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Investigation of Radial Electric Field Effects on Global Neoclassical Transport and Neoclassical Viscosity Torque in Three-Dimensional Magnetic fields

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Stellarators, together with tokamaks, are leading candidates for magnetic confinement fusion reactors because of their intrinsic stability and capability for steady-state operation. However, their three-dimensional asymmetric fields give rise to distinctive neoclassical transport regimes compared to tokamaks - most notably the $1/\nu$ regime and $\nu-\sqrt{\nu}$ regime – which should be well analyzed to optimize magnetic configurations. Although effective helical ripple, routinely evaluated with the local $1/\nu$-transport based code NEO, has long served as a conventional reference model because of its intuitiveness and computational speed, it faces two important limitations. First, its formulation is restricted to the $1/\nu$ collisionality regime and therefore omits $\nu-\sqrt{\nu}$ and other non-$1/\nu$ physics. Second, its local approximation neglects finite orbit width effects, preventing a full assessment of radial transport.

As part of a broader effort to develop the first Korean stellarator concept, we apply the global Monte-Carlo code FORTEC-3D [2,3] to analyze neoclassical transport in stellarator magnetic fields. FORTEC-3D follows full particle orbits across a wide range of collisionalities, providing a more comprehensive assessment of confinement properties.

We first benchmarked FORTEC-3D against NEO for several magnetic configurations, including NCSX and quasi-symmetry (QA, QH) equilibria. Benchmarking shows that FORTEC-3D and NEO agree closely when the radial electric field E_r is negligible and transport is dominated by the $1/\nu$ regime. However, when a finite E_r develops, the two codes show inconsistent results because particles migrate into the $\nu-\sqrt{\nu}$ regime, which NEO cannot capture. To clarify the impact of E_r, we computed spectra of neoclassical toroidal (NTV) and poloidal viscosity (NPV) torques in NCSX configuration as functions of E_r. Preliminary results show that increasing E_r shifts the dominant (m,n) Fourier modes contributing to NTV and NPV, as reported in [4].

These findings suggest that a configuration deemed favourable in a purely $1/\nu$ framework may lose its advantage once a radial electric field arises and $\nu-\sqrt{\nu}$ regime transport makes a substantial contribution. Ongoing work will extend the analysis to a broader set of equilibria and parameter scans, providing design guidelines for stellarator optimization.

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References

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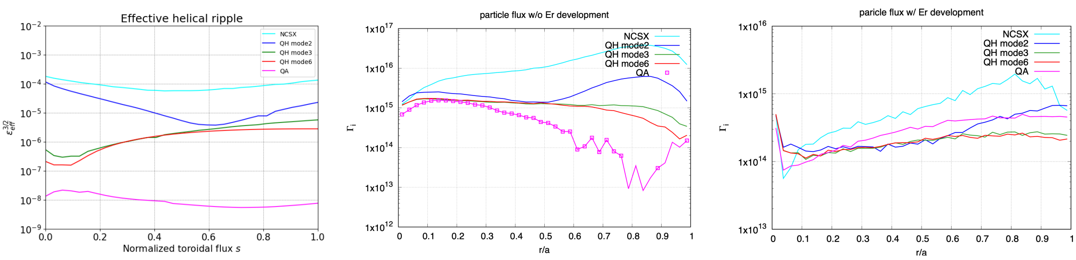

Figure 1. NEO result (left) and FORTEC-3D result without (middle) and with E_r (right).
One can see consistency between left and middle graph. However, when electric field develops, tendency of flux changes.

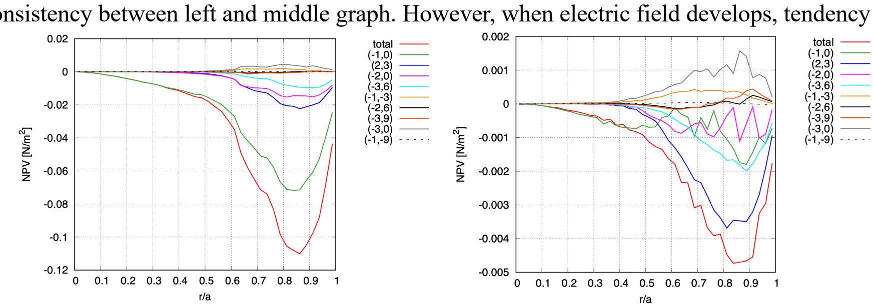

Figure 2. NPV result in NCSX without (left) and with E_r (right).
One can see that dominant (m, n) modes are different whether electric field develops or not.