SPL power coupler double walled tube thermo-mechanical studies

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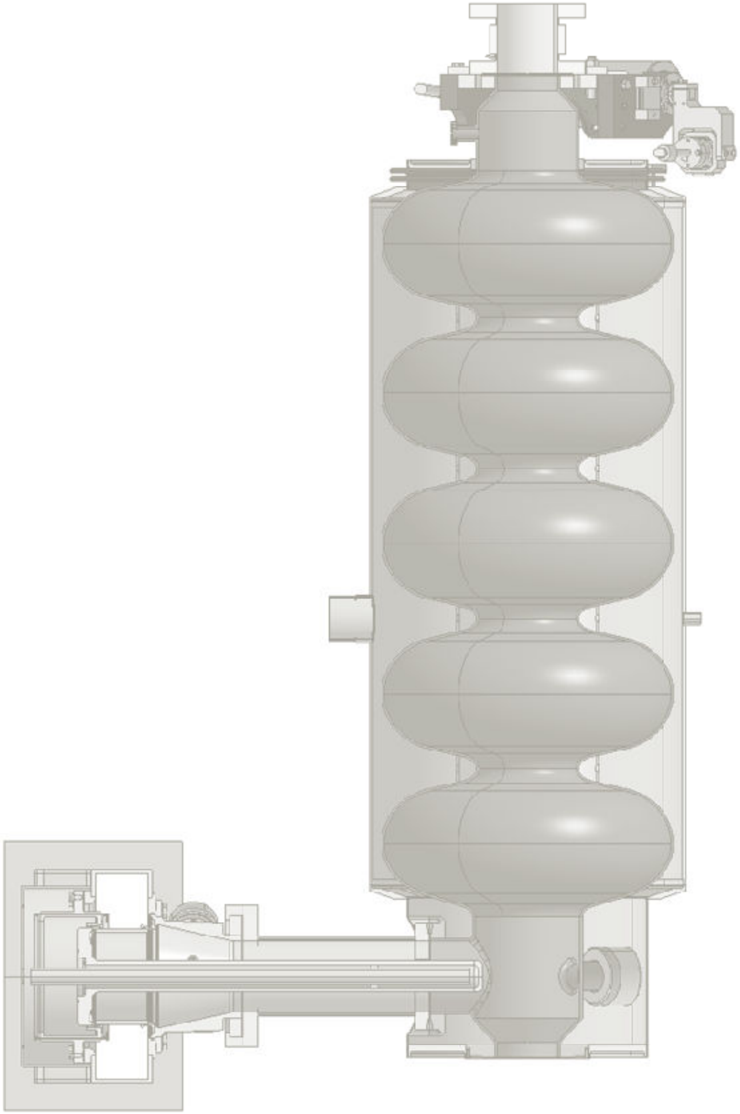
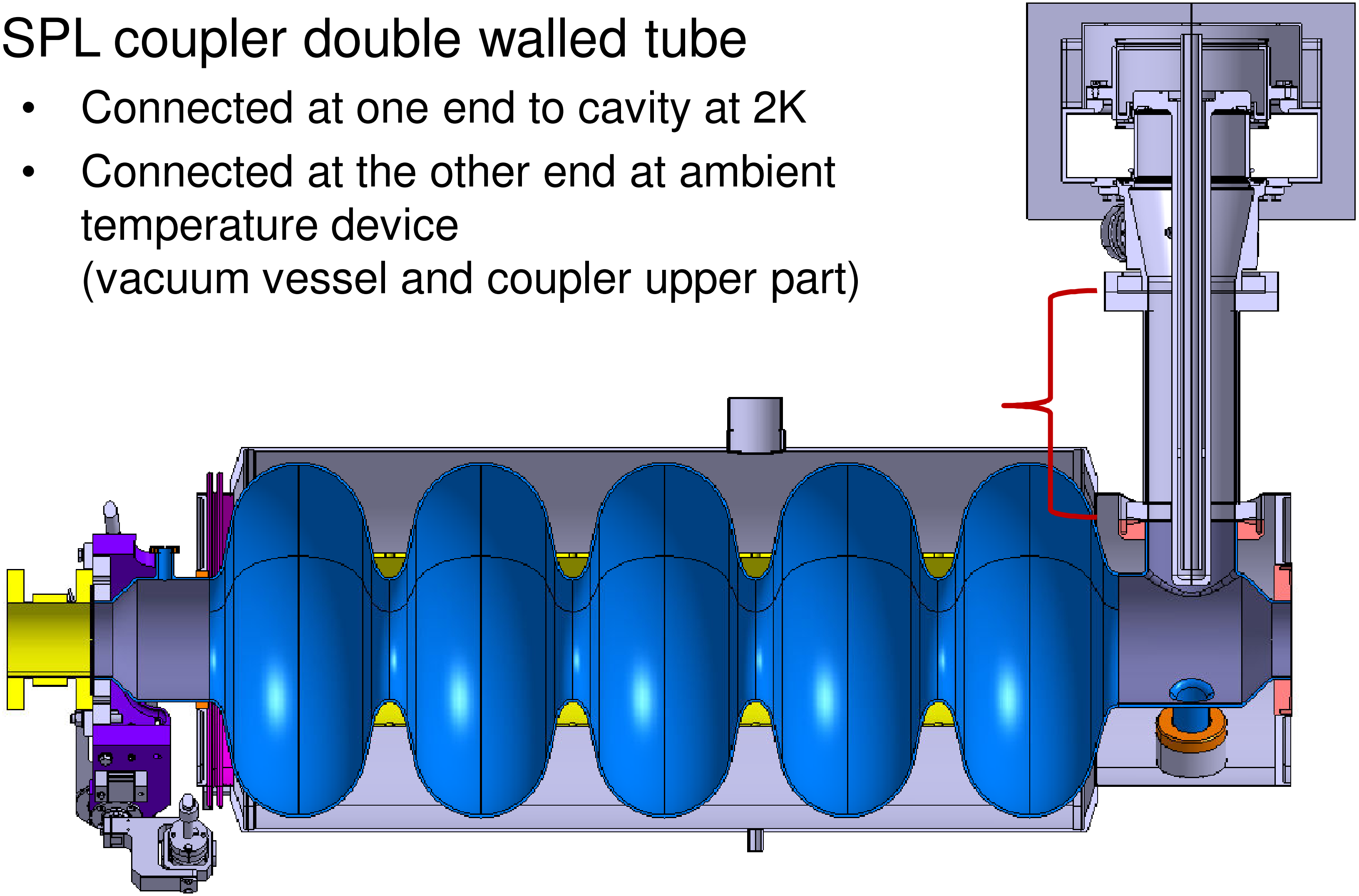
Overview

- Introduction
- Thermal studies
- Mechanical considerations
- Conclusions



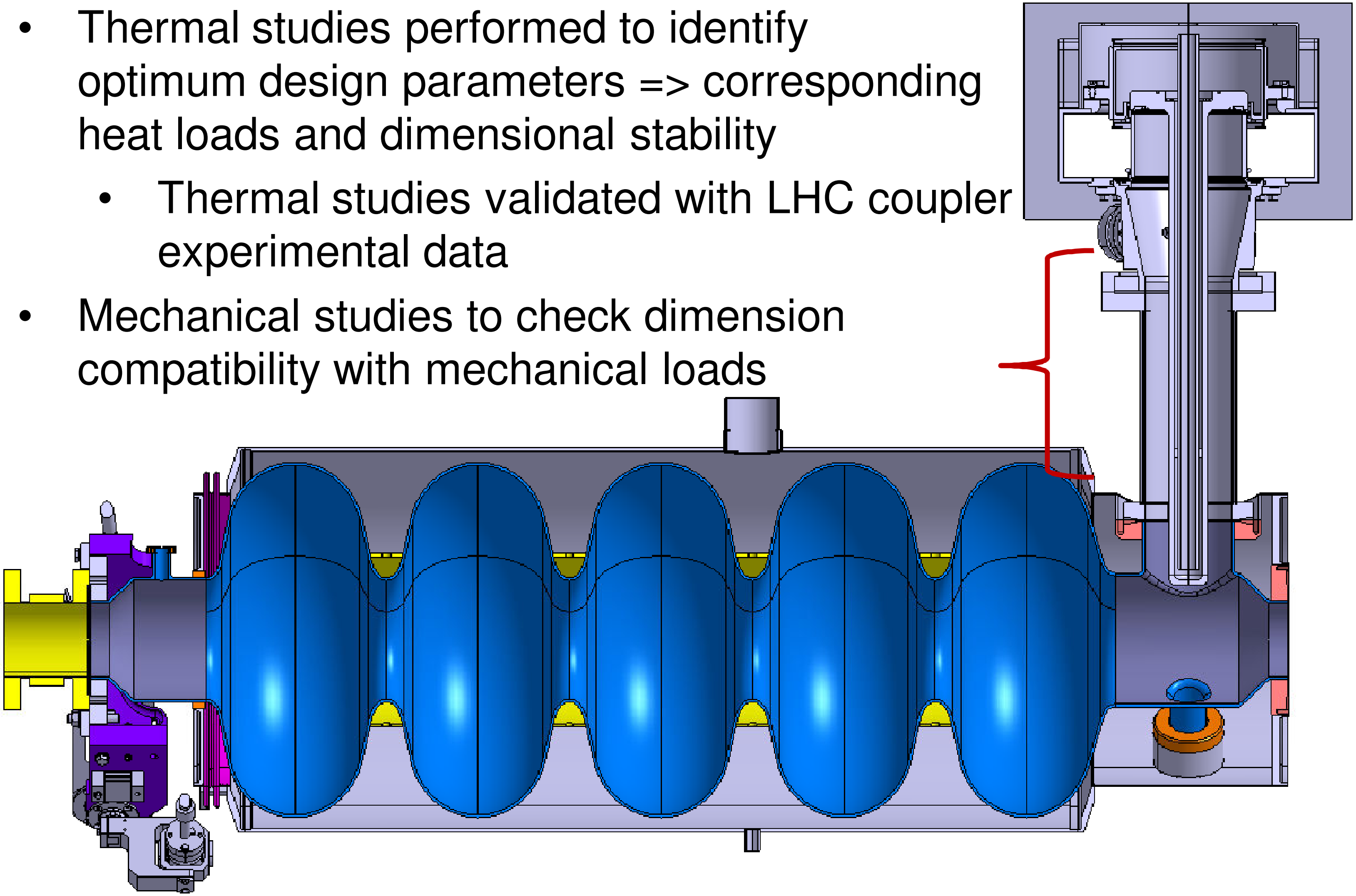
Introduction

- SPL coupler double walled tube
  - Connected at one end to cavity at 2K
  - Connected at the other end at ambient temperature device
    (vacuum vessel and coupler upper part)



Introduction

- SPL coupler double walled tube
  - Thermal studies performed to identify optimum design parameters => corresponding heat loads and dimensional stability
    - Thermal studies validated with LHC coupler experimental data
  - Mechanical studies to check dimension compatibility with mechanical loads



Thermal studies

- Model description
- Model applied to LHC double wall tube for comparison to experimental data
- Results for SPL double wall coupler
- Few words about the antenna

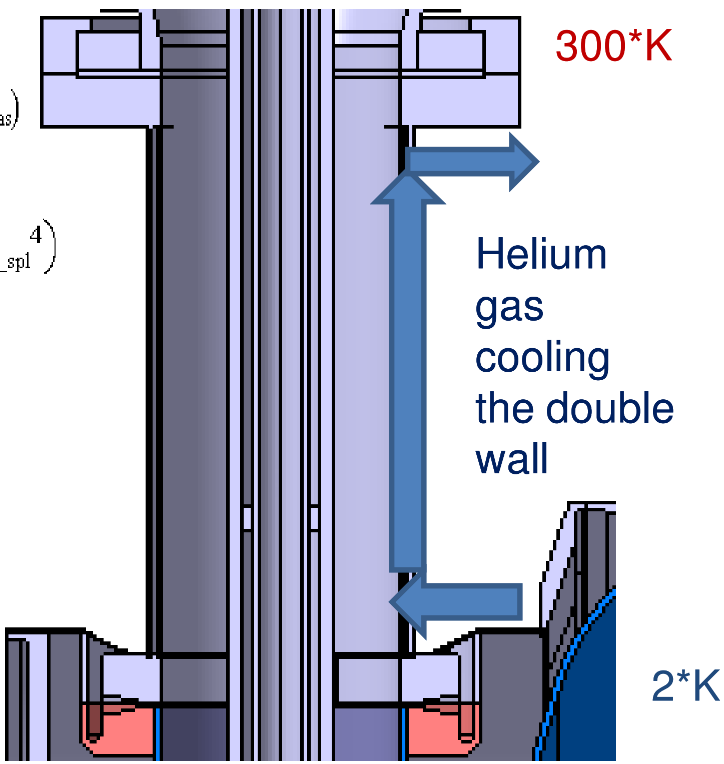
Thermal studies

- Model description
  - Copper on Stainless steel wall
  - Semi-analitical model taking into account
    - **Conduction** through the tube $$Q_{cond}(T_a, T_b, i) := \int_{T_b}^{T_a} \frac{\lambda_{ss}(T)\cdot S_{cond\_tube\_coupleur}}{l_i}\,dT$$
    - **Convection** $$Qcv(T_{wall}, T_{gas}, h_c, S_{convection}) := h_c(T_{gas})\cdot S_{convection}\cdot(T_{wall} - T_{gas})$$
    - **Radiation** between warm and cold parts $$Q_{rad\_antenne\_wall} := A_{wall}\cdot \varepsilon_{antenne\_wall}(T_{wall\_spl})\cdot F_{wall\_antenne}\cdot \sigma_z\cdot\left(T_{antenne}^{\;4} - T_{wall\_spl}^{\;4}\right)$$
    - **Power dissipation** (average) in the wall when coupler on

$$P_{diss\_ext} := \int_0^{h_{tube\_coupleur}} \frac{\left(I_{peak\_wall}(x)\right)^2}{2}\cdot R_{ext\_elect}\left(Temp_{tube\_coupleur}(x)\right)\,dx$$

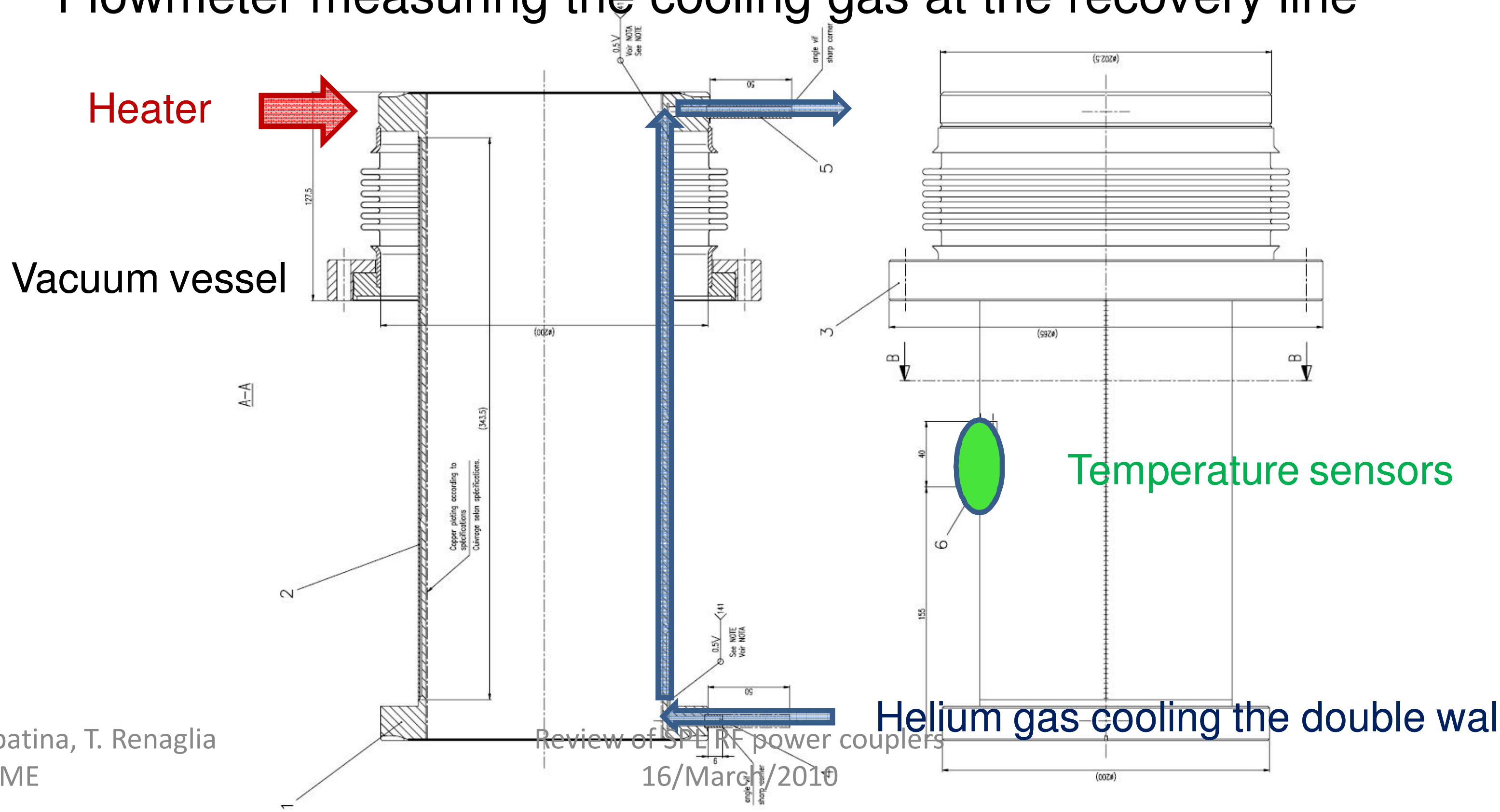
$$I_{peak\_wall}(x) := I_0\cdot 2\cdot \sin\left(\frac{\omega_0}{c}\cdot x\right) \qquad I_0 := \sqrt{2\cdot\frac{p_f}{Z_0}}$$

$$R_{ext\_elect}(T) := \frac{\rho_{CU\_RRR30}(T)}{\delta\left(\rho_{CU\_RRR30}(T), \omega_0\right)\cdot \pi\cdot d_{tube\_coupleur\_int}}$$



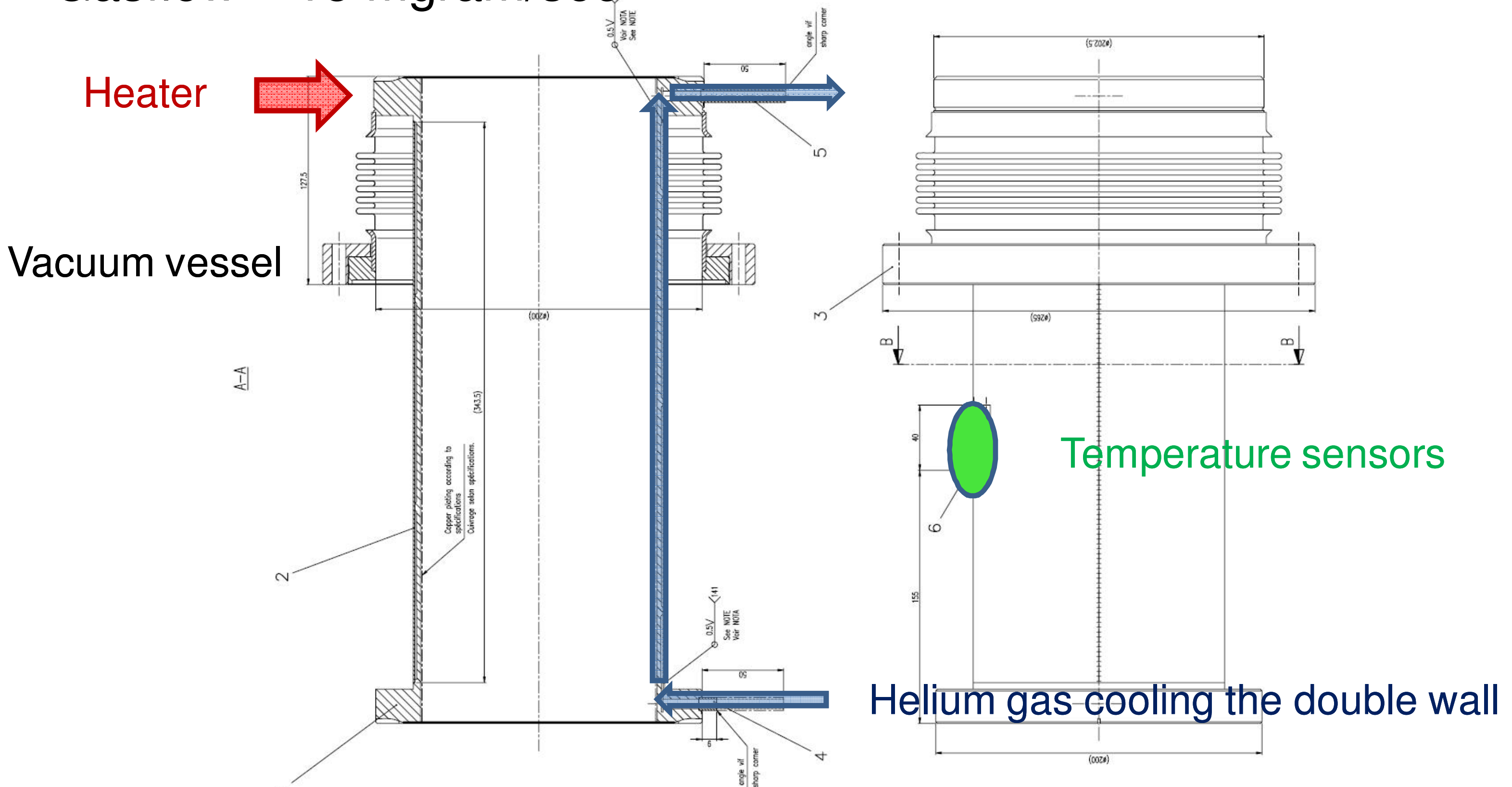
Thermal studies

- LHC Double walled tube
  - Connected to the vacuum vessel via a bellow
  - Lower part at 4.5 K and upper part
  - Heater at upper part to insure 30 ºC of flange temperature
  - Temperature sensors
  - Flowmeter measuring the cooling gas at the recovery line



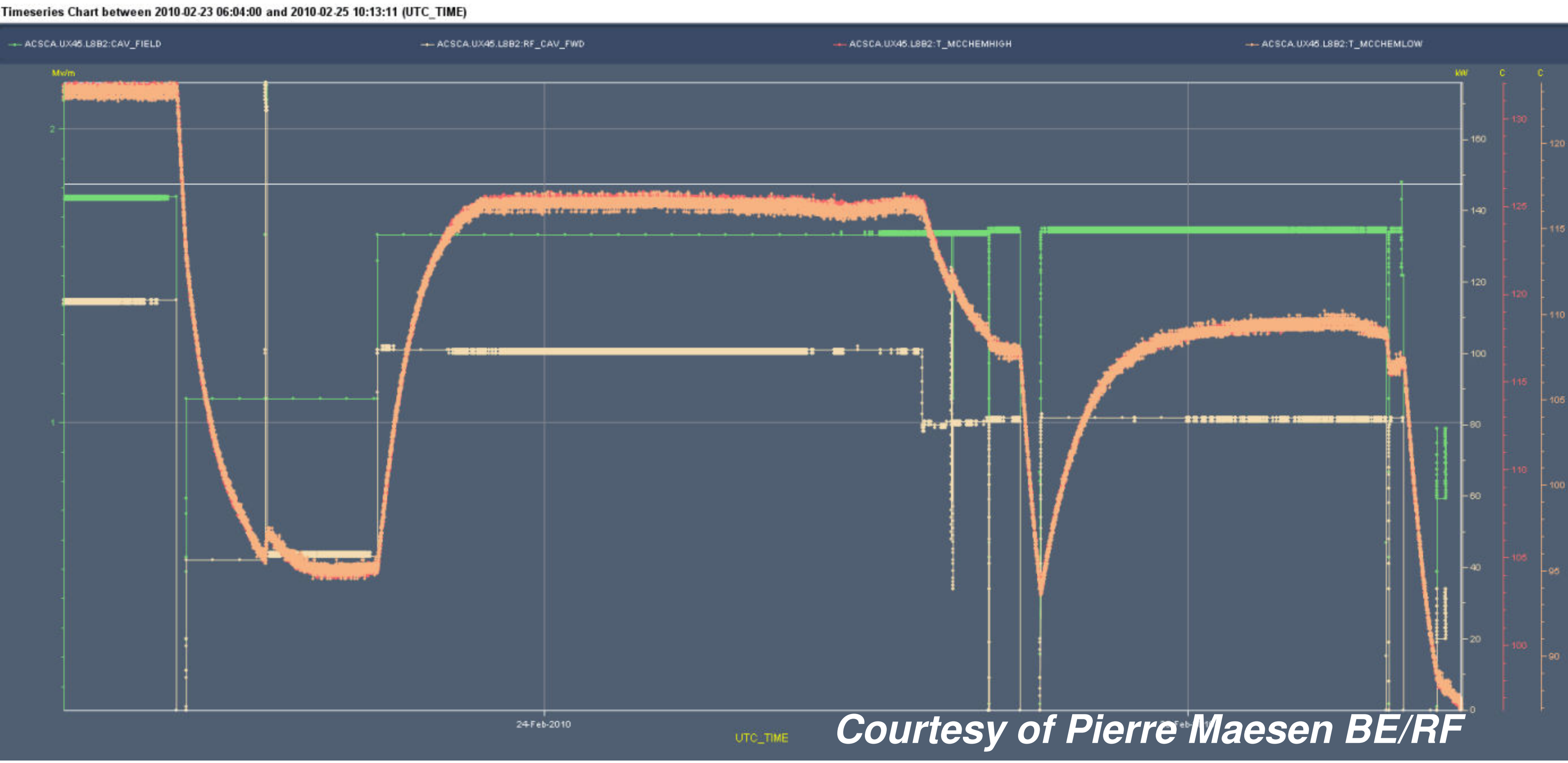
Thermal studies

- LHC Double walled tube
  - 250 kW CW, 400 MHz, 75 Ω
  - H=395 mm; D=144 mm; eint=2.5 mm; eext=1 mm
  - Copper on stainless steel; Copper RRR = 30   (Sergio Calatroni)
  - Gasflow ~ 18 mgram/sec



Thermal studies

- LHC Double walled tube
  - Experimental results (measured wall temperature for different input power)



Thermal studies

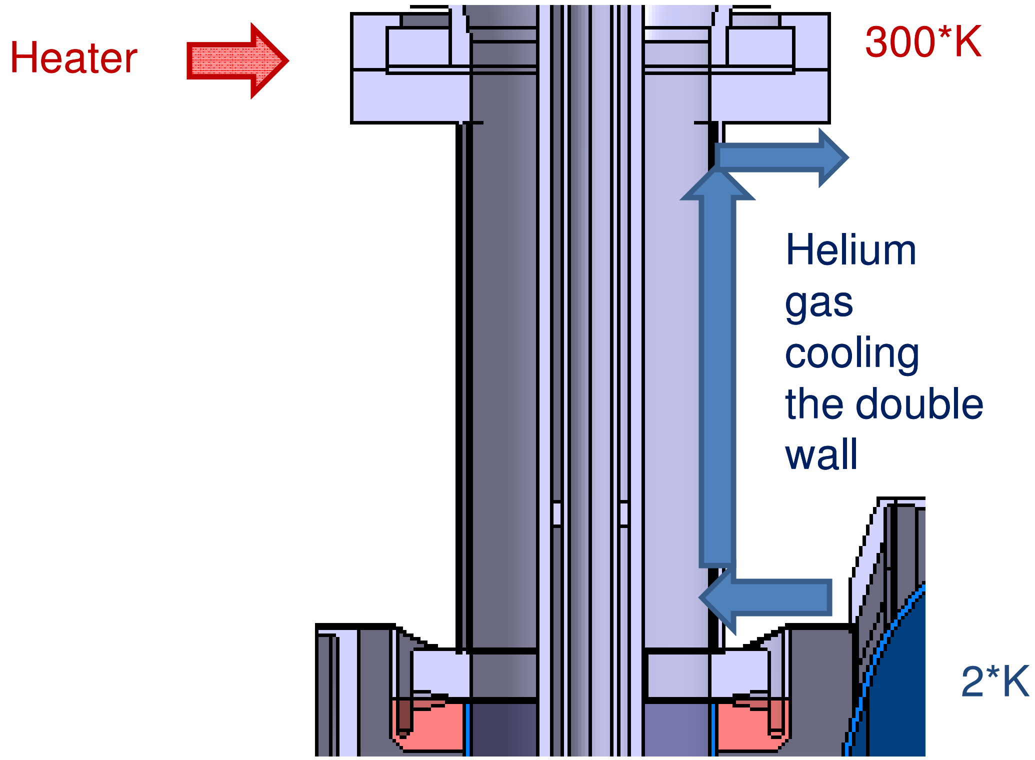
- LHC Double walled tube
  - Calculated / measured results
    (wall temperature for different input power)

Input power	0 W	40 kW	80 kW	100 kW
Calculated temperature at sensor position	92 K	105 K	118 K	125 K
Measured temperature	95 K	105 K	118 K	125 K

  - => model validated

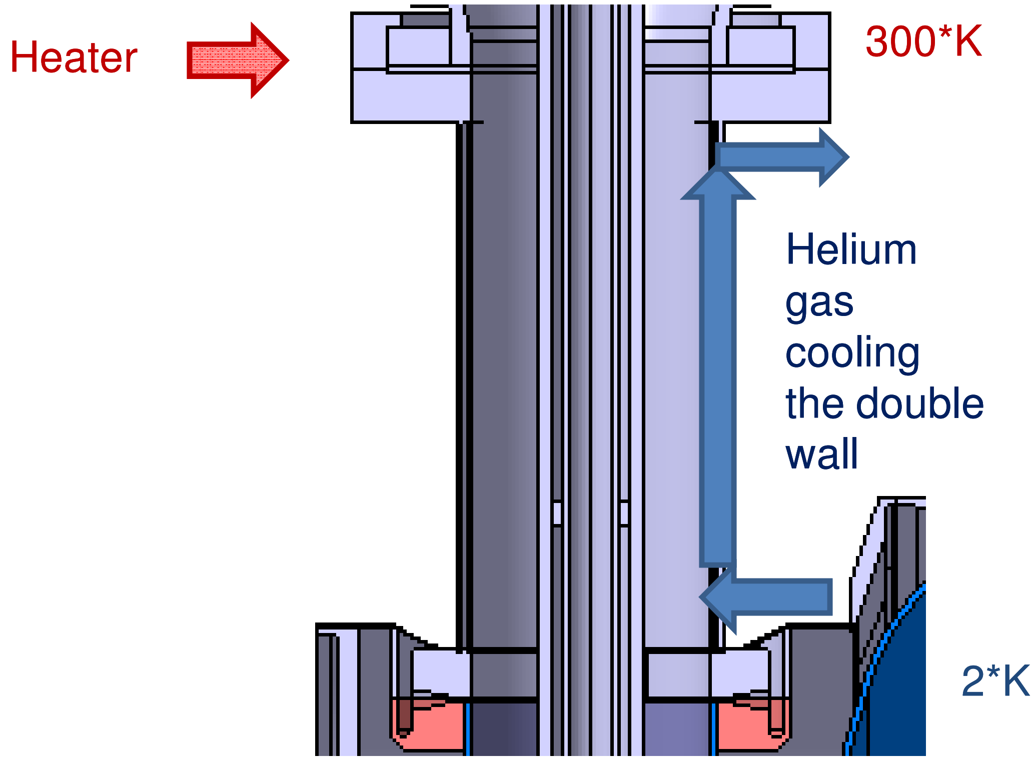
Thermal studies

- SPL Double walled tube
  - Cooling gas at 4.5 K input
  - Lower part at 2 K and upper part at 300 K
  - Heater at upper part to insure 30 ºC of flange temperature



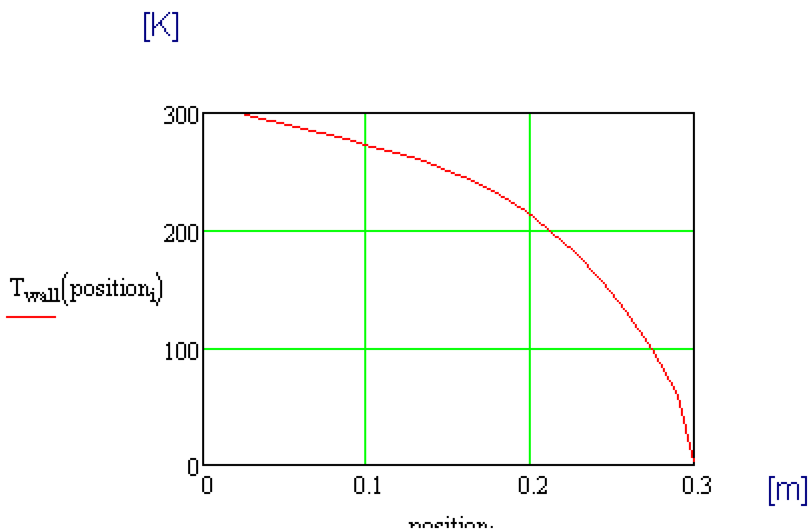
Thermal studies

- SPL Double walled tube
  - 1000 kW pulsed (100 kW average), 704.4 MHz, 50 Ω
  - H=300 mm; D=100 mm; eint=1.5 mm; eext=2 mm
  - Copper on stainless steel; Copper RRR = 30 (Sergio Calatroni)

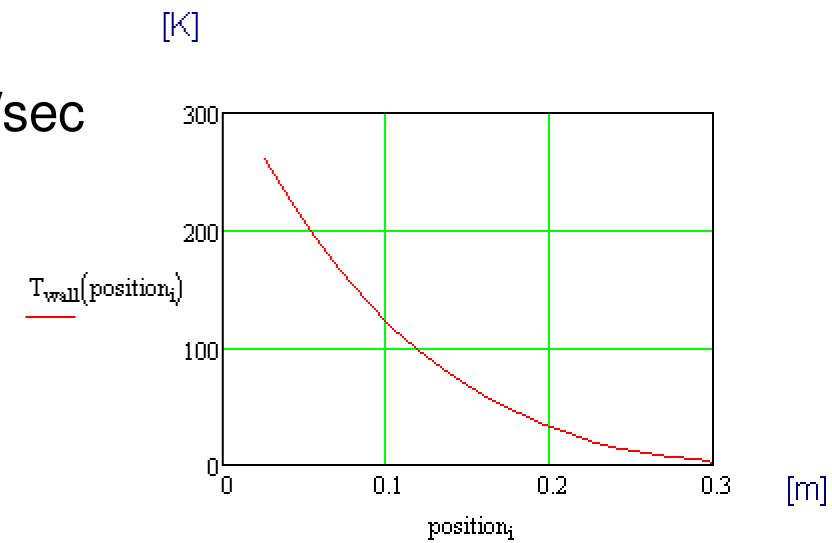


Thermal studies

- Why cooling the wall?
  - No cooling
    temperature profile
    => Gives 21W to 2K



  - Cooling with 42 mgram/sec
    temperature profile
    => Gives 0.1W to 2K



Thermal studies

- Why a heater at the top flange?
  - The heater insures 30 ºC of flange temperature
  - If no heater, in order to have the same temperature at the flange when no power on
    for the same thickness => height of more than 1m

Thermal studies

- Some results

Massflow mgram/sec	21		23		28		35		42	
Power	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Temp. gas out	286 K	277 K	283 K	273 K	271 K	242 K	255 K	205 K	232 K	180 K
Q thermal load to 2K	2.4 W	0.1 W	1.7 W	0.1 W	0.4 W	0.1 W	0.1 W	0.1 W	0.1 W	0.1 W
Q heater	19 W	32 W	21 W	34 W	29 W	38 W	39 W	41 W	46 W	44 W
ΔL	0.1 mm (0.63-0.53)mm				0.05 mm (0.66-0.61)		~ 0 mm (0.67-0.67)			

- => if we want negligible heat load to the 2K, the exit part of the cooling tube shall be insulated (since temperature < 290K)

Thermal studies

- Few words about the antenna : BRIEF ESTIMATIONS
  - For a heat exchange coeff of 50 W/m2*K

    => ΔT antenna/air=30 deg

  - For an airflow of 0.833m3/min

    => ΔT air in/out=9.5 deg

$$P_{diss\_average\_antenne} = 56.954\,W$$

$$d_{antenne\_ext} = 0.043\,m$$

$$h_{type\_air} := 50 \cdot \frac{W}{m^2 \cdot K}$$

$$S_{echange}(h) := \pi \cdot (d_{antenne\_ext} - 0.002 \cdot 2 \cdot m) \cdot h$$

$$S_{echange}(h_{tube\_coupleur}) = 0.037\,m^2$$

$$\Delta T_{antenne\_air} := \frac{P_{diss\_average\_antenne}}{h_{type\_air} \cdot S_{echange}(h_{tube\_coupleur})}$$

$$\Delta T_{antenne\_air} = 30.99\,K$$

$$c_{v\_air\_300K} := 1.2 \cdot \frac{kg}{m^3} \cdot 0.719 \cdot 10^3 \cdot \frac{joule}{kg} \cdot K^{-1}$$

$$v_{air} := 200 \cdot \frac{km}{hr}$$

$$debit\_air\_cooling\_antenne := v_{air} \cdot S_{air}$$

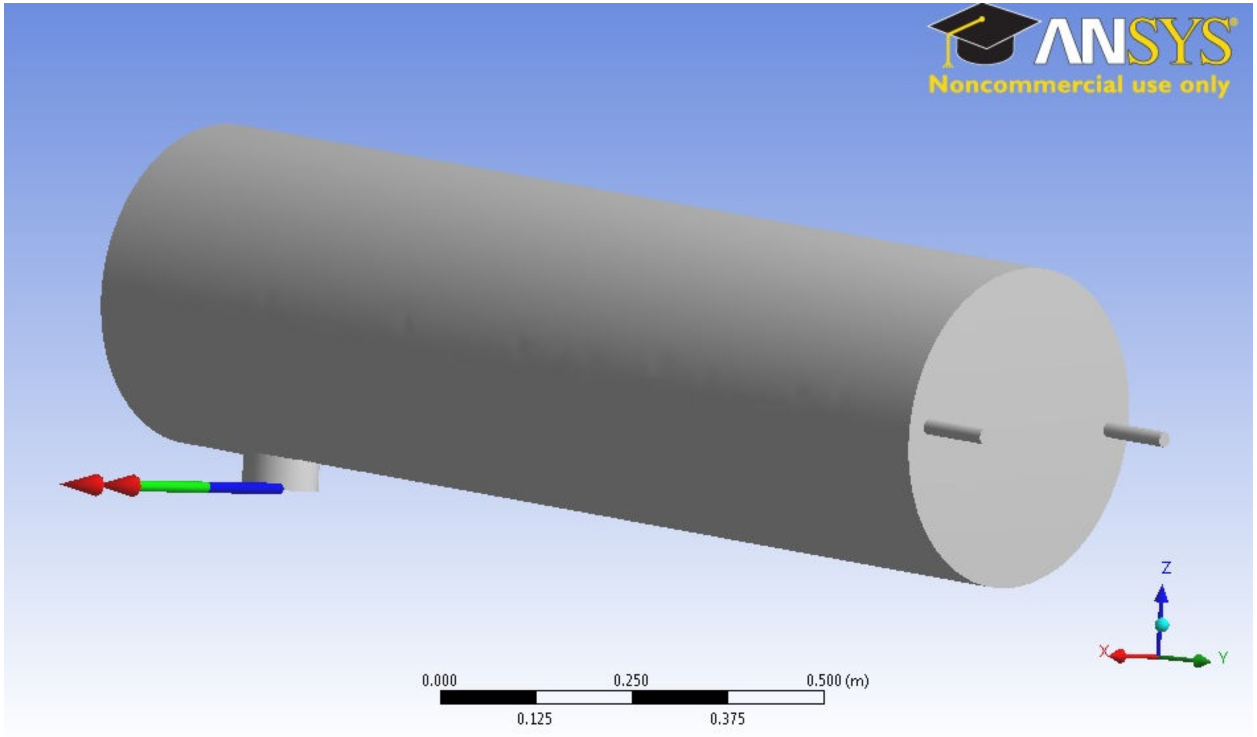
$$debit\_air\_cooling\_antenne = 0.833\,\frac{m^3}{min}$$

$$\frac{P_{diss\_average\_antenne} \cdot 2}{c_{v\_air\_300K} \cdot debit\_air\_cooling\_antenne} = 9.506\,K$$

Mechanical studies

- Verification of maximum stress and max deformation for different STATIC load cases
  - Cavity supported on the double wall only (cantilever)
  - Cavity simply supported at the other end

- Load applied to the double wall by the cavity under own weight
  - Factor ~ 70 of torque applied to the double wall between
    - Cantilever
    - Supported at the other extremity



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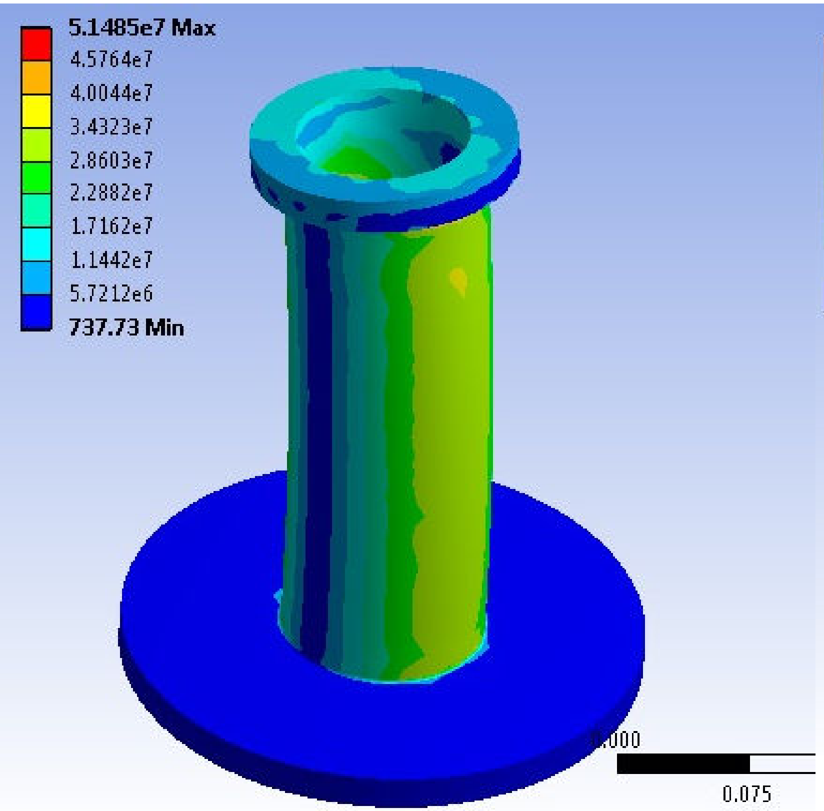
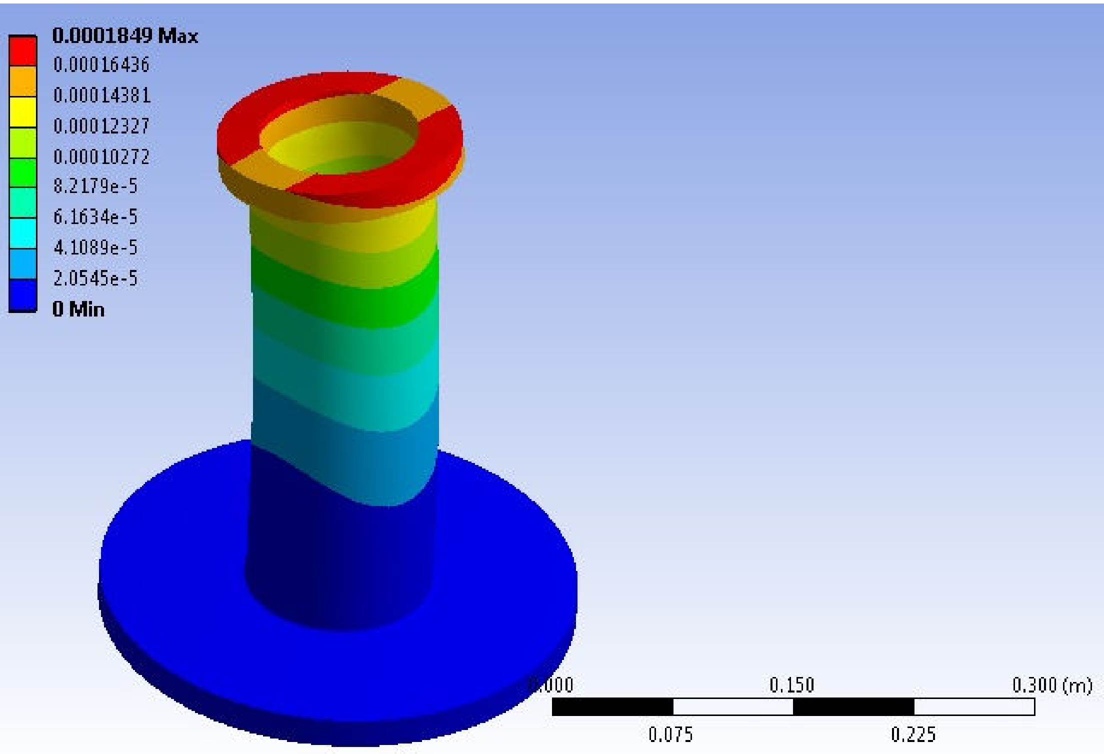
Mechanical studies

- Maximum stress and max deformation
  - Cavity supported on the double wall only (cantilever)

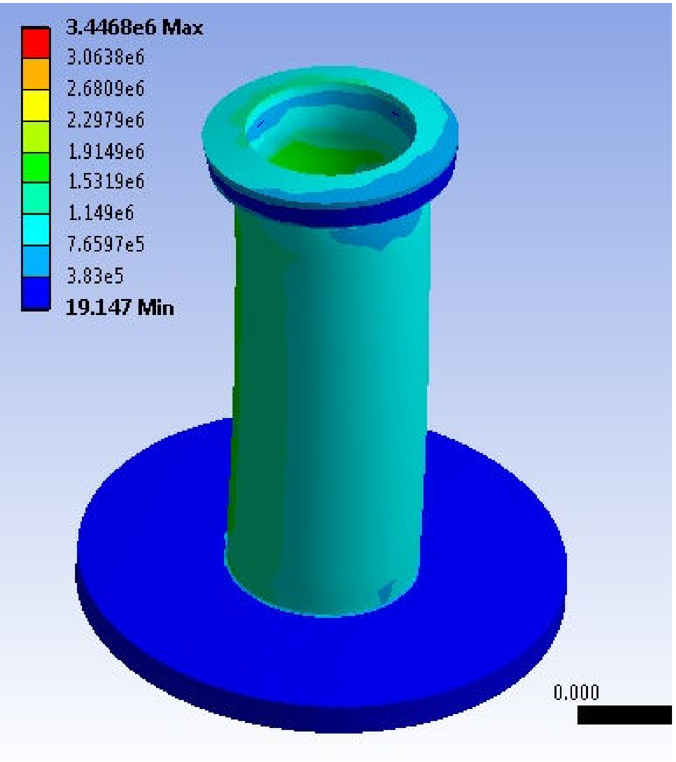


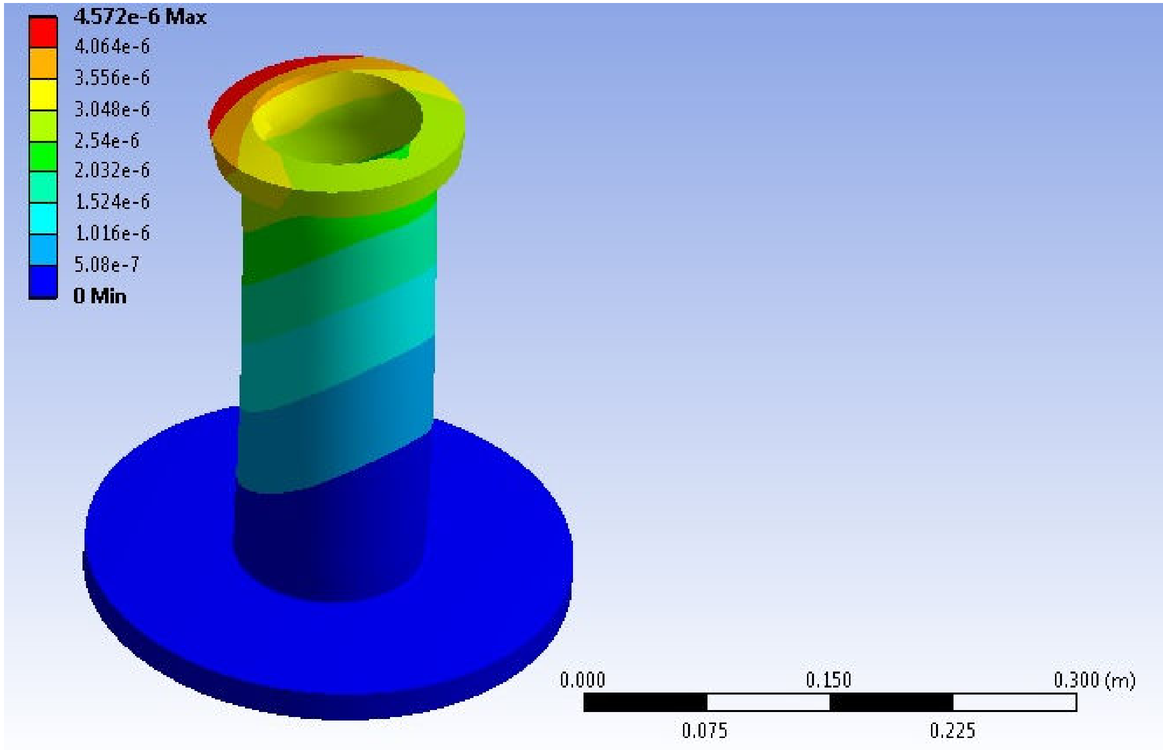


Unacceptable

Mechanical studies

- Maximum stress and max deformation
  - Cavity simply supported at the other end





  - Acceptable

Conclusions

- Thermal
  - For presented geometry (300mm x 1.5mm int + 2mm ext), we can reduce down to negligible the thermal loads to 2K, but:
    - Heater needed at the upper flange
    - Exit tube of the cooling gas has to be insulated
  - Induced height modification of the double wall by power on/off depend on gas flow but in the order of 0.1mm

- Mechanical
  - From the point of view of mechanical behaviour of the double wall, for the presented geometry:
    - The cavity supported only by the double wall => not acceptable
    - The cavity supported by the double wall + supported at the other extremity => acceptable
  - Dynamic behavior to be checked also