Effect of Reynolds stress on momentum balance and flows in HSX

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Overview

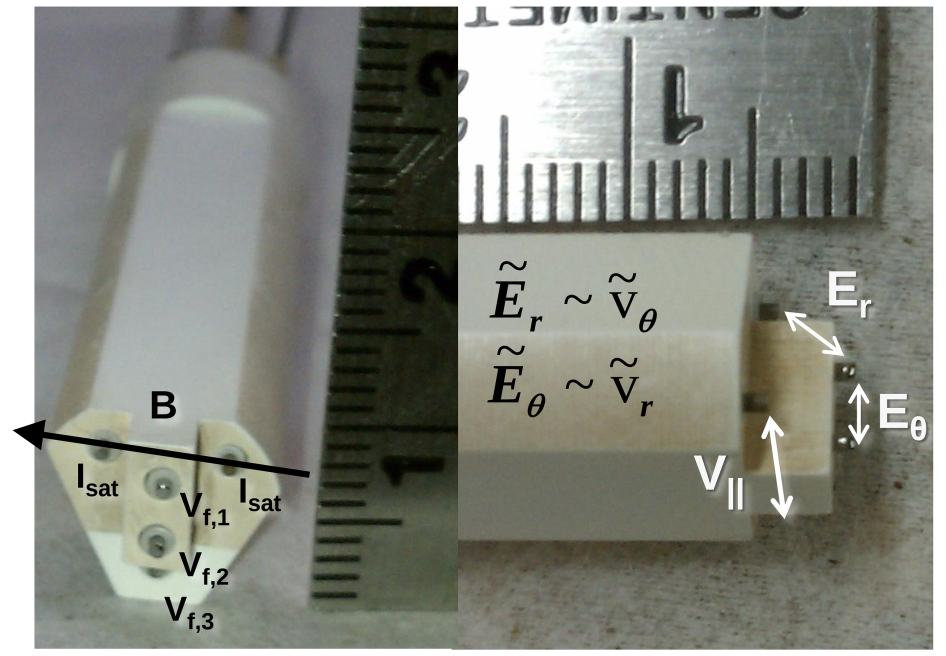
- *How optimized must a magnetic configuration be for E_r to be determined through non-neoclassical processes?*
- Measurements with both Langmuir probes and CHERS indicate that E_r can deviate from neoclassical calculations which calculate particle flux and enforce the ambipolarity condition
- Local measurements of Reynolds stress indicate a flow drive corresponding qualitatively to the deviation in the measured radial electric field
- For a sufficiently quasi-symmetric magnetic configuration, the neoclassical viscosity can be compensated for by the Reynolds stress (or Maxwell stress) due to turbulence
- Future plans: New probe installation to get a better estimate of flux surface average value of Reynolds stress term in the momentum balance
- Neoclassical transport to be scaled by varying magnetic configuration and collisionality to test when non-ambipolar particle transport and neoclassical viscosity dominate the Reynolds stress term in the momentum balance to determine the radial electric field

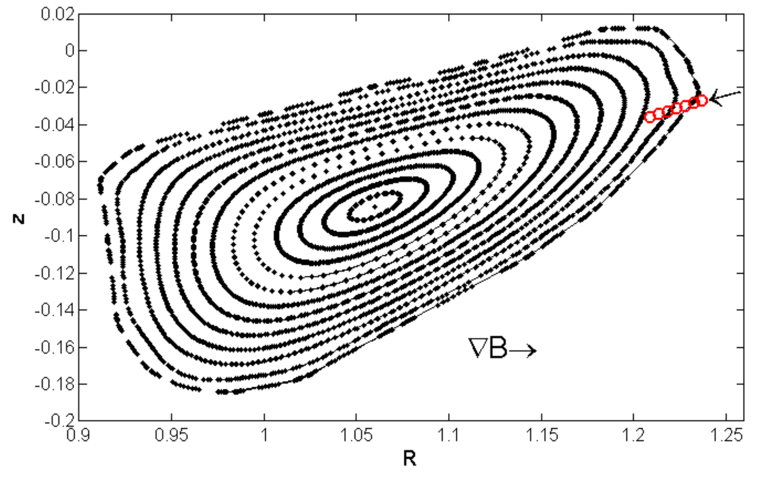
Langmuir Probe Setup

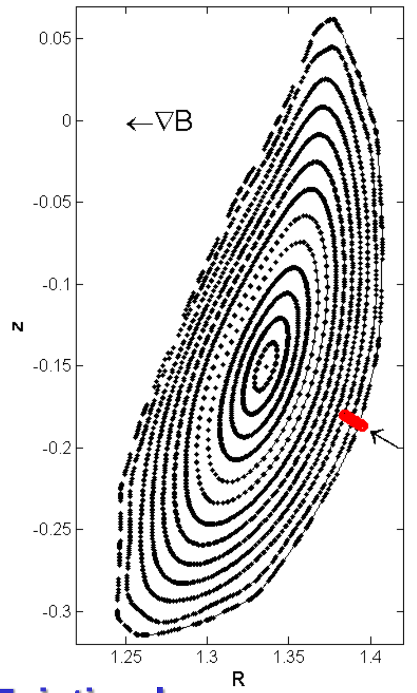
- 5-pin Langmuir probe measures floating potential to infer E_r and E_θ, and differential ion saturation current pins are configured as a mach probe for $V_{||}$
- Fluctuating velocity components obtained from measured fluctuating ExB velocities, assuming ∇T_e fluctuations are negligible:

$$\tilde{v}_\theta \sim \tilde{E}_r = \frac{d\tilde{V}_f}{dx_r} \qquad \tilde{v}_r \sim \tilde{E}_\theta = \frac{d\tilde{V}_f}{dx_\theta}$$

- Fluctuating $v_r v_\theta$ profile taken on shot-by-shot basis from single port location, radial derivative taken to estimate Reynolds stress flow drive



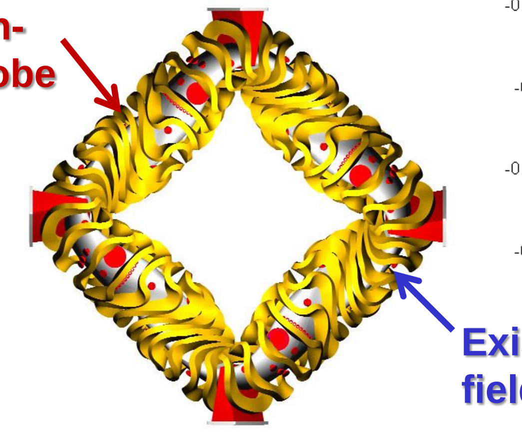




Additional Langmuir probe installation

- Need the flux surface average value of Reynolds stress to properly account for it in momentum balance
- Current probe location is in region of low field and bad curvature, where trapped particle and resistive ballooning instabilities are expected to be destabilized
- Additional probe installation on high-field side of magnetic surface should provide better estimate of flux-surface average value of the Reynolds stress

Planned high-field side probe



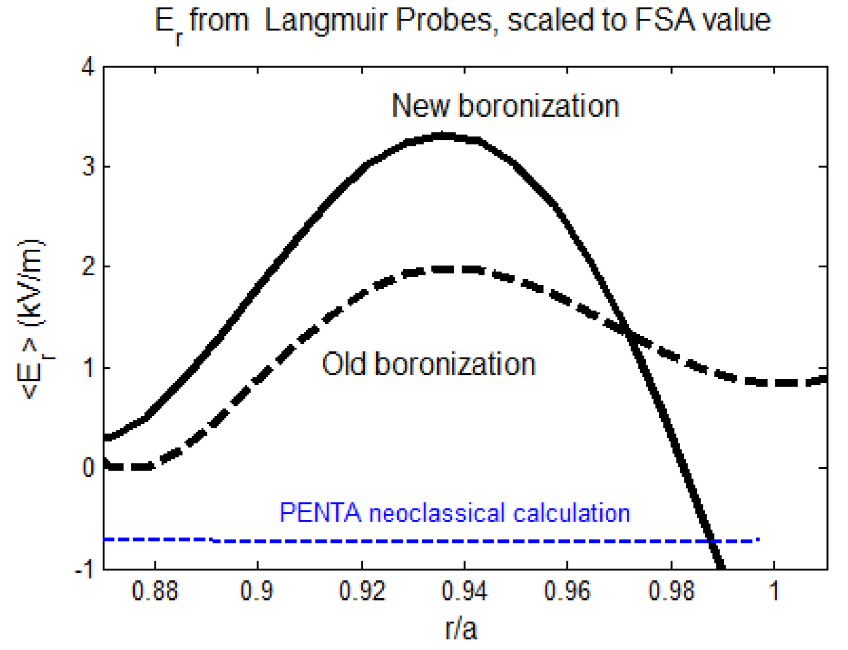
Existing low-field side probe

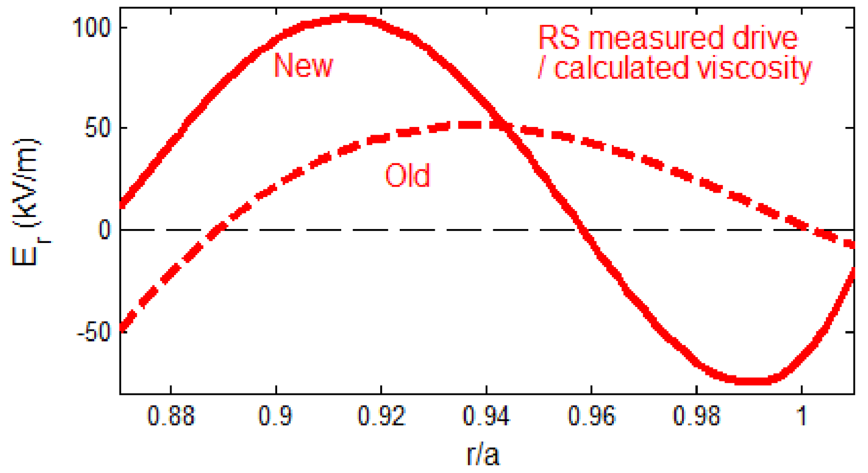
Deviation of E_r from Neoclassical Prediction

- Using Langmuir probes to measure the radial floating potential profile on a shot-by-shot basis, E_r was found to deviate from the neoclassical calculations made using the PENTA code [1,2]
- No T_e gradient information available, but based on edge Thomson scattering measurements and a reasonable assumption of temperature gradient, this affect should not greatly affect interpretation of E_r from floating potential signals
- Given a small enough non-ambipolar neoclassical particle flux, other effects can compete to determine the radial electric field [3,4]

$$\vec{J}\times\vec{B} - \nabla p - \frac{\partial(\rho\vec{V})}{\partial t} = \nabla\cdot\left(\rho\vec{V}\vec{V} + \vec{\vec{\pi}}\right)$$

Reynolds stress — Viscosity (NC + turbulent)

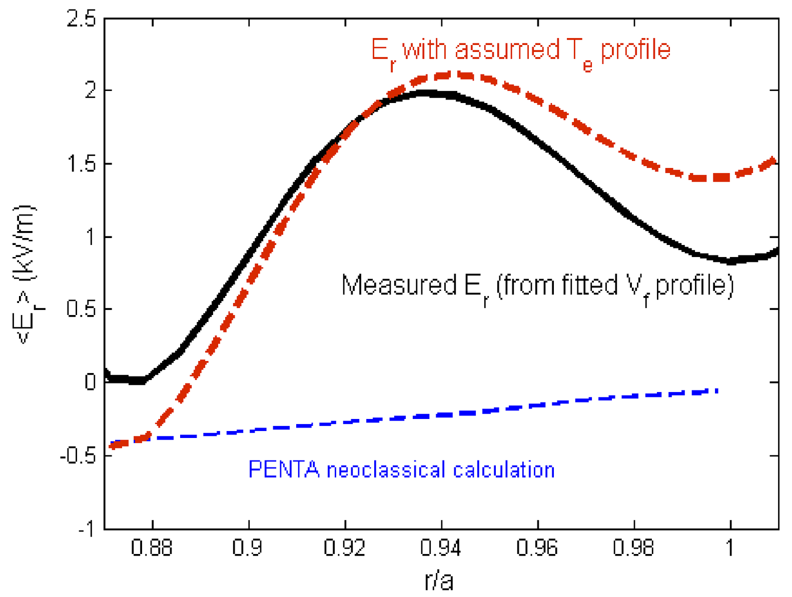




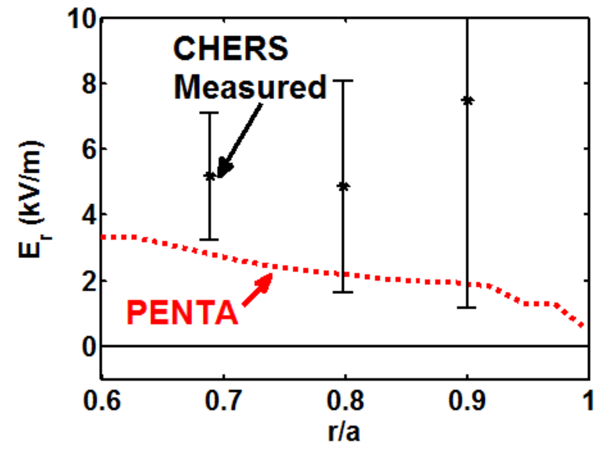
- Deviation of E_r from neoclassical prediction corresponds qualitatively to large measured Reynolds stress flow drive
- Measured Reynolds stress drive and deviation from neoclassical E_r calculation both increase with changing impurity content (wall conditioning)
- Neoclassical calculations are relatively insensitive to expected experimental changes
- Locally measured Reynolds stress and modeled neoclassical viscosity greatly over-predict rotation and resultant Er
  - May be due to location of measurement on a flux surface (new probe should help)
  - T_e fluctuations may also be playing a role
- Reynolds stress flow drive estimated from poloidal momentum balance [4] and a rough estimate of neoclassical plus neutral viscosity:

$$\frac{\partial}{\partial t}\langle v_\theta\rangle = 0 = -\frac{\partial}{\partial r}\left(r^2\langle\tilde{v}_r\tilde{v}_\theta\rangle\right) - \mu_\theta\langle v_\theta\rangle - \nu_{in}\langle v_\theta\rangle$$

$$\langle v_\theta\rangle_{RS} = -\left(\frac{1}{\mu_\theta+\nu_{in}}\right)\frac{\partial}{\partial r}\left(\langle\tilde{v}_r\tilde{v}_\theta\rangle\right)$$

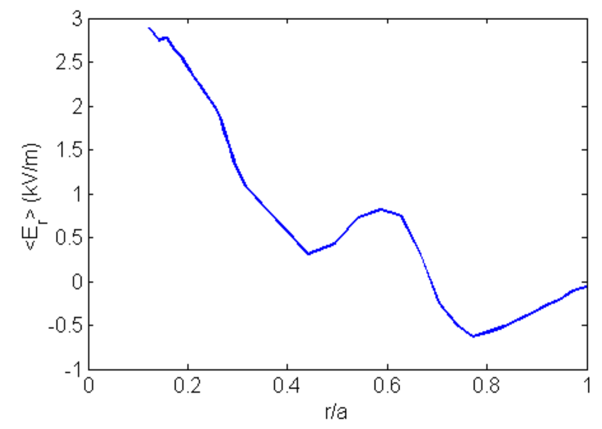


CHERS also measures possible deviation from neoclassical predictions in CH4 plasmas (different plasma parameters)



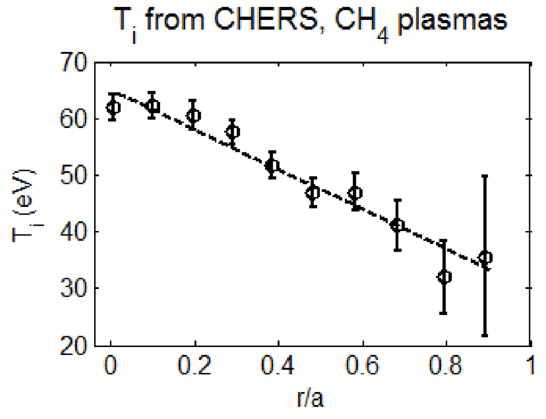
[A. Briesemeister et. al., PPCF 2012 (pending)]

PENTA Neoclassical E_r Predictions

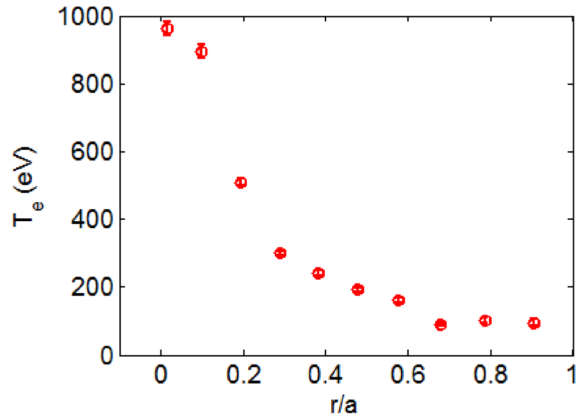


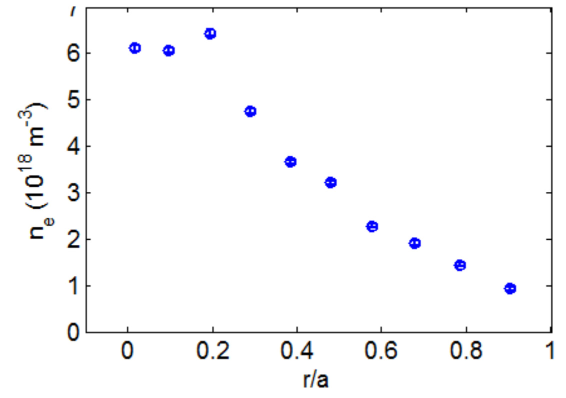
- "Ion root" solution exists at all positions across the minor radius, so "electron root" solutions in the core are not plotted here

- PENTA code [1,2] calculates the neoclassical particle fluxes for a set of plasma parameters in a given magnetic configuration, then finds the ambipolar radial electric field
- PENTA uses monoenergetic DKES transport coeffecients, corrects for momentum conservation



- T_i from CHERS measurement in a methane discharge
- T_i input into calculations is scaled down to account for removal of C ion species from plasma
- Neoclassical calculations relatively insensitive to changes in T_i

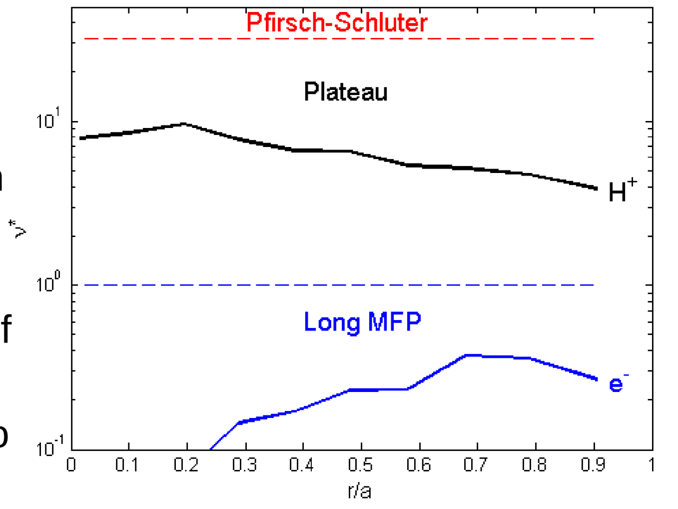




Planned Experiments

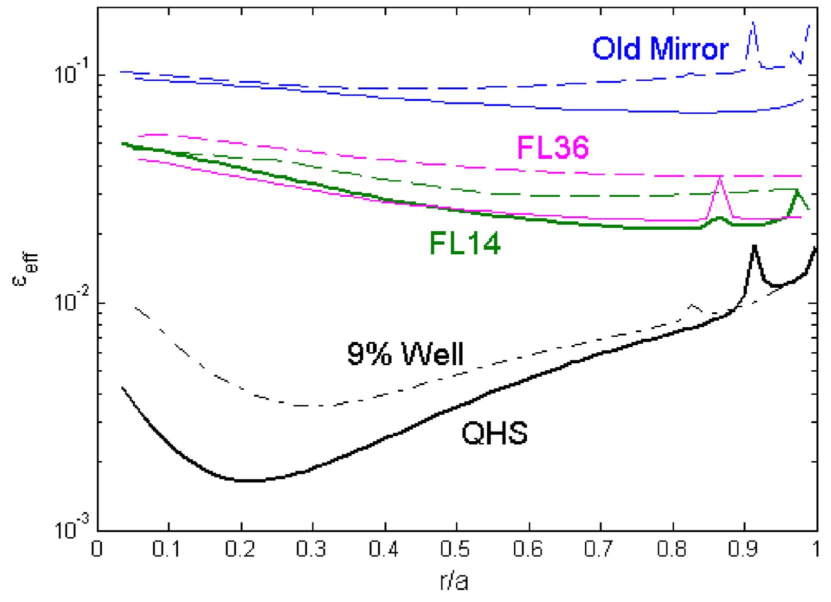
Collisionality scan

- Neoclassical 1/ν transport occurs only in the long mean free path collisional regime
- Ions are solidly in the plateau regime and no direct ion heating is available, so ion particle transport is relatively fixed experimentally
- Electron collisionality will be scanned to test scaling of deviation of E_r and $V_{||}$ from neoclassical calculations
- Expectation is that less collisional electrons will lead to larger deviation from neocassical, and vice-versa



Alternate Magnetic Configuration

$$\nu_j^* = \frac{\nu_j}{\epsilon\omega_{bj}} \propto \frac{n}{T^2}$$



- Compare neoclassical particle transport in different magnetic configurations
- Effective ripple is a measure of particle loss in collisionless regime for E_r=0 [5]
- For a given percentage of auxiliary coil current, pick configuration with most effective ripple to compare to optimized QHS configuration
- Expectation would be for E_r measurements to more closely match the neoclassical calculation in configuration with designed symmetry broken

Summary

- For a sufficiently optimized magnetic configuration, Reynolds stress can contribute to or even dominate neoclassical non-ambipolar transport in the determination of the radial electric field and rotation
- E_r measured in HSX is different than what is calculated from the ambipolarity condition of neoclassical transport calculations in the edge
- Additional Reynolds stress probe is planned to get a better estimate of the flux surface average value of the Reynolds stress flow drive
- Proposed experiments will explore the scaling of deviation from neoclassical calculations with breaking of the designed symmetry, as well as the scaling with electron collisionality and neoclassical electron particle transport

References

1) D.A. Spong, *Phys. Plasmas* 12 (2005) 056114.
2) J. Lore at al., *Phys. Plasmas* 17 (2010) 056101.
3) P. Helander and A.N. Simakov, *Phys. Rev. Lett.* 101 (2008) 145003.
4) P. Helander and A.N. Simakov, *Contrib. Plasma Phys.* 50 (2010) 695.
5) V.V. Nemov et al., *Phys. Plasmas* 6 (1999) 4622.

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