MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

Pedestal turbulence characterization in AUG and JET

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[6]*See Mailloux et al 2022 (https://doi.org/10.1088/1741-4326/ac47b4) for the JET Contributors*

EUROfusion

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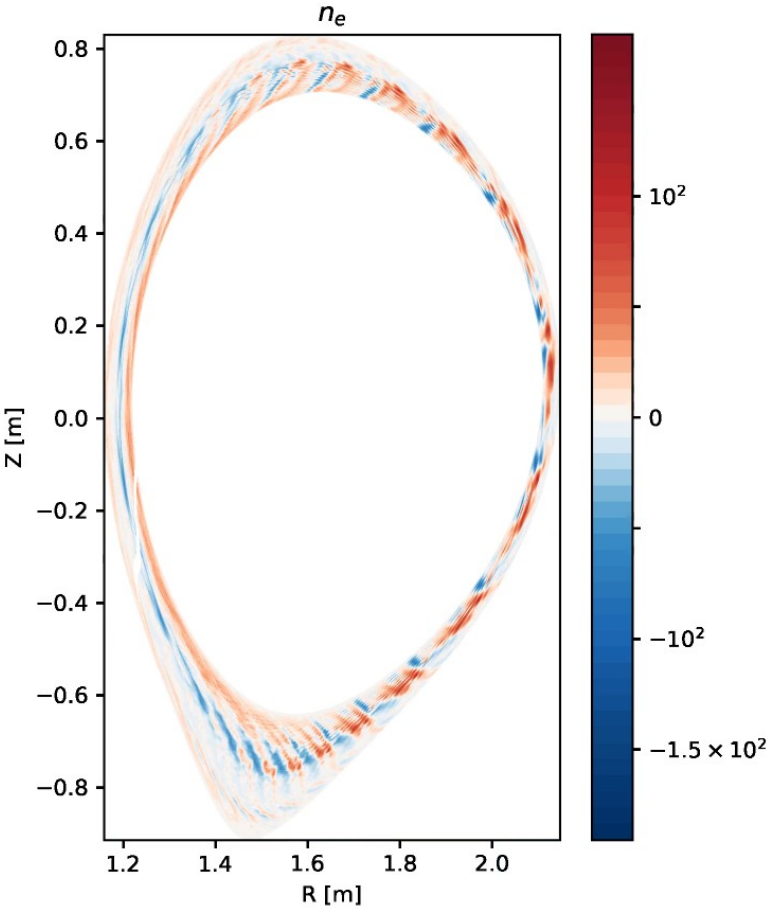
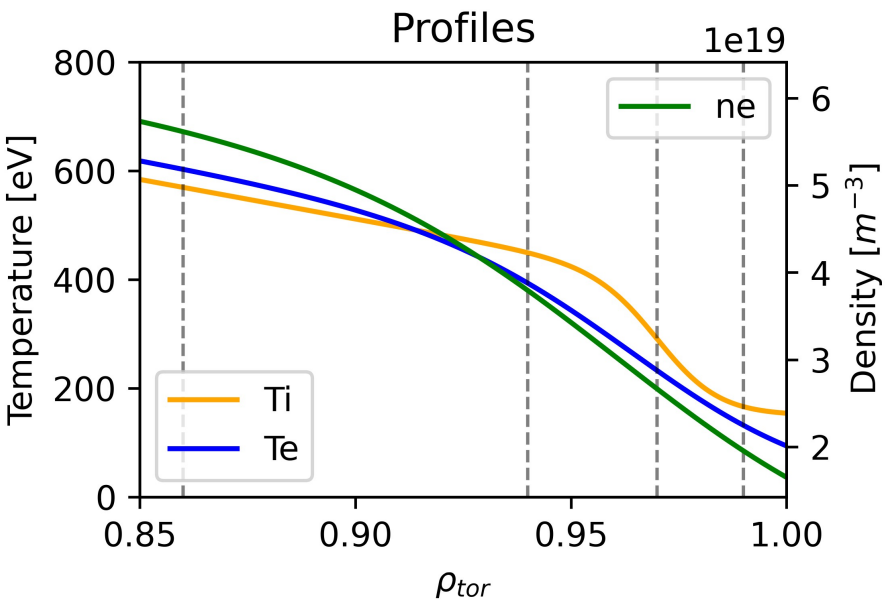
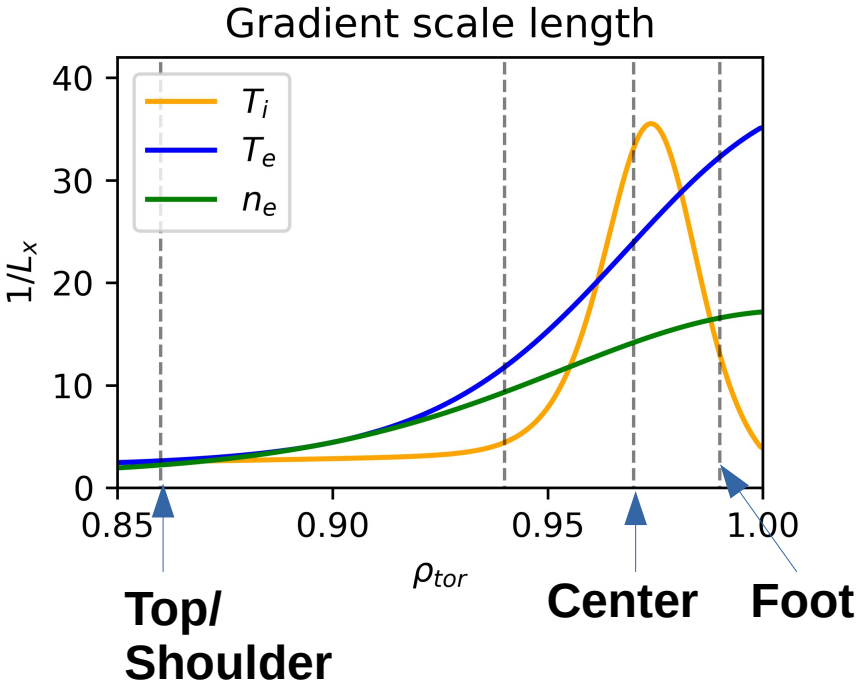
Part I: AUG pedestal



ELMy H-mode pedestal from AUG

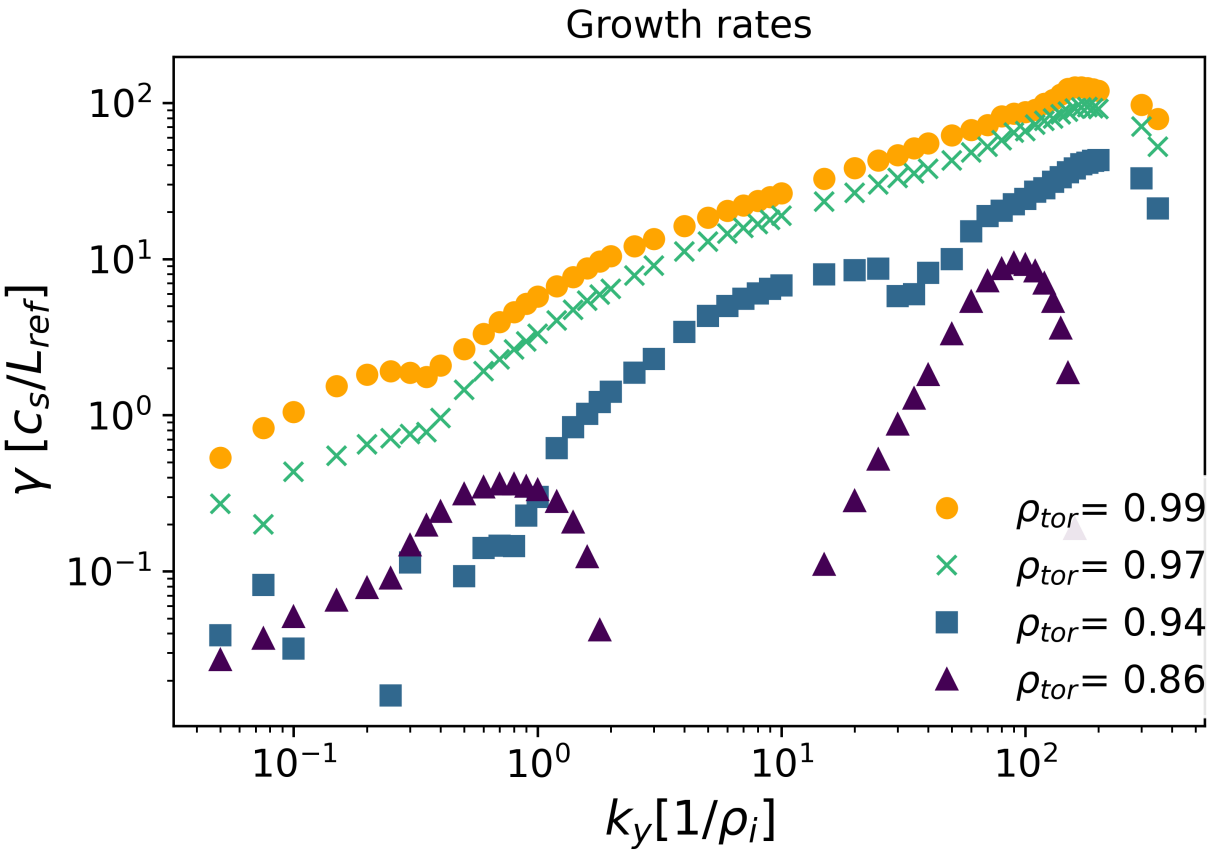




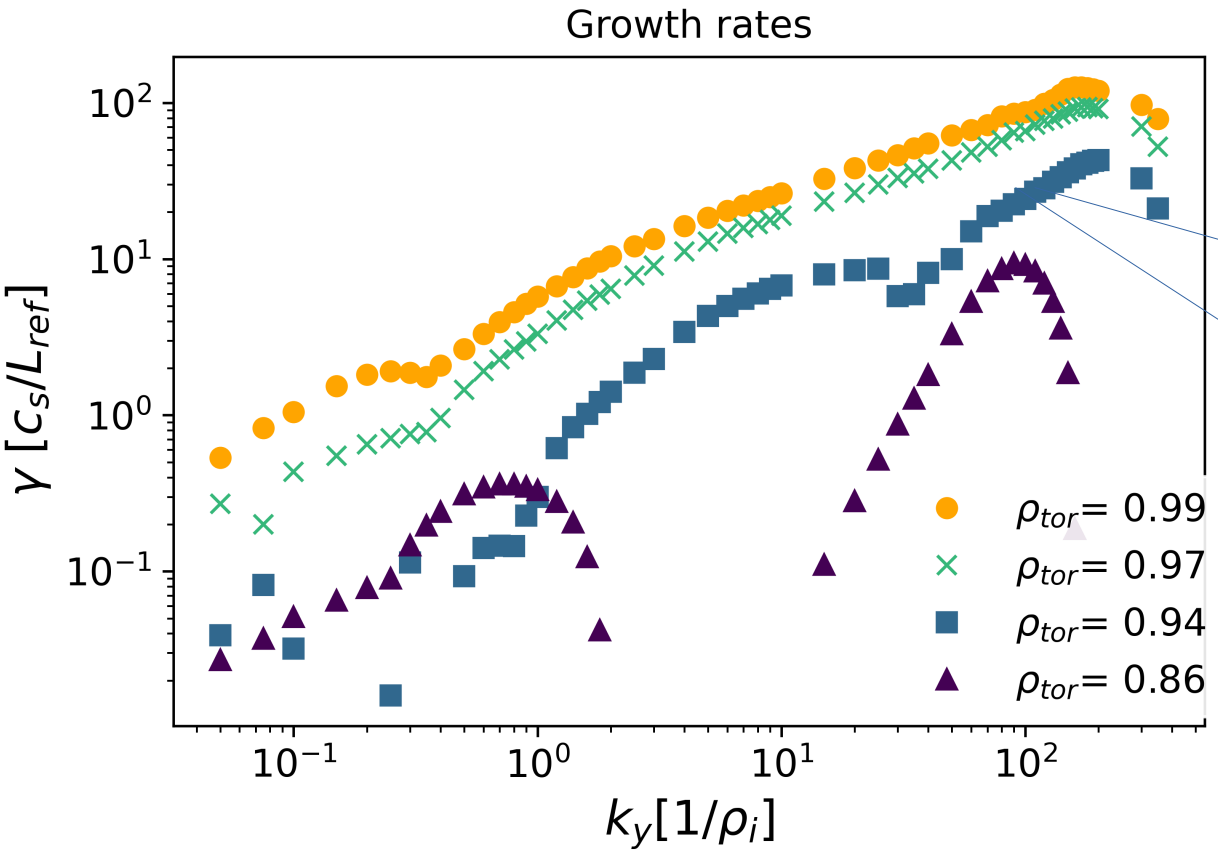
- Asdex Upgrade #31529 *[1]*
- NBI + ECRH heating, P_{tot} ~ 8.7MW
- On-axis B-field -2.5 T, plasma current 1MA
- ELM- synchronized profiles (6ms after ELM, almost pre-ELM)
- pressure-constrained magnetic equilibrium

[1] Cavedon et al., PPCF, 2017

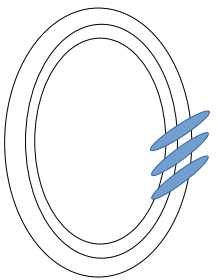
Linear instabilities

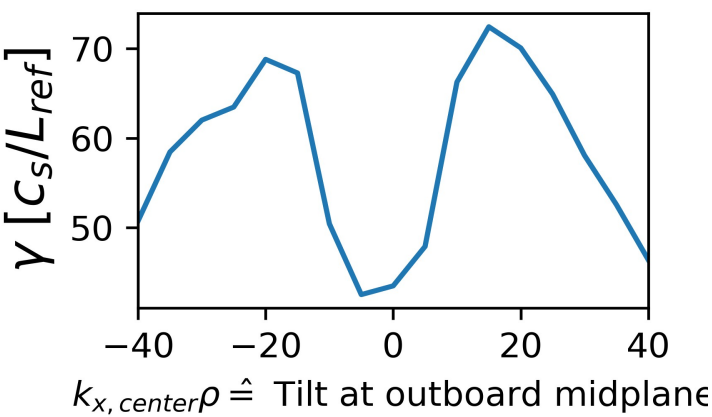


Linear instabilities

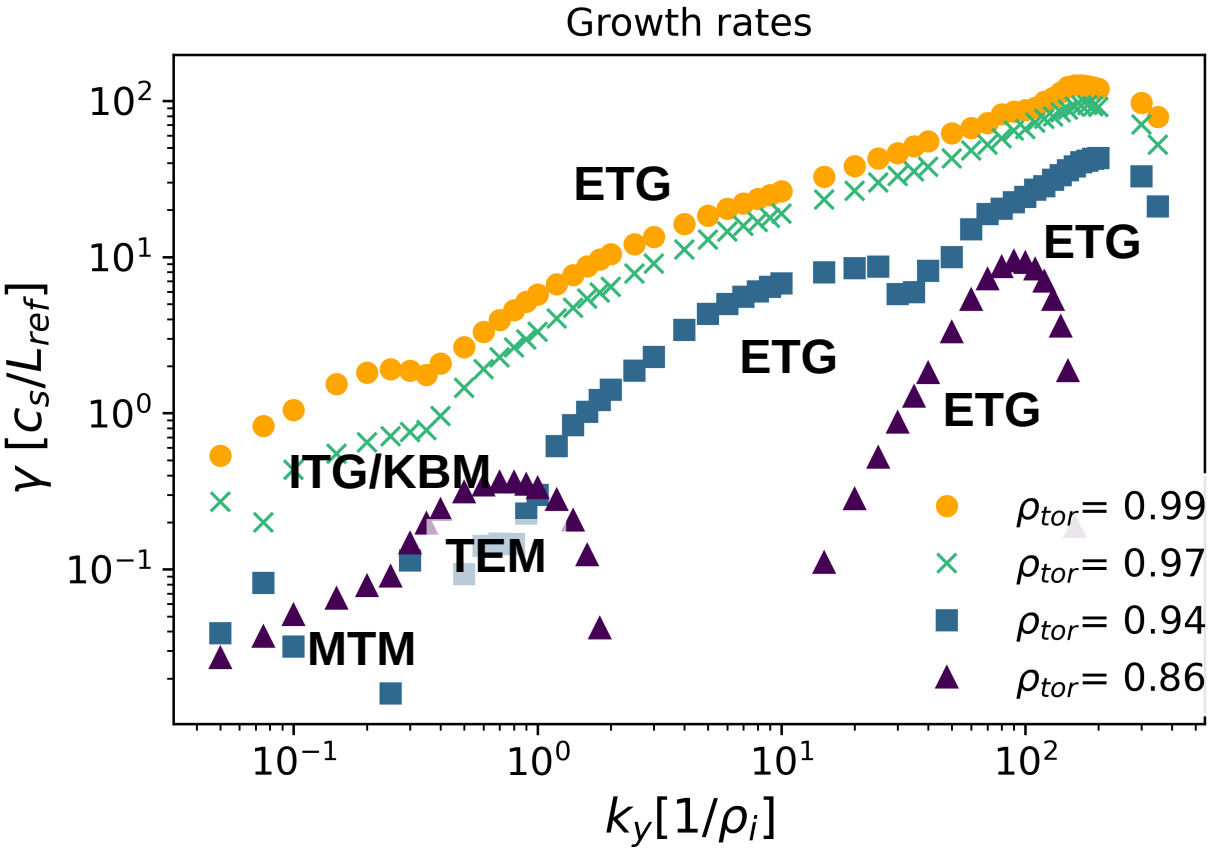


Growth rates are max. over k_x at outboard midplane.
e.g. ρ_{tor} = 0.97, k_y = 110





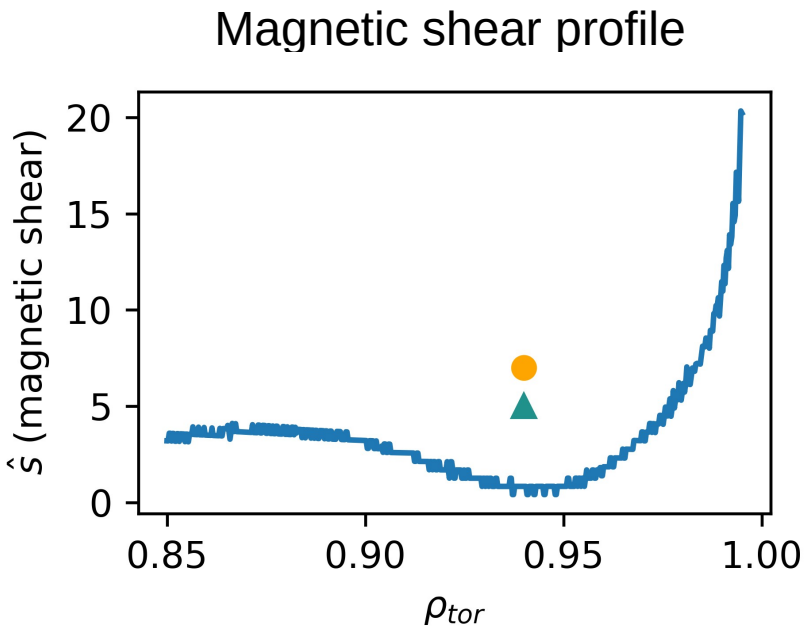
Linear instabilities

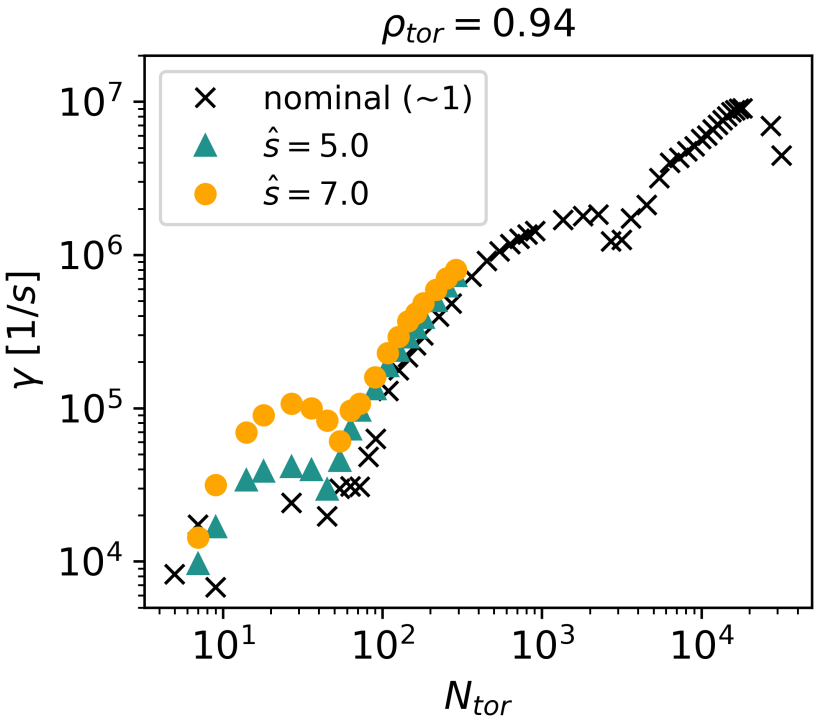


- **Ion scales:**
  Top: TEM/MTM → Center: ITG/KBM
  Growth rate gap at ρ_{tor}= 0.94 (blue)
- **Electron scales:** ETG
  with additional intermediate k_y
  ETG instabilities towards pedestal center
- Overall growth rates increase towards pedestal center/ foot

TEM: Trapped Electron Mode
MTM: Micro Tearing Mode
ETG: Electron Temperature Gradient Mode
ITG: Ion Temperature Gradient Mode

Pressure and magnetic shear effect



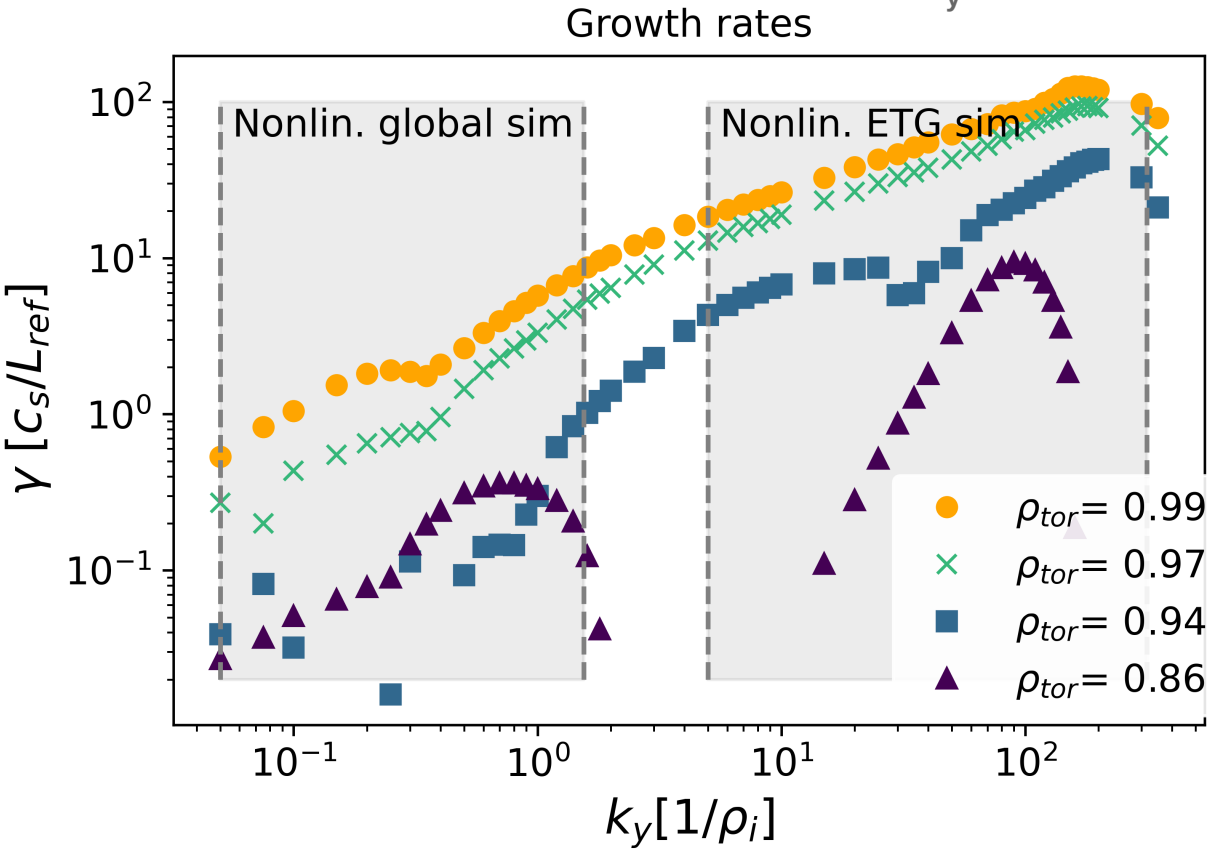


At ρ_{tor}= 0.94 ion scale growth rates increase with increasing(!) magnetic shear

→ In 2nd stability region at nominal parameters

Linear instabilities

Nonlinear simulation domains in k_y:



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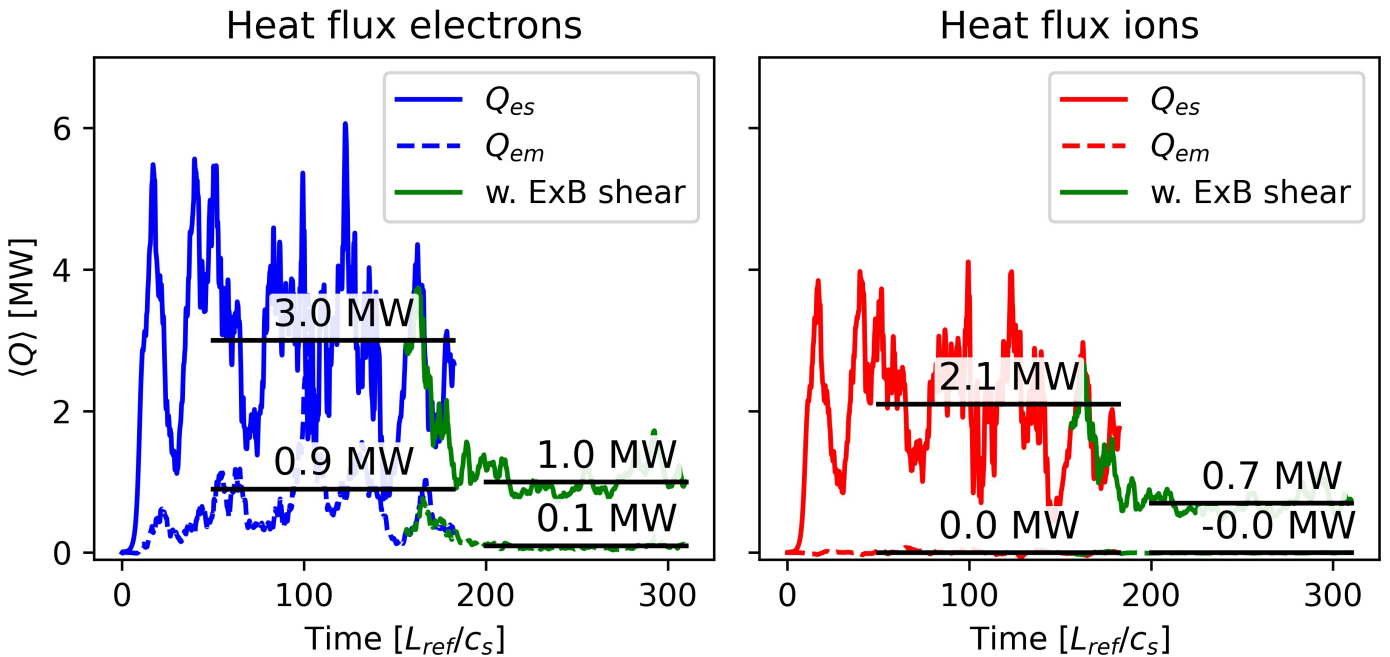
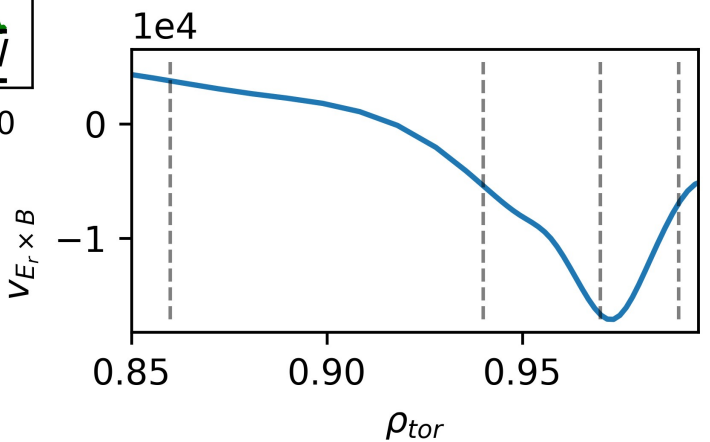
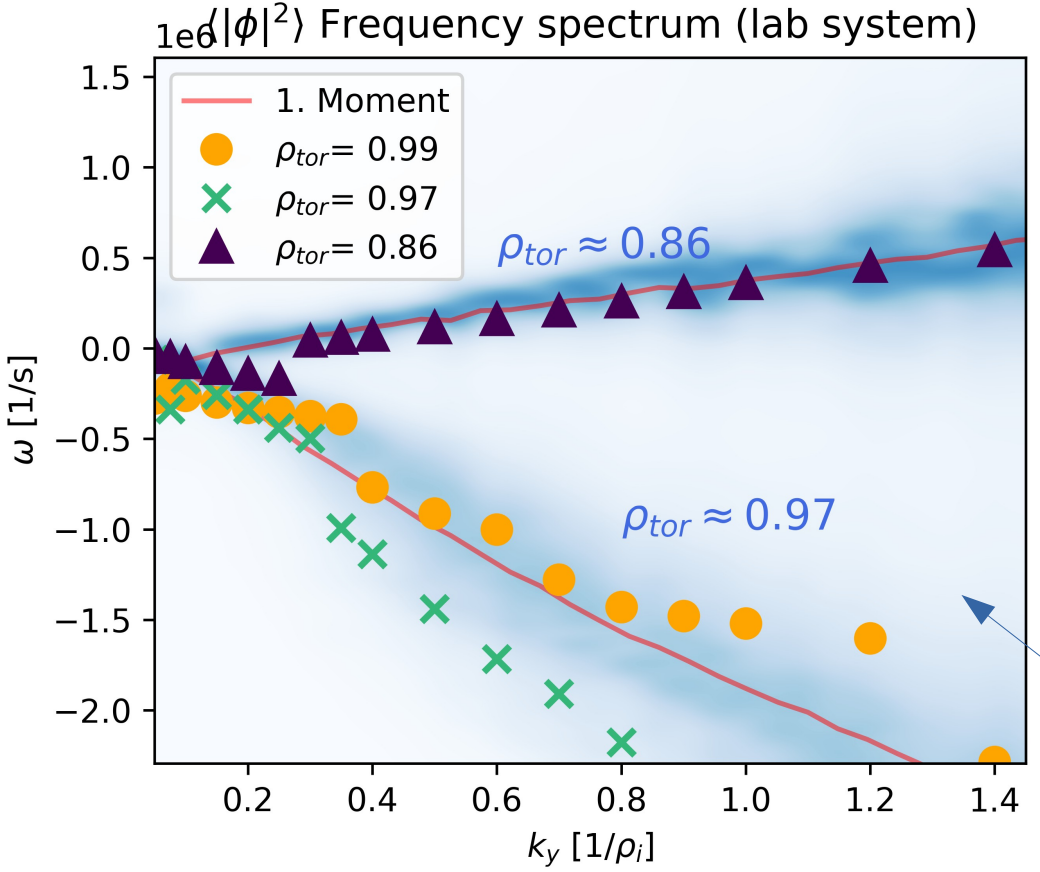
Global, ion scale: Turbulent heat fluxes



- Electrostatic heat flux dominates
- ExB shear reduces heat fluxes by ~3



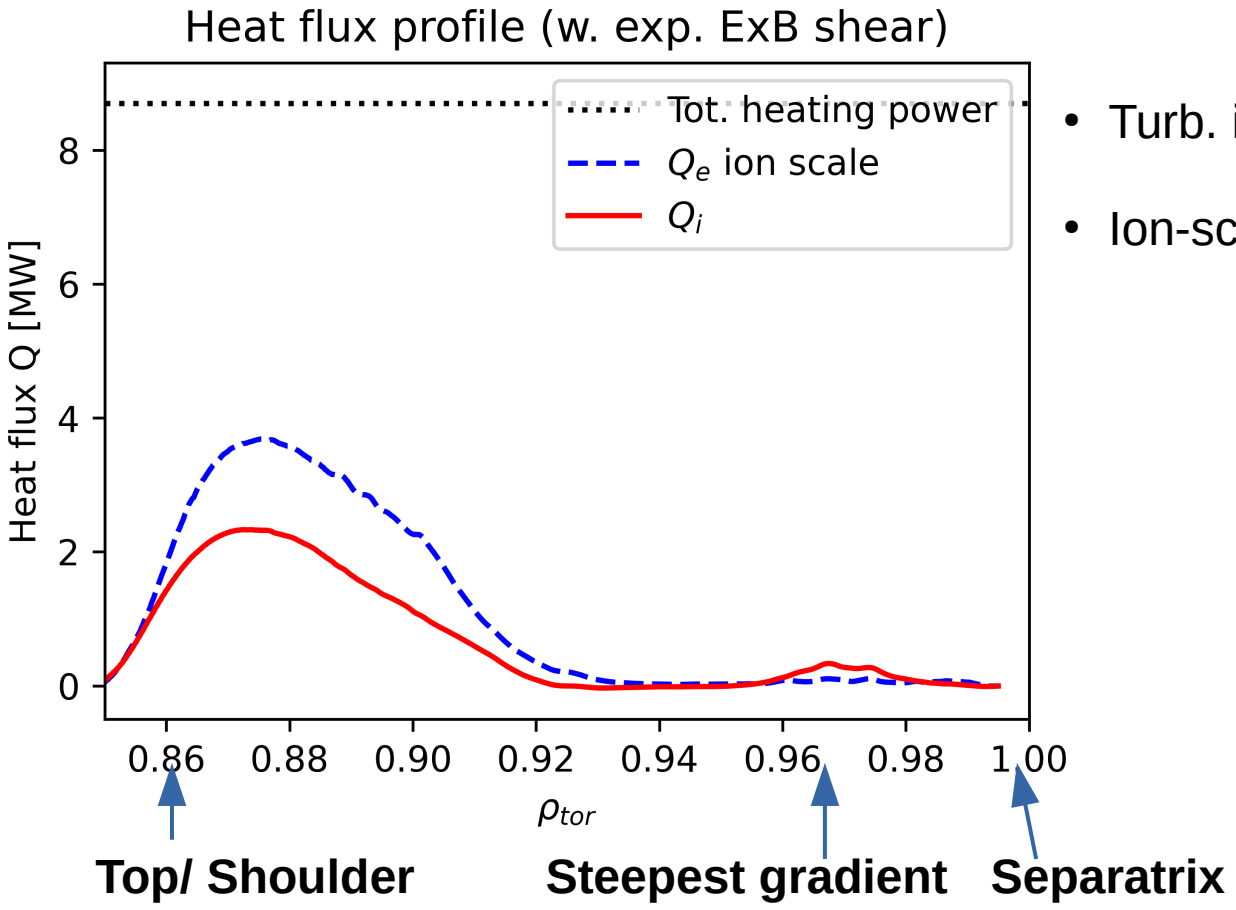
Connecting linear instabilities and nonlinear modes



- Linear frequencies remain present at pedestal top and center
  → encouraging for quasi-linear models in pedestal
- MTM is suppressed in global, nonlinear simulations

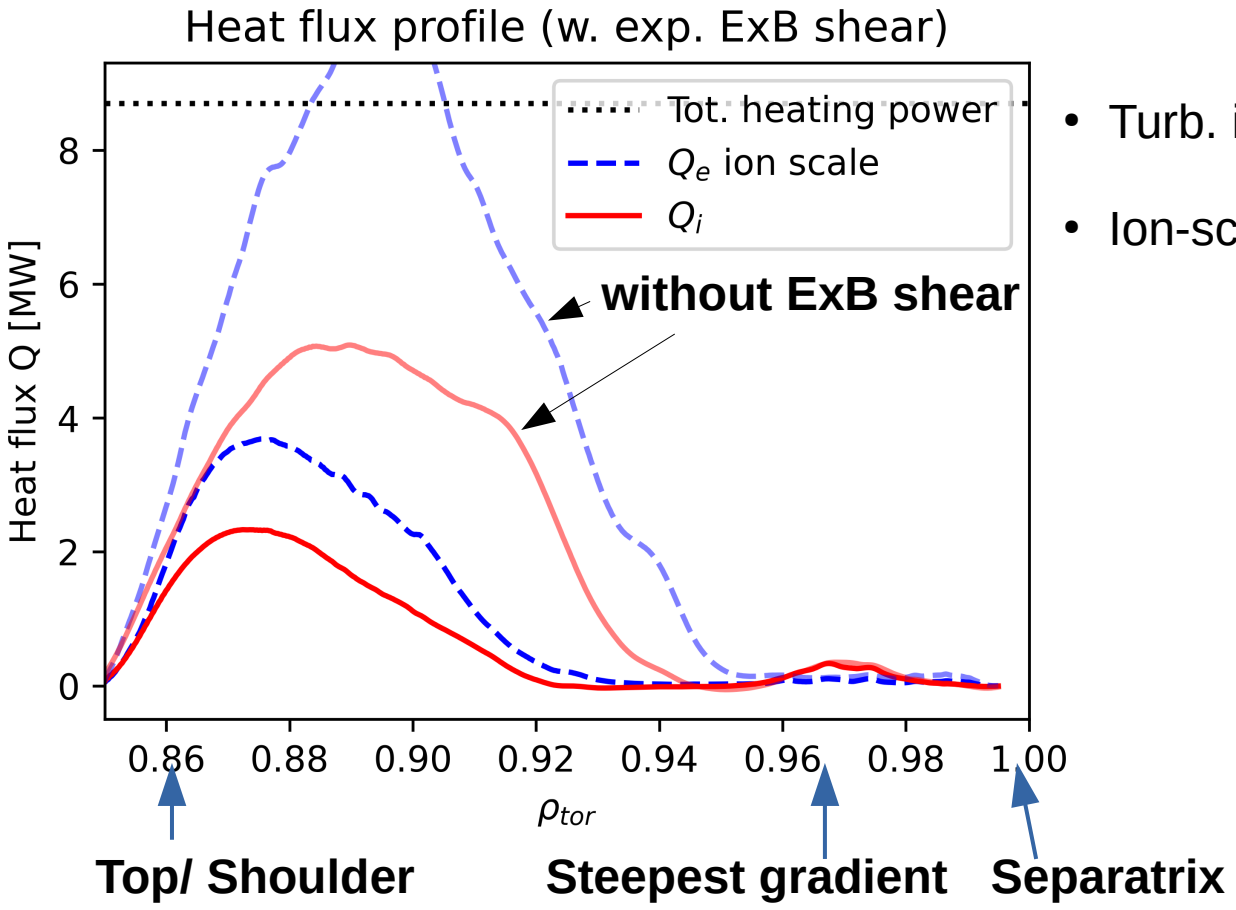
Blue background: Nonlinear frequency distribution

Heat flux structure in pedestal



- Turb. ion heat flux vanishes in center
- Ion-scale electron heat flux vanishes as well

Heat flux structure in pedestal



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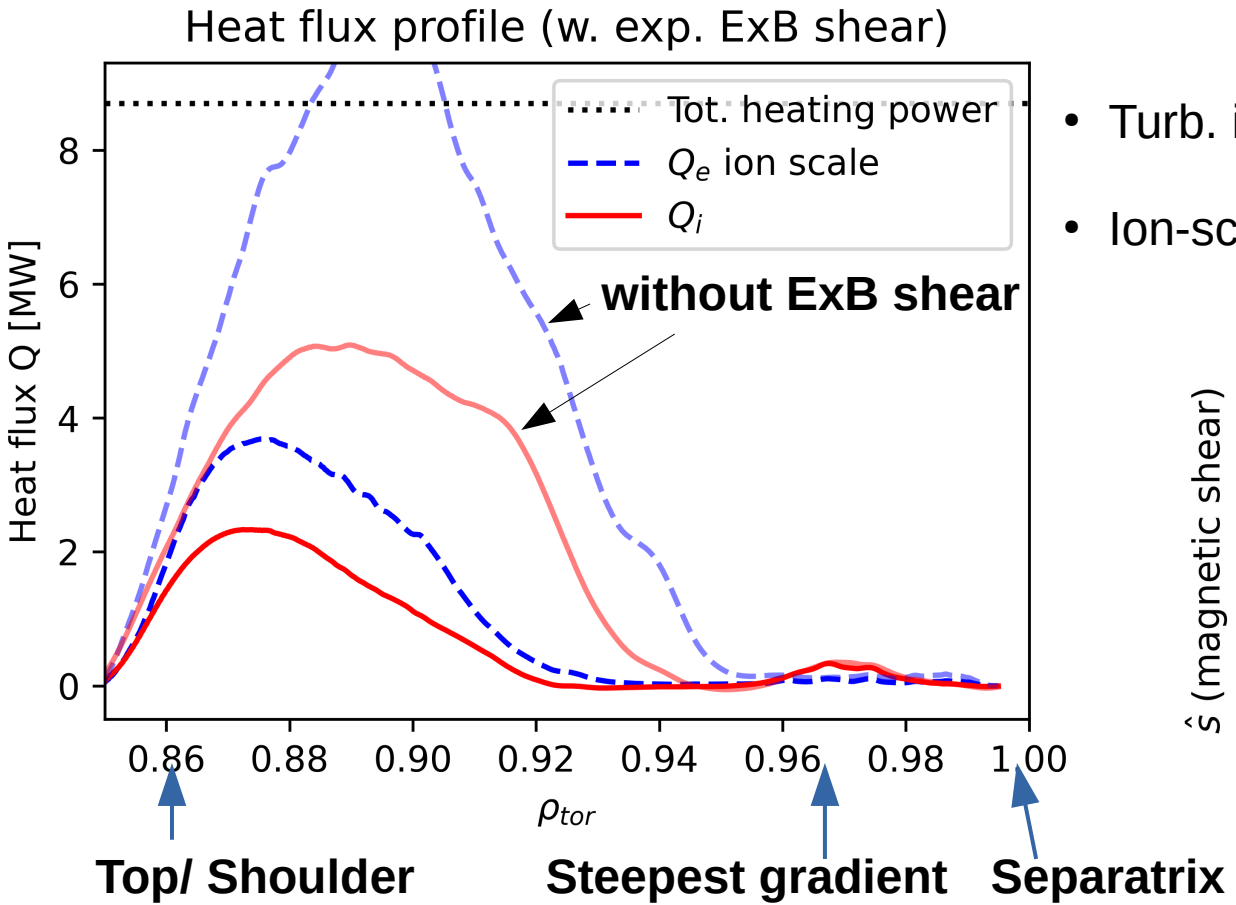

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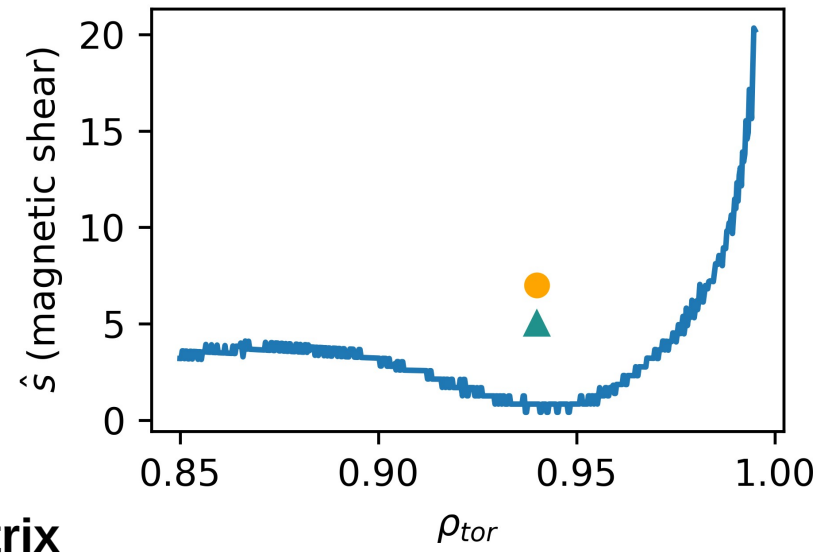
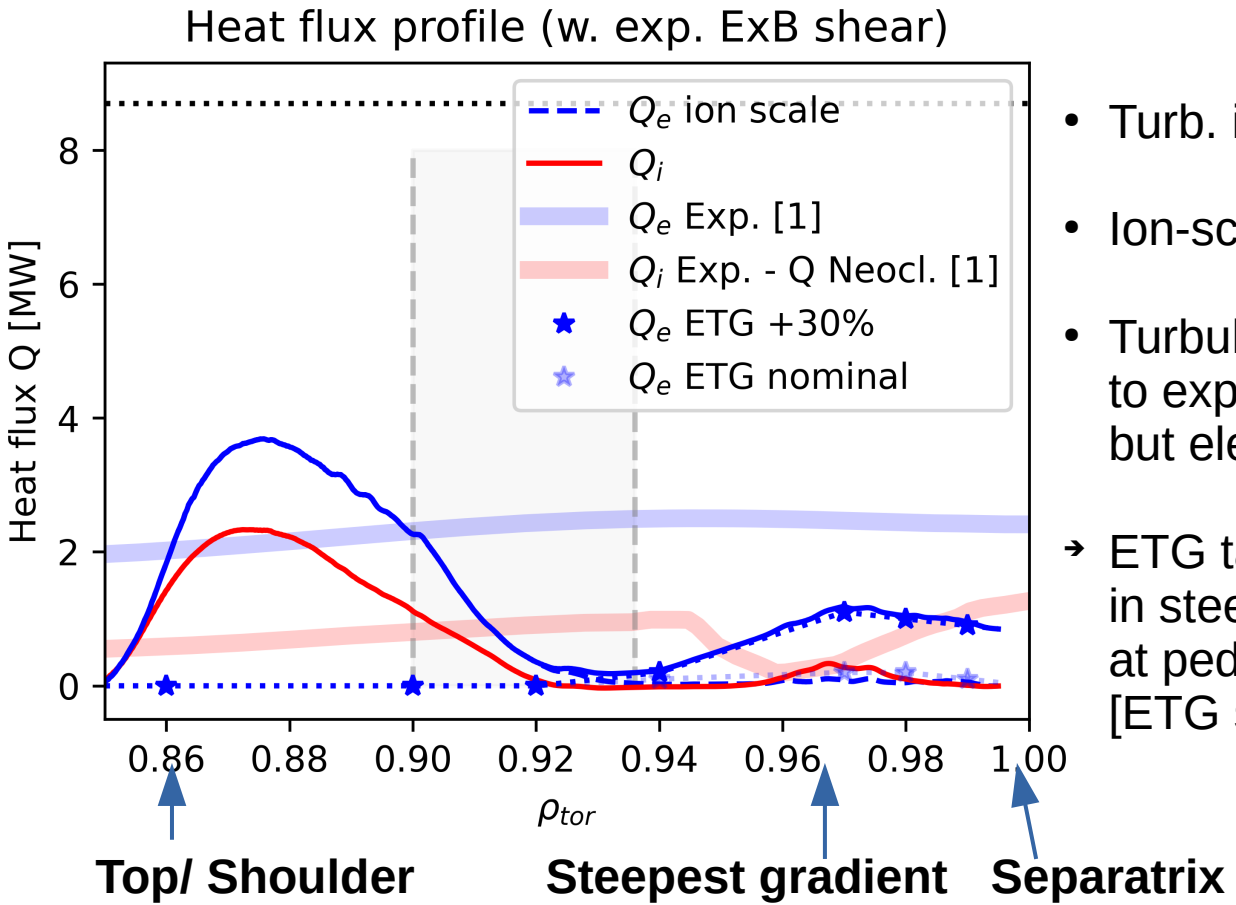


Heat flux structure in pedestal

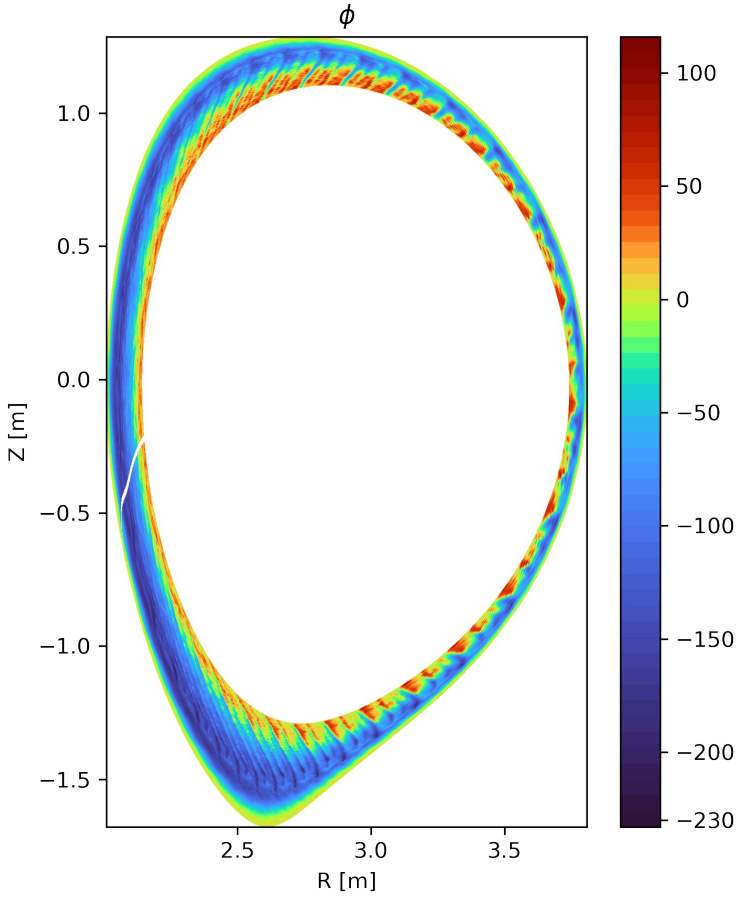


- Turb. ion heat flux vanishes in center
- Ion-scale electron heat flux vanishes as well
- Turbulent heat flux levels are comparable to experimental results [1], but electron heat flux in center missing?

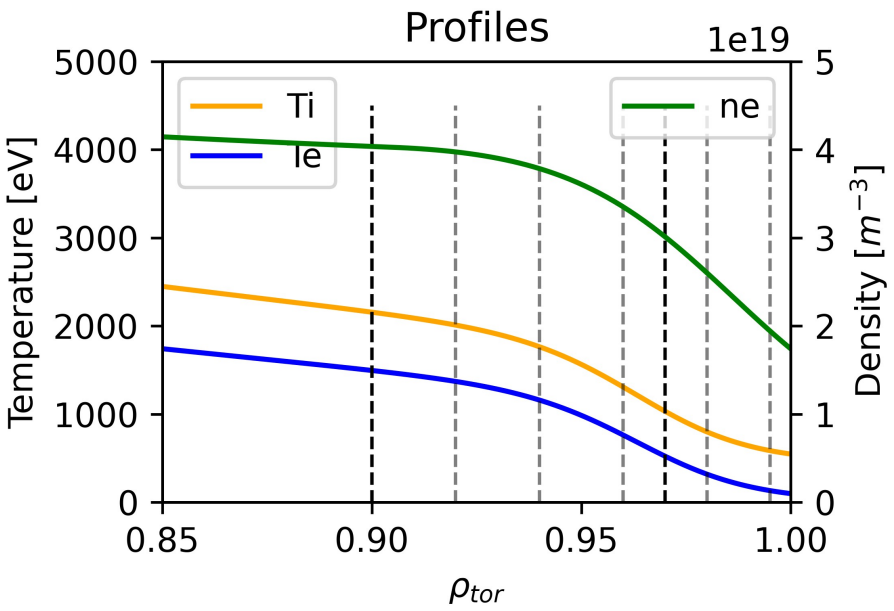
➔ ETG takes over electron heat transport in steep gradient region from TEM at pedestal top. [ETG sims currently under review]

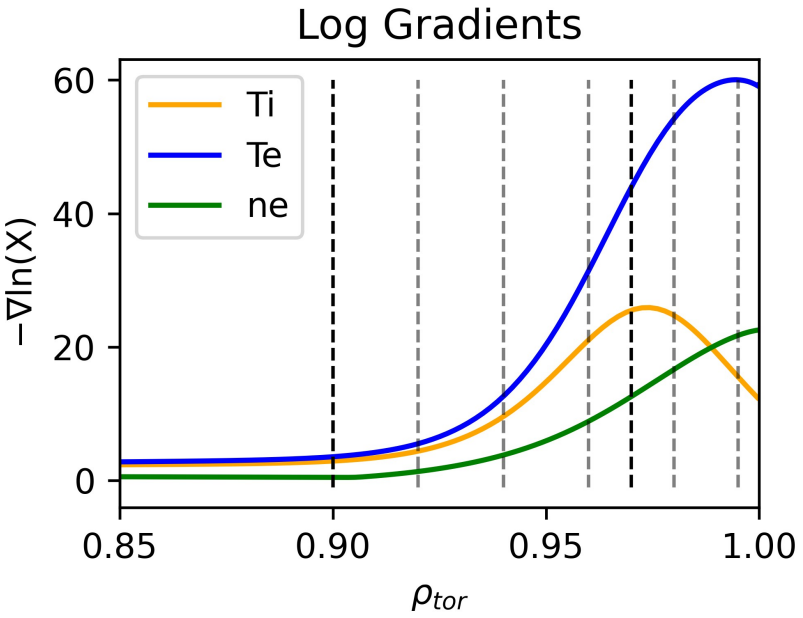
[1] Viezzer et al., PPCF, 2020

Part II: JET pedestal



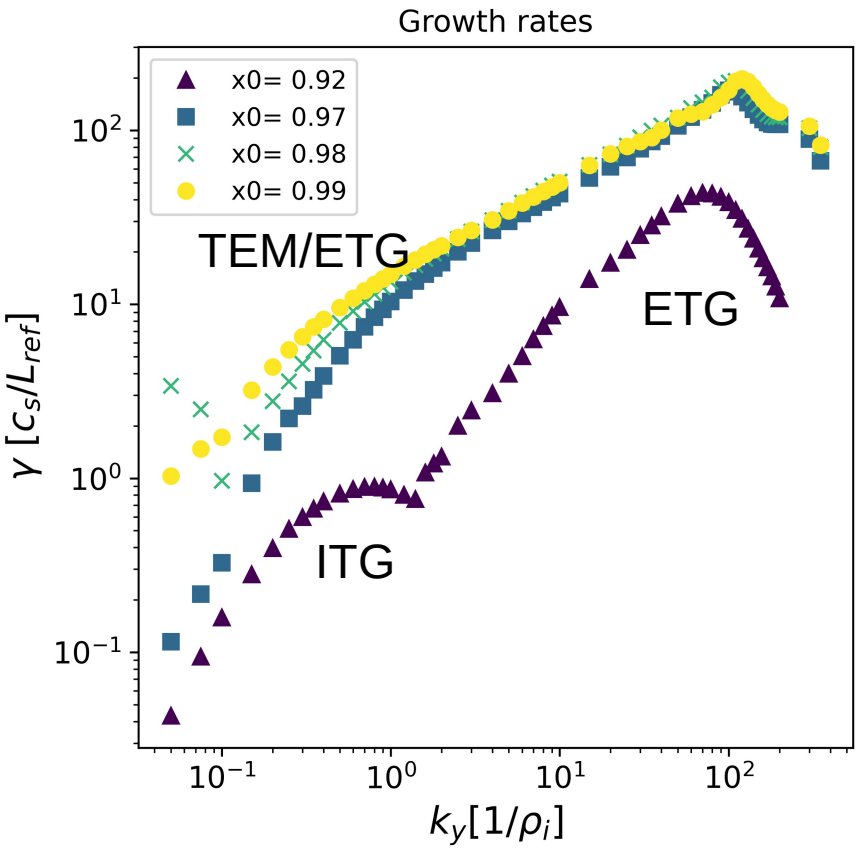
Profiles





- ELMy H-mode JET #97781 (hybrid scenario, high beta)
- P_{tot}= 33 MW

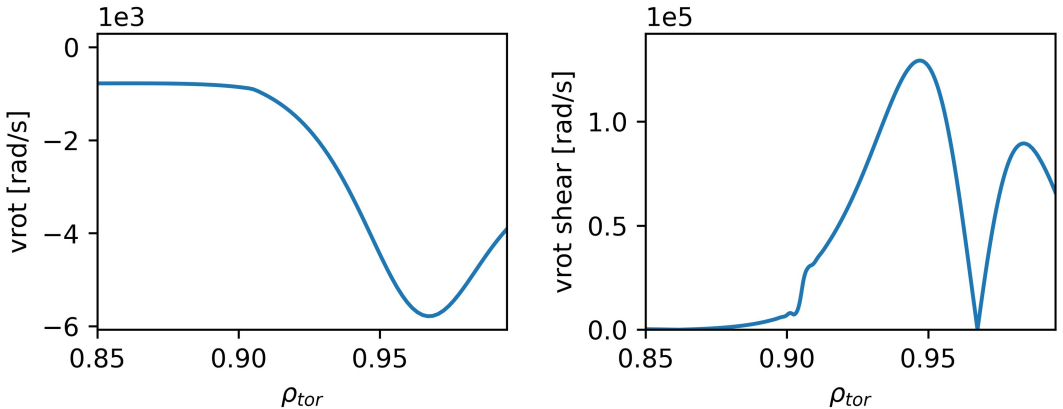
Linear instabilities



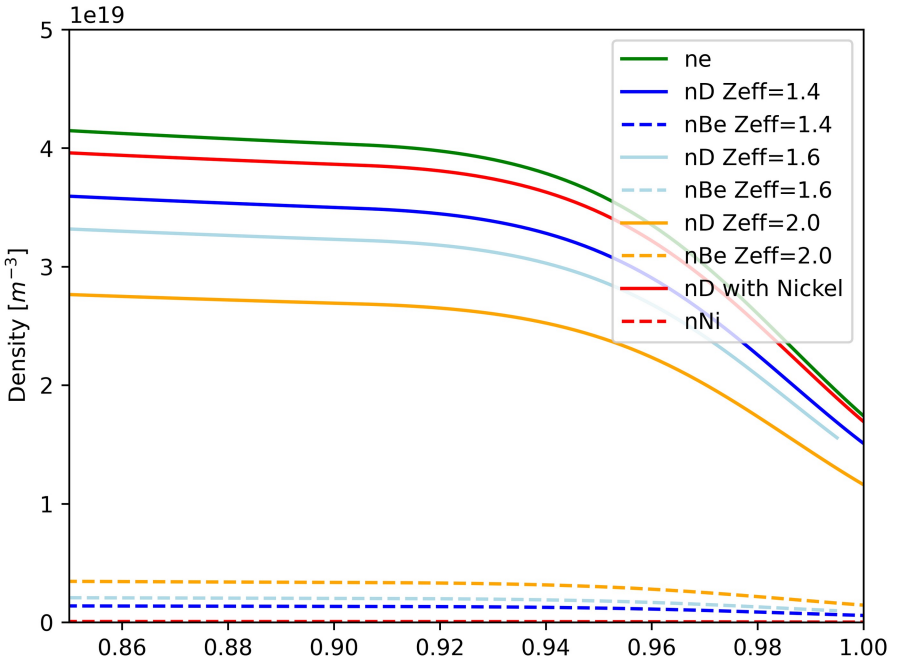
- Pedestal top:
  ITG (in contrast to TEM @ AUG)
  & ETG
- Pedestal center / foot:
  TEM/ETG +
  possibly KBM/ MHD-like modes
  at largest scales
- ITG presence consistent with
  Hatch et al, Nucl. Fusion, 2019
  Hatch et al, Nucl. Fusion, 2017

ExB shear and impurities

V_{rot} due to E_r
(neoclassic approximation using D. Hatch script):

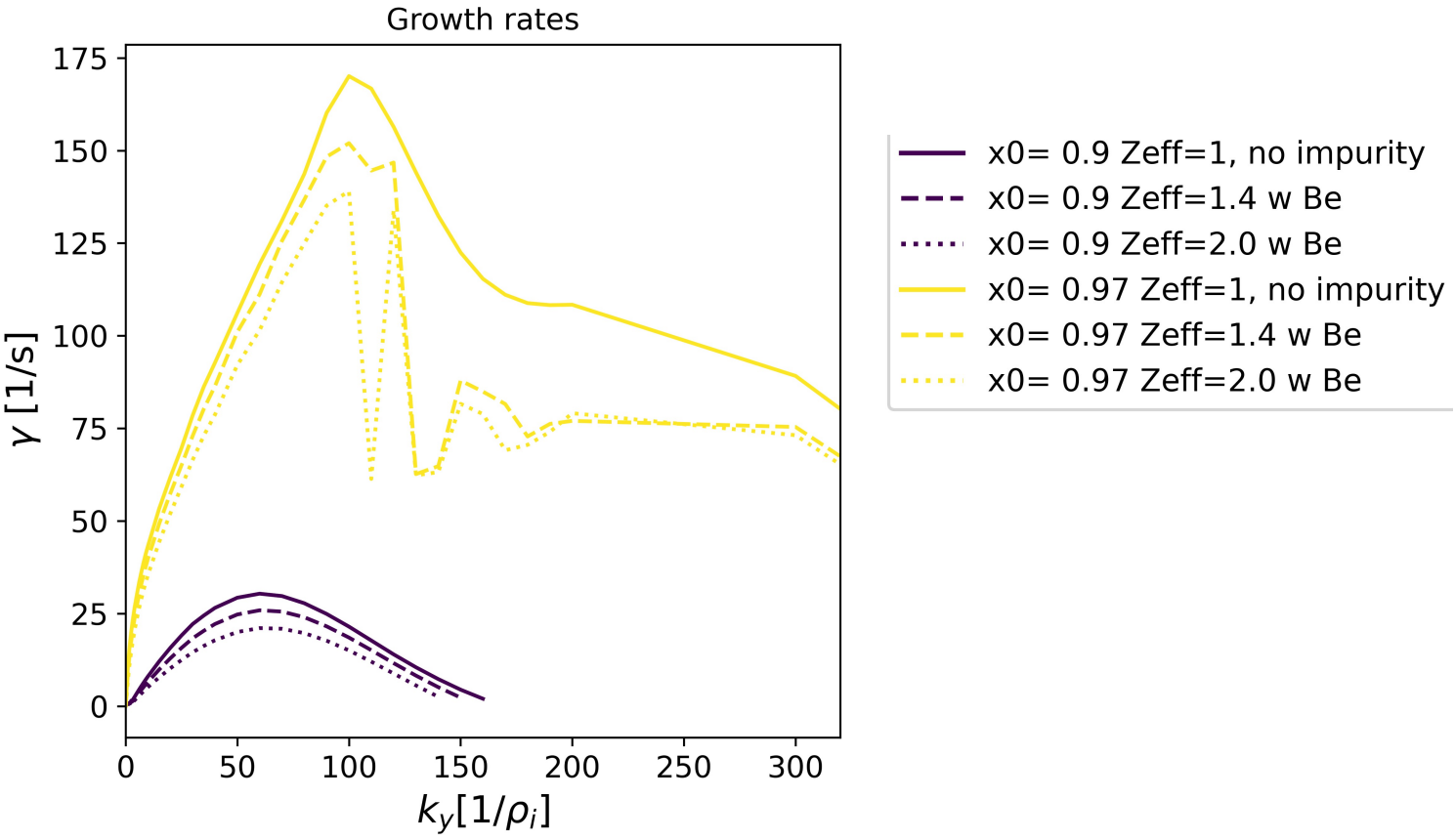


Some impurity variations within experimental uncertainty:

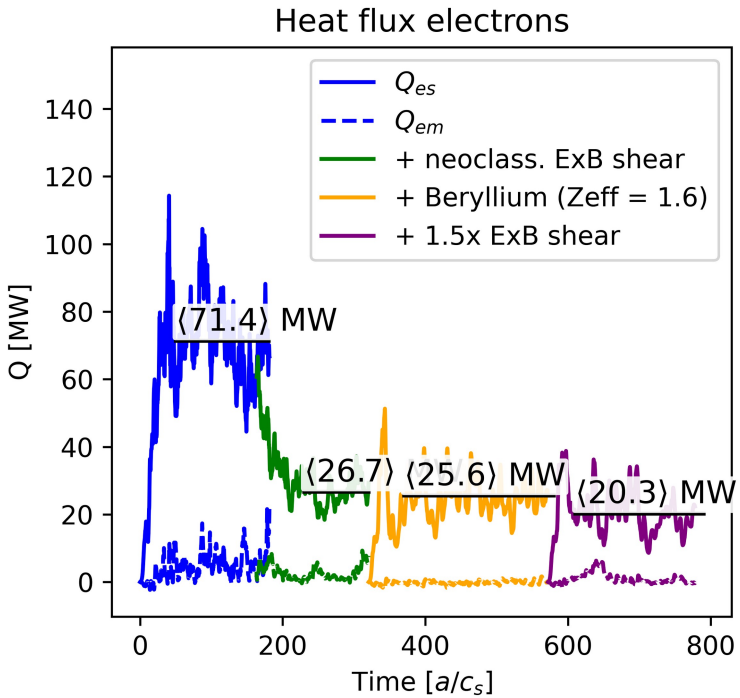


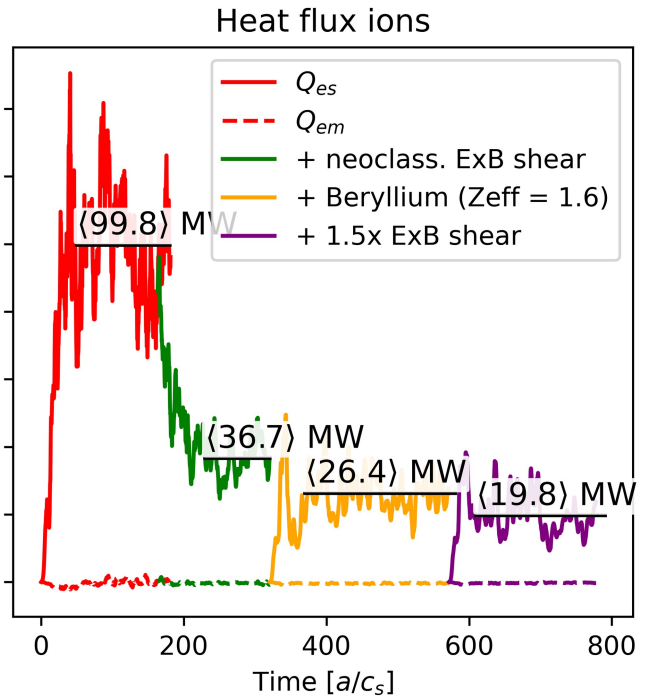
Focus on Be, because it has strongest main ion dilution for given Z_{eff}

Impurities lower growth rates



Pedestal transport sensitive to ExB shear and impurities

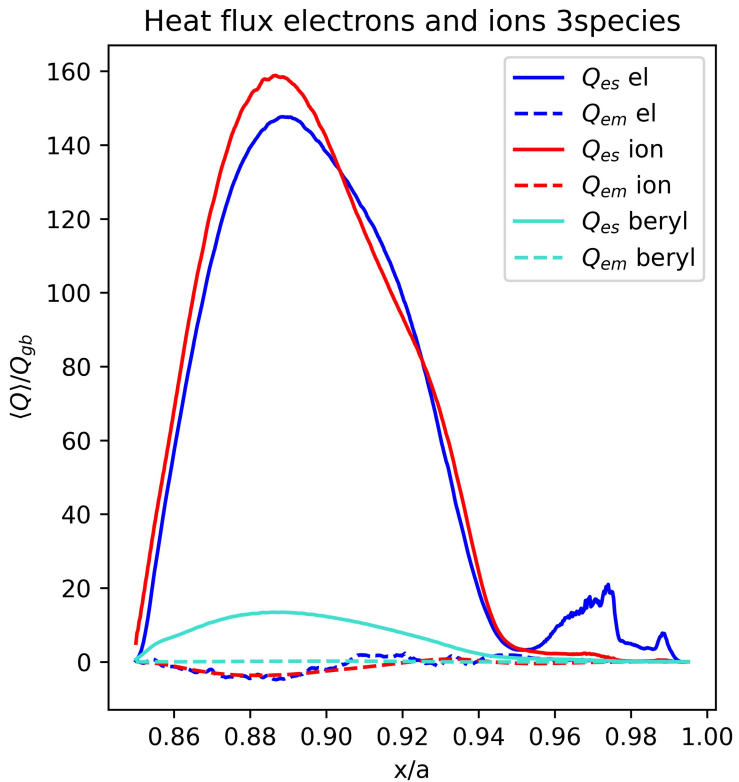


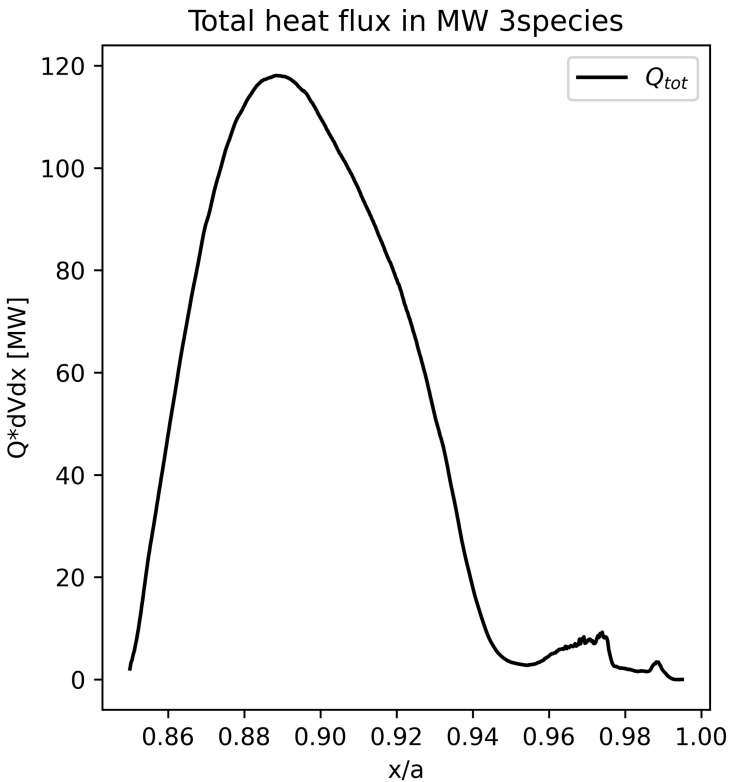


Global, nonlinear, 3 species GENE simulations

- Dominantly electrostatic heat flux
- increased relative ion heat flux in comparison to AUG
- ExB shear and impurities decisive in setting turbulent transport level

Heat flux profile





- Similar structure to AUG but smaller region of vanishing heat flux
- Local electron heat flux peak in steep gradient region
- With current settings unreasonably high peak heat flux
- Small-scale ETGs pending

Conclusions

- **Transport in AUG #31529 pedestal is multi-channel & multi-scale:**
  - Electrostatic TEM with electromagnetic MTM contributions at pedestal top
  - Reduction of growth rates and transport locally by interplay of low magnetic shear and increasing pressure gradient
  - ExB shear strongly suppresses heat flux in all ion-scale(!) channels
  - Electron heat flux changes scale across pedestal: From TEM to ETG
- **Transport in JET #97781:**
  - Dominant ITG contribution at pedestal top
  - Sensitive to ExB shear and impuritity level (ion transport)

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ASDEX Upgrade

Thank you for your attention!

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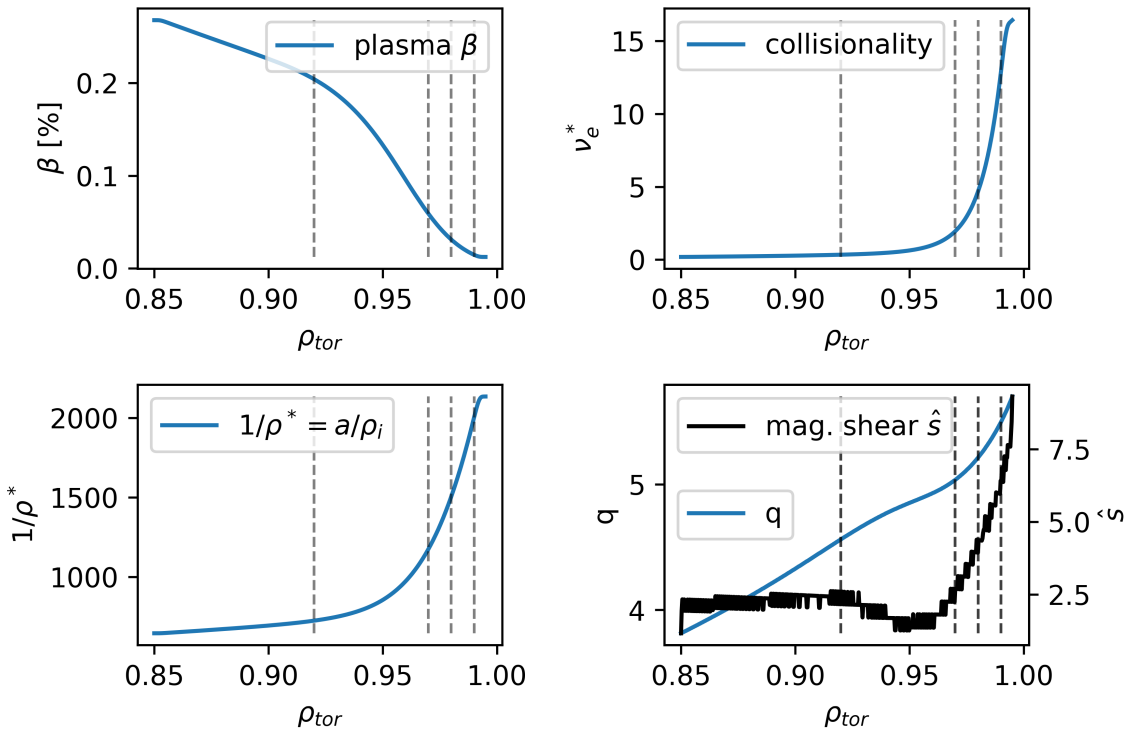
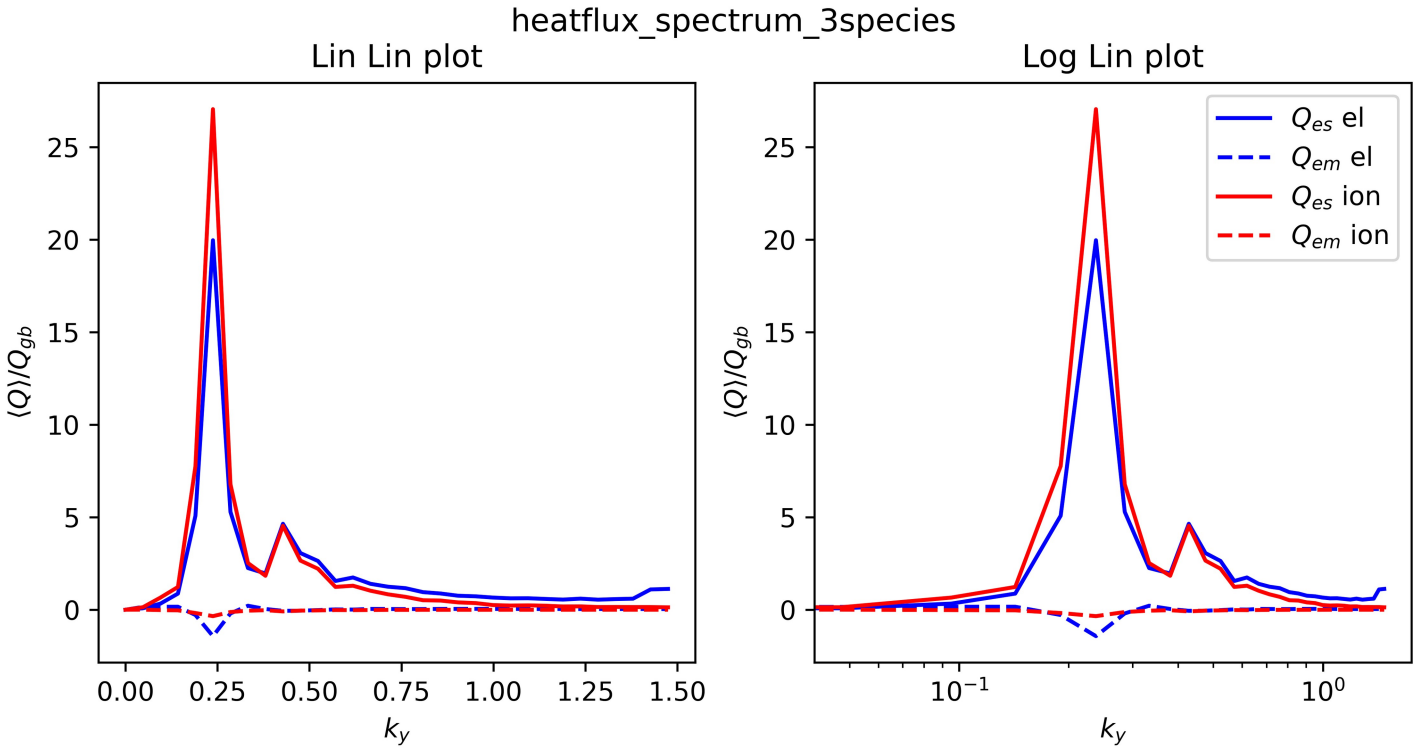
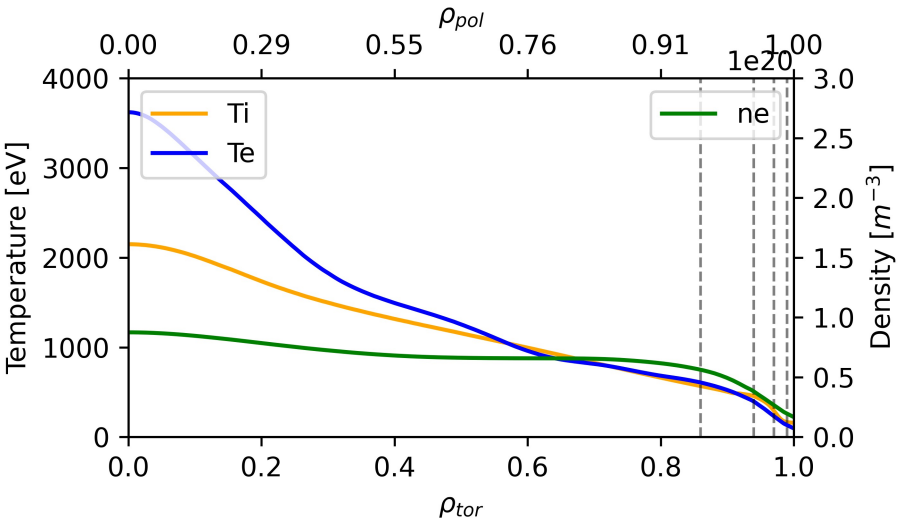
Other profiles JET



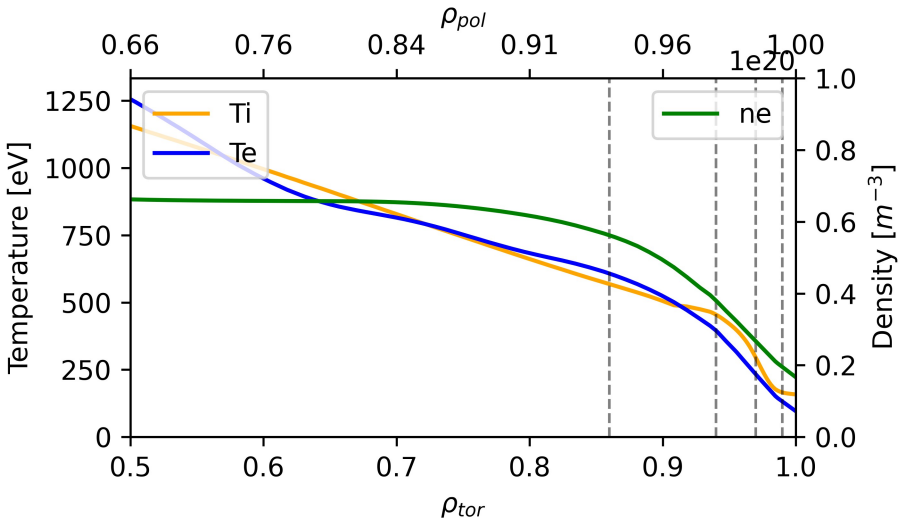
Heat flux spectrum JET



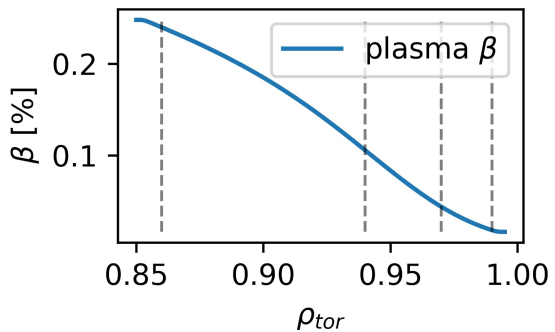
Full profiles AUG

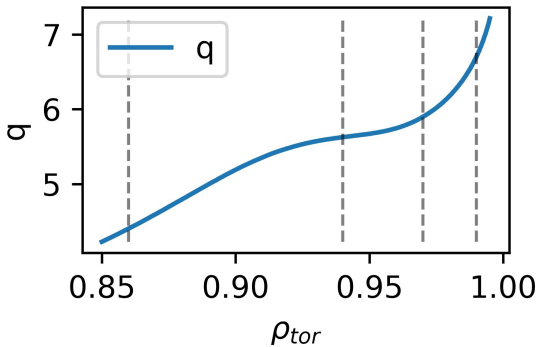


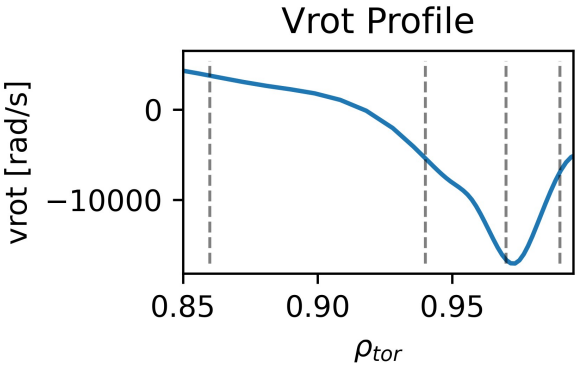
Zoom in:

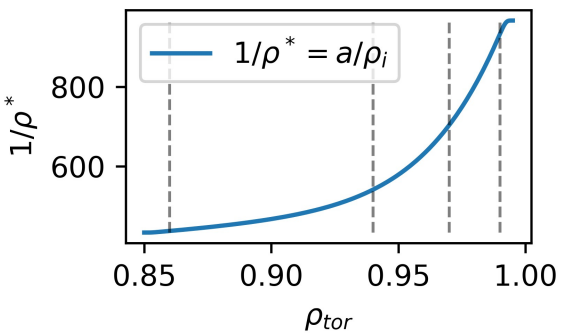


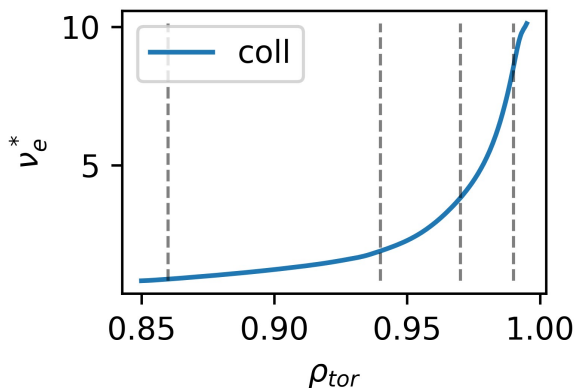
Other profiles AUG

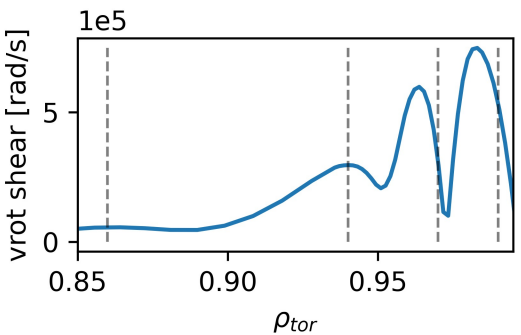




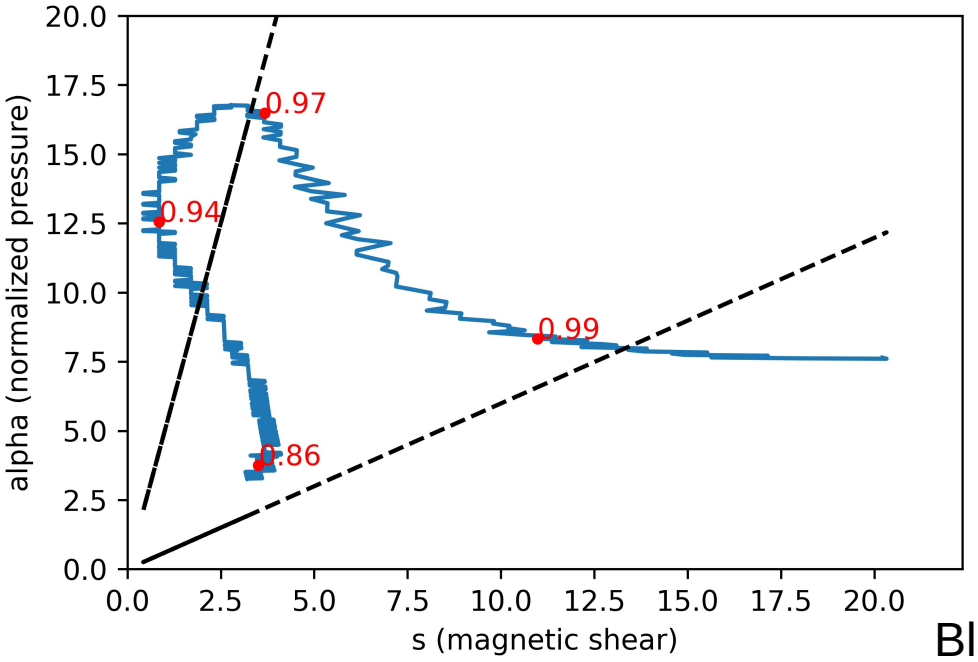








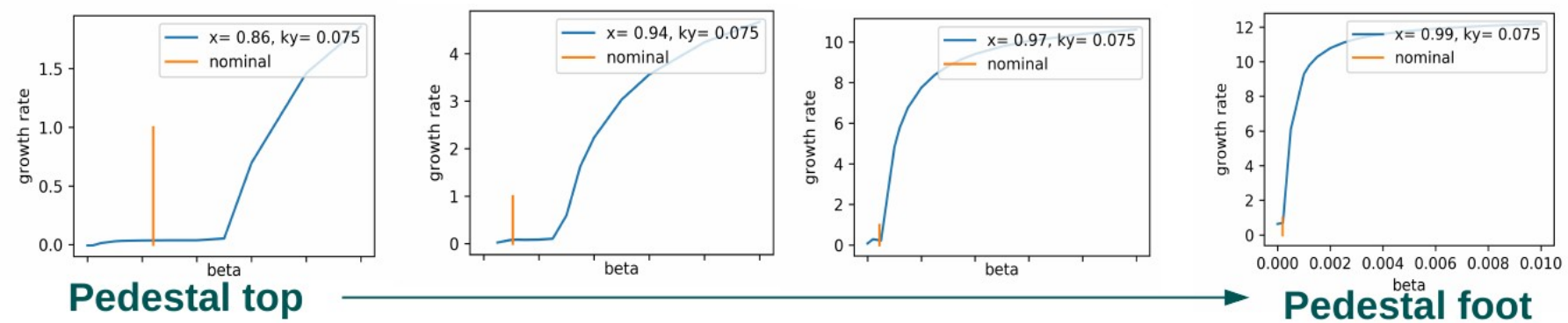
Pedestal in s-alpha



Black lines not accurate. Just an Illustration of possible stability boundaries.

Close to linear KBM threshold

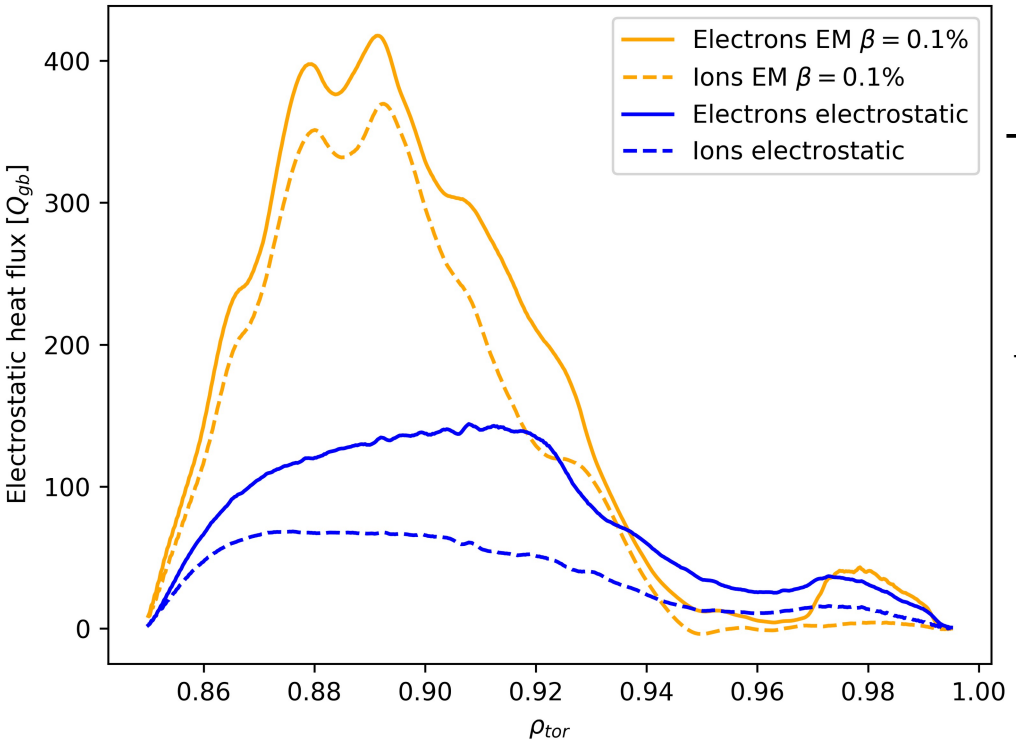
The pedestal is close to a linear KBM threshold. (In agreement with [4])
Distance decreases towards pedestal foot.



KBM: Kinetic Ballooning Mode

[4] Hatch et al, Nucl. Fus., 2015

Influence of EM-fluctuations



- the electrostatic(!) heat flux increases strongly when EM flucutations are included

→ EM + ES fluctuations are not independent