Thermal studies & measurements for SPS-DQW

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EN-MME

with inputs from J. Apeland, K. Brodzinski, O. Capatina, T. Capelli, R. Leuxe, S. Verdú Andrés, C. Zanoni and many others

HL-LHC 8th Collaboration meeting – CERN – 16/10/2018

Outline

1. Introduction
2. Thermal balance for DQW
3. Comparison with measurements at SM18
4. Summary and conclusions

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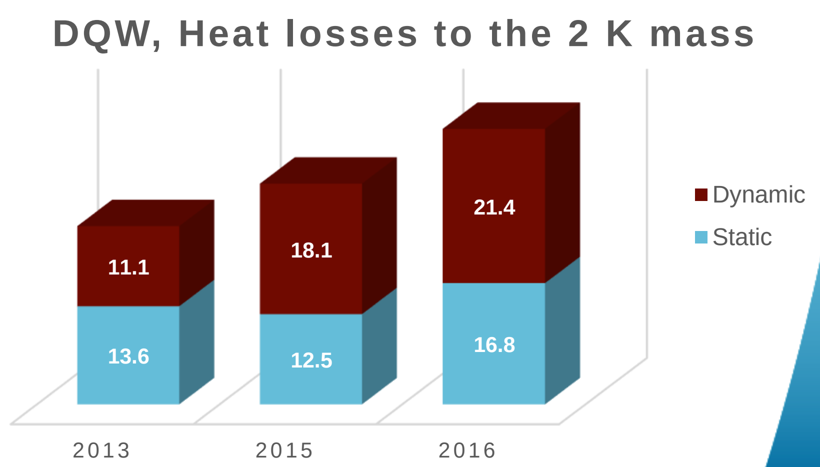
Introduction – Evolution of the heat budget

- Heat budget, DQW cryomodule

Static loads	2013		2015		2016	
	2 K	80 K	2 K	80 K	2 K	80 K
Radiation	0.2	6.8	2	40	3.4	30
CWT	3	12.6	0.2	2	0.2	10
Supports	0.2	3.3	2	50	2	40
RF / FPC	4	100	4	100	4	100
Instrumentation	1	0	1	0	2.3	10
HOM/Pickup	-	0	3	50	3.9	40
Tuner	0.2	100	0.3	10	1	10
Total static	**13.6**	**222.7**	**12.5**	**252**	**16.8**	**240**

Dynamic loads	2013		2015		2016	
	2 K	80 K	2 K	80 K	2 K	80 K
Cavity	6	0	6	0	11	0
Beam	0.5	0	0.5	0	0.5	0
RF / FPC	4.6	20	5.6	10	4.9	10
HOM/Pickup	-	-	6	20	4	10
Total dynamic	**11.1**	**20**	**18.1**	**30**	**21.4**	**20**

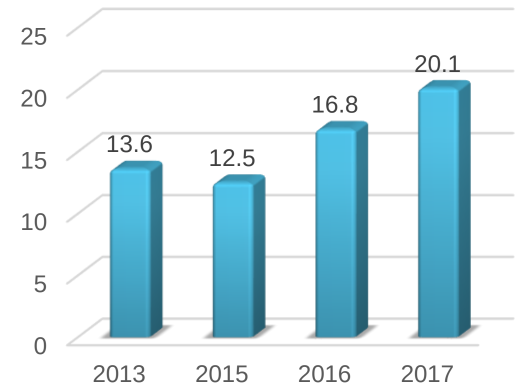


Introduction – Evolution of the heat budget

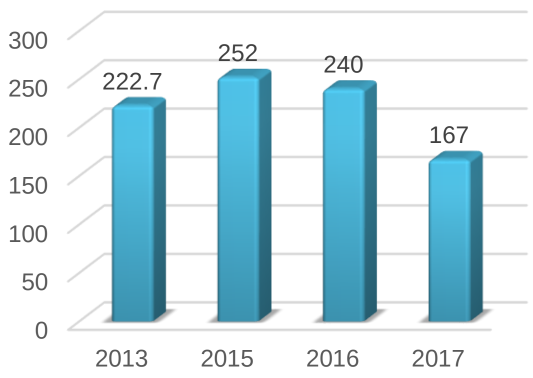
- Heat budget, DQW cryomodule – December 2017

Static loads	2013		2015		2016		2017	
	2 K	**80 K**	**2 K**	**80 K**	**2 K**	**80 K**	**2 K**	**80 K**
Radiation	0.2	6.8	2	40	3.4	30	3.3	8
CWT	3	12.6	0.2	2	0.2	10	0.1	28
Supports	0.2	3.3	2	50	2	40	2.1	21
RF/FPC	4	100	4	100	4	100	5.3	72
Instrumentation	1	0	1	0	2.3	10	2.4	8
HOM/Pickup	-	0	3	50	3.9	40	5.5	15
Tuner	0.2	100	0.3	10	1	10	1.4	15
Total static	**13.6**	**222.7**	**12.5**	**252**	**16.8**	**240**	**20.1**	**167**

Static heat losses to 2K bath



Static heat losses to termal intercept



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RF/FPC	4	100	4	100	4	100	5.3	72
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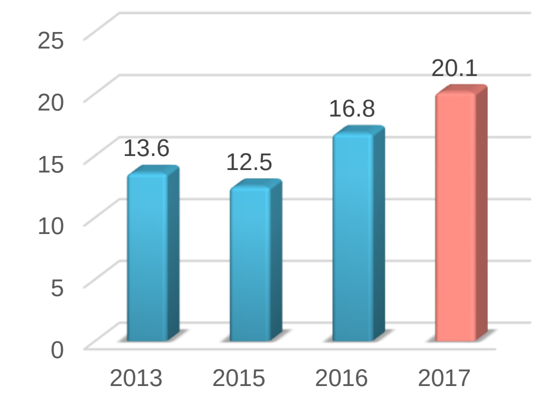
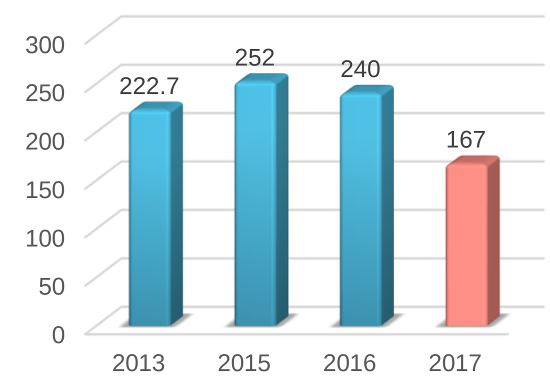


Static heat losses to termal intercept



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Total static	**13.6**	**222.7**	**12.5**	**252**	**16.8**	**240**	**20.1**	**167**

Some considerations:

- Update of latest heat loss estimations (November 2016).
- Use of **experimental values** for intercept estimations
- **Margin with respect to the ideal calculations**, to keep into account uncertainties (position and temperature of interceptors, machining tolerances, etc.) **removed**
- Conservative approach in the temperature estimations

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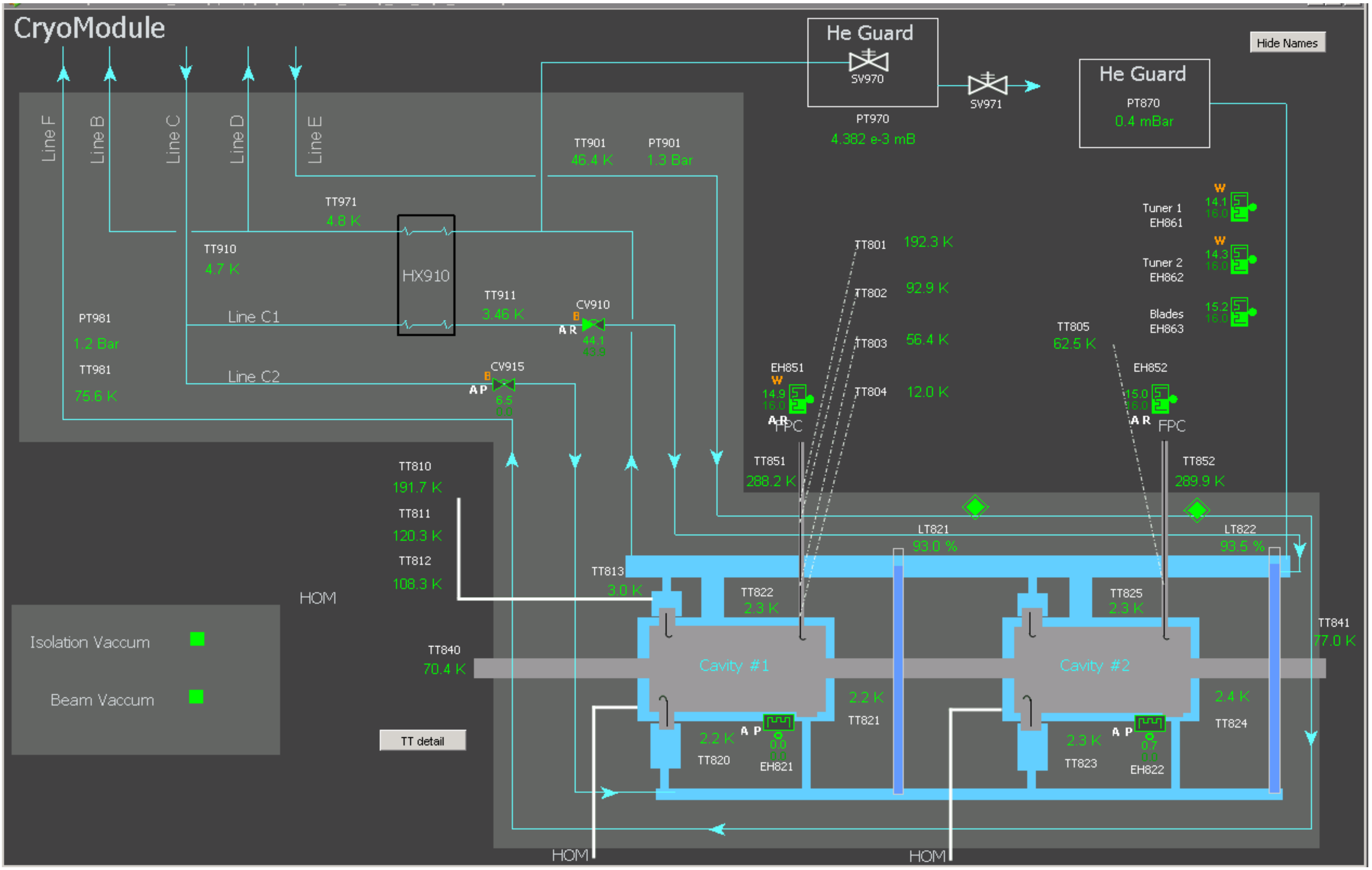
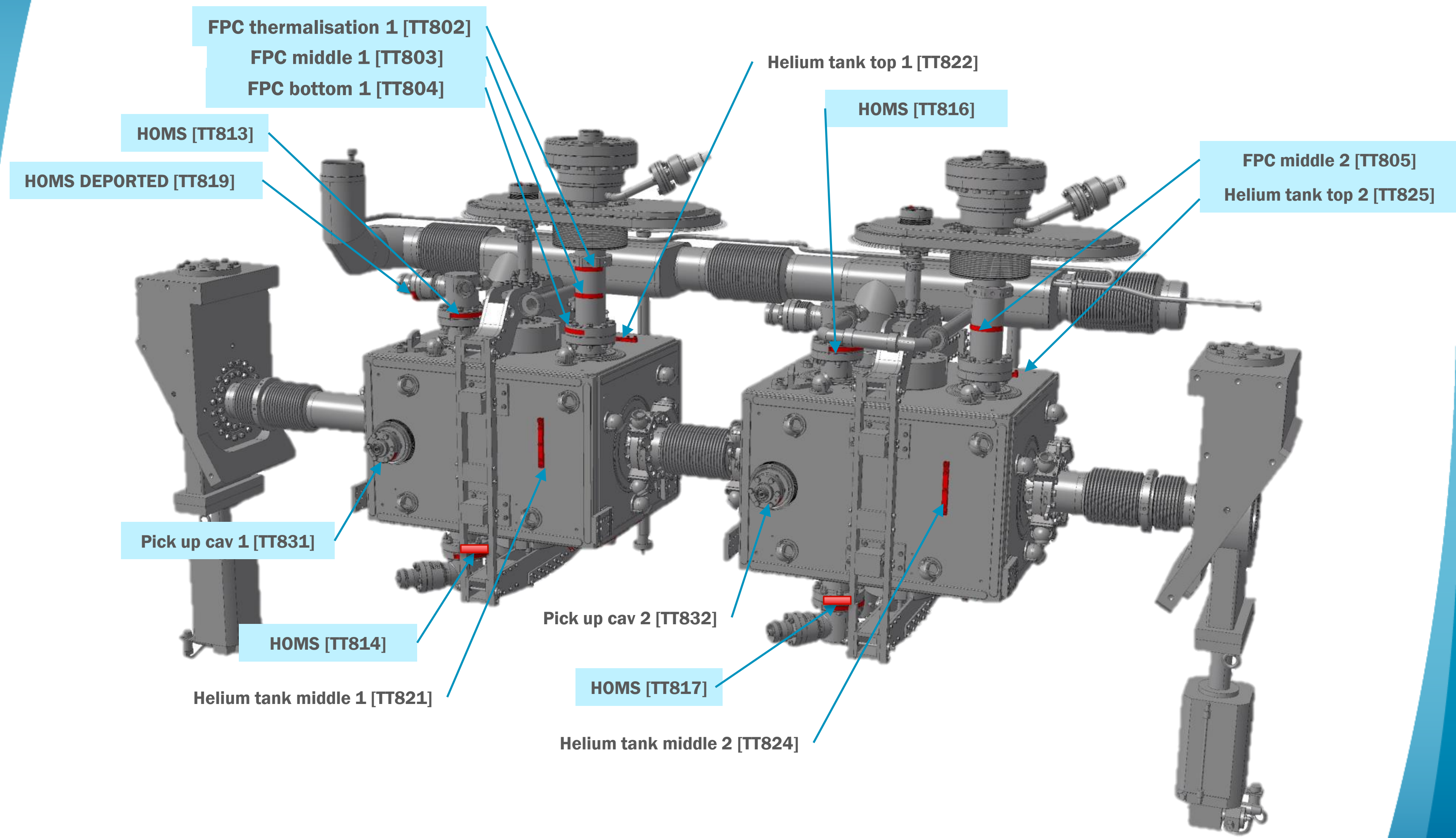
Introduction – Experimental measurements

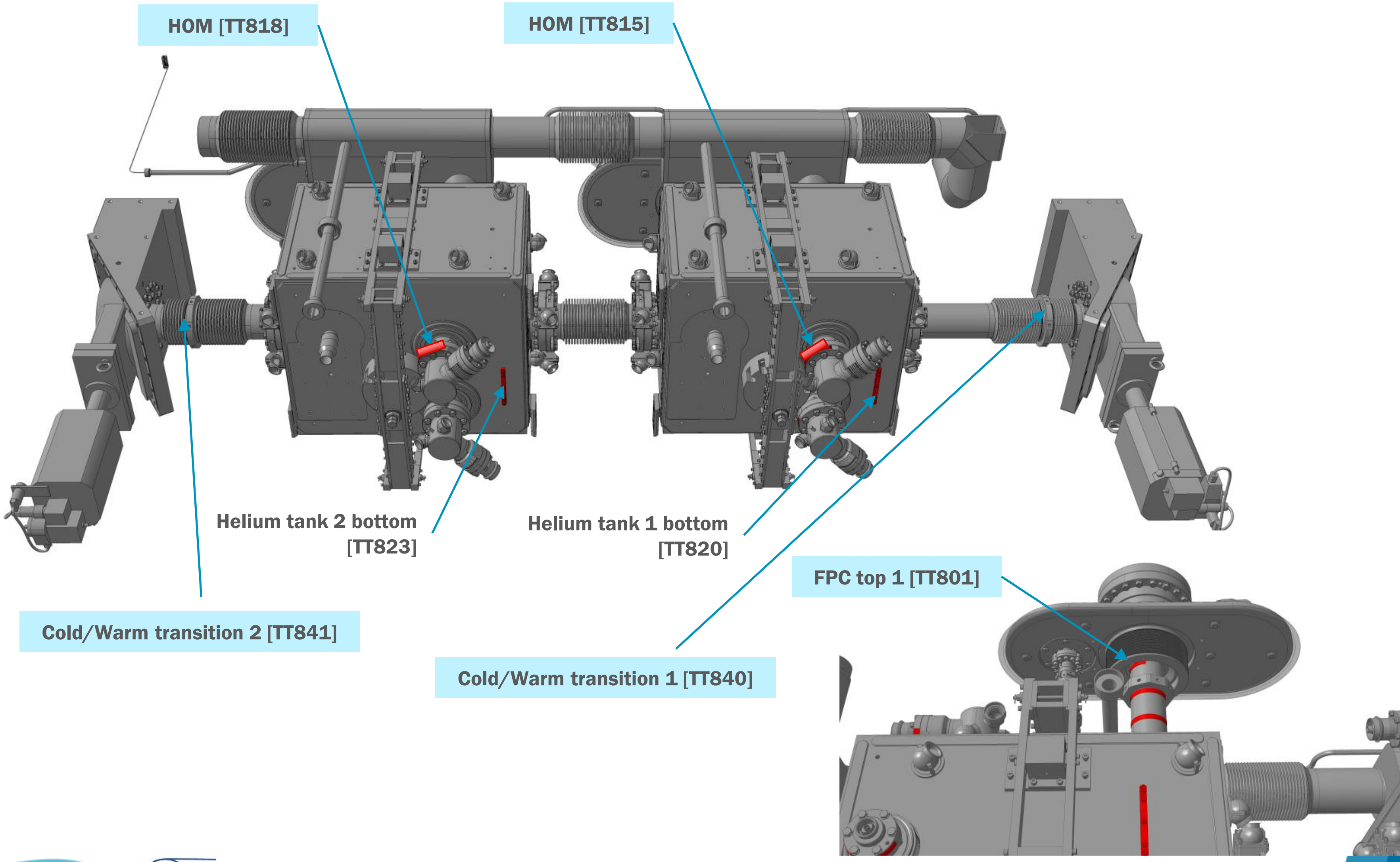
- Experimental data from cooldown at **SM18** – 14.12.2017.



Introduction – Experimental measurements



Introduction – Experimental measurements



Outline

1. Introduction

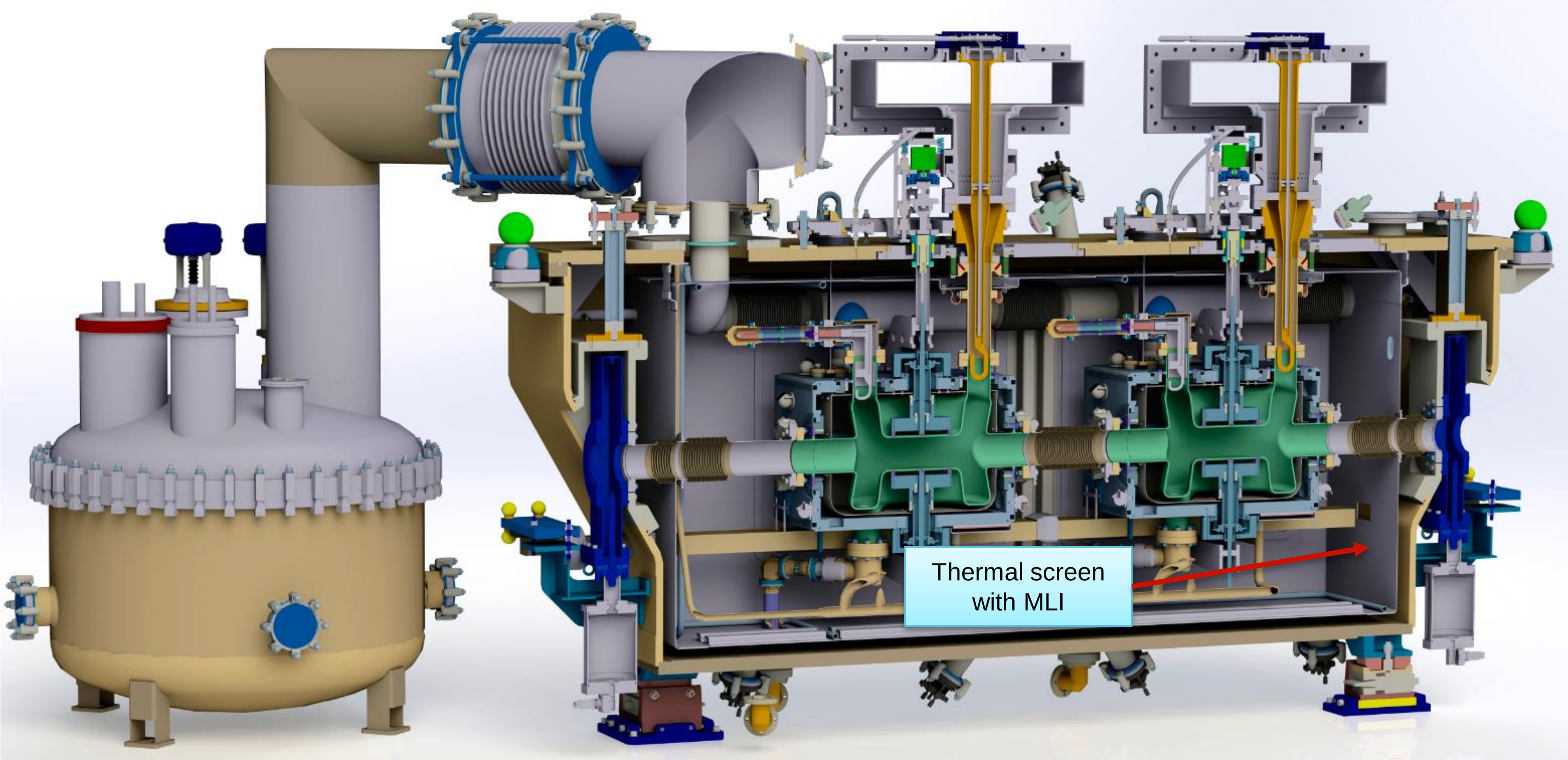
2. Thermal balance for DQW & experimental measurements
   - Radiation
   - Cold-warm transitions
   - Supporting system
   - Fundamental power coupler
   - Instrumentation
   - HOM couplers and pickup port
   - Tuner

3. Comparison with measurements at SM18

4. Summary and conclusions

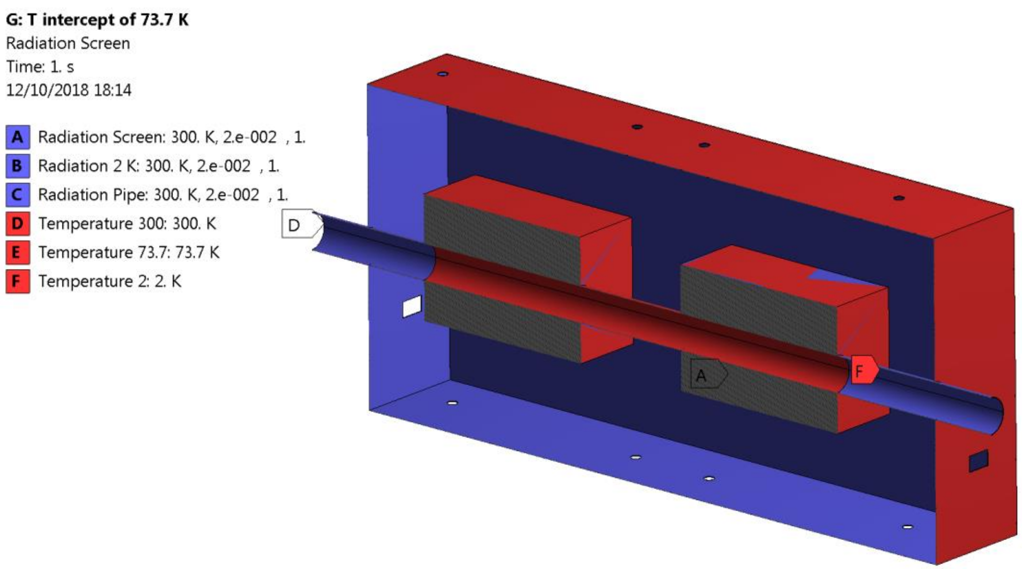
Thermal balance – Radiation

- Radiation losses: minimized by the introduction of a **thermal screen**, with **MLI** on the inner and outer surfaces of the screen and the cold mass



Thermal balance – Radiation

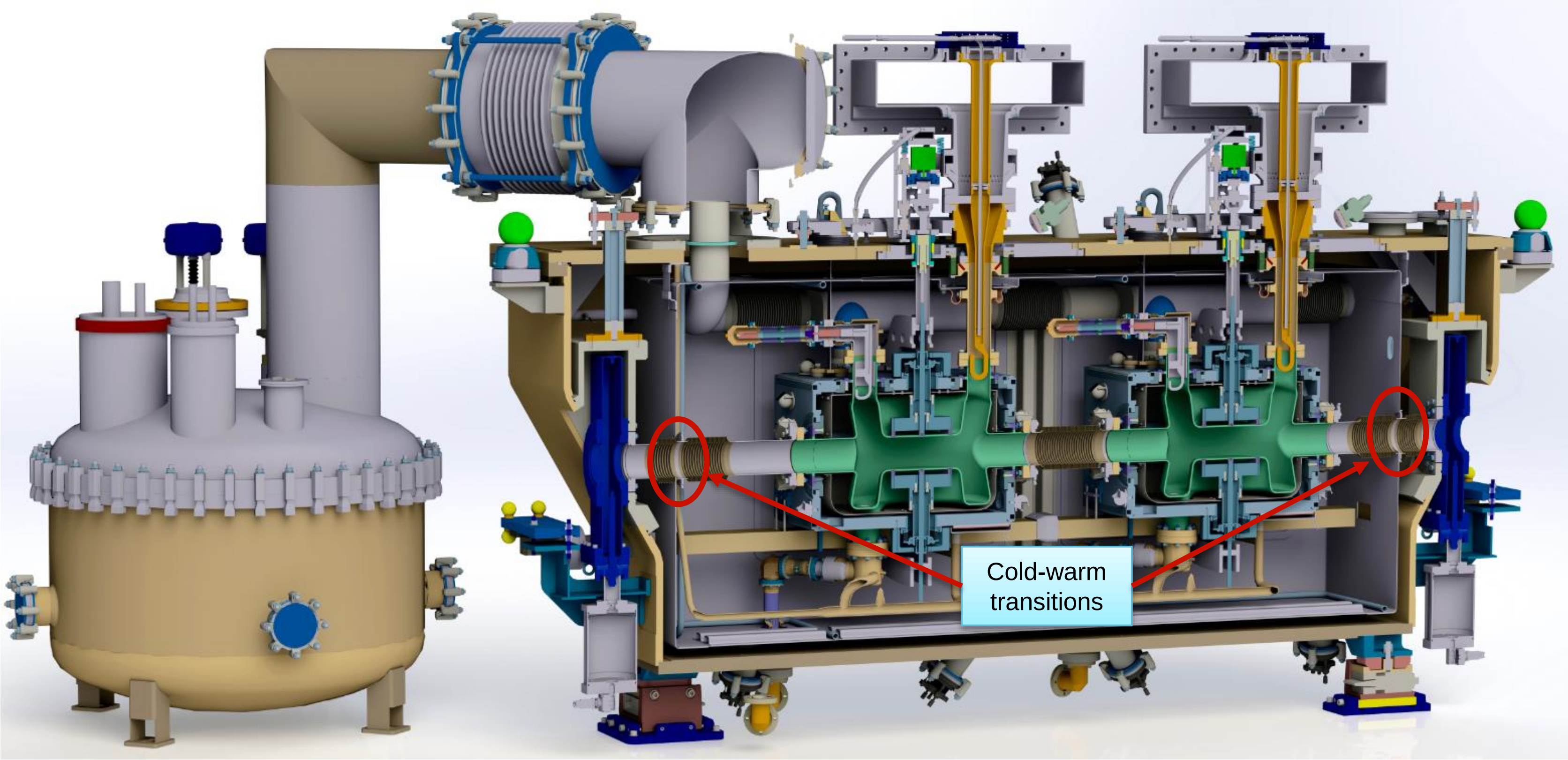
- Holes are present in the thermal screen, to allow measurements for the aligning system and instrumentation. Holes act almost as black bodies.
- Temperature of the thermal shield extracted from the cold-warm transitions measurements.
- Surfaces inside the thermal shield can radiate to the ambient at 300 K.



- Thermal load (LHC measurements, V. Parma and R. Bonomi) ~ 0.15 W
- Additional heat losses because of holes ~3.1 W
- Numerical results:
  - **3.3 W** to the 2 K bath
  - **8 W** to the interceptors

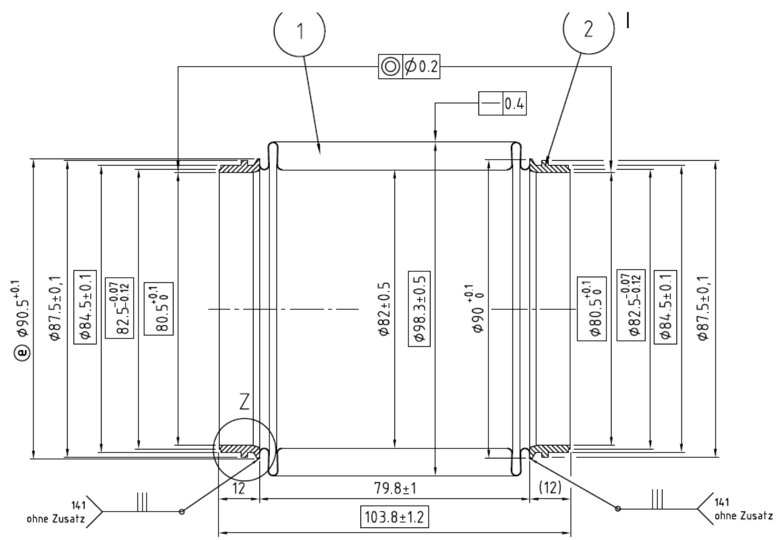
Thermal balance – Cold-warm transitions

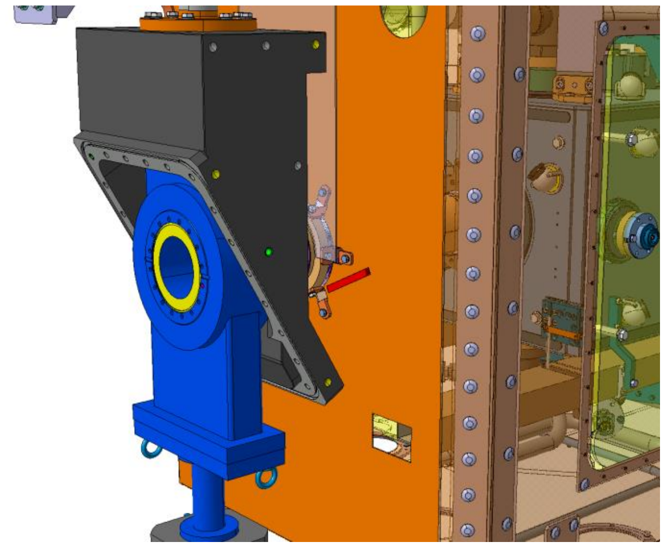
- Cold-Warm transitions (CWT) connect the cold mass to the warm beam pipe
- Losses are dominated by **conduction**

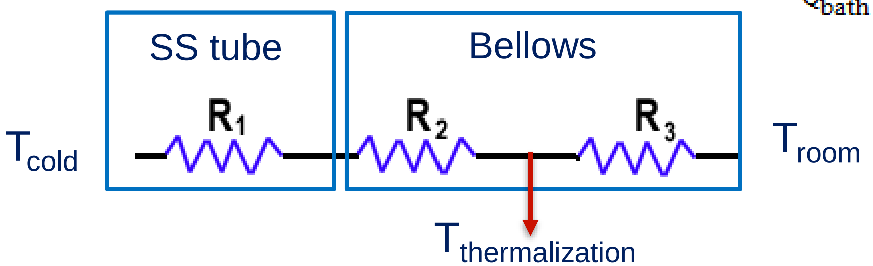


Thermal balance – Cold-warm transitions

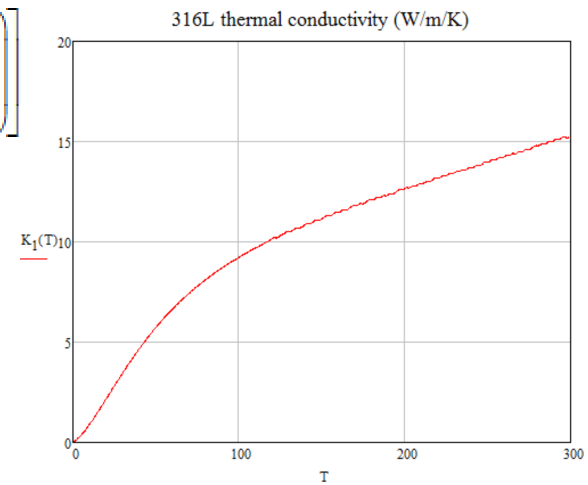
- Losses on the CWT are minimized by the presence of the stainless steel **bellows**
- Very **high thermal resistance** introduced







$$Q_{bath} := \left[\frac{A_1}{L_1}\cdot\left(\int_{T_{x1}}^{T_A} K_1(T)\,dT\right)\right]$$



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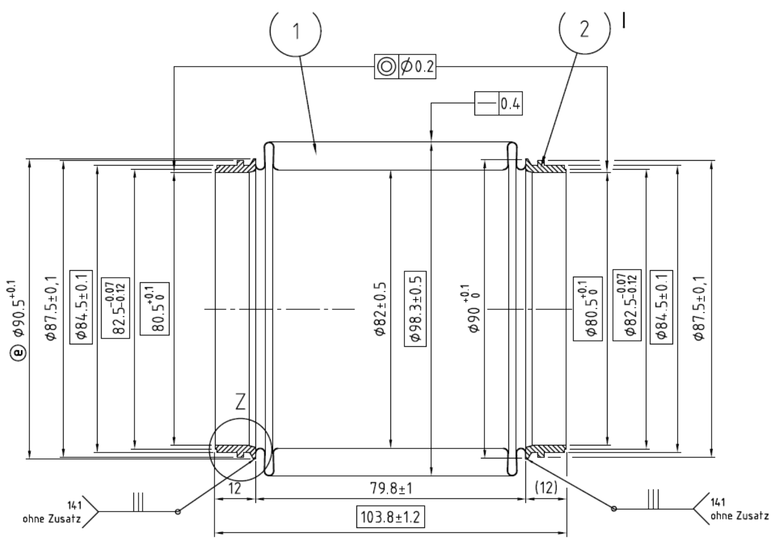
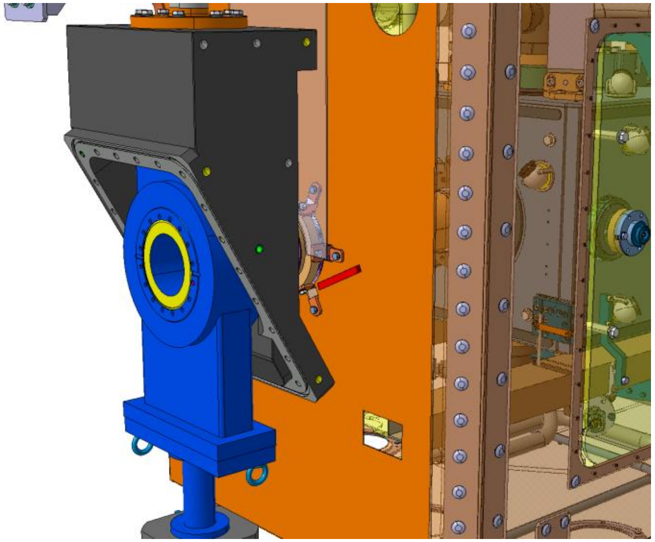
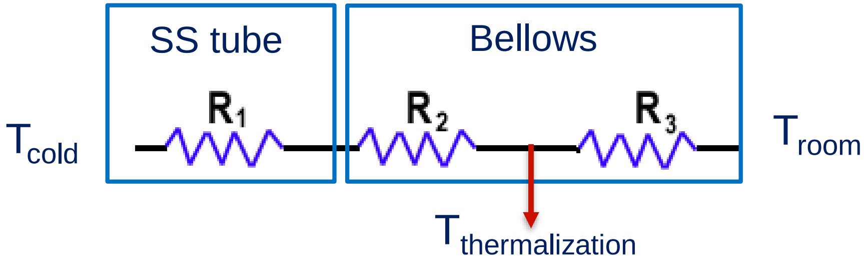


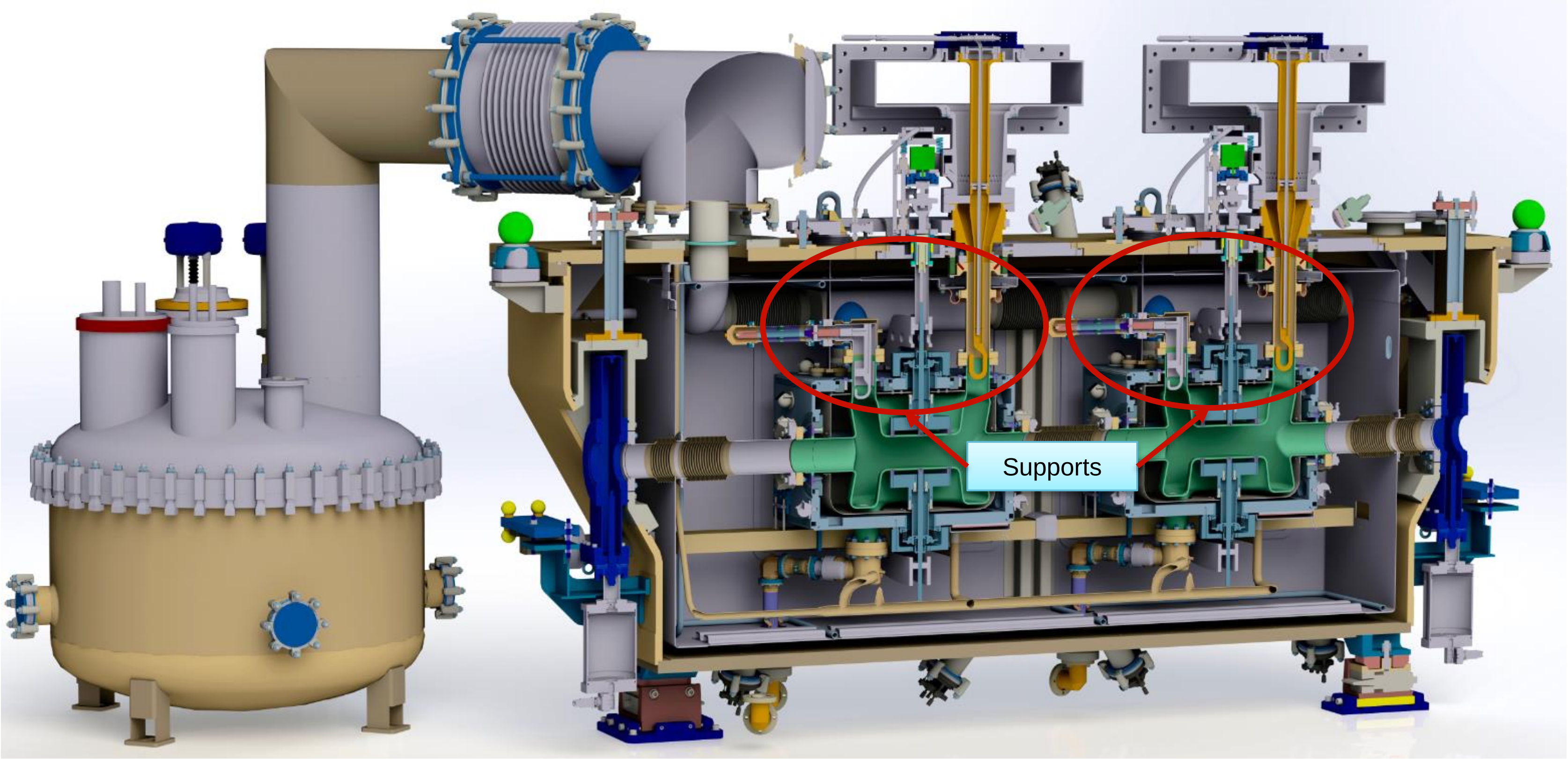




- Thermalization between the bellows and the stainless steel tubes: experimental values of $T_{thermalization}$
- Simple analytical calculation: **0.35 W/CWT** to 2 K **without heat interceptors**, **0.04 W/CWT intercepting**
- **14 W/CWT** to the interceptors

Thermal balance – Supports

- The supports connect the cavity to the cryomodule and the He line
- Losses are dominated by **conduction**



Thermal balance – Supports

- **Three** different supports considered: cavity and He line.
- Intercept temperature as average between CWT and available intercept temperature measurements.

Thermal balance – Supports

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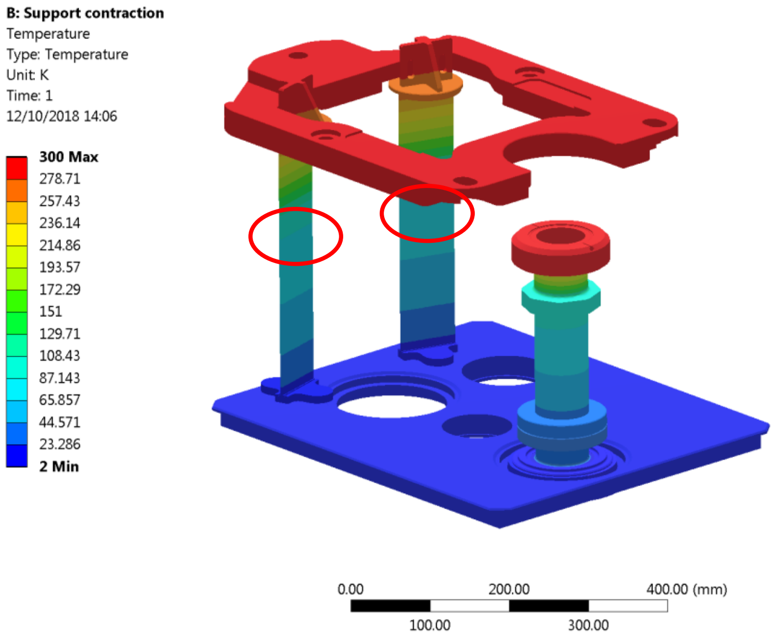
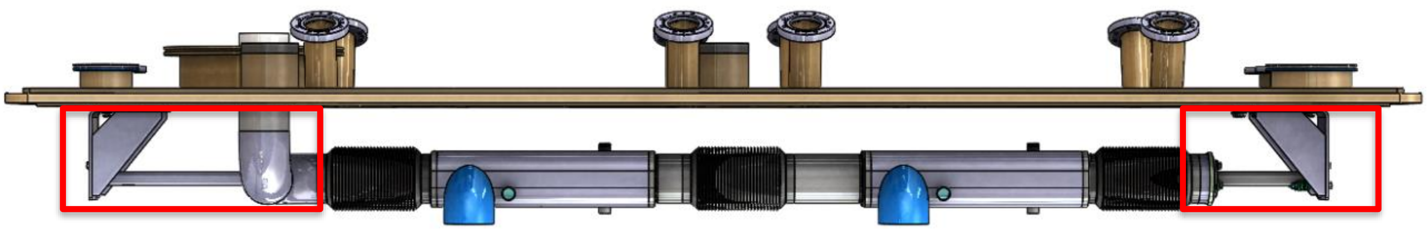
Blade support of each cavity

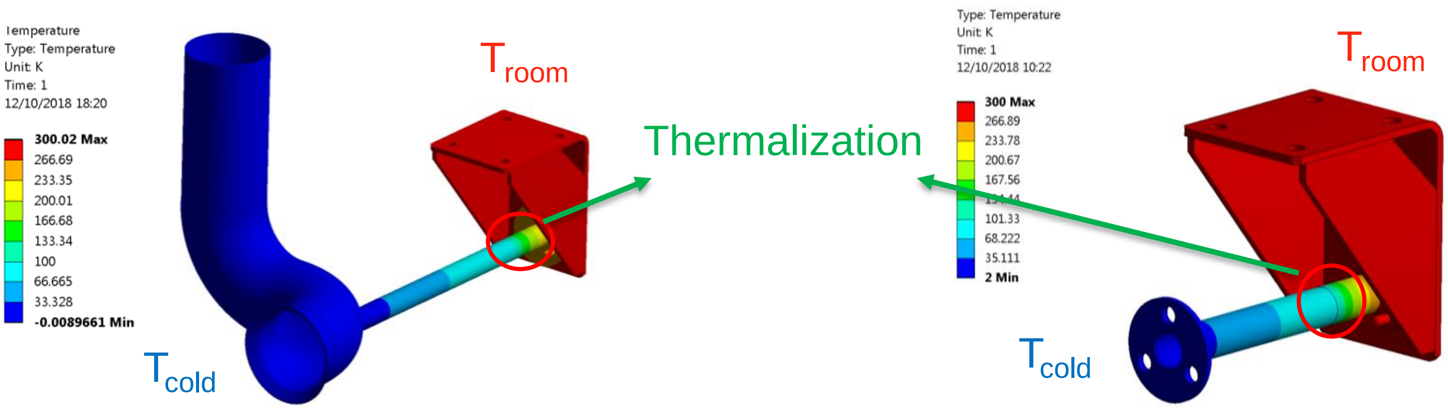


- Sensitivity analysis for the position of the thermalizations.
- Numerical calculation (ANSYS):
  - **0.9 W per support** to 2 K.
  - **7.7 W** per support to the interceptors

Thermal balance – Supports

- **Three** different supports considered: cavity and **He line**.
- Intercept temperature as average between CWT and available intercept temperature measurements.



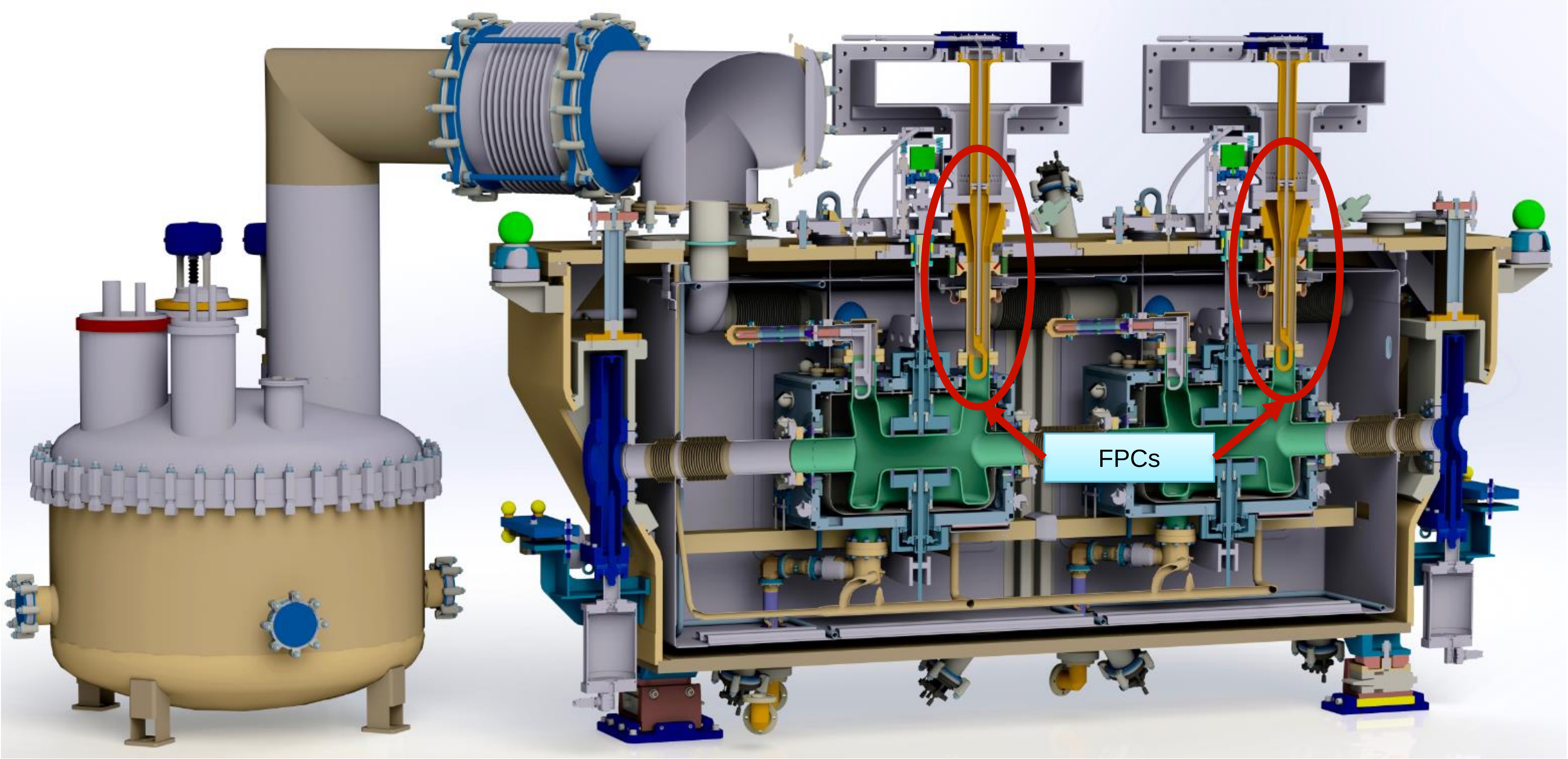


- **0.3 W** to the 2 K bath
- **3.8 W** to the intercepts

- **0.1 W** to the 2 K bath
- **1.3 W** to the intercepts

Thermal balance – FPC

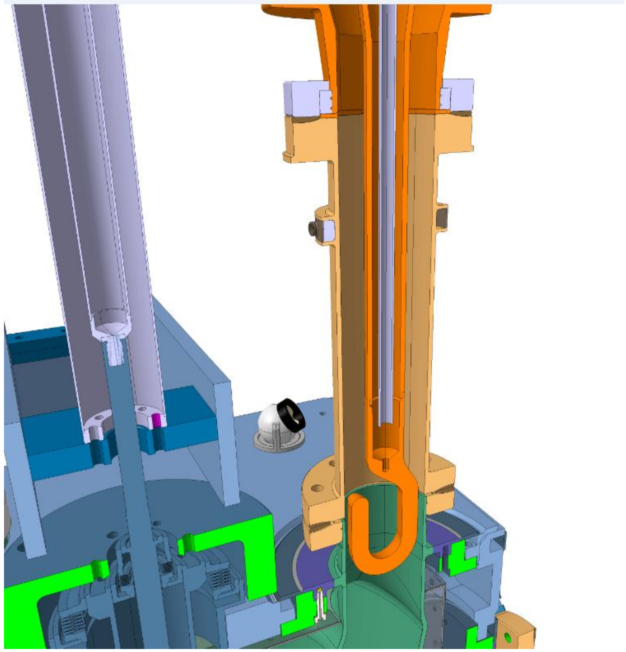
- It brings the RF power to the cavity
- Exchanges heat with the cold mass by **radiation** (antenna) and by **conduction** (can)



Thermal balance – FPC

FPC can – 316LN, copper coated

- Temperature at the intercept:
  - FPC 1: measured
  - FPC 2: extrapolated from measurements and FPC 1
- Analytical calculation: **radiation + conduction**
  - **5.3 W** to 2 K bath for two FPCs
  - **72 W** to intercept for two FPCs



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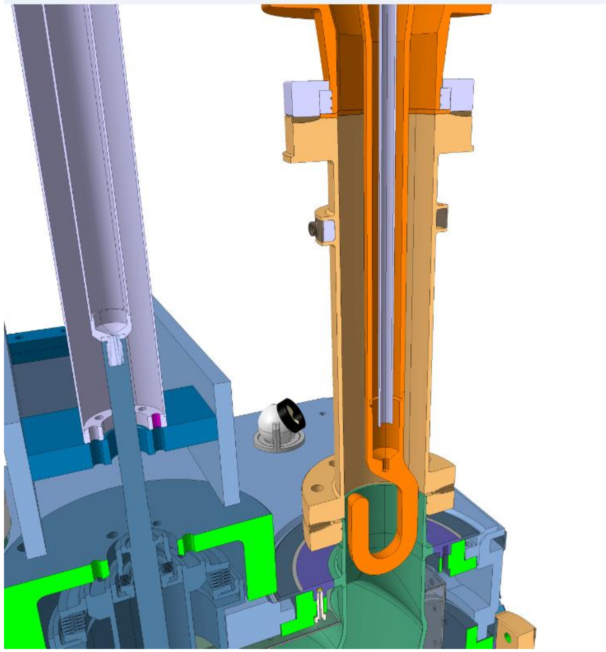

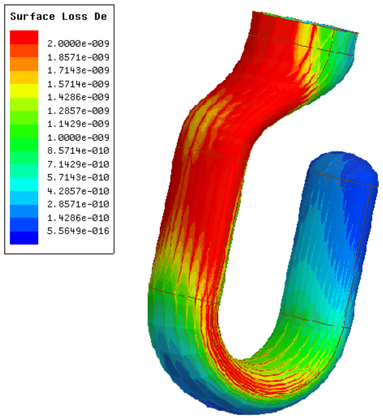

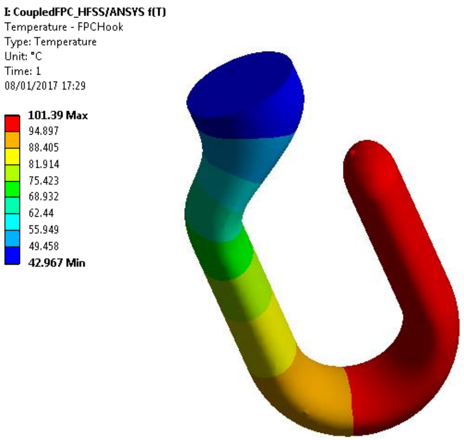

FPC antenna – Copper OFE

- Heating on the antenna generated when RF on
- Can lead to **high temperatures** of Cu (creep, outgassing, high radiation to cold mass)
- Each hook radiates **~0.8 W** to the cold mass

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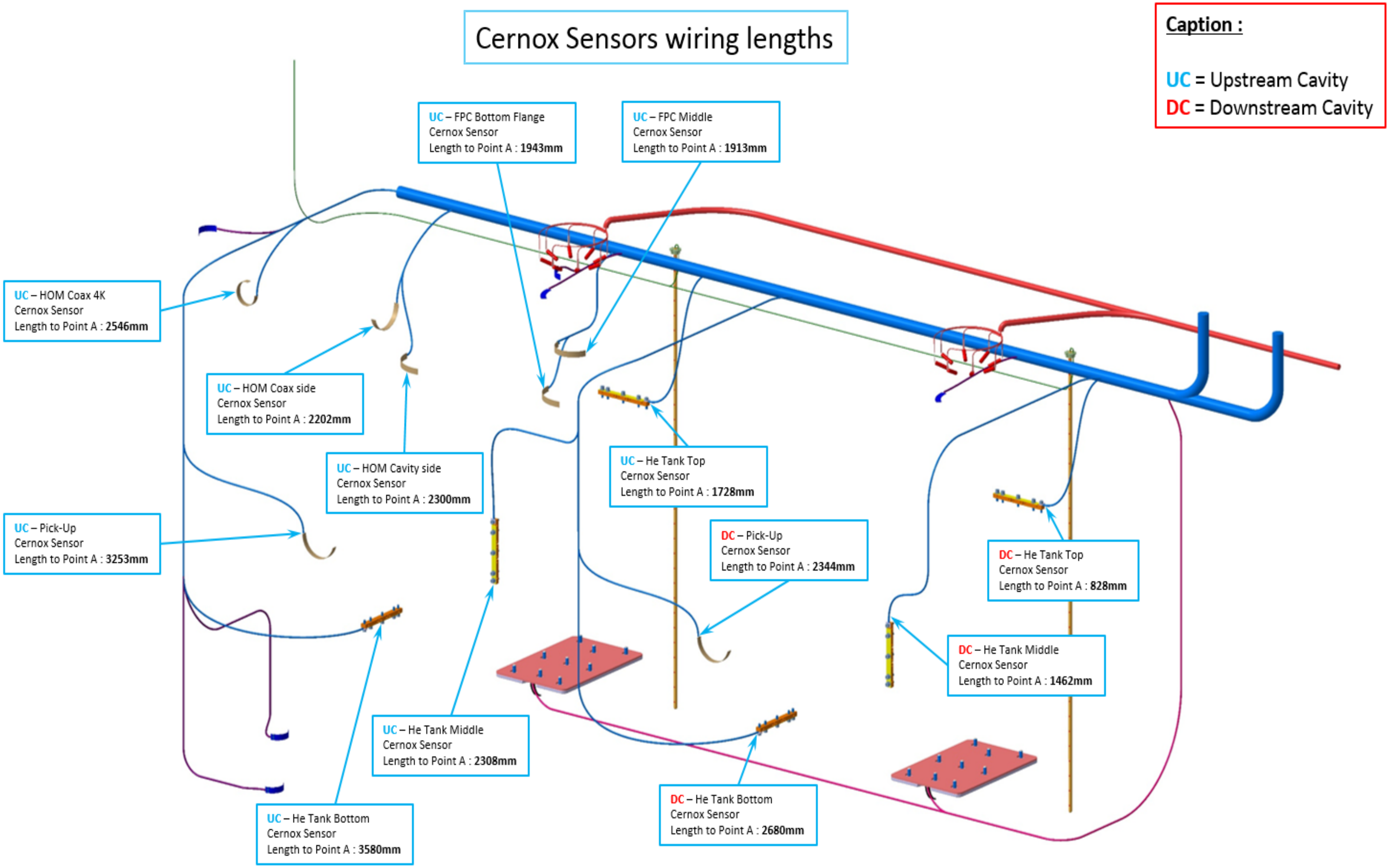
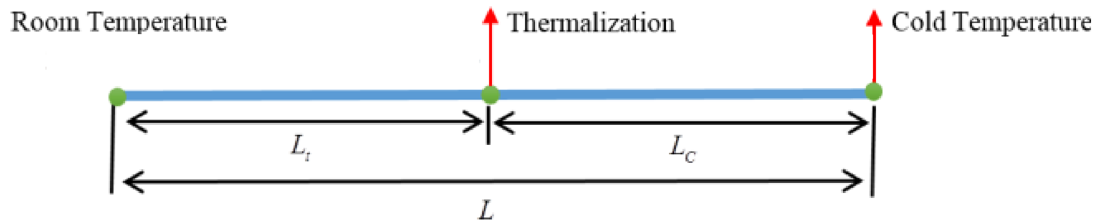
Thermal balance – Instrumentation



Thermal balance – Instrumentation

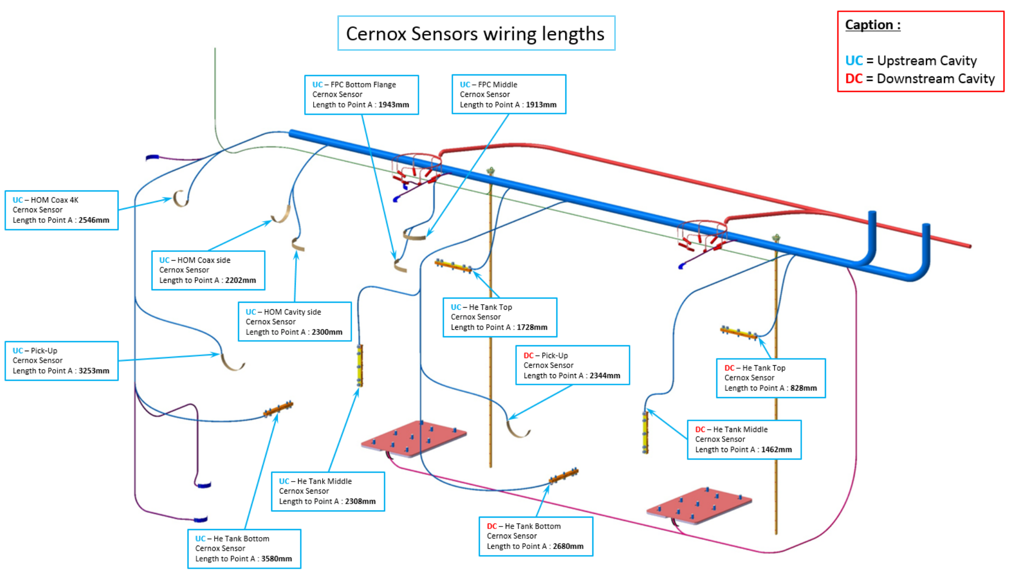


$$\dot{q} = \frac{A}{L}\int_{T_{low}}^{T_{high}} \kappa(T)dT$$

- Constant cross section of the cables
- Temperature of the thermalization: average of available experimental measurements.
- Some cables are considered shorter than they really are: conservative approach
- Thermalization length factor 0.7
- Only conduction losses

2.4 W to 2 K bath

8 W to intercept



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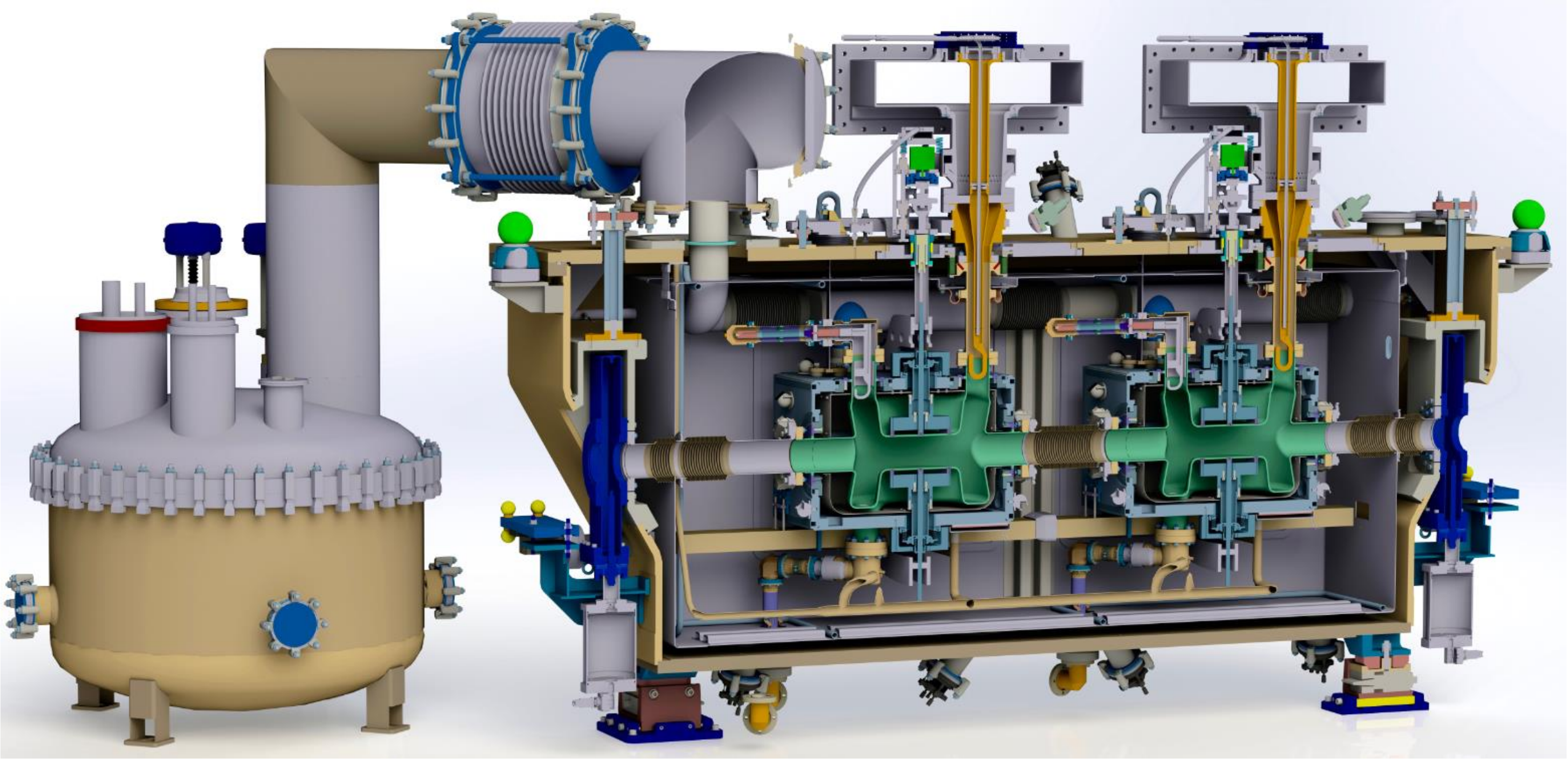
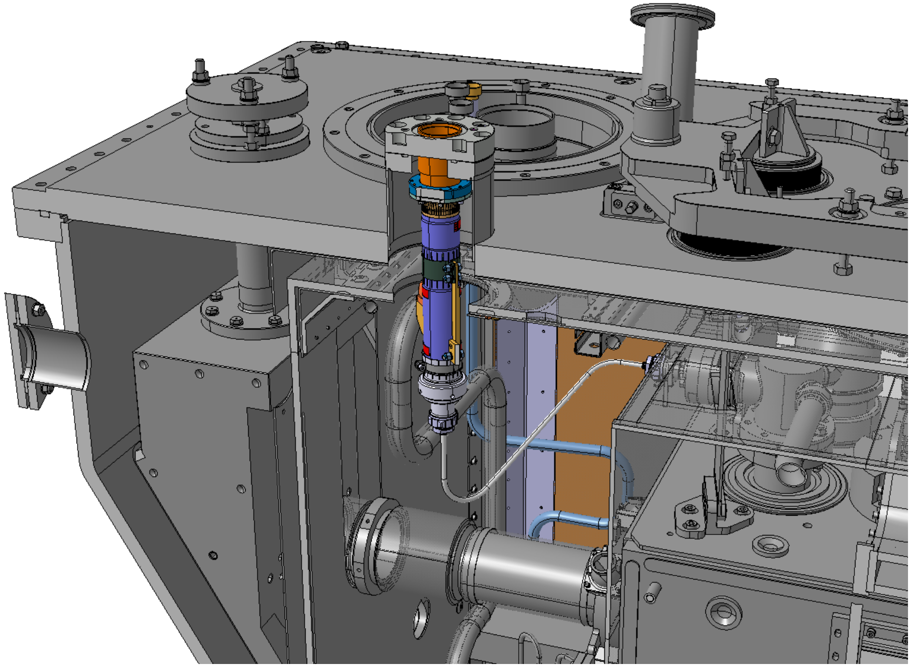
Thermal balance – HOMs and Pickup ports

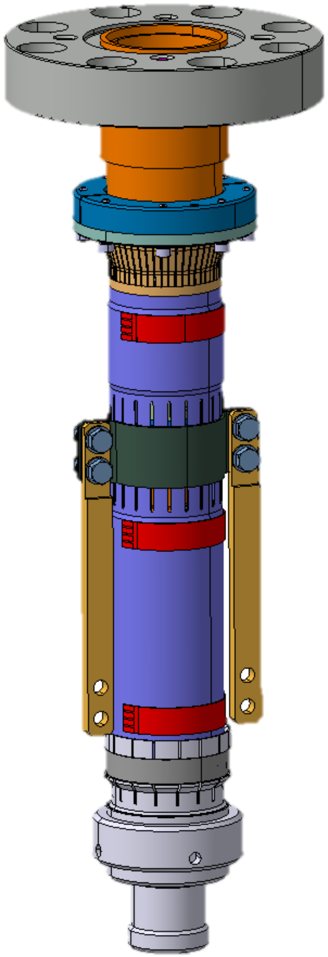
- 1 upper HOM, 2 lower HOM and 1 pickup port per cavity.
- Losses are exchanged by **conduction** in the coaxial lines and cables



Thermal balance – HOMs and Pickup ports

- **Coaxial lines**
  - Stainless steel tubes, Cu coating: 5 microns
  - Interception needed both on inner and outer conductors
  - Inner tube: interception with a ceramic electrical insulator, thermal conductor
  - Calculation performed analytically: **coax. line + cable**





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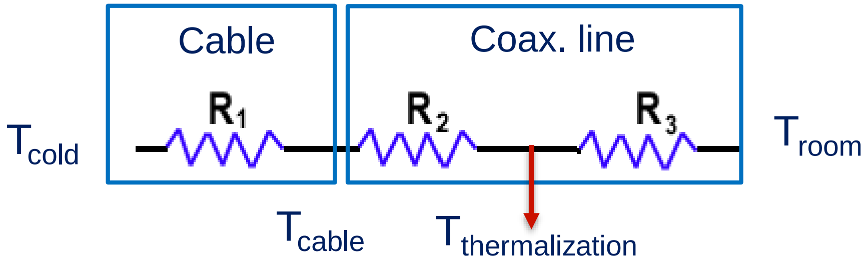

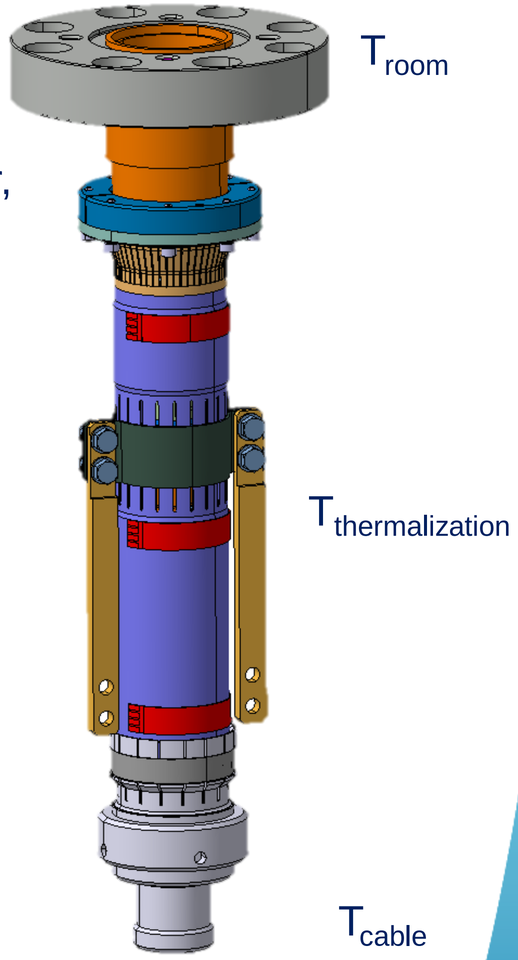

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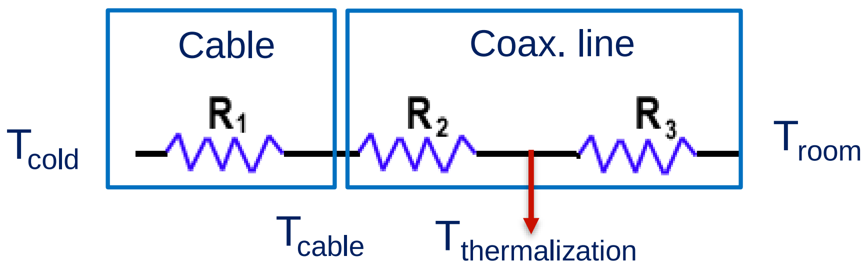
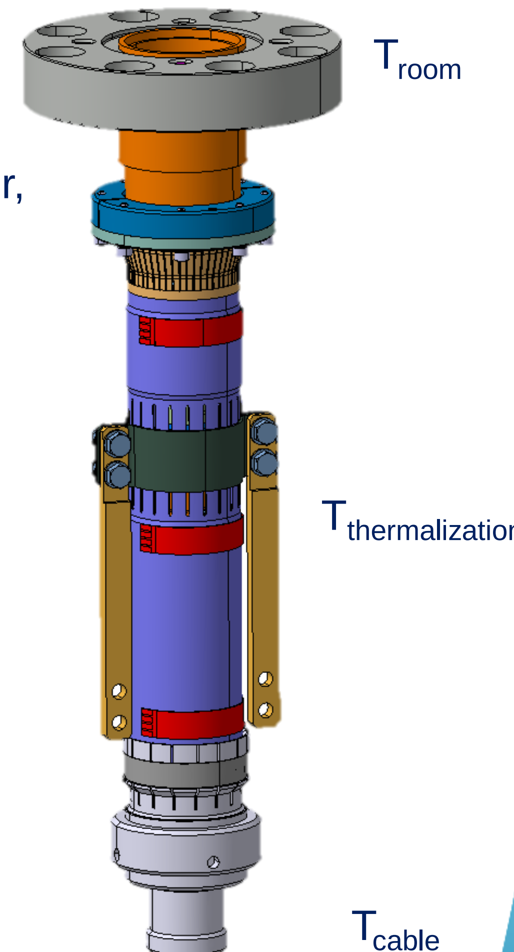


  - Cables assumed as a system of resistances in parallel

$$Q_{bath} := \left(\frac{A_{2i}}{L_2}\cdot\int_{T_{x1}}^{T_{int}} k_{ss}(T)\,dT\right) + \left(\frac{A_{2e}}{L_2}\cdot\int_{T_{x1}}^{T_{int}} k_{ss}(T)\,dT\right) + \left(\frac{A_{2i\_coating}}{L_2}\cdot\int_{T_{x1}}^{T_{int}} k_{cu}(T)\,dT\right) + \left(\frac{A_{2e\_coating}}{L_2}\cdot\int_{T_{x1}}^{T_{int}} k_{cu}(T)\,dT\right)$$



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Thermal balance – HOMs and Pickup ports

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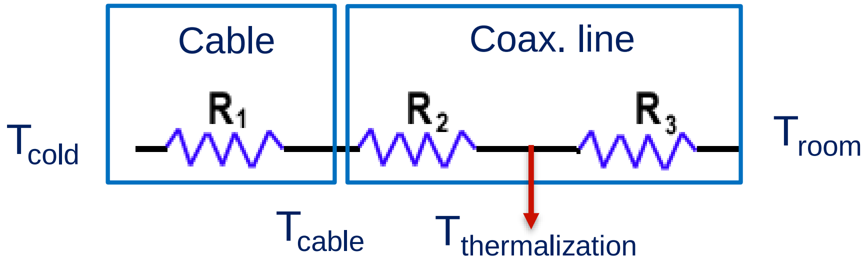

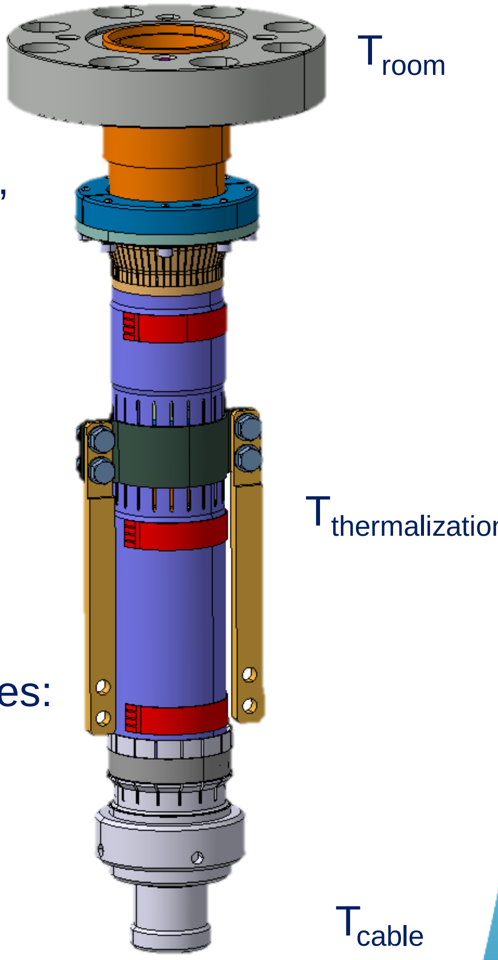

  - Temperature of the intercept assumed similar in all HOM lines: **conservative** approach
  - Simple analytical calculation:
    - **HOMs: 4.9 W** to 2 K and **13 W** to the intercepts
    - **Pickups: 0.6 W** to 2 K and **2 W** to the intercepts

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Thermal balance – HOMs and Pickup ports

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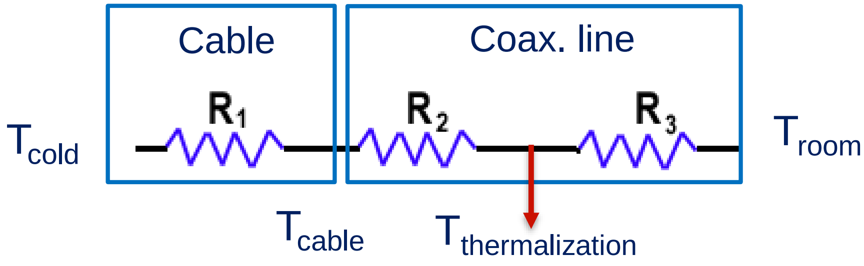
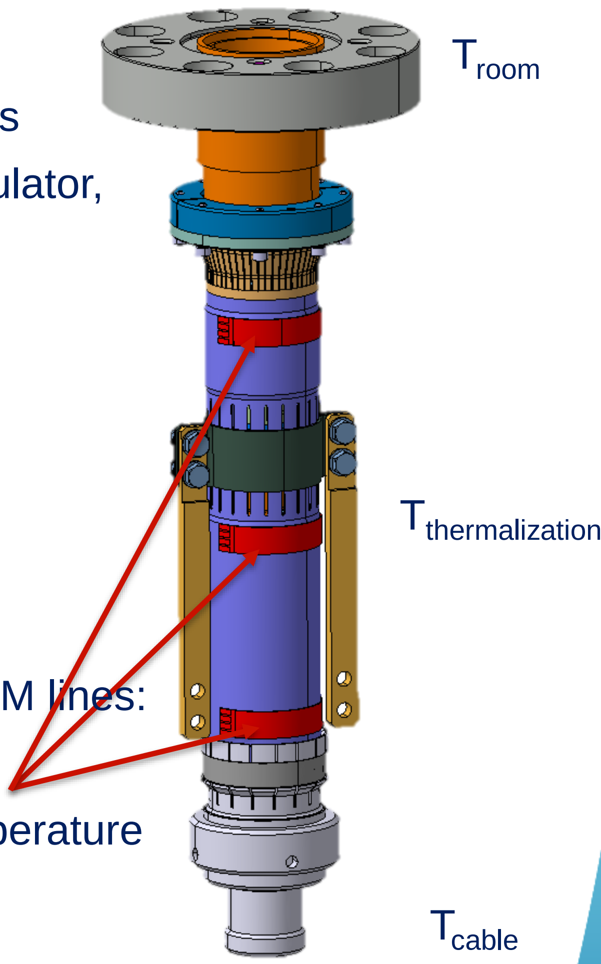
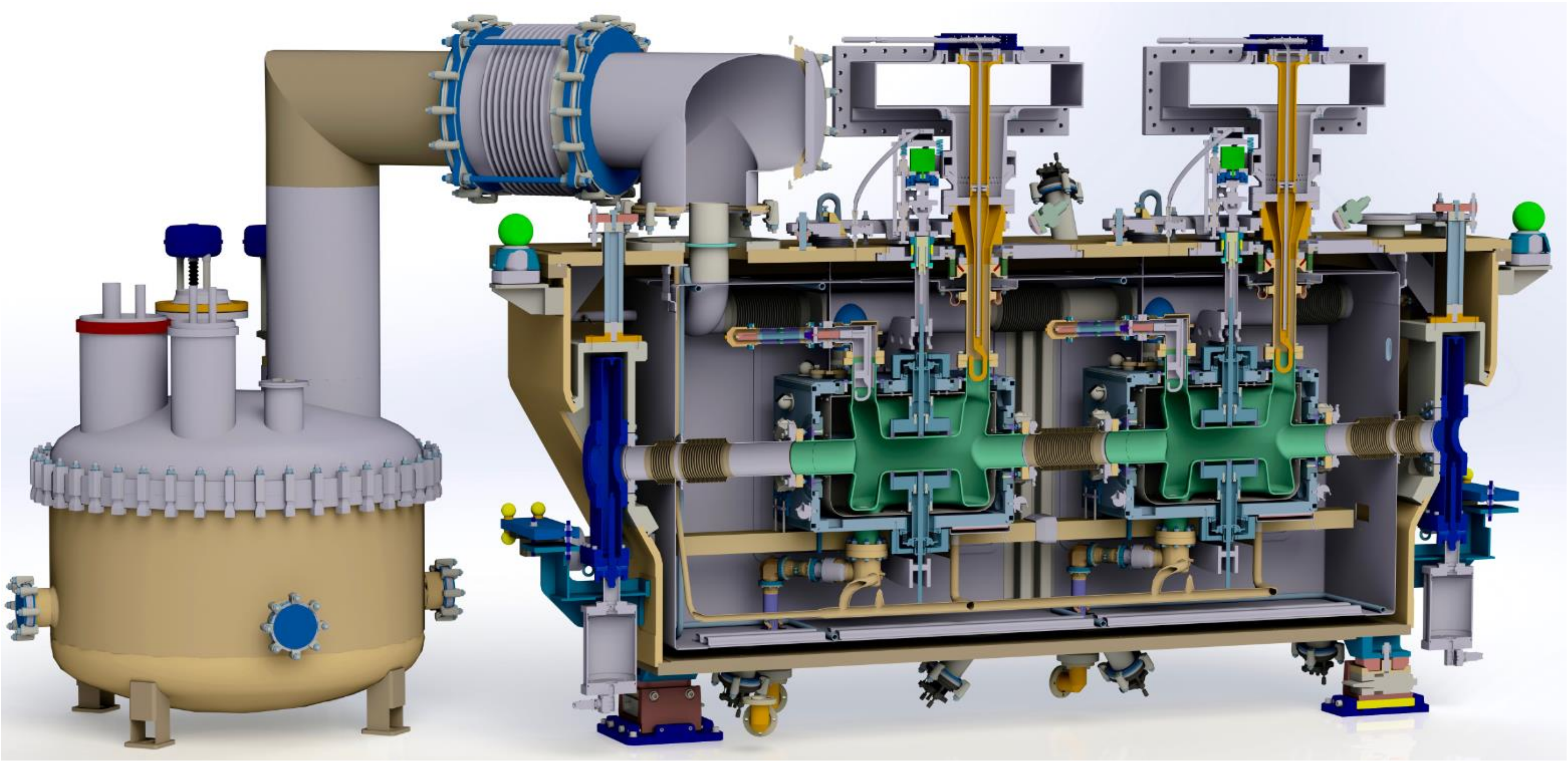




  - Temperature of the intercept assumed similar in all HOM lines: **conservative** approach
  - Alternative method: integrating between available temperature measurements in the HOM line:
    - **HOMs: 1.3 W** to 2 K and **12 W** to the intercepts

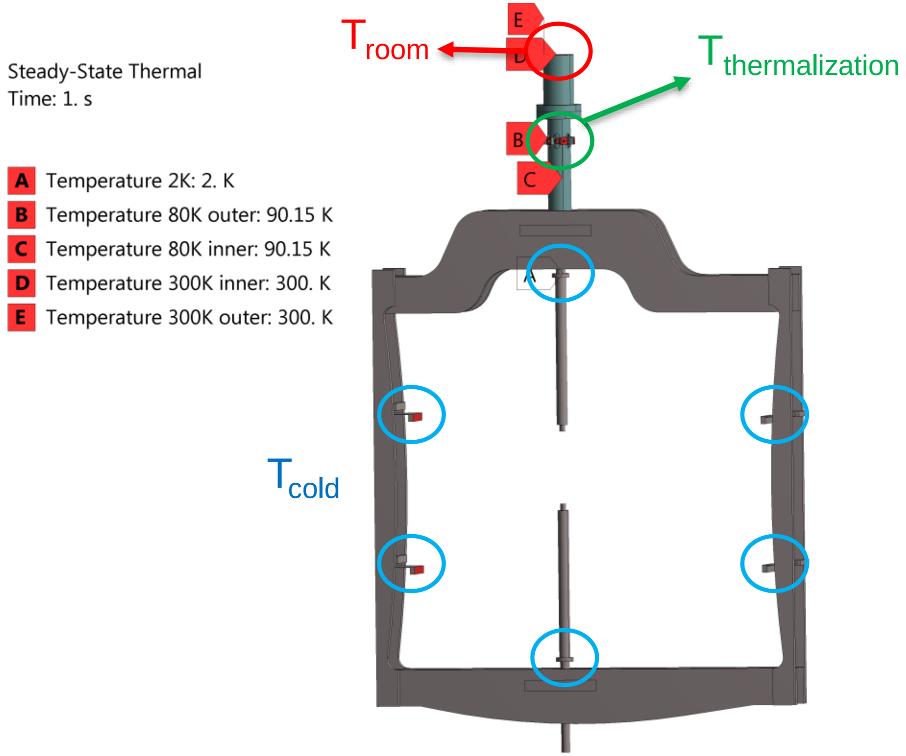
Thermal balance – Tuning system

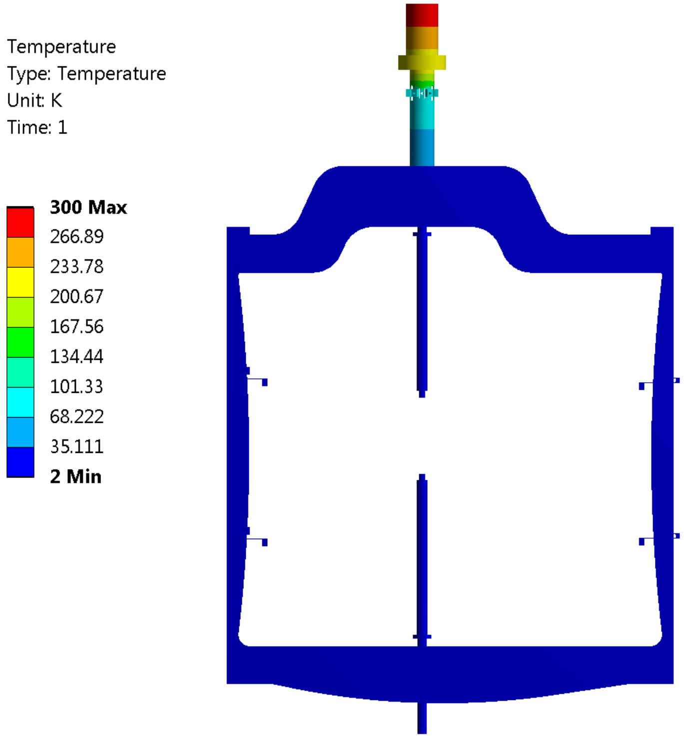
- Tuning system locally deforms the cavity to change its fundamental frequency
- Losses are dominated by **conduction**



Thermal balance –Tuning system

- Simplification of the tuning frame geometry.
- Frame blades in contact with the cold mass
- Thermalization of the frame assumed at the average temperature of the thermalization measurements.





- **0.7 W/tuner** to 2 K and **7.6 W/tuner** to the intercepts

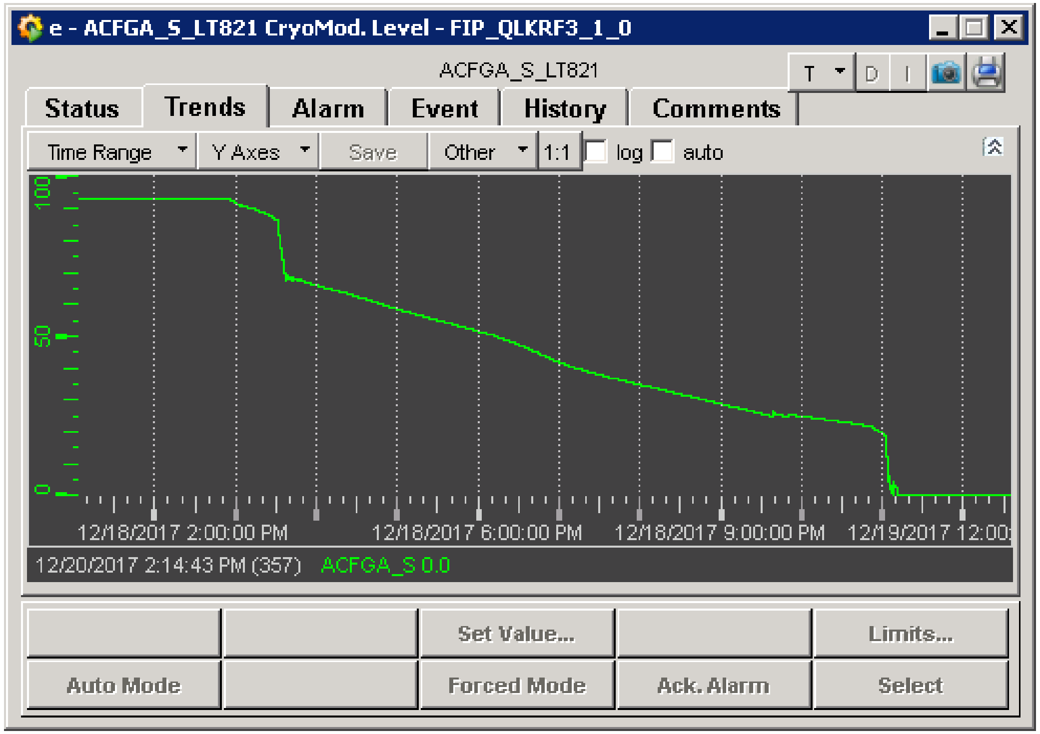
Outline

1. Introduction
2. Thermal balance for DQW
3. Comparison with measurements at SM18
4. Summary and conclusions

Comparison with measurements at SM18

- Total estimated heat loss is **20.1 W** to the 2 K bath and **160 W to the intercept**
- Calculations are done using, in general, **conservative approaches**
- Experimental results obtained from the evaporation of He at SM18

The heat load to 2 K is measured at level of **18 W**



VERY GOOD AGREEMENT BETWEEN NUMERICAL ESTIMATIONS AND EXPERIMENTAL RESULTS!

Outline

1. Introduction
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Summary and conclusions

- The thermal balance of the cryomodule, estimated at first in 2013, has been continuously updated and reviewed with the design advancement
- This last update considers values extracted from **experimental measurements** of the cryomodule cooldown in SM18.
- The calculations done for evaluating the total heat losses encompass **analytical**, **semi-analytical** and **numerical methods**
- **No safety margins** on the heat losses are contained in the estimation. However, **conservative hypothesis** have been considered during the numerical evaluation of the loads.
- **Very good agreement** between estimated and measured heat loss to the **2 K bath!**

Thank you for your attention!