Recently, full-f gyrokinetic simulations, in which the total particle distribution is evolved based on the first principle, are regarded as powerful tools to investigate the turbulent transport and profile formations. Rich physics has been revealed by full-f gyrokinetic simulations in axisymmetric tokamak plasmas. However, full-f gyrokinetic simulations in non-axisymmetric, or three-dimensional plasma equilibria such as stellarators and/or helical devices have not been reported so far. The absence of the toroidal symmetry is ubiquitous even in tokamaks due to error fields by the coil imperfection in realistic devices, MHD activities, and externally imposed non-axisymmetric perturbations. Hence, full-f gyrokinetic simulations in three-dimensional configurations will lead to the better understanding of the plasma transport phenomena both in tokamaks and stellarators.

In this work, we present the first numerical results of full-f gyrokinetic simulations in three-dimensional plasma equilibria. A full-f global gyrokinetic code based on the Eulerian approach, GT5D [1], is extended to treat three-dimensional equilibria by developing a new interface between GT5D and VMEC [2], where VMEC is a widely-used numerical tool to construct a three-dimensional equilibrium. What is difficult in implementing three-dimensional geometries of VMEC in GT5D is the treatment of the boundary at the plasma edge due to the difference between the shapes of their numerical meshes. GT5D solves the gyrokinetic equation in Cylindrical coordinates, while VMEC provides equilibrium quantities in the magnetic coordinates. Since Cylindrical meshes of GT5D requires the quantities outside the last closed flux surface (LCFS), the quantities of VMEC should be extrapolated outside the LCFS.

To resolve the issue, we extend GT5D so as to solve the gyrokinetic equation in the magnetic coordinates instead of Cylindrical ones. This enables us to avoid the numerical difficulty at the plasma edge region, since any quantities outside the LCFS are no longer required. On the other hand, owing to the usage of the magnetic coordinates in GT5D, another numerical problem arises at the plasma core, where a pole singularity of the finite difference scheme should be removed. For this purpose, Morinishi’s finite difference operator for Cylindrical coordinates [3] is extended to non-orthogonal systems by properly defining the Jacobian and metrics around the pole. The extended scheme guarantees the conservation of the particle and energy numerically at the pole. In the presentation, we will also present the first numerical verifications of full-f gyrokinetic simulations in three-dimensional plasma equilibria by comparing the neoclassical transport coefficients of GT5D+VMEC to those obtained by FORTEC-3D [4], where FORTEC-3D is a global neoclassical transport code based on the Monte Carlo method. The radial electric field is another key physics in three-dimensional equilibria. The radial electric field is determined by the ambipolar condition of the neoclassical particle transport, and the quasi-steady state values of both codes are benchmarked.