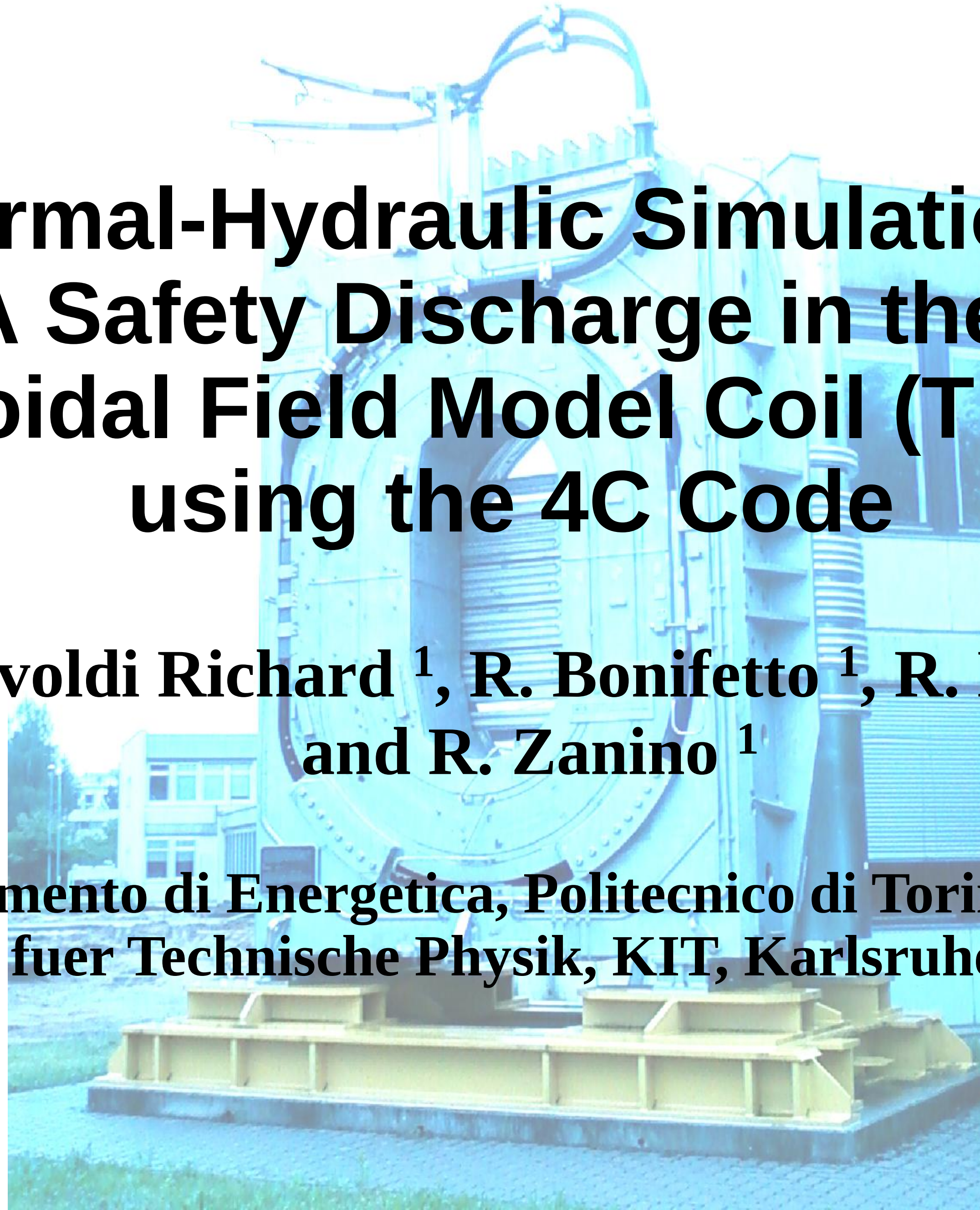

Thermal-Hydraulic Simulation of 80 kA Safety Discharge in the ITER Toroidal Field Model Coil (TFMC) using the 4C Code

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Outline

- The 4C code
- Safety discharges in the TFMC
- Model description
- Preliminary results
- Conclusions

The 4C code

[LSR et al., *Cryogenics* (2010)]

- Integrated model of:
  - SC cable-in-conduit conductors (1-D +)
  - Coil structures - e.g., casing, RP, … (2-D +)
  - Casing cooling channels, where present (1-D)
  - External cryogenic circuit (1-D or 0-D components)

- Validated against:
  - 25 kA safety discharge in the Toroidal Field Model Coil [R.Zanino et al., *IEEE TAS* (2011)]
  - Cooldown of a W7-X Non Planar Coil [R.Bonifetto et al., *Fus. Eng. Des.* (2011)]

- Applied to the analysis of different magnet systems, e.g., ITER TF coils [R.Zanino et al., *Fus. Eng. Des.* (2010),], JT60-SA TF coils [R.Bonifetto et al., *Fus. Eng. Des.* (2011)], KSTAR PF1 coils [to be presented at *SOFE* 2011]

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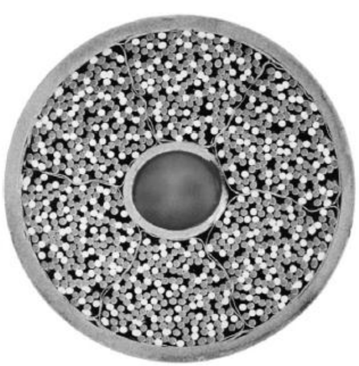
The Toroidal Field Model Coil (TFMC)

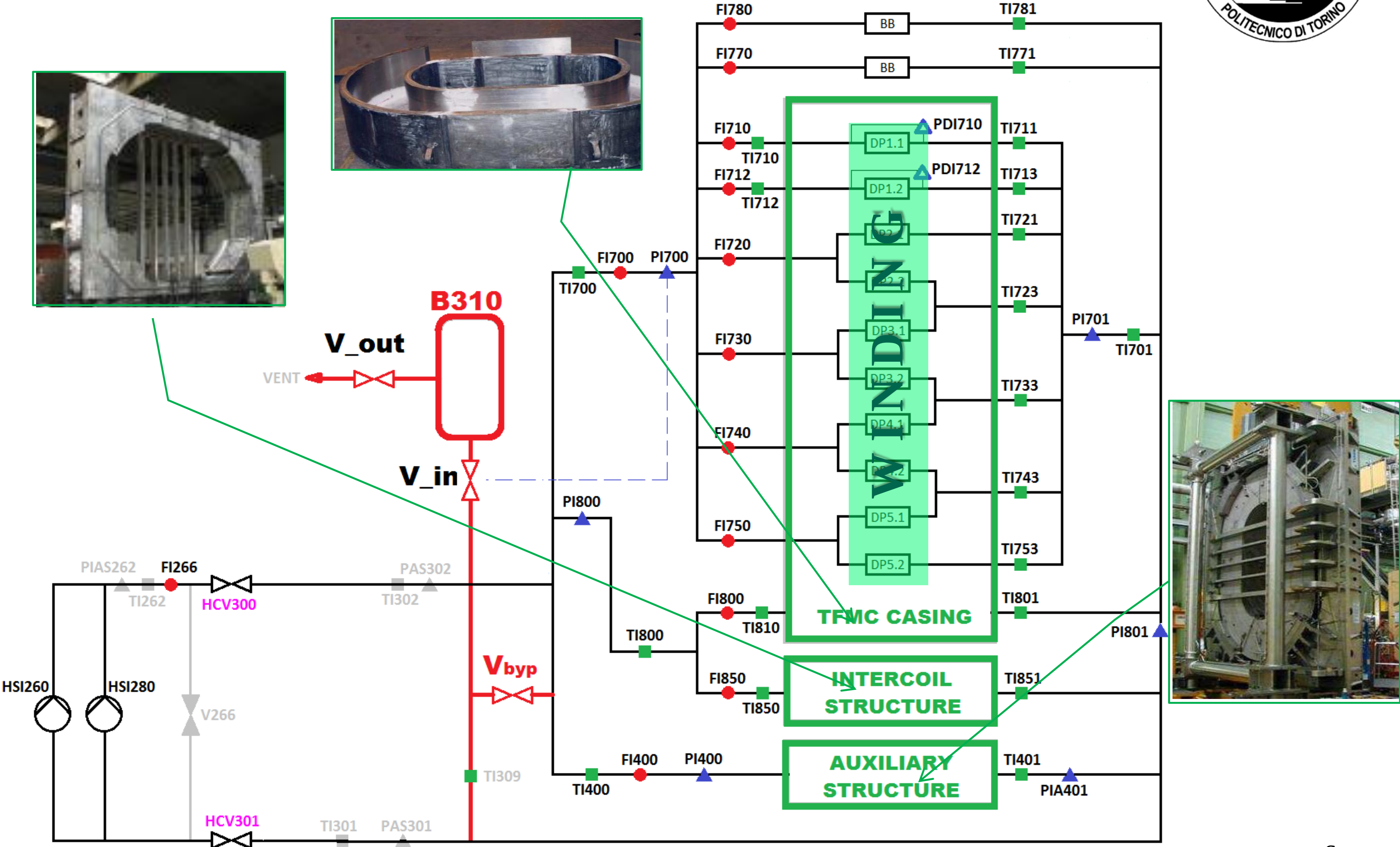
- Racetrack coil made by 10 Cable-In-Conduit Nb_3Sn superconductors layer-wound on radial plates, embedded in SS casing
- Tested in 2001 (alone) and 2002 (with LCT coil) in the TOSKA facility @ KIT, Germany
- Peak current 80 kA, peak field ~ 10 T, SHe @ 4.5 K, 5 bar



The safety discharge (SD) in the TFMC

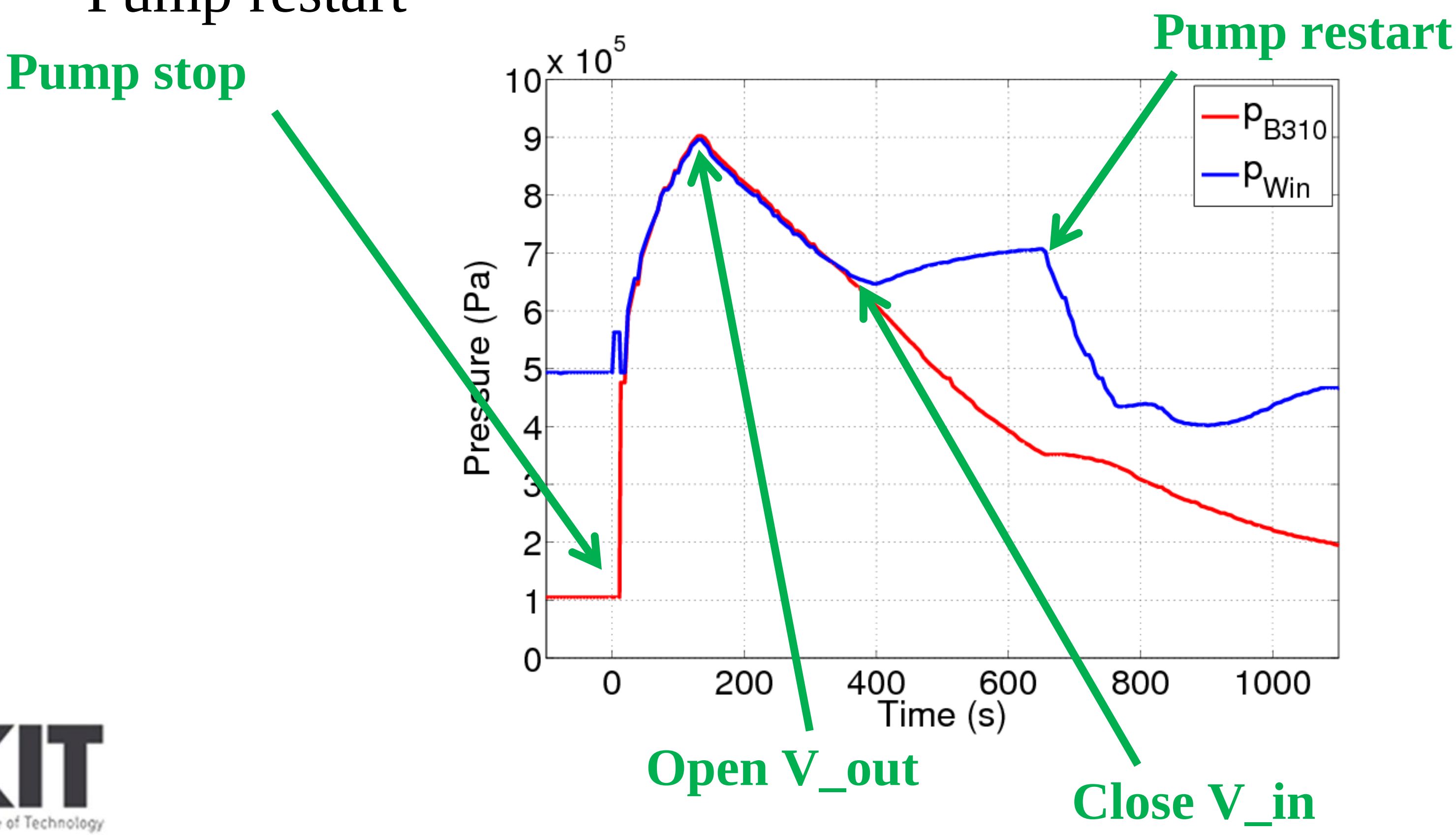
	"standard" 25 kA	80 kA
Heat deposition	O(0.1 MW) peak O(0.4 MJ) total	O(1 MW) peak O(4 MJ) total
Helium ΔT_{max}	~ 1 - 2 K (winding) ~ 0.5 - 1 K (casing)	~ 14 - 17 K (winding) ~ 16 - 18 K (casing)
Cryogenic circuit	Not needed	NEEDED! (Drivers = heating + circuit control)

TFMC cooling circuit



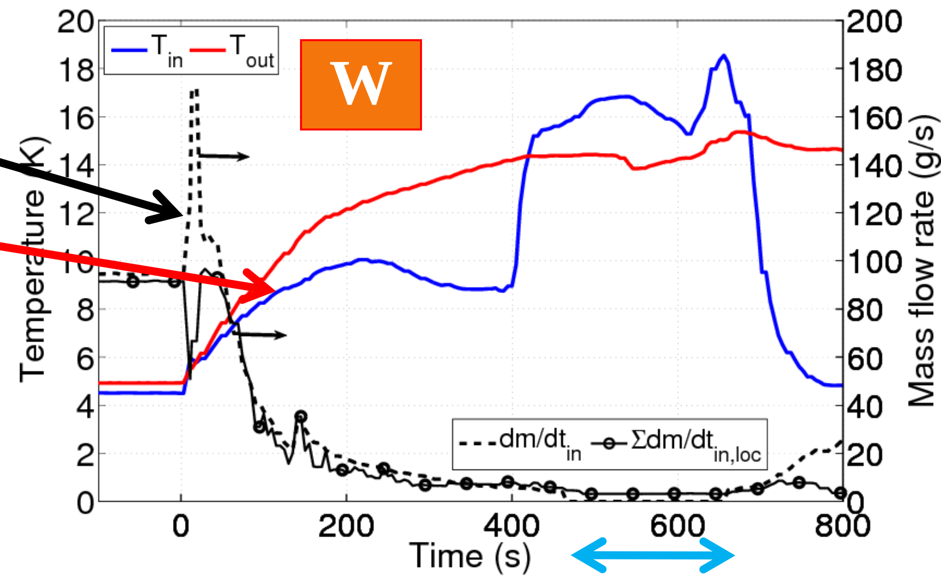
Circuit control during 80 kA SD

- Pump stop at current dump
- Bypass of pumps + He release to cold storage vessel B310
- Venting to the gasometer when pressure in the tank > 9 bar
- Pump restart

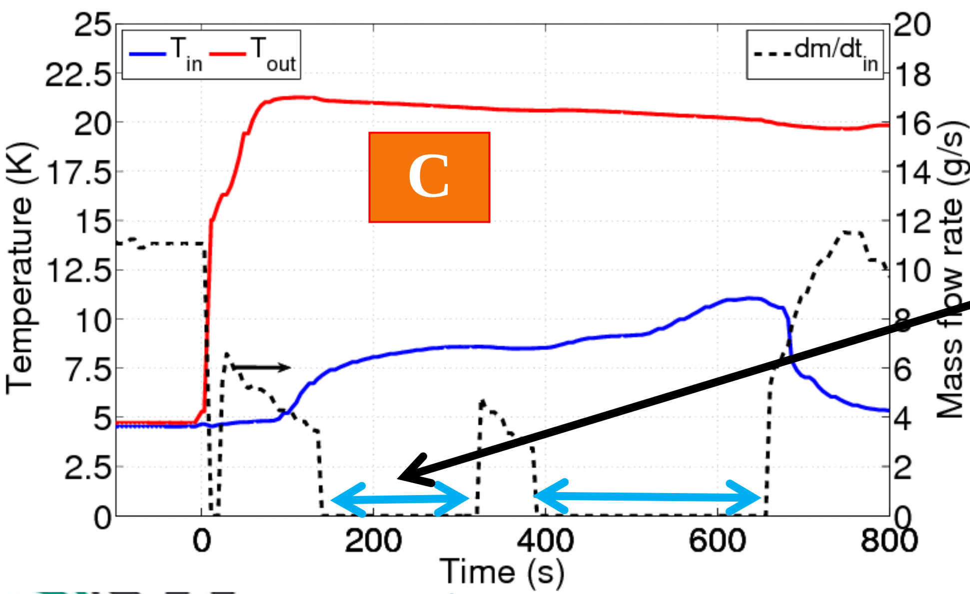


Transient induced by 80 kA SD (I)

- Inlet mass flow rate compressible behavior
- **Hot He *entering* the winding from by-pass and outlet of parallel, until closure of V_in**



Backflow @ inlet



Backflow also in initial phase

Backflow @ inlet

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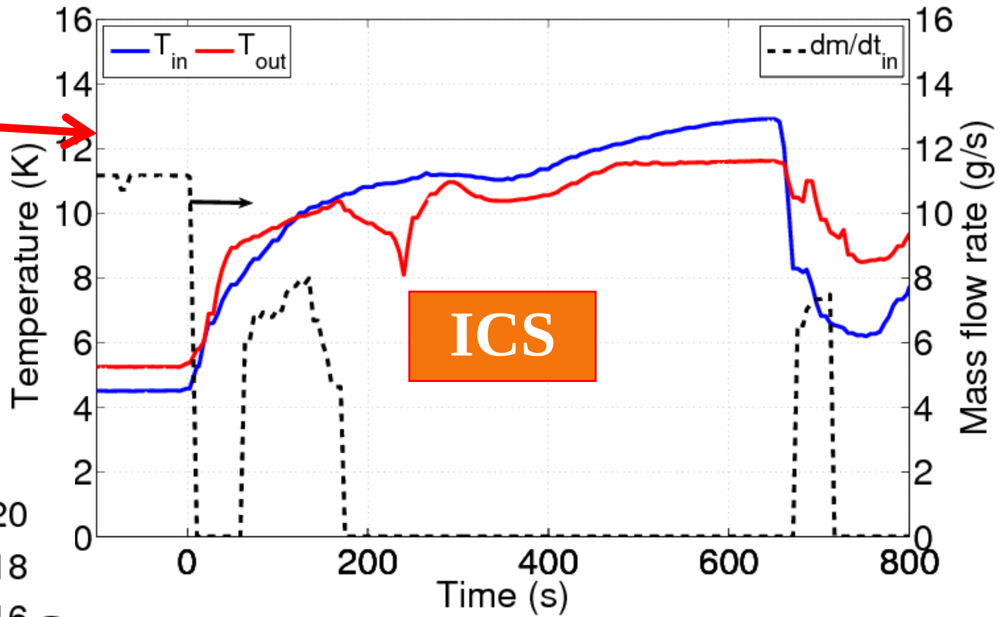
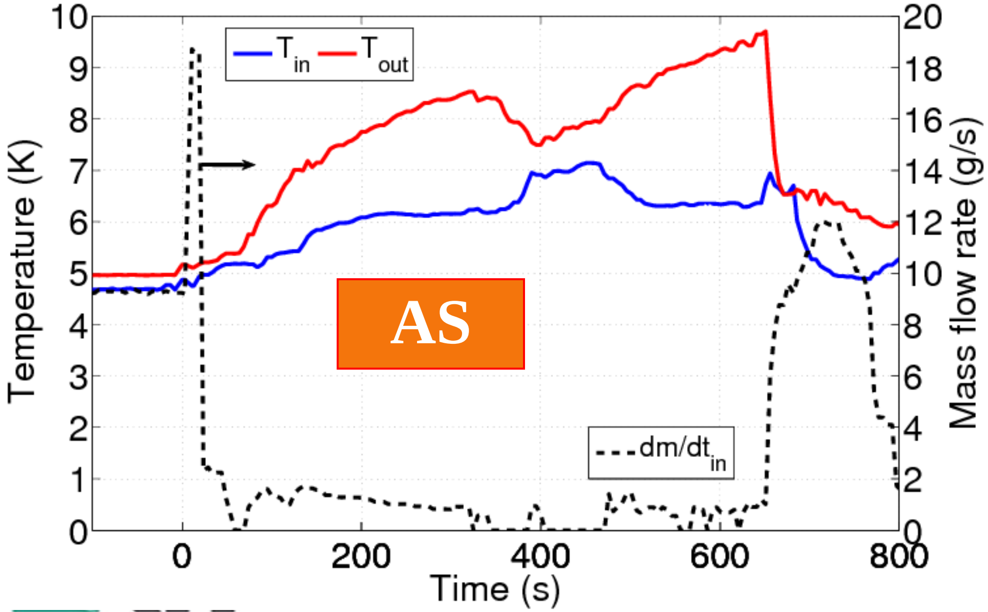
Transient induced by 80 kA SD (II)

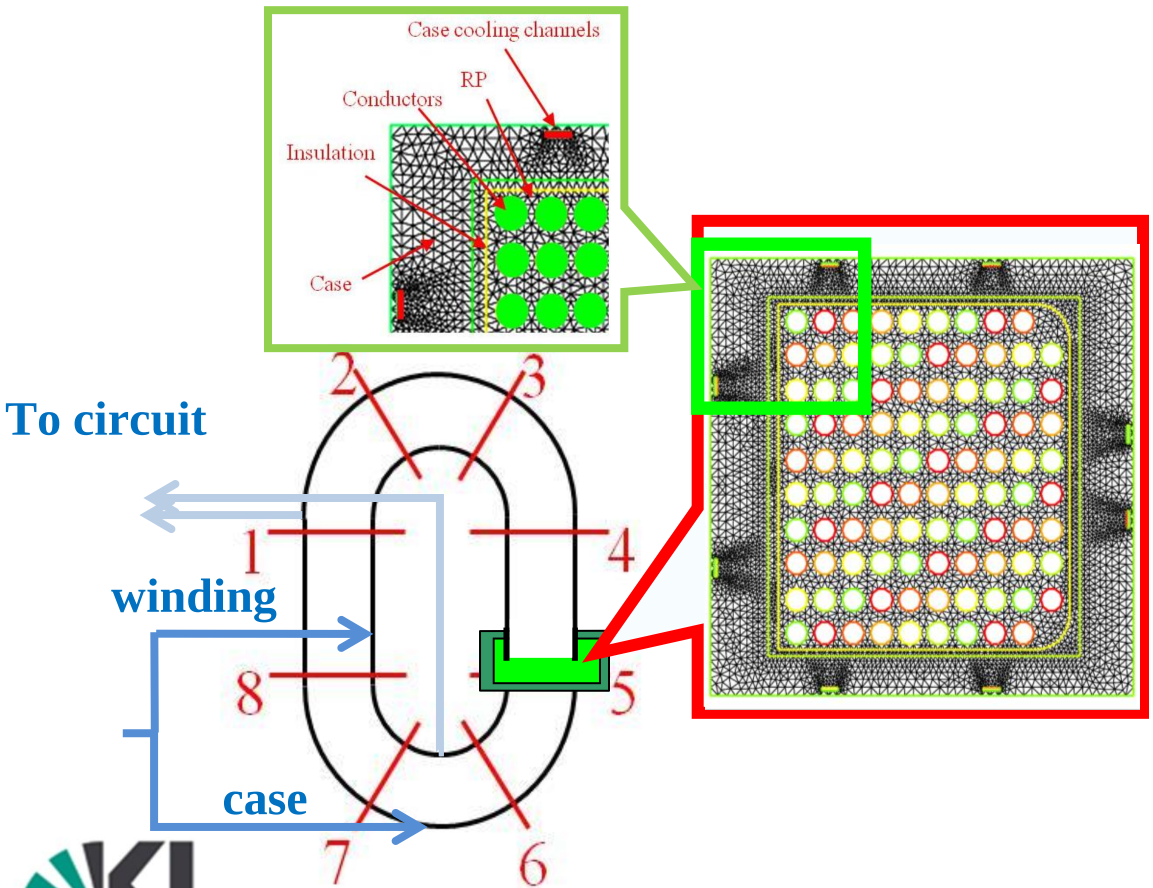
• He with T> 10 K @ in/out, but no way to assess if heat is generated inside or due to complete reverse flow

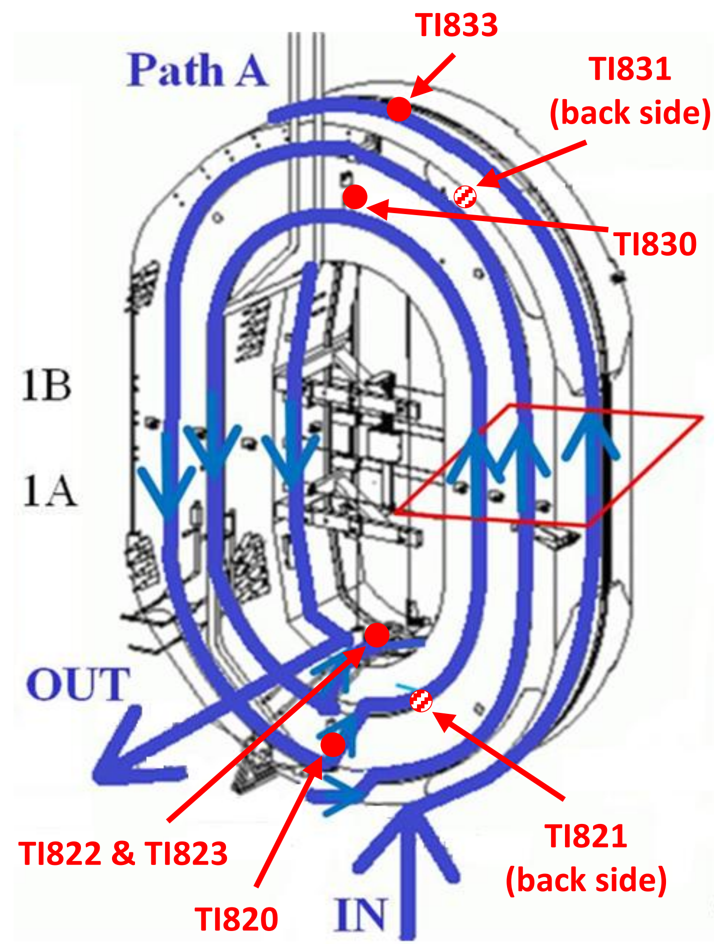




4C modeling of the 80 kA SD *Coil*

- 10 TFMC conductors + 2 casing cooling channels
- Radial plates + casing (2D cuts)

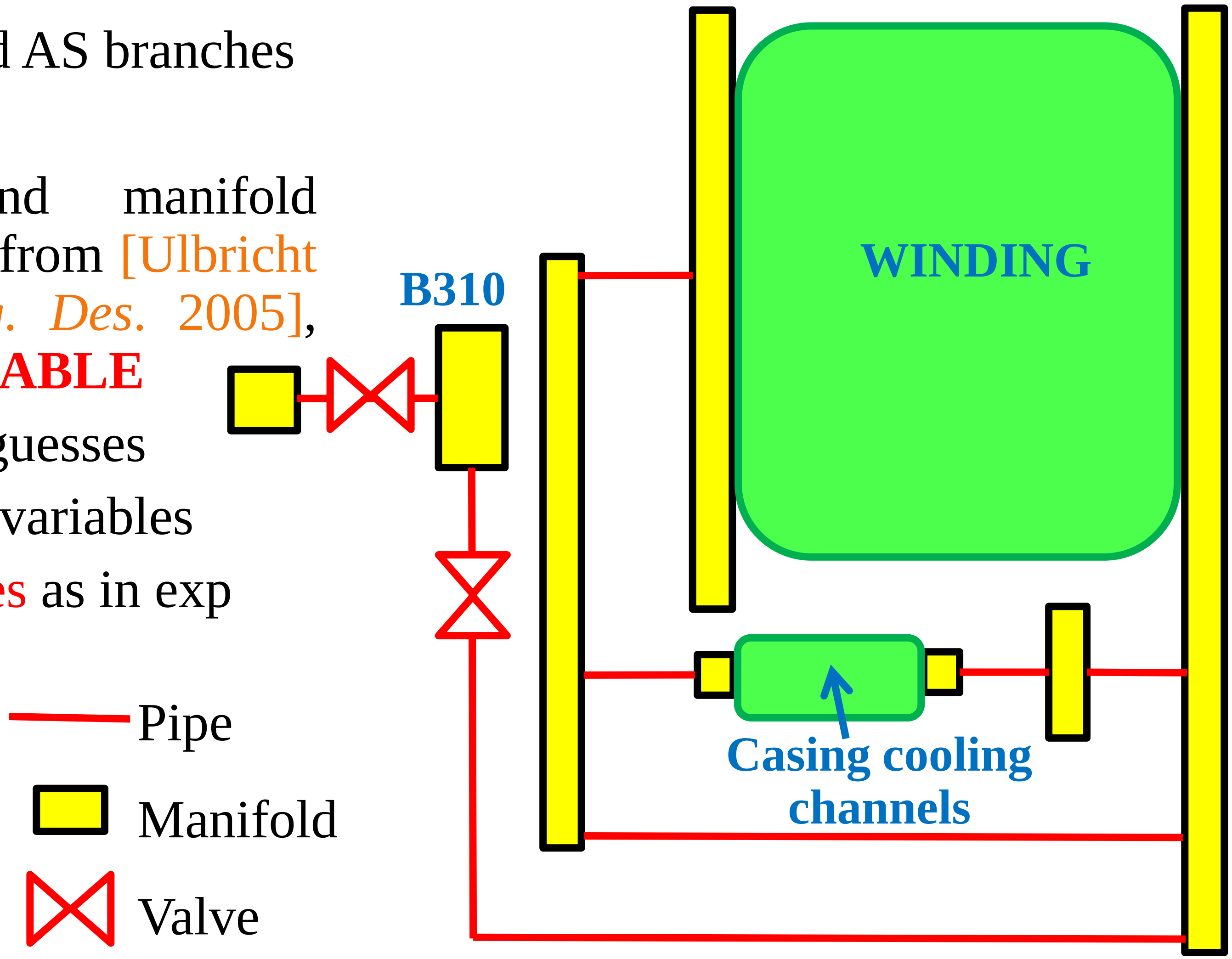




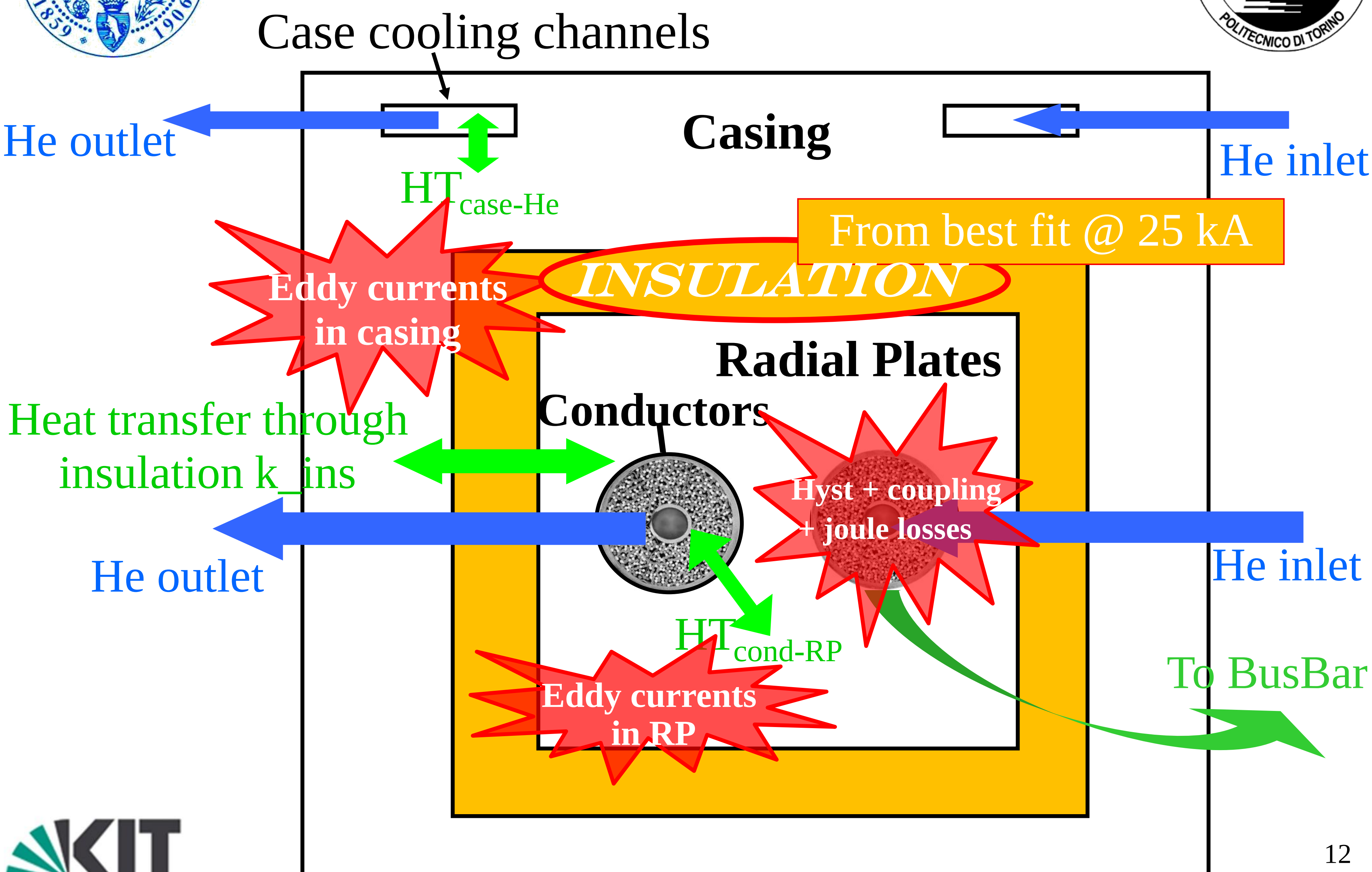
4C modeling of the 80 kA SD
External circuit model

Main assumptions:

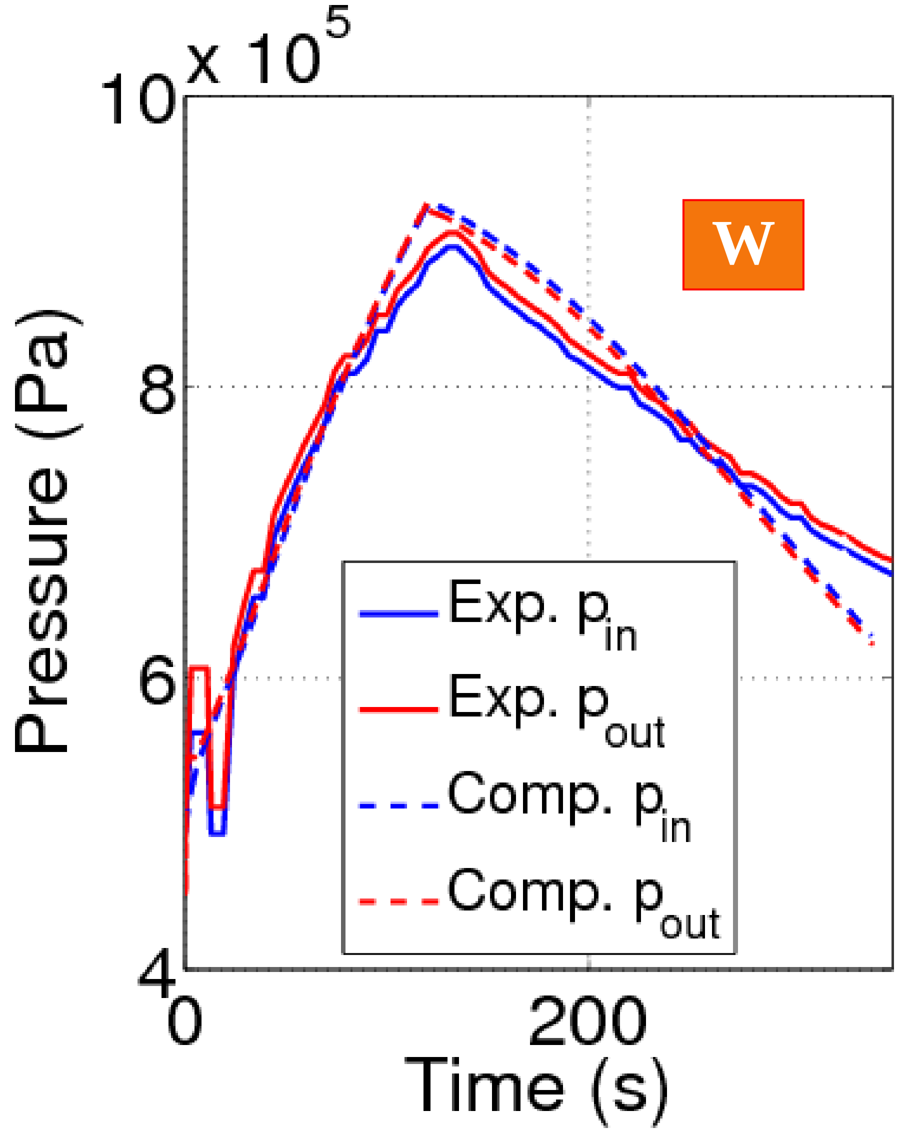
- Neglect ICS and AS branches
- Neglect BB
- Get pipe and manifold geometrical data from [Ulbricht *et al., Fus. Eng. Des.* 2005], **WHERE AVAILABLE**
- Make educated guesses for the missing variables
- Control variables as in exp



Coil thermodynamic system

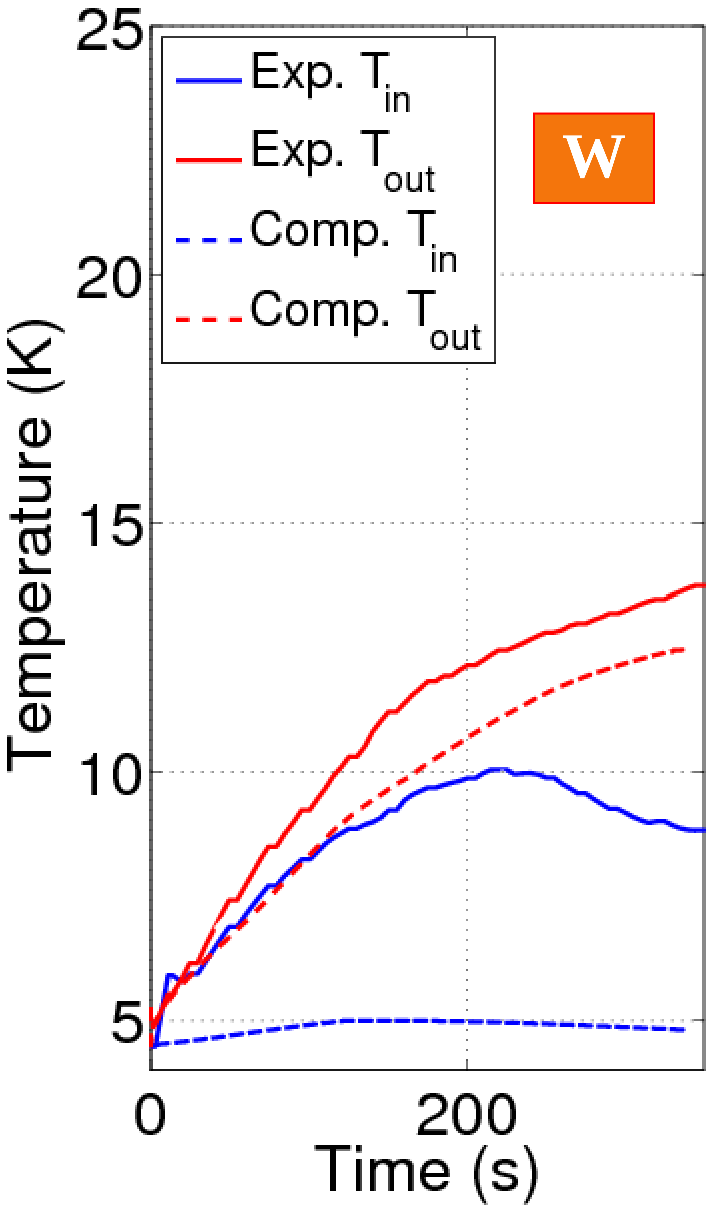


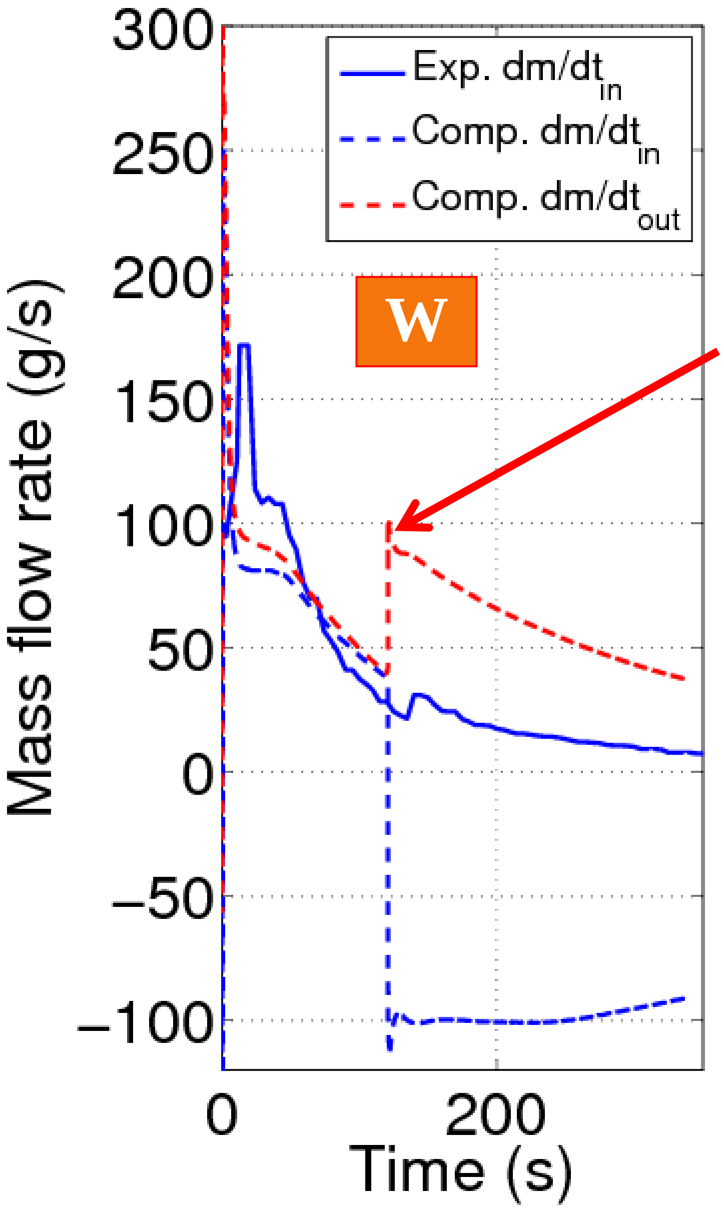
Preliminary results (I)



Similar picture for casing

Preliminary results (II)

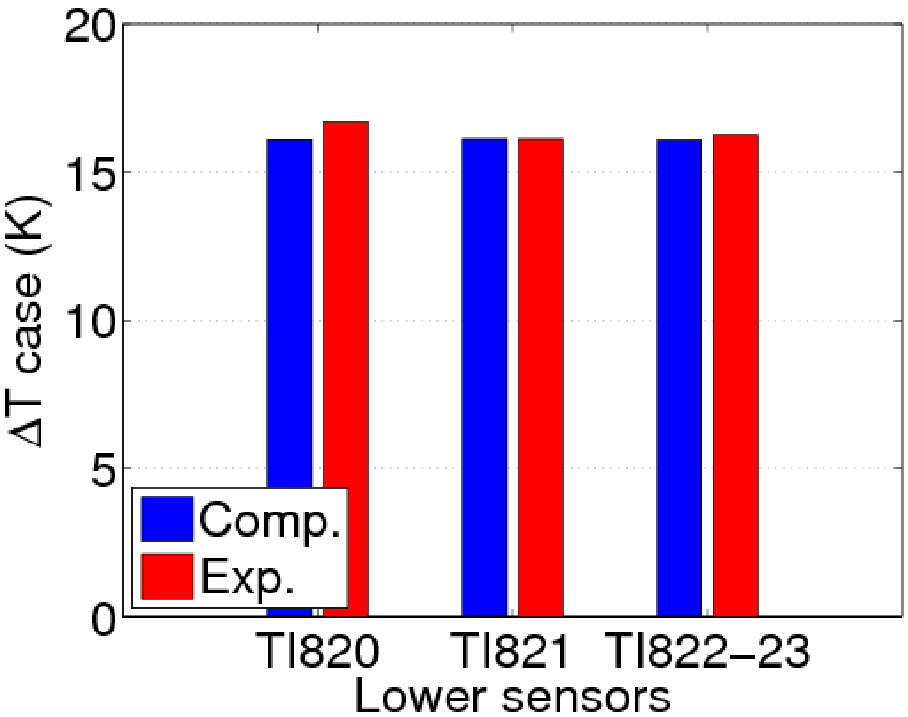


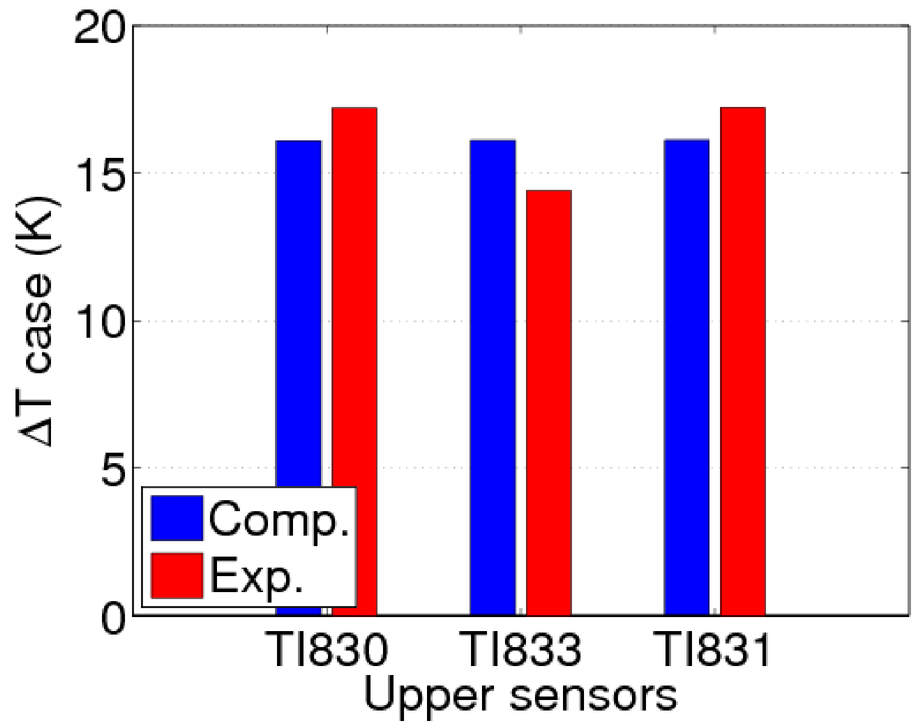


- Qualitative agreement up to venting
- Effect of opening V_{out} strongly overestimated

Preliminary results (IV)

Max temperature increase on casing surface





- Very good agreement in the variables only indirectly influenced by model of the circuit

Conclusions

• After the successful validation against the TFMC 25kA SD, the 4C code has been applied here to the analysis of the 80 kA SD in the TFMC

• The problem is much more complex, because the pumps are turned off at the dump and the rest of the transient is un-driven and therefore very sensitive to the cryogenic cooling circuit details (some of which are however not known –TFMC tests date back to 2001!)

• In the un-driven phase of the transient, the main qualitative features of the thermo-dynamic variables have been reproduced