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Reduced energetic particle transport models enable comprehensive time-dependent tokamak simulations

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The inclusion of the reduced-physics energetic particle (EP) *kick model* for EP transport in TRANSP has resulted in a dramatic improvement of interpretive and predictive capabilities for time-dependent tokamak simulations including the effects of EP transport by instabilities. The kick model has recovered the measured toroidal Alfvén eigenmode (TAE) spectrum on NSTX-U and has reproduced details of the fast ion diagnostic data measured on DIII-D for EP modes and tearing modes. Being able to predict the occurrence and effect of those instabilities is one of the grand challenges for fusion and a necessary step to mitigate their negative effects. The kick model has proven the potential of phase-space resolved EP simulations to unravel details of EP transport for detailed theory/experiment comparison and for scenario planning based on optimization of NBI parameters. Work is also ongoing to complement the kick model approach with the RBQ1D model based on the resonance-broadening quasi-linear theory to develop a self-consistent, numerically efficient predictive EP transport model. On NSTX-U, the kick model successfully reproduces the stability of co- and counter-propagating TAEs driven unstable by NB injection. The model successfully reproduces the transition from a co-TAE dominated scenario to one with coexhisting co- and counter-TAEs. Based on the analysis, strategies for mitigating the instabilities are developed through TRANSP by varying the NB injection parameters. The phase space resolution implemented in the model is also crucial for its successful validation against fast ion diagnostics data from Fast Ion D-Alpha (FIDA) and neutral particle analyzers (NPA). For DIII-D discharges with strong Alfvénic activity, the amplitude of the instabilities used in the simulation is first adjusted to match the measured neutron rate. The inferred FIDA and NPA signals based on the simulation are then compared with the experimental data for validation, showing excellent agreement. Initial analysis via the RBQ1D model gives similar results, indicating its potential for predictive simulations. Enhancements to TRANSP via the inclusion of reduced EP transport models are playing an important role in scenario development including realistic treatment of fast ion transport by instabilities, e.g. to optimize the scenario by tailoring NB injection power and voltage.

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