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Simulations of the global, neoclassical, radial electric field in W7-X

Transport phenomena in fusion plasma devices can be categorized into turbulent and neoclassical parts. Although the primary contribution to particle and heat losses in both tokamaks and optimized stellarators is originates from turbulence, the significance of neoclassical transport theory should not be overlooked. Its applications, for example the prediction of the bootstrap current, are of great importance in fusion research. This work focuses specifically on the neoclassical radial electric field in stellarators.

In a quasi-neutral plasma close to thermodynamic equilibrium (with comparable electron and ion temperatures, i.e., $T_e \approx T_i$), the electric field within the plasma vessel is commonly negative, and referred to as an ion root. However, in cases where the electron temperature significantly exceeds the ion temperature ($T_e \gg T_i$), the electric field takes on a positive value, known as an electron root. This can be achieved through, for instance, ECRH heating. In the majority of the plasma vessel, the local neoclassical transport theory accurately predicts this behavior as a consequence of the ambipolarity condition governing ion and electron fluxes. However, the theory encounters limitations where a transition occurs between the two solutions. Moreover, since the electric field undergoes a sign change during the transition, the strongly sheared $\mathbf{E} \times \mathbf{B}$ flow is likely to impact turbulence. To gain a deeper understanding of the physics behind this phenomenon, comprehensive simulations of global neoclassical transport become necessary. In this study, we present the first self-consistent simulations of global neoclassical radial electric field using the particle-in-cell code EUTERPE.

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