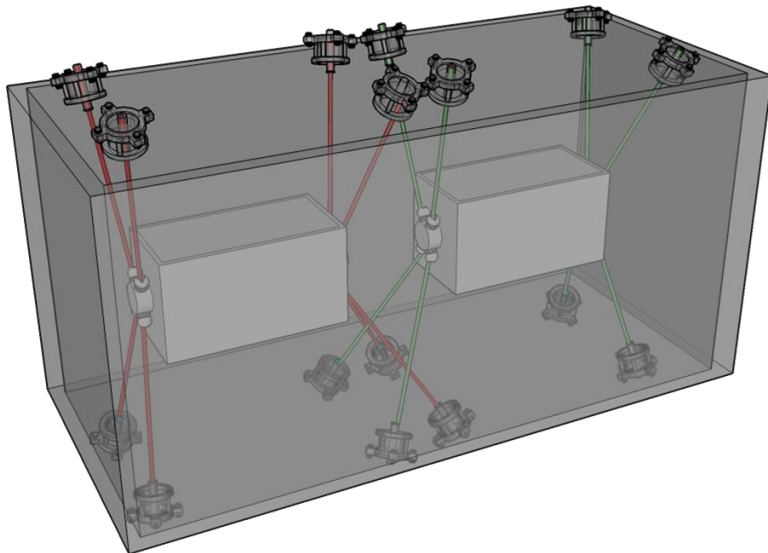




Results of the cold test on the RFD prototype Oct 2023-May 2024



Vivien RUDE

2024-07-04

On behalf :

Praneeth Sarvade,

Daniel Szarata

Clara Cala Franco

Julia Calmels

Mateusz Sosin

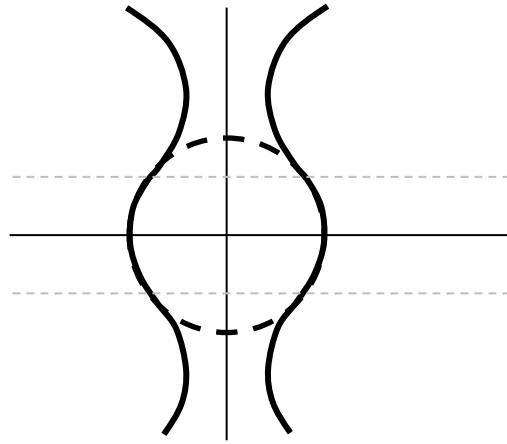
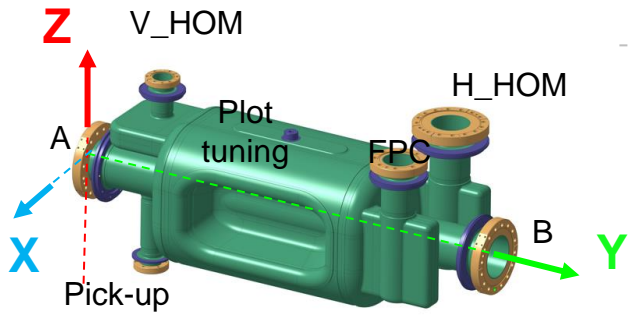
Outline

- Introduction
- Measurement at ambient pressure
- Measurement under vacuum
- Measurement at COLD
- Warm-up
- Conclusion

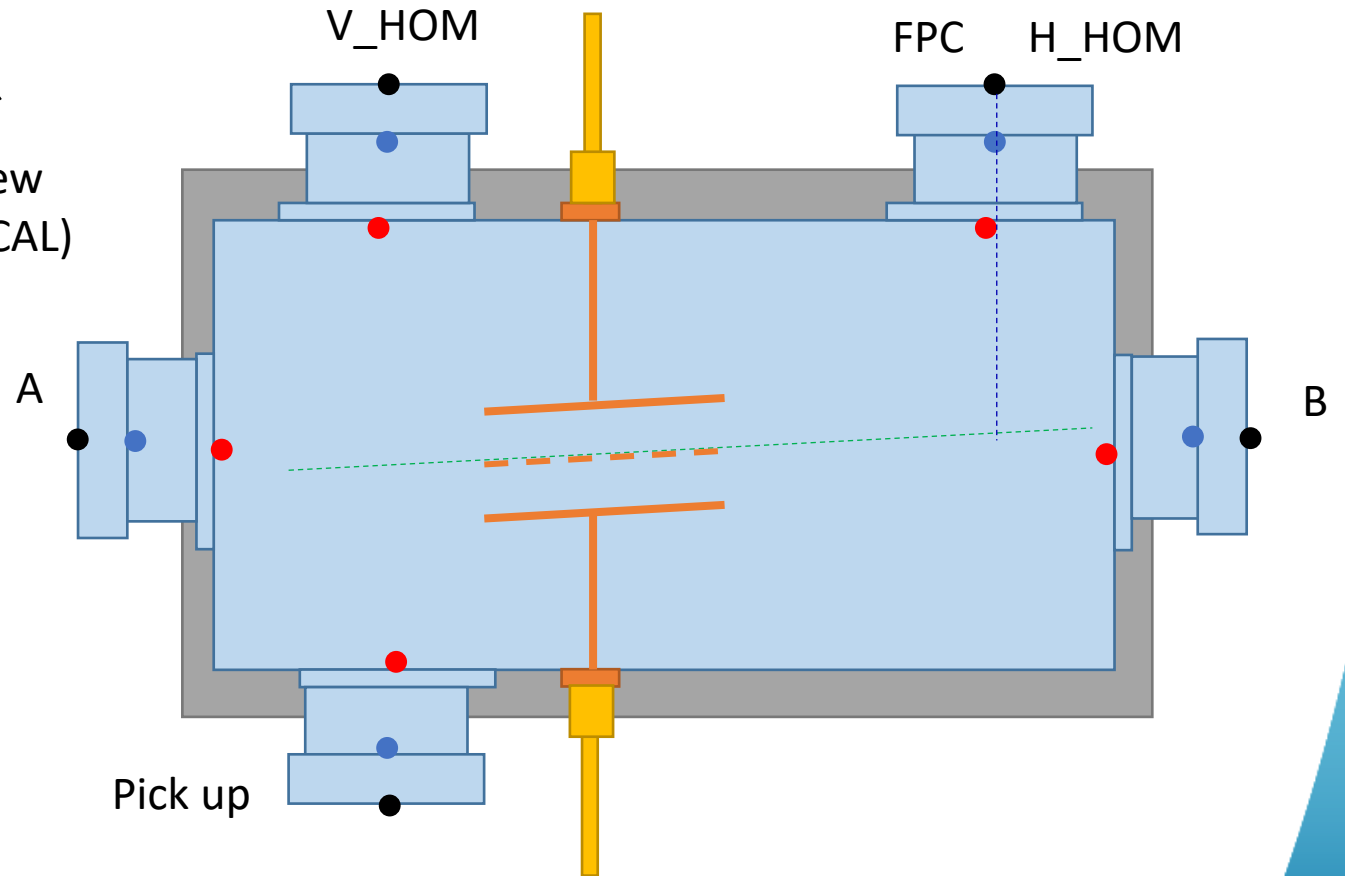
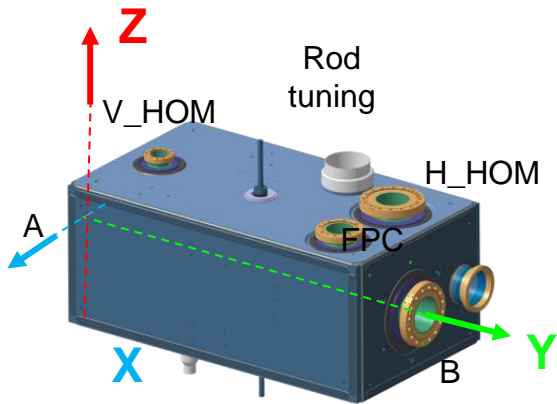
Introduction



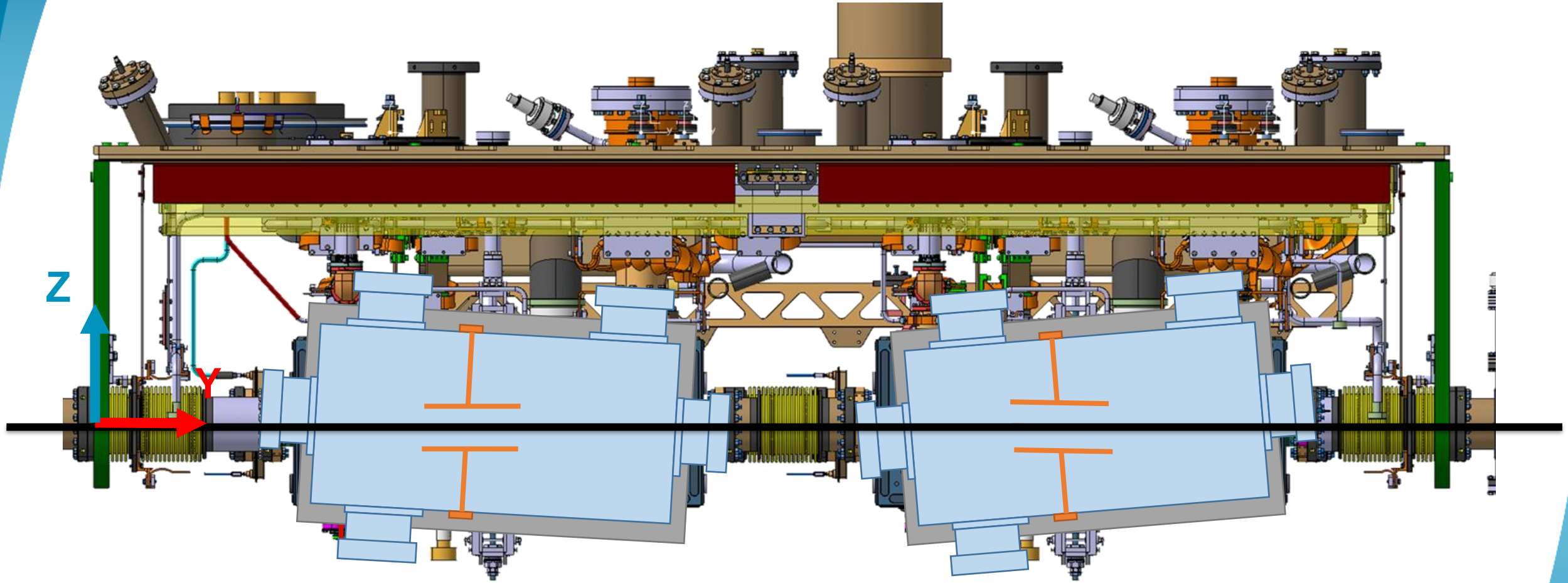
Axis of the capacitive plates



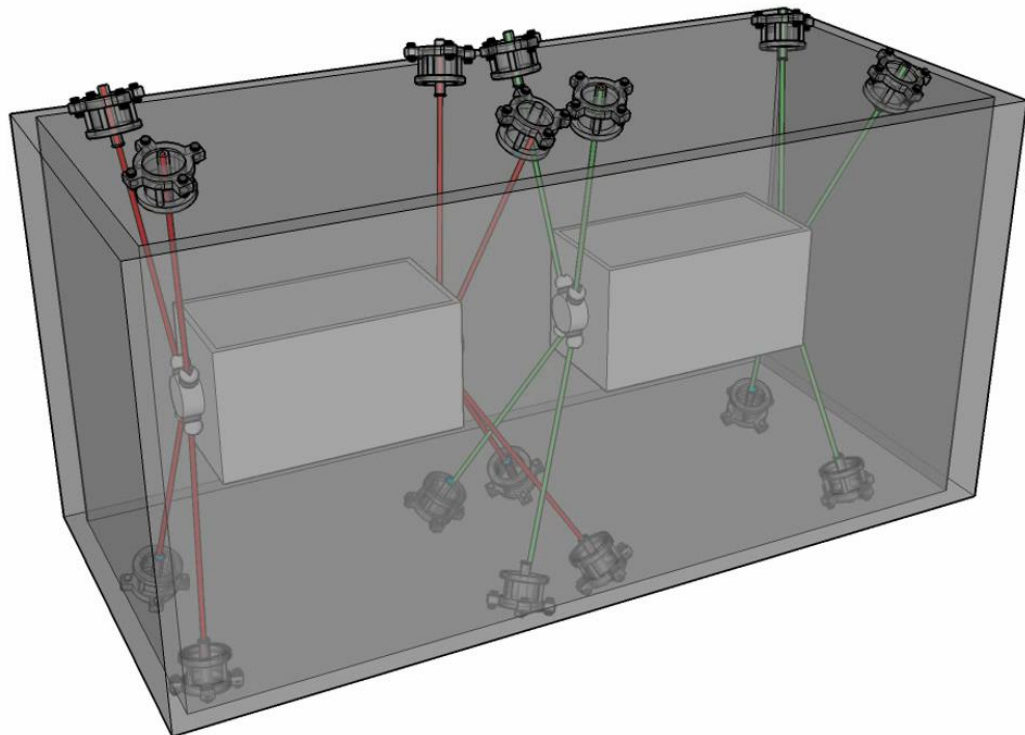
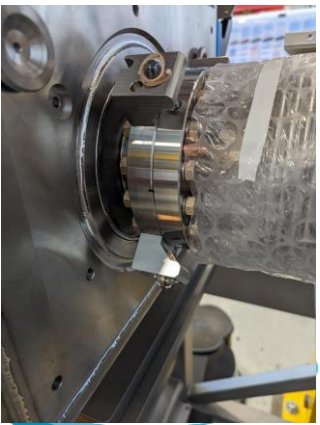
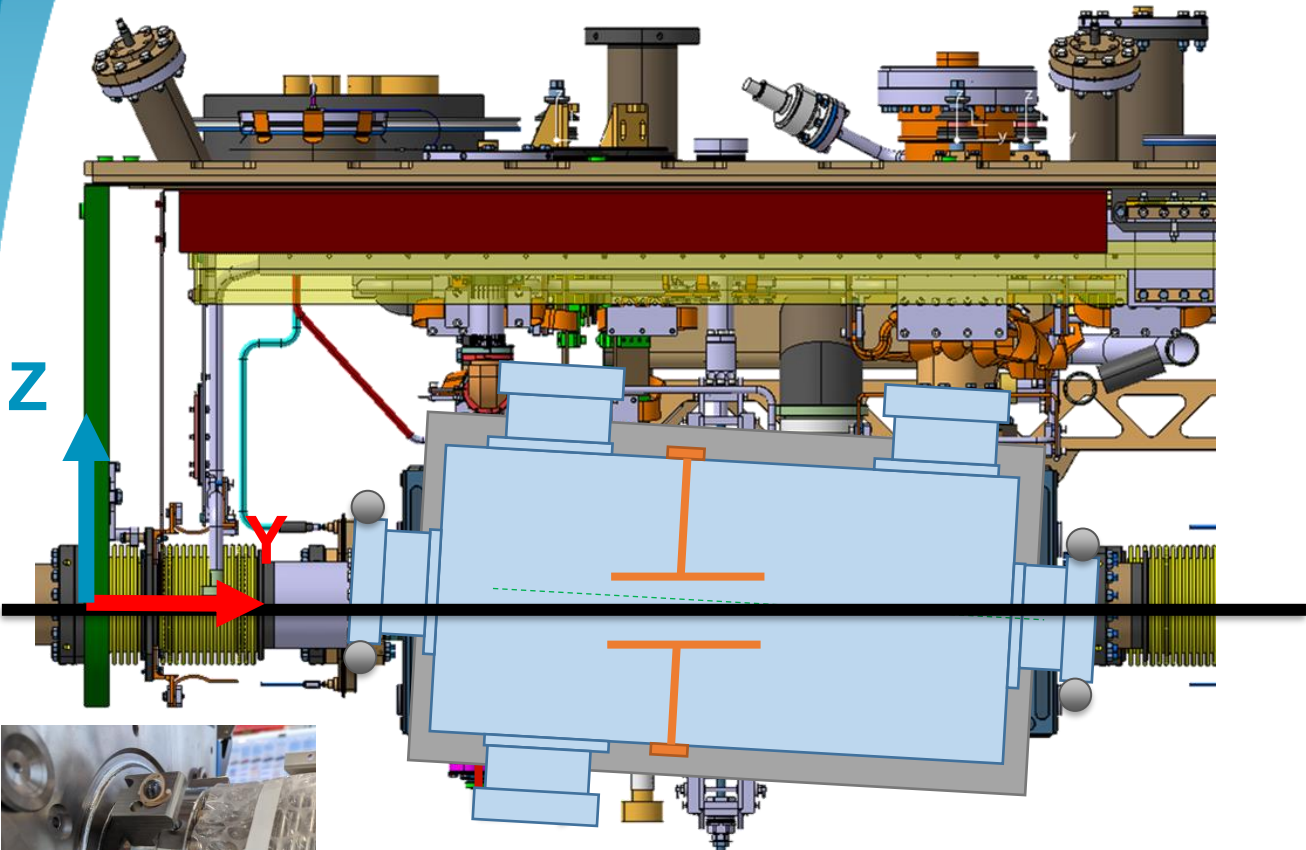
Side view (VERTICAL)



Alignment of the axis of the capacitive plates on the cryomodule



FSI configuration

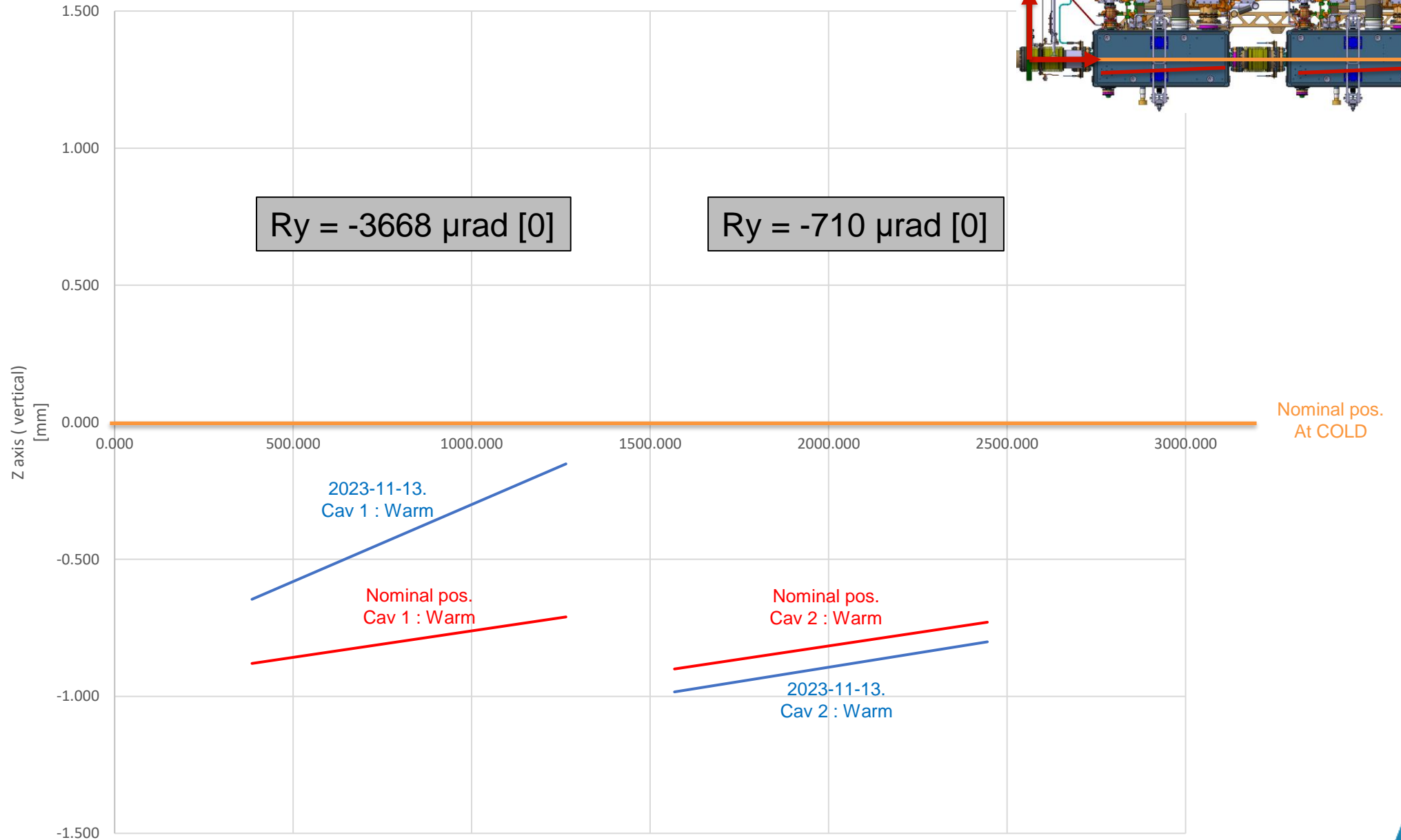
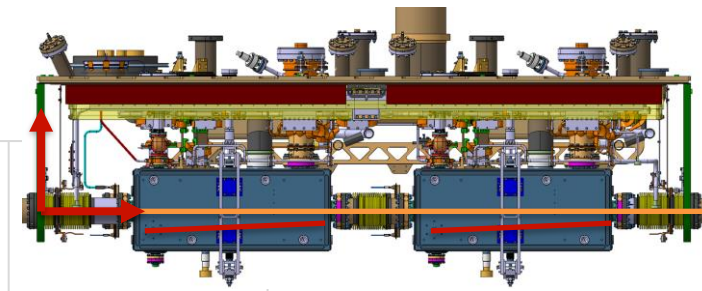


EDMS : 2996397



Vertical position : 10 November 2023

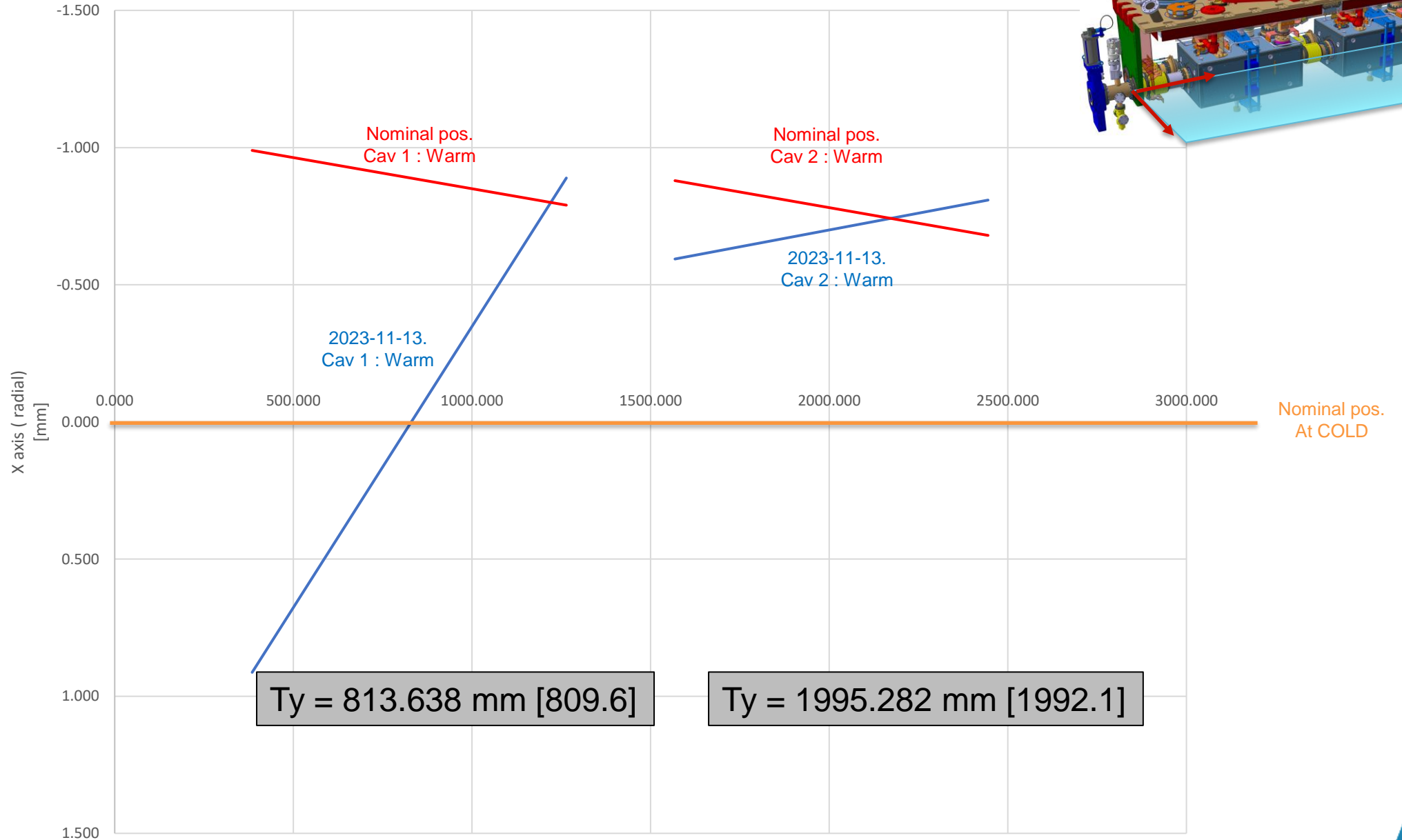
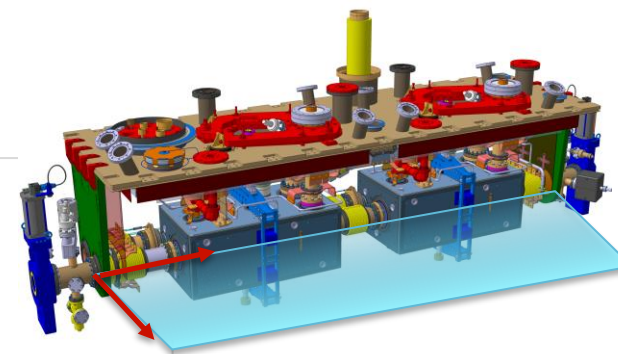
Vertical position of the cavities w.r.t. Nominal



Vertical Accuracy : +/- 0.03 mm

Radial position : 10 November 2023

Radial position of the cavities w.r.t. Nominal



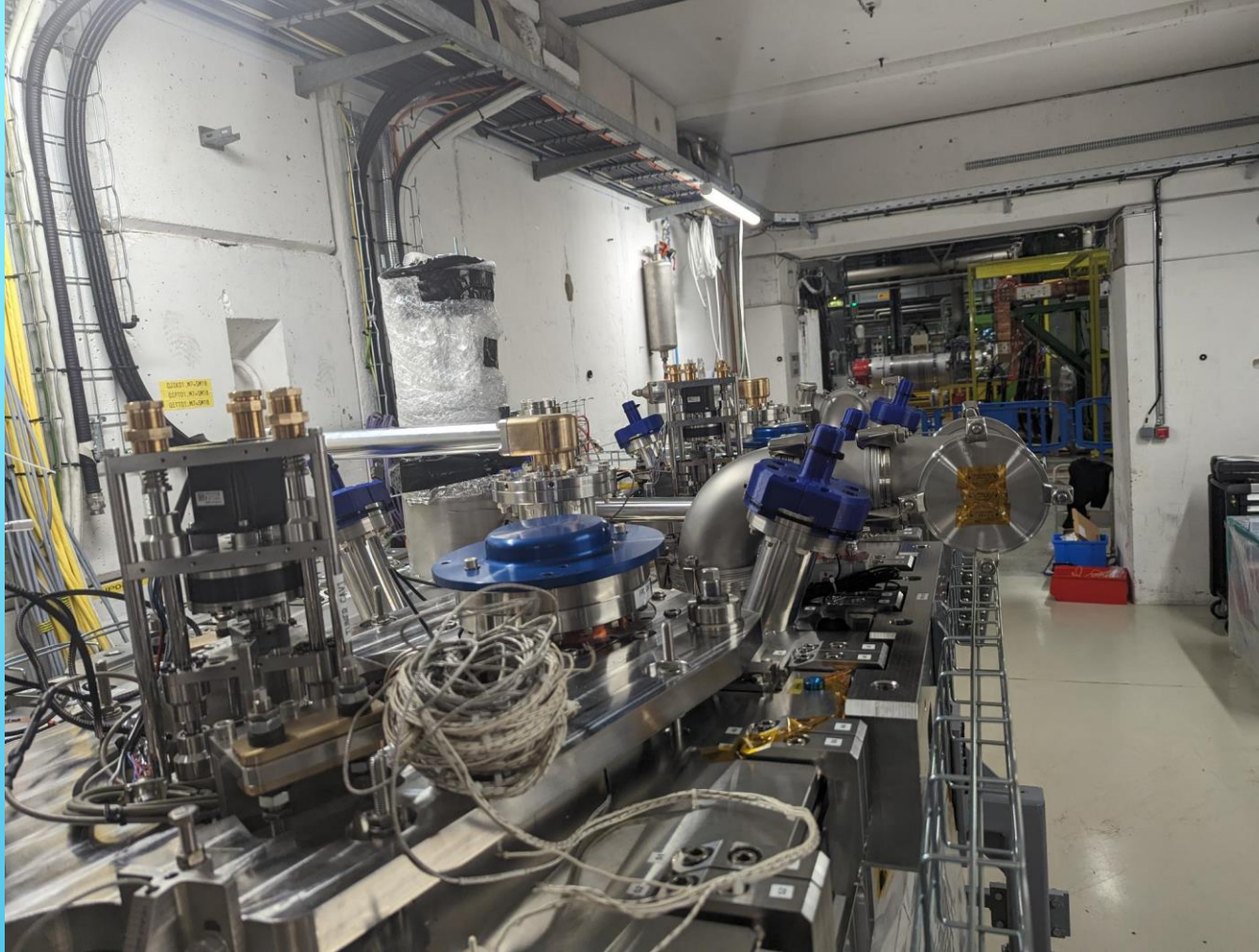
Ty = 813.638 mm [809.6]

Ty = 1995.282 mm [1992.1]

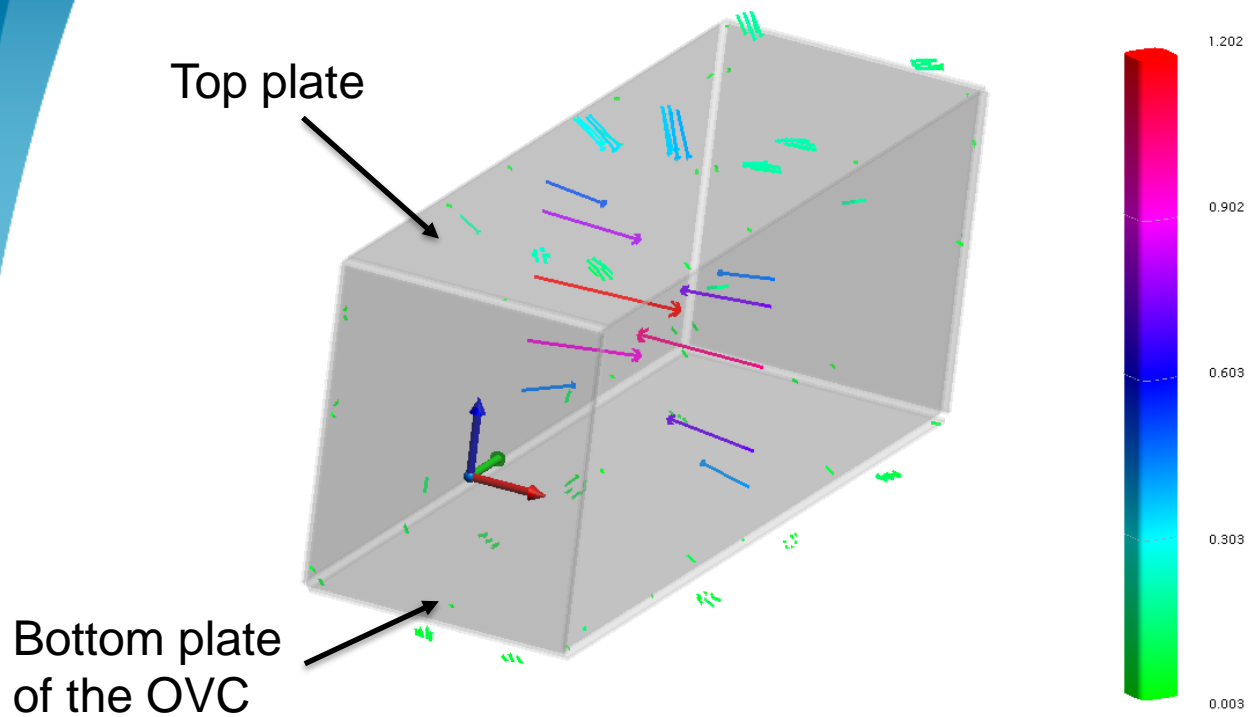
Cavity 1 : Radial Accuracy : +/- 0.10 mm
 Cavity 2 : Radial Accuracy : +/- 0.05 mm

Under vacuum : 15 November 2023

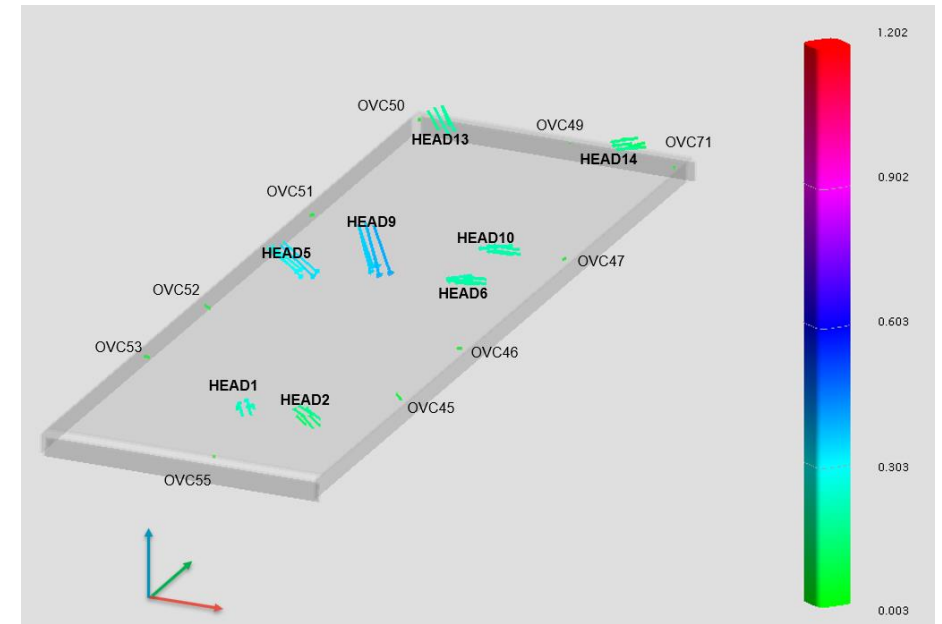
EDMS : 2999338



Impact of vacuum on cryomodule



Zoom on the top plate



Fiducials on top plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|-------|-----------------|-----------------|-----------------|
| OVC45 | -0.04 | -0.01 | 0.05 |
| OVC46 | -0.03 | -0.02 | 0.00 |
| OVC47 | -0.04 | 0.00 | -0.01 |
| OVC49 | 0.00 | 0.00 | 0.00 |
| OVC50 | 0.00 | 0.00 | 0.02 |
| OVC51 | 0.04 | 0.02 | 0.01 |
| OVC52 | 0.05 | 0.00 | -0.02 |
| OVC53 | 0.05 | 0.00 | 0.00 |
| OVC55 | -0.01 | 0.00 | -0.03 |
| OVC71 | -0.01 | 0.01 | -0.02 |

Fiducials on bottom plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|-------|-----------------|-----------------|-----------------|
| OVC57 | -0.02 | -0.02 | 0.02 |
| OVC58 | -0.01 | -0.02 | 0.02 |
| OVC59 | 0.00 | 0.01 | 0.00 |
| OVC61 | 0.05 | 0.04 | -0.01 |
| OVC62 | -0.04 | -0.01 | 0.02 |
| OVC63 | -0.05 | 0.01 | 0.04 |
| OVC66 | -0.03 | 0.00 | 0.06 |
| OVC67 | -0.03 | -0.02 | 0.05 |
| OVC68 | -0.02 | -0.02 | 0.04 |

FSI Heads on top plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|--------|-----------------|-----------------|-----------------|
| HEAD1 | -0.10 | 0.20 | -0.03 |
| HEAD2 | -0.12 | 0.07 | 0.03 |
| HEAD5 | 0.25 | 0.01 | -0.18 |
| HEAD6 | -0.20 | 0.01 | -0.03 |
| HEAD9 | 0.11 | 0.01 | -0.35 |
| HEAD10 | -0.21 | 0.00 | -0.02 |
| HEAD13 | 0.12 | -0.07 | -0.12 |
| HEAD14 | -0.14 | -0.01 | -0.04 |

FSI Heads on bottom plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|--------|-----------------|-----------------|-----------------|
| HEAD3 | -0.03 | -0.01 | 0.04 |
| HEAD4 | -0.02 | 0.02 | 0.06 |
| HEAD7 | 0.04 | 0.00 | -0.03 |
| HEAD8 | -0.03 | -0.04 | -0.02 |
| HEAD11 | -0.01 | 0.03 | -0.02 |
| HEAD12 | -0.04 | 0.01 | -0.06 |
| HEAD15 | -0.09 | 0.03 | 0.00 |
| HEAD16 | -0.04 | 0.01 | 0.02 |

Impact of vacuum on alignment of the cavities

14-Nov-2023 10:59:45

Roll TANK1 = -3.724 mrad [2023-11-13 : roll = -3.551 mrad]

Scale TANK1 = 1.000000 ppm

FUV = 0.9

Roll TANK2 = 0.345 mrad [2023-11-13 : roll = 0.224 mrad]

Scale TANK2 = 1.000000 ppm

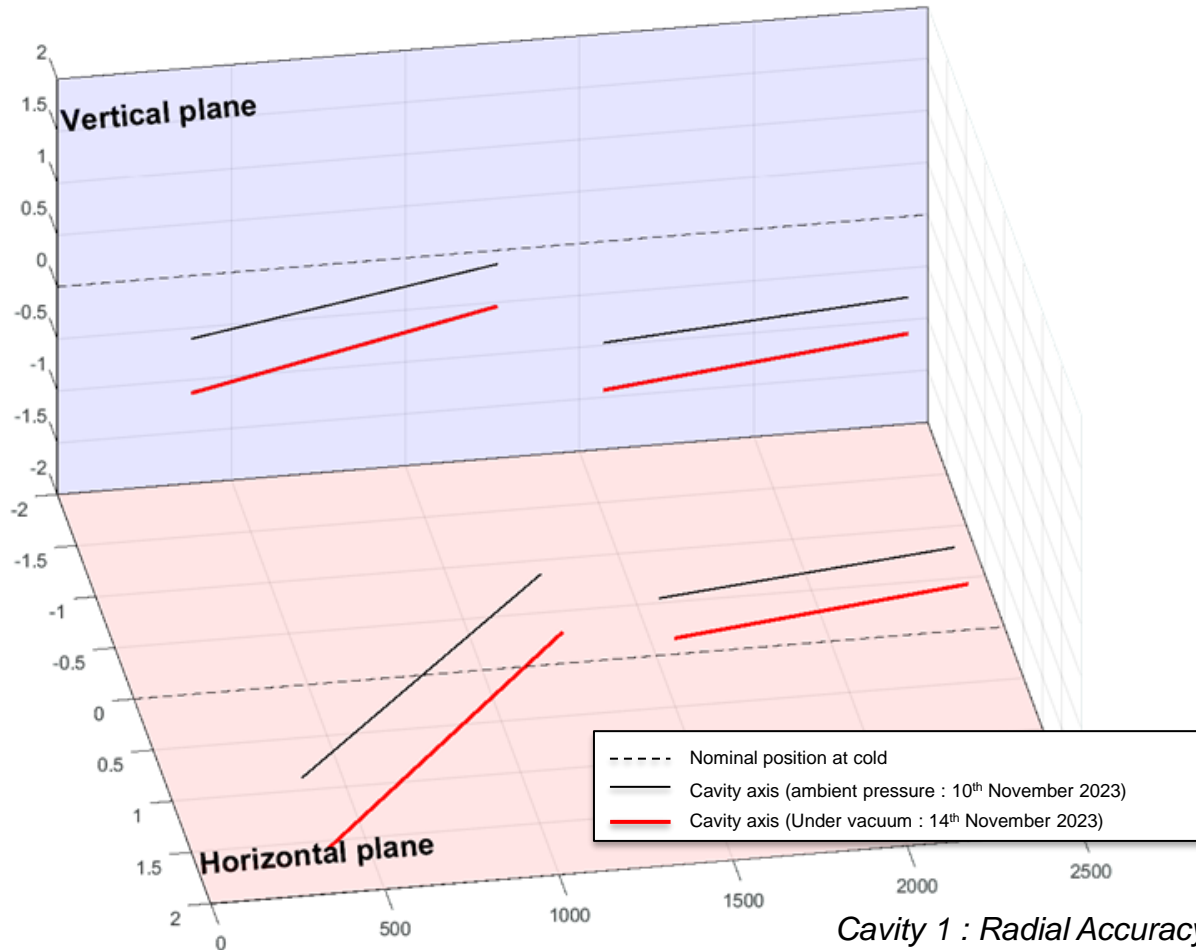
T° = 295 K

Pressure = 0 Bar



Max residual = 29 microns

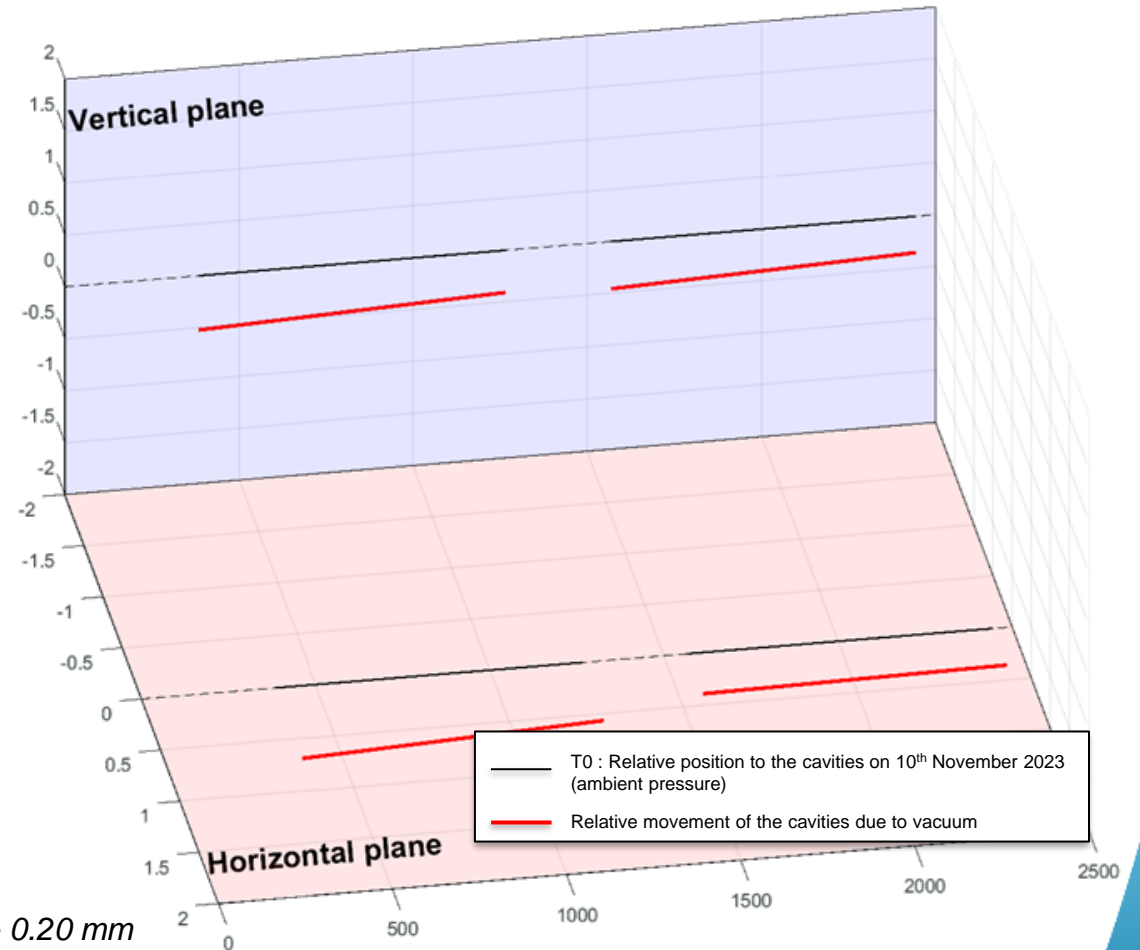
Absolute position



Cavity 1 : Radial Accuracy : +/- 0.20 mm
 Cavity 1 : Vertical Accuracy : +/- 0.05 mm

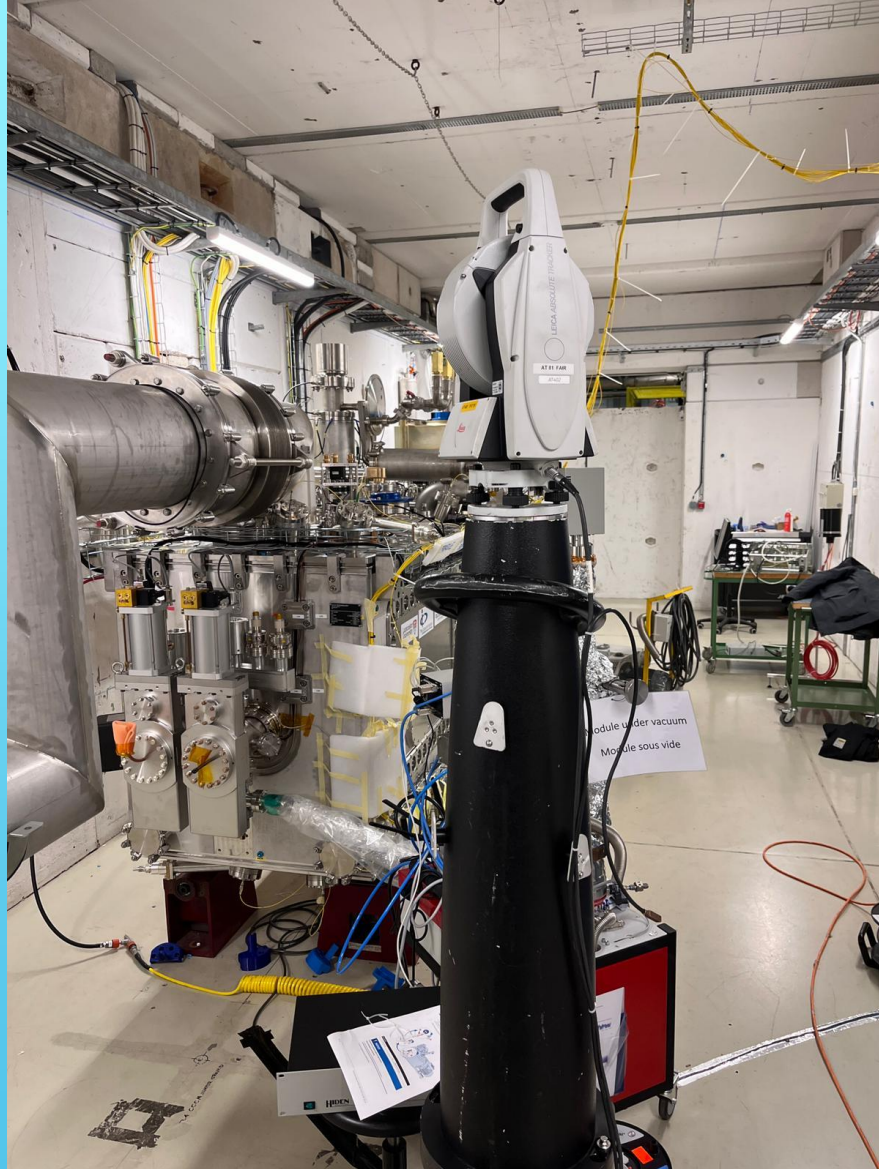
Cavity 2 : Radial Accuracy : +/- 0.10 mm
 Cavity 2 : Vertical Accuracy : +/- 0.05 mm

Relative position



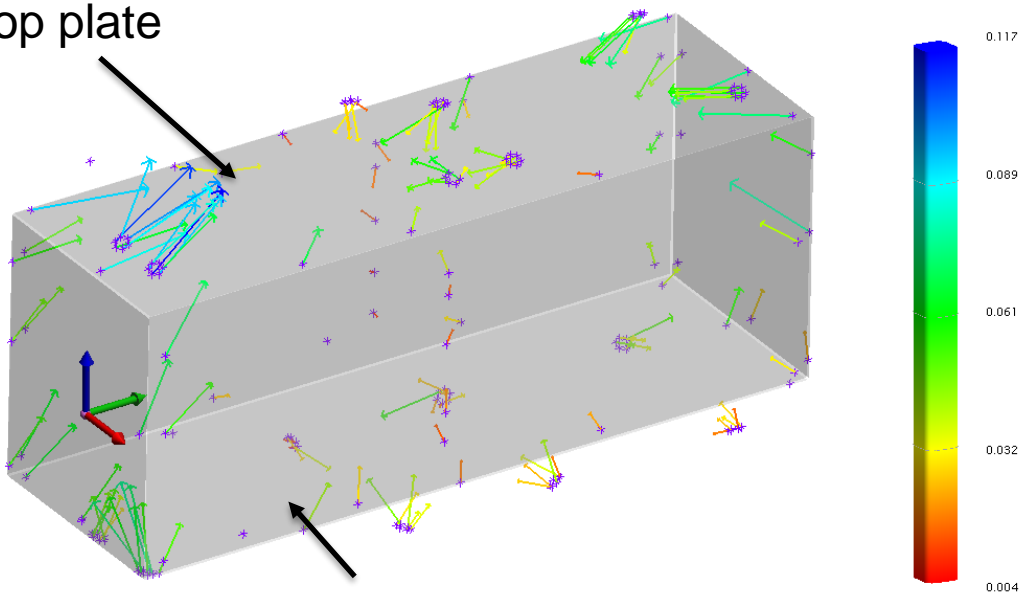
Cold condition : 30 November 2023

EDMS : 3009547



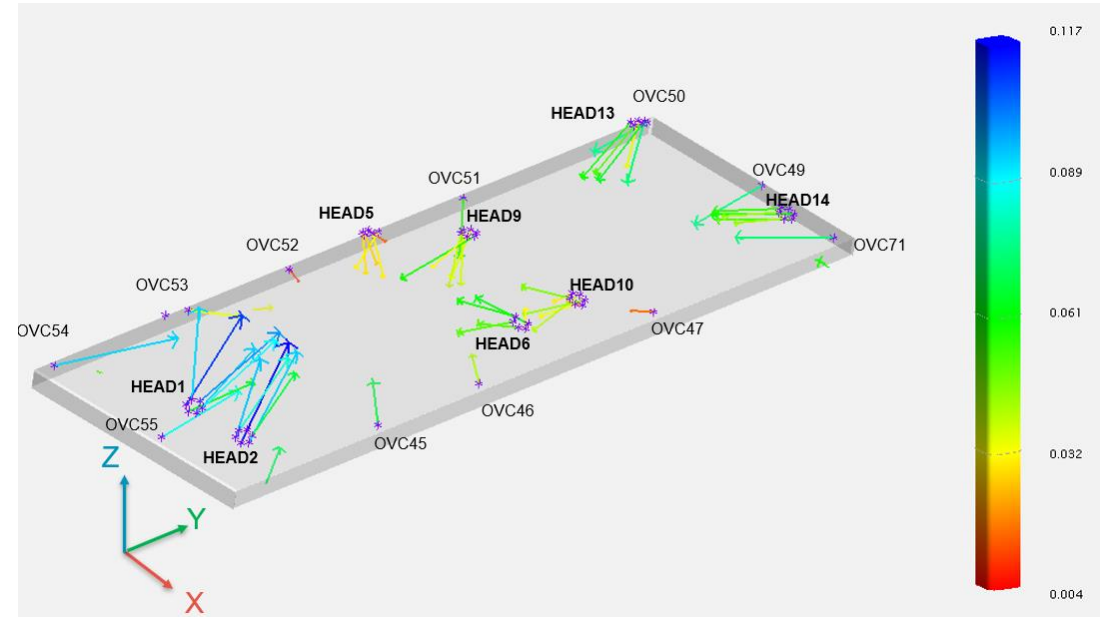
Impact of cold on cryomodule

Top plate



Bottom plate of the OVC

Zoom on the top plate



Fiducials on top plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|-------|-----------------|-----------------|-----------------|
| OVC45 | -0.05 | 0.05 | -0.01 |
| OVC46 | -0.03 | 0.03 | 0.00 |
| OVC47 | -0.01 | -0.01 | 0.00 |
| OVC49 | 0.01 | -0.08 | 0.00 |
| OVC50 | 0.02 | -0.07 | 0.01 |
| OVC51 | 0.04 | -0.04 | -0.02 |
| OVC52 | 0.01 | 0.00 | -0.01 |
| OVC53 | 0.03 | 0.02 | 0.00 |
| OVC54 | 0.03 | 0.09 | 0.01 |
| OVC55 | -0.01 | 0.09 | 0.00 |
| OVC71 | -0.03 | -0.07 | 0.01 |

Fiducials on bottom plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|-------|-----------------|-----------------|-----------------|
| OVC57 | 0.02 | 0.01 | 0.05 |
| OVC58 | -0.01 | 0.03 | 0.03 |
| OVC59 | -0.01 | 0.01 | 0.01 |
| OVC62 | 0.03 | -0.01 | 0.05 |
| OVC63 | 0.03 | 0.00 | 0.03 |
| OVC67 | 0.03 | 0.03 | 0.05 |
| OVC68 | 0.02 | 0.02 | 0.05 |

FSI Heads on top plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|--------|-----------------|-----------------|-----------------|
| HEAD1 | -0.03 | 0.08 | 0.01 |
| HEAD2 | -0.04 | 0.08 | 0.02 |
| HEAD5 | 0.01 | -0.01 | -0.02 |
| HEAD6 | -0.05 | 0.01 | -0.02 |
| HEAD9 | 0.00 | -0.02 | -0.03 |
| HEAD10 | -0.03 | -0.01 | -0.02 |
| HEAD13 | 0.02 | -0.05 | -0.02 |
| HEAD14 | -0.02 | -0.04 | 0.00 |

FSI Heads on bottom plate

| | ΔX (mm) | ΔY (mm) | ΔZ (mm) |
|--------|-----------------|-----------------|-----------------|
| HEAD3 | -0.02 | -0.01 | 0.06 |
| HEAD4 | 0.01 | 0.00 | 0.04 |
| HEAD7 | 0.00 | 0.01 | 0.03 |
| HEAD8 | 0.01 | 0.00 | -0.01 |
| HEAD11 | -0.01 | -0.01 | 0.02 |
| HEAD12 | 0.01 | -0.02 | 0.01 |
| HEAD15 | 0.00 | -0.01 | 0.02 |
| HEAD16 | 0.03 | 0.00 | 0.02 |

Impact of cold on alignment of the cavities

21-Nov-2023 00:00:16

FUV =1.1

Max residual =34 microns

Roll TANK1 =-3.674 mrad [2023-11-21 : roll =-3.674 mrad]

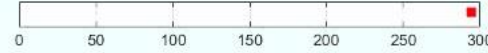
Roll TANK2 =0.313 mrad [2023-11-21 : roll =0.313 mrad]

Scale TANK1 =1.000000 ppm

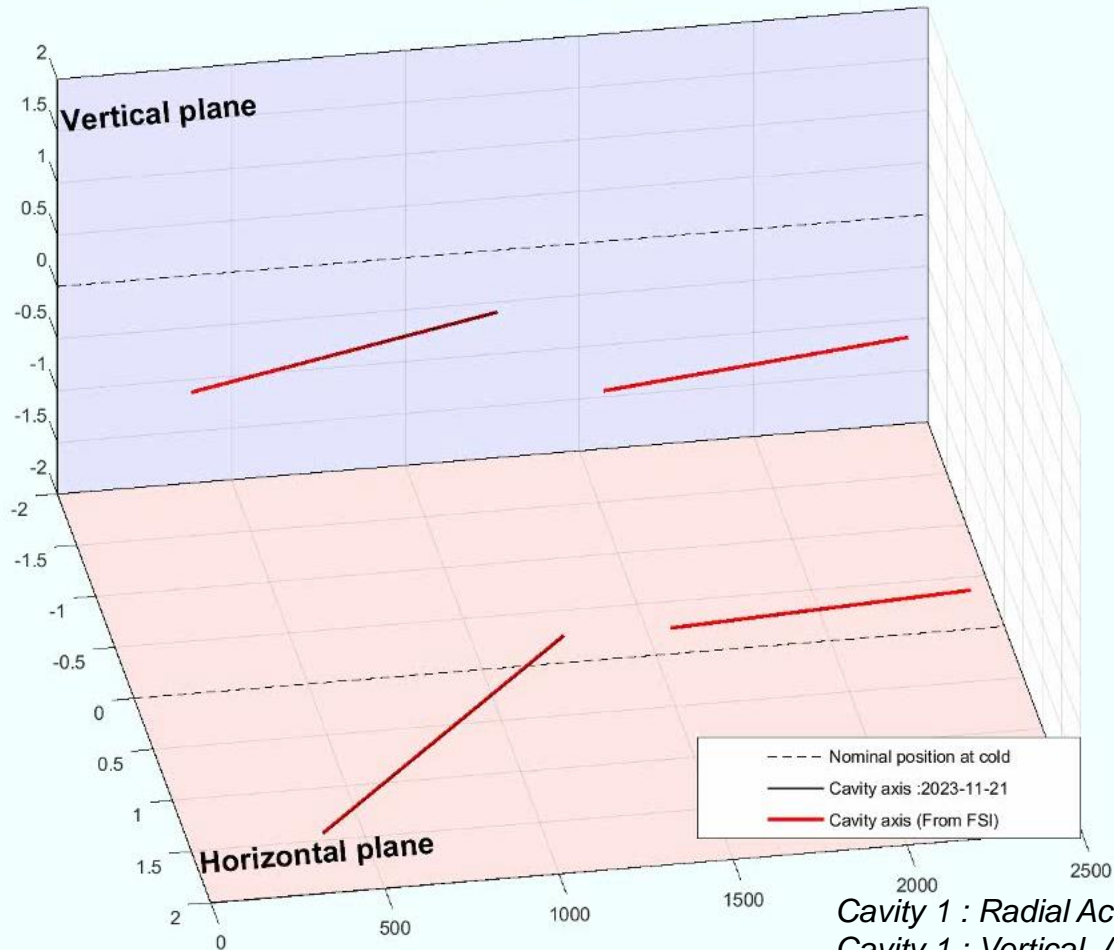
Scale TANK2 =1.000000 ppm

T°=294 K

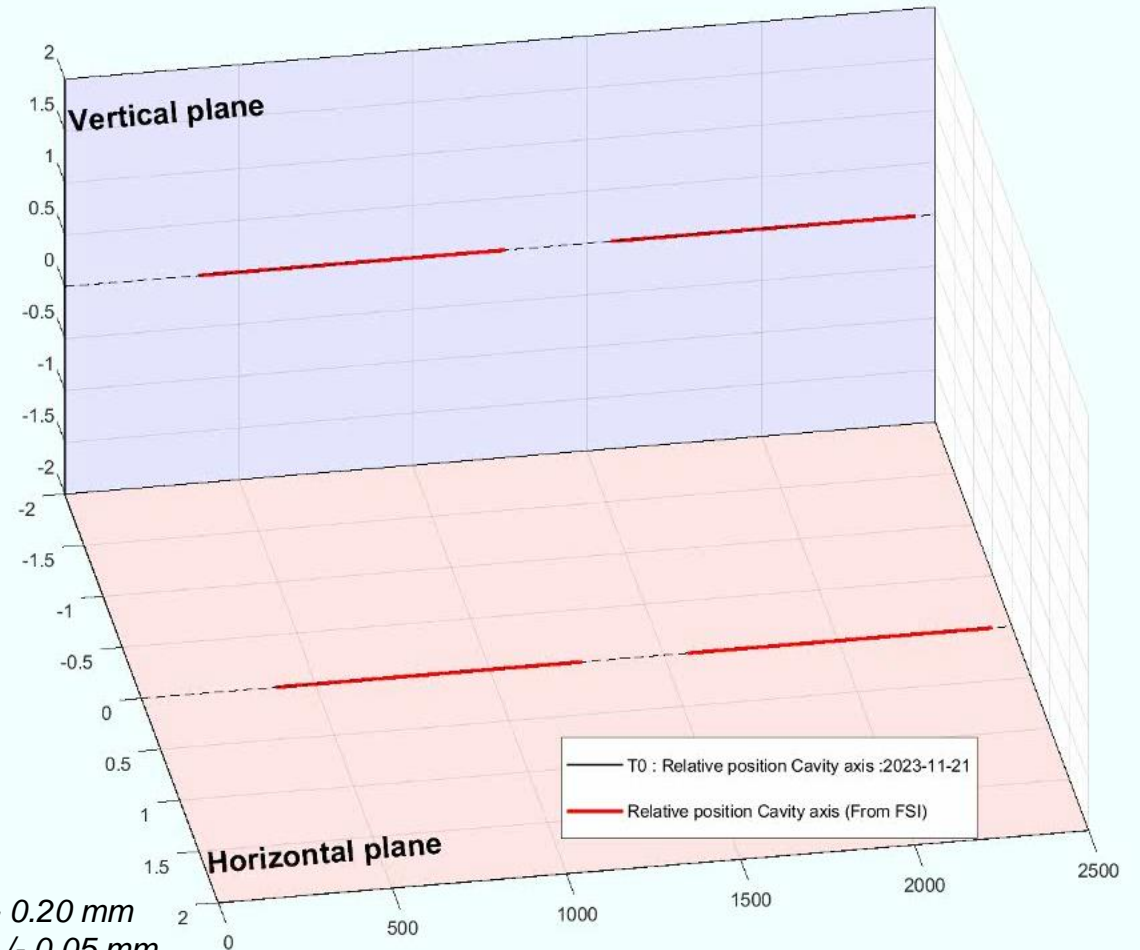
Pression=0 Bar



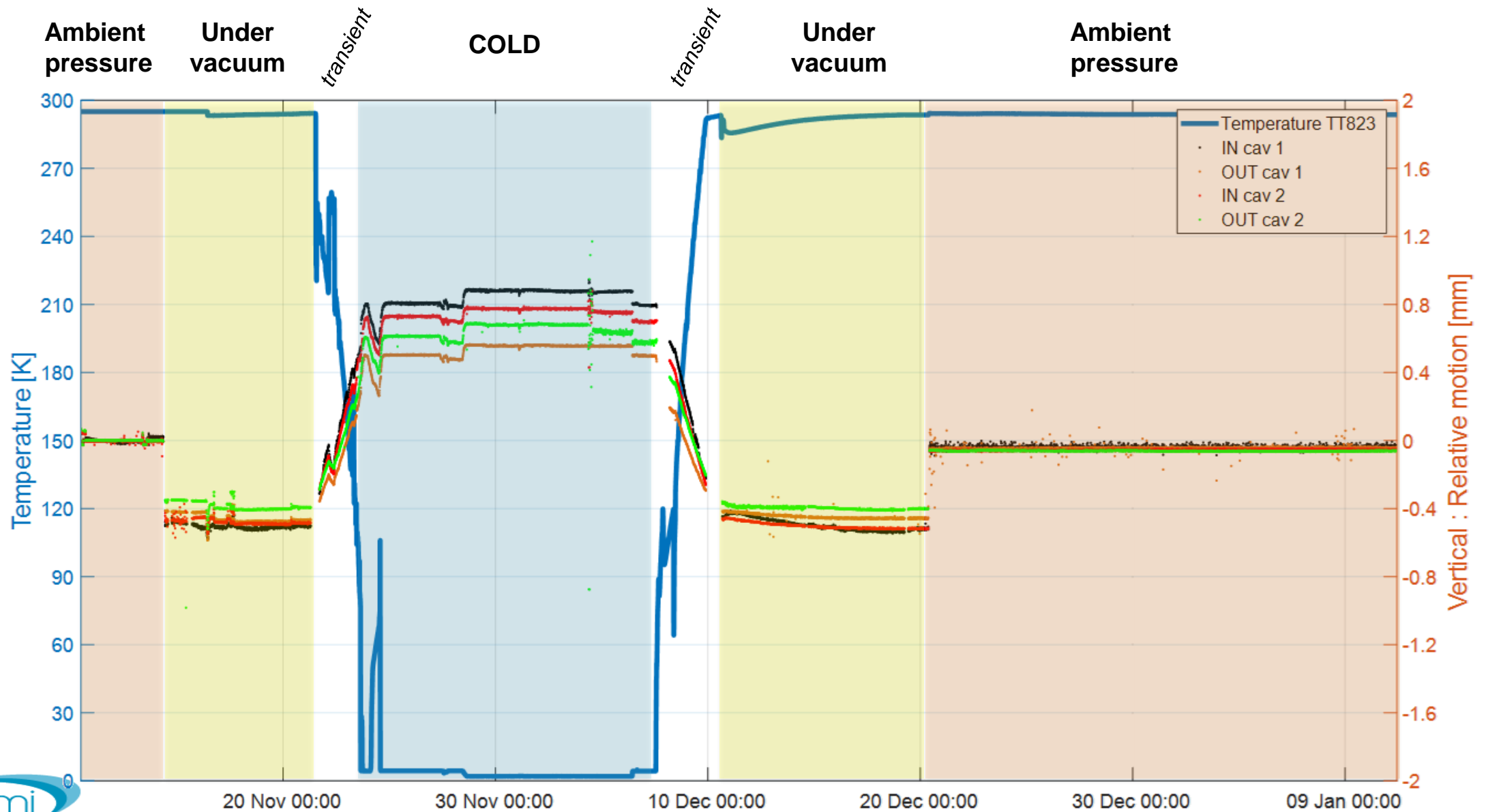
Absolute position



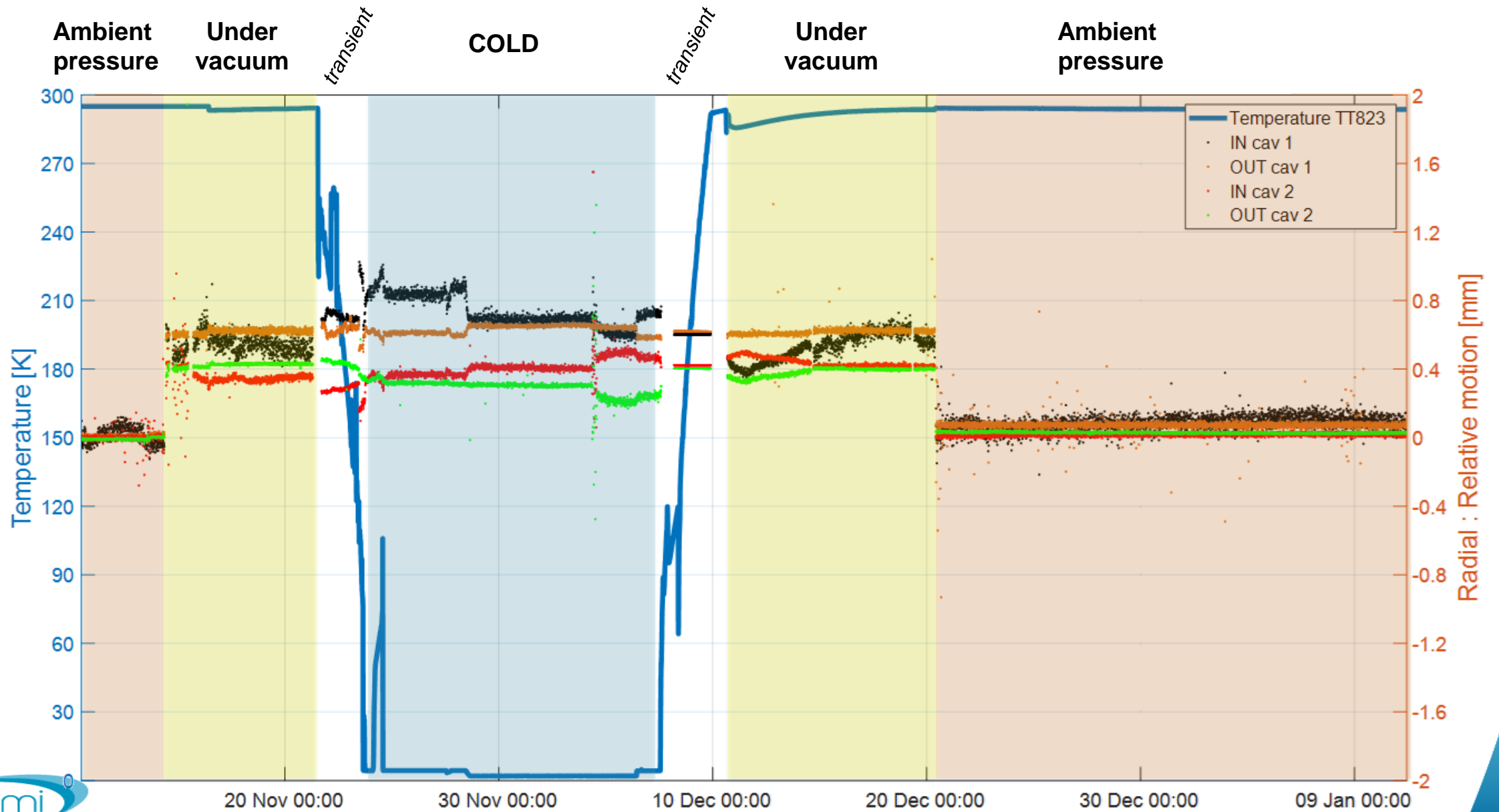
Relative position



Vertical : Relative motion of the cold mass inside the cryomodule

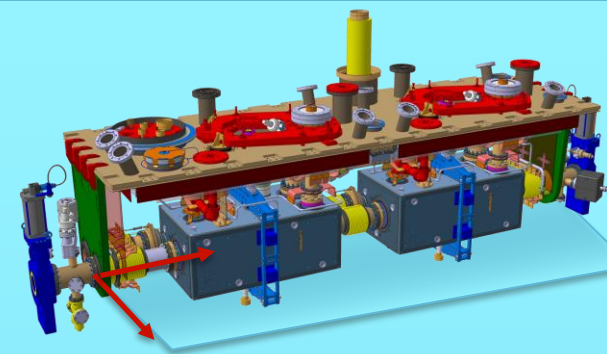


Radial : Relative motion of the cold mass inside the cryomodule



Conclusion of the first cooling down

For cavity 2



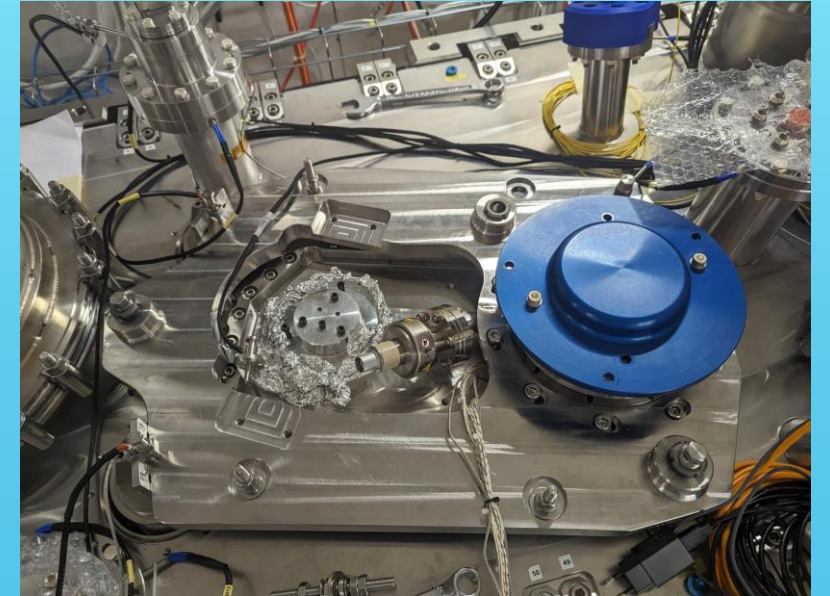
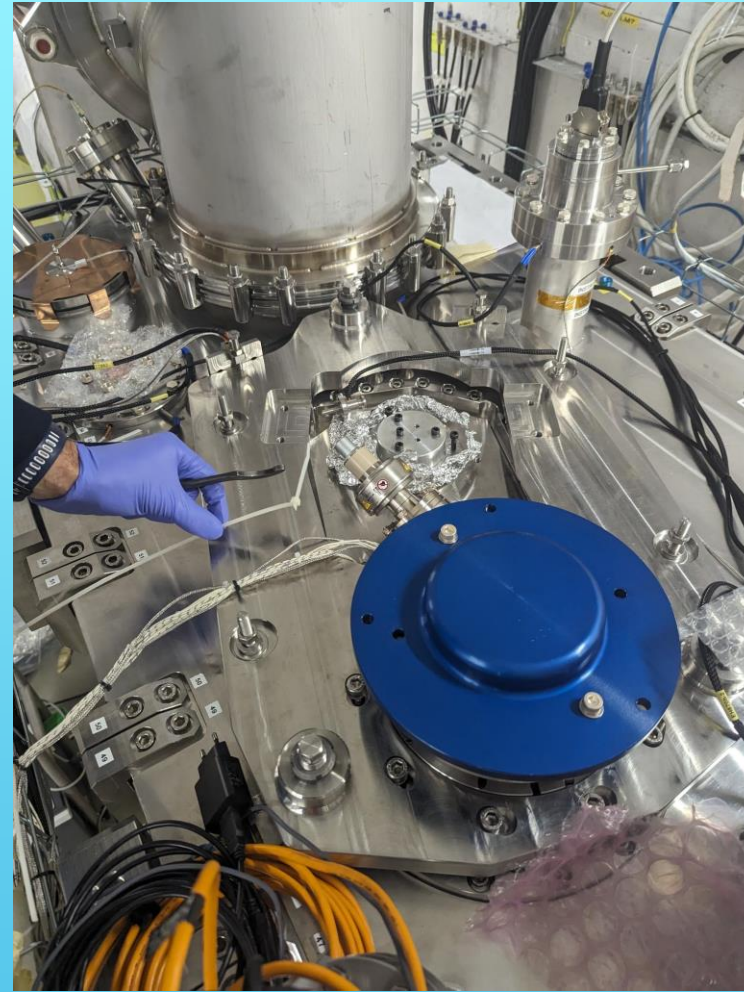
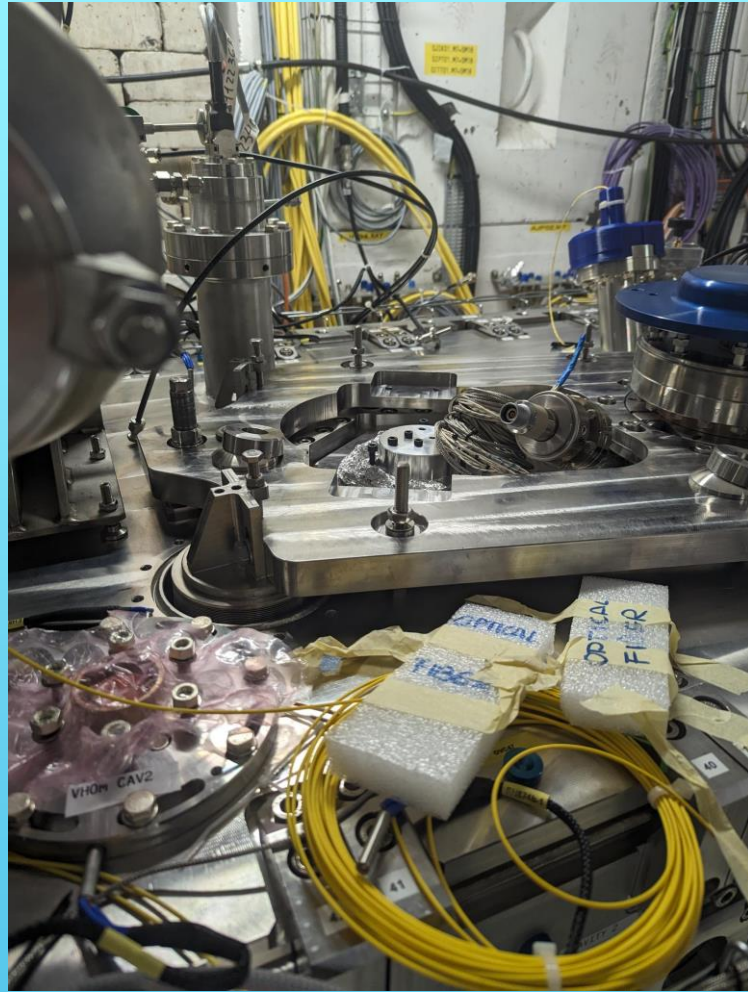
| | Vertical | | Radial | |
|-------------------|------------------|------------------|------------------|------------------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Impact of vacuum | -0.44 \pm 0.05 | -0.33 \pm 0.05 | +0.44 \pm 0.20 | +0.42 \pm 0.20 |
| Impact of cooling | +1.24 \pm 0.05 | +1.00 \pm 0.05 | 0.00 \pm 0.20 | -0.10 \pm 0.20 |
| TOTAL | +0.80 | +0.67 | +0.44 | +0.32 |

| | Vertical | | Radial | |
|----------------------------|----------|----------|---------|----------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Simulation (from Teddy) | [+0.90] | [+0.73] | [+0.88] | [+0.68] |

| | Vertical | | Radial | |
|------------|-----------|-----------|-----------|----------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Difference | - 0.10 mm | - 0.06 mm | - 0.44 mm | -0.36 mm |

Alignment of cavities (March 2024)

EDMS : 3065306

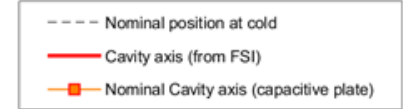
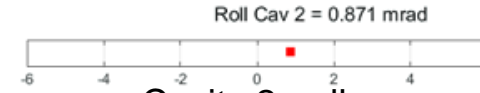
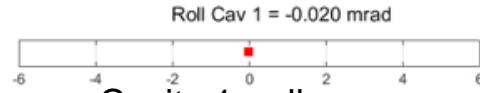


AFTER alignment

25-Mar-2024 11:29:31

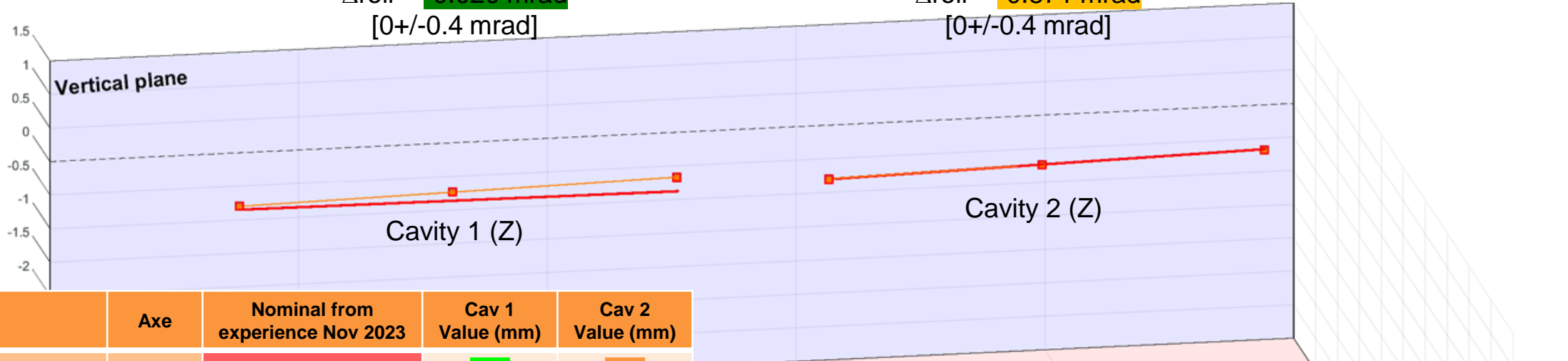
FUV =1.1

Max residual =34 microns

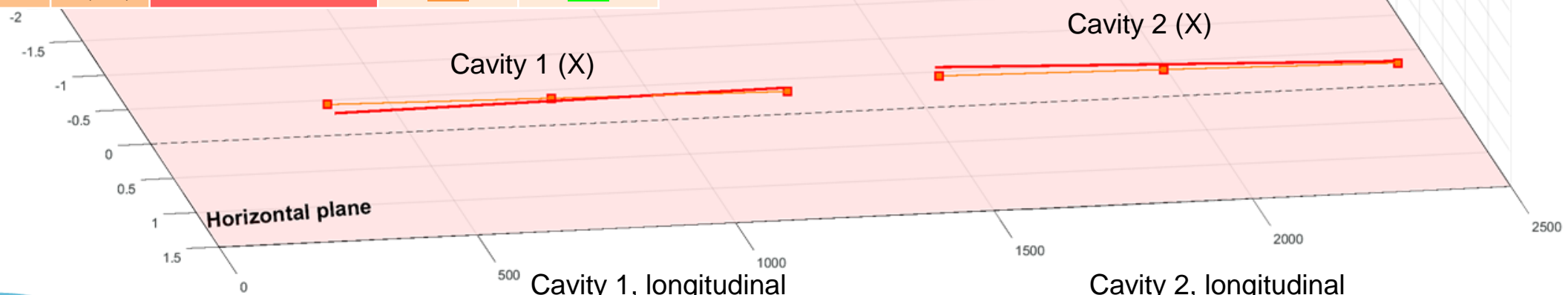


Cavity 1, roll
 $\Delta\text{roll} = -0.020 \text{ mrad}$
 [0+/-0.4 mrad]

Cavity 2, roll
 $\Delta\text{roll} = -0.871 \text{ mrad}$
 [0+/-0.4 mrad]



| | Axe | Nominal from experience Nov 2023 | Cav 1 Value (mm) | Cav 2 Value (mm) |
|-----------------------|--------|----------------------------------|------------------|------------------|
| Plaque capacitive IN | X (mm) | -0.44 | -0.38 | -0.57 |
| | Z (mm) | -0.80 | -0.85 | -0.79 |
| Plaque capacitive OUT | X (mm) | -0.32 | -0.38 | -0.36 |
| | Z (mm) | -0.67 | -0.89 | -0.65 |



Cavity 1, longitudinal
 $\Delta Y = +3.55 \text{ mm}$
 [0+/-0.1 mm]

Cavity 2, longitudinal
 $\Delta Y = +2.54 \text{ mm}$
 [0+/-0.1 mm]

Shape of the cryomodule

Repeatability :

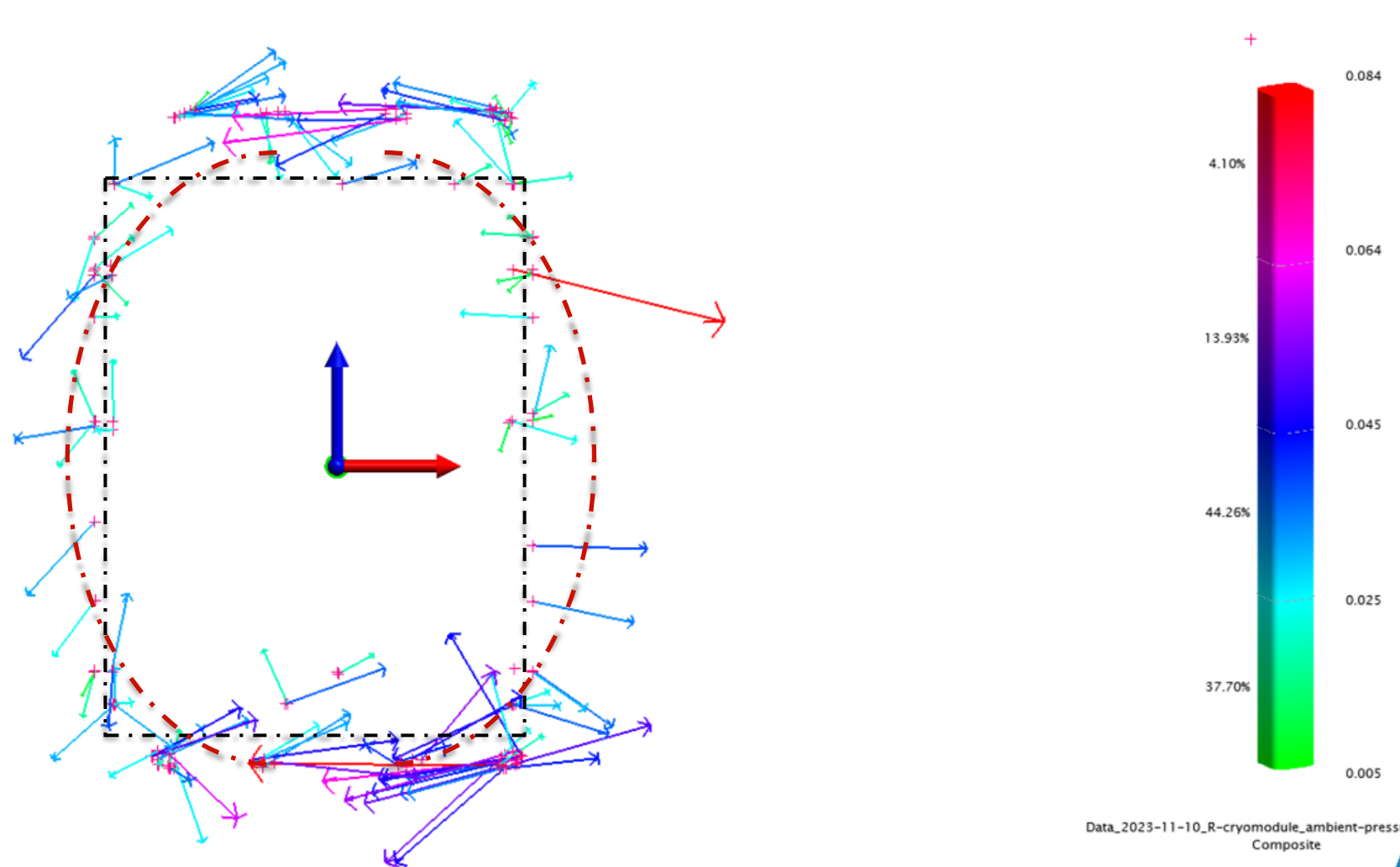
- **Ambient pressure**
- **Under vacuum**
- **At cold**

Ambient pressure : 27 March 2024

EDMS : 3065306

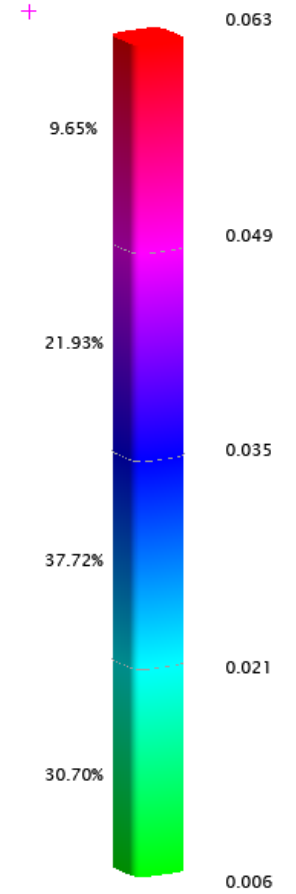
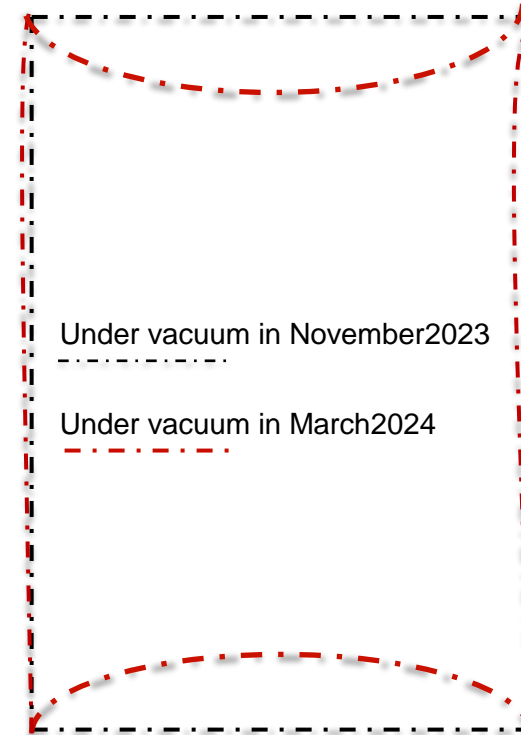
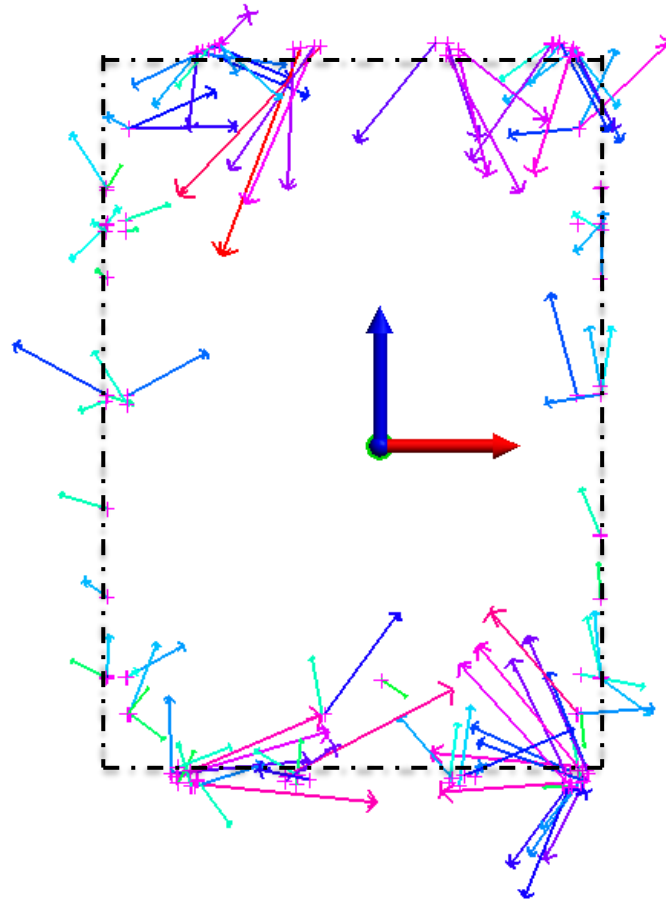
The differences between the two measurements indicate an oval-shaped deformation since the cold test conducted in December 2023.

Repeatability : 40 microns at 1 sigma



Repeatability : 40 microns at 1 sigma

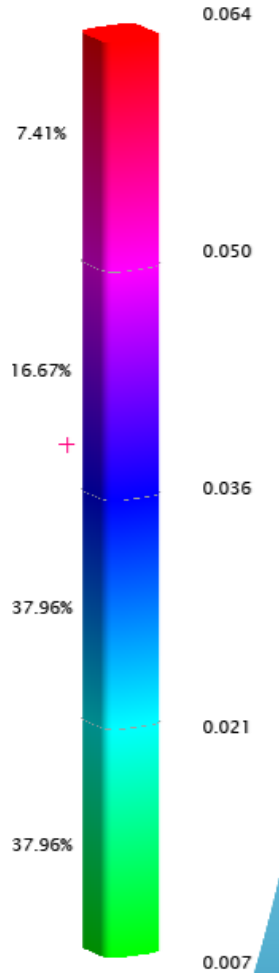
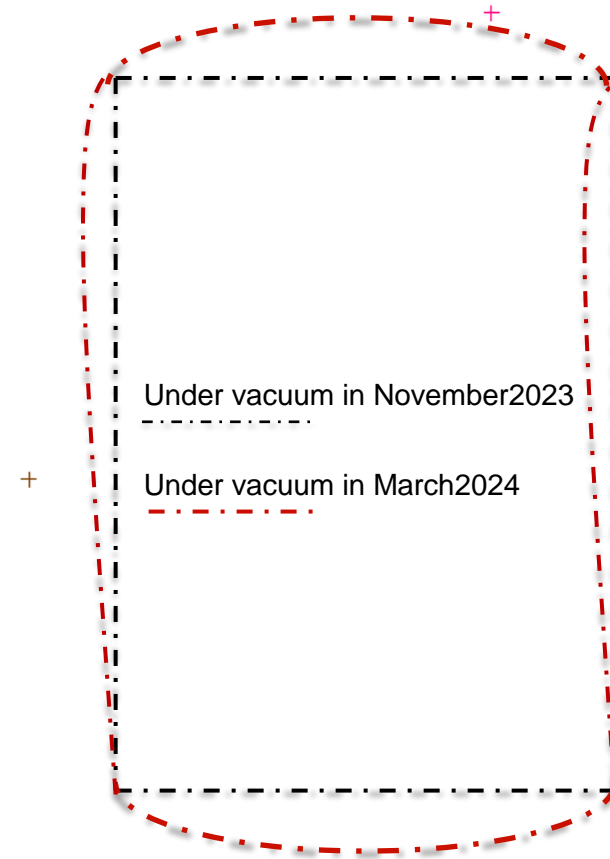
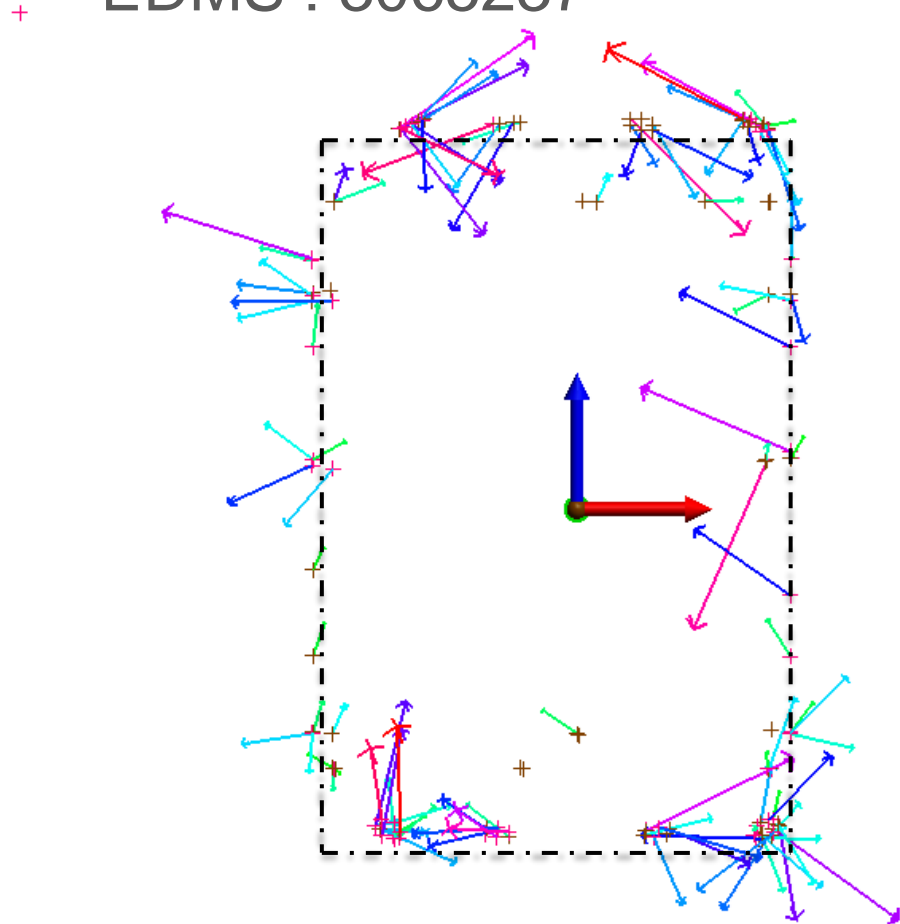
EDMS : 3065227



2023-11-15_Rcryomodule_under_vacuum.txt-USM Composite®

Repeatability : 40 microns at 1 sigma

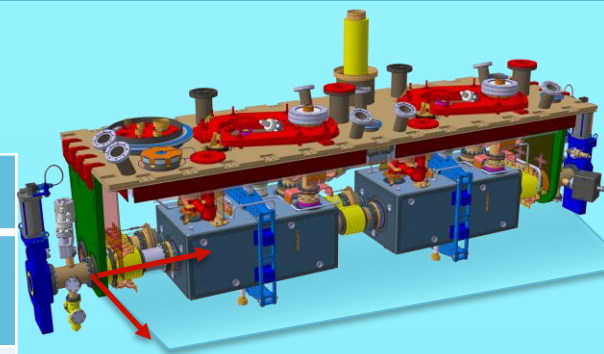
EDMS : 3065237



2023-11-29_Rcryomodule_at_COLD.txt-USMN Composite

Conclusion of the second cooling down

For cavity 2



| Experience from first cooling down Nov 2023 | Vertical | | Radial | |
|---|------------------|------------------|------------------|------------------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Impact of vacuum | -0.44 \pm 0.05 | -0.33 \pm 0.05 | +0.44 \pm 0.20 | +0.42 \pm 0.20 |
| Impact of cooling | +1.24 \pm 0.05 | +1.00 \pm 0.05 | 0.00 \pm 0.20 | -0.10 \pm 0.20 |
| TOTAL | +0.80 | +0.67 | +0.44 | +0.32 |

| Experience from second cooling down May 2024 | Vertical | | Radial | |
|--|------------------|------------------|------------------|------------------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Impact of vacuum | -0.48 \pm 0.03 | -0.35 \pm 0.03 | +0.39 \pm 0.10 | +0.40 \pm 0.10 |
| Impact of cooling | +1.22 \pm 0.03 | +1.10 \pm 0.03 | +0.35 \pm 0.10 | +0.02 \pm 0.10 |
| TOTAL | +0.74 | +0.75 | +0.74 | +0.43 |

| | Vertical | | Radial | |
|-------------------------|----------|----------|---------|----------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Simulation (from Teddy) | [+0.90] | [+0.73] | [+0.88] | [+0.68] |

Conclusion

- Repeatability deformation of the cryomodule : **40 microns at 1 sigma**

| | Initial baseline | Today |
|-----------------------------|----------------------------|----------------------------|
| Hypothesis | A-priori Sigma = 20µm (1σ) | A-priori Sigma = 40µm (1σ) |
| Tx (mm) Radial | 0.040 | 0.080 |
| Ty (mm) Longitudinal | 0.040 | 0.090 |
| Tz (mm) Vertical | 0.025 | 0.050 |
| Rx (rad) | 0.000030 | 0.00060 |
| Ry (rad) | 0.000200 | 0.000400 |
| Rz (rad) | 0.000080 | 0.000160 |
| Scale | 0.000050 | 0.000100 |

Goal : < 0.25 mm (3σ)

- Repeatability displacement of cavities between the 2 cooling down

| Total displacement (vacuum + cold) | Vertical | | Radial | |
|---------------------------------------|----------------------|----------------------|----------------------|----------------------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| First cooling down (Nov 2023) | +0.80 +/-0.05 | +0.67 +/-0.05 | +0.44 +/-0.20 | +0.32 +/-0.20 |
| Second cooling down (May 2024) | +0.74 +/-0.03 | +0.75 +/-0.03 | +0.74 +/-0.10 | +0.43 +/-0.10 |

**Thank you
for your attention**

Spare

For cavity 1

| Experience from first cooling down Nov 2023 | Vertical | | Radial | |
|---|--------------|--------------|--------------|--------------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Impact of vacuum | -0.48 | -0.40 | +0.58 | +0.60 |
| Impact of cooling | +1.38 | +0.98 | +0.14 | +0.05 |
| TOTAL | +0.90 | +0.59 | +0.72 | +0.65 |

| Experience from first cooling down Nov 2023 | Vertical | | Radial | |
|---|--------------|--------------|--------------|--------------|
| | IN (mm) | OUT (mm) | IN (mm) | OUT (mm) |
| Impact of vacuum | -0.57 | -0.47 | +0.54 | +0.52 |
| Impact of cooling | +1.36 | +0.92 | +0.56 | +0.15 |
| TOTAL | +0.79 | +0.45 | +1.11 | +0.66 |