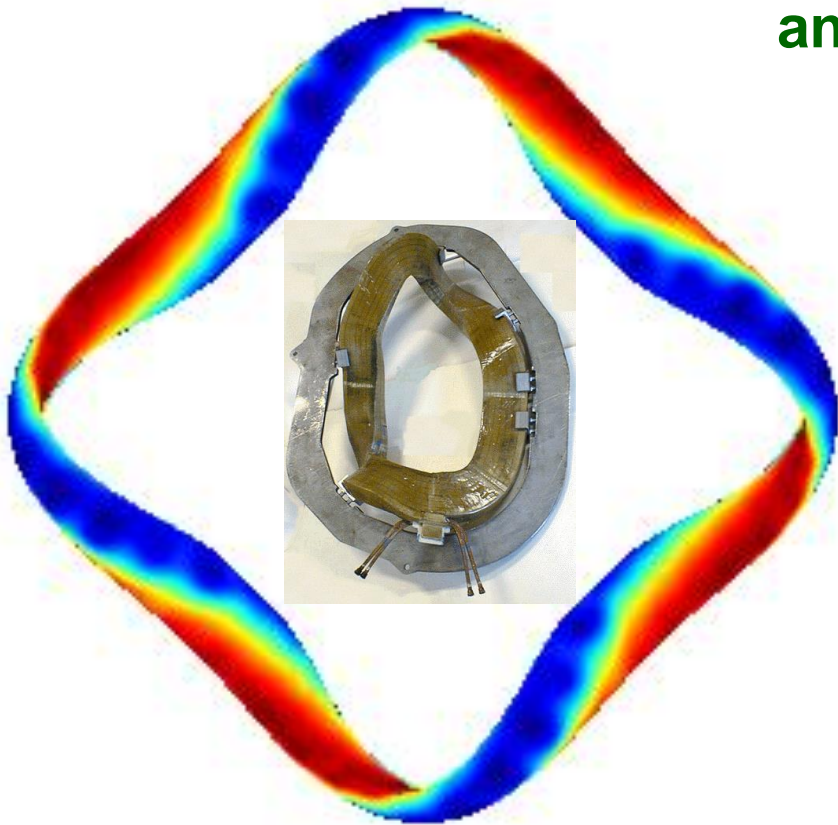


First Experiments Testing the Working Hypothesis in HSX:

Does minimizing neoclassical transport also reduce anomalous transport?



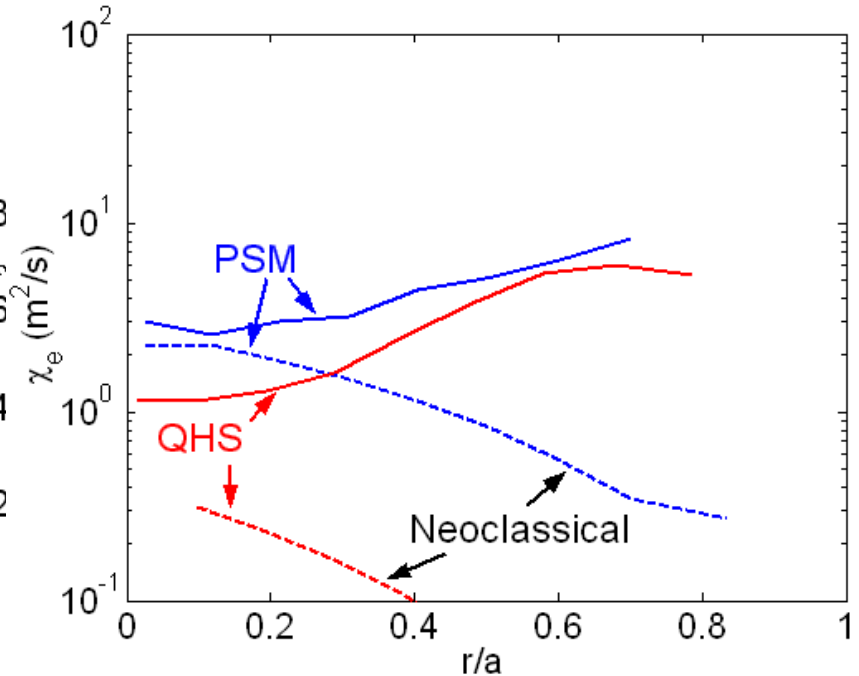
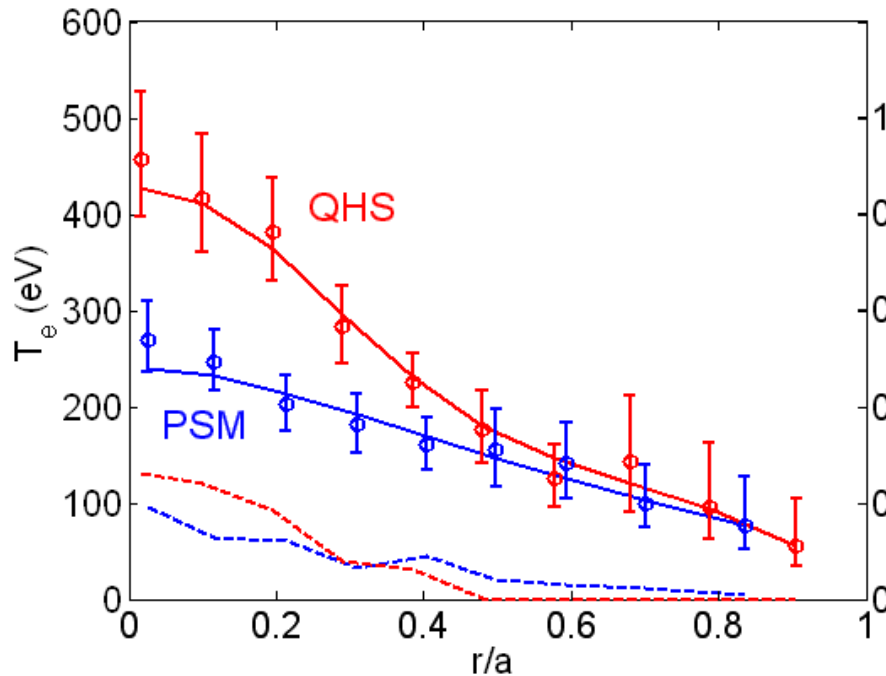
J. N. Talmadge
HSX Plasma Laboratory
University of Wisconsin-Madison

Special acknowledgement to J. Canik,
K. Likin, C. Clark and the HSX Team,
D. Spong of ORNL

HSX has already demonstrated **reduced thermal conductivity** and **reduced viscous damping**

Higher QHS T_e with same absorbed power

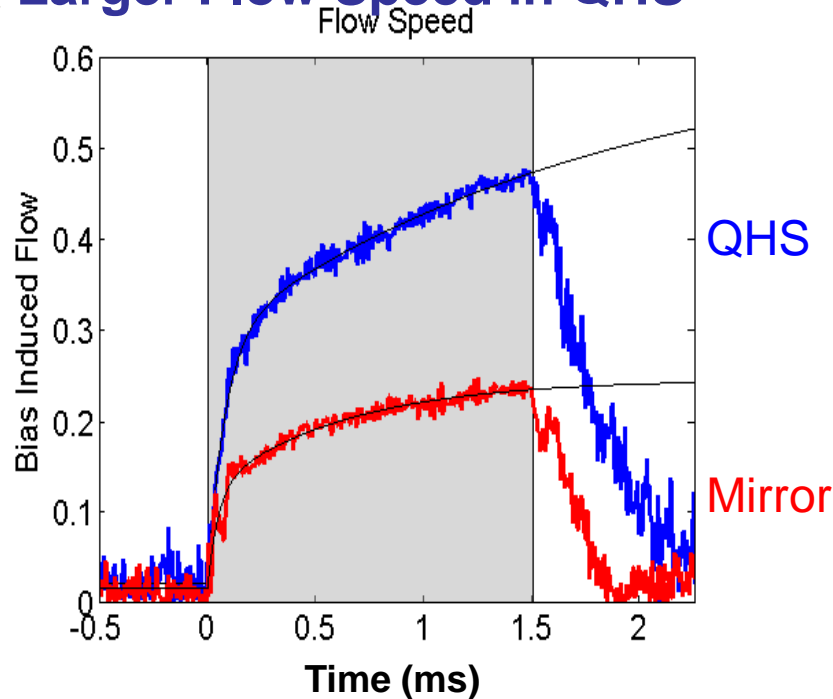
Thermal diffusivity at $r/a=.3 \sim 1\text{m}^2/\text{s}$ for QHS, $\sim 3\text{ m}^2/\text{s}$ for PSM



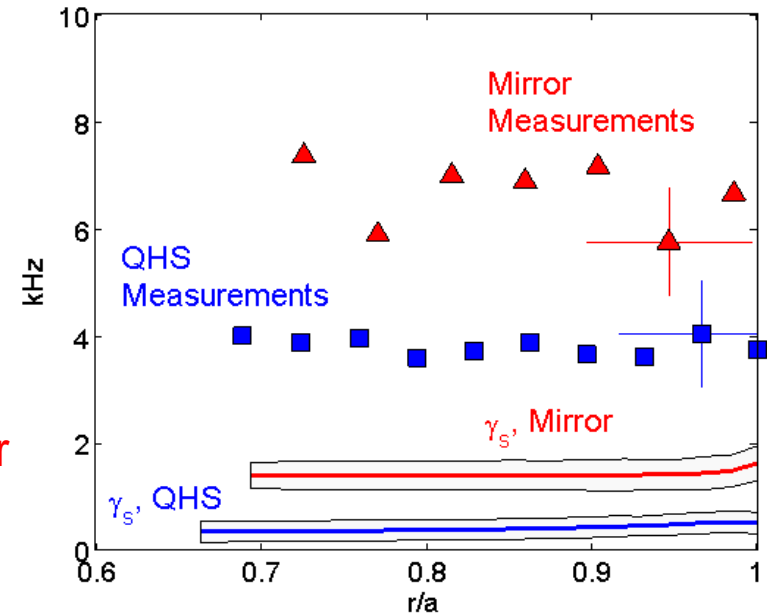
- Central T_e increases by 200 eV with quasisymmetry
- Mirror configuration close to neoclassical at core; QHS is anomalous
- QHS has longer confinement time: $\tau_E^{\text{QHS}} \sim 1.5\text{ ms}$, $\tau_E^{\text{PSM}} \sim 0.9\text{ ms}$

HSX has already demonstrated reduced thermal conductivity and **reduced viscous damping**

Larger Flow Speed in QHS



Slow decay rate reduced in QHS



- Higher flow for less drive with quasisymmetry
- Slow decay rate lower in QHS, but anomalous momentum damping also exists (as in tokamaks)

→ Potential for higher shear flow with quasisymmetry

How we test the working hypothesis in HSX

- Goal is to compare anomalous thermal conductivity in two configurations with different effective ripple, but with most parameters fixed
 - Adjust absorbed power to match density and temperature profiles
 - No need to scale anomalous transport when profiles match
- Match plasma volume, transform, well depth as much as possible
- Minimize movement of magnetic axis between configurations
 - Power deposition profile should be similar
 - Don't want magnetic axis to be out of line with the Thomson laser path

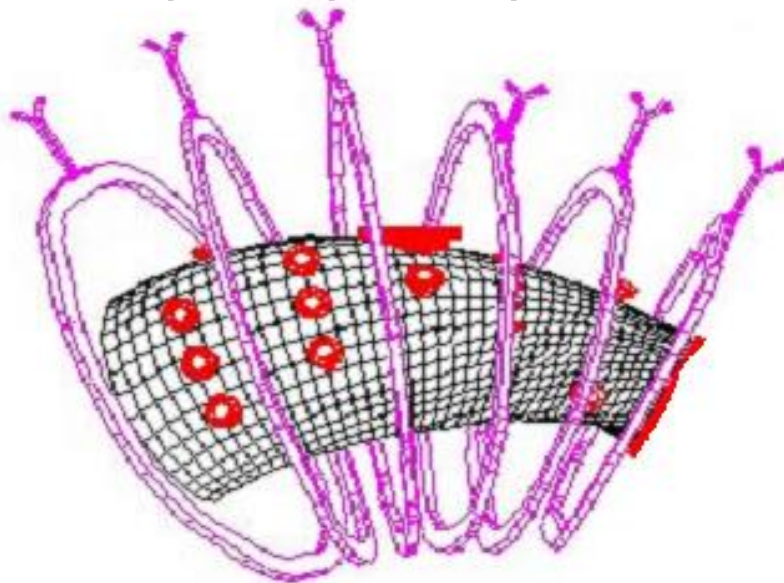
How we test the working hypothesis in HSX

- Minimize nonthermal contribution to stored energy
 - At low power and high density, stored energy from integrated Thomson profiles is similar to flux loop measurements
 - When $W_{\text{flux loop}} > W_{\text{Thomson}}$, ECE and soft X-ray data confirm presence of nonthermal electrons
- From the power deposition and the temperature profile obtain the experimental thermal conductivity
 - Calculate anomalous component by subtracting neoclassical contribution
 - ➔ Does the configuration with lower effective ripple have reduced anomalous transport?

Symmetry is broken with auxiliary coils

- Phasing currents in auxiliary coils breaks quasihelical symmetry ($n=4, m=1$) with $n = 4$ & $8, m = 0$ mirror terms
- Neoclassical transport and parallel viscous damping increased

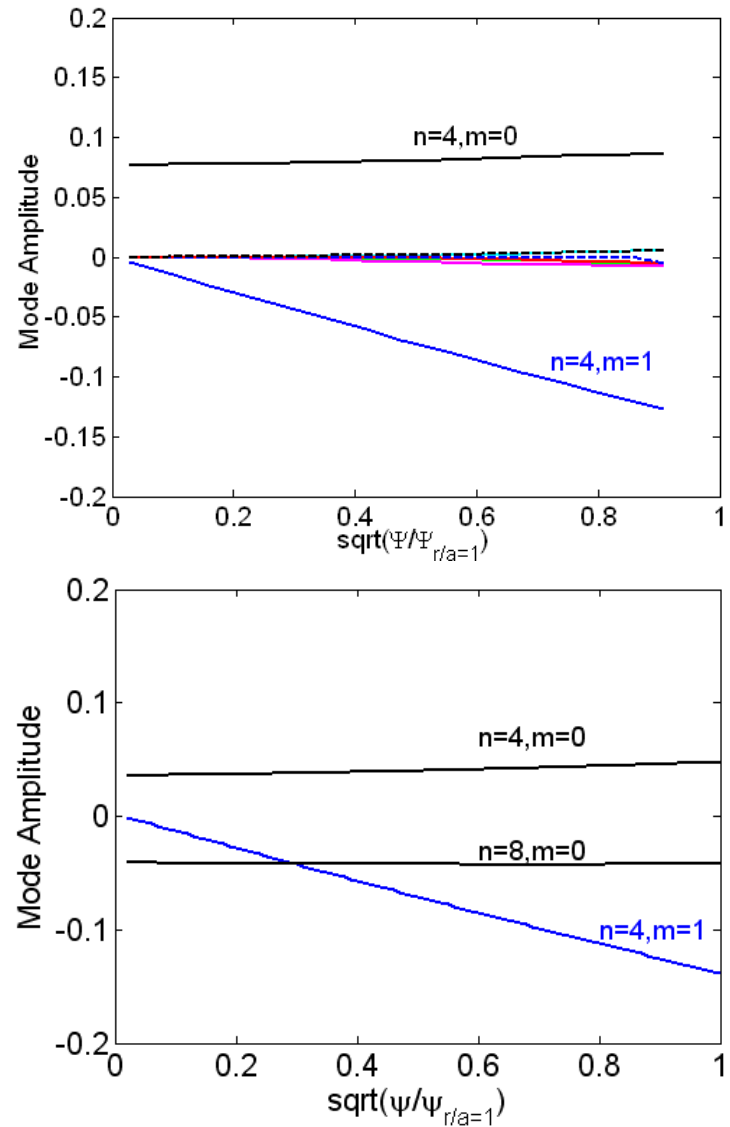
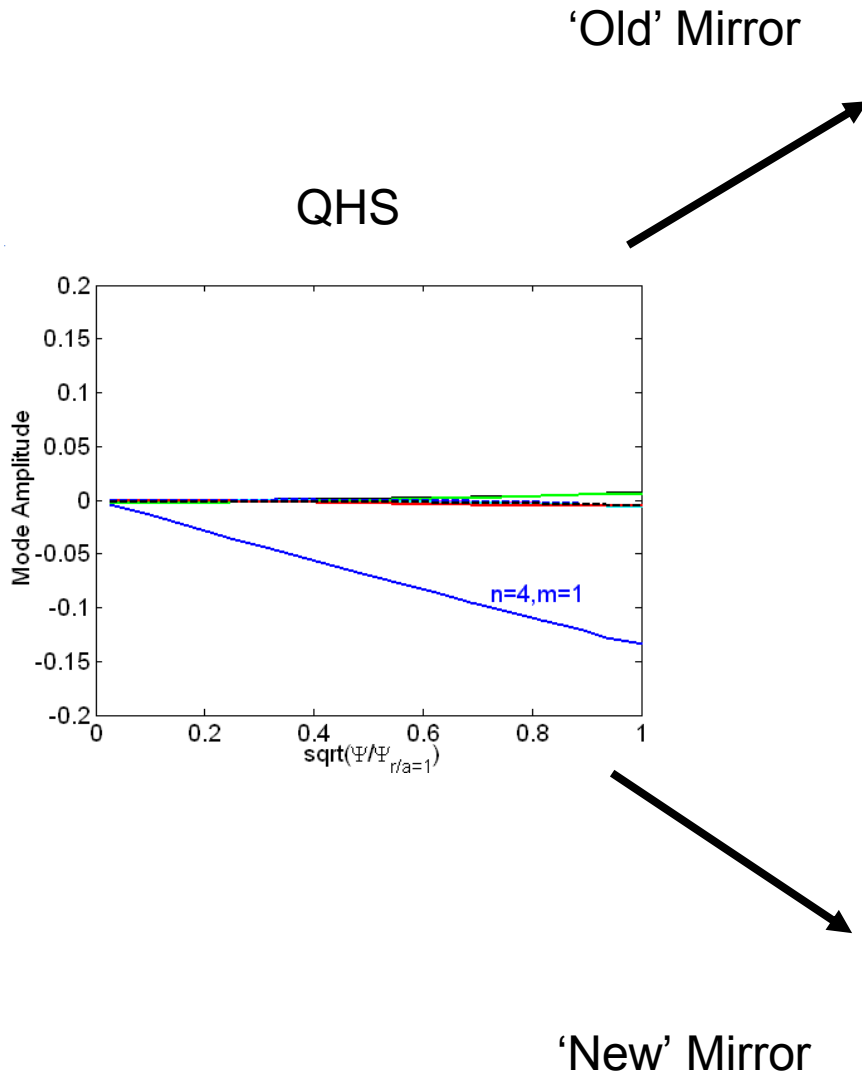
+	+	+	-	-	-	'Old' Mirror
-	+	+	+	-	-	'New' Mirror



1 2 3 4 5 6

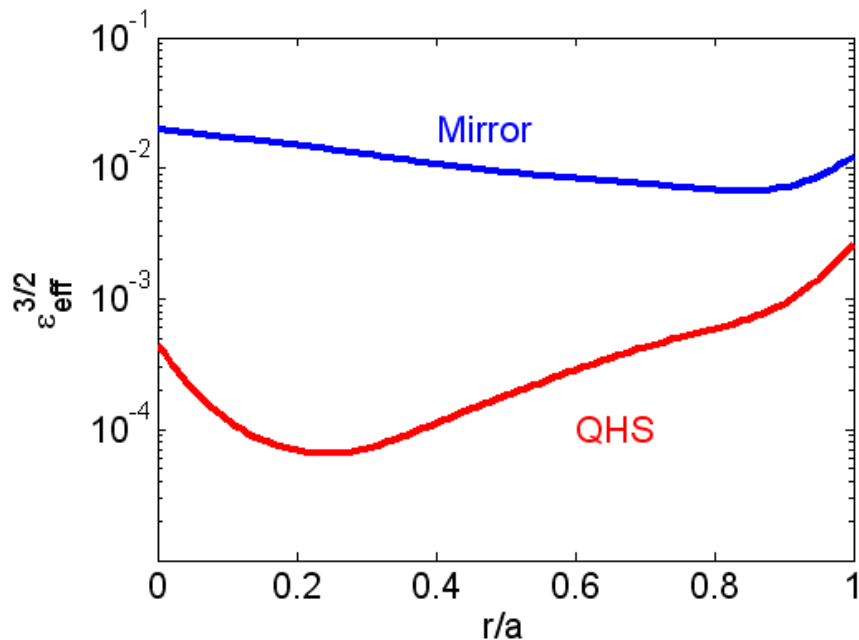
Minimal displacement
of magnetic axis at
ECH and TS ports

'New' mirror excites $n = 4$ and 8 , $m=0$ modes

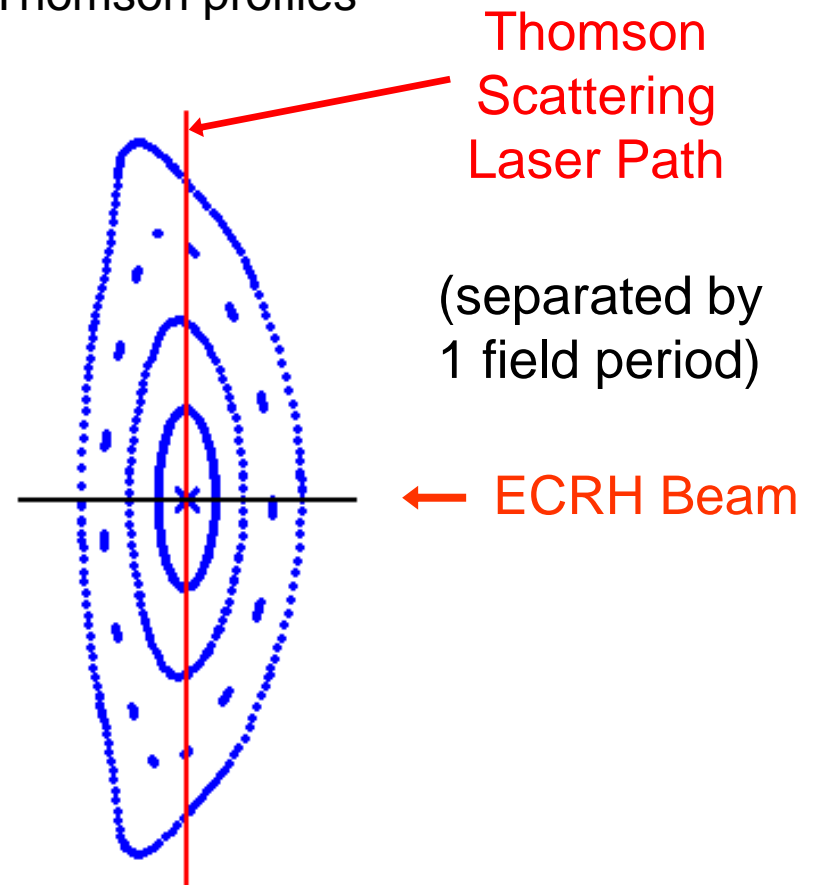


New mirror configuration increases effective ripple while keeping magnetic axis stationary

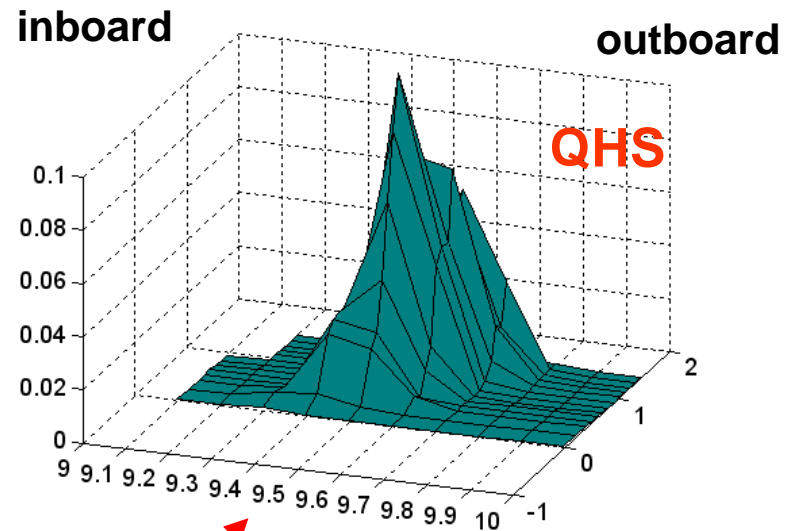
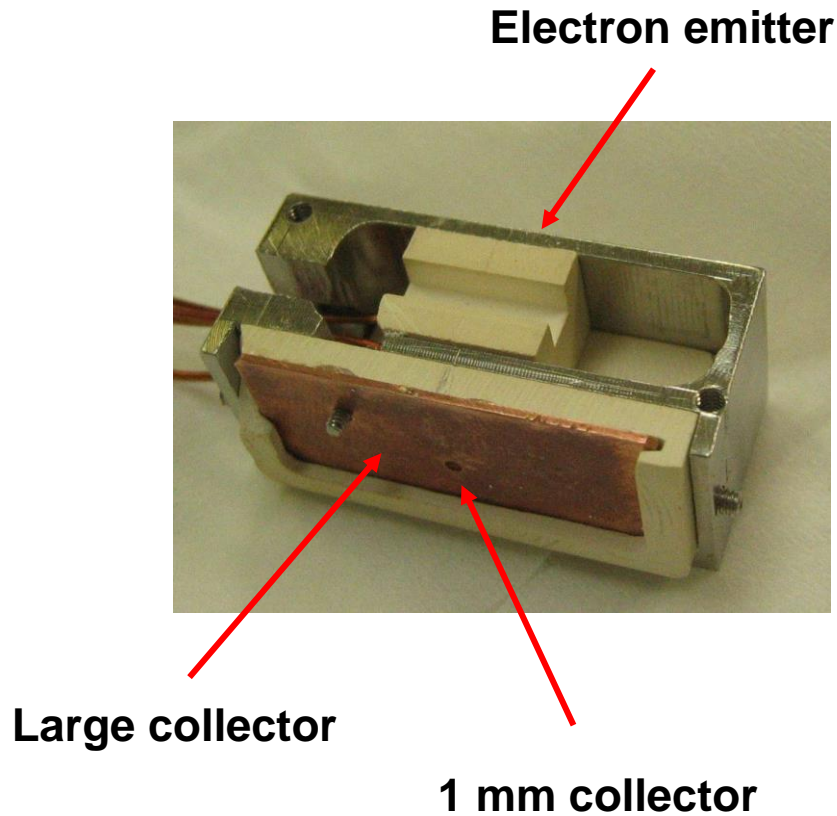
ϵ_{eff} increases by factor of 8
at $r/a \sim 2/3$



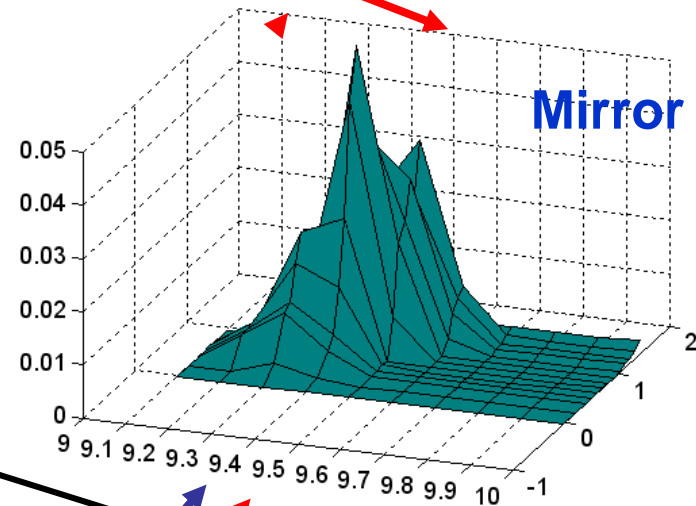
New Mirror Configuration allows for both on-axis heating and on-axis Thomson profiles



Verification of ~ 1 mm shift in magnetic axis



QHS peak

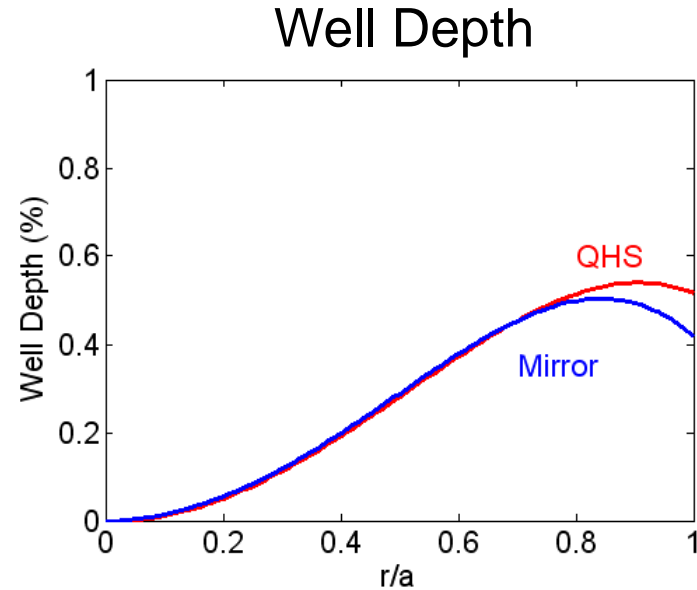
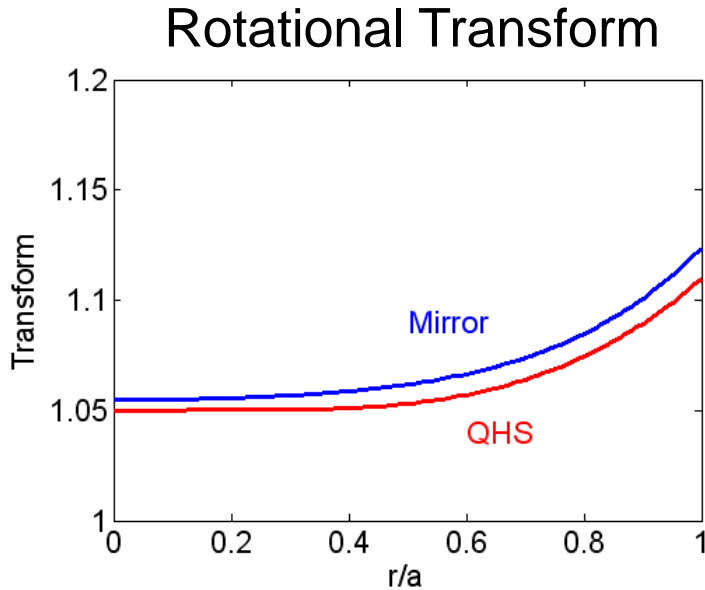


Mirror peak

QHS peak

1 mm Shift

.... while transform, well depth and volume remain almost fixed



	QHS	'New' Mirror
Transform ($r/a = 2/3$)	1.062	1.071
Volume (m^3)	0.384	0.355
Axis location (m)	1.4454	1.4447
ϵ_{eff} ($r/a = 2/3$)	0.005	0.040

< 1%

< 10%

< 1 mm shift

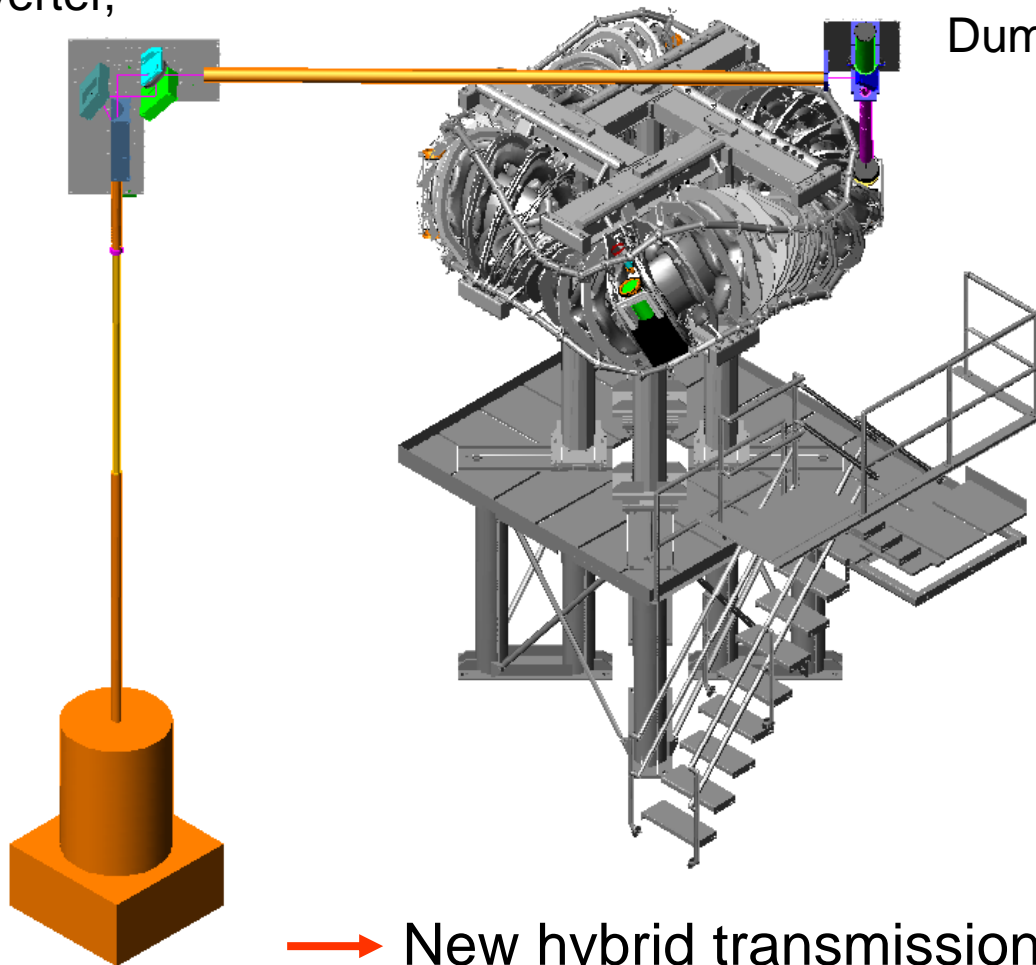
factor of 8

Second harmonic X-mode at $B = 0.5$ T tests confinement of electrons at low collisionality

Mode Converter,
2 Focusing
Mirrors +
Polarizer

Focusing Mirror - Switch,
Dummy Load

28 GHz /
200 kW
Gyrotron

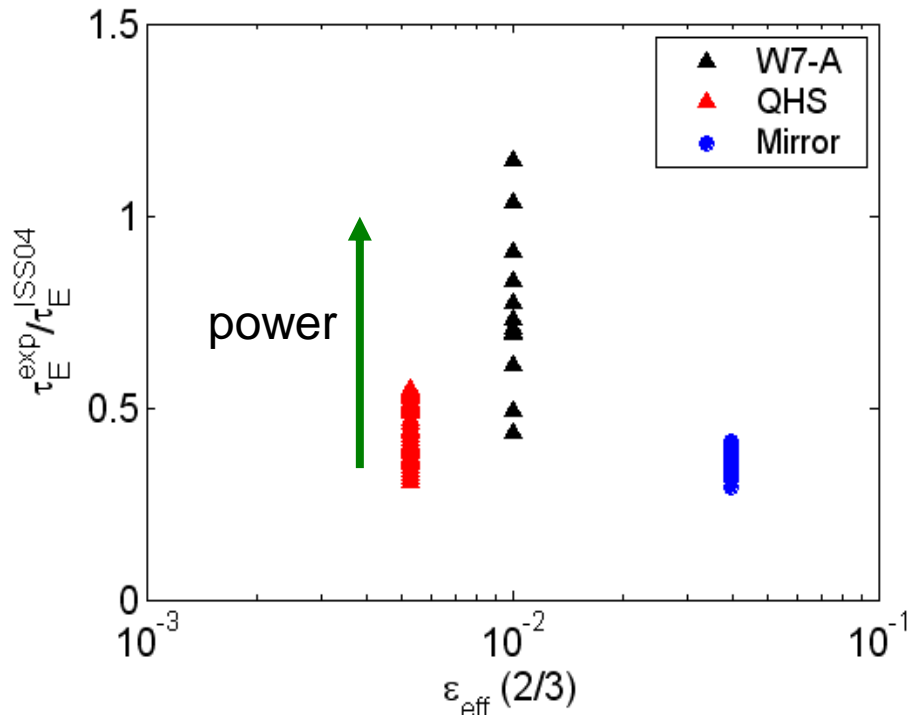


Hybrid transmission line
(waveguides plus mirrors)
has better performance
compared to old waveguide
line

- Higher mode purity
- Accurate wave polarization
- Less power in the side-lobes
- Higher arc threshold

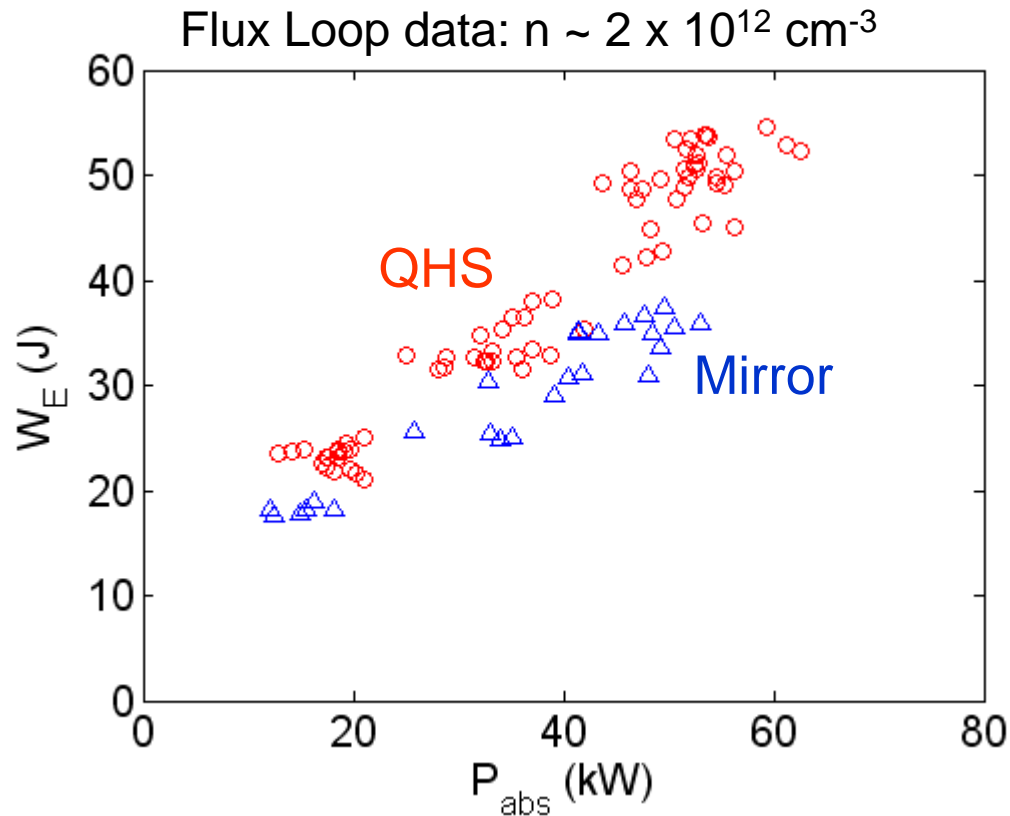
→ New hybrid transmission line doubles
absorbed power

Confinement time normalized to ISS04 similar to W7-A



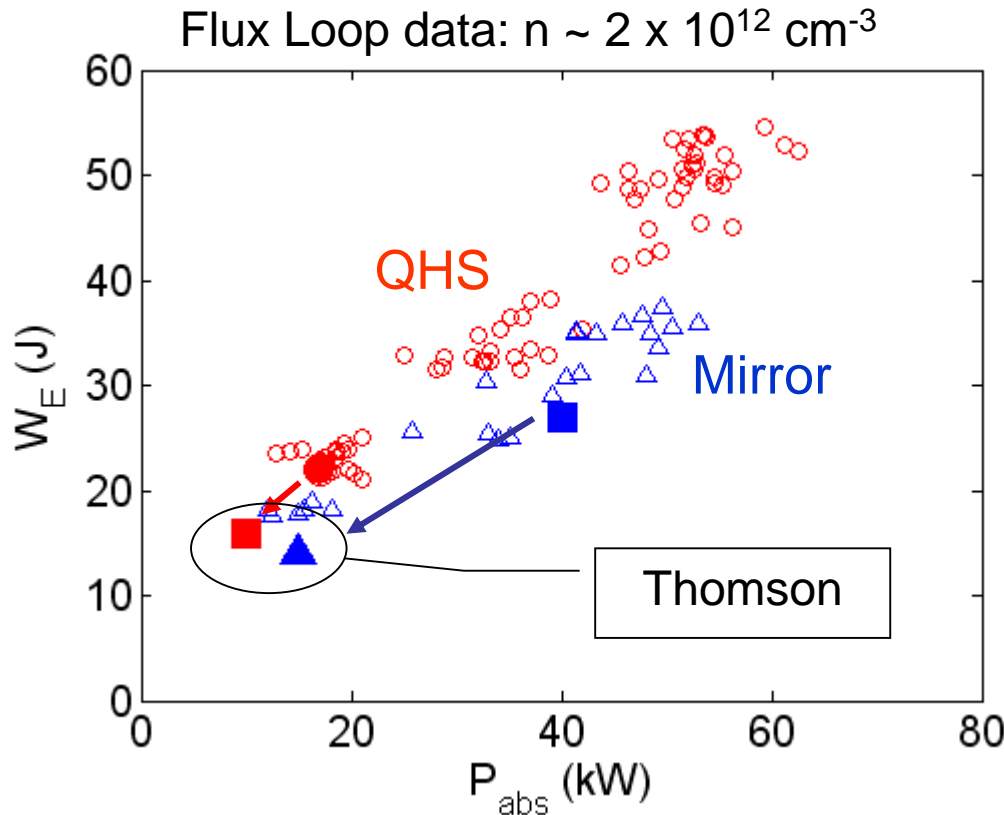
- Normalized confinement in HSX increases with power, as in W7-A
- At similar powers, normalized confinement for HSX and W7-A are also similar

Confinement time higher in QHS than Mirror



- Confinement time is weak function of power
→ divergence from ISS04 scaling law

Matching profiles requires more power in Mirror



To obtain similar T_e and n_e profiles in QHS and Mirror Gyrotron power:

QHS: 25 kW

Mirror: 70 kW

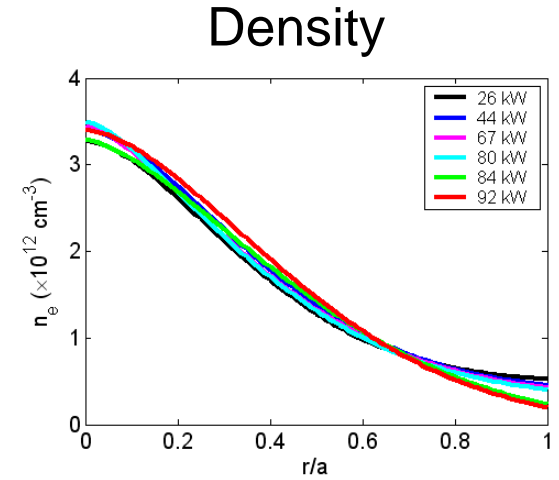
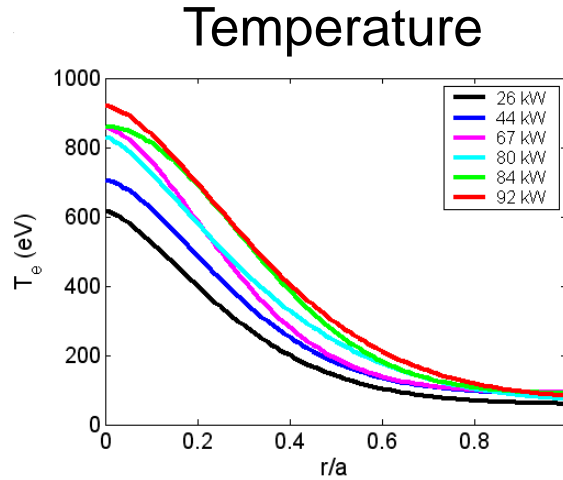
→ Almost 3x power needed in Mirror over QHS

→ More power leads to larger nonthermal fraction of stored energy

→ Discrepancy between flux loop and Thomson larger for Mirror at higher power

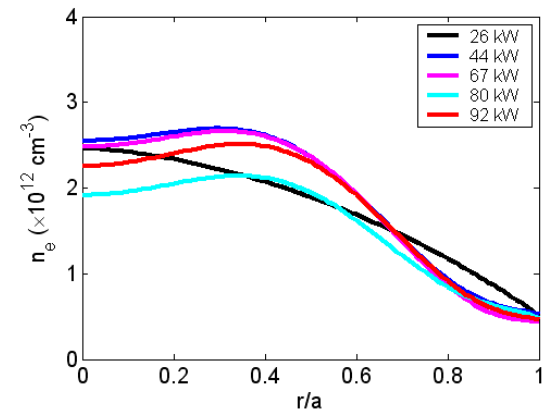
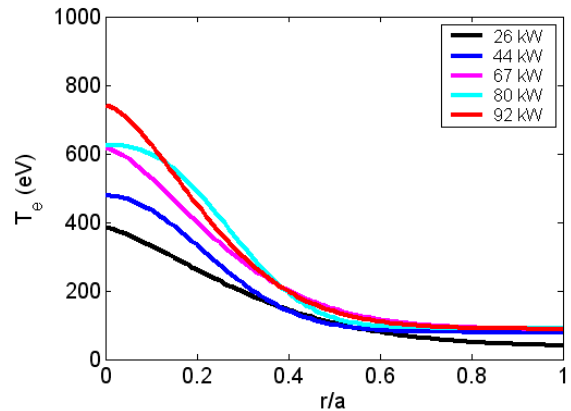
Increasing power in Mirror flattens density profile

- With increasing power, density profile in QHS remains roughly fixed



QHS

- Mirror density profile is peaked at low power, then hollow at higher power



Mirror

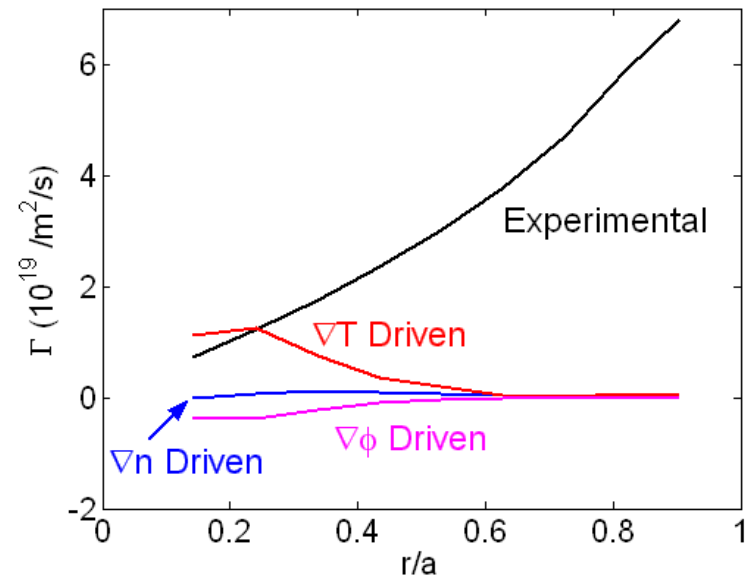
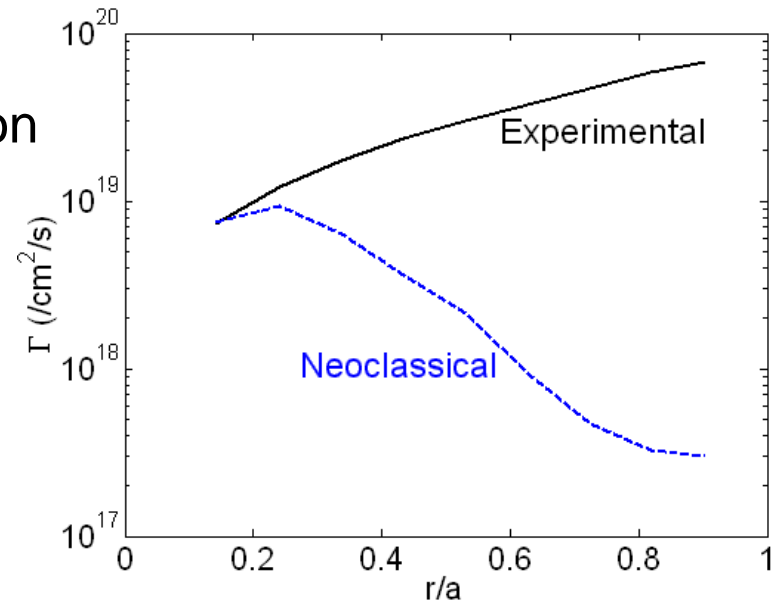
$$\Gamma = -n \left\{ D_{11} \left(\frac{n'}{n} - \frac{qE_r}{T} \right) + D_{12} \frac{T'}{T} \right\}$$

D_{12} is smaller in QHS due to quasisymmetry

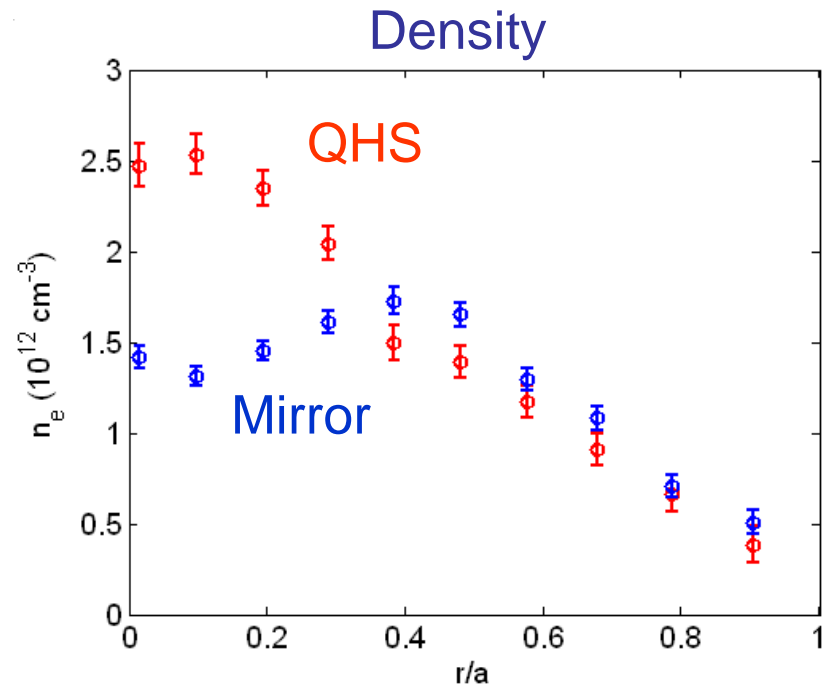
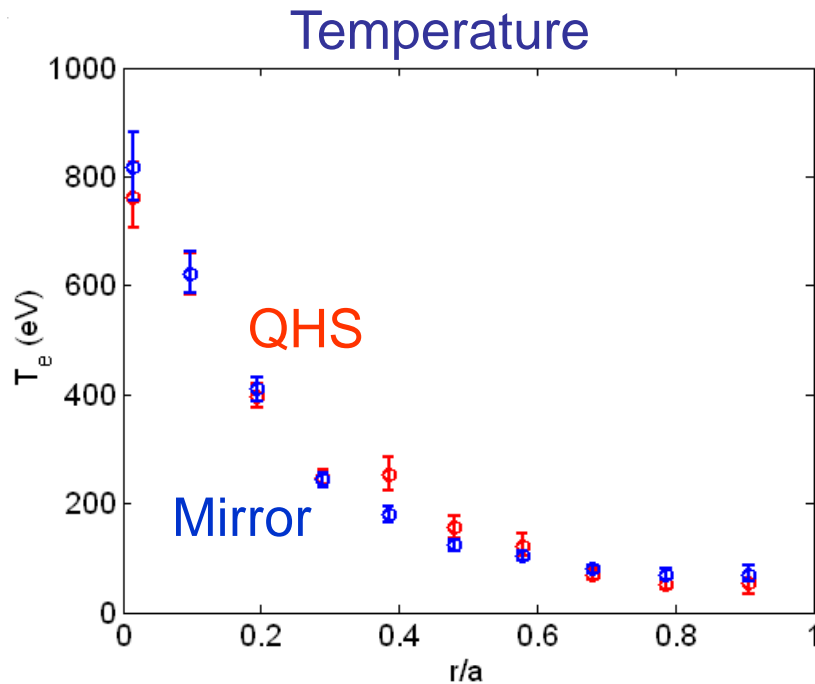
Neoclassical Thermodiffusion Accounts for Hollow Density Profile in Mirror Configuration

- Figure shows experimental particle flux from H_α + DEGAS, neoclassical prediction
- In region of hollow density profile, neoclassical and experimental fluxes comparable
- The ∇T driven neoclassical flux is dominant

$$\Gamma = -n \left\{ D_{11} \left(\frac{n'}{n} - \frac{qE_r}{T} \right) + D_{12} \frac{T'}{T} \right\}$$

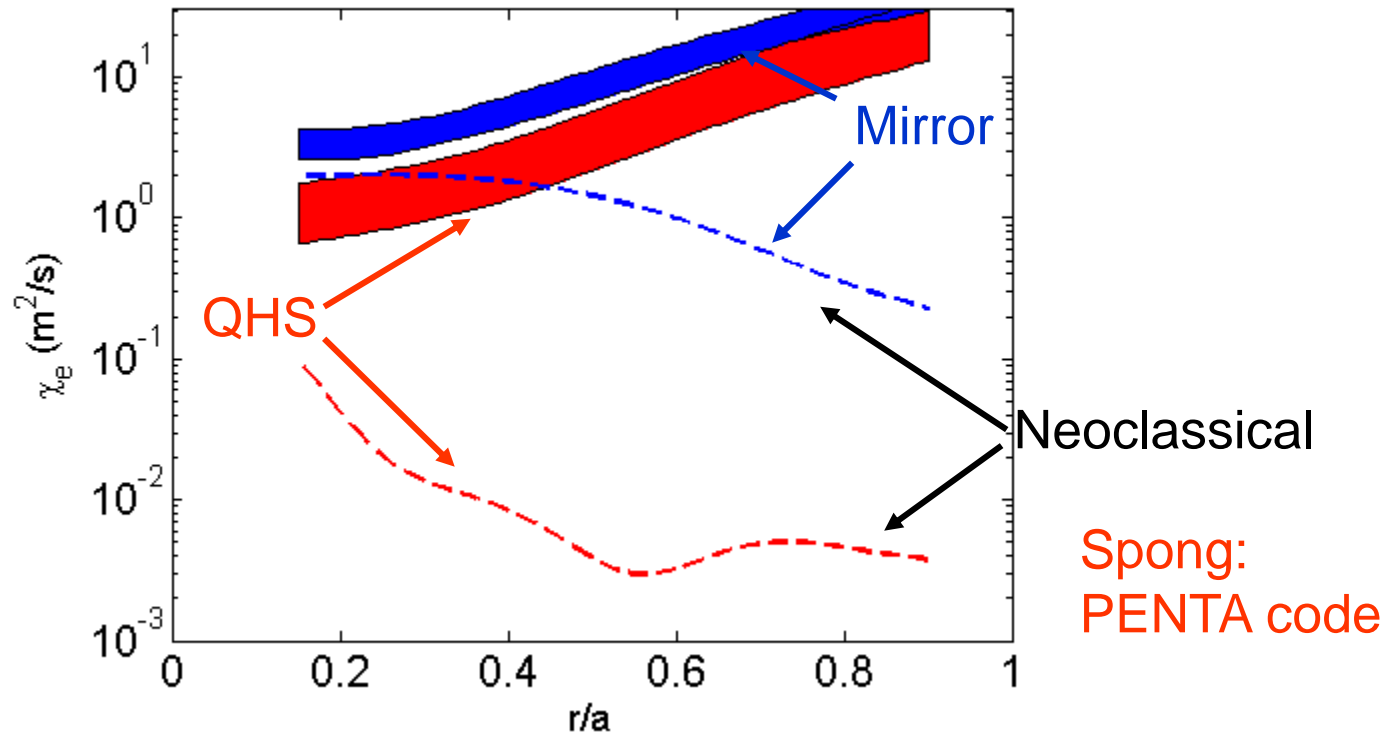


Electron temperature profiles can be well matched between QHS and Mirror



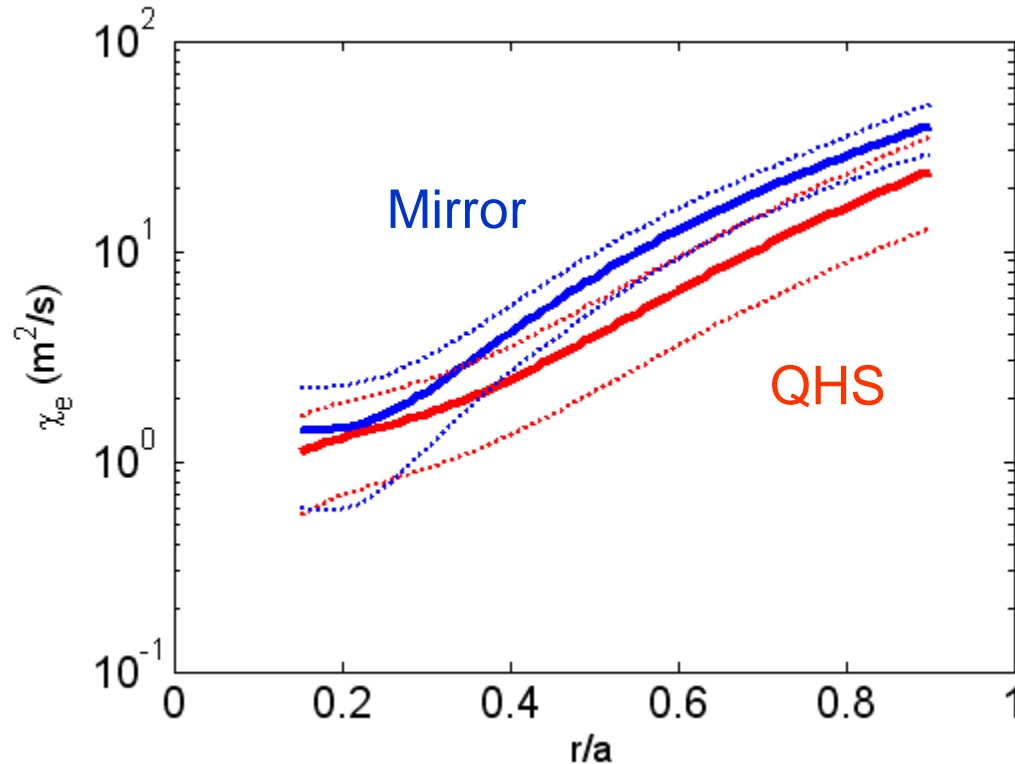
- Temperature profiles match with 70 kW in Mirror, 25 kW in QHS
- Density profiles don't match because of thermodiffusion in Mirror

Experimental thermal conductivity lower in QHS than Mirror in the core



- Error bar due to uncertainty in profiles and absorbed power
- Mirror conductivity is close to neoclassical in the core
- Neoclassical thermal conductivity in QHS is far below Mirror
 - Does this decrease translate to a reduction in anomalous?

Anomalous conductivity is difference between experimental and neoclassical



- At the plasma core: Mirror experimental conductivity = QHS anomalous + Mirror neoclassical

→ **At these operating conditions:** unclear there is difference in anomalous transport between QHS and Mirror

More to come

- New Mirror configuration allows factor of 8 variation in effective ripple
- Lower effective ripple in QHS leads to:
 - Reduction in momentum damping, thermodiffusion, energy transport
- Anomalous transport, as of now, is similar for QHS and Mirror: → nonthermal population is a concern
- Improvements in testing working hypothesis
 - Increasing field to 1 T
 - Fundamental heating with ordinary mode at densities up to $1 \times 10^{13} \text{ cm}^{-3}$ should reduce nonthermal problem
 - Electric field and turbulence measurements: Edge probes, reflectometer, 16 channel ECE, CHERS (summer 2007).
 - Comparisons of flows and electric field to PENTA code (Spong)