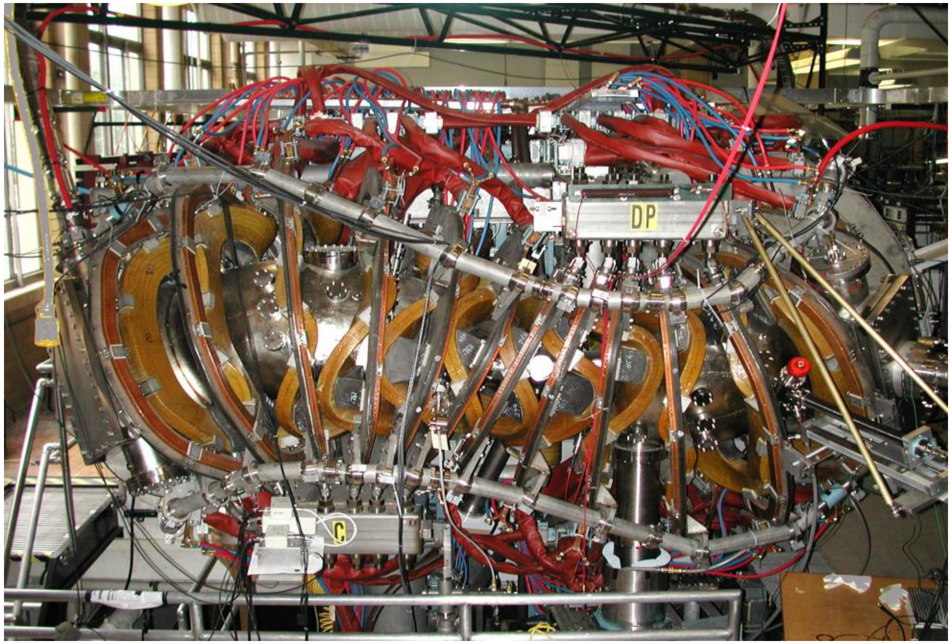
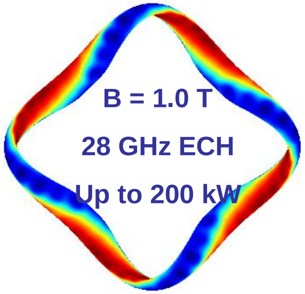
Transport Improvements in Stellarators with Quasisymmetry

Mission: To demonstrate the potential benefits of quasisymmetry





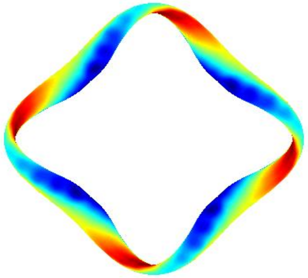
QHS

B = 1.0 T

28 GHz ECH

Up to 200 kW

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



Mirror

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

Presented by D.T. Anderson for the HSX Team

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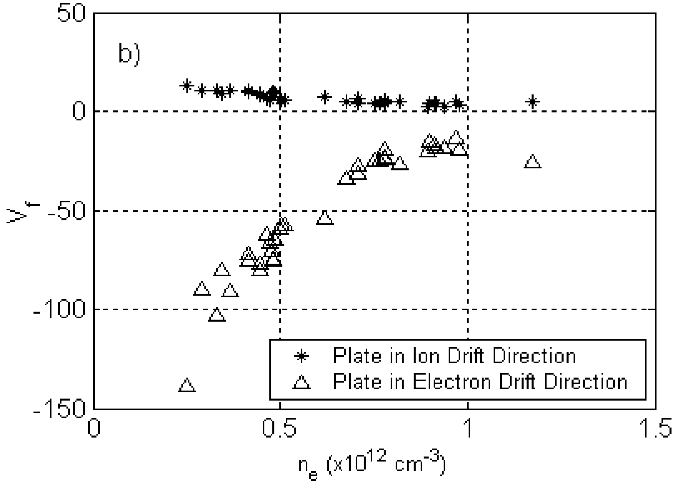
Reduction in Transport with Quasisymmetry is Evidenced by:

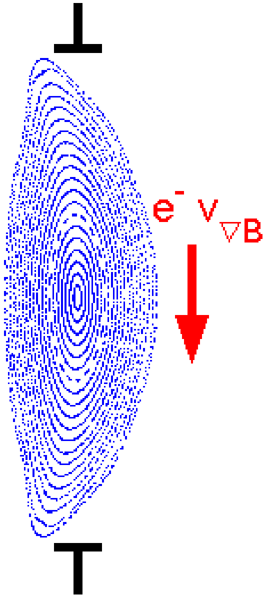
- **Reduction in direct loss orbits of deeply trapped electrons**
- **Higher X-ray flux and longer decay time**
- **Decreased parallel viscous damping and larger driven flows**
- **Peaked density profiles associated with reduced thermodiffusion (that often leads to hollow density profile).**
- **Increased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

Edge fluctuation characteristics and temperature/density profiles are similar outside r/a~0.6 with and without quasisymmetry for <u>present operating conditions</u>

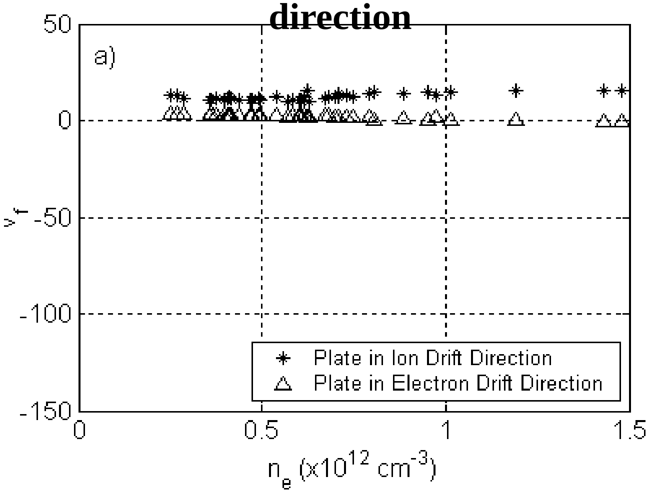
Better Confinement of Deeply Trapped Electrons with Quasisymmetry

Floating potential without symmetry driven negative at low densities



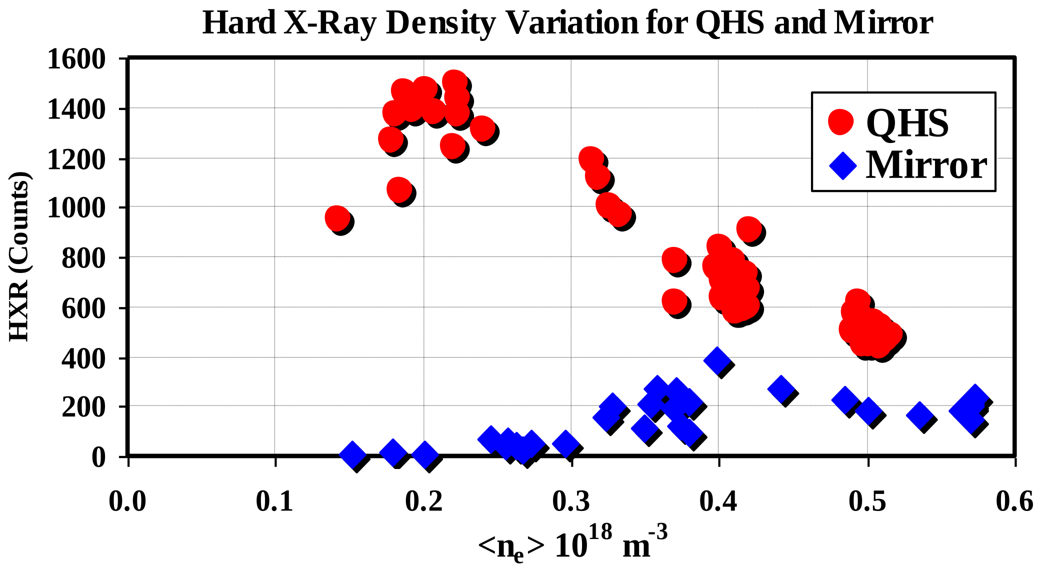


Floating potential with symmetry low and almost independent of direction

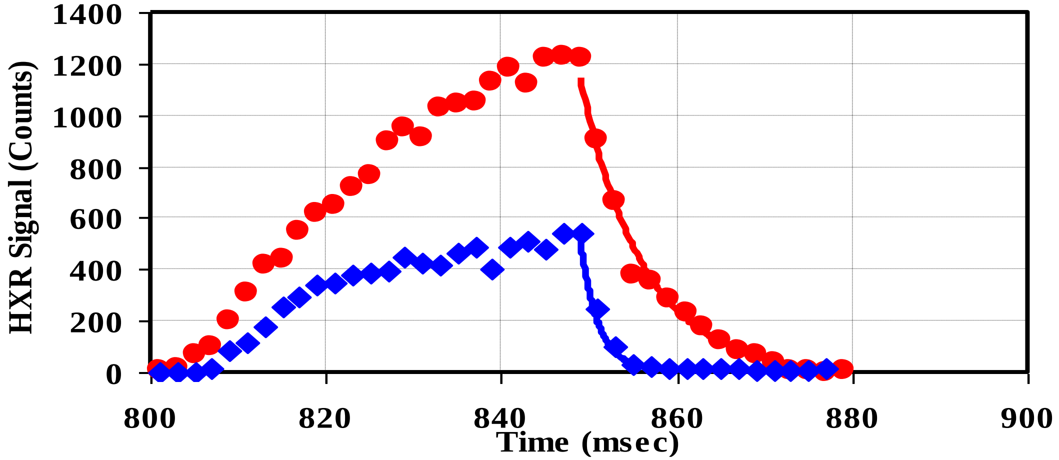


Potential on plate in electron drift direction driven negative when symmetry is broken

Larger X-Ray Flux with Quasisymmetry



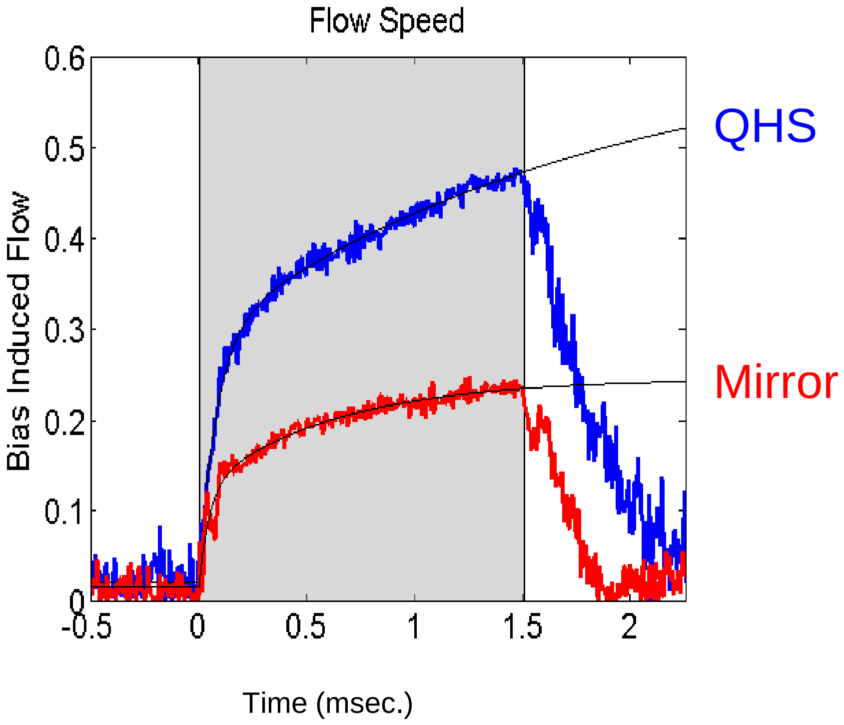
Flux increases with lower density for QHS



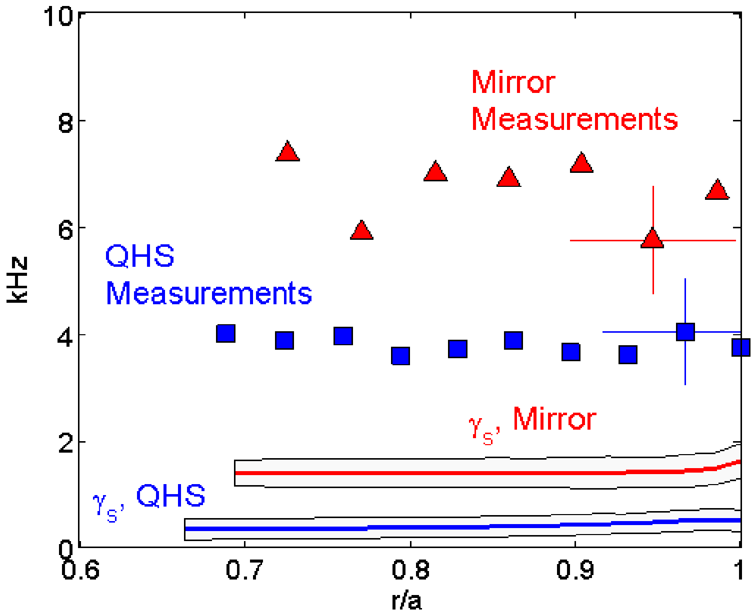
Decay time >3x longer with symmetry

Quasisymmetry leads to reduced viscous damping, larger flows

Larger Flow Speed

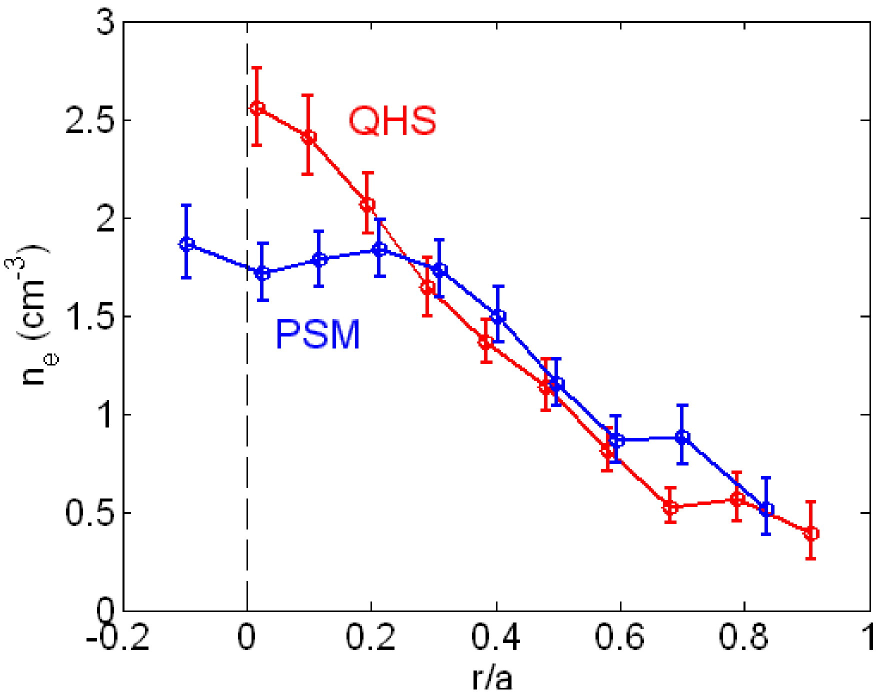


Parallel viscous damping reduced



Reduced Particle Transport leads to Peaked Density Profiles in QHS

Peaked density profiles in QHS

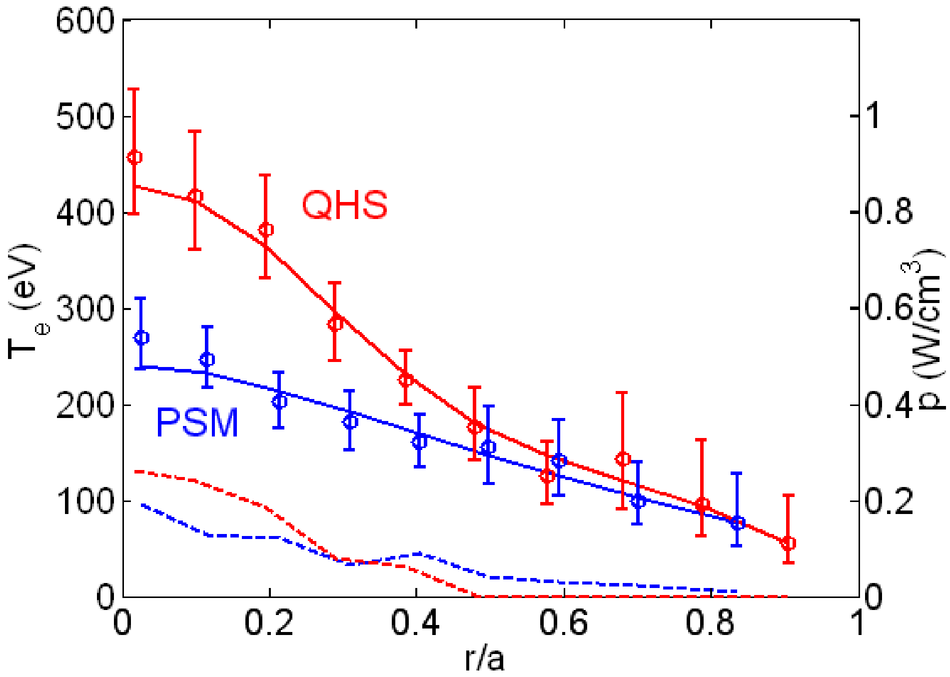


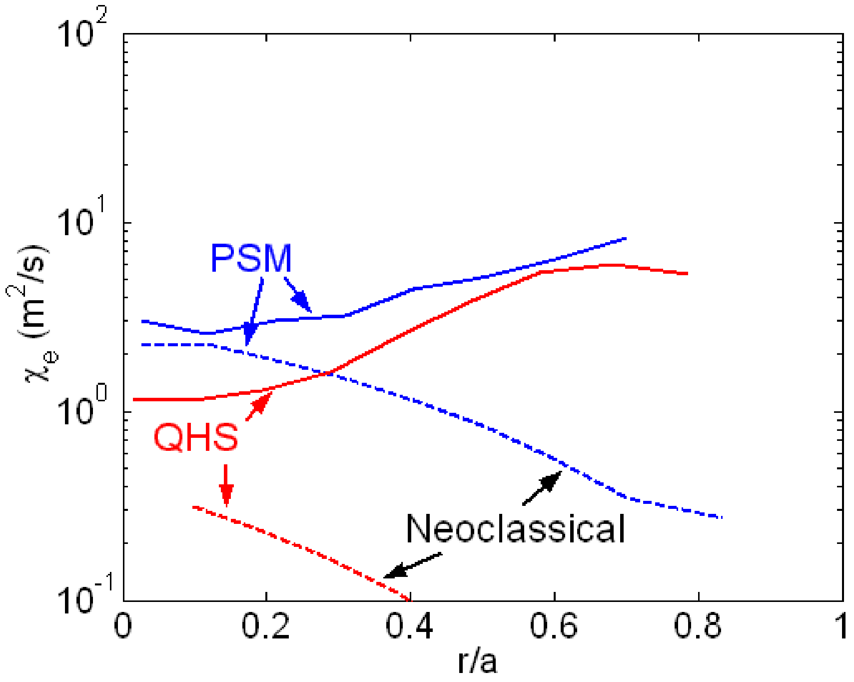
$$_{ij} = \frac{2}{\sqrt{}} \int_0^{\infty} \quad - \quad g_i g_j D(K)$$

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

$$Q_k = -nT_k L_{21}^k \left\{ \frac{n'}{n} - \frac{q_k E_r}{T_k} + \left(\frac{L_{22}^k}{L_{21}^k} - \frac{3}{2} \right) \frac{T_k'}{T_k} \right\}$$

Higher QHS T_e with same absorbed power





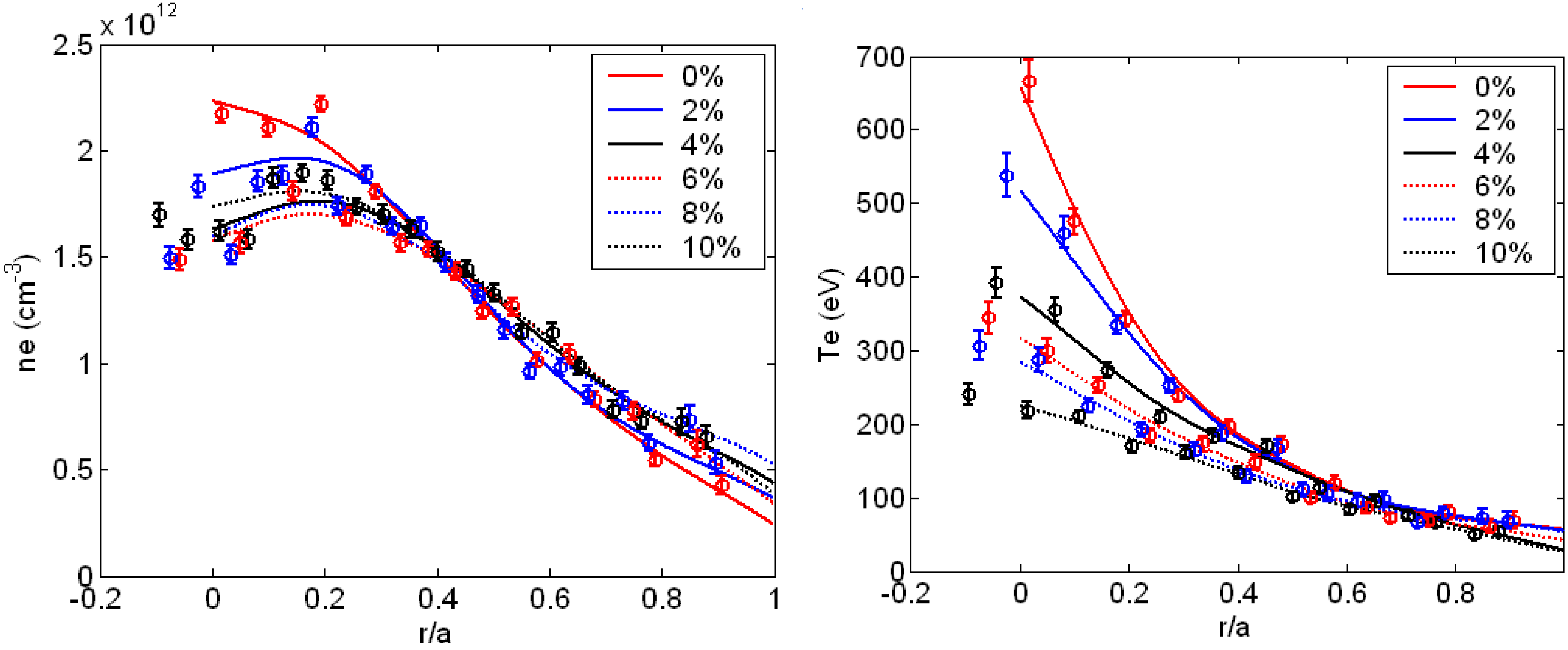
Heating in QHS at r/a ~ 0.1 to mimic PSM p_{abs} profile

- Total absorbed power in both configurations is ~ 10 kW

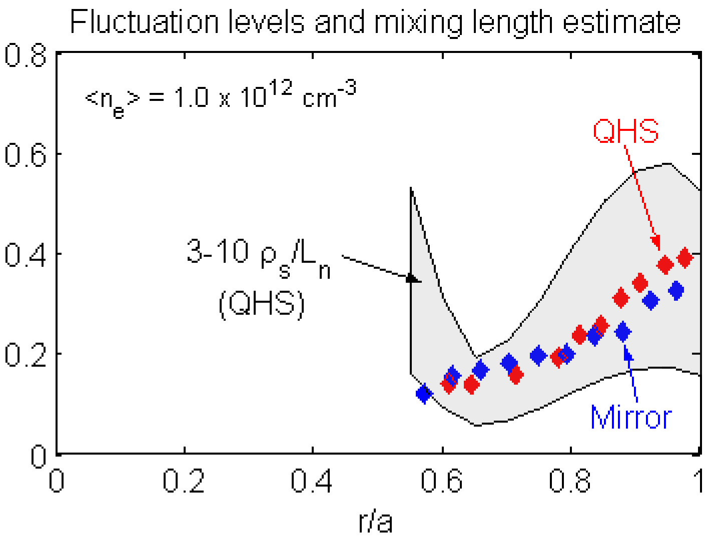
Central temperature in symmetric configuration ~ 200 eV higher

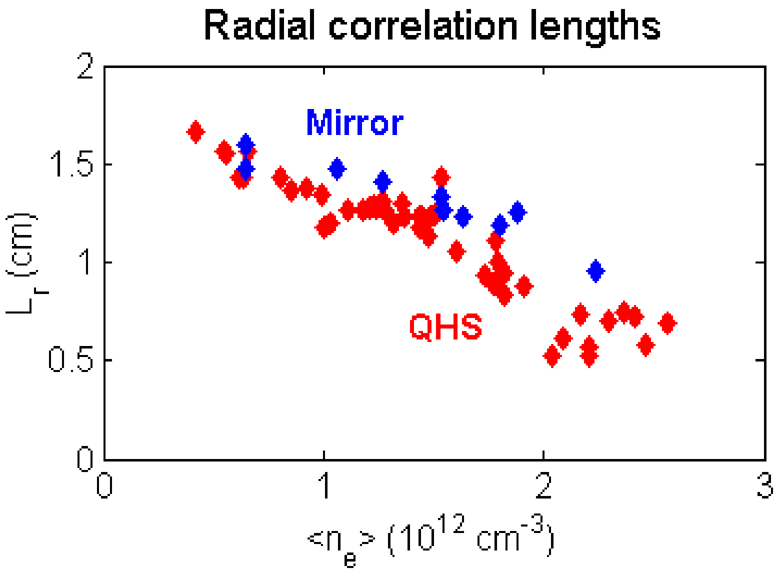
Thermal diffusivity at r/a~0.3 is reduced in QHS compared to Mirror (~1 vs. ~3 m^2/s)

QHS has longer confinement time: τ_E^{QHS} ~ 1.5 ms, τ_E^{PSM} ~ 0.9 ms

x 10^12
2.5
2
1.5
1
0.5
0
ne (cm^-3)
-0.2
0
0.2
0.4
0.6
0.8
1
r/a
0%
2%
4%
6%
8%
10%
700
600
500
400
300
200
100
0
Te (eV)
-0.2
0
0.2
0.4
0.6
0.8
r/a
0%
2%
4%
6%
8%
10%

No Large Differences in Fluctuation Characteristics Between Configurations



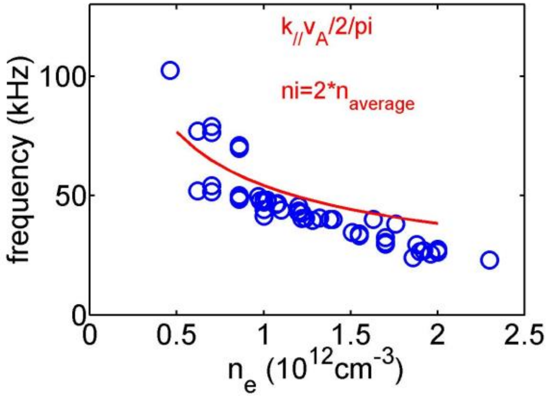


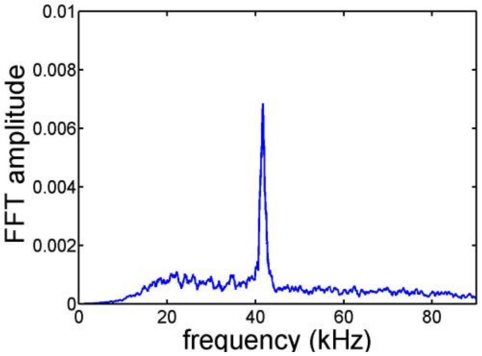
- Fluctuation levels (from ion saturation current) at the edge are same in QHS and Mirror – similar to mixing length estimates
- Correlation lengths ($L_r \approx k_\theta^{-1}$) and times are similar over a range of densities
- Turbulent diffusivities (L_r^2/τ) are ~ 20 m^2/s at high density – on the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

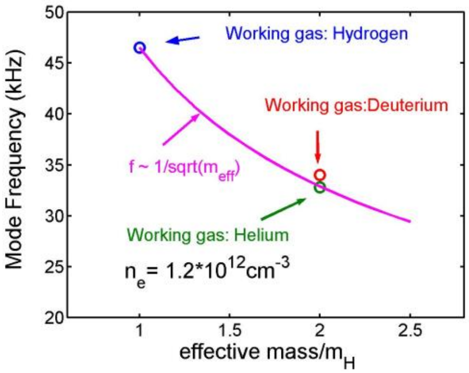
MHD Mode Observed only in QHS Plasmas

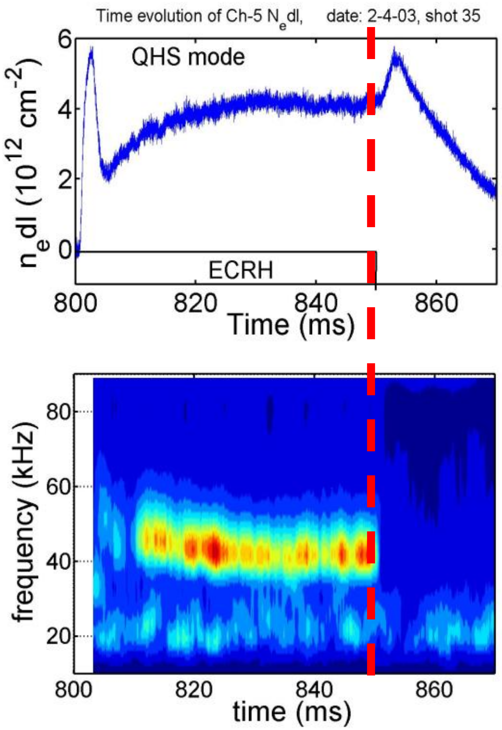
Possible n=1,m=1 GAE mode observed only in QHS discharges

(STELGAP code
D. Spong, ORNL)









Scaling consistent with Alfvenic modes

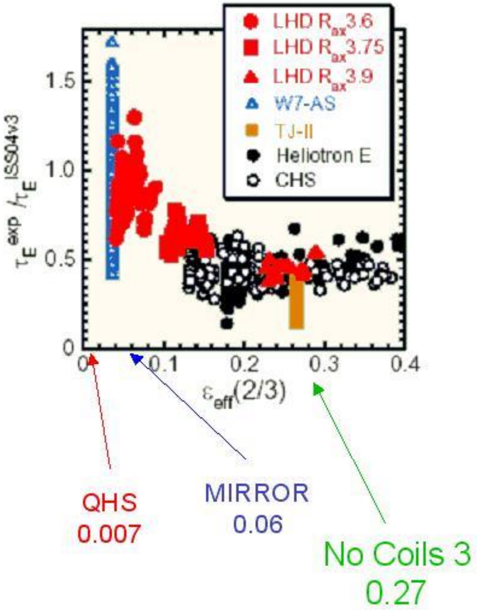
Long Range Plans

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-mι|) 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=1.0T (Spring) $\tau \sim B^{0.84}$
  - -Fundamental heating (increase density, $\tau \sim n^{0.6}$)
  - -Increase heating power to 200 kW with new T.L. (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
- Confirm neoclassical improvements
- Continue installation of 2nd 200 kW 28 GHz ECH system
  - -power modulation experiments; heat pulse χe in addition to power balance
  - -steerable launcher for Te 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**
- **Effective ripple seems to make a difference in anomalous transport**
- **Advanced stellarators offer potential of tokamak-like confinement (or better) while minimizing current driven effects**
    - **-Disruptions**
    - **-Current drive/BS alignment**

Something punchy here!