10th CWGM (IPP Greifswald)

Proposal : Simulation / Experimental studies on flow and viscosity in helical plasmas

S. Satake, H. Takahashi: NIFS (LHD)

A. Alonso, J.L. Velasco : CIEMAT (TJ-II)

Background / motivation

◆ **Flow and viscosity in plasmas**

→ important to understand transport (both neoclassical and turbulence, interaction b/w them), confinement, and stability (ex. Hidalgo's talk)

◆ **Helical magnetic field geometry**

→ flow / viscosity strongly depend on the configuration, collisionality and radial electric field

→ self-consistent treatment of the ambipolar condition is required

→ variation in poloidal and toroidal as well as in radial directions

→ variety of configurations and parameters (within a device, among devices)

⇓

There are wide varieties of research subjects to be challenged in experiments, theories, and simulations.

Objects of the research on flow & viscosity in helical plasmas in CWGM

1. Prepare and benchmark the tools for simulations in helical plasmas

   To make reliable ways of calculating neoclassical viscosity and flow in 3-D helical plasmas.

   - DKES, PENTA (mono-energy + momentum correction, local, multi ion species)
   - FORTEC-3D (non mono-energy & global, single species)

   Benchmark using LHD and TJ-II configurations is ongoing now (Velasco and Satake). Other NC codes (especially global ones)?

2. Applications to experiment analyses
   - Biasing experiment → Can control plasma rotation easily. LHD biasing system has high enough voltage to see nonlinear dependence of NPV. TJ-II can modulate bias voltage (low- and high-freq.)→estimation of plasma conductivity and viscosity from experiments.
   - Comparison with Reynolds stress, damping rate of zonal flows → TJ-II and HSX have good diagnostic of potential and flow. LHD → new XICS.
   - Ambipolar condition and NC viscosity in HSX (problem of ion peaked flux at $E=E_{res}$ in PENTA) ← FORTEC-3D can resolve it?
   - Promote cross-machine comparisons to cover the variety of parameter and configuration dependence of F&V.

Appendix

Approaches by theory & simulation

- **Analytic, semi-analytic (bounce-averaged DKE)**
  - intuitive, quantitative understanding on flow / viscosity in helical plasmas. Difficult to apply to complicated magnetic geometries of recent helical devices.

- **DKES code (momentum method)**
  - offers generic way to evaluate F&V. With Sugama-Nishimura's momentum correction method, it is applicable to quasi-symmetric configurations.
  - Limitation from the mono-energy approximation and neglect of magnetic drifts (large-$E \times B$ rotation approx.).

- **Monte-Carlo method**
  - The δf MC simulation is adopted for direct evaluation of F&V in realistic helical magnetic configurations / parameters.
  - Non-local calculation including the magnetic drifts (both normal and tangential to flux surfaces), compressive $E \times B$ flow.
  - Applications → Neoclassical toroidal viscosity in tokamaks w/ RMP.
    <u>Neoclassical viscosity in LHD baising plasmas.</u>
    Today's my talk

Approaches by experiments

In LHD (and some smaller helical devices : H-J, TU-heliac, CHS)

(*ex.* Kitajima, Takahashi et al., IAEA FEC 2010)

- Poloidal rotation is excited by the $J \times B$ torque of biasing current. Transition in biasing voltage-current relation is observed which is accompanied with transition in plasma confinement.
- Related to the nonlinear dependence of NPV on $E \times B$ rotation speed.
- Amplitude of the viscosity depends on the magnetic axis position.
- HIBP (only core region). Available measurement is limited.

In TJ-II (C. Hidalgo et al., PPCF 2004, A. Alonso et al., Eur. Phys. Lett. 2009 J. L. Velasco, today's talk)

- Biasing experiments are conducted to study improved confinement regimes and the effects of sheared $E \times B$ rotation in turbulence.
- Study flow dynamics under the effect of a controlled force using low- and high-frequency modulations of biasing current.
- Good measurements by probes and HIBPs → spatial profile and time evolution of the plasma potential and the $E \times B$ flow can be observed.
- Detailed viscosity calculation by DKES and comparisons with $J \times B$ force.

In HSX (R.S. Wilcox et al., 18th ISHW 2012@Australia, today's talk)

- Measurement of E_r and E_θ using Langmuir probe.
- Evaluation of Reynolds stress from measurement and comparison with NC viscosity using PENTA code.

Benchmark test b/w DKES and FORTEC-3D codes

J. L. Velasco and S. Satake

- Magnetic field → VMEC code
  Test case configuration of TJ-II and LHD plasmas are chosen from published papers.
- DKES calculation → Scan the E_r-dependence
- FORTEC-3D code → Scan the E_r-dependence, or solve time evolution towards an ambipolar state

Time evolution of radial electric field : $\epsilon_\perp \frac{\partial}{\partial t} E_\rho(\rho, t) = -e\left(Z_i \Gamma^i_D - \Gamma^e_D\right)$

(FORTEC-3D can solve only one species at once)

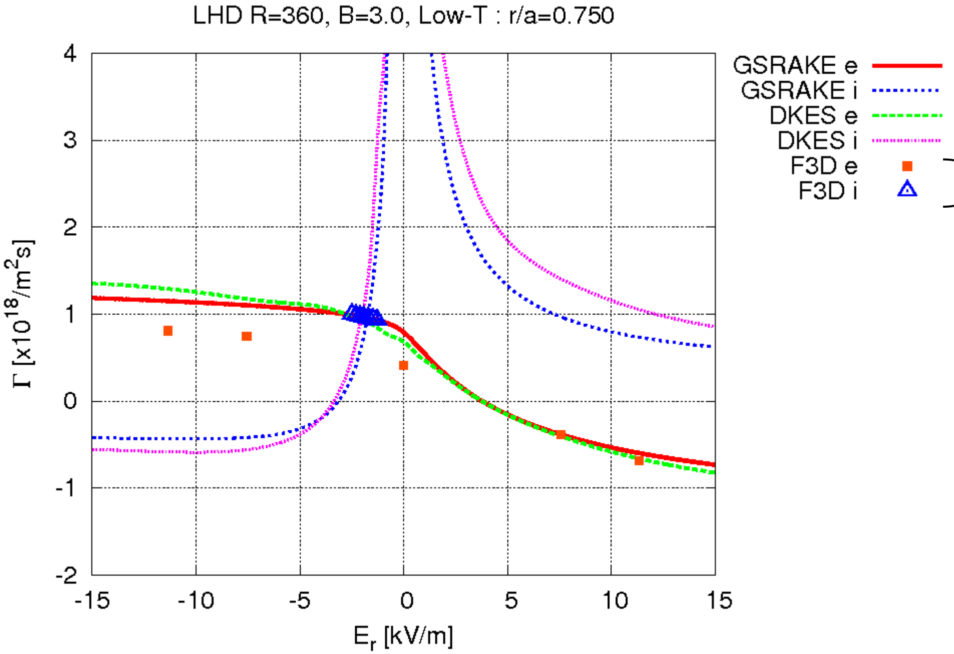
FORTEC-3D

DKES
(or GSRAKE)

- In FORTEC-3D, parallel flow evolves in time as a result of the balance of poloidal and toroidal viscosities and $E \times B$ rotation.
  → Difficult to obtain a steady-state solution in some cases.

- Primary test cases went well, though we find quantitative difference b/w DKES and FORTEC-3D simulation results.
- Reasons of the difference – Parallel flow? Magnetic drift? Non-local effect? Mono-energy treatment? ← Needs consideration.
- FORTEC-3D is very heavy code …

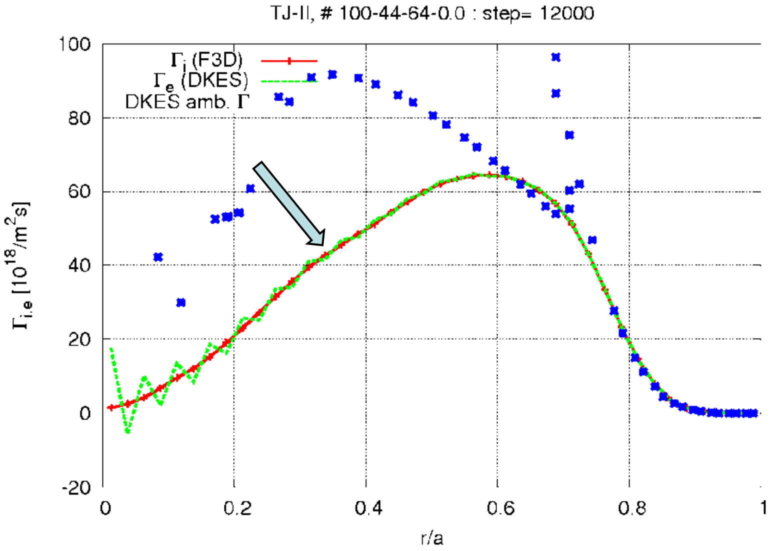
Examples of $E_r - \Gamma$ relation

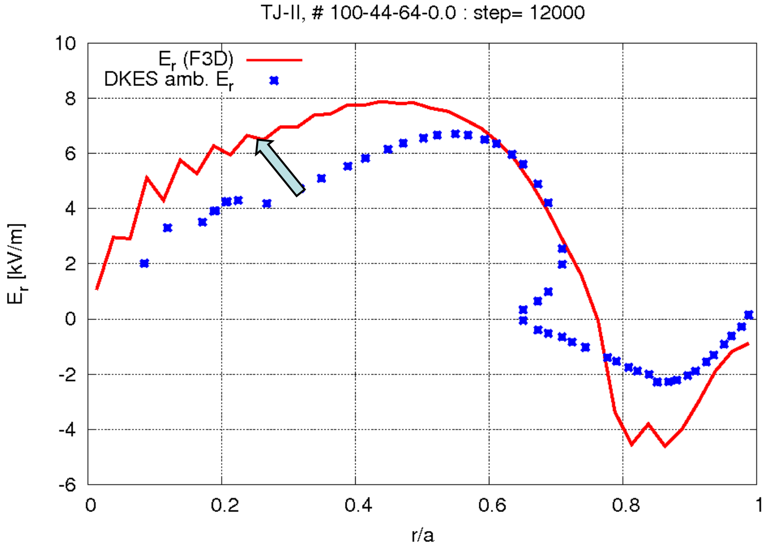


Electron : Fixed E_r profile
Ion : E_r evolves in time

Left : E_r-dependence of particle flux in a LHD case.

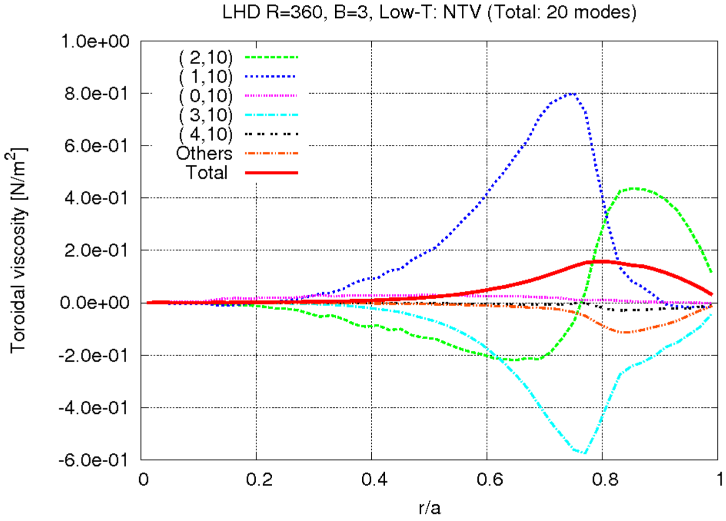
Bottom: Ambipolar flux and E_r in a TJ-II case.

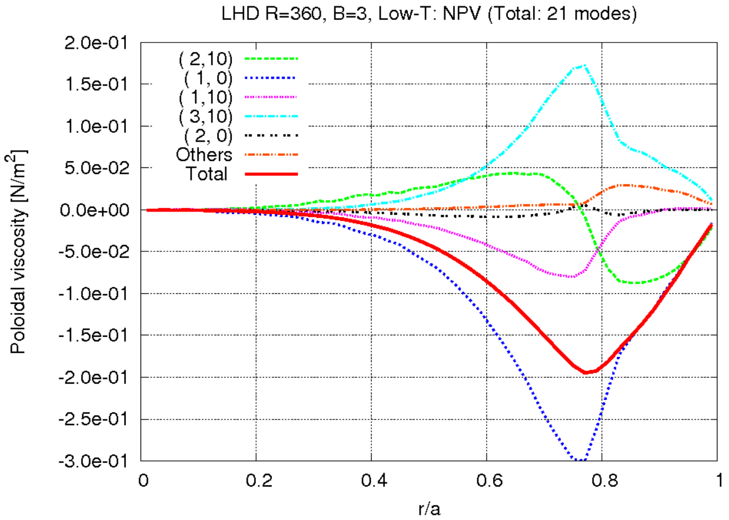




Examples of neoclassical viscosity profile

LHD

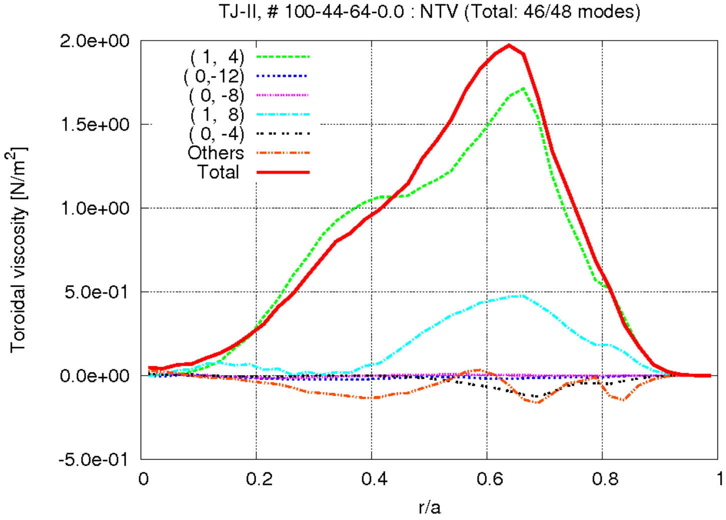

LHD R=360, B=3, Low-T: NTV (Total: 20 modes)

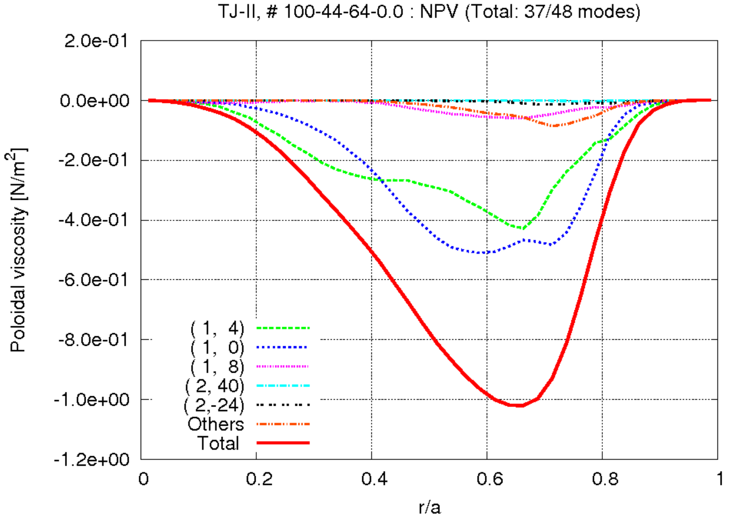

LHD R=360, B=3, Low-T: NPV (Total: 21 modes)

Toroidal

Poloidal

TJ-II


TJ-II, # 100-44-64-0.0 : NTV (Total: 46/48 modes)


TJ-II, # 100-44-64-0.0 : NPV (Total: 37/48 modes)