Thermo-mechanical models & needs for benchmarking

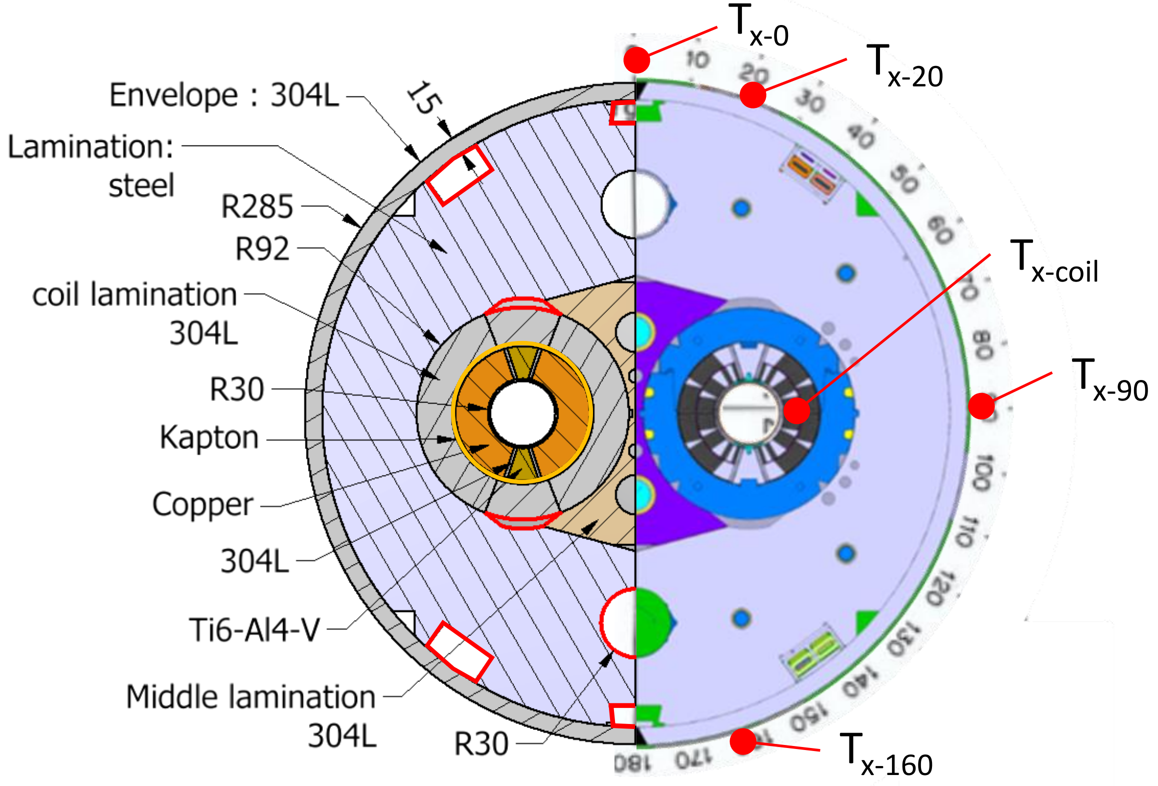
- Models are being developed to understand :
  - Effect of hydraulics on temperature distribution during transients
  - Influence of features at extremities on temperature distribution
- The model needs to be benchmarked to validate the efficiency of potential mitigation actions

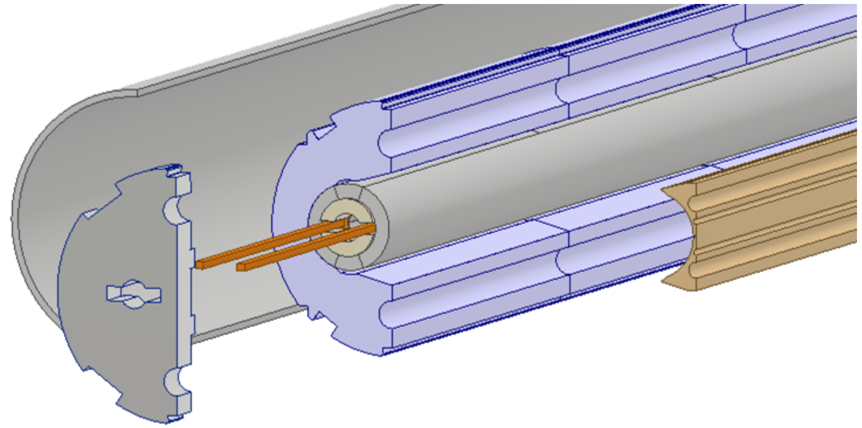
Model used for FEM analyses

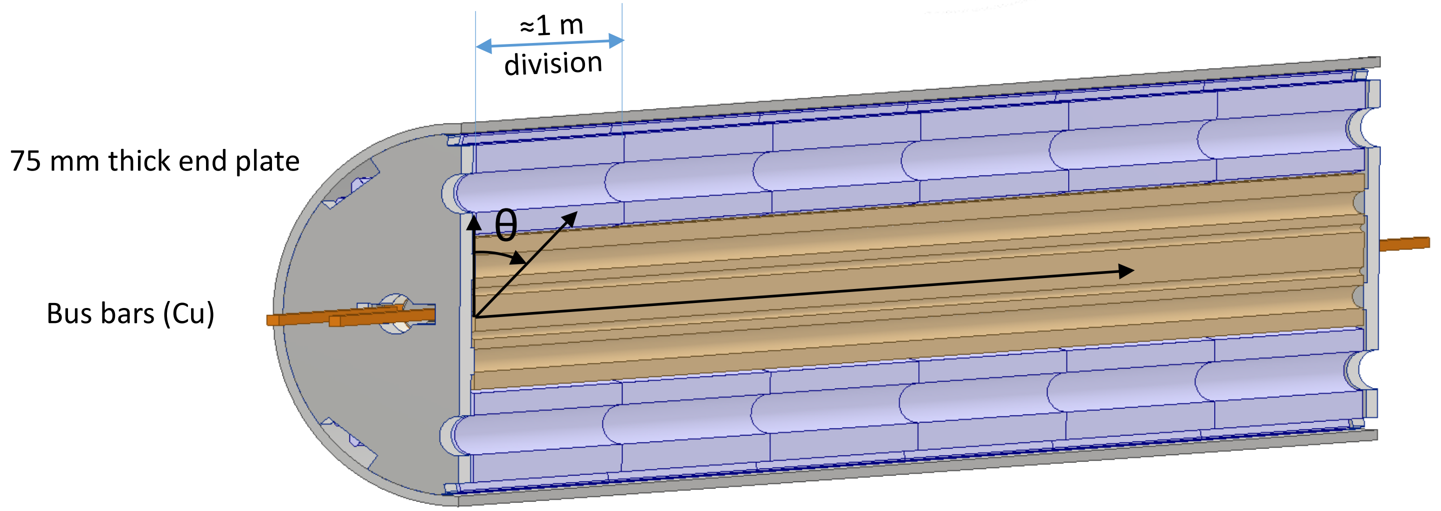
- Preliminary models were developed to identify key features to be detailed
- Reference model
  - Simplified features*
  - Gas temperature
    - Convective heat transfer applied to surfaces (red lines)
    - The CM is divided in 6 sub-divisions to represent the gas temperature evolution along the circuit
    - Every hour the gas temperature along the CM is updated based on surface temperature evolution
  - Heat transfer coefficient
    - Calculated for each channel
    - Constant over time and [200-300] K range
- Probe naming : $T_{\text{distance to 1st lamination / angle to vertical}}$

* Cryogenic material properties in spare slides

Calculations model / detailed 3D model

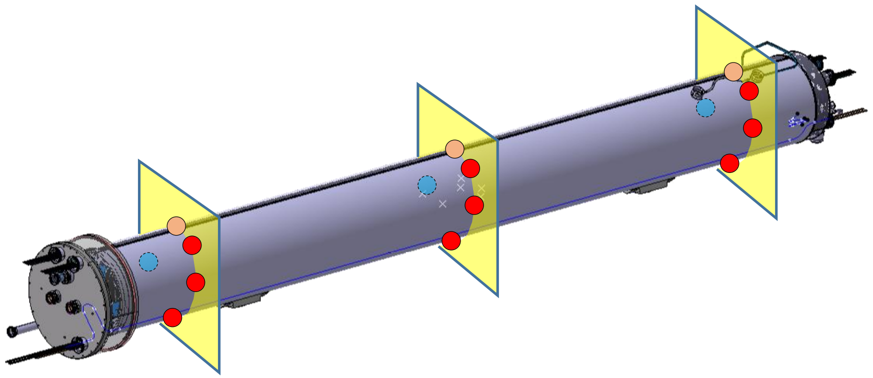




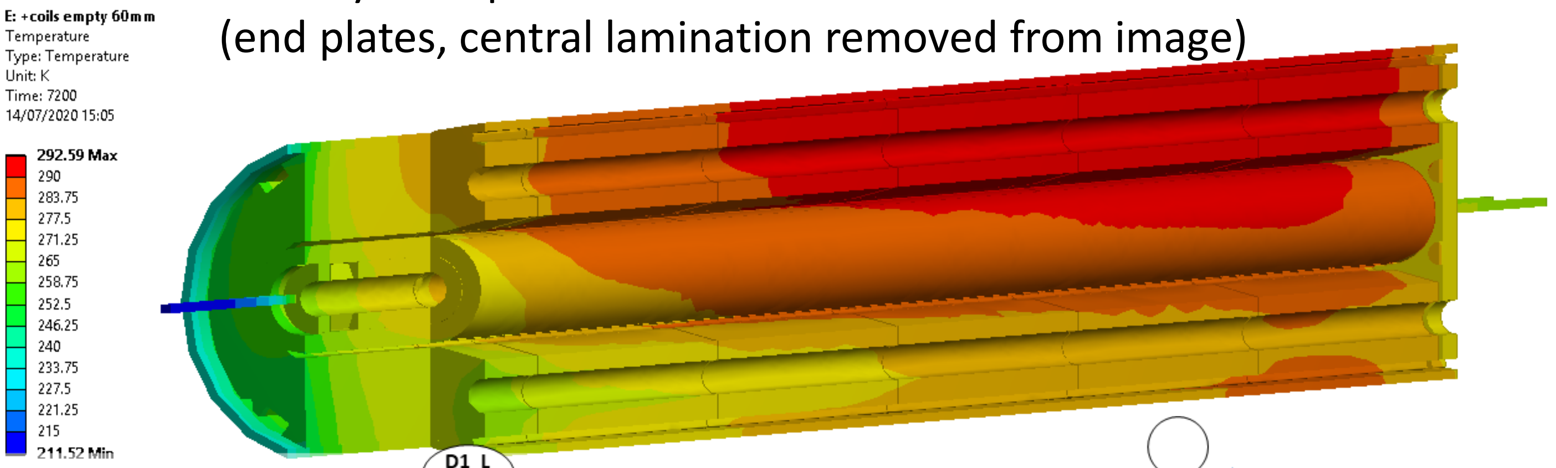


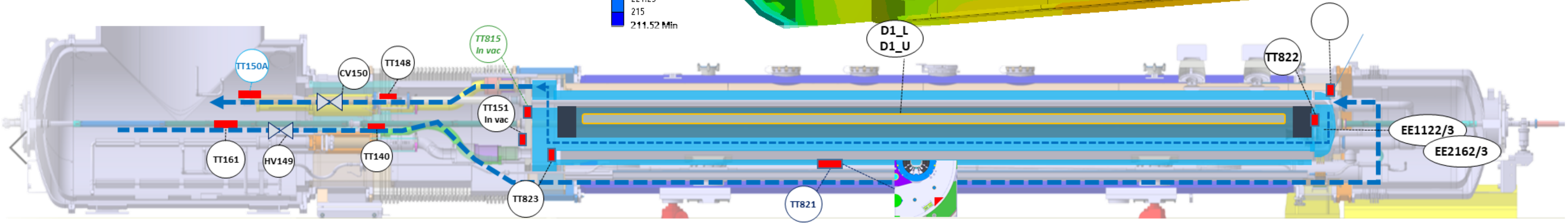
Why & how benchmarking

- Simulations provide temperature distributions function of time
- By benchmarking the external temperature distribution with measurements, the model may provide reliable internal temperature distributions and information on features contributions
- The current temperature mapping does not inform on structural temperature distribution
- Temperature sensors shall be installed on the lamination area not to be too influenced by end plate cooling where gradients may be high



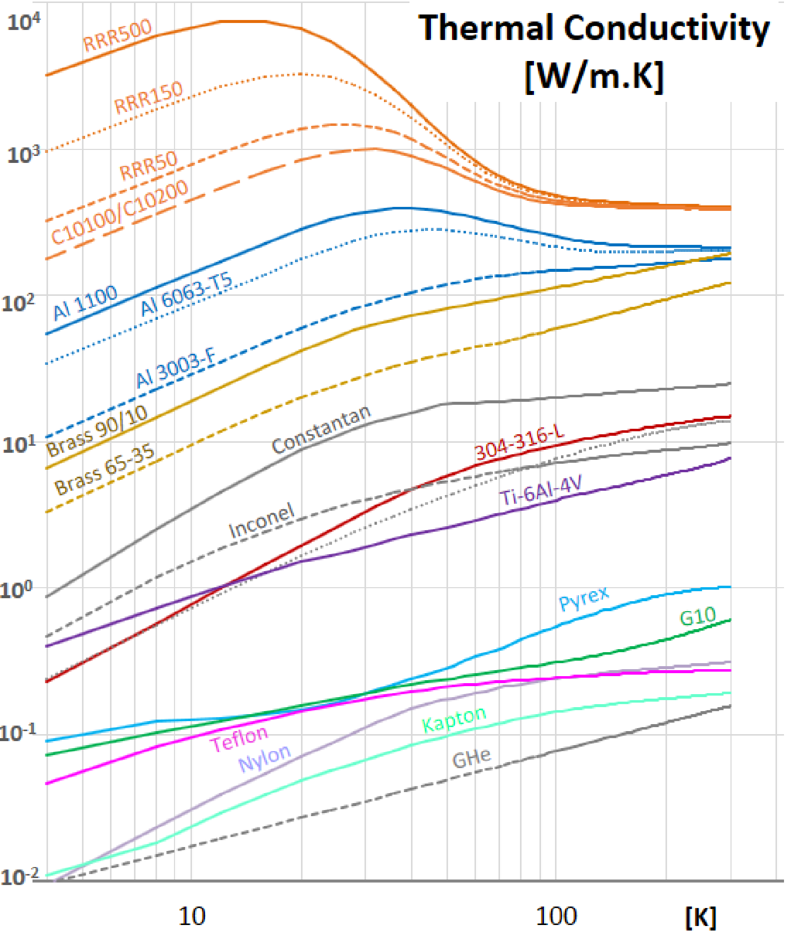
Dummy example of cool down at t=2h after CD start
(end plates, central lamination removed from image)



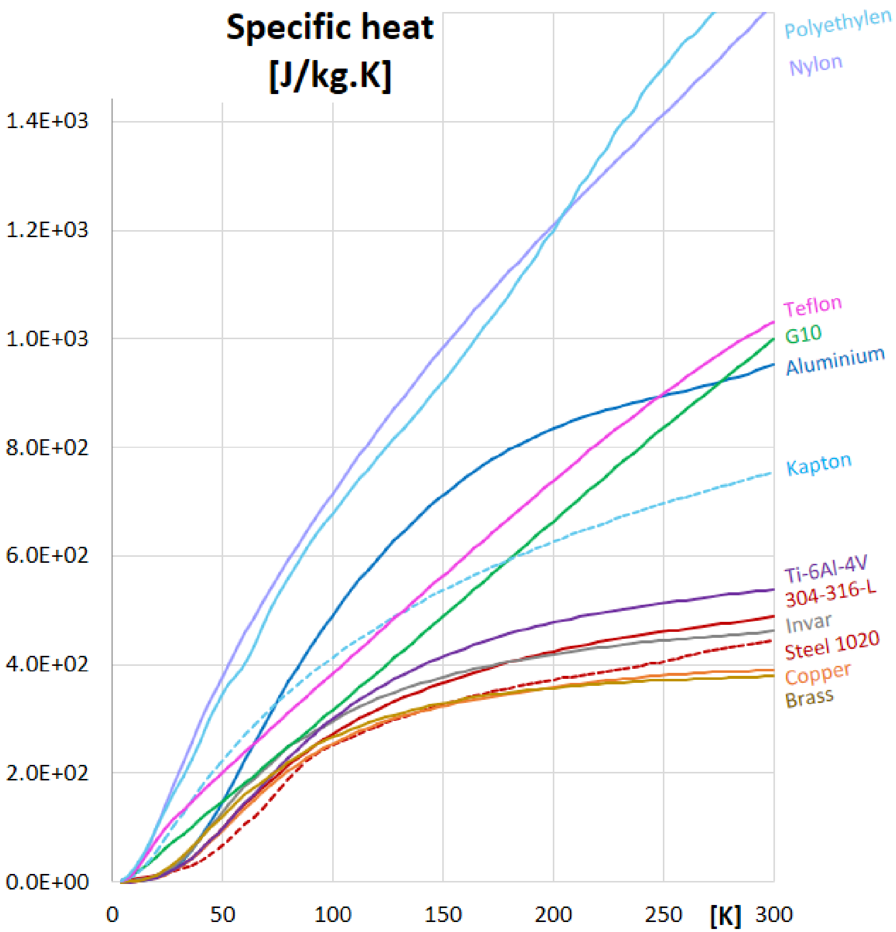


Proposed tests plan

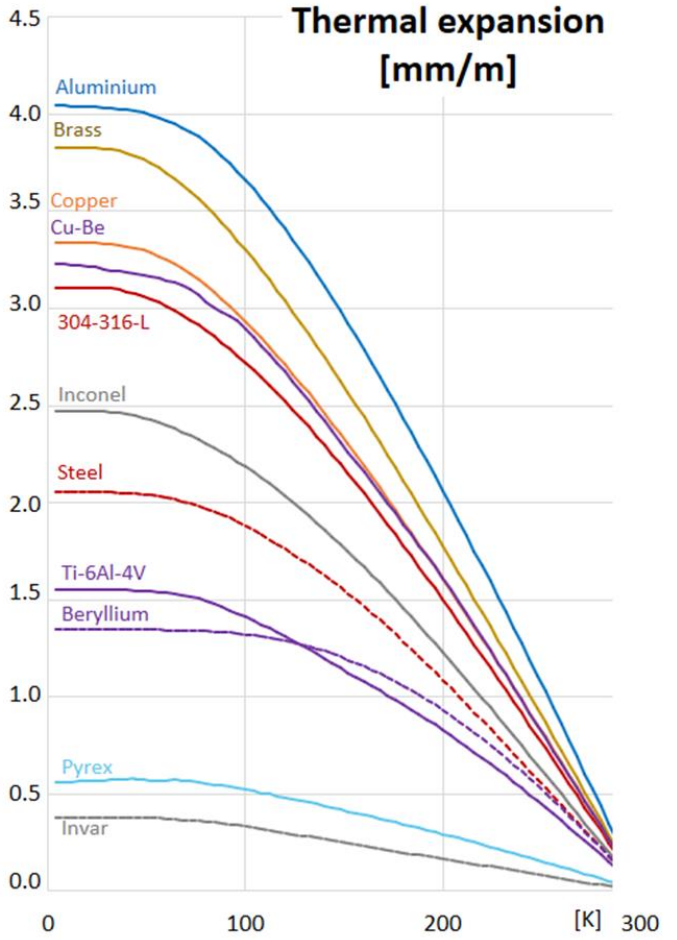
- Study Heat diffusivity through structure to validate the model
  1. CD : 60 g/s and fixed $T_{gas\text{-}in}$ @ 250 K, 200K, 150K, 80K and 4.5K, wait until temperature stability (could be up to 15 h each step)
  2. WU : 60 g/s and fixed $T_{gas\text{-}in}$ @ 80 K, 150K, 200K, 250K and 300K, wait until temperature stability (could be up to 15 h each step)
  3. Redo 1&2 with 30 g/s
- Benchmark the model input “gas temperature gradient”
  1. CD : 30 g/s and ΔT of 60K
  2. WU : 30 g/s and ΔT of 60K
  3. CD : 60 g/s and ΔT of 30K
  4. WU : 30 g/s and ΔT of 60K
- Remarks:
  - Mass flows can be adjusted to optimize test plan with CRG (for ex : 20 g/s instead of 30 g/s)
  - CD or WU : 60 g/s mass flow with ΔT of 30 K shall be performed to benchmark previous CD/WU and study thermo-mechanics of past tests



Thermal Conductivity
[W/m.K]
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
RRR500
RRR150
RRR50
C10100/C10200
Al 1100
Al 6063-T5
Al 3003-F
Brass 90/10
Brass 65-35
Constantan
Inconel
304-316-L
Ti-6Al-4V
Pyrex
G10
Teflon
Nylon
Kapton
GHe
10
100
[K]



Specific heat
[J/kg.K]
1.4E+03
1.2E+03
1.0E+03
8.0E+02
6.0E+02
4.0E+02
2.0E+02
0.0E+00
0
50
100
150
200
250
[K]
300
Polyethylen
Nylon
Teflon
G10
Aluminium
Kapton
Ti-6Al-4V
304-316-L
Invar
Steel 1020
Copper
Brass



Thermal expansion
[mm/m]
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Aluminium
Brass
Copper
Cu-Be
304-316-L
Inconel
Steel
Ti-6Al-4V
Beryllium
Pyrex
Invar
0
100
200
[K]
300