NEWGAIN - ASTERICS
Mini workshop LBNL/FRIB/CEA

Cryogenic Design Overview

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NEWGAIN NEW GANIL INJECTOR

GANIL SPIRAL2 laboratoire commun CEA/DRF CNRS/IN2P3

FRANCE 2030

outline

1. Introduction / magnet cooling

- Magnet immersed in a liquid helium bath – 1.1 bar, 4.31 K
- The different heat loads vaporize liquid helium
- Cold vapors liquefied by condensers connected to the second stage of cryocoolers
- Adjustment between cooling power and heat load by heaters that vaporize liquid
- Thermal shield circuit connected to the first stage of cryocoolers
- Heat loads: 7 W dynamic + static heat loads (radiation + conduction)
- HTS current leads
- PED: burst disc and valve to protect the system against over pressure

2. Magnet and satellite synoptic

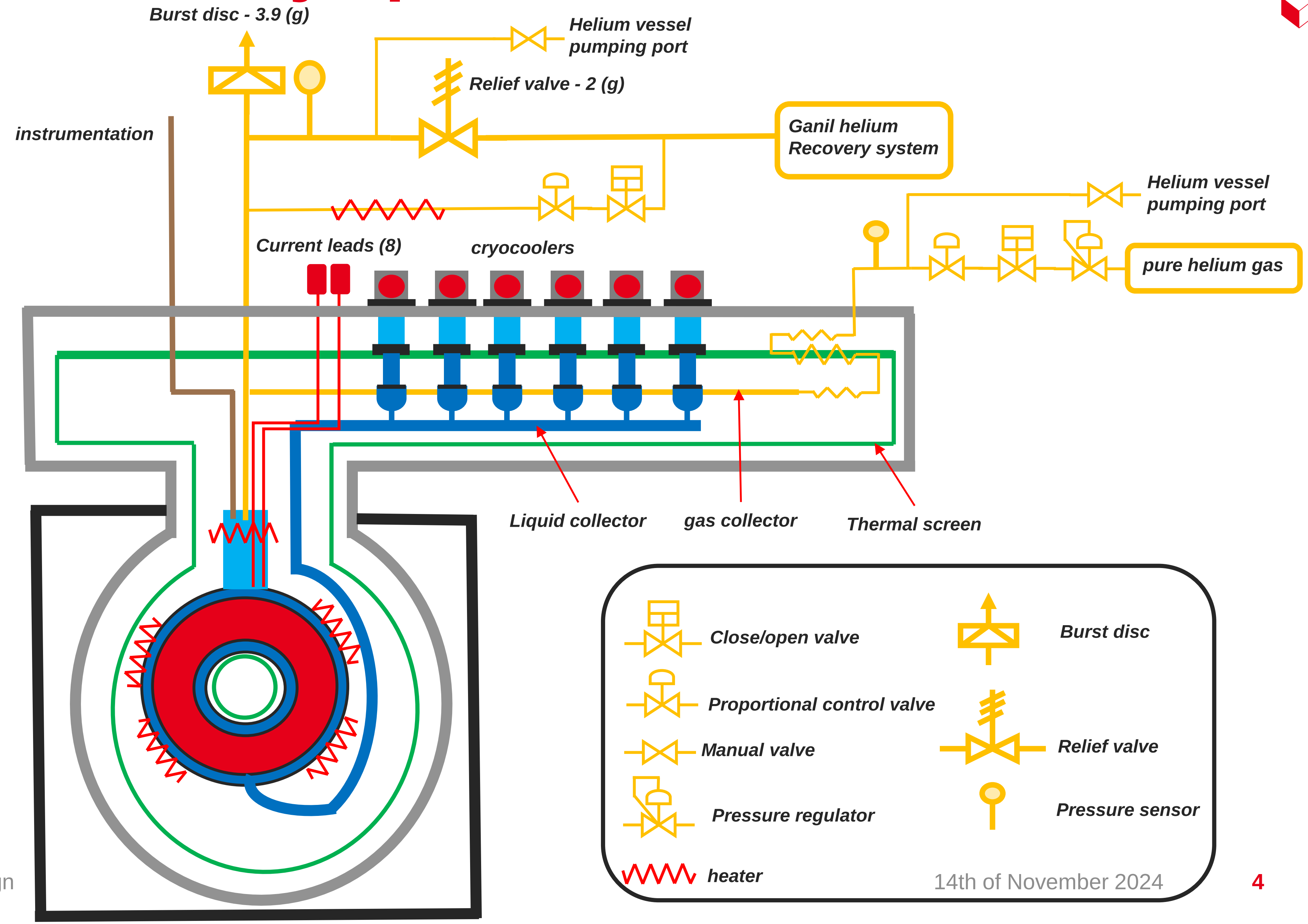
❖ **Operating pressure**

1.1 bar

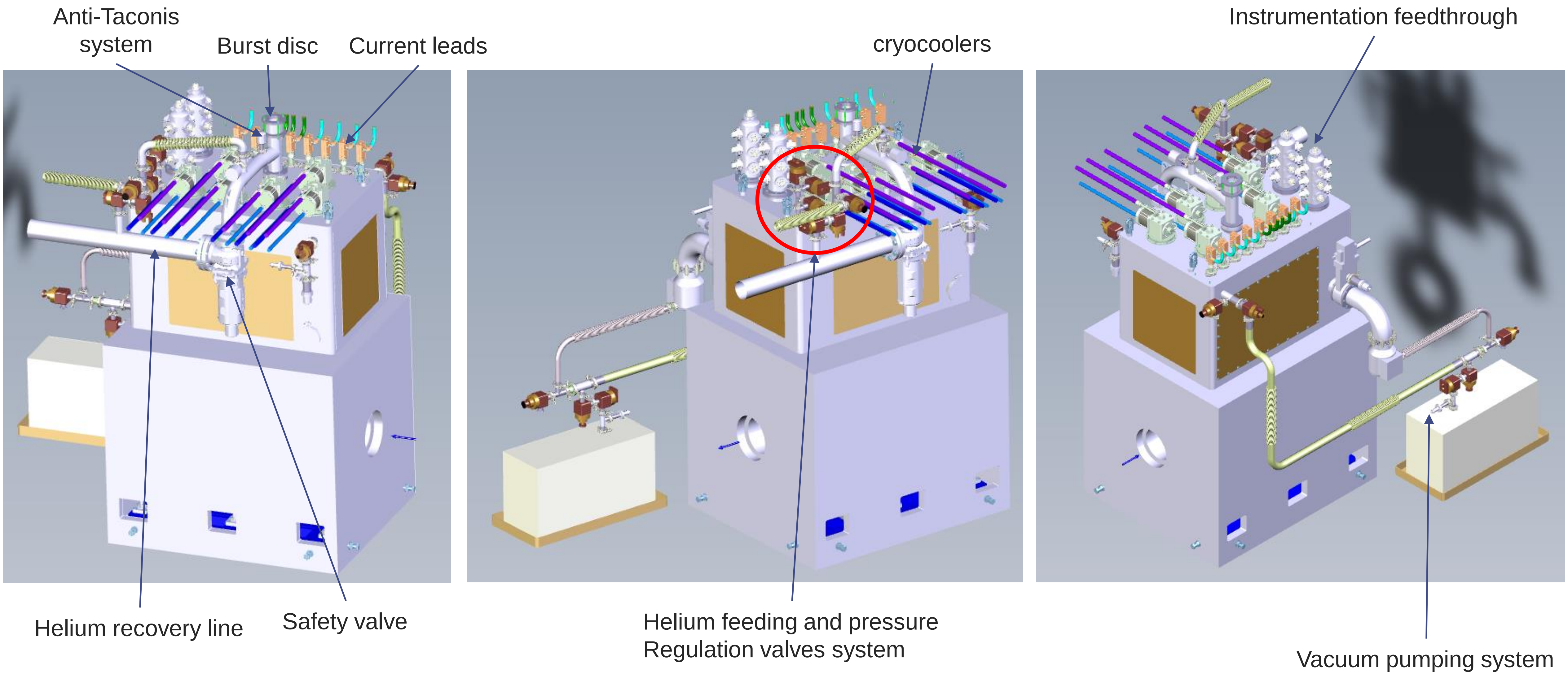
➢ $T_{liquid} = T_{sat} = 4.31$ K

❖ **Operating modes**

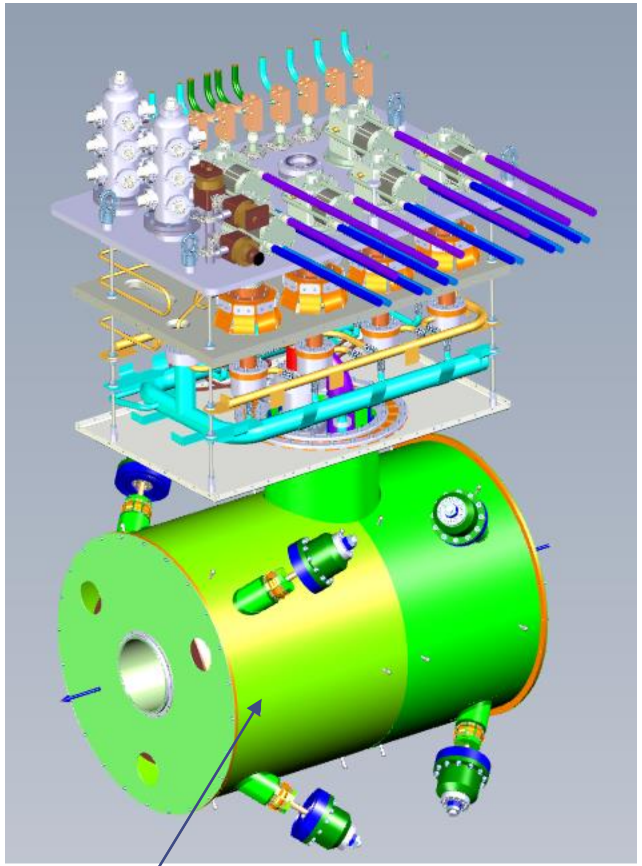
- Cool down
- Normal operation
- Quench
- Major default
- Warm up

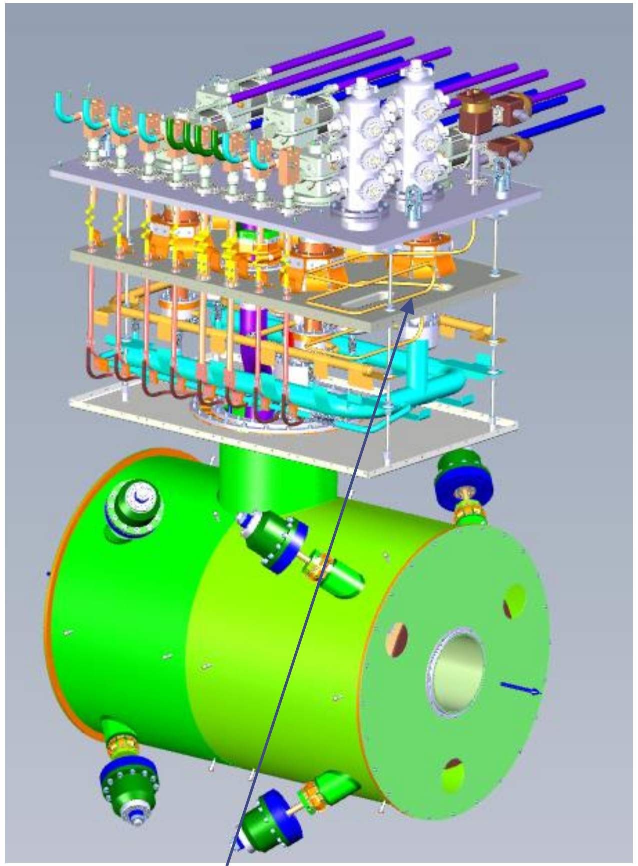


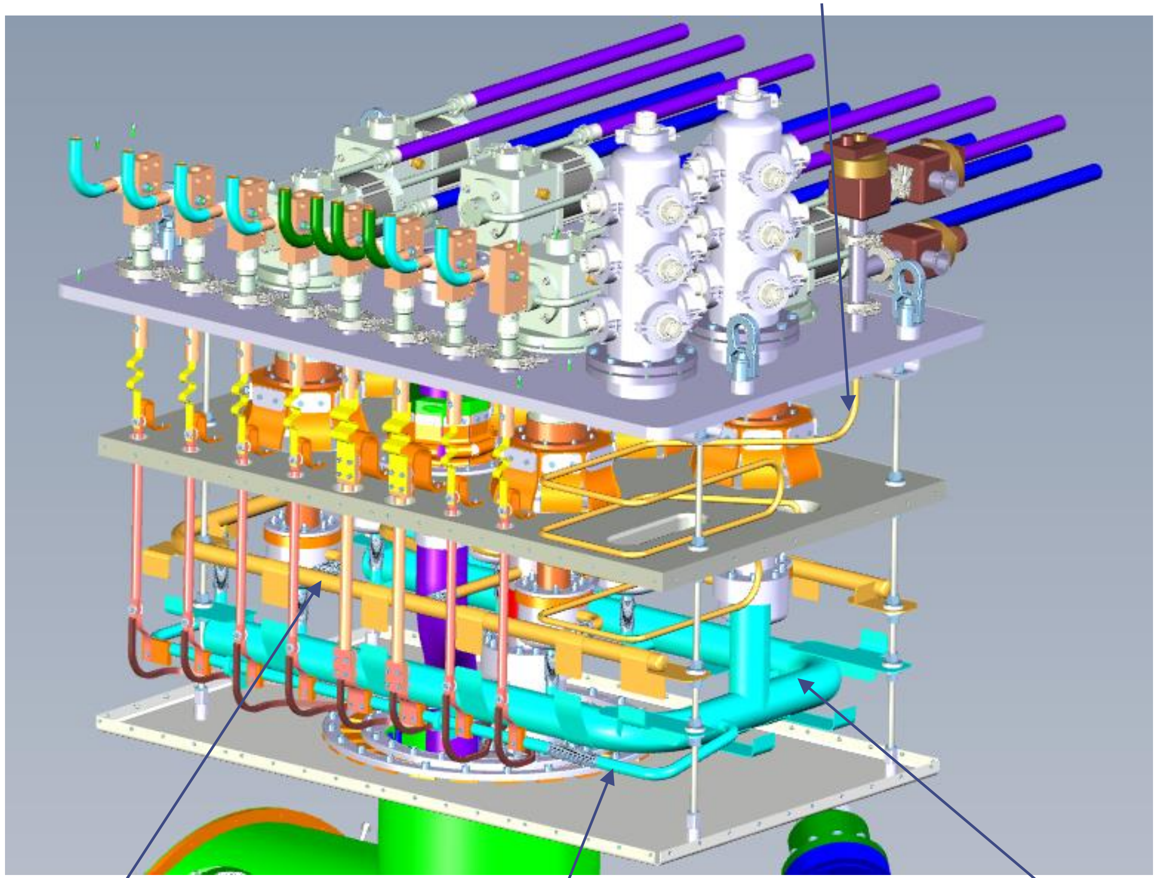
3. Cryogenic design (1/3)



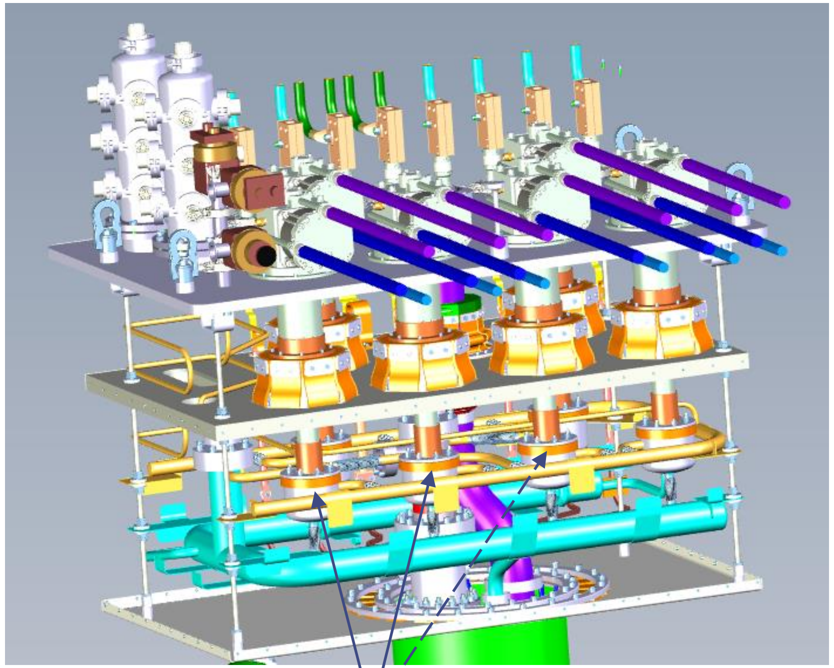
3. Cryogenic design (2/3)



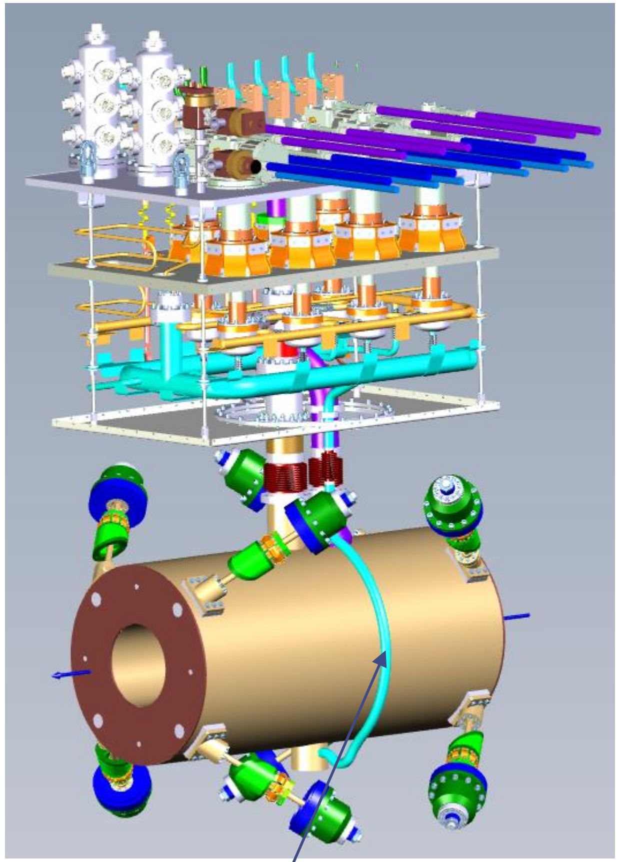




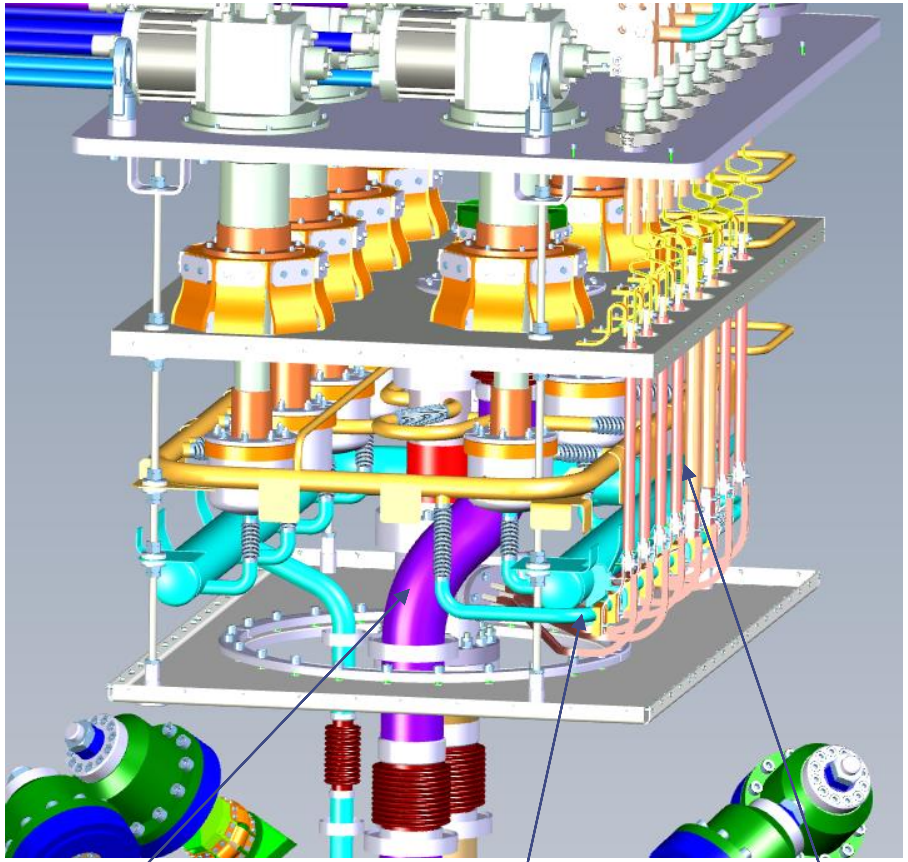
3. Cryogenic design (3/3)



Condenser connected to
Second stage of cryocoolers
Feed by the gas collector



Liquid helium
Feeding pipe

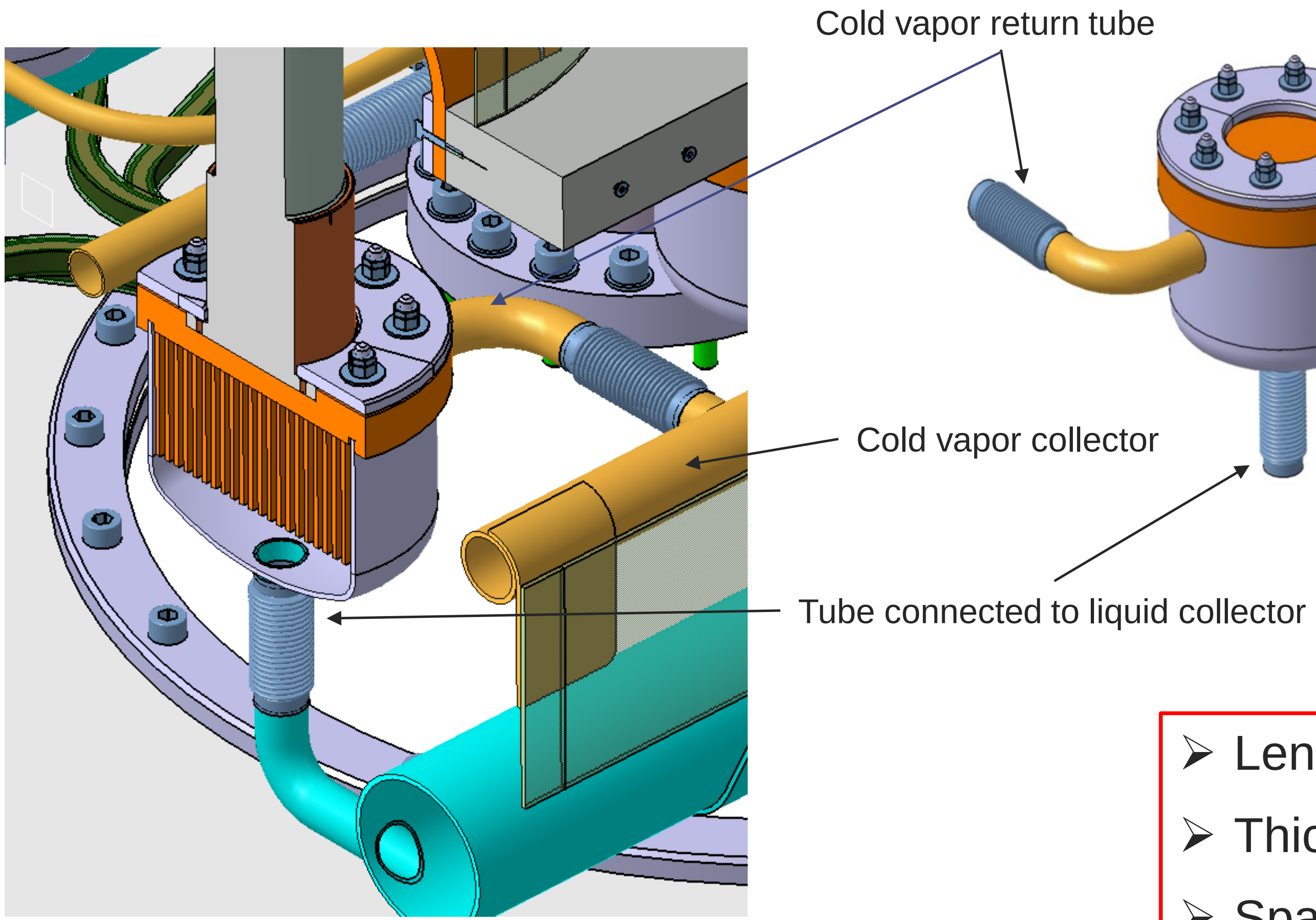


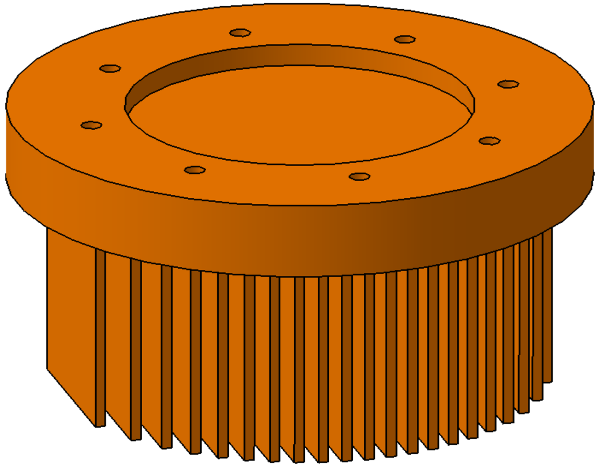
Pressure exhaust
tube (PED)

Liquid helium tube
connected to bottom
of current leads

HTS Current
leads

4. Condenser – same principle as Venus (1/2)





Copper RRR 100

- Length of fins: 48 mm
- Thickness of fins: 2 mm
- Space between fins: 2.5 mm

4. Condenser – same principle as Venus (2/2)

Heat transfer coefficient for condensation process

Heat transfer in R-5 (condensation process)

$$h_l = 0.943\left[\frac{\rho_l(\rho_l - \rho_v)\,g h_{fg} g k_l^3}{L\mu_l \Delta T}\right]^{0.25} = 1322\ \mathrm{W/m^2K},$$

where ρ_l = liquid density, ρ_v = gas density, h_{fg} = latent heat, k_l = LHe thermal conductivity, L = length of fins in HX-2, and μ_l = liquid helium viscosity.

Experimental helium liquefier with a GM cryocooler

Anup Choudhury; Santosh Sahu

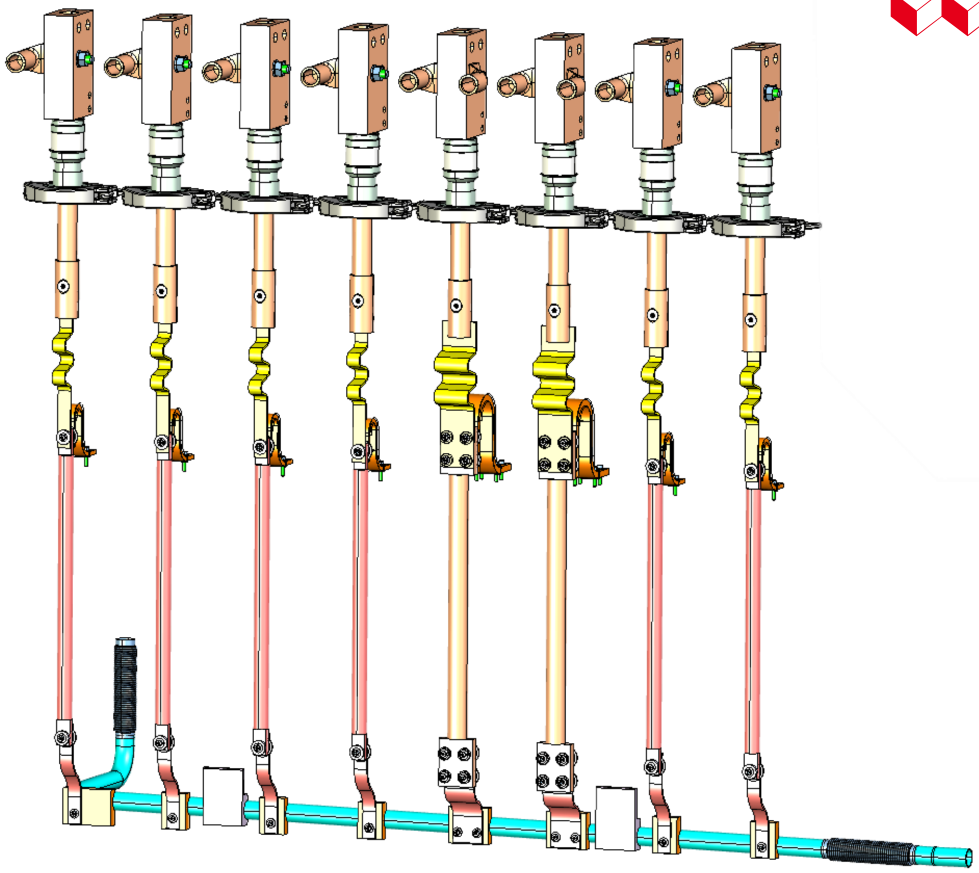
Applied to our condenser, we have for **1** condenser:

- **5 W** as condensation if ΔT = 0.01 K (very conservative)
- **8.4 W** as condensation if ΔT = 0.02 K (average from litterature)

  - Considering **6** condensers with **1.8 W** or **2 W** absorbed at the second stage, we have enough margin for liquefaction (**>>10 W**)

5. Current leads

- HTS current leads to limit thermal losses
- Two current leads type:
  - 450 A for the sextupole (1 pair)
  - 210 A for the solenoids (3 pairs)
- One resistive part in brass 70/30 and one HTS part using commercial current leads
- 50 K stage cooled down by conduction
- 4.2 K stage cooled down by conduction through a LHe pipe



For brass 70/30

$$\dot{Q}_{L\ 450\ A} = 22.46\ W\ per\ CL$$

$$\dot{Q}_{L\ 210\ A} = 10.48\ W\ per\ CL$$

$$\dot{Q}_{L\ total} = 107.81\ W$$

$$\dot{Q}_{L\ without\ I} = 12.1 * 2 + 5.7 * 6 = 58\ W$$

For the HTS part

$$\dot{Q}_{L\ 450\ A\ HTS110} = 96\ mW\ per\ CL$$

$$\dot{Q}_{L\ 210\ A\ HTS110} = 60\ mW\ per\ CL$$

6. Thermal budget at 4 K with 6 cryocoolers (1/2)

Assumption: intercept at 50 K on cryocooler first stage			
	Q (W)	number	Q tot (W)
Dynamic heat load	7	1	7
Tie rods	0.18	8	1.44
Current leads	0.096/0.06	2/6	0.552
PED tube (with below)	0.07	1	0.07
Radiation			0.2
total (W)			~ 9.26 W

- **Cryocooler: 1,8 W at 50 Hz or 2 W at 60 Hz**
- **6 cryocoolers: 10,8 W or 12 W**
- **20% margin -> 11.1 W of cooling power**
- **Choice to be finalized**

6. Thermal budget at 4 K with 5 cryocoolers (2/2)

Assumption: intercept at 50 K on cryocooler first stage			
	Q (W)	number	Q tot (W)
Dynamic heat load	7	1	7
Tie rods	0.18	8	1,44
Current leads	0.096/0.06	2/6	0.552
PED tube (with below)	0.07	1	0.07
Radiation			0.2
Failed cryocooler	0.76	1	0.76
total (W)			~ 10 W

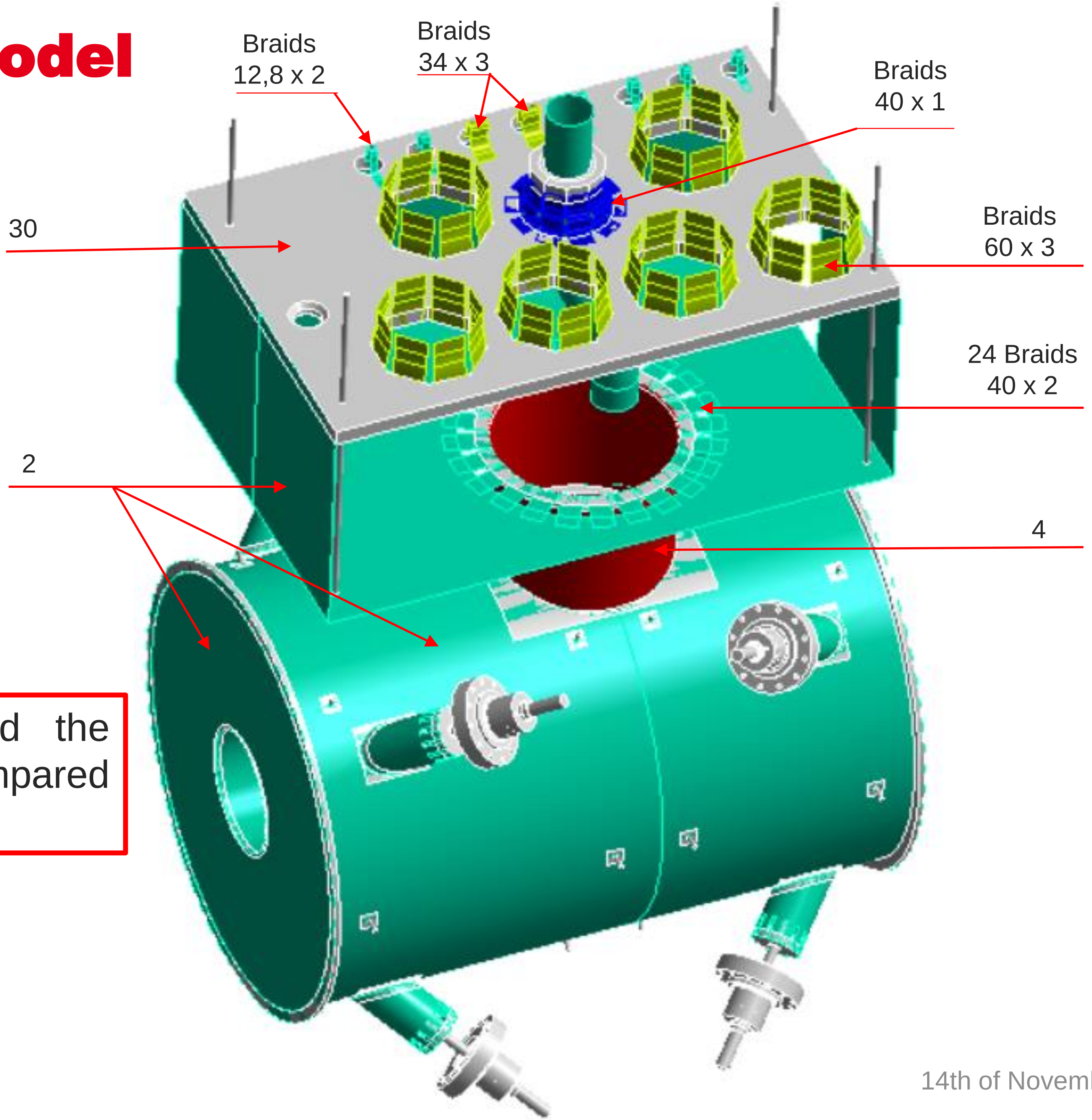
- **Cryocooler: 1,8 W at 50 Hz or 2 W at 60 Hz**
- **5 cryocoolers: 9 W or 10 W**
  - **50 Hz ok if $P_{dynamic}$ < 6 W**
  - **60 Hz ok if $P_{dynamic}$ < 7 W**

7. Thermal shield model

Geometry

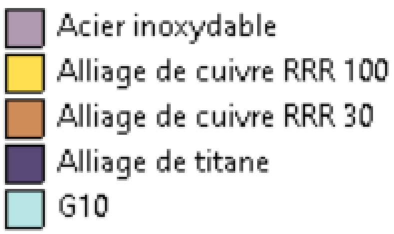
Thickness (mm)

- 4,
- 3,
- 2,
- 1,



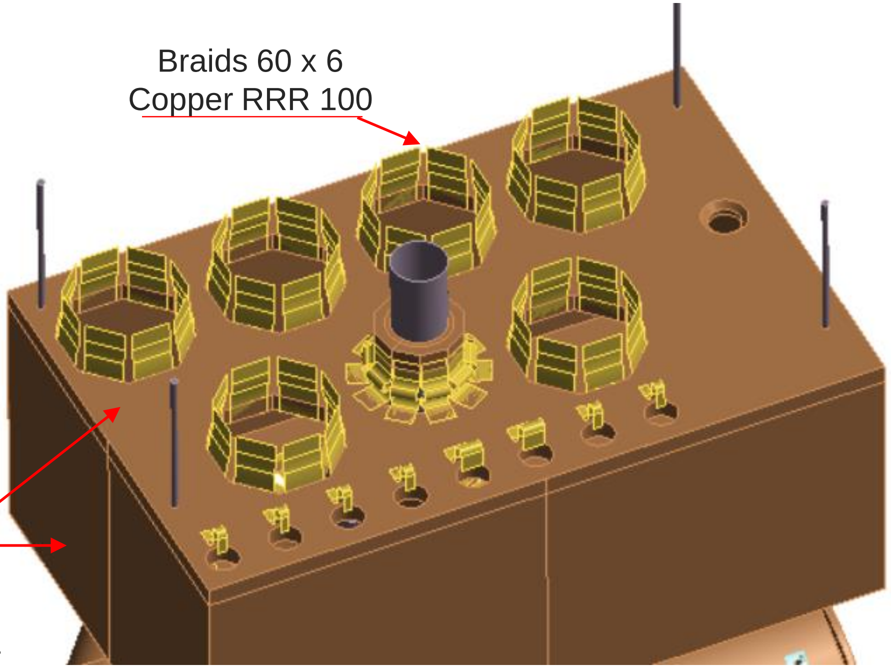
For the calculation, we reduced the thickness of the braids by 50% compared to the design.

Materials



Braids 60 x 6
Copper RRR 100

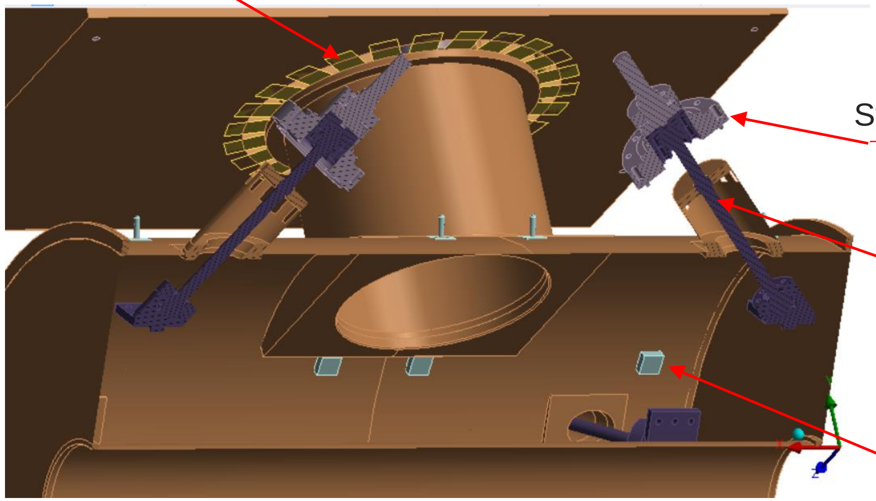
Copper RRR 30



24 Braids 40 x 4
Copper RRR 100

CTWS
Stainless steel

CTWS
Titanium



M10 Tie rod
Stainless steel
A4

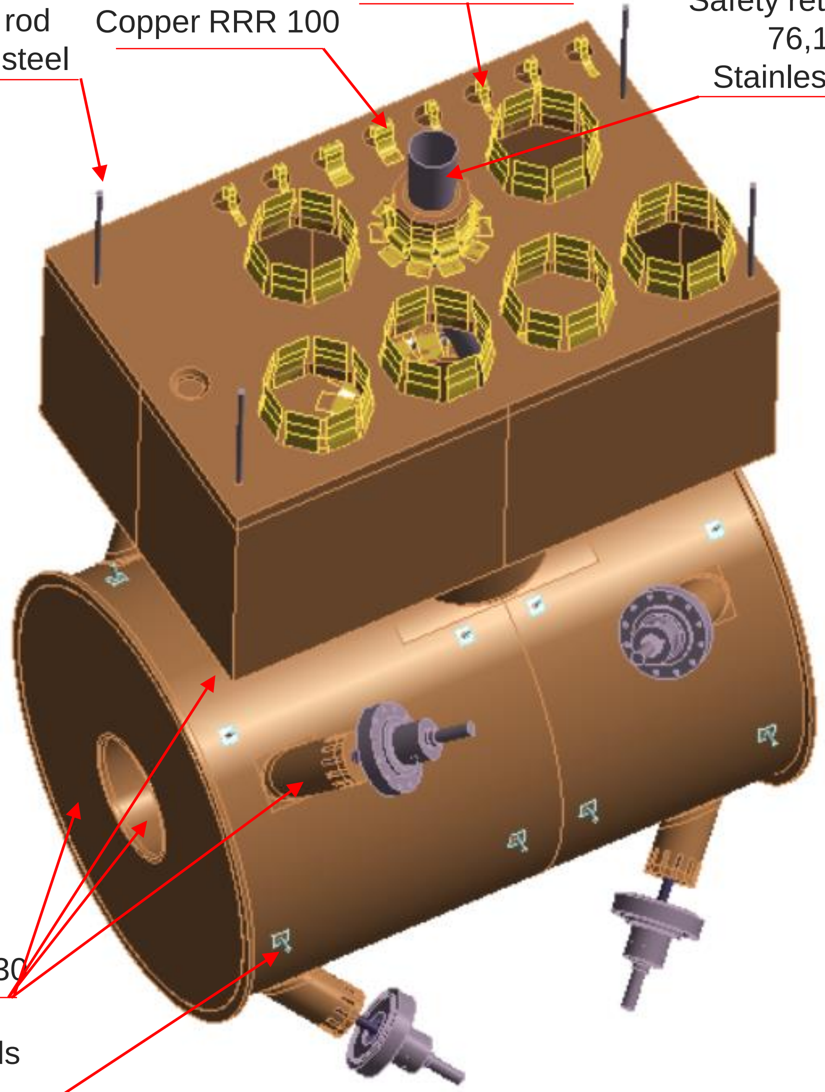
HTS 110 -1000A
Braids 34 x 6
Copper RRR 100

HTS 110 - 500A
Braids 12,8 x 4
Copper RRR 100

Safety return tube
76,1x2
Stainless steel

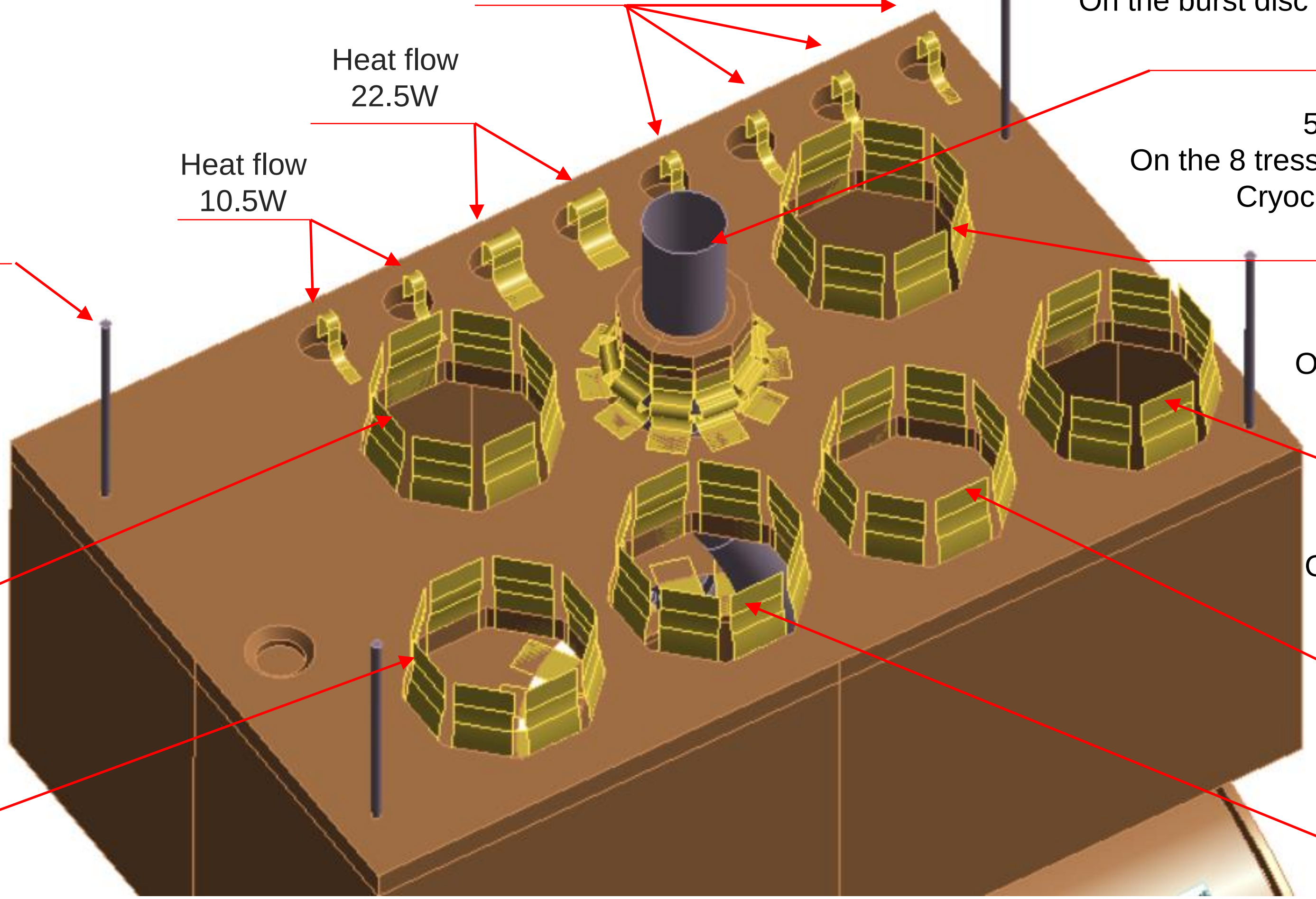
Copper RRR 30

2x12 - M8 studs
G10 or Peek



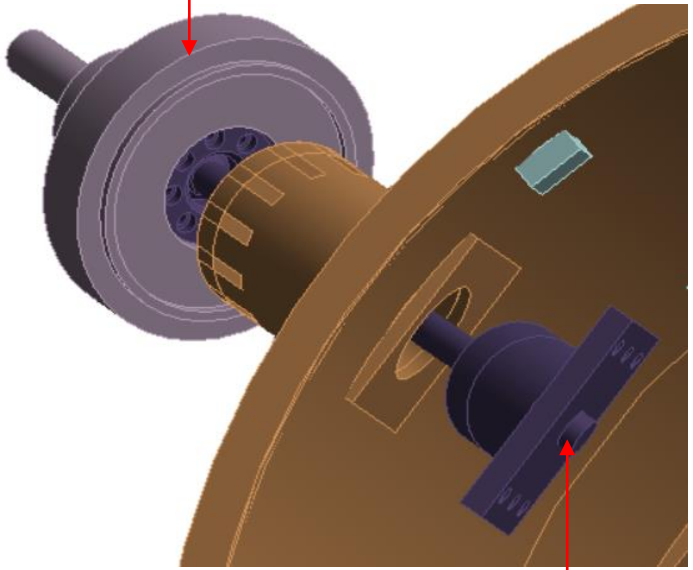
Boundaries conditions

Heat flux of 3 W/m^2 on all external surfaces (radiation)



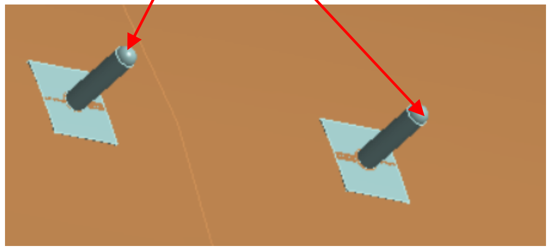
Boundaries conditions

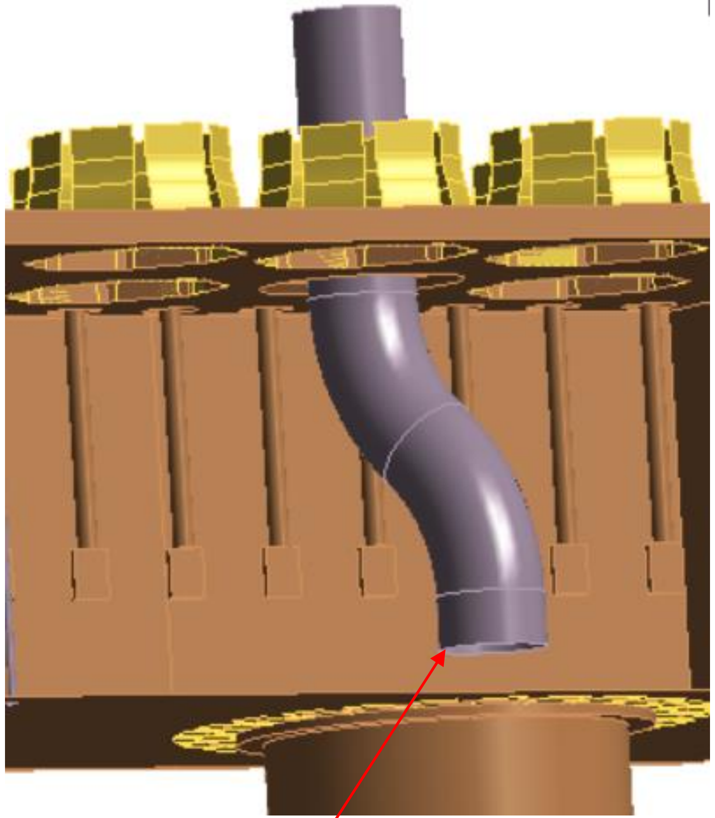
295.15 K
On the interface between the 8 tie rod
And the vacuum vessel (304L)



4 K
On the interface between the 8 tie rod
And the helium tank (304L)

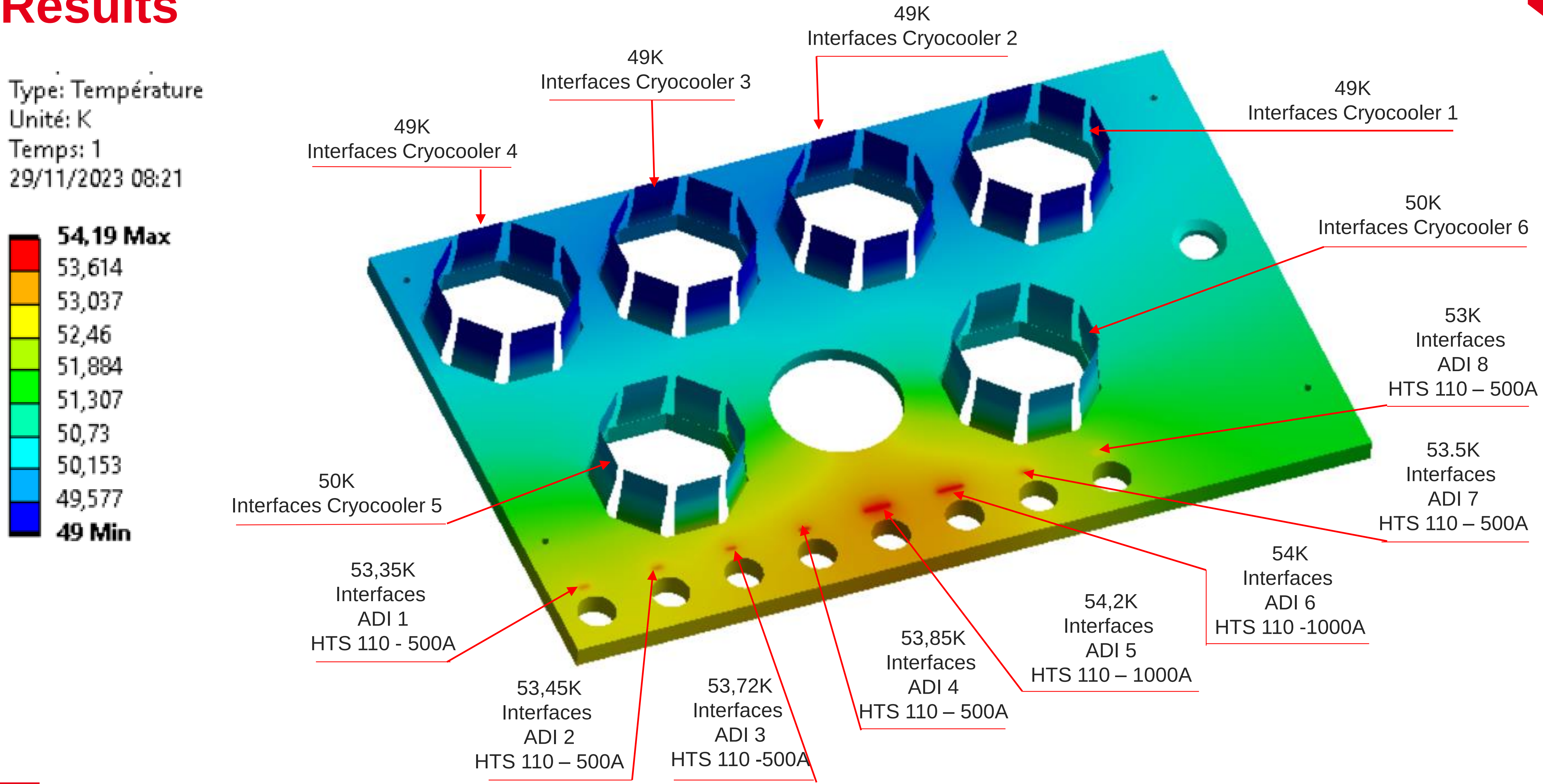
295.15 K
On the extremity of the 2x12 spacers Ø 8 mm (Peek)
In contact with the internal wall
Of the vacuum vessel (304L)



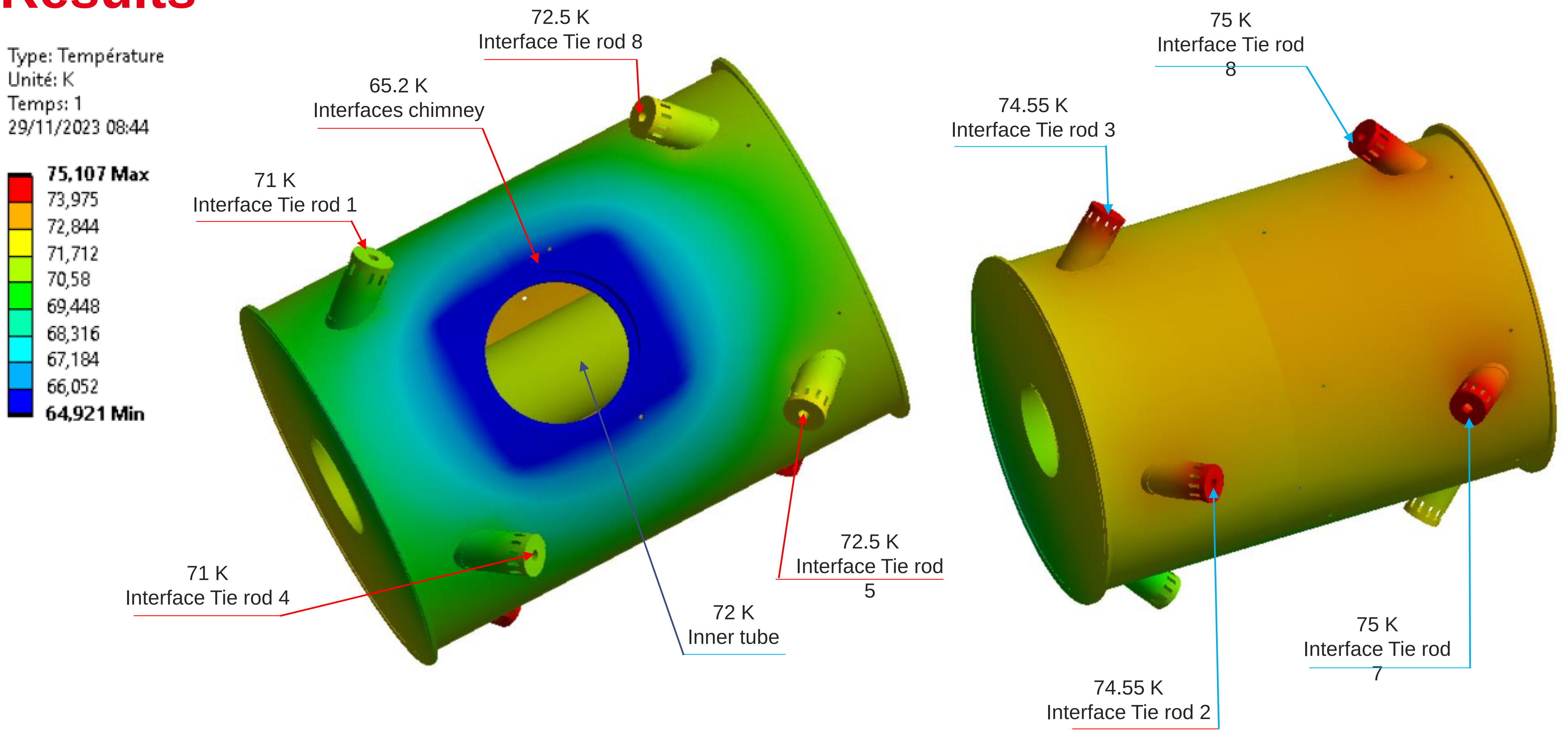


4 K
On the PED tube (304L)

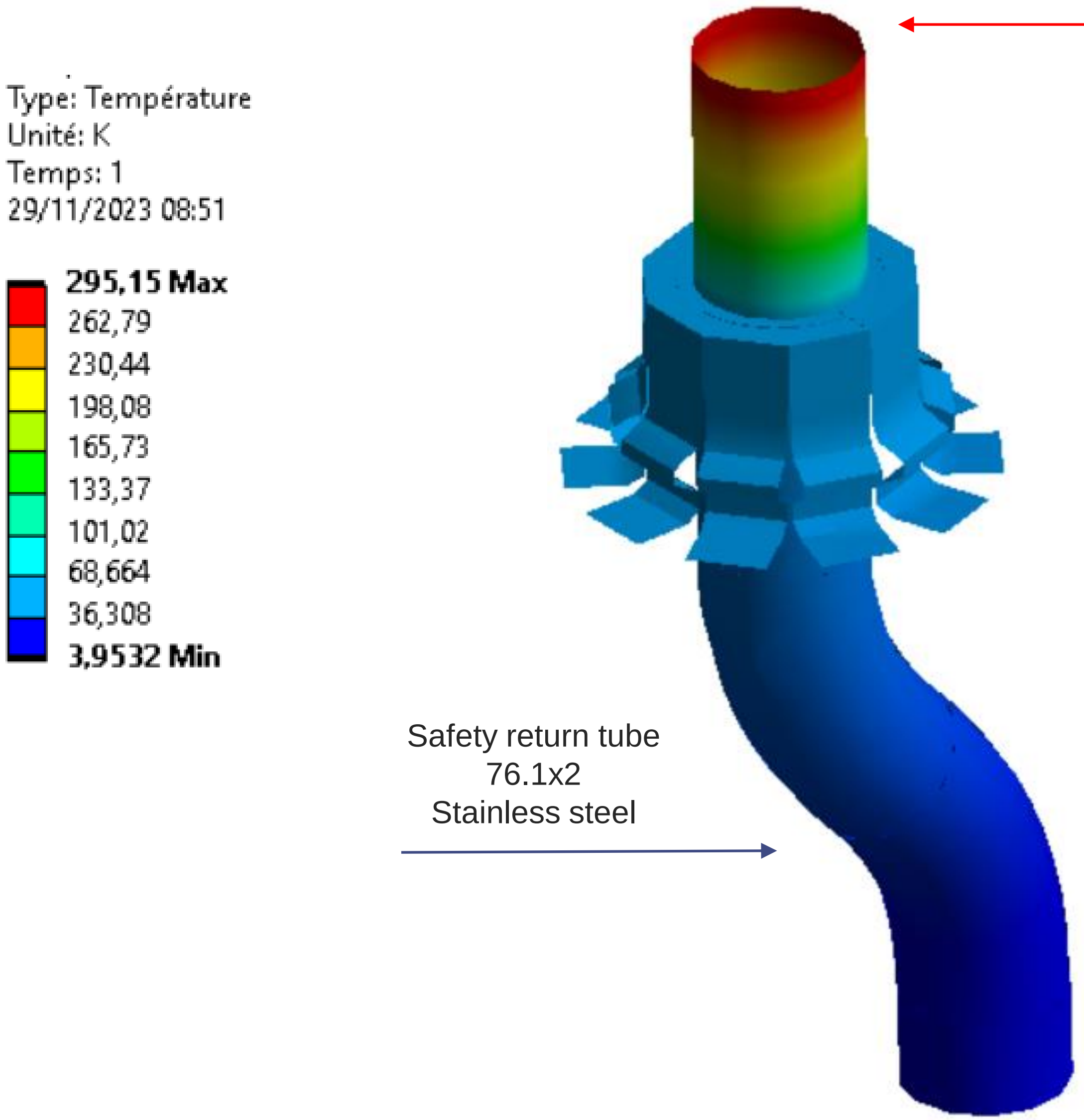
Results


Type: Température
Unité: K
Temps: 1
29/11/2023 08:21
54,19 Max
53,614
53,037
52,46
51,884
51,307
50,73
50,153
49,577
49 Min
49K Interfaces Cryocooler 2
49K Interfaces Cryocooler 3
49K Interfaces Cryocooler 1
49K Interfaces Cryocooler 4
50K Interfaces Cryocooler 6
53K Interfaces ADI 8 HTS 110 – 500A
53.5K Interfaces ADI 7 HTS 110 – 500A
50K Interfaces Cryocooler 5
54K Interfaces ADI 6 HTS 110 -1000A
53,35K Interfaces ADI 1 HTS 110 - 500A
54,2K Interfaces ADI 5 HTS 110 – 1000A
53,85K Interfaces ADI 4 HTS 110 – 500A
53,45K Interfaces ADI 2 HTS 110 – 500A
53,72K Interfaces ADI 3 HTS 110 -500A

Results


Type: Température
Unité: K
Temps: 1
29/11/2023 08:44
75,107 Max
73,975
72,844
71,712
70,58
69,448
68,316
67,184
66,052
64,921 Min
72.5 K
Interface Tie rod 8
65.2 K
Interfaces chimney
71 K
Interface Tie rod 1
71 K
Interface Tie rod 4
72 K
Inner tube
72.5 K
Interface Tie rod 5
75 K
Interface Tie rod 8
74.55 K
Interface Tie rod 3
75 K
Interface Tie rod 7
74.55 K
Interface Tie rod 2

Results

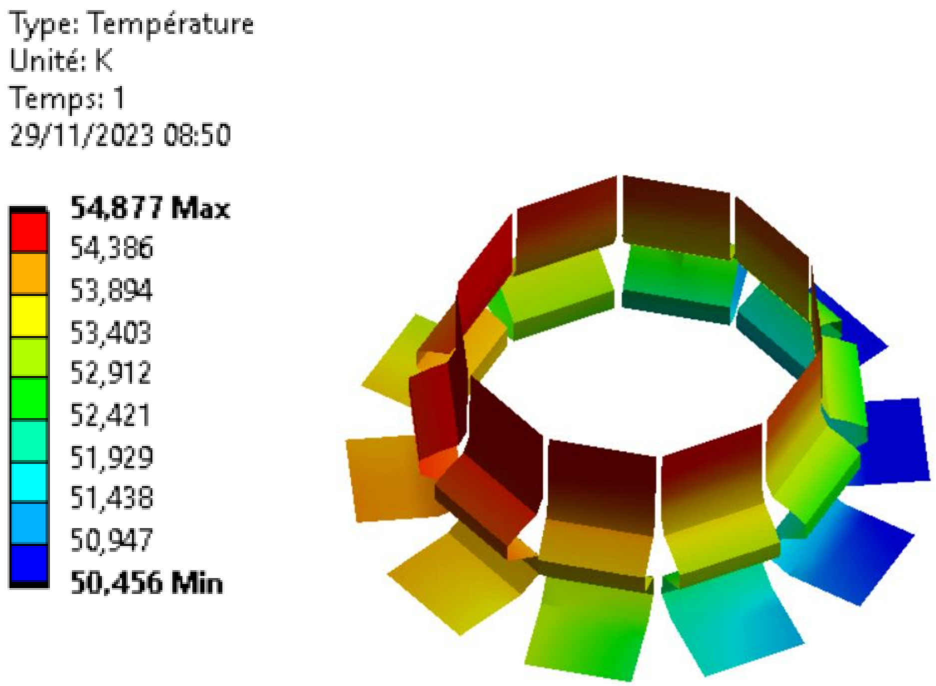


295.15K

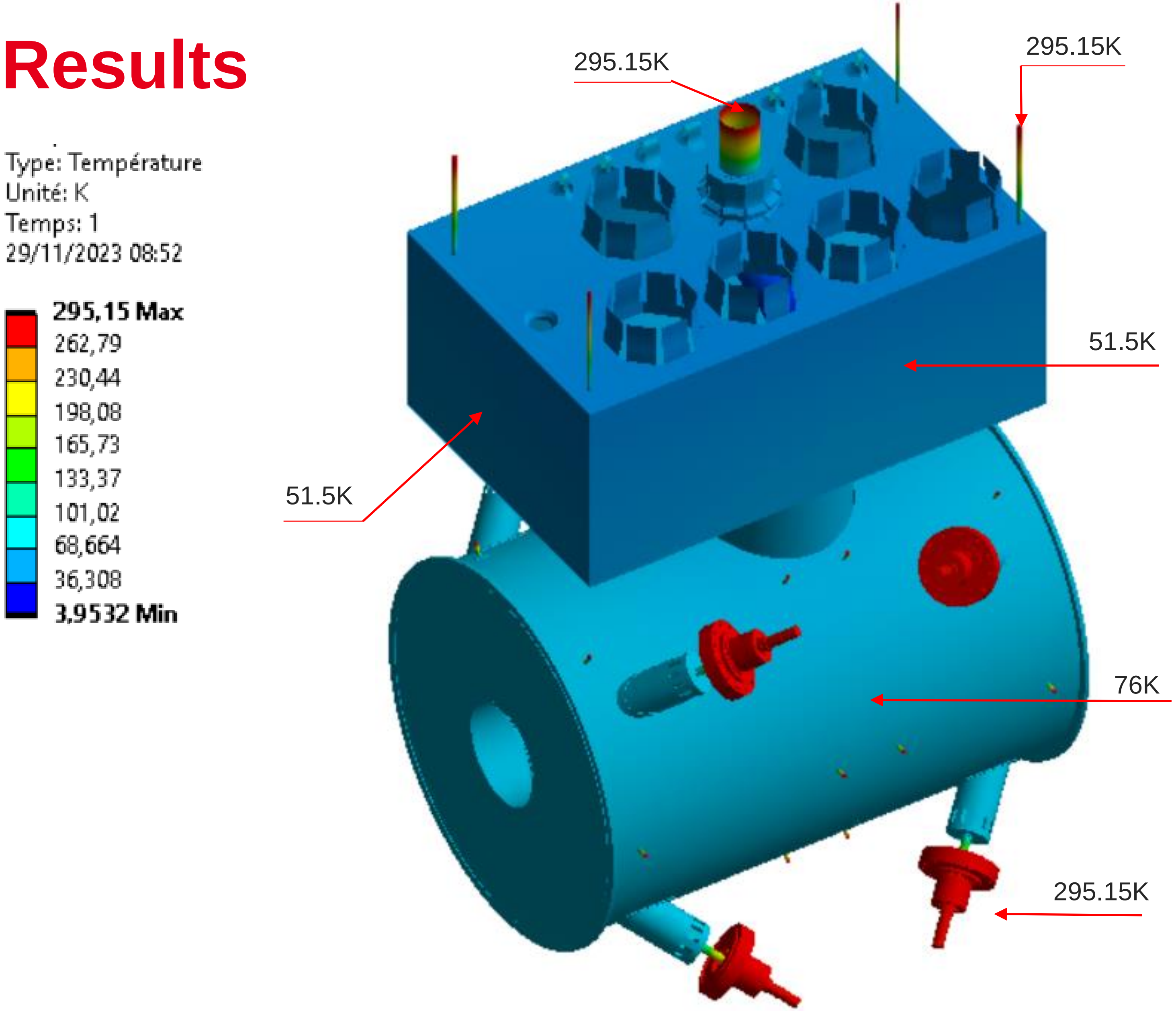
Safety return tube
76.1x2
Stainless steel

4K

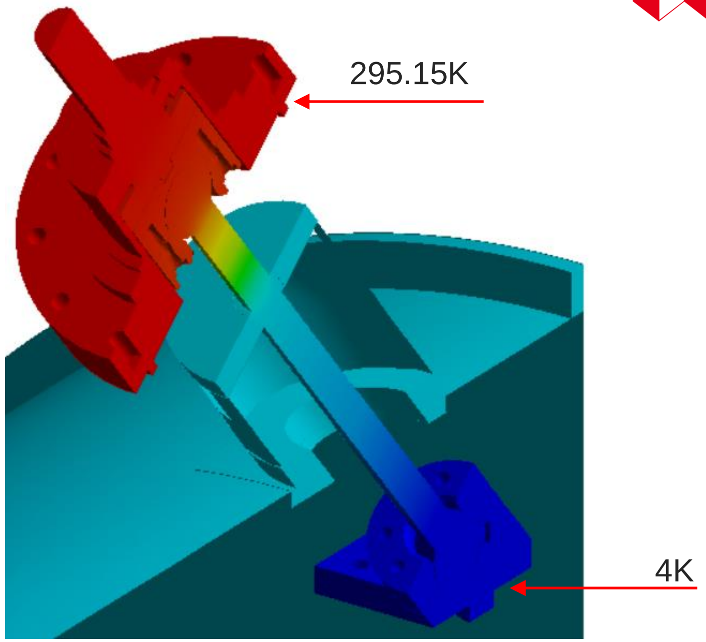
- 0.07 W on liquid



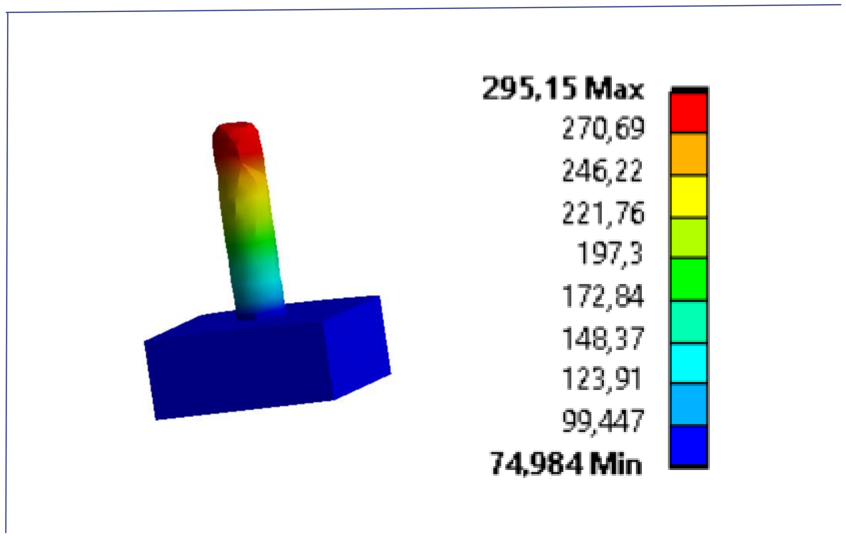
Results



Type: Température
Unité: K
Temps: 1
29/11/2023 08:52
295,15 Max
262,79
230,44
198,08
165,73
133,37
101,02
68,664
36,308
3,9532 Min
295.15K
295.15K
51.5K
51.5K
76K
295.15K

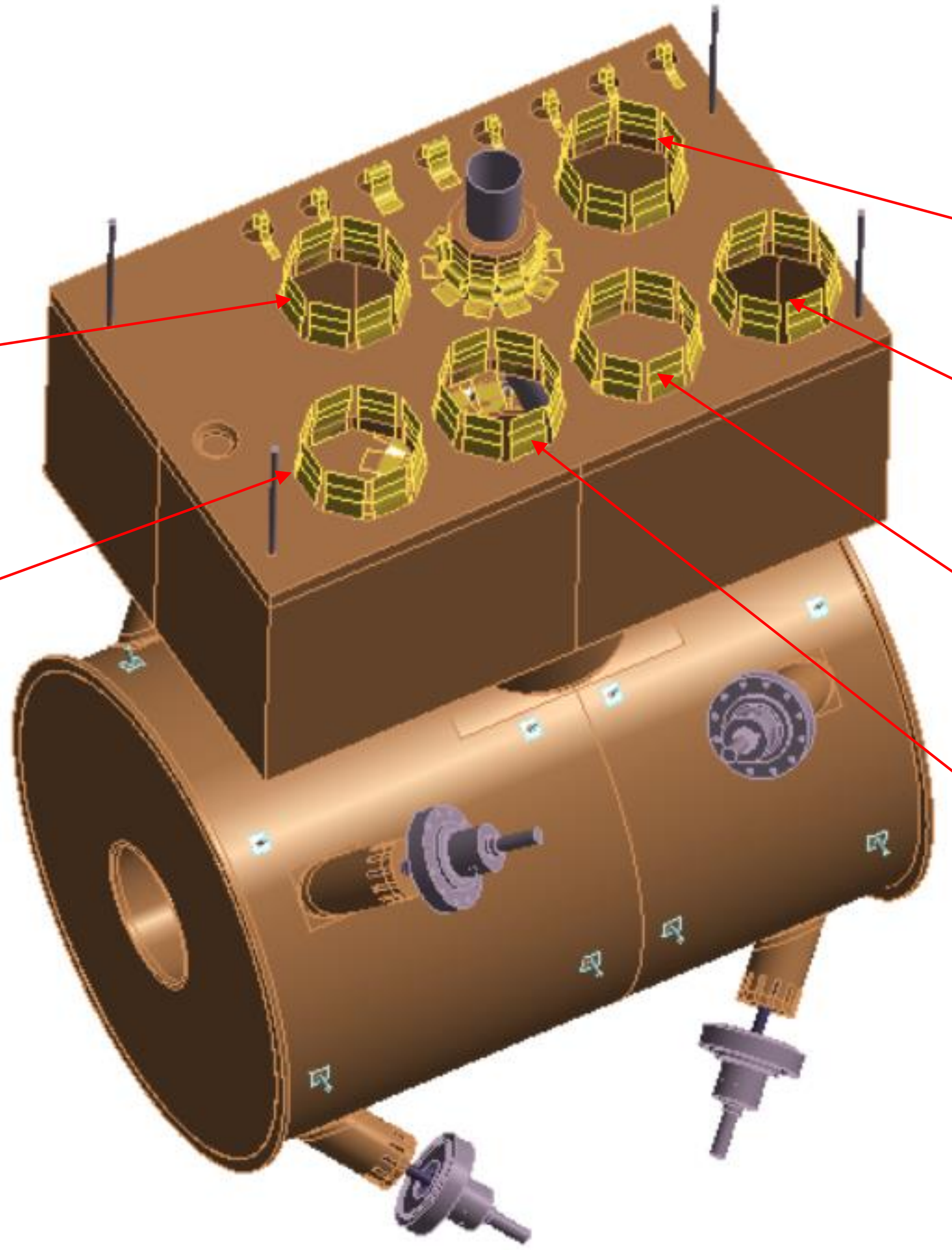


295.15K
4K



295,15 Max
270,69
246,22
221,76
197,3
172,84
148,37
123,91
99,447
74,984 Min

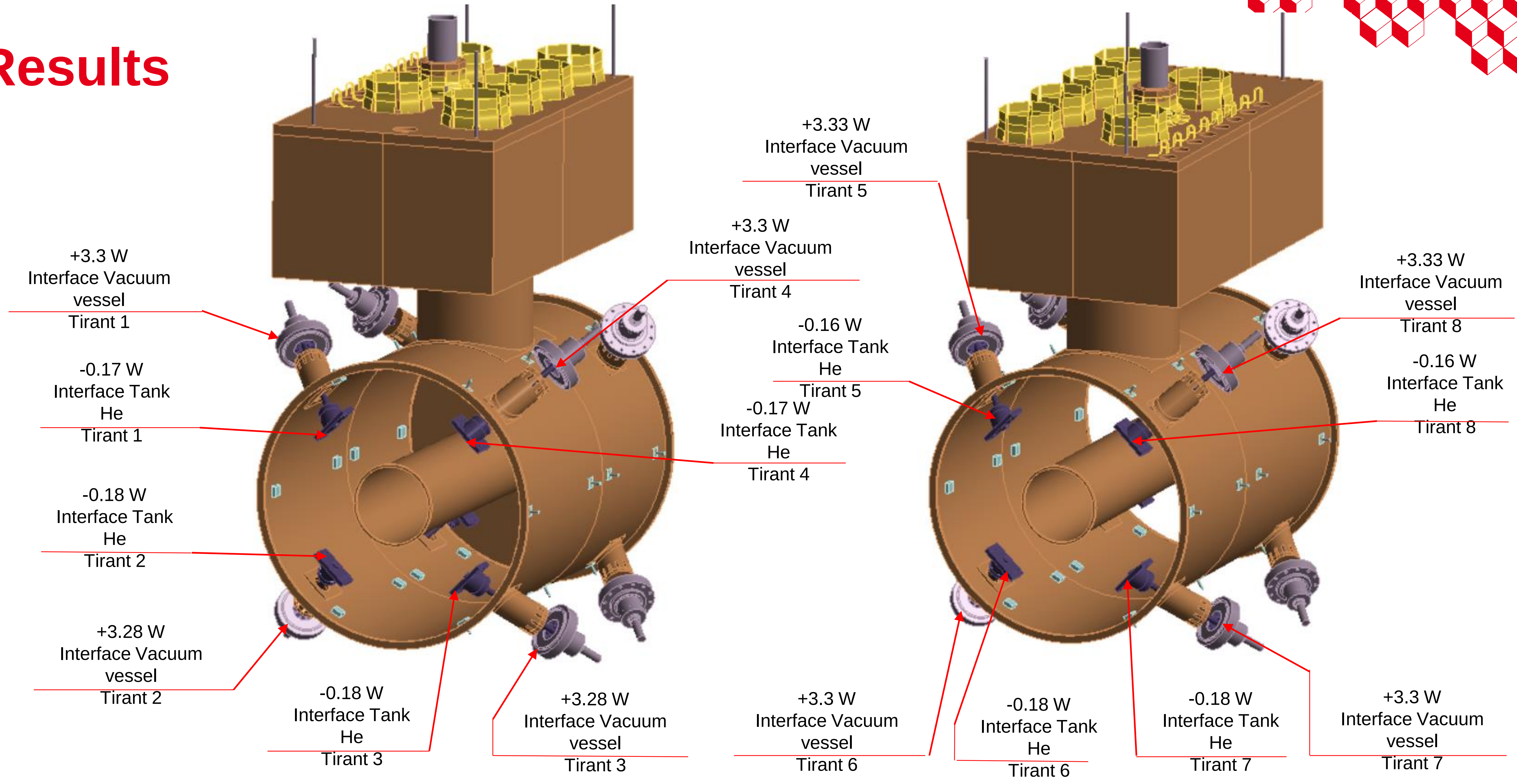
Results



- Each cryocooler absorbs less than 42 W
- 173 W absorbed by the 6 cryocoolers
- 252 W available (42 W per cryocooler)

- **Large thermal margin at first stage**

Results


+3.3 W Interface Vacuum vessel Tirant 1
-0.17 W Interface Tank He Tirant 1
-0.18 W Interface Tank He Tirant 2
+3.28 W Interface Vacuum vessel Tirant 2
-0.18 W Interface Tank He Tirant 3
+3.28 W Interface Vacuum vessel Tirant 3
+3.3 W Interface Vacuum vessel Tirant 4
-0.17 W Interface Tank He Tirant 4
+3.33 W Interface Vacuum vessel Tirant 5
-0.16 W Interface Tank He Tirant 5
+3.3 W Interface Vacuum vessel Tirant 6
-0.18 W Interface Tank He Tirant 6
-0.18 W Interface Tank He Tirant 7
+3.3 W Interface Vacuum vessel Tirant 7
+3.33 W Interface Vacuum vessel Tirant 8
-0.16 W Interface Tank He Tirant 8

7. Thermal budget at 50 K - summary

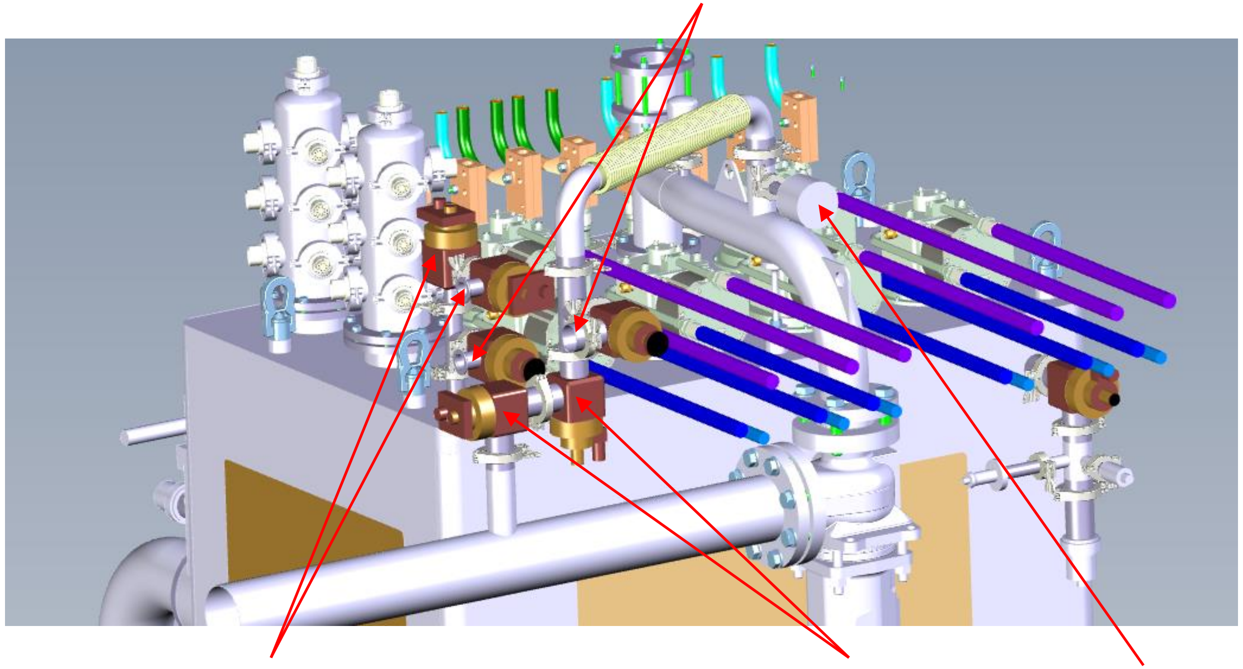
Assumption: intercept at 50 K on cryocooler first stage			
	Q (W)	number	Q tot (W)
Current leads	22.5/10.5	2/6	108
Tie rods	3.3	8	26.4
radiation			28
Satellite tie rod	1.1	4	4.4
spacers	0.26	24	6.24
total (W)			~ 173 W

- Cryocooler: 42 W at 50 K
- 6 cryocoolers: 252 W of cooling power available
- Estimated heat load: 173 W
- Margin: 31 %

8. Cool down(1/2)

- **Rinses:**
  - pumping by helium gas supply circuit and by PED outlet
  - filling with helium gas by helium supply circuit
  - 3 rinses considered, need for a mobile primary pumping group (12 m^3, maximum vacuum at 5.10^{-3} mb) (use just for rinsing)

Pumping ports + manual valves



Warm gas helium feeding, feeding and P regulated by valves (1 proportional and 1 open/close)

Pressure regulation valves (1 proportional and 1 open/close)

Pressure sensor

8. Cool down (2/2)

- **Cool down strategy:**

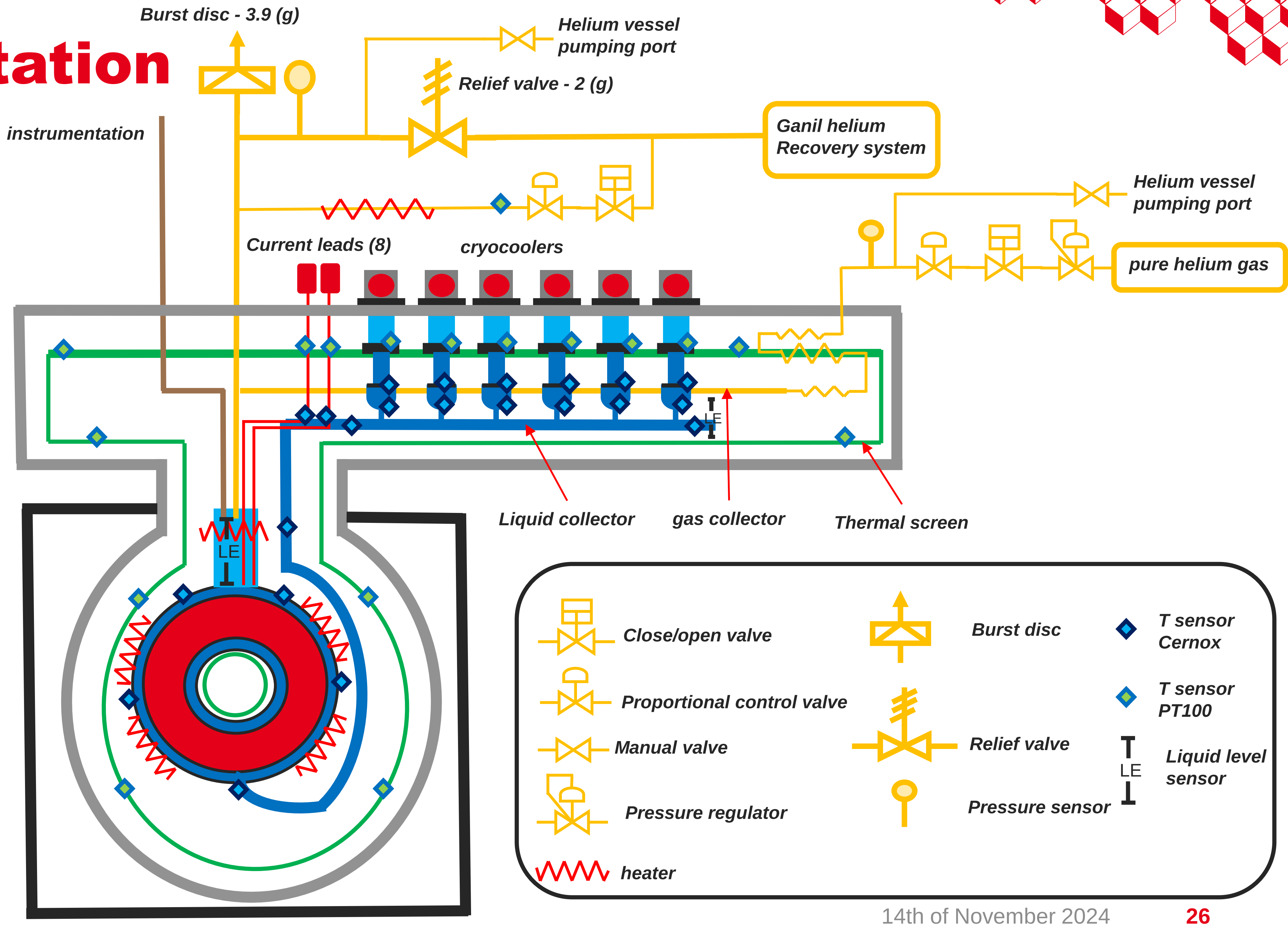
  - ➢ Helium gas supply: 1 open/close valve for sealing and a regulation valve in series (Cv = 0.25)

  - ➢ The control valve will adjust the flow of helium gas to maintain a pressure of 1.2 bar in the helium vessel: 1 regulation system foreseen

  - ➢ The gas will cool via the condensers, the pressure will decrease and the difference in density between the cold gas and the hot gas will initiate a convection movement of the helium between the "liquid" collector and the "gas" collector.

  - ➢ Cooling time estimated at 5/6 days

9. Instrumentation



9. Instrumentation - summary

Equipment / sensors	number
Liquid level sensors	4 (only 2 for operation)*
Cernox	22
PT100	22
heaters	2 (+2)* (Lhe level regulation) + 4 (dynamic load)
Pressure sensors	1 (digital) + 1 (with needle)
Proportional valves	2
Open/close valves	2

*: even if it is redundant heaters or level sensors, it is foreseen to connect the wires up to the leak tight feedthrough if they need to be used. Thus, we can connect them outside and avoid magnet warm up to open the satellite.

10. CONCLUSIONS:

- The magnet is cooled by immersion in a liquid helium bath at 1.1 bars and 4.3 K
- The liquid is produced by condensers coupled to the second stage of cryocoolers
- The thermal screen is cooled by coupling with the first stage of cryocoolers
- The calculations and simulations show that we have enough margin with 6 cryocoolers:
  - The maximum total heat load at 4 K is 9.3 W for a cooling power of 10.8 W (12 W also possible)
  - Simulation of thermal screen shows a heat load of 173 W on the first stages for 252 W available
- It is also possible to operate with 5 cryocoolers if one failed
- A system of pipes and valves has been design for the cool down and for the pressure regulation during operation
- The instrumentation has been design to have enough information for the cool down and the operation
- The system is protected from over pressure by a safety valve and a burst disc

Thank you

Questions?