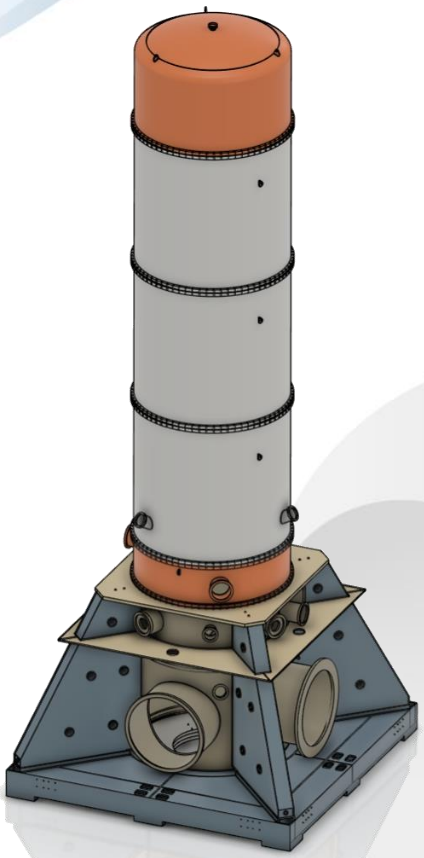
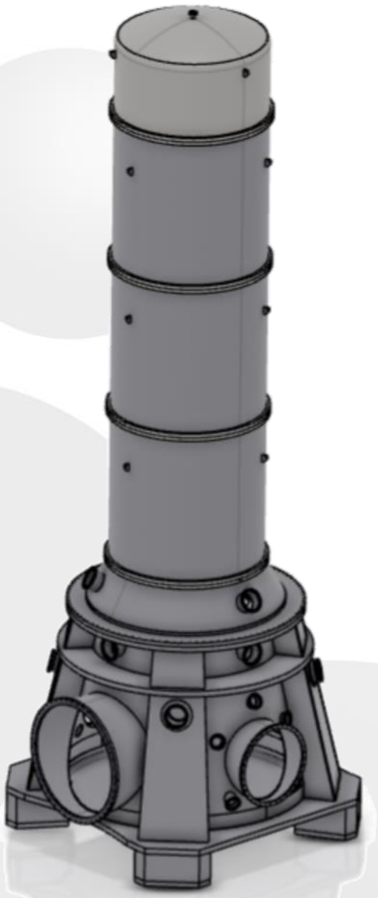
# Workshop R&Ds – Towers & Cryostats





EGO EUROPEAN GRAVITATIONAL OBSERVATORY

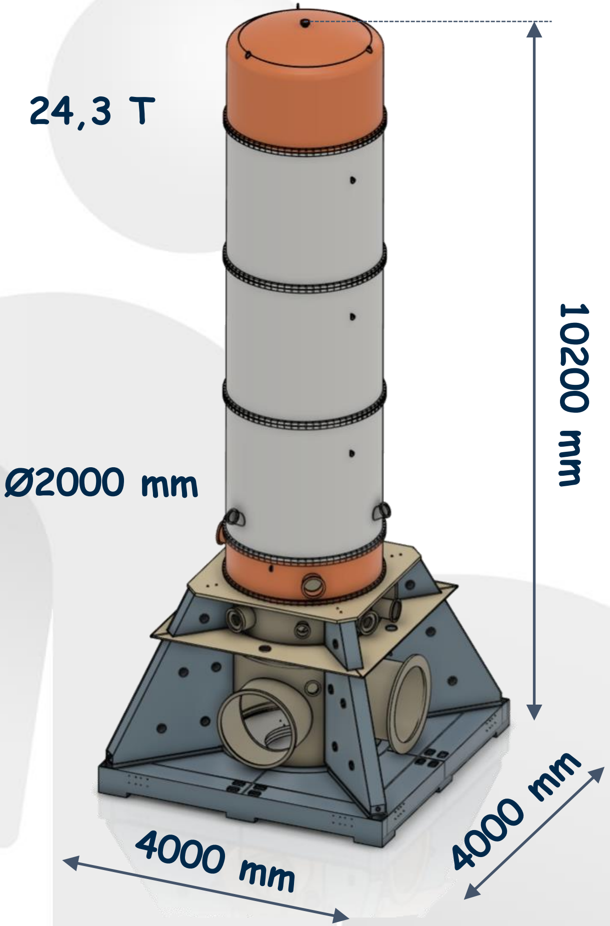
KIT Karlsruher Institut für Technologie

# Towers

# Virgo Tower analysis

- Meeting with European Gravitational Observatory's engineer's teams in March 2023 at the Beampipes for Gravitational Wave Telescopes 2023 at CERN
- They were interested on Modal Analysis & Harmonic Responses on actual VIRGO's towers to design ET's Tower
- Comparisons of the results with actual measures take on site

3D Export file sent by E.G.O.

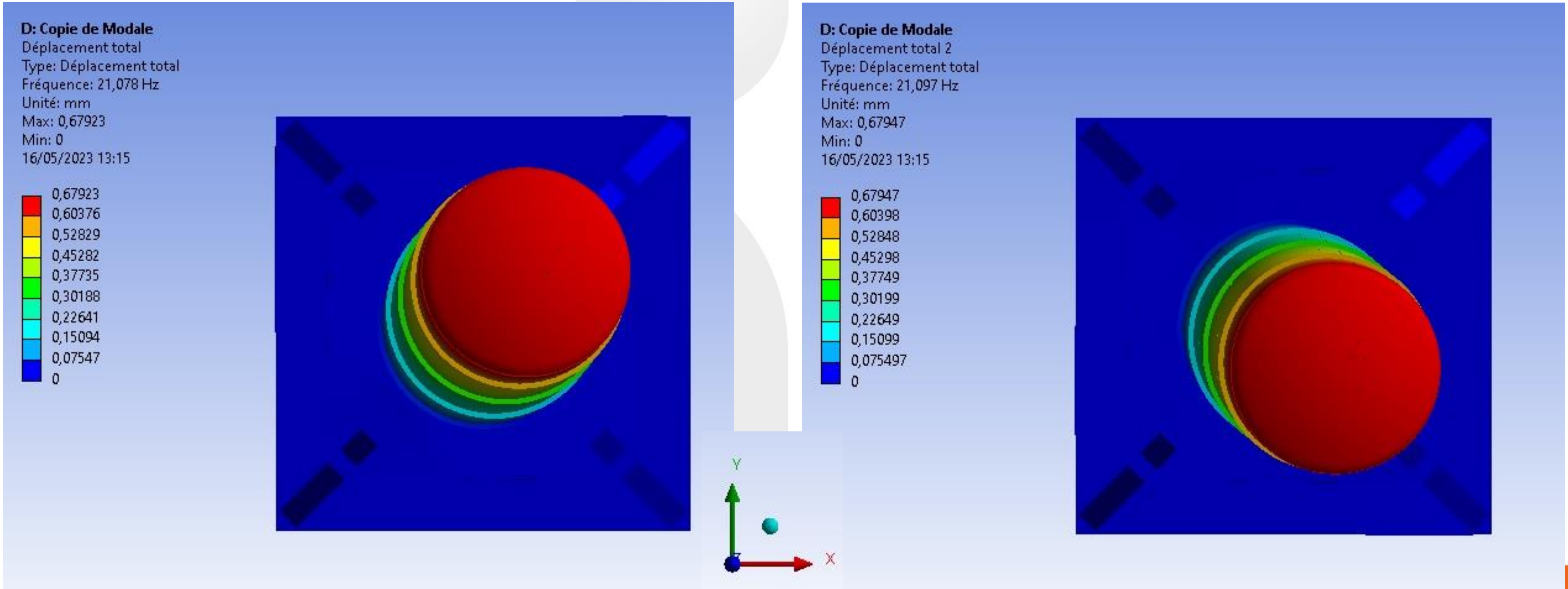



Reconstruction

# Virgo Tower – Modal Analysis

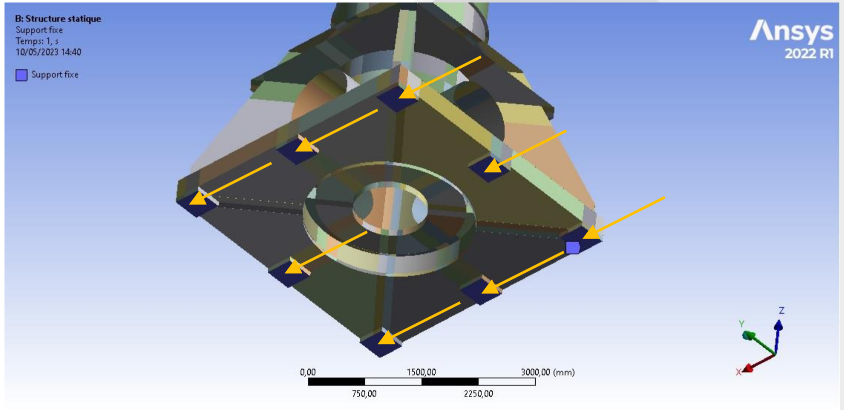
First Mode = 21,08Hz
X:9% / Y:13%

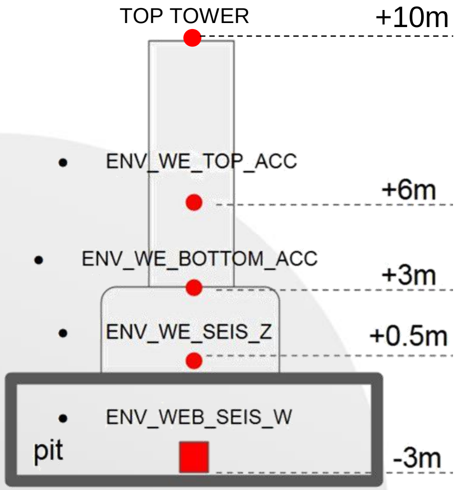
- Second Mode = 21,10Hz
  X:13% / Y:9%



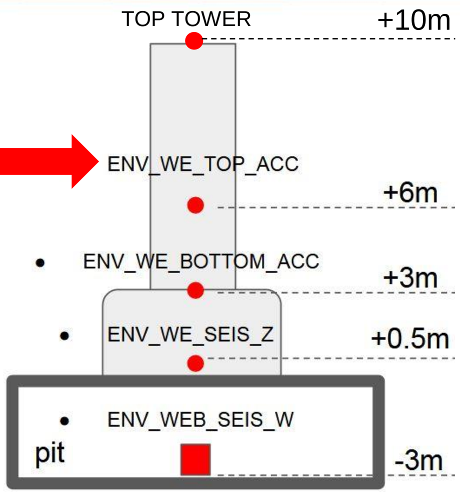
# Virgo Tower – Harmonic Response Analysis in X or Y axis

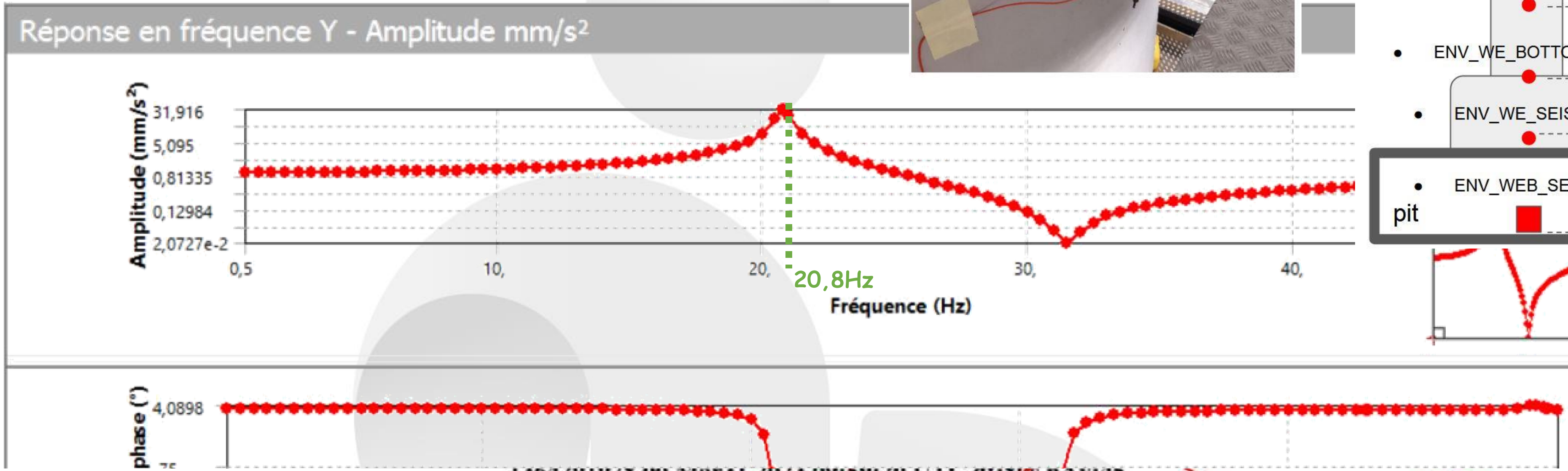
- 1mm/s² acceleration's input on X or Y axis
- 0-50Hz applied on earth node fixed
- The values of the damping coefficient is 2% for welded assemblies of steel structure thanks to Eurocode 8 - Design of structures for their resistance to earthquakes
- *Ansys Generate values of amplitude compared to modal frequency responses of the distant points created where accelerometers are installed on Virgo*

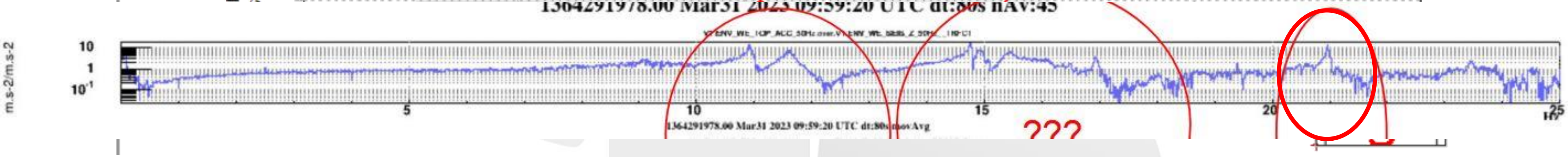


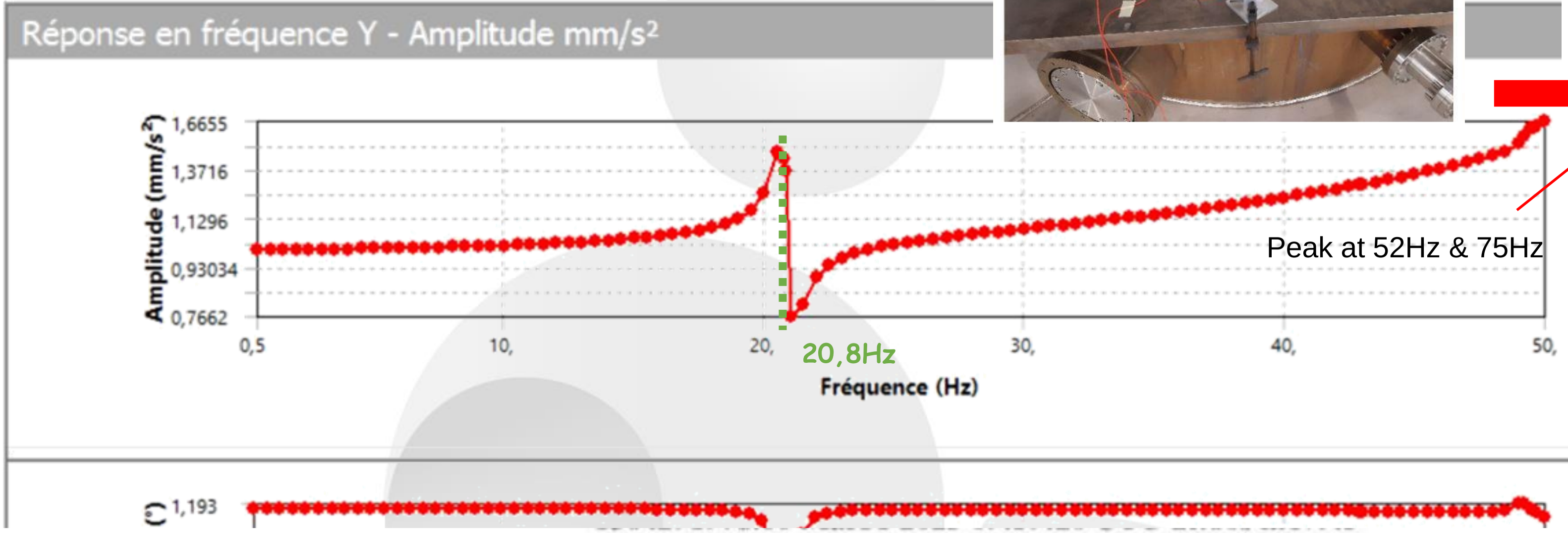
# Top Accelerometer – Acceleration Displacement on Y

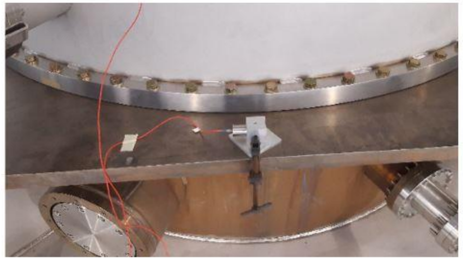



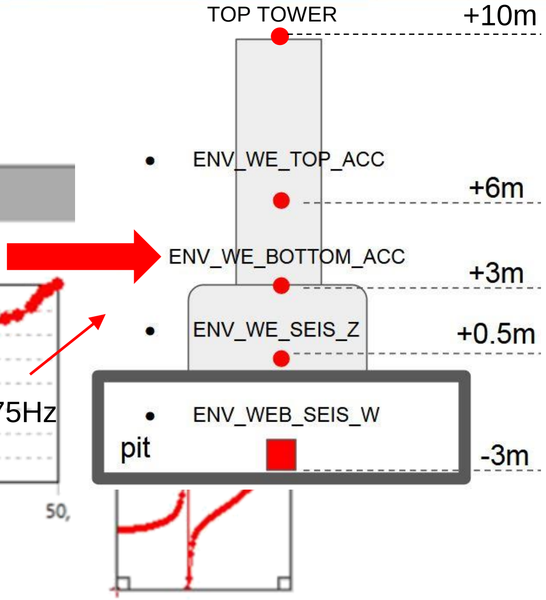



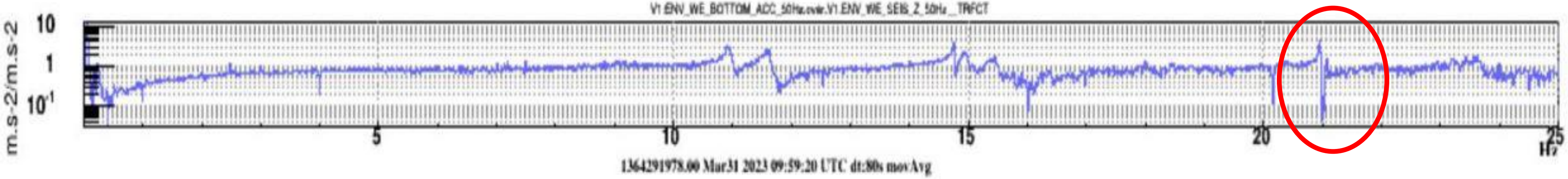
# Bottom Accelerometer - Acceleration Displacement on Y



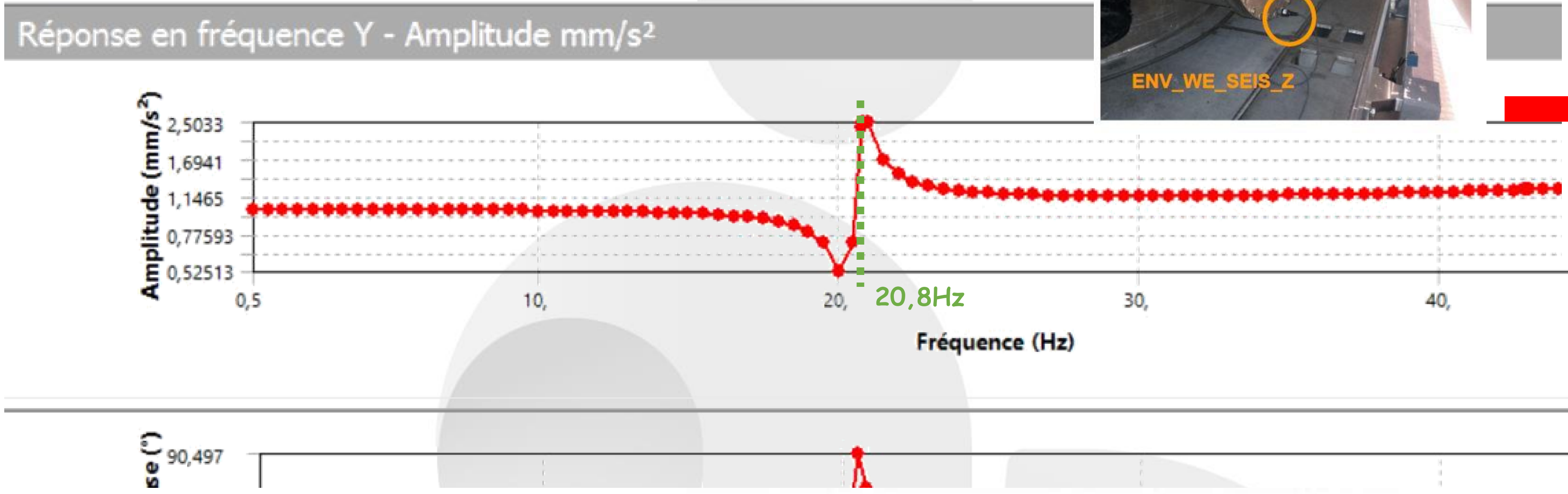

ENV_WE_BOTTOM_ACC



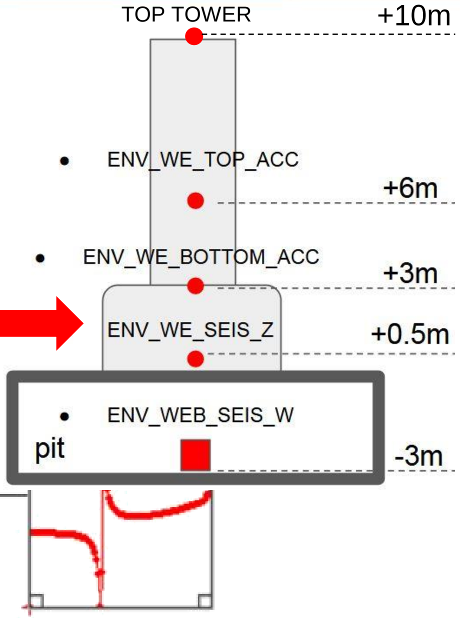


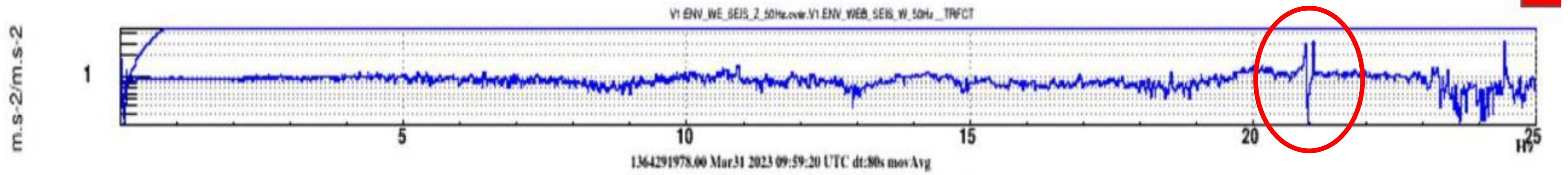



# SEIS Accelerometer – Acceleration Displacement on Y







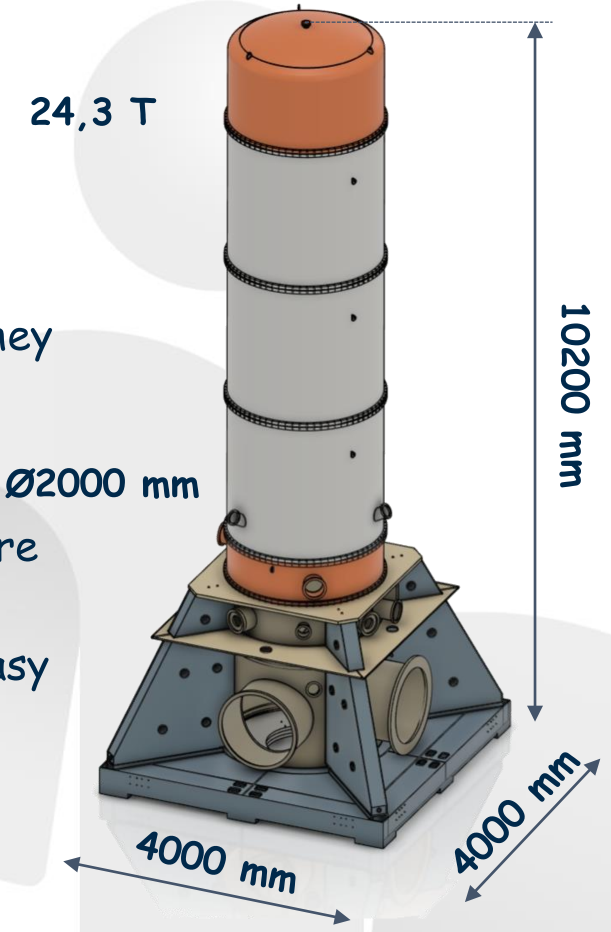



# ET Tower analysis

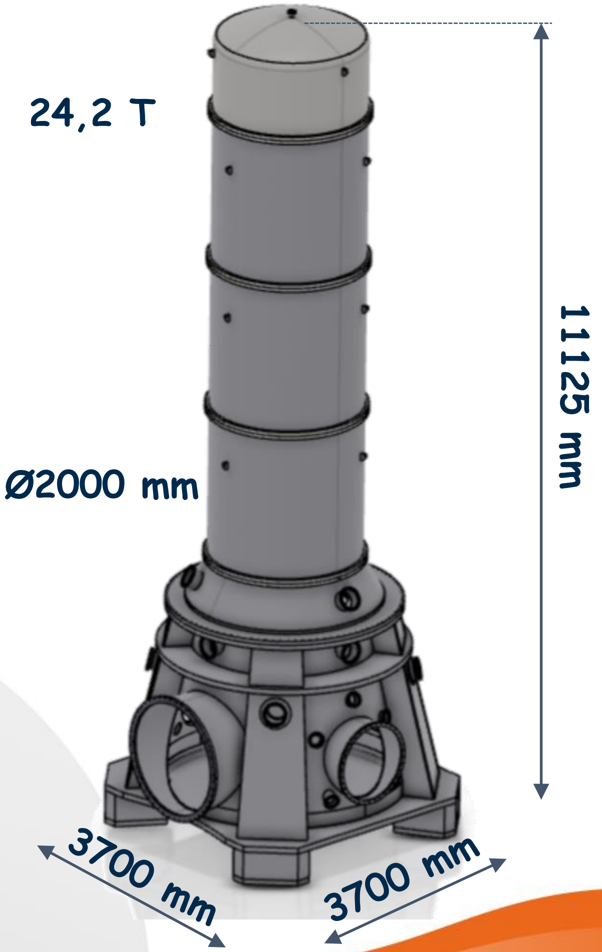


- After Virgo towers' simulation they sent us volumic model and CAD drawings of the actual Einstein Telescope warm towers' concept
- The work were the same as before and optimisation if it's possible
- Bigger vacuum chamber for an easy access in case of handling

VIRGO Tower's




Einstein Telescope Tower's

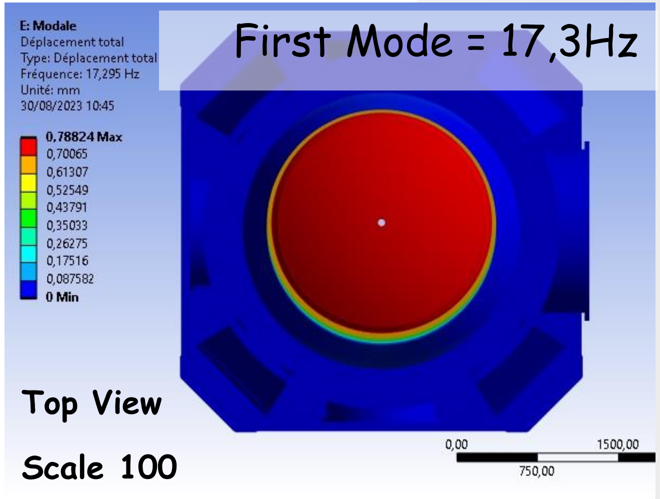


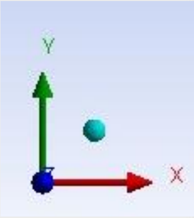
# ET Tower analysis - Modal Analysis

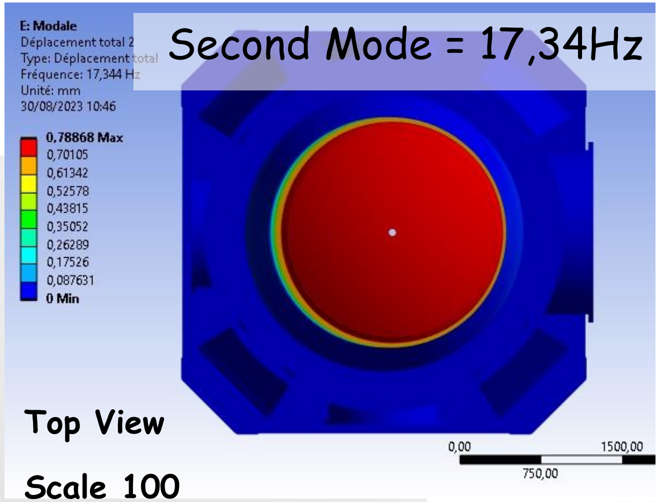
***** MODAL MASSES, KINETIC ENERGIES, AND TRANSLATIONAL EFFECTIVE MASSES SUMMARY *****

| | | | | EFFECTIVE MASS | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MODE | FREQUENCY | MODAL MASS | KENE | X-DIR | RATIO% | Y-DIR | RATIO% | Z-DIR | RATIO% |
| 1 | 17.30 | 1.611 | 9509. | 0.2519E-02 | 0.01 | 4.108 | 16.97 | 0.1779E-06 | 0.00 |
| 2 | 17.34 | 1.609 | 9552. | 4.100 | 16.94 | 0.2443E-02 | 0.01 | 0.1990E-04 | 0.00 |
| 3 | 36.37 | 1.403 | 0.3664E+05 | 0.3509E-06 | 0.00 | 0.6925E-08 | 0.00 | 0.5339E-05 | 0.00 |
| 4 | 36.70 | 2.724 | 0.7240E+05 | 0.3202E-06 | 0.00 | 0.5234E-04 | 0.00 | 0.9992E-10 | 0.00 |
| 5 | 45.28 | 1.206 | 0.4880E+05 | 0.2023E-05 | 0.00 | 0.4281E-06 | 0.00 | 0.2293E-07 | 0.00 |
| 6 | 45.33 | 1.208 | 0.4899E+05 | 0.3458E-05 | 0.00 | 0.4569E-06 | 0.00 | 0.2473E-07 | 0.00 |
| 7 | 71.37 | 1.163 | 0.1169E+06 | 0.5552E-03 | 0.00 | 0.9955E-03 | 0.00 | 0.1943E-06 | 0.00 |
| 8 | 71.42 | 1.142 | 0.1150E+06 | 0.7557E-02 | 0.03 | 0.1382E-03 | 0.00 | 0.2324E-06 | 0.00 |
| 9 | 72.84 | 6.502 | 0.6809E+06 | 10.92 | 45.13 | 0.8869E-02 | 0.04 | 0.1430E-02 | 0.01 |
| 10 | 74.29 | 5.355 | 0.5833E+06 | 0.8869E-02 | 0.04 | 10.28 | 42.49 | 0.1169E-03 | 0.00 |
| 16 | 92.91 | 1.608 | 0.2740E+06 | 0.1654E-03 | 0.00 | 0.3179E-06 | 0.00 | 0.7371 | 3.05 |
| 17 | 93.40 | 2.911 | 0.5012E+06 | 0.3328E-02 | 0.01 | 0.5215E-05 | 0.00 | 9.270 | 38.30 |
| sum | | | | 15.05 | 62.17 | 14.62 | 60.41 | 10.01 | 41.36 |

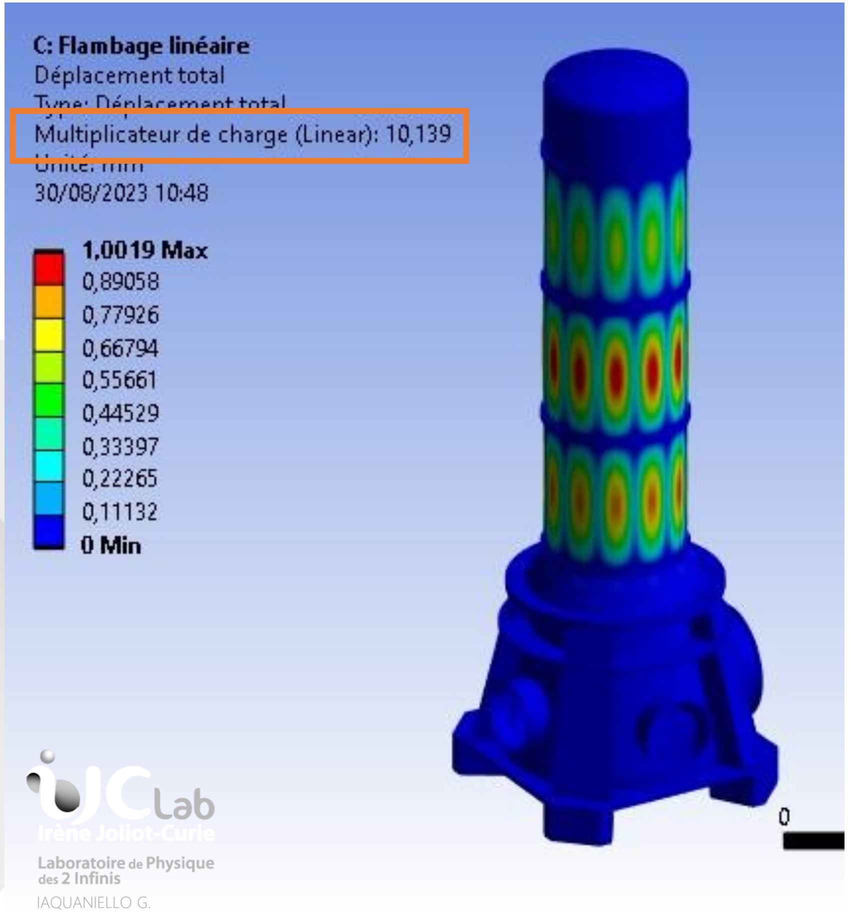
First modes ~ 17,3 Hz – X & Y Axis



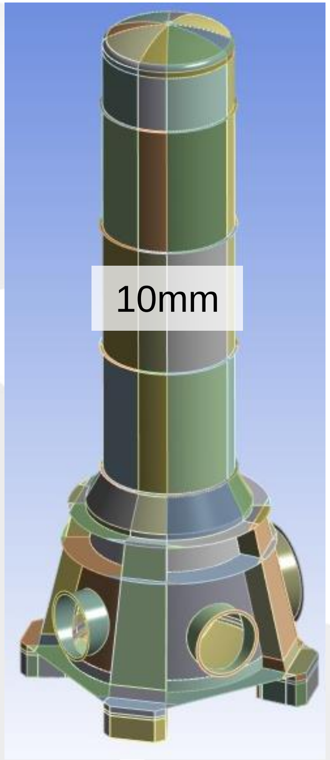



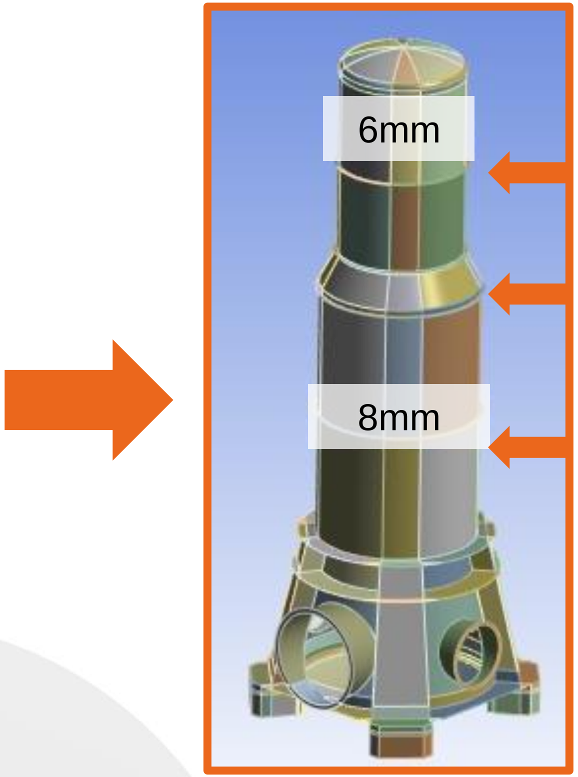
- According to the french CODAP (Construction code for unfired pressure vessels) the Charge multiplier ≥ 3
- According to ANSYS Simulation, the results of the charge multiplier is 10,139



# ET Tower analysis

- After I made simulations, i purposed 4 changes on tower's design
- Position's changes of the conical ferrule
- According to CODAP standards for buckling, I decreased tubes thicknesses
- Increasing the base diameter of the upper tower
- Equalize tubes lenghts of the upper tower to limit buckling effect because flanges act like stiffeners
- Increasing by 8,3Hz the first mode response
- Diminution by 800kg the mass' tower




| | | |
|---|---|---|
| 1st Mode | 17,3 Hz | 25,6 Hz / +8,3Hz |
| Buckling | 10,1 | 3,7 / -6,4 |
| Mass | 24,2 T | 23,4 T / -0,8T |

# Conclusion

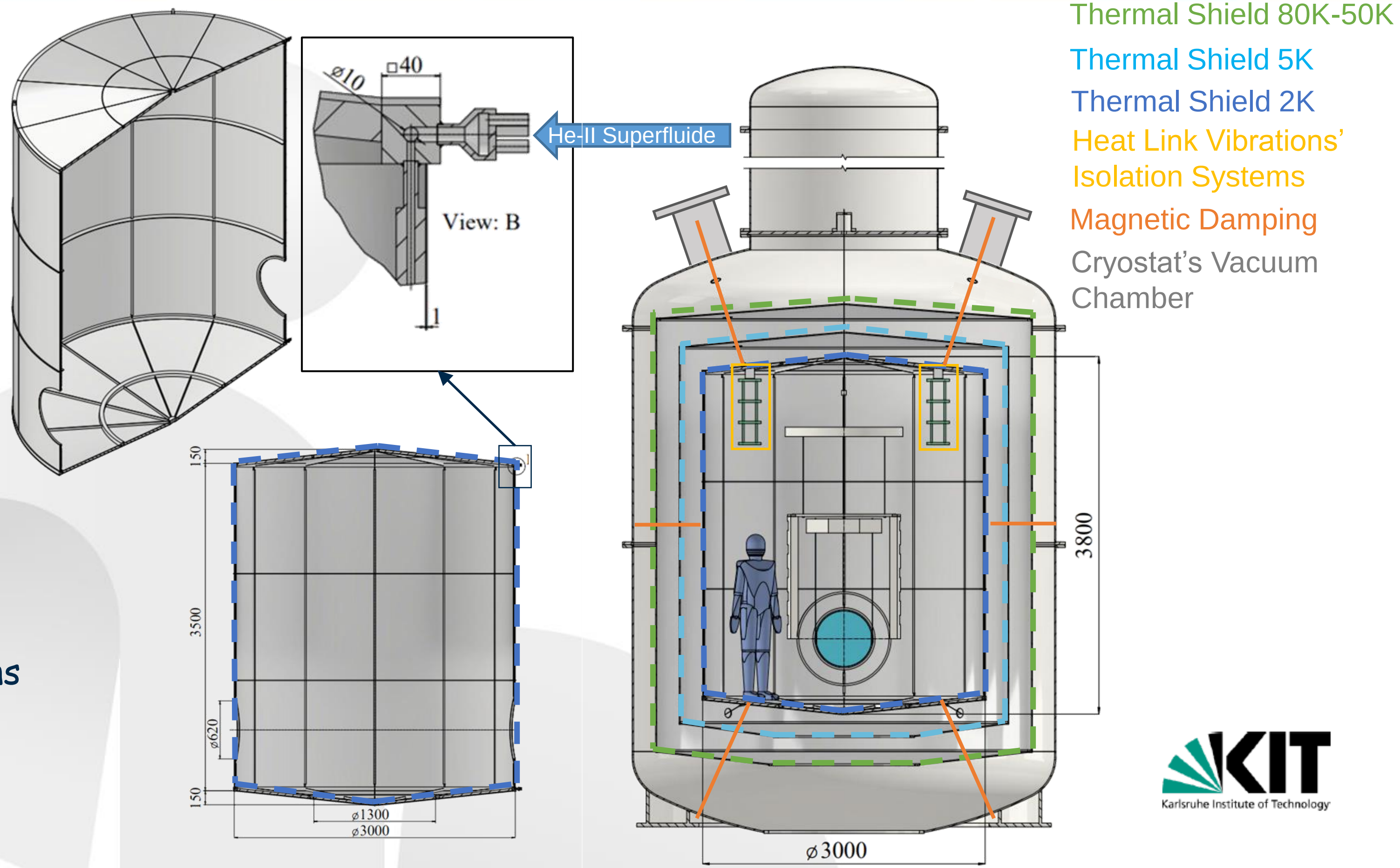
**Next steps** :

- Waiting for the next choices, especially on suspensions to continue our work

# Cryostats

# Low-noise thermal shielding

- Active cooling of the two external thermal shield respectively to 80K-50K and 5 K with supercritical helium flow
- The third shield is cooled at 2K via thermal conduction through static superfluid helium He-II, avoiding macroscopic fluid flow.
- He-II is superfluid, so it allows an rapid cooling and transits less mechanical vibrations
- => R&T IN2P3 : Etudes de l'amortissement magnétique des écrans thermiques cryogénique d'Einstein Telescope & acquisition de compétences dans la suspension d'éléments sensibles (IJCLab)



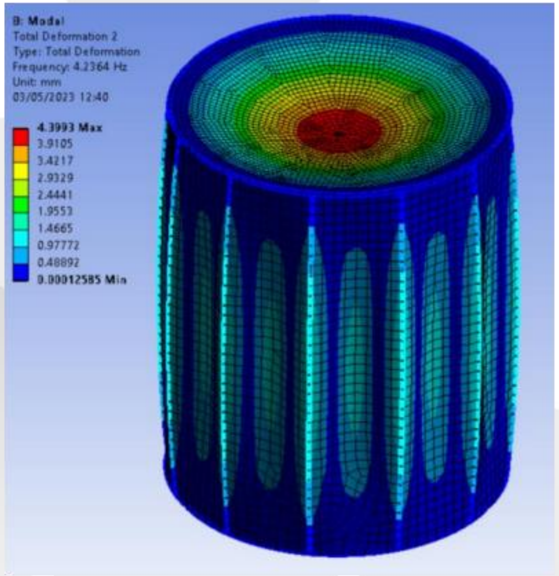

KIT Karlsruhe Institute of Technology

***Reference*** *: L Busch, G Iaquaniello, P Rosier, M Stamm, and S Grohmann - Low-noise thermal shielding around the cryogenic payloads in the Einstein Telescope (2023)*

# 2K Shield Optimisation

- 1st design (by K.I.T.) : 1st modal mode was too low
  - 10mm extruded squared profiles
  - 1mm thickness' panels in Aluminium serie 1000
- 2nd design (by IJCLab) :
  - 20x20mm vertical extruded profiles
  - 60x6mm horizontal extruded profiles
  - 0,5mm thickness' panels in Aluminium serie 1000
  - Top's, bottom's and lateral's cryostat's reinforcement
  - Adding an access on top for the suspensions' chain

First mode: 4.2 Hz

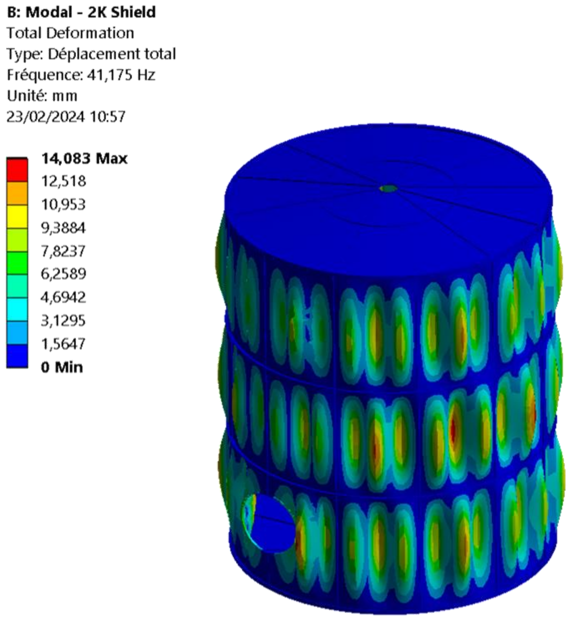



Mass : 380kg

+36,9Hz

+35kg

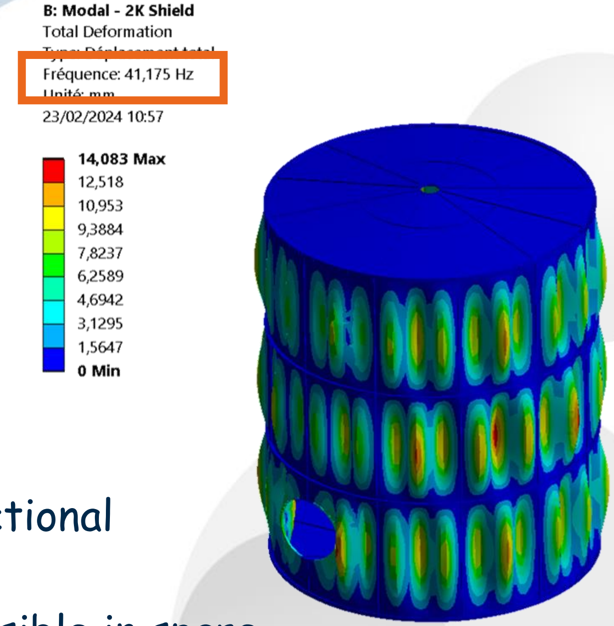
First Mode : 41,1Hz

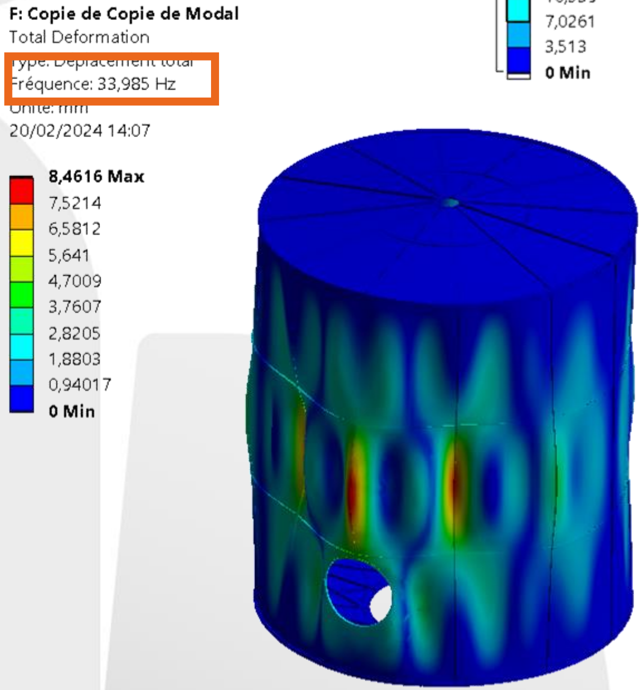


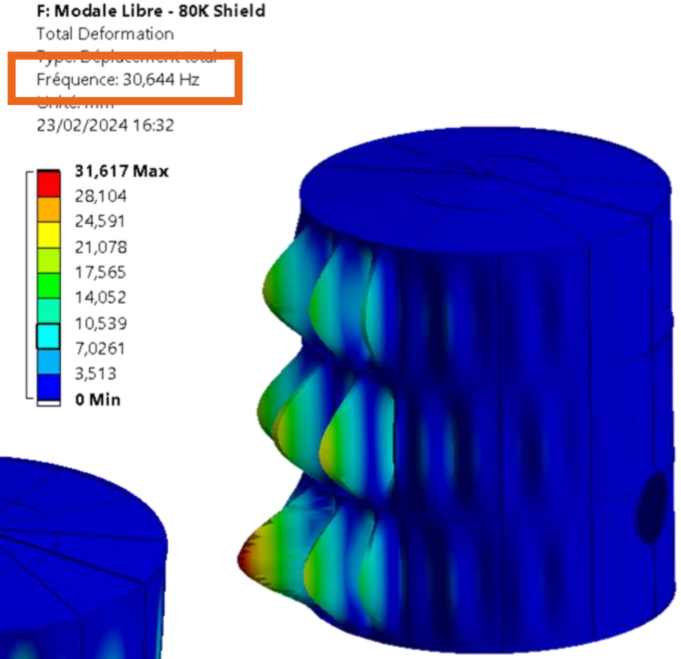

Mass : 415kg

# Shields optimizations

- <u>Static Structural Analysis :</u>
  - Total & Directional displacement
  - Von Mises (visible in spare slides)
  - Mass
- <u>Modal Analysis :</u>
  - Results had to be greater than 30 Hz modal frequency



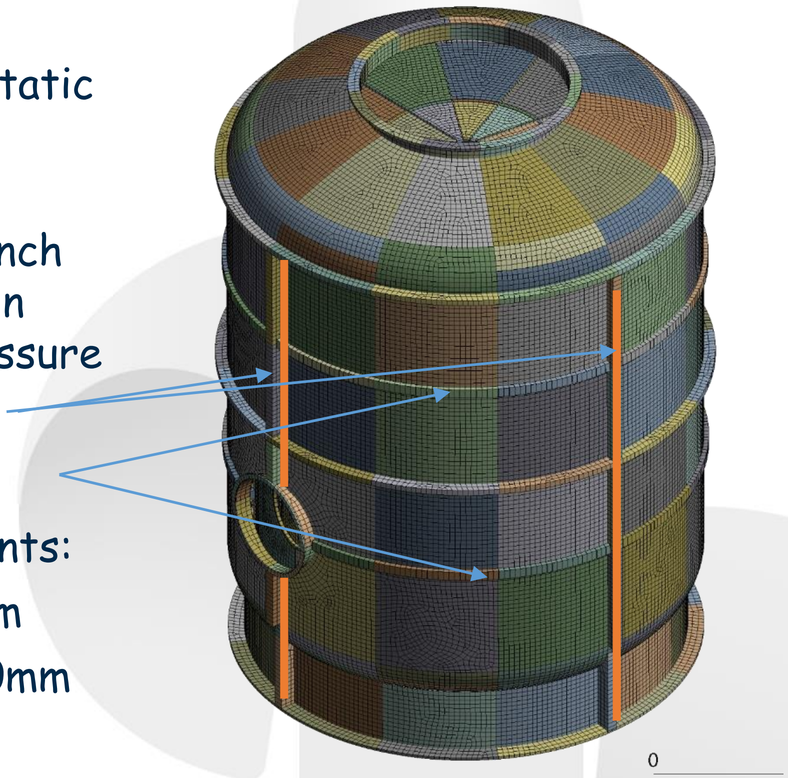



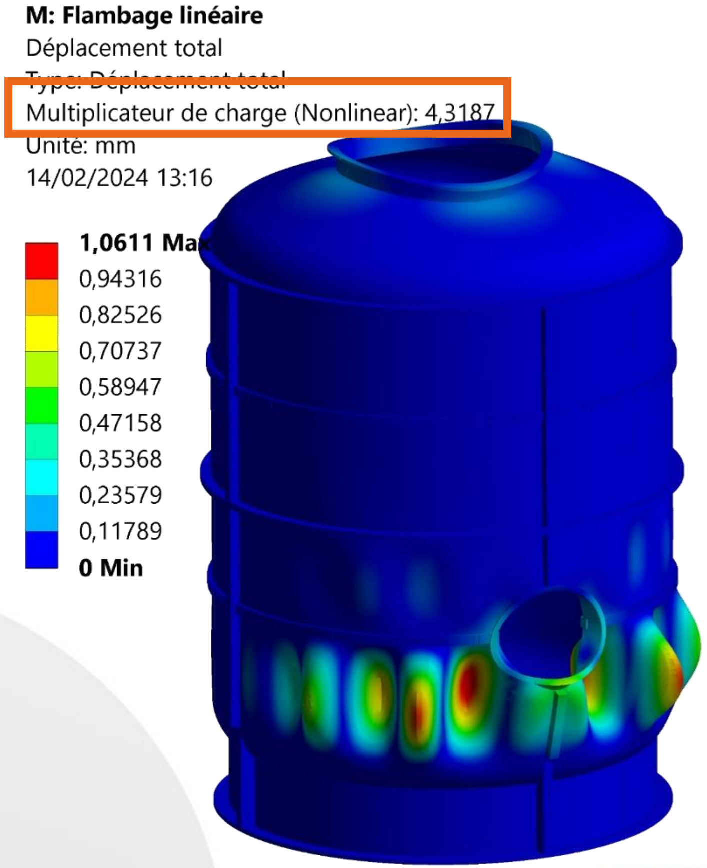
# Cryostat vacuum chamber optimization's



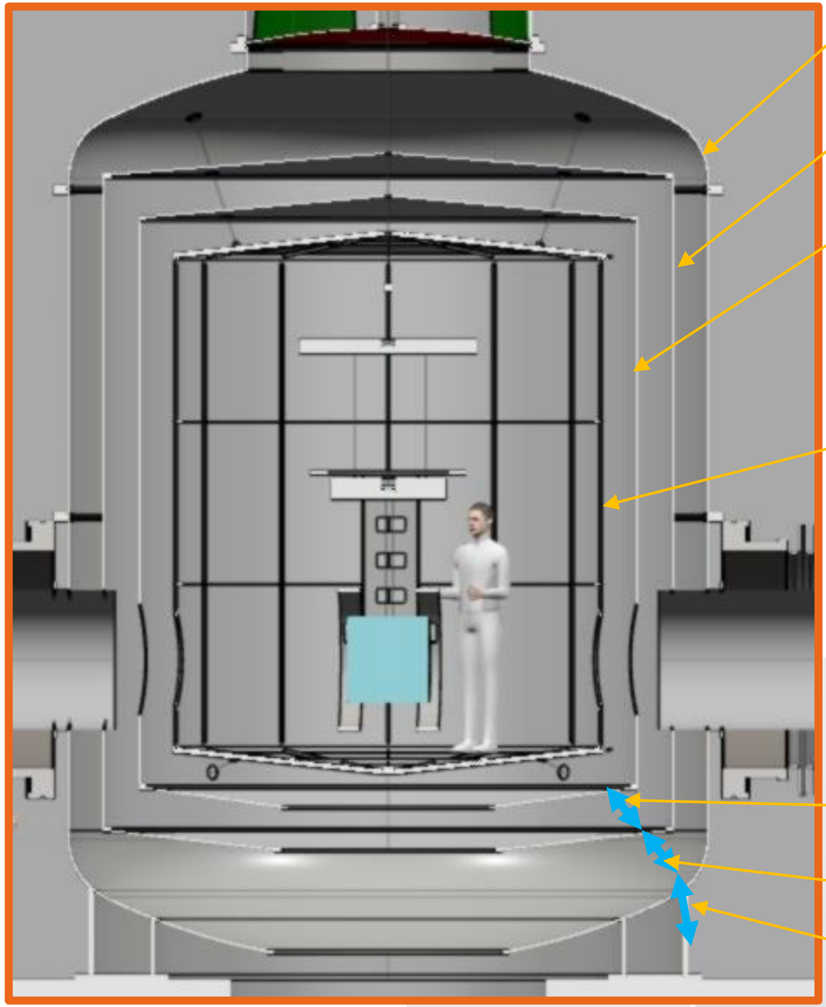
- Linear Buckling (in large static displacement mode) :
  - charge multiplier > 3 according to the French CODAP - Construction code for unfired pressure vessels

- Adding some reinforcements:
  - 4 vertical 100x100mm
  - 2 horizontal 100x100mm





# Summary of the CAD from KIT



18,8 T / Stainless Steel = after check

80K / 831 Kg / alu = after optimization

5K / 646 Kg / alu = after optimization

2K / 415 Kg / alu = after optimization

Total : 20,7 T

240 mm

270 mm

270 mm

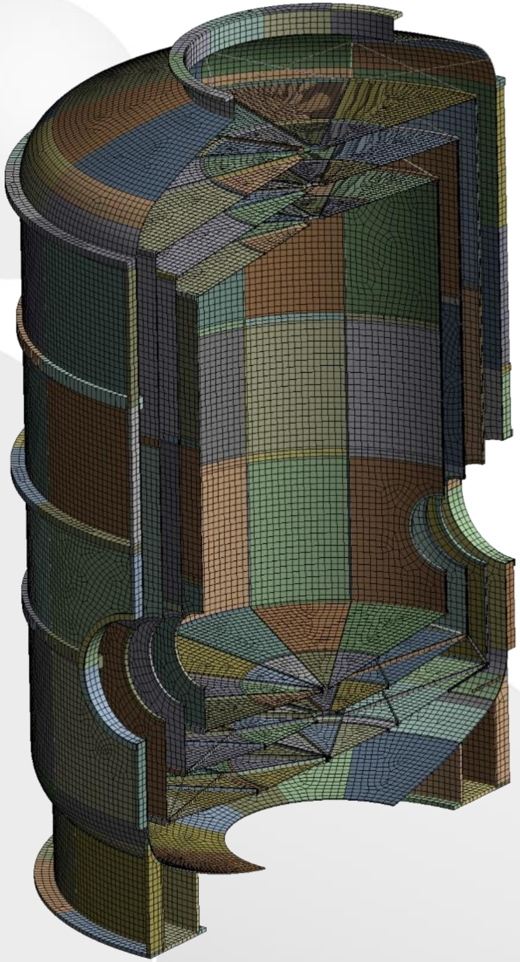
# Global model's simulation

# Suspension

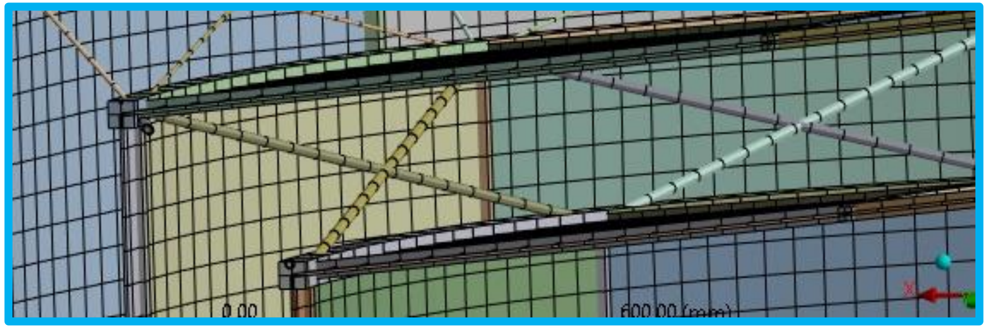
# Global model's simulation

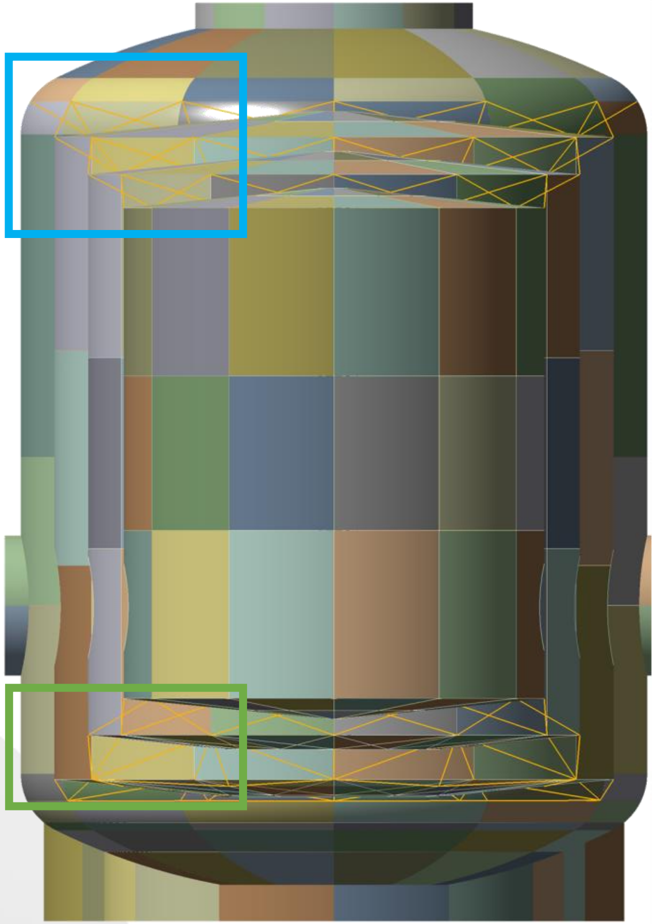
In first phase, in rigid design approach, need of a support structure which must be rigid enough to allow up to 1.7 tons of shields, at 30 Hz mini modal frequency, and with low conductive heat transfer.

The total heat transfer at 2K, 5K, 80K and 300K stages can be extracted to evaluate the efficiency of the insulation compromise (material and section / rigidity)

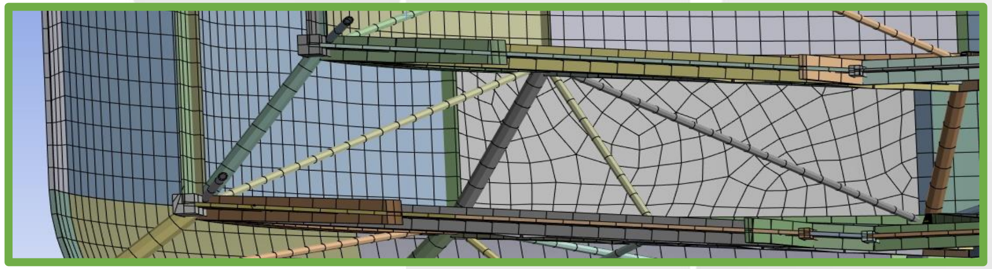


# Global model's simulation



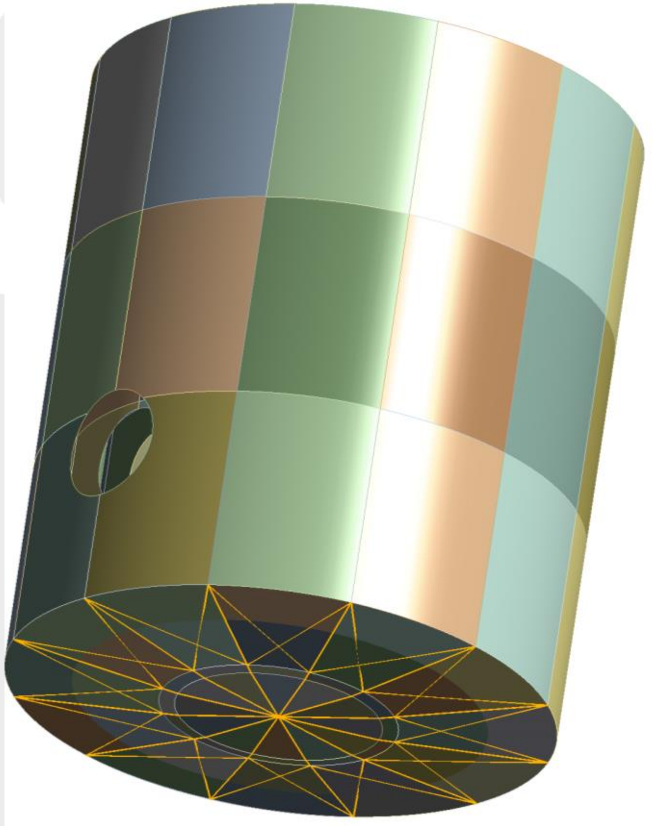



- Support structure built with stainless steel and/or glass fiber rods' and tubes'
- Try to had an homogeneity between diameters of tubes & rods

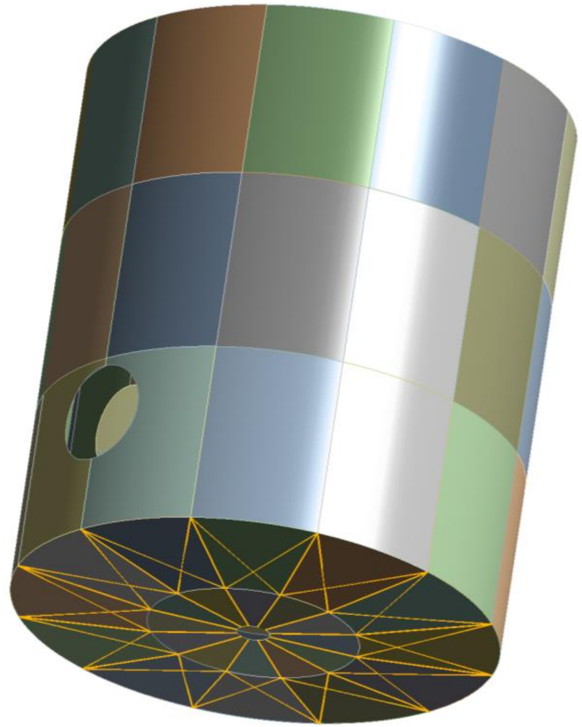


# Reinforcements

- After the first iterations, to increase the first modal analysis responses', I had to added reinforcements, 10x50mm, on the bottom of 5K & 80K shields



80K



5K

# Modal results: significant modes

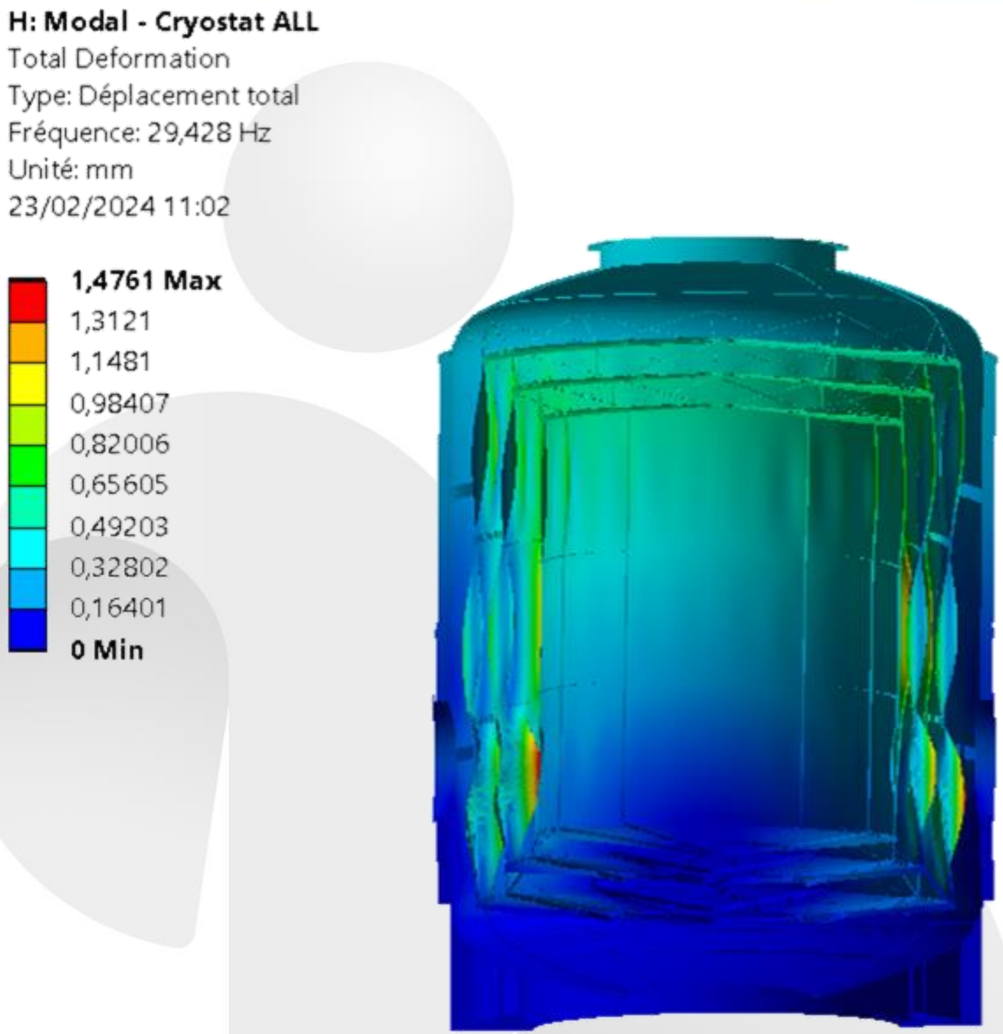
First mode : 29,43 Hz on Y Axis

Third Mode : 30,69 Hz on X Axis

***** MODAL MASSES, KINETIC ENERGIES, AND TRANSLATIONAL EFFECTIVE MASSES SUMMARY *****

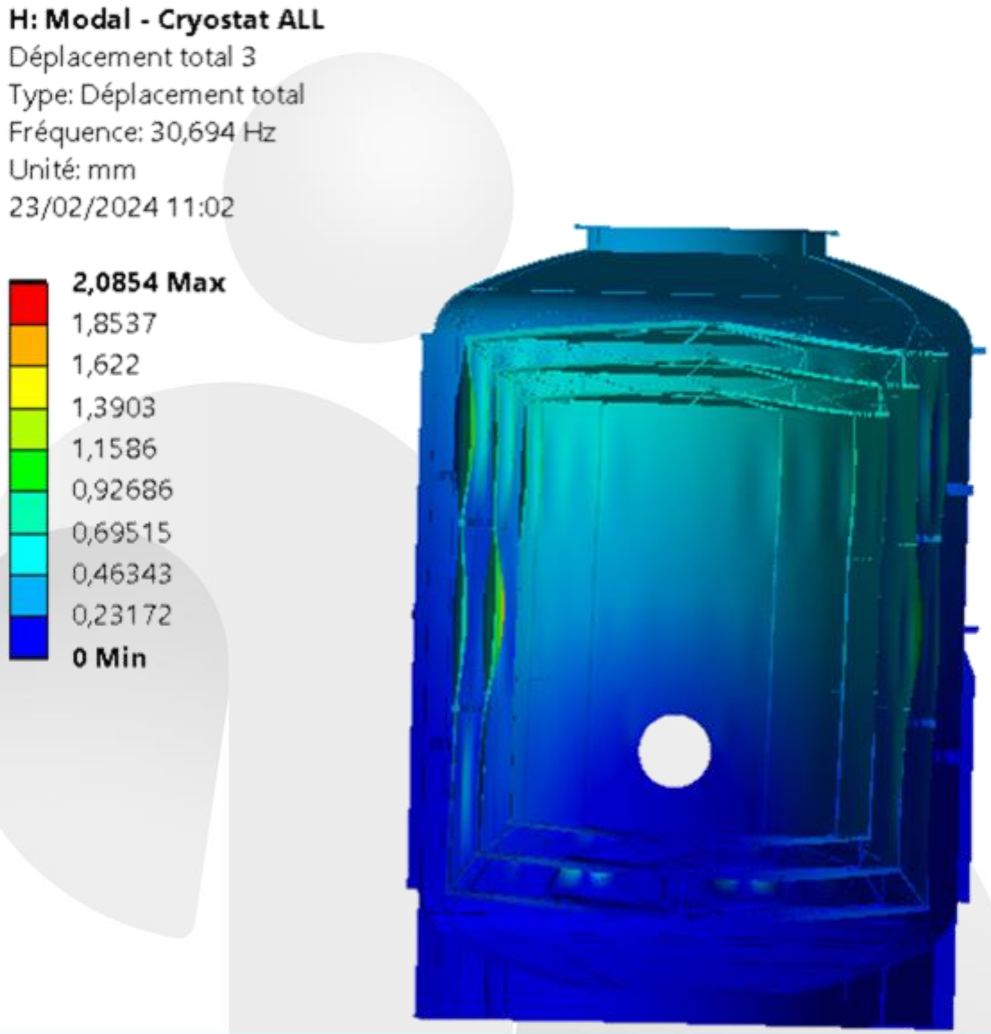
| MODE | FREQUENCY | MODAL MASS | KENE | \| | EFFECTIVE MASS X-DIR | RATIO% | Y-DIR | RATIO% | Z-DIR | RATIO% |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 29.43 | 0.5345 | 9137. | \| | 0.2890E-04 | 0.00 | 8.588 | 41.59 | 0.1011E-03 | 0.00 |
| 2 | 30.64 | 0.2849E-01 | 528.1 | \| | 0.3058E-01 | 0.15 | 0.1767E-03 | 0.00 | 0.3022E-03 | 0.00 |
| 3 | 30.69 | 0.2822 | 5247. | \| | 8.740 | 42.32 | 0.4712E-04 | 0.00 | 0.1158E-04 | 0.00 |
| 4 | 30.90 | 0.5669E-01 | 1069. | \| | 0.7709E-02 | 0.04 | 0.2009E-03 | 0.00 | 0.1680E-02 | 0.01 |
| 5 | 31.01 | 0.6856E-01 | 1301. | \| | 0.2795E-02 | 0.01 | 0.6413E-03 | 0.00 | 0.1034E-03 | 0.00 |
| 6 | 31.04 | 0.2566E-01 | 488.2 | \| | 0.8823E-02 | 0.04 | 0.6674E-03 | 0.00 | 0.1450E-01 | 0.07 |
| 7 | 31.94 | 0.1227E-01 | 247.1 | \| | 0.2985E-02 | 0.01 | 0.2800 | 1.36 | 0.8624E-03 | 0.00 |
| 8 | 32.14 | 0.3381E-02 | 68.93 | \| | 0.5236E-01 | 0.25 | 0.1281E-03 | 0.00 | 0.2322E-05 | 0.00 |
| 9 | 32.16 | 0.6341E-02 | 129.4 | \| | 0.7839E-01 | 0.38 | 0.2529E-02 | 0.01 | 0.1114E-03 | 0.00 |
| 10 | 32.17 | 0.2104E-02 | 42.97 | \| | 0.1620E-02 | 0.01 | 0.4266E-03 | 0.00 | 0.9237E-05 | 0.00 |
| 11 | 32.27 | 0.2020E-02 | 41.52 | \| | 0.2848E-05 | 0.00 | 0.3412E-05 | 0.00 | 0.2176E-04 | 0.00 |
| 12 | 32.28 | 0.2881E-02 | 59.26 | \| | 0.2899E-04 | 0.00 | 0.5874E-06 | 0.00 | 0.2077E-03 | 0.00 |
| 13 | 32.43 | 0.1745E-02 | 36.23 | \| | 0.3736E-02 | 0.02 | 0.1319E-04 | 0.00 | 0.4398E-04 | 0.00 |
| 14 | 32.53 | 0.7507E-02 | 156.8 | \| | 0.1042E-02 | 0.01 | 0.1502E-07 | 0.00 | 0.1100E-01 | 0.05 |
| 15 | 32.54 | 0.1379E-01 | 288.1 | \| | 0.1592E-05 | 0.00 | 0.2917E-03 | 0.00 | 0.3082E-01 | 0.15 |
| 16 | 32.61 | 0.5142E-02 | 107.9 | \| | 0.1355E-02 | 0.01 | 0.3848E-04 | 0.00 | 0.1100E-03 | 0.00 |
| 17 | 32.69 | 0.1746E-02 | 36.82 | \| | 0.3744E-04 | 0.00 | 0.3897E-04 | 0.00 | 0.4079E-02 | 0.02 |
| 18 | 32.70 | 0.2001E-02 | 42.25 | \| | 0.6735E-04 | 0.00 | 0.1523E-03 | 0.00 | 0.3574E-02 | 0.02 |
| 19 | 32.73 | 0.2637E-02 | 55.76 | \| | 0.1704E-02 | 0.01 | 0.1494E-03 | 0.00 | 0.6778E-03 | 0.00 |
| 20 | 32.75 | 0.4223E-02 | 89.40 | \| | 0.2201E-05 | 0.00 | 0.2237E-02 | 0.01 | 0.8976E-02 | 0.04 |
| sum | | | | \| | 8.933 | 43.26 | 8.875 | 42.98 | 0.7720E-01 | 0.37 |

# Mode 1 in vertical Y direction



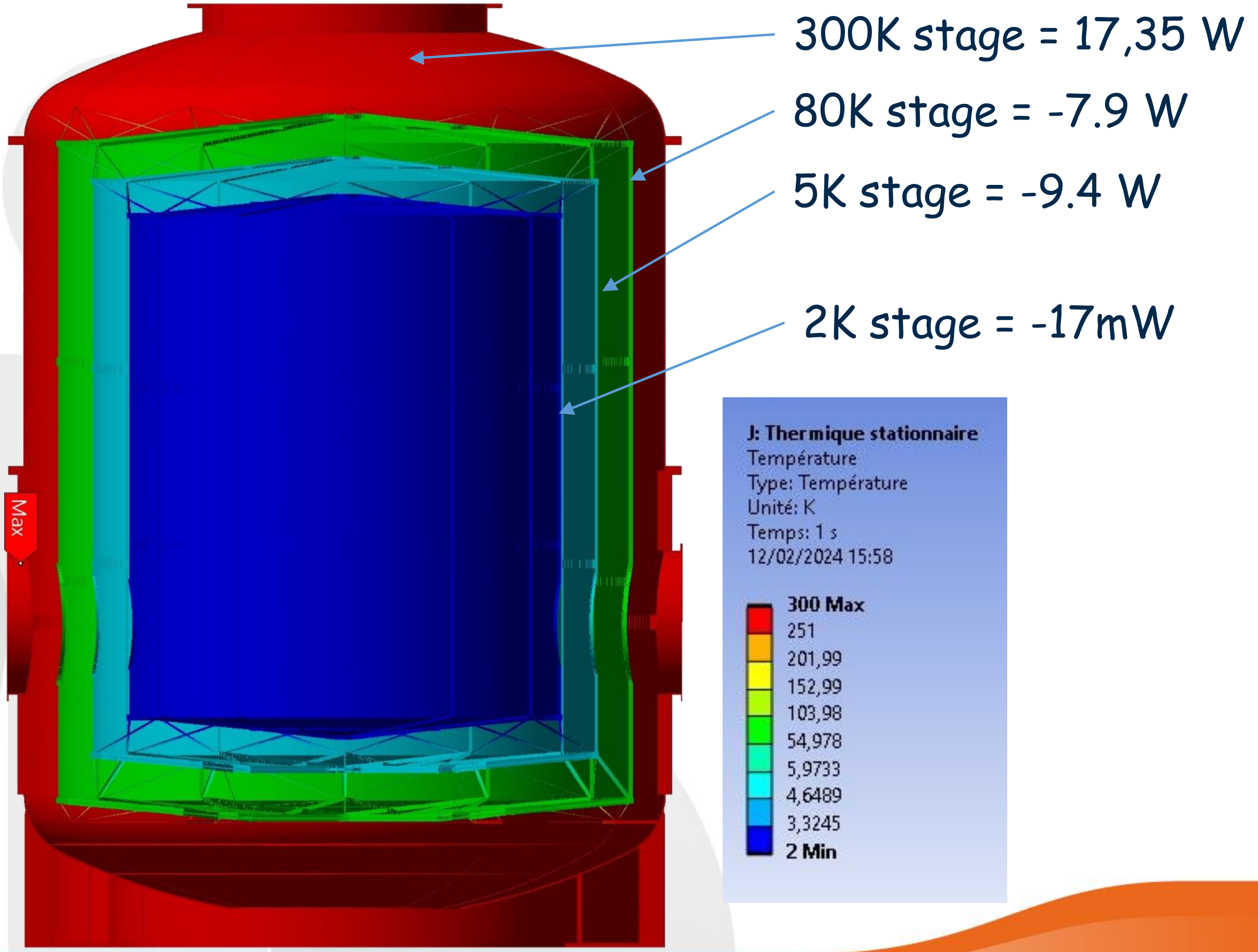
# Mode 3 in lateral X direction





# Thermal results: conductive heat transfer total

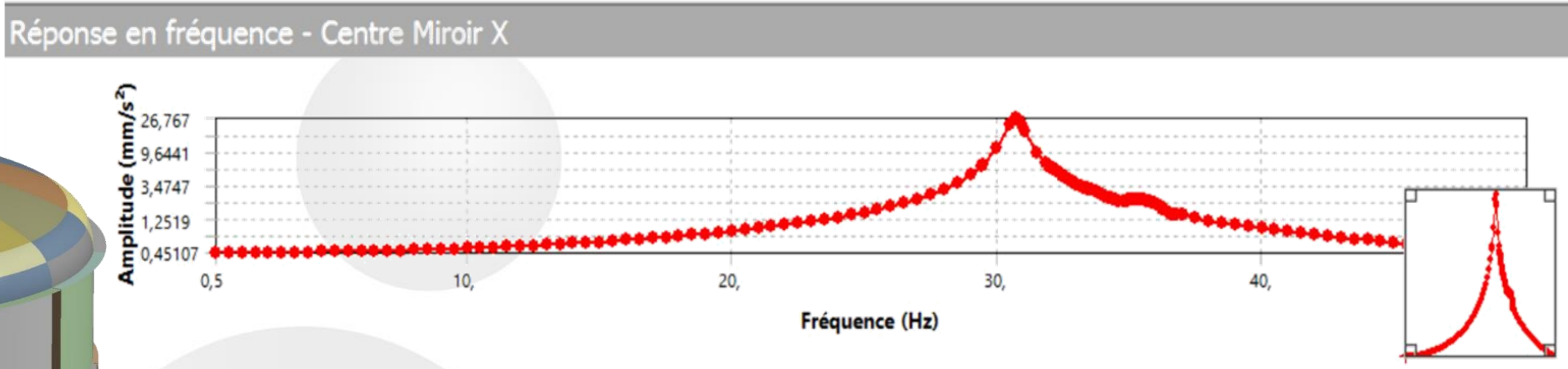


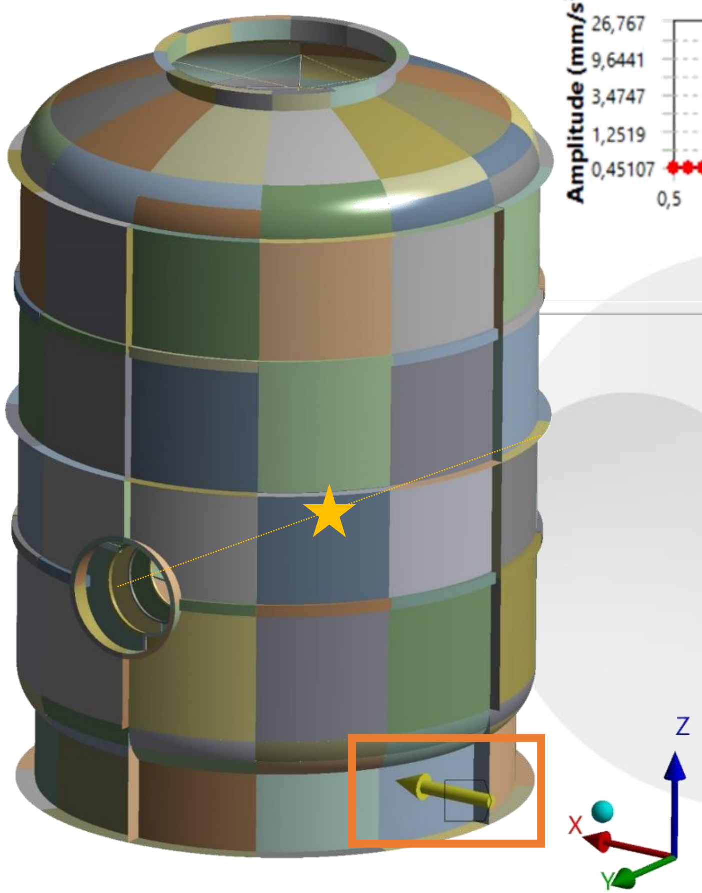



- Possibilities to decrease conductive heat transfer by :
  - Adding Fiber Glass rods instead of Stainless Steel
  - Using carbon PEEK interfaces between shields & Rods

# Harmonic Responses – X Axis

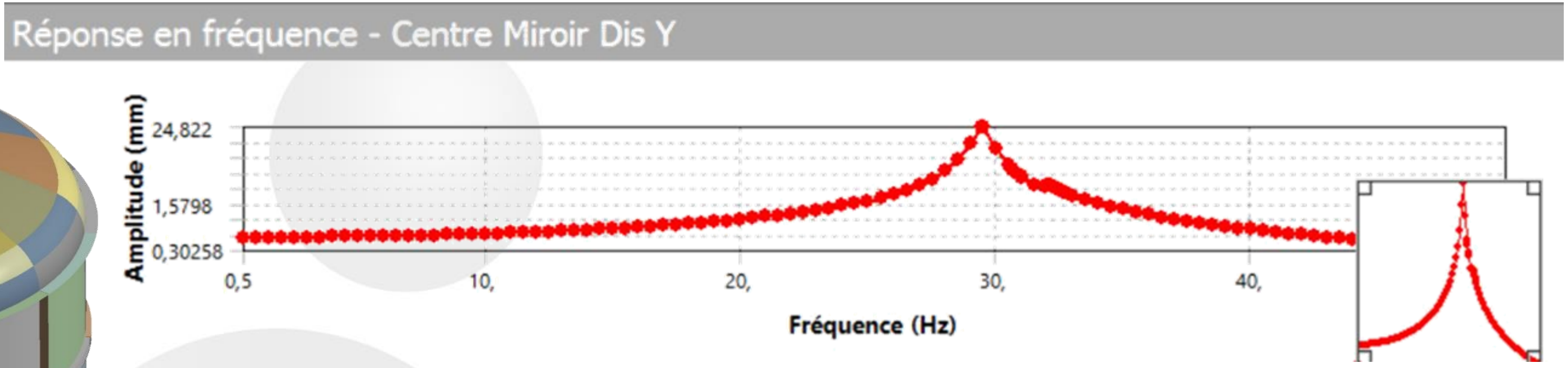


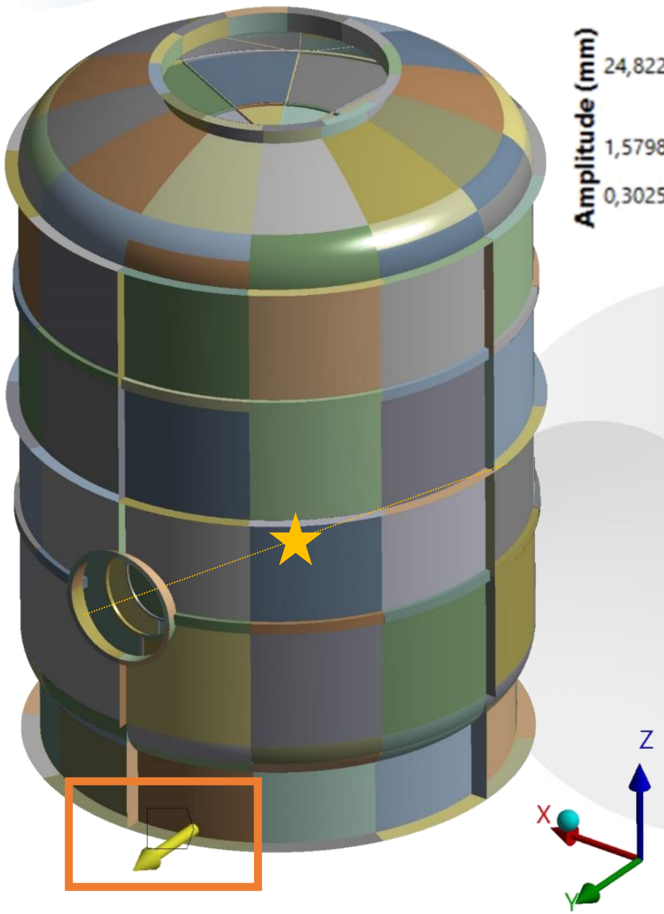



- *Analysis settings* :
  - 2% damping for welded assemblies of steel structure according to Eurocode 8 - Design of structures for their resistance to earthquakes
  - Input 1mm on X axis on cryostat vaccum chamber's ground feet
- It's the results on centre vaccum where the mirror is

# Harmonic Responses – Y Axis




- Analysis settings :
  - 2% damping for welded assemblies of steel structure according to Eurocode 8 - Design of structures for their resistance to earthquakes
  - Input 1mm on Y axis on cryostat vaccum chamber's ground feet
- It's the results on centre vaccum where the mirror is
- Here is a proposal for a rigid support not sensitive to **resonant** vibration effect below 29 Hz.
  => But is still not a low vibration transmitter after 21 Hz on Y axis & 22 Hz on X axis as there is no passive vibration insulation (ratio output/input > 1)

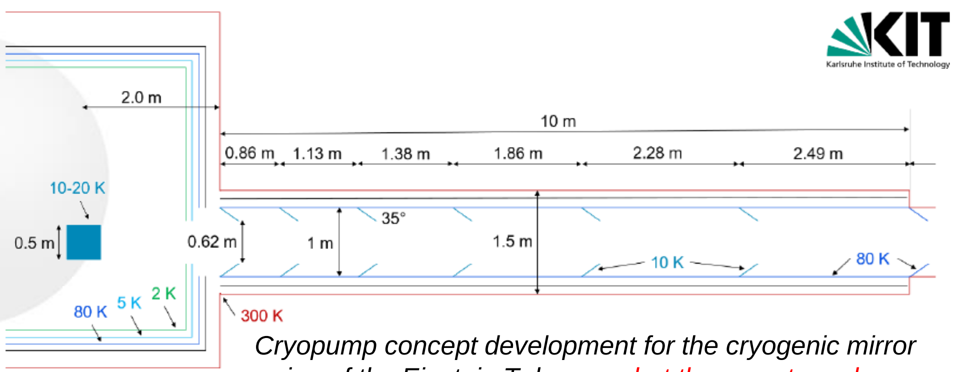
# Conclusion

**Next steps** :

- If needed, find solution to increase the first modal response
- Refine design details such as :
    - Rods fixation on shields
    - PEEK interfaces on shields to decrease thermal responses
- Perform thermal radiation analysis between shields
- Add a wide baffle studies on 2K Shield with an active vibration insulation
- Organize a discussion with Michael @ KIT about design details about thermal shields and interfaces

# Cavern

# Inputs




*Cryopump concept development for the cryogenic mirror region of the Einstein Telescope* <u>*but the cryoptraps beam tubes are attached to the payload*</u>

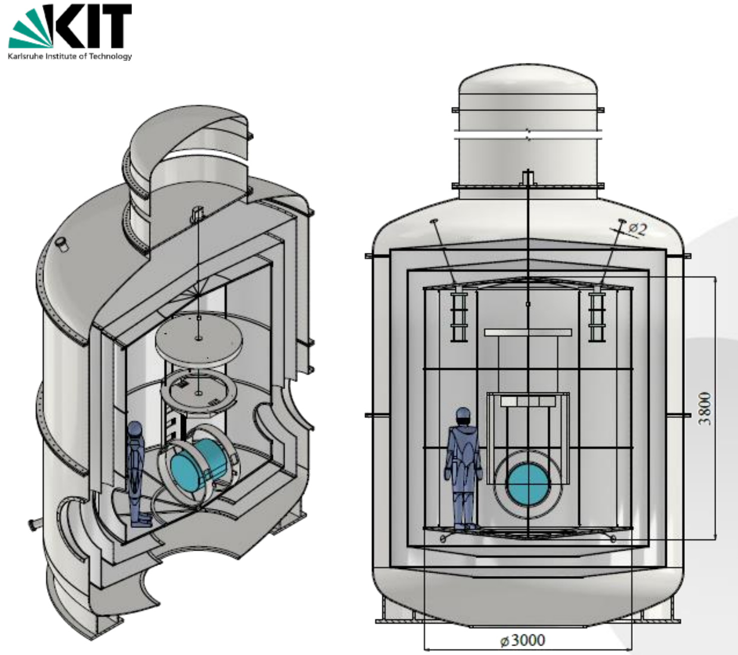



**Figure 1.** Conceptual layout of thermal shields for cryogenic ET-LF payloads within a dummy cryostat.

*Low-noise thermal shielding around the cryogenic payloads in the Einstein Telescope*

*ET-caverns-DesignReportUpdate2020*

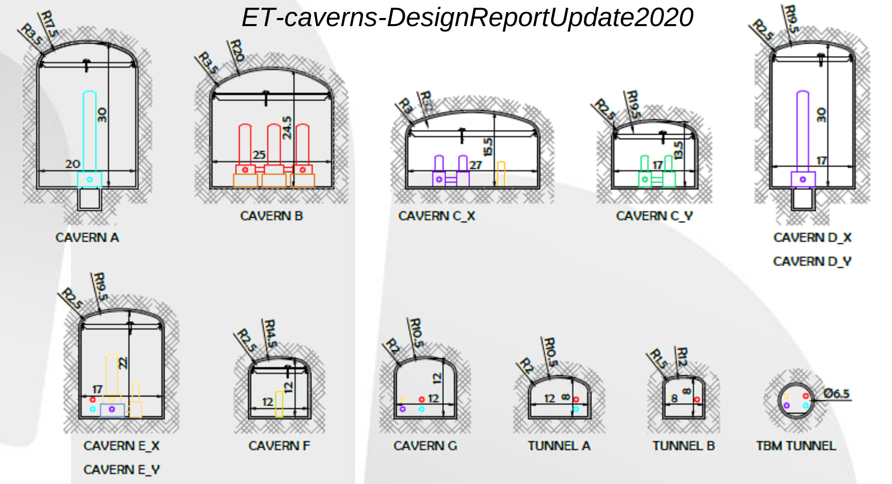
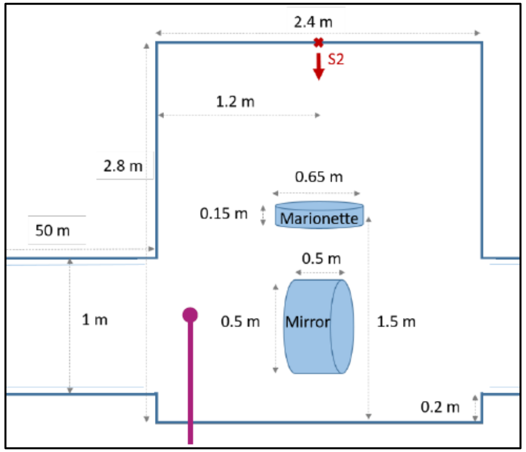
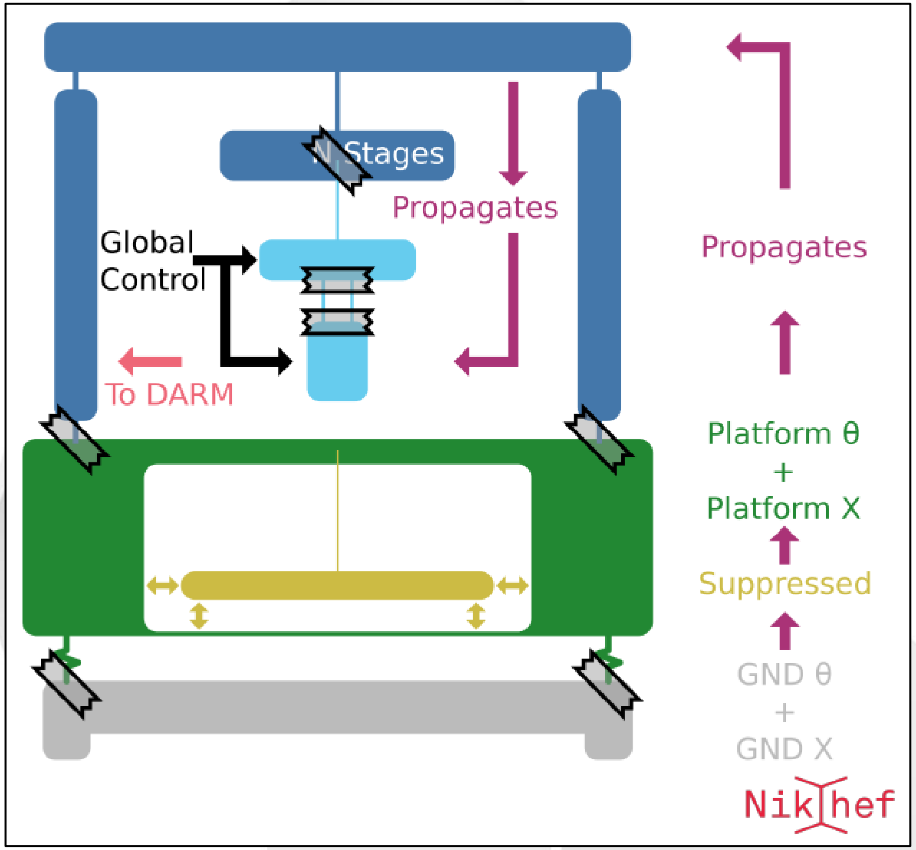


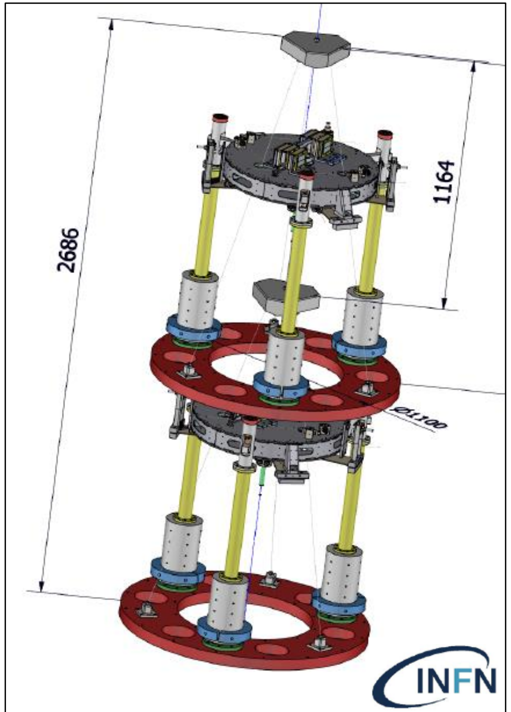

Figure 7.16: Sizes of Caverns.



# Inputs

- ePIP : Pair of superattenuator proposed by Francesco Fidecaro (INFN design)
- ANM proposed by Conor M. Mow-Lowry (Nikhef design) cuts all seismic background noise prior to mirror suspension

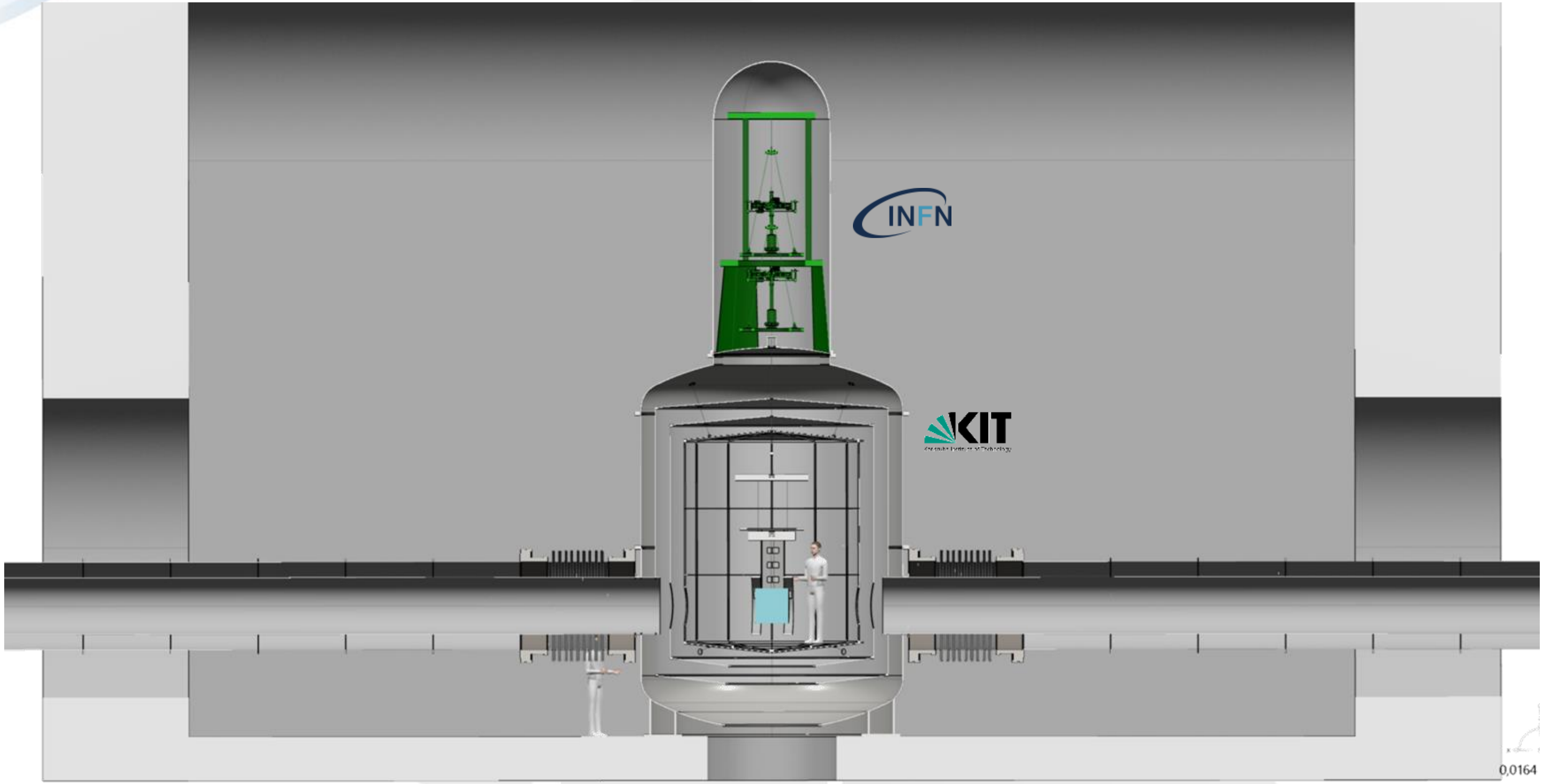


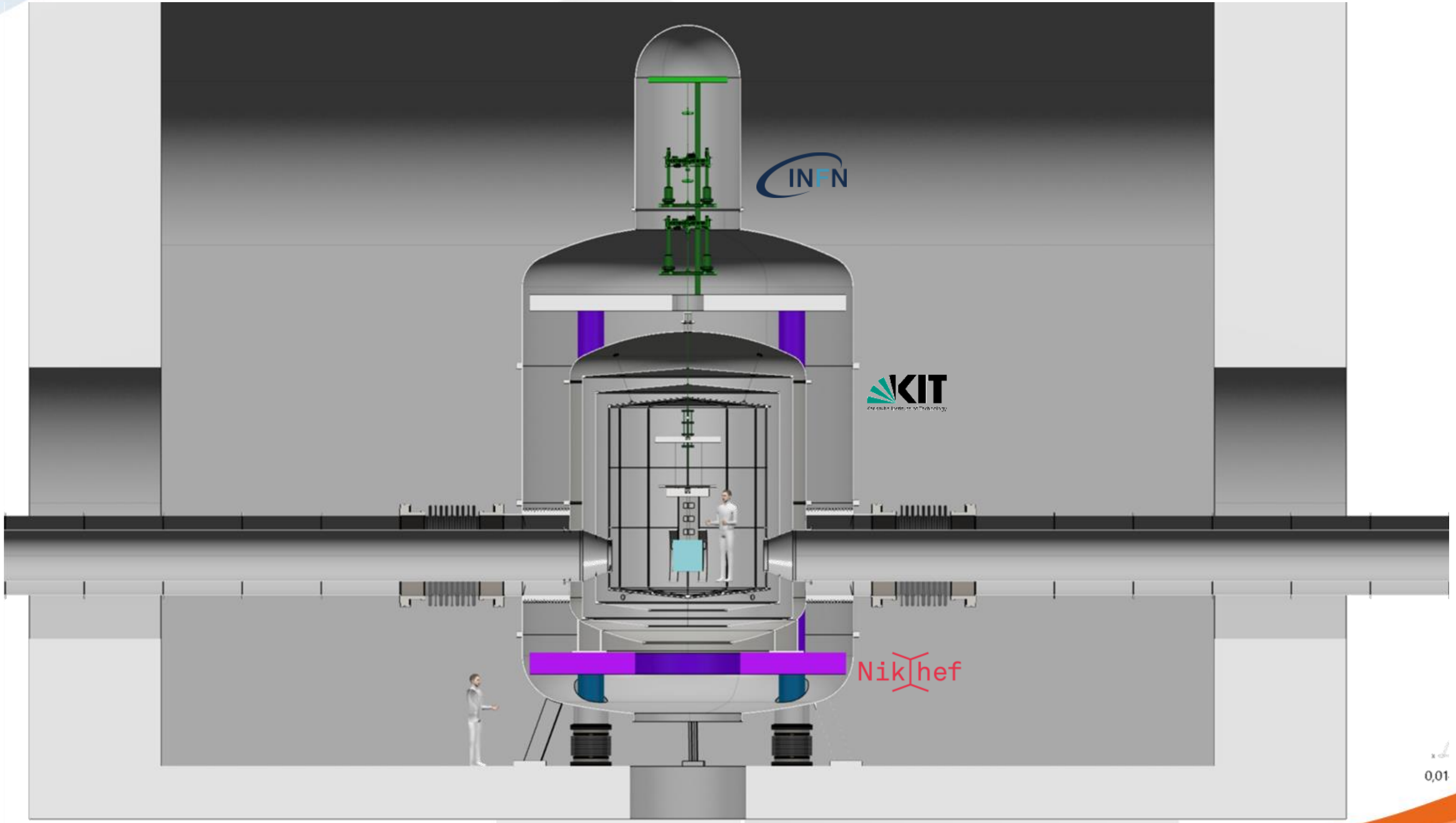
*ET-0375A-23 - Novel prototype filter for the ET Superattenuator*

# 2.1 Single-cavern with Super Attenuator and without Active Seismic Platform (ASP)

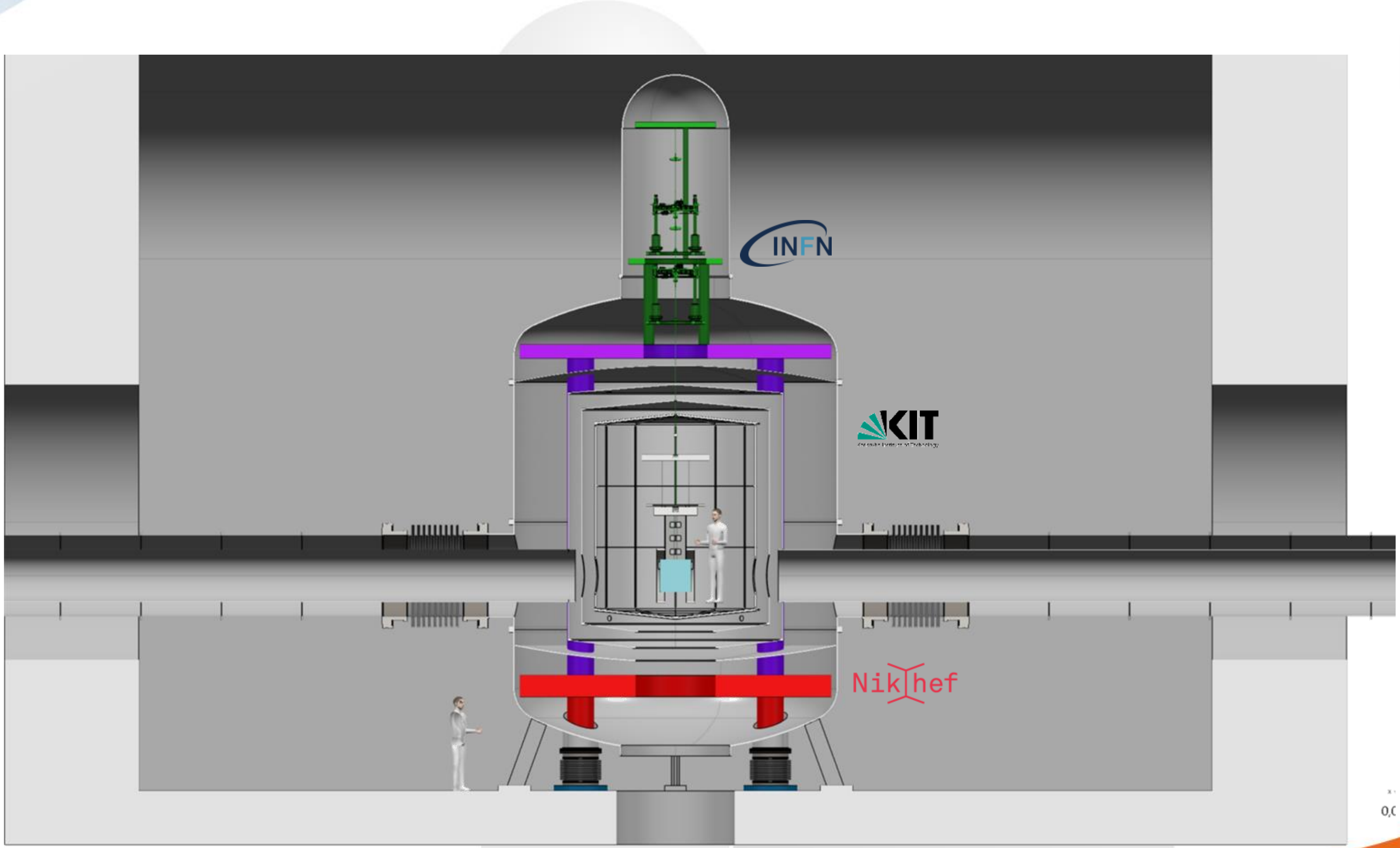


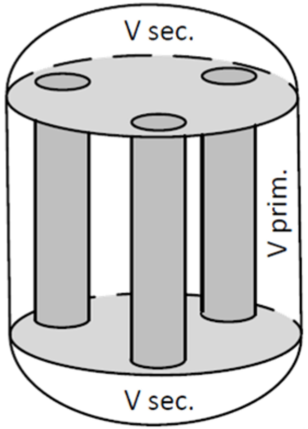


# 2.2 Single-cavern with Super Attenuator, Active Seismic Platform and nested vacuum

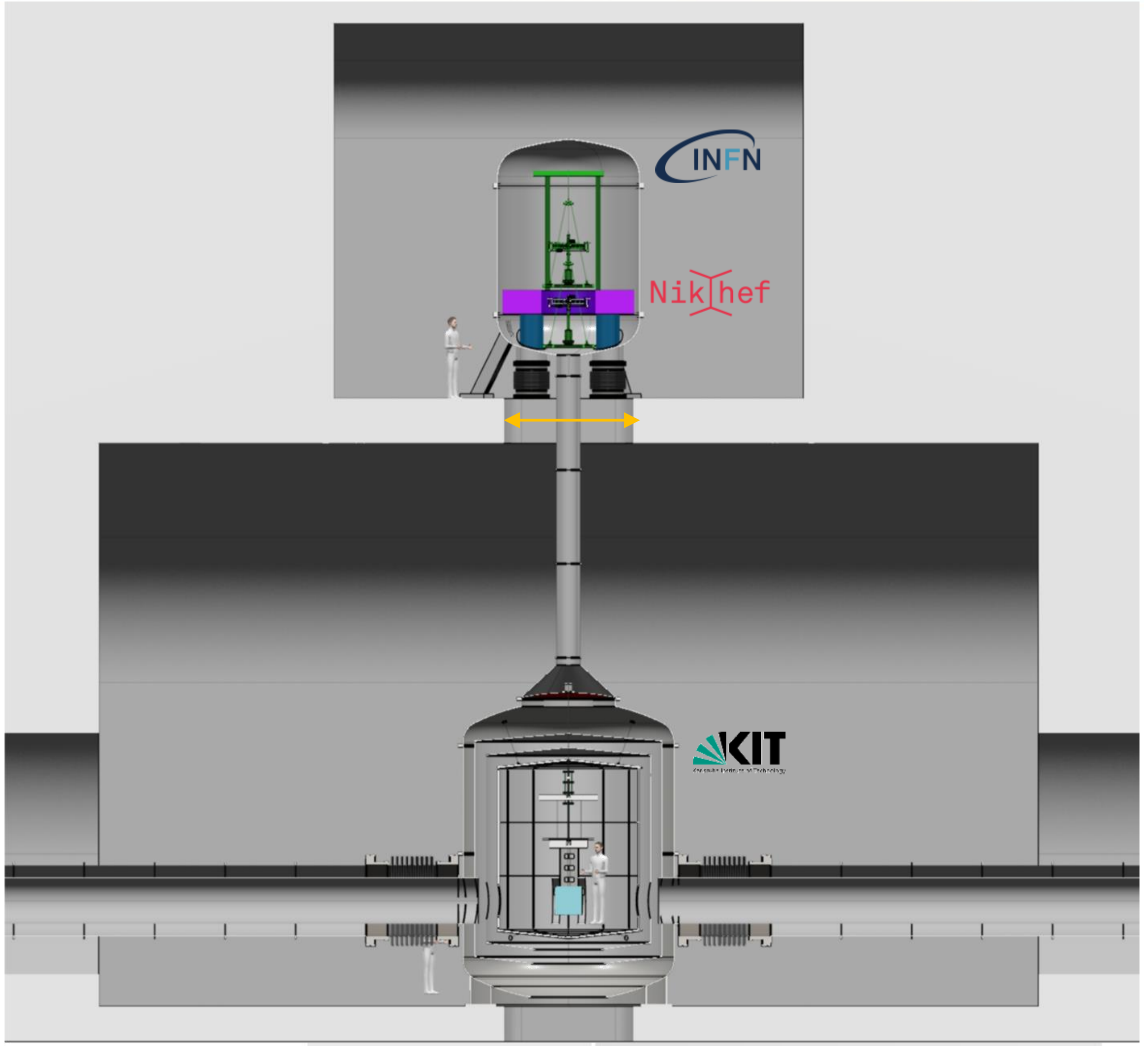


## 2.3 Single-cavern with Super Attenuator, Active Seismic Platform and separated vacua



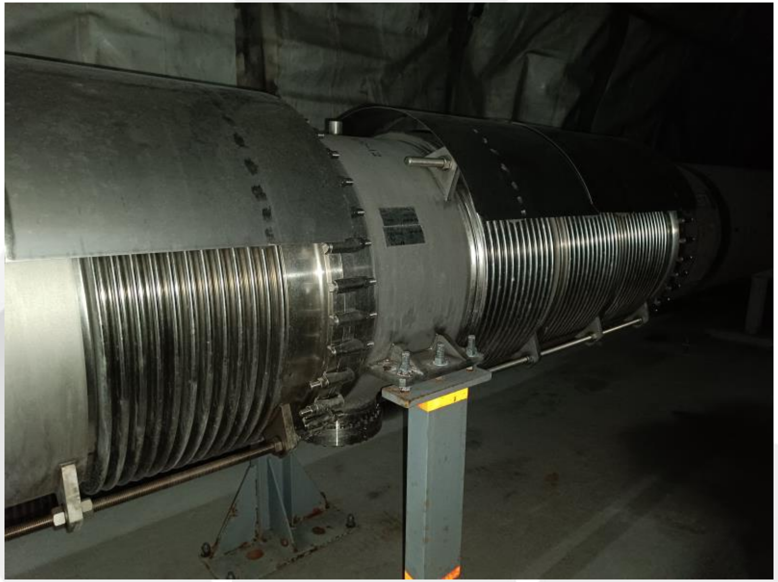



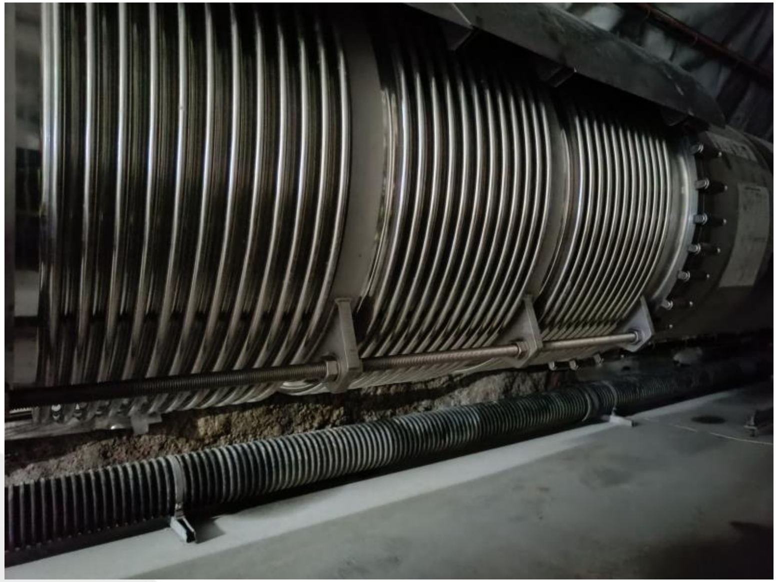
# 2.4 Double-cavern with Super Attenuator, Active Seismic Platform and nested vacuum



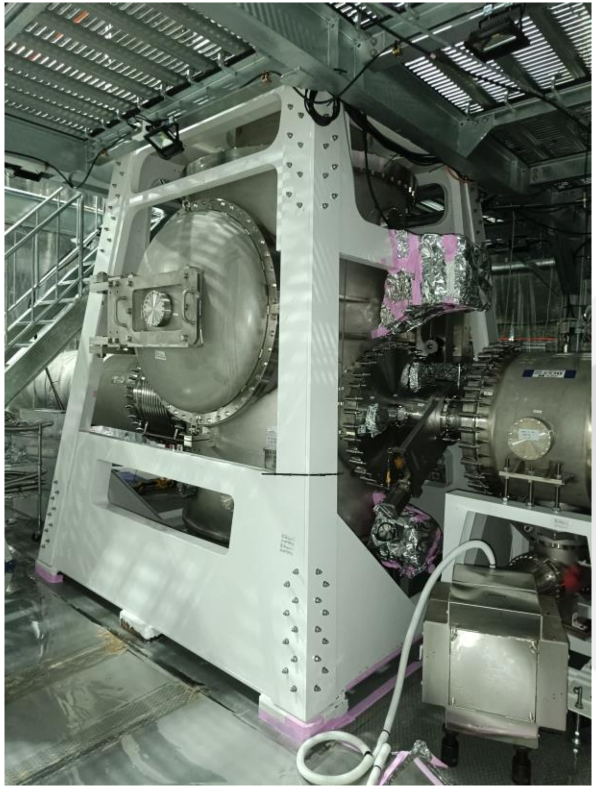
# Kagra's visit by ISB team and Philippe Rosier

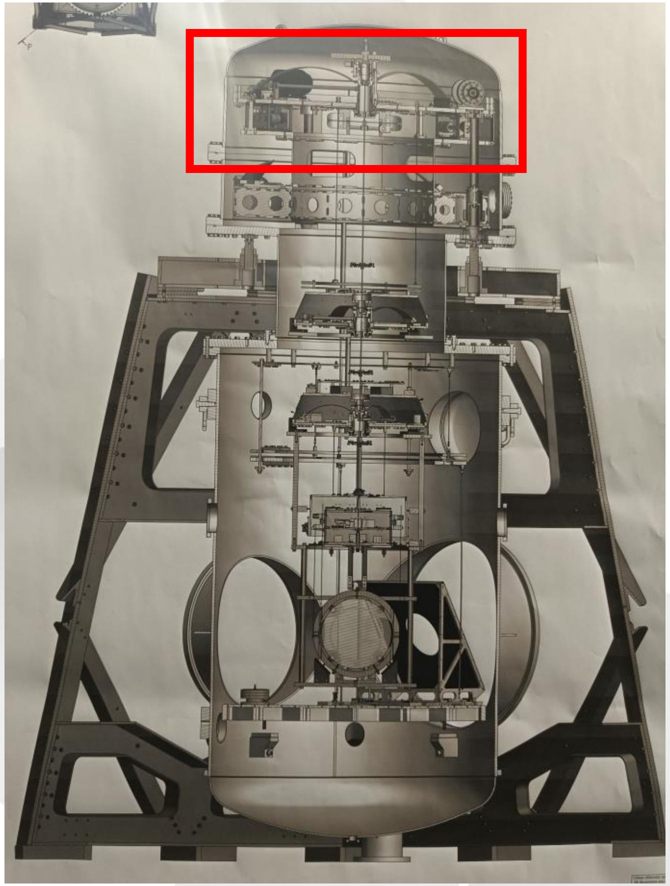
# Beam tube & cavern



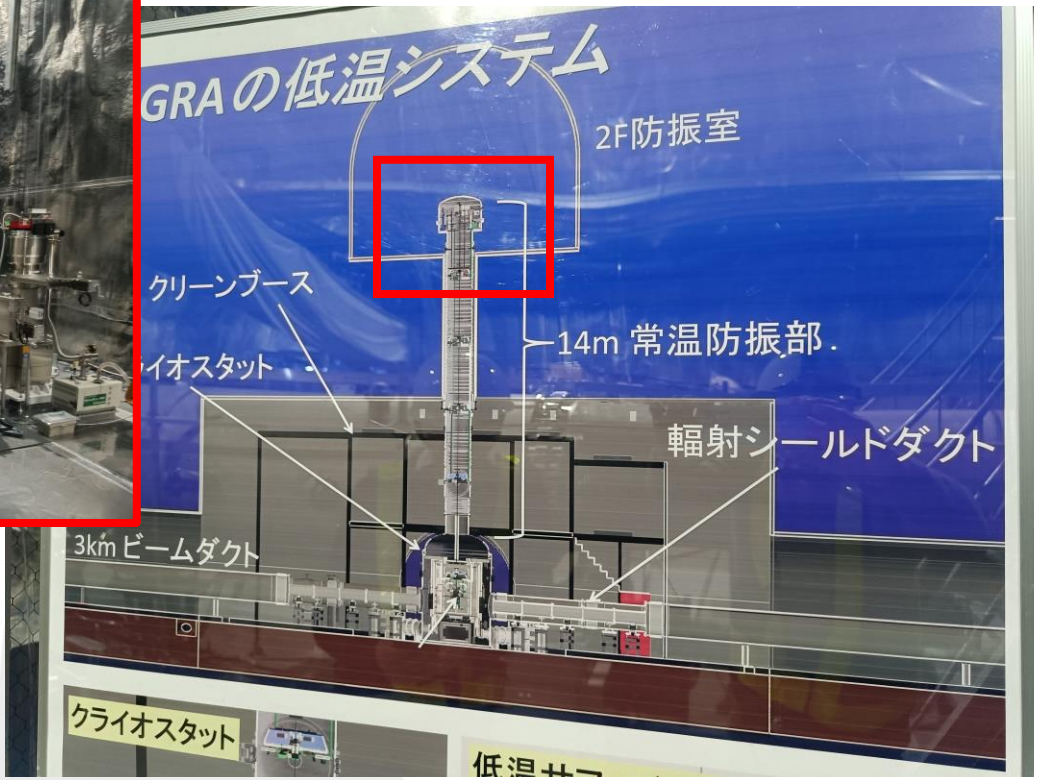


# Warm tower & suspension system

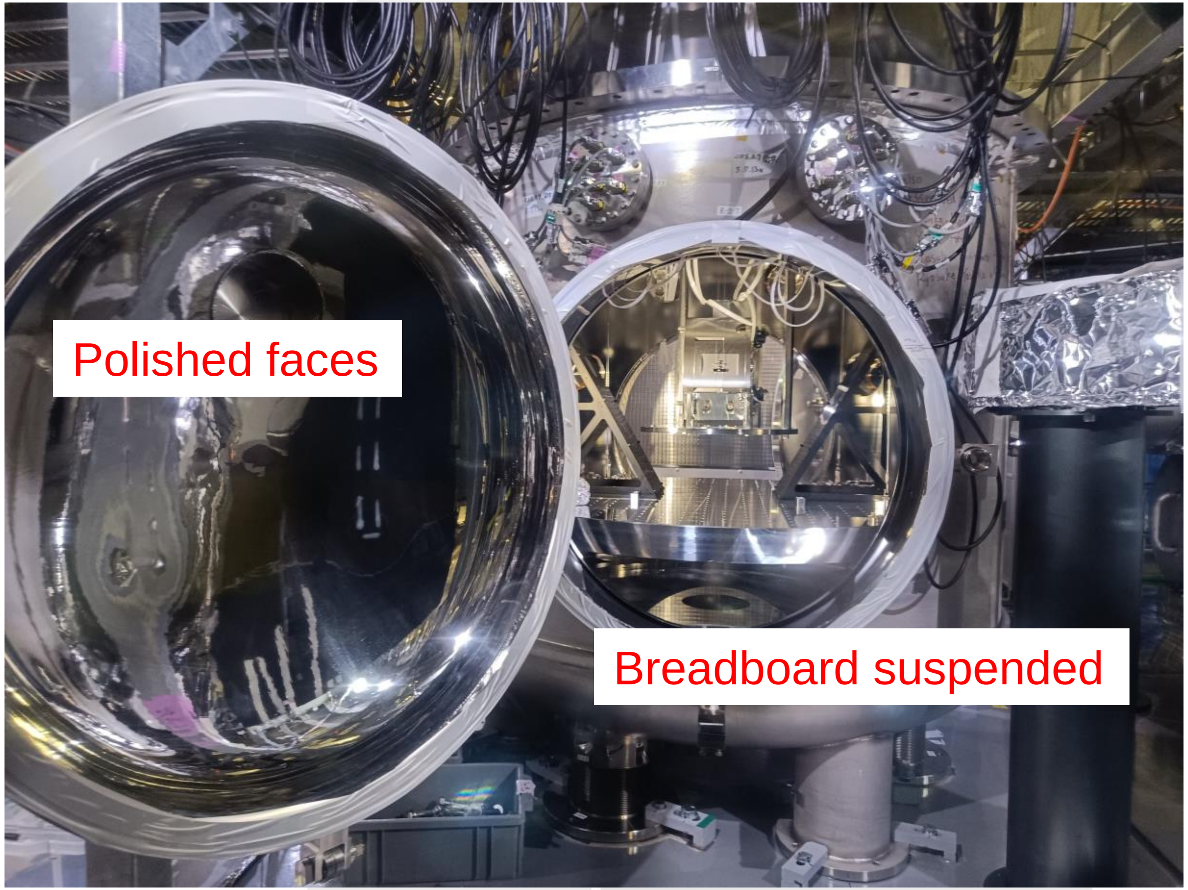




# Double Cavern




# Cryostat



# Conclusion

<u>Next steps</u> :

- Refine the need for civil engineering (and for the engineering team) – domain outside the towers, installation and interfaces
- Towers and mirrors inventory / naming
- Define allocated volumes => build up a general CAD model ?
- Interfaces lists' to do or to update
- Develop internal mechanical systems for the tower (cryostat, screen, suspensions, assembly procedures and tools)
- Feasibility pre-procedures (installation, assembly, maintenance, tooling) to predict impact on interfaces
- More face to face meeting which are more efficient but most expensive

# Thanks for your attention

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