, 2018.
[3] E. Fable et al., Plasma Physics and Controlled Fusion, 55(12):124028, 2013.

*E-mail: markus.weiland@ipp.mpg.de