MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Wendelstein 7-X

Global gyrokinetic analysis of Wendelstein 7-X discharge: unveiling the importance of trapped-electron-mode and electron-temperature-gradient turbulence

Felix Wilms, Alejandro Banon Navarro, Thomas Windisch, Frank Jenko, W7-X Team

Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany

Max Planck Institute for Plasma Physics, Wendelsteinstraße 1, 17491 Greifswald, Germany

EUROfusion

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- Simulations mainly performed in flux-tube domain, things like radial electric field or other global effects (mostly) missing

In this talk

- Present (preliminary) results of first-ever global W7-X simulation with experimental parameters

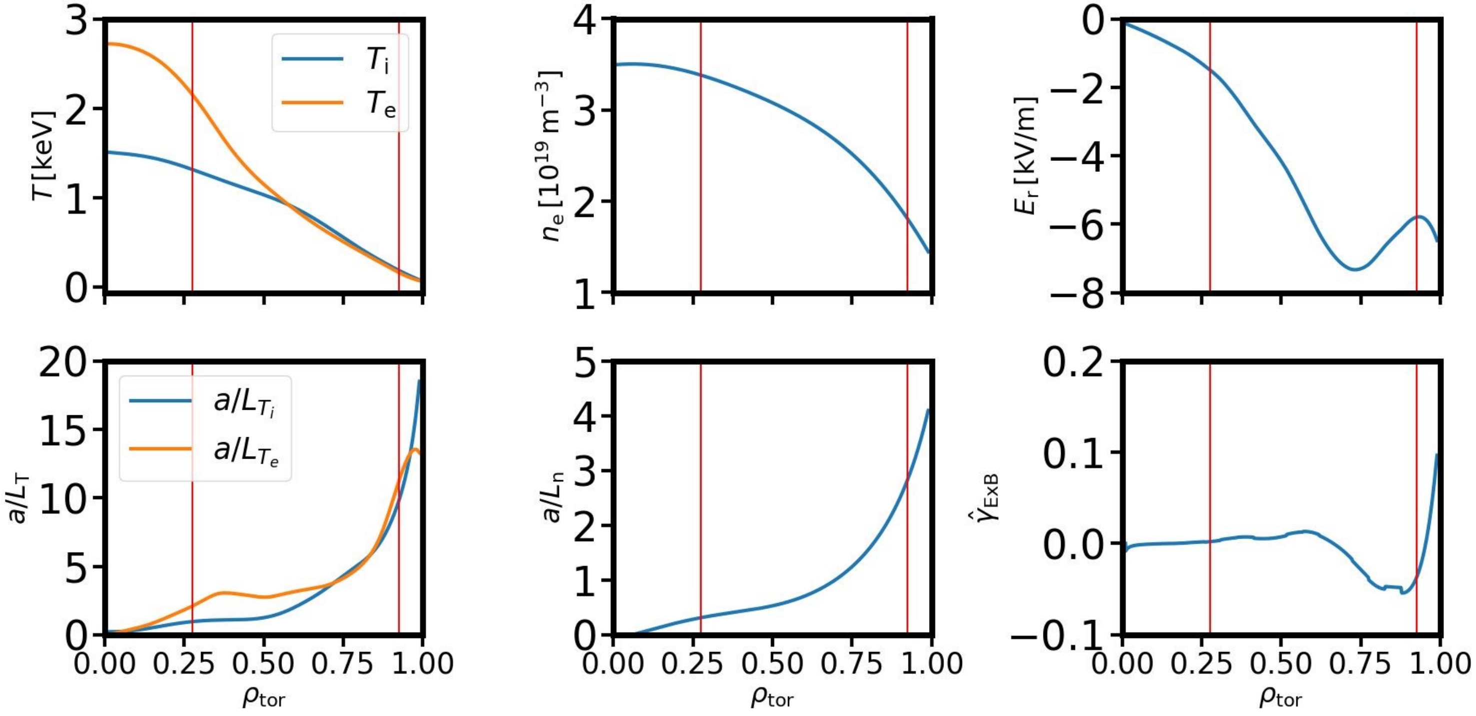
- Compare radially global (RG) simulation with flux-tube (FT) and full-flux-surface (FFS) simulations to identify impact of E_r and ExB-shear

- Identify ion-scale core turbulence present

- Discuss impact of ETGs

The discharge

- Use parameters of W7-X discharge 20181016.037 (t=4-5 s) [Xanthopoulos et al., 2021]



- We focus primarily on $\rho_{tor} \in [0.3, 0.8]$

- Simulations include: kinetic electrons, EM effects, collisions, radial electric field

- FFS simulations with constant E_r, FT simulations no E_r (in the beginning)

Comparison between simulation domains

- Compare global fluxes against local results => more diagnostics available
- FFS: 5 radial positions, FT: 4 different tubes per position ($\rho_{tor} \in [0.4, 0.8], \alpha \in [0, 0.75] * 2\pi/5$)

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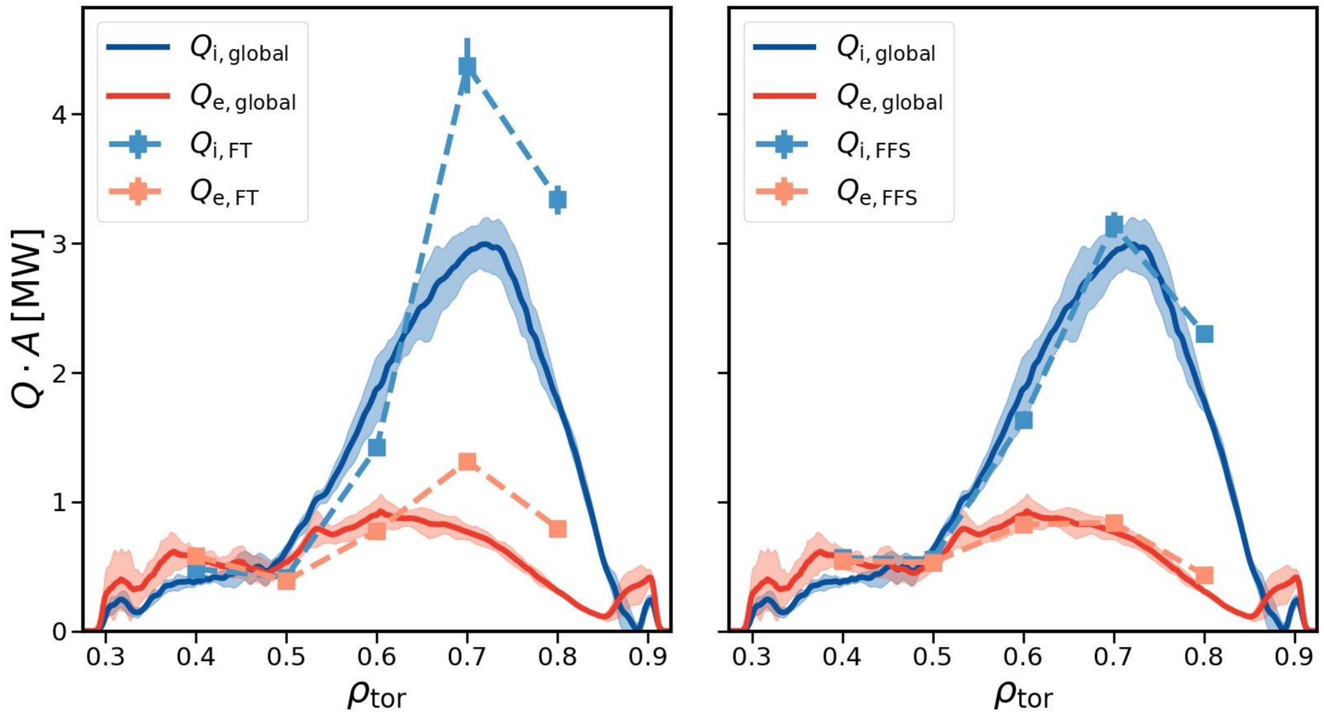
  FT transport too high in the outer regions



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- Disagreement might be
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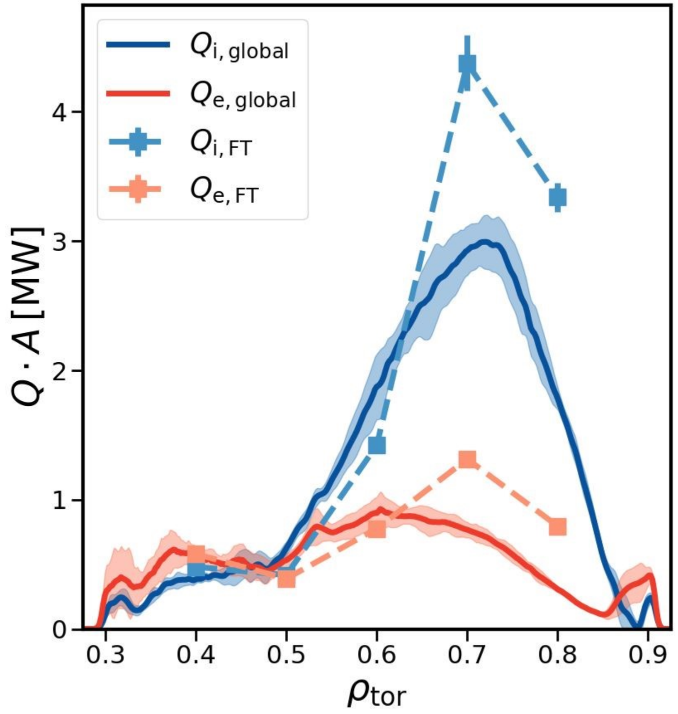

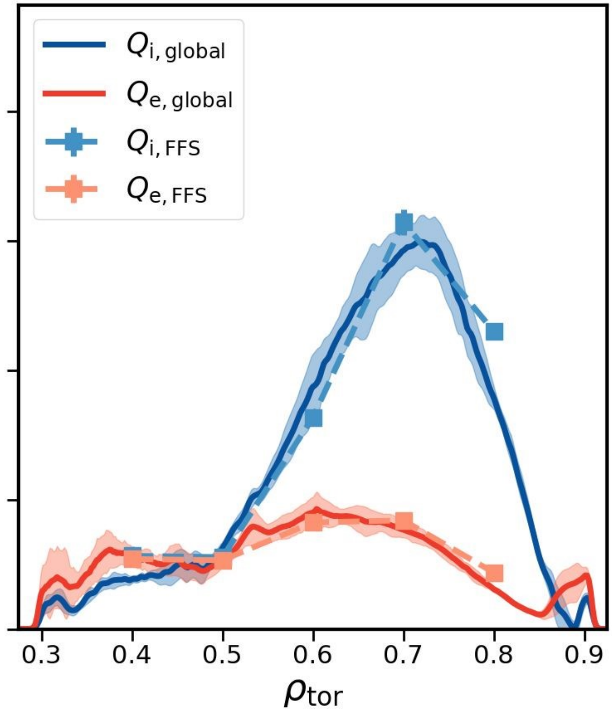

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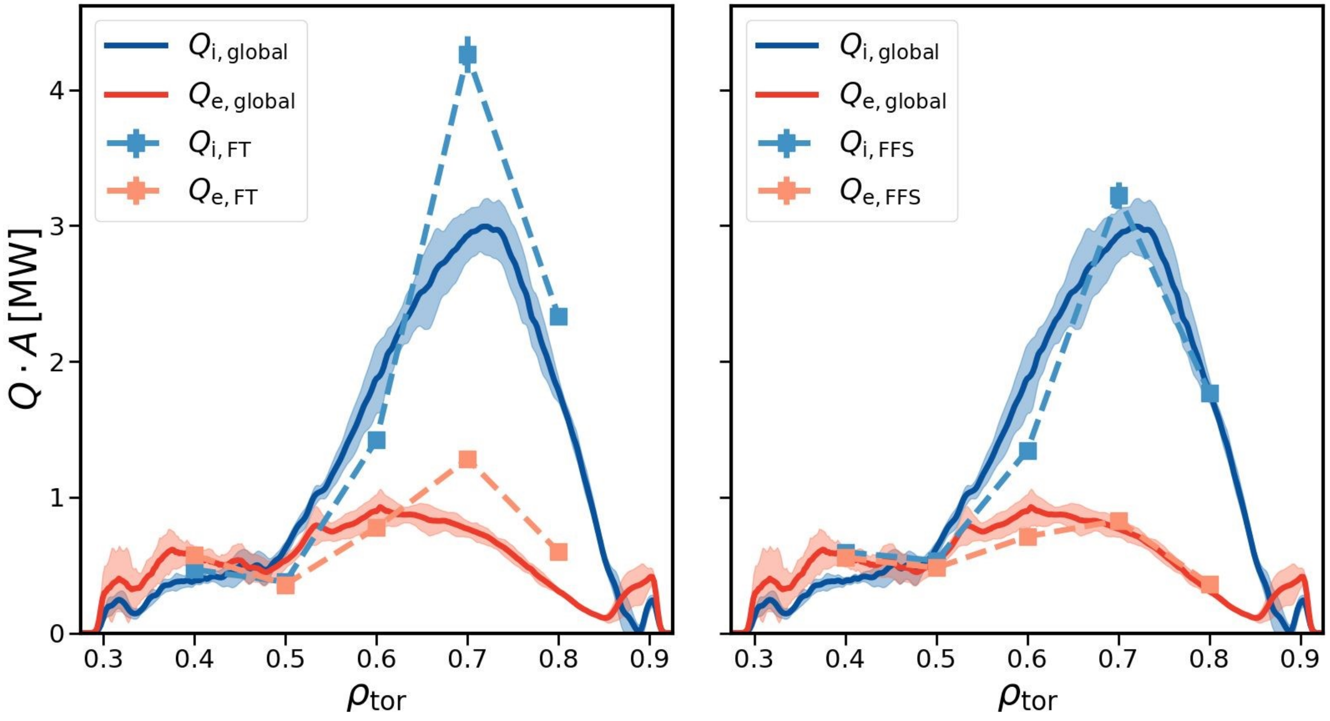

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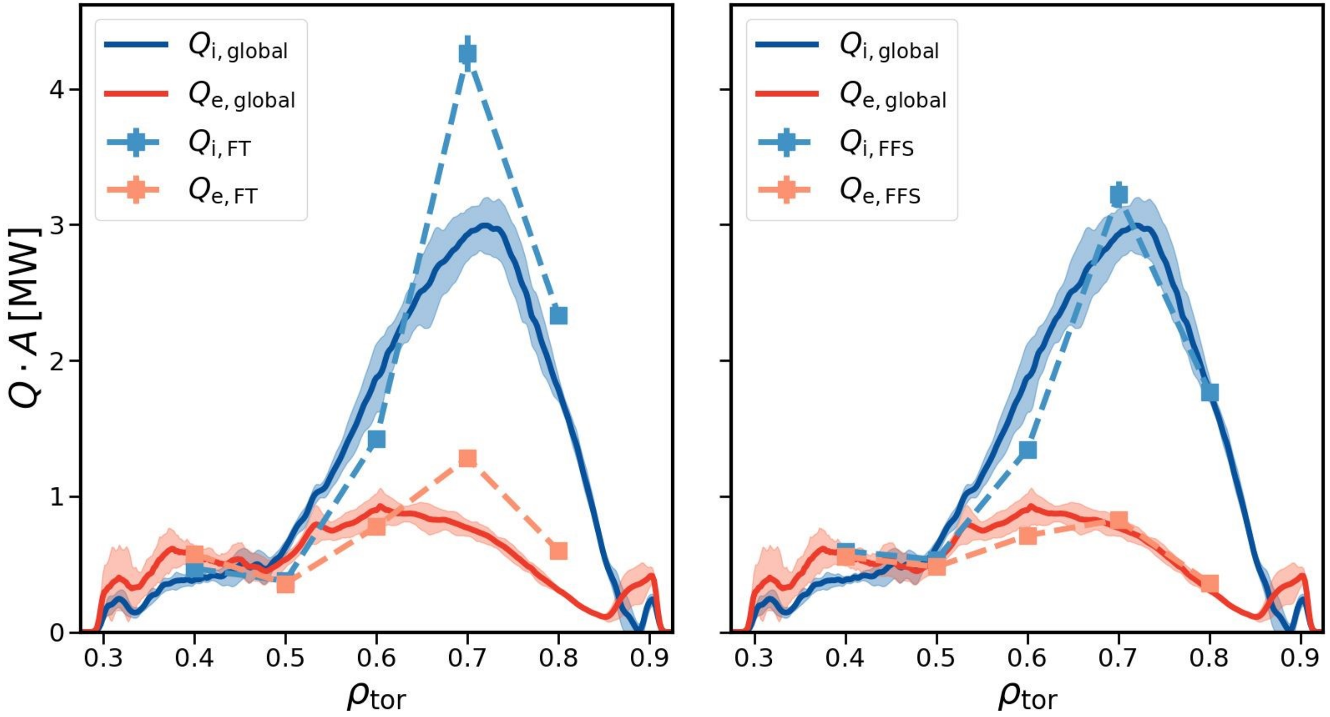

	$Q_{\rm ions} \cdot A$ [MW]	$Q_{\rm electrons} \cdot A$ [MW]
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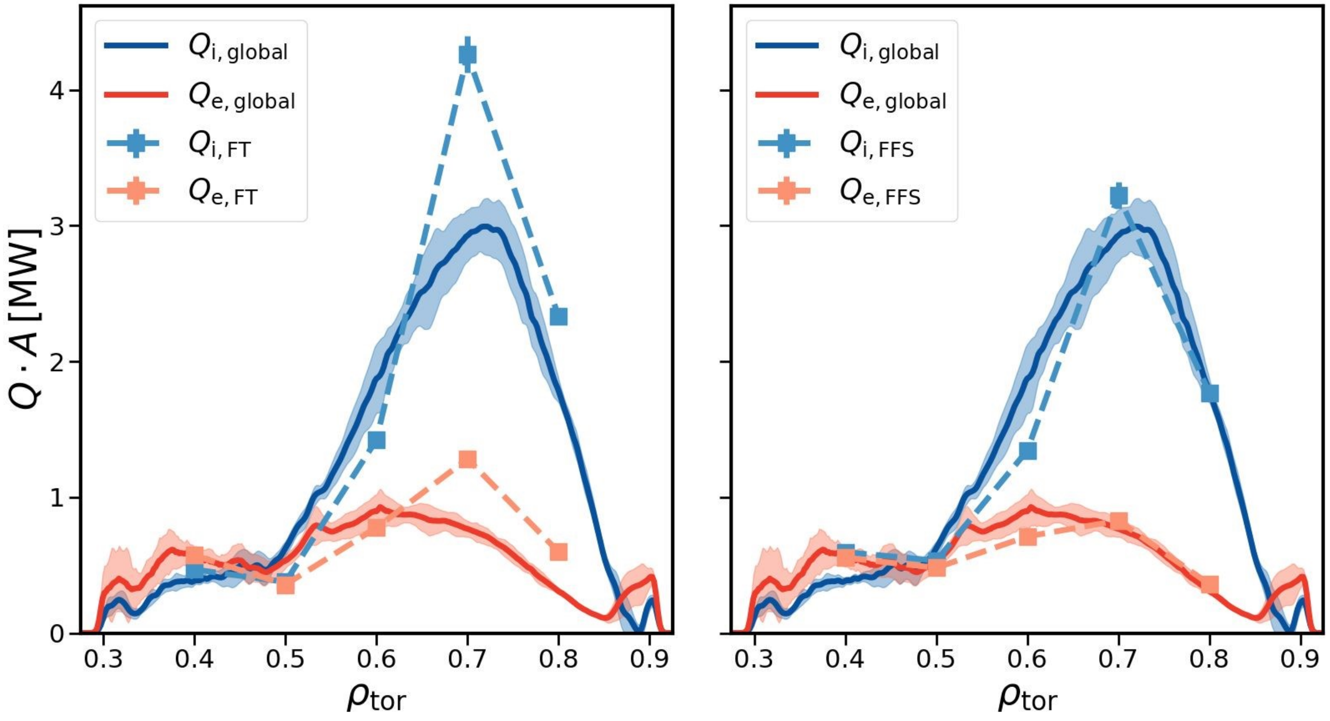
=> E_r-shear even has noticeable effect in standard discharges; what happens e.g. with pellets?



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- $\rho_{tor} > 0.5$: Q_i too high, Q_e too low

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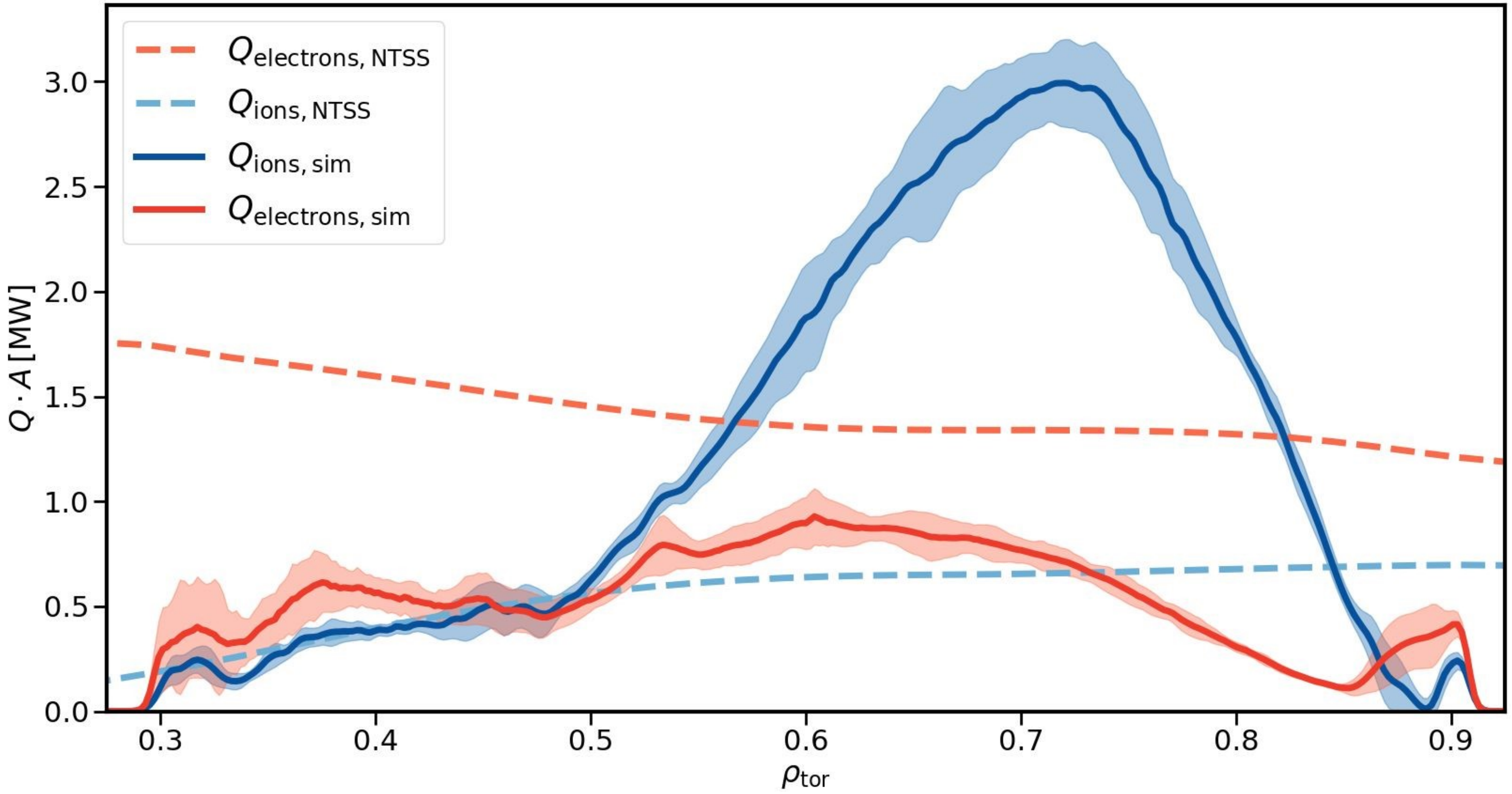

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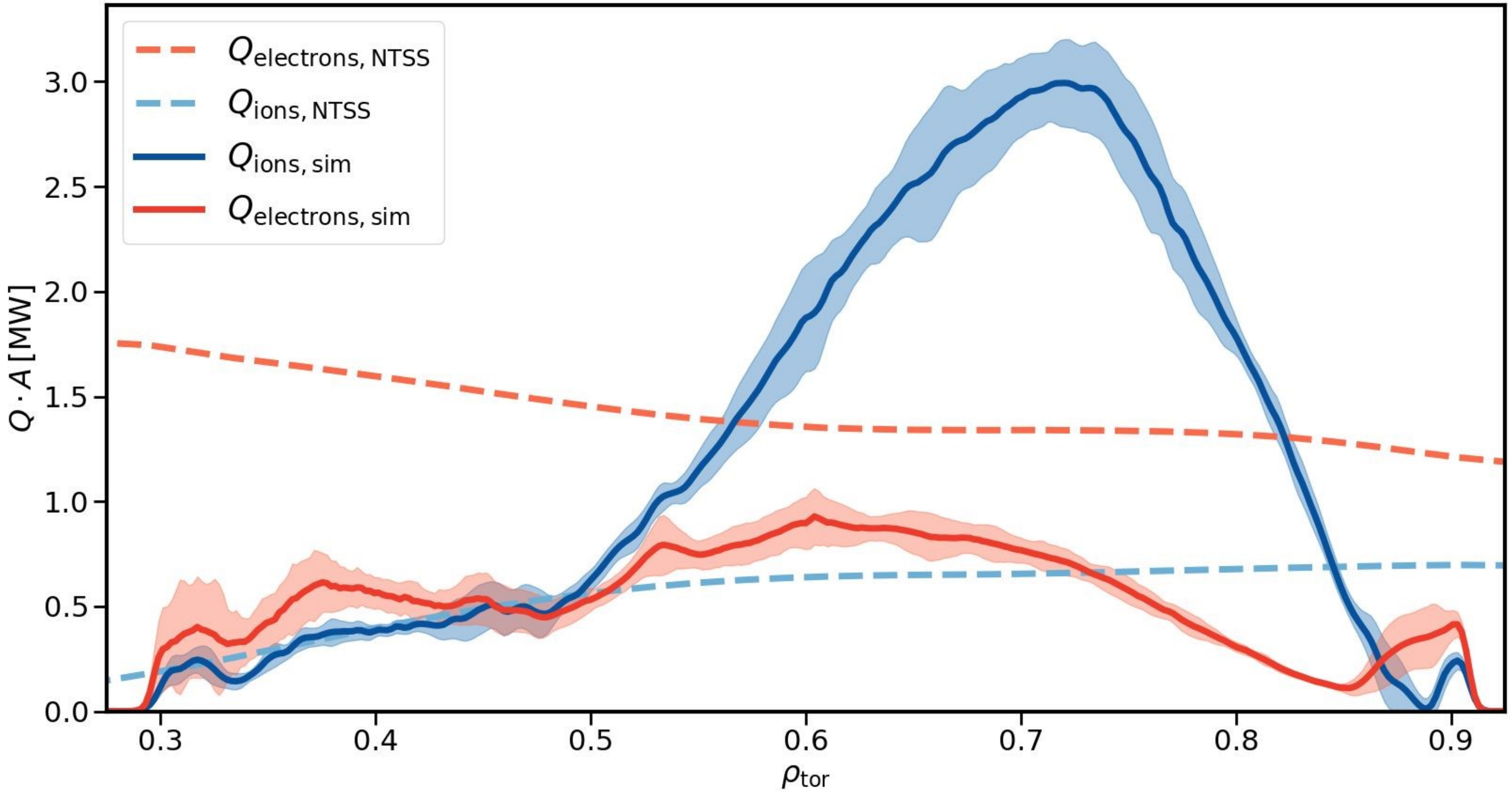

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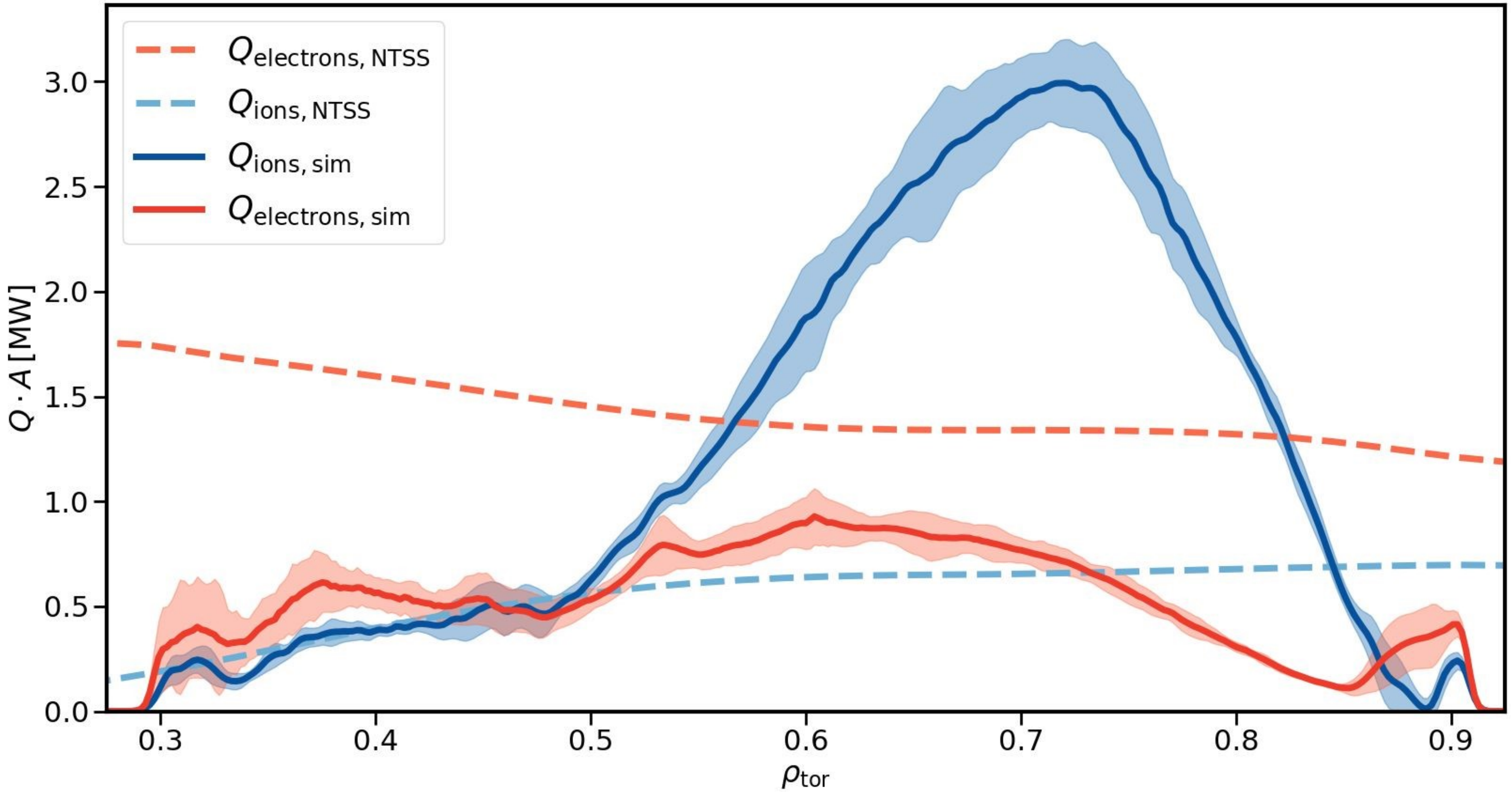
⇒ Presence of TEMs?



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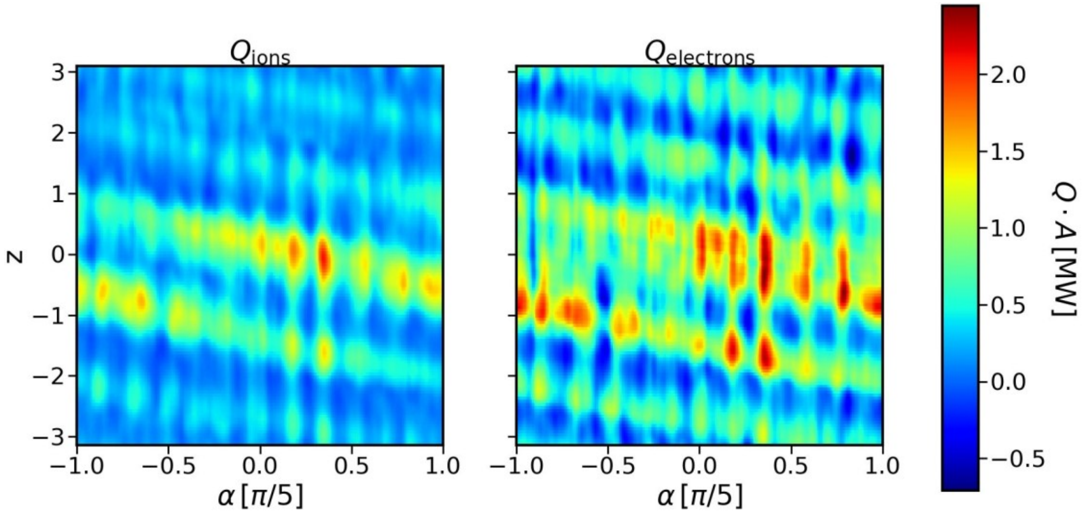
- RG/FFS: While Q_i is slightly more localised, Q_e clearly shows multiple maxima in z direction for every field line



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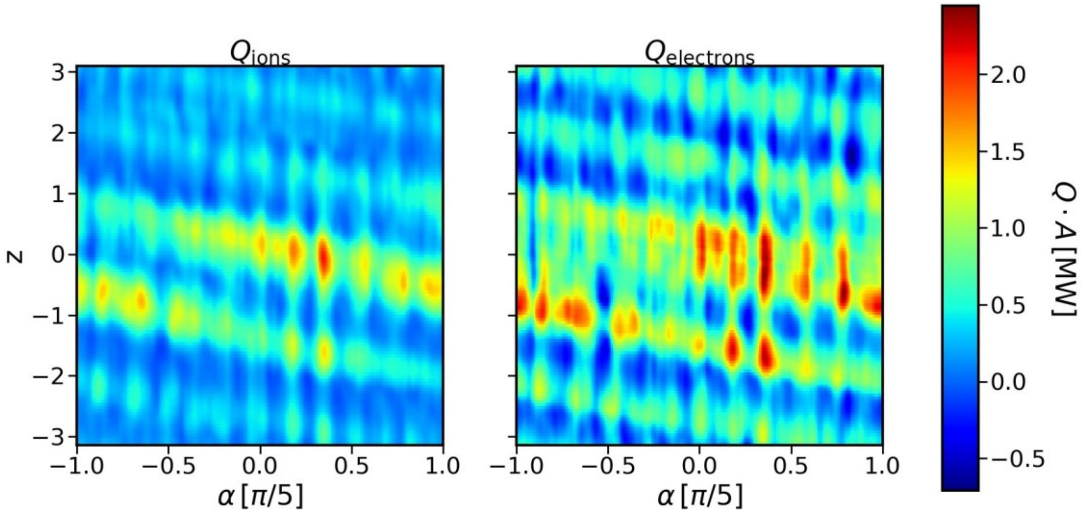

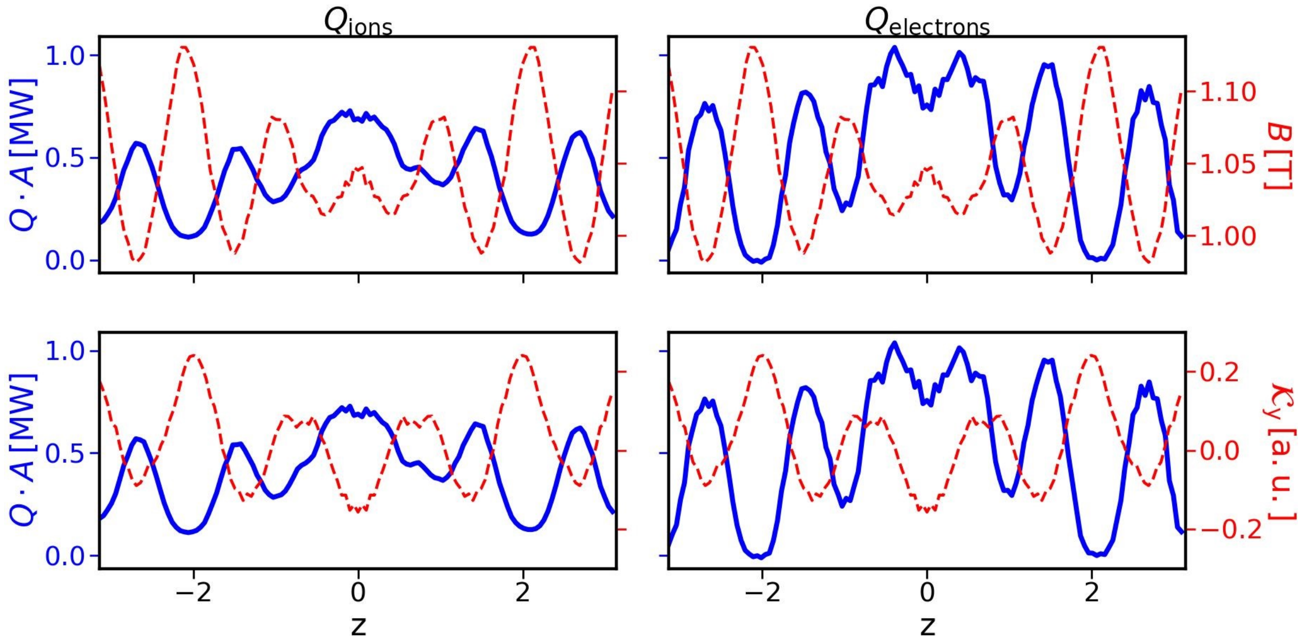

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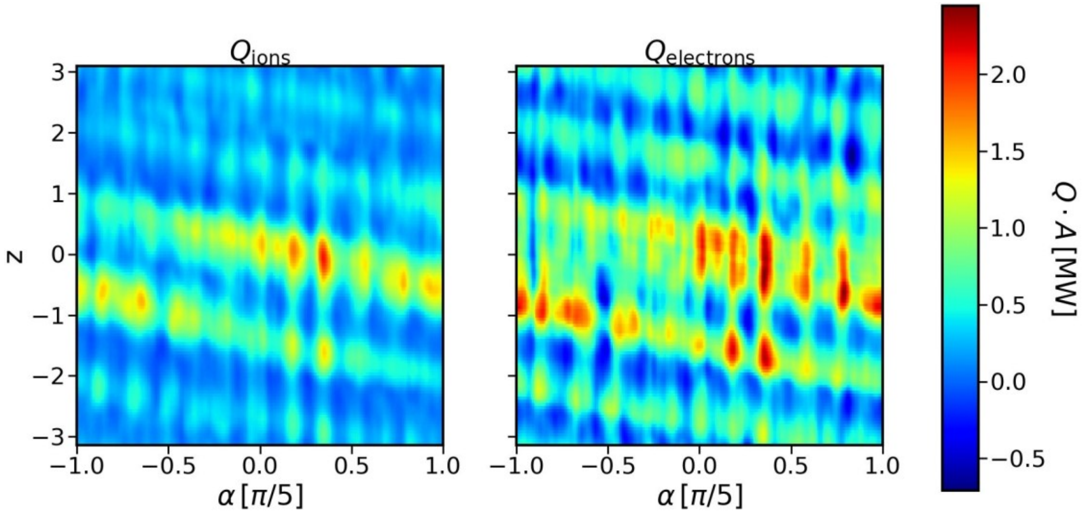

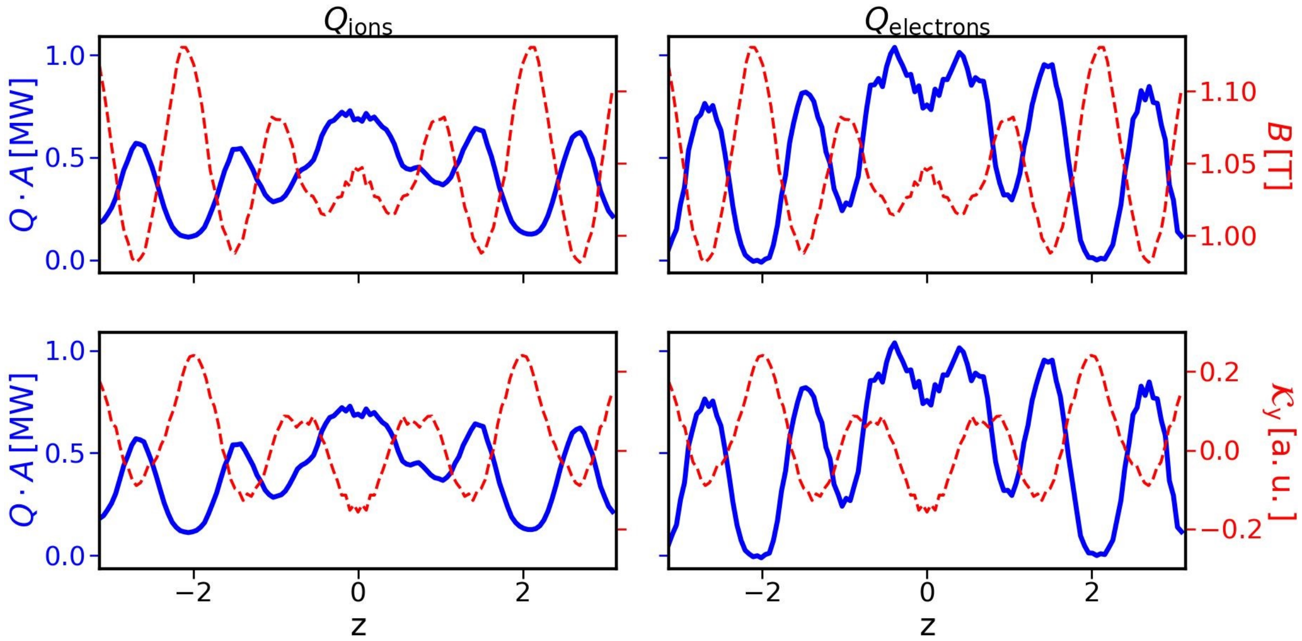

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$\Rightarrow$ Possible ITG-TEM hybrid?

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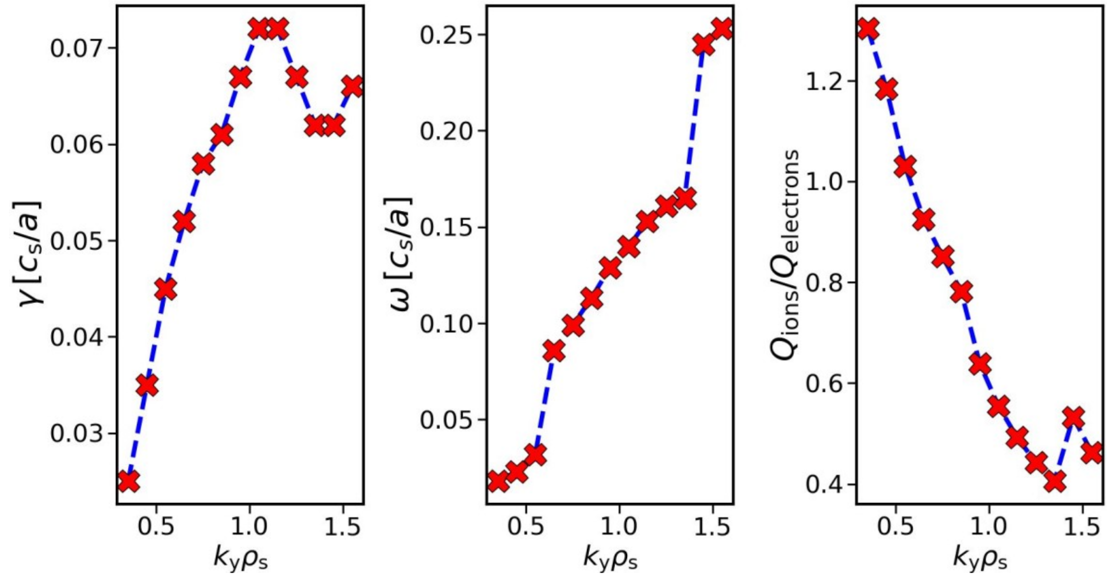
- Linear spectra show increasing growth rates, all having positive frequency

- Quasilinear heat flux ratios indicate strong coupling between ion and electron channels [Xanthopoulos et al., 2007]



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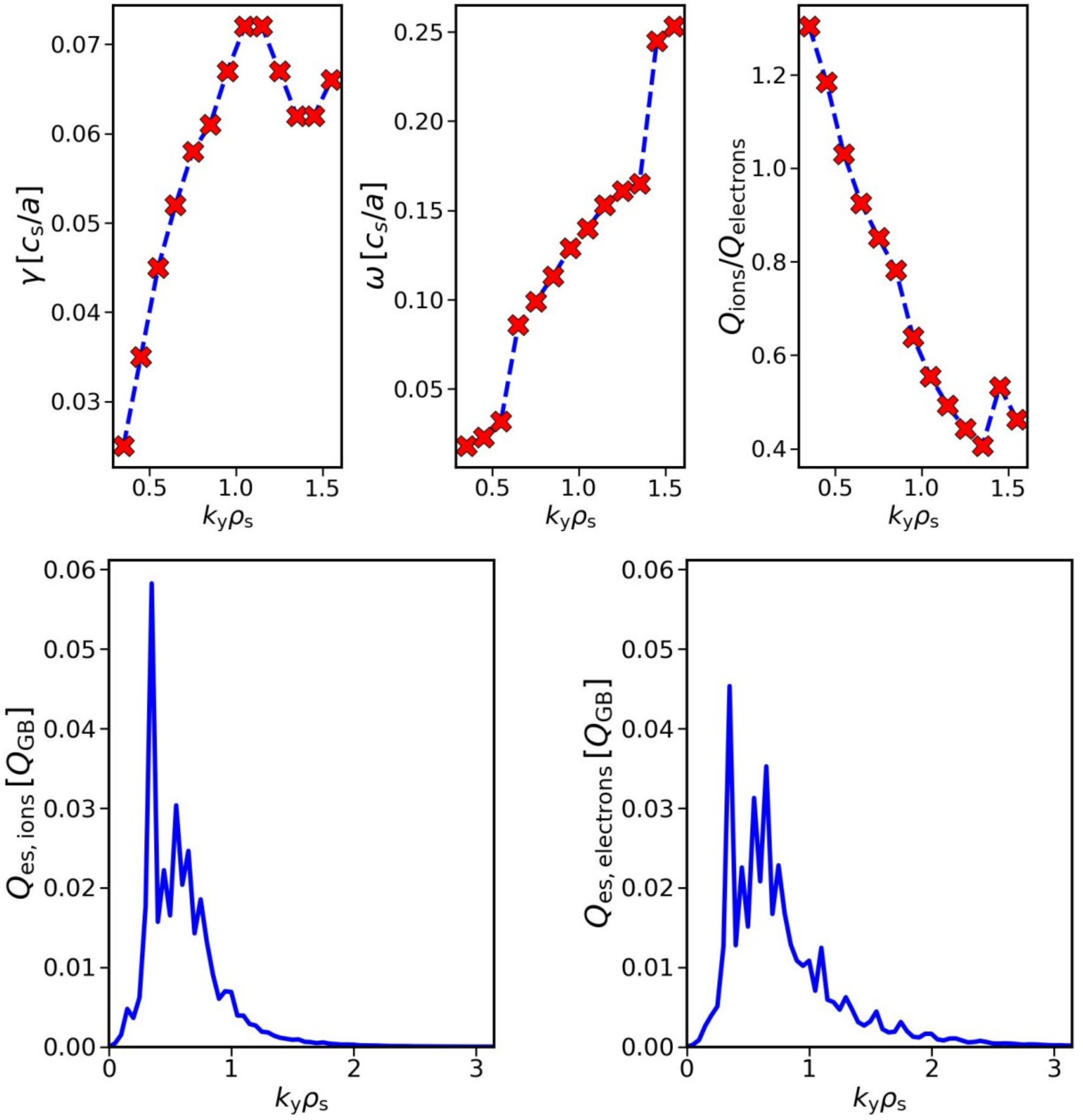

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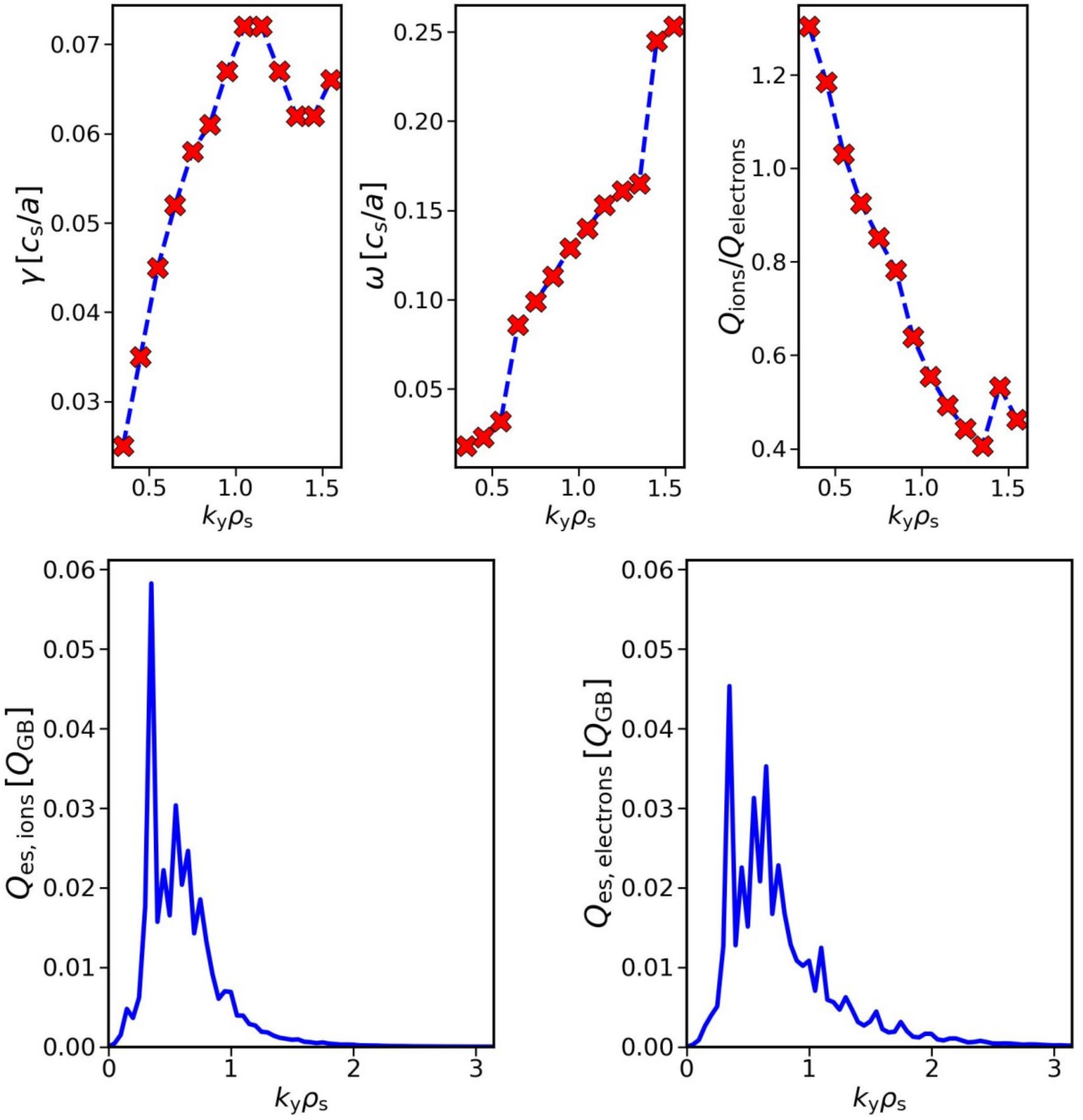
- Positive frequency + trapped electron characteristics => ITG-TEM hybrid



Turning off gradients

Case	$Q_\mathrm{i} \cdot A$ [MW]	$Q_\mathrm{e} \cdot A$ [MW]
Full	0.42 ± 0.05	0.49 ± 0.07
$a/L_{T_e} = 0$	0.49 ± 0.06	0.07 ± 0.01
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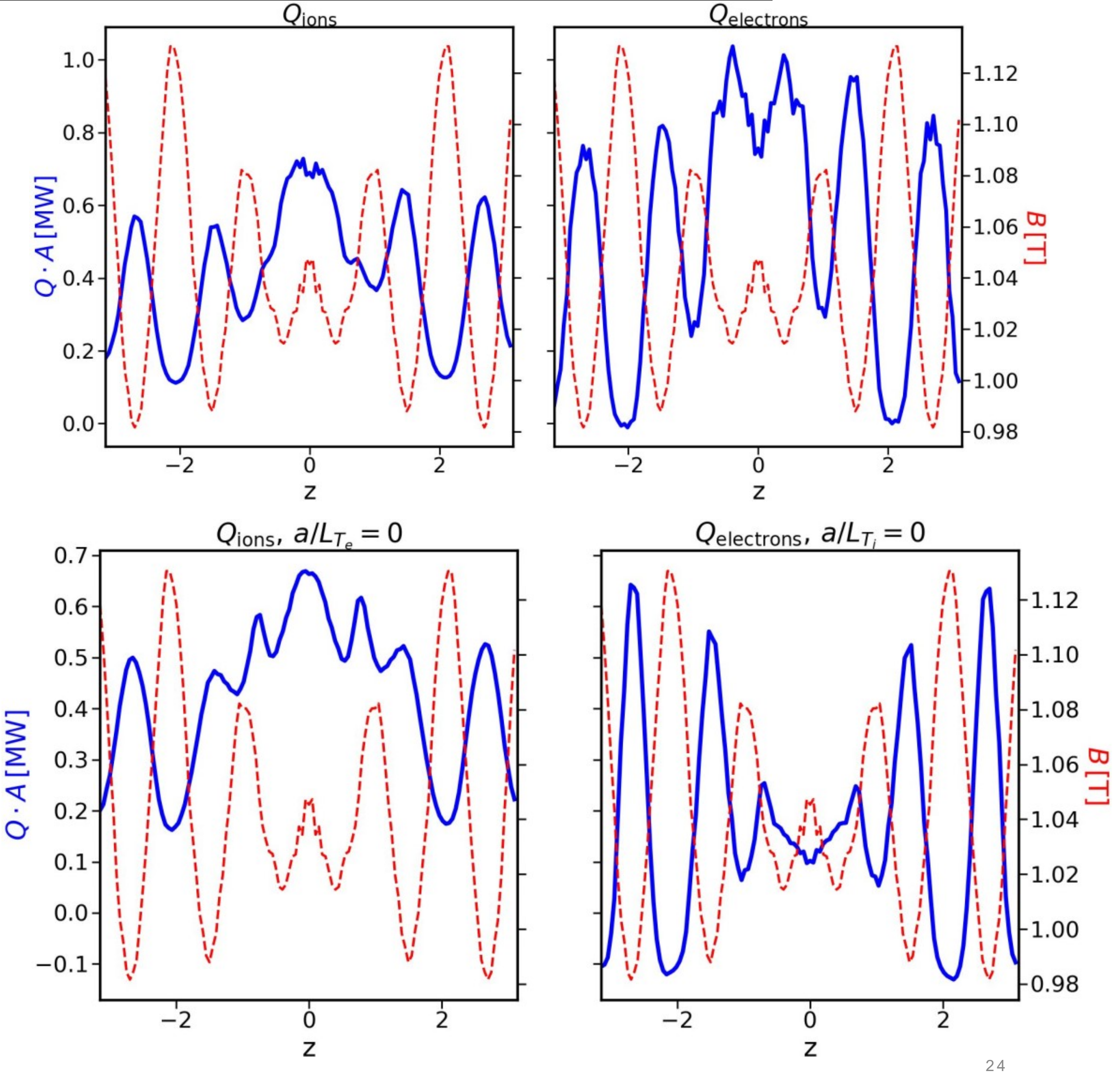

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=> **Most likely, one sees an ITG-TEM hybrid in the experiment**

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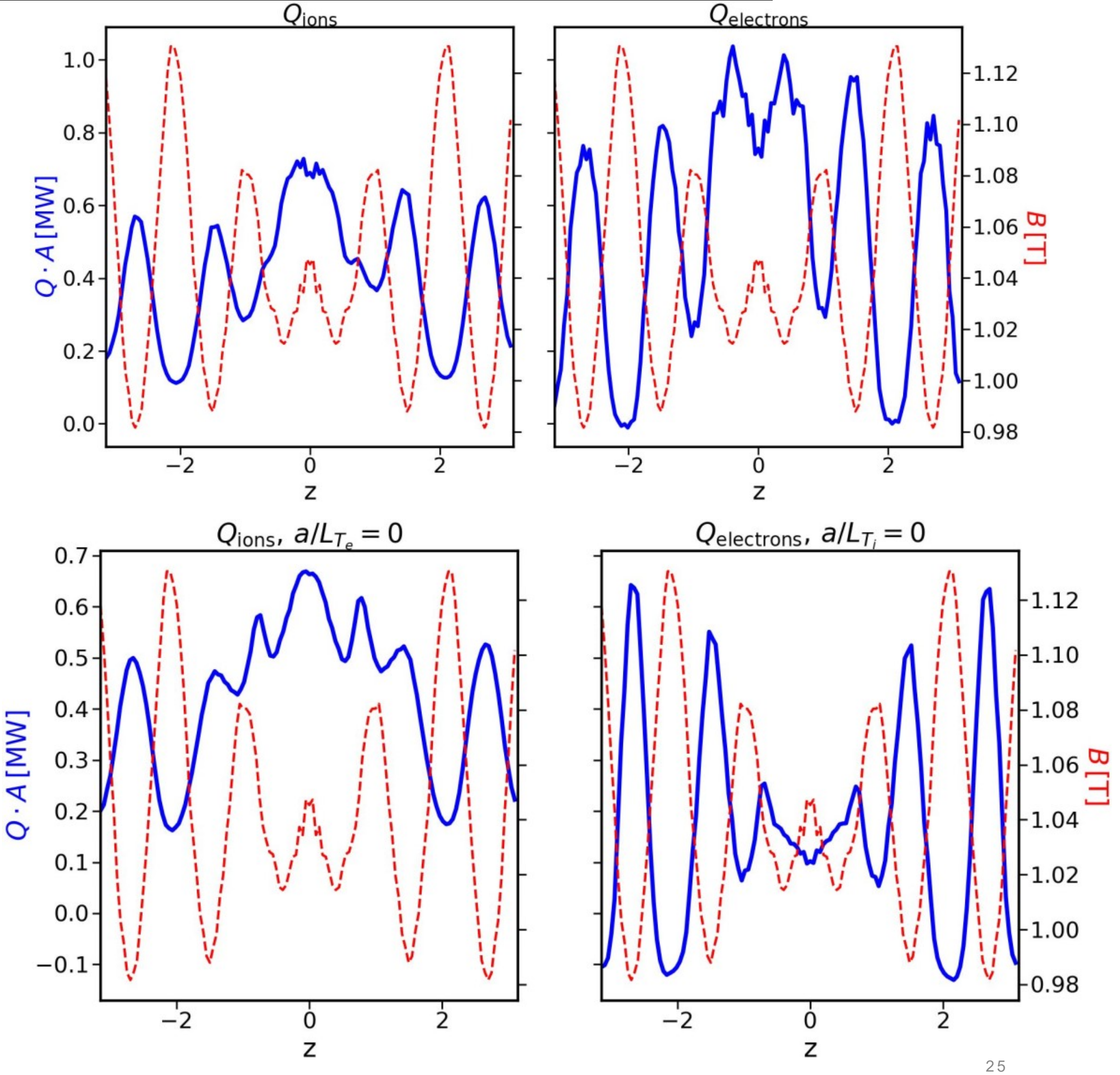

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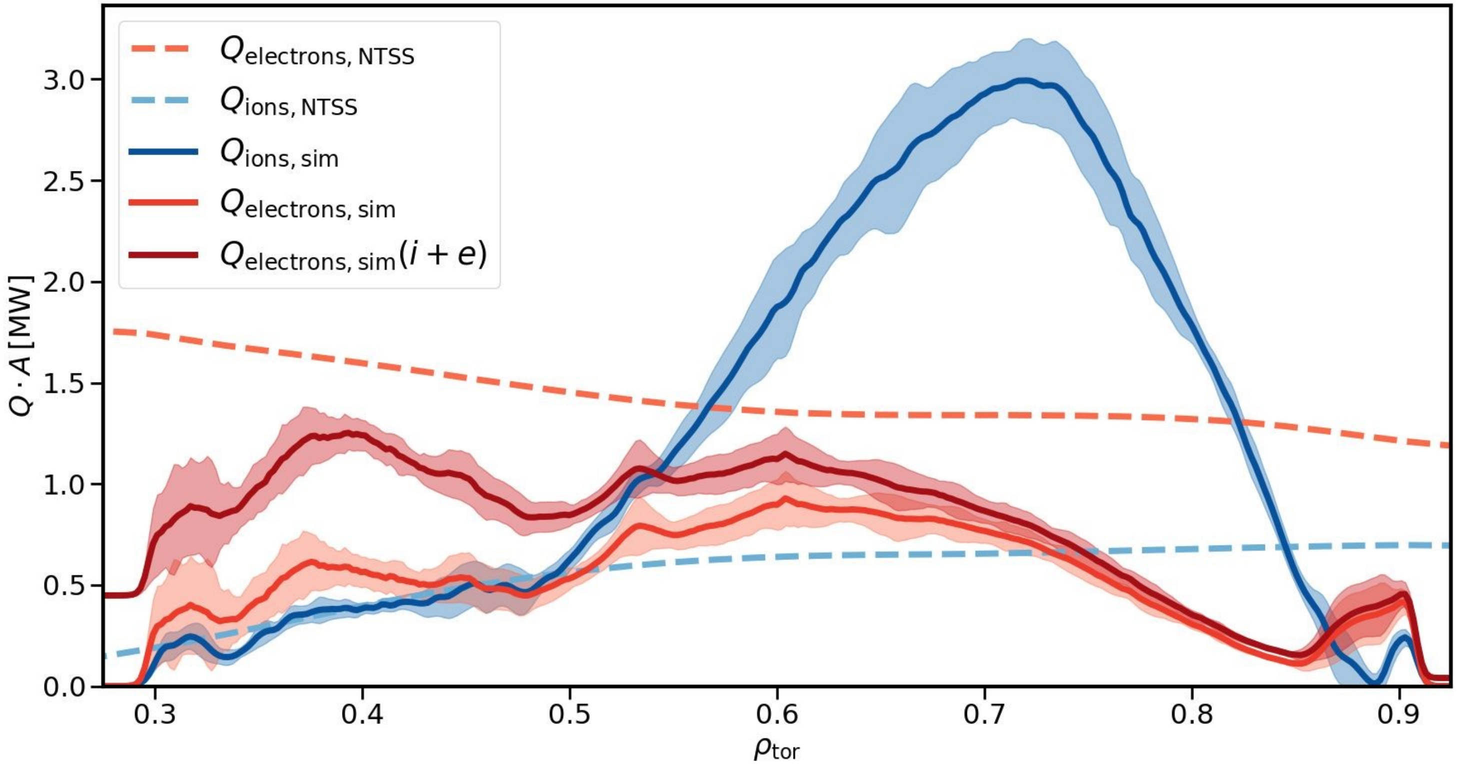

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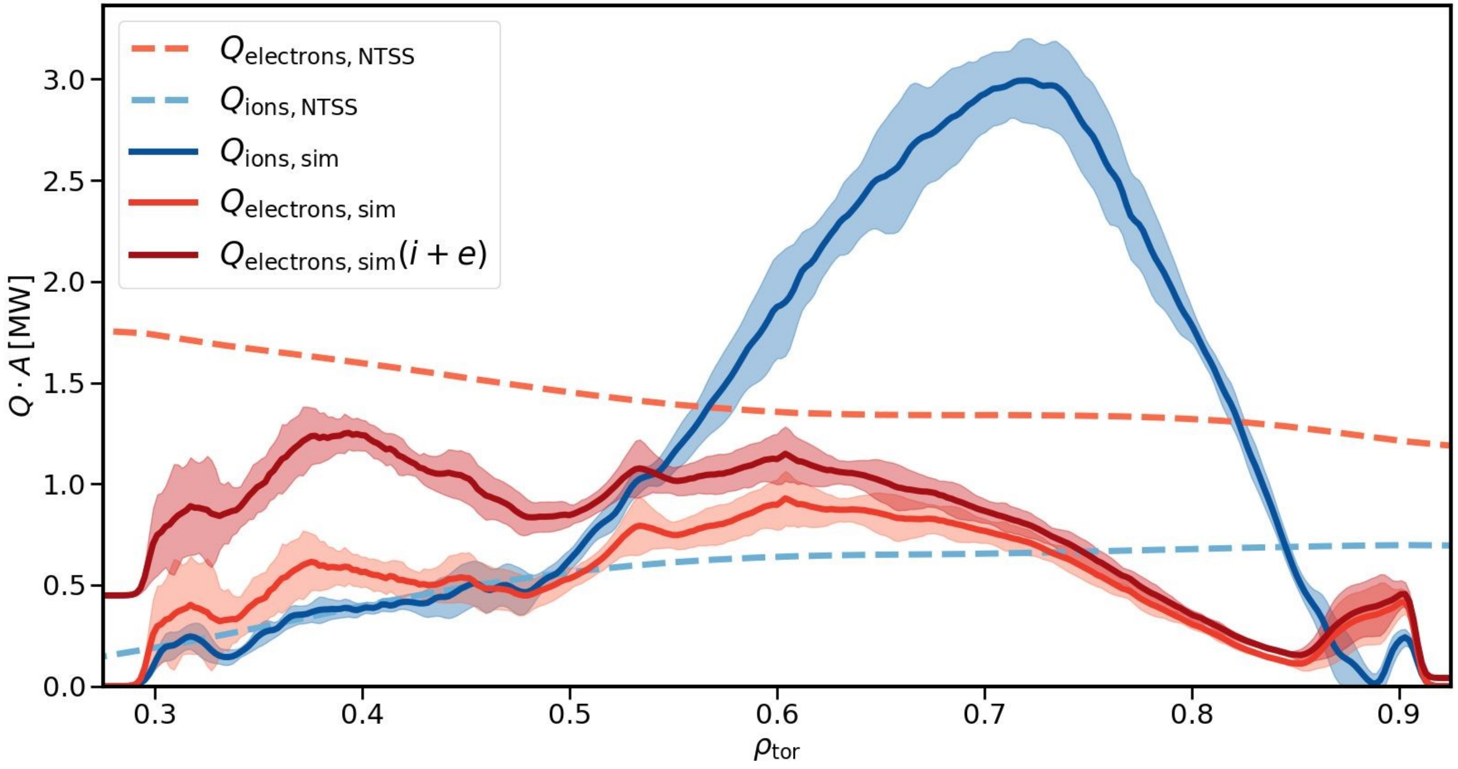


⇒ **ETGs contribute significantly in the core, in agreement with [Weir et al., 2021]**

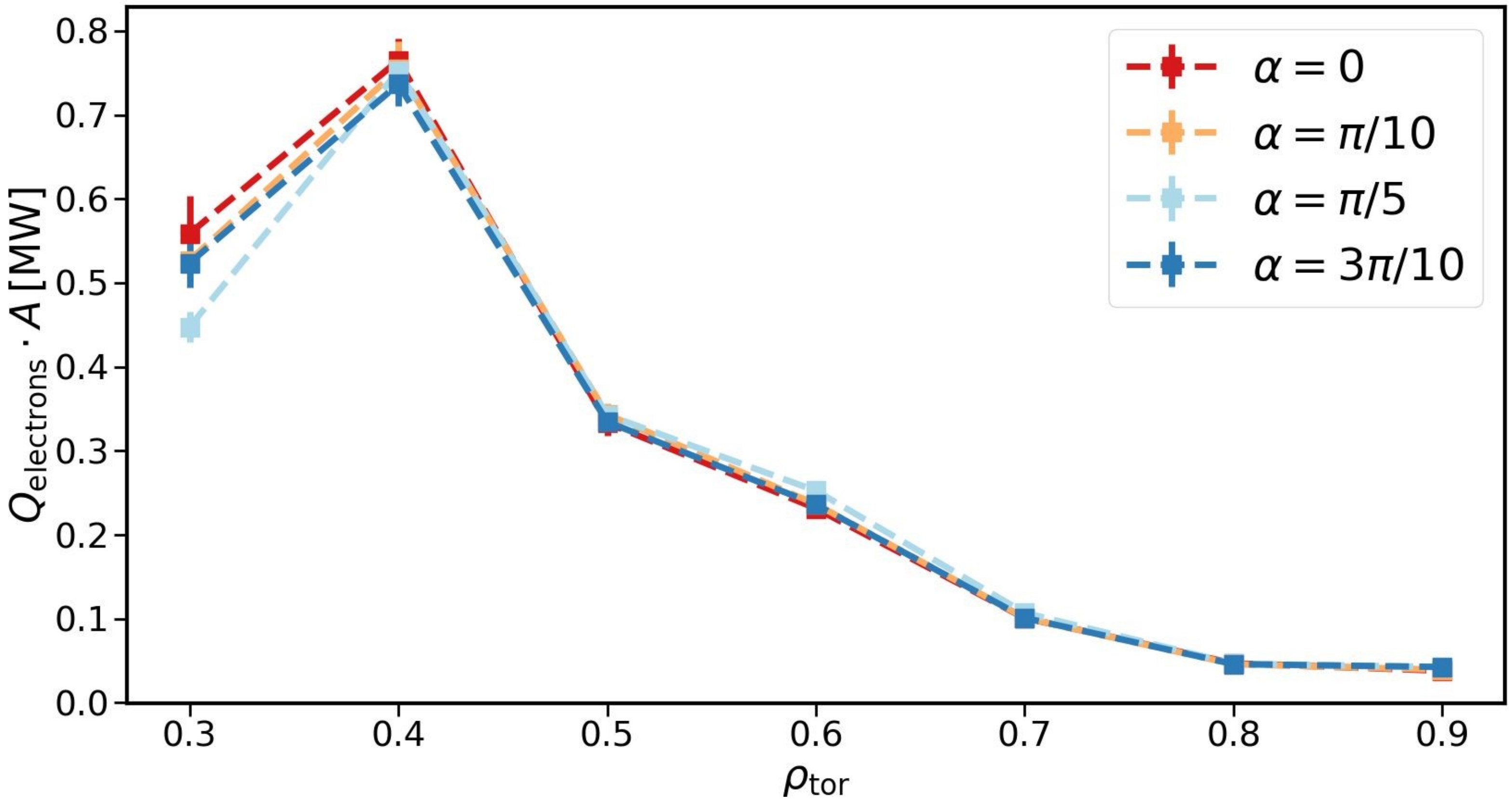
- Taking into account electron scales important for flux-matching and profile prediction of W7-X

Analysis of ETG transport

- Start by comparing ETG heat flux of different field lines

- Only very small variation for most of the radial positions

=> Use $\alpha = 0$ from now on



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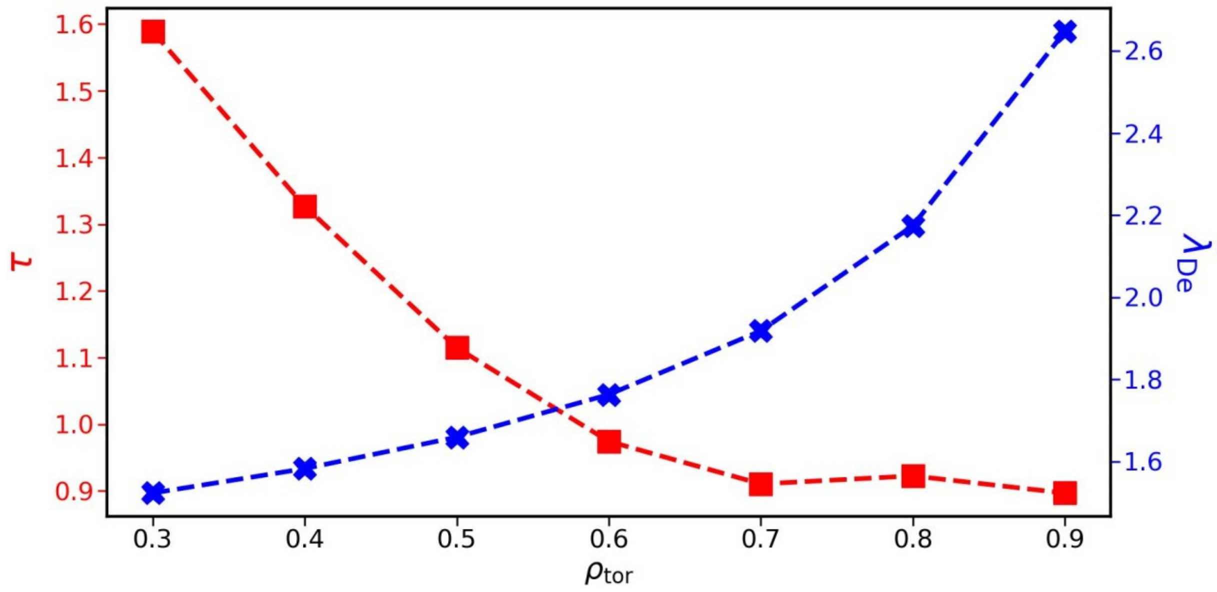
Several factors could play a role:

- Large $\tau = T_e/T_i$ is known to stabilise ETG



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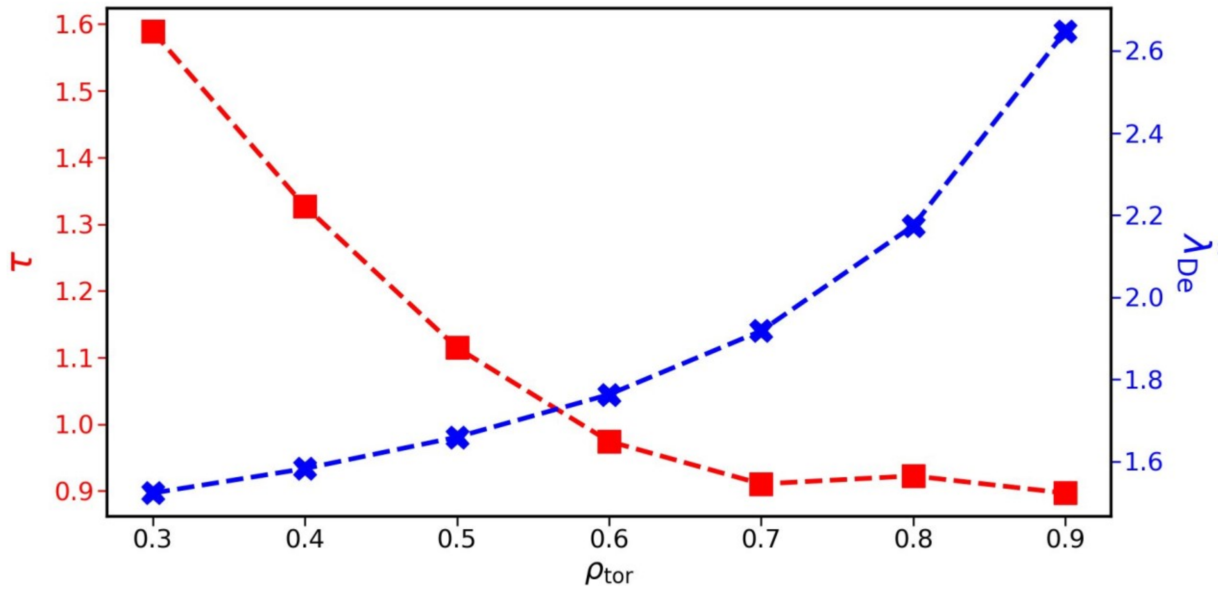

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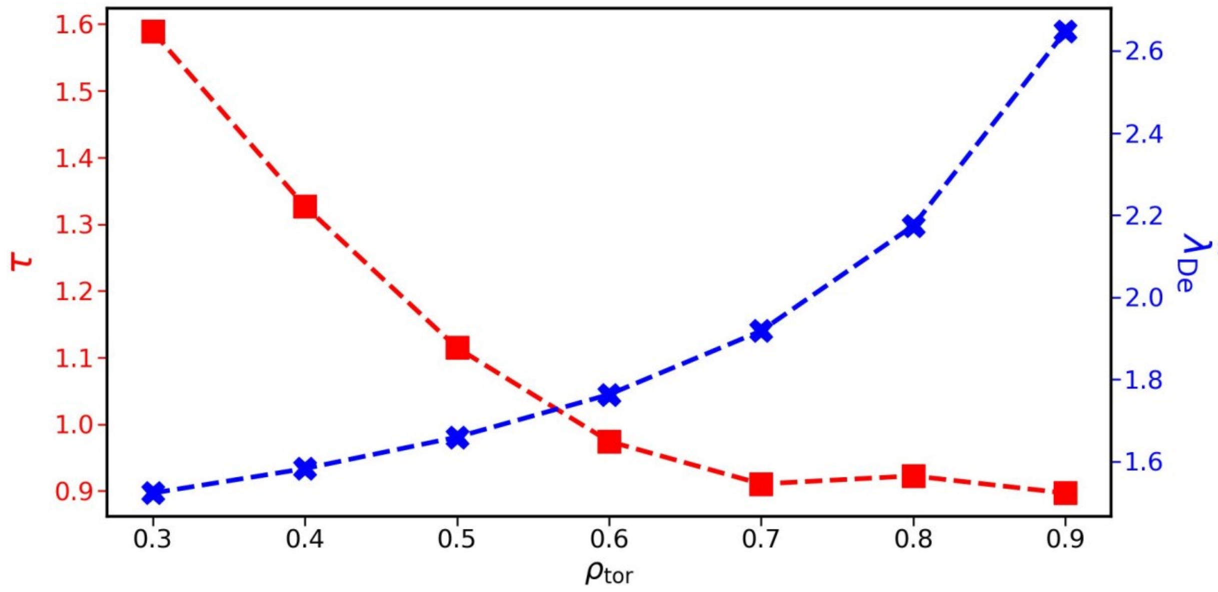

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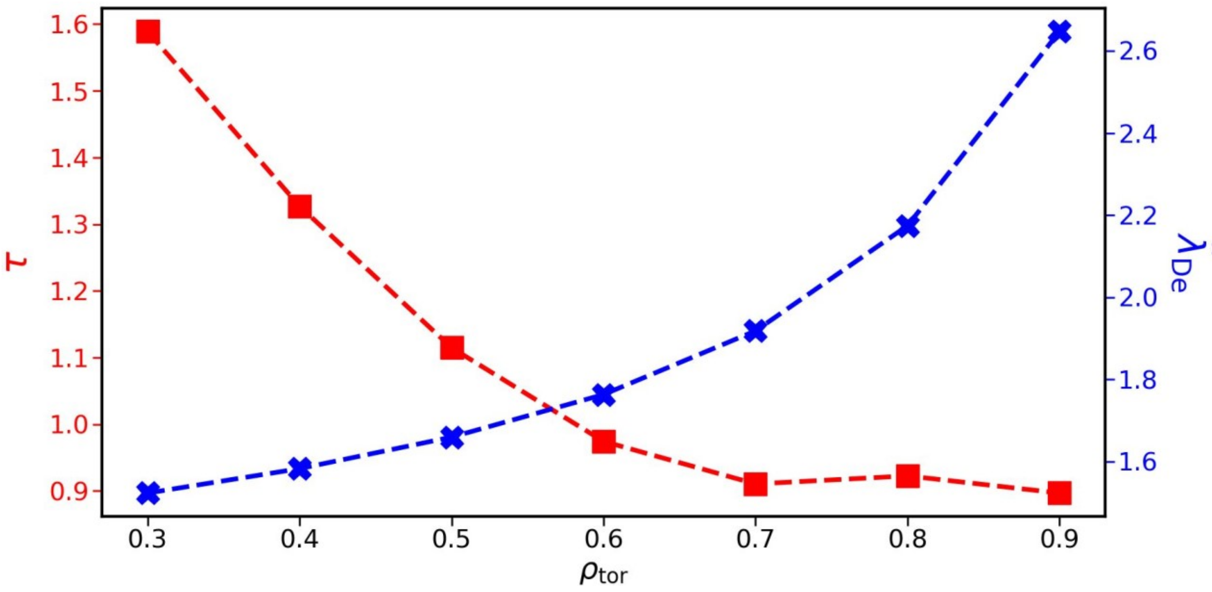

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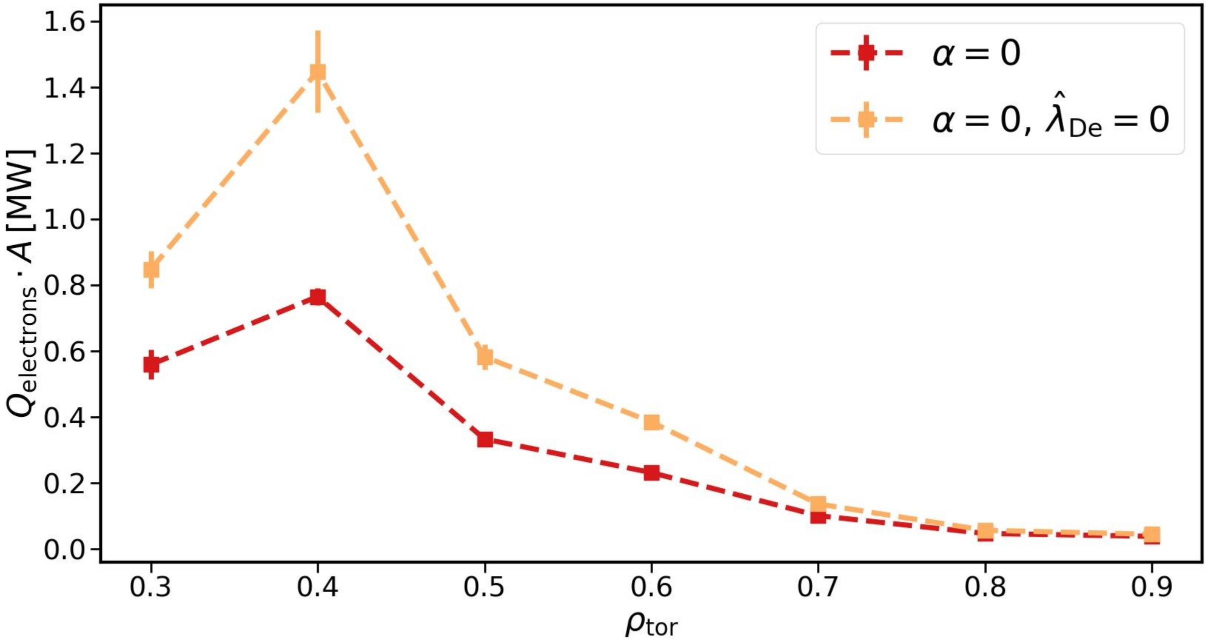
  => Simulations without Debye shielding still show weak ETGs in the outer region



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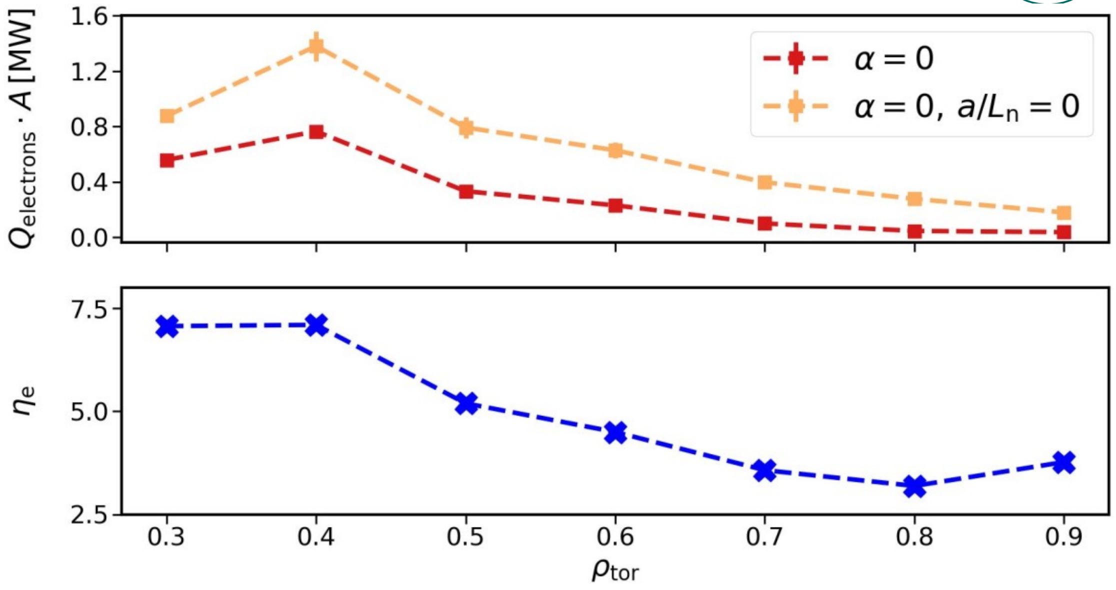

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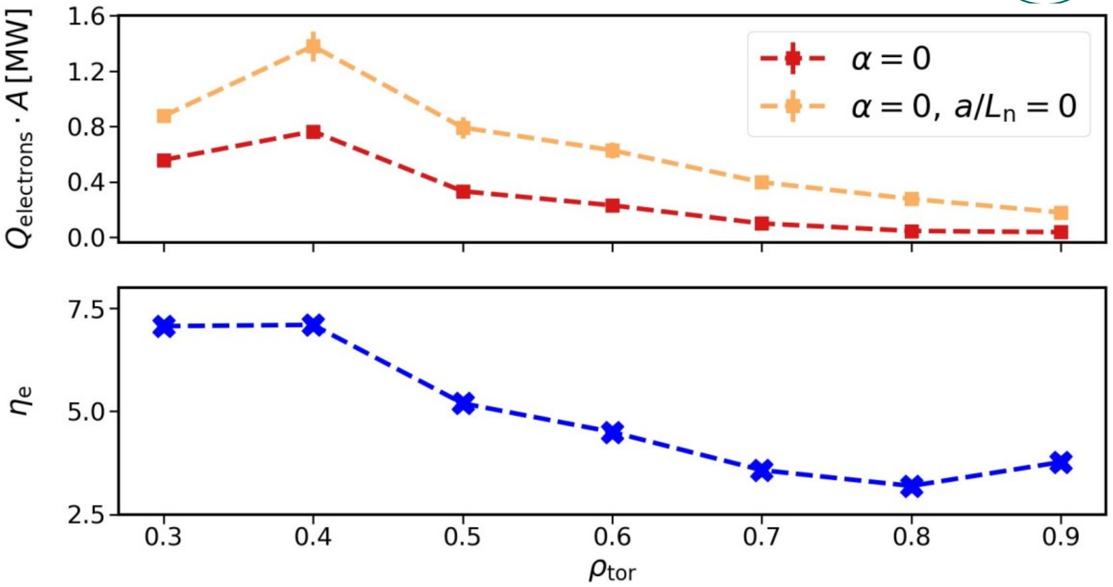

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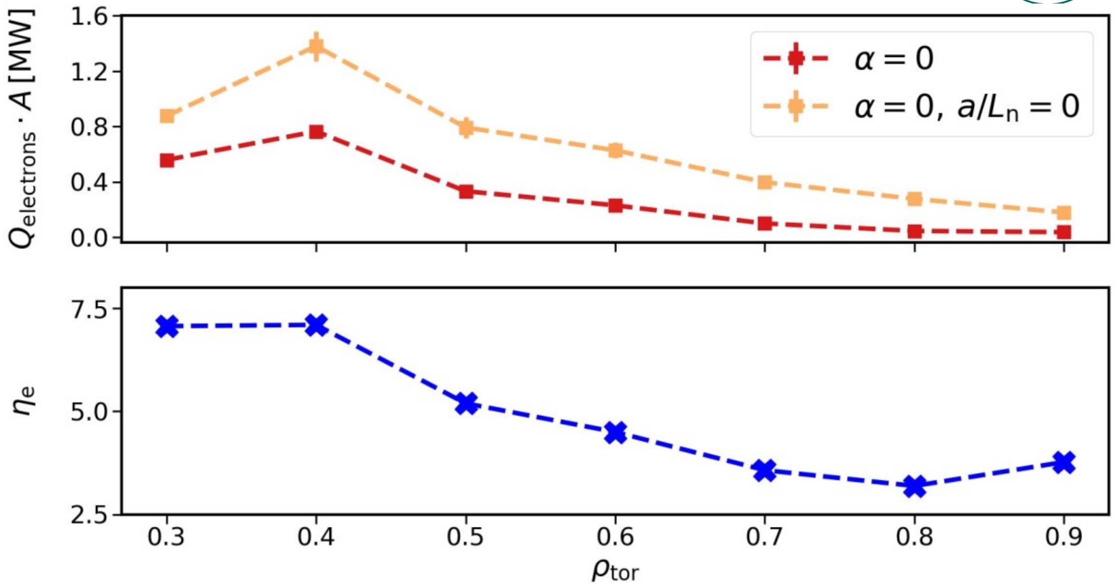

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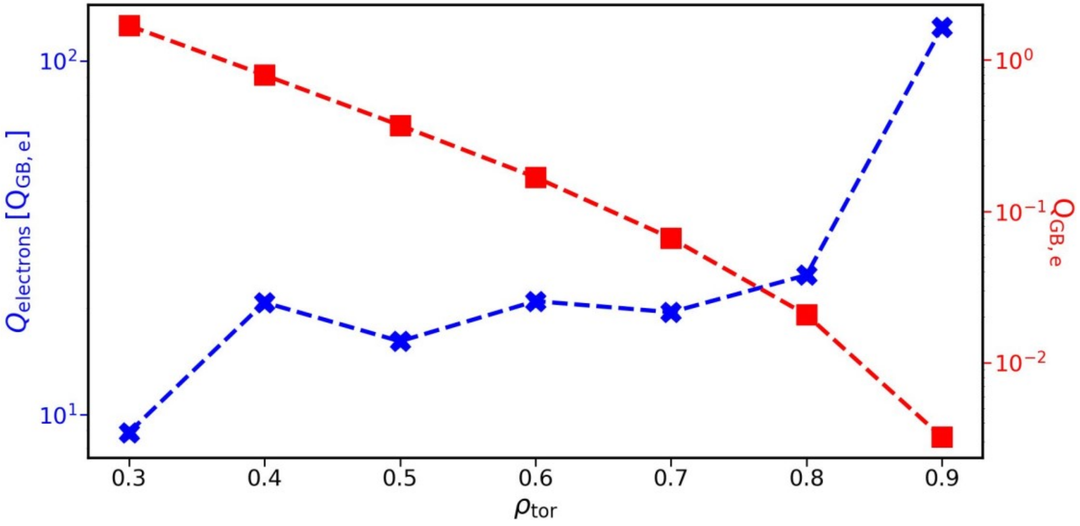
- a/L_{T_e} increases, but e.g. T_e decreases as well
- Normalised electron heat flux (in Gyrobohm units) increases by one order of magnitude
- Gyrobohm scaling factor decreases by two orders
  => Product of the two (times area) will decrease overall



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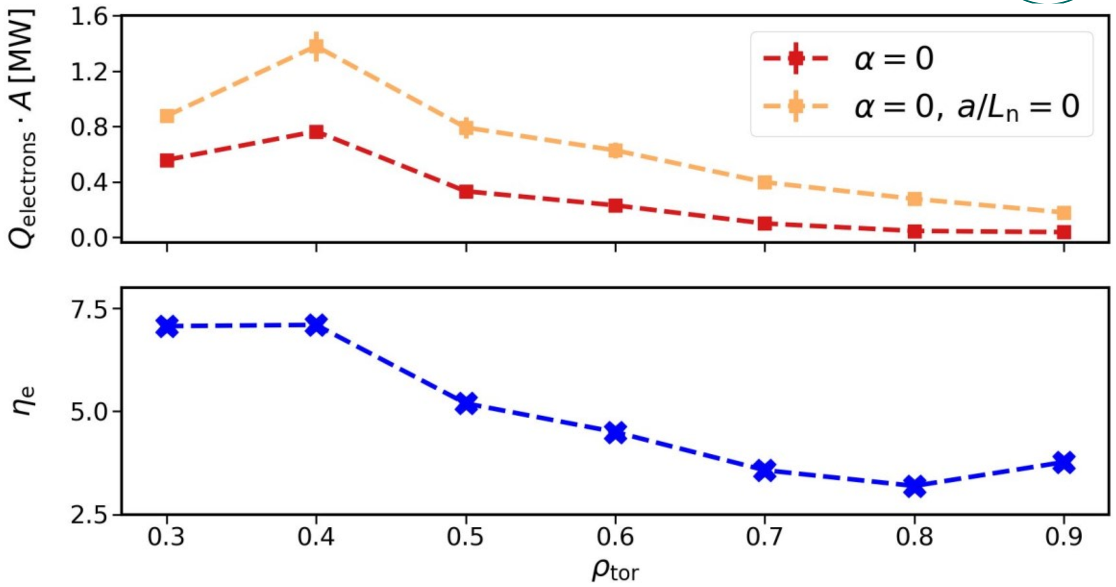

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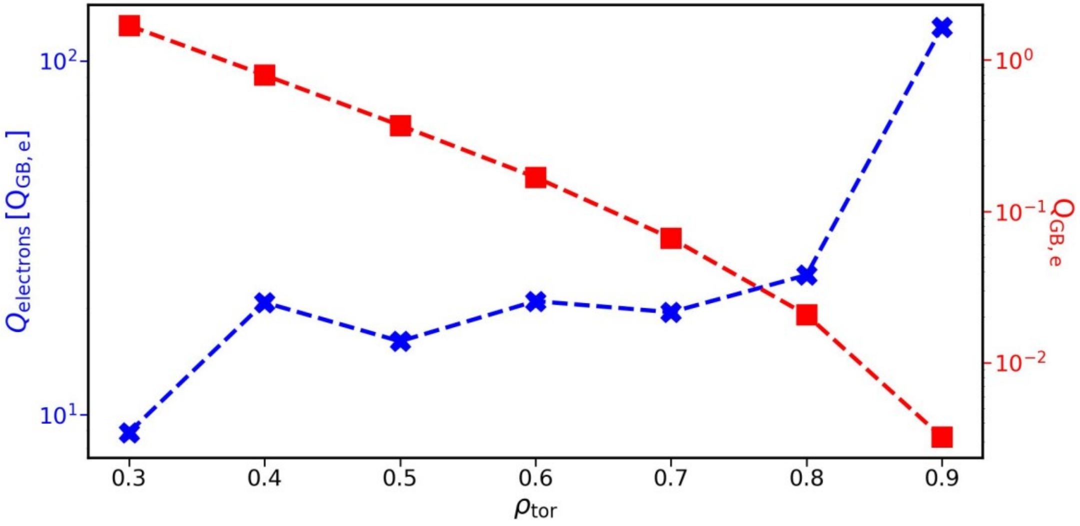

- Impact of geometry on ETG stiffness will be investigated in the future

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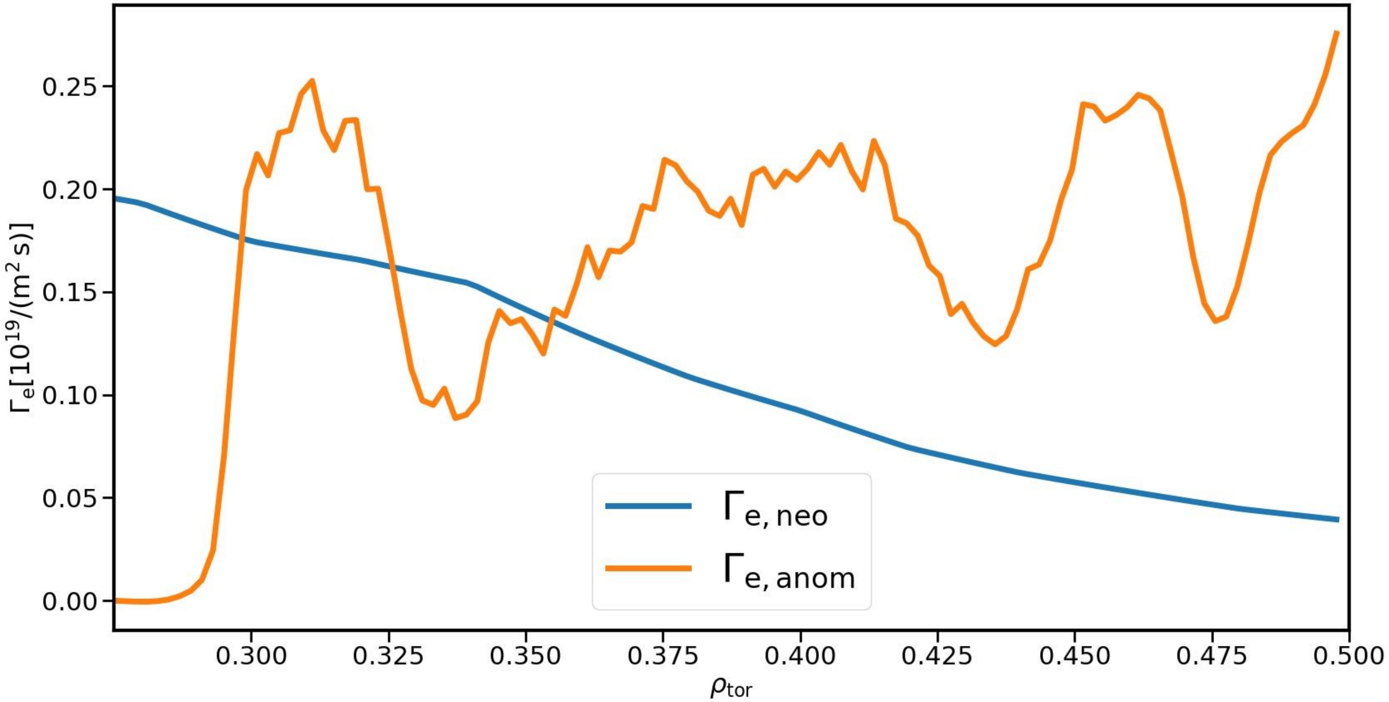
- Ongoing work at IPP Garching, but very expensive (if done with GENE-3D)

- Even without flux-matching, one can argue about the role of electron-induced turbulence

Alternative: Look at particle transport

- Gas puff: Assume $\Gamma_{tot} = 0$ in the core
- GENE-3D particle transport is too positive



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$\Rightarrow$Lower Γ by

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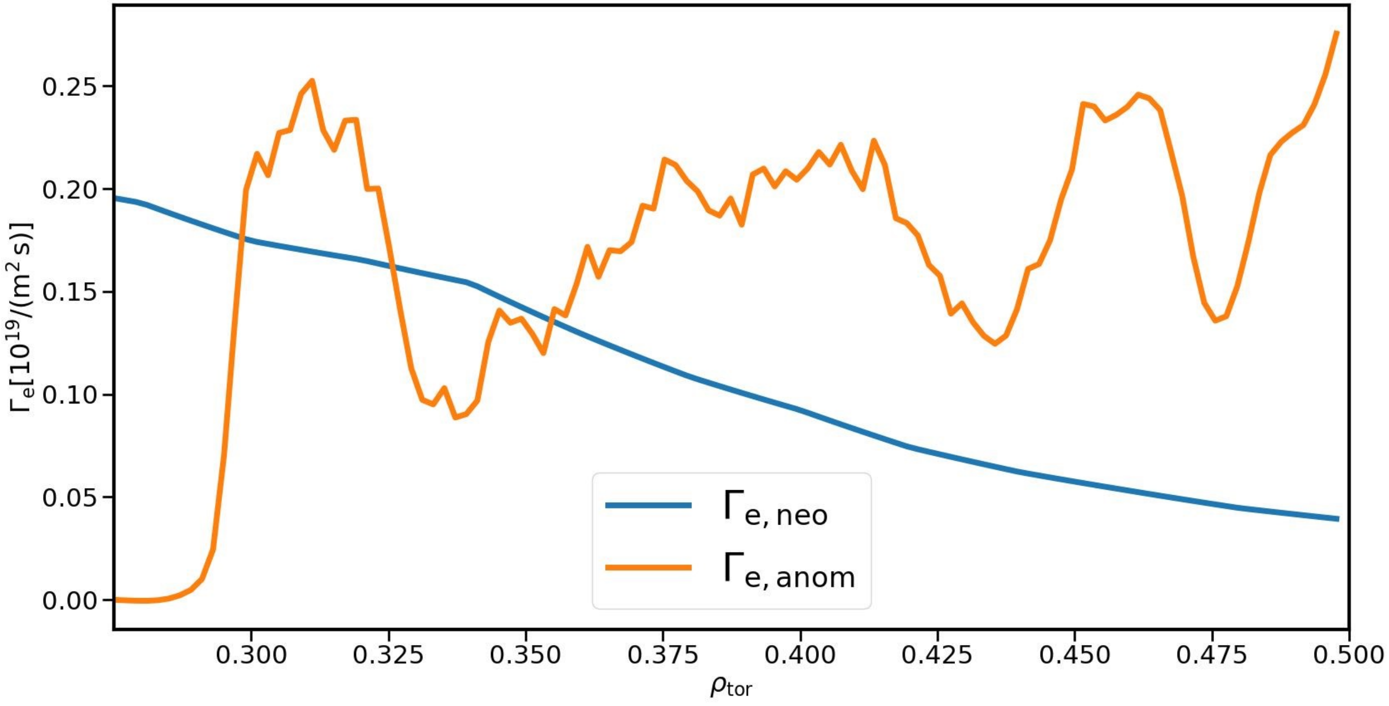
b) $\frac{a}{L_{T_e}}$ ⬆ [Thienpondt et al. 2023]



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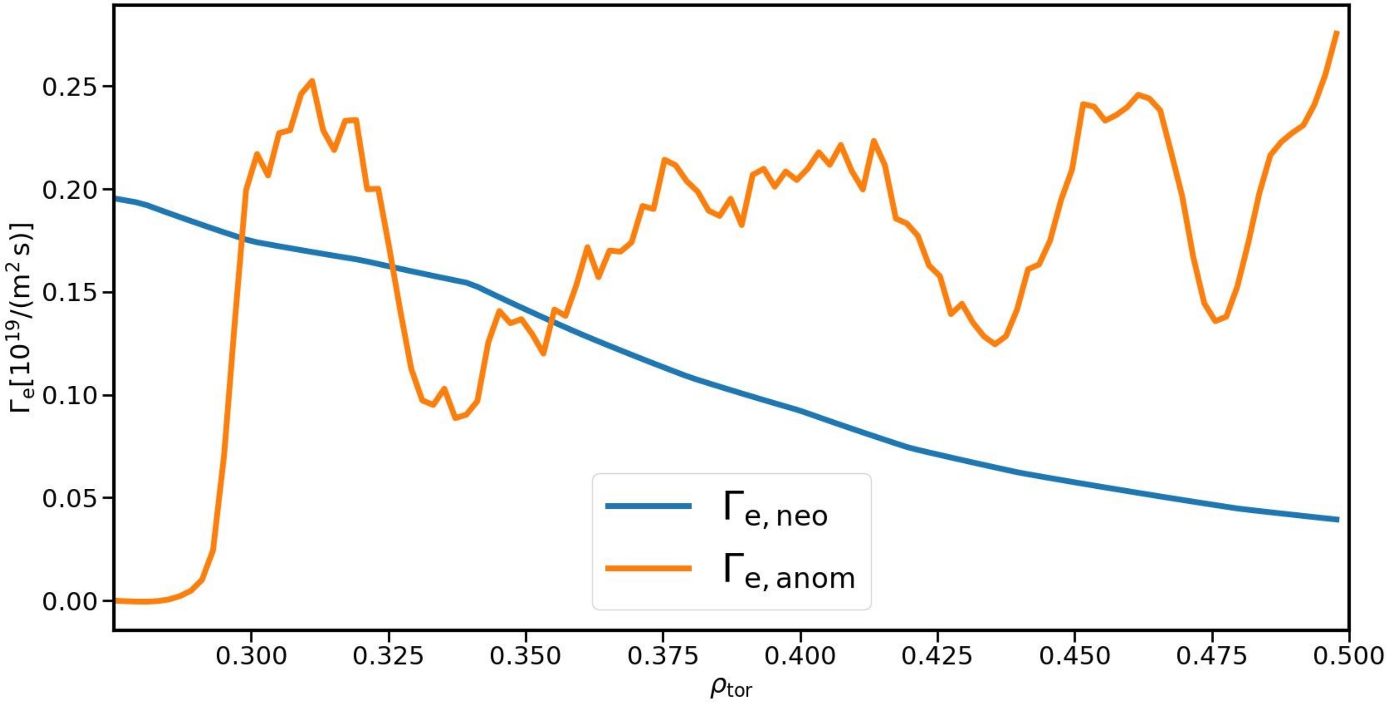

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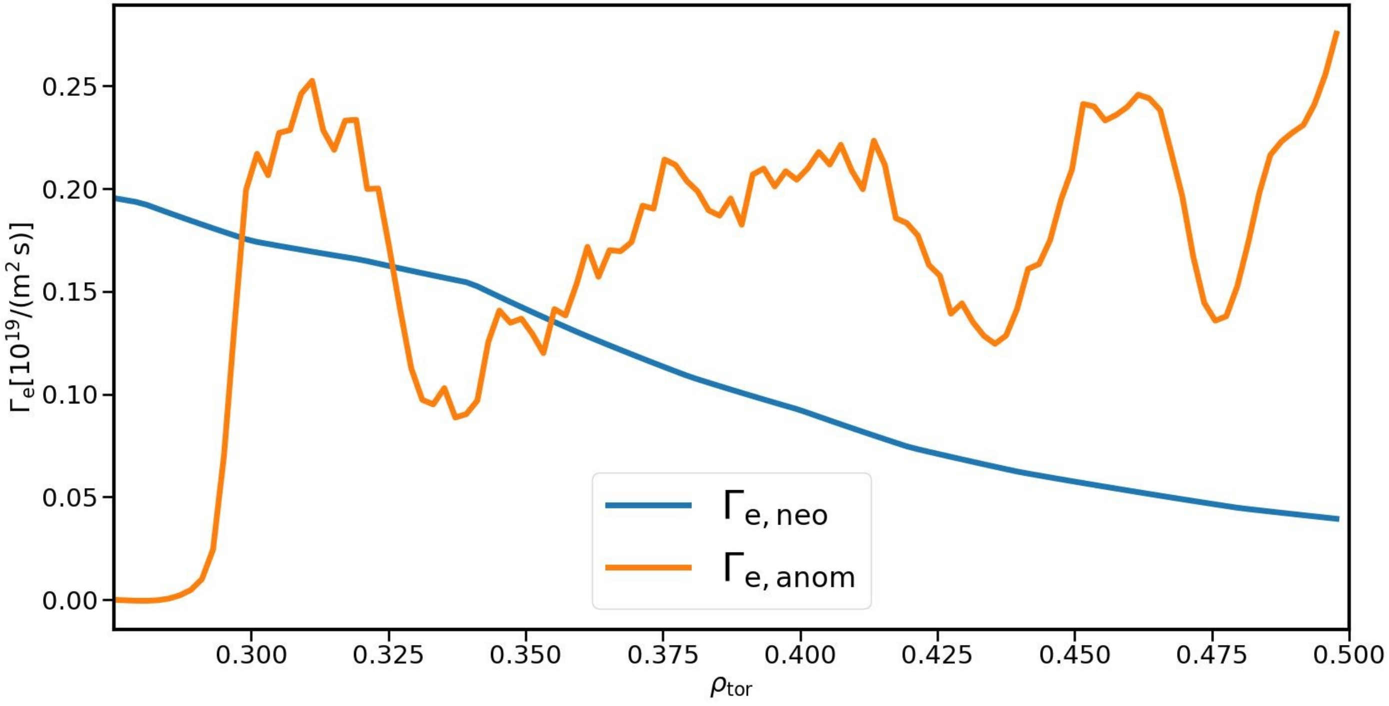

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$\Rightarrow$Even without matching power balance, electron-induced turbulence most likely a key player in core transport

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- Take it with a grain of salt: TANGO runs of multiple experimental discharges ongoing (D. Fernando), which will give further insight