Turbulent transport in the central part of JET hybrid H-modes (low shear high beta)

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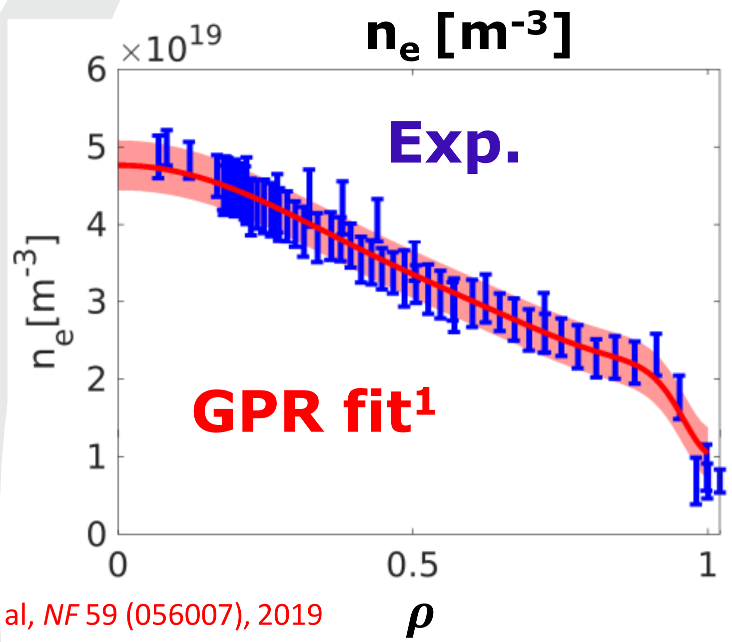
A. Loarte, A. Najlaoui

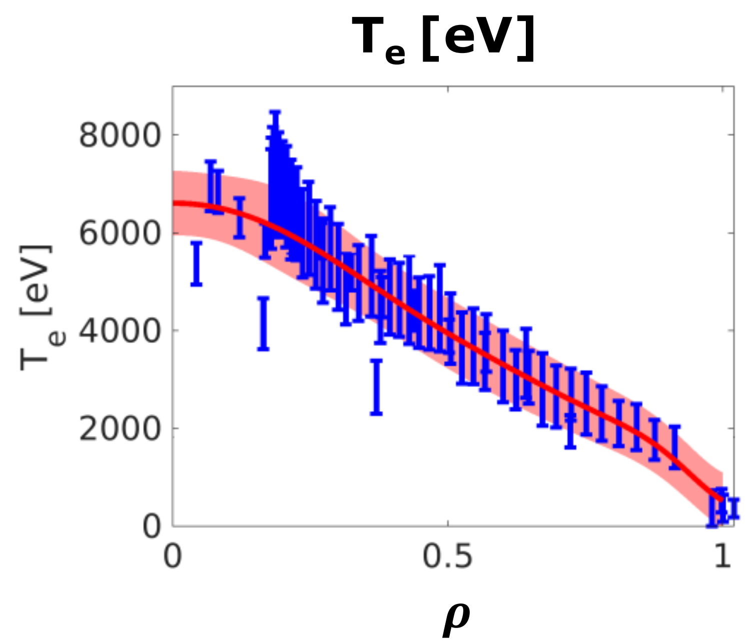
N. Kumar PhD thesis (2021)

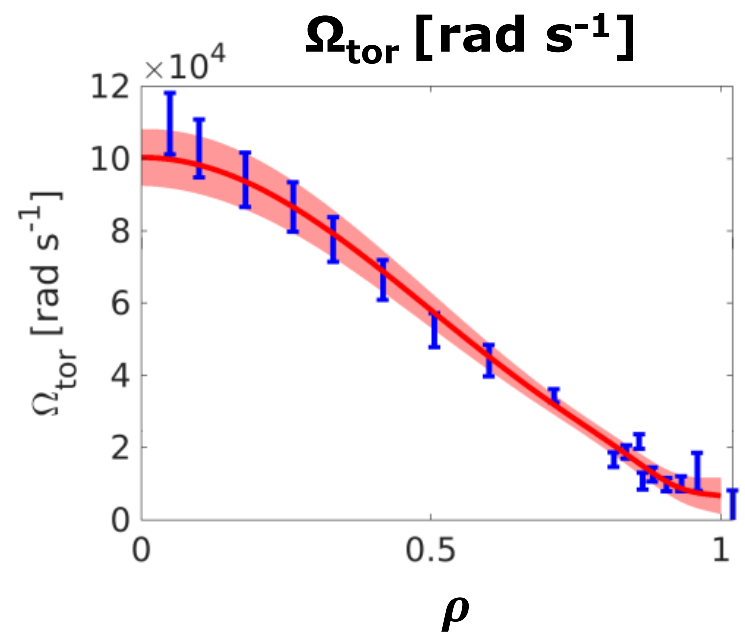
N. Kumar *et al.* Nucl. Fusion **61** (2021) 036005

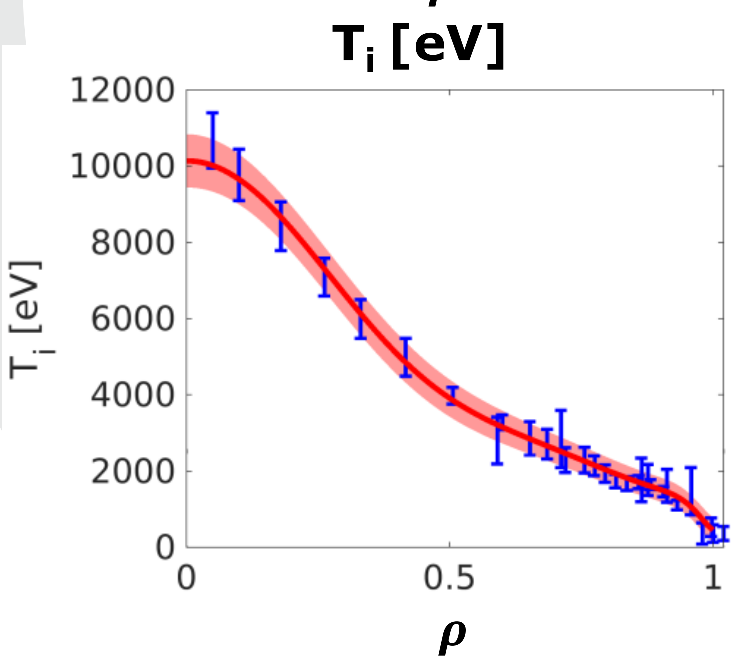
Reference JET hybrid H-mode (C wall era)

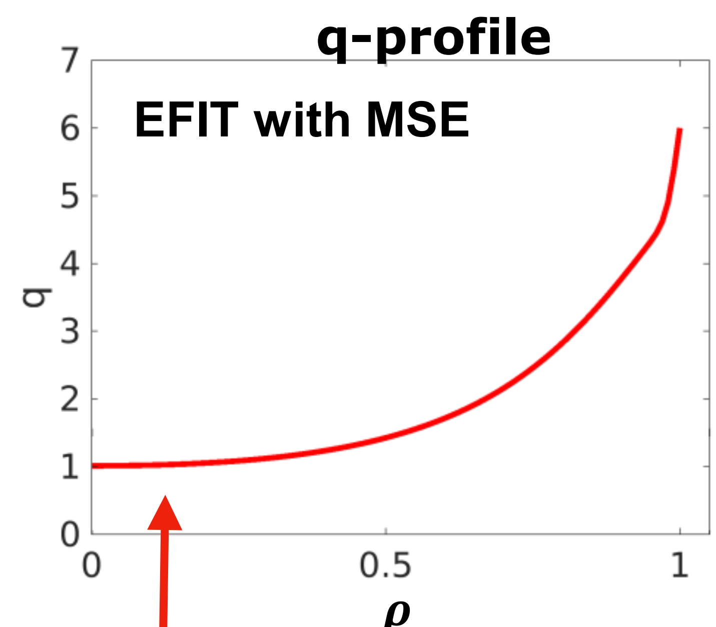


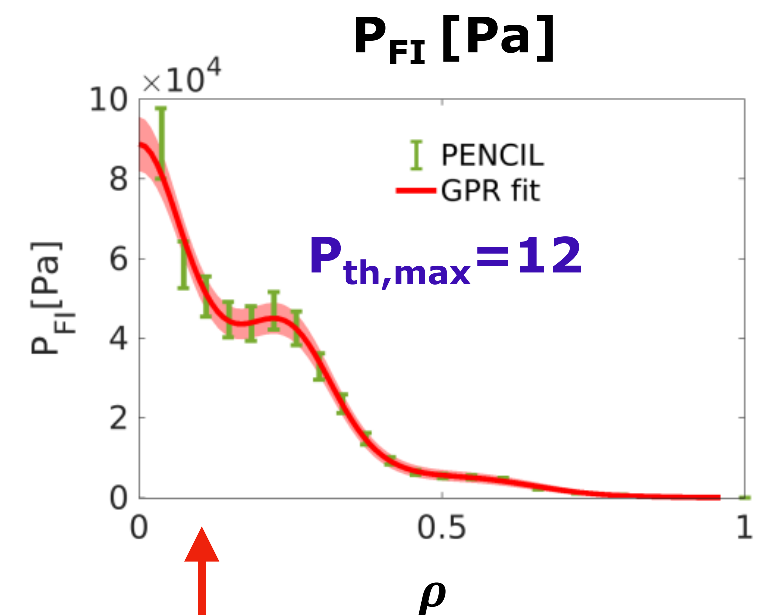
[1] A. Ho et al, *NF* 59 (056007), 2019











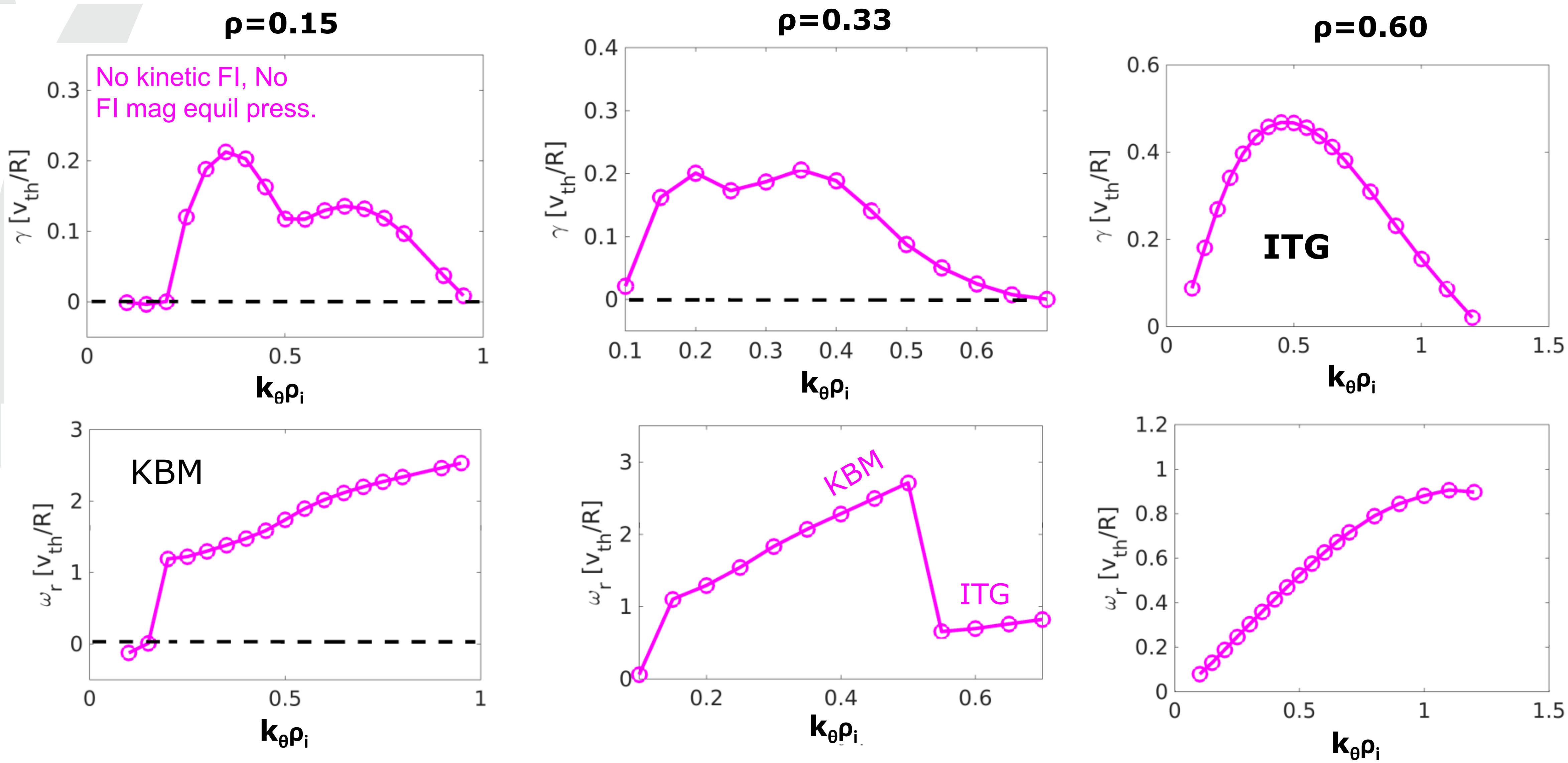
#75225

flat q profile

sizeable fast ion population (NBI)

Linear stability (local)

ρ	$\frac{R}{L_{Ti}}$	$\frac{R}{L_{Te}}$	$\frac{R}{L_{Tf}}$	$\frac{T_e}{T_i}$	$\frac{T_f}{T_i}$	$\frac{R}{L_{nC}}$	$\frac{R}{L_{ne}}$	$\frac{R}{L_{nf}}$	β_{ref} [%]	q	$\hat{s}$	u	u´	ν x 10^{-2}
0.15	4.2	1.9	1.8	0.69	5.6	-0.70	1.5	0.80	4.6	1.10	0.05	0.31	0.59	1.5
0.33	7.7	4.1	9.6	0.84	6.1	-1.51	2.7	8.97	2.6	1.14	0.21	0.32	1.31	1.9
0.60	5.9	5.5	9.6	1.05	4.6	4.41	3.3	7.96	1.0	1.74	1.42	0.24	0.24	3.4



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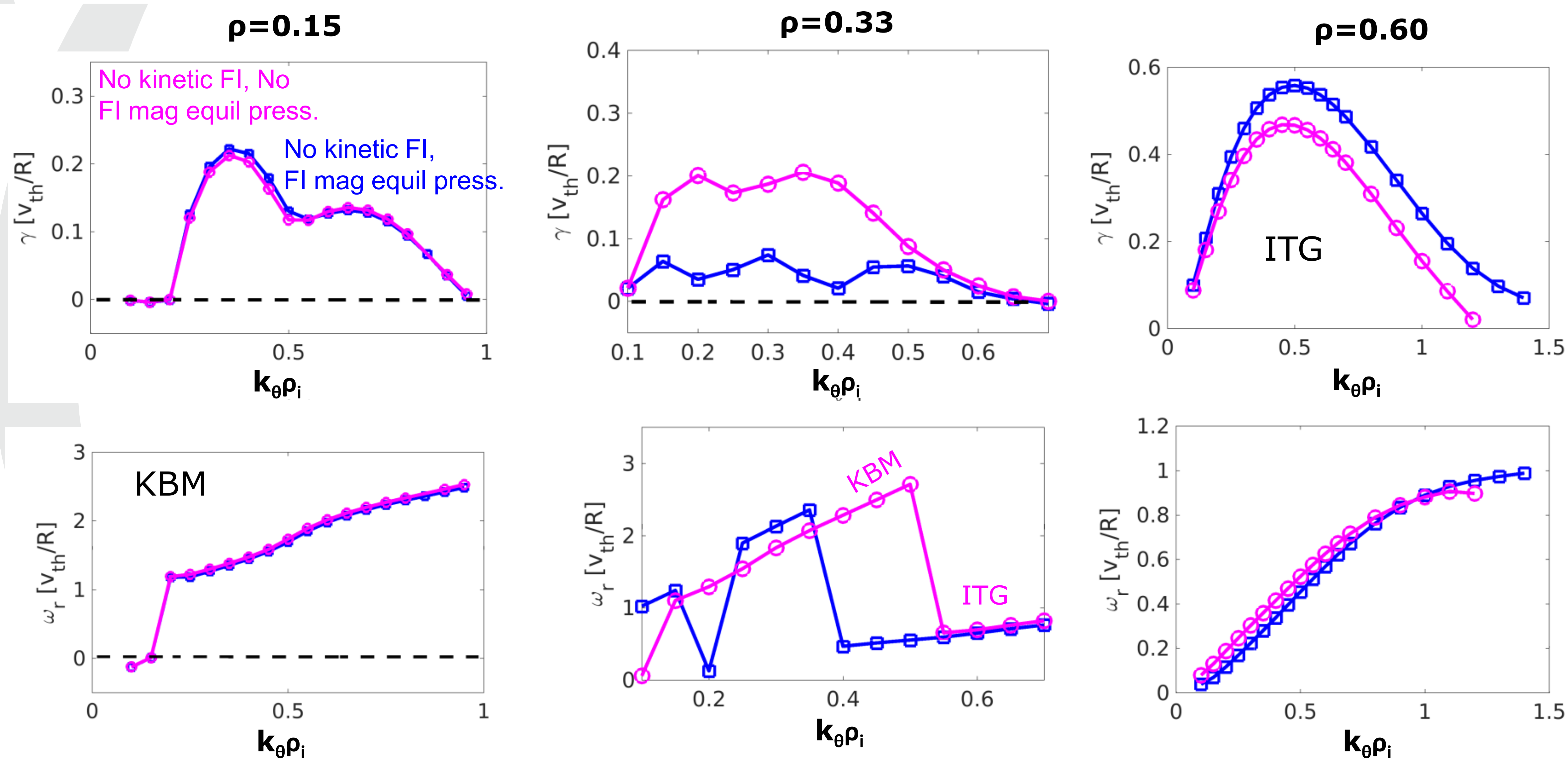

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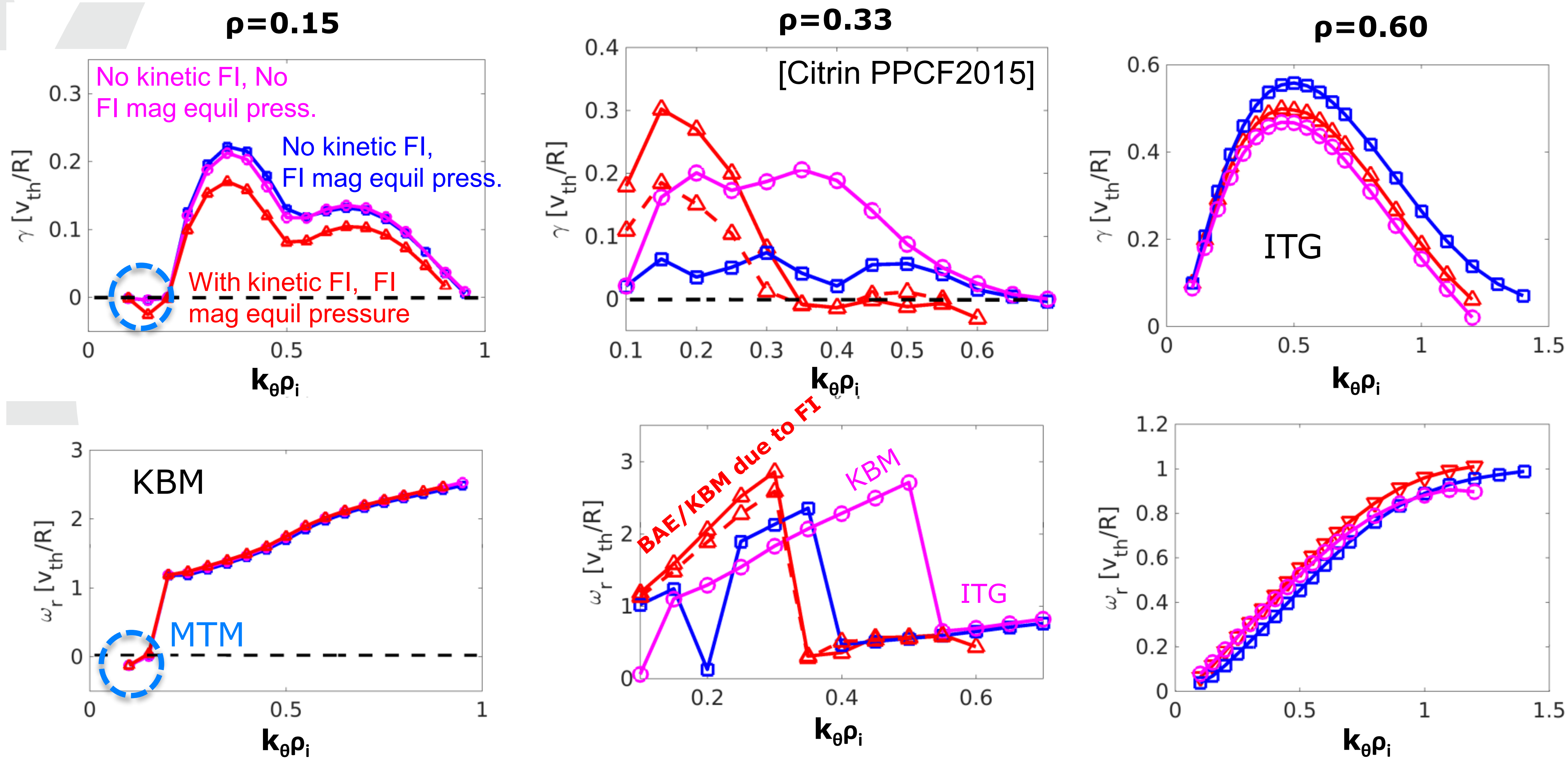

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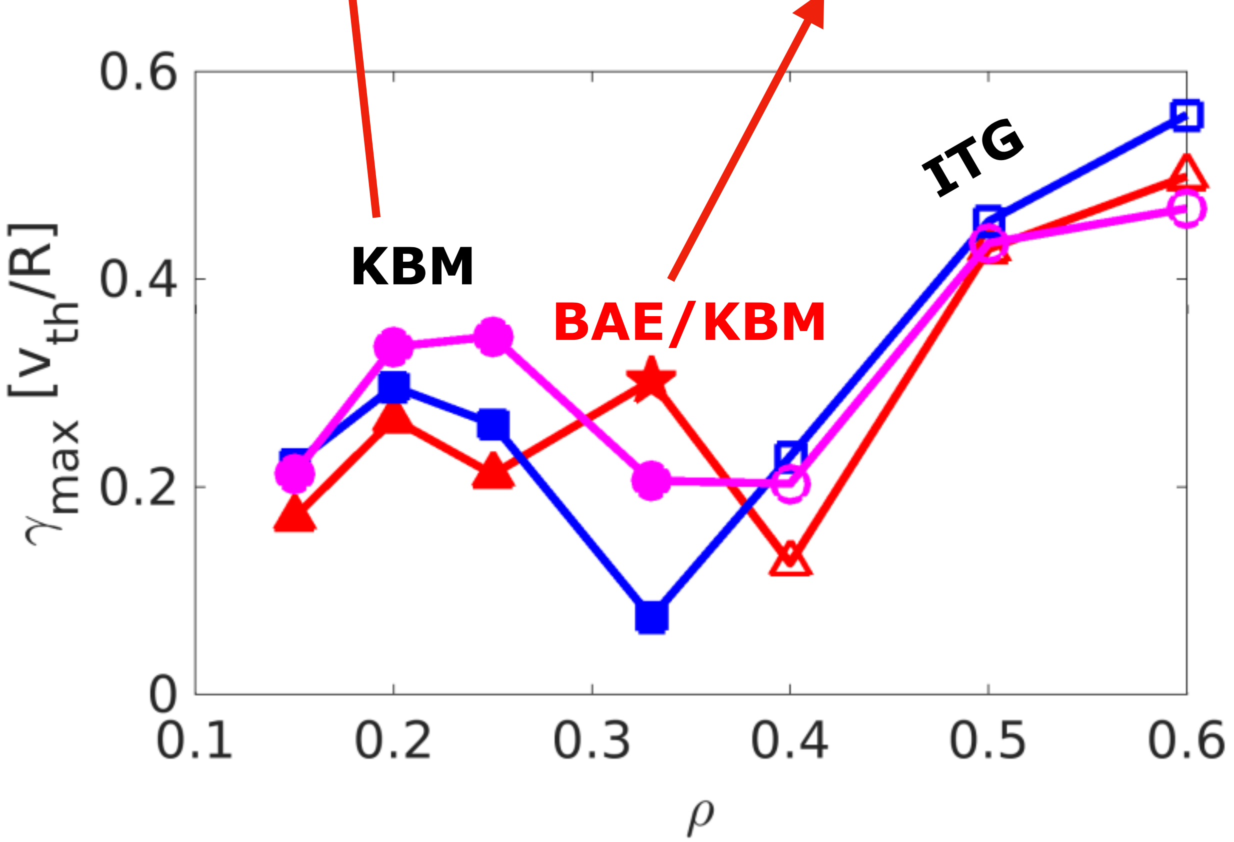
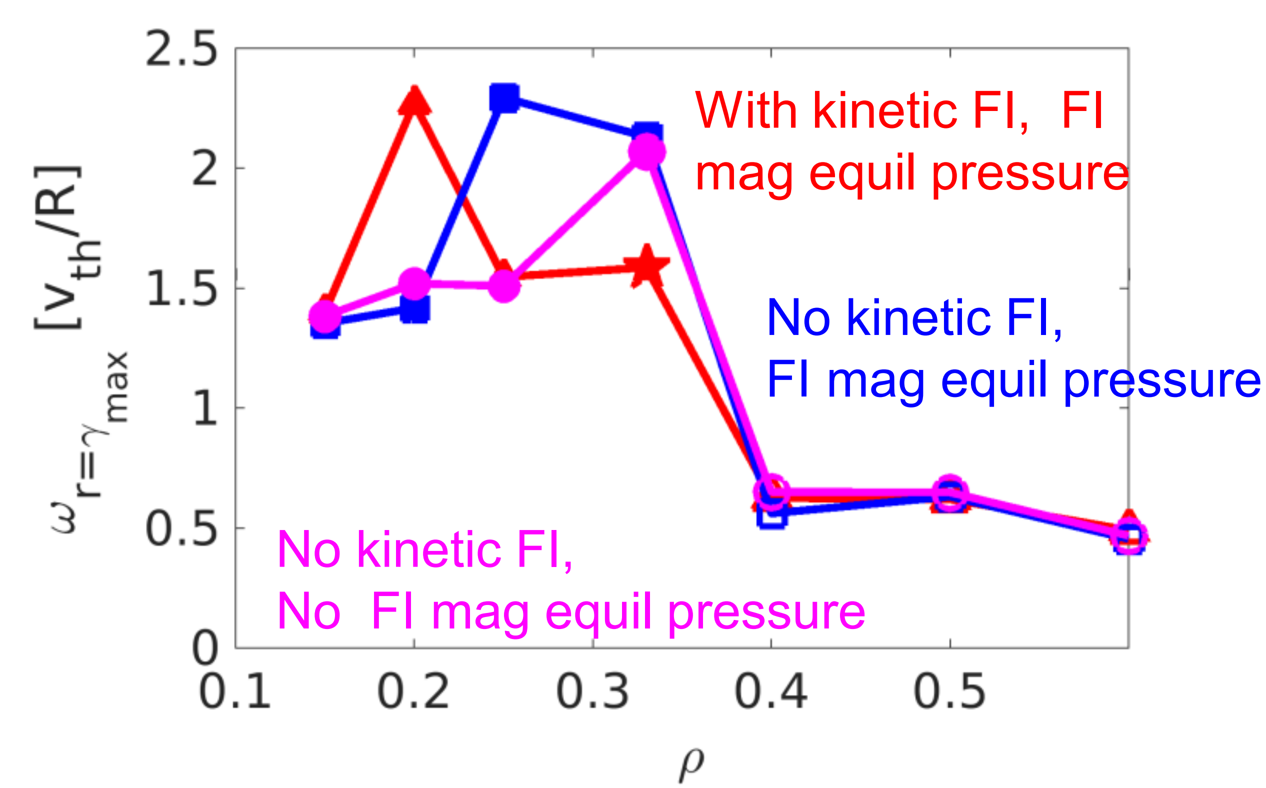
Also found in Moradi NF 2014

See Citrin PPCF2015





Non-linear fluxes

- Question: are standard QL models applicable for KBM turbulence?
- Focus on ρ=0.15, no fast-ion, no ExB shear
- Flux-tube delta-f gyrokinetic simulations (GKW)

  - Actual magnetic equilibrium (Miller), collisions, rotation, EM fluctuations ($A_{//}$ and $B_{//}$), Carbon impurities, **No fast ions**, and no $\boldsymbol{E} \times \boldsymbol{B}$ **shear**
  - $k_\theta \rho_i$= [0.1 - 1.5]
  - $K_r \rho_i$= $+12.30$ to -12.3
  - **Perpendicular grid discretisation [N_x, N_y]= [509, 16]**
  - Parallel direction discretization =32
  - Parallel velocity grid points= 64
  - Magnetic moment grid points = 16
  - **Large N_x and small time step ($\Delta t = 1.5 \times 10^{-4}\ R/v_{thi}$)➔ computationally very expensive**

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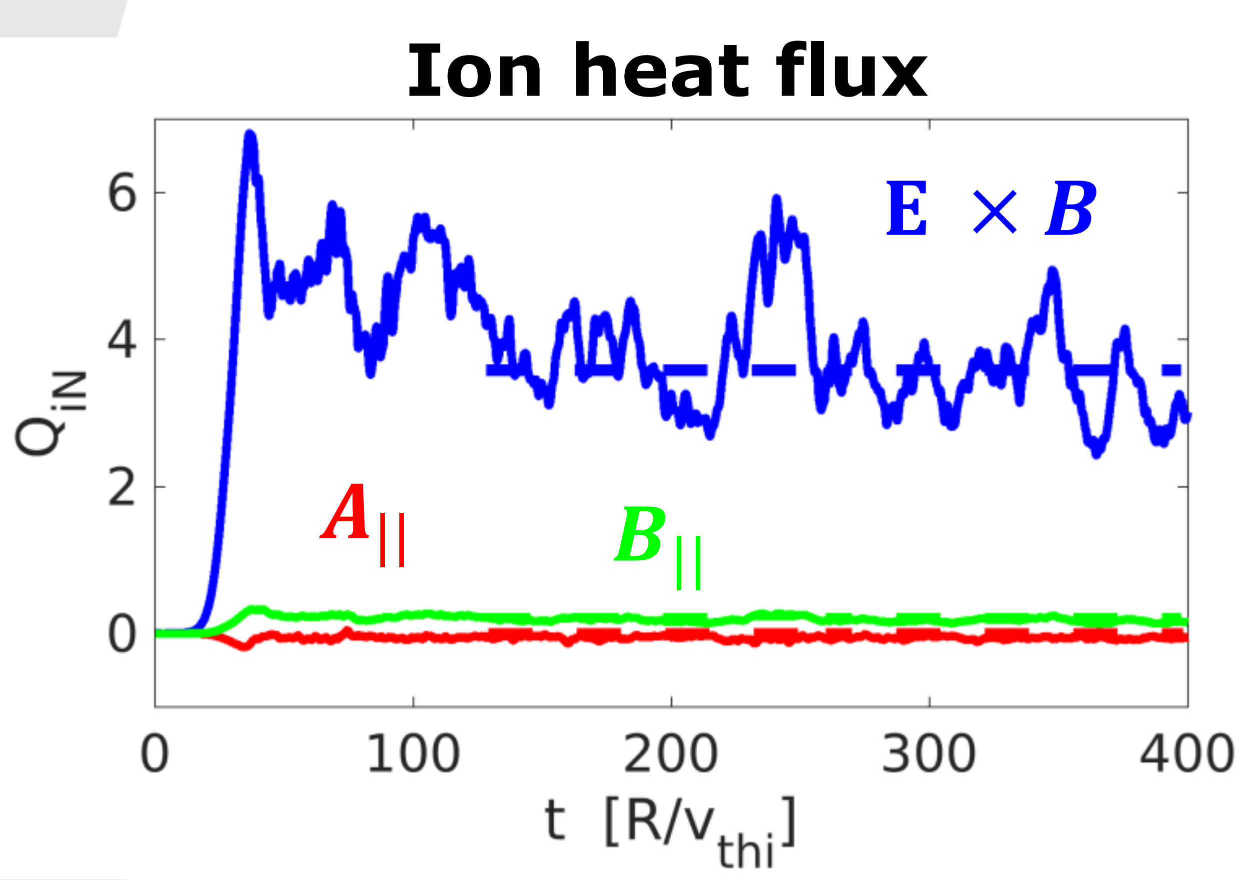
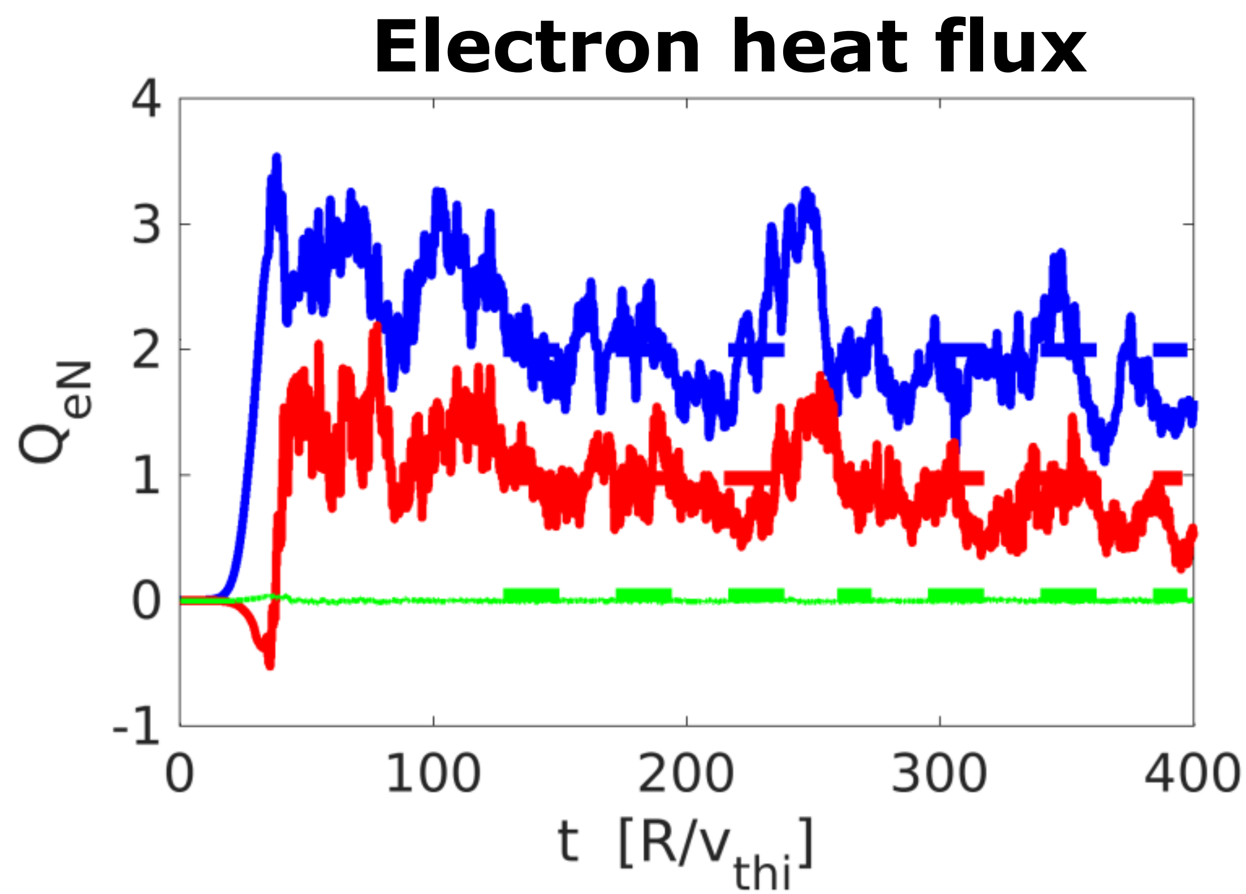
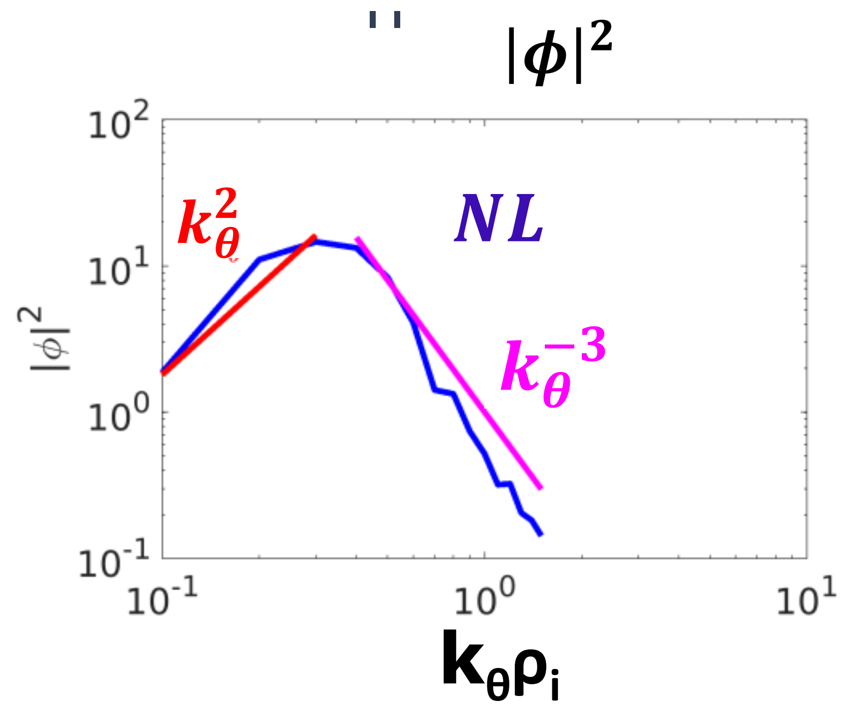
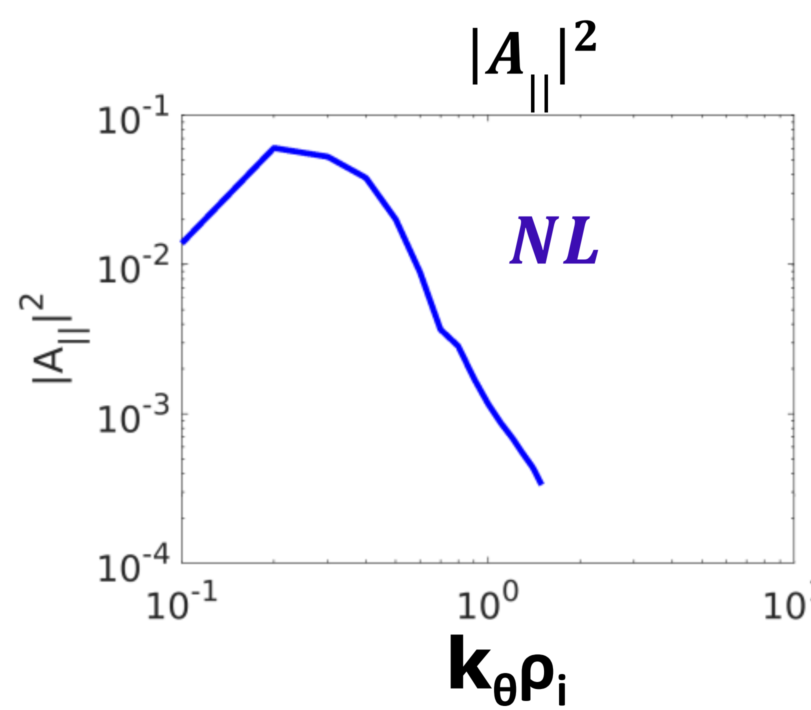
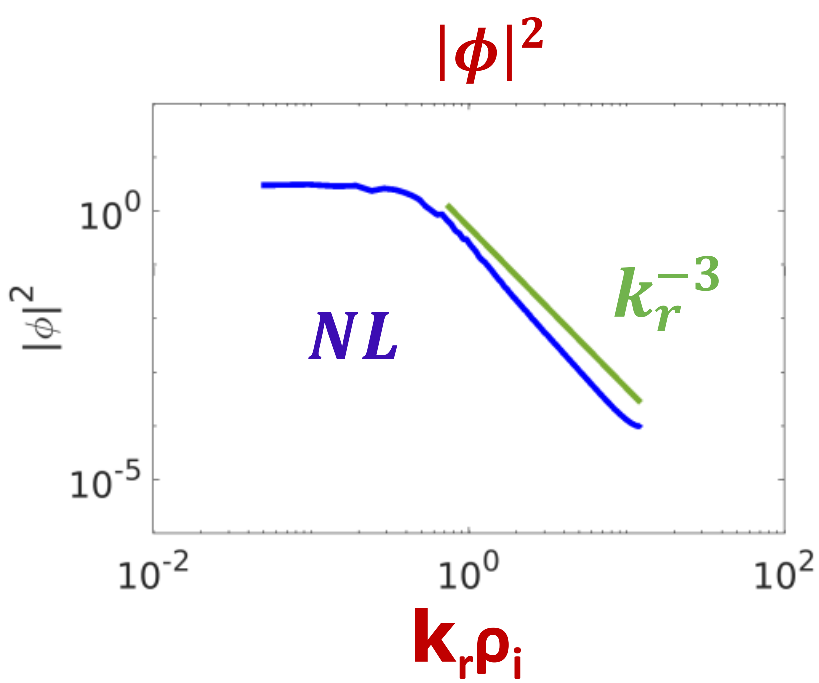


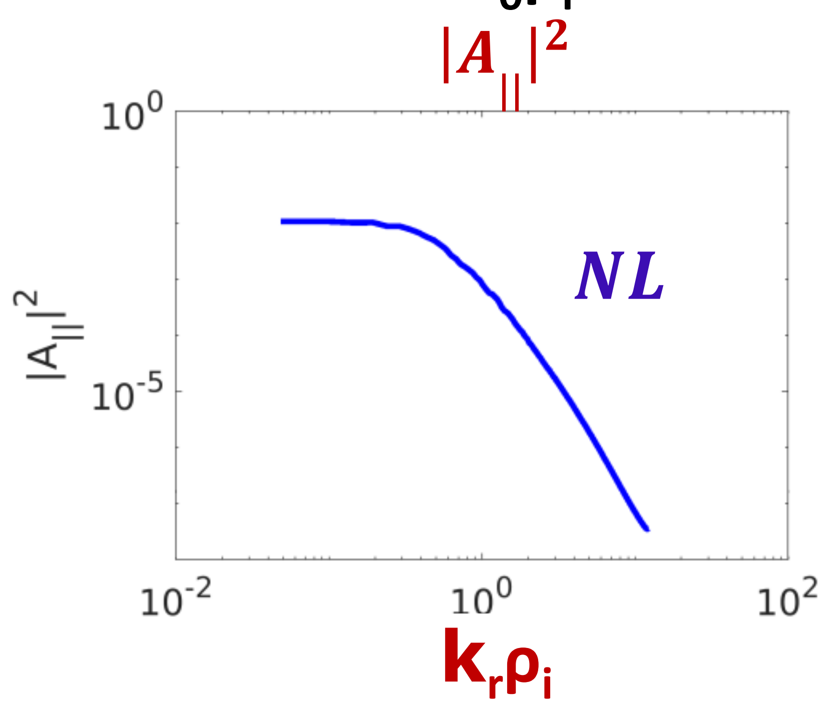


Time averaged spectra









Test of quasi-linear saturation models

- **Mixing length model [1]:**

$$W1 = \mathcal{A}_{QL}^2 = C1 max\left[\frac{\gamma}{\langle k_\perp^2 \rangle}, 0\right]$$

- **Qualikiz Model [2]:** Saturated mode amplitude

$$W_n = C_n \mathcal{S}_k \max\left[\frac{\gamma}{\langle k_\perp^2 \rangle}\right]$$

$k_\theta \rho_i^{max}$ **wave vector at max($\frac{\gamma}{k_\perp^2}$)**

$$\mathcal{S}_k = \left(\frac{k_\theta \rho_i}{k_\theta \rho_i^{max}}\right)^{x_n} \quad \text{for} \quad k_\theta \rho_i < k_\theta \rho_i^{max}$$

$$\mathcal{S}_k = \left(\frac{k_\theta \rho_i}{k_\theta \rho_i^{max}}\right)^{-3} \quad \text{for} \quad k_\theta \rho_i > k_\theta \rho_i^{max}$$

$W2$ with $\mathbf{x_2 = 1}$

$W3$ with $\mathbf{x_3 = 2}$

QL fluxes computed as:

$$Q_{s,E\times B}^{QL} = \sum_{k_r, k_\theta} Q_{s,E\times B}^{N} \mathcal{A}_{QL}^2$$

$$Q_{s,A_\parallel}^{QL} = \sum_{k_r, k_\zeta} Q_{s,A_\parallel}^{N} \mathcal{A}_{QL}^2$$

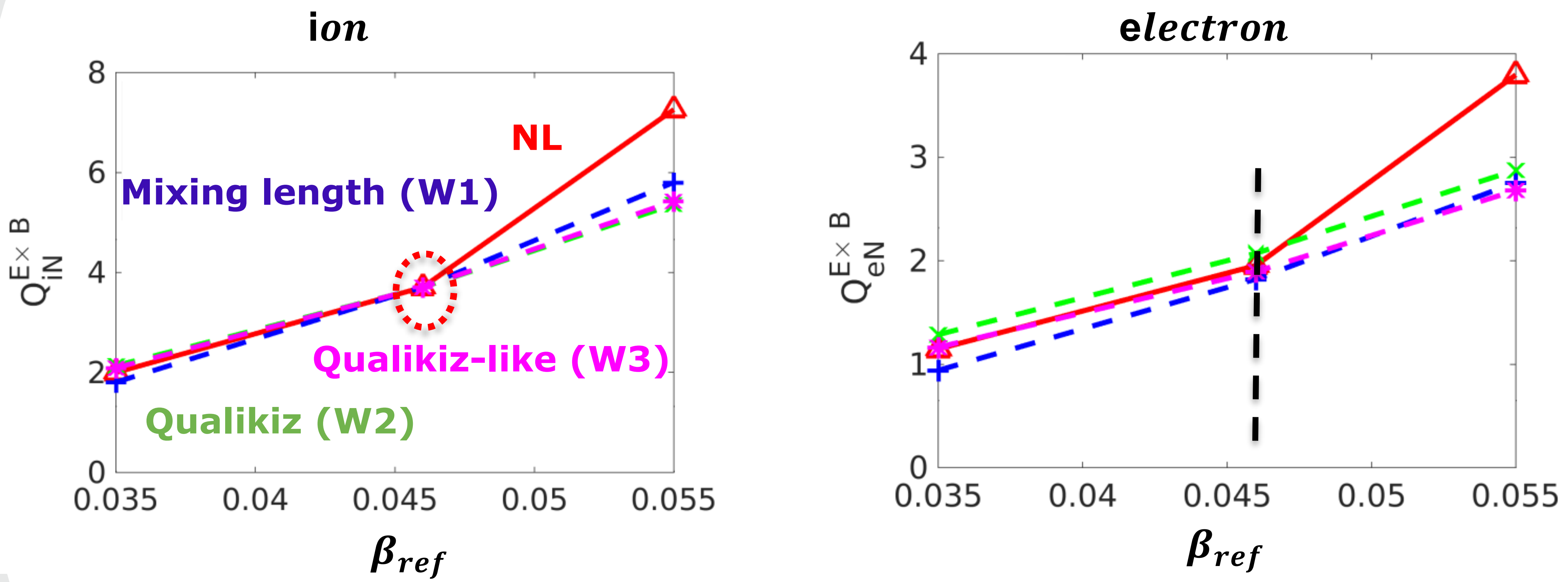
[1] T. Dannert et al, *PoP* **12** (072309), 2005

[2] C. Bourdelle, et al, *PoP* **14** (112501), 2007

Test of quasi-linear saturation models

Comparison of non-linear and quasi-linear ion and electron $E \times B$ heat fluxes with beta

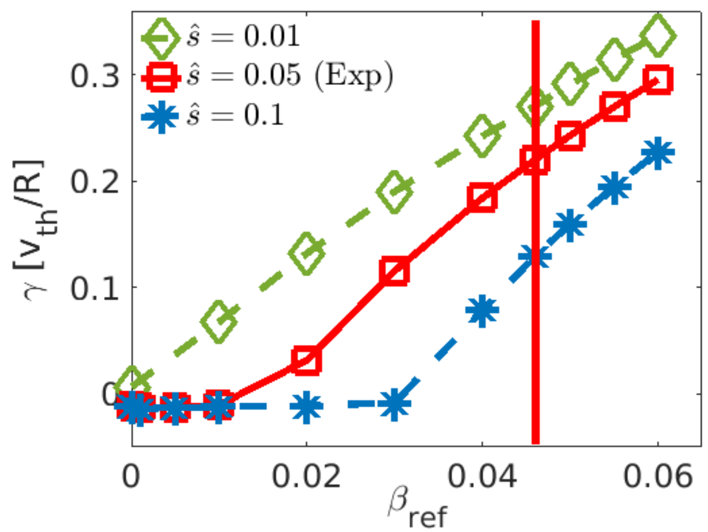
C1=12.4 ; C2=4.24; C3=4.32

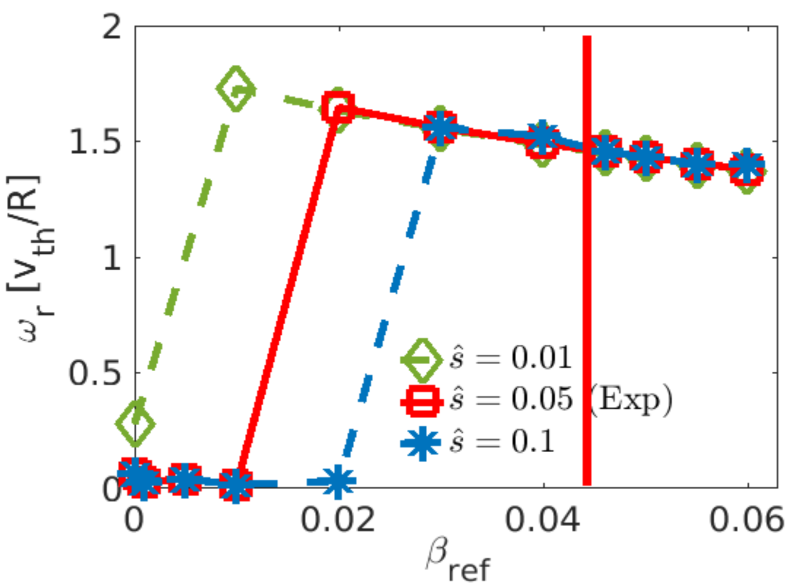


- All quasilinear models comparable to $E \times B$ part of electron and ion heat fluxes with β
- Steeper increase at high β underestimated by 20 to 25%

Summary

- AITG/KBM linearly unstable in the central region of JET hybrid H-mode
  - Key player: low magnetic shear and high beta





- Non-linear saturated turbulence leads to significant fluxes
- Rudimentary tests suggest that QL approximation is applicable
  - *See A. Najlaoui presentation for more extensive validation*
- Would deserve to be addressed:
  - local/global comparison
  - physical mechanism for NL saturation

Backup

Mode structure for different $\hat{s}$ at $\rho = 0.15$