Topic: TH

Manipulating ambipolar electric field to improve confinement in stellarators

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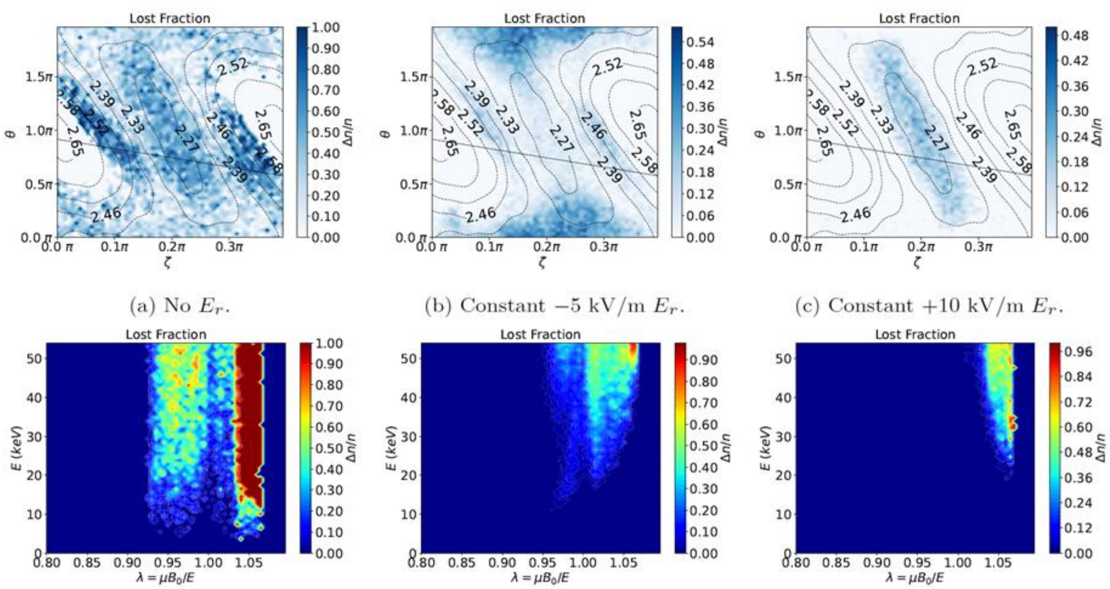
Neoclassical ambipolar radial electric field E_r could suppress microturbulence and improved confinement in the stellarators. It can also affect energetic particle transport and be modified by energetic particle radial drift, which induces a radial current that changes the E_r. Preliminary study on the LHD stellarator has shown that perpendicular beam injection can modify the *Er* and leads to significant density peaking as compared to the parallel beam injection. The intrinsic 3D magnetic field in the stellarators provides a unique possibility of manipulating the *Er* by deliberately injecting the neutral beam (NBI) into certain regions of the phase space to induce a radial current. The goal is to maximize the effects of E_r by pinching inward or losing outward, depending on ion or electron root, a small amount of low energy NBI in order to minimize thermal plasmas turbulent transport and alpha particle loss in an optimized stellarator reactor. Detailed study of phase space dependence of the fast ion loss may also help removal of helium ash after alpha particles deposit most of their birth energy to thermal plasmas but are still much more energetic (e.g., ~100s keV) than thermal plasmas.

In this work, global gyrokinetic code GTC has been utilized to study interactions between fast ions and neoclassical ambipolar electric field E_r, as well as their effects on plasma confinement in the LHD and W7-X stellarators. We will report detailed studies of phase space structures of fast ion transport, self-consistent simulations of the E_r and its suppression of microturbulence, and the interactions between the E_r and fast ions to assess the feasibility of controlling E_r by the NBI in the stellarators.



(a) No E_r. (b) Constant -5 kV/m E_r. (c) Constant $+10$ kV/m E_r.

(d) No E_r. (e) Constant -5 kV/m E_r. (f) Constant $+10$ kV/m E_r.

Fig. 1: *The initial position of lost fast ions in the flux-surface (Boozer angles θ-ζ plane, upper panels) and in the energy and pitch angle (E-λ plane, lower panels) at a mid-radial location of normalized poloidal flux function ψ=0.2 in W7-X. Three cases are plotted: E_r=0 (left column), E_r=-5kV/m (middle column), and E_r=10kV/m (right column). The background color represents the loss fraction. The black solid line in the upper row is magnetic field line and the dashed contours represent the amplitude of the magnetic field.*

Phase space structures and Er effects-- GTC simulations of collisionless fast ions loss in the W7-X and LHD show that the lost fast ions originate from localized regions of the phase space, e.g., helically trapped particles with large perpendicular kinetic energy in the weak magnetic field regions of the W7-X as shown in Fig. 1. The lost regions in the phase space can be significantly affected by radial electric fields associated with a change of electrostatic potential much smaller than the particle kinetic energy, which can have important implications for the alpha particles in the future stellarator fusion reactors. Similar results were obtained for the LHD. These localized phase space structures of the lost fast ions provide an opportunity for inducing radial current to control the E_r by injecting NBI into desired locations of the phase space.

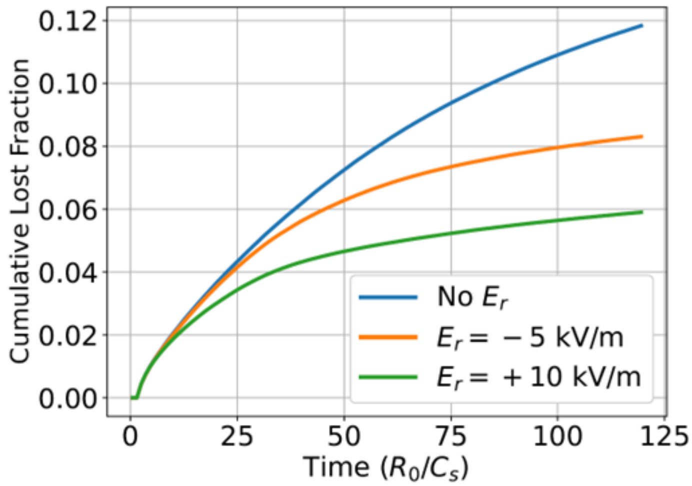


Fig. 2: *Time history of cumulative faction of lost particles for various E_r values.*

The uniform E_r significantly reduces the lost fraction as shown in Fig. 2 by moving fast ions across the lost and confined regions of the phase space. As a result, the lost region in the phase space is also modified by the E_r as shown in Fig. 1. Note that the uniform E_r has no effects on particle confinement in the axisymmetric tokamak, where only the E_r shear can affect the particle orbit and confinement.

Manipulating E_r using fast ions—As a proof of principle test, we perform GTC simulations by artificially adding a small localized radial current carried by fast ions to induce a large E_r in the W7-X equilibrium with an electron root. We fix the total beam energy density $\alpha=\beta_{beam}/\beta_{total}$ =1.29%, but vary the radial profiles with different peaks of β_{beam}. The simulations show that a large localized radial electric field E_r can be induced by realistic amount of fast ion radial current (Fig. 3). Such a large E_r can suppress microturbulence as shown in earlier GTC simulations [2]. Finally, we have performed LHD experiments with various NBI energy and pitch to study effects of fast ion distribution on the E_r. Analysis of measured E_r profiles dependent on fast ions distribution and their effects on the plasma confinement will be reported.

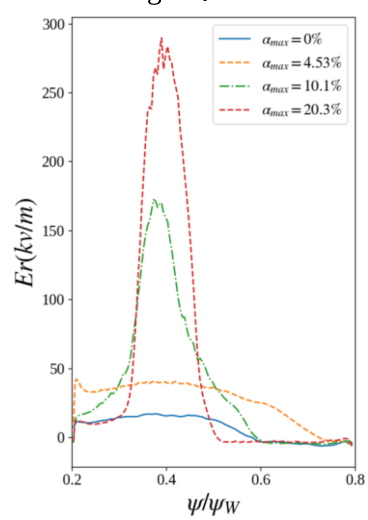


Fig. 3: *Radial profiles of the E_r from GTC simulations of the W7-X equilibrium with various localized radial current of fast ions.*

References:

[1] Z. Lin et al, Science **281**, 1835 (1998).

[2] J. Y. Fu et al, Phys. Plasmas **28**, 062309 (2021).

Acknowledgments:

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