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Study of MHD Activity and Edge Plasma on the GOLEM Tokamak with Implications for the Wendelstein 7-X Stellarator

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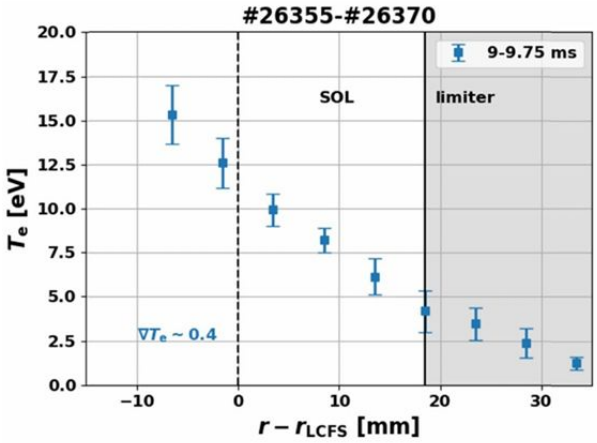
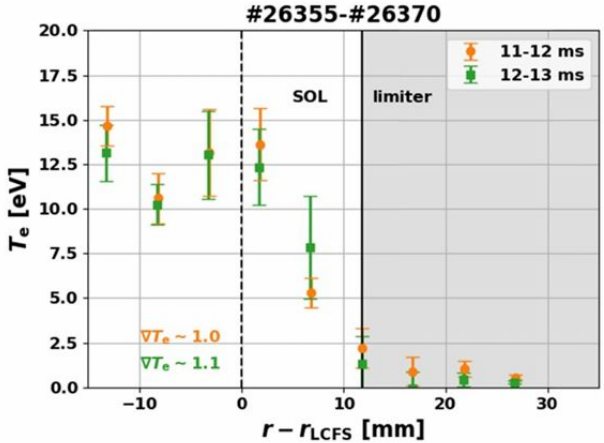
Motivation

Motivation

- **<u>spontaneous</u>** transport barrier (TB) formation in **<u>He</u>** plasma on a tokamak w/ **<u>circular configuration</u>** (GOLEM)
  - typically - tokamaks w/ divertor configuration





[1] P. Macha *et al* 2023 *Nucl. Fusion* 63 104003

Motivation

- latest research - scaling of T_e **gradient** dependency on discharge parameters (working gas pressure p_{He}, heating power P_h)
  - better understanding of conditions leading to TB formation
  - however - which mechanisms cause this phenomenon? still unsure
- recent measurements - possible correlation with **MHD activity**?

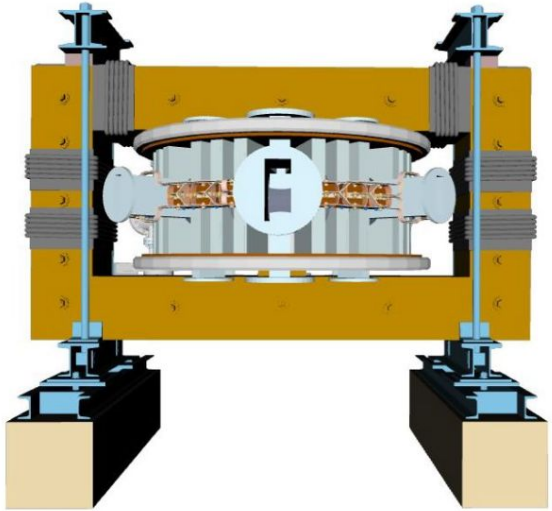
Diagnostics

Diagnostics

Basic diagnostics
- plasma current I_p
- loop voltage U_l

Magnetics
- Mirnov coils

Diamagnetic loop
- plasma energy



[2] G. Emma *et al* 2025 Characterisation of Edge Plasma Transport Phenomena in the GOLEM Tokamak

Electric probes
- Langmuir probe
- ball-pen probe

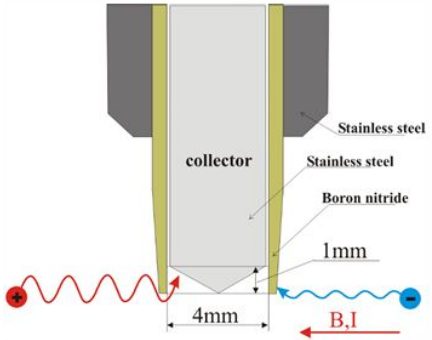
Fast cameras
- radial + vertical view

Spectroscopy
- spectrometers

Electric probes

- **Langmuir probe (LP)**:
  - measurement of **floating potential U_{fl} ≠ plasma potential ϕ**
- **ball-pen probe (BPP)**
  - modified version of LP - reduced collection of electrons => $U_{fl}^{BPP} \approx \phi$
  - in reality used BPP is not ideal =>

$$\phi = U_{\mathrm{fl}}^{\mathrm{BPP}} + \alpha_{\mathrm{BPP}} T_{\mathrm{e}}, \quad \alpha_{\mathrm{BPP}}\,(\mathrm{He}) \doteq 0{,}9 \quad \alpha_{\mathrm{BPP}}\,(\mathrm{H}) \doteq 0{,}25$$

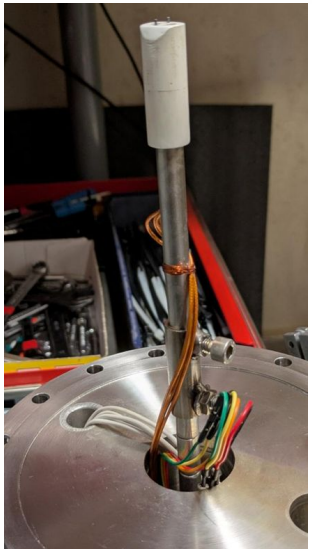


[3] J. Adamek *et al* A novel approach to direct measurement of the plasma potential. *Czech. J. Phys.* 54 (Suppl 3), C95 (2004)

Electric probes

- **combined LP+BPP**
  - **fast measurement** of T_e: $T_e = \frac{U_{fl}^{BPP} - U_{fl}^{LP}}{\alpha_{LP+BPP}}$, $\alpha_{LP+BPP}\,(\mathrm{He}) \doteq 2.0$ $\alpha_{LP+BPP}\,(\mathrm{H}) \doteq 2.5$
- new probes installed
  - recalibration - thank you Vašek!

[4] V. Sedmidubsky 2025 GOLEM double probe-head progress report



[4] V. Sedmidubsky 2025 GOLEM double probe-head progress report

Basic theory

Radial profiles

- once we know the radial profile of plasma potential $\phi(r)$
  - **radial el. field**:

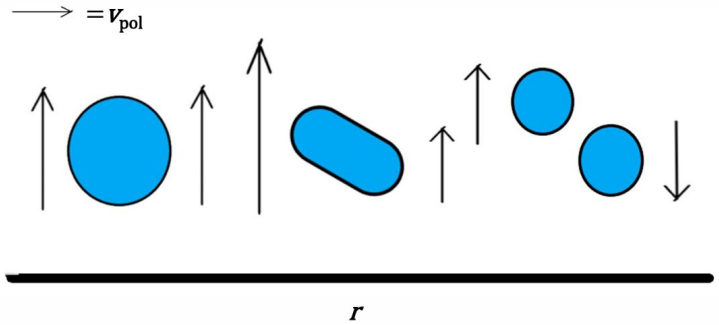
$$E_{\mathrm{r}}(r) = -\frac{\mathrm{d}\phi}{\mathrm{d}r}$$

- combination of E_{r} and B_{t} => **ExB** drift
  - **poloidal velocity**: $v_{\mathrm{pol}}(r) = \frac{E_{\mathrm{r}}}{B_{\mathrm{t}}}$
- **shearing rate**:

$$\omega_{\mathrm{E\times B}}(r) = \frac{\mathrm{d}v_{\mathrm{pol}}}{\mathrm{d}r}$$

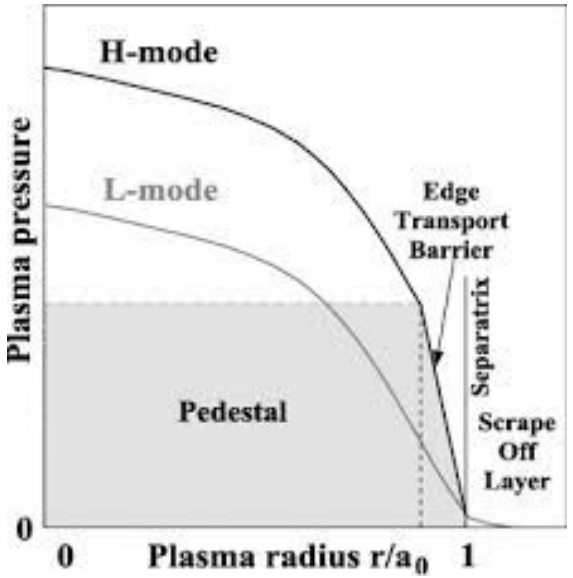
Shear layers, transport barriers

- **shear layers** = regions of tokamak edge plasma, where v_{pol} is sheared
  - turbulent structures (blobs) => edge loss => negative impact on plasma confinement
  - shear flows => tearing of blobs => reduction of energy loss at the edge => possible suppression of turbulent transport



Shear layers, transport barriers

- **transport barriers (TB)** = regions of tokamak plasma where turbulent transport of particles/heat is greatly reduced
  - significant impact on better plasma confinement in tokamaks
  - GOLEM case - formation of T_e gradient (no effect on density) at plasma edge

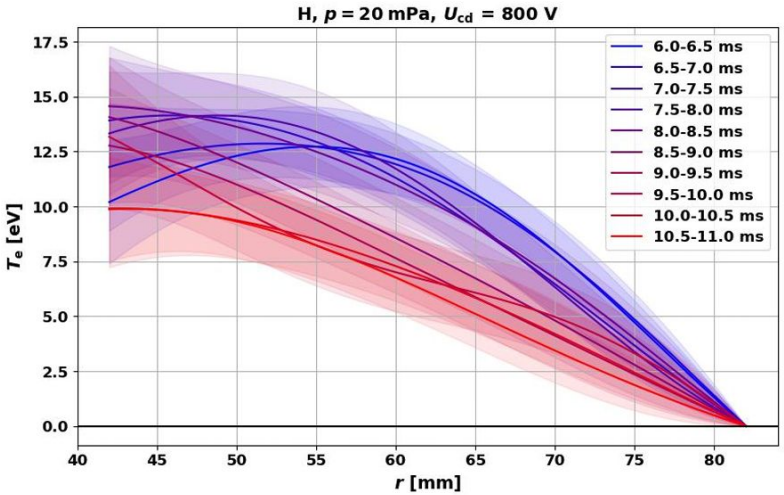


[5] P. Lang et al 2013 Nucl. Fusion 53. 043004.

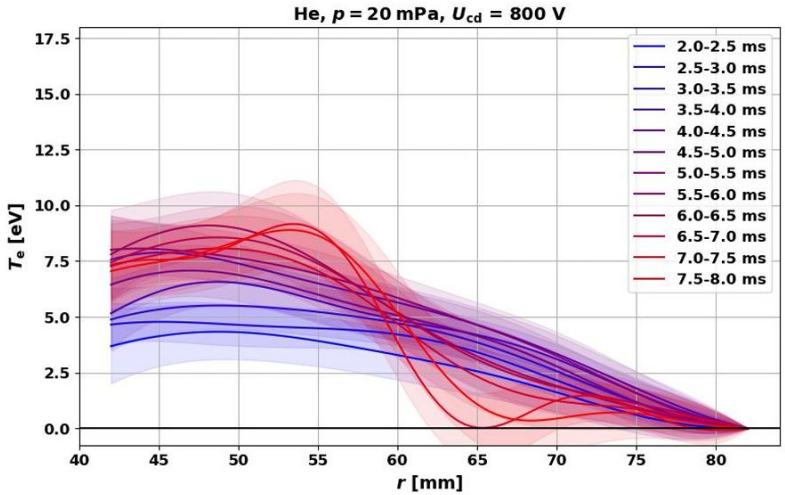
Past results

Past results

- TB formation observed in most of performed He discharges, **not observed in H discharges**



H

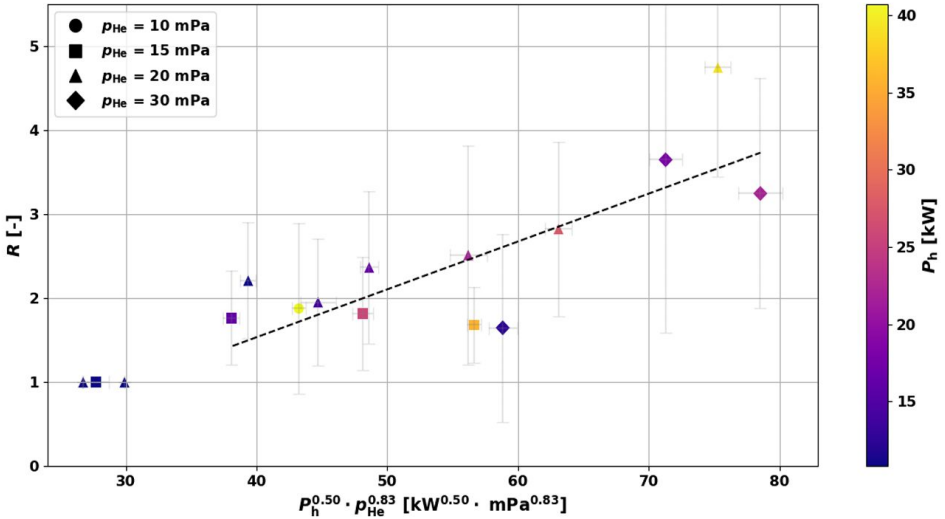


He

Past results

- **scaling**: dependence of T_e **gradient** formation intensity (R) on p_{He} as well as P_h

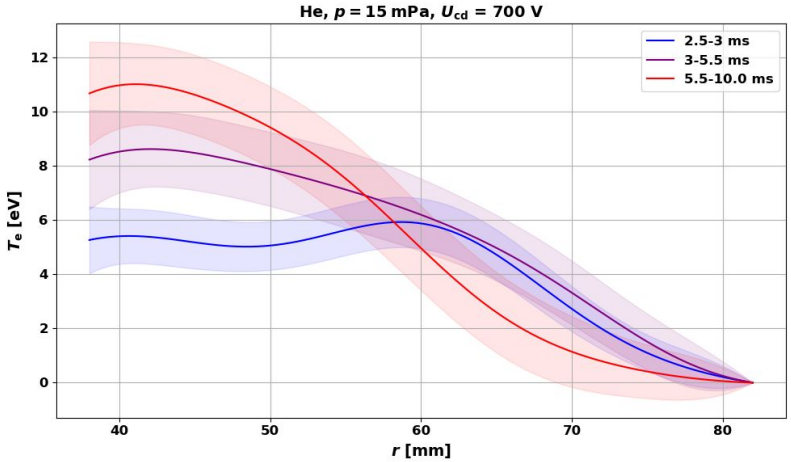
$$R = \frac{(\nabla T_e^{max})^{at}}{(\nabla T_e^{max})^{bt}} \sim P_h^{0,50} \cdot p_{He}^{0,83}$$



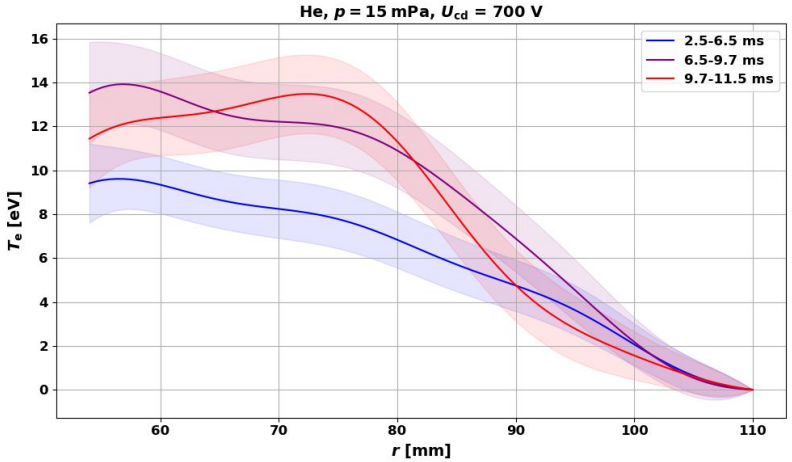
Current results

Current results

- lots of modifications on GOLEM since (vessel, new probe, new MHD ring) - impact on TB formation?
- old vs new T_e profile => **TB still present, higher T_e values**



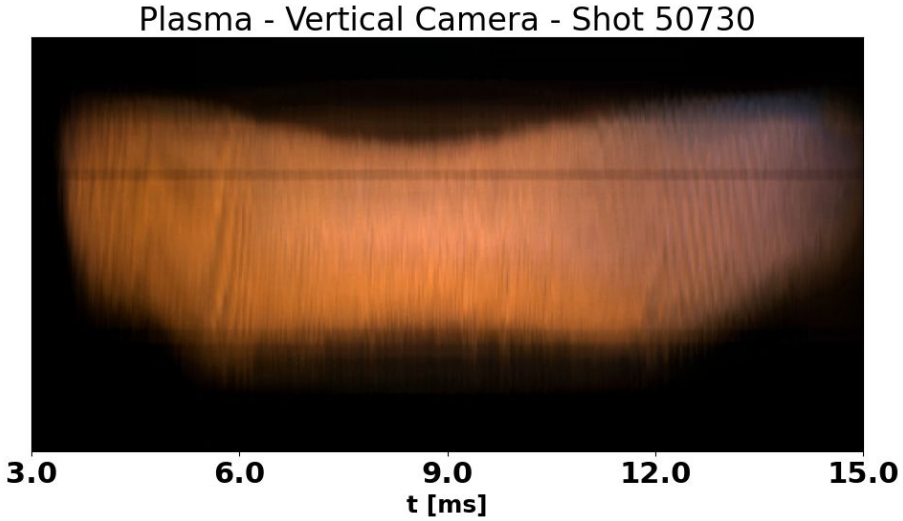
old



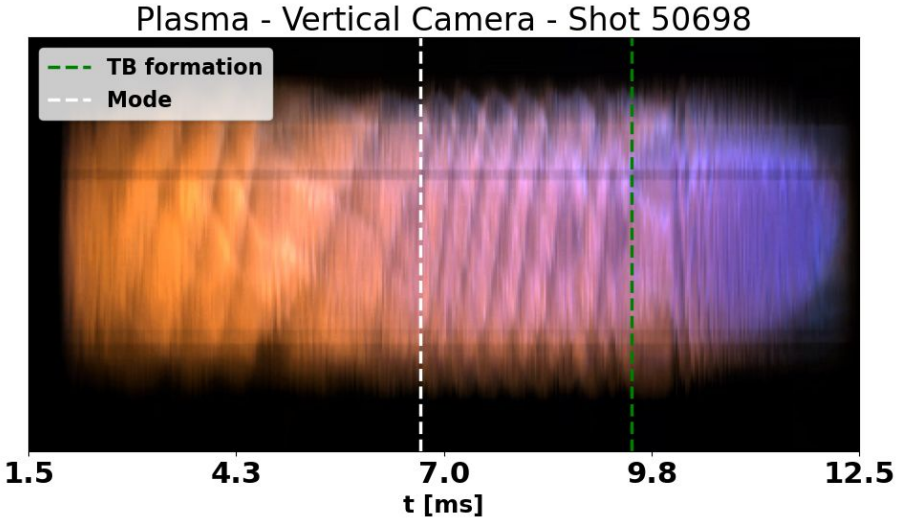
new

Current results

- SUMTRAIC 2025 - observation of **oscillations** (possible mode?) preceding TB formation via fast cameras



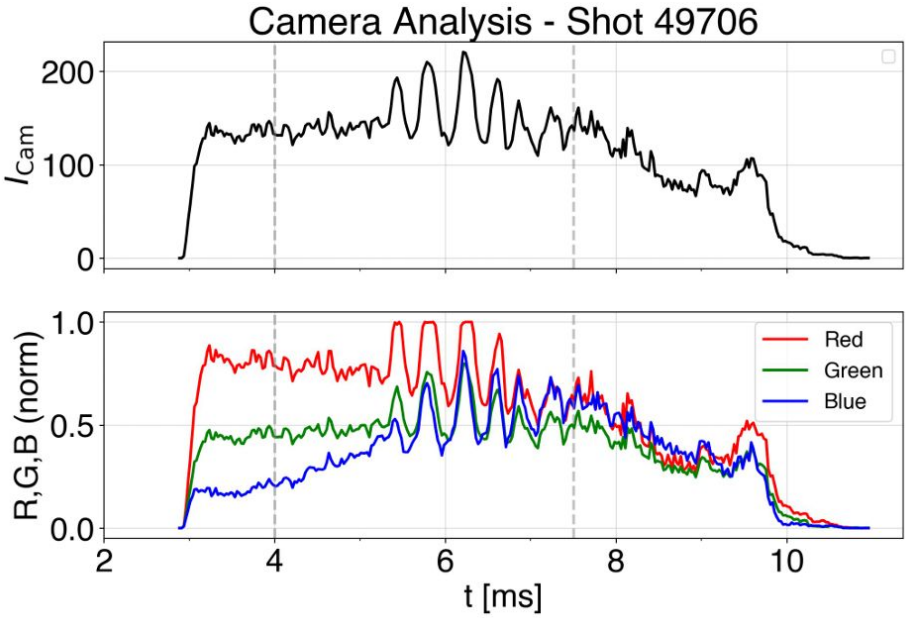
no TB formation



with TB formation

Current results

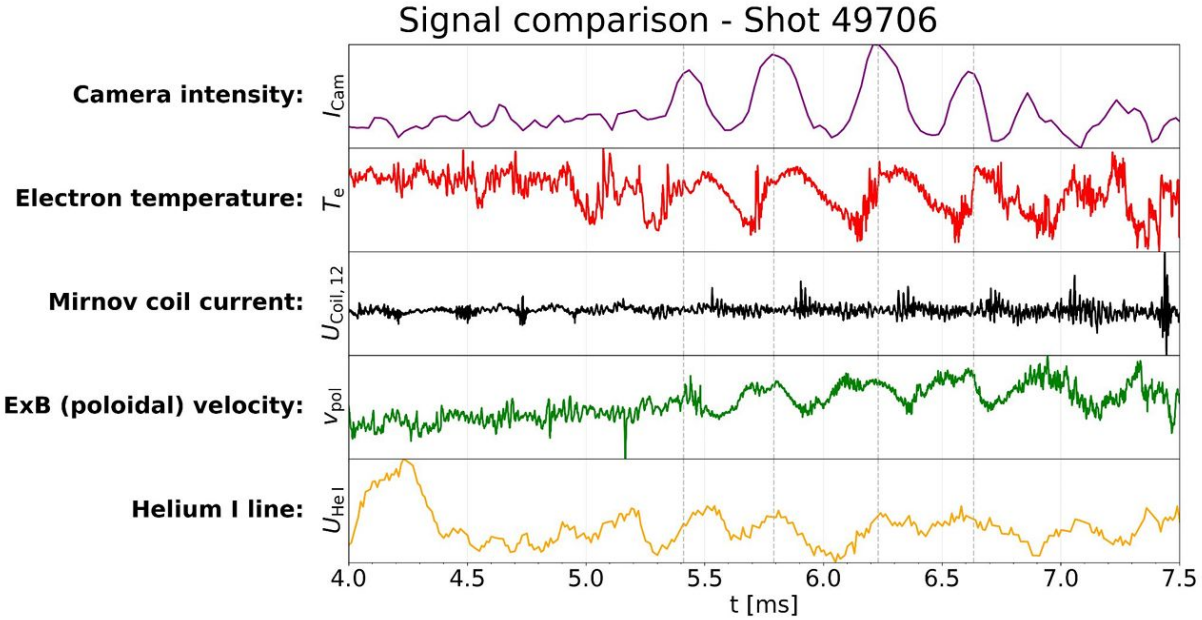
- analysis of RGB and total intensity:



[2] G. Emma *et al* 2025 Characterisation of Edge Plasma Transport Phenomena in the GOLEM Tokamak

- oscillations also observed in other diagnostics
  - probes
  - magnetics
  - spectroscopy

Current results

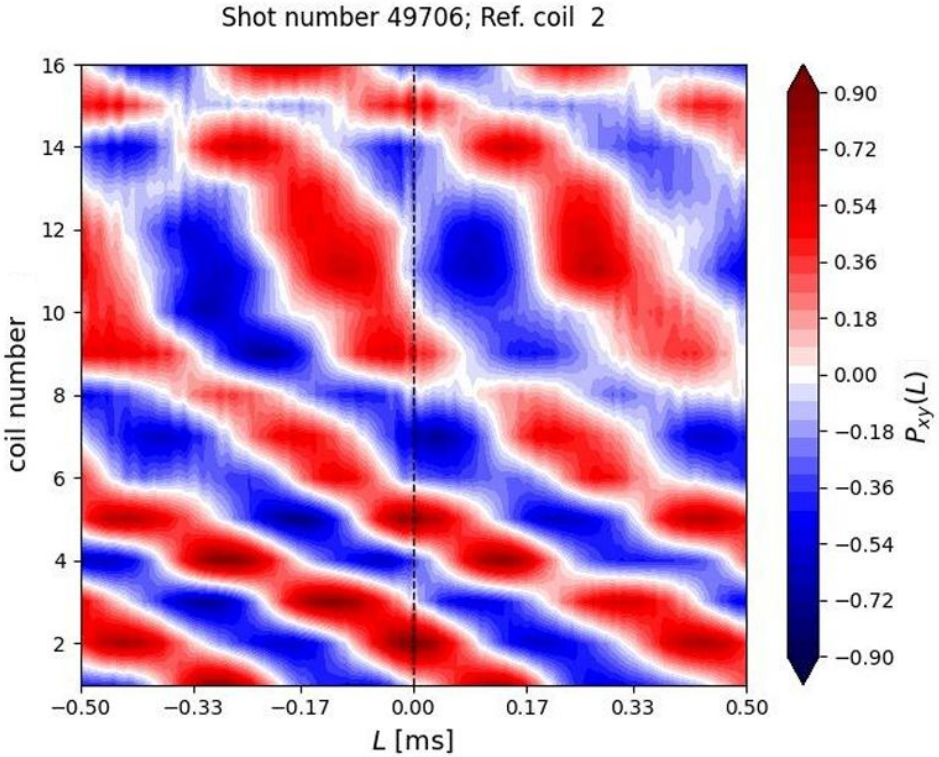


[2] G. Emma *et al* 2025 Characterisation of Edge Plasma Transport Phenomena in the GOLEM Tokamak

- further focus on Mirnov coil signals
- oscillations might determine presence of MHD mode

Current results

- Pearson correlation of signals from individual coils
- what can we see?
  - mode rotation present
  - mode number $m = 4$
  - possibility of magnetic islands?



[2] G. Emma *et al* 2025 Characterisation of Edge Plasma Transport Phenomena in the GOLEM Tokamak

Future plans/TODO list:

- perform similar analysis for **more shot series/discharge parameters**
- **utilize more diagnostics** aside from probes
  - probes + **fast cameras, magnetics (+ diamagnetic loop?)**
- further investigation of turbulent plasma transport
  - possible research on **Wendelstein 7-X** Stellarator

Summary

- existence of **spontaneous formation of TB in He plasma** on GOLEM tokamak (**circular configuration**)
  - GOLEM case - formation of T_e gradient
- old results
  - **scaling** - better understanding of **conditions leading to formation**, **key mechanisms** still unsure
- new results
  - **TB still present, higher T_e values**
  - **oscillations** from fast cameras data and other diagnostics
  - possible **MHD mode preceding TB formation**

Resources:

- [1] P. Macha *et al* 2023 *Nucl. Fusion* 63 104003
- [2] G. Emma *et al* 2025 Characterisation of Edge Plasma Transport Phenomena in the GOLEM Tokamak
- [3] J. Adamek *et al* A novel approach to direct measurement of the plasma potential. *Czech. J. Phys.* 54 (Suppl 3), C95 (2004)
- [4] V. Sedmidubsky 2025 GOLEM double probe-head progress report
- [5] P. Lang *et al* 2013 Nucl. Fusion 53. 043004.