Neoclassical Predictions of 'Electron Root' Plasmas at HSX

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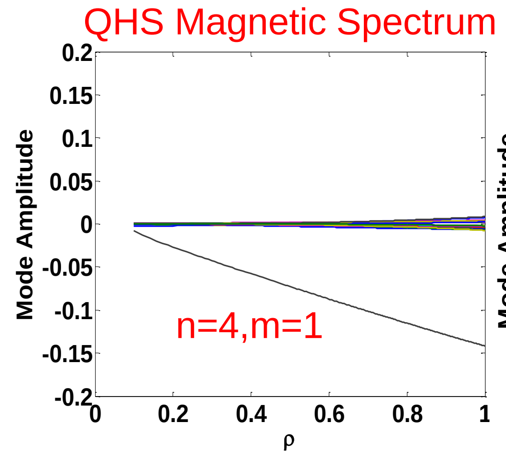
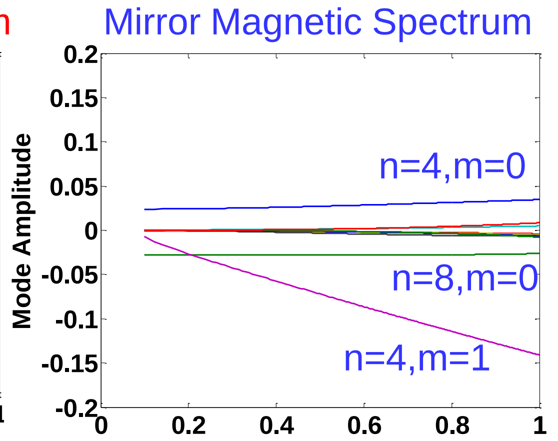
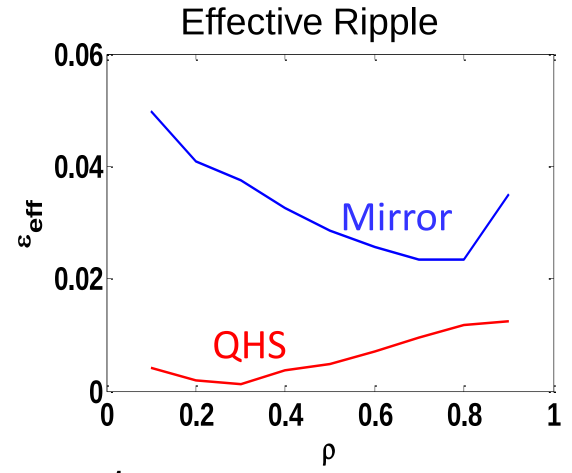
Overview

- Strongly peaked electron temperature profiles and large positive radial electric field predictions are evidence of a neoclassical transport barrier in HSX plasmas.
- Turbulent + neoclassical transport simulations reproduce experimental profiles only when ExB shear suppression included.
- Power balance shows reduced electron thermal transport due to quasi-symmetry and suggests reduction in anomalous transport.
- Inclusion of momentum correction and parallel flows (via the PENTA code) important in neoclassical calculations for the quasi-symmetric configuration.

The HSX Stellarator







Parameters

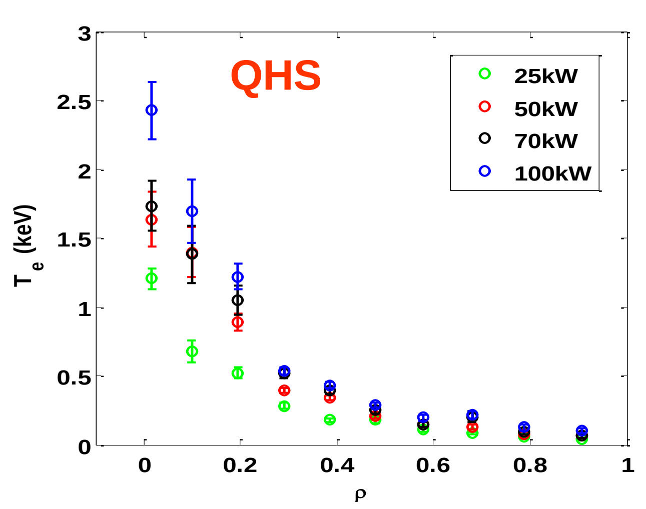
<R>	1.2 m
<a>	0.12 m
ι	1.05 →1.12
B_0	0.5 -1.0 T
ECRH 28 GHz	<100 kW

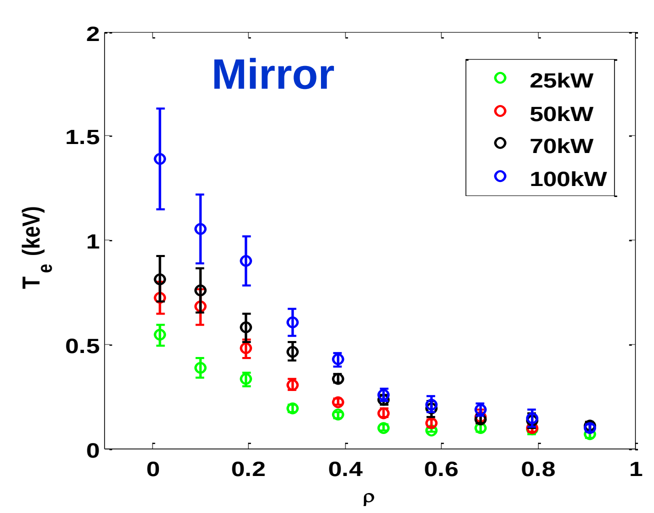
- Ion temperature approximately 50-100eV from impurity spectroscopy.

1. Peaked T_e Profiles from Thomson Scattering

Power Scan Comparison

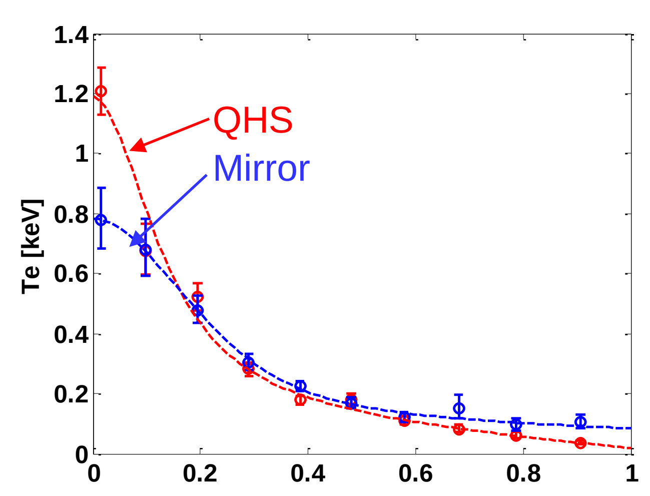
- Electron temperature profiles are strongly peaked in the core for all powers in the QHS configuration.
- Mirror profiles have lower temperatures, but peaking may begin at a larger radius.
- Sharp change in T_e gradient is indicative of a transport barrier.
- Several helical devices see heat transport barriers caused by 'Electron root" E_r in the core
  - CERC (Core Electron Root Confinement)
- CERC not expected in configurations with low field ripple.

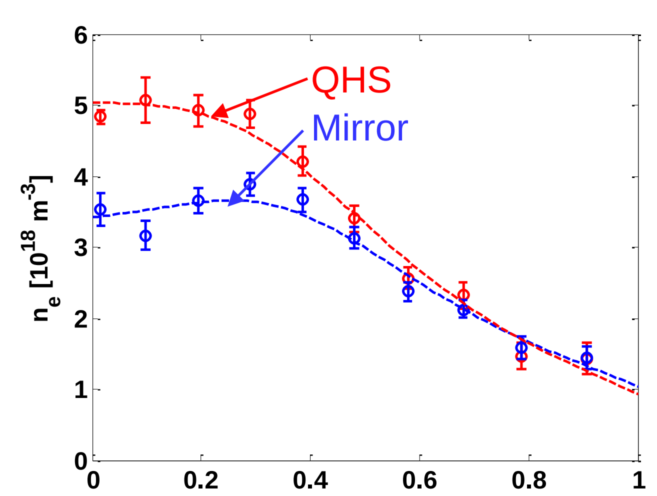




Matching Profiles

- To minimize the difference between the profiles, ~2x the injected power (1.5x the absorbed power) is needed in Mirror.
- Closely matching the profiles allows for better comparison of anomalous transport (experimental minus neoclassical).





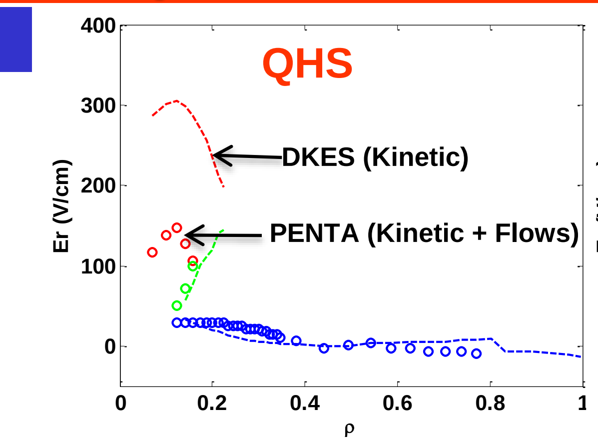
2. Transport Calculations Show Reduced χ_e, Predict Large E_r and ExB Shear

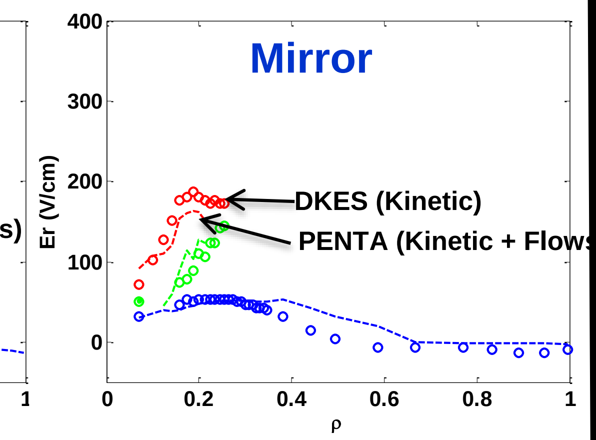
Standard Neoclassical Calculations

- Monoenergetic transport coefficients are calculated using the DKES code, which is valid for arbitrary 3D toroidal magnetic fields.
- DKES uses a non-momentum conserving collision operator that neglects parallel flows and interspecies collisions.
- Radial electric field determined by solutions to ambipolarity constraint.

$$\sum_s e_s \Gamma_s(E_r) = 0$$

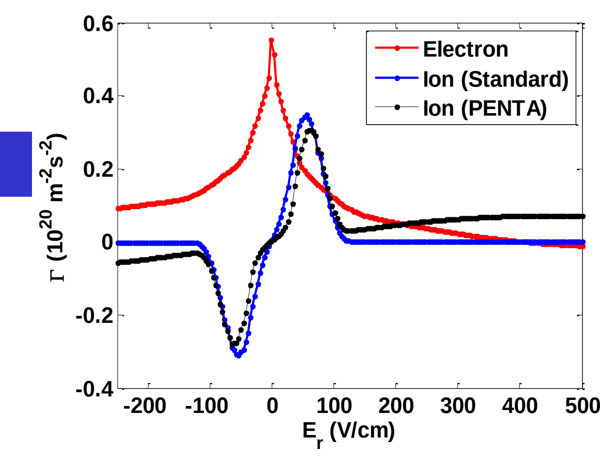
- $|E_r|$ can have a reduce fluxes.
- E_r shear can affect turbulent transport

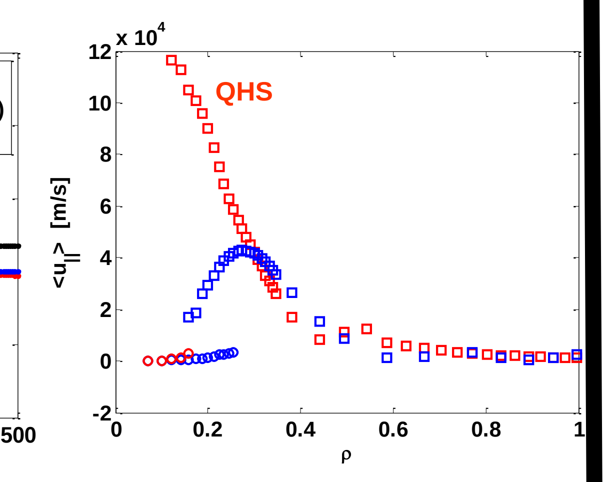




Neoclassical Calculations with Flows

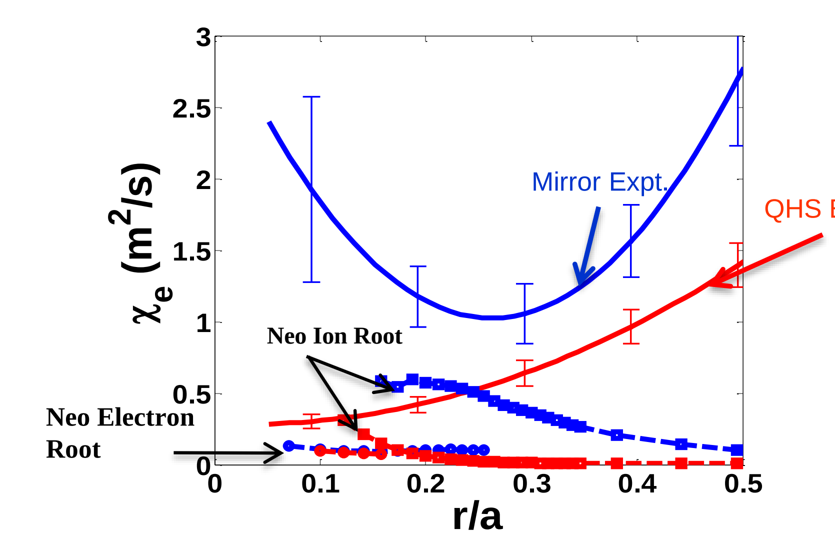
- The PENTA code (D. Spong) based upon a moments method (Sugama and Nishimura, 2002) calculates the neoclassical fluxes and flows using a momentum conserving collision operator.
- The QHS configuration has reduced flow damping due to the direction of symmetry in the magnetic field strength.
- This symmetry results in larger parallel flows and increased ion particle flux – smaller E_r
- The Mirror configuration, without a direction of symmetry, does not show these effects.





Experimental and Neoclassical Transport Reduced in QHS

- Experimental χ_e from power balance.
- Anomalous transport may also be reduced in core.
- Depends on which ambipolar root chosen.
- Measurements of E_r forthcoming.

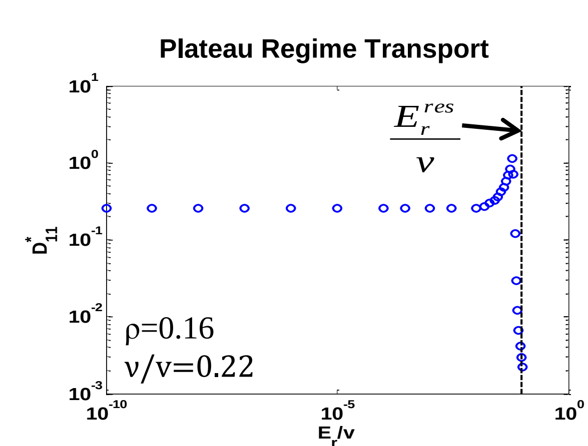


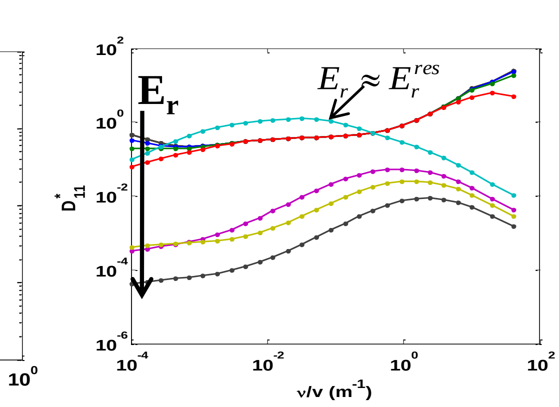
Electron Root Predictions due to Poloidal Resonance

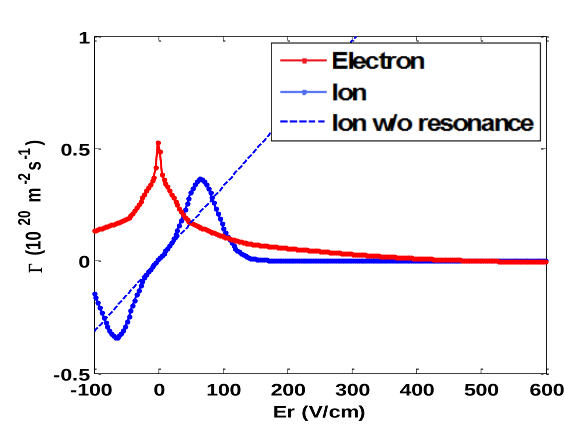
- The electron root solutions in HSX plasmas are due to the poloidal resonance of the ions and Te>>Ti.

$$E_r^{res} = \frac{|m-nq|}{m} v_{Ta} B_p$$

- For E_r greater than the poloidal resonance transport coefficients are strongly reduced.
- The reduction in the ion particle flux results in large, positive roots.
- Large E_r also reduces electron transport – neoclassical transport reduction.







3. Effect of ExB Shear on Turbulent Transport Simulations

Quasi-linear Weiland model has been used to model turbulent transport

- Like a tokamak, QHS has a single class of trapped particles.
- With local geometry considerations, good agreement with 3D gyrokinetic GS2 results.

ExB shear turbulence suppression needed to model core heat transport

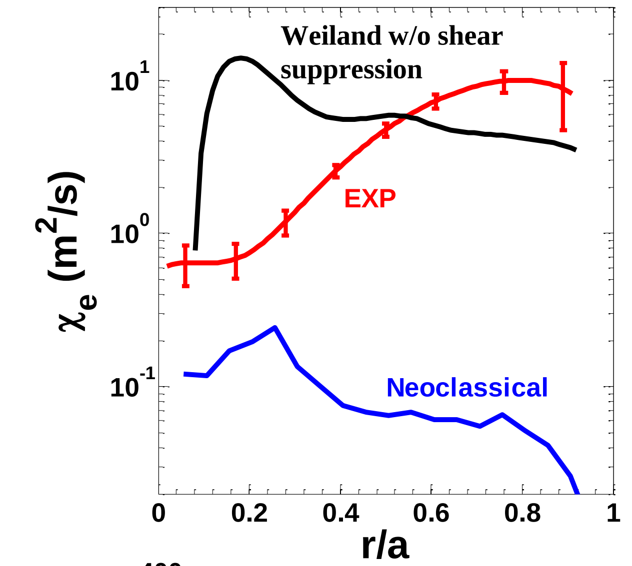
- Without shear suppression χ_e from Weiland model much larger than experiment in core
- Including E_r shear and quench rule in model can explain T_e peaking.

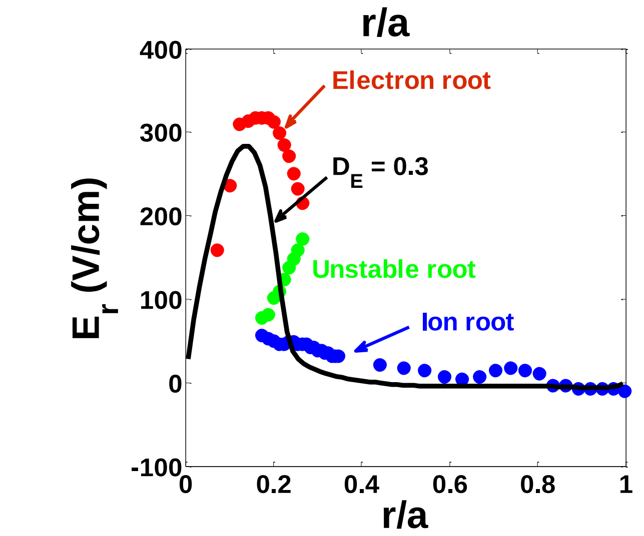
$$\frac{\partial E_r}{\partial t} - \frac{\partial}{\partial V}\left[\langle(\nabla V)\rangle D_E\left(\frac{\partial E_r}{\partial r} - \frac{E_r}{r}\right)\right] = \frac{e}{\varepsilon_\perp}(\Gamma_e - \Gamma_i)$$

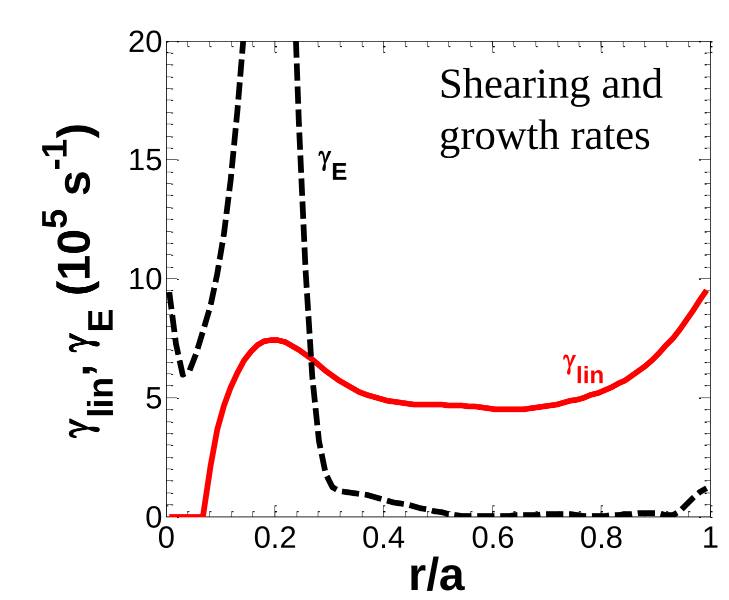
- Anomalous diffusivity scaled by quench rule:

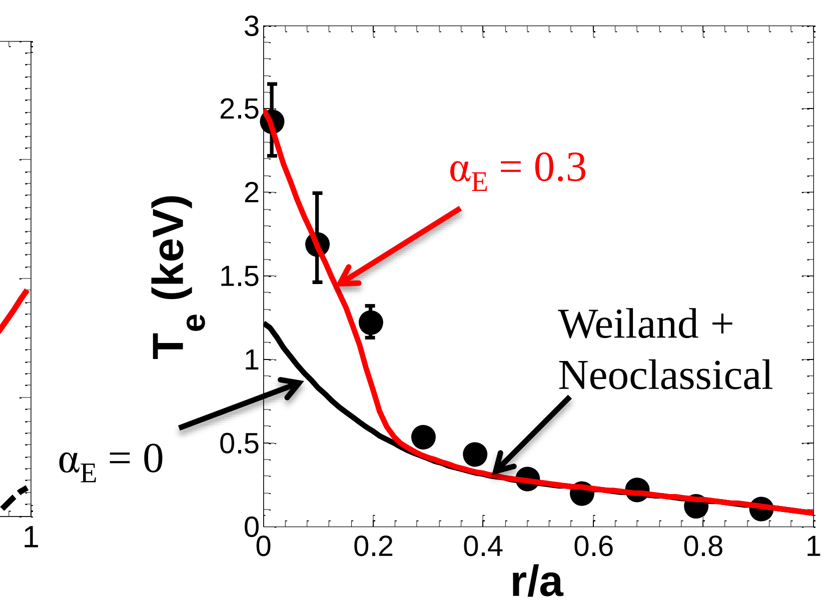
$$\max\left(1 - \alpha_E \frac{\gamma_E}{\gamma_{max}}\right)$$

γ_E = shearing rate
γ_{max} = maximum growth rate









Future Work

Obtain additional evidence of transport barrier

- Two new diagnostics will be coming online at HSX to make radial electric field calculations.
  - ChERS (A. Briesemeister poster)
  - Novel HIBP planned
- 16 channel ECE system to look for root jumping and temporal T_e evolution
- Density and power scans to look for threshold behavior

Improve theoretical calculations

- GNET code to model distribution function and ECRH driven fluxes.
  - Should be included in ambipolarity constraint
- Investigate predicted and measured effects on particle transport.

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