Relativistic Boltzmann collision operator for runaway-avalanche studies

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Avalanche runaway generation is a critical threat to large tokamaks such as ITER: according to the Rosenbluth-Putvinski theory [1], a small seed population of fast electrons will multiply through knock-on collisions by a factor of order $\eta \sim \exp(3I[\mathrm{MA}])$, which for plasma currents of order $I = 10$-$15\,\mathrm{MA}$ means that a single fast electron can convert the entire ohmic current to runaway current.

The exponential sensitivity of the avalanche multiplication factor η to the details of the runaway-generation dynamics shows a need for more accurate models of large-angle collisions. Existing models of large-angle collisions that have been used in magnetic-confinement fusion studies [1, 2] have two main flaws: (i) they do not conserve electron momentum or energy, and (ii) they double count collisions with small-angle collisions, which are typically accounted for with a Fokker-Planck collision operator. We have developed a new large-angle collision operator based on the full relativistic Boltzmann equation which resolves these issues. We use kinetic simulations to show how the new improved collision operator modify the avalanche growth rates obtained with previous models. In particular, we compare results with the steady-state theory of Rosenbluth and Putvinski, as well as with theoretical predictions of a recent study [3] for avalanche generation in near-threshold electric fields $E \sim E_c$ in the presence of synchrotron-radiation losses.

References

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