MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Wendelstein 7-X

Full-flux-surface effects on electrostatic turbulence in Wendelstein 7-X-like plasmas

Felix Wilms, Alejandro Banon Navarro, Frank Jenko

EUROfusion

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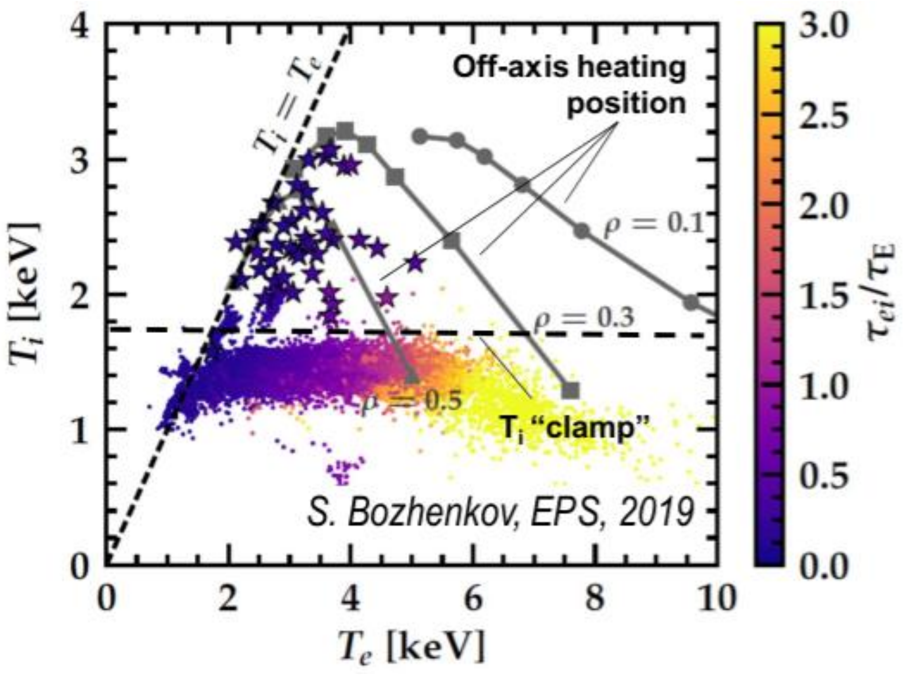
High-performance pellet discharges in W7-X

- Standard gas-puff discharges in W7-X do not exceed ion temperatures of ~1.5 keV: „T_i“-clamping



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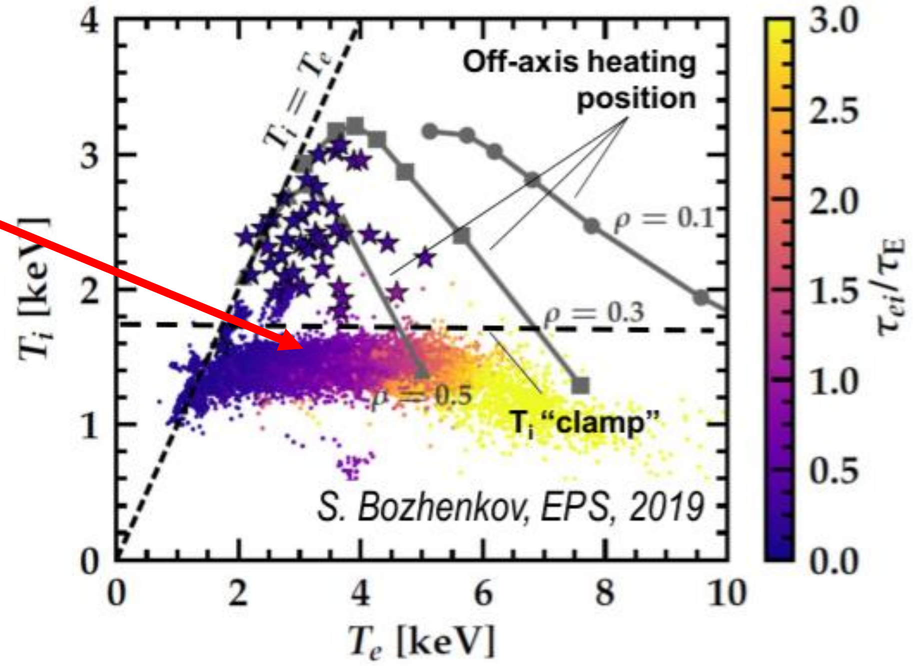

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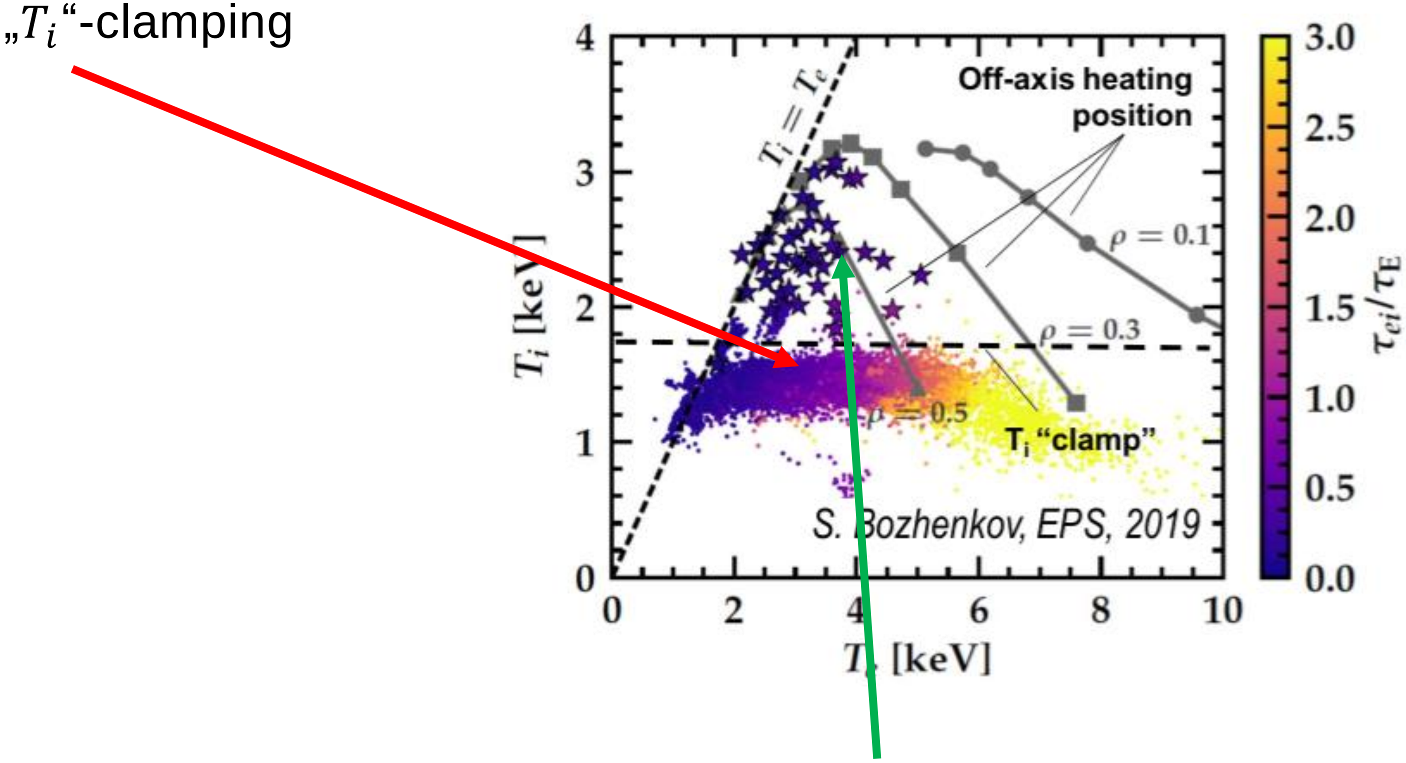
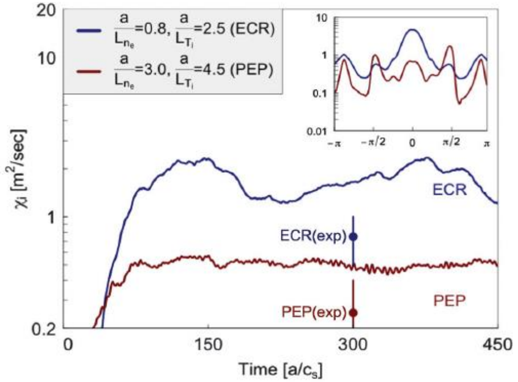


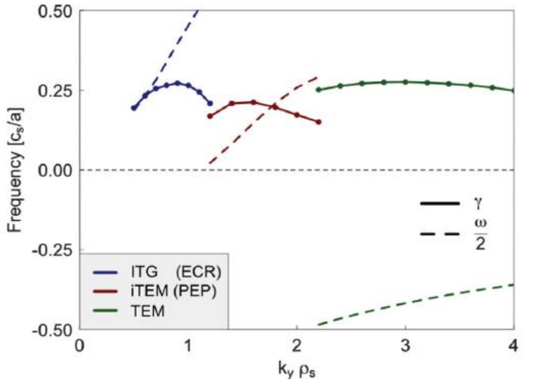
- Fuelling the plasma with frozen hyrodgen pellets+ increased heating: clamping is broken

Current explanations (Xanthopoulos et al., PRL, 2020)

1. FT simulations with kinetic electrons:

Decrease of η_i closer to 1 $\Rightarrow$Transition from **ITG** to **iTEM** mode, which is stabilised by “max-J”-property





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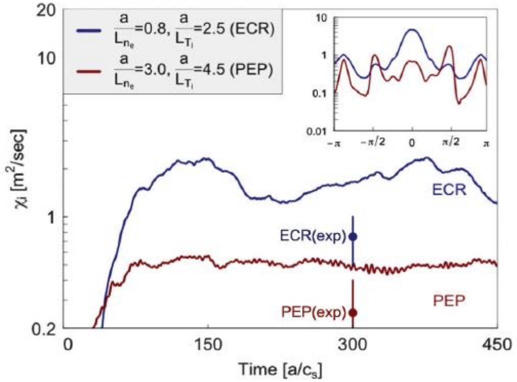
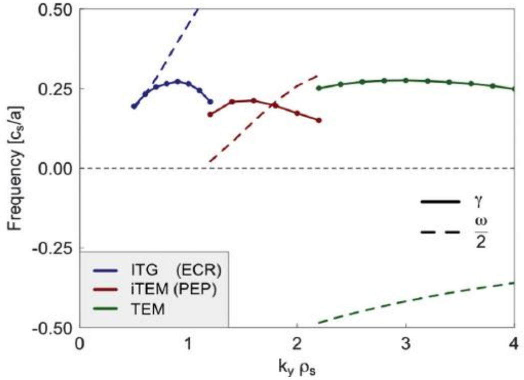
2. FFS simulations with adiabatic electrons:
Radial electric field dislocates ITG into regions of better curvature,
therefore providing less ITG drive; however, increase in E_r not enough to
compensate increase in temperature gradient $\Rightarrow$ secondary effect





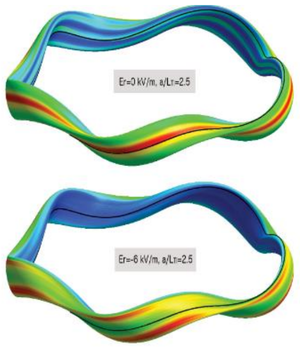
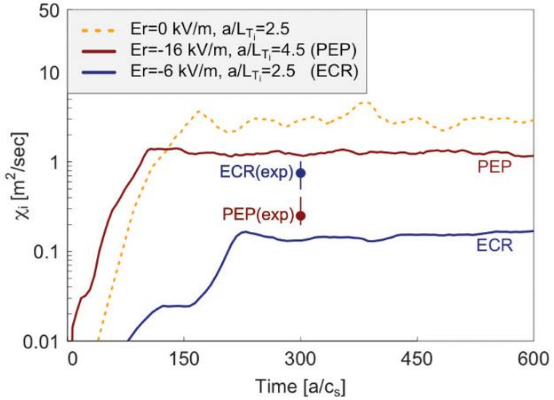


FIG. 3. Time-averaged density fluctuations on the magnetic surface of the W7-X stellarator from the simulations corresponding to Fig. 2 (rescaled with respect to their individual maximum value to facilitate inspection). The magnetic field line $a = 0$ is shown in black.



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GENE-3D can do both things simultaneously

→ „Stability valley“ in nonlinear FFS

The setup

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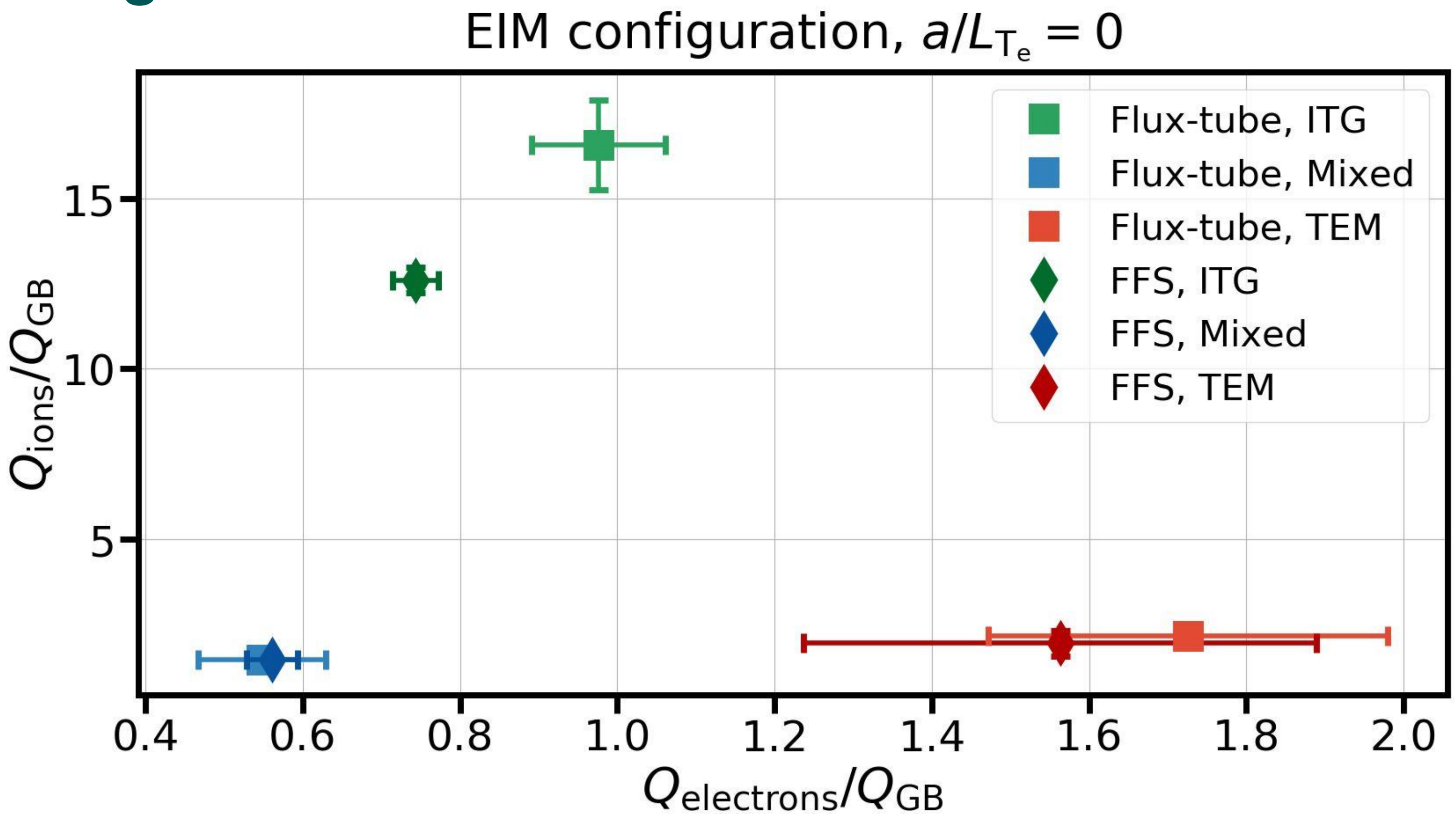
Case	$\boldsymbol{a/L_{T_i}}$	$\boldsymbol{a/L_n}$	$\boldsymbol{\eta_i}$
ITG	2.5	0.0	∞
Mixed	2.5	2.5	1
TEM	0.0	2.5	0

Standard configuration



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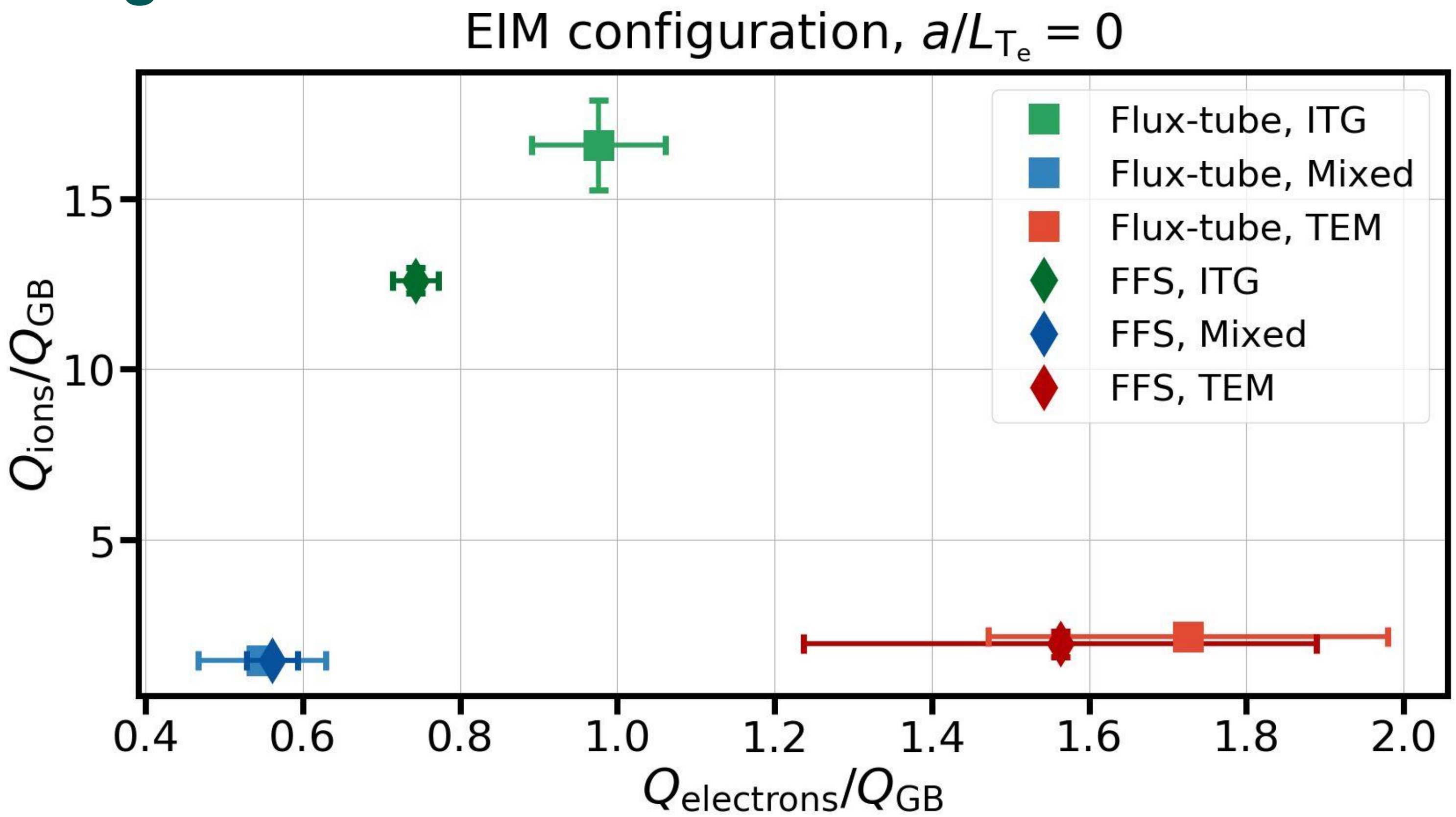

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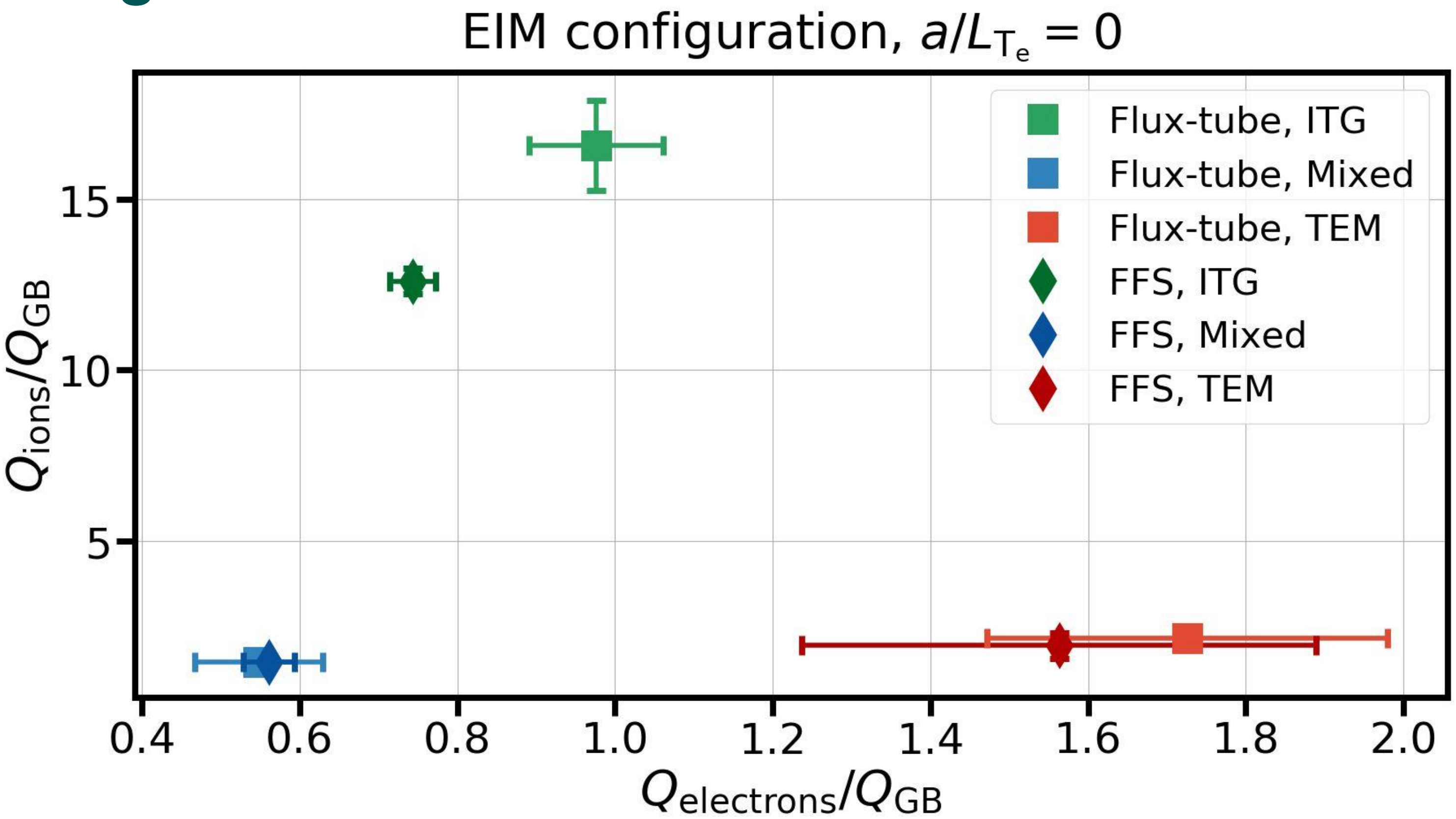

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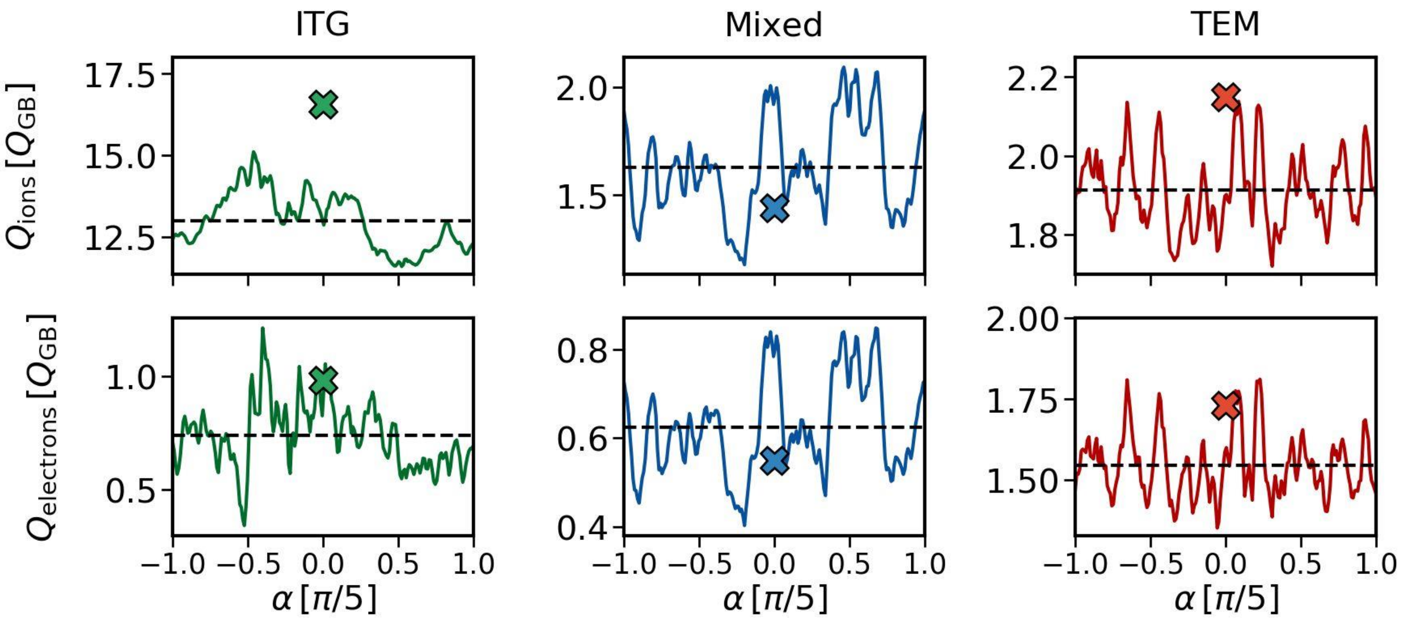
Variation across field lines

- Heat flux spread homogeneously over field lines in FFS (std < 20% of mean)
- Crosses indicate heat fluxes of FT simulation at the corresponding position



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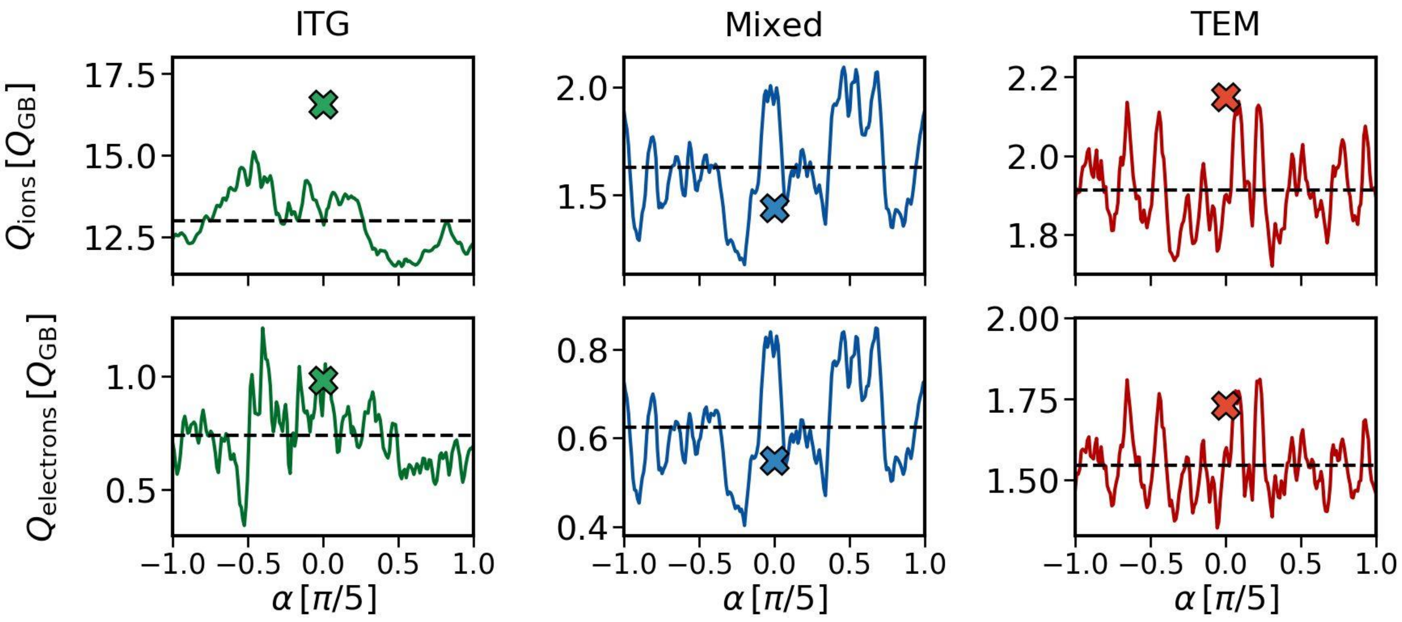

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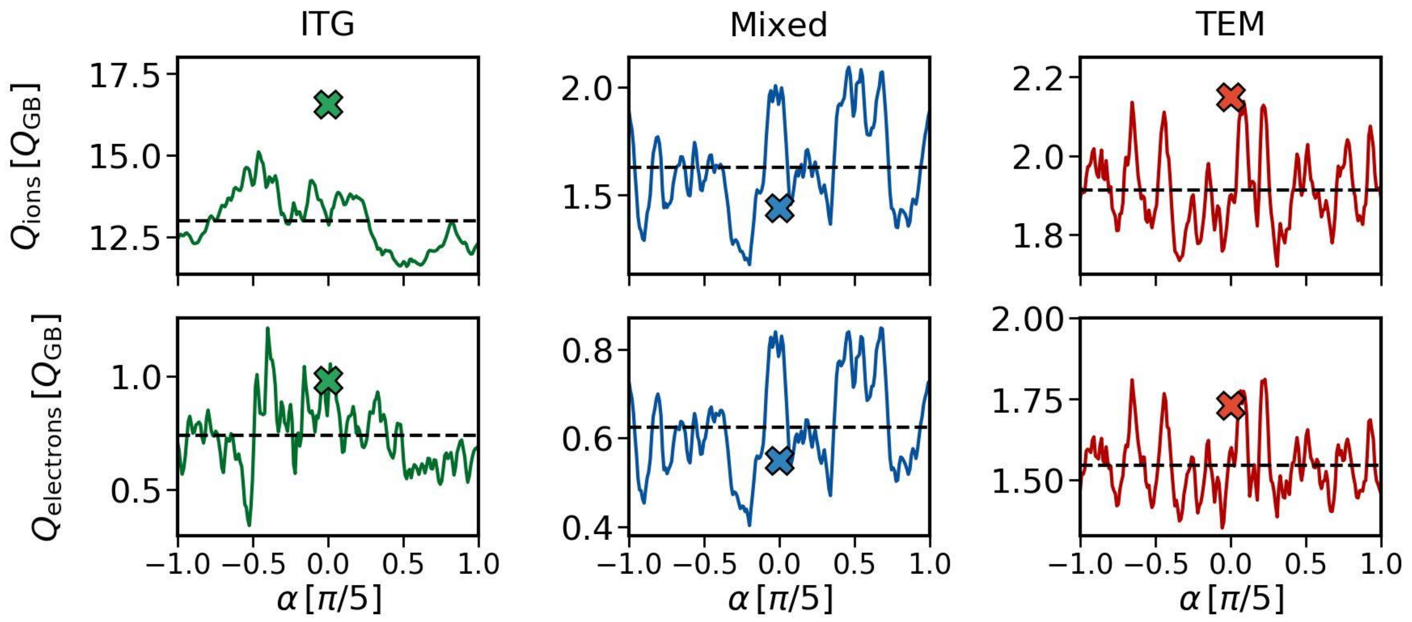
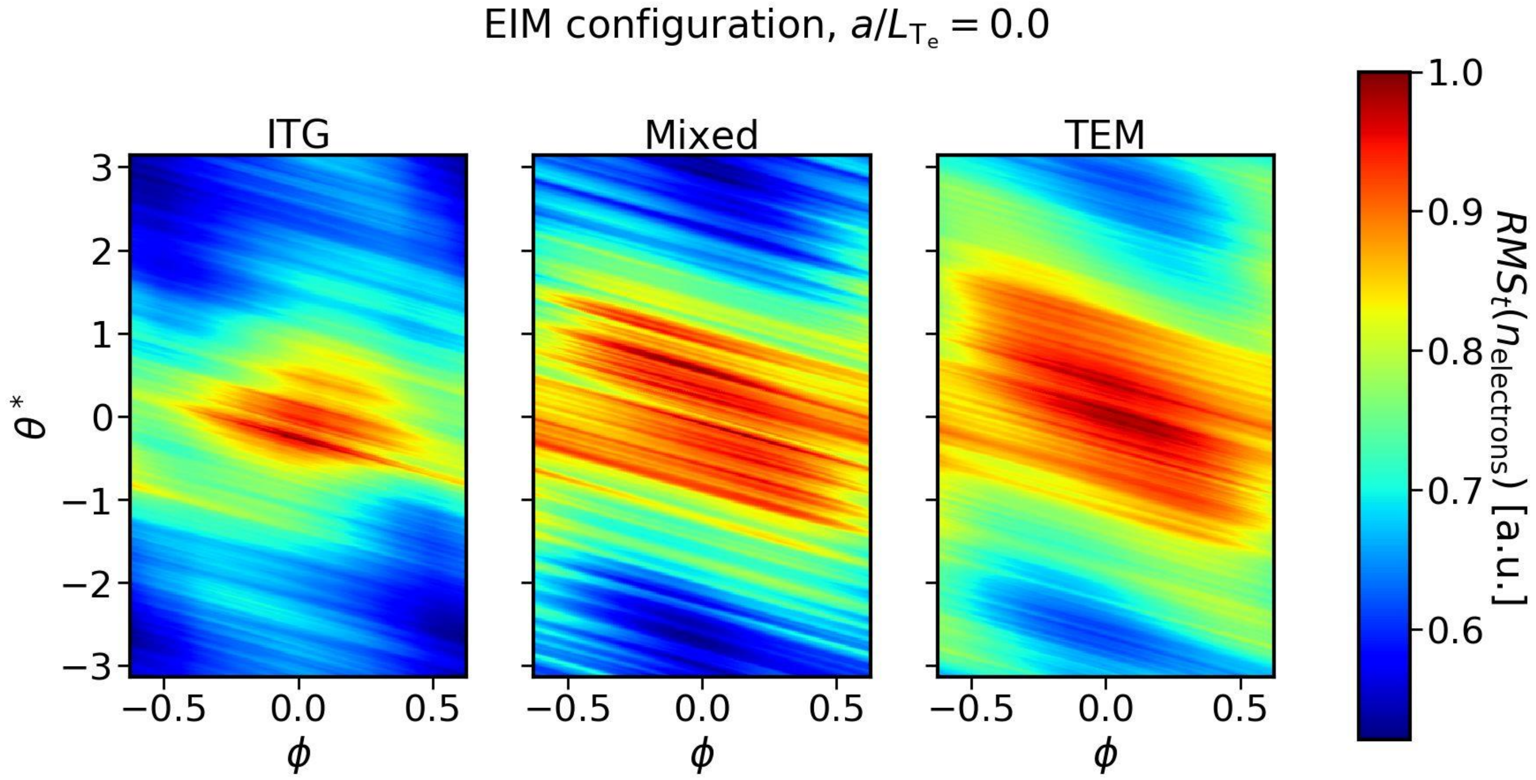
- However, ion heat flux differs by ~30% for the ITG case
  - => Even patching together multiple flux-tubes could still give different result (will be investigated later in more detail)



Structure of turbulence

- „Where do the experimentalists have to look?“



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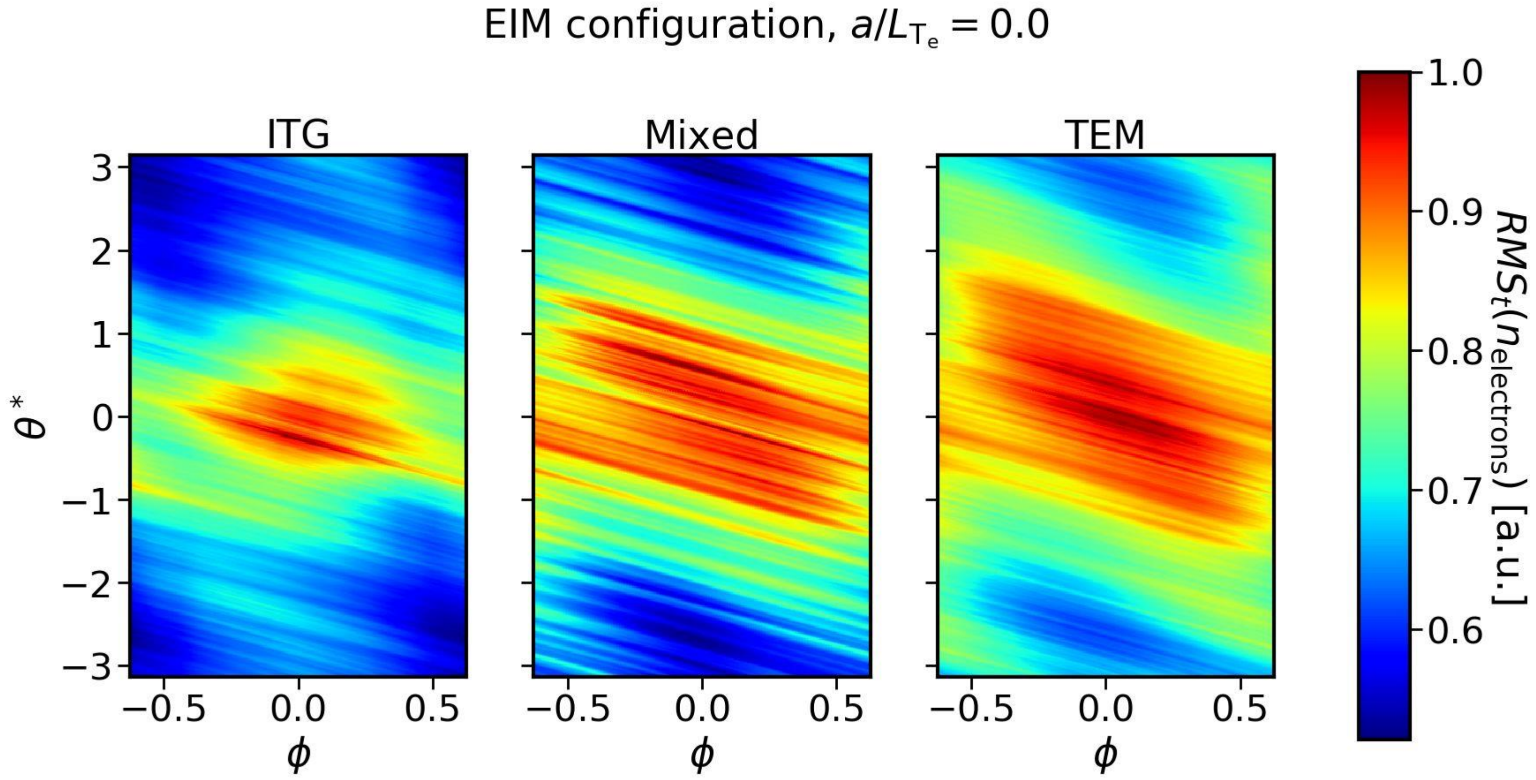

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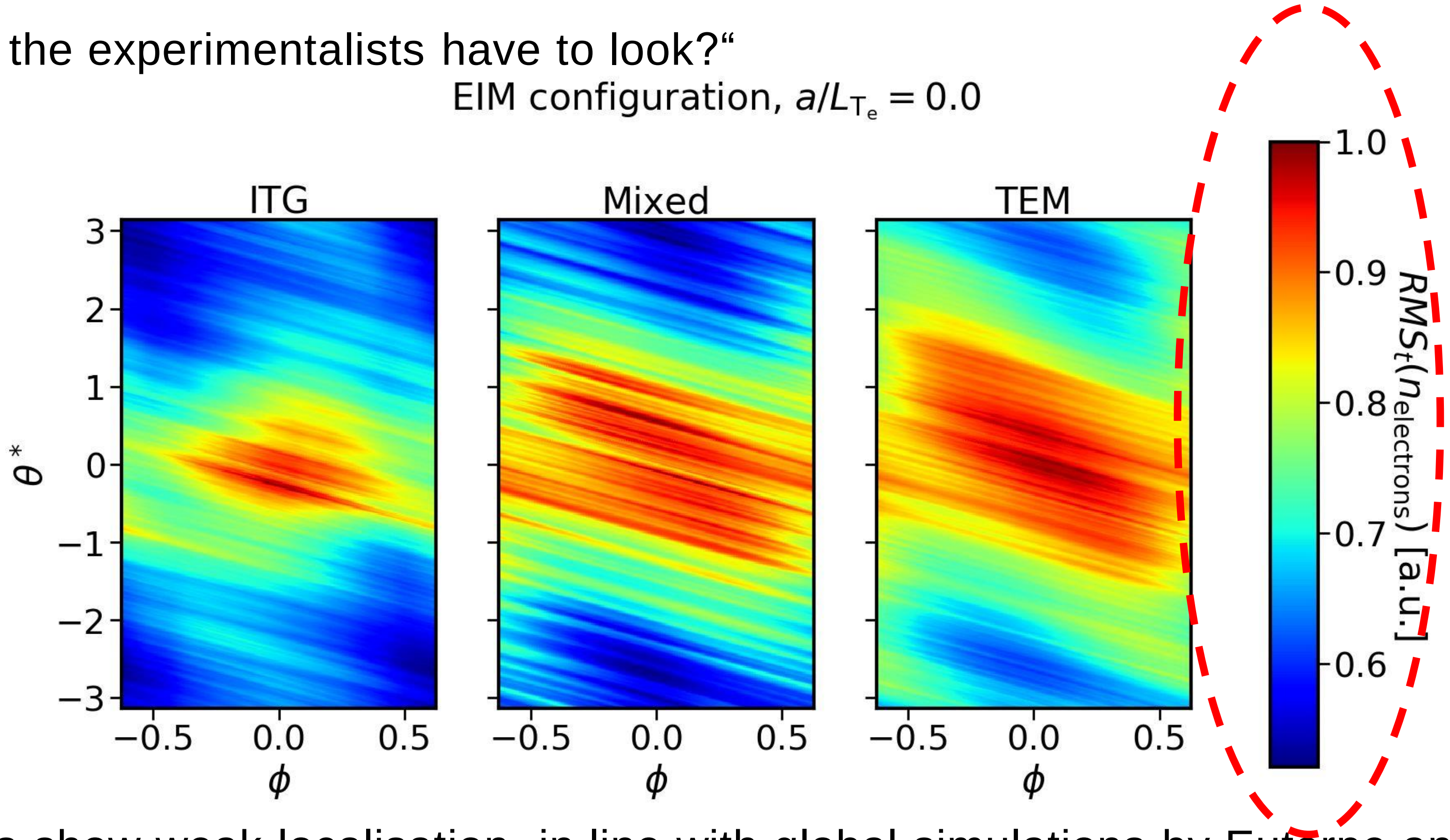

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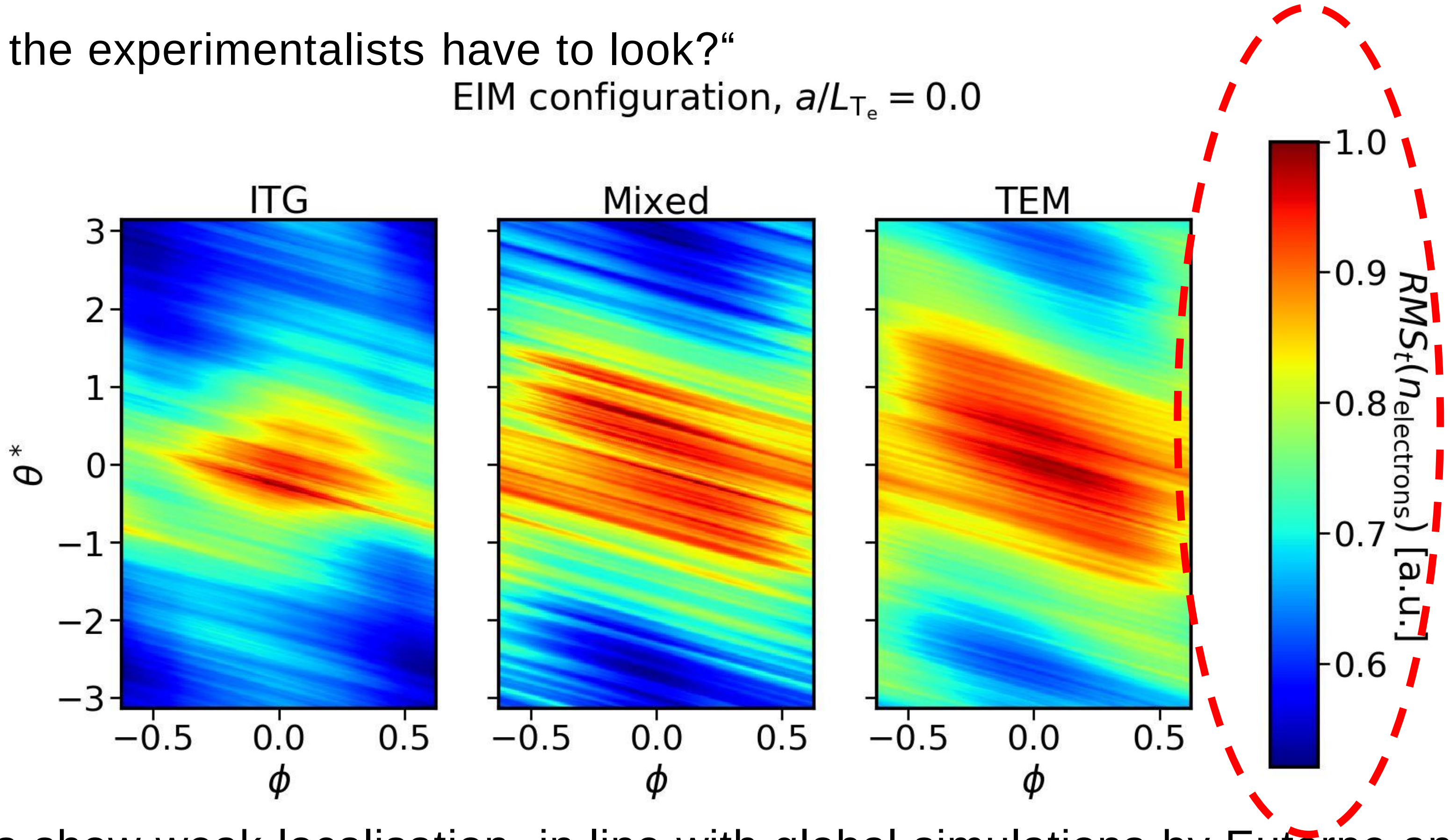
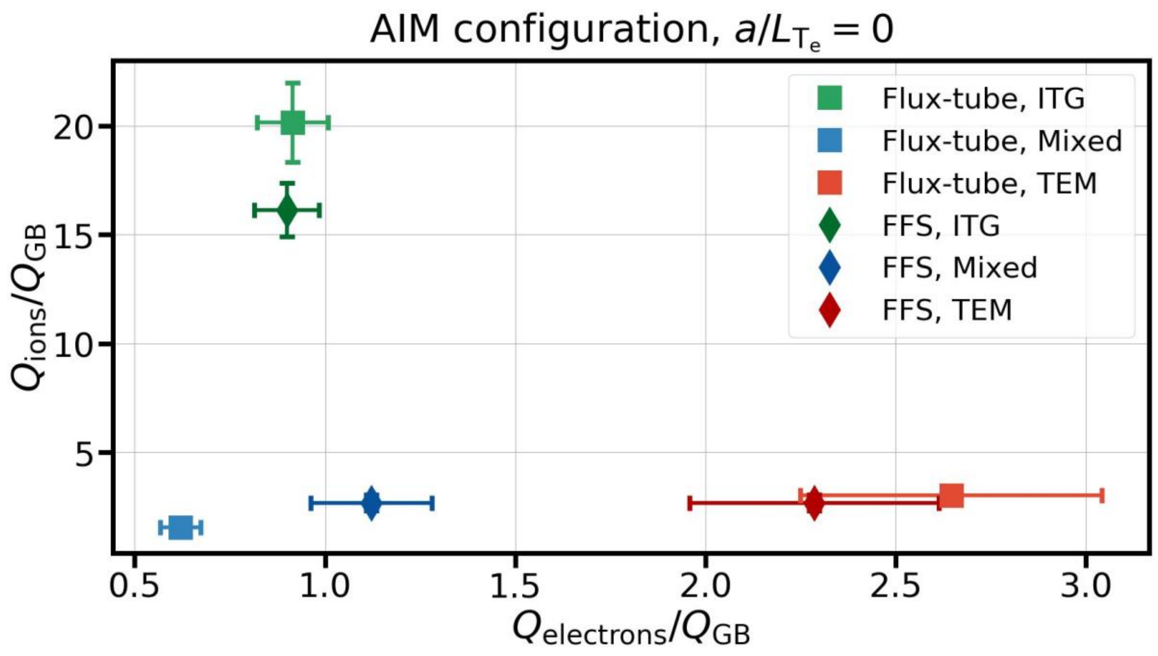


- Simulations show weak localisation, in line with global simulations by Euterpe and GENE-3D (Sanchez et al., NF 2023)
- TEM and Mixed cases are more uniform than ITG

Stability valley in Low-mirror (AIM)

- AIM configuration also shows strong reduction going from the ITG to Mixed, while TEM is also much more benign than ITG



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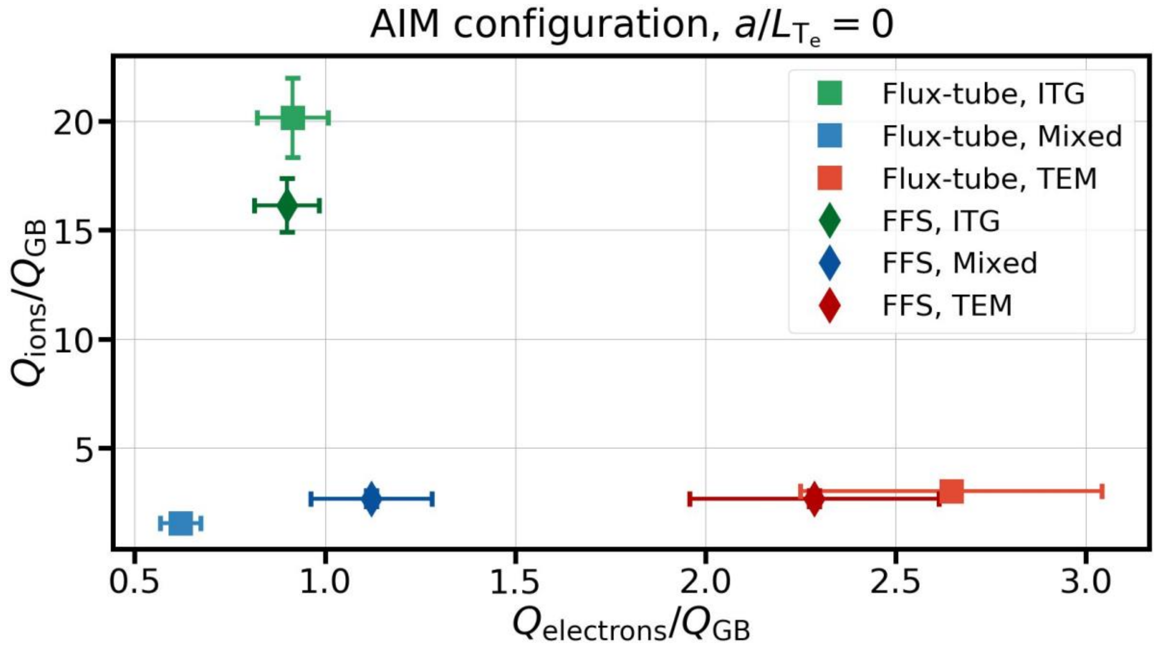

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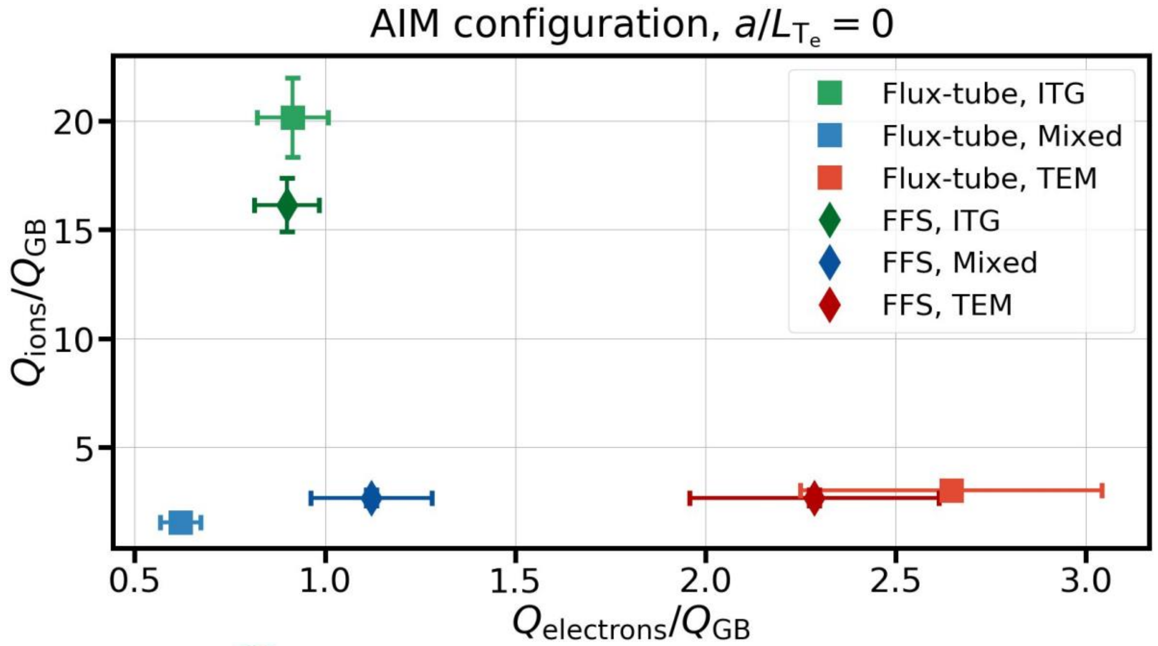

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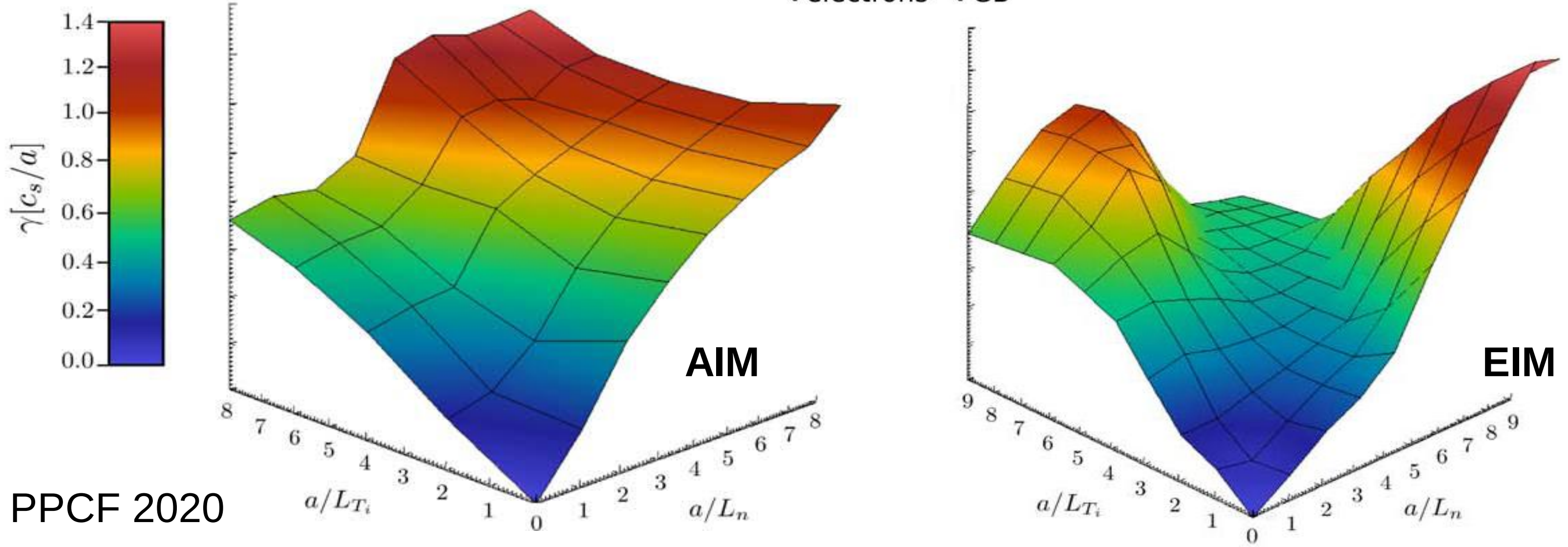

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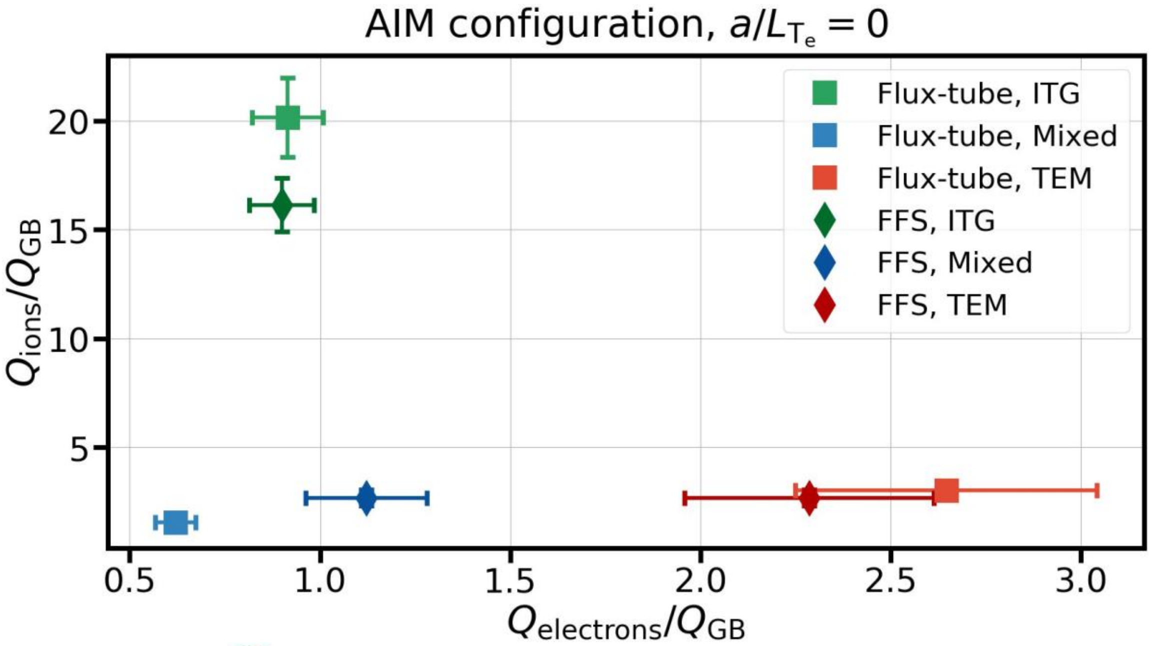

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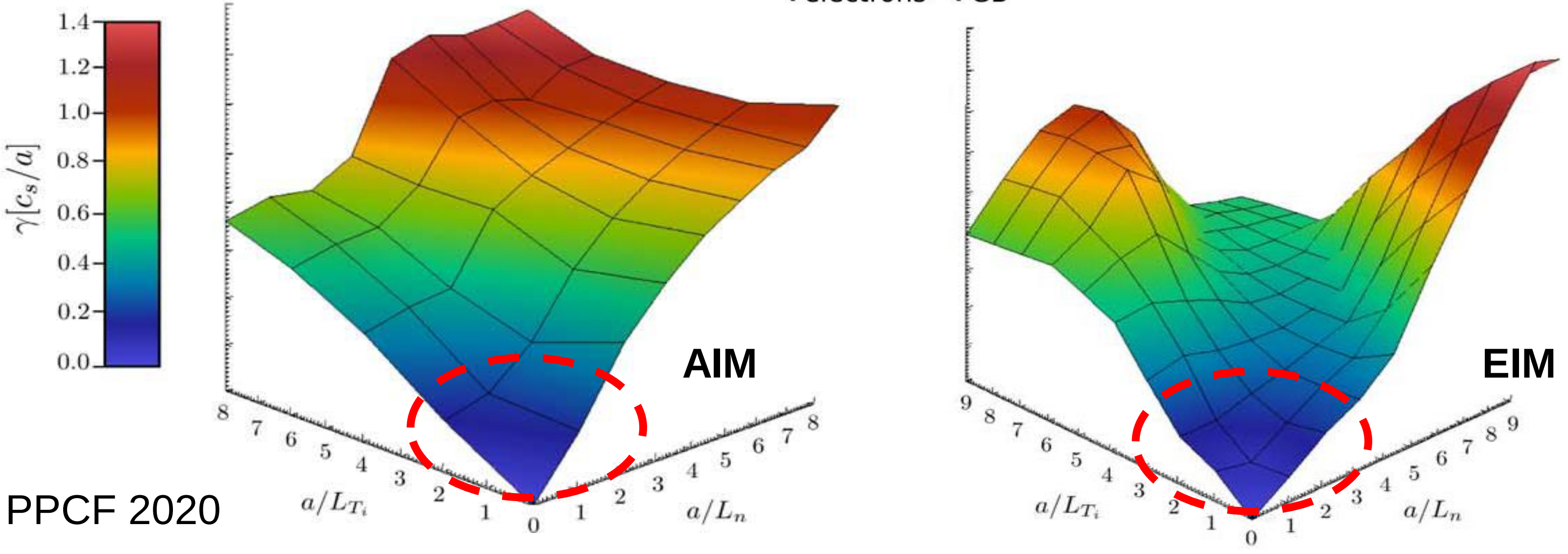

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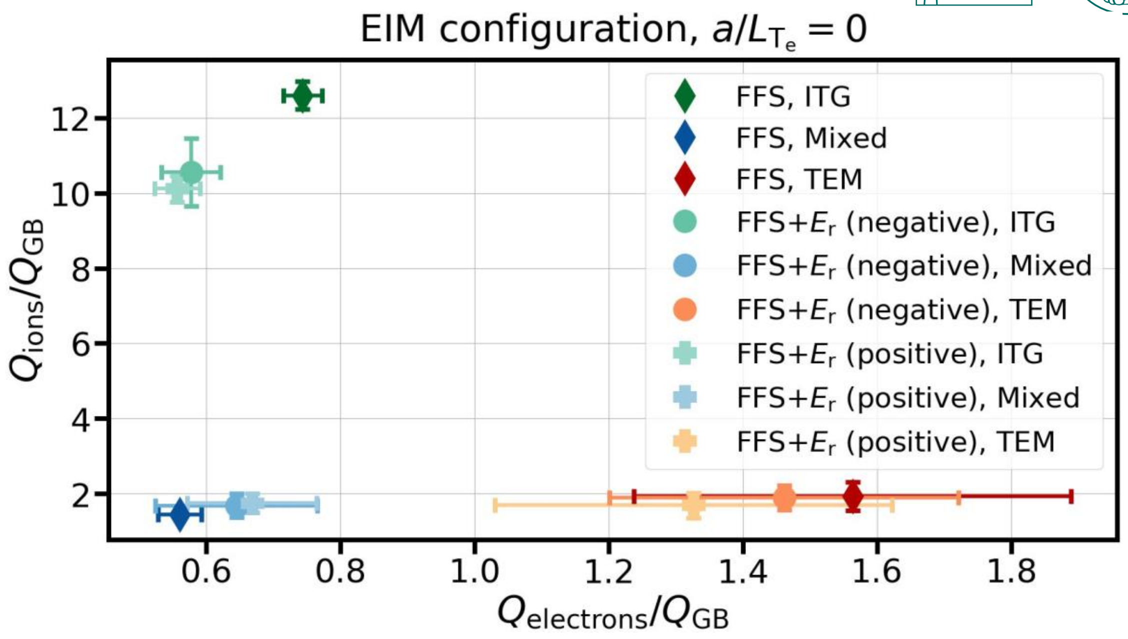

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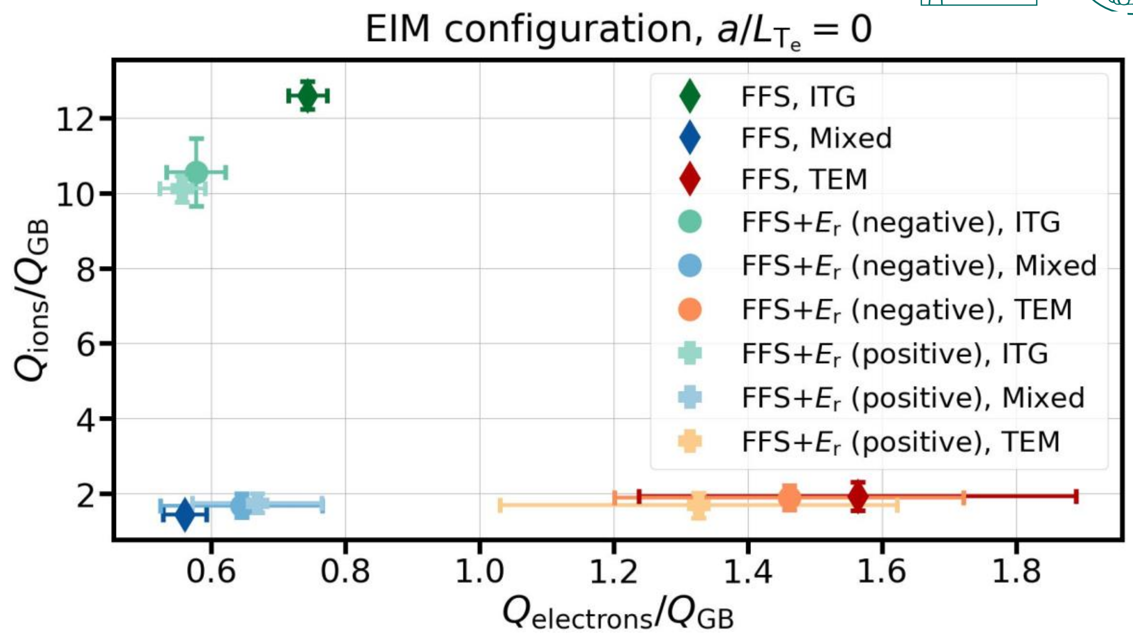

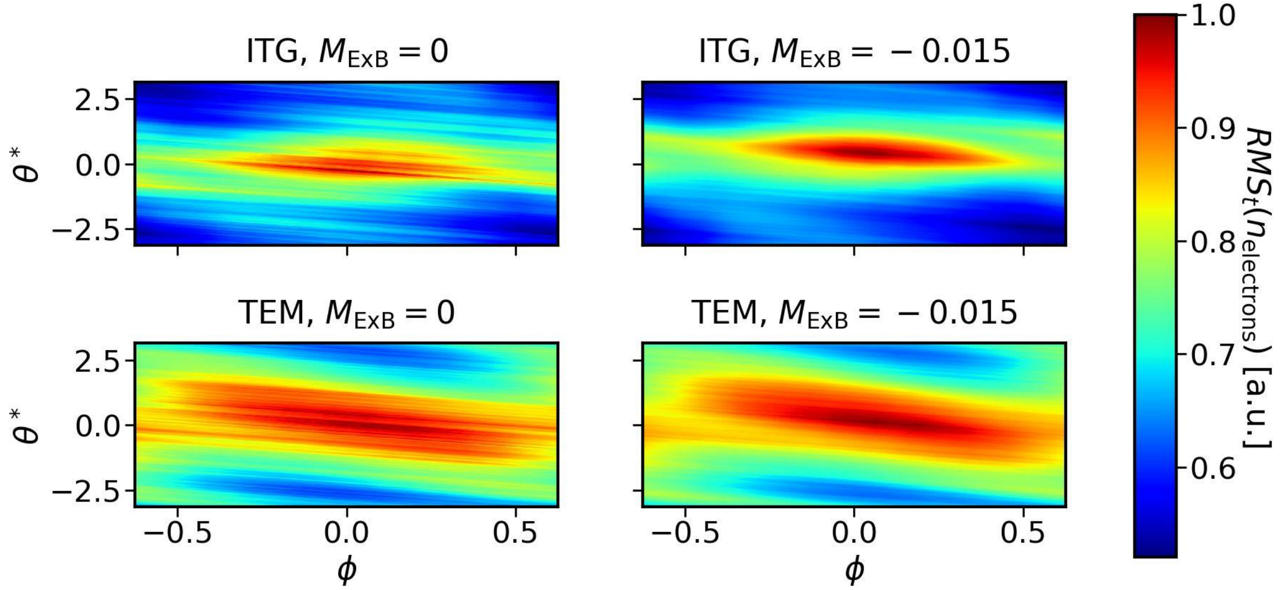

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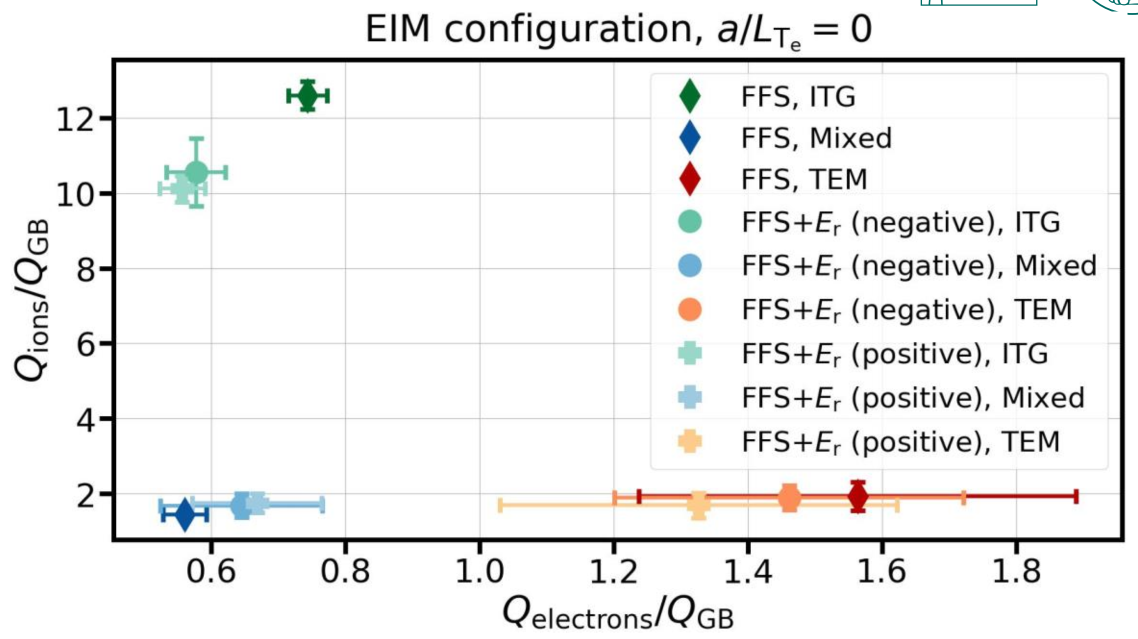

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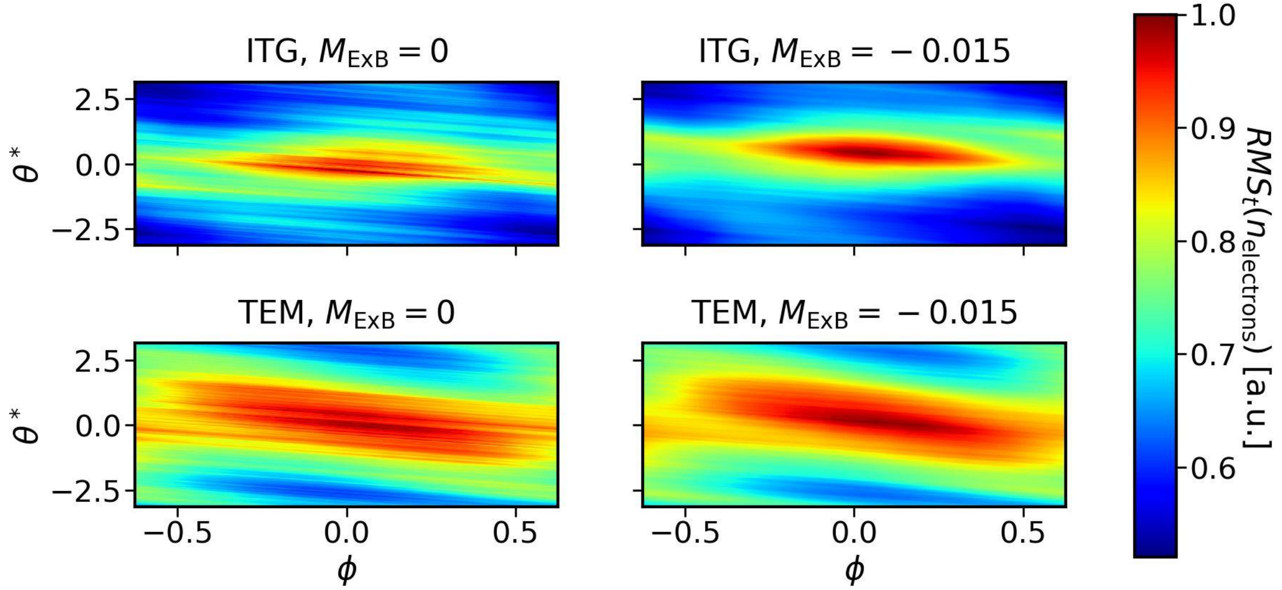
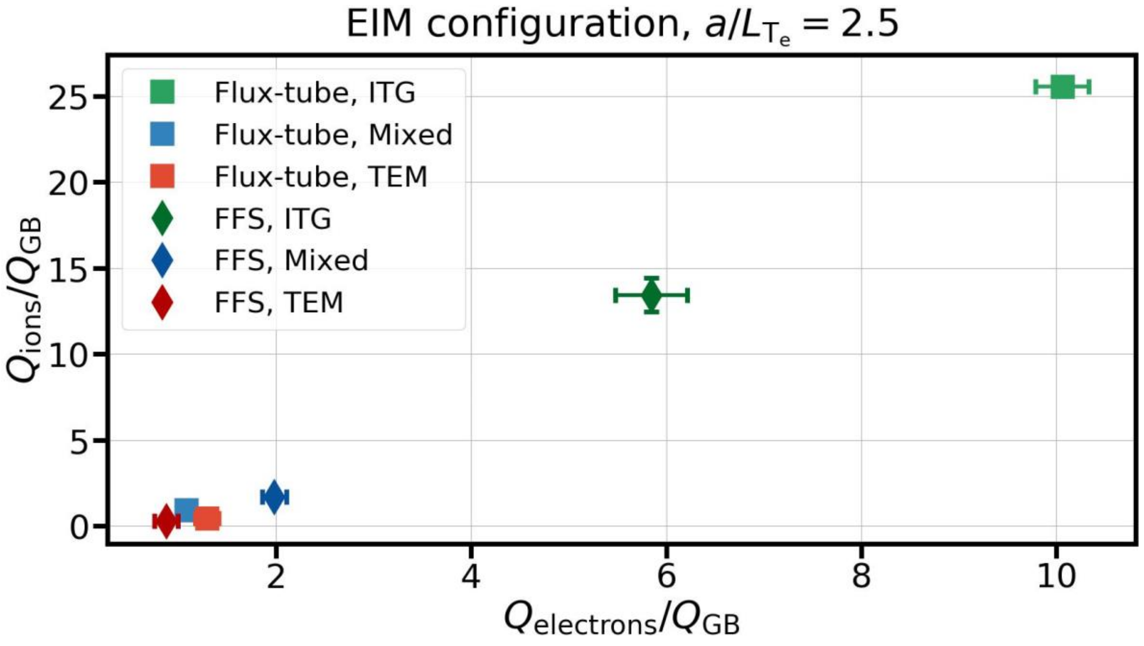
2) Mach number too low to cause serious dislocation (see later)



Adding an electron temperature graident

- ITG case seems to be further destabilised
- Possible reason: excitation of ITG/∇T-TEM hybrid



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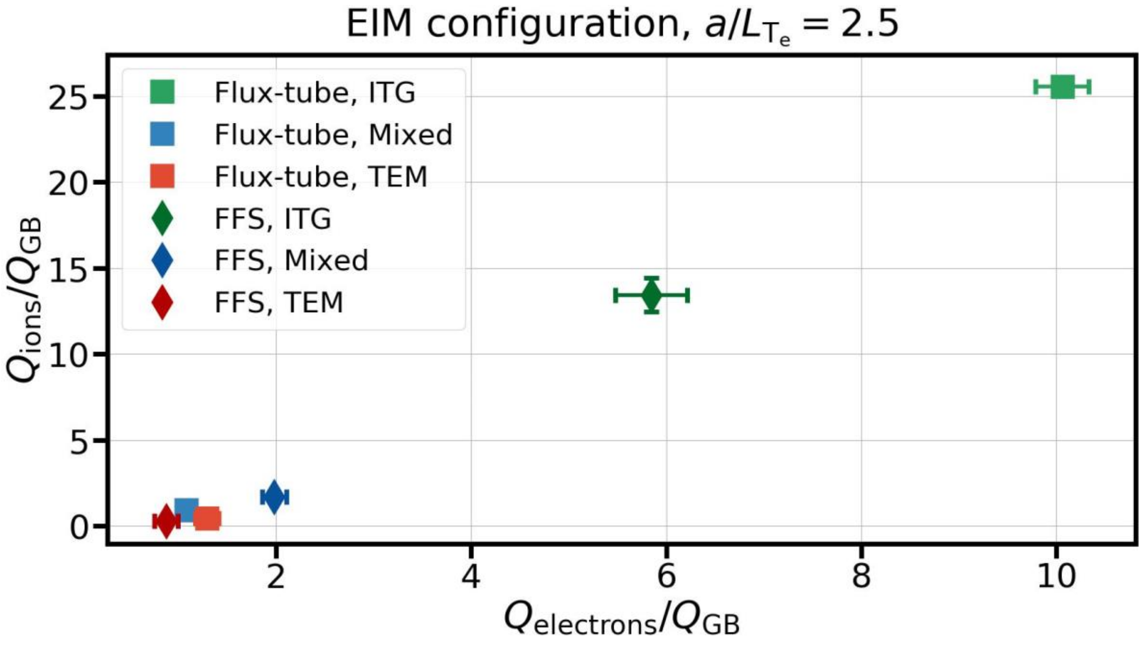

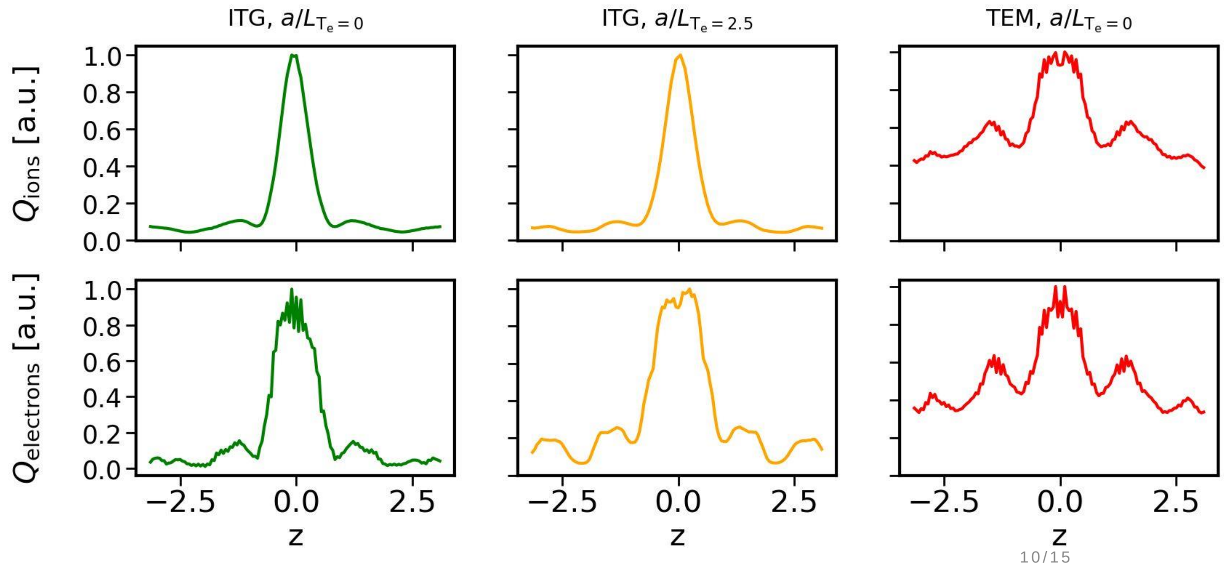

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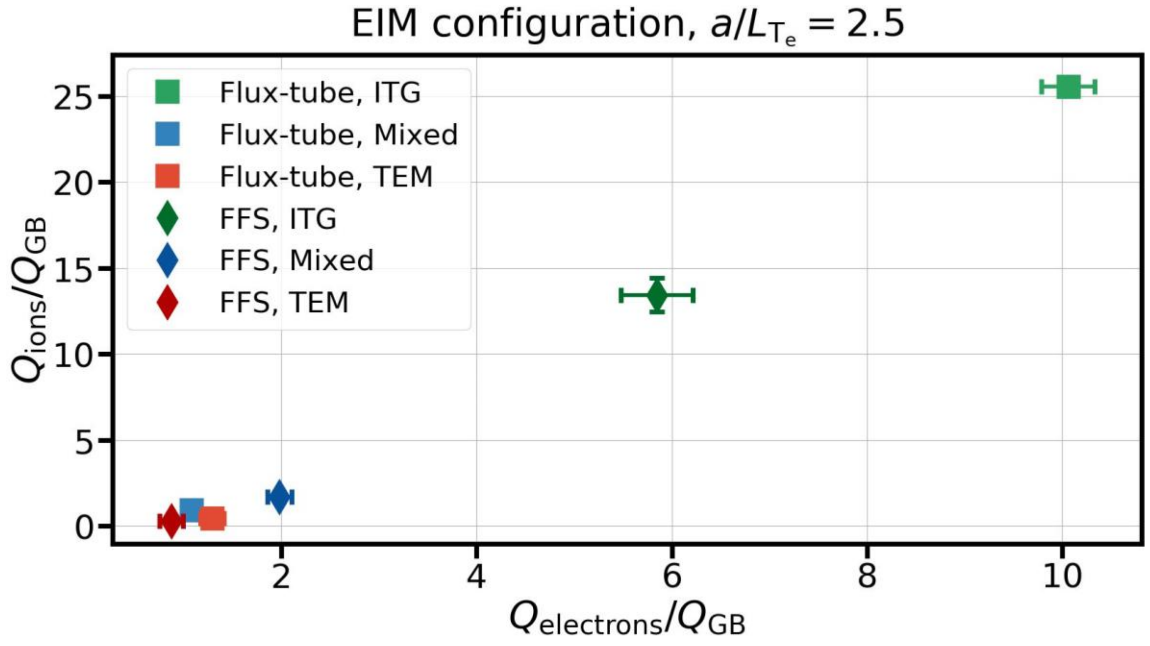
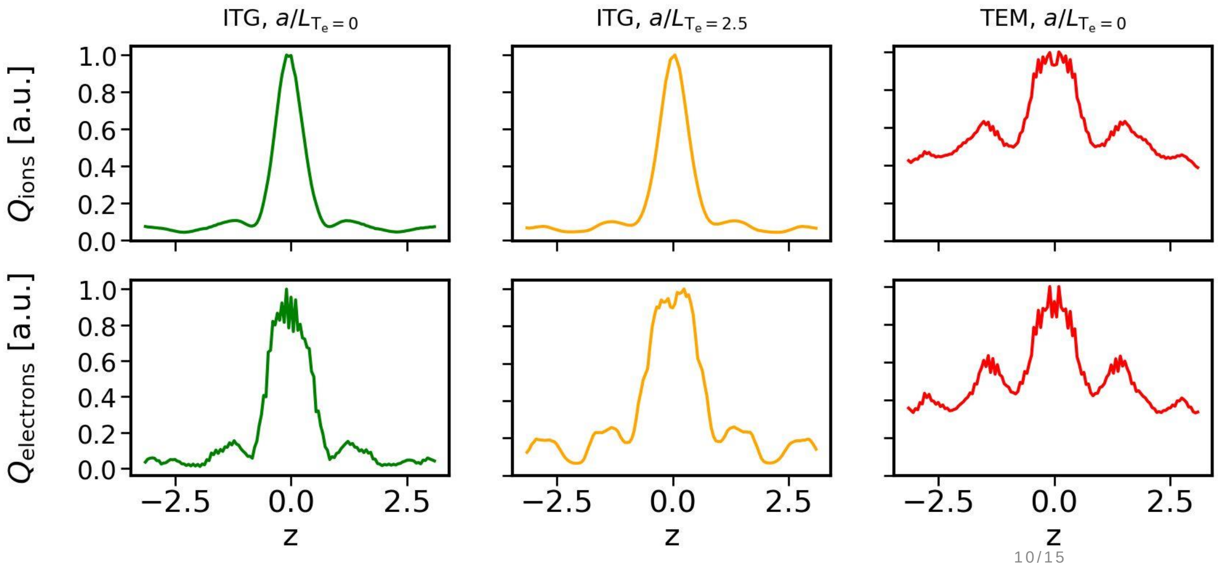
- Look at structures along magnetic field lines:
  - Ion heat flux structuer fairly unaffected
  - Electron heat flux starts to develop local maxima at positions of magnetic wells, just like the TEM case





Mixed and TEM: FT and FFS comparison

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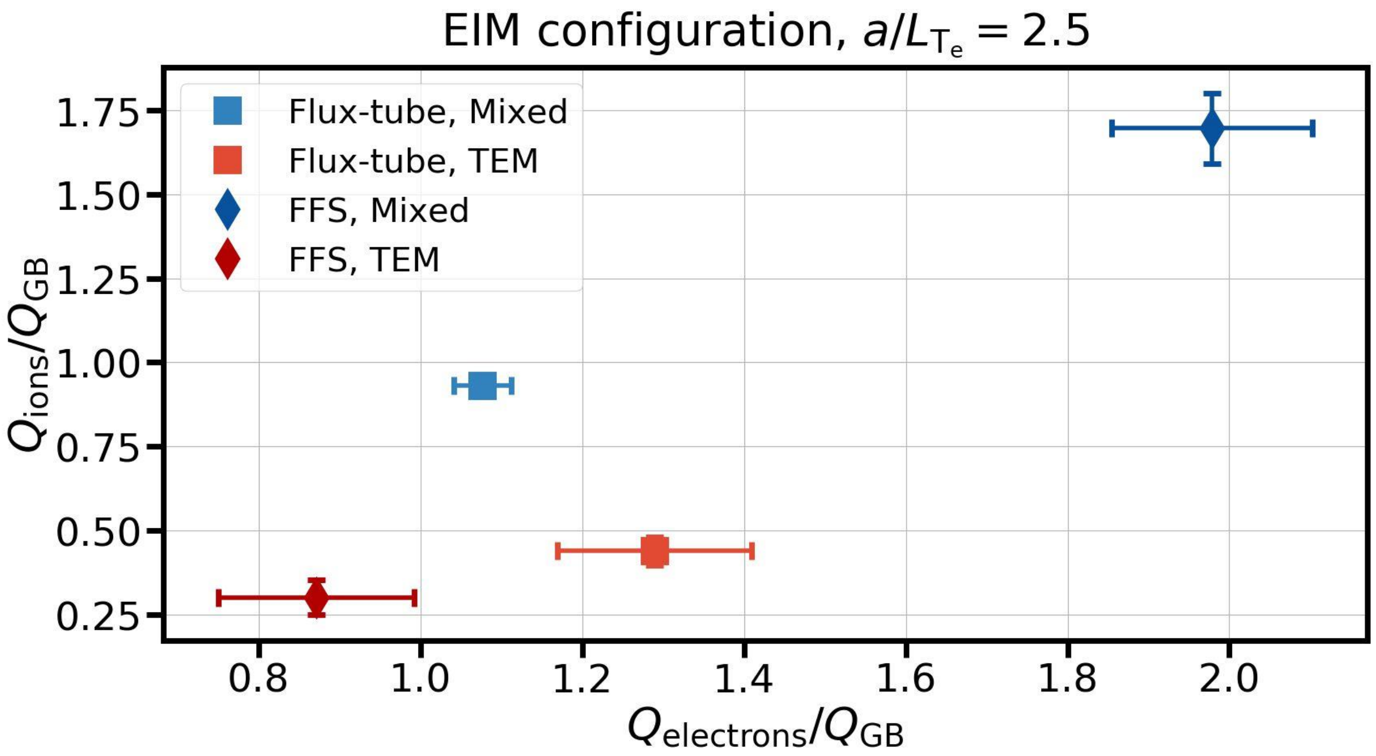

Mixed and TEM: FT and FFS comparison

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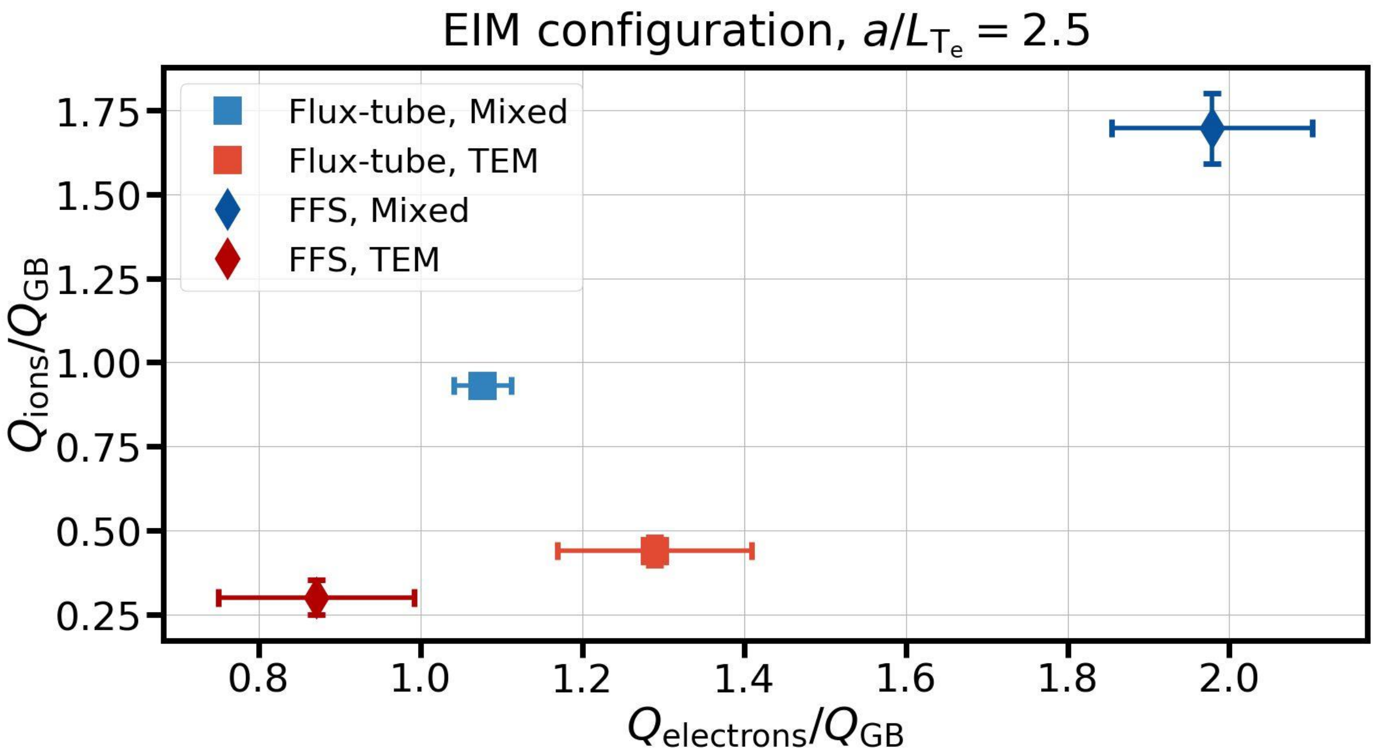
- FT predicts that total transport of TEM and Mixed case is very similar, Mixed case has lower electron transport

- Mixed case in FFS has significantly more transport in both channels than TEM



Variation of fluxes across field lines

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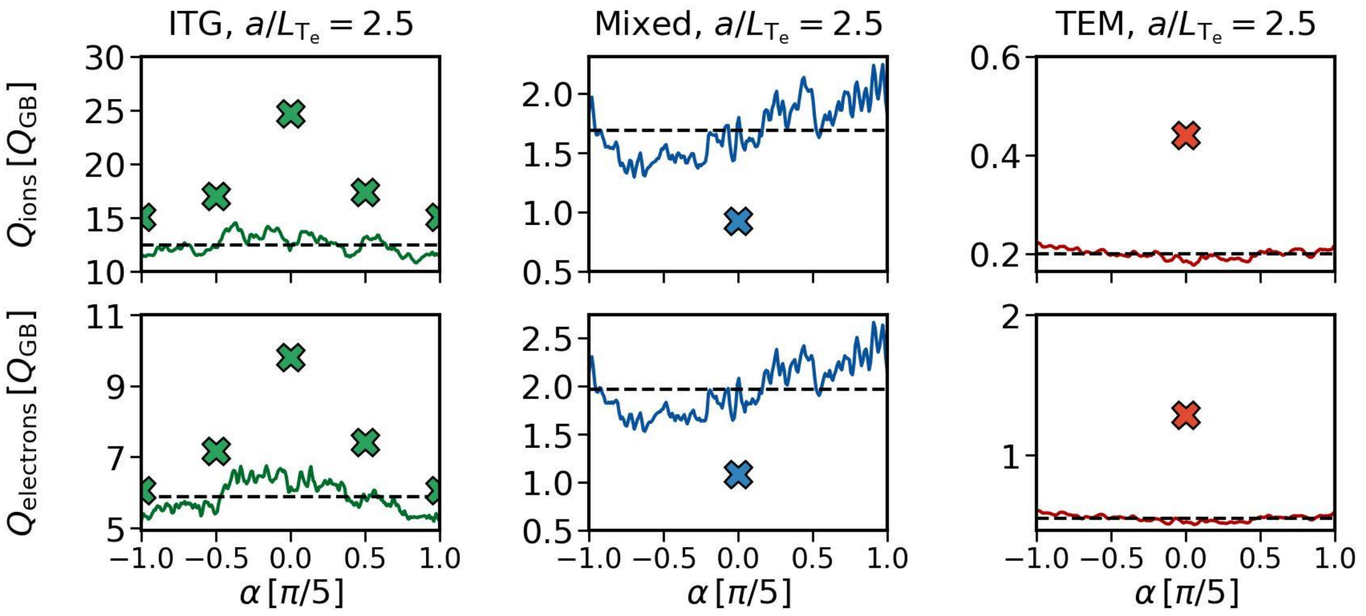

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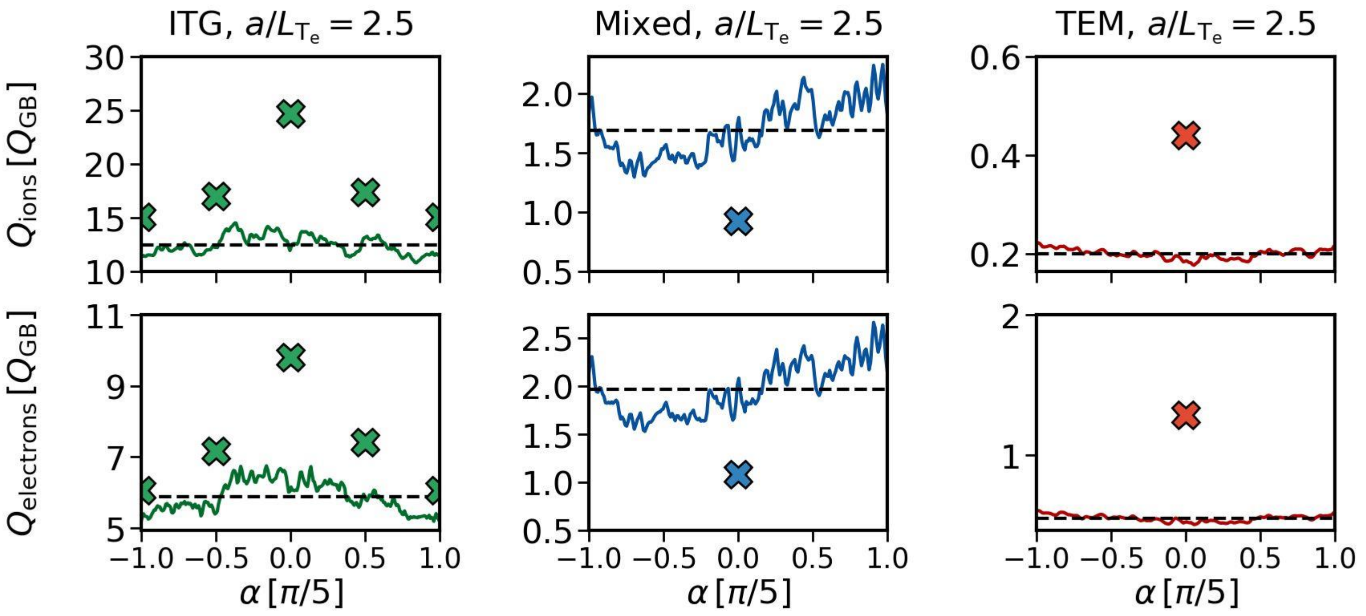

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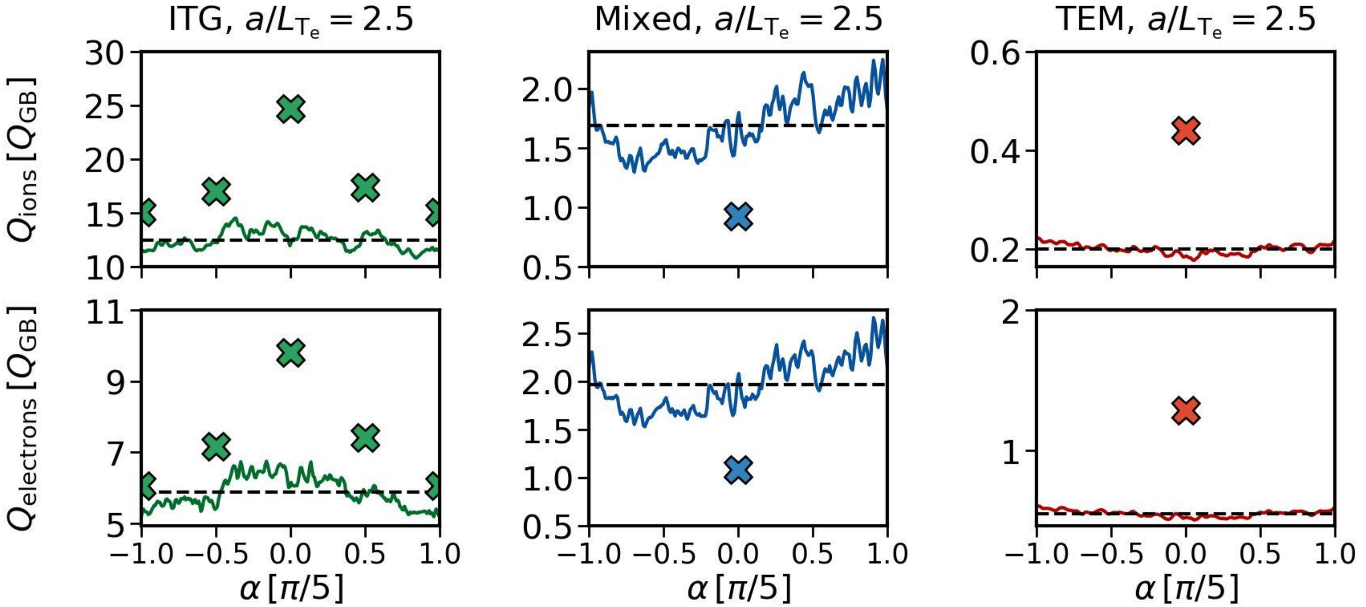

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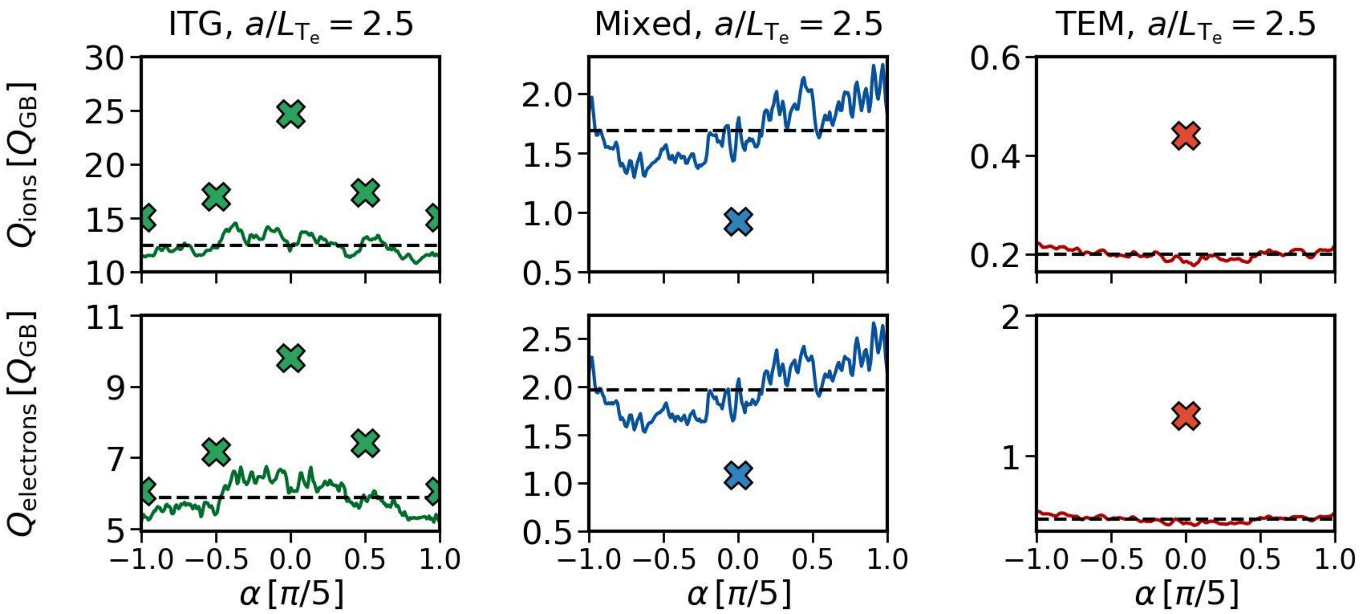

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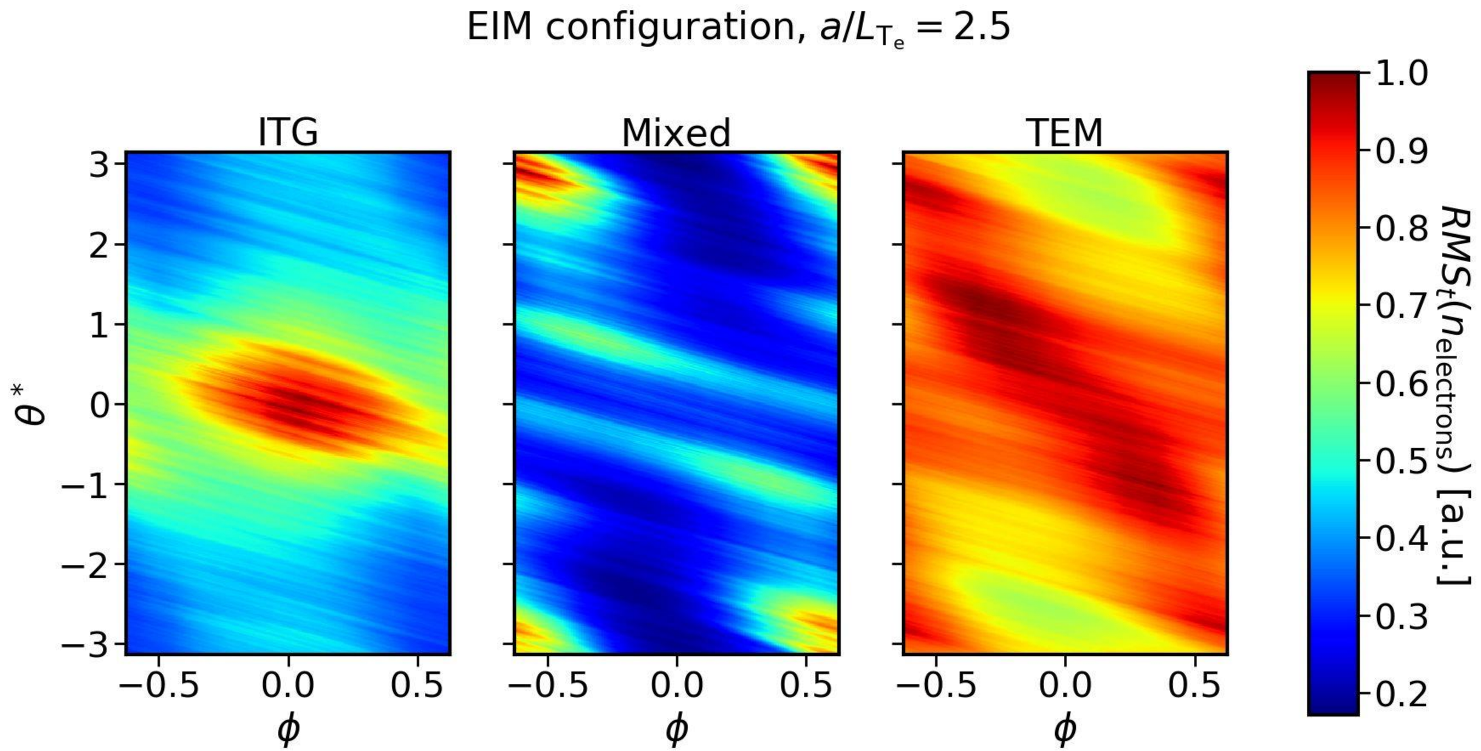
- Mixed case does not seem to have transport peaking at $\alpha = 0$ => using only one flux-tube might be misleading

Localisation of cases with electron temperature gradient

- ITG and TEM case show similar structural behaviour compared to the cases with a/L_{T_e}=0



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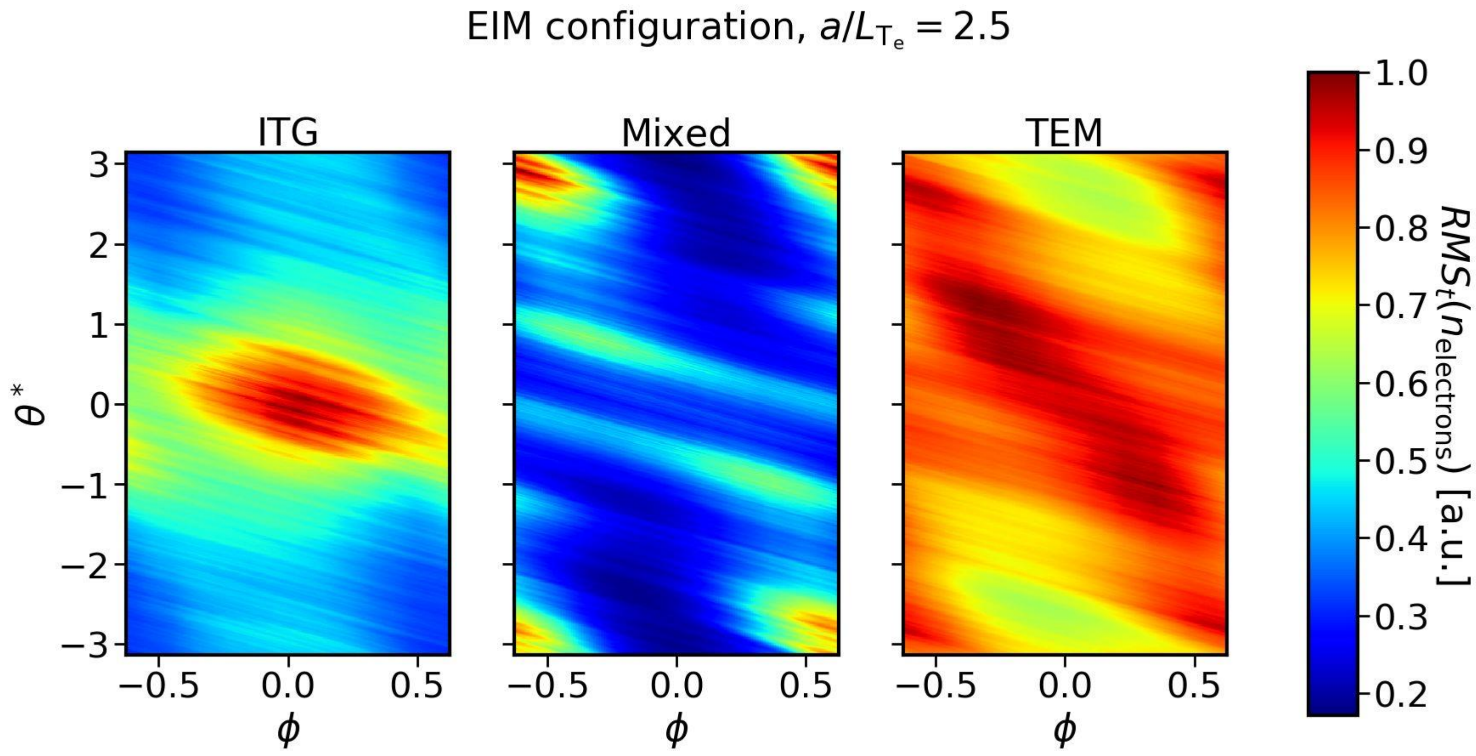

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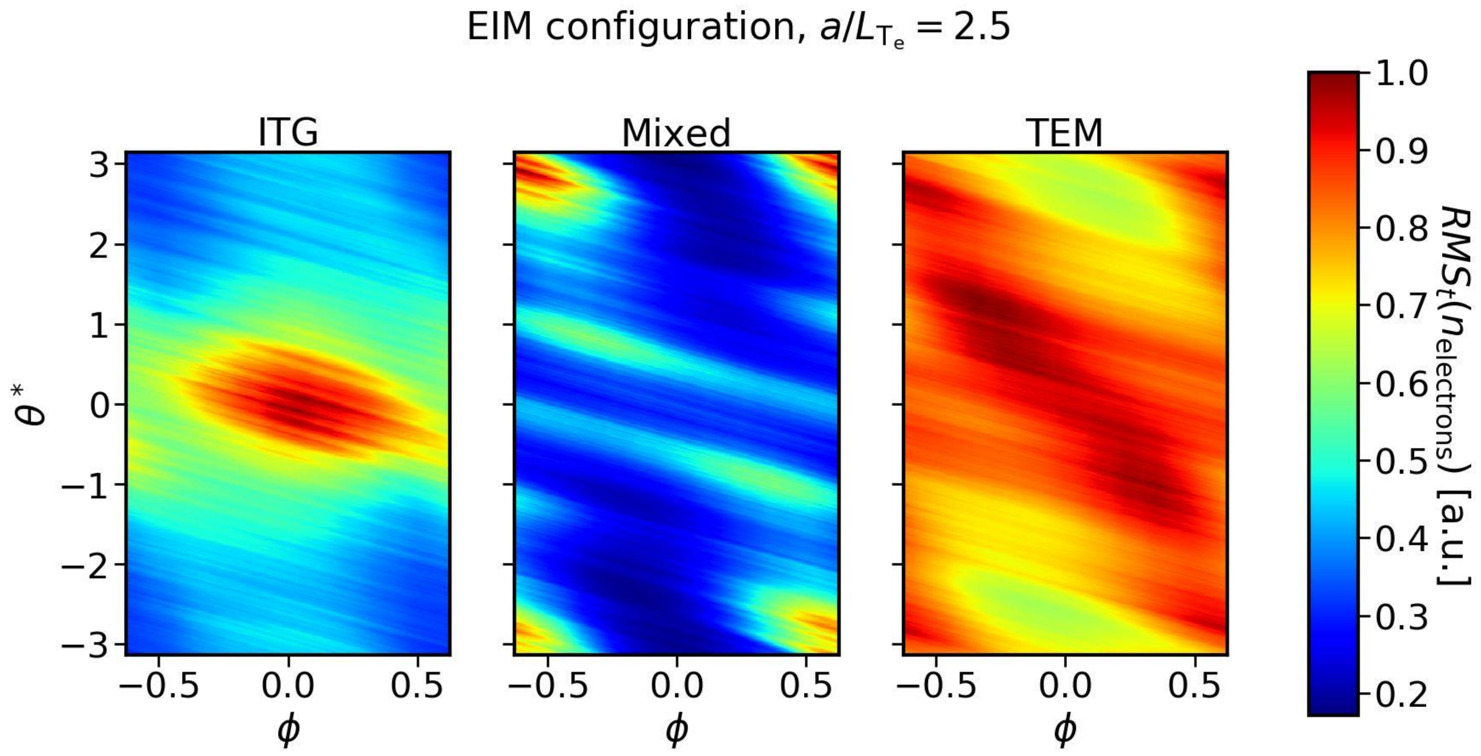
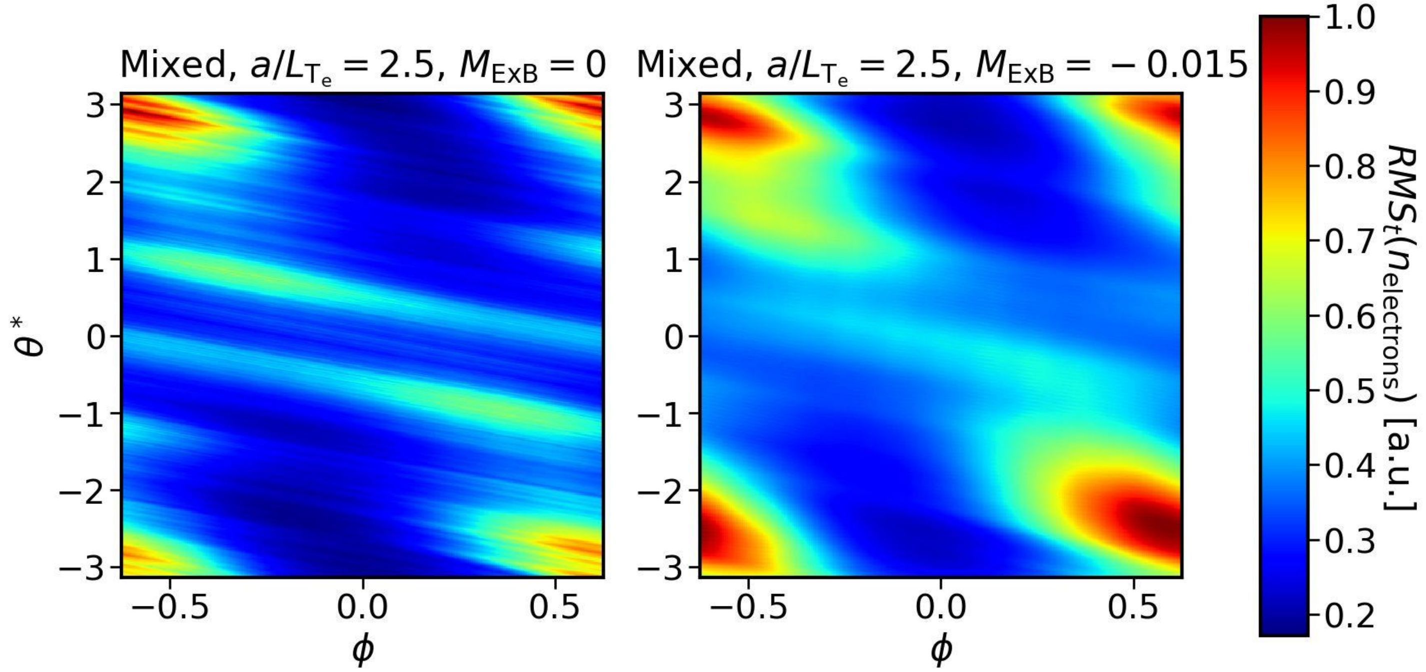


Mixed case with radial electric field

- Heat flux changes from $(Q_{ions}, Q_{electrons})/Q_{GB} = (1.7, 1.98) \rightarrow (1.26, 1.46)$

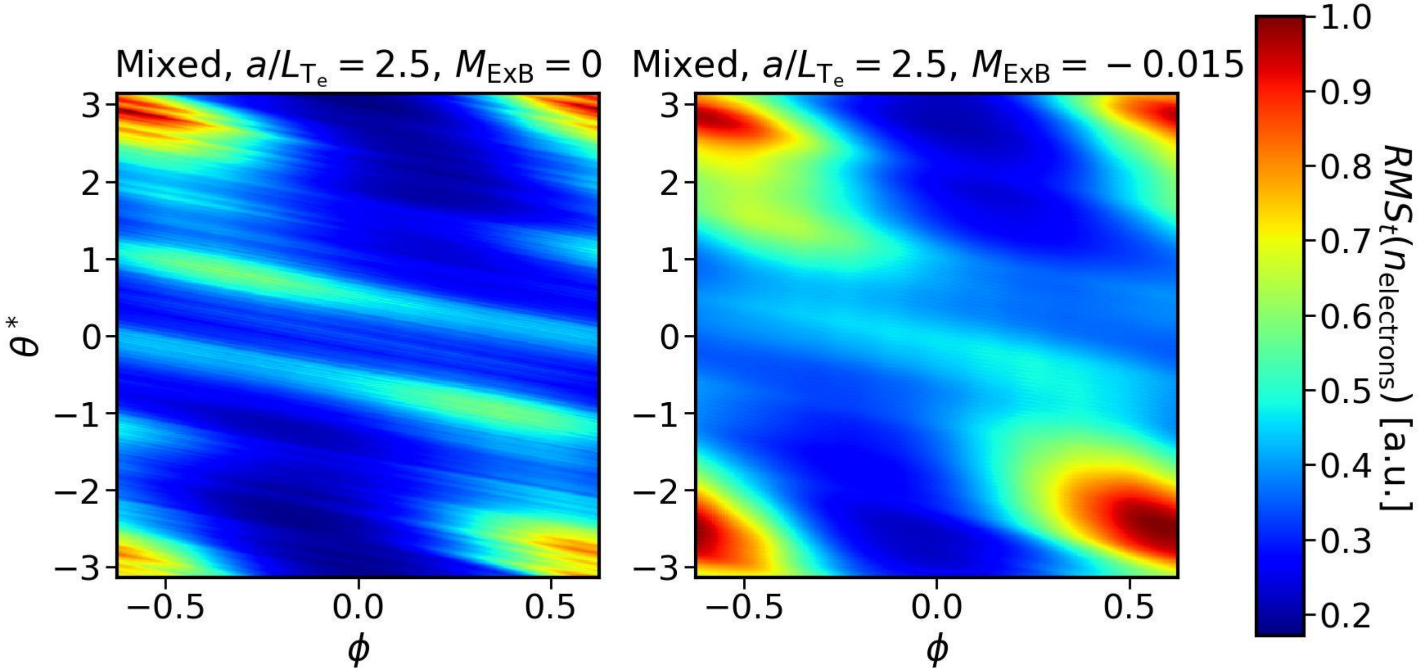
- Despite strong localisation, no significant displacement



Mixed case with radial electric field

- Heat flux changes from $(Q_{ions}, Q_{electrons})/Q_{GB} = (1.7, 1.98) \rightarrow (1.26, 1.46)$

- Despite strong localisation, no significant displacement



- Reason:
  if velocity in advective term is supposed to cause dislocation on equilibrium scales, then it should be comparable to equilibrium-scale velocity, i.e. c_s
  => would require $M_{ExB} \sim 1$

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4) FFS simulations with finite a/LTe show significant disagreement with FT simulations, highlighting the importance of surface-effects for realistic scenarios