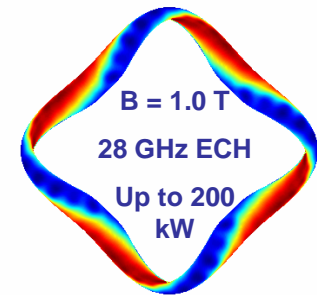
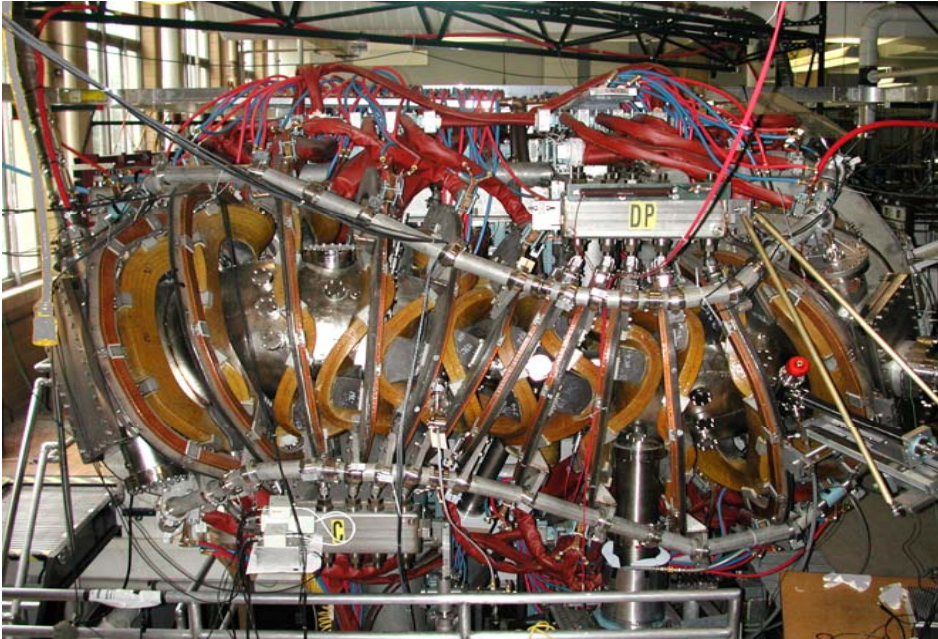


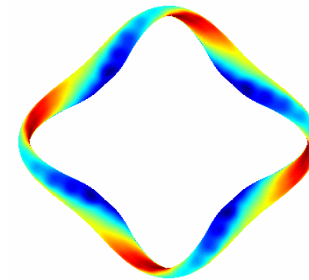
Transport Improvements in Stellarators with Quasisymmetry

Mission: To demonstrate the potential benefits of quasisymmetry



QHS

$$B = B_0 [1 + \varepsilon_h \cos(N - m\iota)\phi]$$



Mirror

$$B = B_0 [1 + \varepsilon_h \cos(N - m\iota)\phi + \varepsilon_M \cos(N\phi)]$$

Presented by D.T. Anderson for the HSX Team

A. Abdou, A.F. Almagri, D.T. Anderson, F.S.B. Anderson, D.L. Brower⁺, J. M. Canik, C. Deng⁺,
W. Guttenfelder, C. Lechte, K.M. Likin, H. Lu, S. Oh, P.H. Probert, J. Radder, V. Sakaguchi, J. Schmitt,
J.N. Talmadge, K. Zhai

HSX Lab, University of Wisconsin-Madison, USA; ⁺University of California-Los Angeles

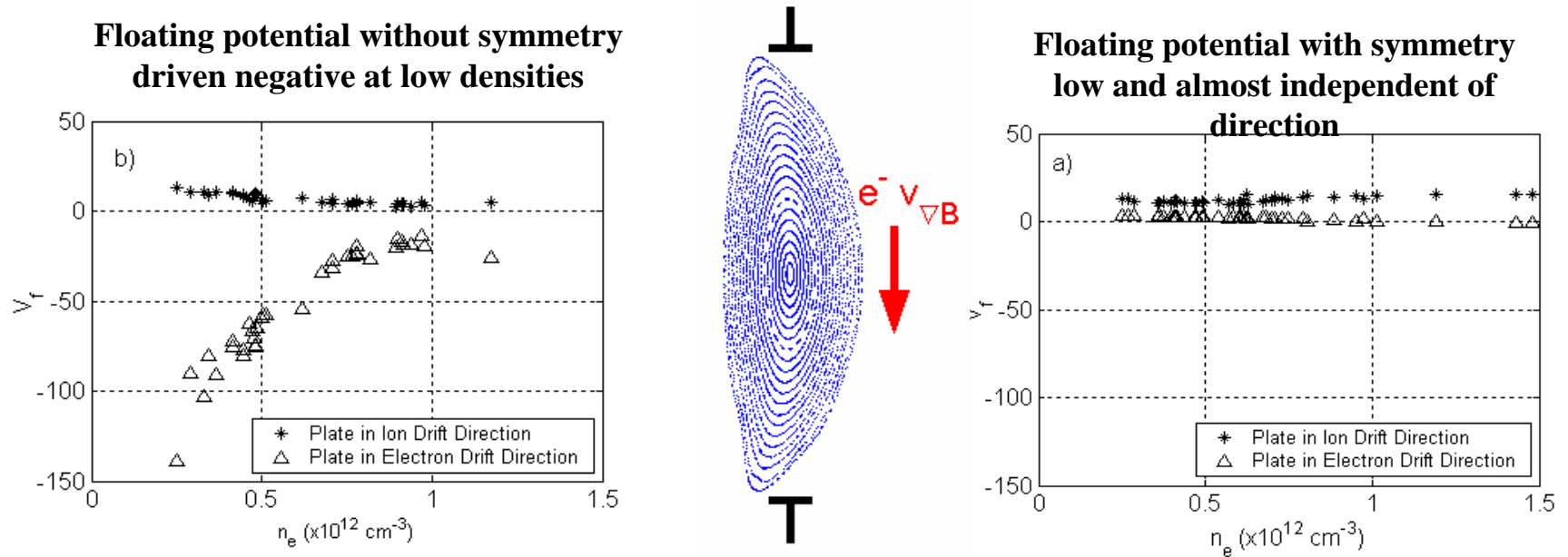
2006 ICC Workshop-Austin, TX

Reduction in Transport with Quasisymmetry is Evidenced by:

- **Reduction in direct loss orbits of deeply trapped electrons**
- **Higher X-ray flux and longer decay time**
- **Decreased parallel viscous damping and larger driven flows**
- **Peaked density profiles associated with reduced thermodiffusion (that often leads to hollow density profile).**
- **Increased central electron temperature**

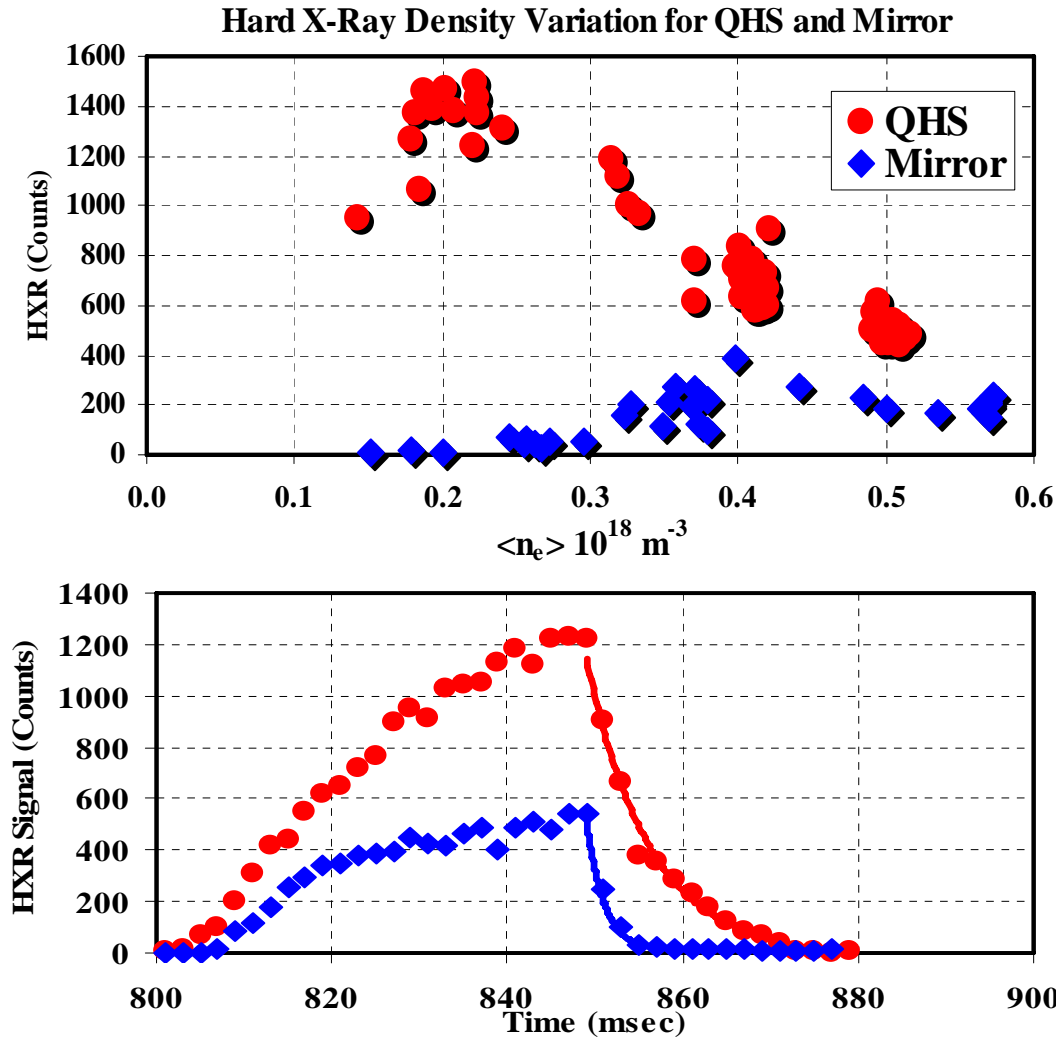
Edge fluctuation characteristics and temperature/density profiles are similar outside $r/a \sim 0.6$ with and without quasisymmetry for present operating conditions

Better Confinement of Deeply Trapped Electrons with Quasisymmetry



Potential on plate in electron drift direction driven negative when symmetry is broken

Larger X-Ray Flux with Quasisymmetry

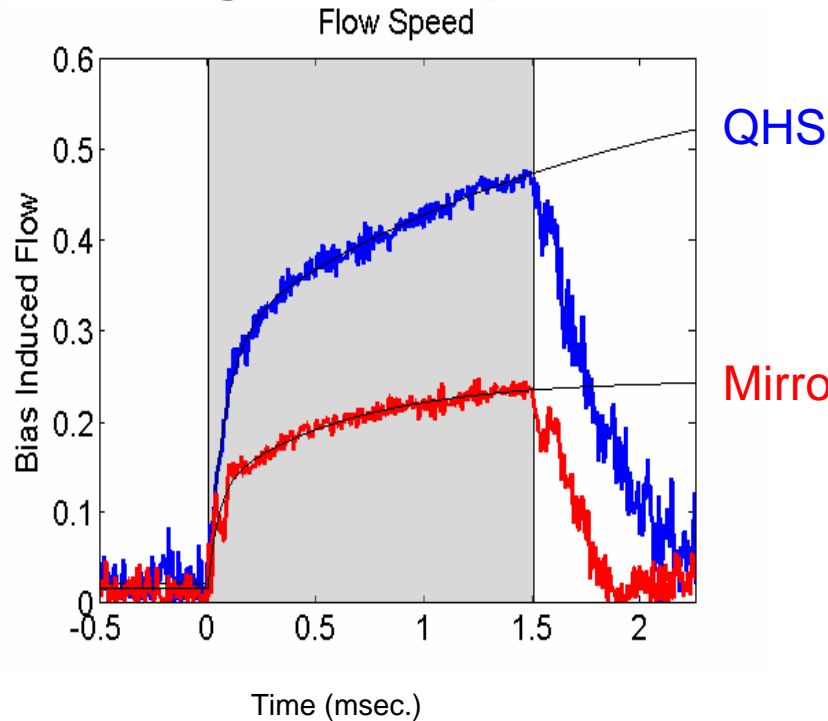


Flux increases with lower density for QHS

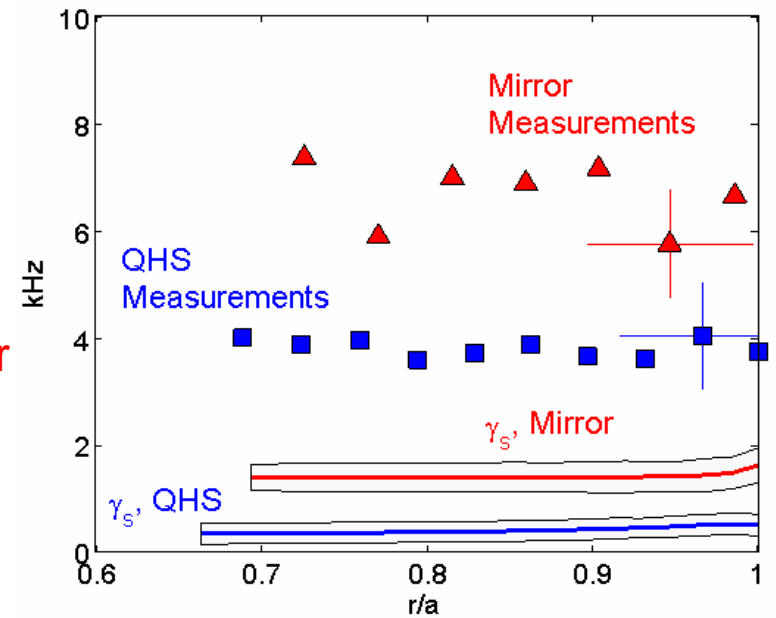
Decay time $>3x$ longer with symmetry

Quasisymmetry leads to reduced viscous damping, larger flows

Larger Flow Speed

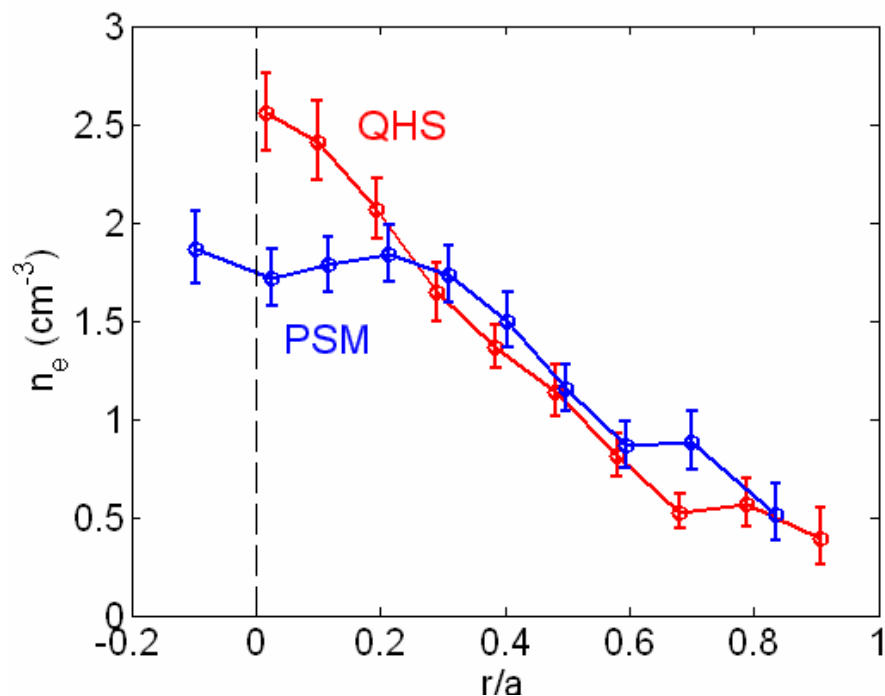


Parallel viscous damping reduced



Reduced Particle Transport leads to Peaked Density Profiles in QHS

Peaked density profiles in QHS



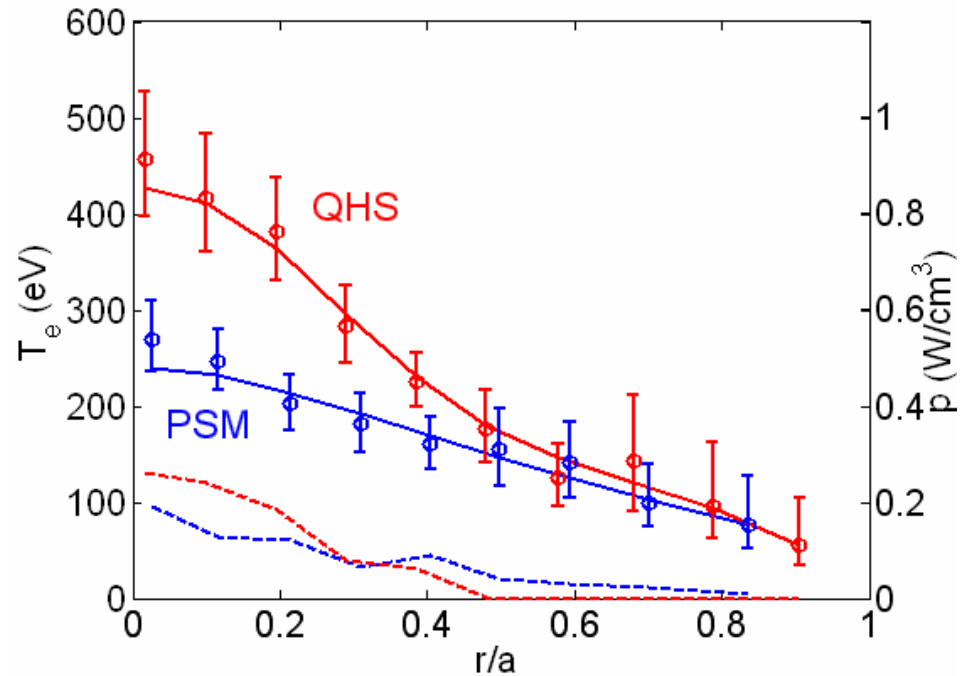
$$\Gamma_k = -nL_{11}^k \left\{ \frac{n'}{n} - \frac{q_k E_r}{T_k} + \left(\frac{L_{12}^k}{L_{11}^k} - \frac{3}{2} \right) \frac{T_k'}{T_k} \right\}$$

Thermodiffusion: Particle flux due to temperature gradient

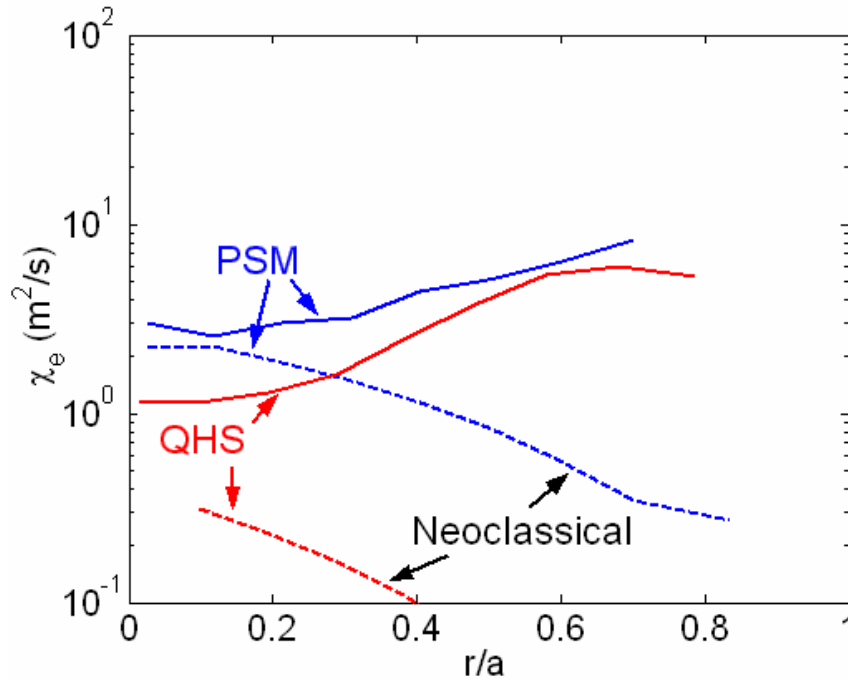
All stellarators show hollow or flat density profiles with central ECH heating

Central Electron Temperature Increases by 200 eV with Quasisymmetry

Higher QHS T_e with same absorbed power



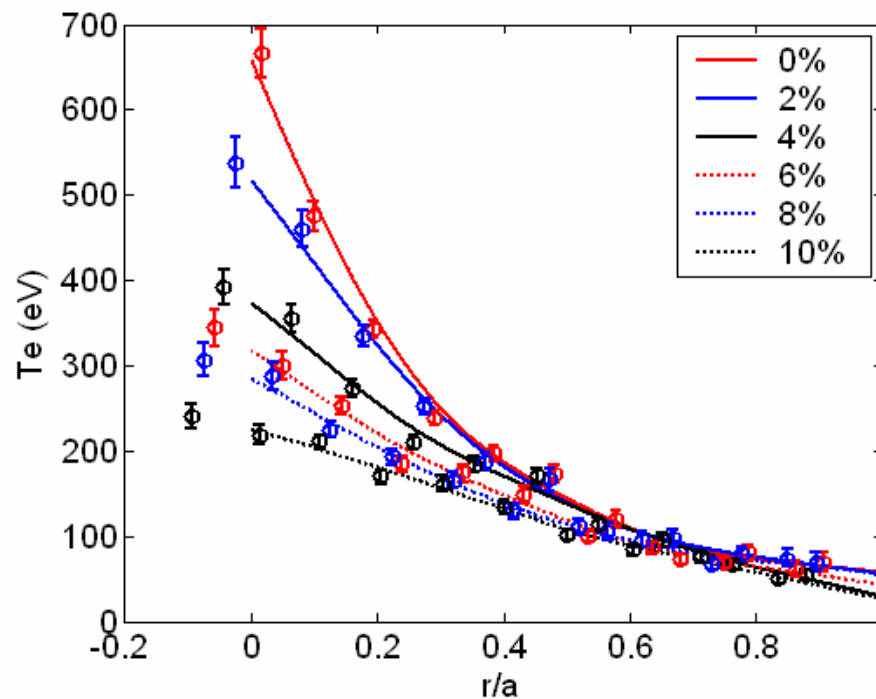
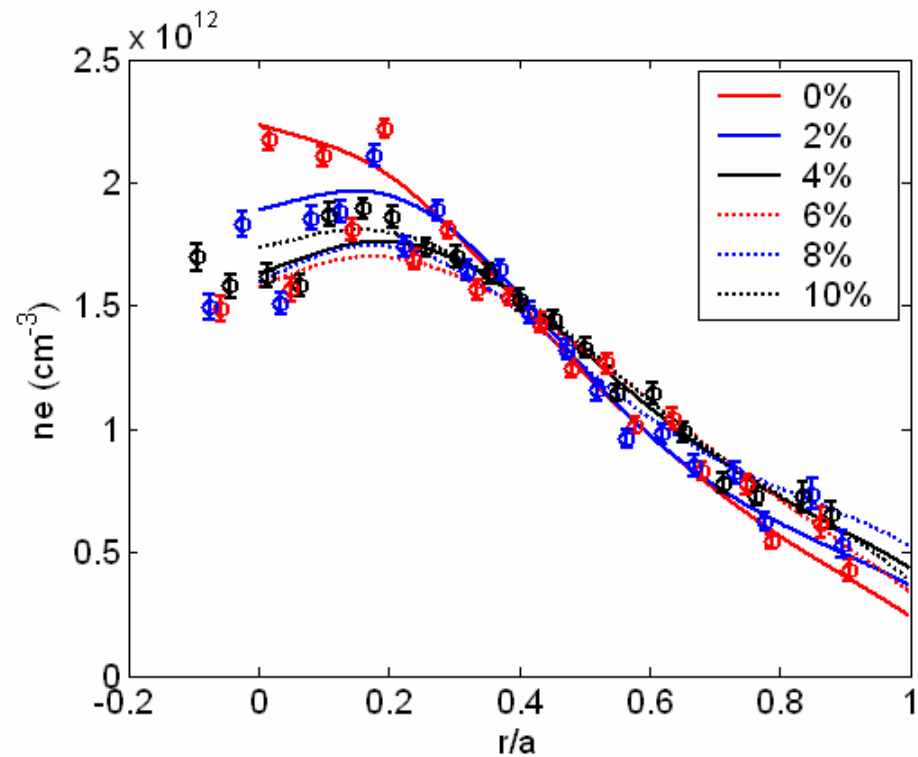
Central Electron Temperature Increases by 200 eV with Quasisymmetry



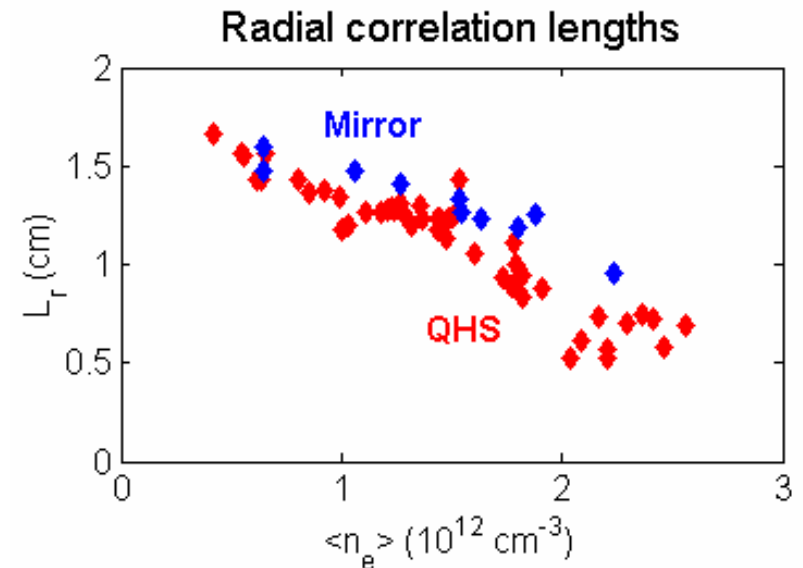
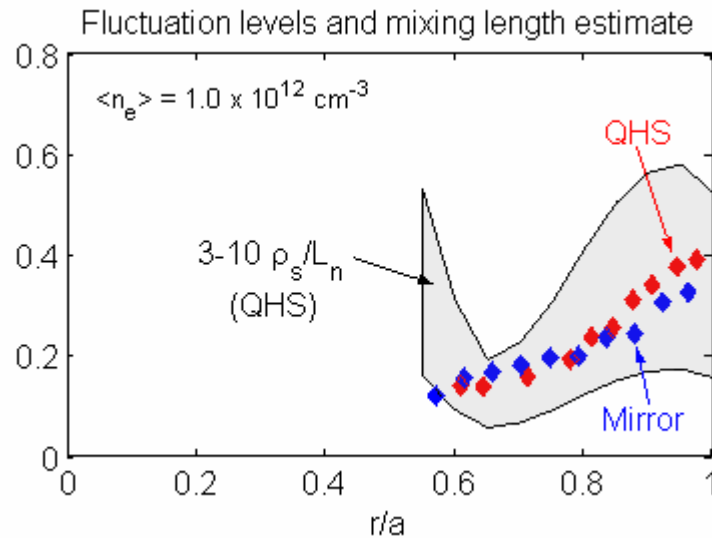
Thermal diffusivity at $r/a \sim 0.3$ is reduced in QHS compared to Mirror (~ 1 vs. ~ 3 m^2/s)

QHS has longer confinement time: $\tau_E^{\text{QHS}} \sim 1.5$ ms, $\tau_E^{\text{PSM}} \sim 0.9$ ms

Symmetry-breaking Effects Profiles in Mirror Scan



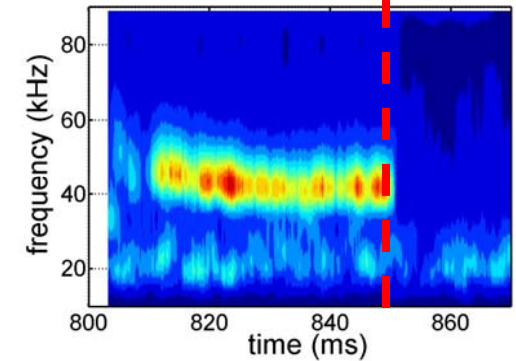
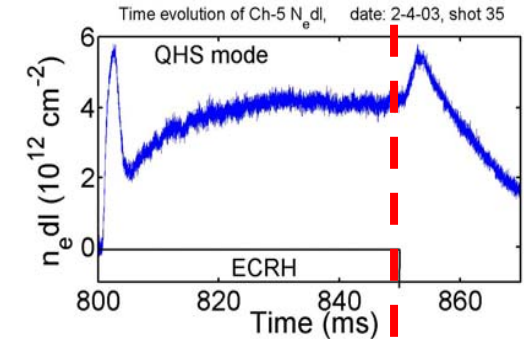
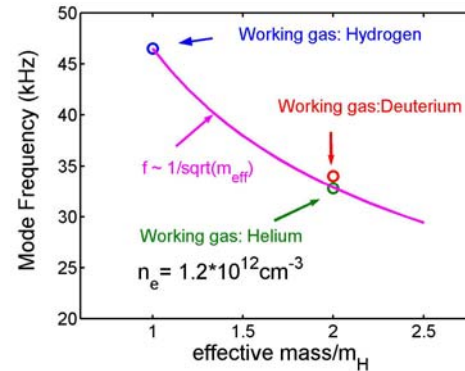
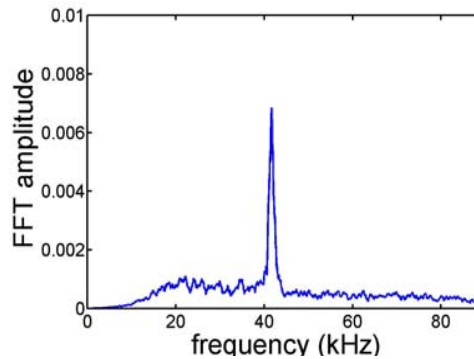
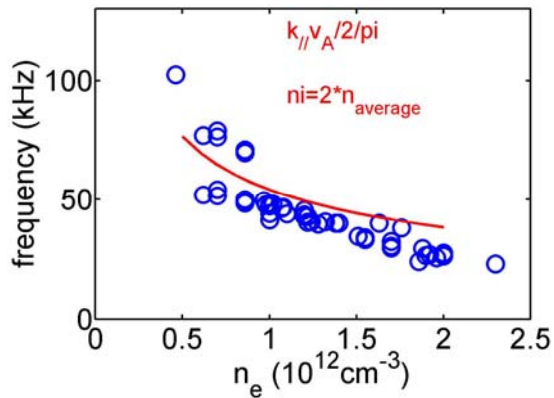
No Large Differences in Fluctuation Characteristics Between Configurations



- Fluctuation levels (from ion saturation current) at the edge are same in QHS and Mirror – similar to mixing length estimates
- Correlation lengths ($L_r \approx k_\theta^{-1}$) and times are similar over a range of densities
- Turbulent diffusivities (L_r^2/τ) are $\sim 20 \text{ m}^2/\text{s}$ at high density – on the order of global transport analysis at the edge.

MHD Mode Observed only in QHS Plasmas

Possible $n=1, m=1$ GAE mode observed only in QHS discharges
(STELGAP code
D. Spong, ORNL)



Scaling consistent with Alfvénic modes

Long Range Plans

Understand neoclassical benefits of quasisymmetry; how much do you need?

Anomalous transport differences between symmetric/non-symmetric operation

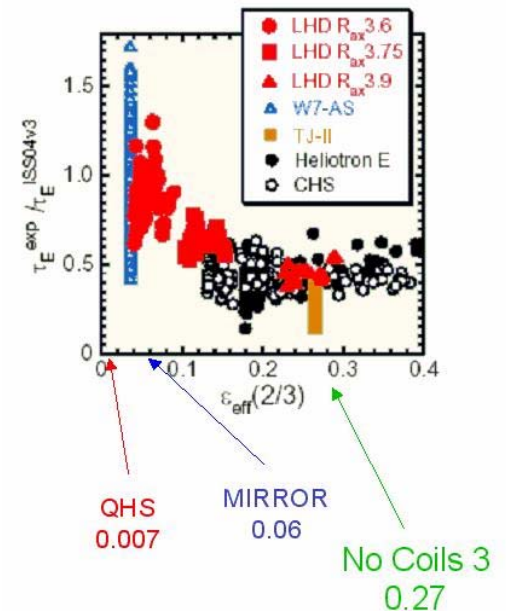
“Appears” effective ripple matters even

at higher collisionality! (Why?) →

Role of high effective transform ($|N-m|$) and low ripple

Investigate β -limits in qhs configuration

- bootstrap current effects
- ballooning modes
- fast particle driven instabilities



Near Term Plans

- **Reduce the anomalous contribution to transport**
 - Increase the field to $B=1.0\text{T}$ (Spring) $\tau \sim B^{0.84}$
 - Fundamental heating (increase density, $\tau \sim n^{0.6}$)
 - Increase heating power to 200 kW with new transmission line (Spring)
- **Measurement of E_r with DNB on loan from MST**
- **Augmentation of probe-based edge fluctuations studies with central measurements with ECE and reflectometer; anomalous transport with QHS**
- **Explore dependence of anomalous transport on effective ripple**
- **Continue installation of 2nd 200 kW 28 GHz ECH system**
 - power modulation experiments; heat pulse χ_e in addition to power balance
 - steerable launcher for T_e profile variation
 - EBW for overdense operation

Concluding Remarks

- **Quasisymmetry Matters!**

- Reduction of direct loss orbits
- Good energetic-particle confinement
- Reduced neoclassical particle and energy transport
- Reduced parallel viscous damping

- **International stellarator database shows lowering the effective ripple decreases anomalous transport**

- **Advanced stellarators offer potential of tokamak-like confinement (or better) while minimizing current driven effects**

- Disruptions
- Current drive/BS alignment