Measurements and neoclassical modelling of radial electric field and flows in HSX

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Abstract

- The radial electric field (E_r) and bootstrap flow (v_{bs}) are obtained in HSX stellarator from Pfirsch-Schlüter effect.
- New measurements show significantly larger flows in broken symmetry ('mirror') configuration.
- Preliminary analysis indicate that flows and E_r in the symmetry configuration may be governed by non-neoclassical processes in the core.

E_r from Pfirsch-Schlüter effect - theoretical background

The parallel ion flow at any location in the plasma is given by,

$$\vec{v}_{||i} = \underbrace{\vec{v}_{bs}}_{\text{flux function}} + \underbrace{\vec{v}_{ps}}_{\text{local}} \tag{1}$$

The Pfirsch-Schlüter flows (v_{ps}) are flows parallel to the magnetic field lines that arise due to incompressibility. For ions,

$$\nabla \cdot (\vec{v}_{\perp i} + \vec{v}_{||i}) = 0 \tag{2}$$

$$\vec{v}_{\perp i} = \frac{\vec{E}_r \times \vec{B}}{B^2} - \frac{\nabla P_i \times \vec{B}}{e n_i Z_i B^2} = -\left(\frac{d\phi}{d\psi} + \frac{1}{e n_i Z_i}\frac{dP_i}{d\psi}\right)\left(\frac{\nabla\psi \times \vec{B}}{B^2}\right) \tag{3}$$

From equations 1,2 & 3, the Pfirsch-Schlüter flow can be written as,

$$\vec{v}_{ps} = \left(\frac{d\phi}{d\psi} + \frac{1}{e n_i Z_i}\frac{dP_i}{d\psi}\right) h\vec{B}$$

where h is a geometrical factor, which is defined by

$$\vec{B} \cdot \nabla h = -2\frac{(\vec{B} \times \nabla B) \cdot \nabla\psi}{B^3}, < hB^2 >= 0$$

$d\phi/d\psi$ can be written as,

$$\frac{d\phi}{d\psi} = \frac{v_{ps}}{hB} = \frac{v_{||i} - v_{bs}}{hB}$$

Therefore, the flux surface function $d\phi/d\psi$ can be obtained by measuring the parallel flow for at least 2 locations on a flux surface.

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CHERS on HSX is modified to measure Pfirsch-Schlüter effect

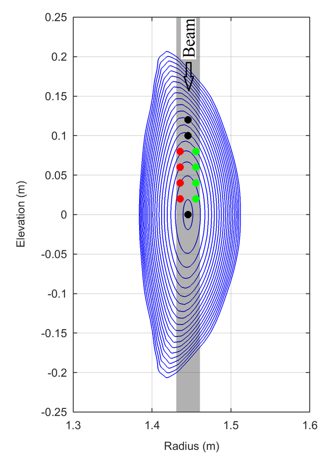


Figure 1: Inboard/outboard measurement locations

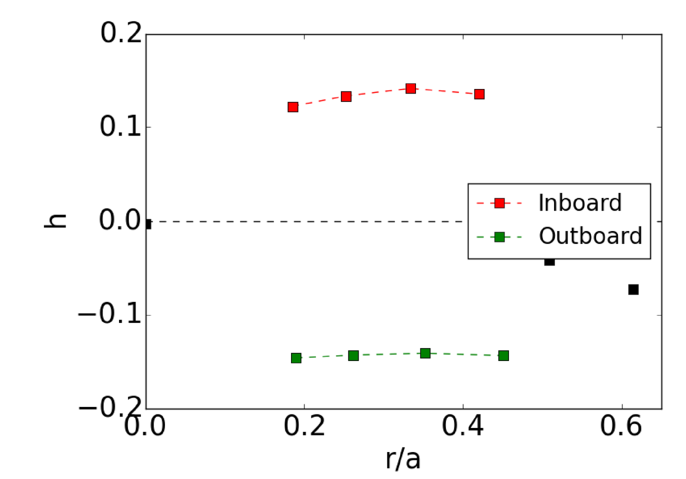


Figure 2: Calculated Pfirsch-Schlüter factor at the measurement locations

Inboard/outboard flow asymmetry has been observed

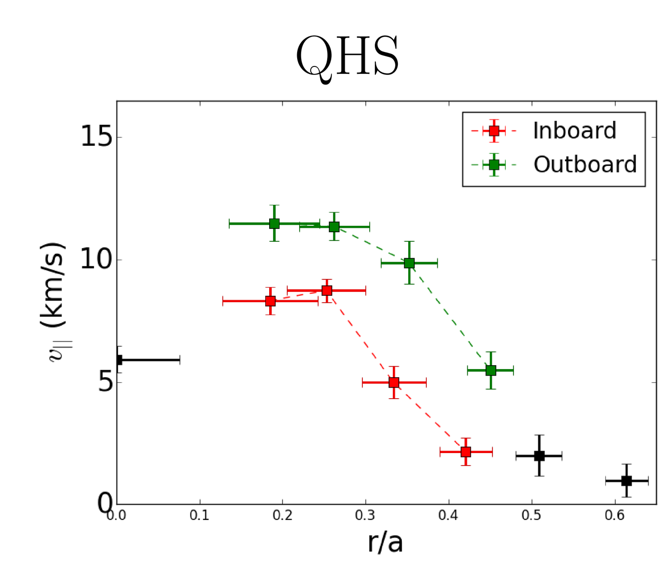


Figure 3: Parallel flows in QHS geometry

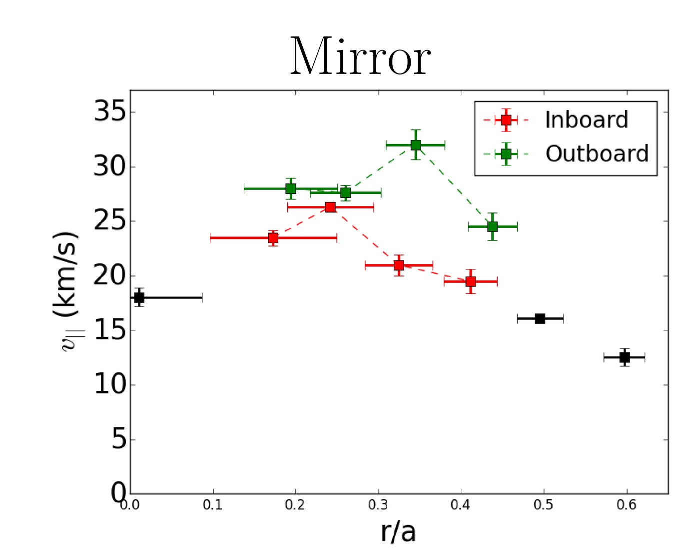


Figure 4: Parallel flows in Mirror geometry

Significantly larger flows are observed in broken symmetry configuration

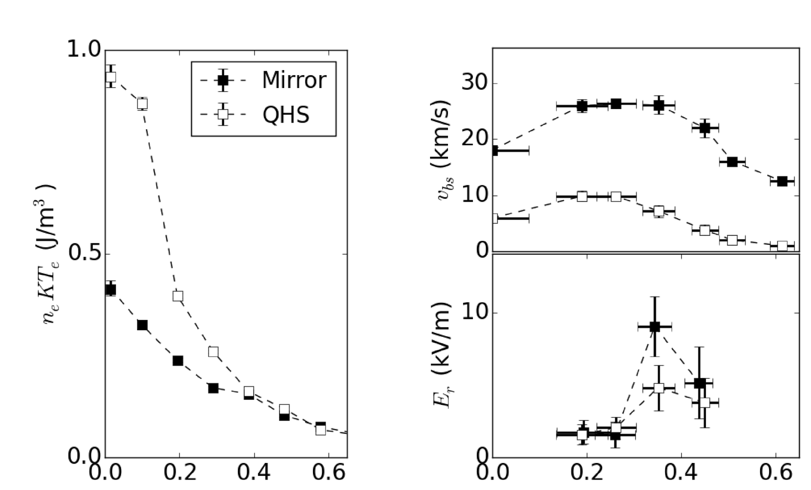
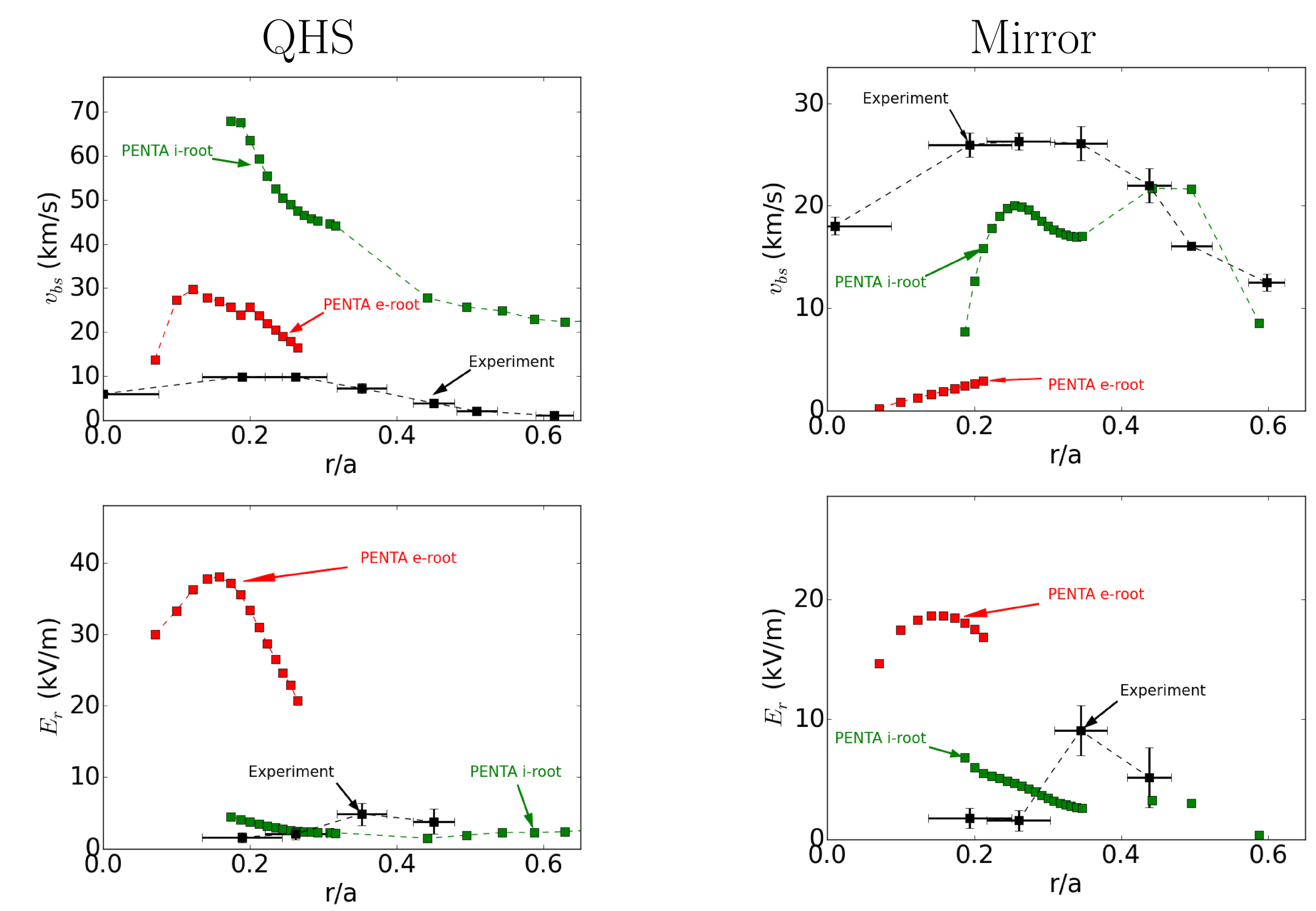


Figure 5: Electron pressure profile (left), bootstrap flow (right top) and E_r(right bottom) for QHS and mirror geometries

Mirror case agrees better with the neoclassical calculation



Neoclassical calculations are done using the PENTA [1] code.

E_r and flows in QHS configuration may be governed by non-neoclassical processes near the core

The radial width over which non-neoclassical processes dominate [2],

$$\Delta r = N\rho_i = \frac{L}{\epsilon_{eff}^{3/2}\lambda_{MFP}}\rho_i$$

where,

- L= macroscopic scale length
- ϵ_{eff}= effective helical ripple
- λ_{MFP}= ion-ion collission mean free path
- ρ_i= ion gyro radius

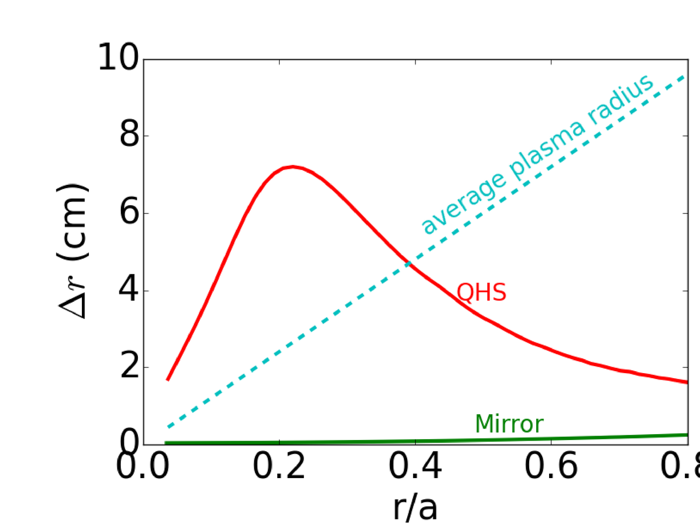


Figure 6: For QHS, Δ_r is higher than average plasma minor radius, near the core.

References

[1] Spong, D. A.,Phys. Plasmas. **12** (2005).

[2] Helander, P. and Simakov, A. N., Phys. Rev. Lett. **101** (2008).