Anomalous Transport Modeling of HSX Plasmas

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Overview

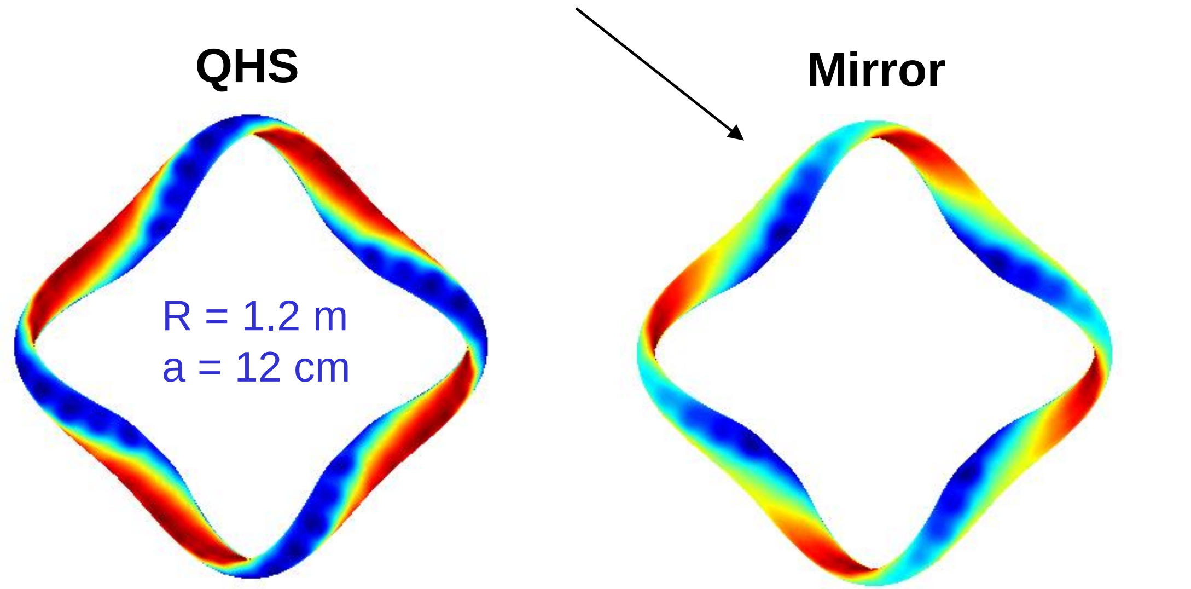
The Weiland ITG/TEM anomalous transport model [1,2] is tested in HSX stellarator plasmas with dominant electron heating

- With geometry simplifications in the quasihelically symmetric configuration, ITG/TEM predicted stability is comparable to 3D gyrokinetic calculations
- Predicted steady state profiles of electron temperature and density are in moderate agreement with experimental profiles

Experimental Details

HSX has a helical axis of symmetry in |B| and a resulting predicted very low level of neoclassical transport

For experimental flexibility, the quasi-helical symmetry can be broken by adding a mirror field



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

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

HSX Plasmas Heated With 28 GHz ECRH

B = 0.5 (1.0) Tesla

P_{ECRH} = 25-100 kW, 2nd harmonic X-mode (fundamental O-mode)

$\langle n_e \rangle \le 3\ (6) \times 10^{12}$ cm^{-3}

$T_e(0) \sim 700\ (1400)$ eV

$$\langle \beta_e \rangle \approx \frac{1}{4000} < \frac{m_e}{m_H} < \beta_e(0) \approx \frac{1}{400}$$

$T_i \sim$ 20-40 eV from impurity Doppler spectroscopy

ITG/TEM Stability

3D ITG/TEM ballooning calculations have demonstrated most unstable eigenmodes in HSX centered about low field, bad curvature region [3,4]

- Dominant particle trapping comes from helical ripple, ε_H (0.14 at r/a=1)
- Reduced connection length, $L_c = q_{eff}R = R/|N-m\iota| \approx 1/3R$
- Low density ECRH plasma → Low electron collisionality

$$\nu_{*e} = \frac{\nu_e/\varepsilon_H}{\varepsilon_H^{1/2}\dfrac{v_{T_e}}{q_{eff}R}} \le 0.1$$

- Max curvature larger than 1/R

$\kappa_{N,max} \sim 1/45$ cm$^{-1} \approx$ **3**$\times 1/R$ (R=1.2 m), $\nabla B/B$ follows similarly

ITG/TEM Weiland Model

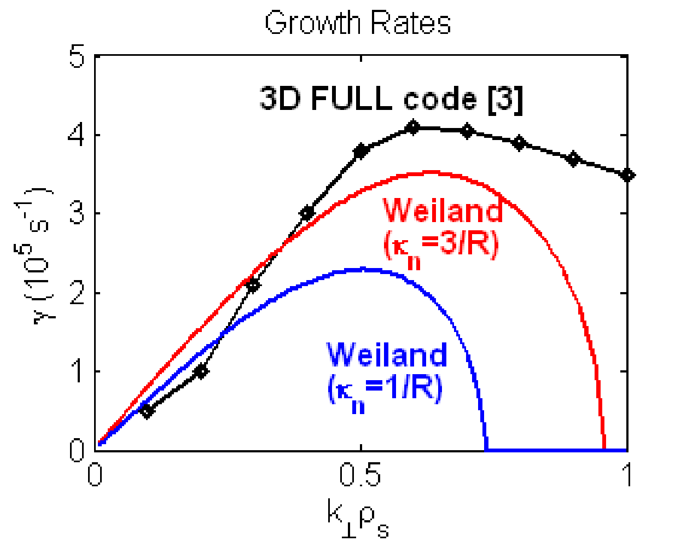
- Fluid toroidal ITG and TEM stability model [1]
- Simplest version includes single ion species, trapped electrons

$$[\chi_e, \chi_i, D, \omega_r, \gamma] = \frac{\rho_s^2 c_s}{L_n} F\left(\frac{R}{L_{Te}}, \frac{R}{L_{Ti}}, \frac{R}{L_n}, \frac{T_i}{T_e}, f_t, k_\perp \rho_s\right)$$

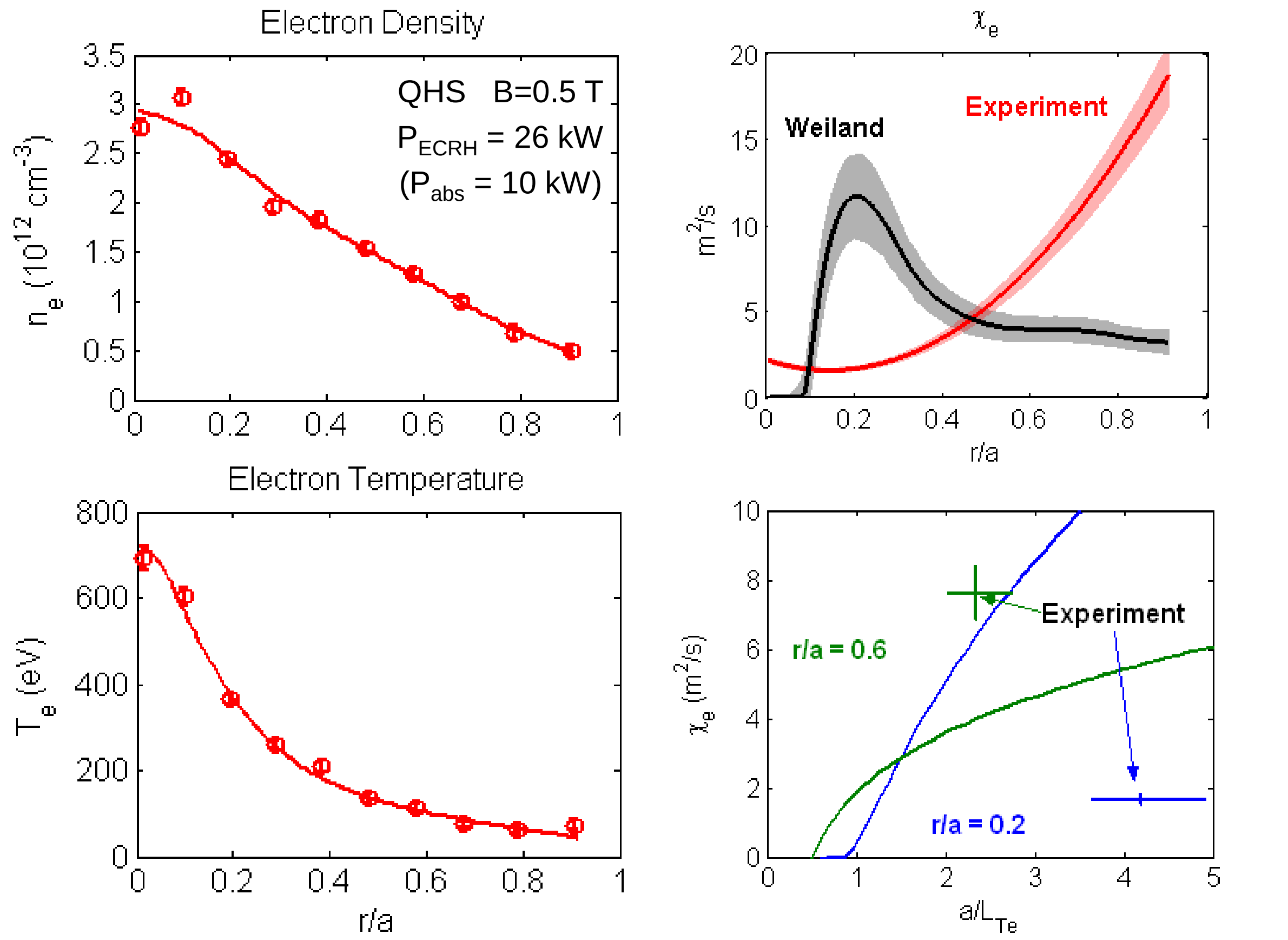
- With geometry approximation, provides reasonable comparison to 3D gyrokinetic FULL code calculations in scaled HSX [3]

Parameters

B = 1.5 T
R = 3.6 m, a = .36 m
r/a = 0.86
$n_i = n_e = 1.9 \times 10^{13}$ cm^{-3}
$T_e = T_i$ = 300 eV
R/L_n = 13.3
$\eta_e = \eta_i$ = 2.66
Z_{eff} = 1
$\beta = 0$, $\nu_e = 0$, $\omega_{E\times B} = 0$,



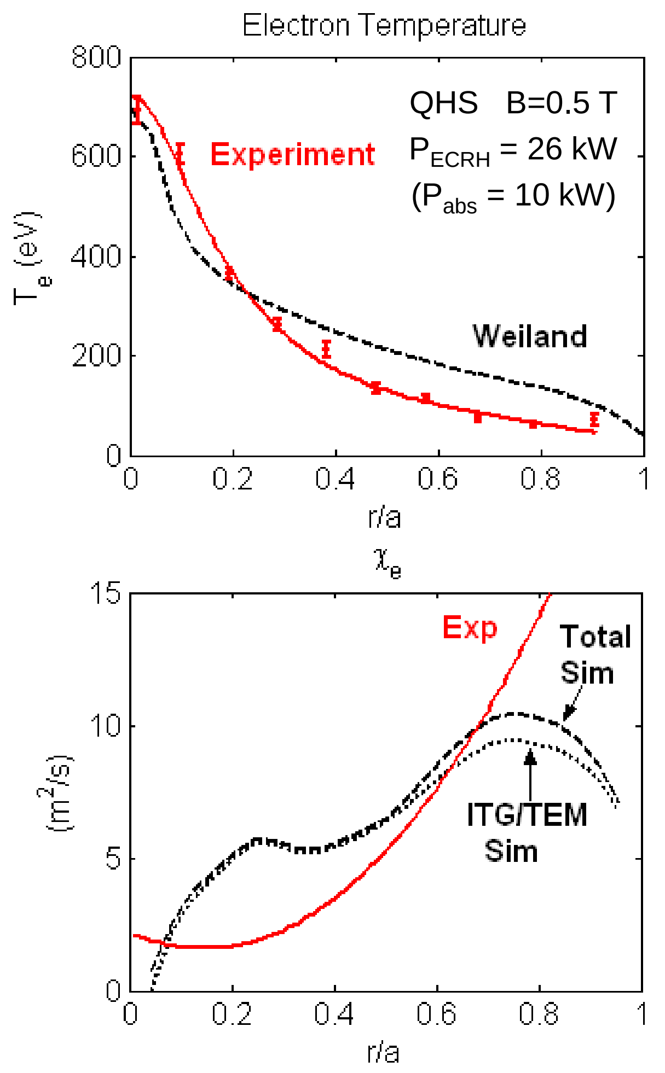
Comparison of Predicted and Experimental χ_e



T_e Simulations

$$\frac{3}{2} n_e \frac{\partial T_e}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r} r n_e \chi_e \frac{\partial T_e}{\partial r} + P_{ECRH} - P_{ei}$$

- Electron energy source from ECRH
  - Total absorbed power from measurements
  - Profile from ray tracing
- Radiation neglected
- $\chi = \chi_{e,NC} + \chi_{e,an}$
- Neoclassical contribution from fit to Monte Carlo mono-energetic diffusion coefficients [5]
- Boundary conditions taken from experiment
- Integrated with Matlab PDE solver
- *No free fit parameters have been used*



T_e, n_e, T_i Simulations

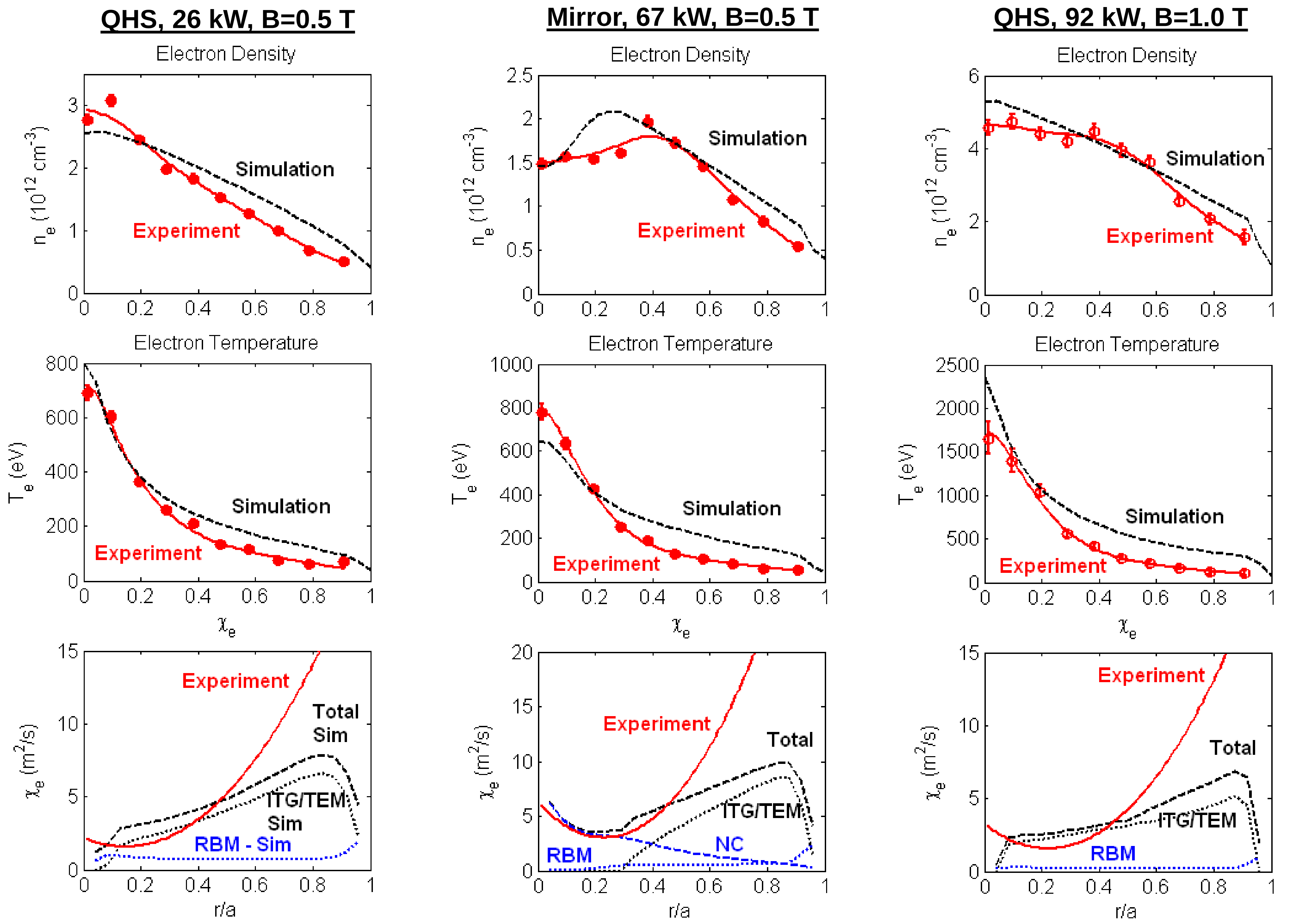
$$\frac{3}{2} n_e \frac{\partial T_e}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r} r n_e \chi_e \frac{\partial T_e}{\partial r} + P_{ECRH} - P_{ei}$$

$$\frac{3}{2} n_i \frac{\partial T_i}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r} r n_i \chi_i \frac{\partial T_i}{\partial r} + P_{ei} - P_{icx}$$

$$\frac{\partial n_e}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r} r D \frac{\partial n_e}{\partial r} + S_{particle}$$

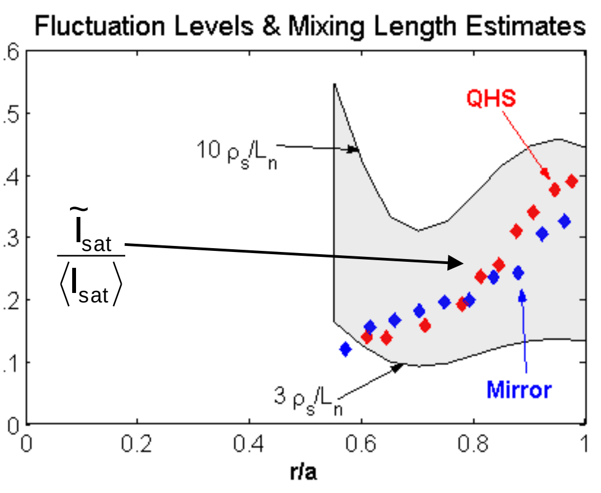
- Particle source from gas puff and recycling
  - Profile based on 3D neutral gas simulations
  - Magnitude allowed to adjust in simulation to match $\langle n_e \rangle_{sim}$ to $\langle n_e \rangle_{exp}$
- Ion energy sink from i-n charge exchange
- Updating ambipolar E_r every 50 μs
- Also including resistive ballooning mode contribution, as used in MMM [2]
- 3D stability calculations [3] in non-symmetric configuration demonstrate eigenmodes and growth rates that are very similar to the quasihelically symmetric case
  - Minor differences due to small local differences in |B| & κ in low field, bad curvature region

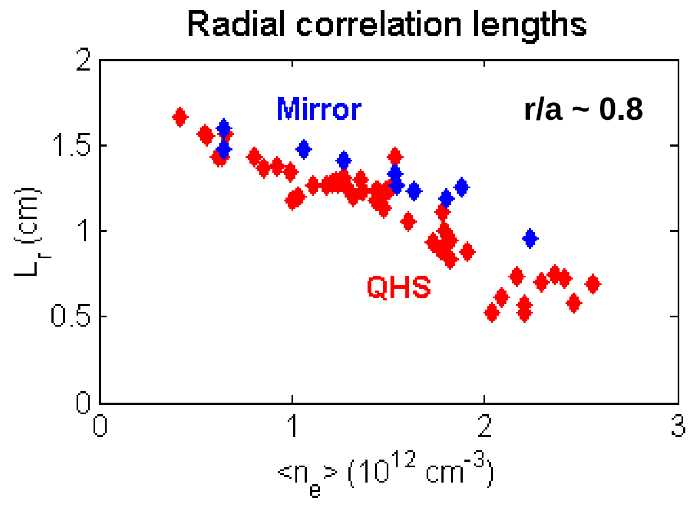
→ Use of same anomalous model and appropriate neoclassical model in simulations

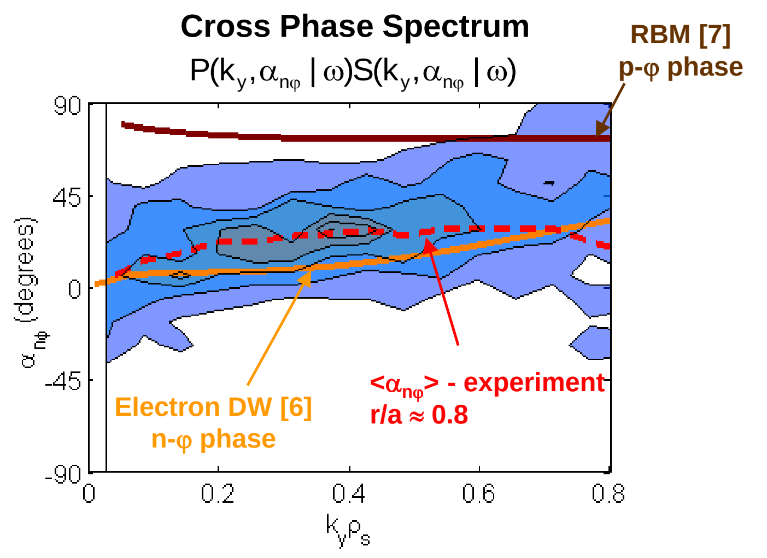


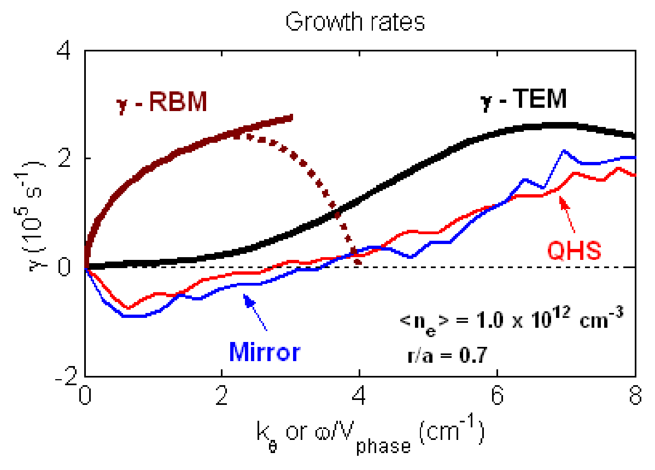
Turbulence Measurements

Measured Turbulence Characteristics are Very Similar in QHS & Mirror With Same Heating Power (50 kW Injected)









Measured growth rates found via bispectral analysis [8]

Future Work

- Weiland stability comparison to 3D gyrokinetic code at very limited conditions

→ Perform stability calculations using 3D gyrokinetic codes (GS2) under broader conditions

→ Calculate quasi-linear fluxes with gyrokinetic code until nonlinear simulations become available

References

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