Simulation of 3D magnetic fields with GBS

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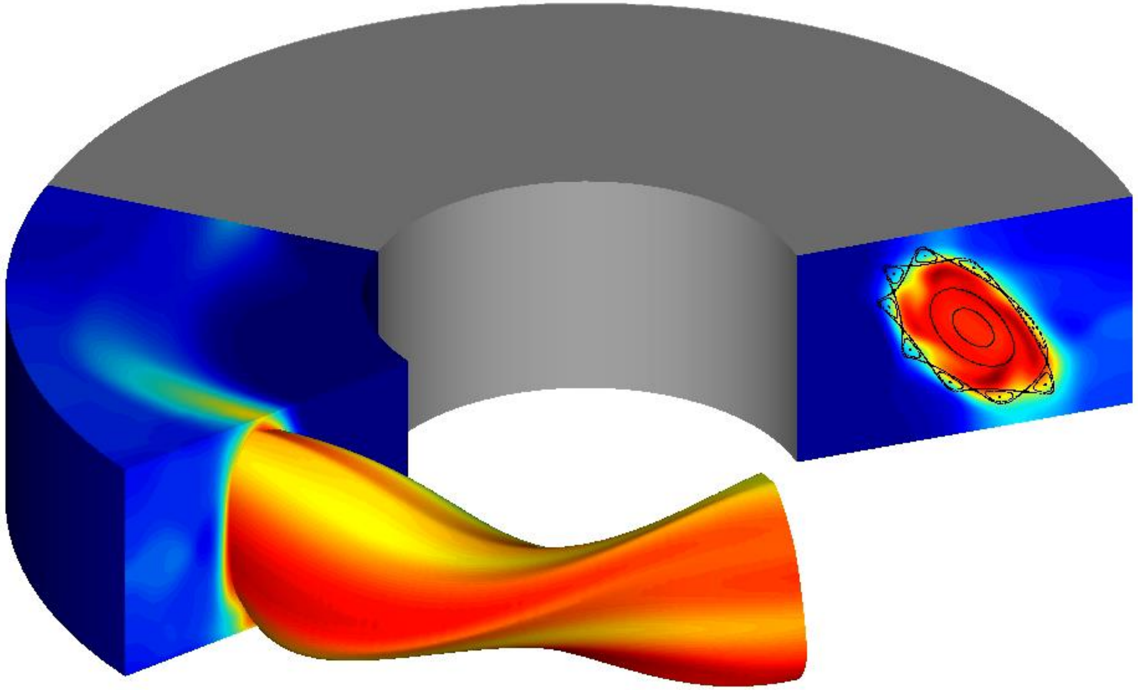
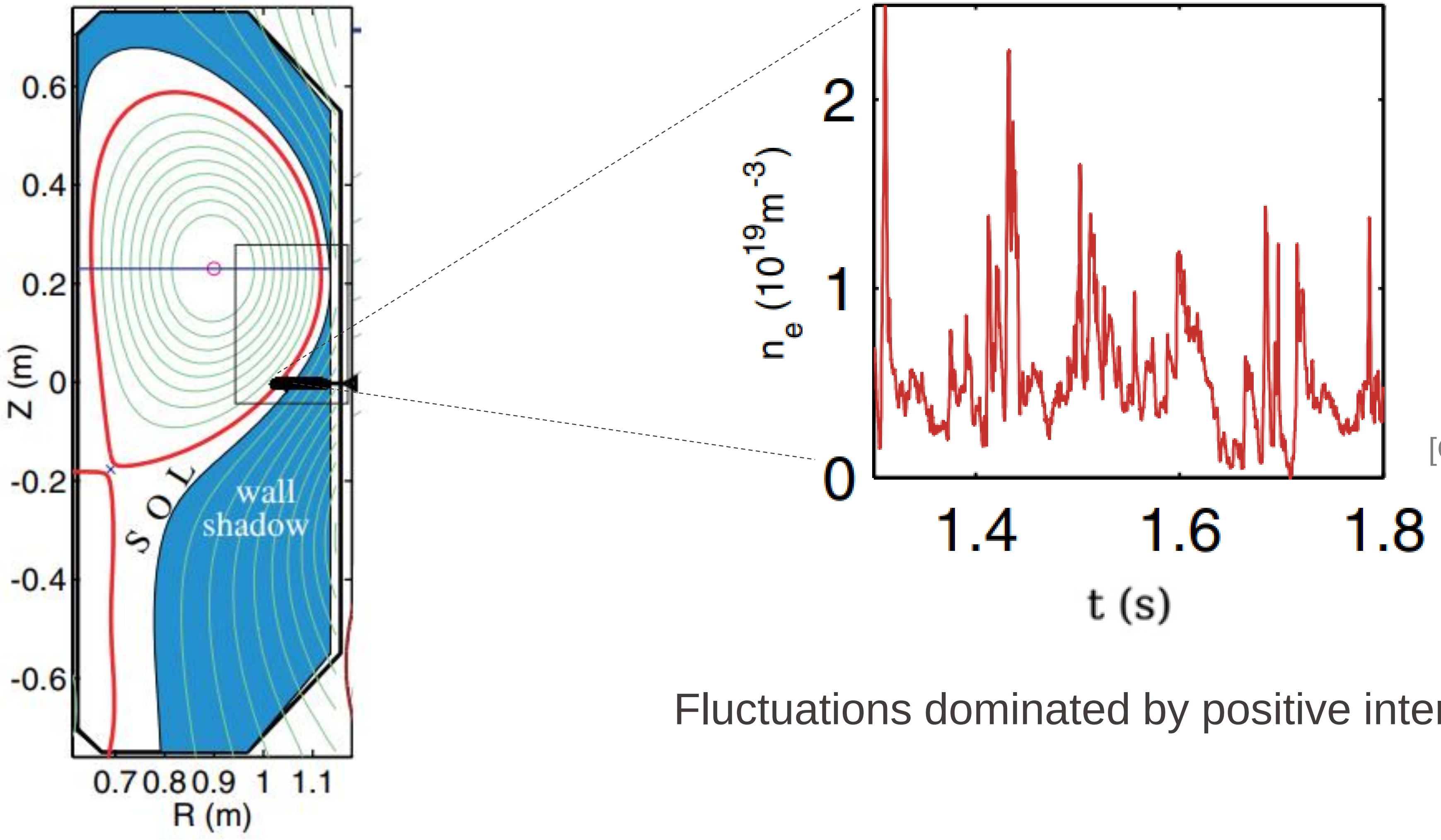


Swiss Plasma Center

TSVV-3, meeting 21 September 2022

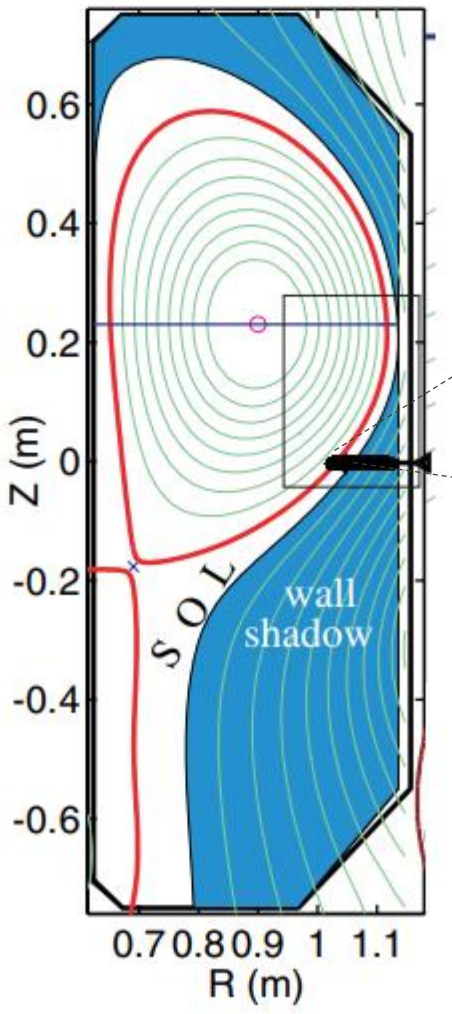
Tokamak boundary: broad-band turbulence and blobs

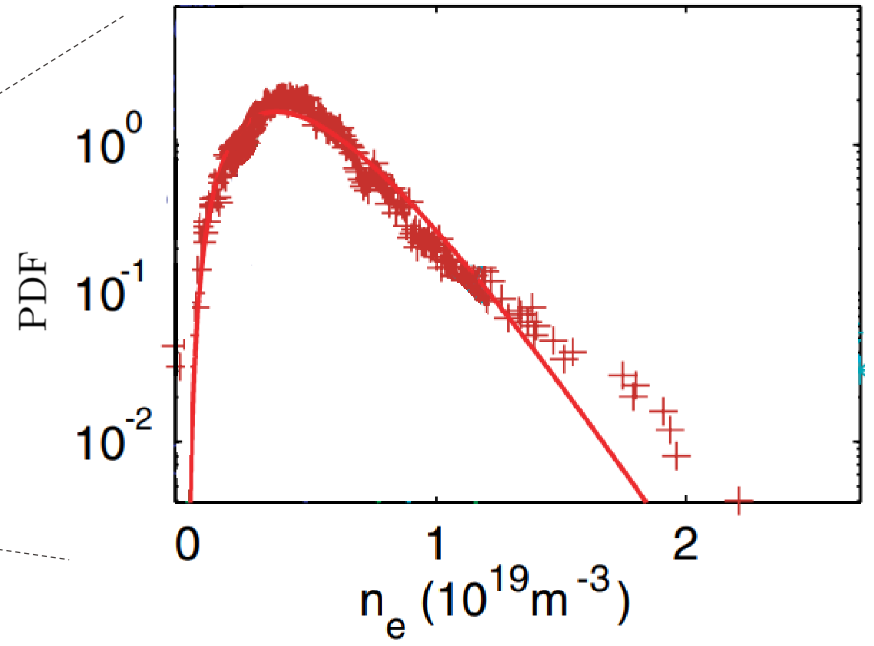


[Graves, 2005]

Fluctuations dominated by positive intermittent events

Tokamak boundary: broad-band turbulence and blobs





[Graves, 2005]

Fluctuations dominated by positive intermittent events

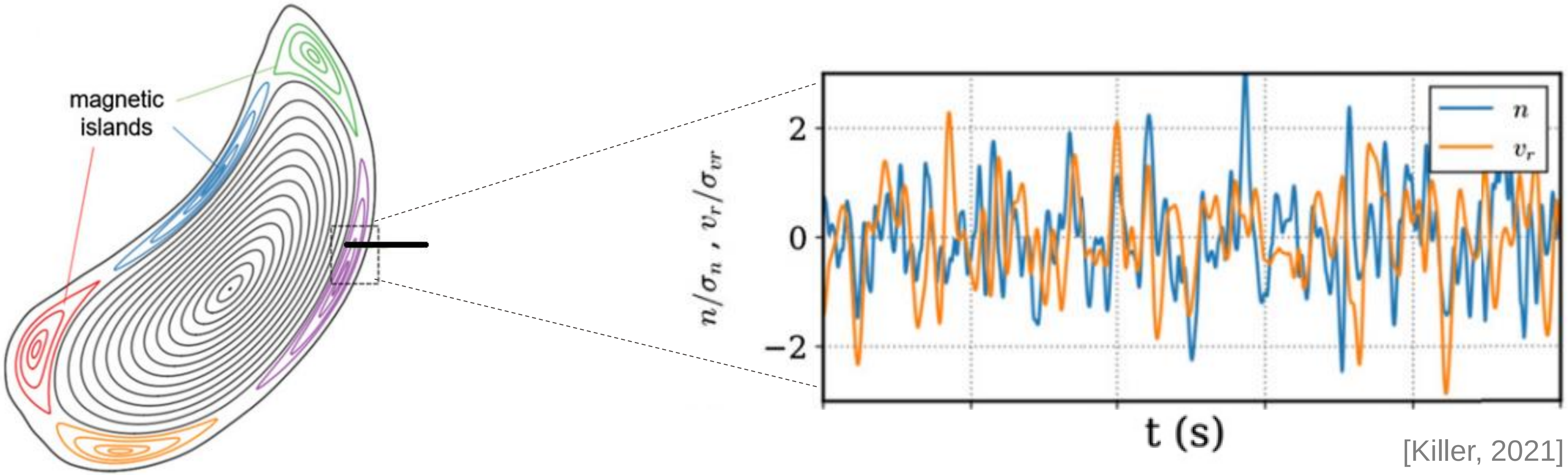
Positively skewed PDF

simulations show the same behaviour

what about the blobs?

Stellarators and tokamaks show different boundary dynamics

- W7-X experiments show filaments bound to their flux surface and **fluctuations normally distributed in the island region**



[Killer, 2021]

Stellarators and tokamaks show different boundary dynamics

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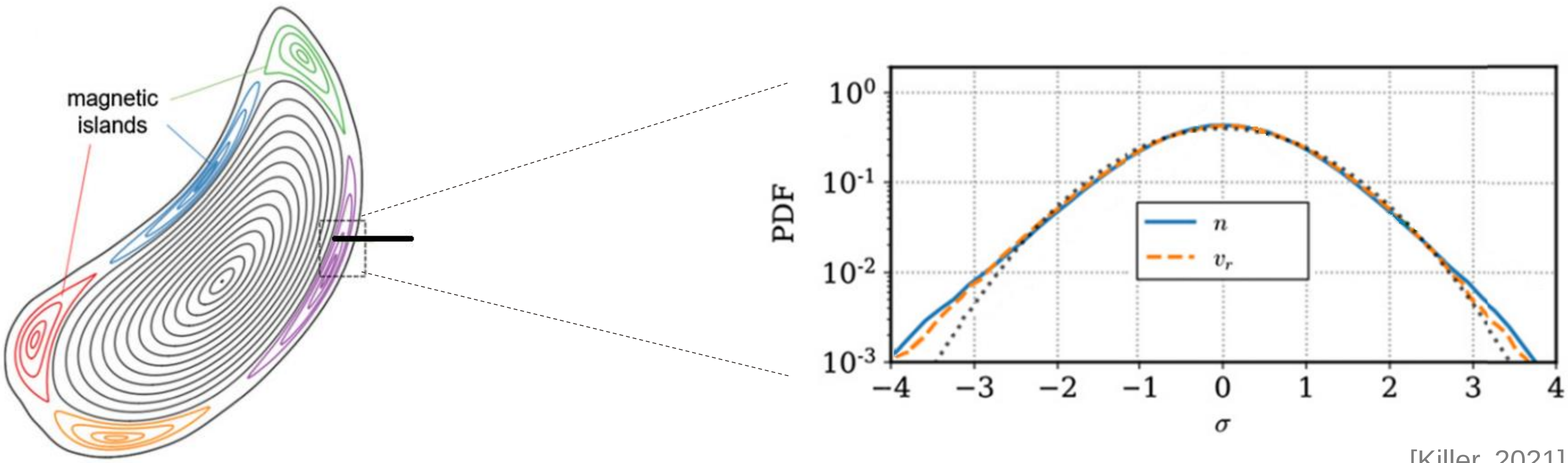
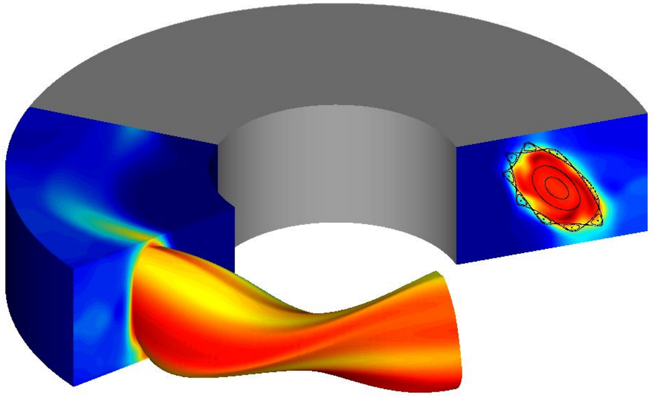


[Killer, 2021]

Stellarator turbulence simulations: current status

- Gyrokinetic δf codes (GENE-3D, Stella, XGC-S, …) – study the core
- Fluid code BOUT++ simulated seeded filament in a rotating ellipse [Shanahan, 2019]
- Progress in Grillix / Gene-(3)X
- GBS: global fluid simulation of a stellarator



Nuclear Fusion 2022
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GBS with 3D magnetic fields

- Set of equations for $n, T_e, T_i, V_{\parallel e}, V_{\parallel i}, \omega, \phi$

  - Electrostatic simulations
  - Boussinesq approximation
  - No neutrals

EPFL

Today I show you an overview on:

1. Initial validation of the code in TJ-K

2. Simulation of a diverted tokamak with RMP’s

TJ-K is a 6 field-period stellarator in Stuttgart

- $R_0 = 60$ cm , $a \sim 10$cm
- Low-temperature plasma: $T_e \sim 10$ eV , $T_i \leq 1$ eV
- $n \sim 10^{17}$ m^{-3}
- $B \sim 70$ mT
- Gases: H, He, Ar, D, Ne
- Plasma heated with microwaves at the UH resonance

G. Birkenmeier Dipl. Thesis

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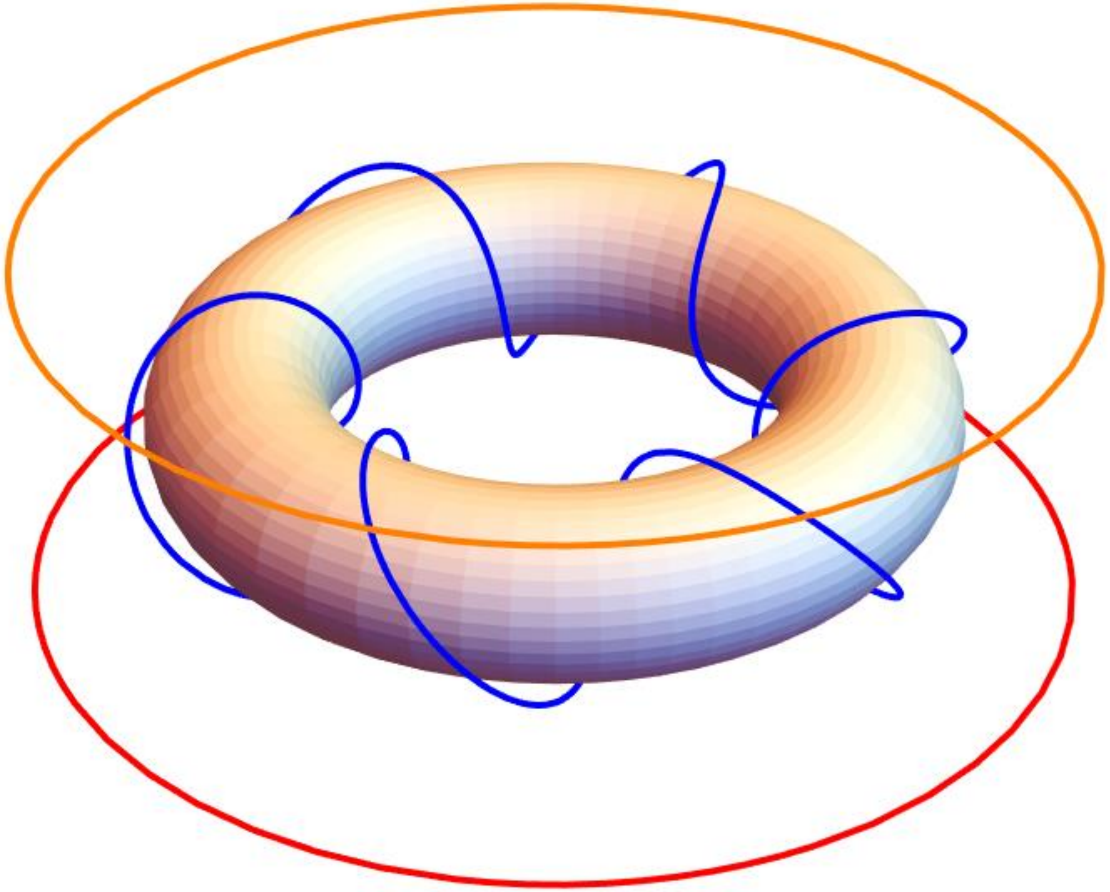
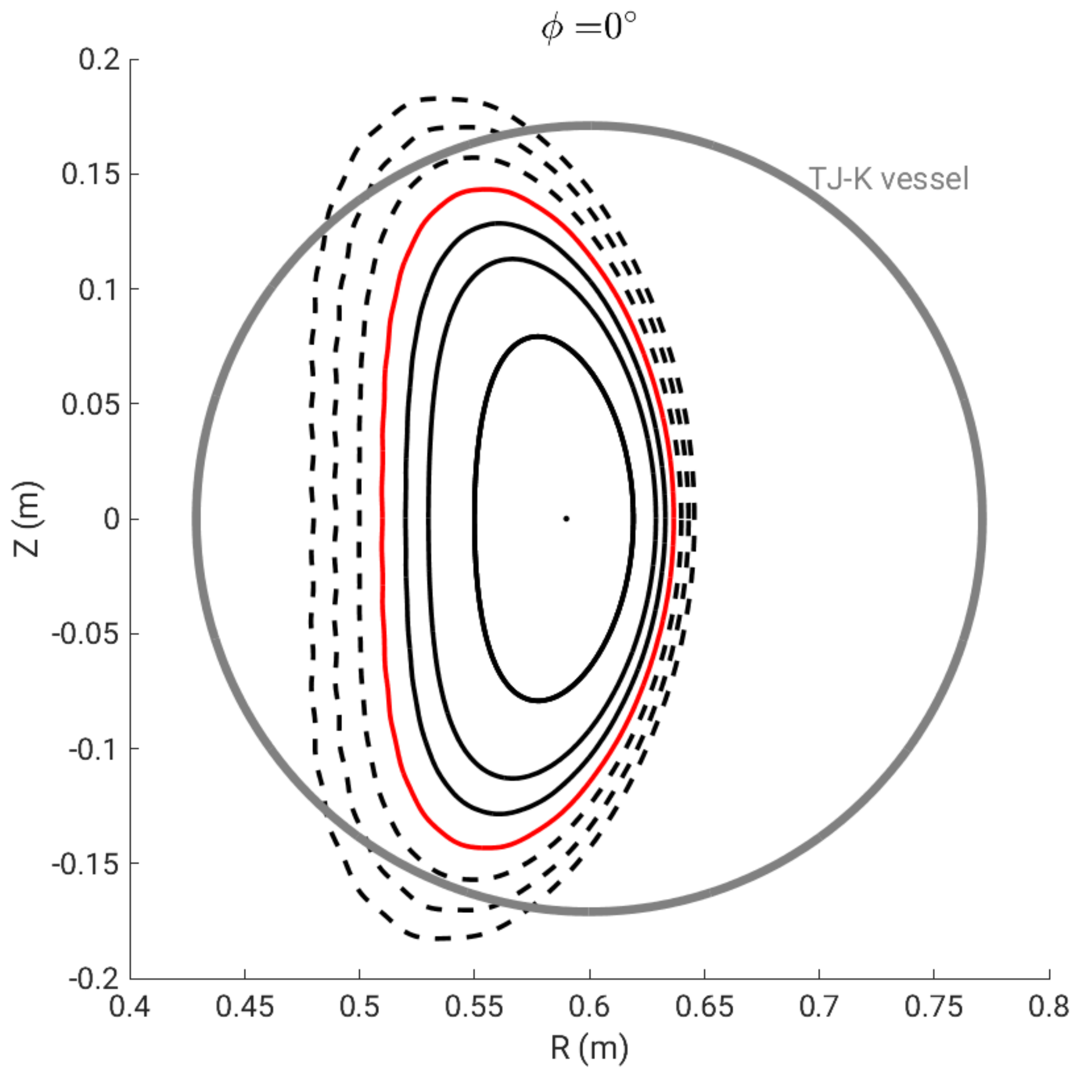
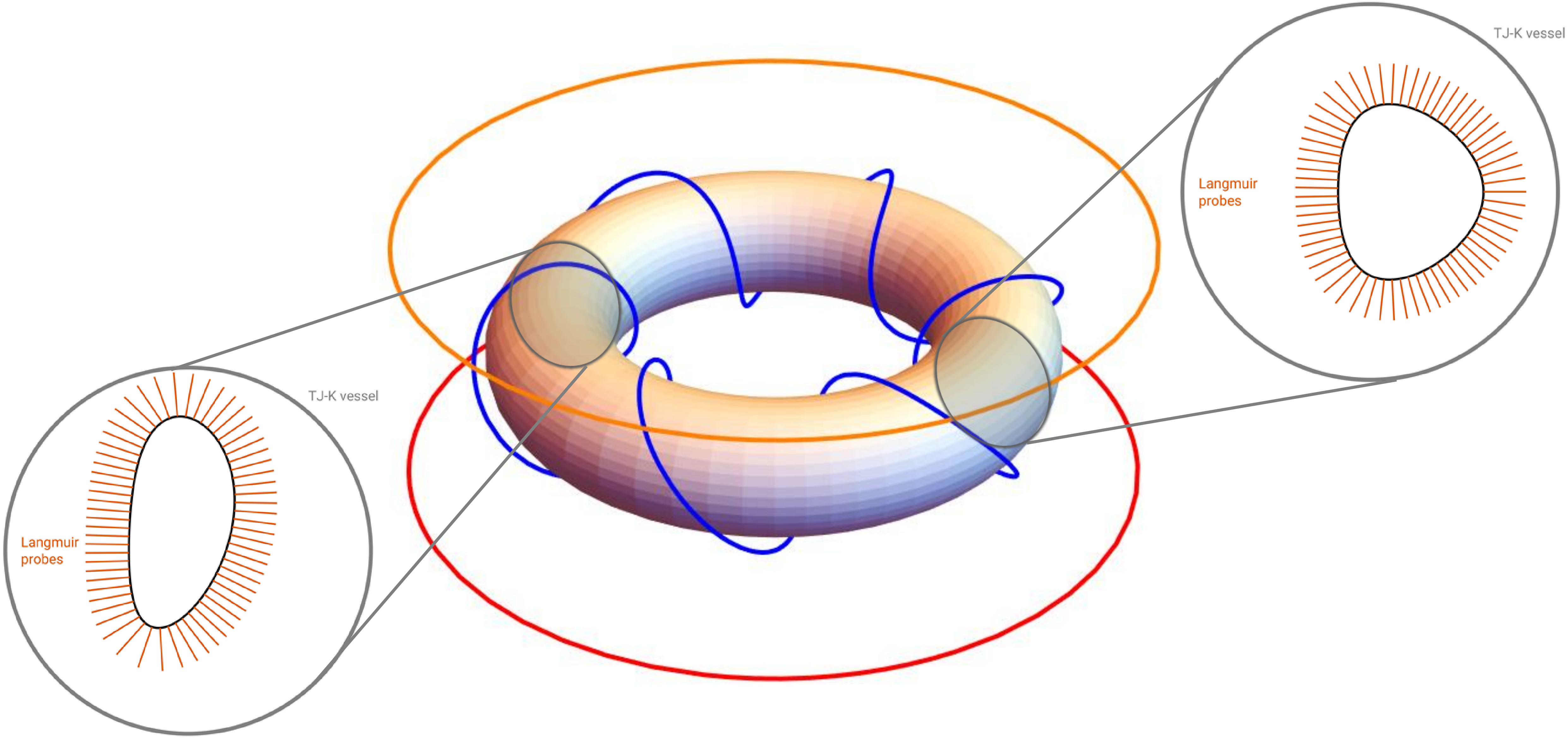


B generated with MAKEGRID

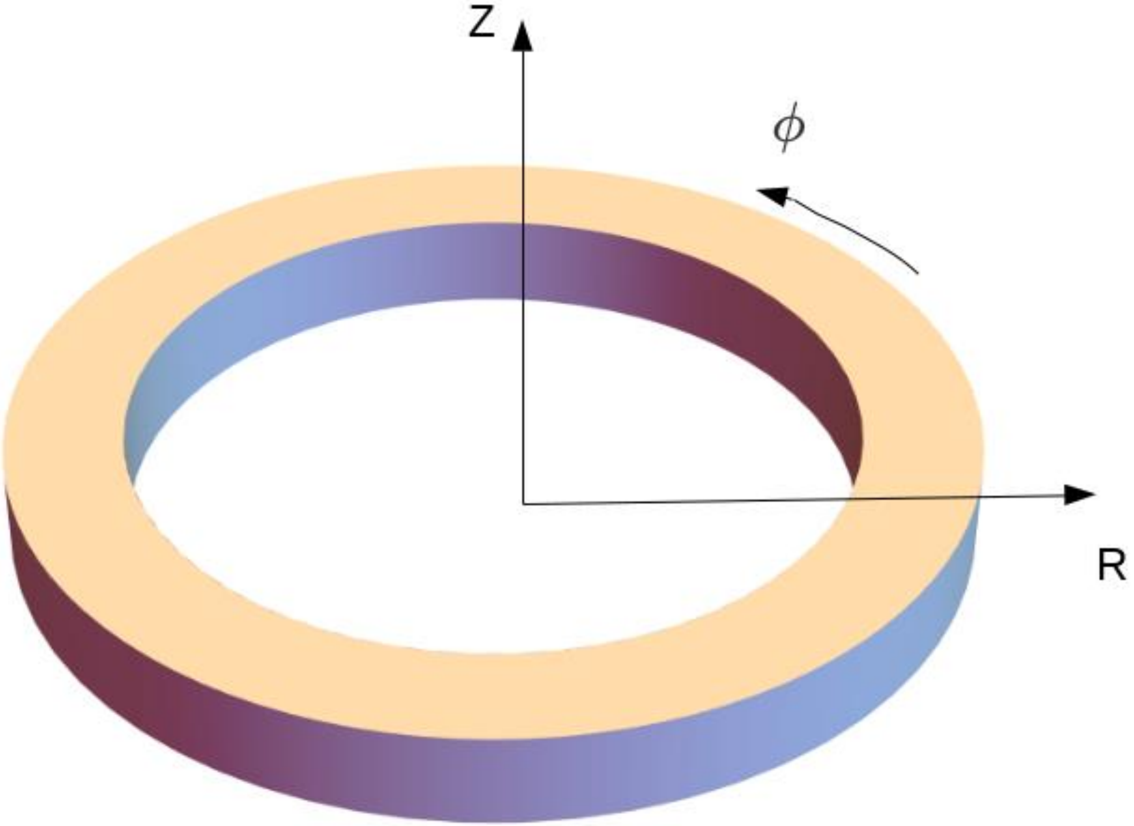
Plasma is limited in TJ-K

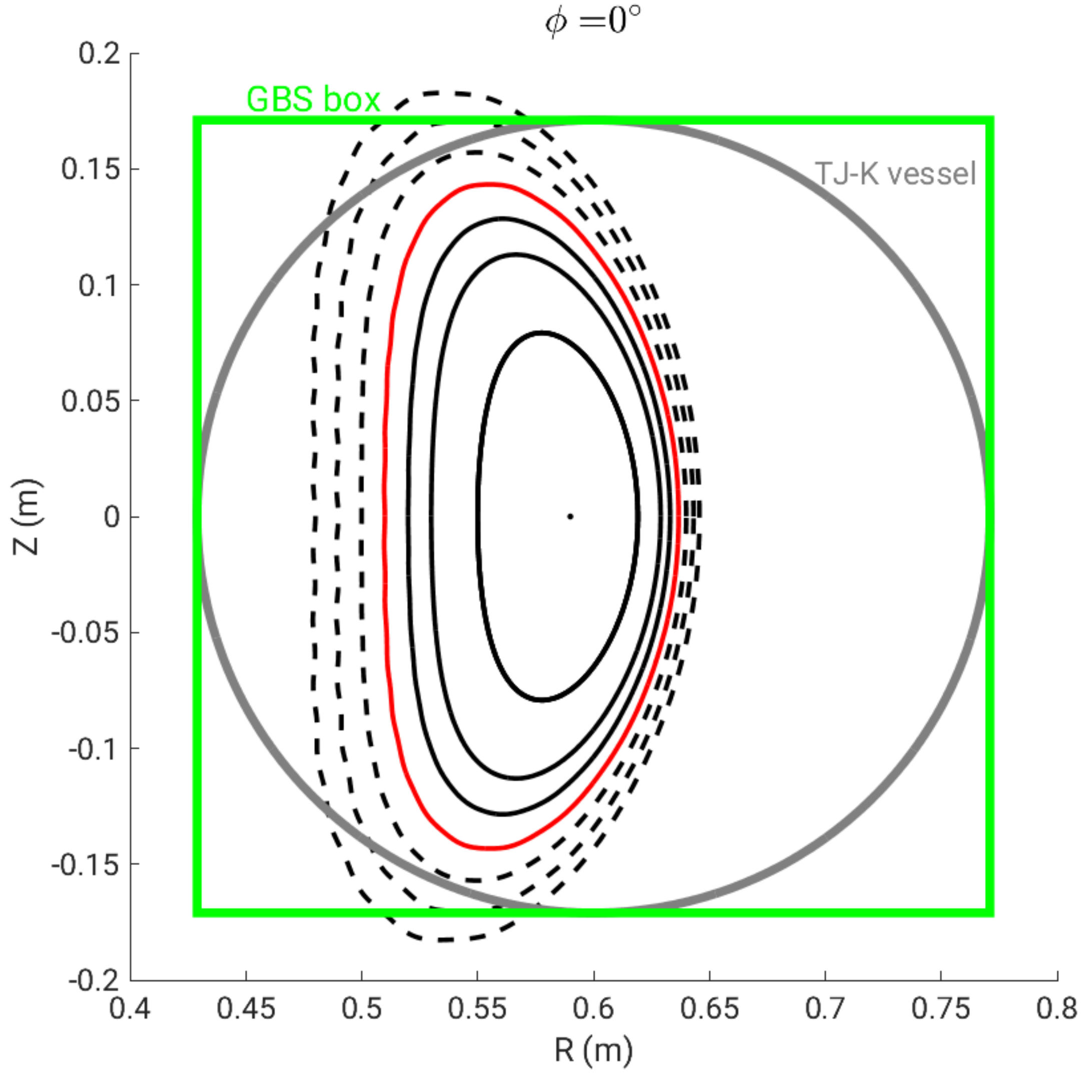


TJ-K is equipped with 2 multi-Langmuir probe arrays

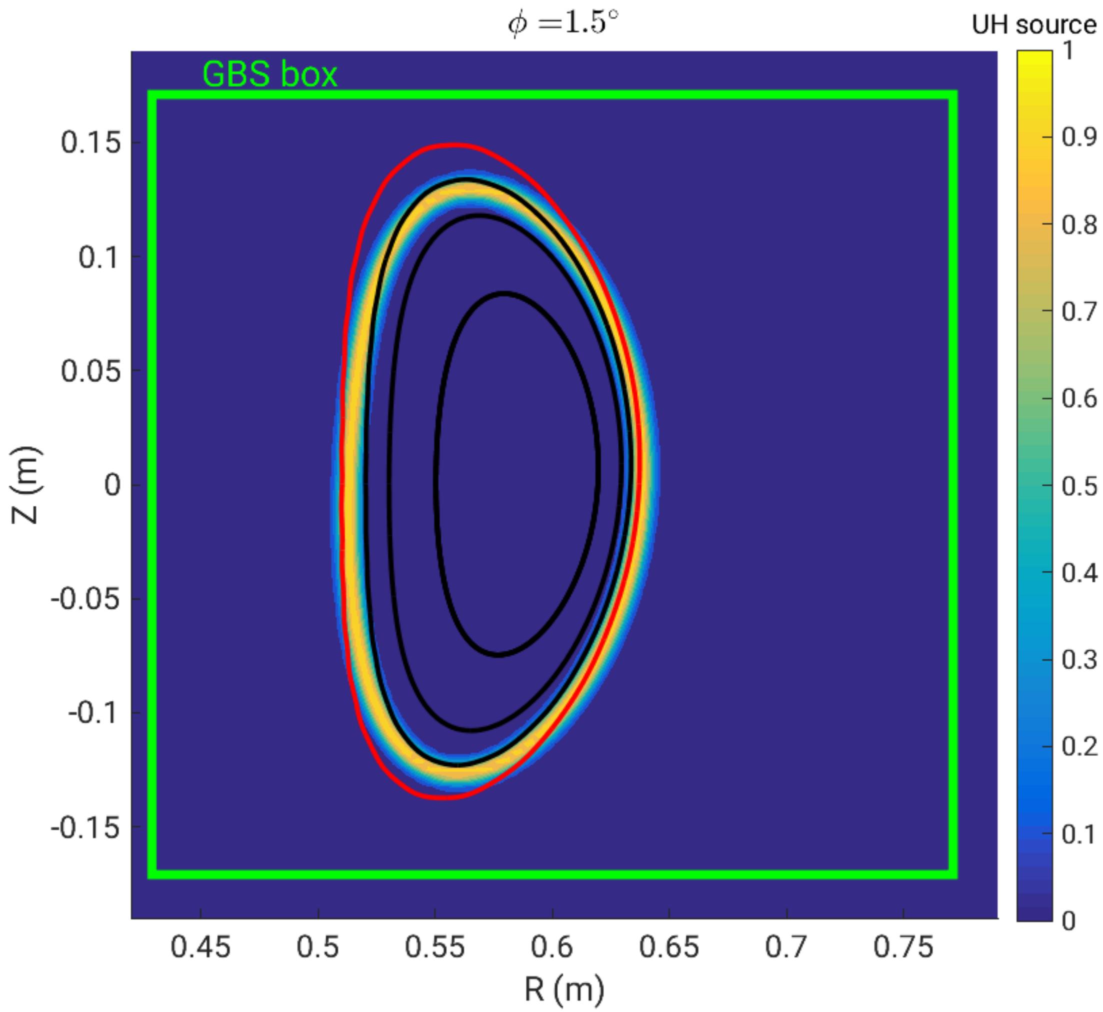


GBS box is tailored to keep plasma limited in the same positions

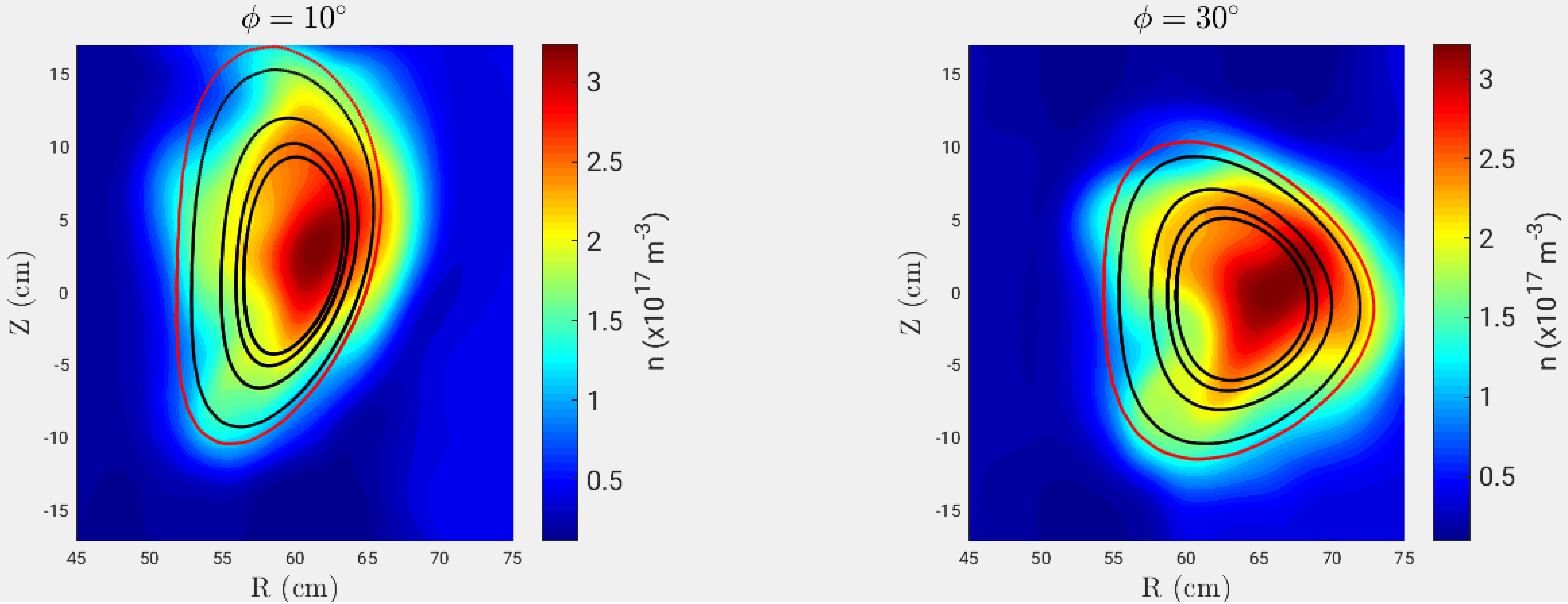




Plasma heated with microwaves at the Upper Hybrid resonance



GBS simulation of a TJ-K Helium plasma



- Low m mode originated from the core
- Large structures detach from the mode

Several quantities considered for the validation

- Density, potential and radial flux power spectra
- Density, velocity and potential fluctuation levels
- Turbulent ExB flux
- Equilibrium electrostatic potential, electron temperature and density
- Equilibrium radial electric field

Hydrogen and Helium

Several quantities considered for the validation

- **Density**, potential and radial flux **power spectra**
- Density, velocity and potential fluctuation levels
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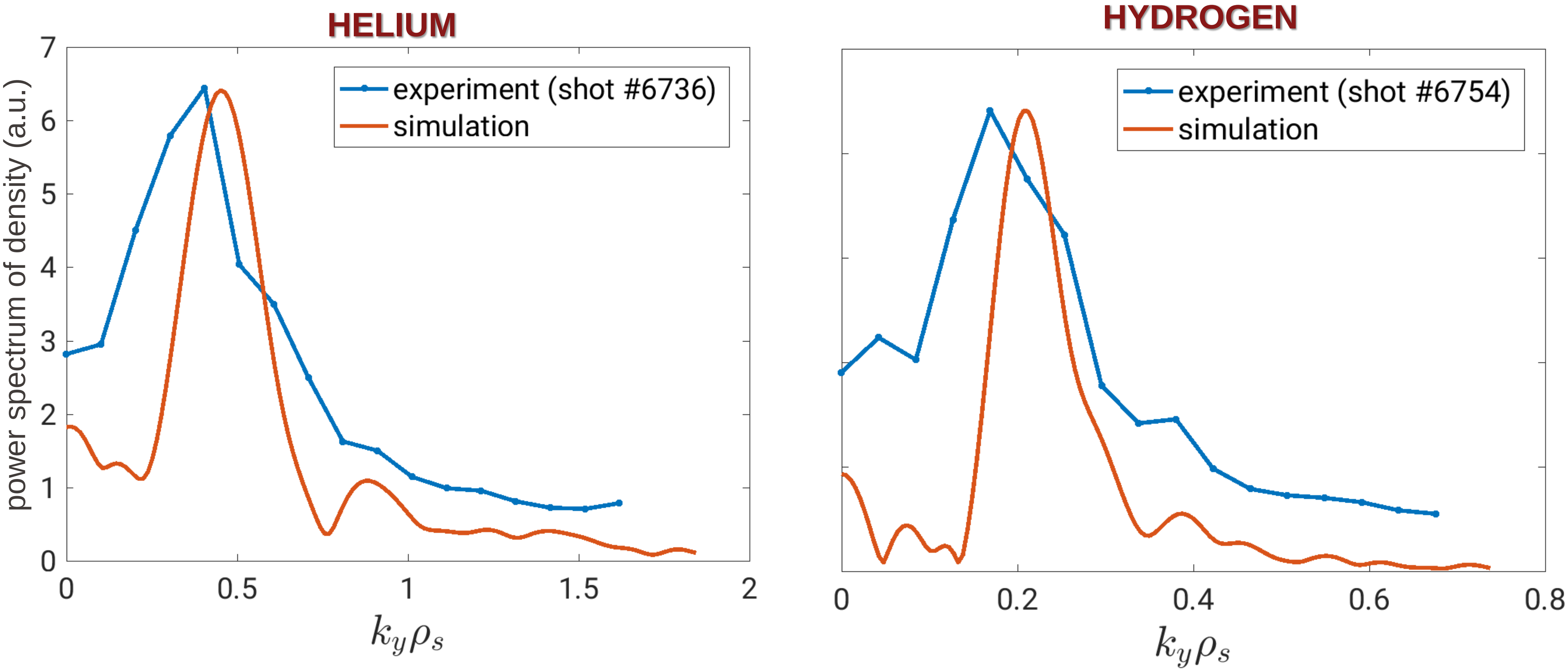
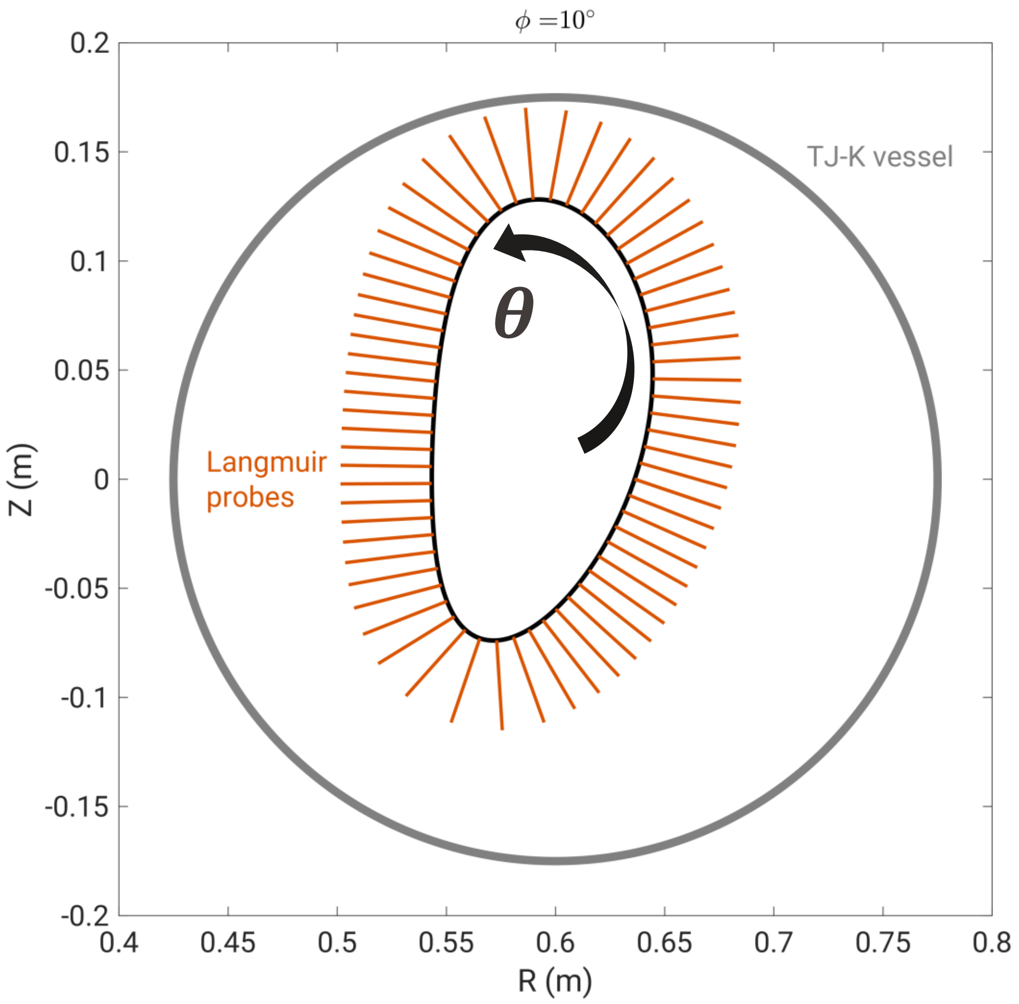
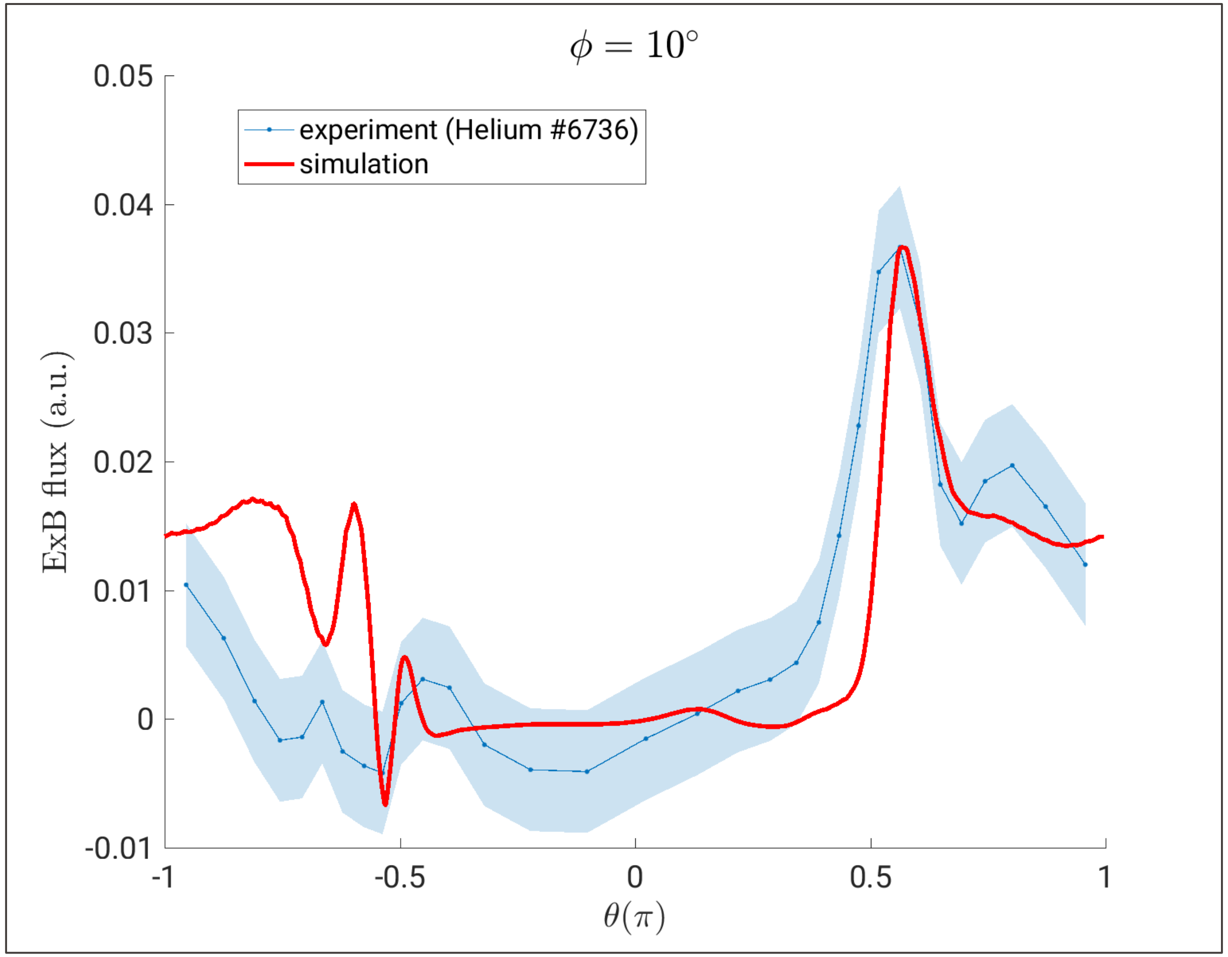
Poloidal spectrum of density fluctuations



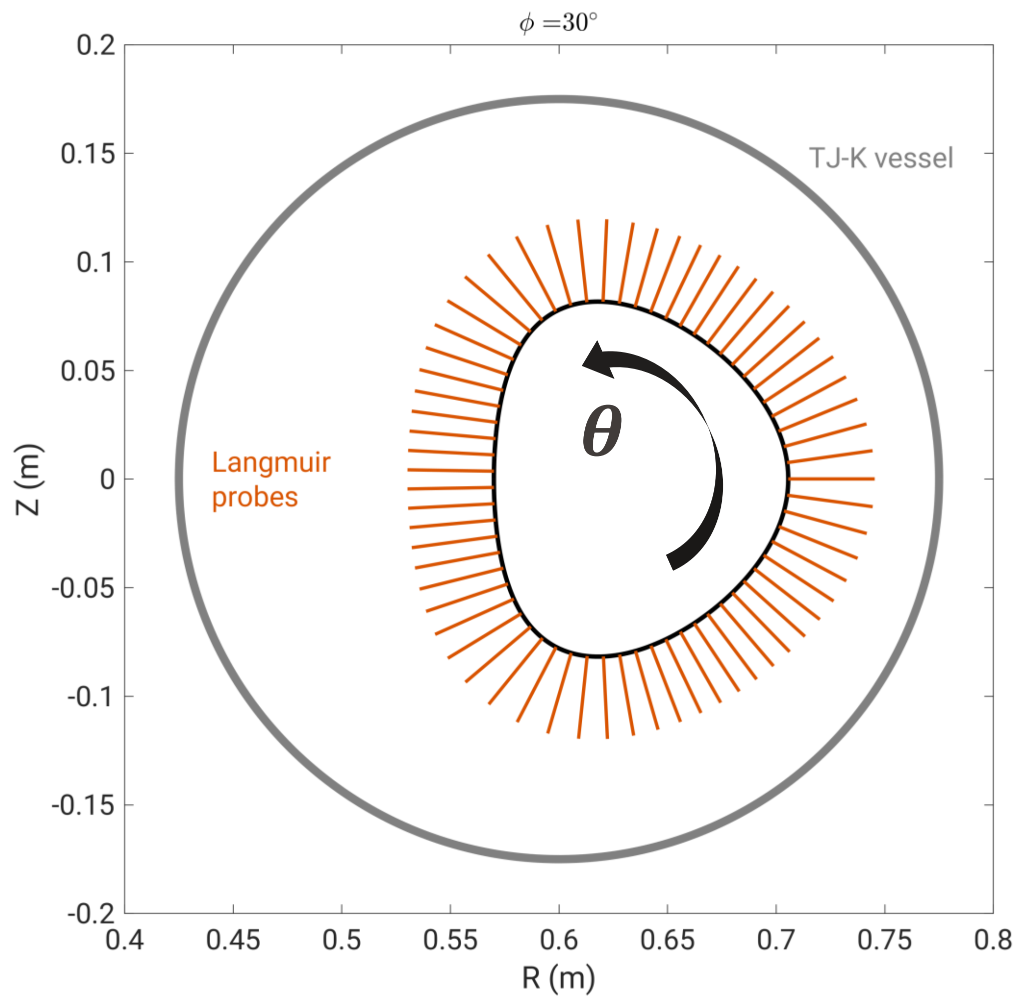
- Simulation retrieves coherent mode detected in the experiment

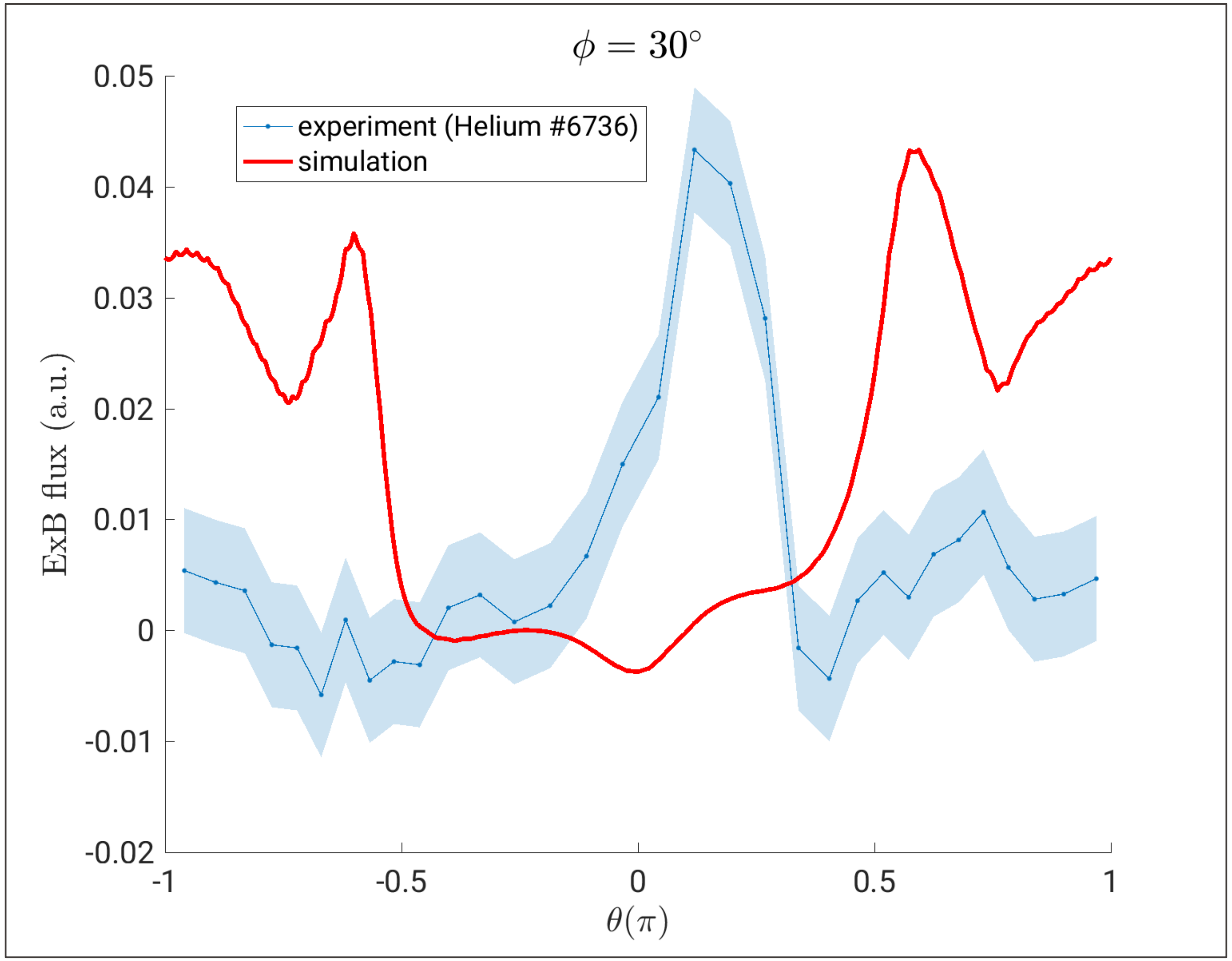
Turbulent ExB flux compares well at $\phi = 10°$





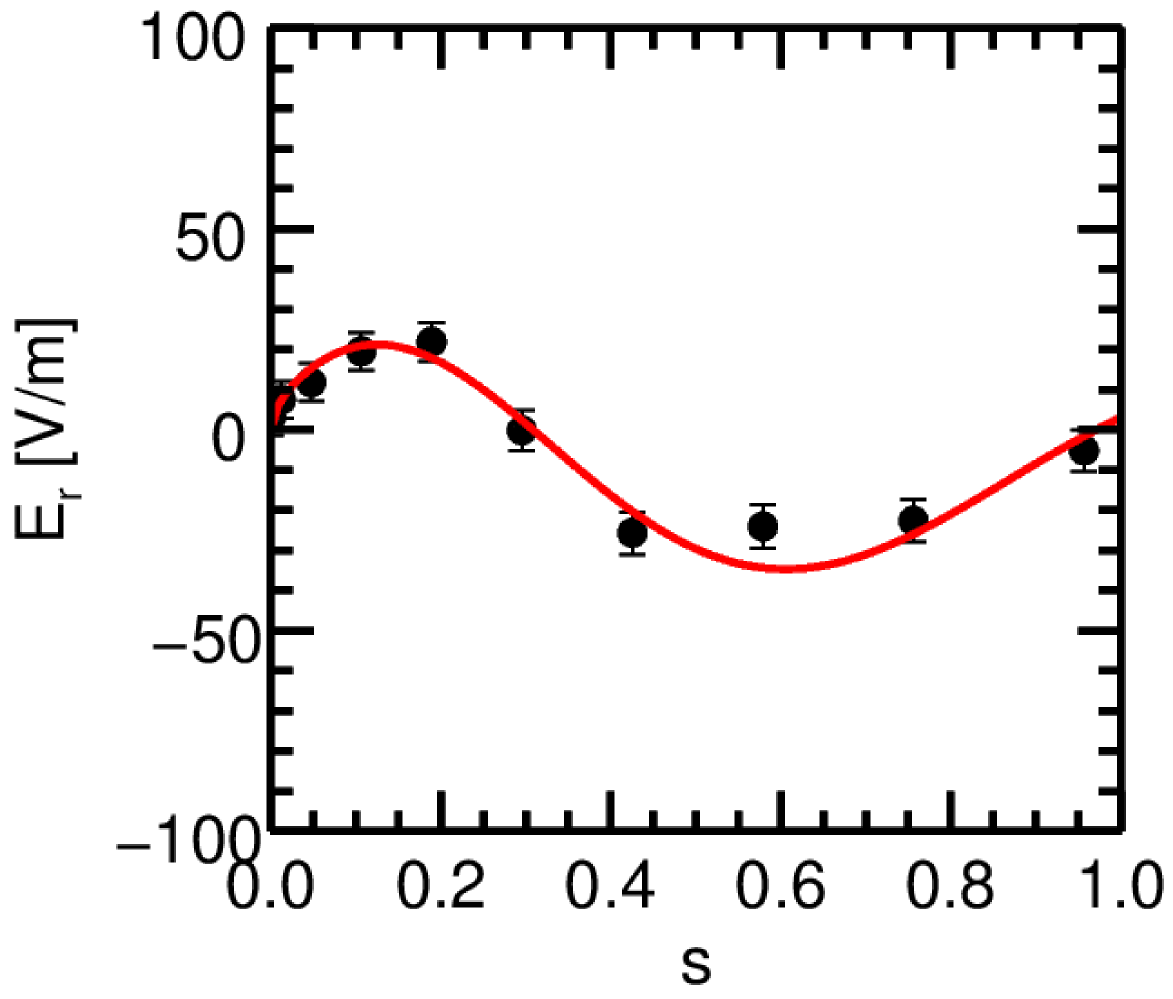
Comparison of the turbulent ExB flux not so good at $\phi = 30°$

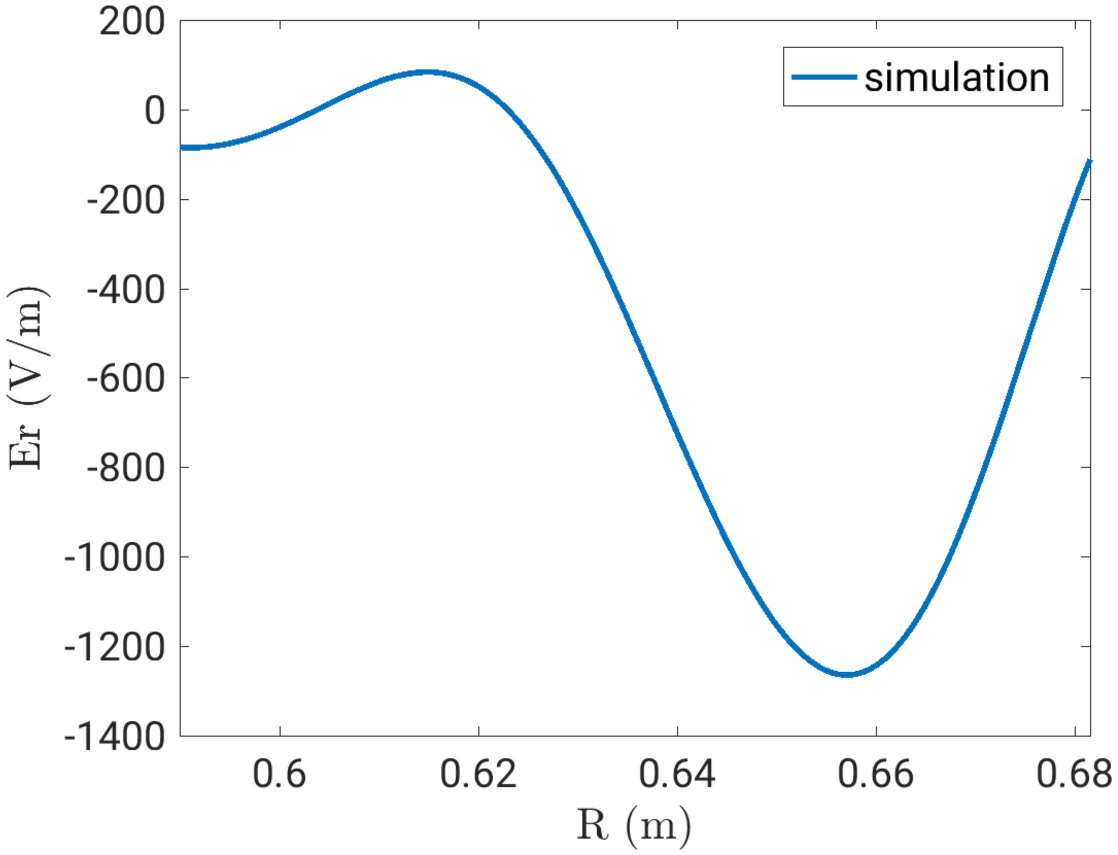




Equilibrium radial electric field is an order of magnitude different

Experiment (#2239)

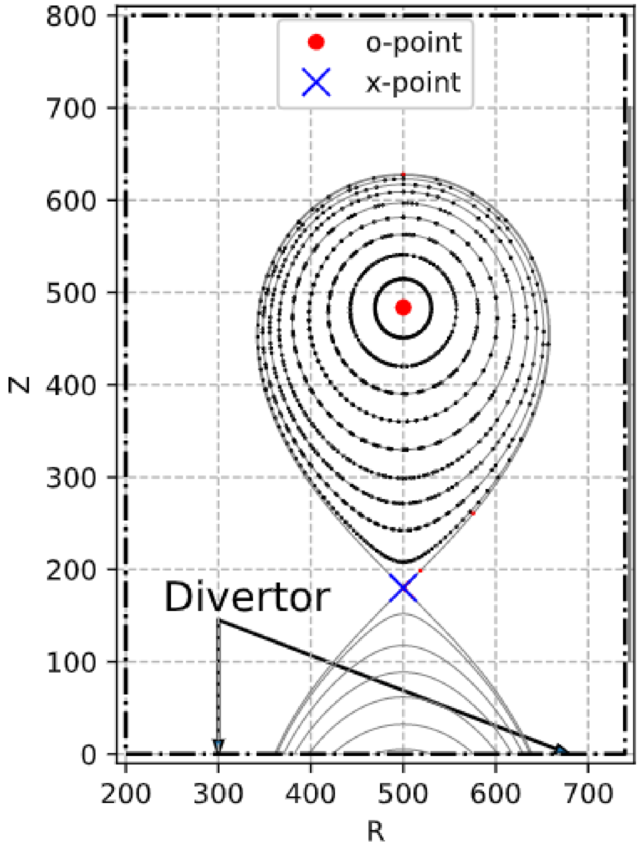




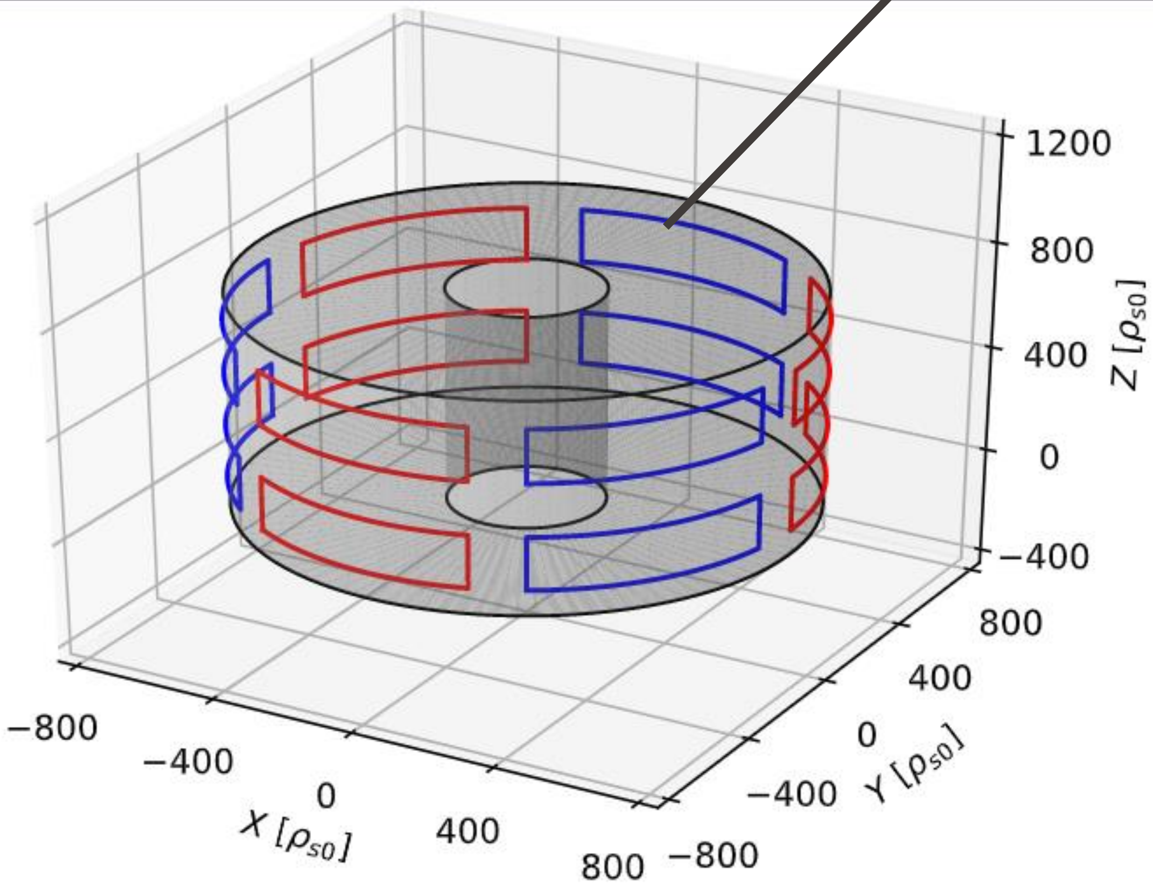
Simulation of diverted tokamak with RMPs

- What is the effect of RMP's on the edge/SOL turbulence?

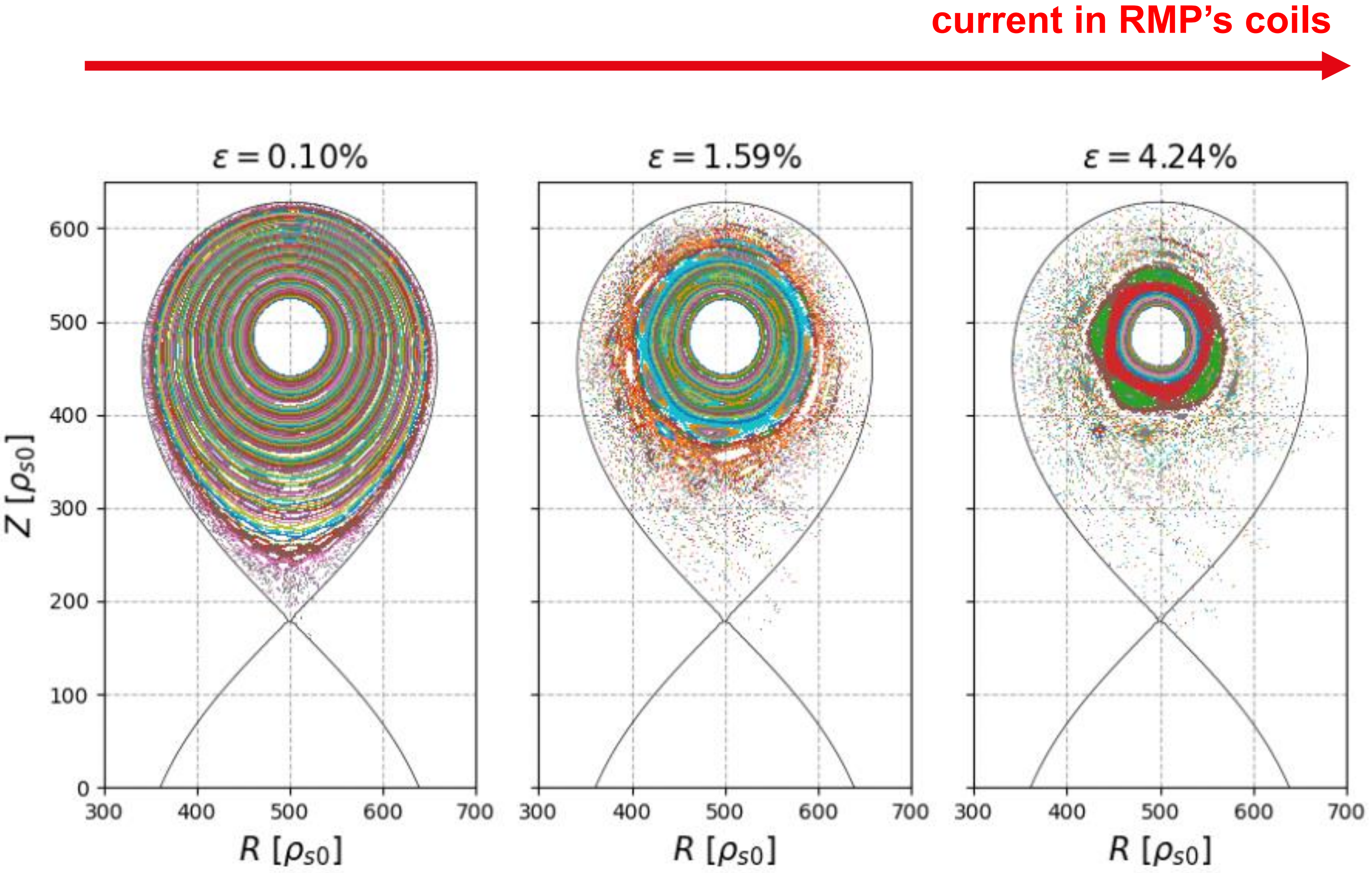
Unperturbed mag. field



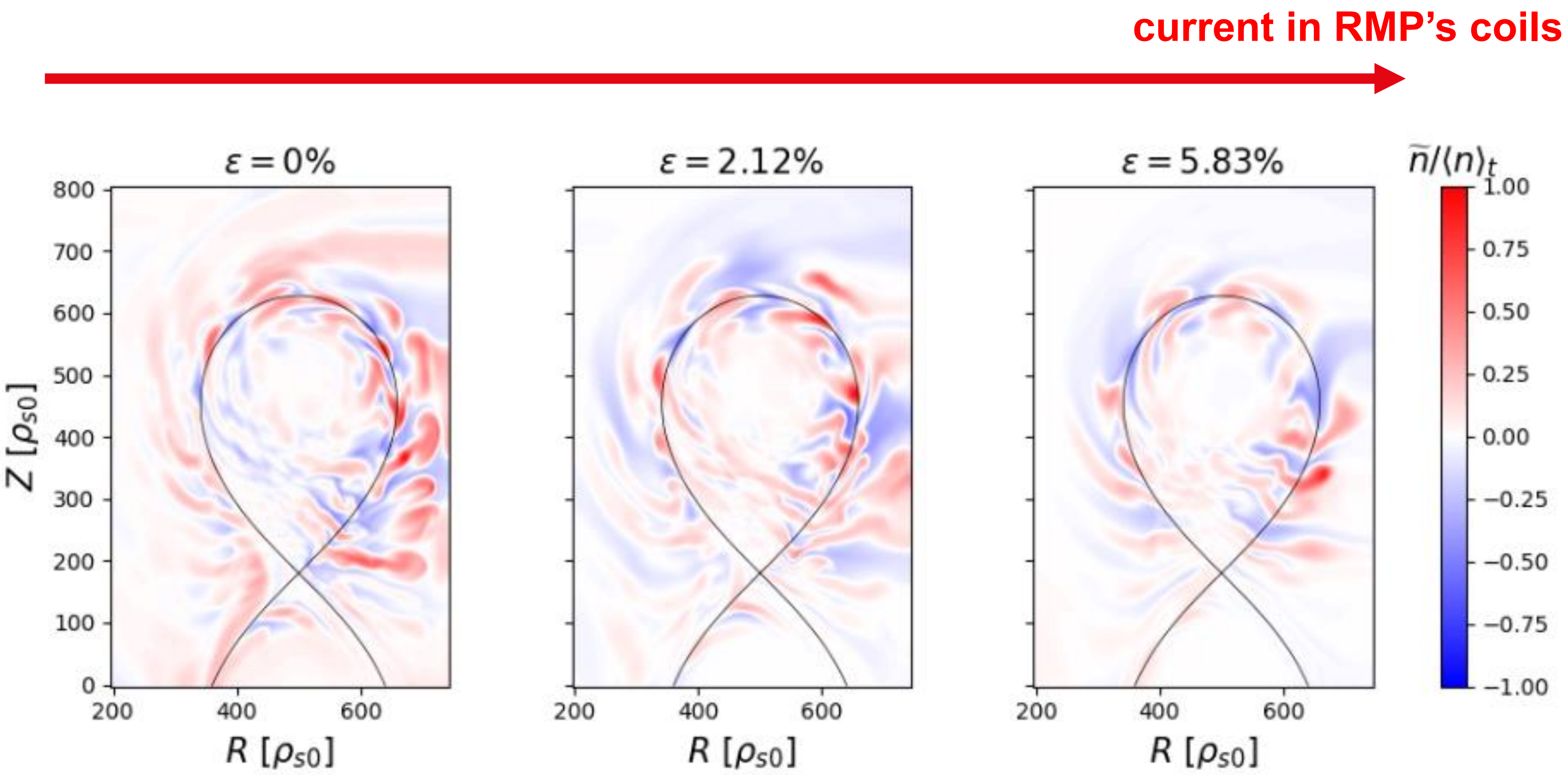
Free parameter: current in the coils



Simulation of diverted tokamak with RMPs



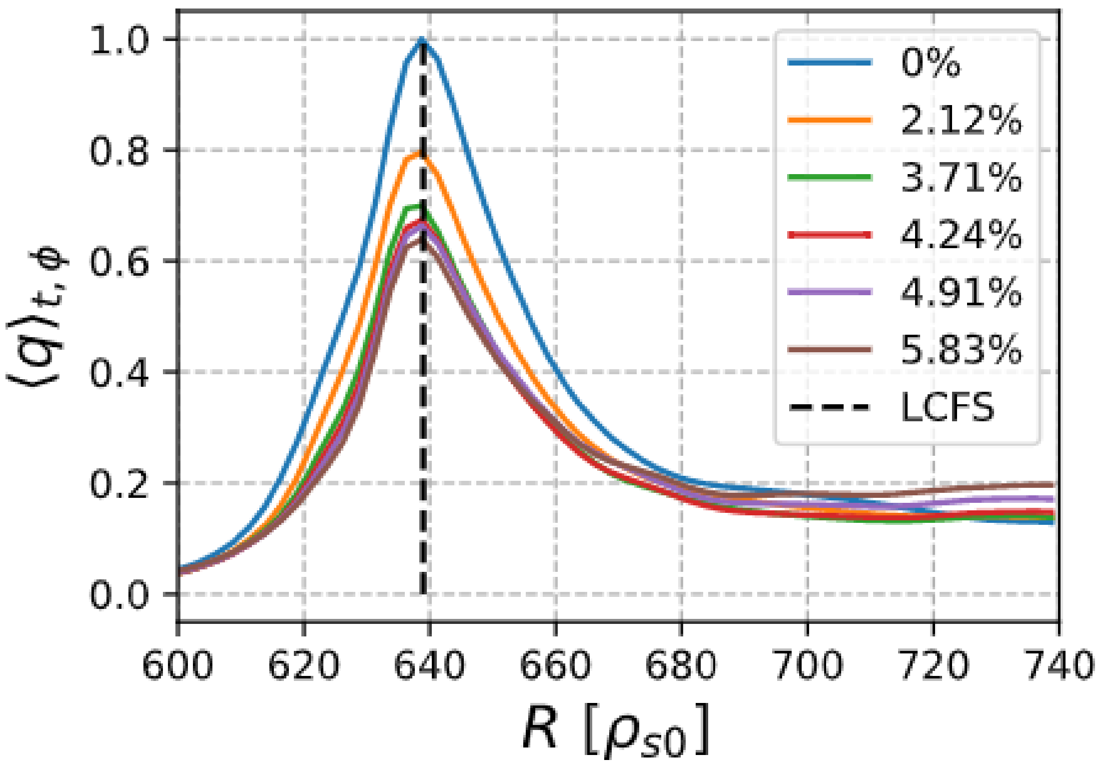
Main turbulence features don't change

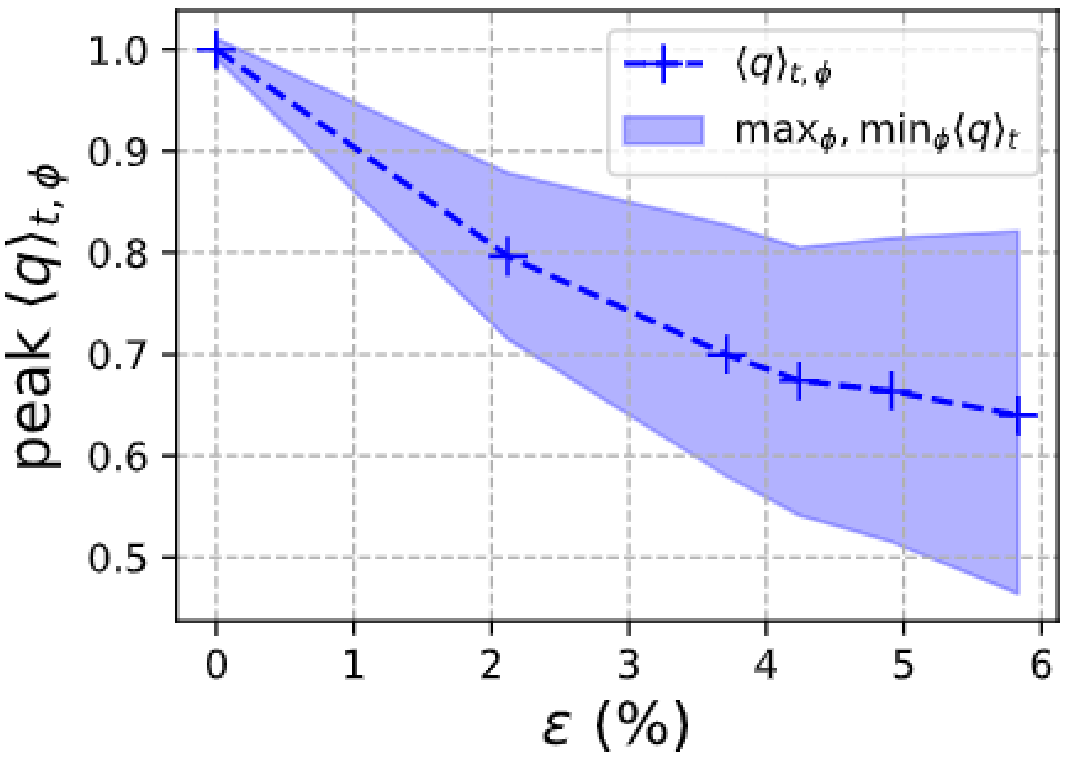


- Ballooning-dominated turbulence
- Number of blobs and size approx. same
- Blob transport in the far SOL ~30%

Peak of the heat flux on divertor is reduced

LFS divertor





Final thoughts

- **TJ-K:** crucial understand the mechanism behind the setting of the **equilibrium electric field**
- **Wall geometry** might affect the comparison on the position of the peak of turbulent ExB-flux
- **RMP's:** Response of the plasma is not included, although not expected to be crucial in the edge

OTHER SLIDES

Boundary Conditions

$$V_{\parallel i} = \pm\sqrt{T_e}F_T \times \mathcal{S}(R,\phi)$$

$$V_{\parallel e} = \pm\sqrt{T_e}\exp\left(\Lambda - \eta_m\right) \times \mathcal{S}(R,\phi)$$

$$\omega = -\cos^2(\alpha)\left[\frac{(\partial_s V_{\parallel i})^2}{F_T^2} \pm \frac{\sqrt{T_e}}{F_T}\partial_s^2 V_{\parallel i}\right]$$

$$\partial_s n = \mp\frac{n}{\sqrt{T_e}F_T}\partial_s V_{\parallel i}$$

$$\partial_s \phi = \mp\frac{\sqrt{T_e}}{F_T}\partial_s V_{\parallel i}$$

$$\partial_s T_i = 0$$

$$\partial_s T_e = 0$$

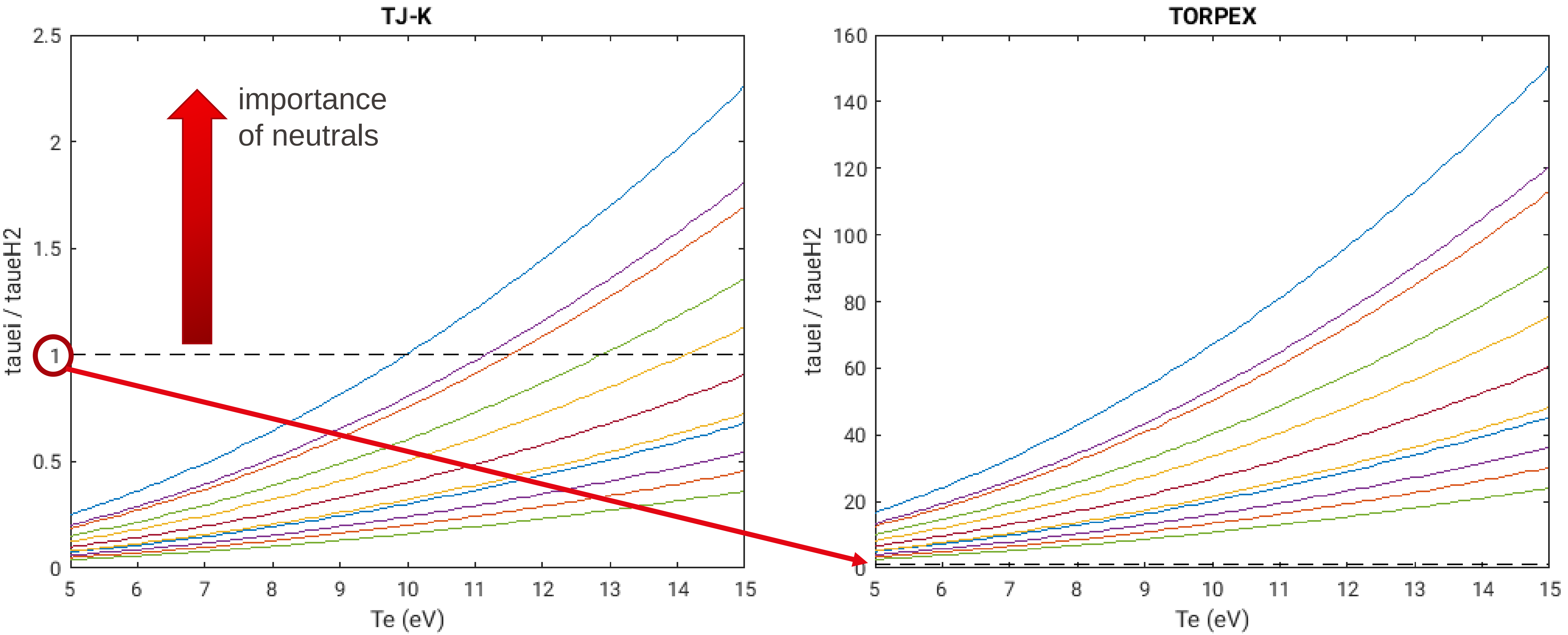
$$F_T = \sqrt{1 + \tau T_i/T_e}$$

$$\Lambda = \ln\left(\sqrt{(m_i/m_e)/(2\pi)}\right)$$

$$\eta_m = (\phi_{\mathrm{MPE}} - \phi_{\mathrm{wall}})/T_e$$

Loizu, 2012

Neutrals do not play a big role in TJ-K



Pattern of the heat flux is not equal to the footprints lobes