Quasisymmetry-Breaking and Increased Parallel Viscous Damping Near Magnetic Islands in HSX

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1. Main Ideas

- Quasisymmetric stellarators have low neoclassical transport due to a single dominant component in the magnetic field spectrum. One mechanism by which quasisymmetry can be broken is by the distortion of a flux surface due to magnetic islands.
- H-modes may occur in narrow rotational transform windows which exclude islands inside the separatrix. On the other hand, internal transport barriers can form near islands and improve confinement. We wish to better understand this trade-off.
- The transform for the quasihelically symmetric (QHS) configuration is 1.05 at the center and 1.12 at the edge. With the auxiliary coil set we can raise and lower the transform and induce natural magnetic islands that are resonant with the transform.
- Additional magnetic spectral components appear due to the islands. At a transform of 1.0, the main helical field component [n,m] = [4,1] interacts with an iota = n/m = 4/4 island to produce [8,5] and [0,3] terms.
- In some cases, the breaking of quasisymmetry can be so large as to raise the effective ripple up to the case of the Mirror configuration, which we use to mimic transport in a more conventional stellarator.
- We show that the fast and slow momentum damping rates, as well as the radial conductivity, peak close to a magnetic island. Regions of large flow shear may develop.
- Experimental measurements using an electrode and Mach probe show a flattening of the potential profile, lower flow velocity and a local increase in the slow damping rate, consistent with the modeling.

(Gerhardt, Anderson, Talmadge PoP 12 012504 (2005).)

2. Configuration Flexibility

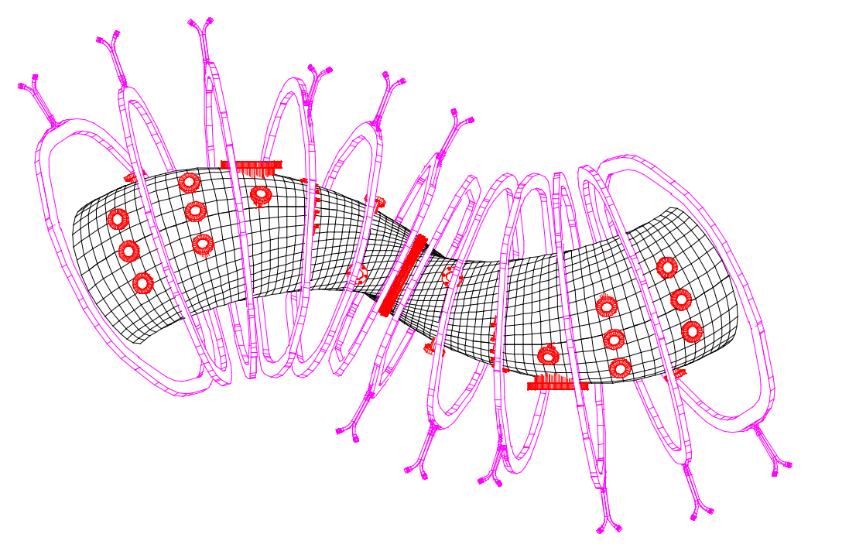
Auxiliary Coils vary neoclassical transport, rotational transform and well depth

QHS: Standard quasihelically symmetric configuration of HSX; No auxiliary coil current

Mirror: Large toroidal mirror [n,m]=[4,0] spectral component. Neoclassical transport and viscous damping increased to level of conventional stellarator

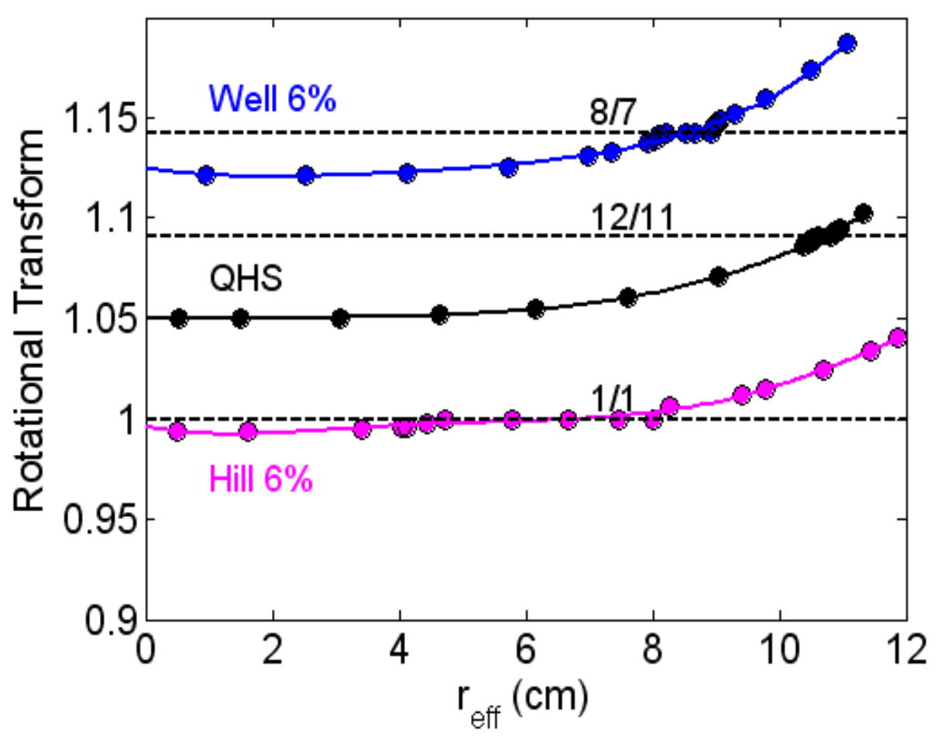
Hill: Lowers rotational transform, places plasma on magnetic hill.

Well: Increases transform and magnetic well depth.



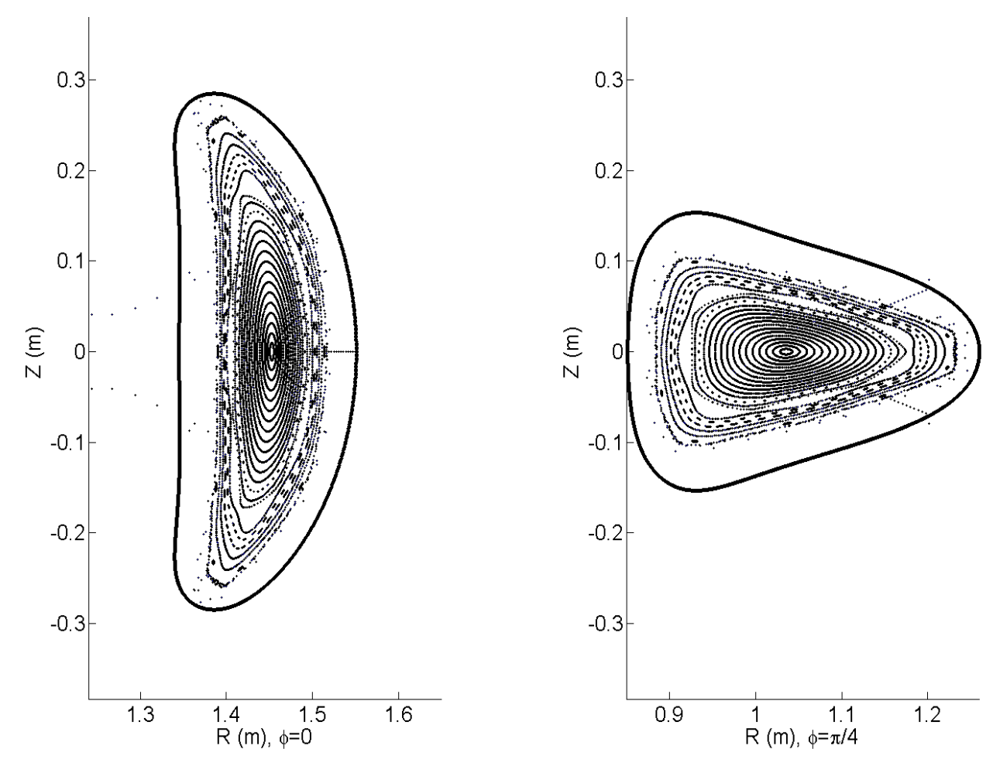
Mirror	+	+	+	-	-	-	-	-	-	+	+	+
Hill	+	+	+	+	+	+	+	+	+	+	+	+
Well	-	-	-	-	-	-	-	-	-	-	-	-

Rotational Transform Profile Determines Location of Natural Magnetic Islands

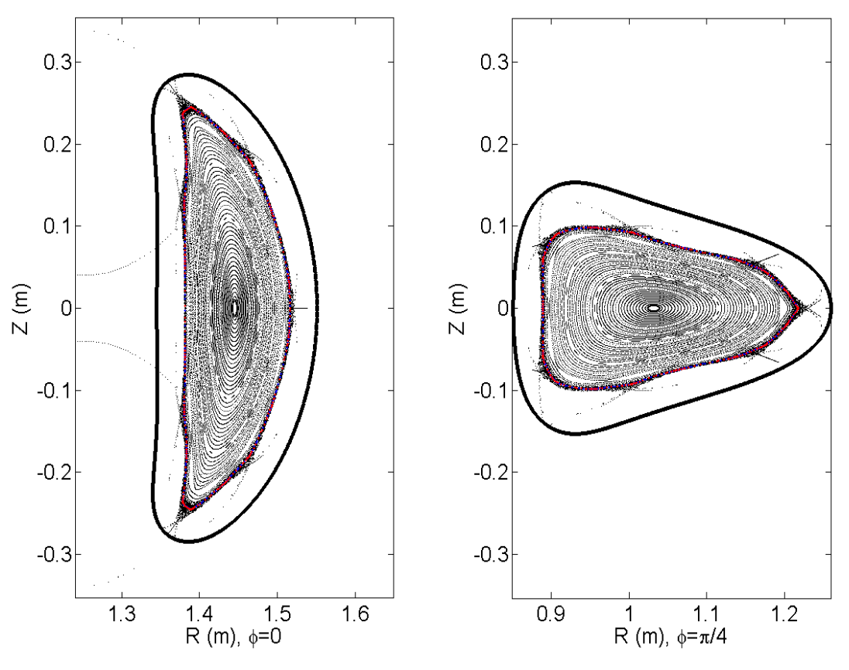


Percentage indicates the ratio of amp-turns in the auxiliary coils to main coil set.

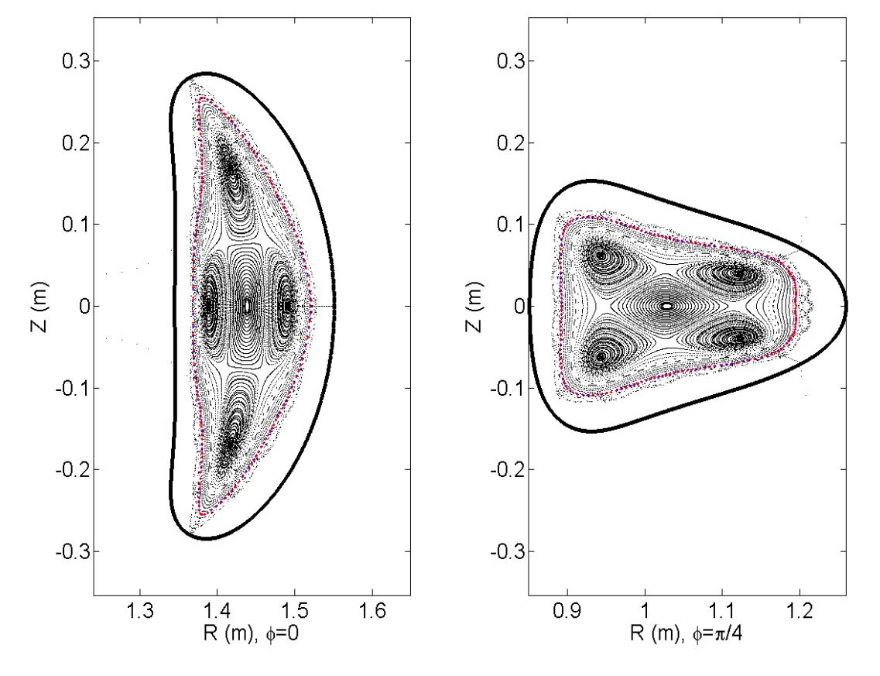
Well 6%, Transform Increased to include 8/7 Resonance



QHS: Standard Configuration with 12/11 Resonance



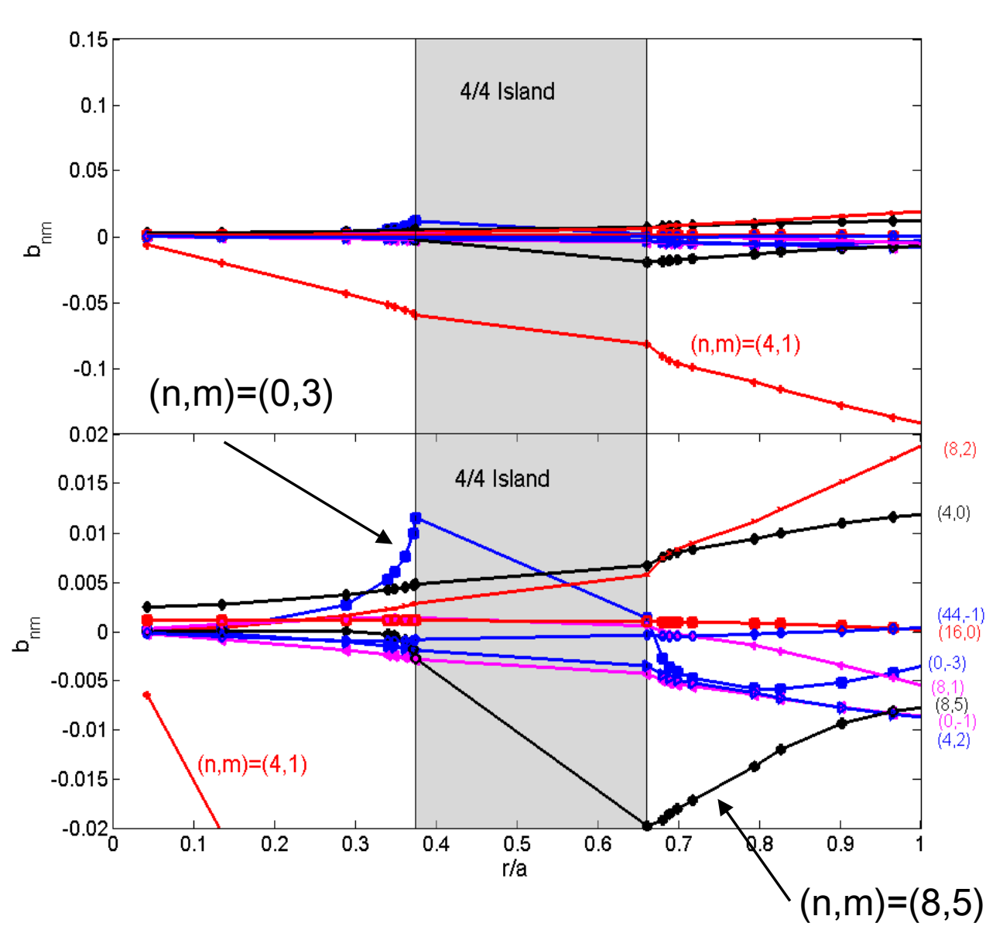
Hill 6%, Transform Lowered to include 4/4 Resonance



3. Islands Break Quasisymmetry

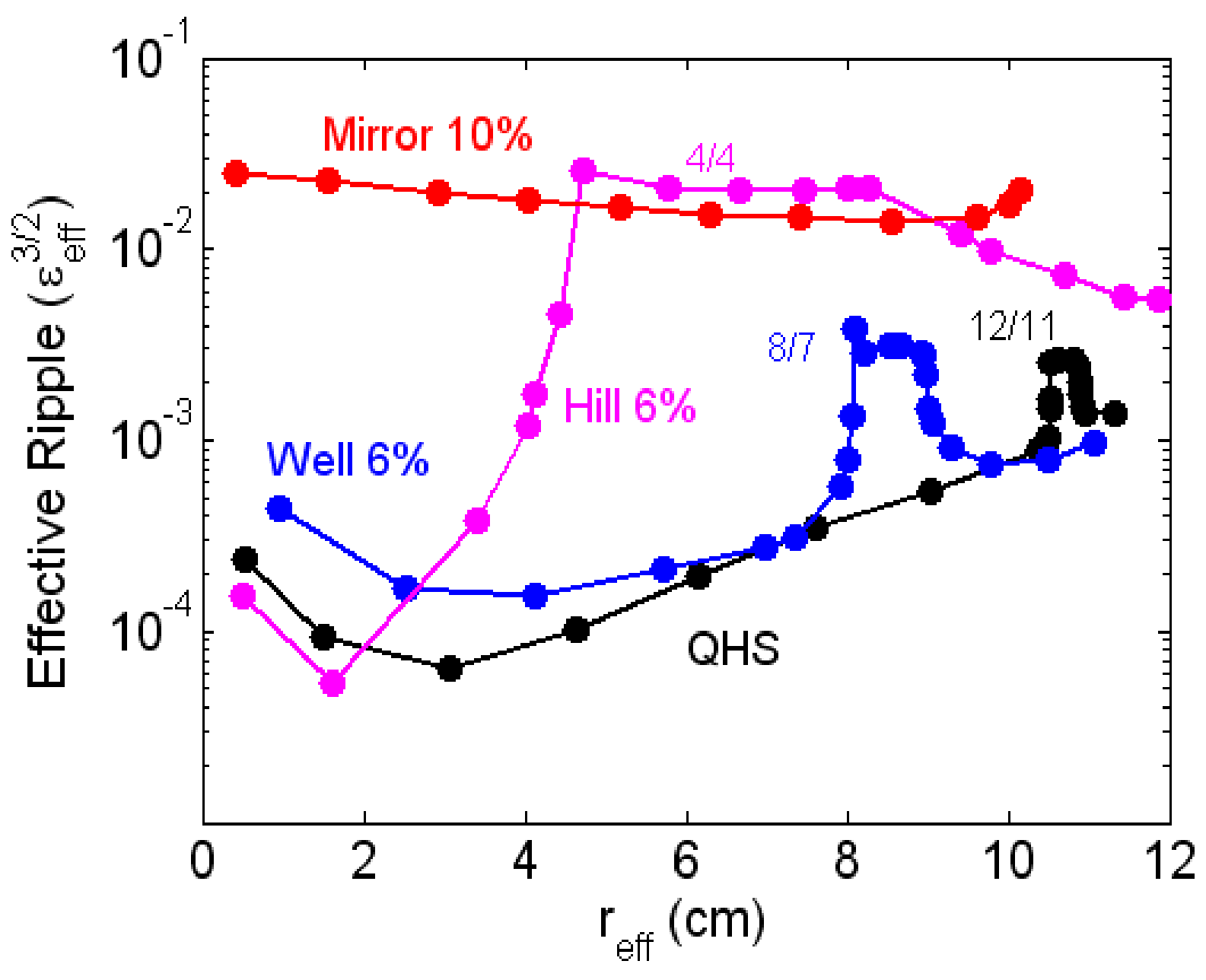
6% Hill

[n,m]=[4,1] main field component beats with 4/4 island to drive [8,5] and [0,3] spectral terms



Effective Ripple Jumps Near Magnetic Island

4/4 island increases $\varepsilon_{eff}^{3/2}$ to level of Mirror 10% configuration



4. Flow Damping and Radial Conductivity Jumps Near the Island

To Model Electrode Biasing, Solve the Momentum Equations on a Magnetic Surface

- Fast and slow damping rates come from the coupled momentum equations on a surface.

$$m_i N_i \frac{\partial}{\partial t} < \mathbf{B}_P \cdot \mathbf{U} > = -\frac{\sqrt{g} B^{\zeta} B^{\alpha}}{c} < \mathbf{J}_{plasma} \cdot \nabla \psi > - < \mathbf{B}_P \cdot \nabla \cdot \mathbf{\Pi} >$$

$$m_i N_i \frac{\partial}{\partial t} < \mathbf{B} \cdot \mathbf{U} > = - < \mathbf{B} \cdot \nabla \cdot \mathbf{\Pi} >$$

- Solve these with Maxwell’s equation.

$$\frac{\partial \langle \mathbf{E} \cdot \nabla \psi \rangle}{\partial t} = -4\pi \left(< \mathbf{J}_{plasma} \cdot \nabla \psi > + < \mathbf{J}_{ext} \cdot \nabla \psi > \right)$$

- Use Hamada coordinates, linear neoclassical viscosities, neglect heat fluxes. Neglect neutrals to emphasize parallel viscosity effects.
- Steady state solution yields radial conductivity.

$$\left\langle \mathbf{J}_{plasma} \cdot \nabla \psi \right\rangle = \sigma_{\perp} \left(\left\langle \mathbf{E} \cdot \nabla \psi \right\rangle - \frac{\left\langle \nabla p_i \cdot \nabla \psi \right\rangle}{e N_i} \right)$$

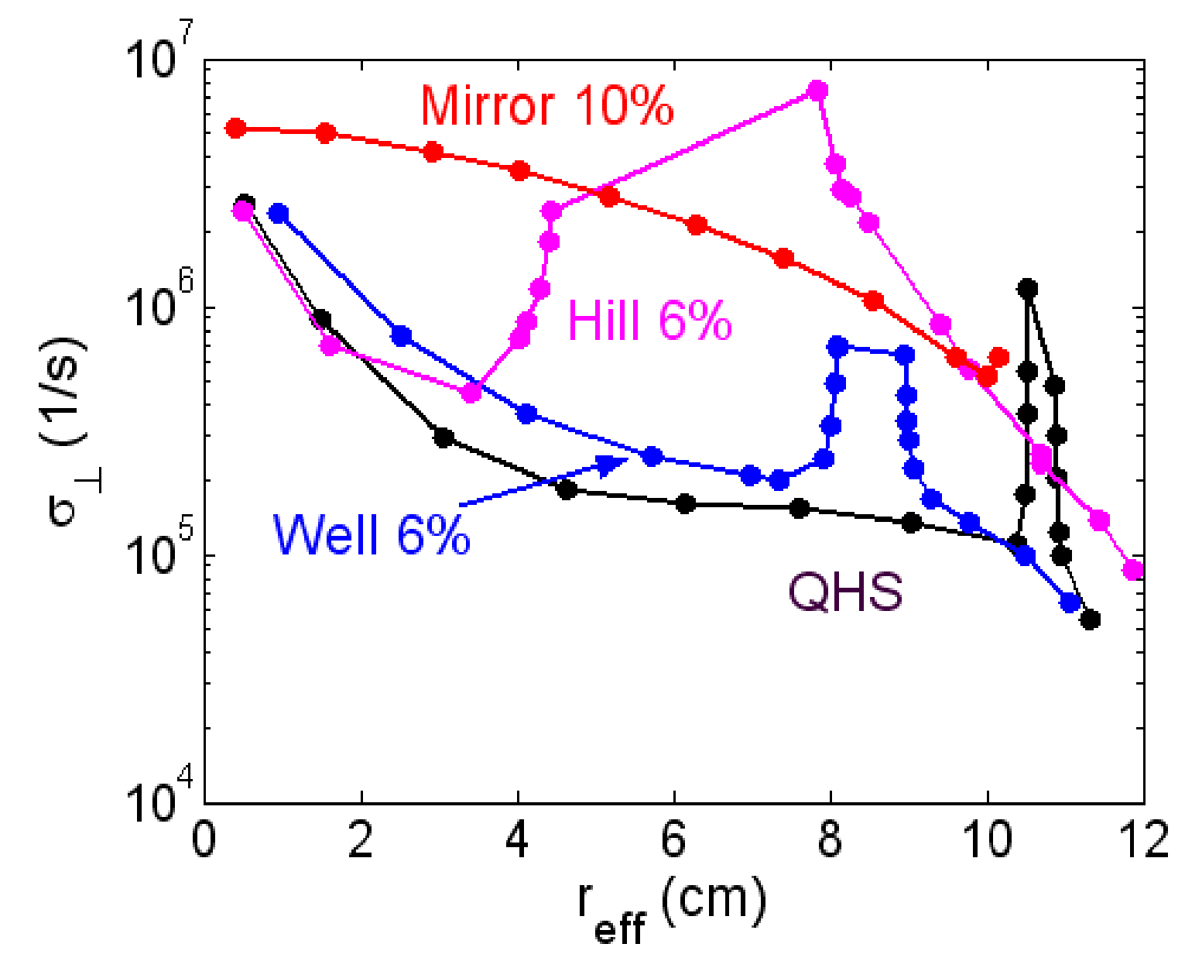
(M. Coronado and J.N. Talmadge, Phys. Fluids B 5, 1200 (1993))

- Assume parabolic density profile, $n_e \sim 1 \times 10^{12}$ cm^{-3}, flat T_i = 20 eV, plateau collisionality. 10 A drawn to an electrode to induce plasma rotation.

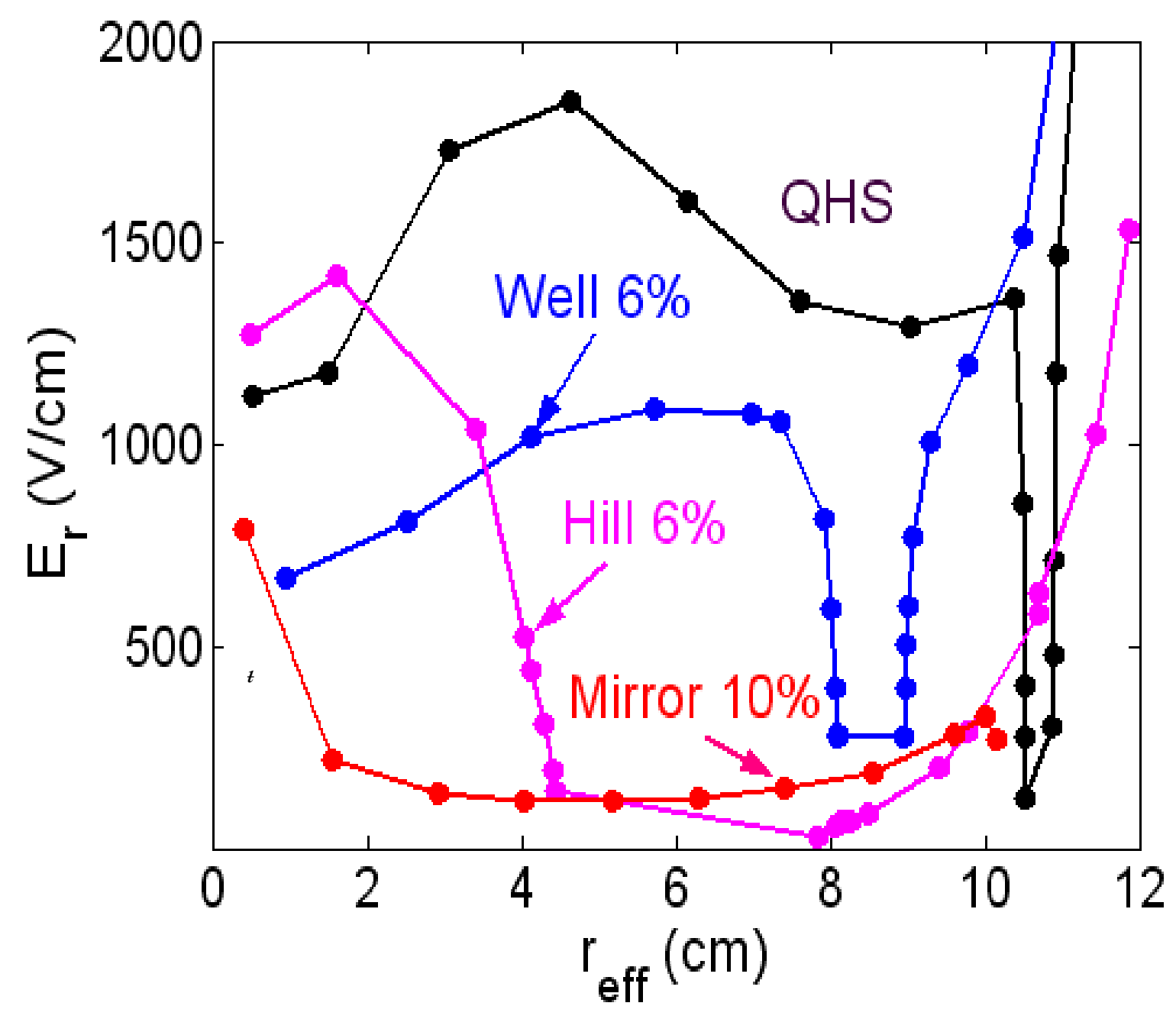
Results

- Near magnetic islands, fast and slow damping rates as well as radial conductivity rise to the level of Mirror 10% values.
- With a biased electrode, one would expect to see a local minimum in the electric field and flow velocity, and a local peak in plasma flow decay rates.
- The large differences in viscous damping for surfaces close to a magnetic island give rise to a shear in the electric field and flow velocity

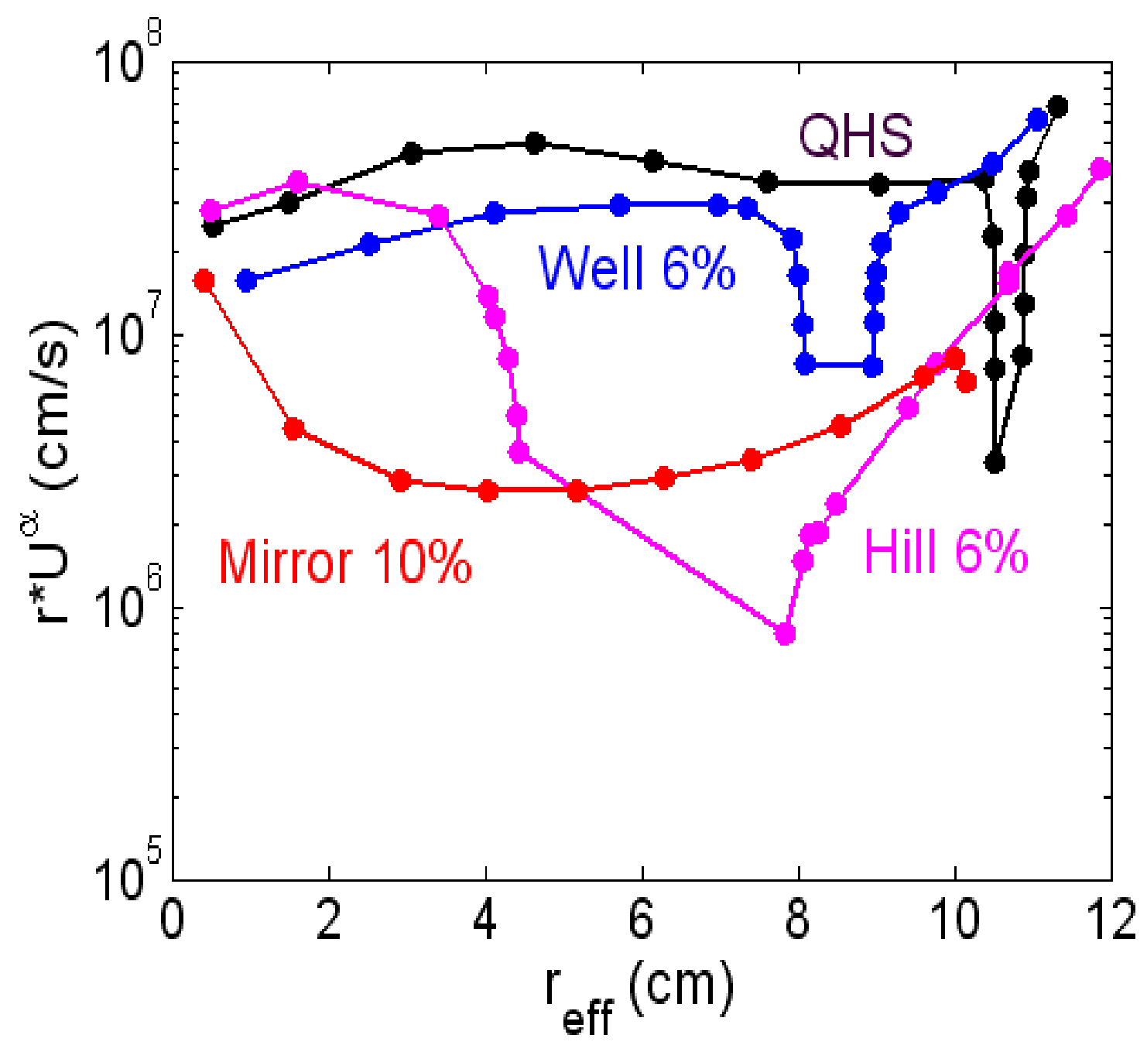
Radial Conductivity



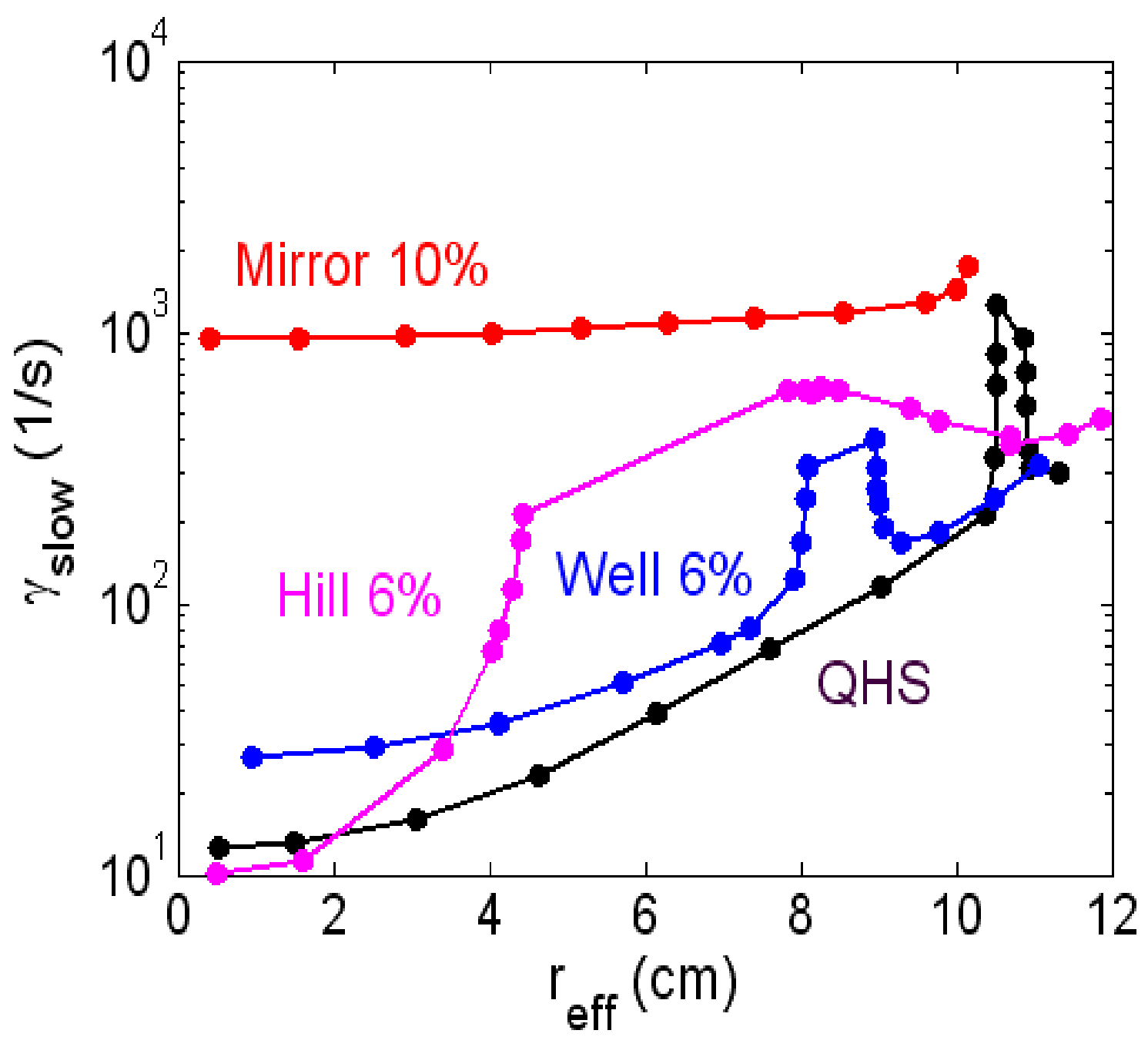
Radial Electric Field



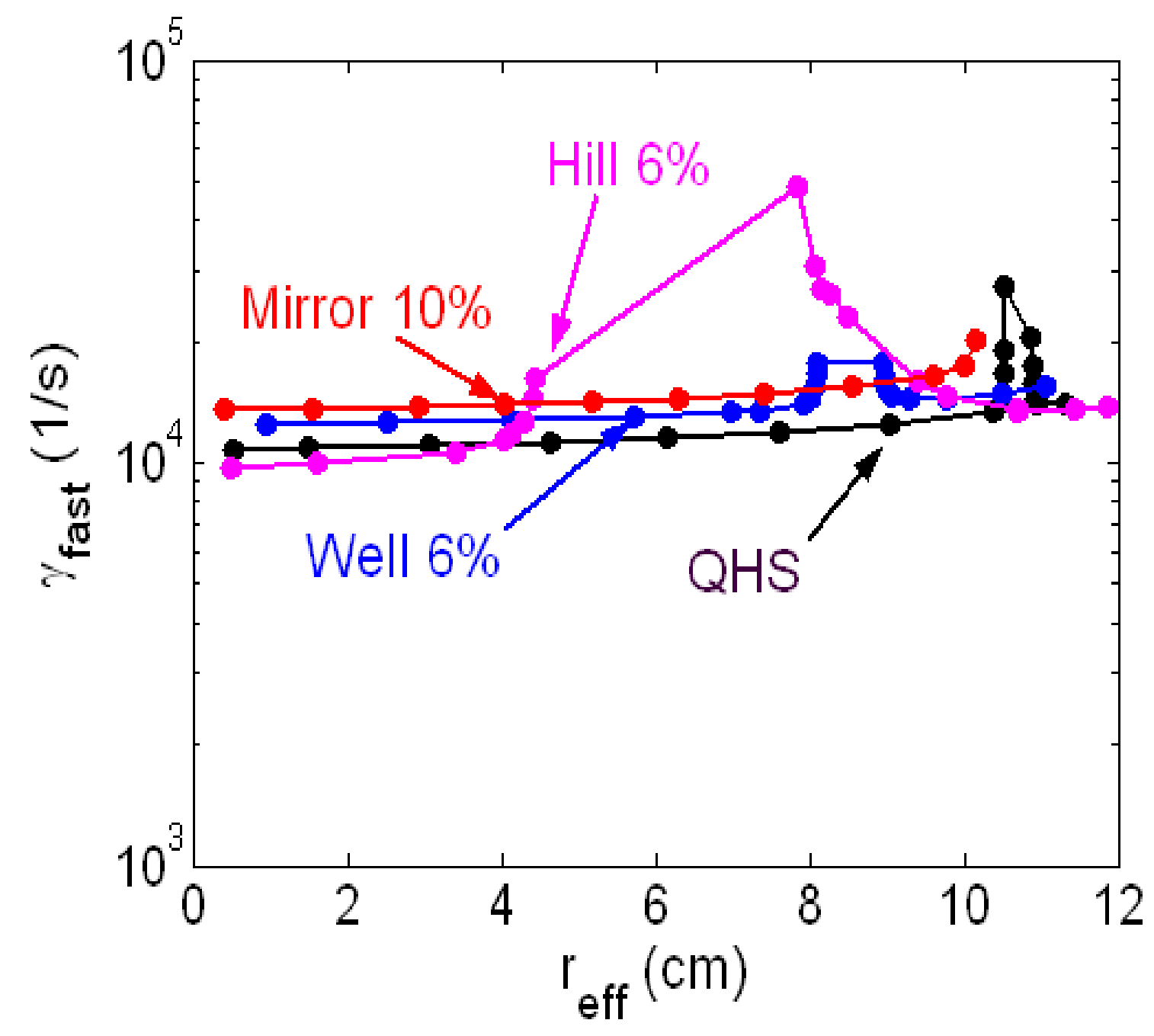
Flow Velocity



Slow Damping Rate

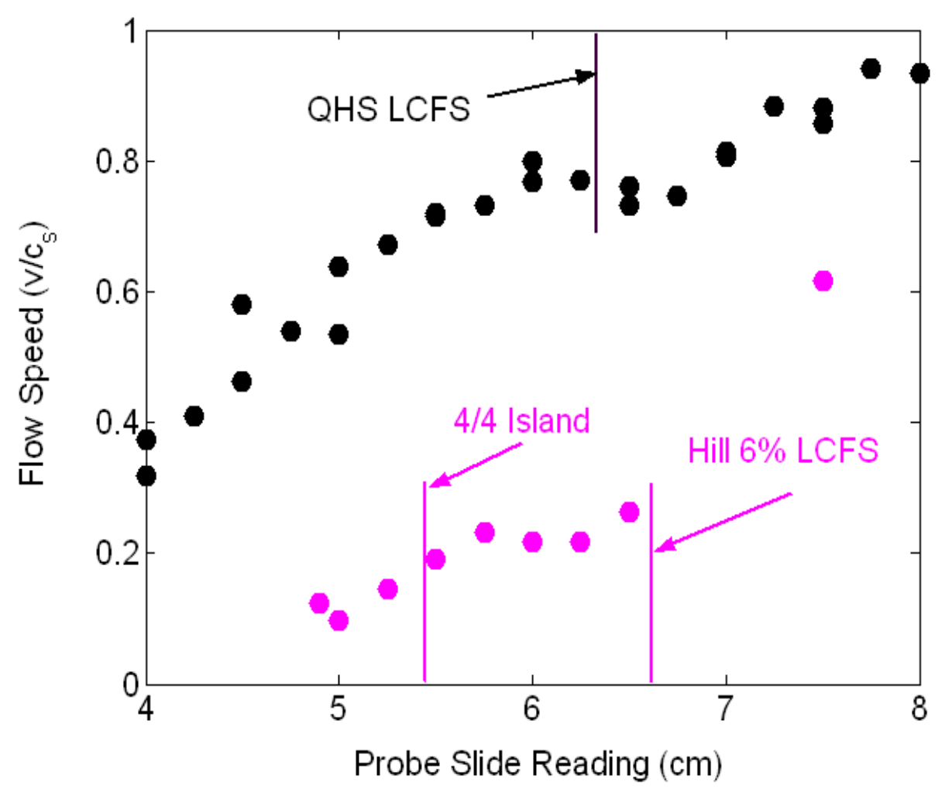


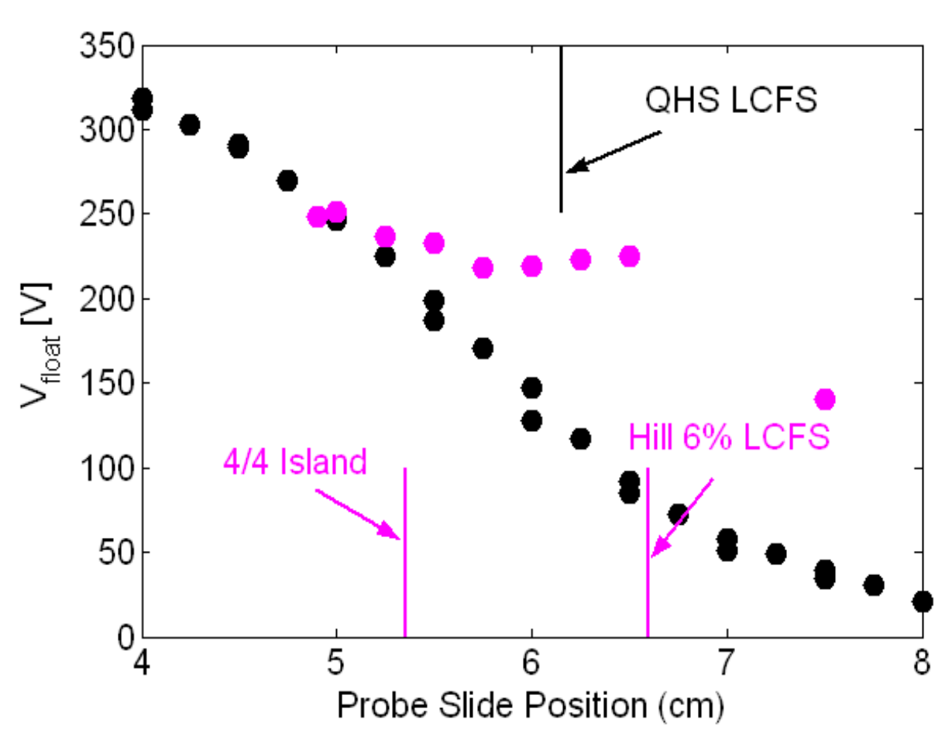
Fast Damping Rate



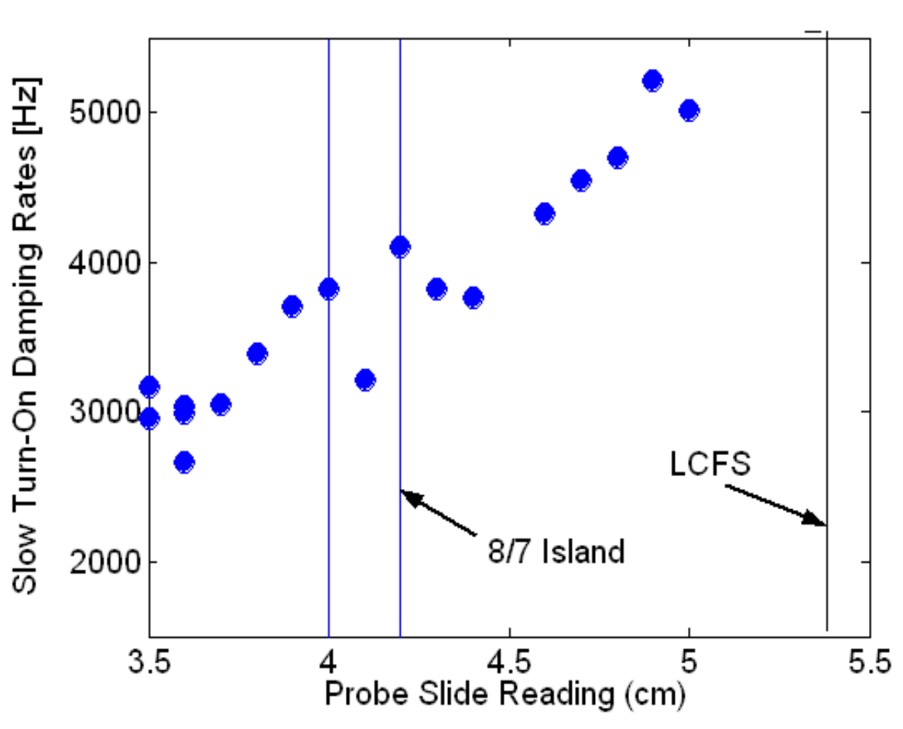
5. Initial Experimental Results

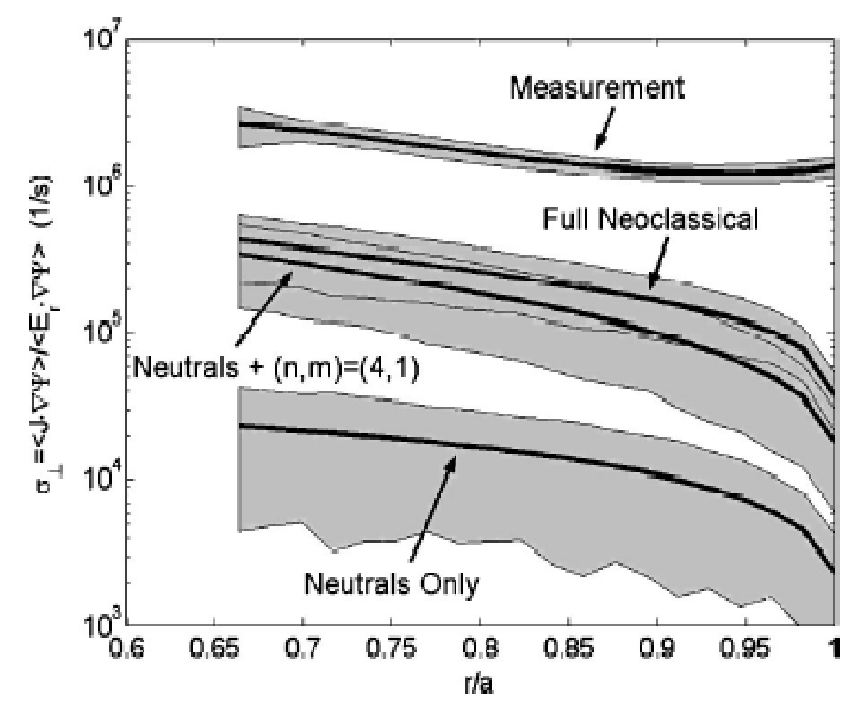
Electric Field and Flow Velocity Much Reduced near Hill 6% 4/4 Island





Evidence of Local Peak in Slow Damping Rate for Well 6% 8/7 Island





Gerhardt, Talmadge, Canik and Anderson, PoP 12, 056116 (2005).

Experimental radial conductivity at edge for QHS ~ 10^6 s^{-1} agrees with estimate above including 12/11 island

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