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Real-time simulation of the NBI fast-ion distribution

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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 fed to real-time transport and equilibrium codes like RAPTOR, which estimate kinetic and current density profiles in real-time. Beyond real-time applications, such fast models are essential for optimization problems, e.g. reactor design studies or discharge planning.

Several sophisticated models exist, that can calculate this beam ion distribution in good agreement with experimental data, such as the Monte-Carlo code NUBEAM. 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 present the novel code RABBIT (Rapid Analytically Based Beam Injection Tool). RABBIT currently takes ≈25\,ms per time step, which is roughly a factor of 1000 faster than the NUBEAM code. The approximations needed to arrive at this goal are discussed. Benchmarks are carried out with the more accurate but also much slower NUBEAM code, indicating a good agreement.

Several applications of the model on different machines are carried out. RABBIT is run in real-time in the discharge control system of ASDEX Upgrade to improve active plasma control.
In addition, RABBIT is being used for accurate equilibrium reconstructions (with the IDE code) in between shots. This facilitates the development of advanced scenarios, where a fine-tuning of the q-profile is desired.

On DIII-D, RABBIT is foreseen to be used in experiments with the goal to demonstrate real-time control of Alfvén eigenmodes (AE). Here, the neutron rate prediction from RABBIT is compared to the measured neutron rate to detect appreciable fast-ion transport. In conjunction with direct AE detection with ECE diagnostics, when detrimental conditions are observed, counter-measures to stabilize AEs can be activated during the discharge.
This could be of great importance for future fusion reactors, where strong AE activity is expected.

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