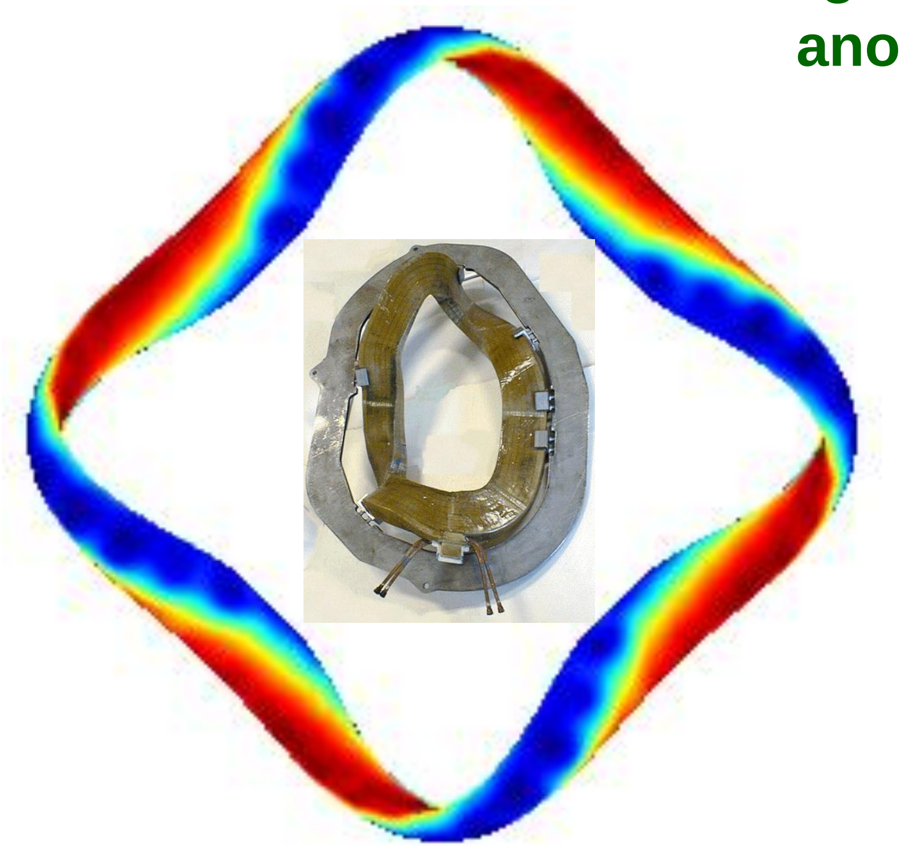
First Experiments Testing the Working Hypothesis in HSX:

Does minimizing neoclassical transport also reduce anomalous transport?



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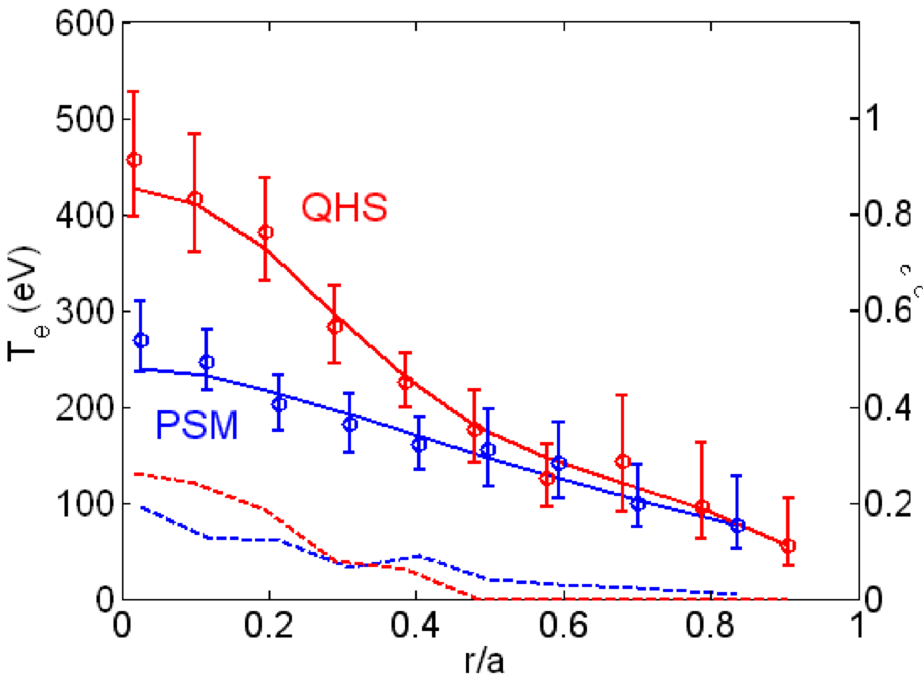
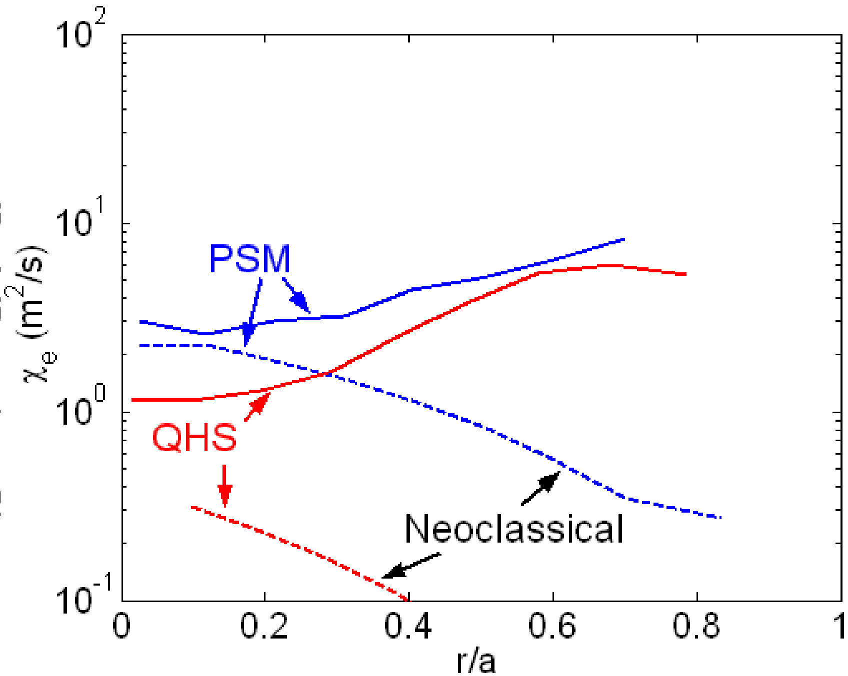
HSX has already demonstrated reduced thermal conductivity and reduced viscous damping

Higher QHS T_e with same absorbed power



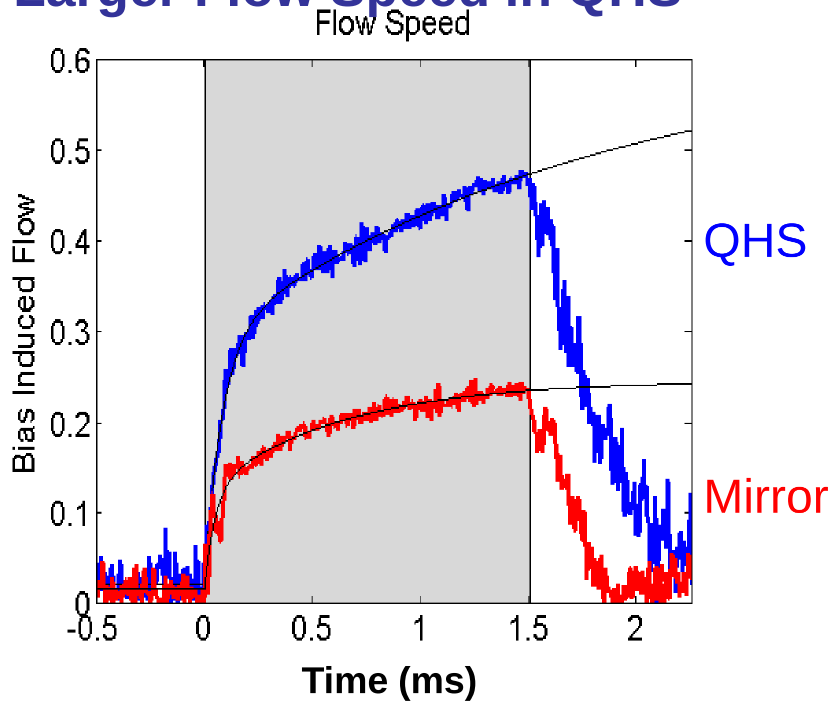
Thermal diffusivity at r/a=.3 ~1m²/s for QHS, ~3 m²/s for PSM



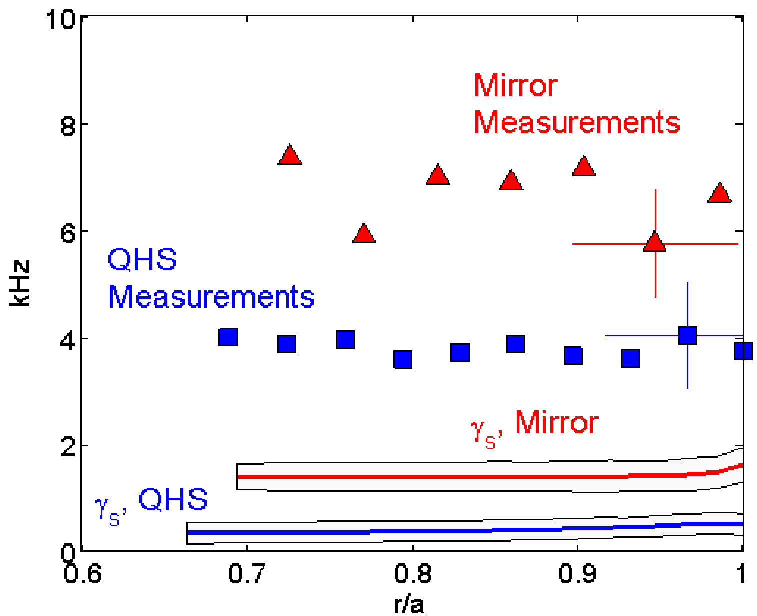
- Central T_e increases by 200 eV with quasisymmetry
- Mirror configuration close to neoclassical at core; QHS is anomalous
- QHS has longer confinement time: $\tau_E^{QHS} \sim 1.5$ ms, $\tau_E^{PSM} \sim 0.9$ ms

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

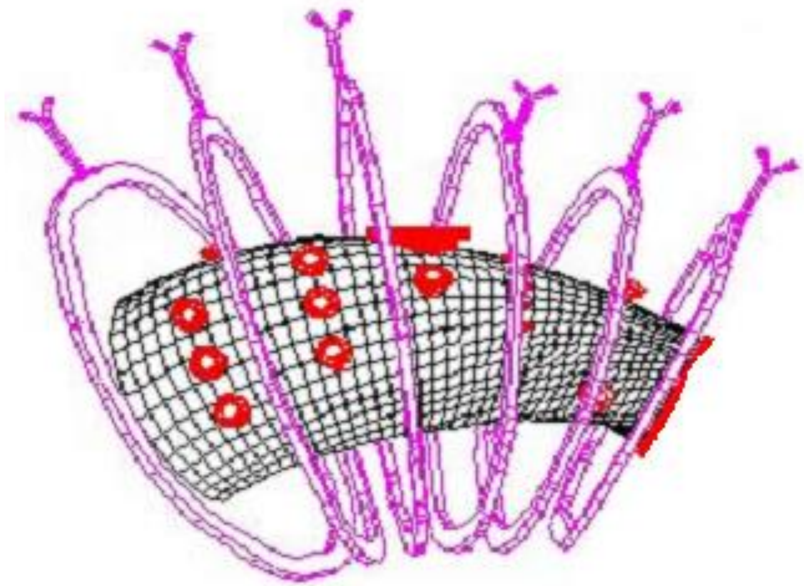
→ Does the configuration with lower effective ripple have reduced anomalous transport?

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

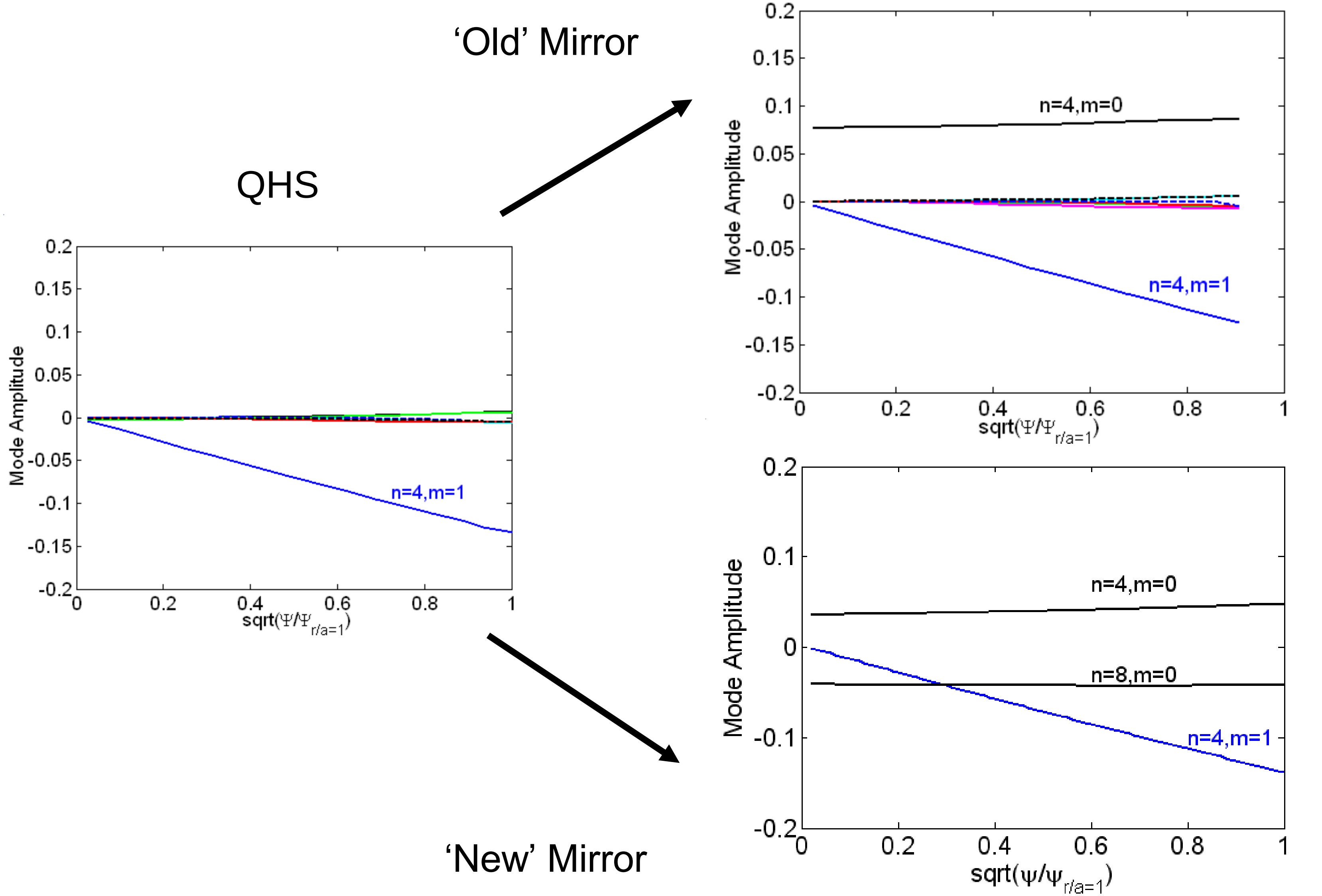
- + + + - - 'New' Mirror



1 2 3 4 5 6

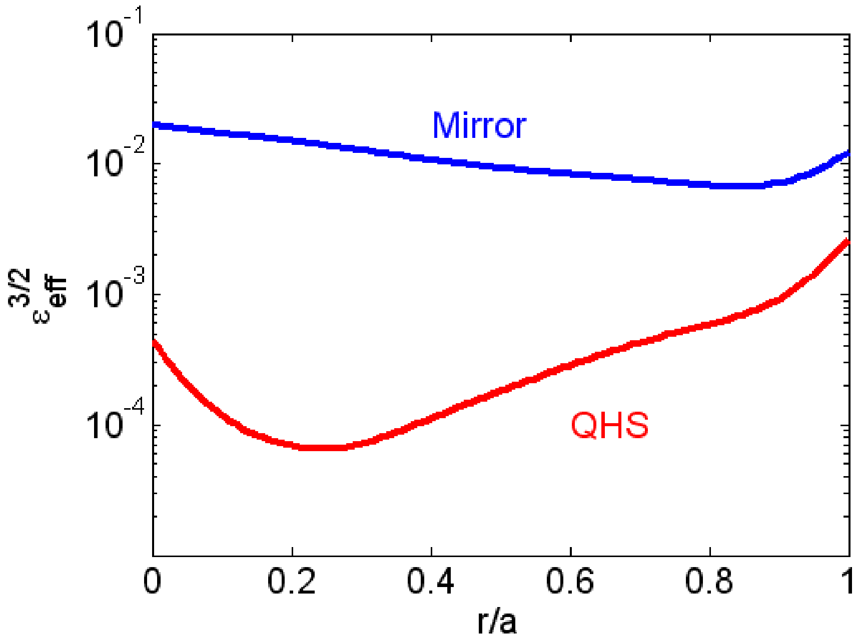
Minimal displacement of magnetic axis at ECH and TS ports

‘New’ mirror excites n = 4 and 8, m=0 modes

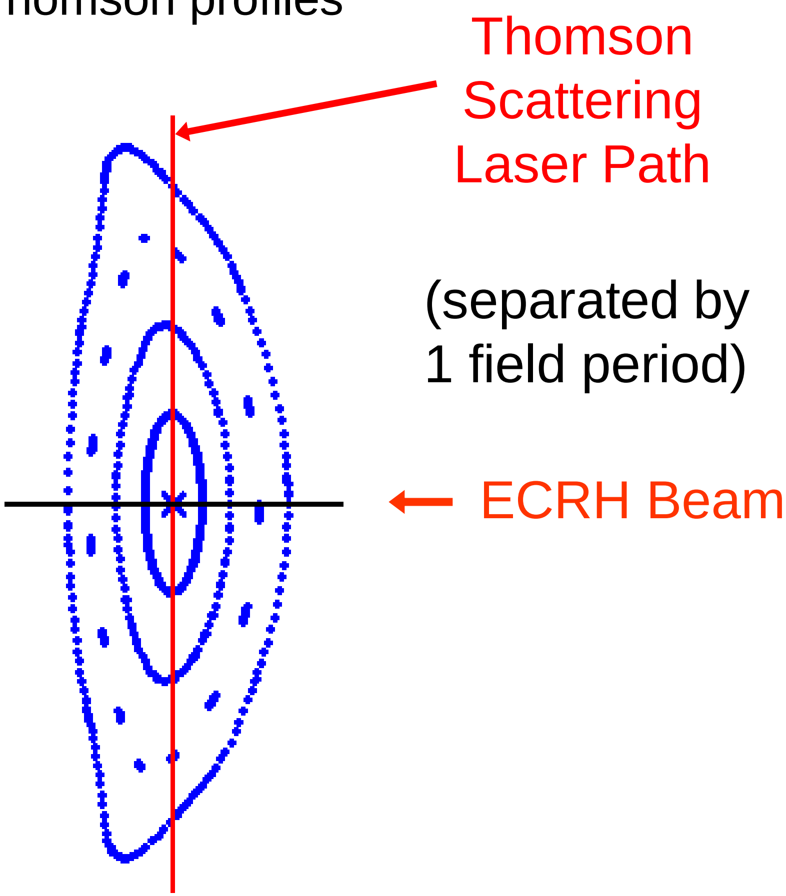


New mirror configuration increases effective ripple while keeping magnetic axis stationary

ε_{eff} increases by factor of 8 at r/a ~ 2/3

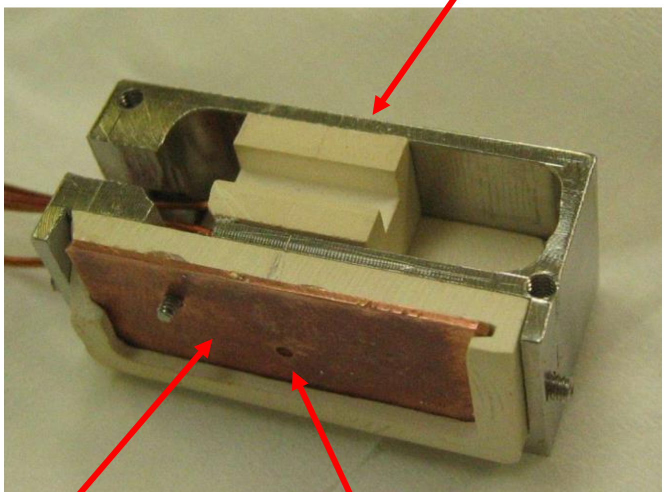


New Mirror Configuration allows for both on-axis heating and on-axis Thomson profiles



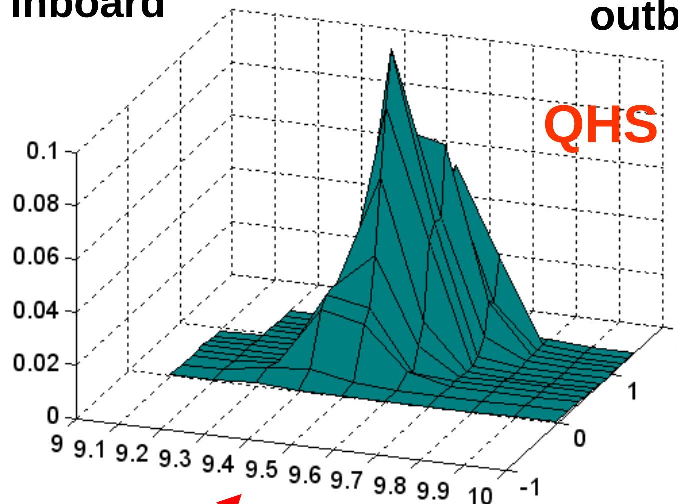
Verification of ~ 1 mm shift in magnetic axis

Electron emitter

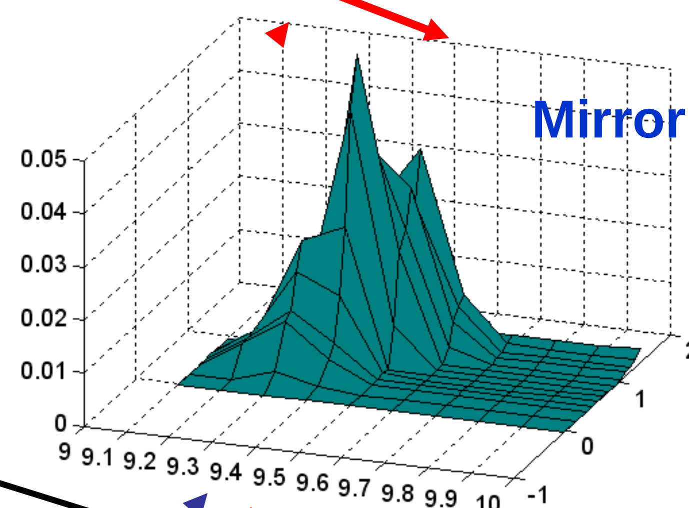


Large collector

1 mm collector



QHS peak

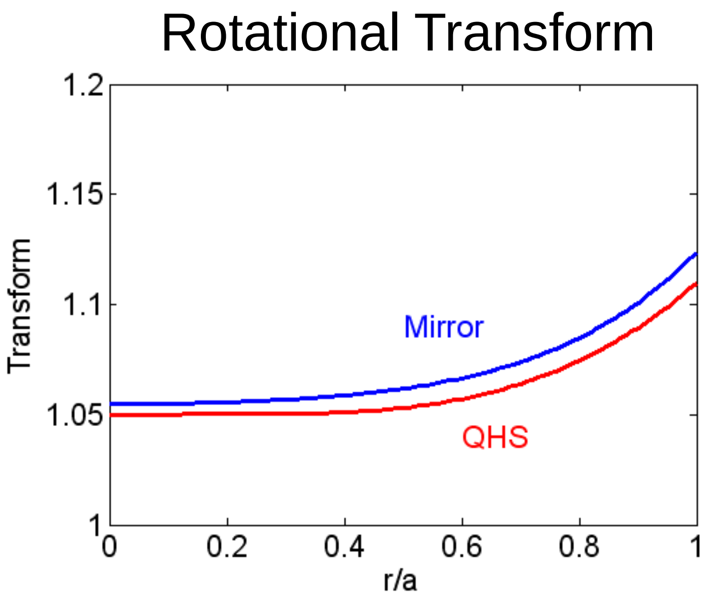


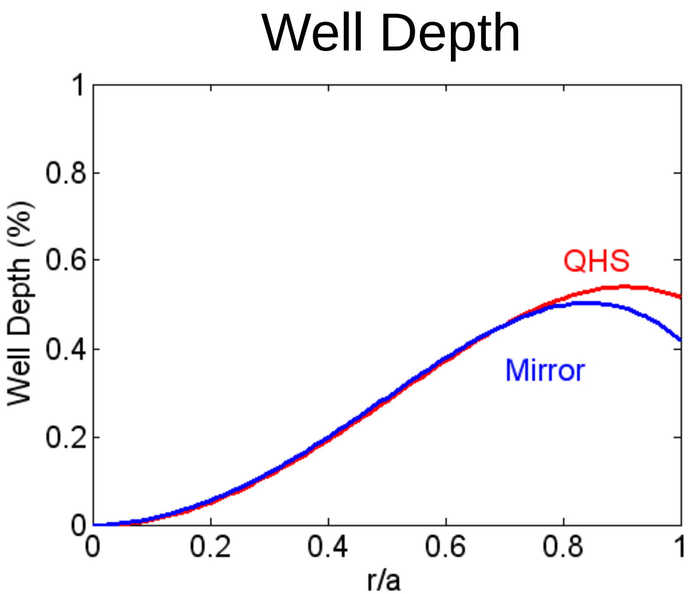
1 mm Shift

Mirror peak

QHS peak

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



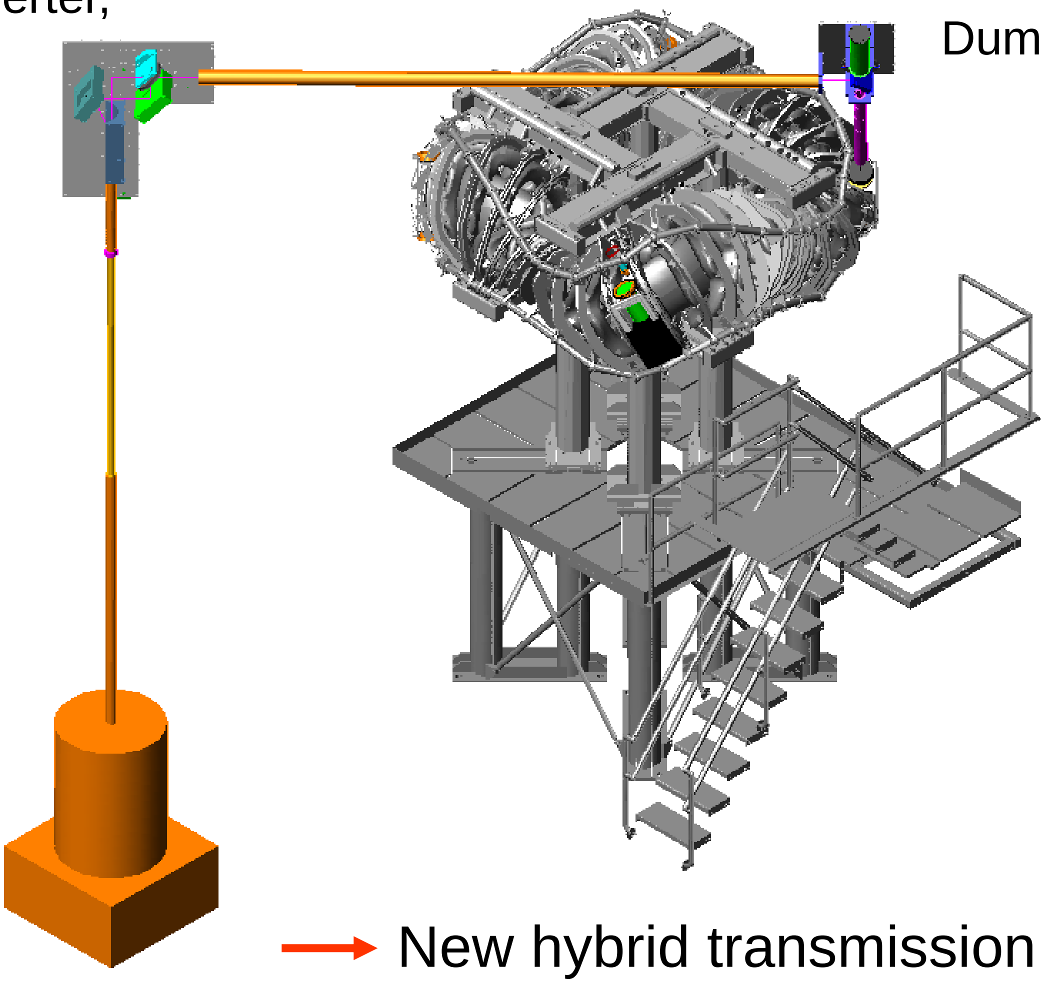


	QHS	'New' Mirror	
Transform (r/a = 2/3)	1.062	1.071	< 1%
Volume (m^3)	0.384	0.355	< 10%
Axis location (m)	1.4454	1.4447	< 1 mm shift
ε_{eff} (r/a = 2/3)	0.005	0.040	factor of 8

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



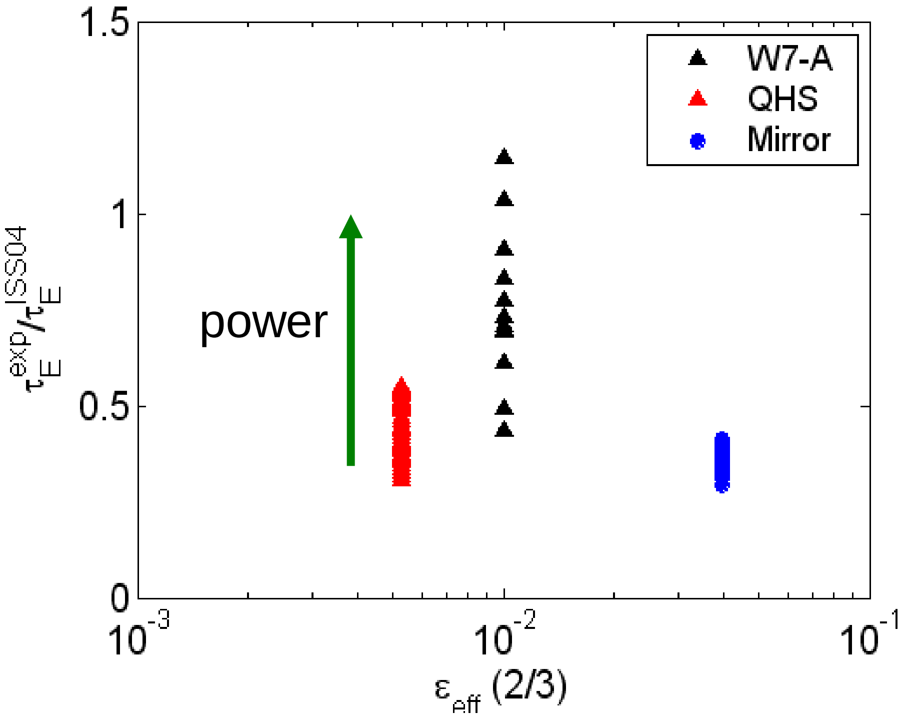
28 GHz / 200 kW Gyrotron

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

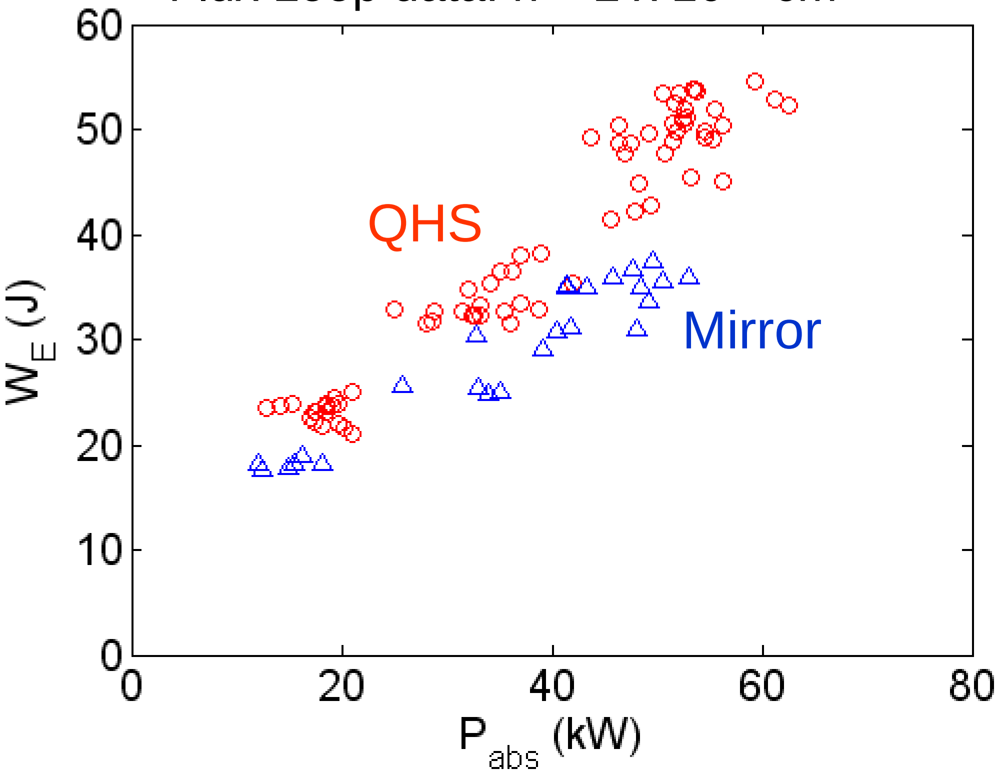
Confinement time normalized to ISS04 similar to W7-A



- 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

Flux Loop data: n ~ 2 x 10^{12} cm^{-3}

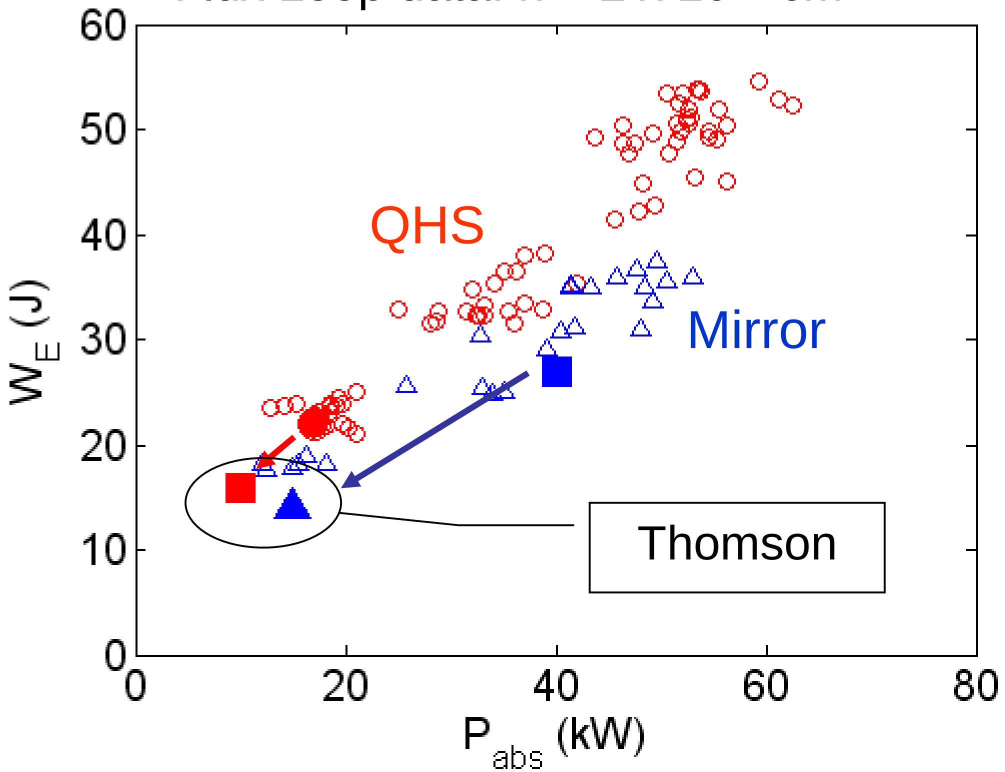


- Confinement time is weak function of power

→ divergence from ISS04 scaling law

Matching profiles requires more power in Mirror

Flux Loop data: n ~ 2 x 10^{12} cm^{-3}



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

QHS: 25 kW

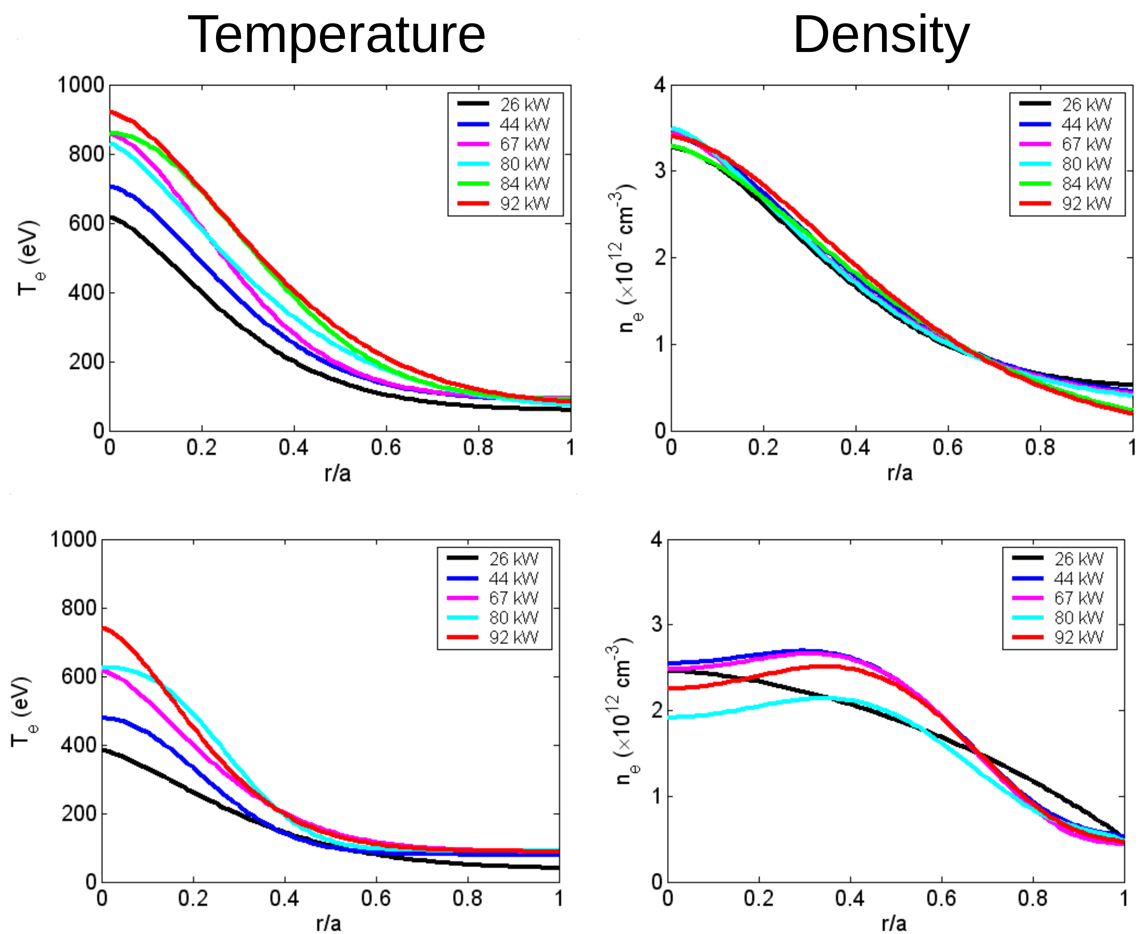
Mirror: 70 kW

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



QHS

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

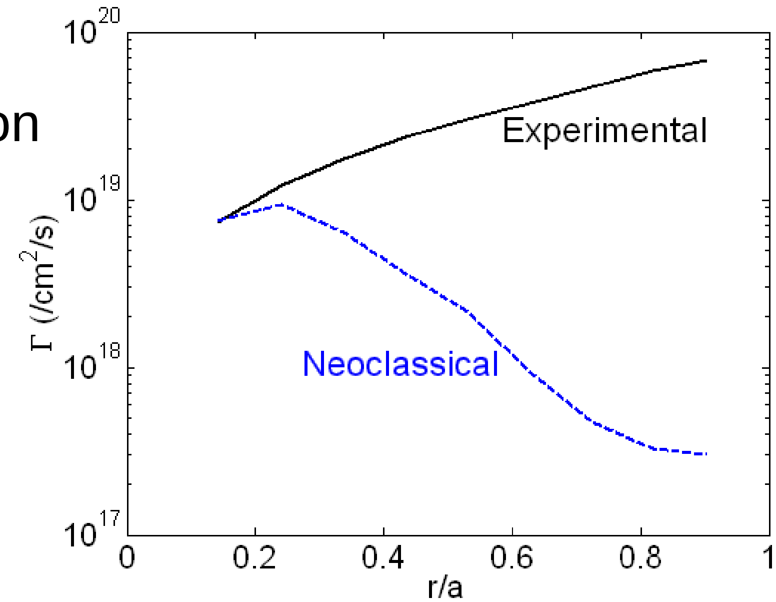
Neoclassical Thermodiffusion Accounts for Hollow Density Profile in Mirror Configuration

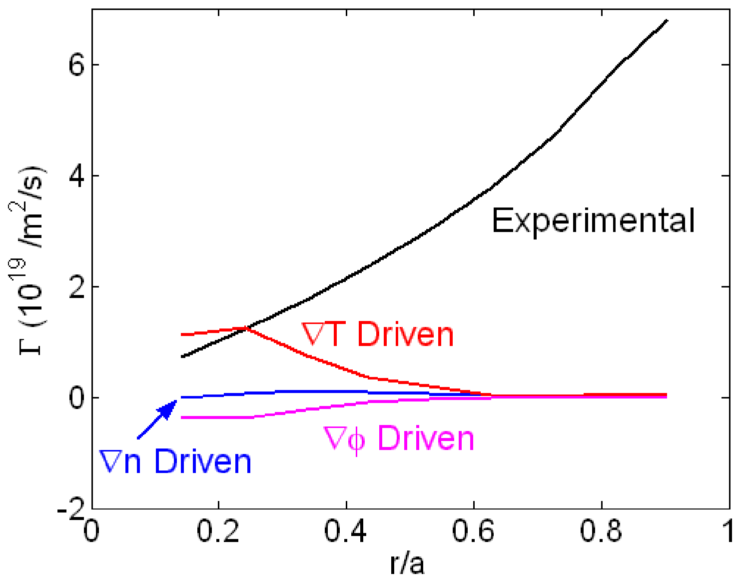
- Figure shows experimental particle flux from H_α + DEGAS, neoclassical prediction

- In region of hollow density profile, neoclassical and experimental fluxes comparable

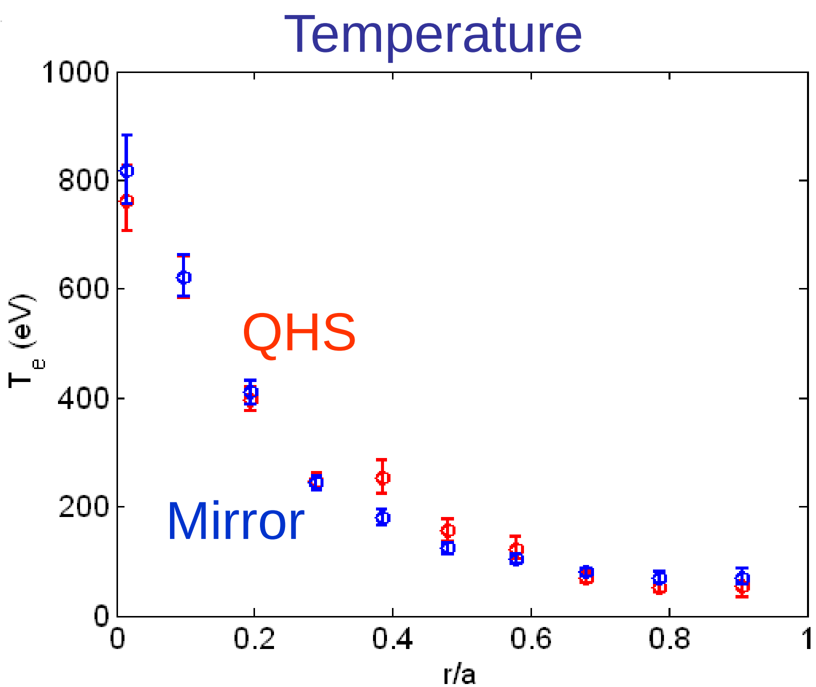
- The ∇T driven neoclassical flux is dominant

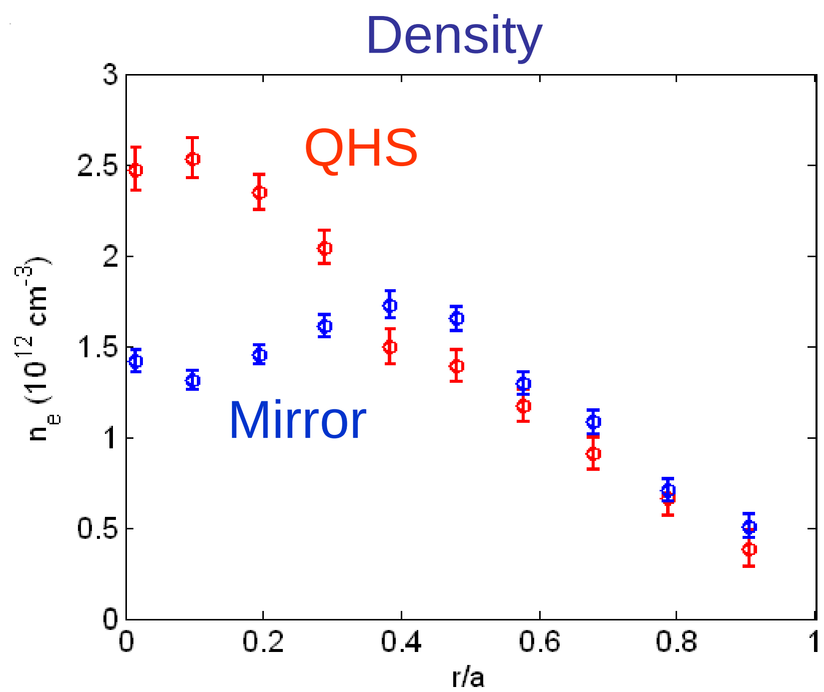
$$\Gamma = -n\left\{ D_{11}\left(\frac{n'}{n} - \frac{qE_r}{T} \right) + D_{12}\frac{T'}{T} \right\}$$





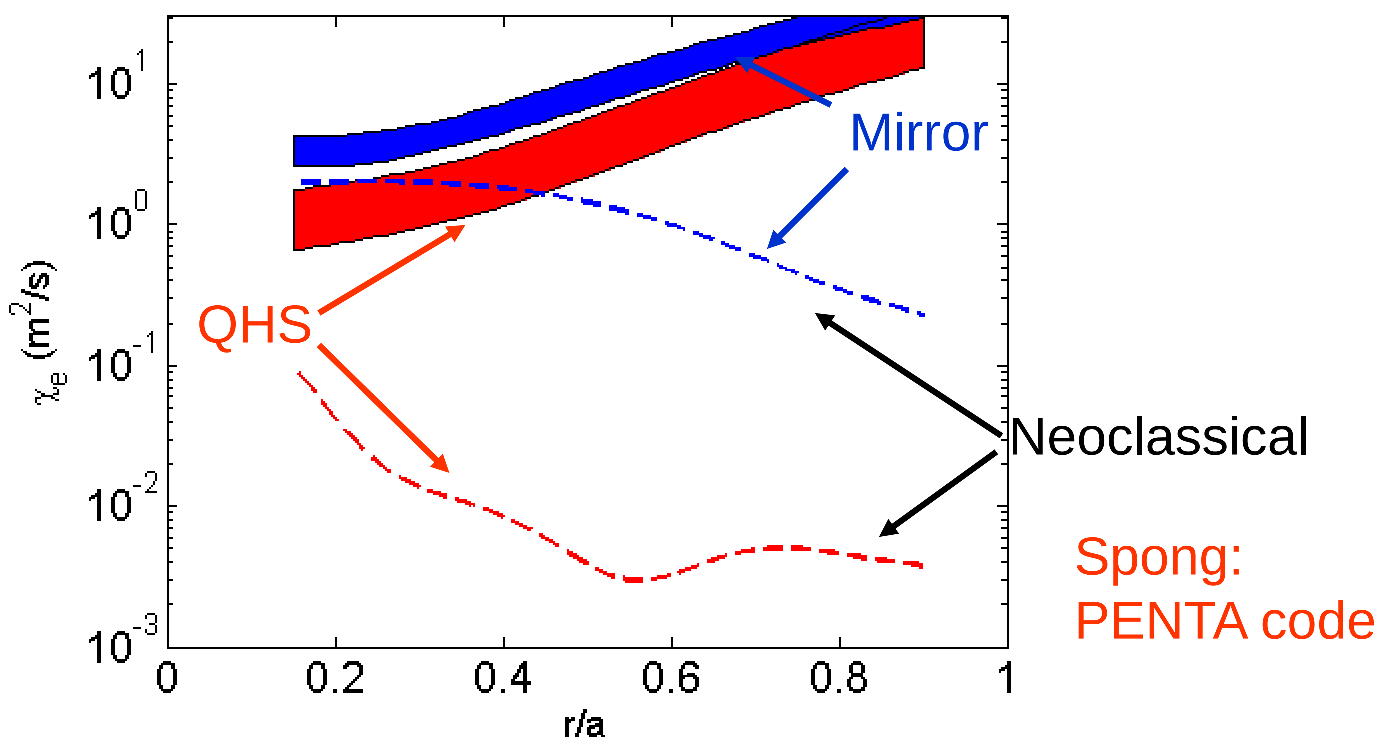
Electron temperature profiles can be well matched between QHS and Mirror





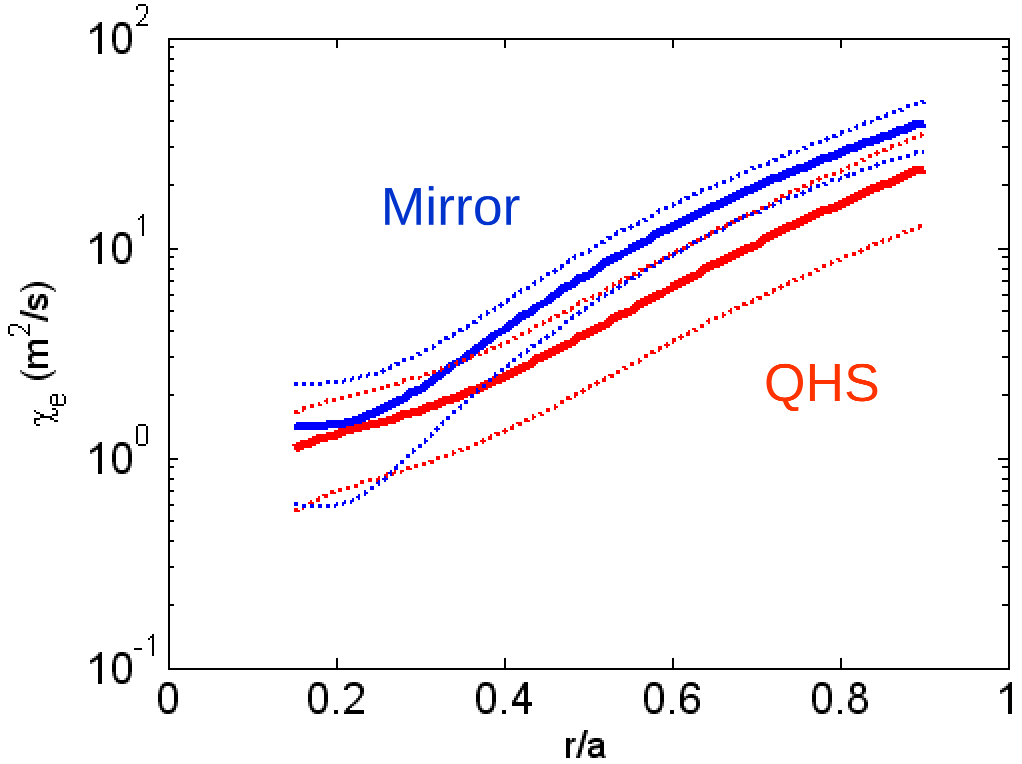
- Temperature profiles match with 70 kW in Mirror, 25 kW in QHS
- Density profiles don't match because of thermodiffusion in Mirror

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 x 10^{13} 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)