Energy confinement time and flattop study in GOLEM

PRPLA

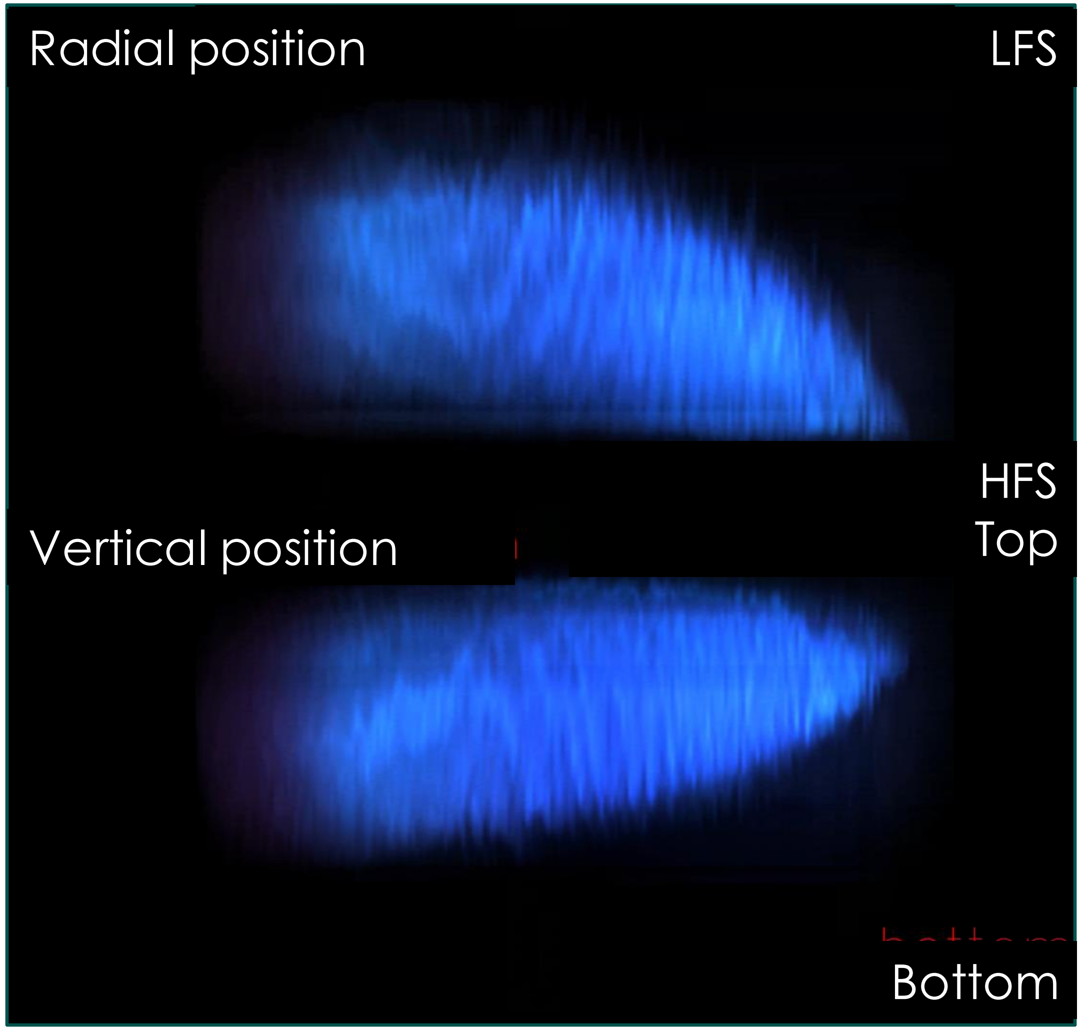
Katherin Paola Gómez Romero

Jorge Paz-Peñuelas Oliván

Objectives

GOLEM sessions

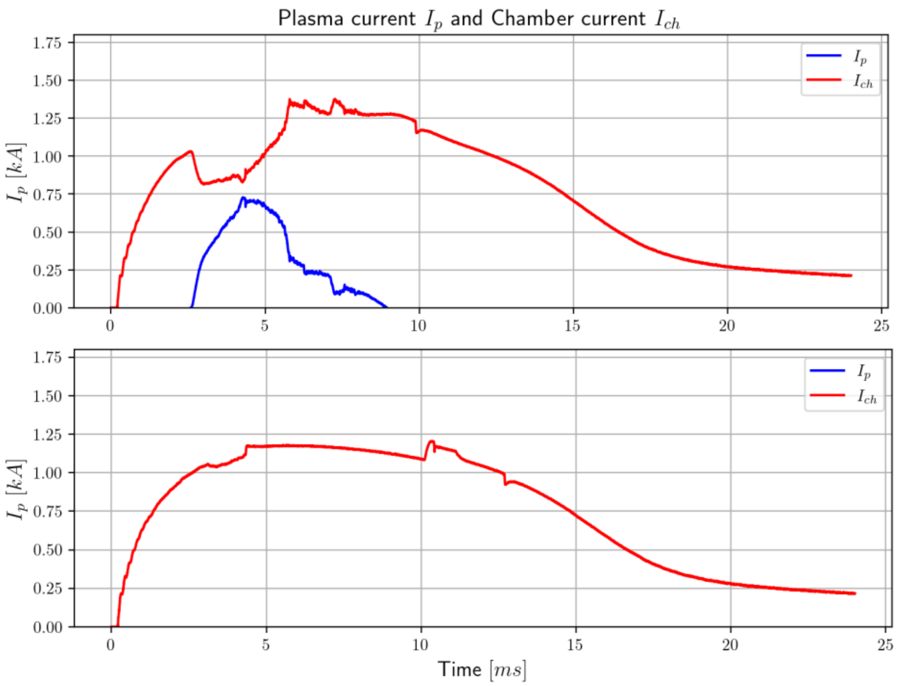
- Play with THE GOLEM and get used to operation, the command line & wall conditioning.
- Figure out position stabilisation.
  - #50108 – Reference shot – 5.78 ms
- Chase a flattop regime.
- Characterise the energy confinement time.
  - U_Bt = 900 V
  - U_cd = 380 V
  - t_Bt = 0 ms
  - t_cd = 200 ms



#50108 plasma position

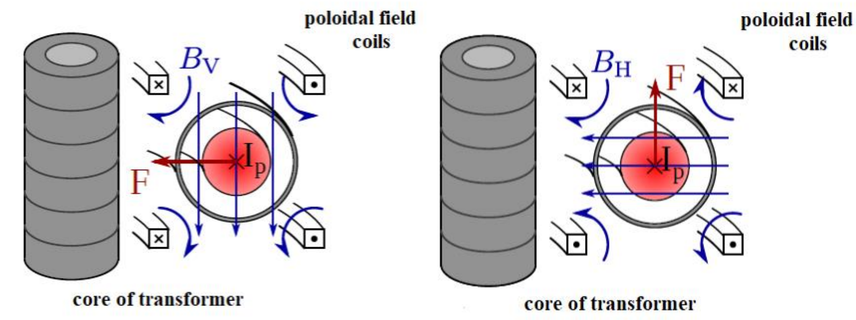
Position control system

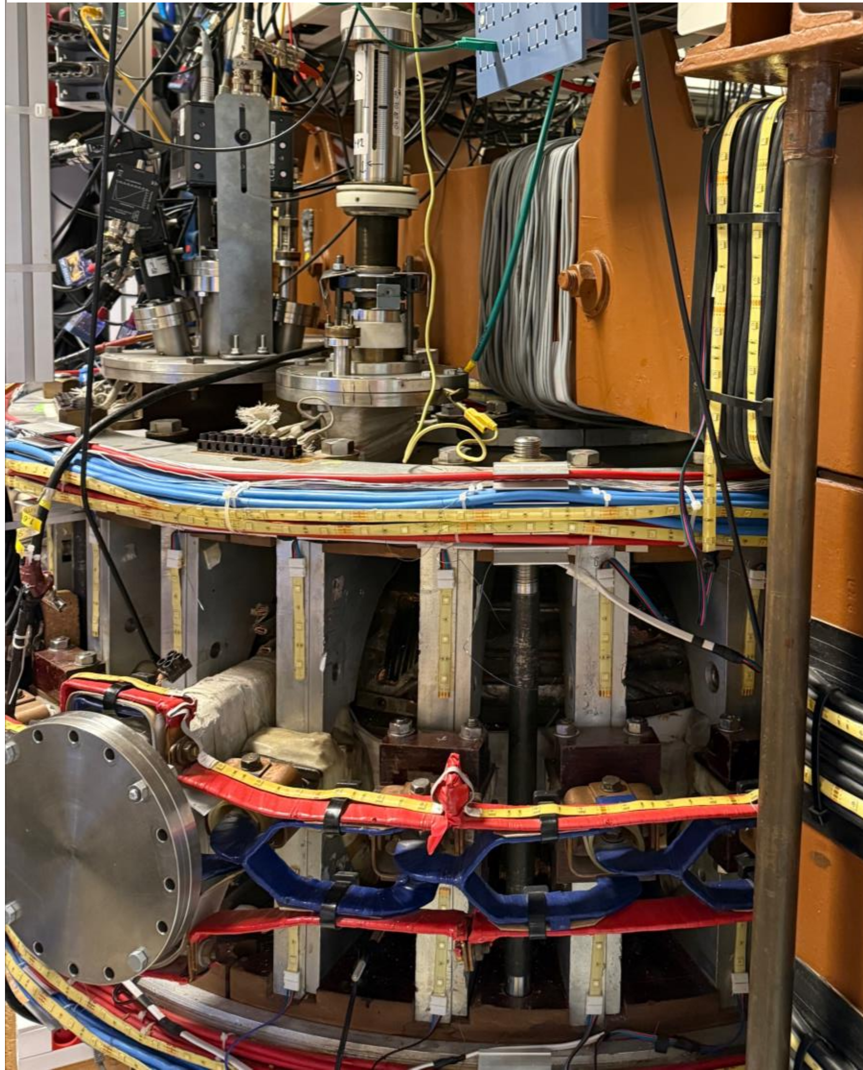
- Main initial limitation for plasma duration.
- A lot of trial and error – not much success.
  - #50109 to #50115
- Engaging position stabilisation too early kills the plasma



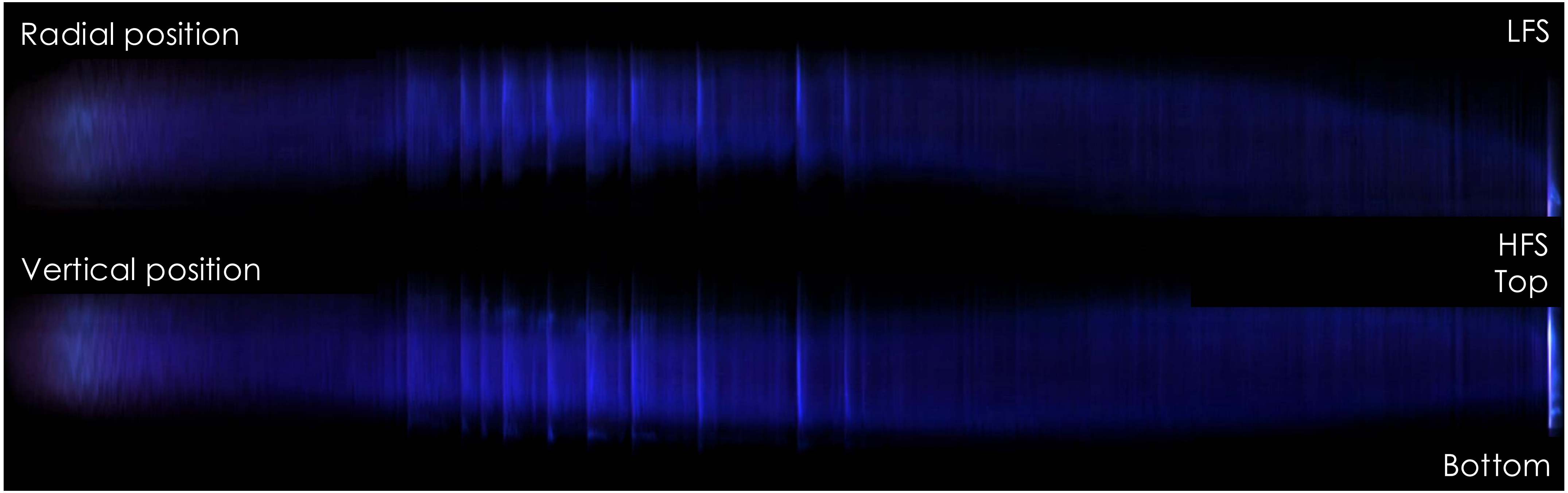
#50113
Pos Stab engaged at 2.5 ms.
Too strong (-20V)
→ kills plasma early

#50114
Pos Stab engaged at 1.5 ms.
No plasma despite softer stabilisation (-15V)





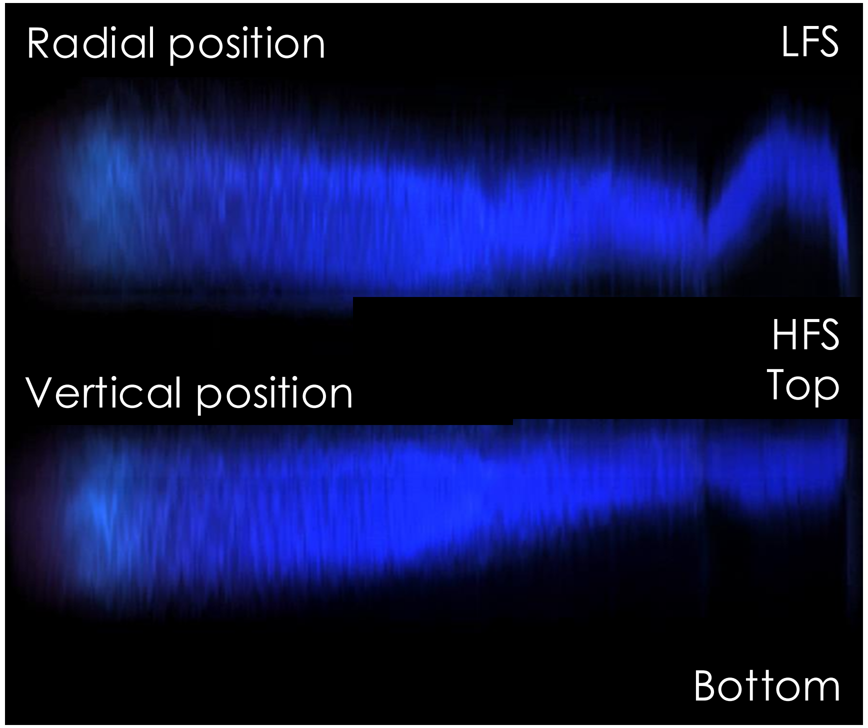
Our results



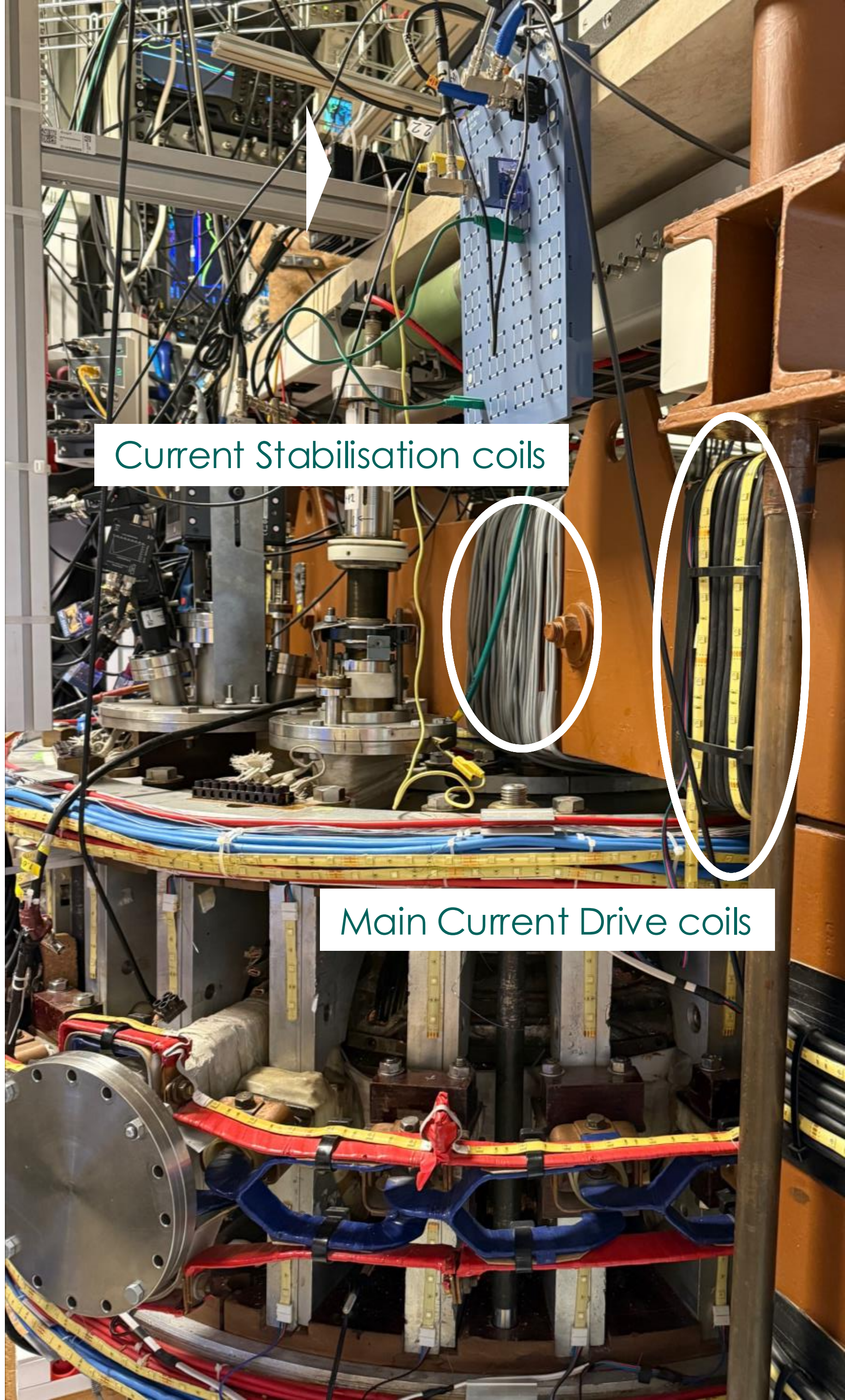
- Change polarization of the terminals.
  - Positive voltage: Move plasma to LFS or top.
  - Negative voltage: Move plasma to HFS or bottom.
- We could use more power in the Radial position.

First contact

- Trial and error: started with a simple waveform with maximum voltage
- Surprising behaviour of the plasma once the stabilised current appears

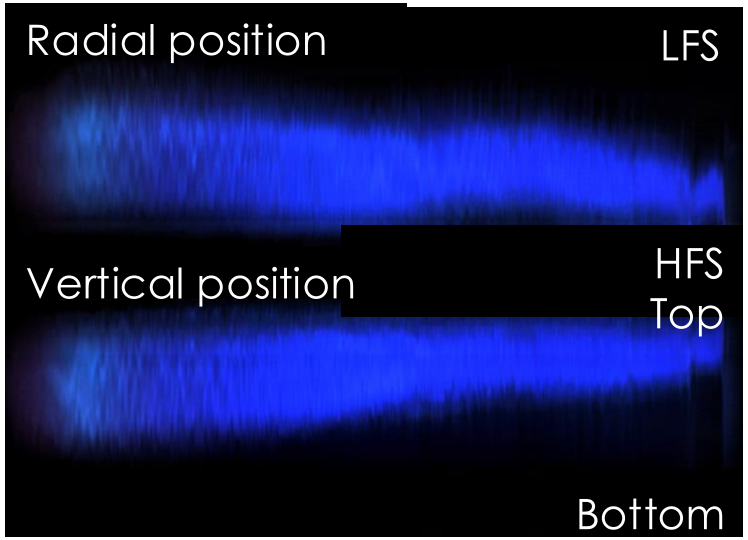


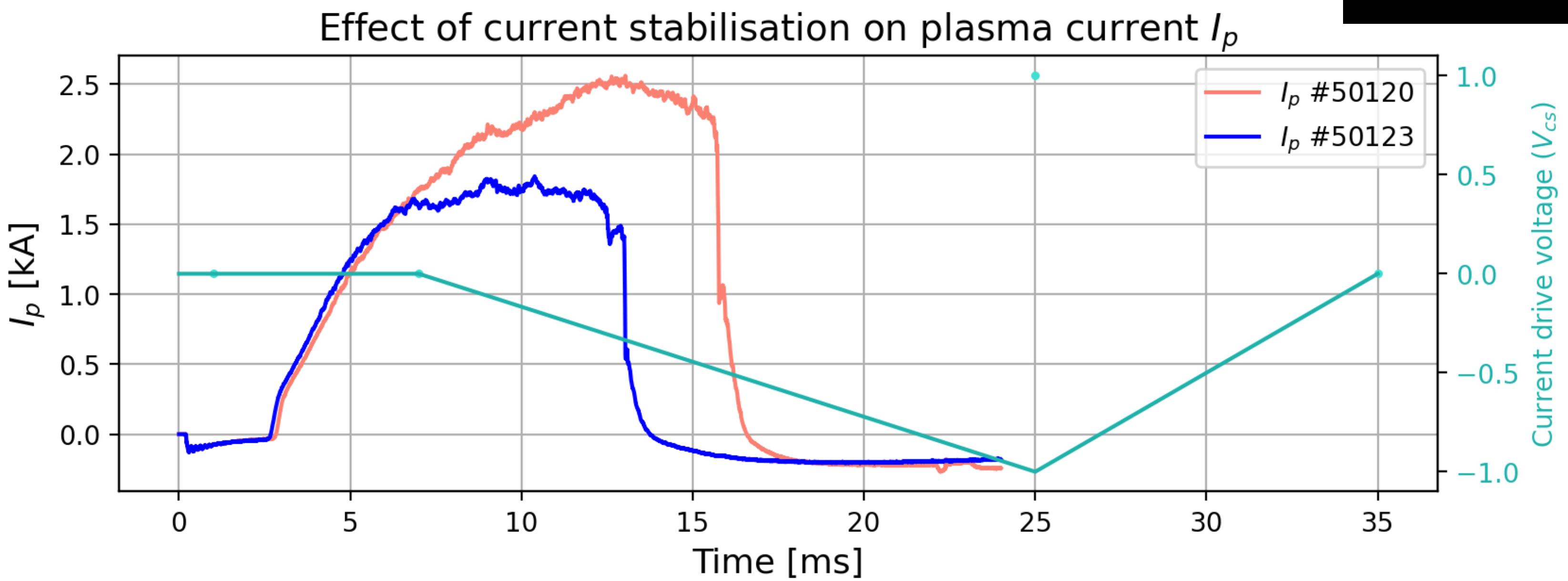
#50121
Current Stab engaged at 7 ms.
Too strong (20V)
→ Plasma presents a weird behaviour at the end



First contact

- Voltage for current stabilization reduced to 1 V.
  - Plasma presents less oscillations.
- Plasma keeps tending to the HFS and the top of the vessel.





#50123
Current stab voltage reduced to 1 V.
→ Plasma tends to HFS

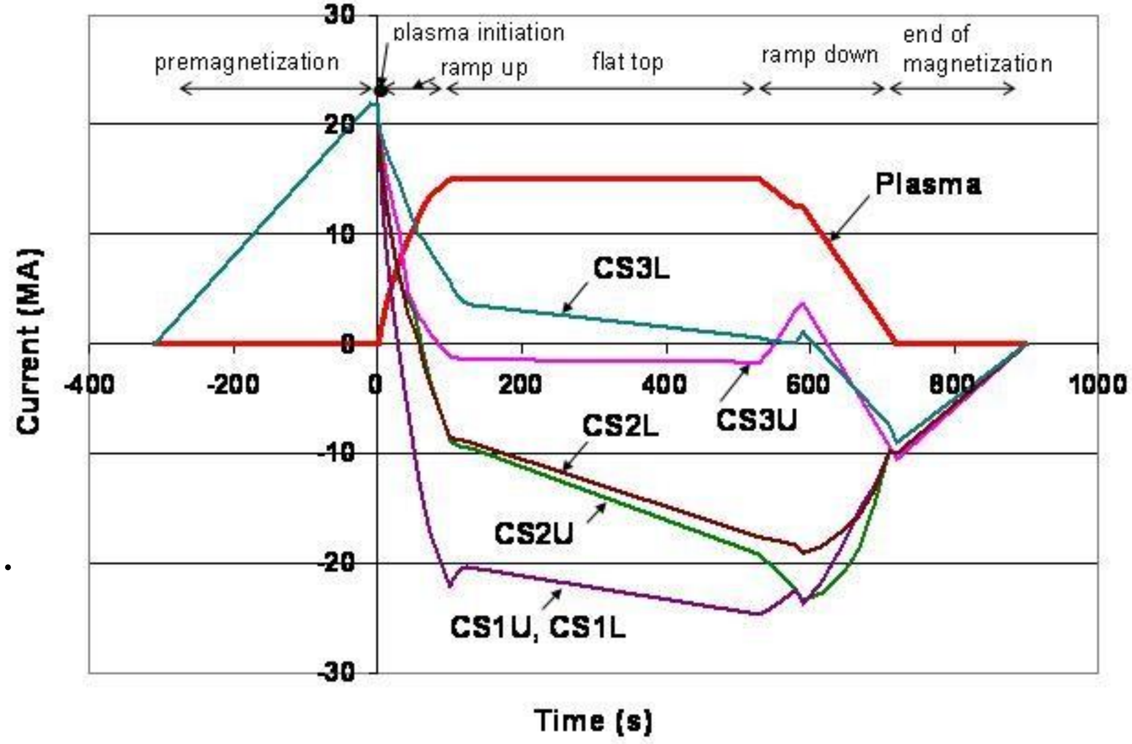
Current drive in a tokamak

- A tokamak is said to be like transformer.
  - Induces plasma I_p and chamber I_{ch} current.
  - Simplifying considerably $I_p \propto I_{\mathrm{cd}}$.
  - Tokamaks not pulse machines?

Wrong approach!

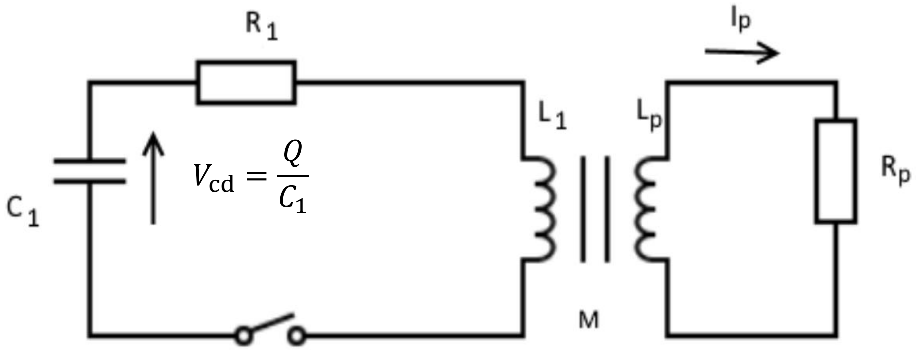
- It is known that $I_p \propto \partial_t I_{\mathrm{cd}}$ (Faraday's law).
  - I_{cd} is controlled through V_{cd}
  - $I_p(V_{\mathrm{cd}})$ very complicated

ITER central solenoid



Current Drive: The GOLEM case

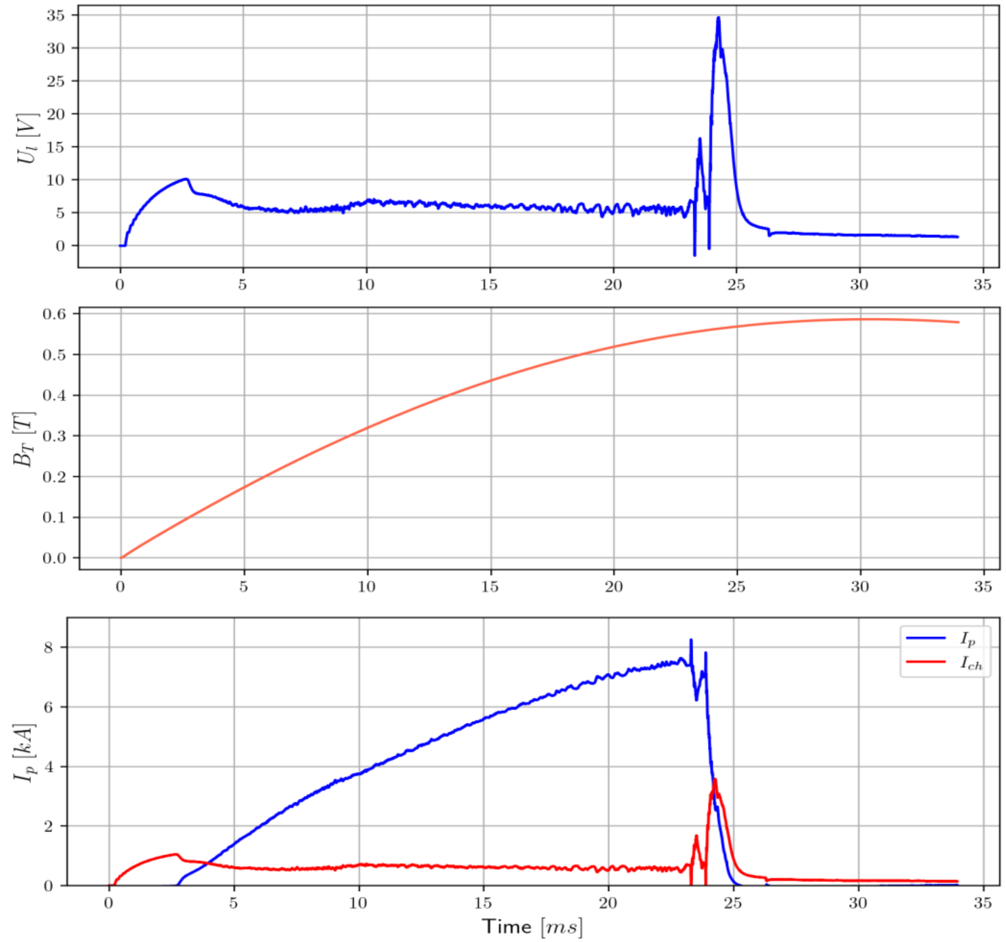
- I_{cd} powered with capacitors.



$$\dot{X} = MX,$$

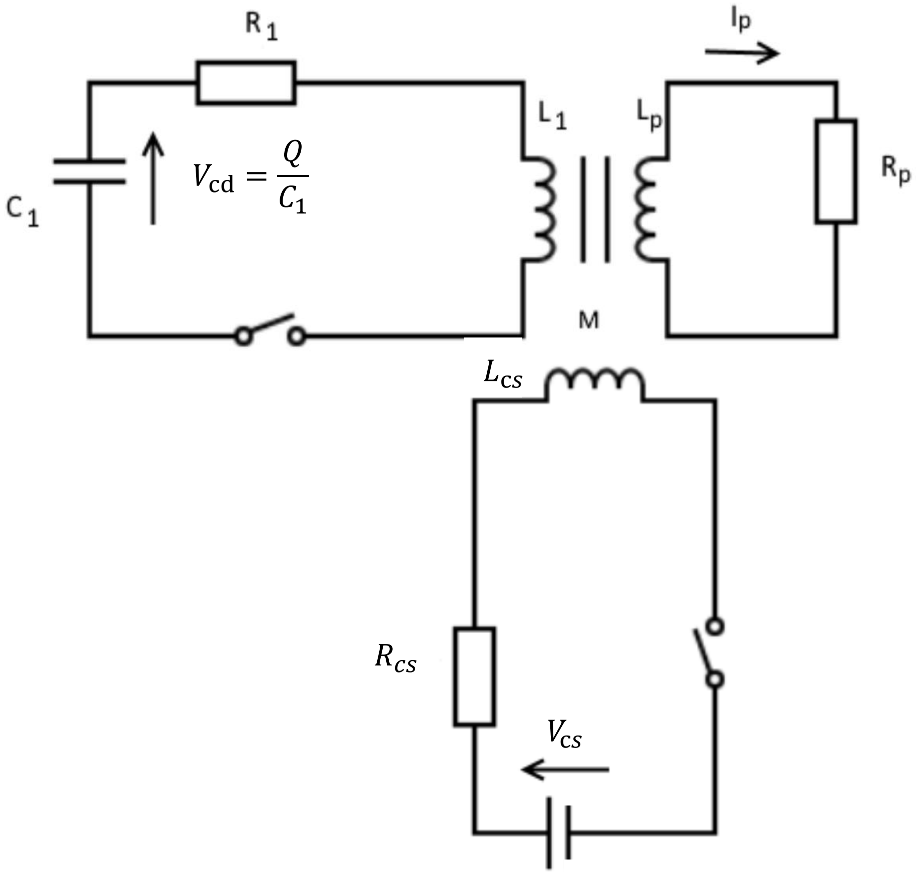
$$\text{where } X = \begin{pmatrix} I_p \\ Q \\ \dot{Q} \end{pmatrix}, \mathrm{M} = \begin{pmatrix} \frac{R_p L_p}{A} & \frac{M}{CA} & \frac{MR}{A} \\ 0 & 0 & 1 \\ \frac{MR_p}{A} & \frac{L_p}{CA} & \frac{L_p R}{A} \end{pmatrix}$$

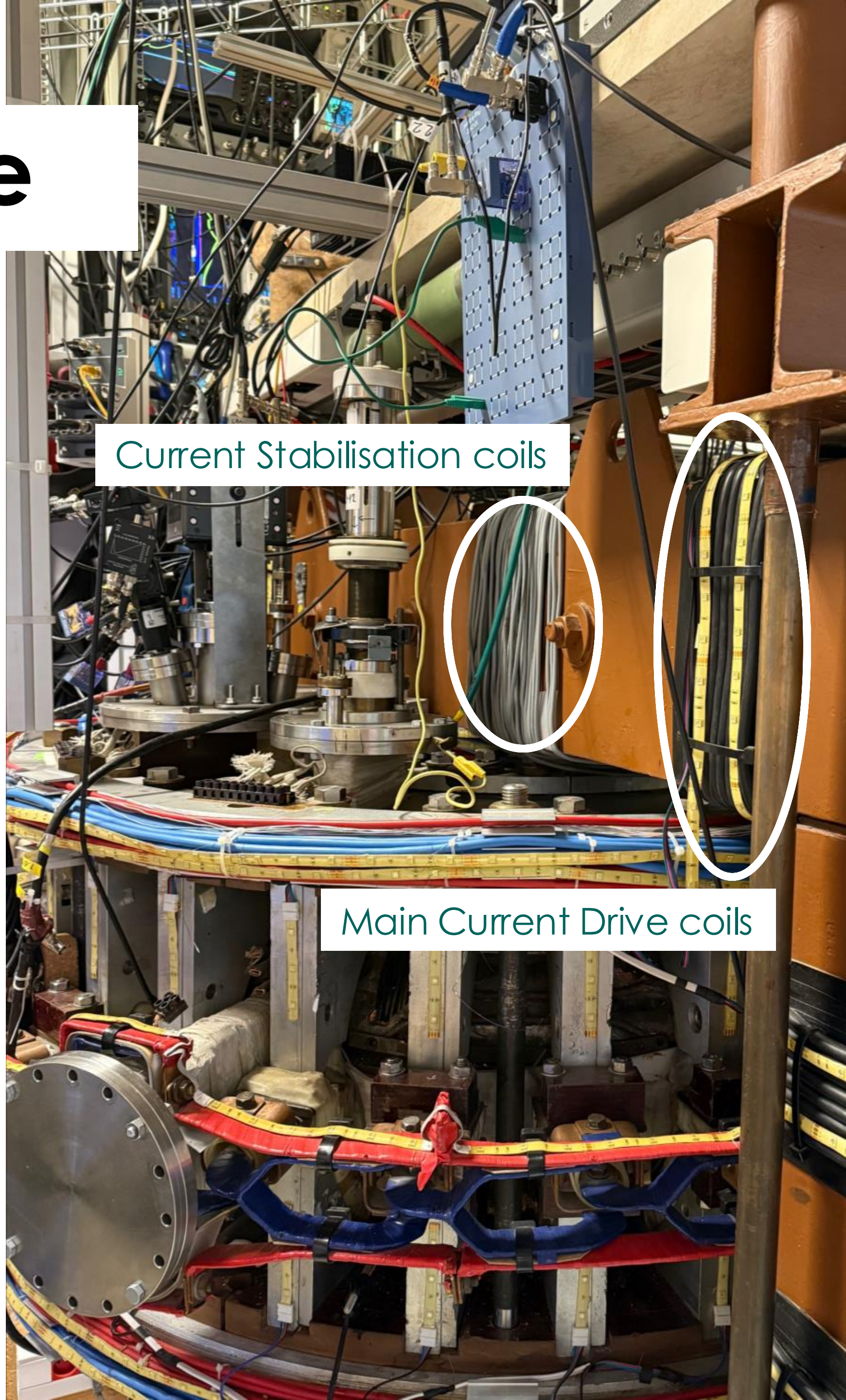
Current stabilisation off - #50151



Current Drive: The GOLEM case

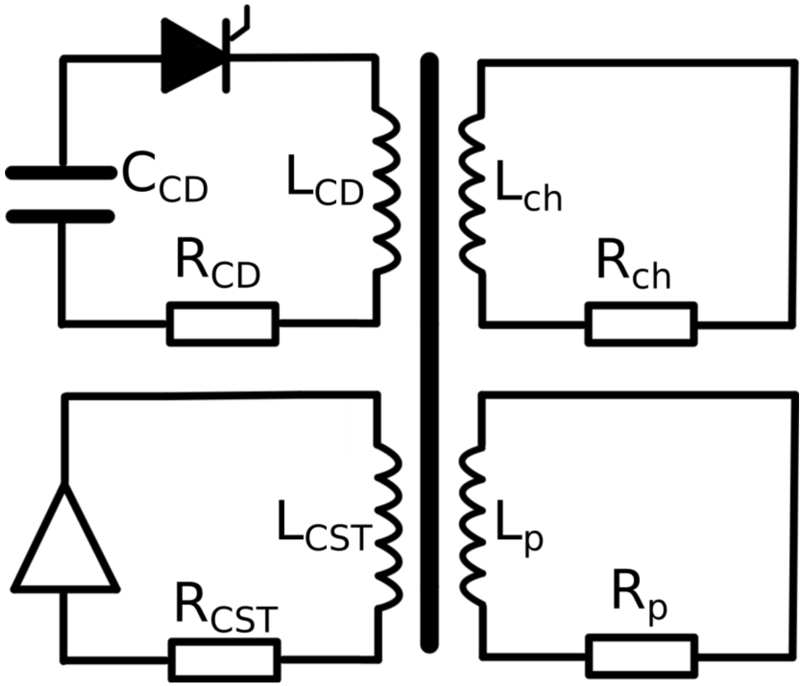
- I_{cd} powered with capacitors.





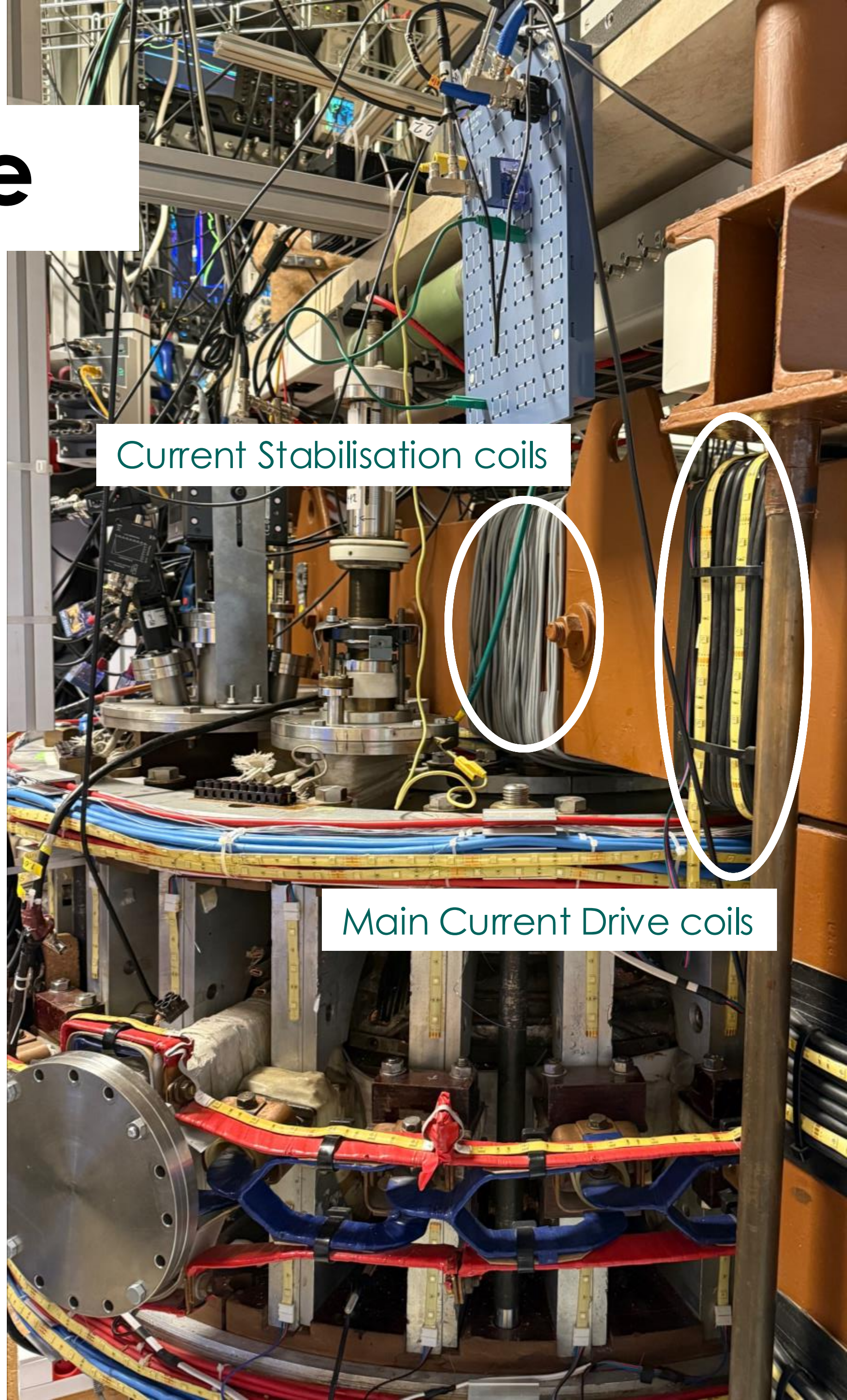
Current Drive: The GOLEM case

- I_{cd} powered with capacitors.

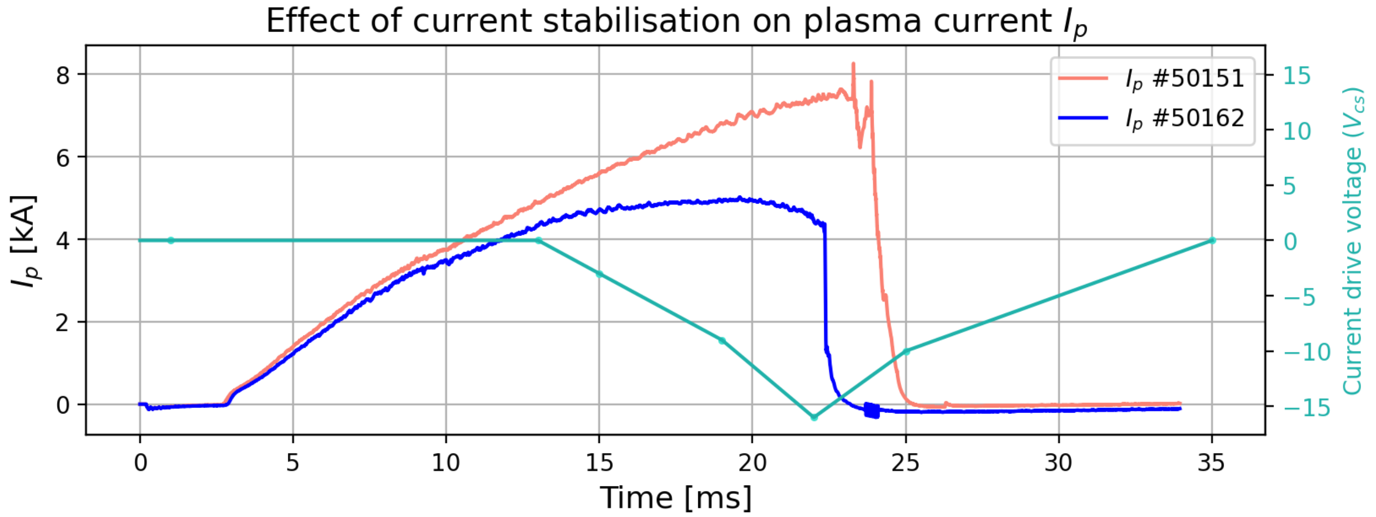


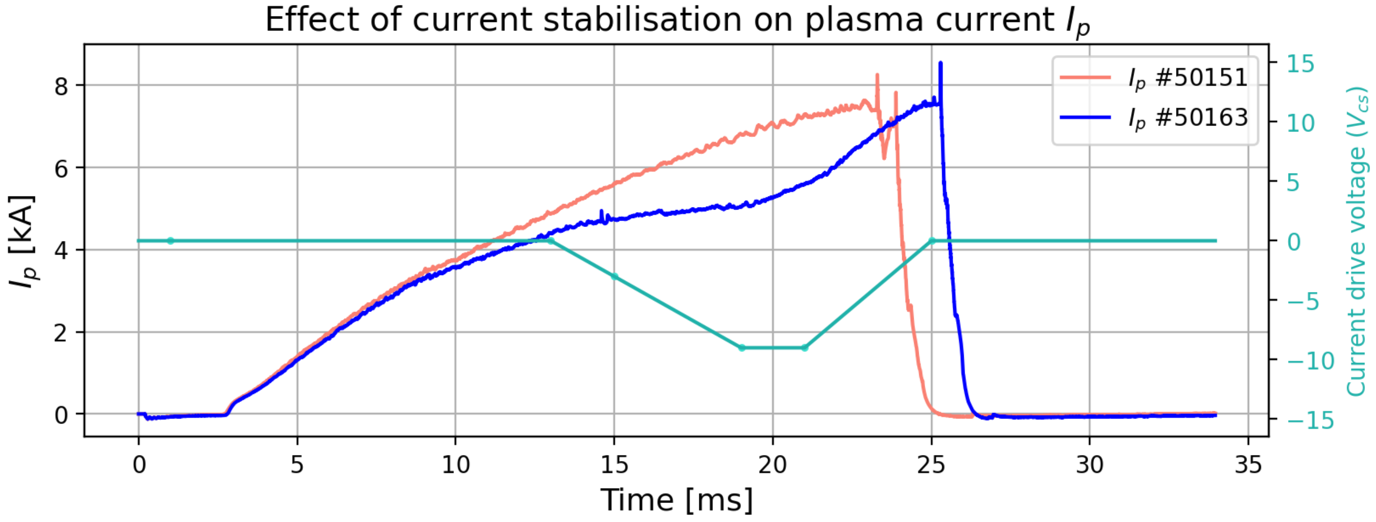
Buryanec, Jan, private communication

- Theoretical prediction left as further work ^^.



Ad-Hoc approach



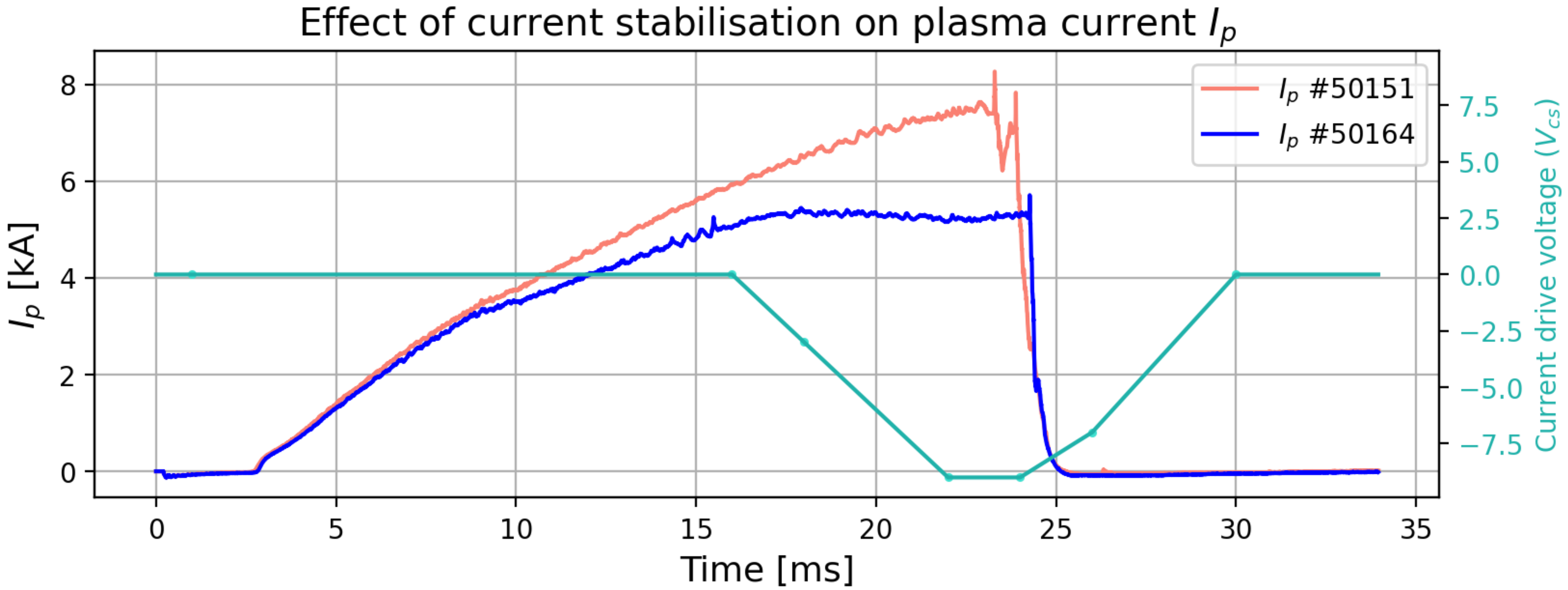


- Current stabilisation influences magnetic flux through the central iron.
  - Can limit the current.
  - $\Delta I_p(V_{CS})$ still unkown.

#50162
Current stab voltage peaks at -15V at the end of the discharge.
→ I_p heavily suppressed.

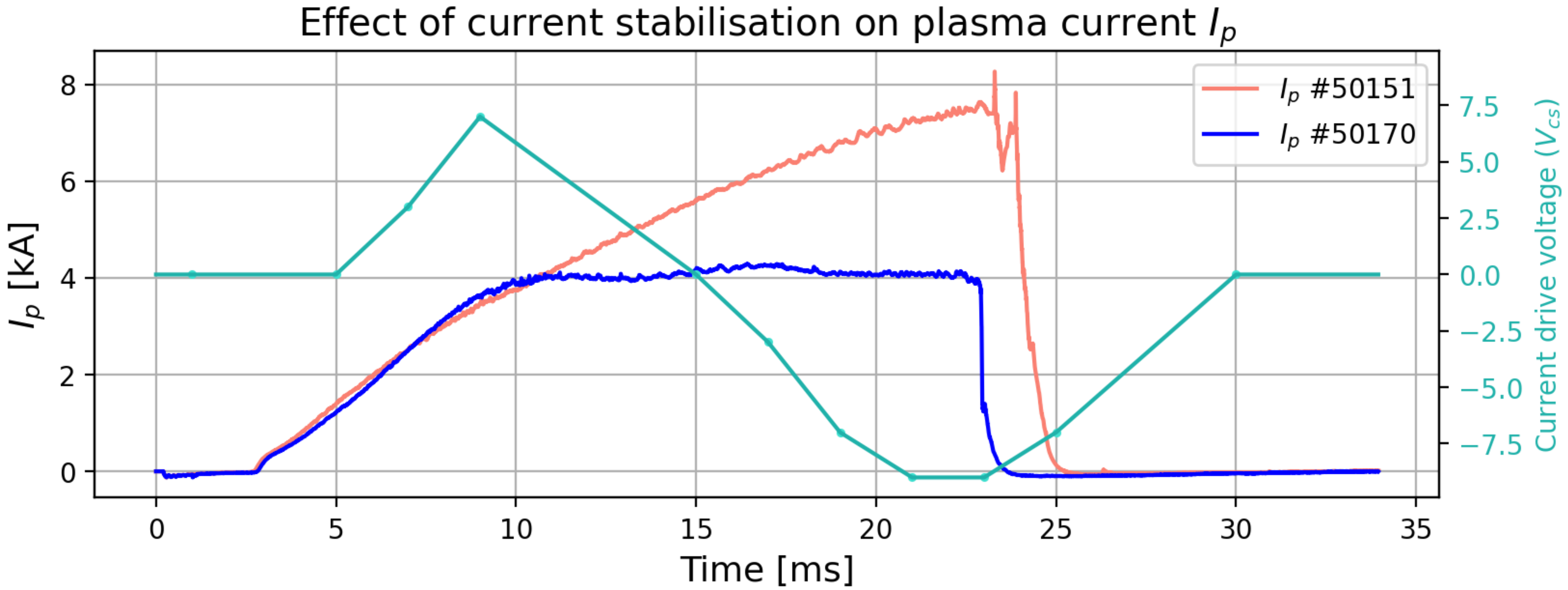
#50163
Current stab begins as #50162 but quickly stops suppressing I_p.
→ I_p recovers & plasma longer.

Insight into $\Delta I_p(V_{CS})$



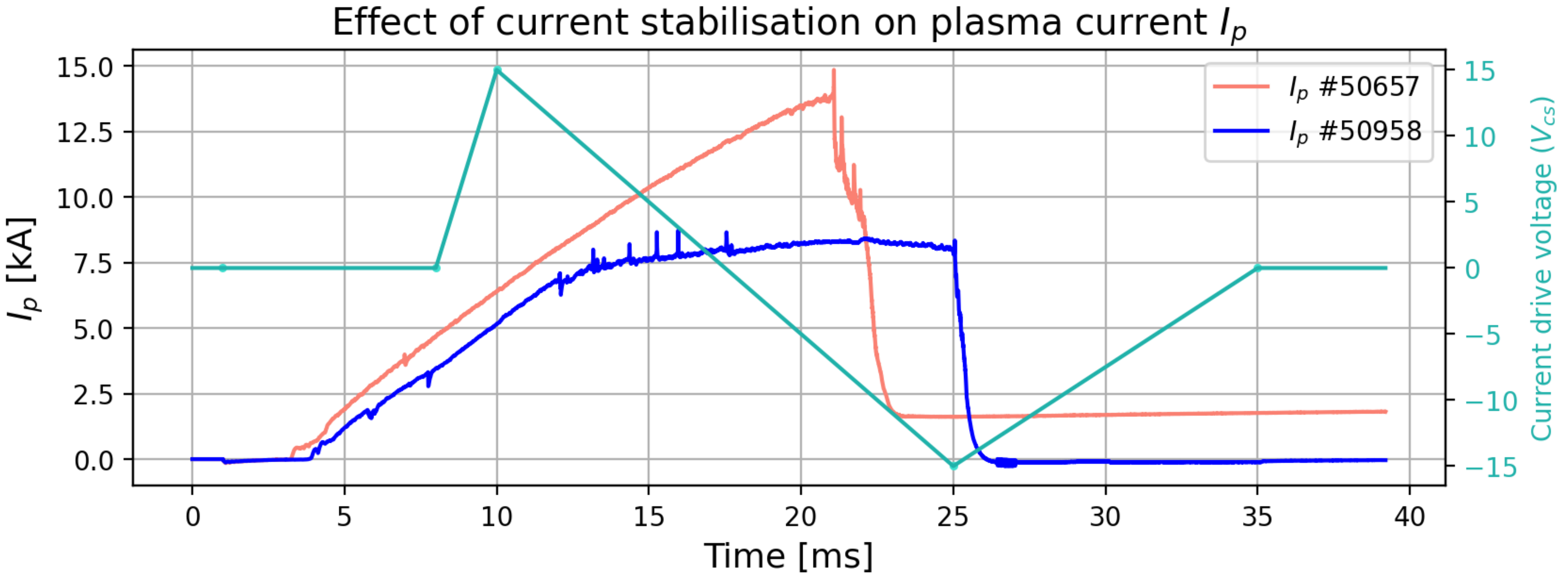
- First small flattop!
- We get an insight into $\Delta I_p(V_{CS})$.
  - $\Delta I_p \propto V_{CS}$?

Happy idea



- Not only limit the current, but also drive it at the beginning.
- ~11 ms of flattop ⁉️
- More insight into $\Delta I_p(V_{CS})$?
  - Engaging the current stabilisation seems to reduce I_p overall.

Flattop application



- Trying to improve the shot by Torino University.
- GOLEM was having a tantrum that day.
- Tried very simple current stabilisation.
  - Mild flattop.

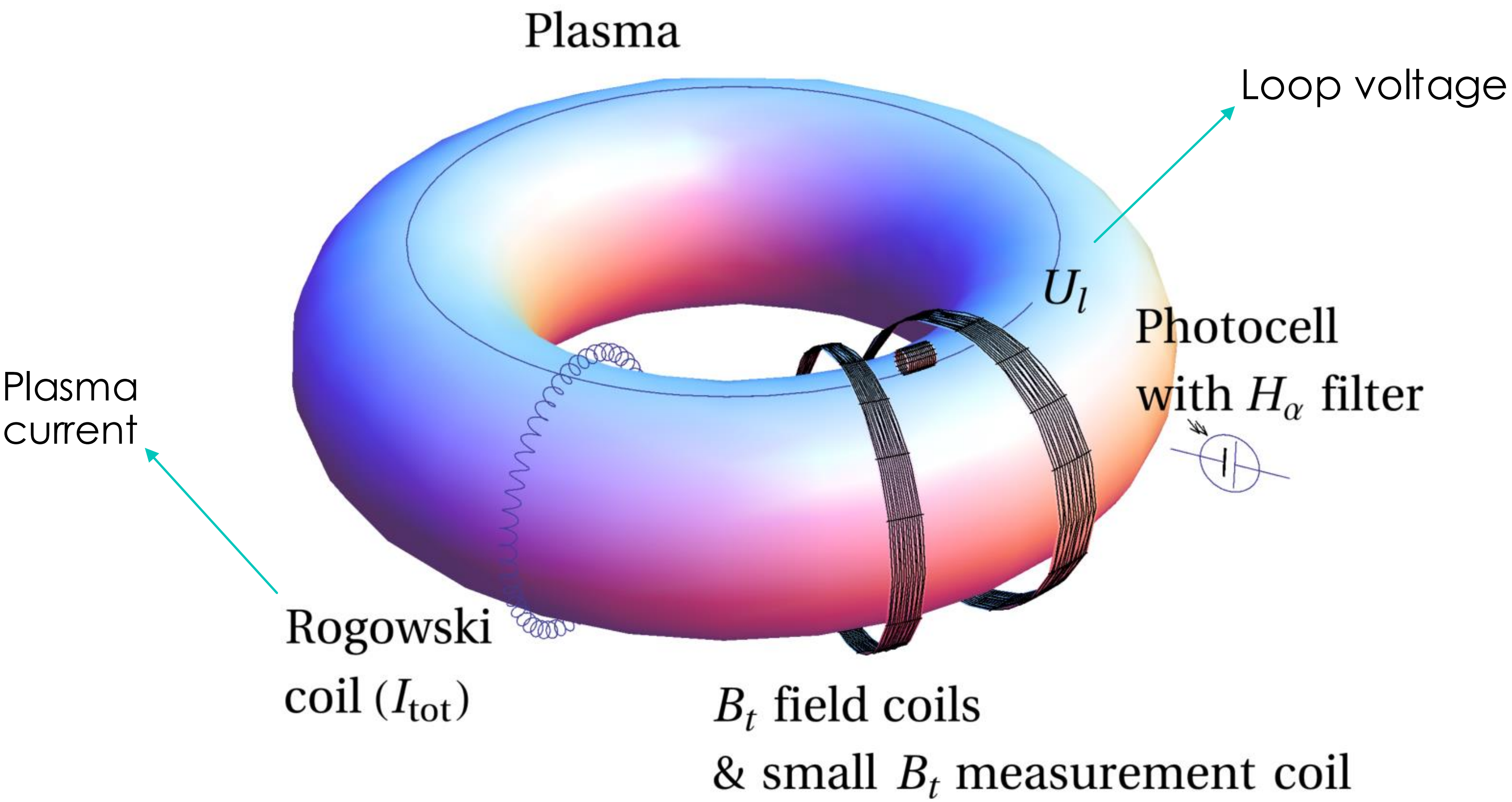
Objective

- Determine if there's a relation between the energy confinement time and the toroidal magnetic field.

Methodology

- Measure plasma current, loop voltage, and toroidal magnetic field by means of different diagnostic methods.
- Determine energy confinement time for different shots with different values for toroidal magnetic field.
- Study the relation between energy confinement time and toroidal magnetic field.

Diagnostics



Physics behind

- Energy stored in the plasma

$$W_p = \frac{1}{3} e n_e T_e V_p$$

- Energy is lost in the plasma. In GOLEM

$$P_{heating} = P_{loss} = \frac{W_p}{\tau_E}$$

- So, the energy confinement time

$$\tau_E = \frac{e n_e T_E V_p}{3 U_l I_P}$$

Physics behind

- For the electron density

$$n_e = \frac{2p_0 V_{ch}}{k_B T_0 V_p}$$

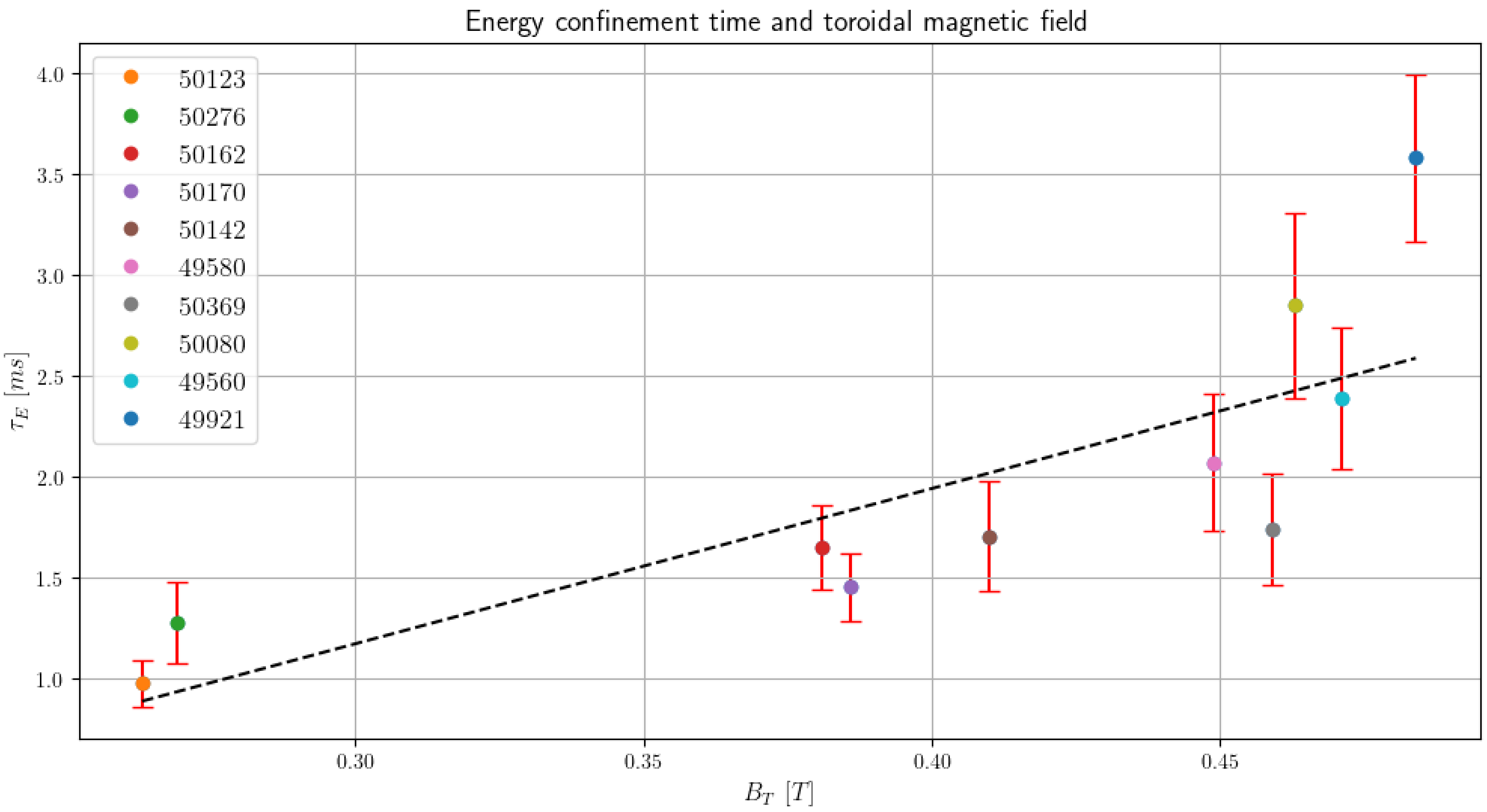
- For the central electron temperature

$$T_e = 0.9R^{-2/3}$$

Spitzer's resistivity

- Other parameters:
  - $V_p = 0.06\ m^3$
  - $V_{ch} = 0.15\ m^3$
  - $T_0 = 300\ K$

Results


Energy confinement time and toroidal magnetic field
50123
50276
50162
50170
50142
49580
50369
50080
49560
49921
4.0
3.5
3.0
2.5
2.0
1.5
1.0
τ_E $[ms]$
0.30
0.35
0.40
0.45
B_T $[T]$

Conclusions and more

Conclusions

- Current and position stabilisation can extend plasma duration (and can also reduce it if incorrectly applied).
- Flattop is challenging to attain analytically, but we gained good intuition for heuristic operation.
- The energy confinement time is increasing with the toroidal magnetic field.
- Holes in the vessel significantly diminish plasma performance.

Future work

- Real control for automatization of position stabilisation.
- Develop full theoretical analytical expression of plasma current drive and current stabilisation.
- Enjoy the flattops at GOLEM!!

The GOALEM

Advancing fusion education