Profound $E \times B$ shear-stabilized turbulence regime in NSTX plasma

G. Avdeeva, J.Candy

Initial goals of this study

More detailed validation of the TGLF model* on NSTX plasmas, focusing on determining key parameters that influence the precision of TGLF in predicting plasma profiles as accurately as for conventional tokamaks.

* Trapped Gyro Landau Fluid (TGLF) model – fast, reduced turbulence model for the prediction of turbulent fluxes *[Staebler G.M. et al., Phys. Plasmas 14, 2007]*

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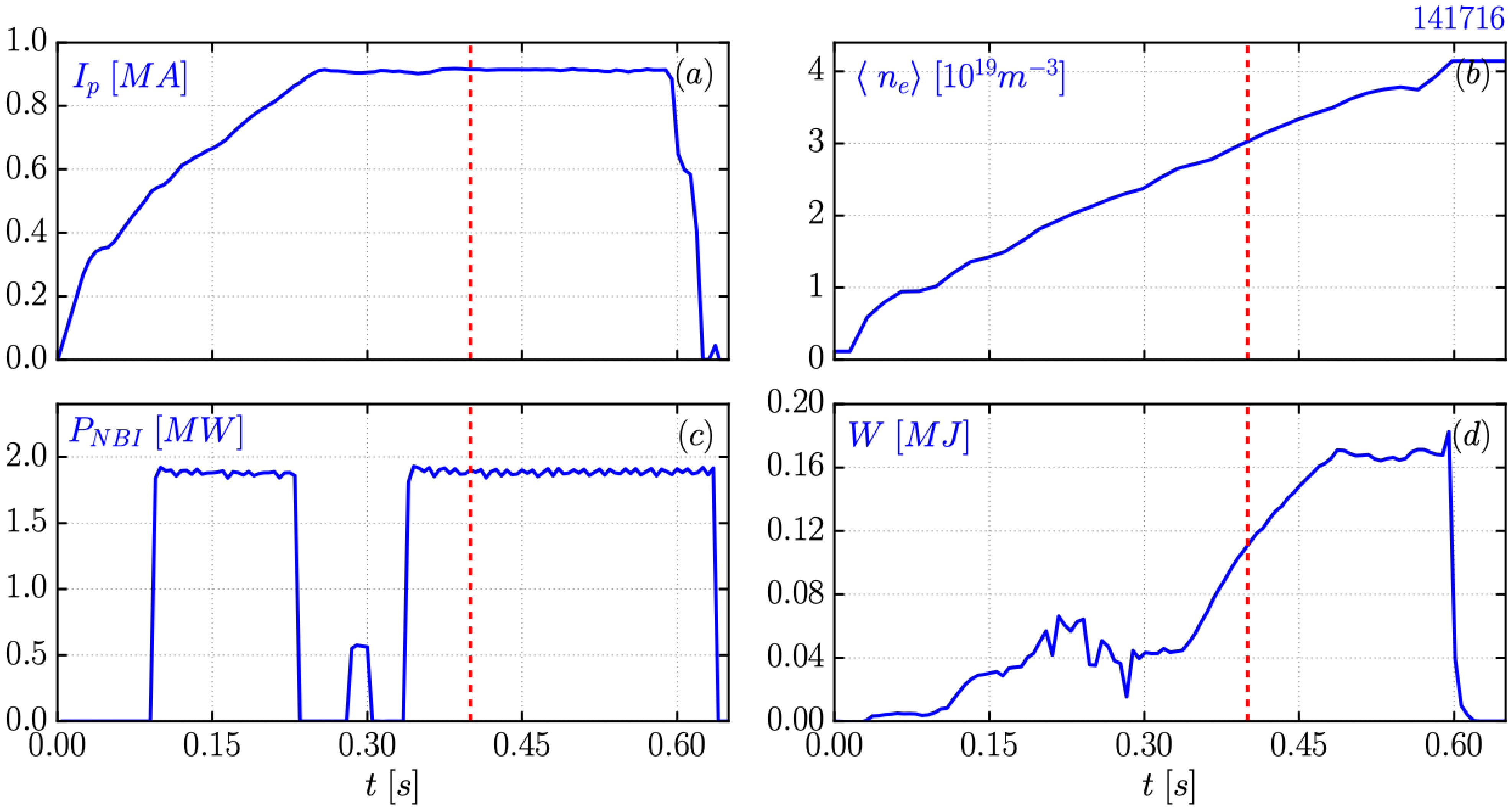
Understanding the extreme discrepancy between CGYRO** simulations and power balance estimates as well as TGLF results on the NSTX case

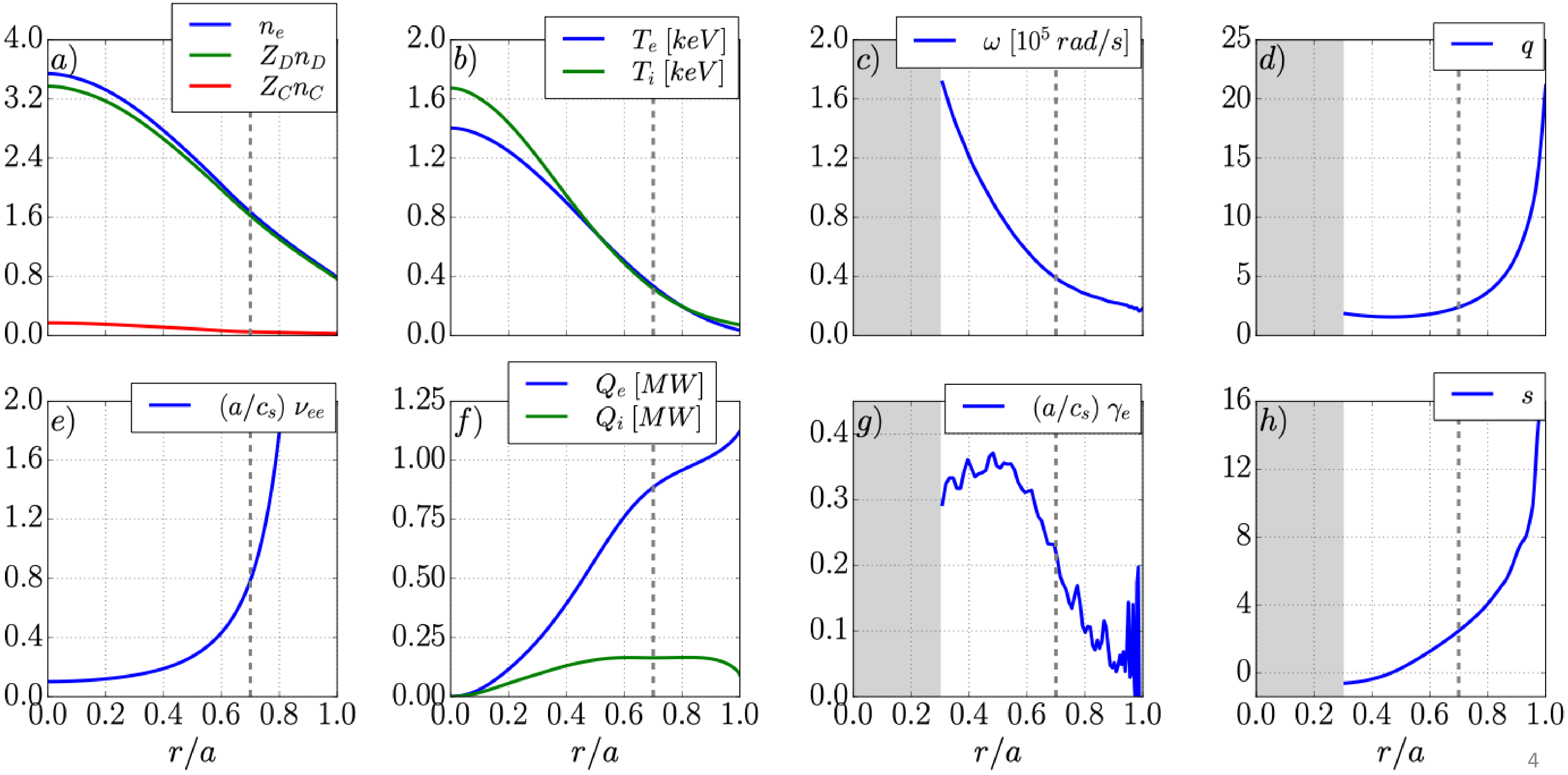
* Trapped Gyro Landau Fluid (TGLF) model – fast, reduced turbulence model for the prediction of turbulent fluxes *[Staebler G.M. et al., Phys. Plasmas 14, 2007]*
** Eulerian gyrokinetic code specifically designed and optimized for collisional, electromagnetic, multiscale simulations [*Candy J. et al., Comput. Phys. 73, 2016*]

We focused on the NSTX L-mode discharge #141716 at t = 400 ms

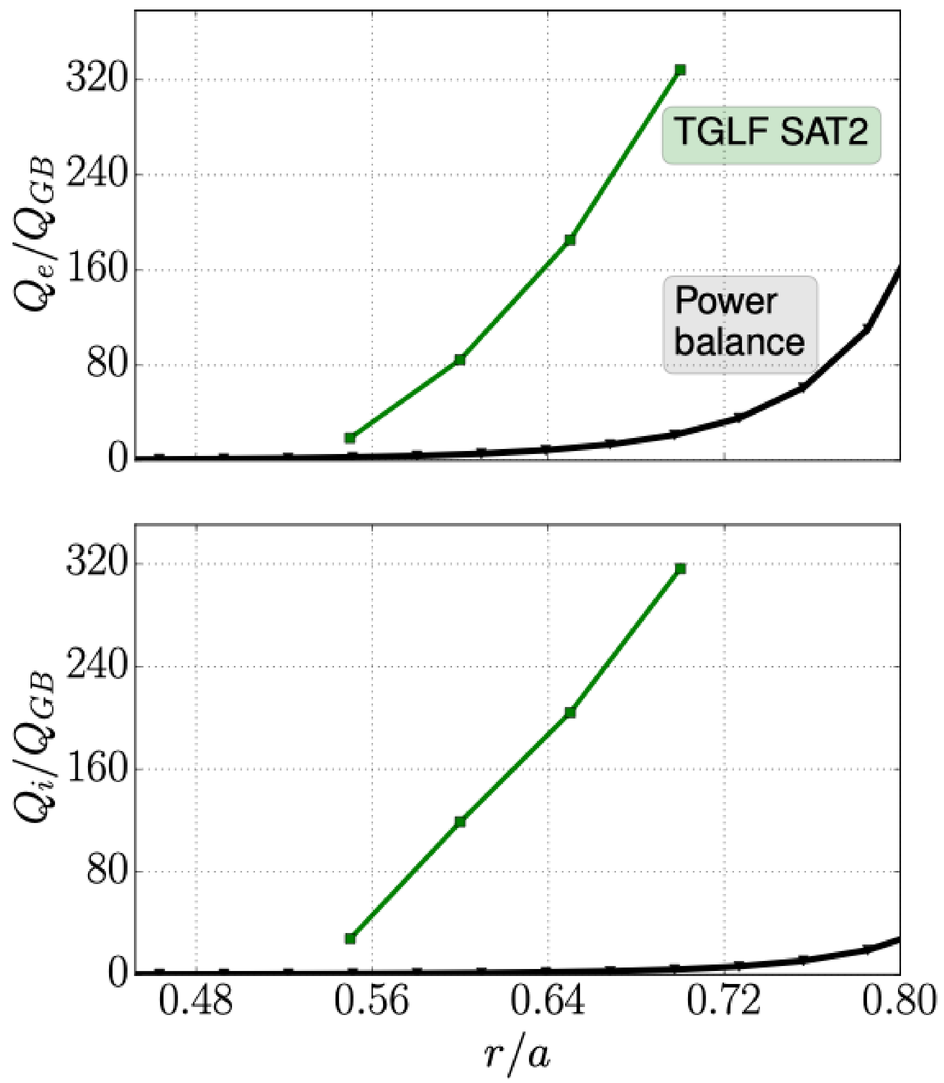


Plasma profiles correspond to Z79 TRANSP ID *

* *Avdeeva G. et al., Nucl. Fusion 63, 2023*



Initial simulations on experimental conditions revealed a big overprediction of fluxes



- Use TGLF SAT2* model as one the latest and most accurate
- Results are similar for electrostatic and electromagnetic TGLF simulations
- TGLF significantly overpredicts fluxes at various radial locations; <u>such trend was observed for other NSTX shots</u>

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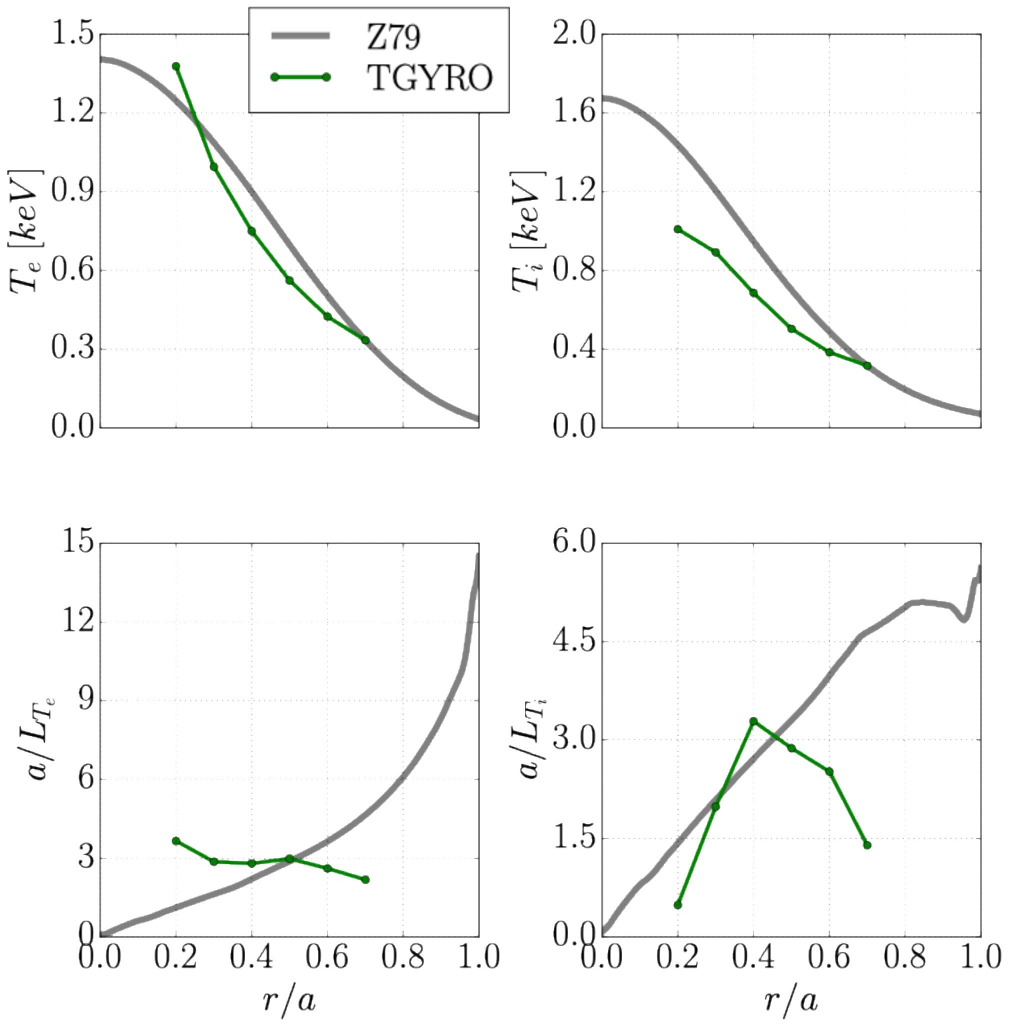

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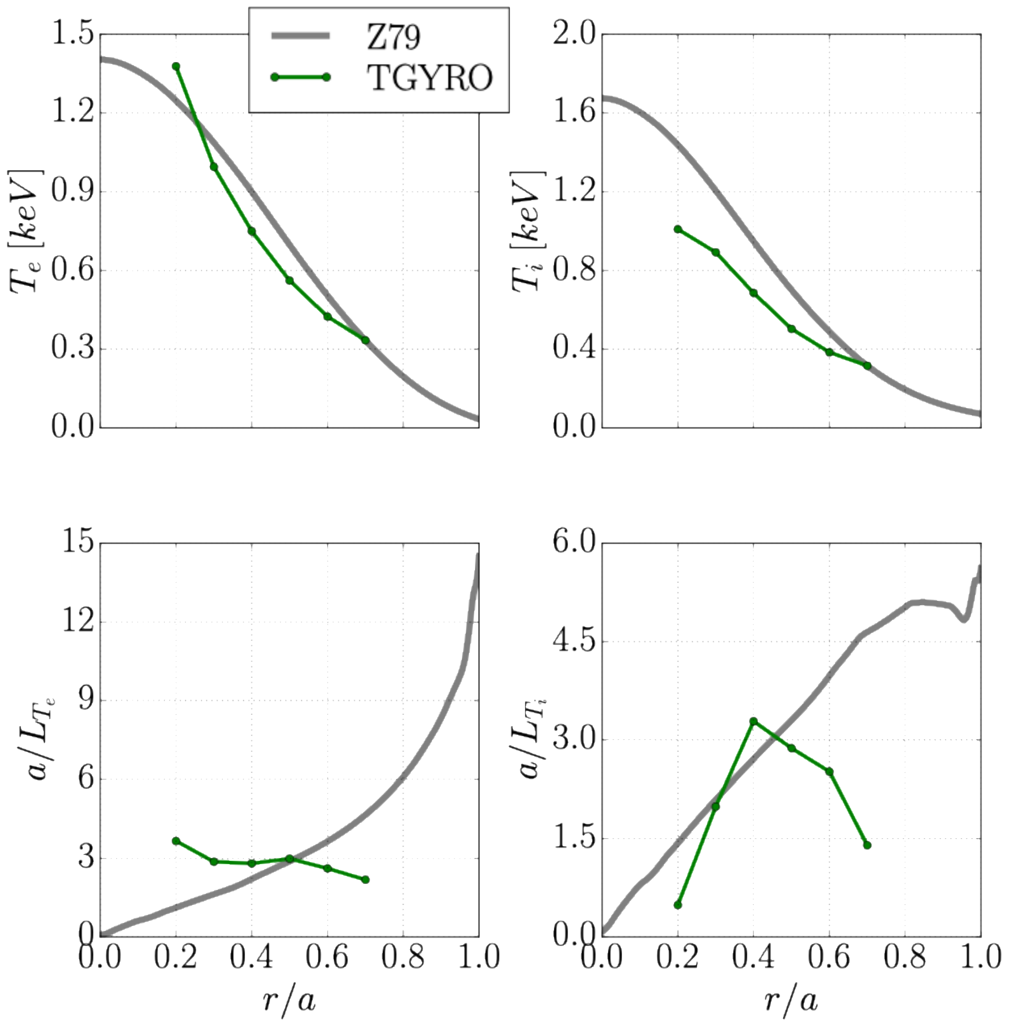

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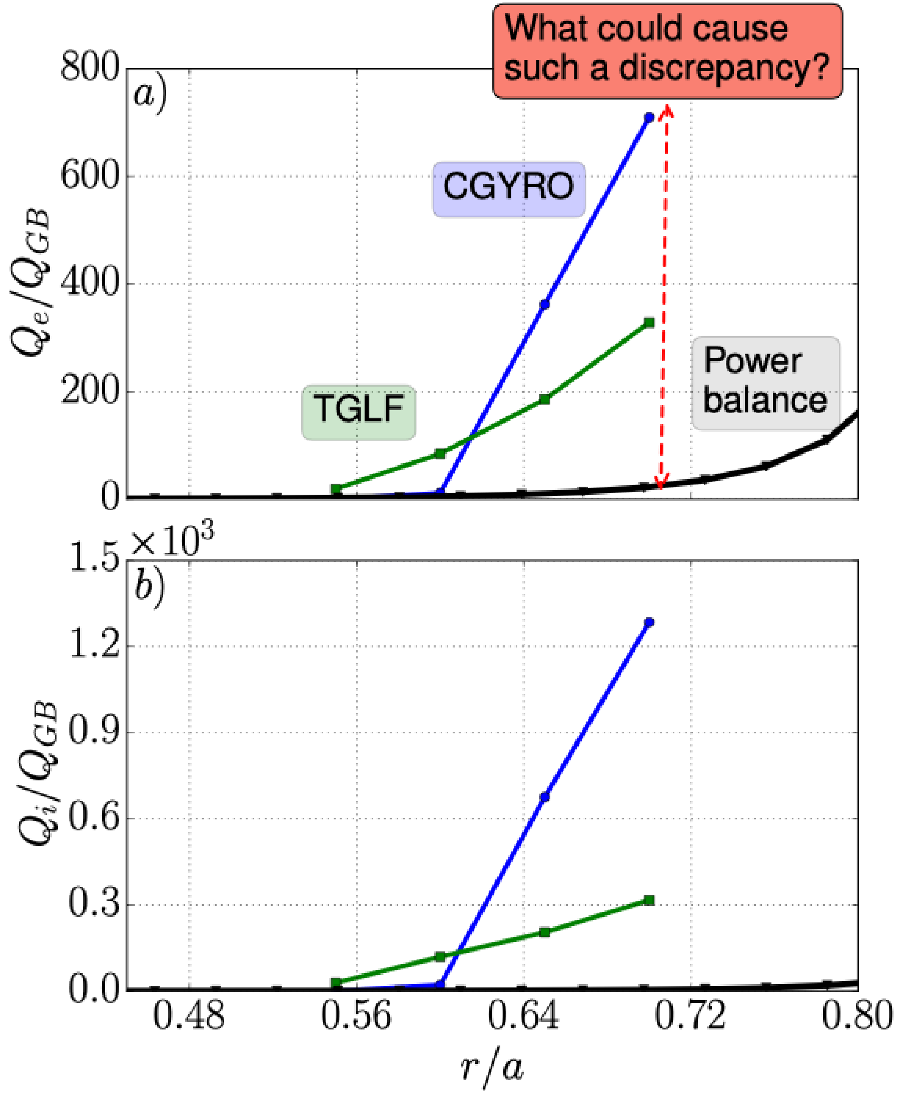
Experiments vs model comparison – uncertainties might play a role

Model (TGLF) vs model (CGYRO) comparison is better

CGYRO simulations shown even larger overprediction of fluxes



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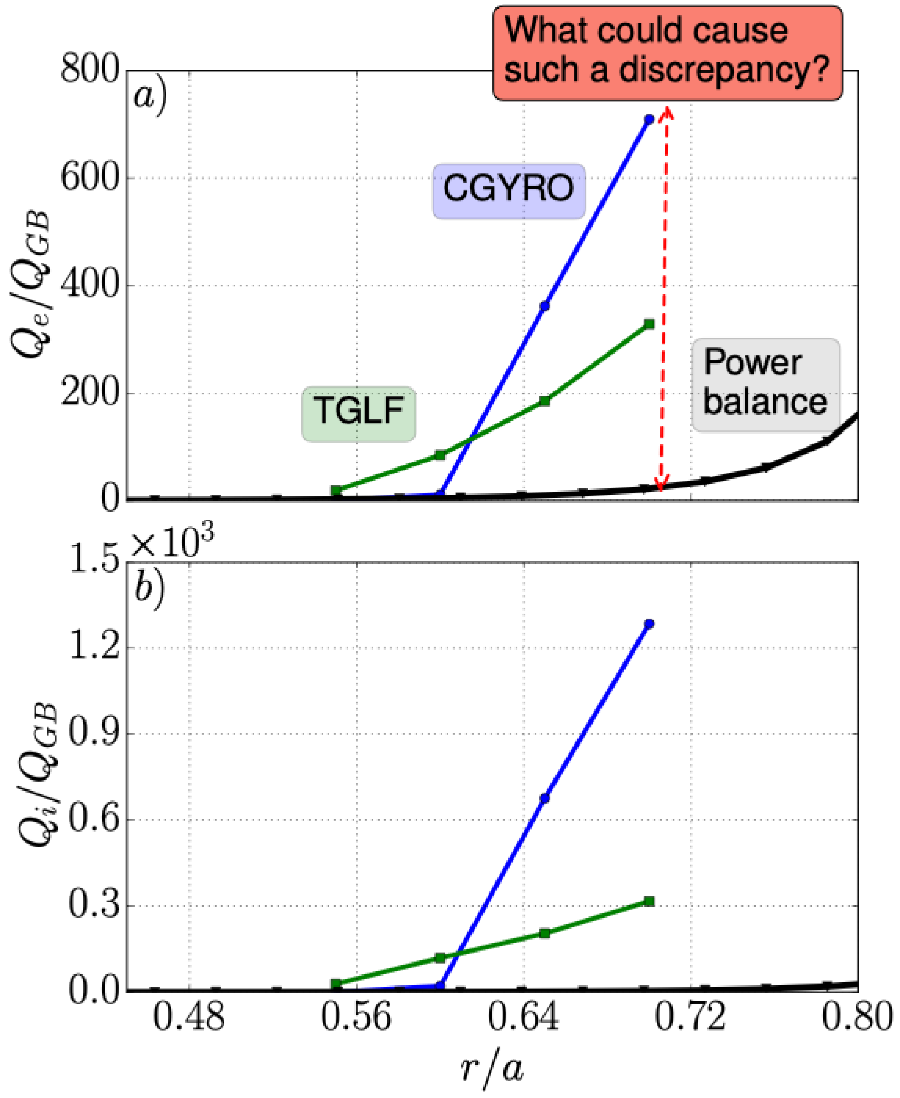


Outline of the talk

- Simulation setup
- Gyrokinetic analysis
  - β_e effect
  - strong $E \times B$ shear stabilization
- TGLF simulations of $E \times B$ shear stabilization
- Summary

Simulations are based on experimental profiles at r/a = 0.7

NSTX - baseline case based on experimental profiles

NSTX (β_e/4) = $^1/_4$ $\beta_{e,unit}$ of **NSTX** case

$$\beta_{e,\mathrm{unit}} = 8\pi n_e T_e / B_{\mathrm{unit}}^2$$

$$B_{\mathrm{unit}}(r) = (q/r)(d\psi/dr)$$

Parameter	Value	Parameter	Value
R_0/r	2.05	Δ	-0.34
q	2.38	s	2.48
κ	1.66	s_κ	0.05
δ	0.14	s_δ	0.17
$(a/c_s)\gamma_E$	0.22	$(a/c_s)\gamma_p$	-1.08
M_D	-0.28	T_i/T_e	0.95
$(a/c_s)\nu_{ee}$	0.79	$\beta_{e,\mathrm{unit}}$	0.194%
a/L_T	4.65	a/L_n	2.07

β_t = 5.5 % - experimental, from EFIT results

Simulations setup

CGYRO numerical settings

- Pure deuterium plasma ($z_{eff} = 1$) with kinetic electrons

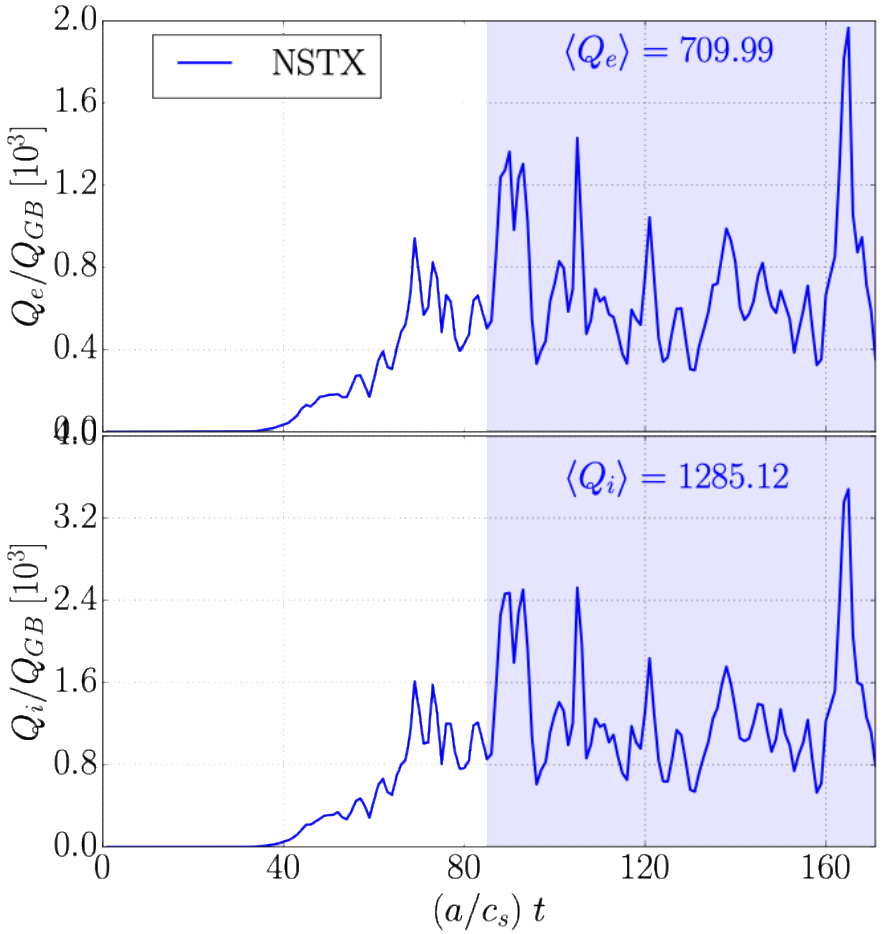
- Three electromagnetic fields are evolved (φ, $A_{||}$, $B_{||}$)

- Spatial resolution

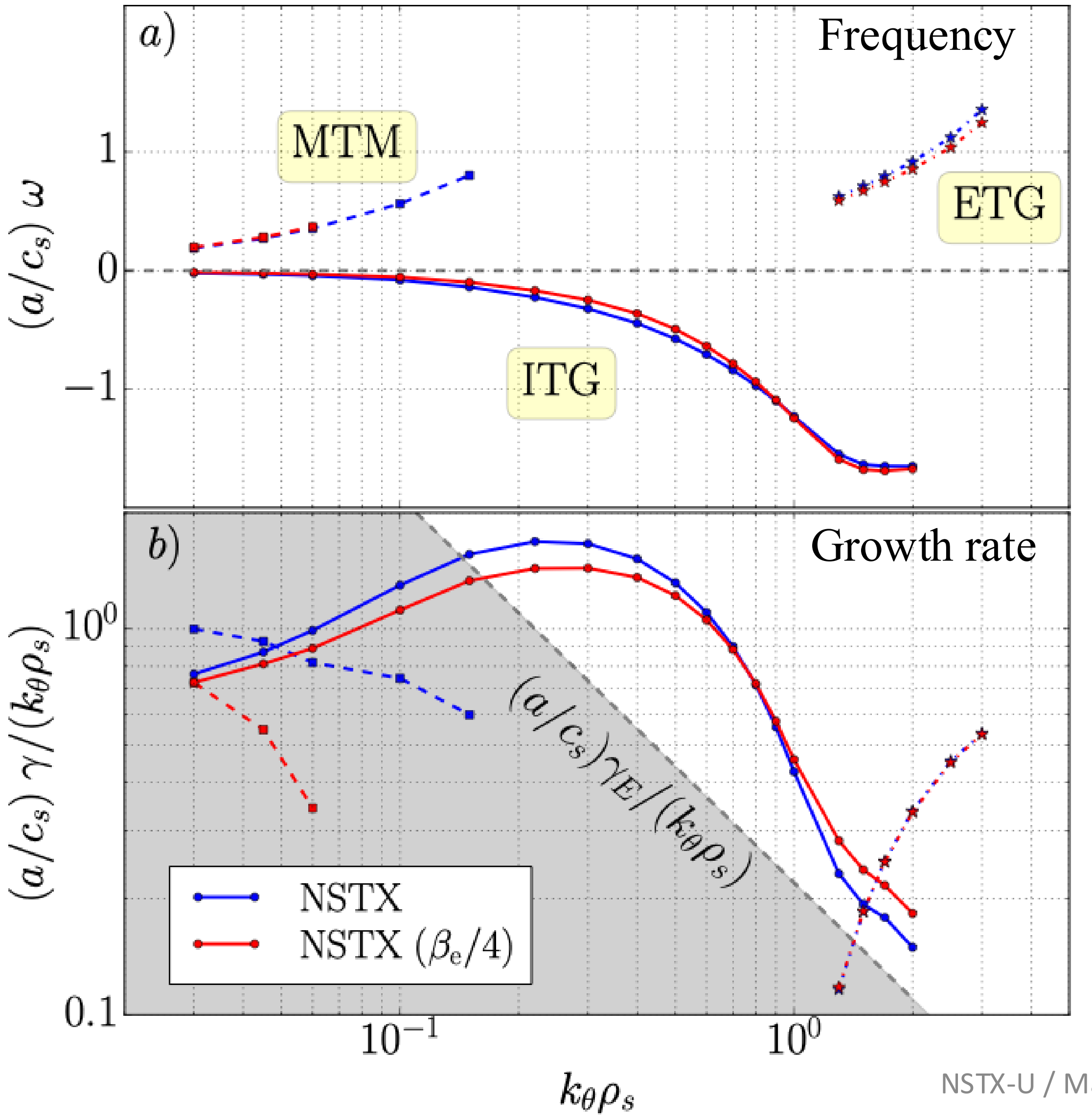
$$\Delta(k_x^0 \rho_s) = 0.043, \ (k_x^0 \rho_s)_{\max} = 6.87$$

$$\Delta(k_\theta \rho_s) = 0.05, \ (k_\theta \rho_s)_{\max} = 1.55$$

- Long simulation time to ensure a good convergence

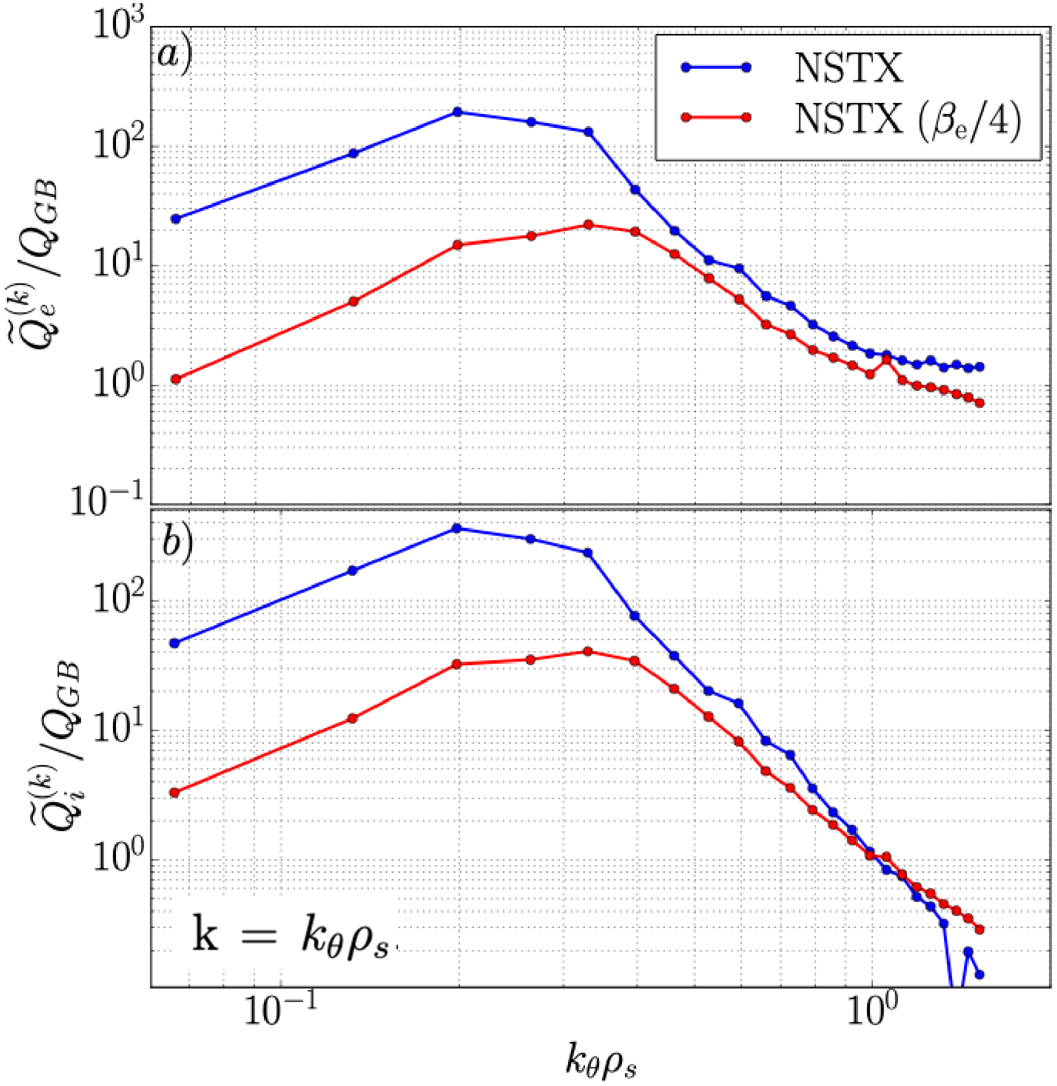


Linear analysis with new CGYRO-DMD solver shows unstable modes which drive the transport



- MTMs are unstable and stabilized by β
- ITG is the main transport driving mode and slightly stabilized by β
- ETG is not sensitive to β

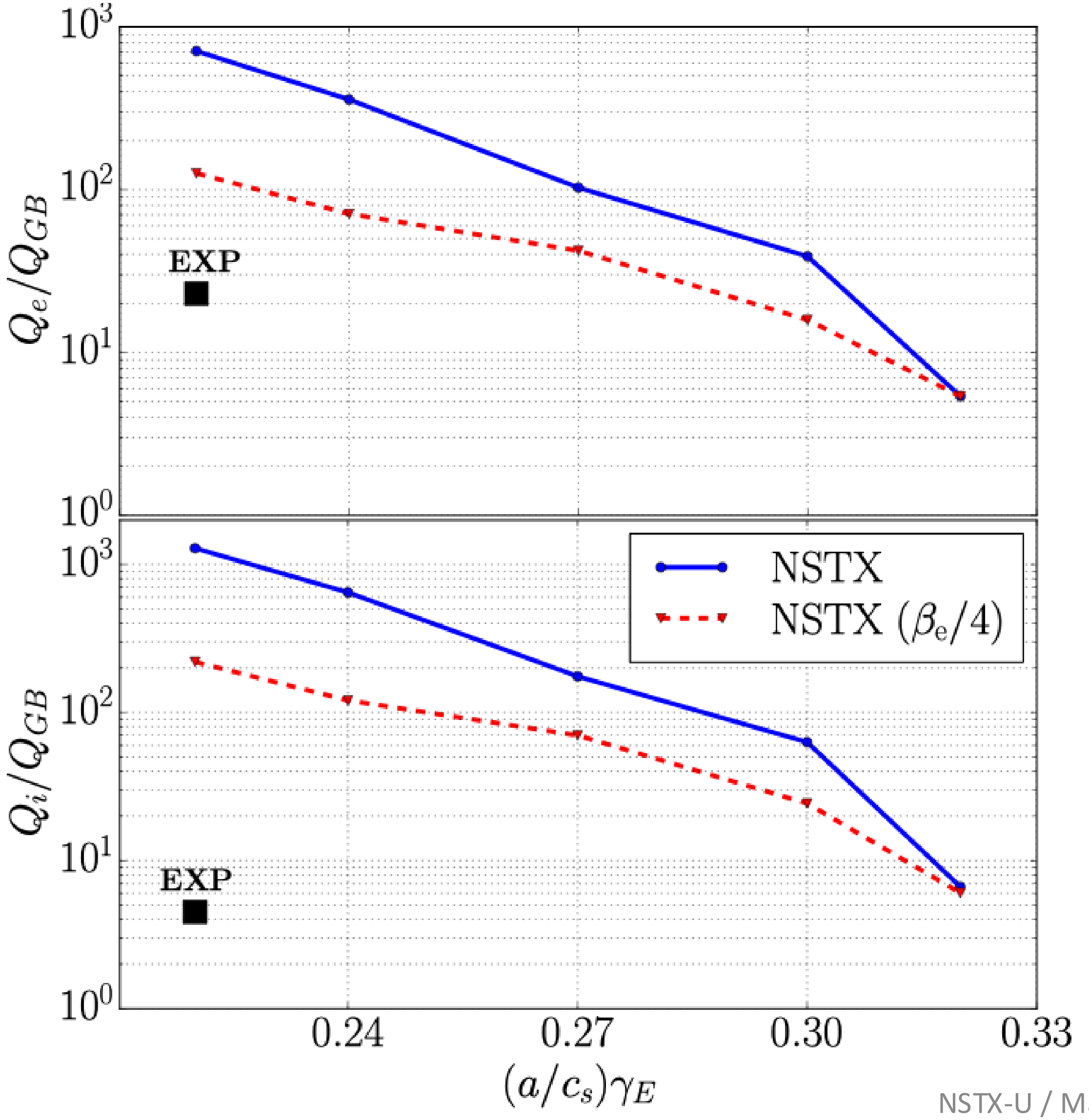
With decrease of β_e fluxes are much lower, but still well above the power balance



	NSTX	NSTX ($\beta_e/4$)	Power balance
Q_e/Q_{GB}	328	286	21
Q_i/Q_{GB}	1285	219	4.5

- Contribution of magnetic fluctuations is negligible in both cases
- β_e destabilization effect can not be explained by the linear physics (**γ^{max} = 0.66**, **γ^{max} = 0.63**)

Increase of $E \times B$ shear brings fluxes in a good agreement with the power balance level



$$\gamma_E \doteq -\frac{r}{q}\frac{d\omega_0}{dr}$$

Waltz ExB shearing rate

- Increase of the shear by 50% brings electron flux in the excellent agreement with the power balance

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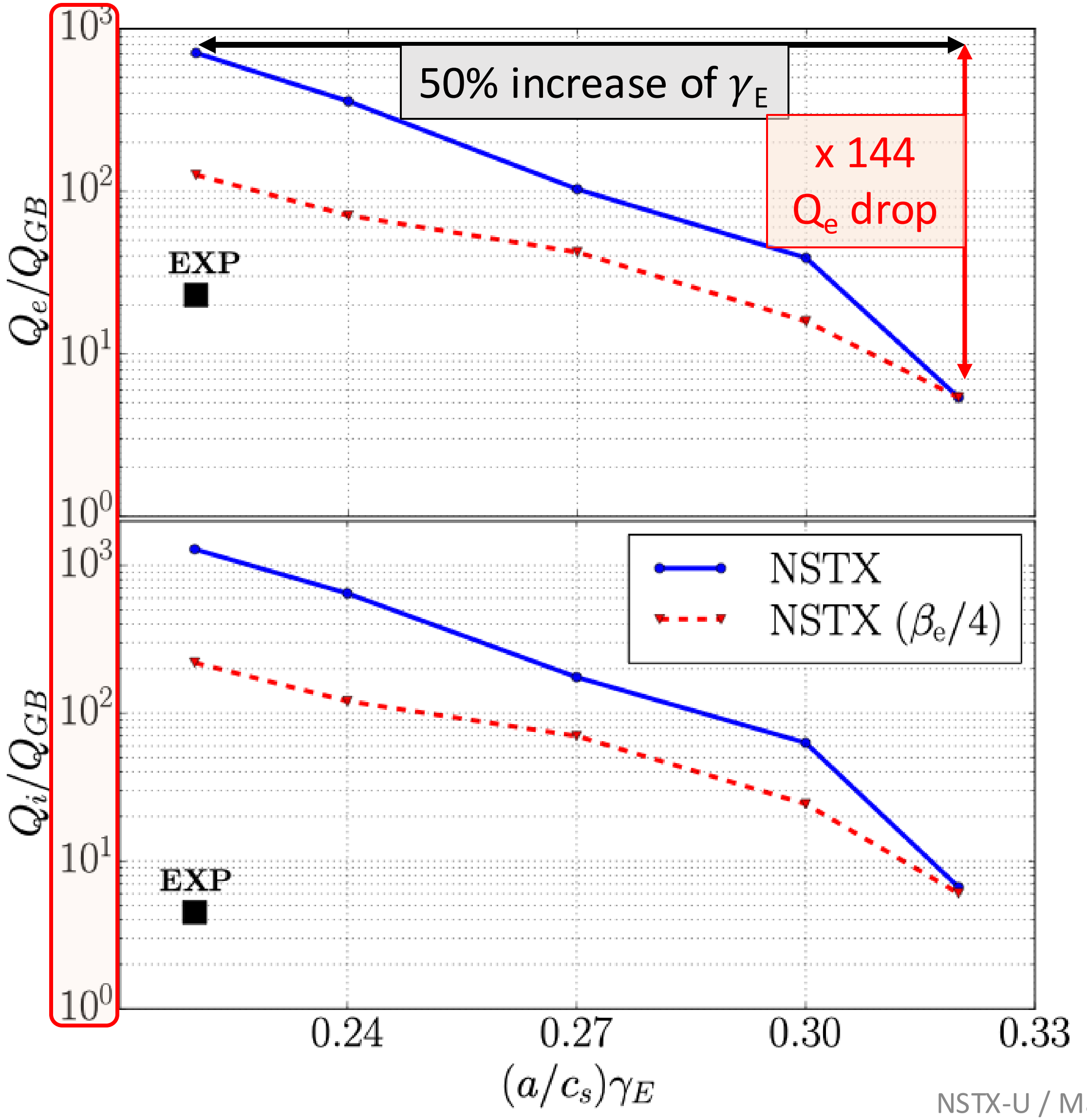

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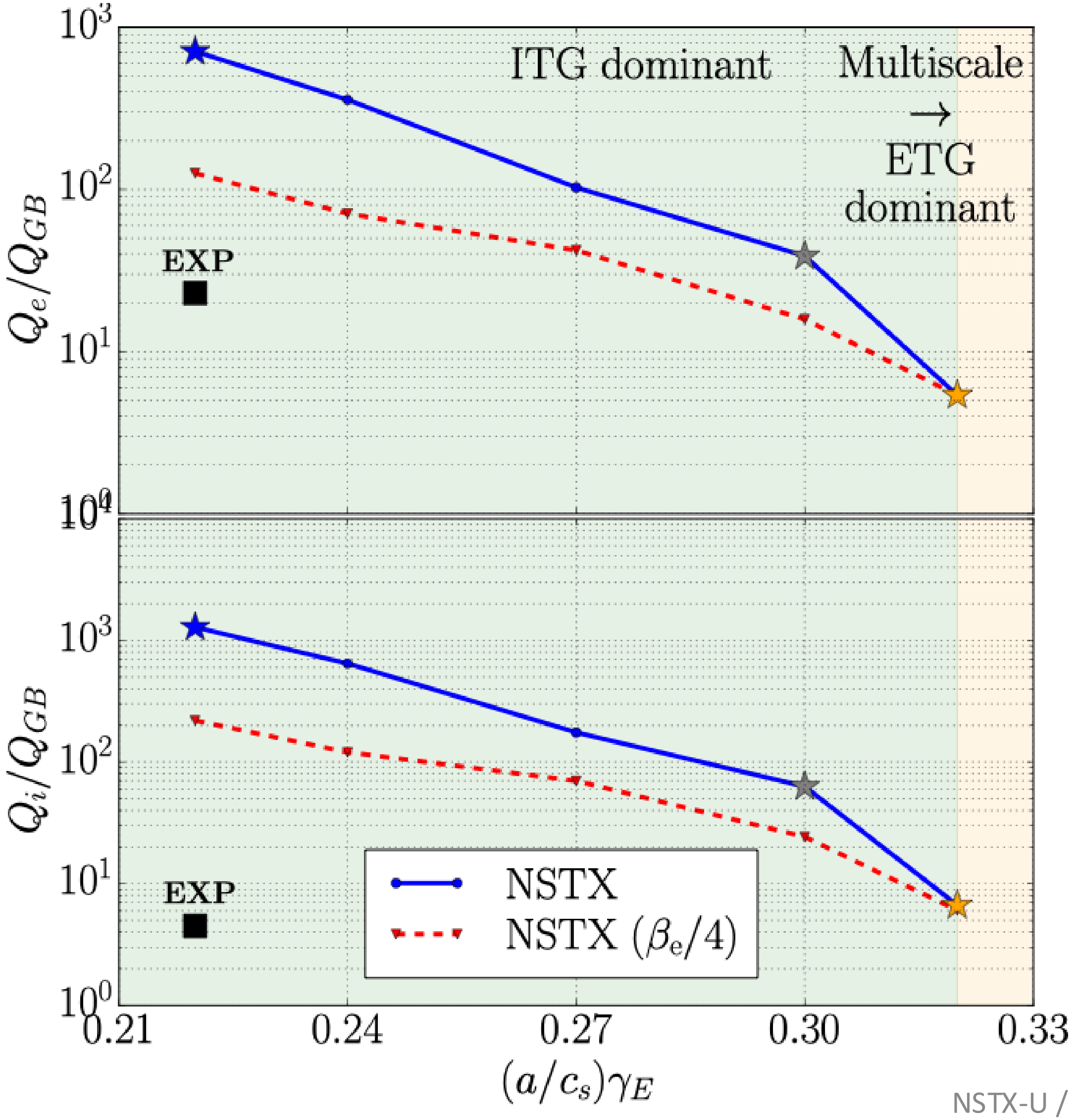
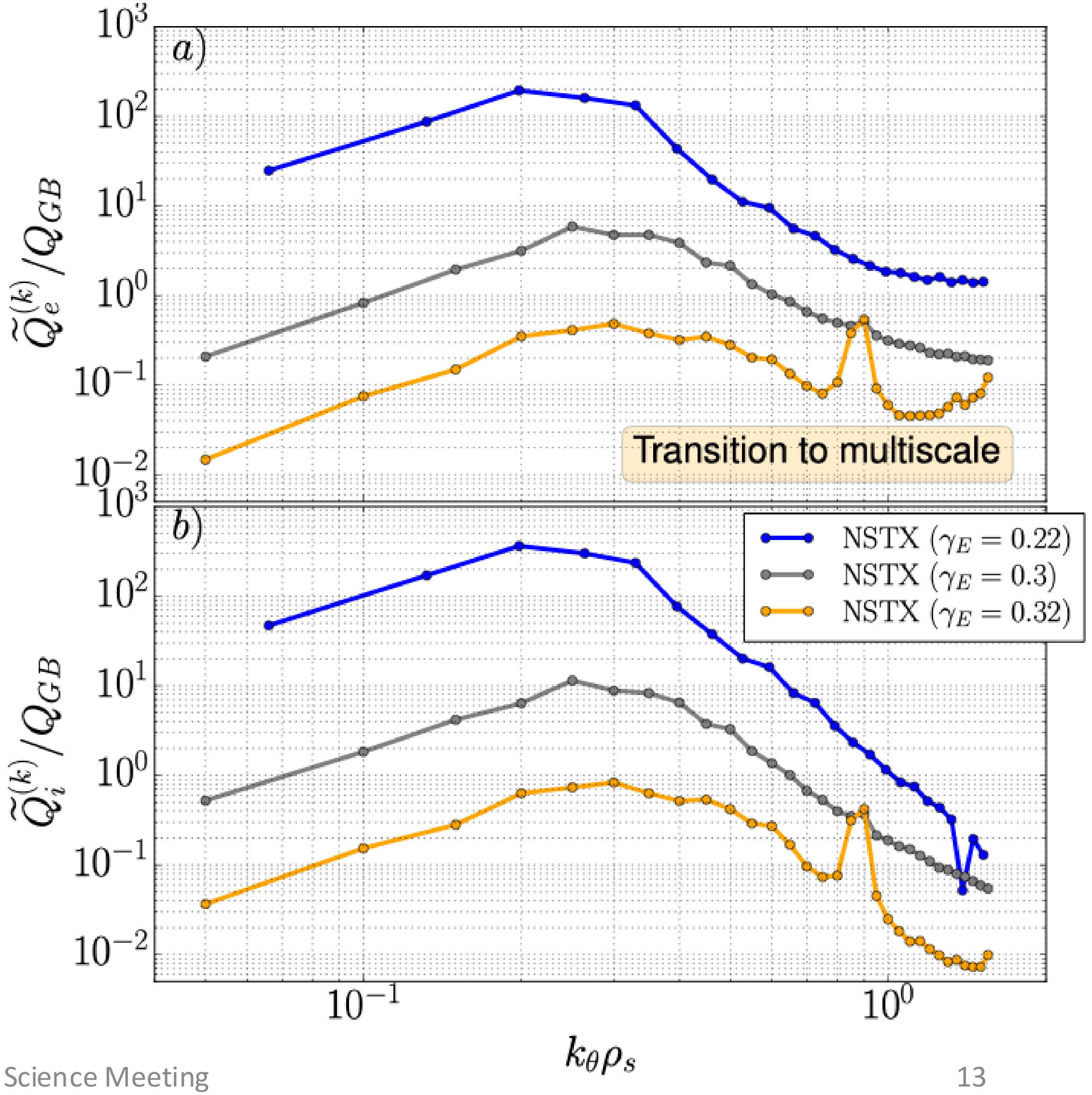
Waltz ExB shearing rate

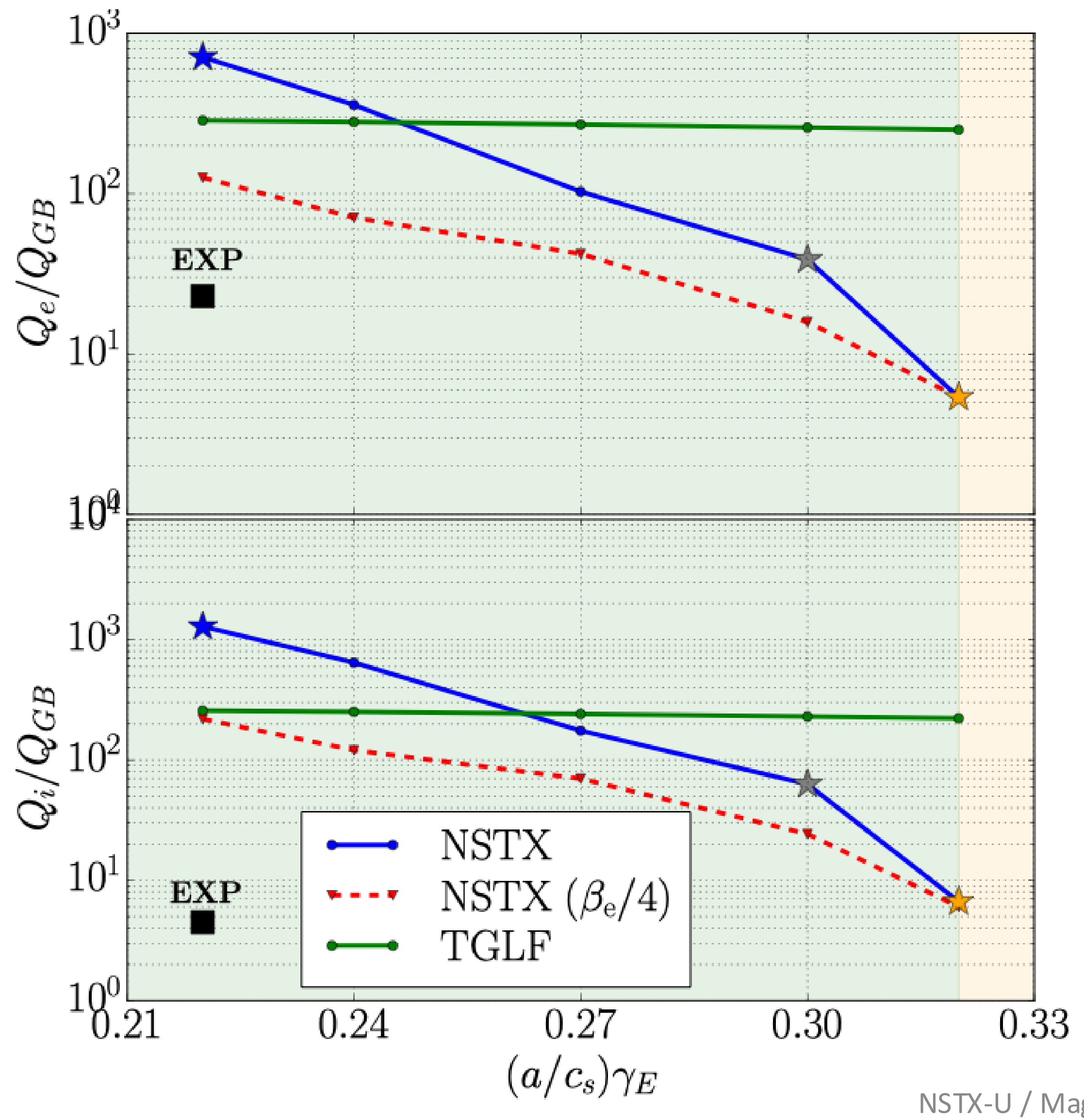
- Increase of the shear by 50% brings electron flux in the excellent agreement with the power balance
- <u>Such rate of $E \times B$ shear suppression is surprisingly strong</u>

Transition from ITG regime to a multiscale is observed with increase of ExB shear





TGLF does not reproduce this $E \times B$ dependency

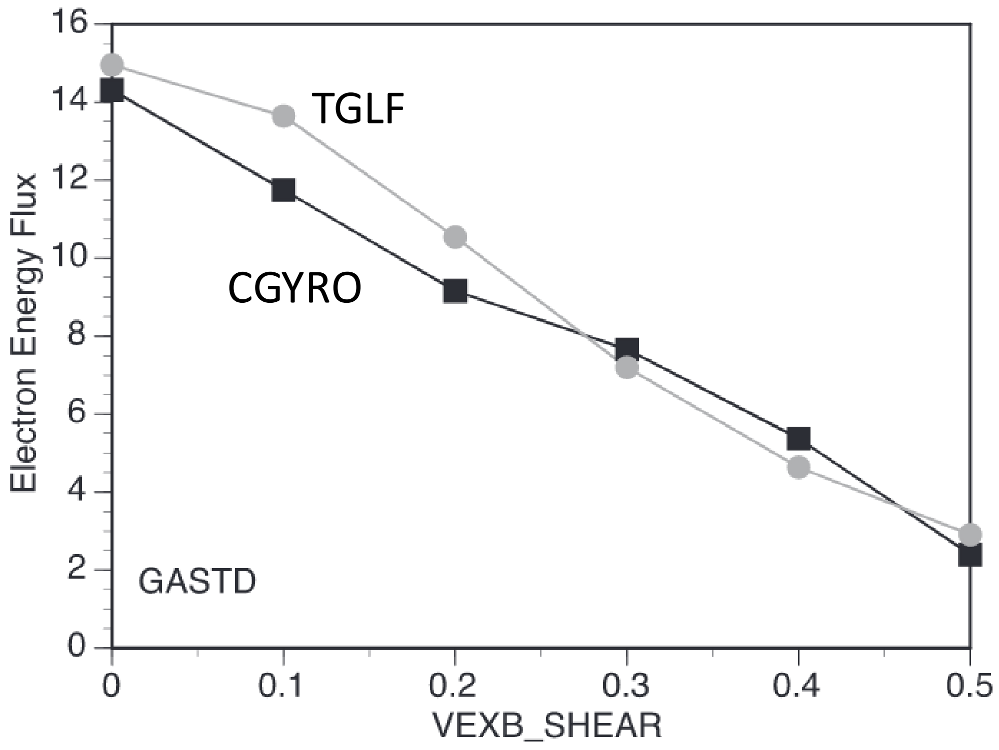


- TGLF results are similar for the NSTX and NSTX ($\beta_e/4$) cases
- TGLF applies the spectral shift model* to include the effect of $E \times B$ shear suppression on turbulent fluxes
- Surprisingly TGLF does not show any significant decrease of the flux with increase of γ_E for this NSTX case

* [Staebler G., et al., Nuclear Fusion 53, 2013]

The NSTX case is very different from the calibration database of the TGLF SAT2 model

- TGLF reproduces $E \times B$ shear dependency accurately for the GASTD case



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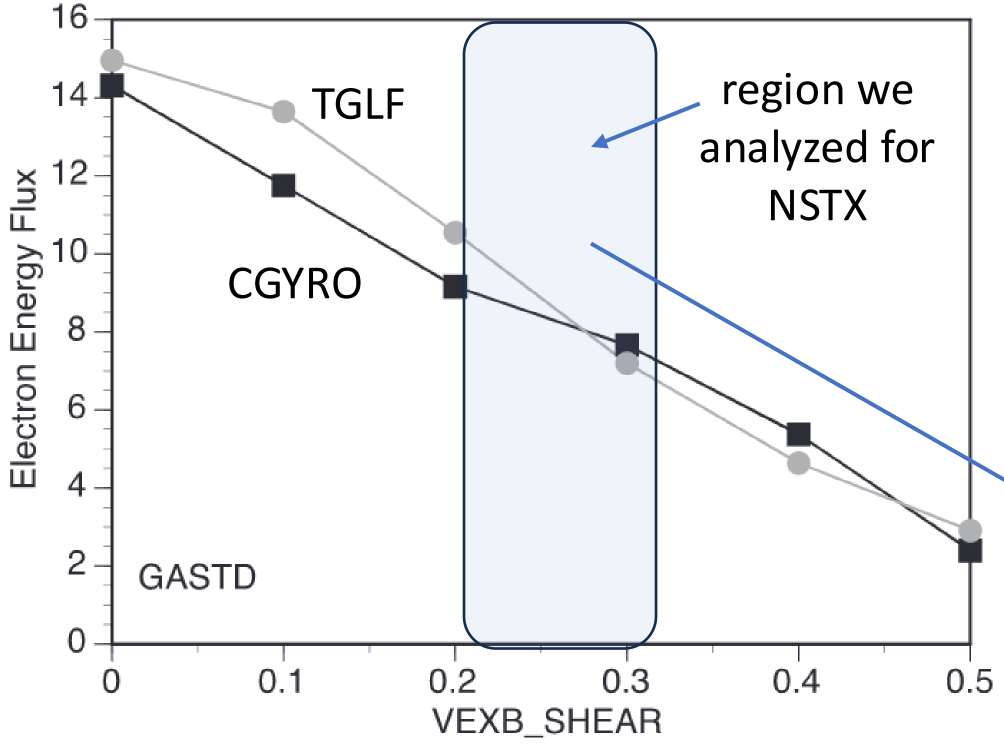
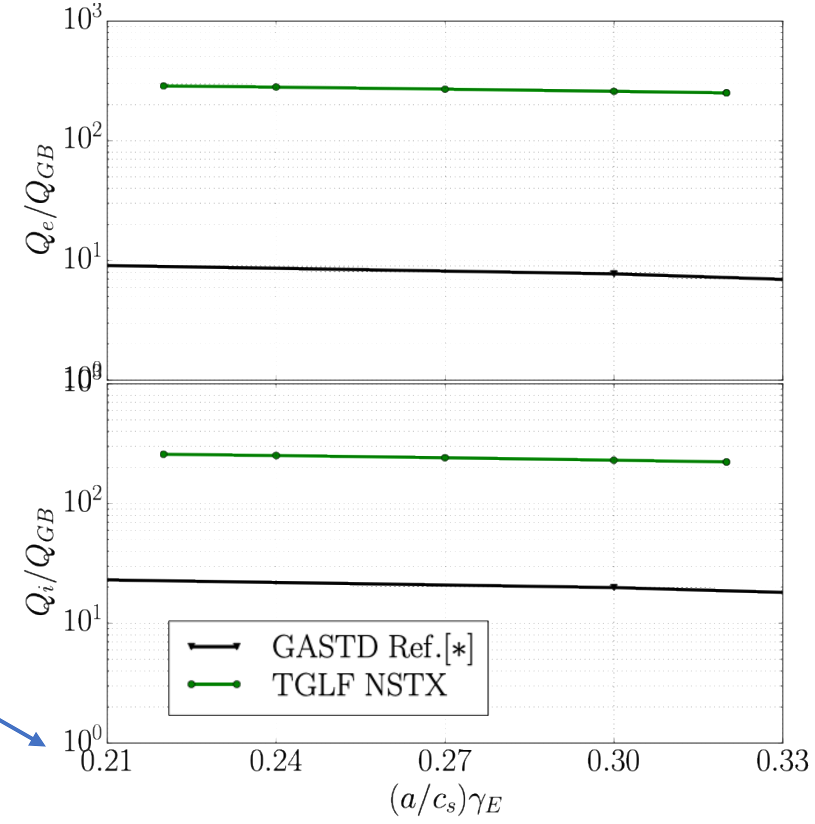
The NSTX case is very different from the calibration database of the TGLF SAT2 model

- TGLF reproduces $E \times B$ shear dependency accurately for the GASTD case
- TGLF reproduces the same $E \times B$ shear dependency for NSTX case as for GASTD case





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Summary

- NSTX L-mode discharge #141716 shows a very strong $E \times B$ shear dependency around experimental value of γ_{E}
- This dependency can not be reproduced by the TGLF model as it is much stronger compared to the one observed for the conventional tokamak parameters

Summary

- NSTX L-mode discharge #141716 shows a very strong $E \times B$ shear dependency around experimental value of γ_{E}
- This dependency can not be reproduced by the TGLF model as it is much stronger compared to the one observed for the conventional tokamak parameters
- **NSTX** baseline case illustrates the difference of nonlinear physics of spherical tokamak confinement regimes compared to the conventional tokamaks and provides a useful dataset for reduced model development

Future work

- Publication of results + analysis of the accuracy of the TGLF model for parameters corresponding to ST; in particular, the effect of small aspect ratio

- Understanding which parameter causes such a strong $E \times B$ shear suppression for ST plasmas

GA codes rotation theory

The rotation profile

The relevant profile that gives a *complete specification of rotation* is the angular frequency $\omega_0(r)$, which in defined consistently throughout GACODE as

$$\omega_0(r) \longrightarrow \frac{cE_r}{RB_p} \ .$$

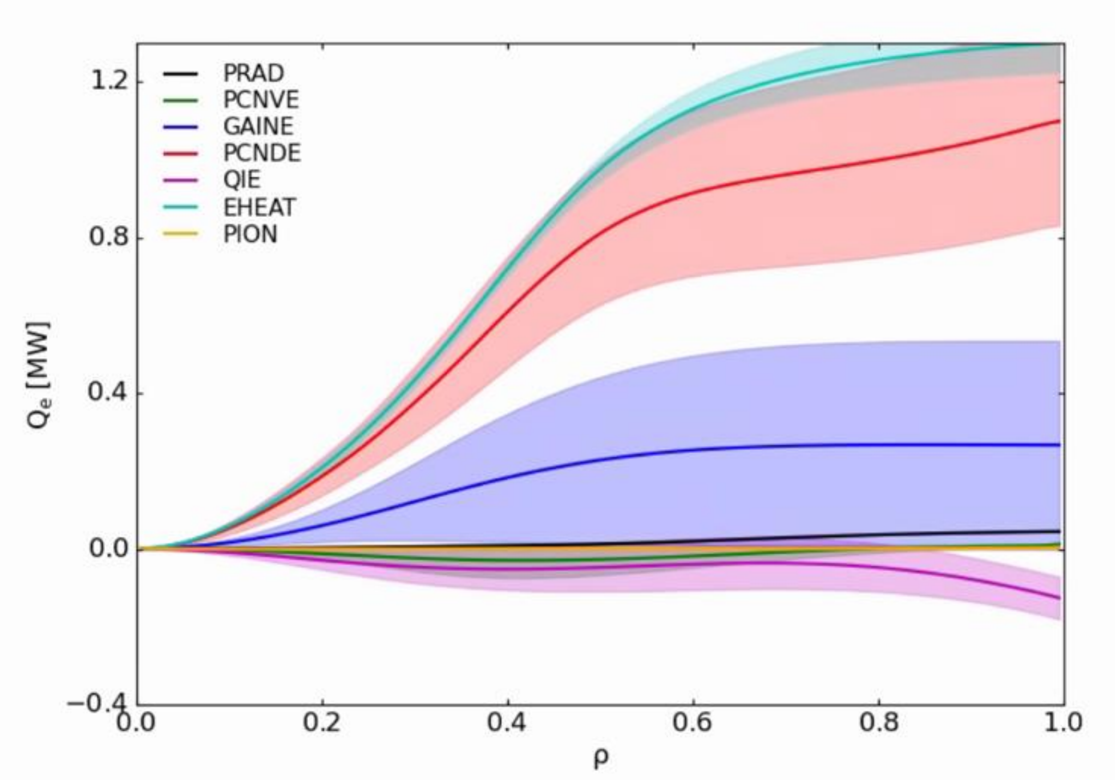
$$E_r = \frac{RB_p}{n_a z_a e}\frac{dp_a}{d\psi} + \frac{U_\varphi}{c}B_p - \frac{U_\theta}{c}B_t \ .$$

$$E_r = -|\nabla r| d\Phi/dr$$

$$\omega_0(\psi) \doteq -c\frac{d\Phi_{-1}}{d\psi} \ .$$

Energy flux calculations in TRANSP

$$S_e = \nabla\Gamma_e = P_{\mathrm{OH}} + P_{\mathrm{NBI}} - P_{\mathrm{rad}} - P_{\mathrm{ioniz}} - P_{ei} - \frac{3}{2} d\left(n_e T_e\right)/\mathrm{d}t$$



Linear sensitivity scan