Vancouver, 24 Sept. 2023

Status report on alignment on RFD prototype : Crab-cavities (Collaboration : STFC / CERN)

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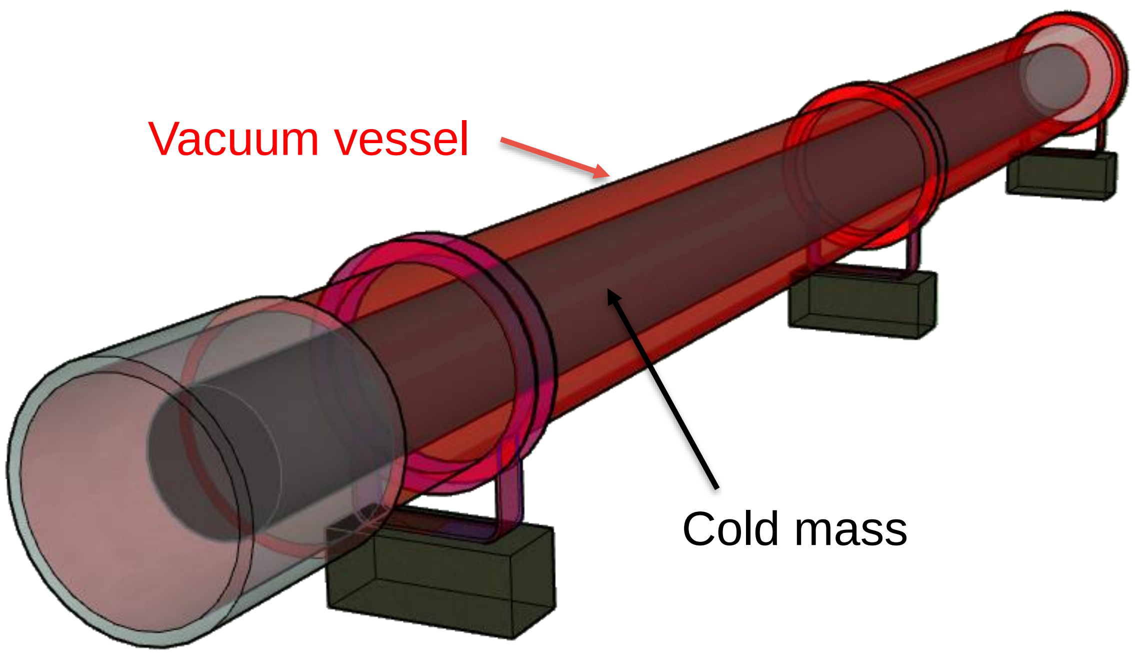
13th HL-LHC Collaboration Meeting, Vancouver (Canada), 25-28 September 2023

Outline

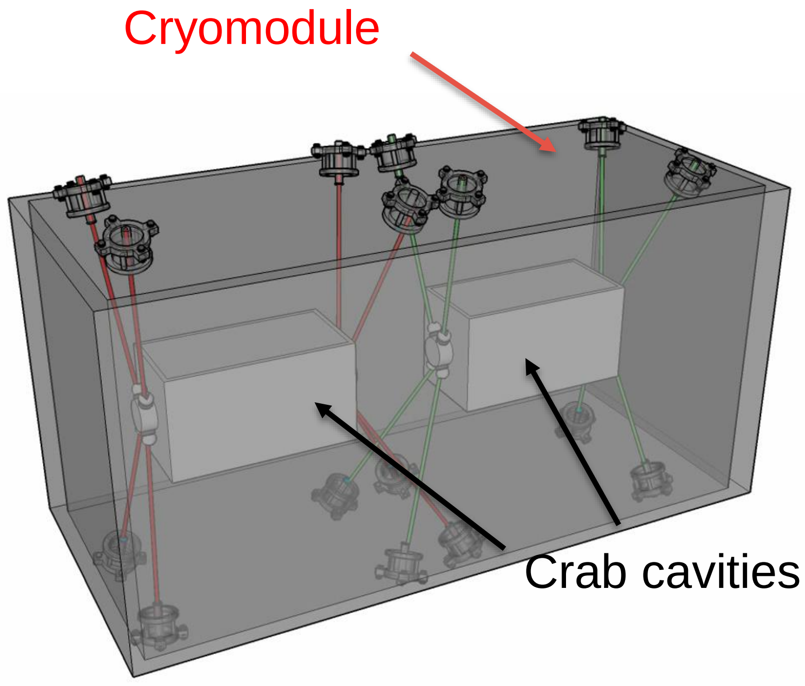
- Alignment objective for HL-LHC internal monitoring
  - Internal monitoring
  - Crab-cavities configuration
  - Alignment requirement
  - Alignment simulation for RFD prototype
- RFD prototype (Survey tasks : STFC-CERN collaboration)
  - Determination of the position of the capacitive plates of the cavities
  - Alignment of the 2 cavities before and after connection in clean room
  - Thermal contraction anticipation
  - Alignment at step 4 : on the trolley
  - Alignment at step 6 : cavities suspended from the top plate
  - Alignment at step 9 : cavities suspended from the top plate inserted in the cryomodule
  - FSI installation
  - Diverse information
  - Schedule expected after reception of the cryomodule at CERN

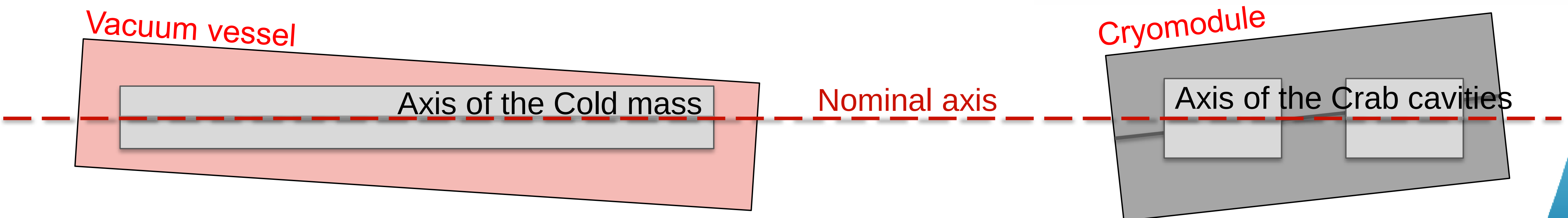
Internal monitoring for “special” components

Q1, Q2a, Q2b, Q3



Crab-Cavities

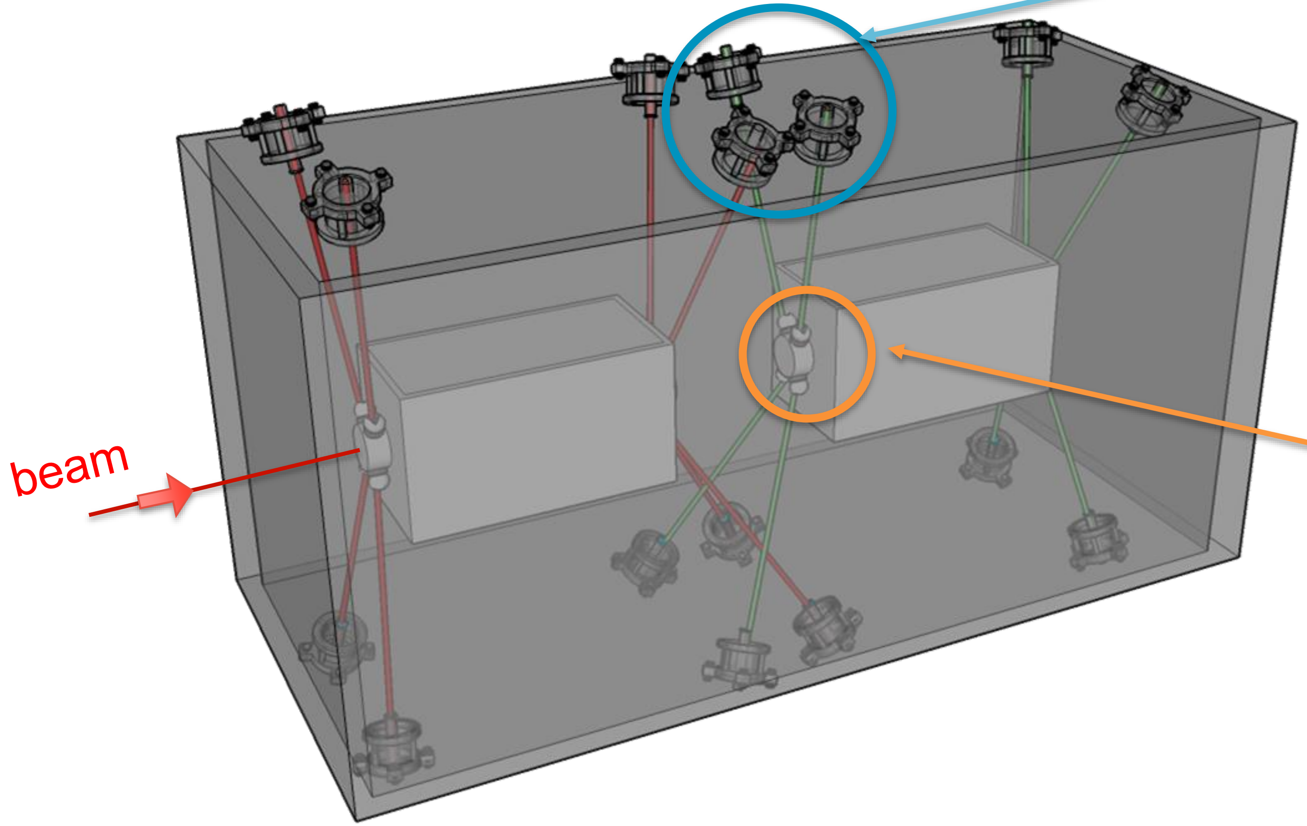




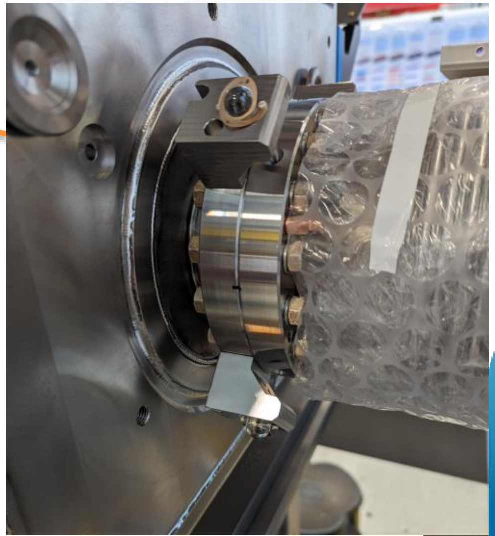
Internal monitoring : Configuration

- **FSI : Frequency Scanning interferometry**
  → Absolute distance measuring interferometric technique

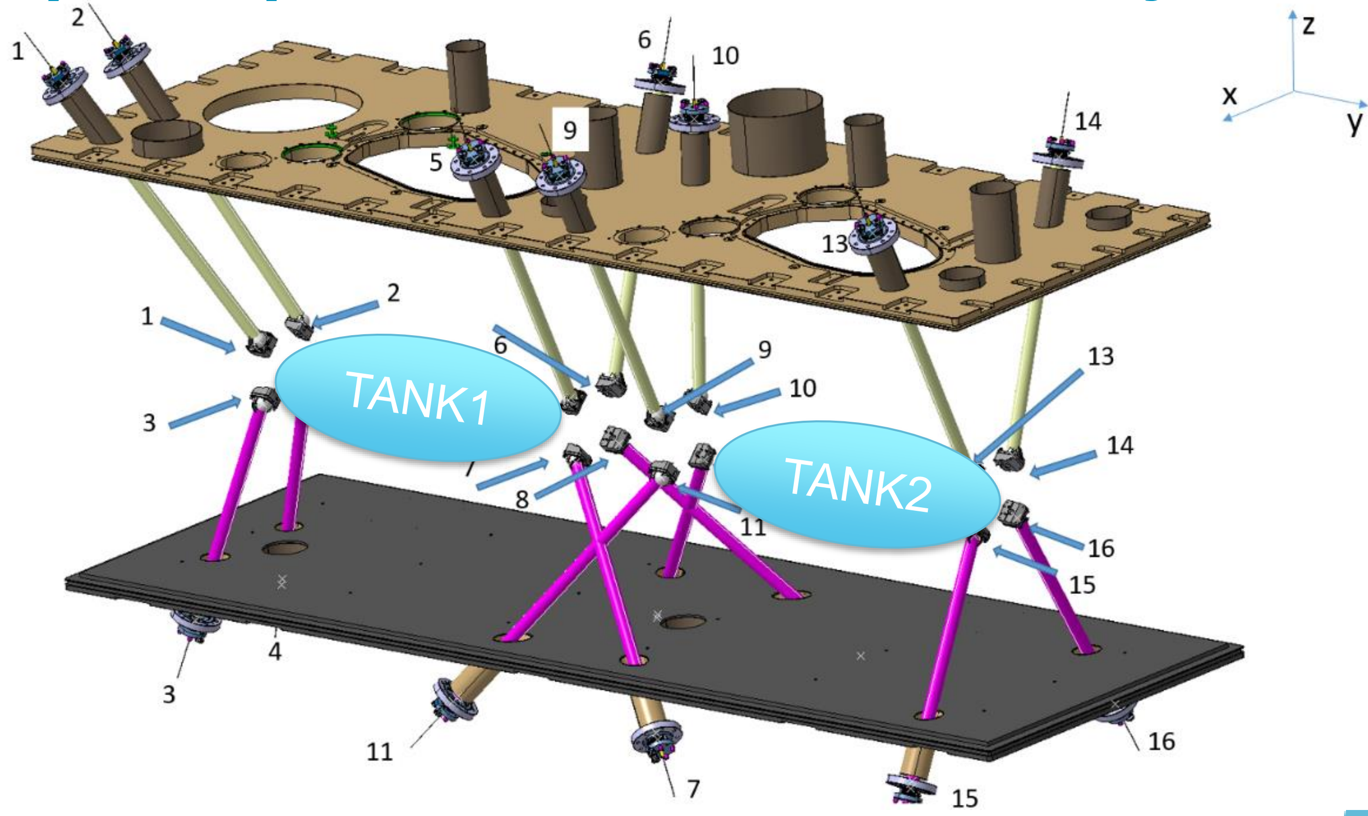
FSI Head (sensor) on the Cryomodule



FSI target on the flange of Helium TANK of the cavities



Configuration (RFD prototype) : Requirement and Uncertainty



	Requirement
Tx (mm) Radial	**< 0.1**
Ty (mm) longitudinal	**--**
Tz (mm) vertical	**< 0.1**
Rx (mrad)	<0.3
Ry (mrad)	<1.7
Rz (mrad)	<0.3
Scale (ppm)	--

TANK 1	Accuracy
Tx (mm) Radial	**0.088**
Ty (mm) longitudinal	**0.044**
Tz (mm) vertical	**0.015**
Rx (mrad)	0.044
Ry (mrad)	0.215
Rz (mrad)	0.233
Scale (ppm)	66

TANK 2	Accuracy
Tx (mm) Radial	**0.021**
Ty (mm) longitudinal	**0.077**
Tz (mm) vertical	**0.011**
Rx (mrad)	0.023
Ry (mrad)	0.180
Rz (mrad)	0.047
Scale (ppm)	101

Outline

- Alignment objective for internal monitoring
  - Internal monitoring
  - Configuration
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  - Simulation for RFD prototype

- RFD prototype (Survey tasks)
  - Determination of the position of the capacitive plates of the cavity
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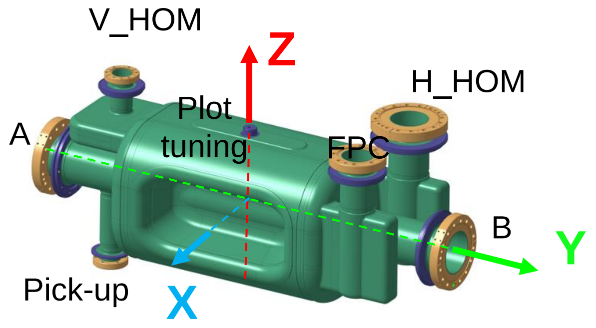
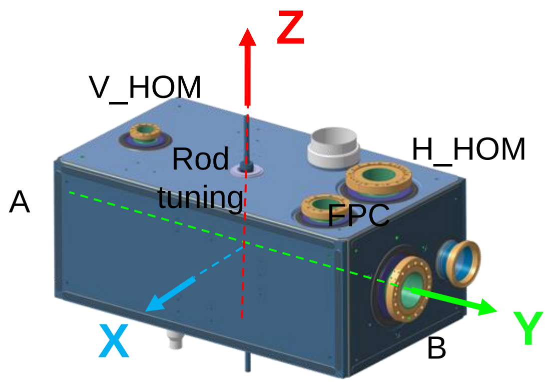
Determination of the position of the capacitive plate of the cavity

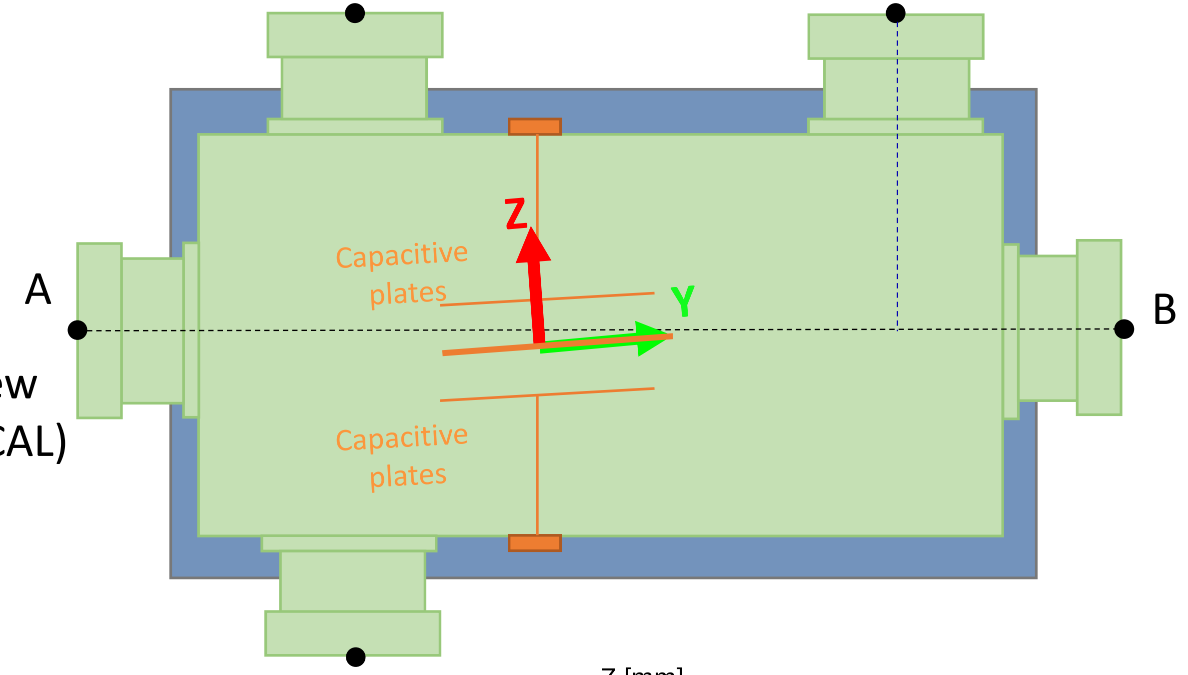
Bare Cavity

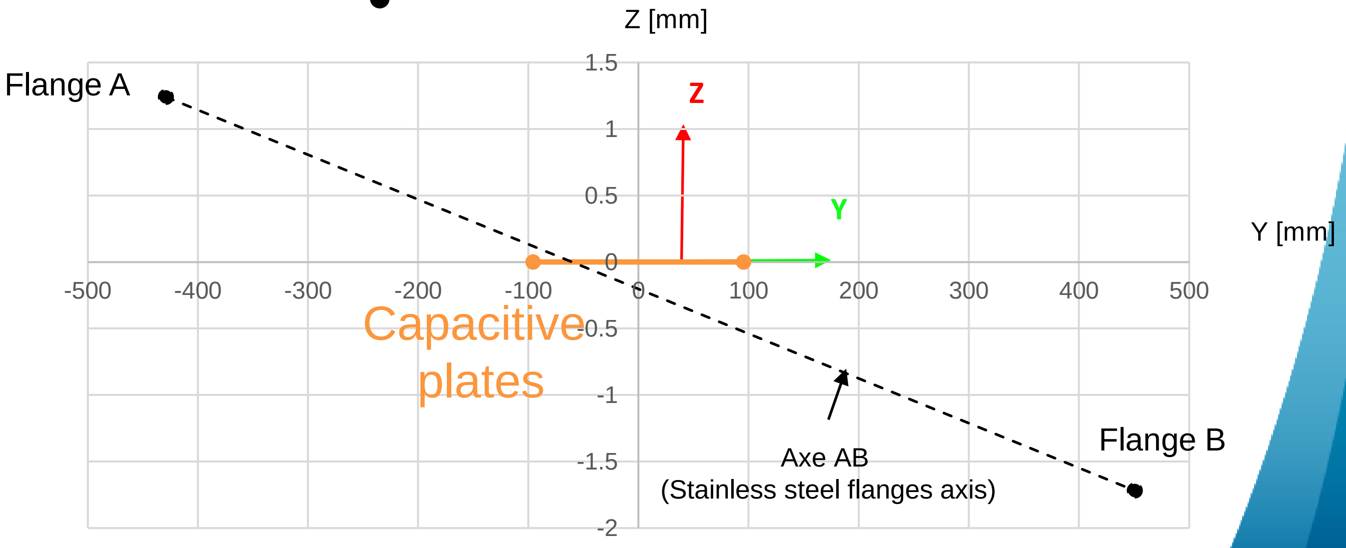


Cavity inside the TANK

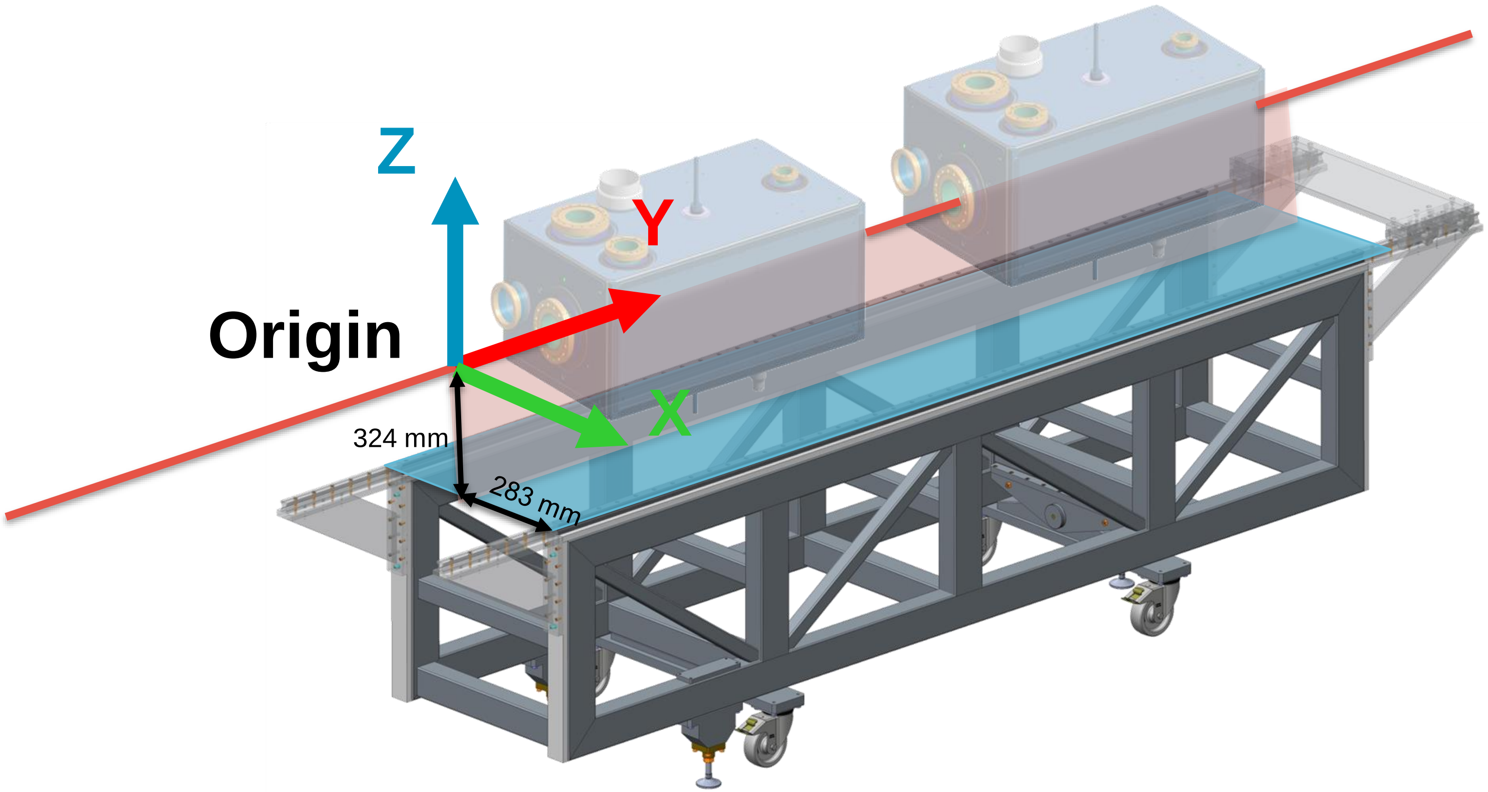


Side view (VERTICAL)





Alignment of the 2 cavities before connection in the clean room



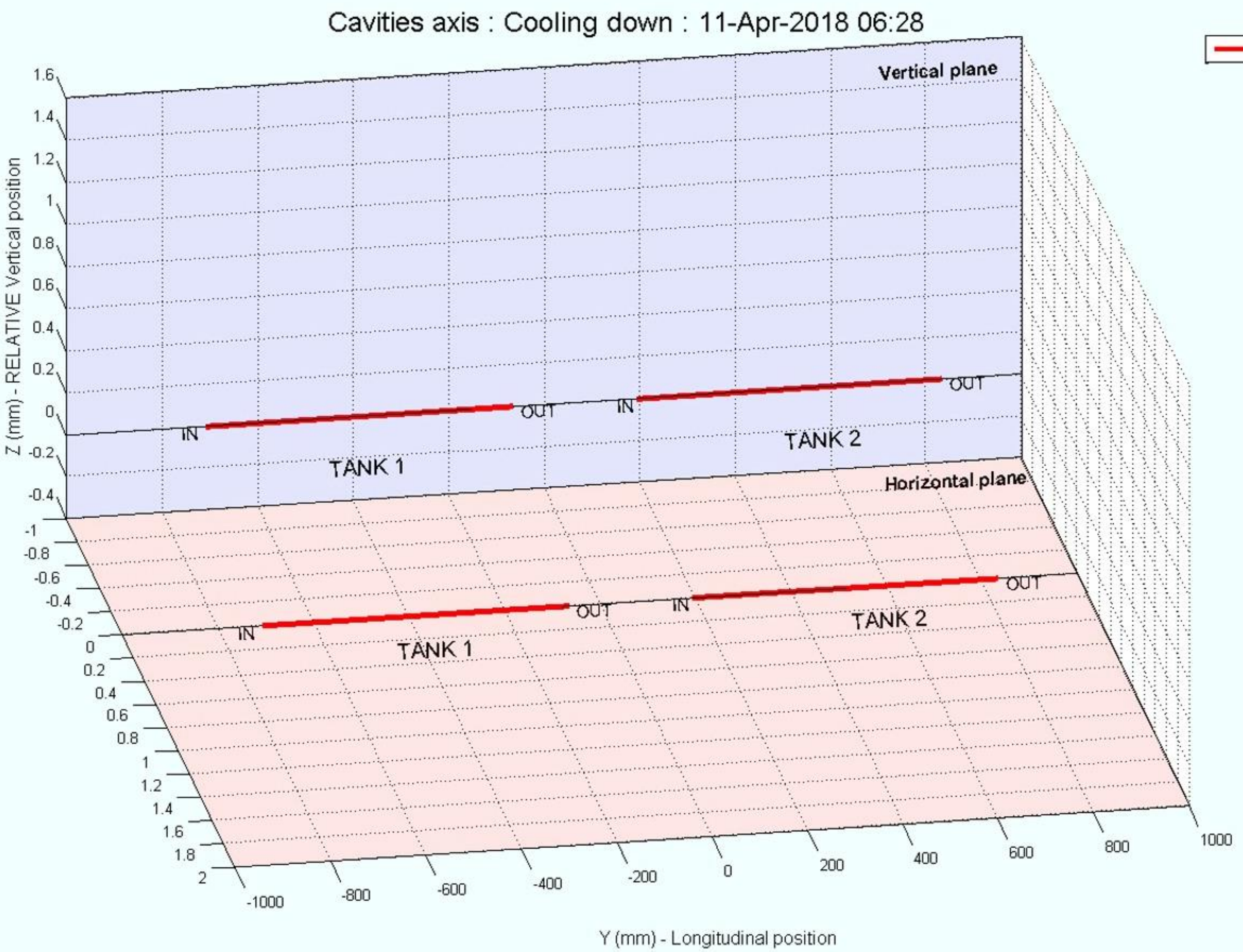
Nominal axis (cavity line)
→ trajectory of the rails

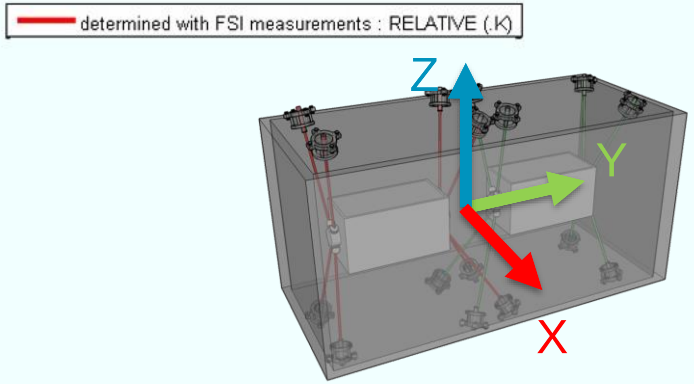
Coordinate frame :

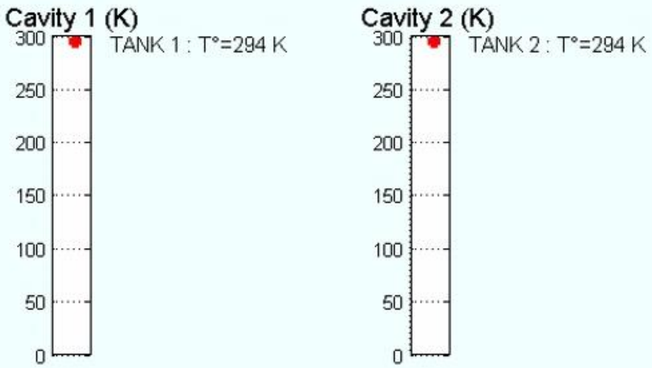
- Primary axis : Nominal axis (cavity line) → trajectory of the rails
- Secondary axis : Normal vector to vertical plane of rails
- Origin : Beginning of the rail

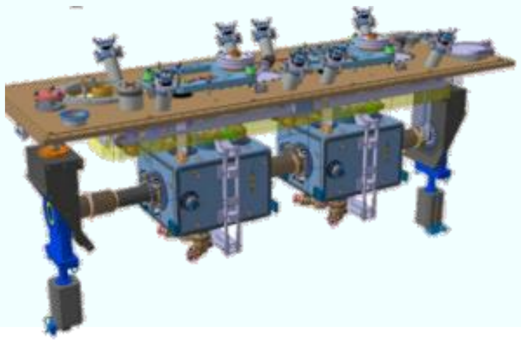
Take into account of thermal contraction and vacuum

Configuration (DQW-SPS-2018) : Cooling down

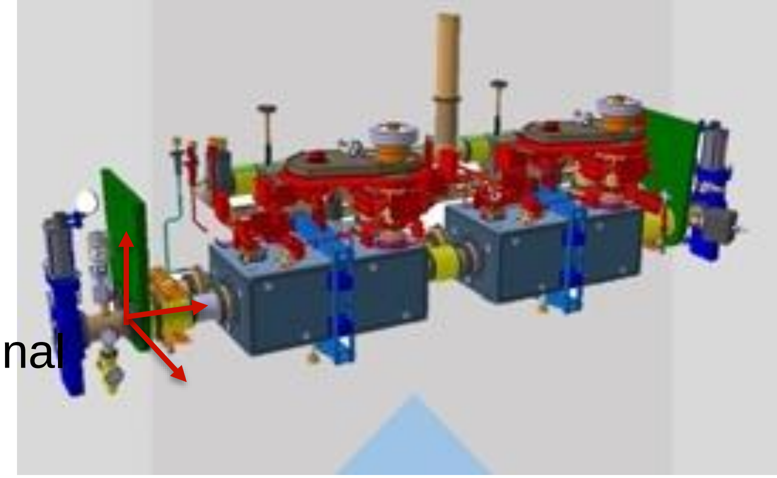






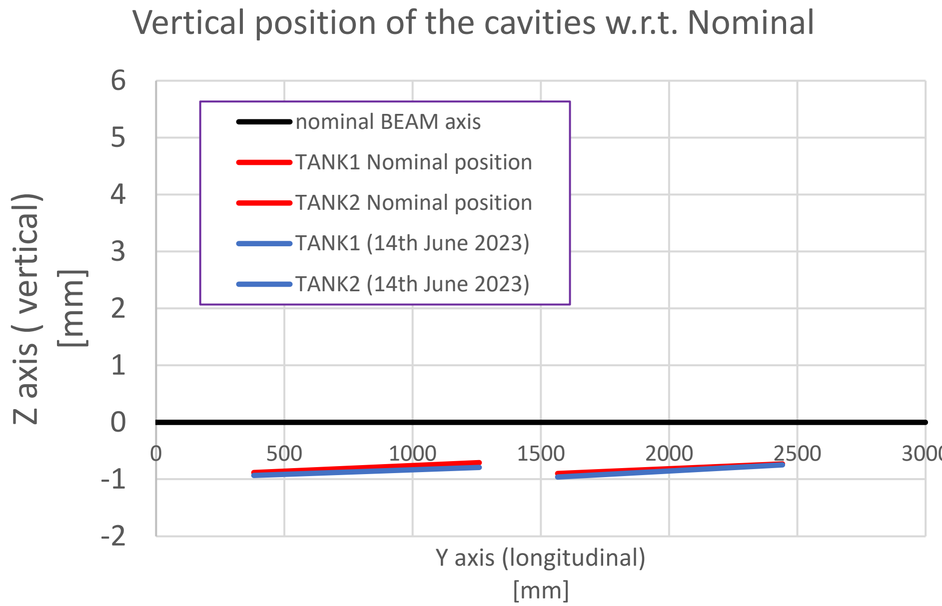


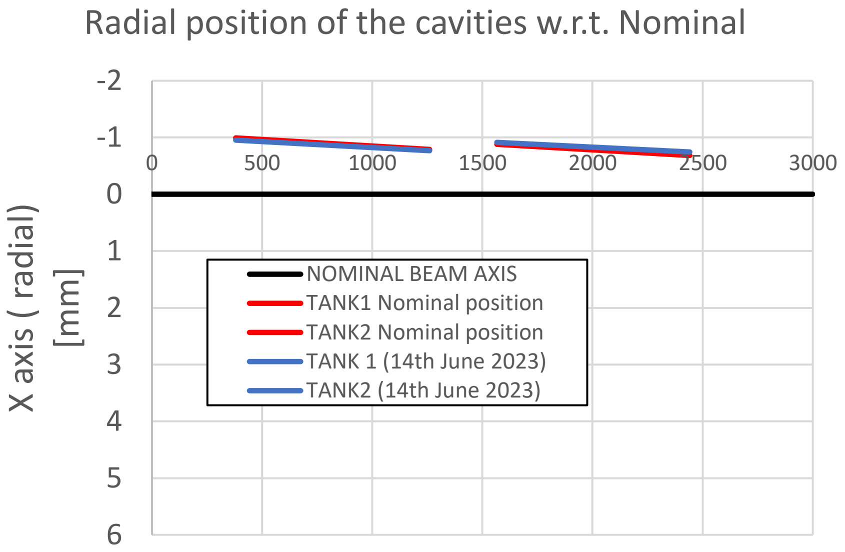
Position after STEP 4 (June 2023)



Vertical : Difference to nominal
Max : 0.1 mm

Radial : Difference to nominal
Max : 0.1 mm

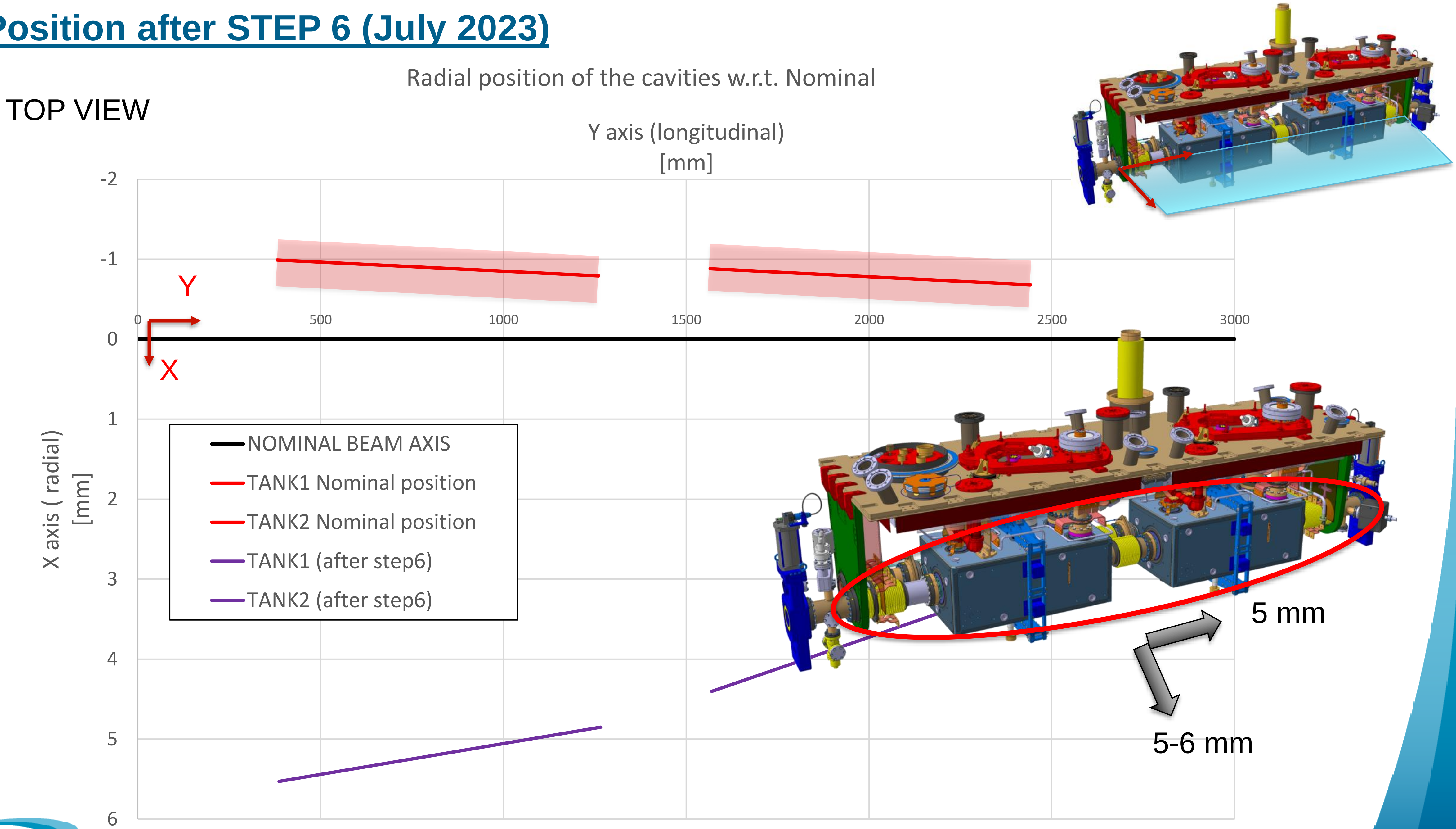




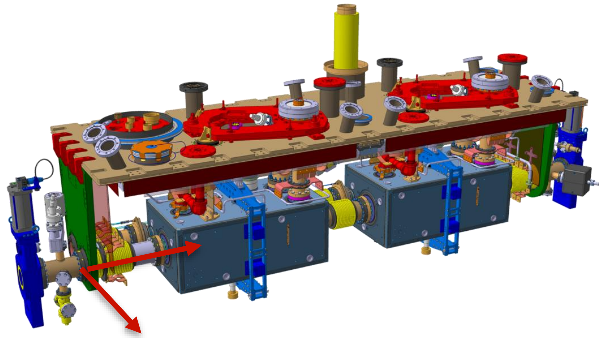
Longitudinal	Nominal	After step 4
TANK1	809.6 mm	809.6 mm
TANK2	1992.1 mm	1992.1 mm

Longitudinal . Difference to nominal
Max : 0.1 mm

Position after STEP 6 (July 2023)

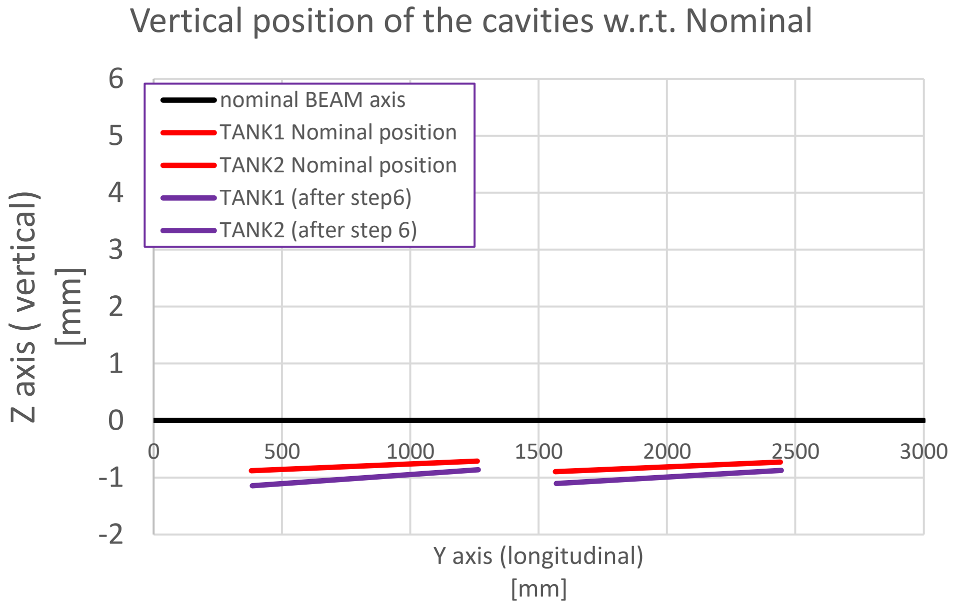


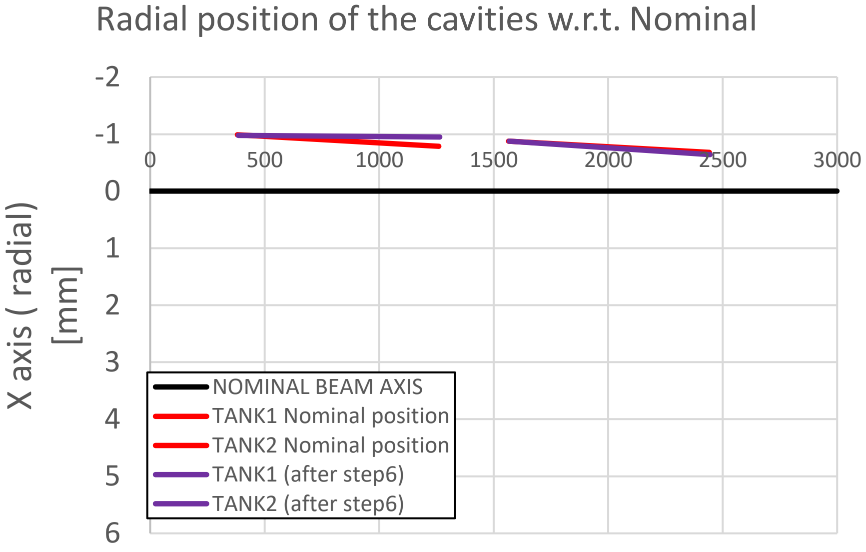
Position after STEP 6 (August 2023)



Vertical : Difference to nominal
Max : 0.2 mm

Radial : Difference to nominal
Max : 0.2 mm

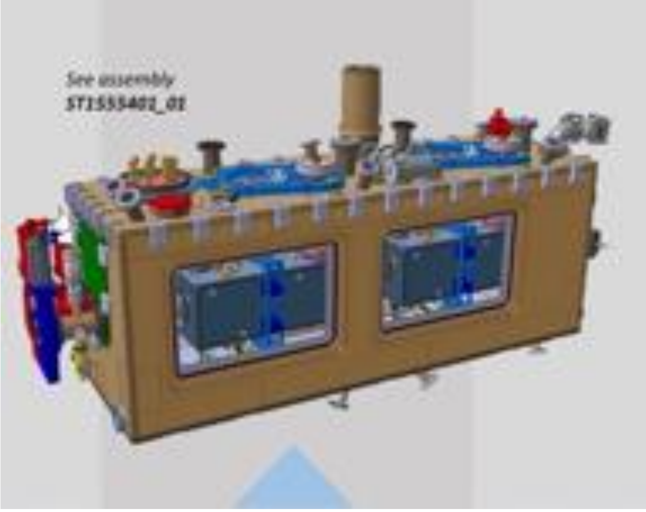




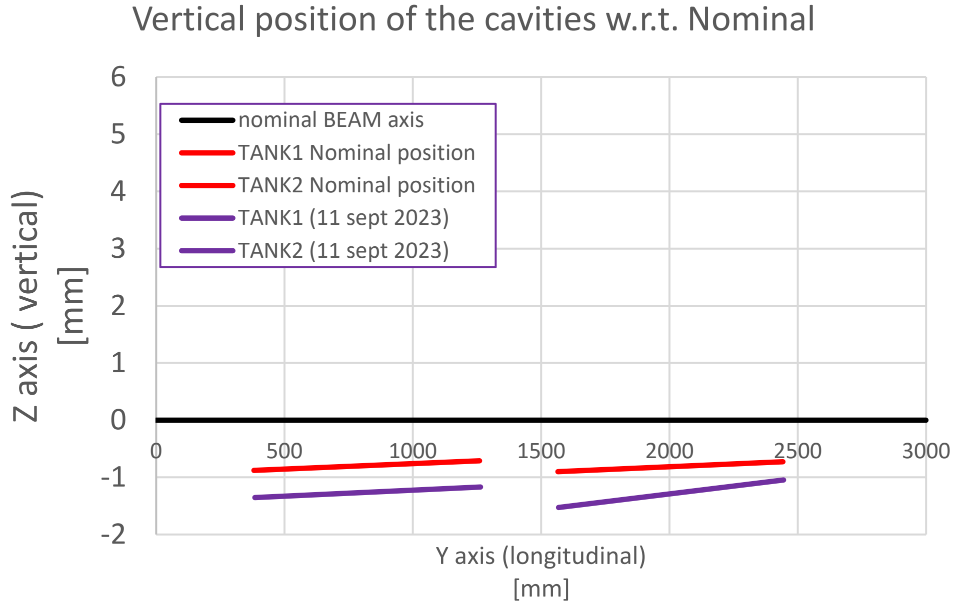
Longitudinal	Nominal	After step 6	Difference to nominal
TANK1	809.6 mm	813.6 mm	+4.0 mm
TANK2	1992.1 mm	1995.5 mm	+3.4 mm

Position after STEP 9 (September 2023)

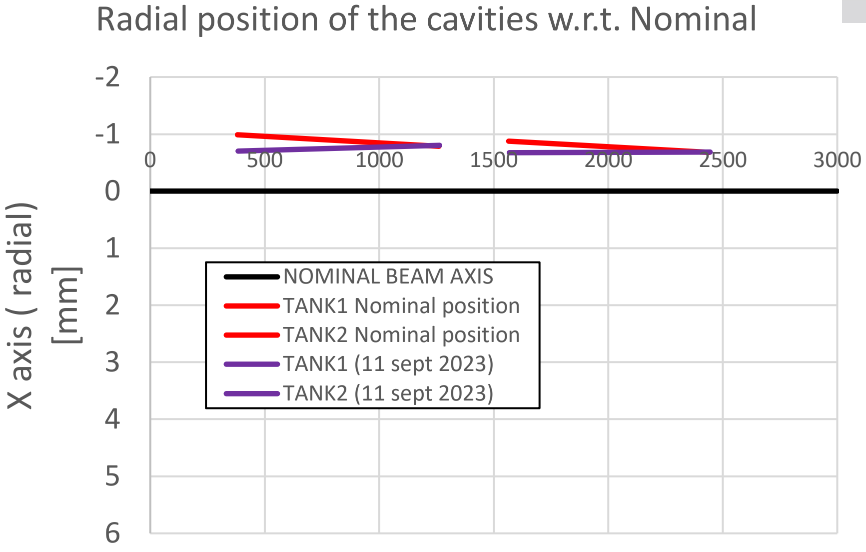
Radial and vertical objectives for the final alignment : < 0.1 mm
(will be done at CERN, before Bunker test)



Vertical : Difference to nominal
Max : 0.6 mm



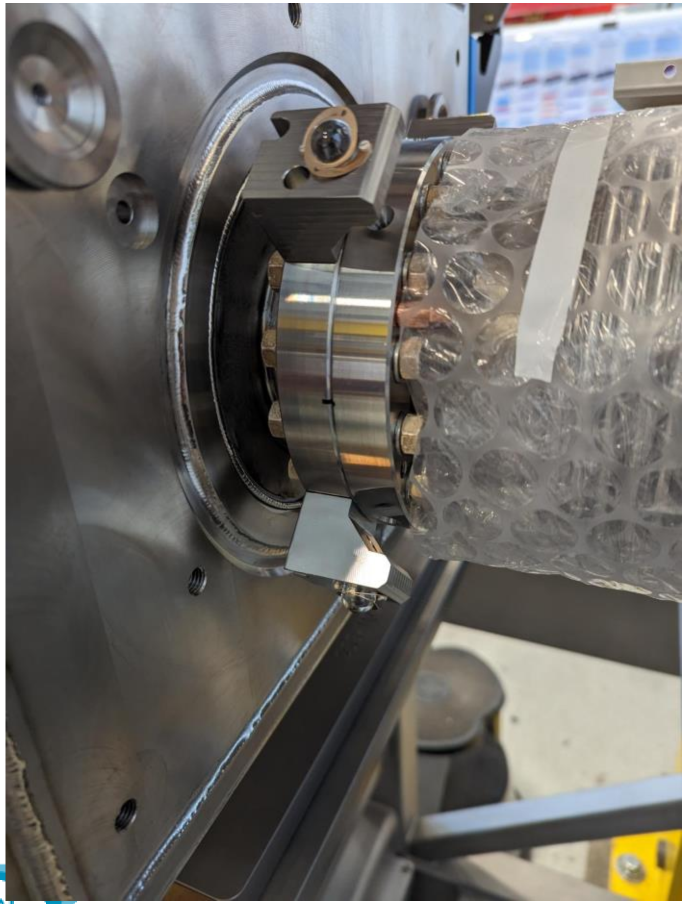
Radial : Difference to nominal
Max : 0.3 mm



Longitudinal	Nominal	After step 9	Difference to nominal
TANK1	809.6 mm	813.5 mm	+3.9 mm
TANK2	1992.1 mm	1995.6 mm	+3.5 mm

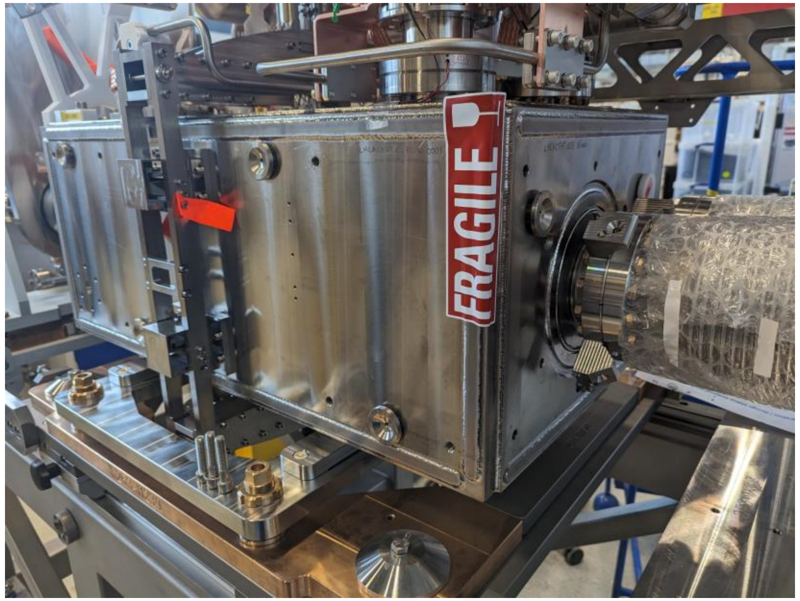
FSI installation

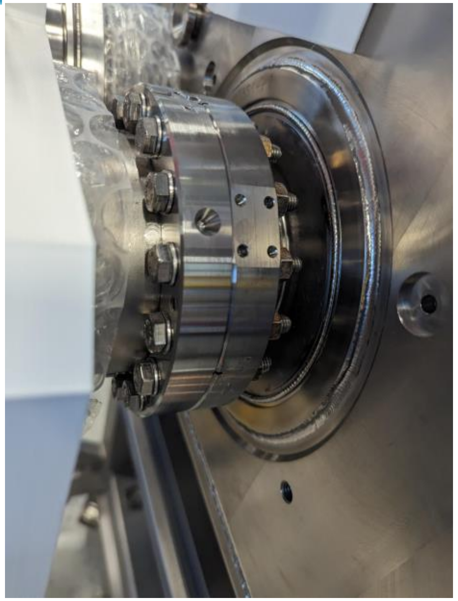
targets

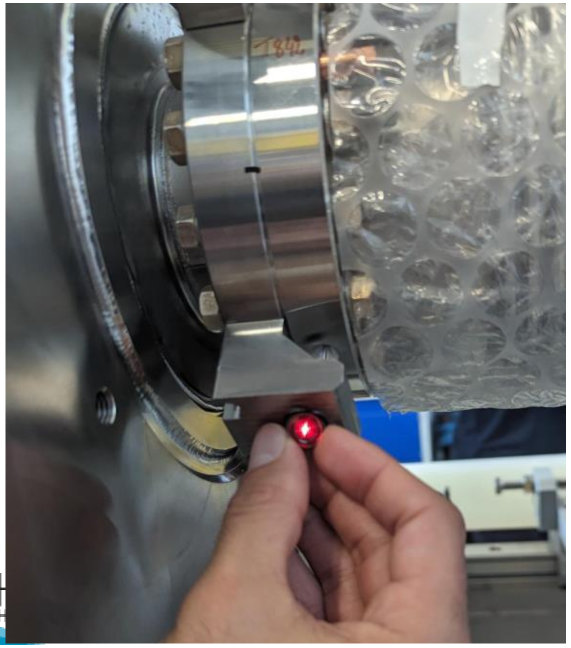


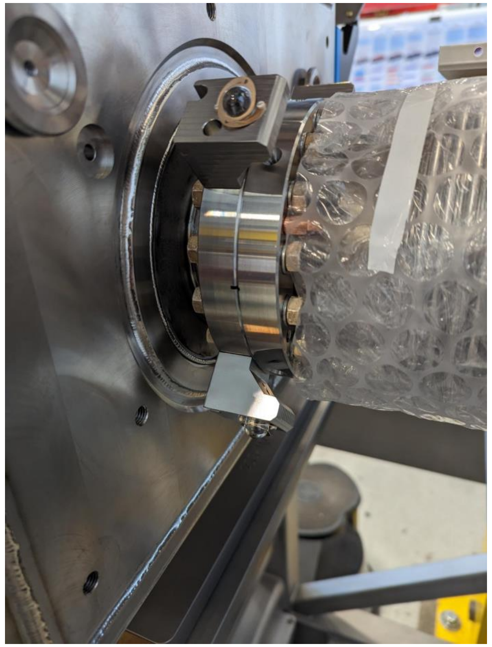
Sensors : FSI Heads

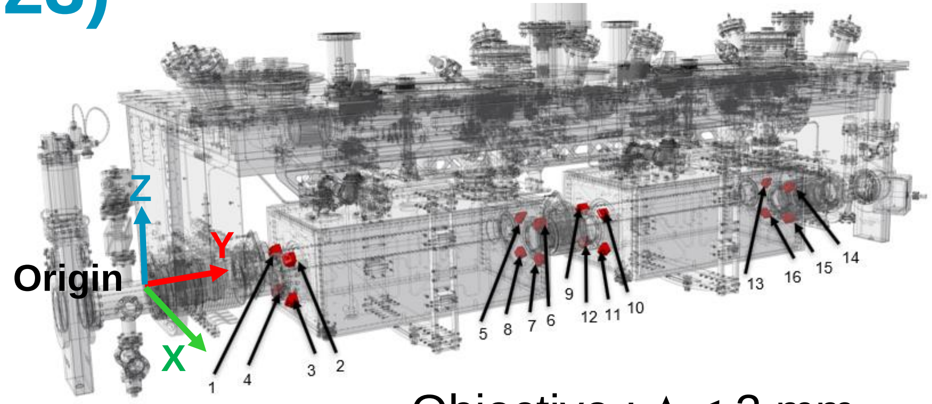
FSI targets (installation done in June 2023)









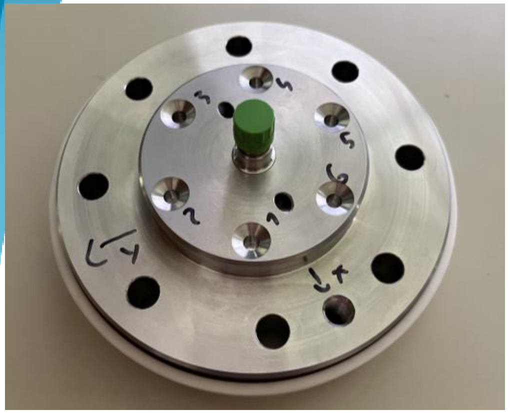


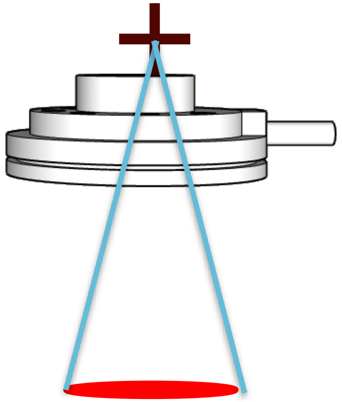
Objective : Δ < 2 mm

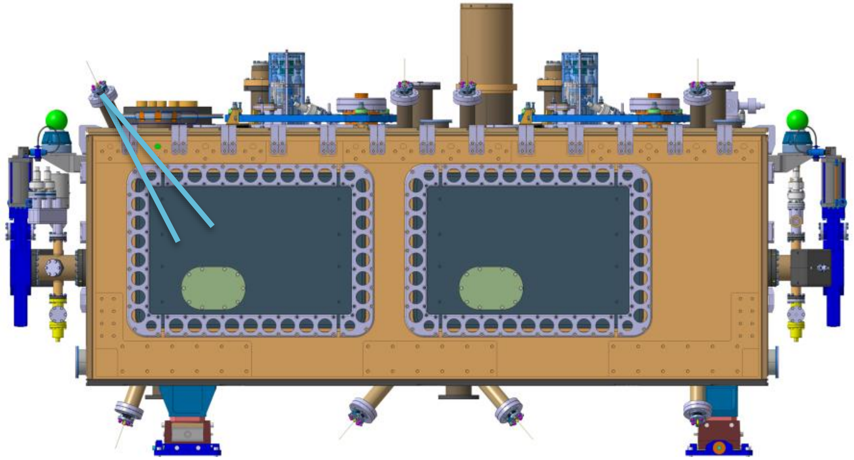
	Difference To nominal position		
	X [mm]	Y [mm]	Z [mm]
1	-1.1	0.4	0.8
2	-0.8	0.2	1.5
3	0.1	-0.3	1.9
4	0.1	-0.2	0.6
5	0.8	0.5	-2.0
6	1.1	0.2	-2.6
7	0.6	-0.4	-2.1
8	0.3	-0.3	-1.7
9	-0.9	2.1	-0.9
10	-0.5	1.8	0.0
11	0.2	2.1	0.4
12	0.3	2.3	-0.7
13	0.3	-1.1	-0.2
14	0.5	-1.4	-0.2
15	0.3	-1.4	0.3
16	0.6	-1.2	0.2

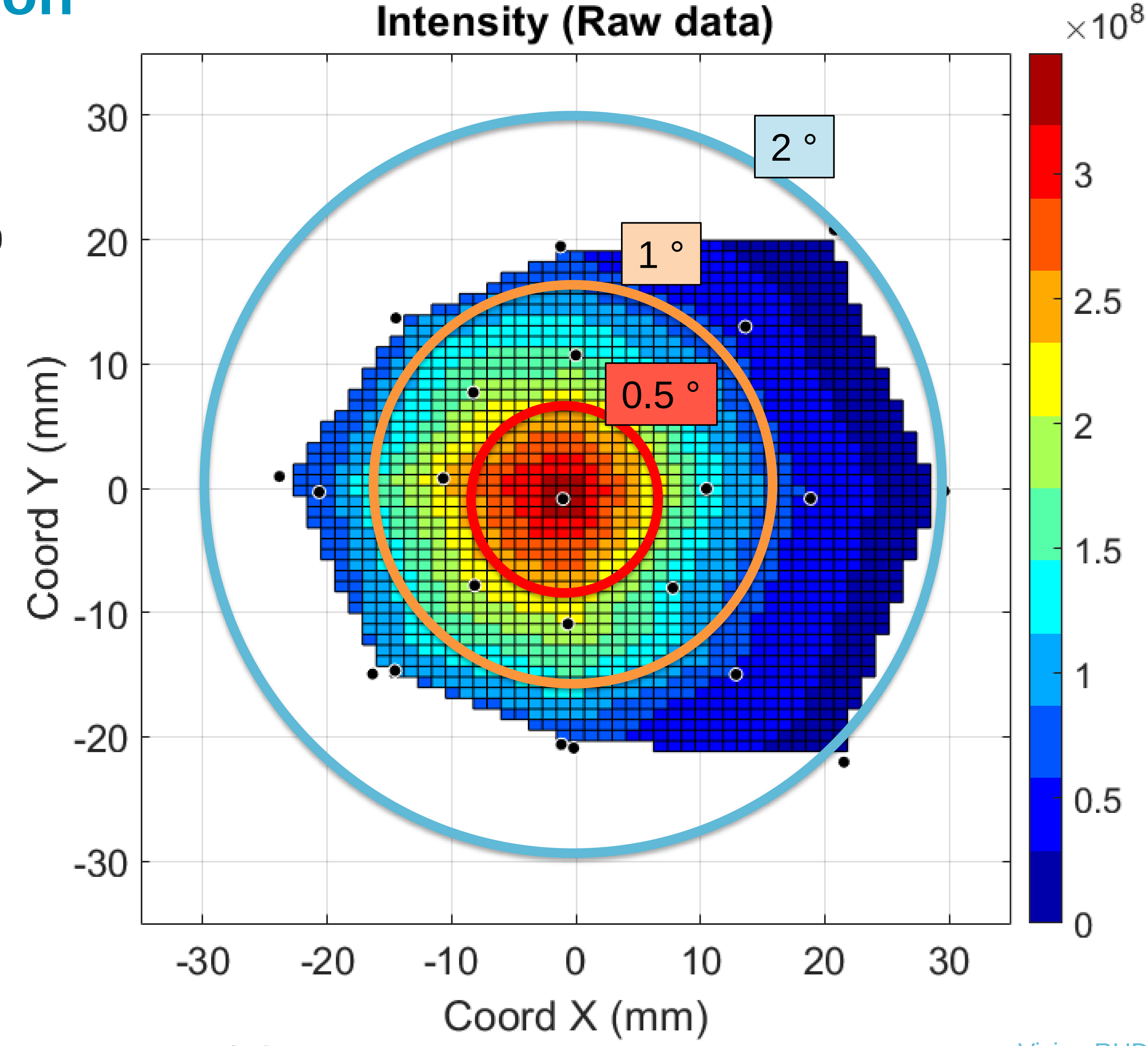
FSI heads / installation on top plate and cryomodule

FSI heads : Calibration





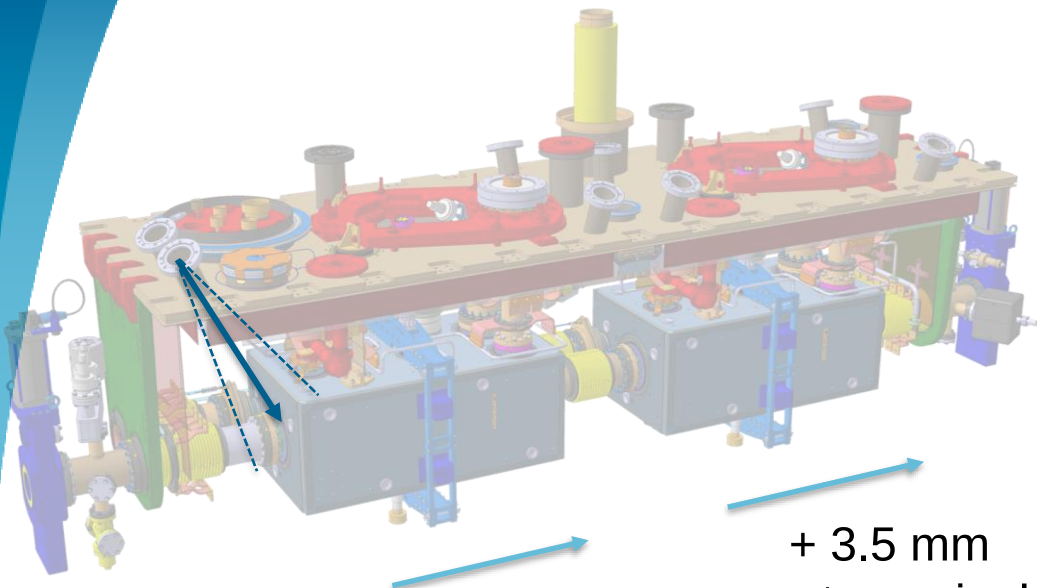




Close to the noise

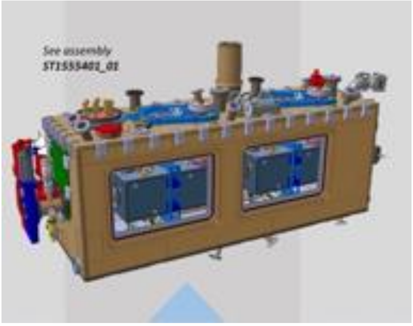
0.5° = 8.7 mrad → 8.7 mm at 1 m

Validation of FSI observation (June and September 2023)



+ 3.5 mm
w.r.t. nominal

+ 3.9 mm
w.r.t. nominal



	Optical sight	After step 4		After step 9	
		WARM Angle (°) [< 0.5°]	Estimated COLD Angle (°) [< 0.5°]	WARM Angle (°) [< 0.5°]	Estimated COLD Angle (°) [< 0.5°]
TANK1	Head1 → Target 1	0.36	0.42	0.40	0.40
TANK1	Head2 → Target 2	0.23	0.33	0.20	0.22
TANK1	Head3 → Target 3	0.05	0.12	0.42	0.29
TANK1	Head4 → Target 4	0.20	0.05	0.55	0.42
TANK1	Head5 → Target 5	0.17	0.22	0.48	0.51
TANK1	Head6 → Target 6	0.32	0.24	0.56	0.53
TANK2	Head7 → Target 11	0.33	0.27	0.47	0.43
TANK2	Head8 → Target 12	0.17	0.09	0.31	0.32
TANK2	Head9 → Target 9	0.40	0.42	0.64	0.60
TANK2	Head10 → Target 10	0.11	0.18	0.34	0.28
TANK1	Head11 → Target 7	0.27	0.24	0.19	0.07
TANK1	Head12 → Target 8	0.25	0.37	0.18	0.26
TANK2	Head13 → Target 13	0.13	0.19	0.37	0.40
TANK2	Head14 → Target 14	0.26	0.31	0.26	0.32
TANK2	Head15 → Target 15	0.23	0.24	0.20	0.27
TANK2	Head16 → Target 16	0.26	0.26	0.13	0.20

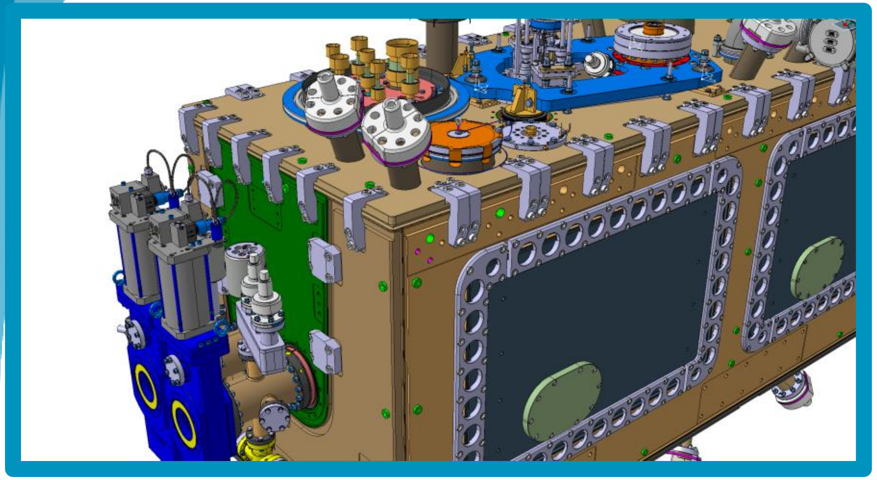
Objective — $\alpha < 0.5\,°$

Acceptable — $0.5\,° < \alpha < 1\,°$

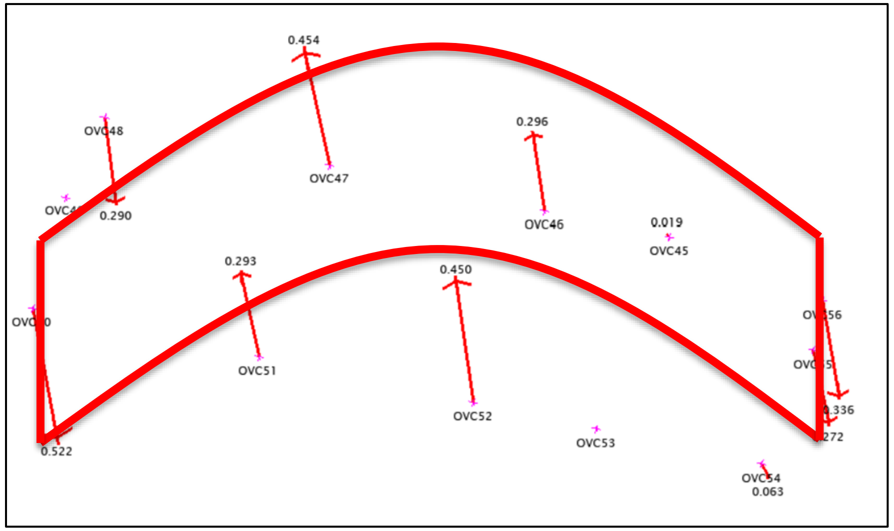
Not acceptable — $\alpha > 1\,°$

Cryomodule and top plate measurement

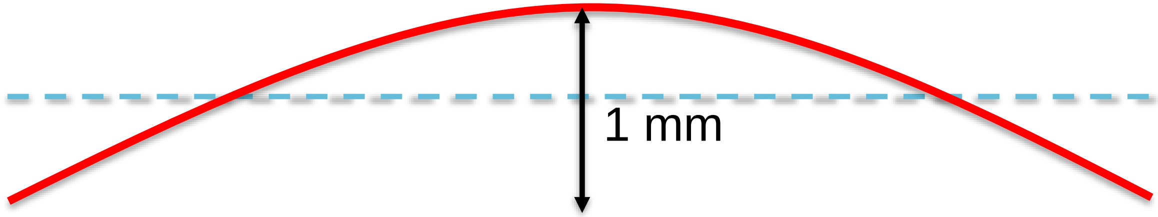
Deformation of the top plate between installation on cryomodule and hanging



Difference



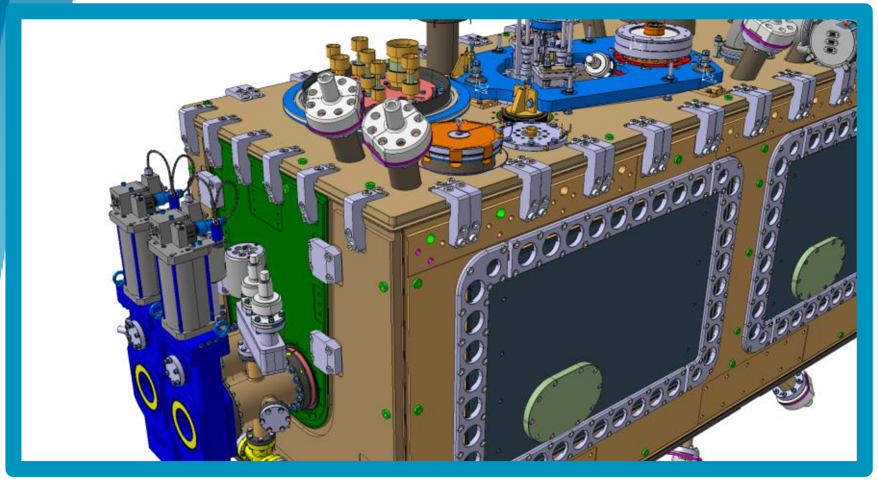
For the test under vacuum scheduled end of September, a special attention will be given



Top plate installed on the cryomodule

Top plate hanging

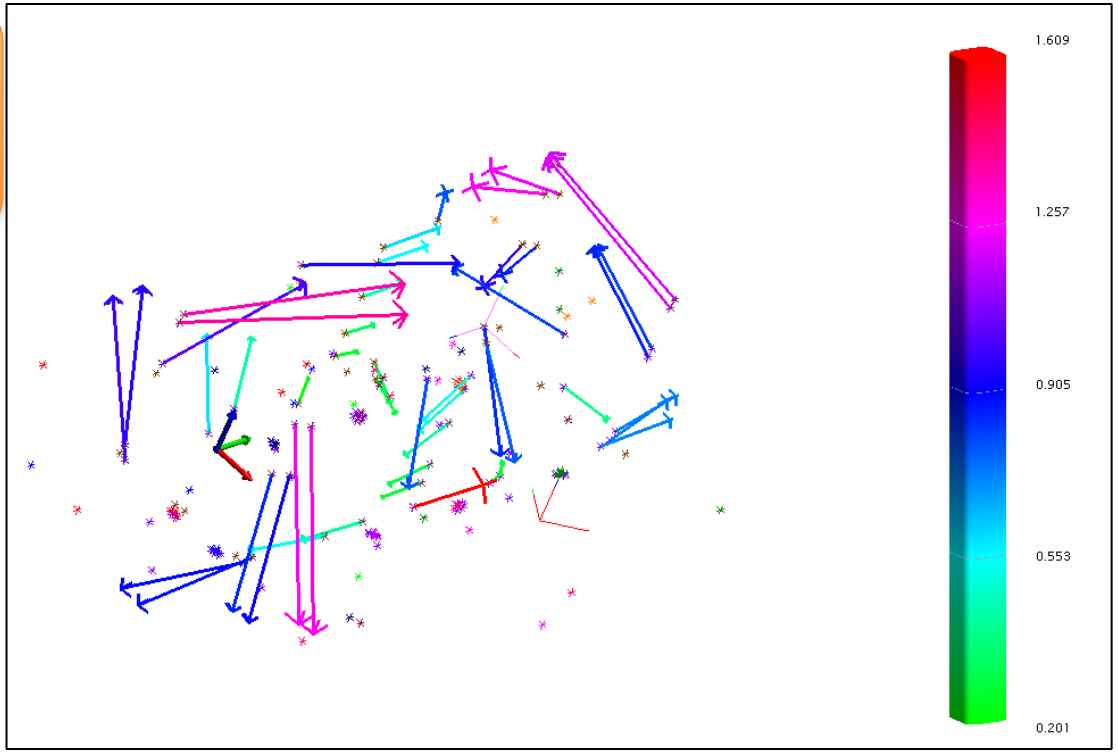
Deformation of the cryomodule with and without the top plate installed on the top



Difference up to 1.6 m

twist

For the test under vacuum scheduled end of September, a special attention will be given



Next step (at CERN)

RFD prototype at CERN

- 2 days of installation and measurement — Installation : FSI system, Optical fibers; Laser Tracker : Measurement of FSI Heads
- Measurement with FSI possible — → Position of the cavities inside the cryomodule
- Test of adjustment system + realignment — Objective : < 0.1 mm w.r.t. nominal

Under vacuum

- 0.5 days of measurement Laser Tracker — Laser Tracker : Impact of vacuum on the cryomodule
- Measurement with FSI possible — → Position of the cavities inside the cryomodule

Cooling down

- 0.5 days of measurement Laser Tracker **if possible** — Laser Tracker : Impact of cooling down on the cryomodule
- Measurement with FSI possible — → Position of the cavities inside the cryomodule

Conclusion

The RFD prototype is ready to go into the SPS accelerator !

Many thanks to STFC team :
- Nik
- Ed
- Luke
- Ryan
- Carlos
- Andy
- …

Many thanks to CERN team :
- Teddy
- Marco
- Kurt
- Simon
- Raphael
- Luca
- Nuria
- Katarzyna
- Rama
- Ofelia
- Julien
- …

Thank you for your attention

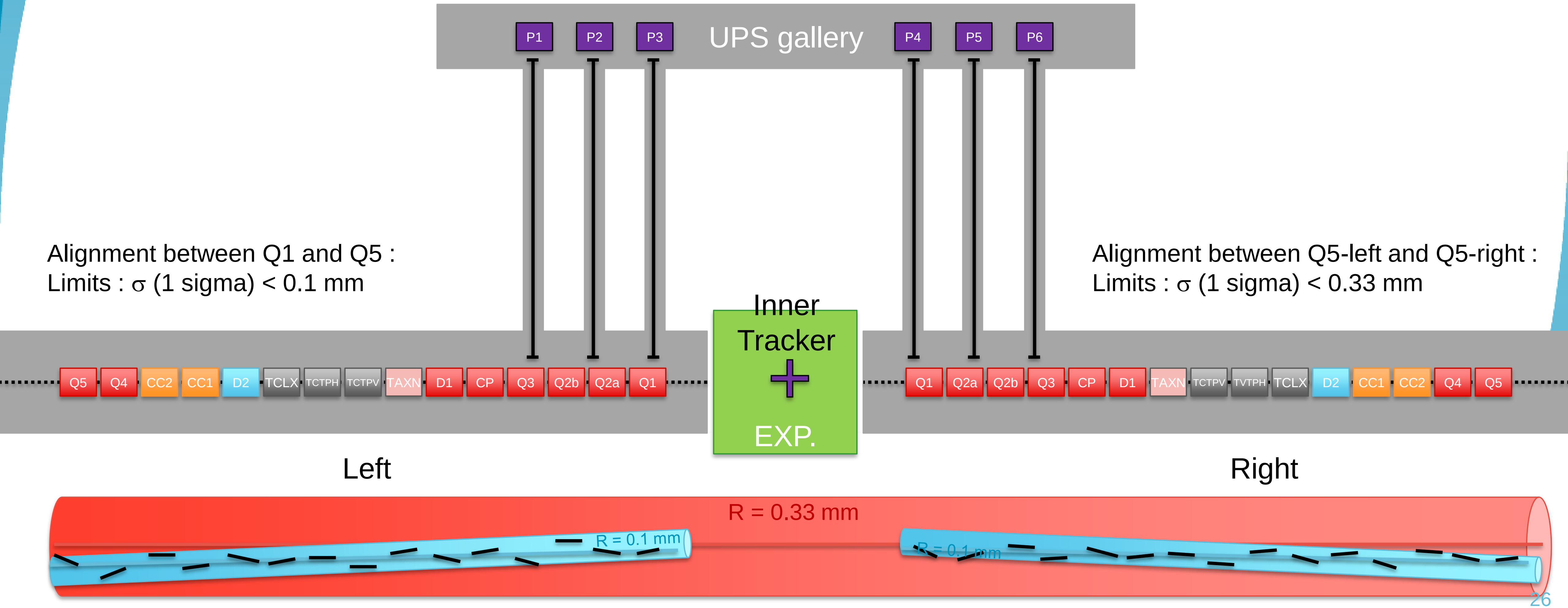
Thank you for your attention

SPARE

Alignment requirements for the cryostat / cryomodule

* On main components

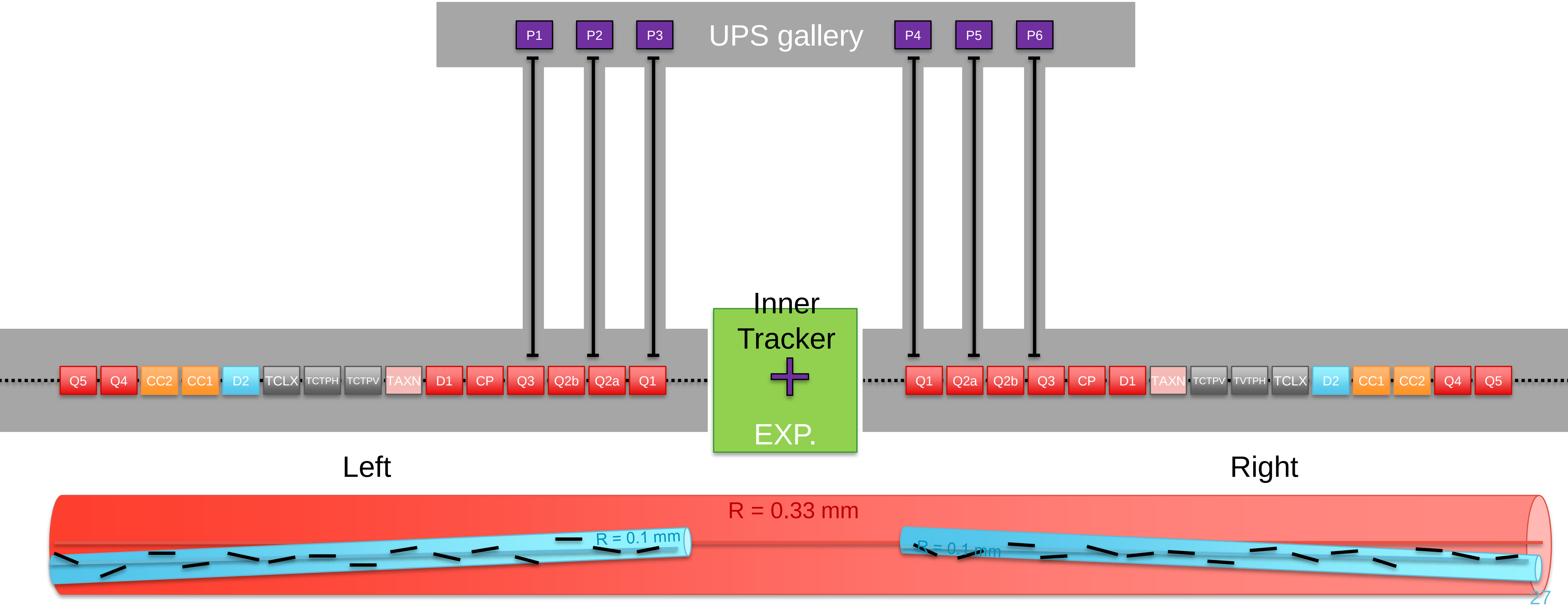
- **Alignment objectives (2023) for FRAS**
  - Position of the components cryostat along one side of the tunnel : +/- 0.1 mm *
  - Position of the components cryostat along one side of the tunnel w.r.t the other side : +/- 0.33 mm *



Alignment requirements for the cryostat / cryomodule

* On main components

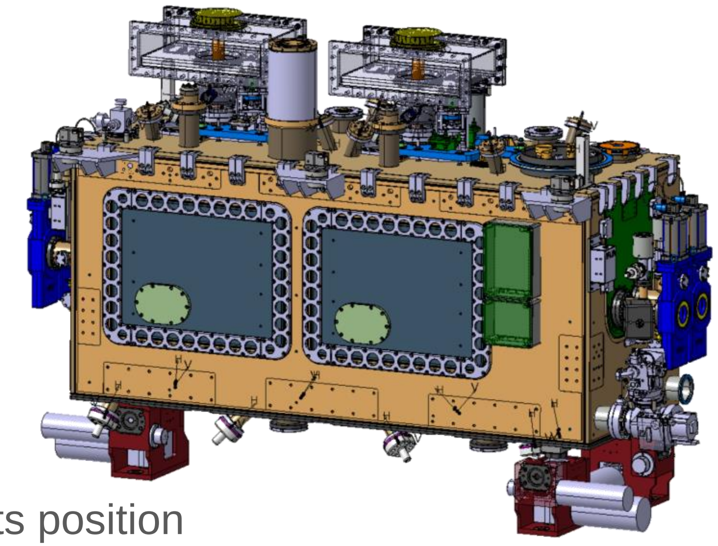
- **Alignment objectives (2023) for FRAS**
  - Position of the components cryostat along one side of the tunnel : +/- 0.1 mm *
  - Position of the components cryostat along one side of the tunnel w.r.t the other side : +/- 0.33 mm *



External monitoring

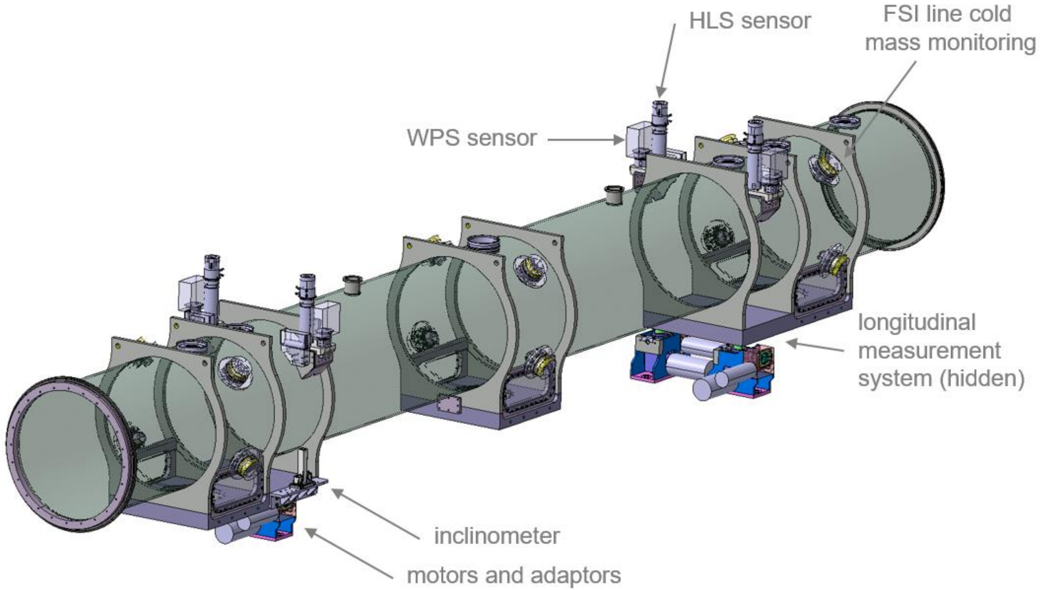
Remote alignment thanks to alignment sensors and actuators:

- FRAS LSS components equipped with reference sensors
  - WPS – Wire Position Sensor (Radial, Vertical position)
  - HLS – Hydrostatic Reference Sensor (Vertical Leveling, roll)
  - Inclinometers – (Roll)
  - Long range monitoring from UPS gallery
  - Longitudinal monitoring
- Each component equipped in motorized adapters – for the remote adjustment of its position

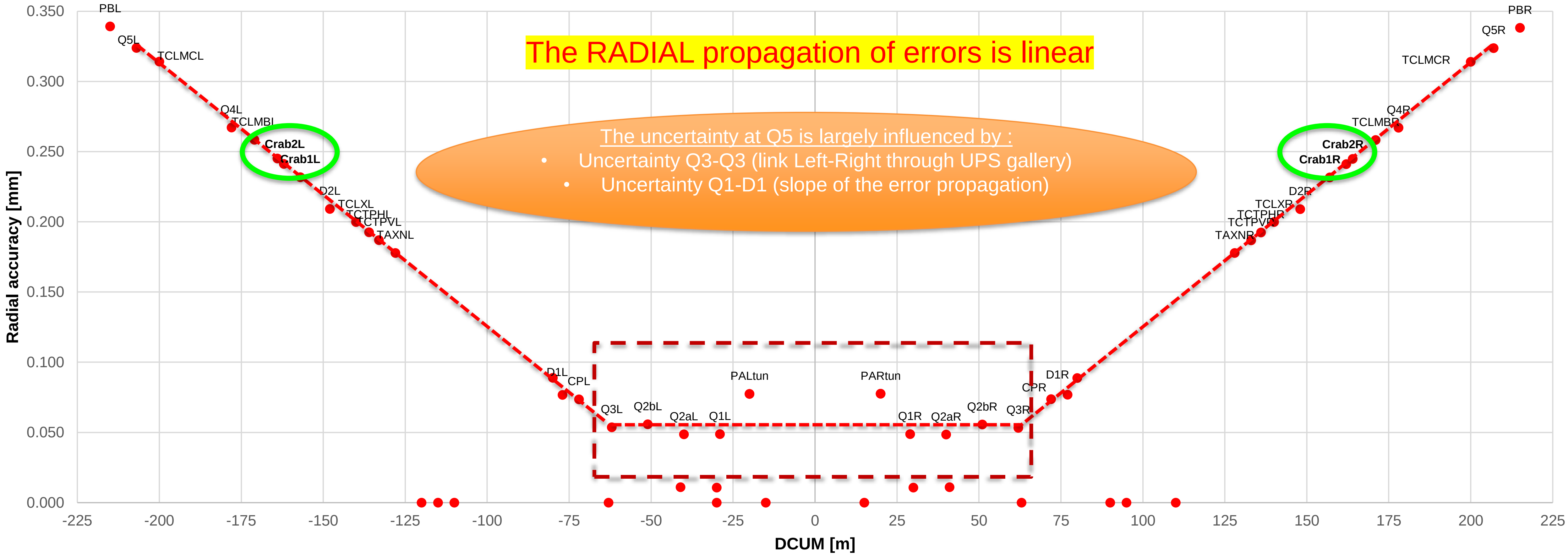


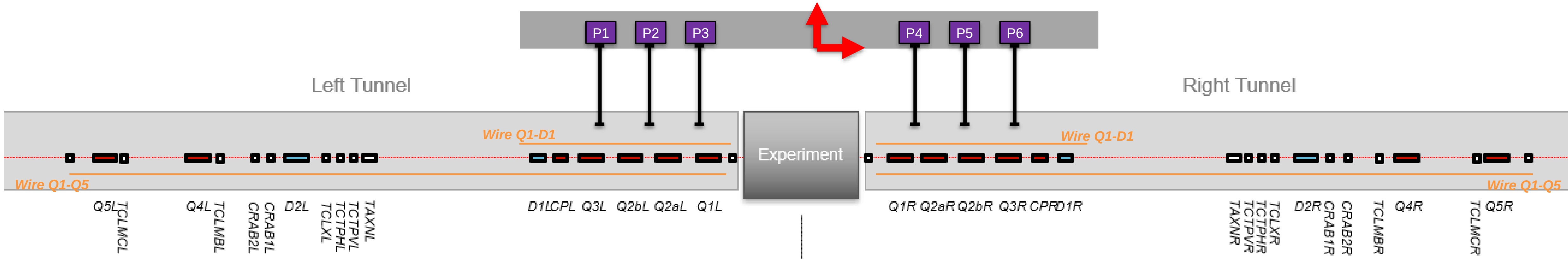
Accuracy of each sensor in the framework of cryostat

Sensors	Technology	Largest standard uncertainties	Uncertainty on 2023	
WPS	Capacitive	Calibration of WPS (if Lcable < 70 m) Calibration of WPS (if 70m < Lcable < 100 m)	5 µm 15 µm	**50 µm** (12 µm for WPS in UPS)
		Shape of wire	10 µm	
		Position of WPS in the framework of the vacuum vessel Position of WPS in the framework of the UPS plate	**50 µm** 2 µm	
HLS	Interferometry	Calibration of HLS	5 µm	**50 µm** (70 µm for HLS double)
		Shape of water	10 µm	
		Position of HLS in the framework of the vacuum vessel	**50 µm**	
Inclinometer	Capacitive Interferometry	Calibration of inclinometer	15 µrad	**150 µrad**
		Position of the inclinometer in the framework of the vacuum vessel	150 µrad	
Long range FSI 14 m	Interferometry	Calibration of the Long range FSI	20 µm	**50 µm**
		Position of the FSI in the framework of the UPS plate	2 µm	
		Position of the target in the framework of the vacuum vessel	**50 µm**	
Longitudinal FSI	Interferometry	Calibration of Longitudinal FSI	10 µm	**300 µm**
		Position of Longitudinal FSI in the tunnel framework	300 µm	
		Position of the target in the framework of the vacuum vessel	**50 µm**	

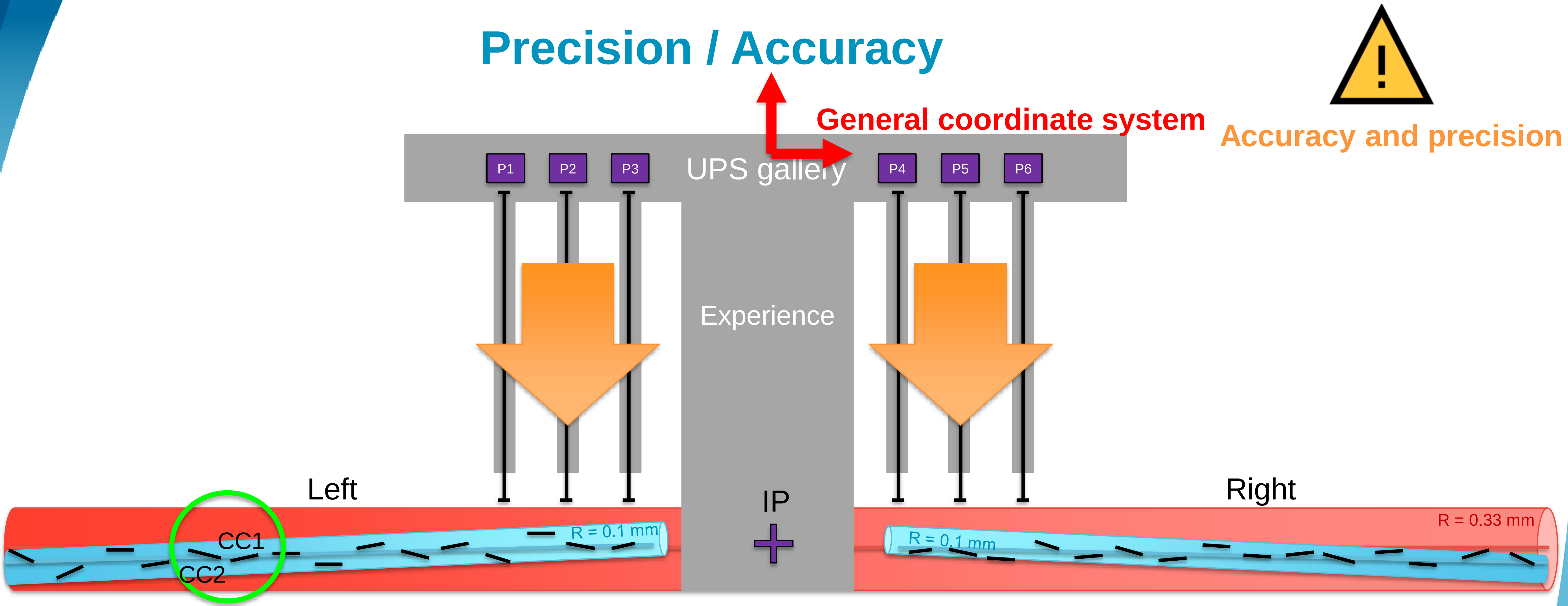


Position accuracy (radial) of the mechanical axis of component in R-general





Precision / Accuracy

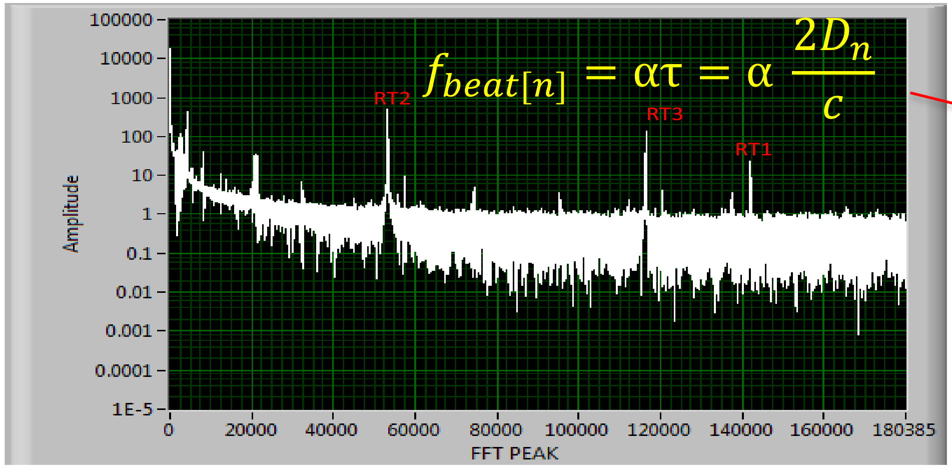


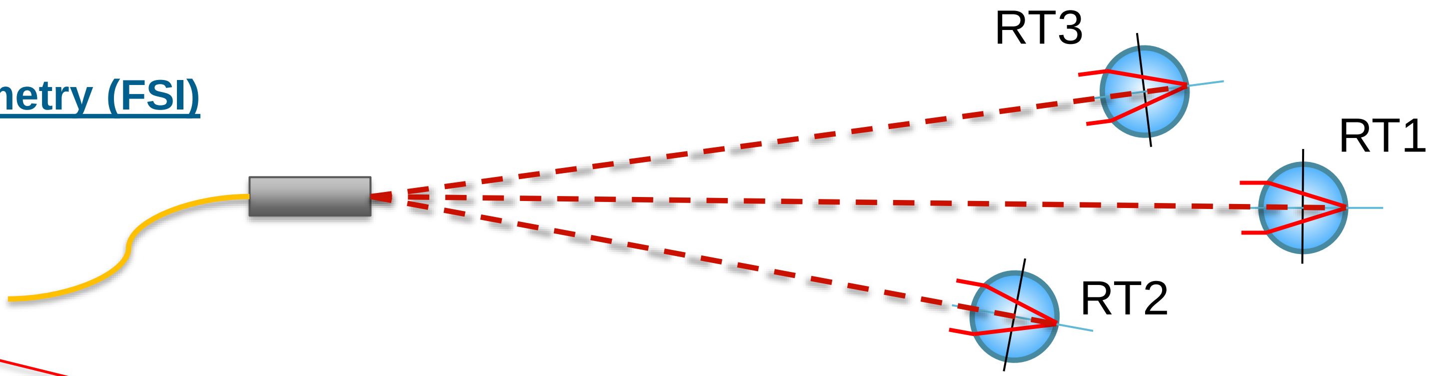
- The "**absolute**" position of CC1 (in general coordinate system) will be known with an **accuracy** of 0.25 mm (1σ)
- The "**absolute**" position of CC2 (in general coordinate system) will be known with an **accuracy** of 0.25 mm (1σ)

  The "**relative**" position of CC1 w.r.t. CC2 will be known with a **precision** of few microns

- The "**relative**" movement of CC1 will be known with a **precision** of few microns

Multi-target Frequency Scanning Interferometry (FSI)





$$D_n = c\,\frac{f_{beat[m]}}{2\frac{dv}{dt}n}$$

α – is a sweep rate of the laser ($\alpha = \frac{dv}{dt}$ - laser frequency change in time);

c – speed of light;

n – refractive index of light transmission medium;

τ – time of flight of laser to the target

from Mateusz Sosin