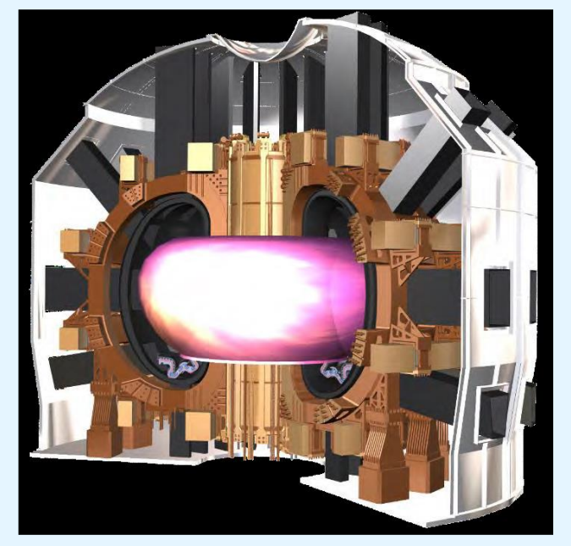
Thermal-hydraulic analyses of the DTT Toroidal Field magnets

R. Bonifetto[1], A. Di Zenobio[2], L. Muzzi[2], S. Turtù[2], R. Zanino[1], A. Zappatore[1] and DTT design contributors*

[1]NEMO group, Dipartimento Energia, Politecnico di Torino, Torino, Italy
[2]ENEA, Frascati, Italy
* See the Appendix B of R. Albanese, A. Pizzuto et al., Fusion Engineering and Design, Volume 122, Pages 274-284, November 2017

Introduction

The fully superconductive Divertor Tokamak Test (DTT) facility, currently under design in Italy, will test several DEMO-relevant divertor solutions


[Interim Design Report, April 2019]

- Major radius R_0 = 2.14 m
- Aspect ratio = 3.3
- Toroidal field on axis = 6 T
- Plasma current = 5.5 MA

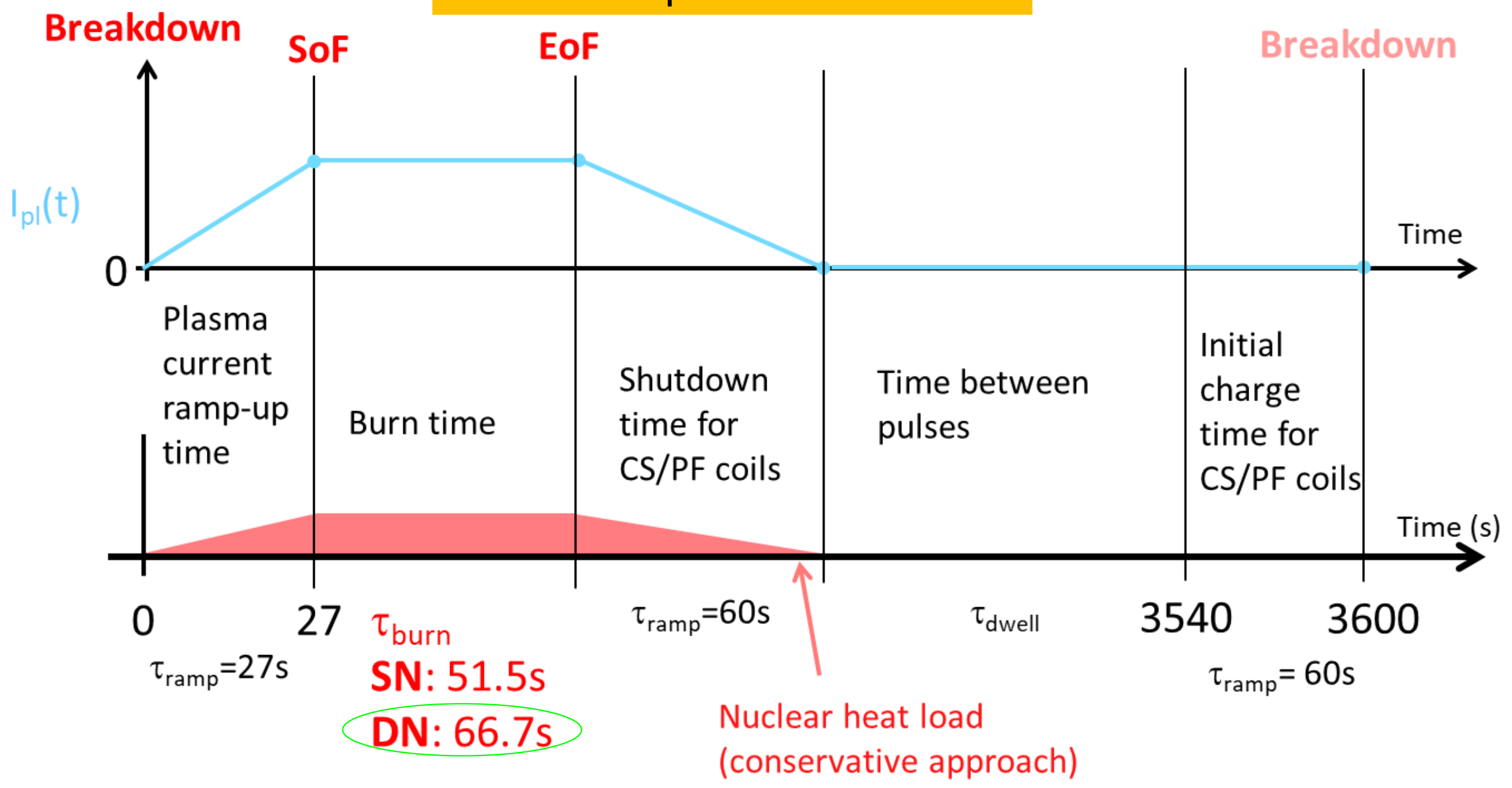
[DTT PID v1.3, May 24, 2019]

Aim of the work

Assess the performance of the DTT TF magnets in normal and off-normal operation with the 4C code

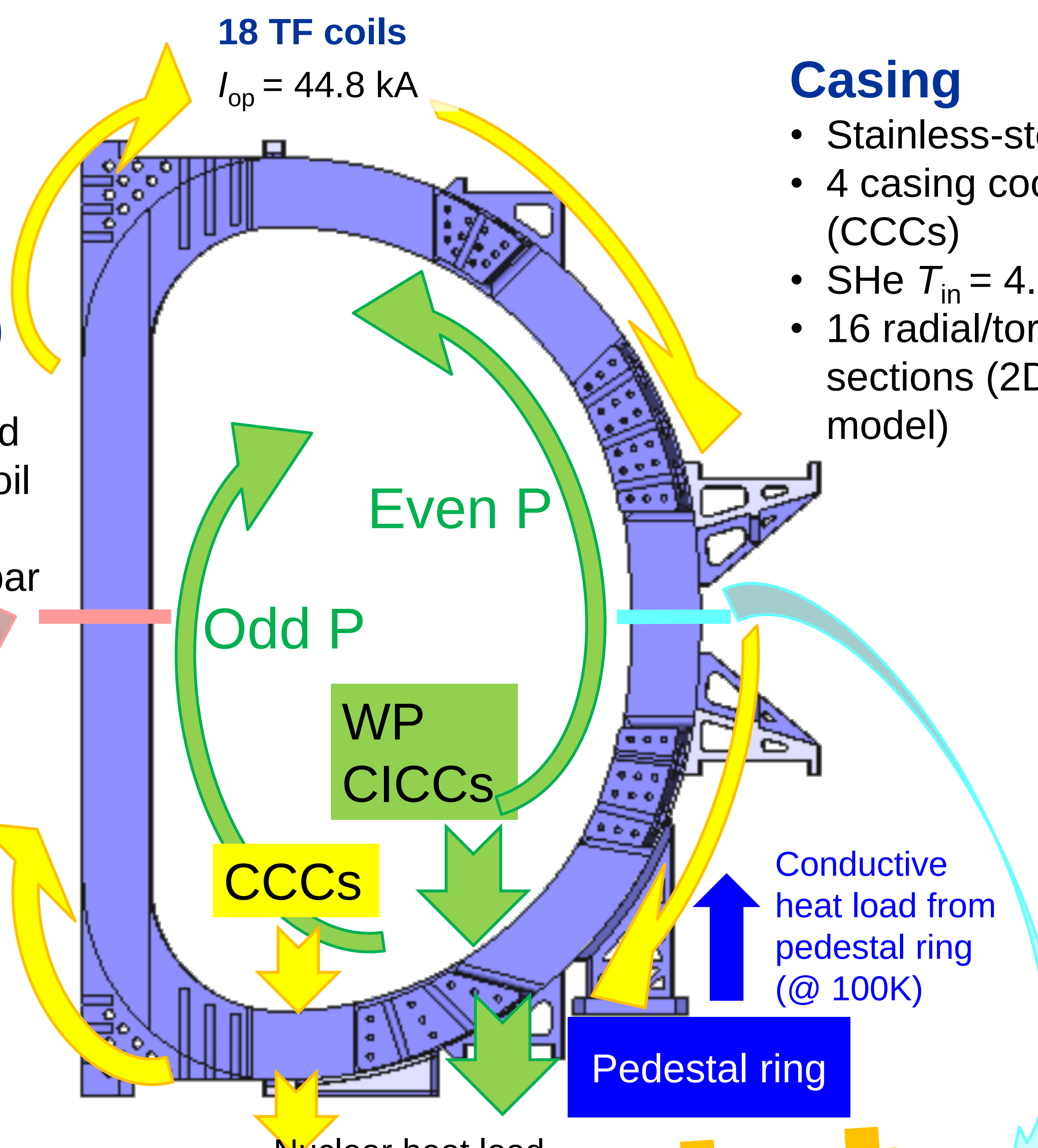
- Develop a model of the ~ 5 m tall TF magnet (WP and casing)
- Assess the impact of different designs
- Compute the effects of a plasma disruption on the TF operation

Reference plasma scenarios



Only Double-Null scenario considered here (longer plasma duration → lowest ΔT_{marg})

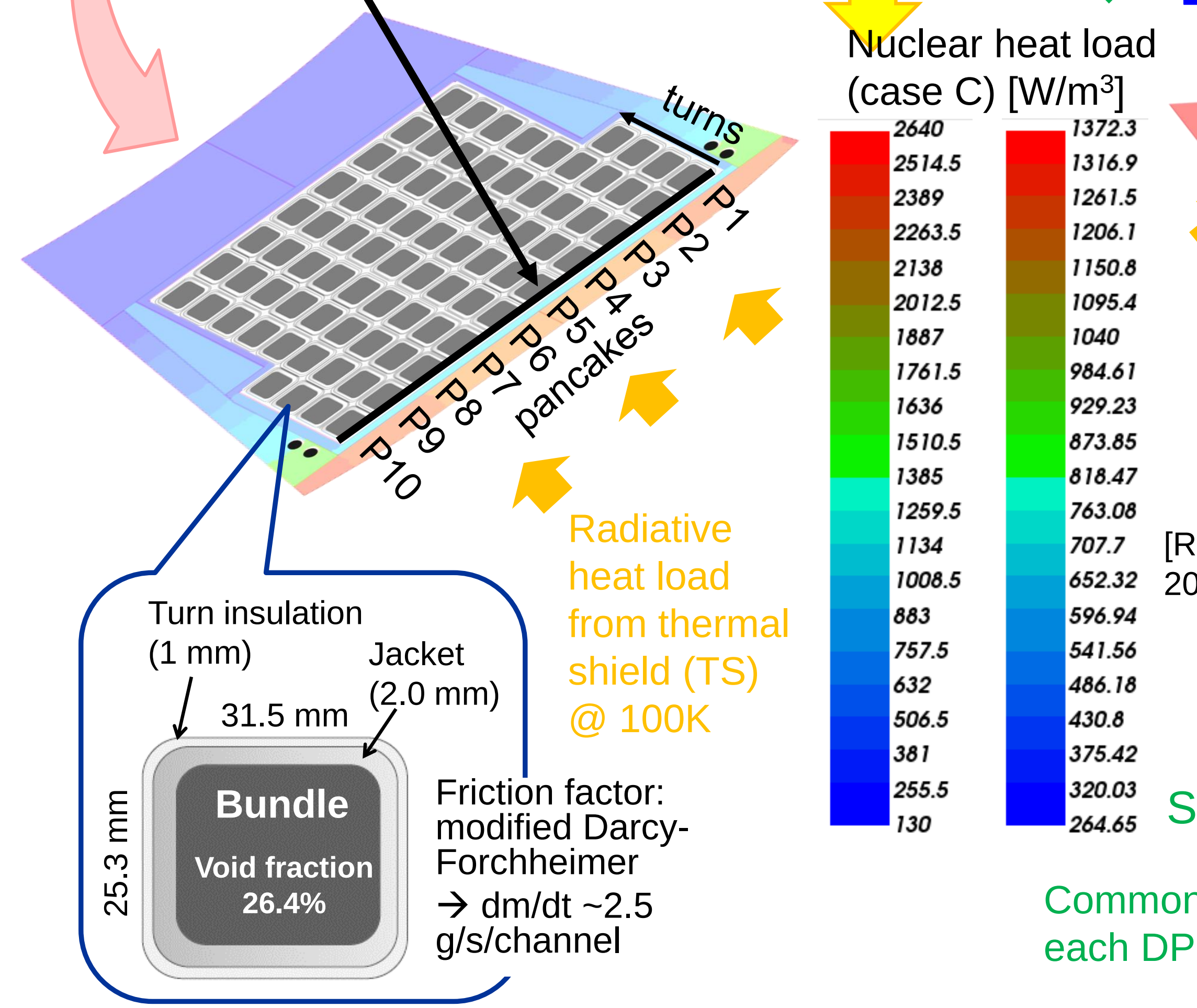
4C code model



Winding Pack (WP)

- Nb_3Sn CICC
- (Double) pancake-wound
- 10 hydraulic channels/coil (1D model)
- SHe T_{in} = 4.5 K, p_{in} = 6 bar

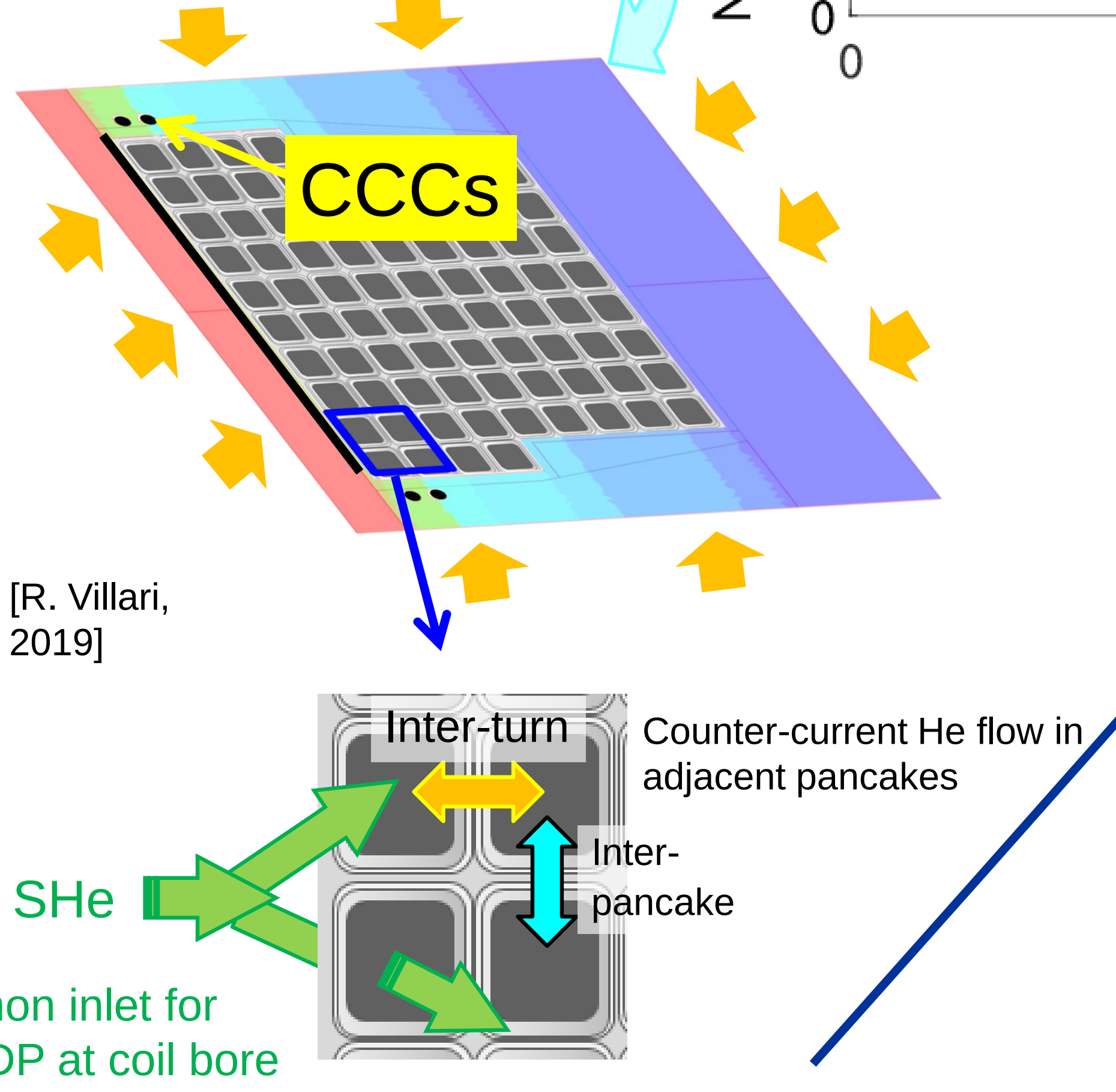
WP detachment from casing at plasma side (→ no thermal contact) when the coil is charged



Friction factor: modified Darcy-Forchheimer
→ dm/dt ~2.5 g/s/channel

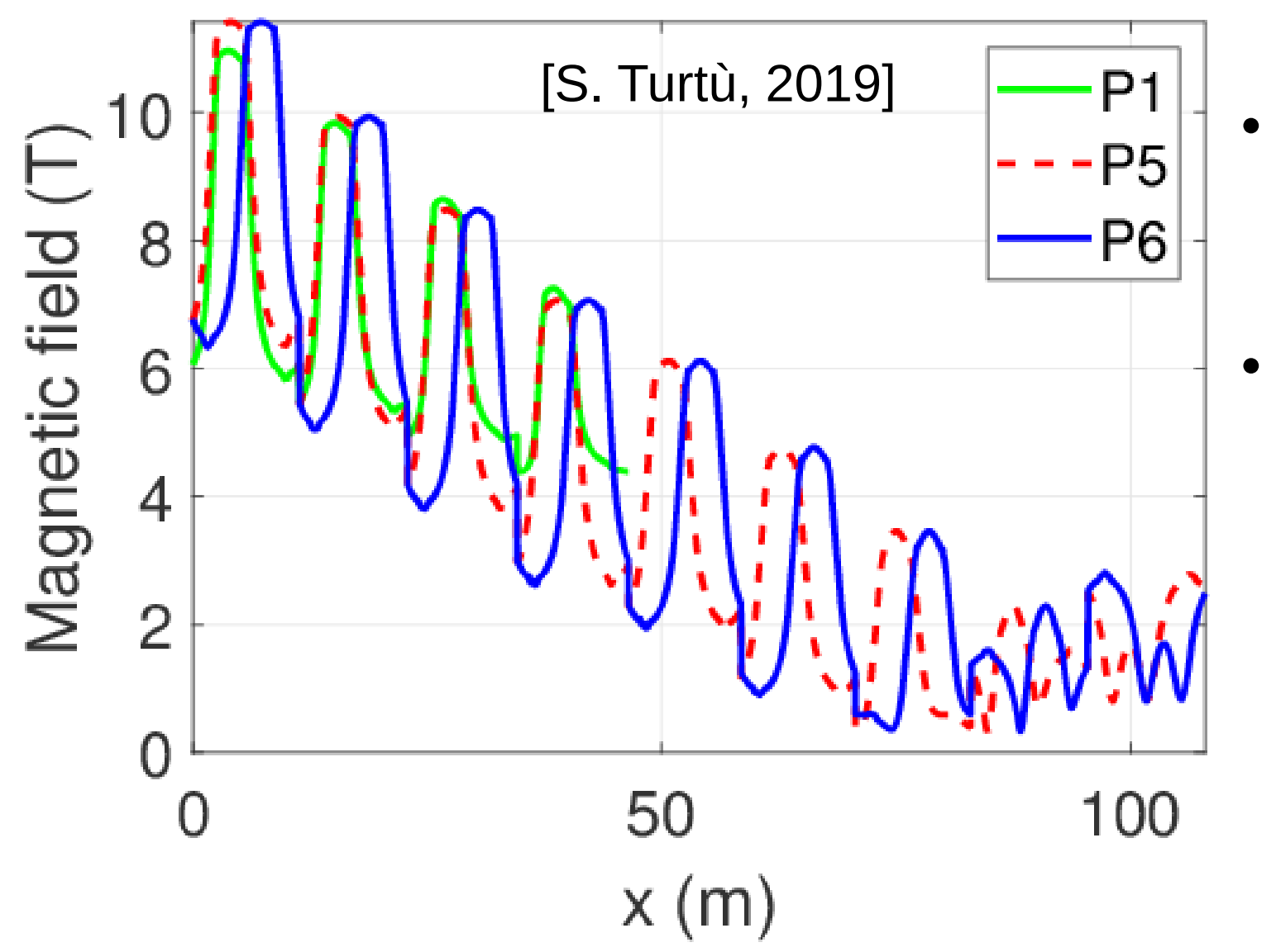
Casing

- Stainless-steel
- 4 casing cooling channels (CCCs)
- SHe T_{in} = 4.5 K, p_{in} = 6 bar
- 16 radial/toroidal cross sections (2D heat diffusion model)

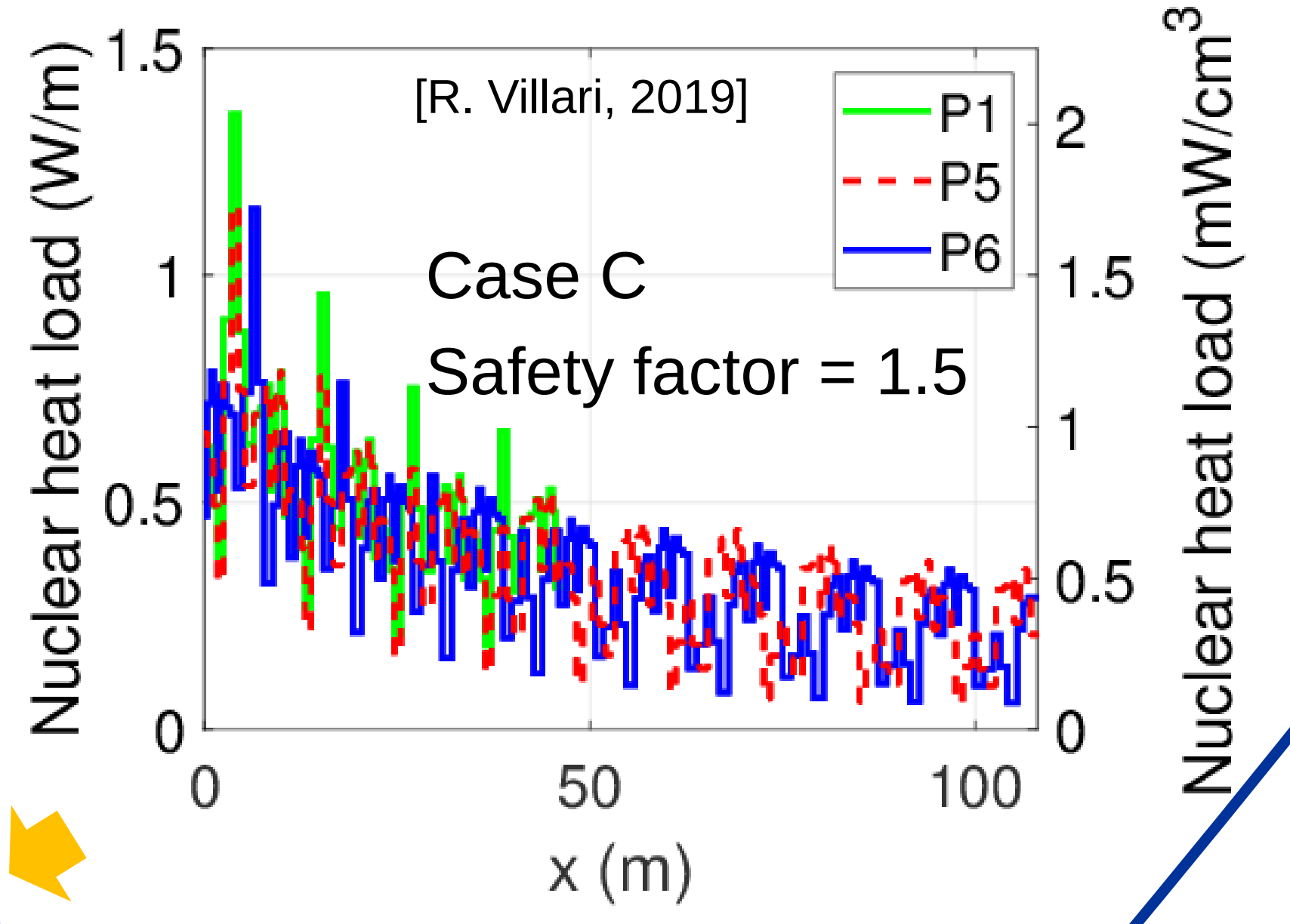


Counter-current He flow in adjacent pancakes

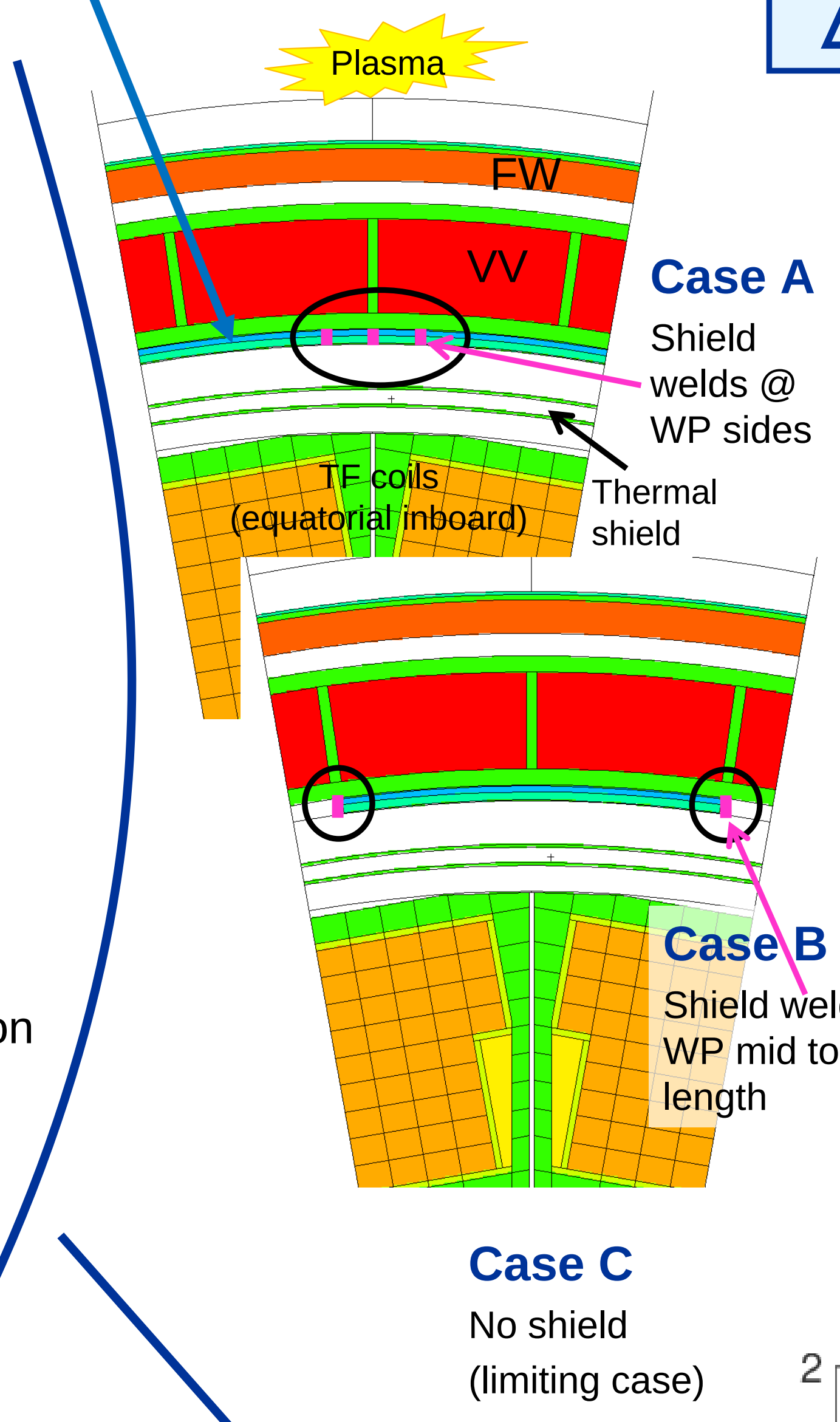
Common inlet for each DP at coil bore



- B gradient on the CICC cross section accounted for
- Effective strain –0.65%



Different neutron shield configurations

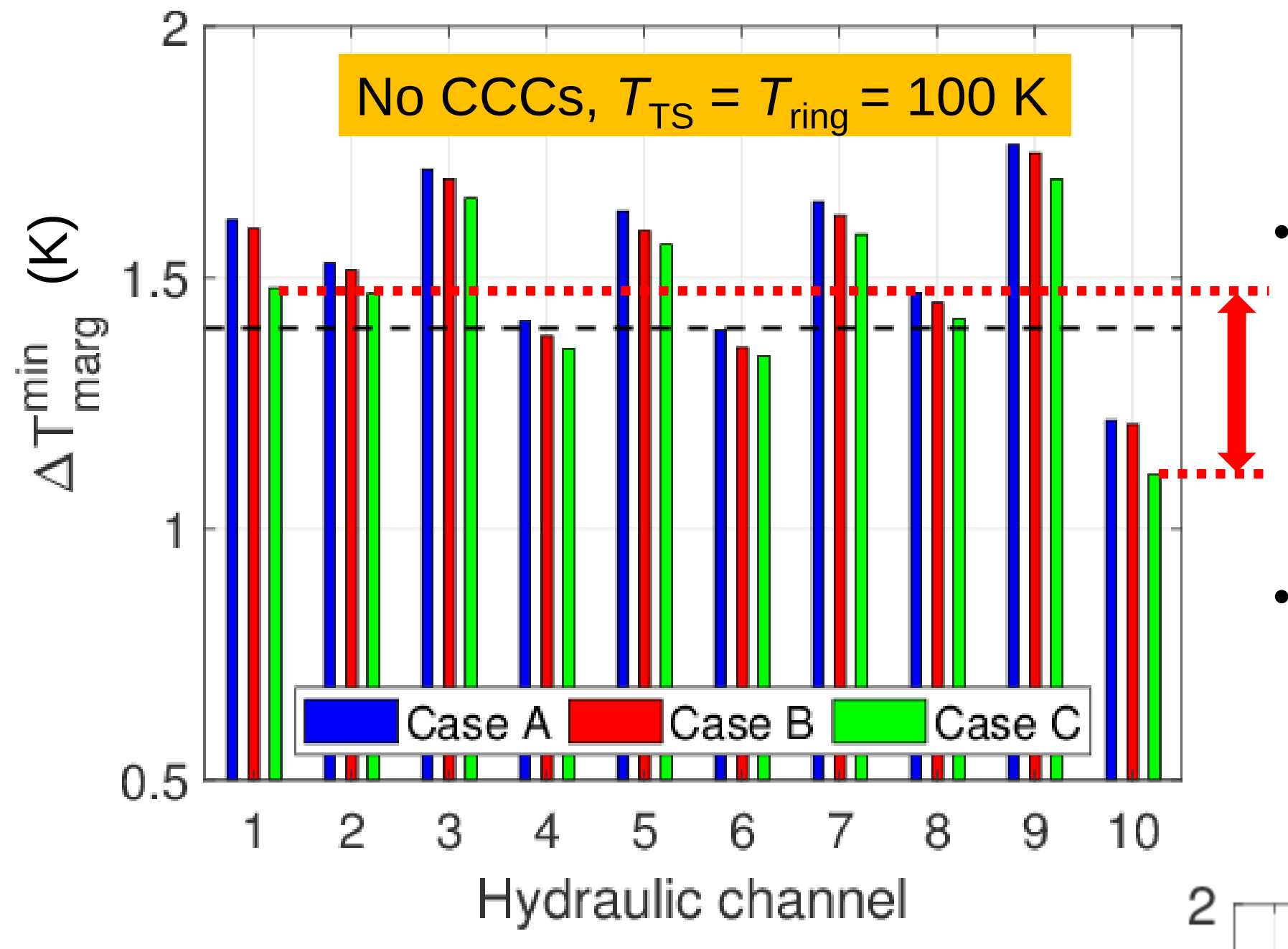


Case A
Shield welds @ WP sides

Case B
Shield welds @ WP mid toroidal length

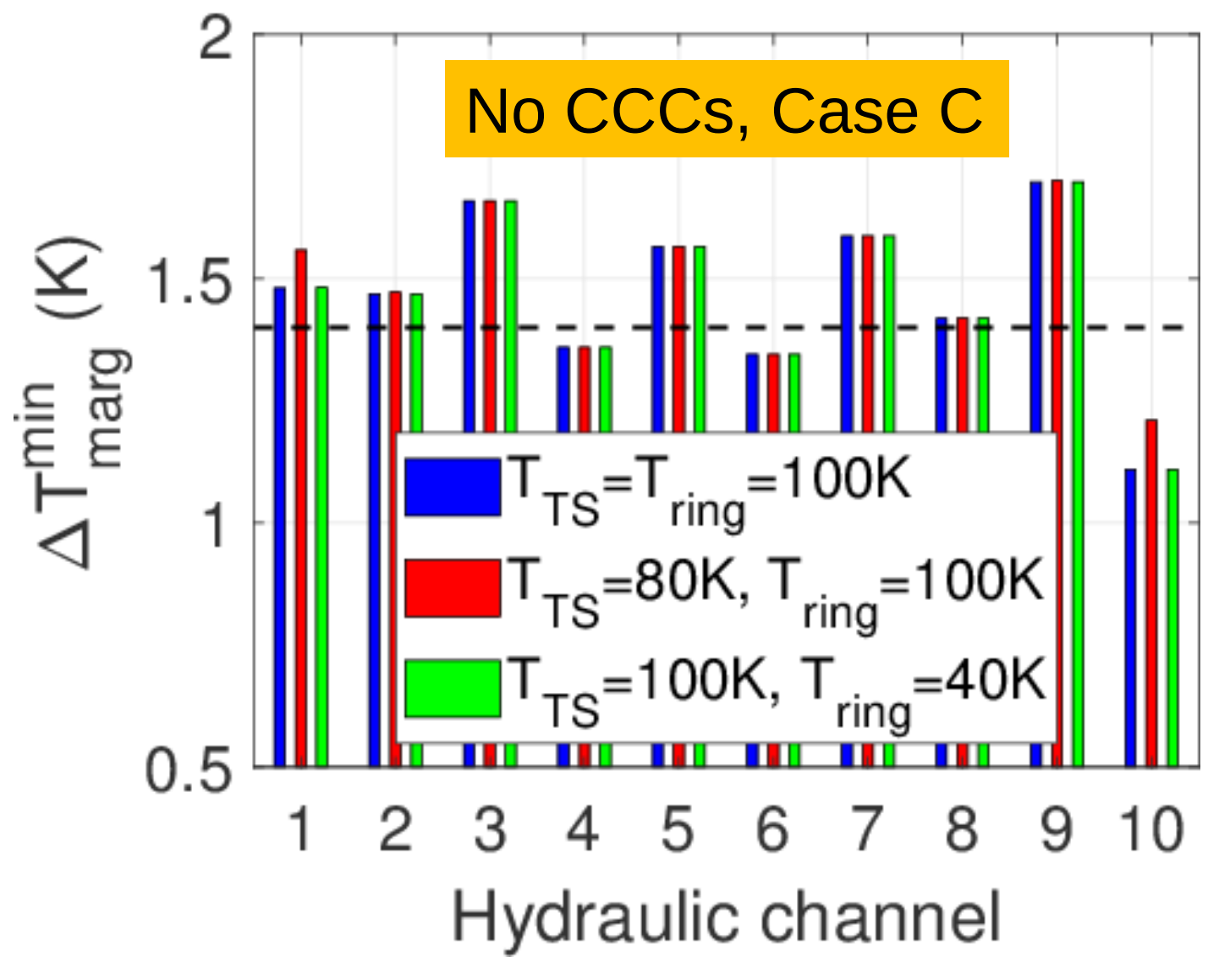
Case C
No shield (limiting case)

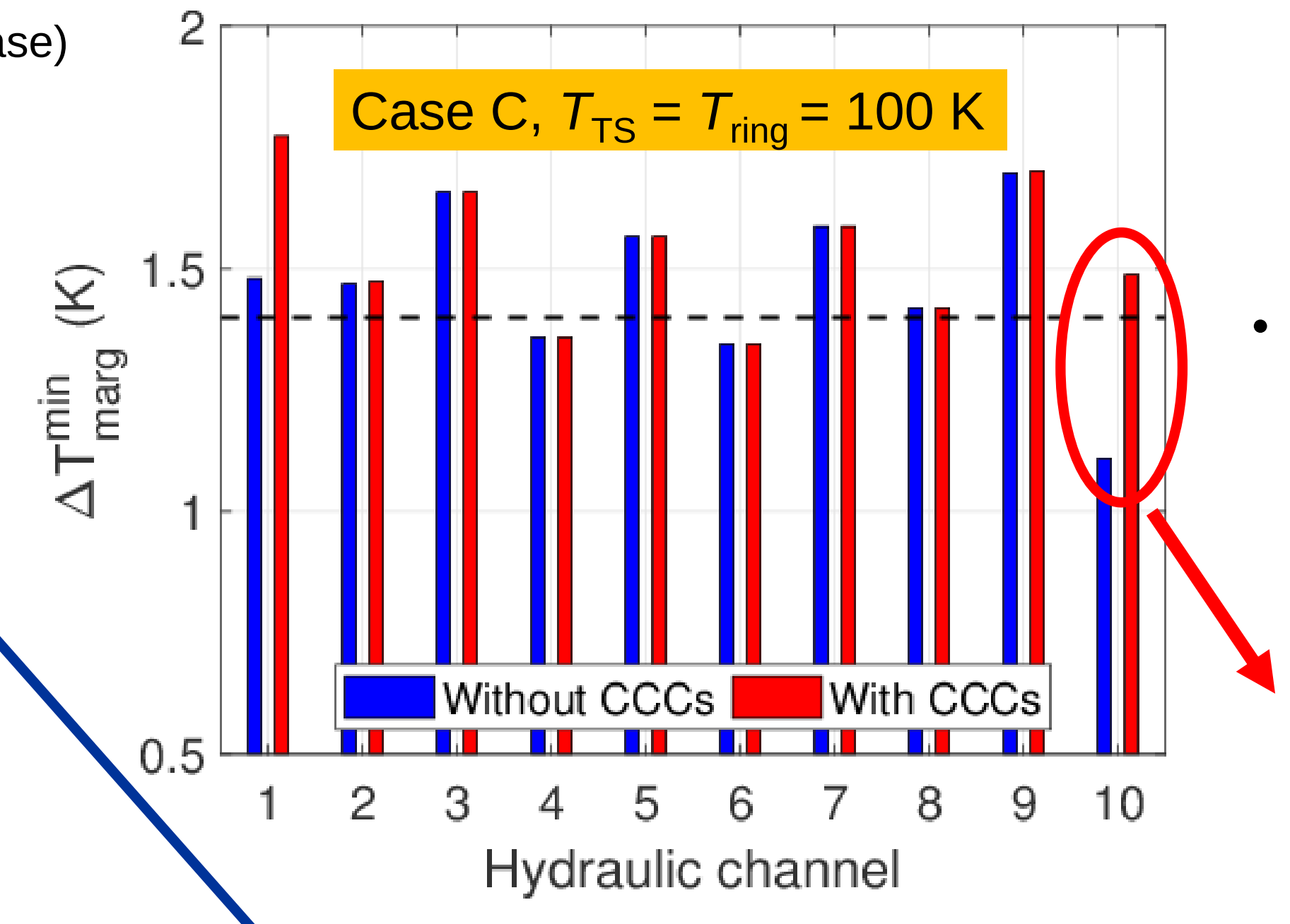
Effect of some parameters on ΔT margin in normal operation



- Non uniformity due to the different heat load accumulated by odd and even Ps before reaching the ΔT_{marg}^{min} location (equatorial IB)
- Without CCCs ΔT_{marg}^{min} < design value (1.4 K) for all cases ➔ **CCCs are needed!**

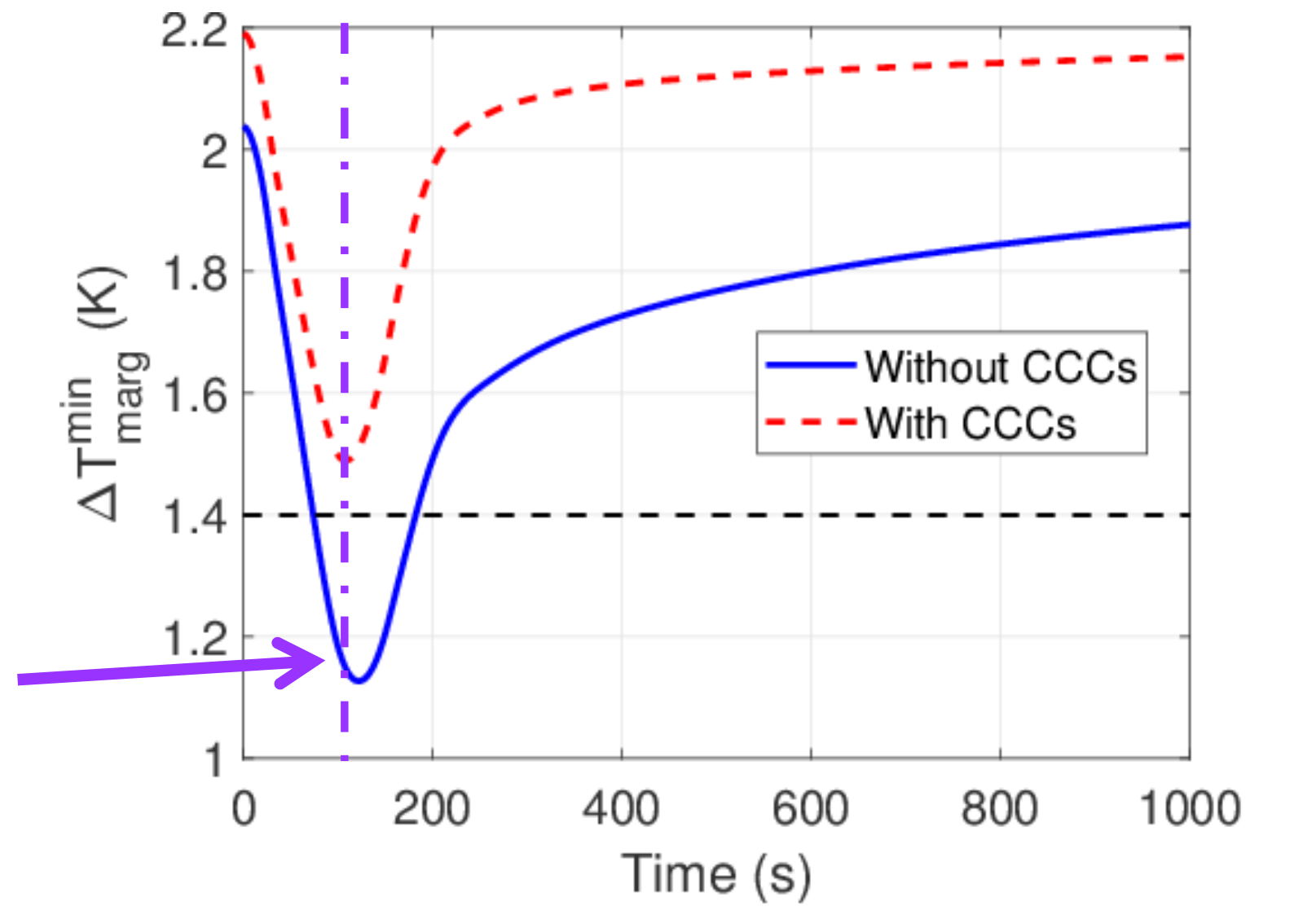
- No impact of static load on central Ps because they are detached from the casing
- TS temperature decrease increases the ΔT_{marg}^{min} on side Ps **BUT it is not sufficient**
- ~no impact of pedestal ring temperature on ΔT_{marg}^{min} ➔ **adding a thermal anchor to the gravity support is useless**



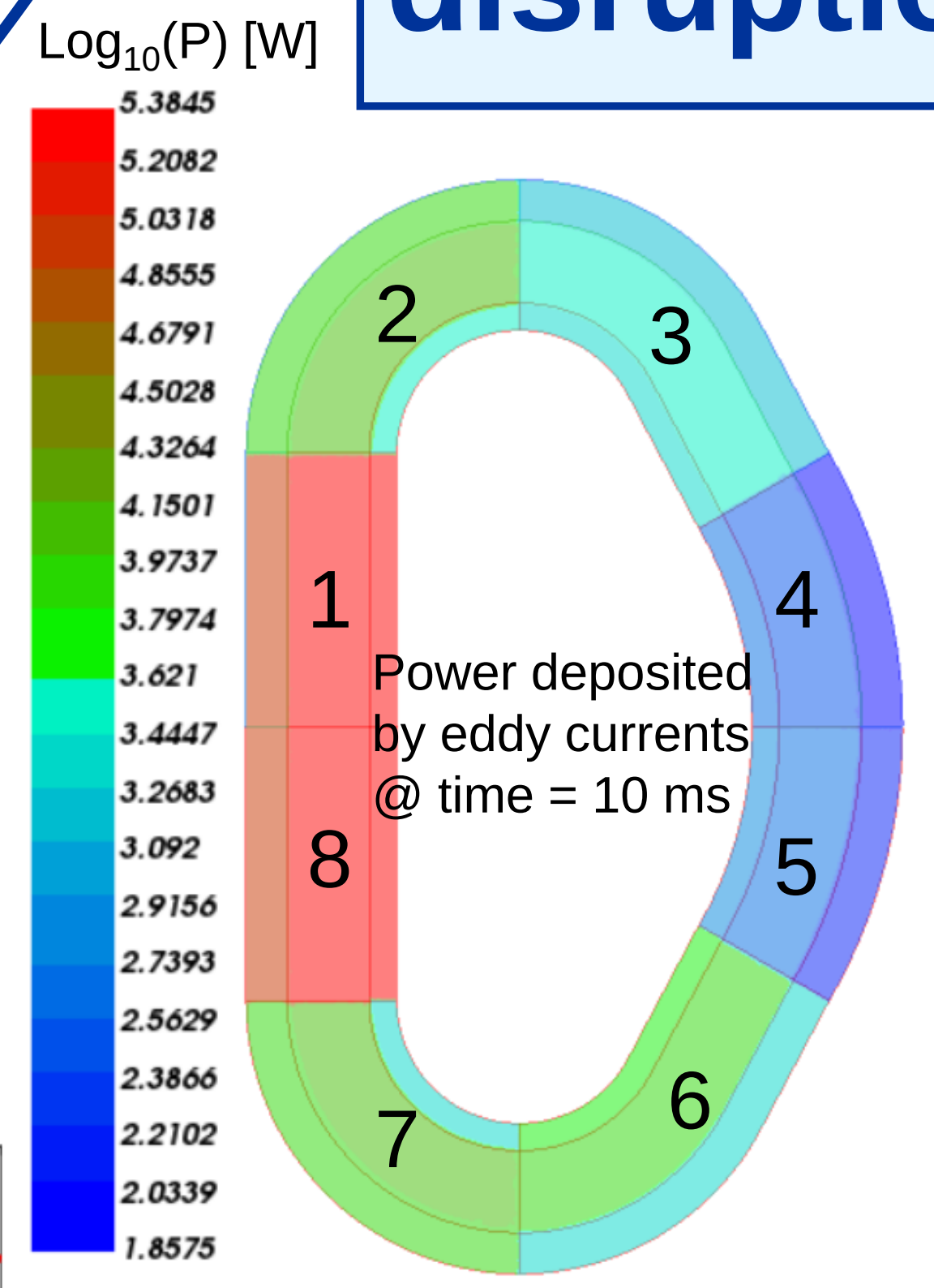


- CCCs reduce the heating of side Ps from casing ➔ **ΔT_{marg}^{min} > 1.4 K** (without reducing the TS temperature) **except in central Ps**

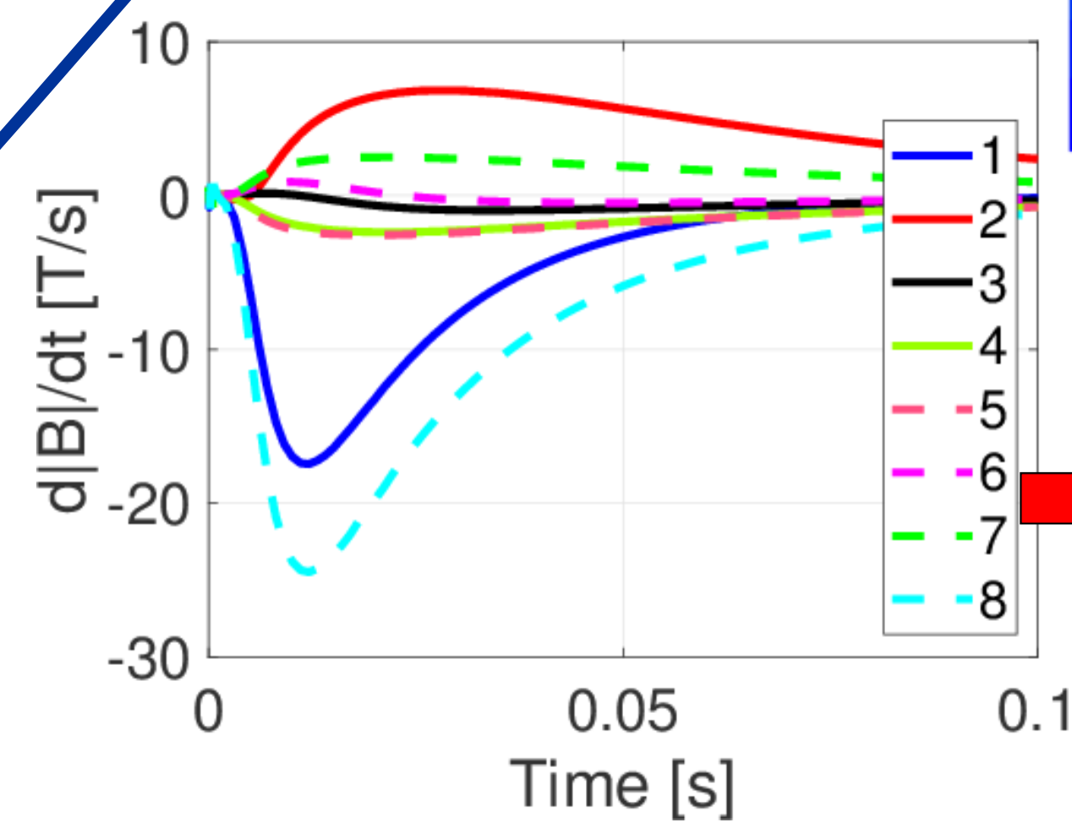
- Minimum margin reached after the end of the plasma burn during the plasma shut down



Plasma disruption



[CREATE, 2019]

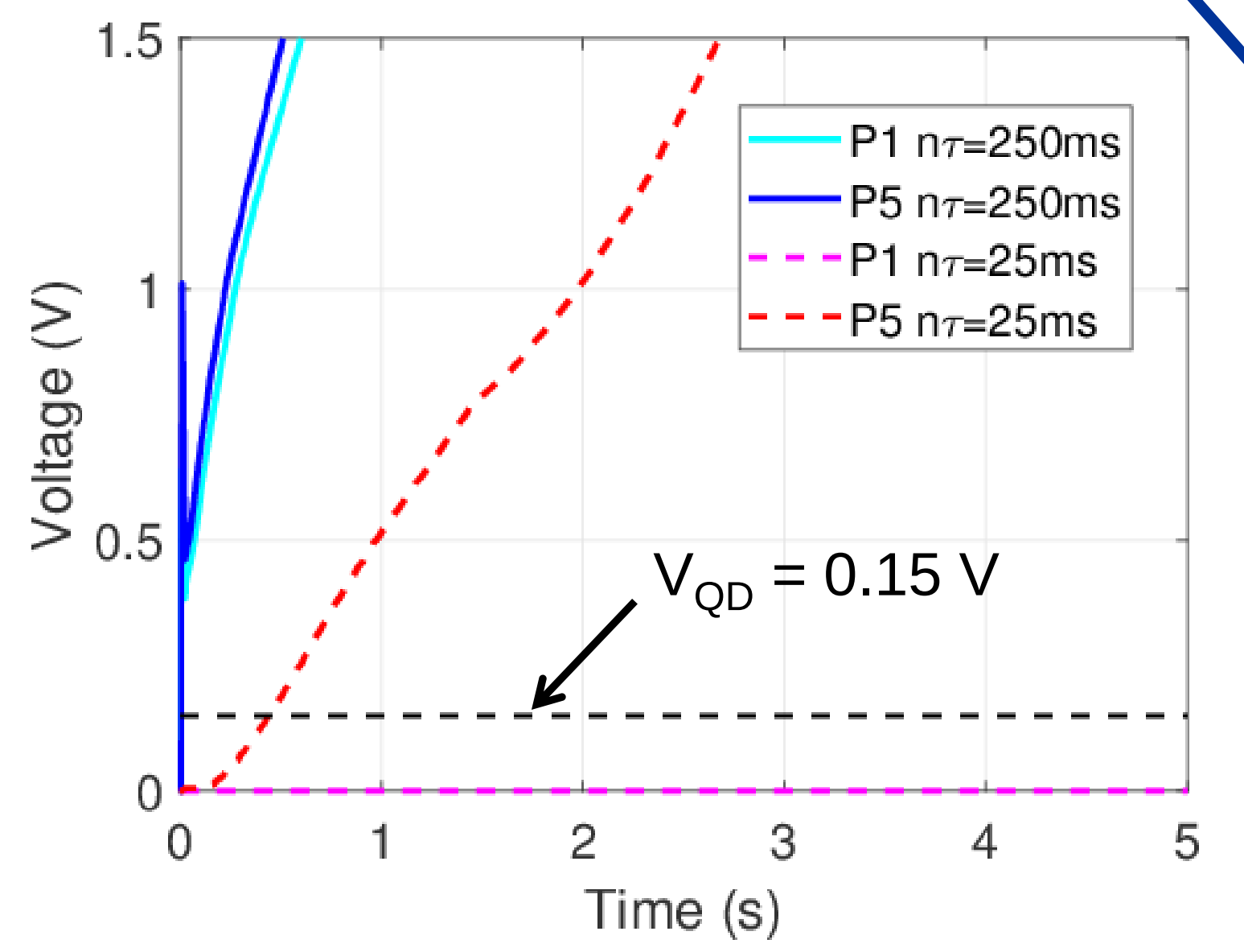


AC losses up to 10-100 W/cm³ in the Nb_3Sn strands (~1-10 kW/m)!

AC losses in the strands initiate a normal zone

- In all Ps for the design $n\tau$ values (250 ms)
- Only in some Ps for lower $n\tau$ values

→ assessment of input uncertainties required



Conclusions and perspective

- 4C code model of DTT TF magnet developed
- Performance assessed for different designs:
  - The neutron shield and the casing cooling channels are needed to fulfill the 1.4 K minimum temperature margin requirement
  - Reducing the radiative heat load alone is not sufficient
- Plasma (major) disruption initiates a quench. The influence of several uncertainties must be investigated.
- In perspective, further support the DTT magnet design
  - Assess impact of input uncertainties ($n\tau$, eddy currents, …) on the effects of the plasma disruption
  - Analyze other relevant transients (cooldown, quench, …)