Theory Based Turbulent Transport Models for Stellarators

via Linear 3D Microstability Calculations

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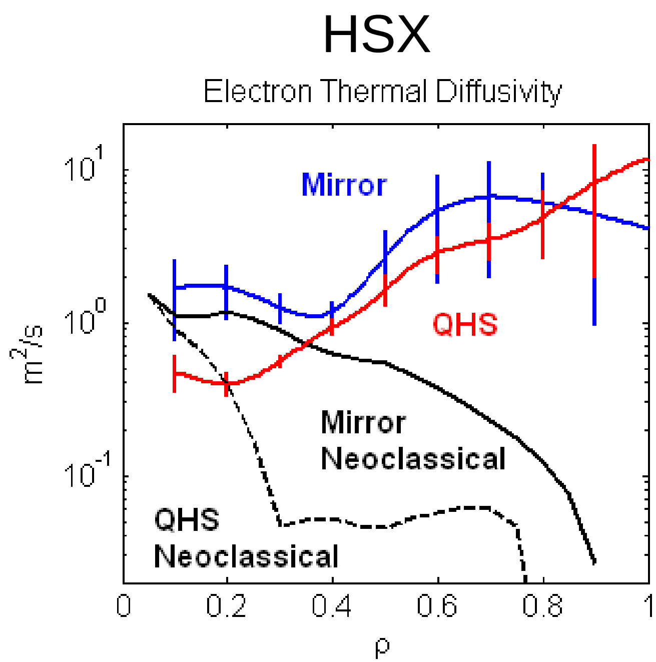
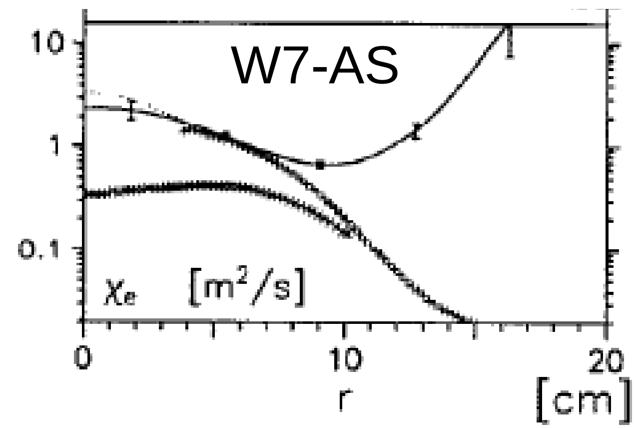
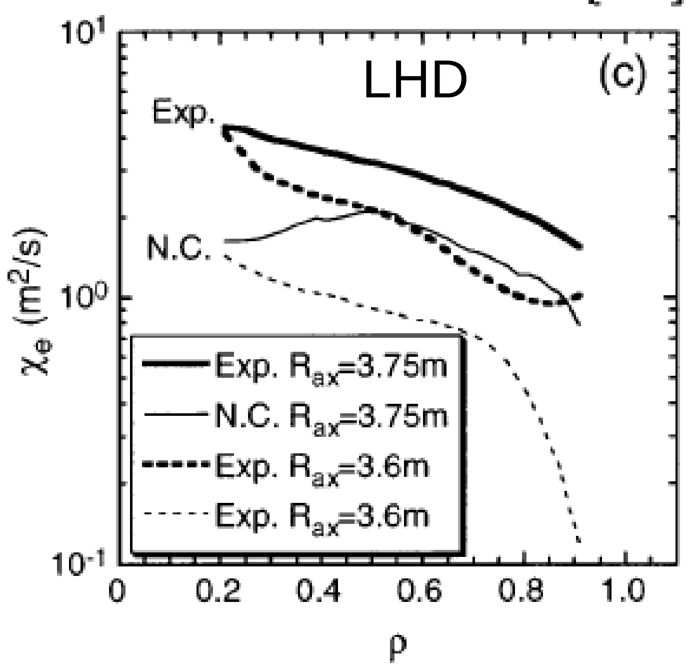
3rd CWGM NIFS October 24, 2007

Anomalous Transport Is Important For Stellarators

- Anomalous contribution important for stellarators, at least some of the time





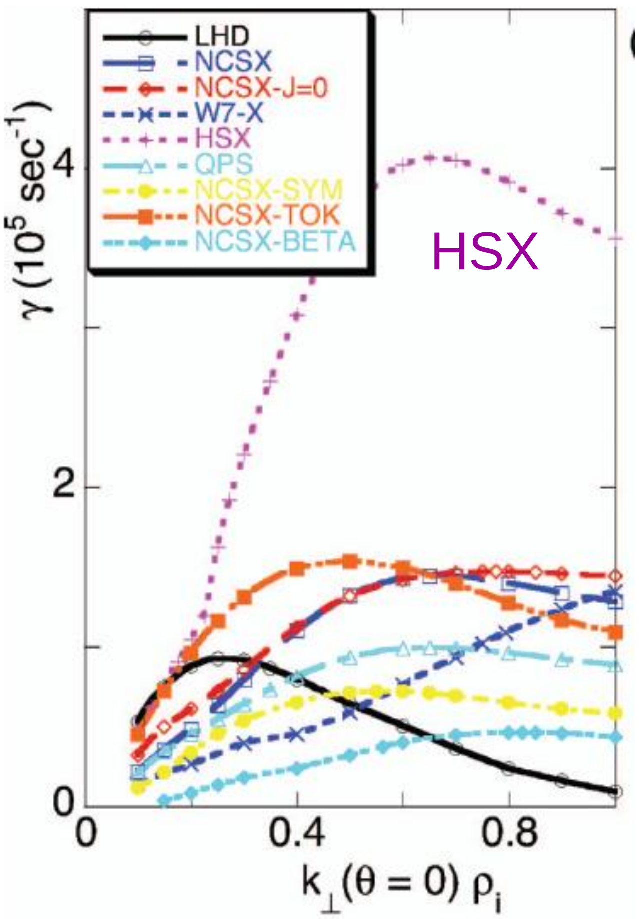


- Likely micro-instabilities
  - Drift waves (ITG/TEM low $k_\perp$, ETG high $k_\perp$)
  - Resistive MHD (high β LHD, ATF, TJ-II)

Tokamak State Of The Art Theory-Based Turbulent Transport Modeling

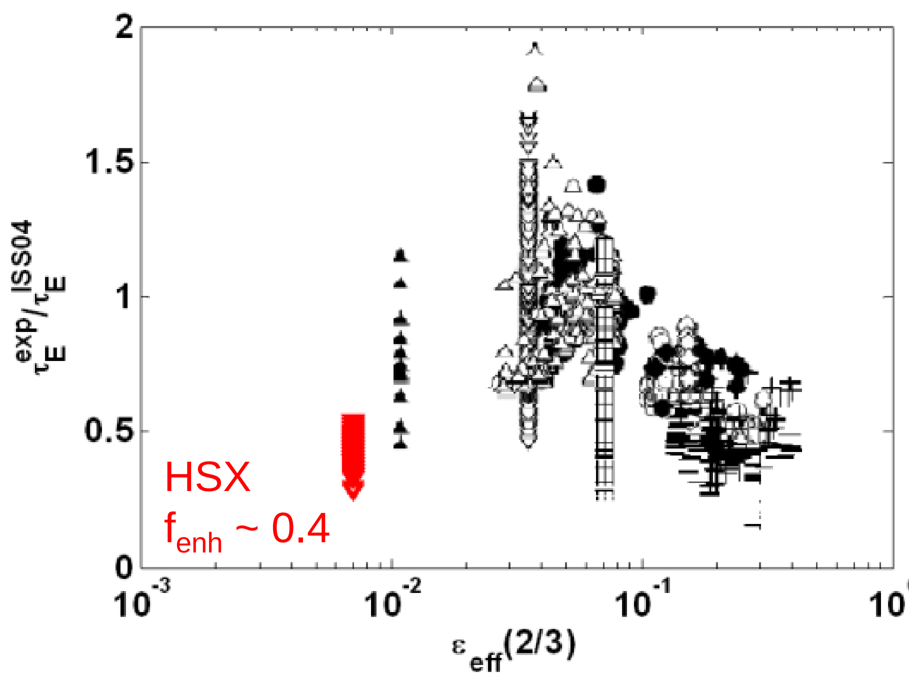
- Quasi-linear in nature, ~ $\gamma_{lin}/k_{\perp}^{2}$ (Weiland, IFS-PPPL, GLF23)
- These are tweaked to “match” non-linear simulations

How Much Does Linear Stability Matter?



Rewoldt et al, 2005

- ITG/TEM calculations for "9" different stellarator configurations
- 2 are operational
- γ^{HSX} ~2-4× larger than others
- f_{enh} ~ 0.4



Tokamak State Of The Art Theory-Based Turbulent Transport Modeling

- Quasi-linear in nature, ~ $\gamma_{lin}/k_\perp^2$
- These are tweaked to “match” non-linear simulations

- Including equilibrium E×B shear is a significant effect
  $\gamma_{lin} \rightarrow \gamma_{net} = (\gamma_{lin} - \alpha_E \omega_E)$, $\alpha_E < 1$ (H-mode, ITB’s)

- Sub-dominant effect from zonal flows
  ~ $\gamma^{\alpha}{}_{lin}\gamma^{1-\alpha}{}_{D}/k_\perp^2$ (GLF23), γ_D ~ zonal flow damping

- Non-linear simulations will certainly be required for each stellarator configuration

⇒ Quickest to start with linear stability (dominant scaling effect)

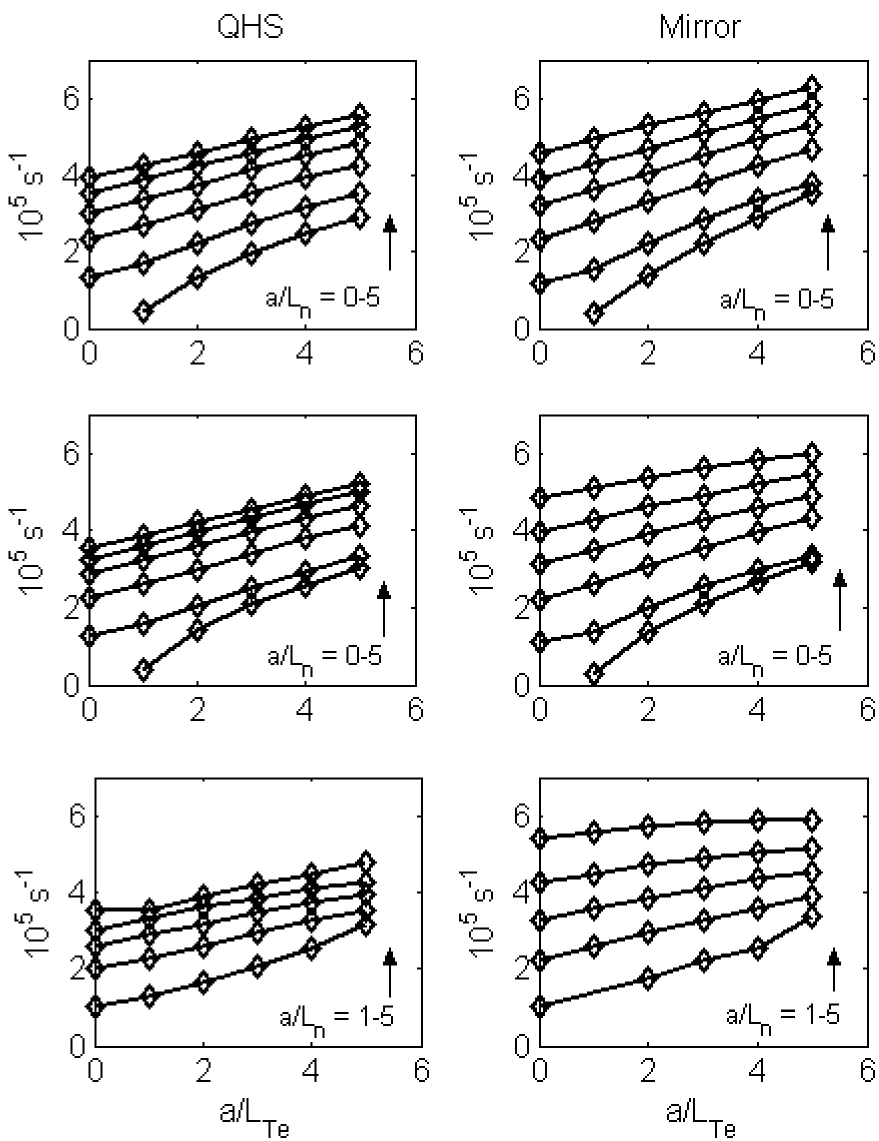
- DW tools exist to do scans including 3D configuration effects
  DALF, EUTERPE, FULL, GENE, GKV, **GS2**

GS2 Scans For Two HSX Configurations

$\rho = 0.86$

$\rho = 0.51$

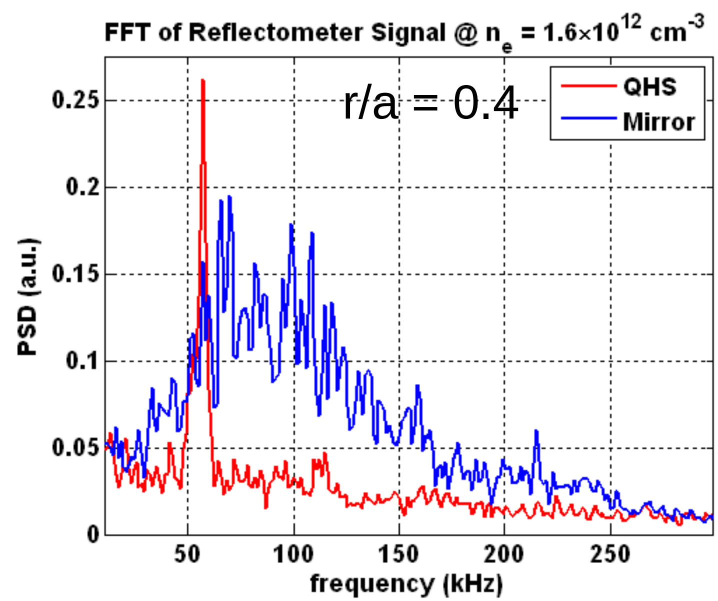
$\rho = 0.24$



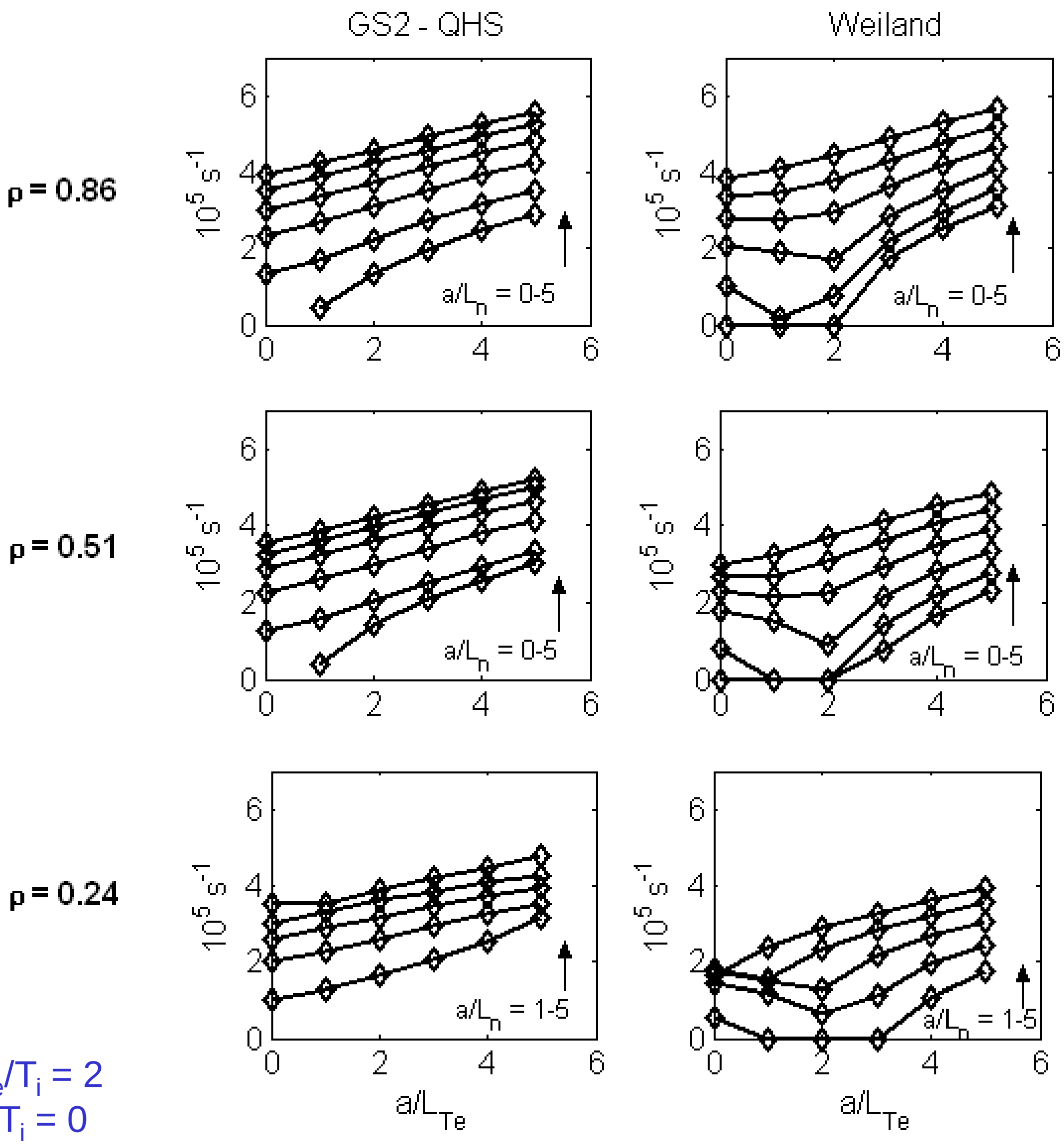
$T_e/T_i = 2$
$\nabla T_i = 0$
$k_\theta \rho_s = 0.8$

3 different radii
~100 calculations per configuration

- Mirror consistently higher than QHS
- Larger discrepancy closer to magnetic axis



QHS Can "Get Away With" a Tokamak Model Because of Quasisymmetry



Weiland model – toroidal ITG/TEM

$\varepsilon_H \rightarrow \varepsilon_T$, $\kappa_T \rightarrow \kappa_H$ (R → R/3)

3 different radii
~100 calculations

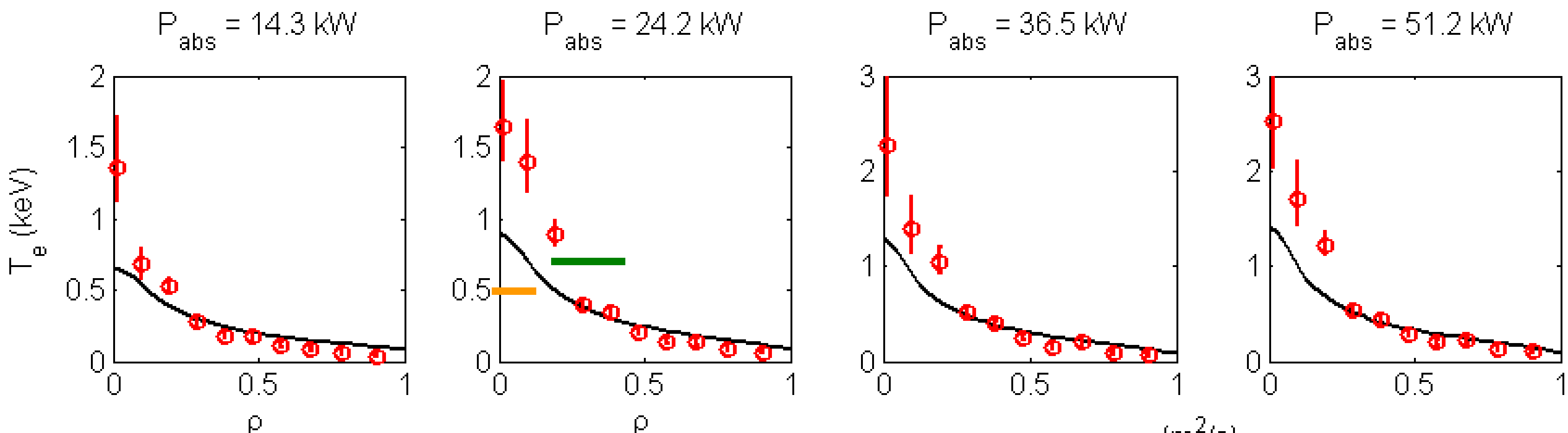
$$\text{mean deviation } f = \frac{1}{N}\sum \frac{\gamma^{\text{Weiland}} - \gamma^{\text{GS2}}}{\gamma^{\text{GS2}}}$$

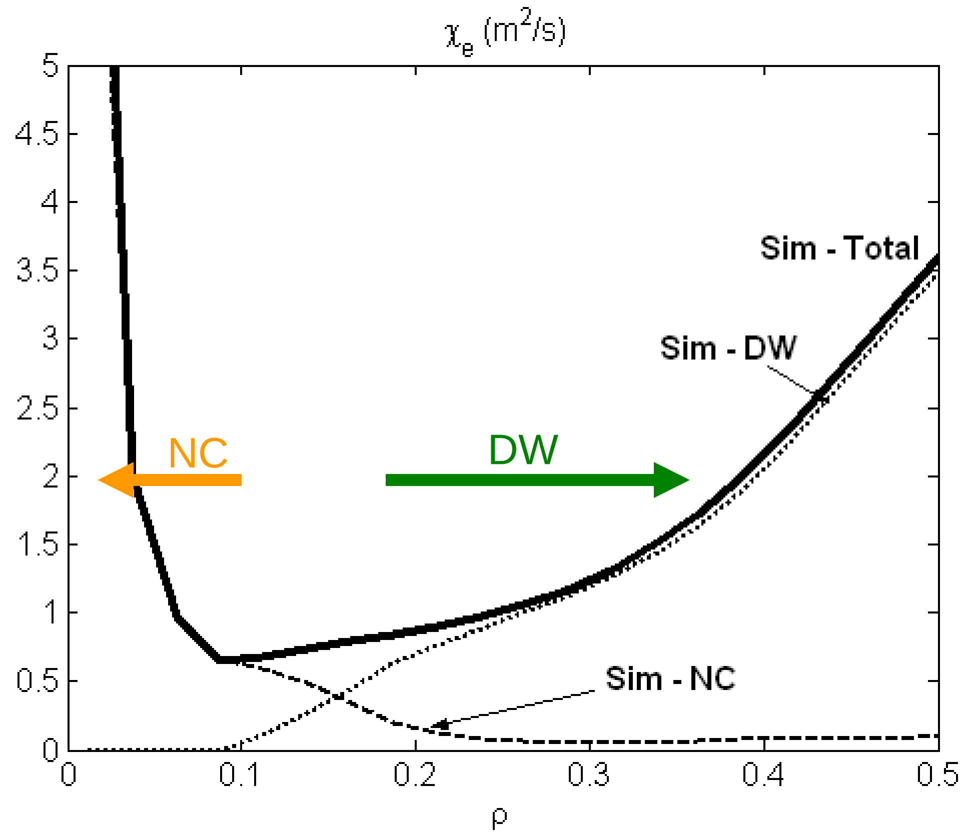
<u>Weiland - HSX approx.</u>
f ~ -30%

<u>Weiland - Tokamak</u>
f ~ -50%

$T_e/T_i = 2$
$\nabla T_i = 0$
$k_\theta \rho_s = 0.8$

Core T_e Underpredicted For QHS Plasma





- Deficiencies in NC near axis
- Anomalous also too big inside ρ ~ 0.2 - 0.3

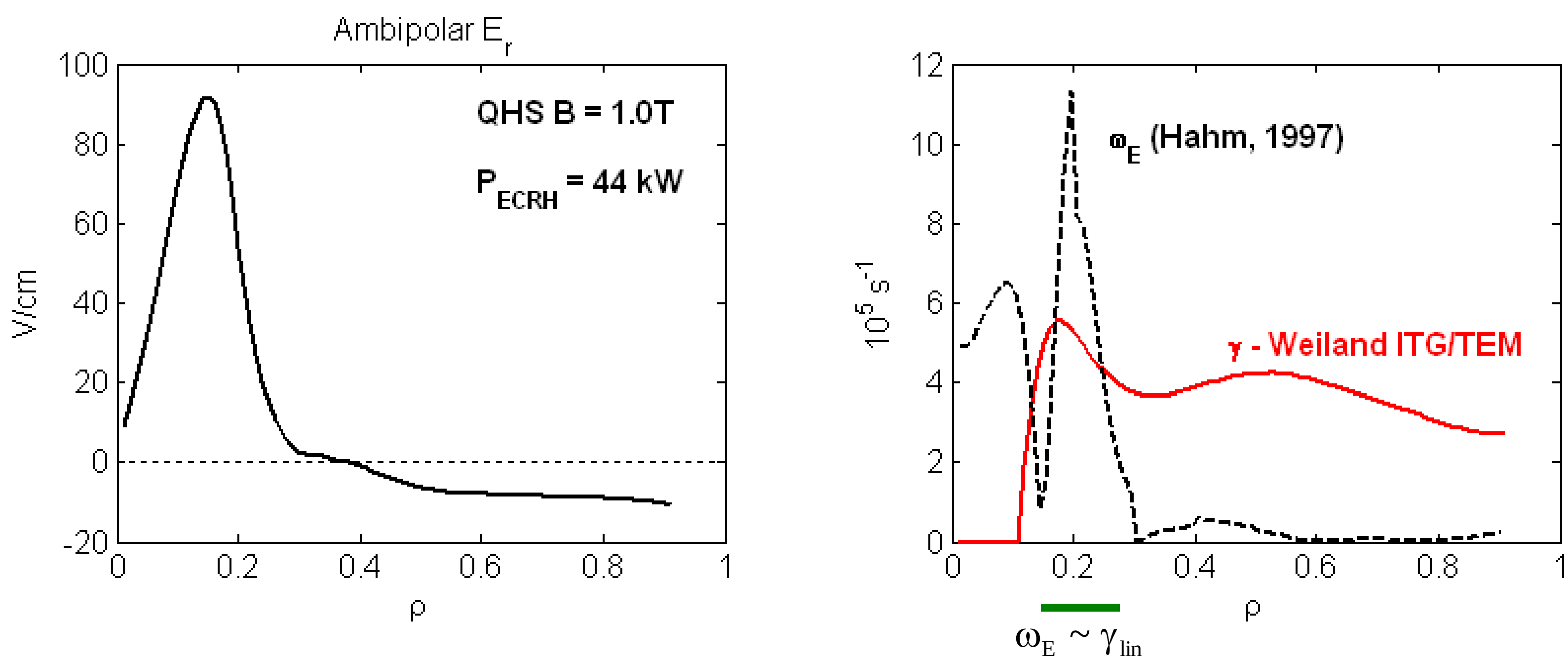
Importance of E×B Shear?

- Based on non-linear simulations, tokamak predictions find good agreement when including E×B shear (ω_E) suppression

$$\left[D,\chi_e,\chi_i\right]=\left[D,\chi_e,\chi_i\right]_{\omega_E=0}\left(1-\alpha_E\frac{\omega_E}{\gamma_{Max(0)}}\right)$$

α_E ~ 0.5 (Kinsey et al 2006)

- This is where stellarators have a significant opportunity to modify turbulence



- Stellarator shear suppression criteria will require non-linear simulations

Ideas For Future Work

- How do you actually deal with different configurations??

⇒ 3D calculations of growth rates & QL transport scaling with gradients… for configurations that actually exist (CHS, H-J, HSX, LHD, TJ-II, W7-AS, etc..)

- **Comparison of quasi-linear transport to experimental transport**
- Comparison of γ_{lin} & $\omega_{E\times B}$ (e.g., from PENTA)
- Comparison to turbulence measurements ($k_\perp$, ω_D, V_{mode})

Additional thoughts

- Models (GLF23, Weiland) include multiple ion species & momentum transport
- Benchmarking of gyrokinetic codes (Mikkelsen, CWGM 1)
- At least for ballooning microstability calculations, use post-processed geometry information from magnetic configuration database (MCD)