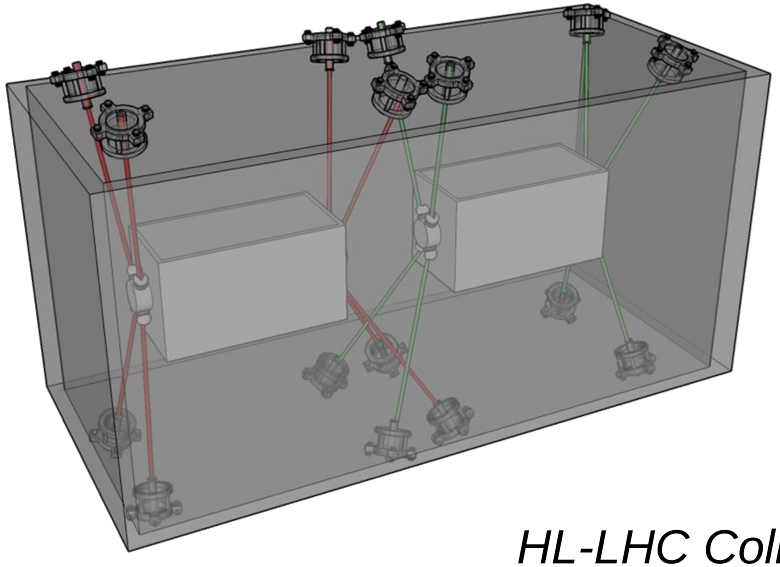
HiLumi
HL-LHC PROJECT

Internal monitoring for Crab-cavities

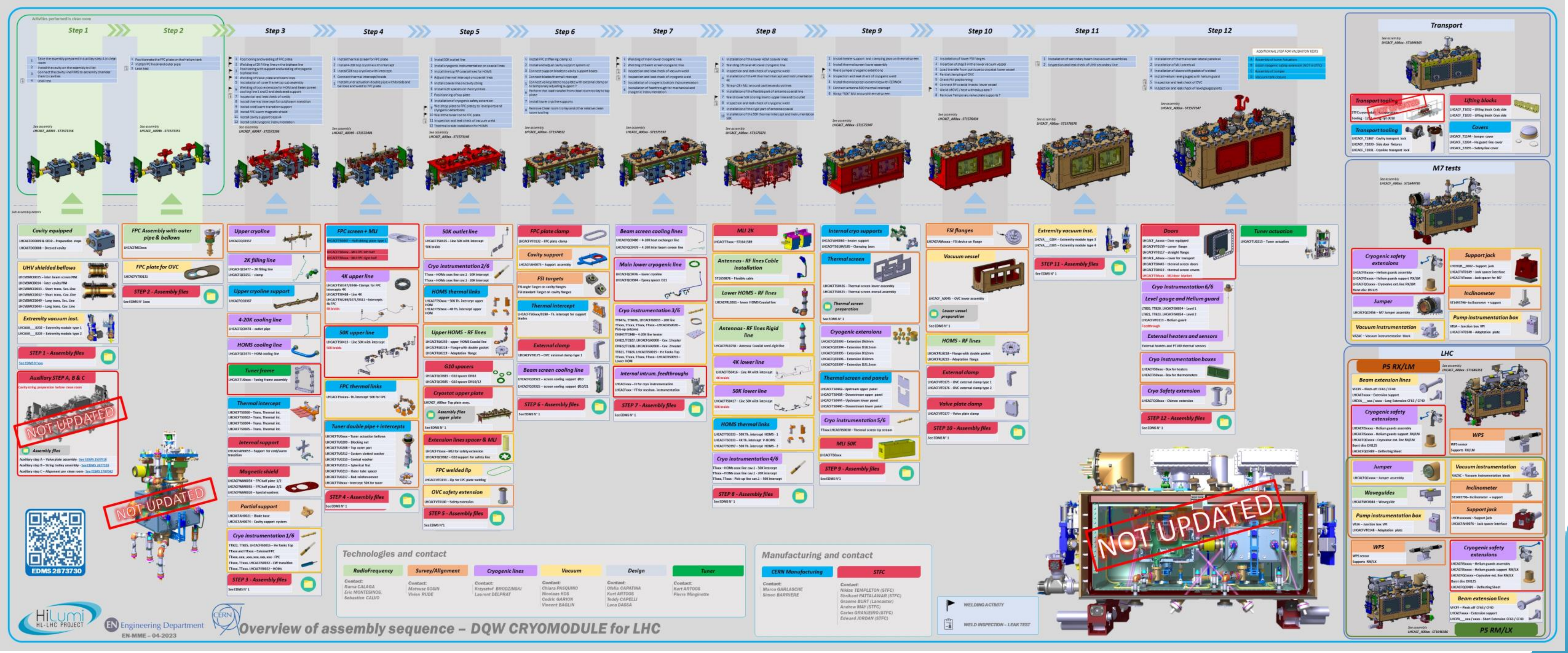


Vivien RUDE

2024-10-14

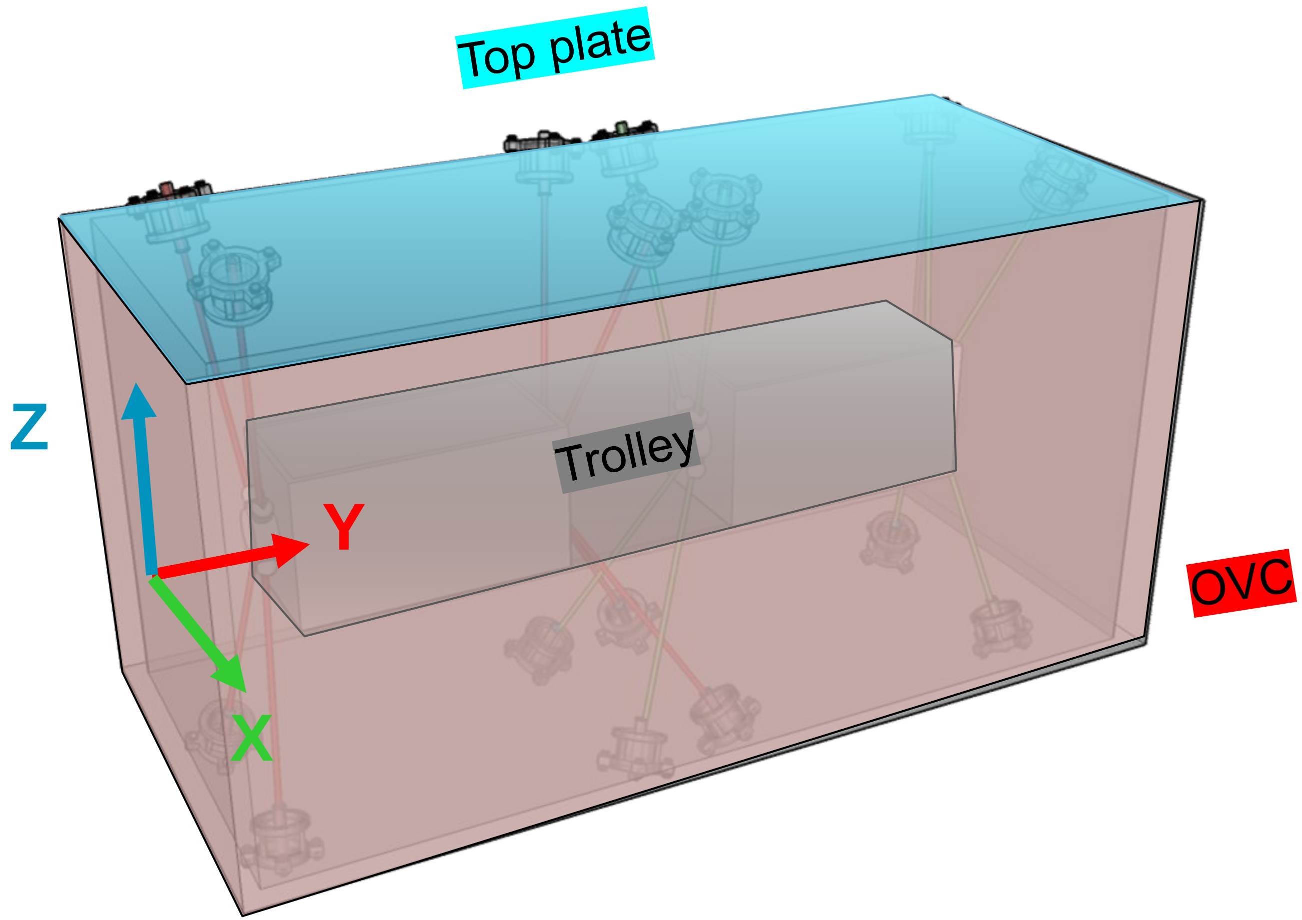
HL-LHC Collaboration Triumf-STFC-CERN

From Teddy Capelli

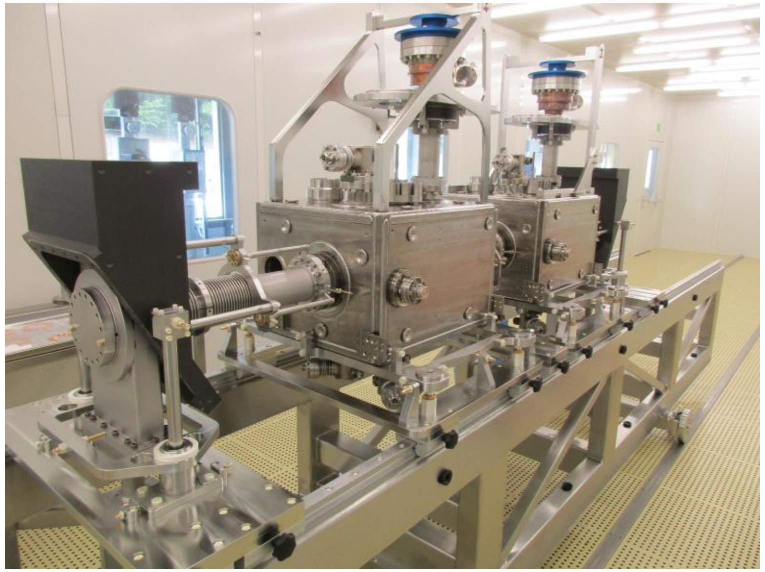


	Step	
Part 0 : CMM data	0	*Validation of trolley*
		Position of the capacitive plates w.r.t. external references → CERN
		Valve plate measurement
Part 1 : in clean room	1-2	*Alignment in ISO5 (before connection in ISO4)*
		Alignment in ISO5 (after connection in ISO4)
Part 2 : before cryostating	4-5	*Alignment of different equipment*
		Installation of FSI supports
		Measurement of FSI supports
		Installation FSI targets
Part 3 : cryostating (top plate)	6	*Alignment of the cavities before cryostating*
		Measurement of the top plate cryomodule
		Alignment trolley and top plate
Part 4 : cryostating (OVC cryomodule)	10	*Measurement of the OVC cryomodule*
		Alignment top plate and OVC cryomodule
Part 5 : after cryostating	10	*Installation of FSI heads on OVC and top plate*
		Measurement of FSI heads on OVC and top plate
		FSI validation (comparison with a laser tracker)
		Alignment with adjustment system
Part 6 : cold test at STFC or Triumf	12	*Measurement ambient pressure*
		Measurement under vacuum
		Measurement at cold
Part 7 : cold test at CERN		*Measurement ambient pressure*
		Measurement under vacuum
		Measurement at cold

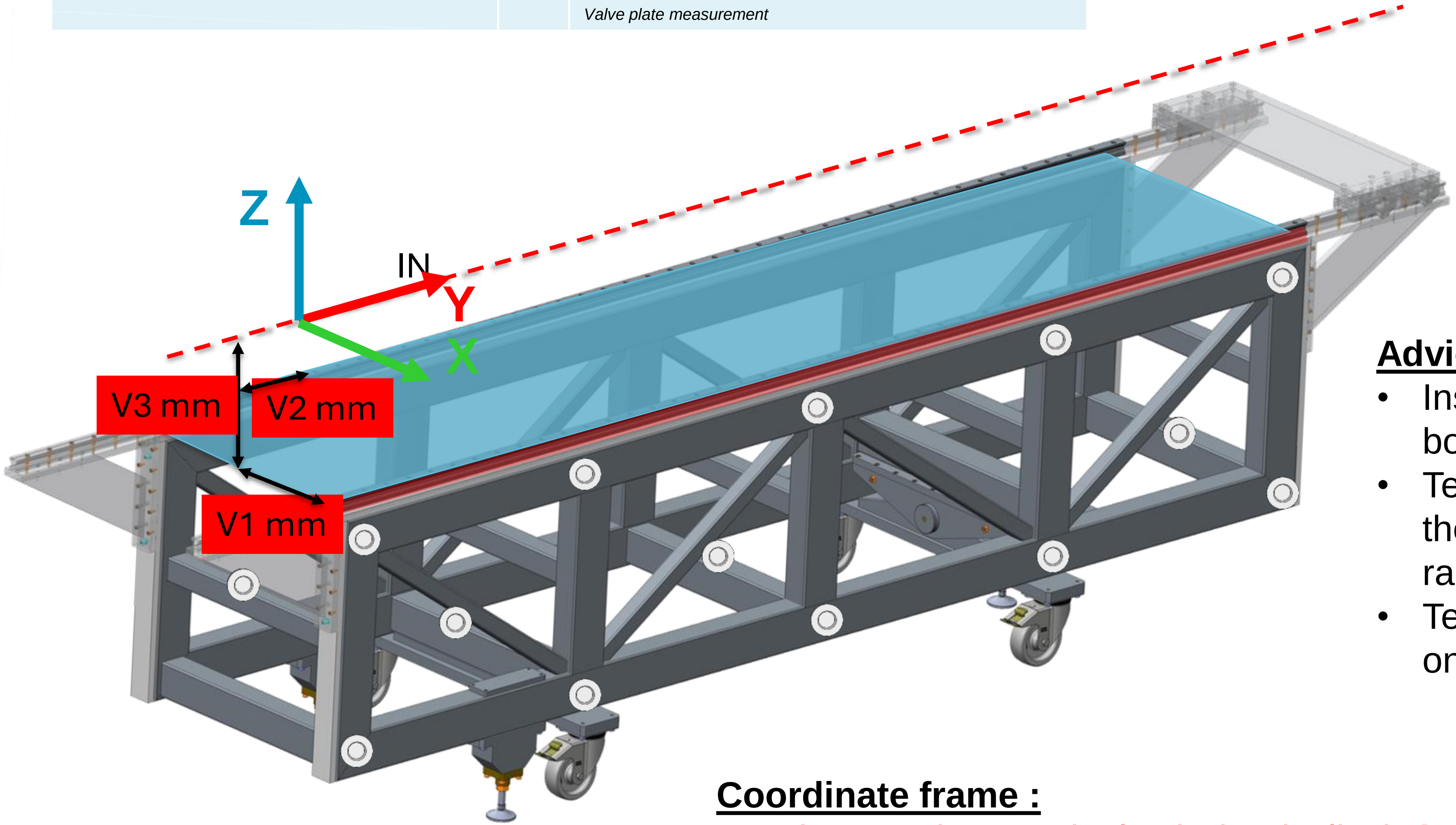
General principle : 3 objects → 3 coordinate systems similar



	Step	
Part 0 : CMM data	0	*Validation of trolley*
		Position of the capacitive plates w.r.t. external references → CERN
		Valve plate measurement



	Step	
Part 0 : CMM data	0	*Validation of trolley*
		Position of the capacitive plates w.r.t. external references → CERN
		Valve plate measurement



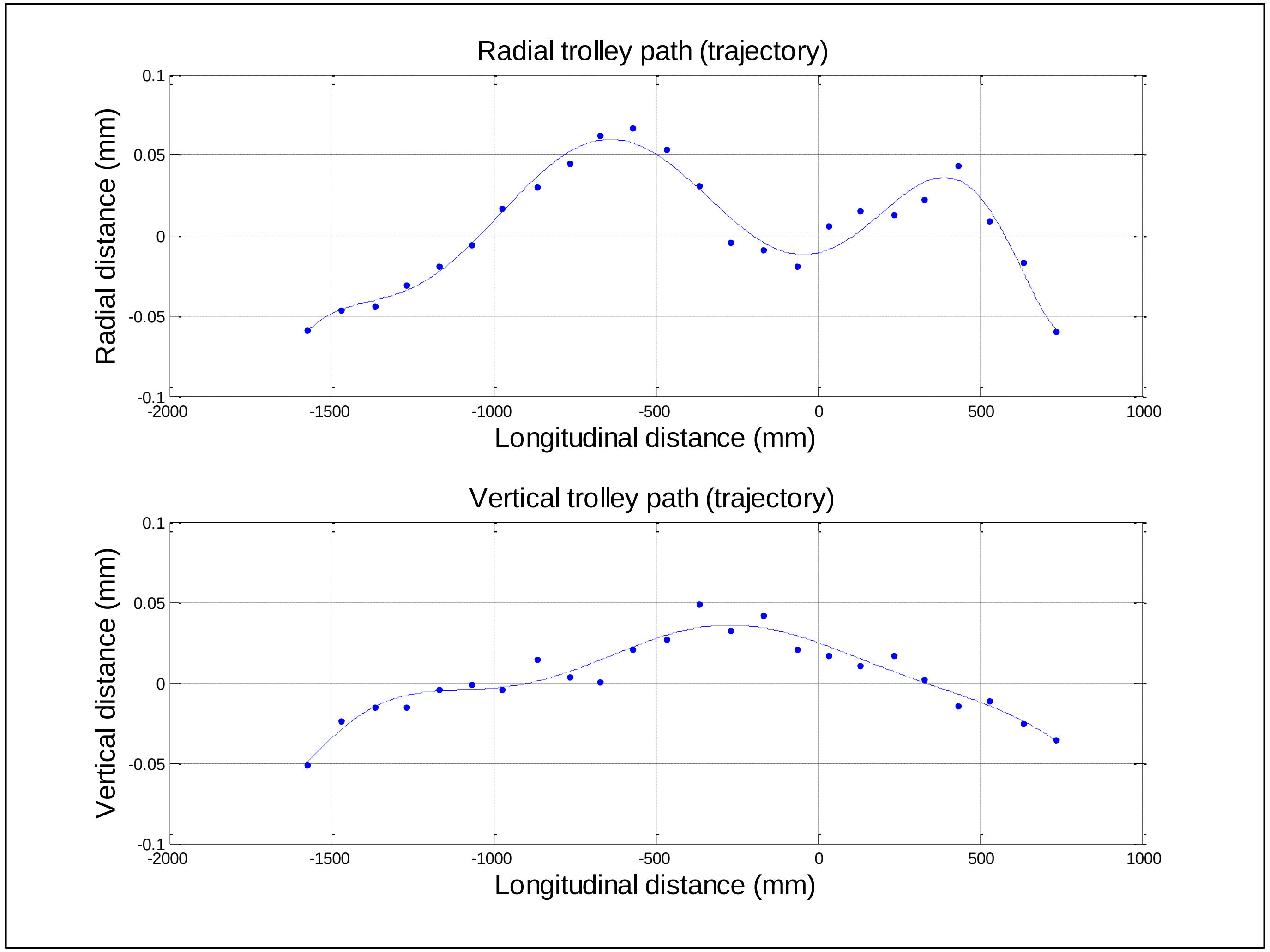
Advice :

- Install fiducial points on both sides of the trolley.
- Test the trajectory of the component on the rails
- Test the impact of load on the trolley

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

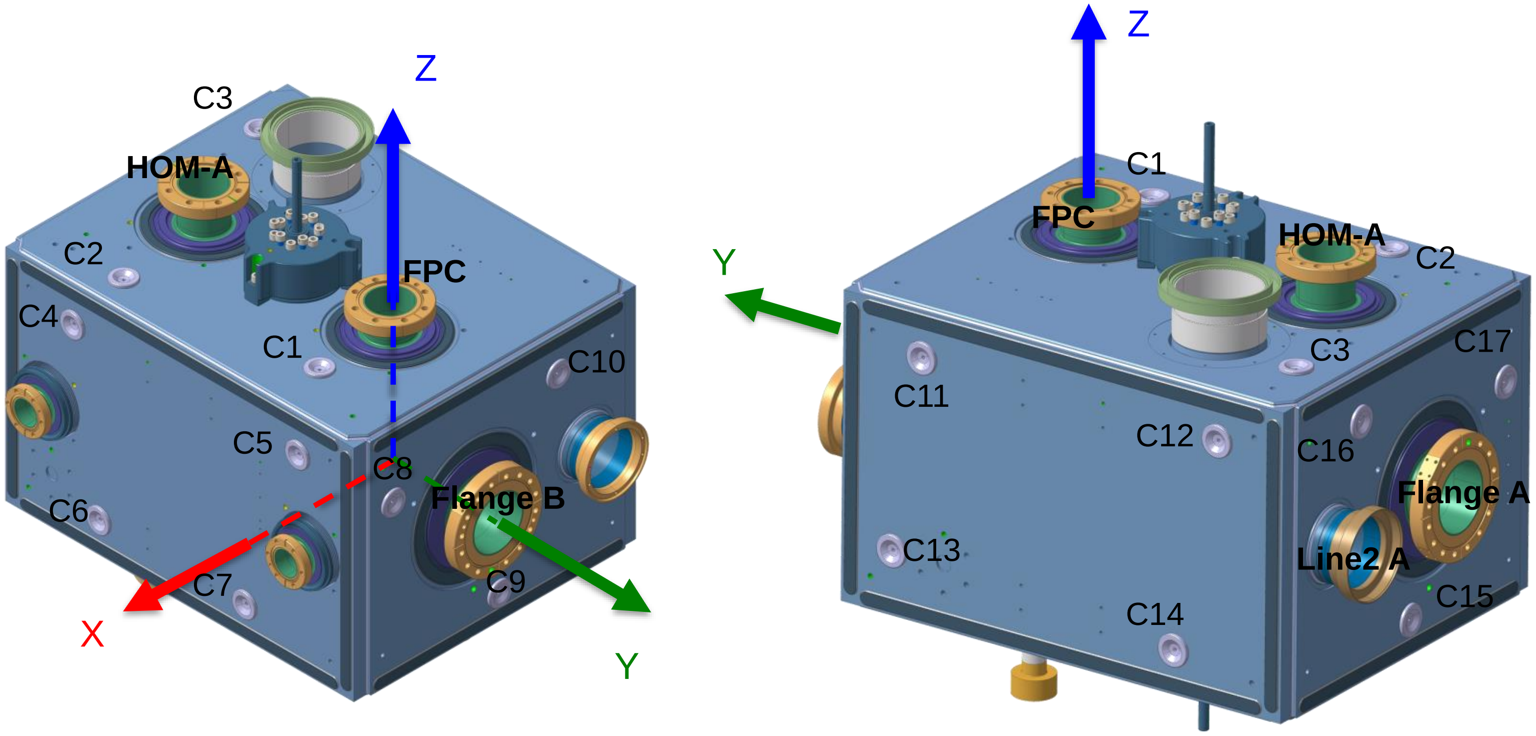
	Step	
Part 0 : CMM data	0	*Validation of trolley*
		Position of the capacitive plates w.r.t. external references → CERN
		Valve plate measurement



	Step	
Part 0 : CMM data	0	*Validation of trolley*
		Position of the capacitive plates w.r.t. external references → CERN
		Valve plate measurement

Final coordinate system (R-capacitive-plates):

- *Y-axis (primary axis): Defined by the capacitive plate axis*
- *Z-axis (secondary axis): Defined from the projection of the center of circle FPC on line of the capacitive axis*
- *Origin: projection of the center of circle FPC on line of the capacitive axis.*



	X (mm)	Y (mm)	Z (mm)
Flange_A_Inox	**0**	**-500.857**	**-0.039**
Flange_B_Inox	**0**	**179.144**	**-0.254**
Flange_FPC_Inox	**0**	**0**	**234.834**
Flange_HOM_A_Inox	**0.381**	**-320.512**	**249.645**
Flange_HOM_B_Inox	**89.659**	**-274.265**	**-250.260**
Flange_HOM_C_Inox	**-90.249**	**-273.956**	**-249.957**
Flange_pick_up_A_Inox	**239.994**	**-385.315**	**-0.423**
Flange_pick_up_B_Inox	**240.000**	**65.110**	**-0.137**
Line2 A	**-194.522**	**-508.330**	**0.298**
Line2 B	**-194.489**	**187.668**	**0.335**
C1	121.217	-0.148	214.856
C2	156.375	-304.377	214.999
C3	-184.520	-410.281	215.239
C4	223.532	-342.117	134.529
C5	223.371	47.401	134.695
C6	223.138	-296.469	-135.616
C7	223.011	-43.997	-135.468
C8	142.837	166.124	82.412
C9	-41.267	166.172	-144.759
C10	-142.858	166.060	132.874
C11	-305.115	30.952	135.617
C12	-304.967	-374.040	135.433
C13	-305.525	69.491	-109.469
C14	-305.465	-316.935	-134.642
C15	-41.117	-486.970	-145.082
C16	-142.617	-487.408	132.577
C17	143.050	-487.184	82.045
Tunning_BOTTOM	-0.947	-160.451	-369.724
Tunning_TOP	0.599	-160.218	369.329
Capacitive_plate_CENTER	**0**	**-160.238**	**0**
Capacitive_plate_IN	**0**	**-250.538**	**0**
Capacitive_plate_OUT	**0**	**-70.099**	**0**
Origine	0	0	0
Axe_X	1000	0	0
Axe_Y	0	1000	0
Axe_Z	0	0	1000
IN	0	-500.857	0
OUT	0	179.144	0

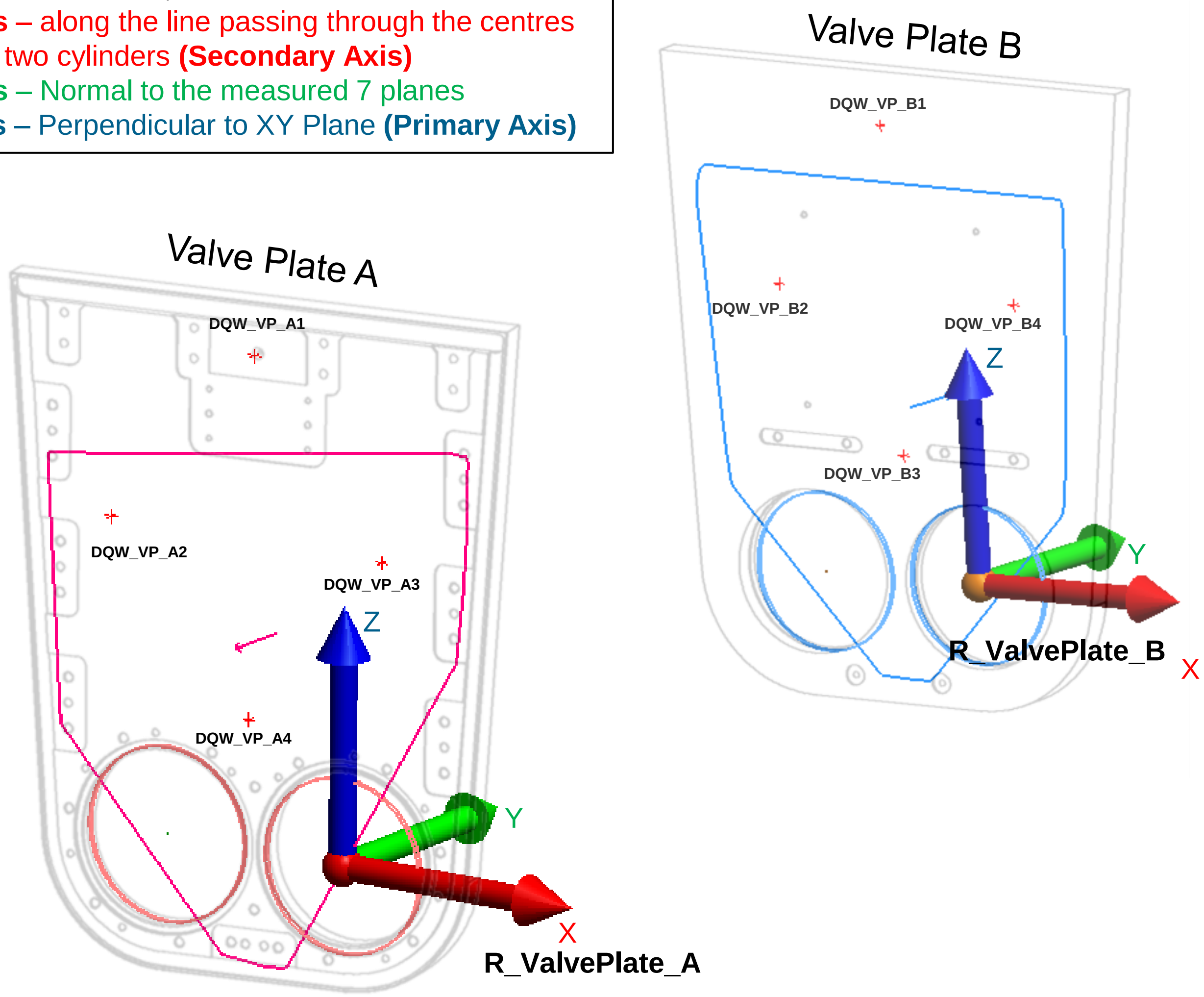
HiLumi HL-LHC PROJECT

	Step	
Part 0 : CMM data	0	*Validation of trolley*
		Position of the capacitive plates w.r.t. external references → CERN
		Valve plate measurement

Coordinate system

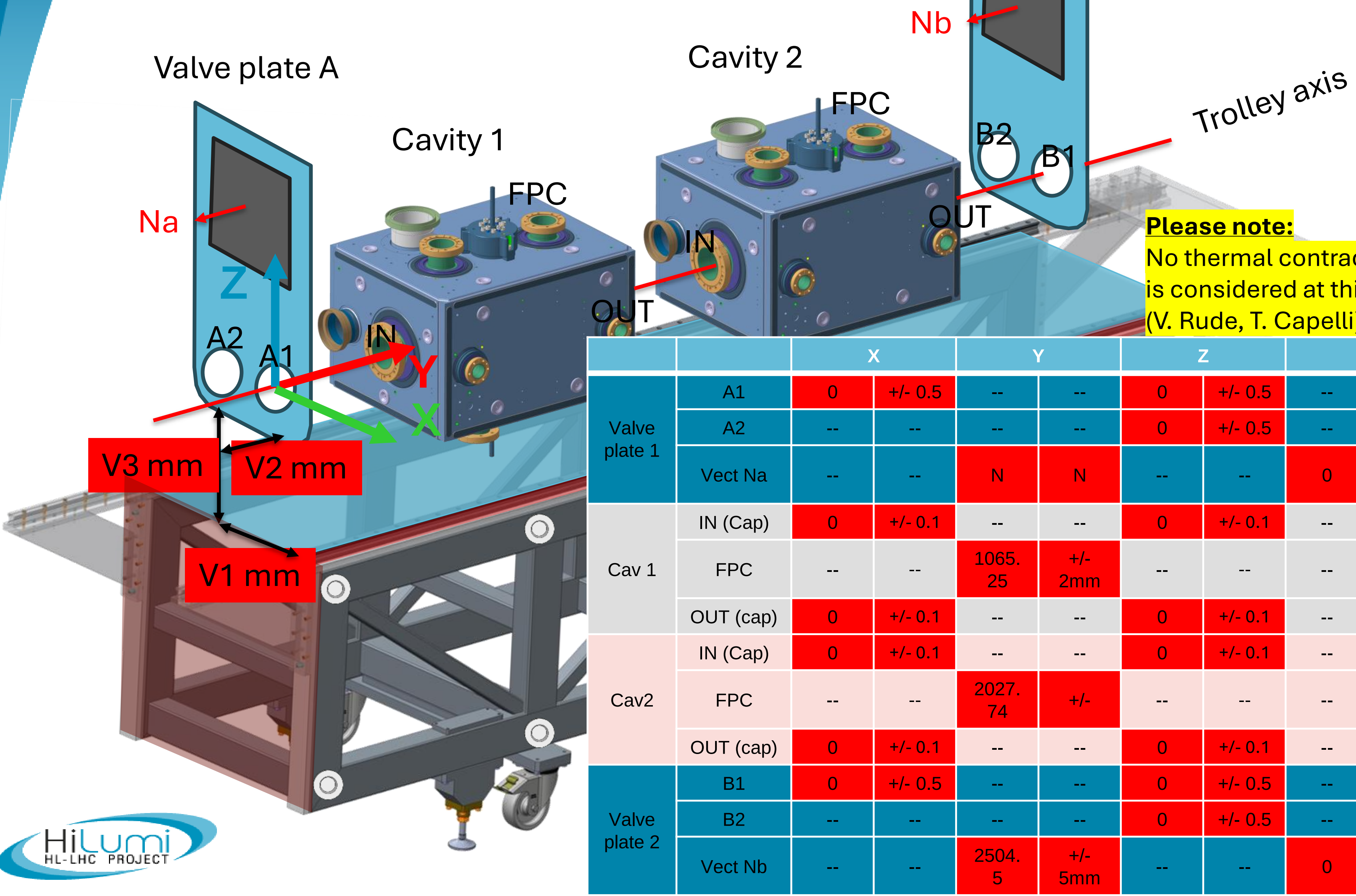
For both Valve Plates,

- **X axis –** along the line passing through the centres of the two cylinders **(Secondary Axis)**
- **Y axis –** Normal to the measured 7 planes
- **Z axis –** Perpendicular to XY Plane **(Primary Axis)**



Valve Plate A

	Step	
Part 1 : in clean room	1-2	*Alignment in ISO5 (before connection in ISO4)*
		Alignment in ISO5 (after connection in ISO4)



Please note:
No thermal contraction or movement due to vacuum is considered at this stage (V. Rude, T. Capelli).

		X		Y		Z		Rx		Ry		Rz	
Valve plate 1	A1	0	+/- 0.5	--	--	0	+/- 0.5	--	--	--	--	--	--
	A2	--	--	--	--	0	+/- 0.5	--	--	--	--	--	--
	Vect Na	--	--	N	N	--	--	0	+/-3.8 mrad	--	--	0	+/-2.5 mrad
Cav 1	IN (Cap)	0	+/- 0.1	--	--	0	+/- 0.1	--	--			--	--
	FPC	--	--	1065.25	+/- 2mm	--	--	--	--	0	+/-1.2 mrad	--	--
	OUT (cap)	0	+/- 0.1	--	--	0	+/- 0.1	--	--			--	--
Cav2	IN (Cap)	0	+/- 0.1	--	--	0	+/- 0.1	--	--			--	--
	FPC	--	--	2027.74	+/-	--	--	--	--	0	+/-1.2 mrad	--	--
	OUT (cap)	0	+/- 0.1	--	--	0	+/- 0.1	--	--			--	--
Valve plate 2	B1	0	+/- 0.5	--	--	0	+/- 0.5	--	--	--	--	--	--
	B2	--	--	--	--	0	+/- 0.5	--	--	--	--	--	--
	Vect Nb	--	--	2504.5	+/- 5mm	--	--	0	+/-3.8 mrad	--	--	0	+/-2.5 mrad

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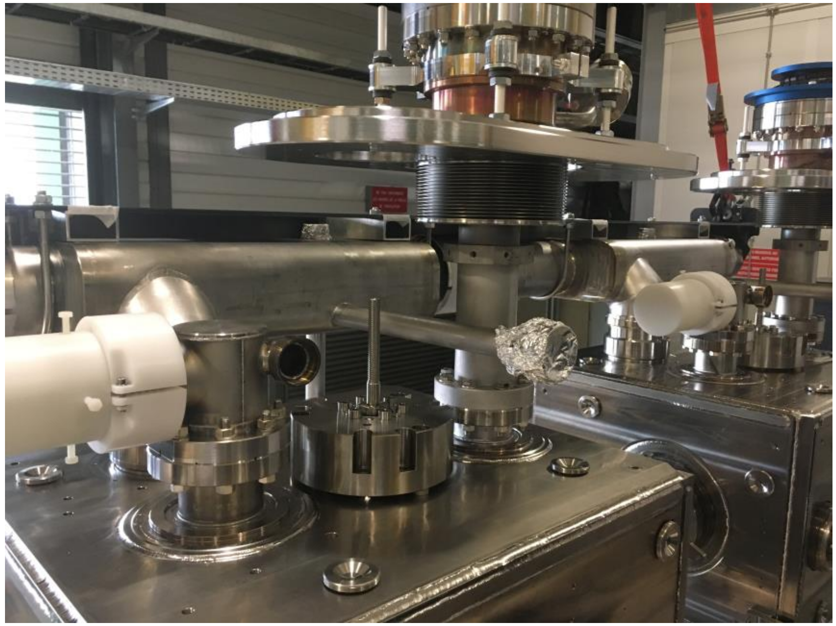
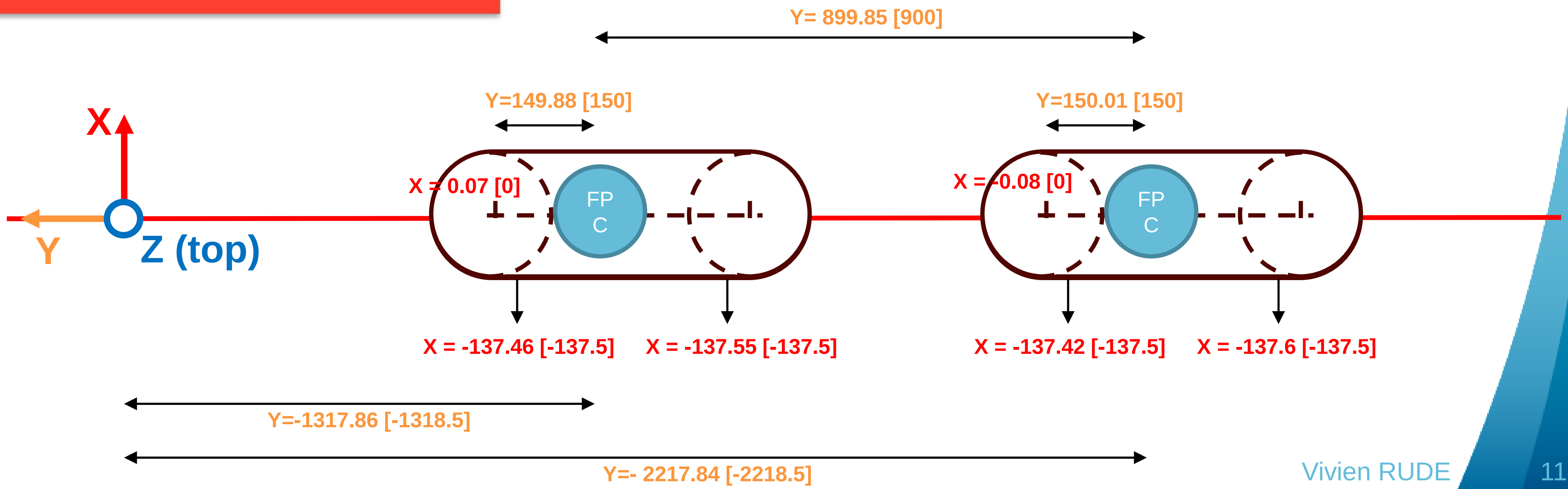
	Step	
Part 2 : before cryostating	4-5	*Alignment of different equipment*
		Installation of FSI supports
		Measurement of FSI supports
		Installation FSI targets



Objective / Results :

- Cryogenic line : at 1 mm
- Oblong bellows plate : at 1 mm
- …



	Step	
Part 2 : before cryostating	4-5	*Alignment of different equipment*
		Installation of FSI supports
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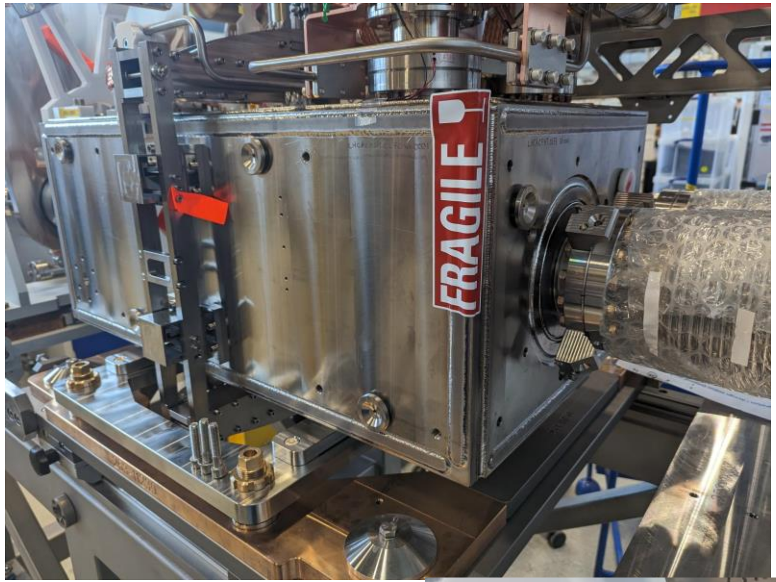
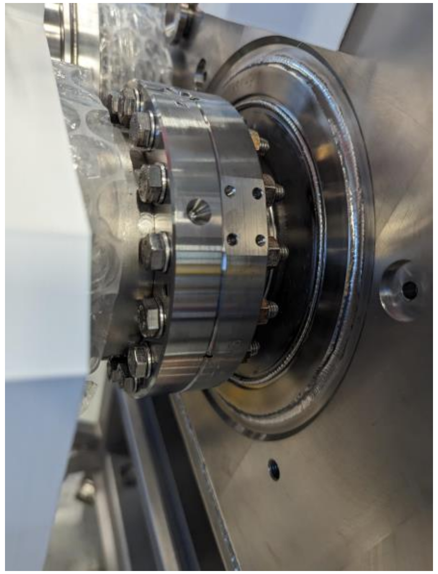
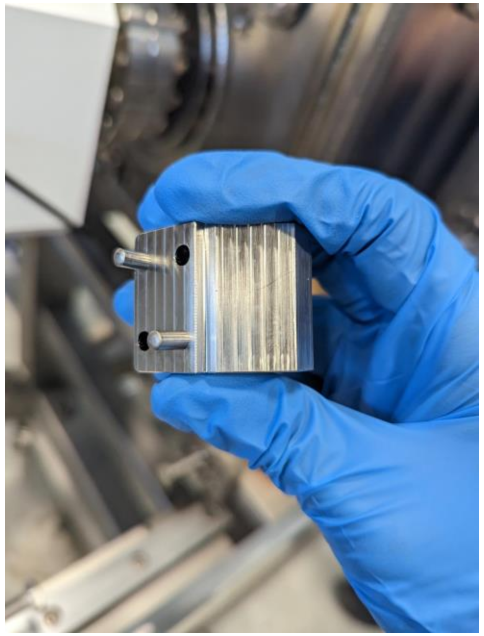
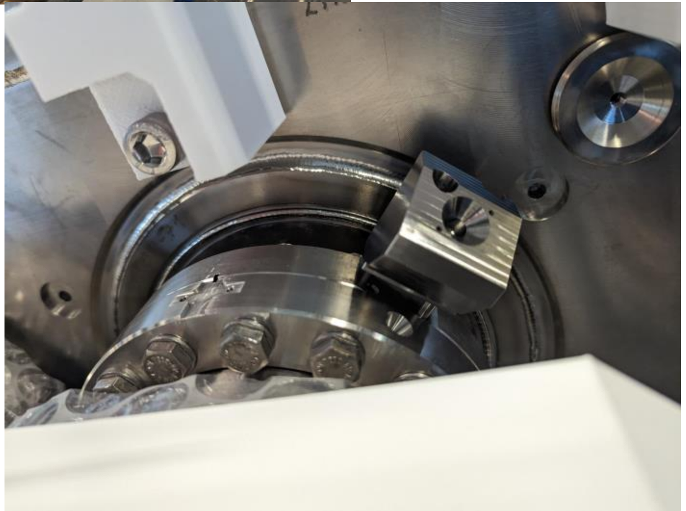
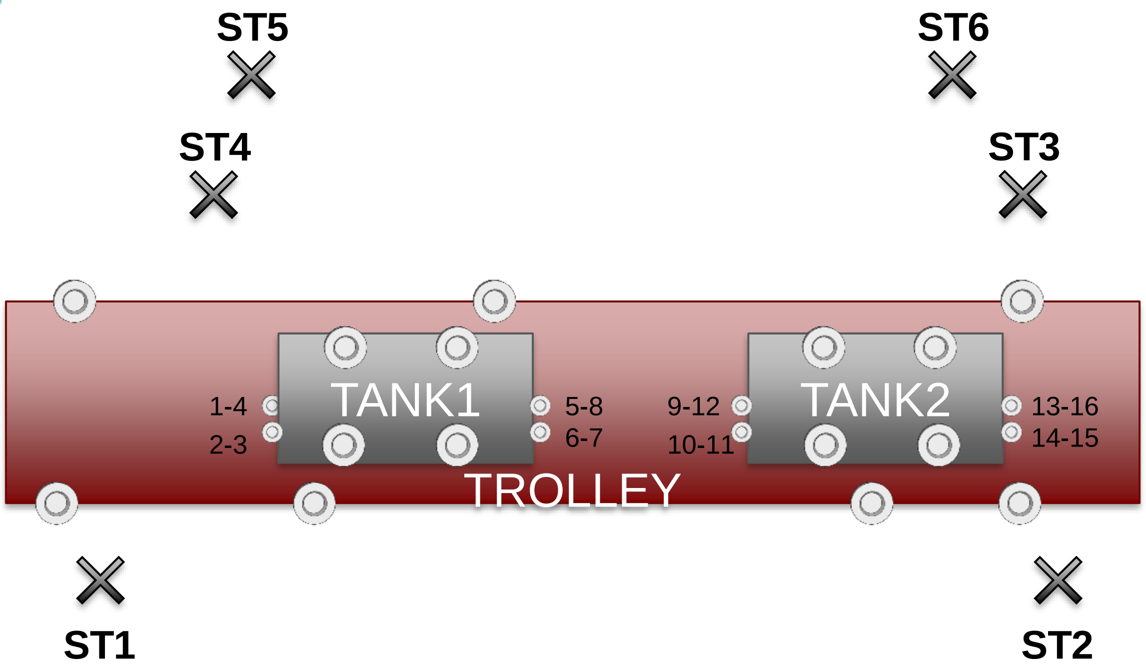


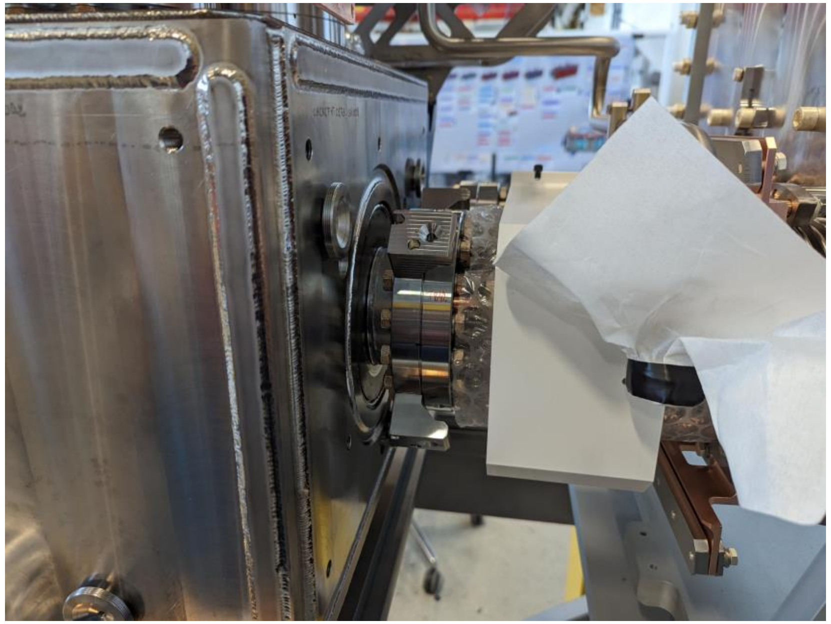


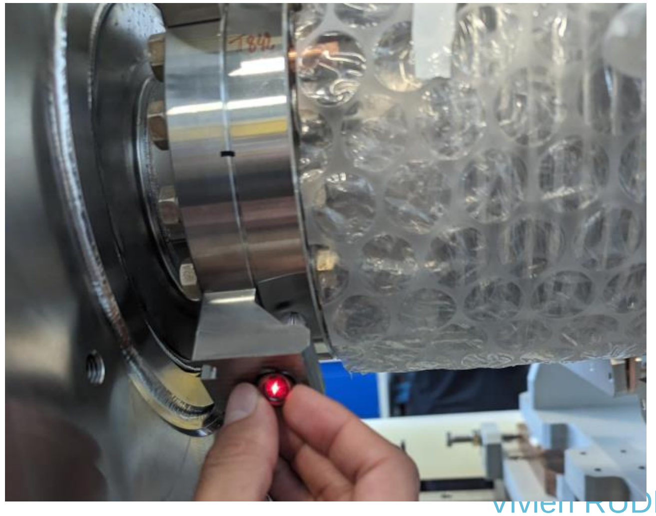




	Step	
Part 2 : before cryostating	4-5	*Alignment of different equipment*
		Installation of FSI supports
		Measurement of FSI supports
		Installation FSI targets



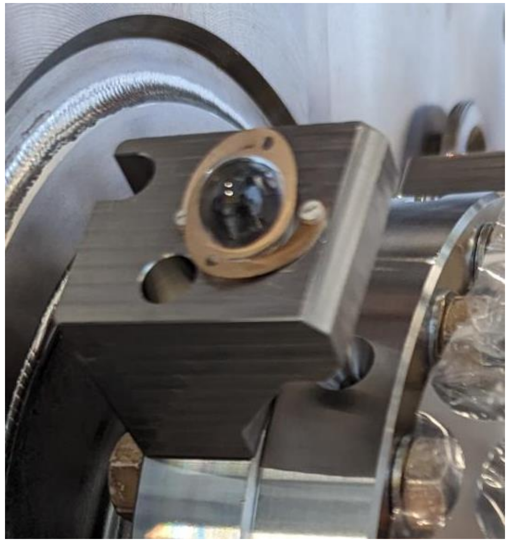


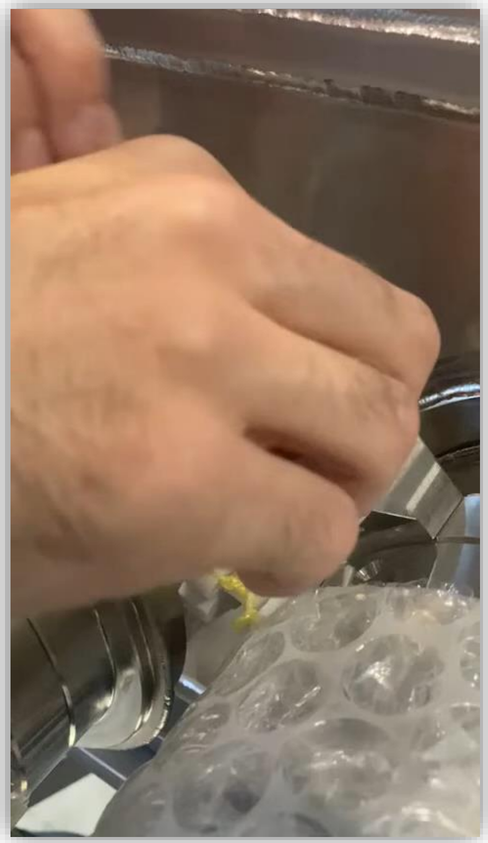


Each FSI supports should be measured 3 times

Max dispersion : 15 µm per axis

	Step	
Part 2 : before cryostating	4-5	*Alignment of different equipment*
		Installation of FSI supports
		Measurement of FSI supports
		Installation FSI targets



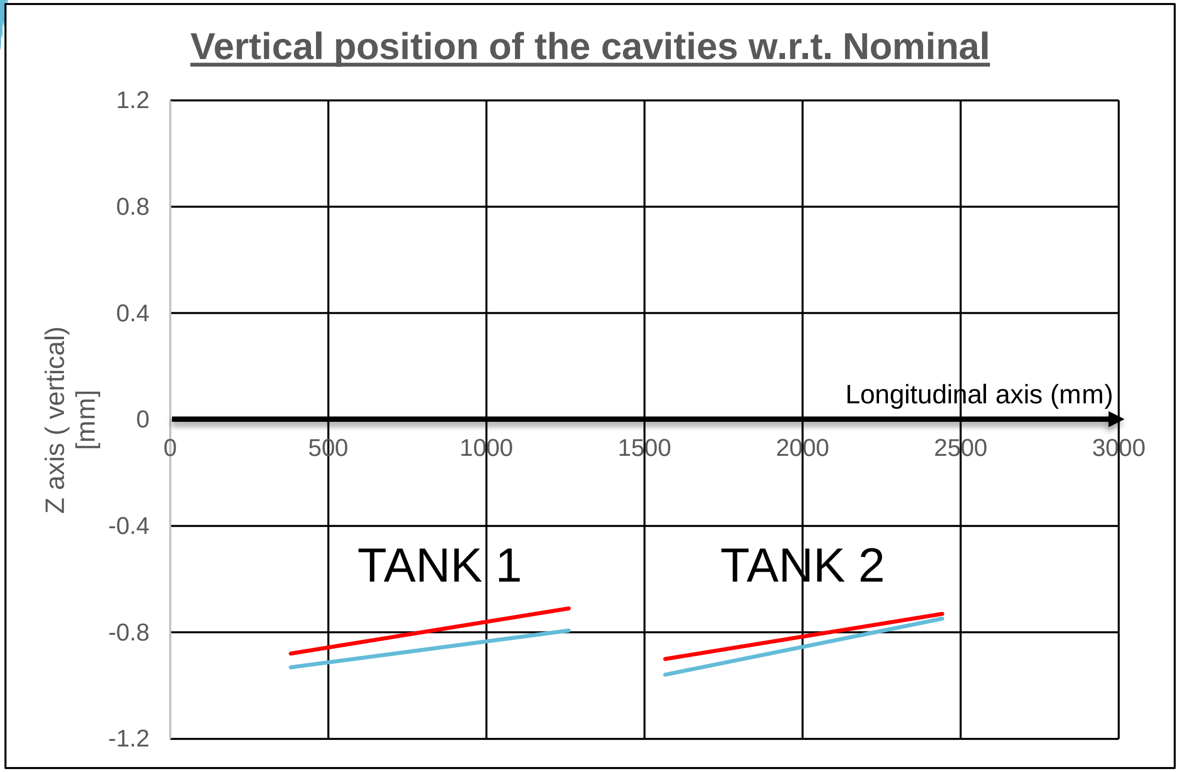


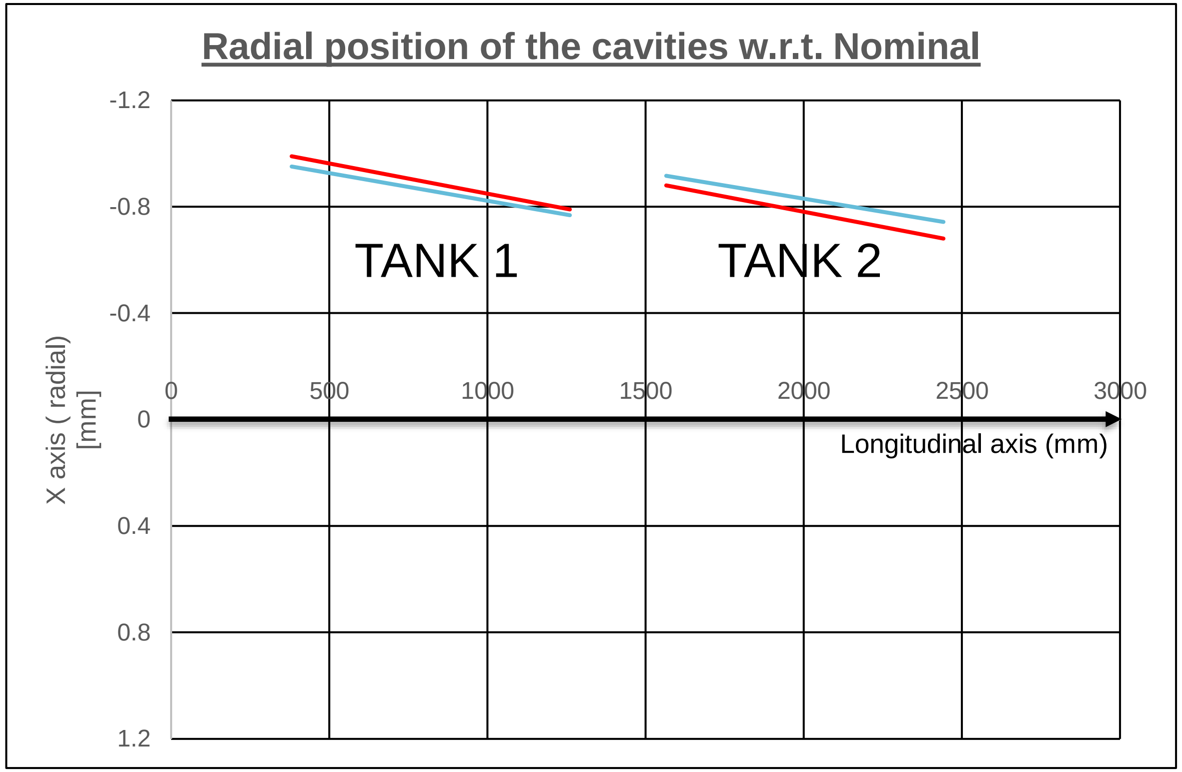
	Step	
Part 3 : cryostating (top plate)	6	*Alignment of the cavities before cryostating*
		Measurement of the top plate cryomodule
		Alignment trolley and top plate

Into taking in account vacuum, cold and hanging motions

Nominal position

Position after alignment

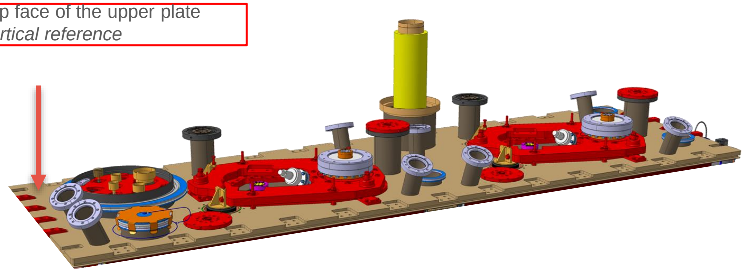




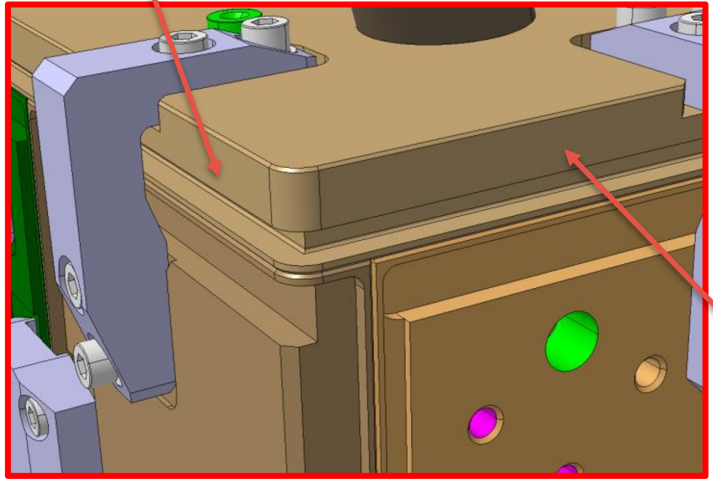
Ry = -180 µrad [0]   Ry = -124 µrad [0]

	Step	
Part 3 : cryostating (top plate)	6	*Alignment of the cavities before cryostating*
		Measurement of the top plate cryomodule
		Alignment trolley and top plate

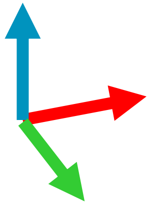
Top face of the upper plate
Vertical reference



Extremity face of the upper plate
Longitudinal reference



Lateral face of the upper plate
Transversal reference

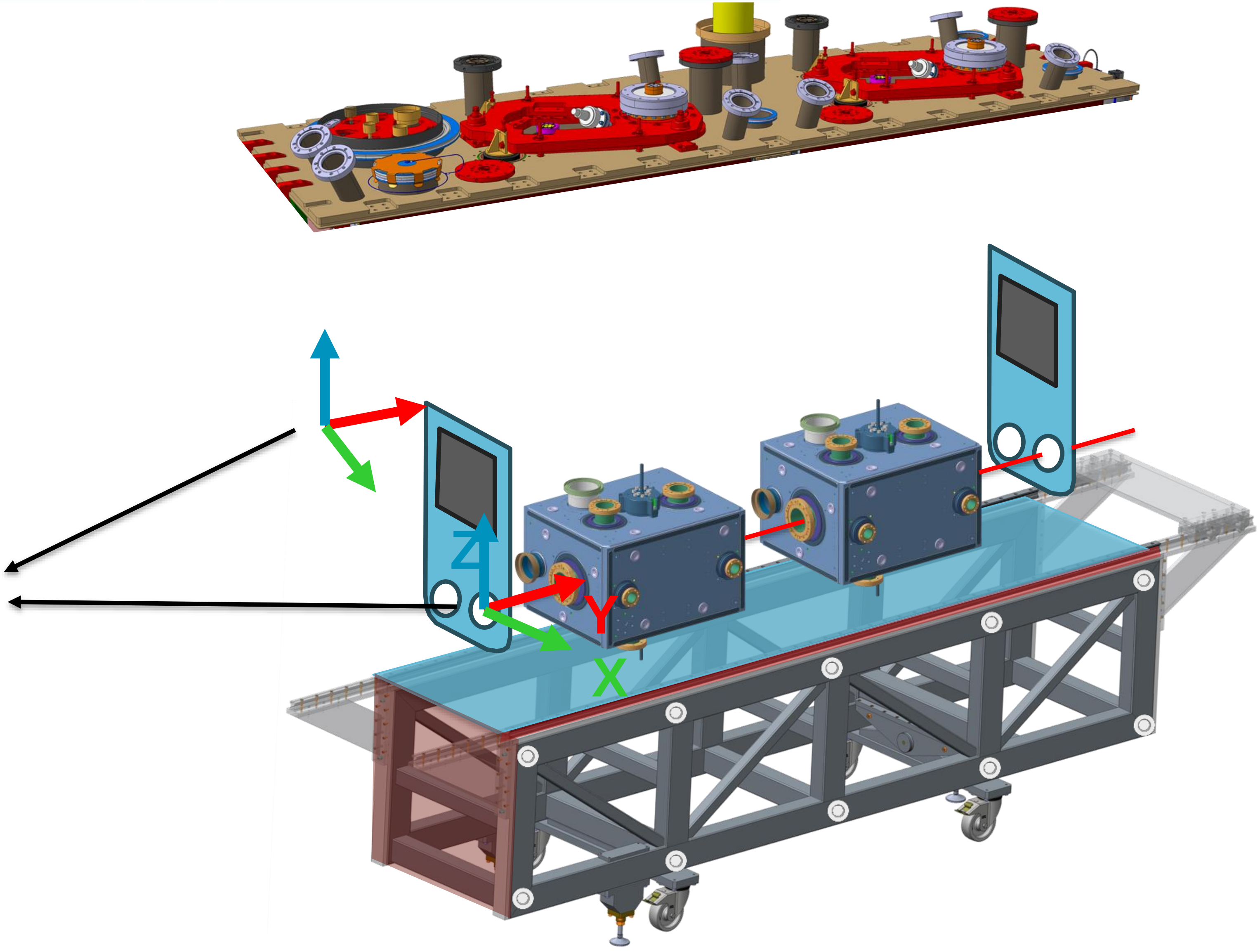


R-top plate

Primary axis : Z : normal vector to top plate (on the edges)
Secondary axis : Y : normal vecor to lateral face
Origin : center of the 3 planes shifted of :

- X = 390 mm
- Y = 0 mm
- Z = 565 mm

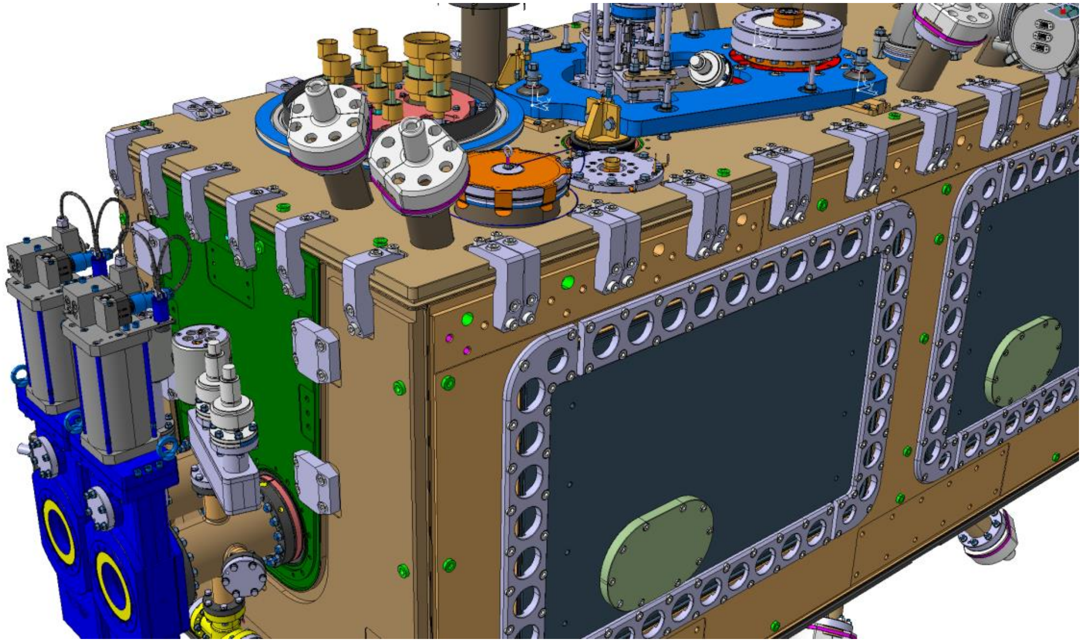
	Step	
Part 3 : cryostating (top plate)	6	*Alignment of the cavities before cryostating*
		Measurement of the top plate cryomodule
		Alignment trolley and top plate

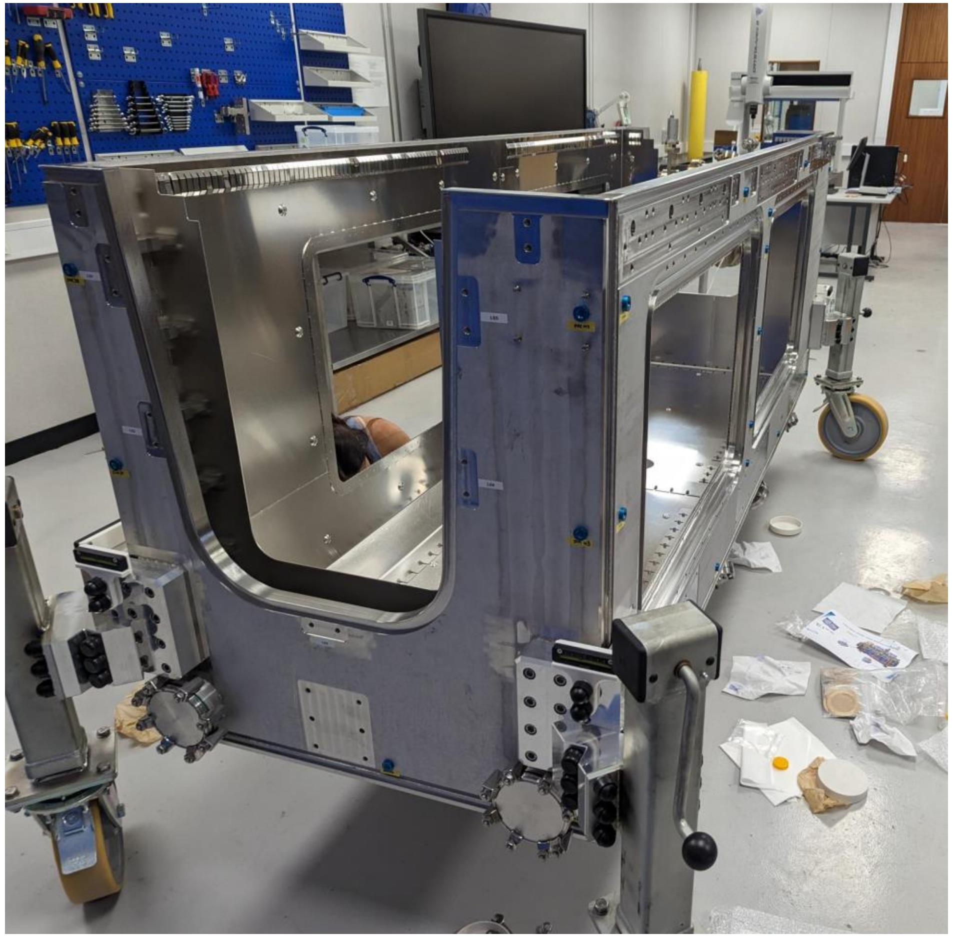


The 2 coordinate systems should be at the same position

	Step	
Part 4 : cryostating (OVC cryomodule)	10	*Measurement of the OVC cryomodule*
		Alignment top plate and OVC cryomodule

Advice :
Install top plate on the OVC.
The coordinate system of the top plate will be the coordinate system of the OVC



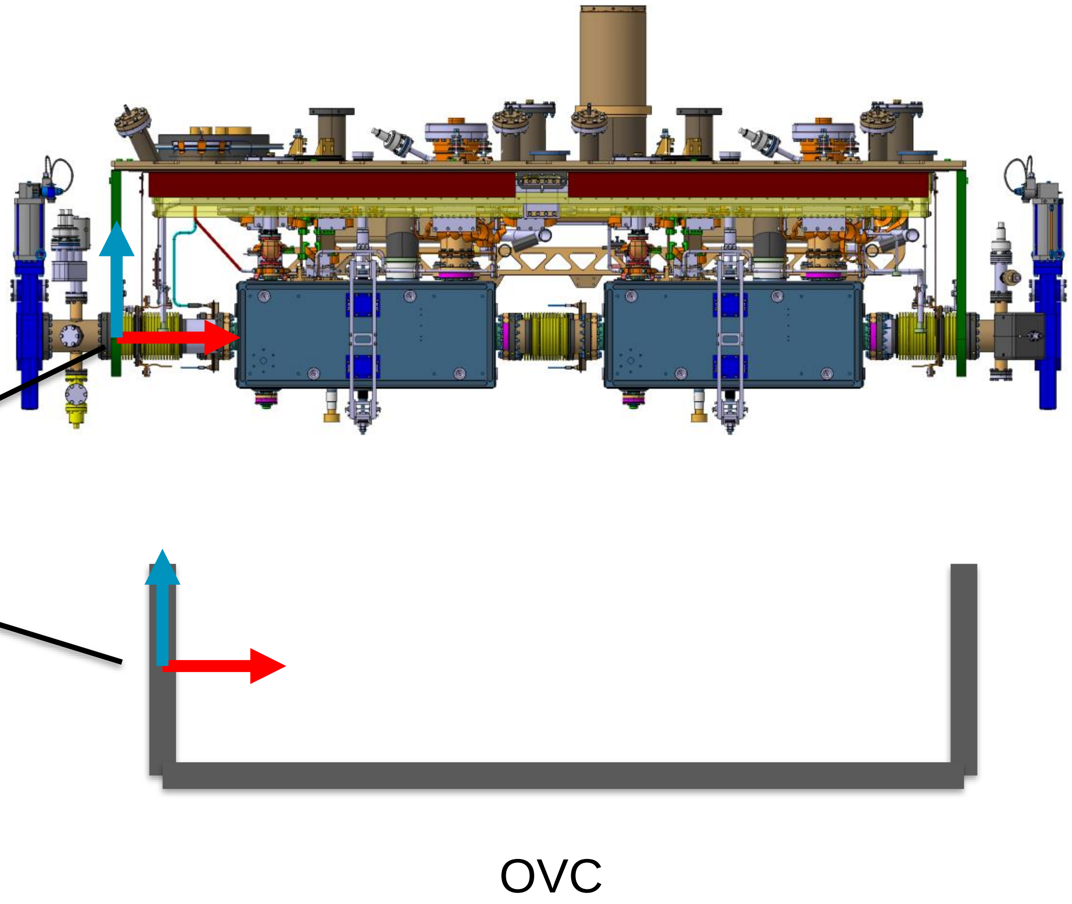


R-top plate = R OVC
Primary axis : Z : normal vector to top plate (on the edges)
Secondary axis : Y : normal vecor to lateral face
Origin : center of the 3 planes shifted of :

- X = 390 mm
- Y = 0 mm
- Z = 565 mm

	Step	
Part 4 : cryostating (OVC cryomodule)	10	*Measurement of the OVC cryomodule*
		Alignment top plate and OVC cryomodule

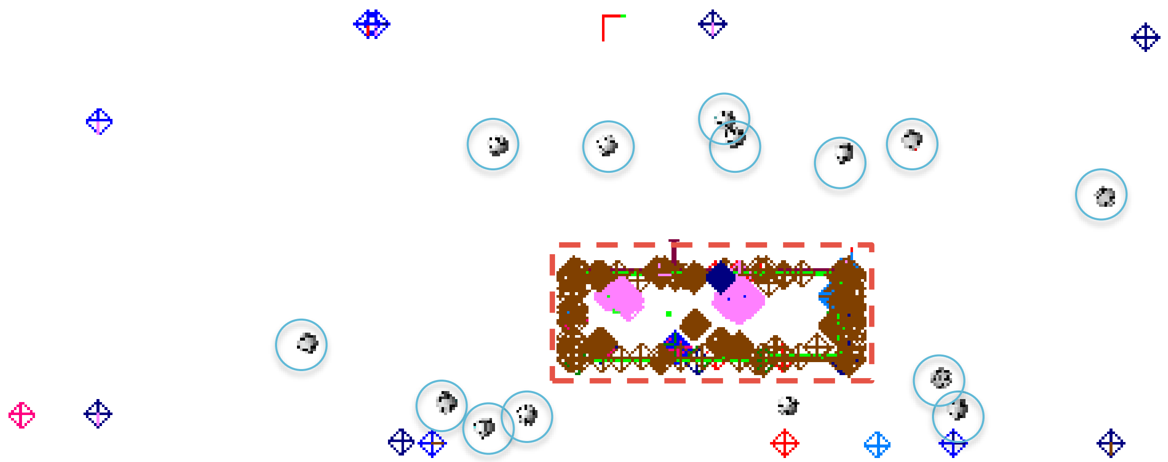
The 2 coordinate systems should be at the same position



	Step	
Part 5 : after cryostating	10	*Installation of FSI heads on OVC and top plate*
		Measurement of FSI heads on OVC and top plate
		FSI validation (comparison with a laser tracker)
		Alignment with adjustment system

	Step	
Part 5 : after cryostating	10	*Installation of FSI heads on OVC and top plate*
		Measurement of FSI heads on OVC and top plate + TANK position
		FSI validation (comparison with a laser tracker)
		Alignment with adjustment system

EDMS : 2996397



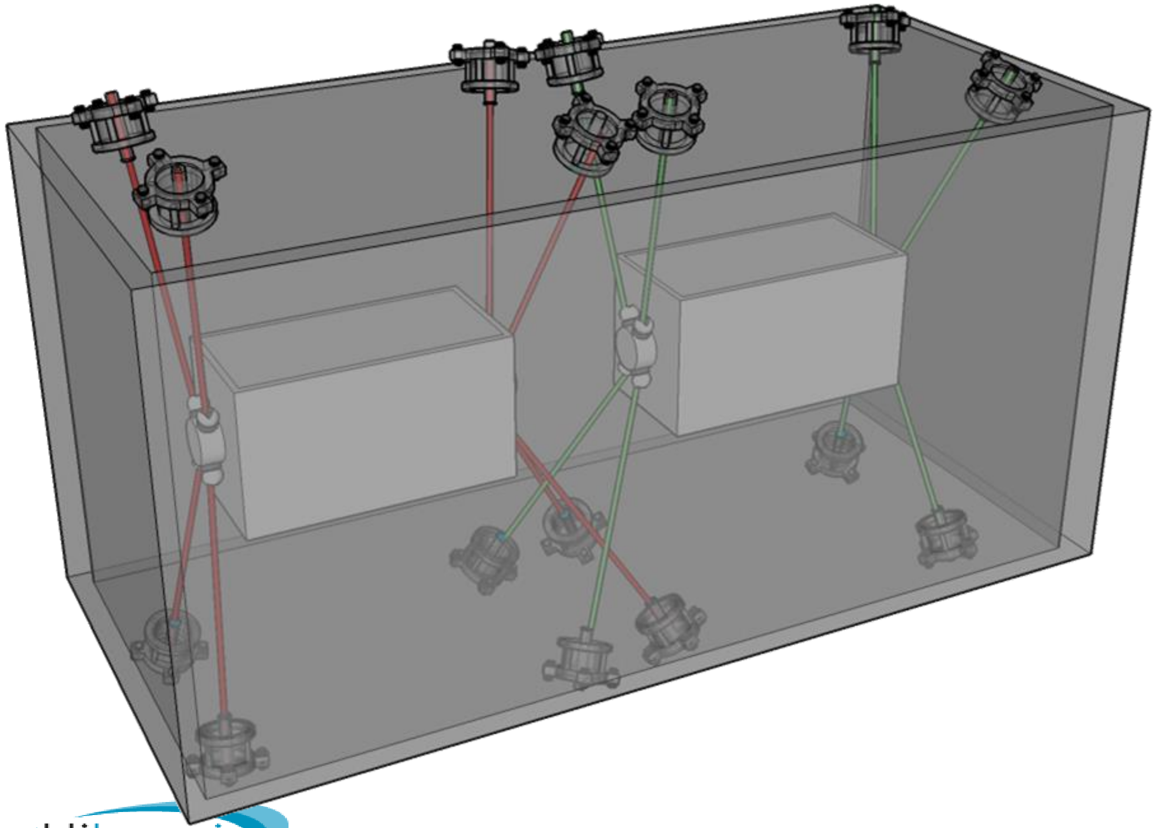
Legend

Station

Cryomodule

	Step	
Part 5 : after cryostating	10	*Installation of FSI heads on OVC and top plate*
		Measurement of FSI heads on OVC and top plate
		FSI validation (comparison with a laser tracker)
		Alignment with adjustment system

Should be less inside :
[-0.040 mm : 0.040 mm]

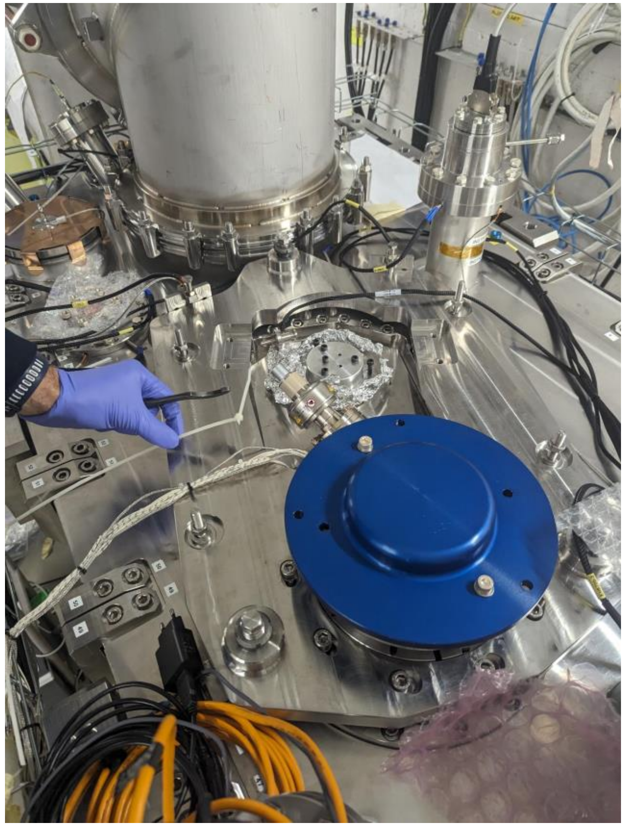


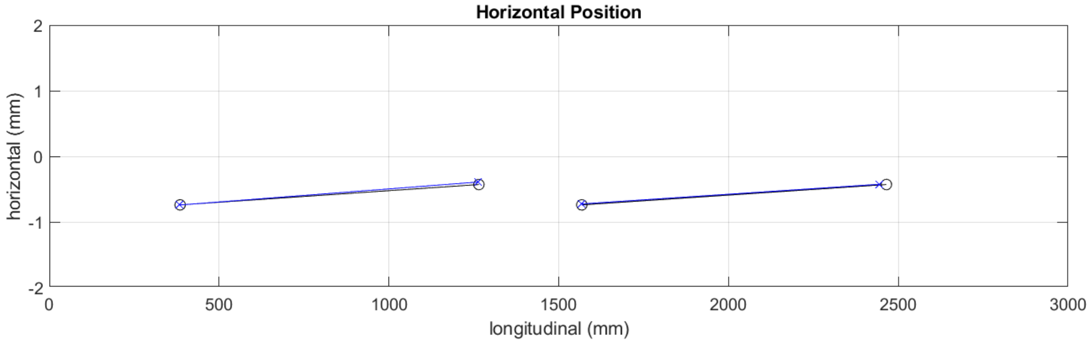
	Head	Target	FSI 3 D distance	Laser Tracker 3 D distance	Comparison
TANK 1	1	1			
TANK 1	2	2			
TANK 1	3	3			
TANK 1	4	4			
TANK 1	5	5			
TANK 1	6	6			
TANK 2	7	11			
TANK 2	8	12			
TANK 2	9	9			
TANK 2	10	10			
TANK 1	11	7			
TANK 1	12	8			
TANK 2	13	13			
TANK 2	14	14			
TANK 2	15	15			
TANK 2	16	16			

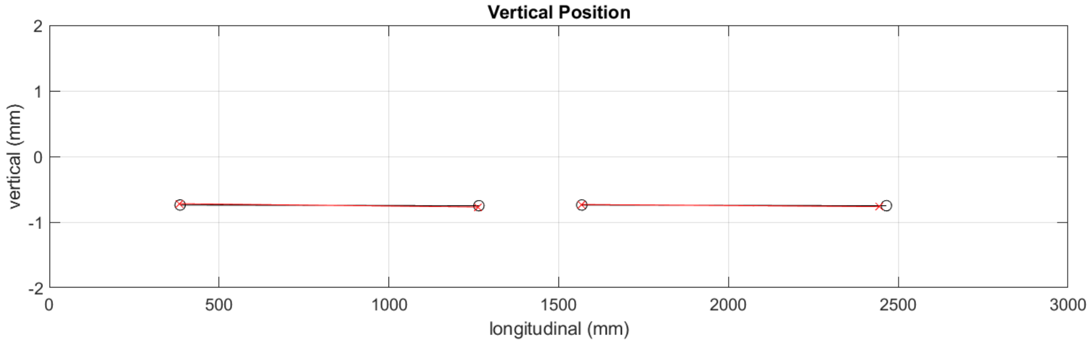
EDMS : 3065249

	Step	
Part 5 : after cryostating	10	*Installation of FSI heads on OVC and top plate*
		Measurement of FSI heads on OVC and top plate
		FSI validation (comparison with a laser tracker)
		Alignment with adjustment system

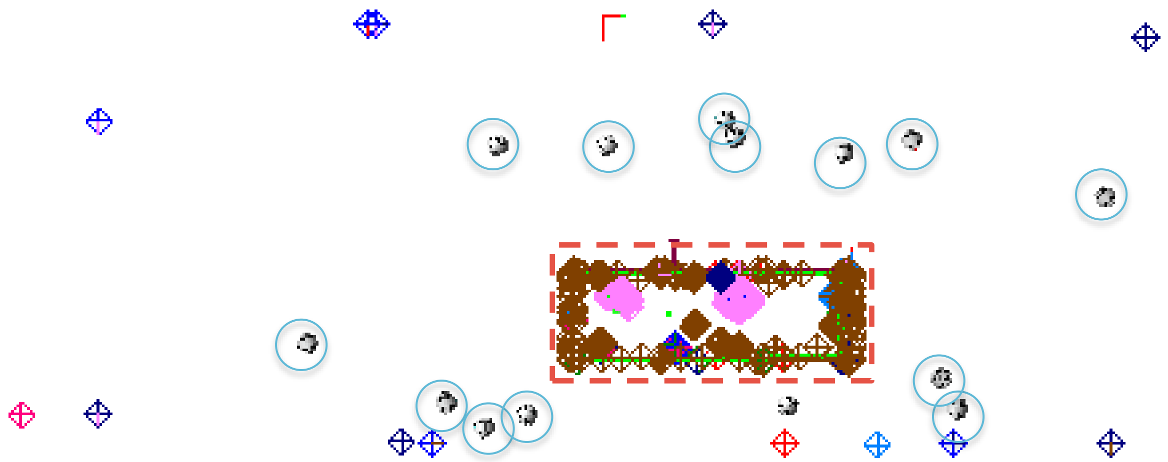
Should be less inside :
[-0.040 mm : 0.040 mm]







	Step	
Part 6 : cold test at STFC or Triumf	12	*Measurement ambient pressure*
		Measurement under vacuum
		Measurement at cold

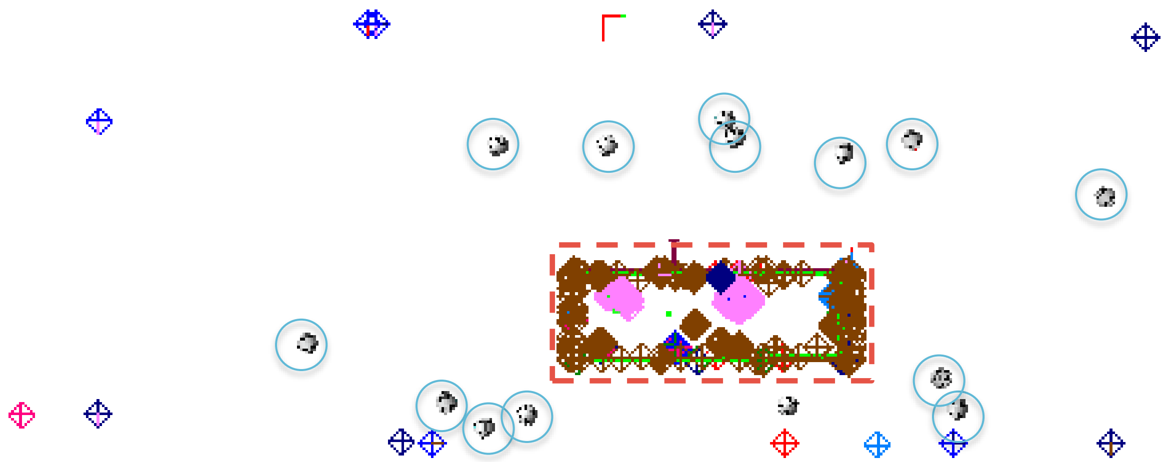


Legend

Station

Cryomodule

	Step	
Part 6 : cold test at STFC or Triumf	12	*Measurement ambient pressure*
		Measurement under vacuum
		Measurement at cold

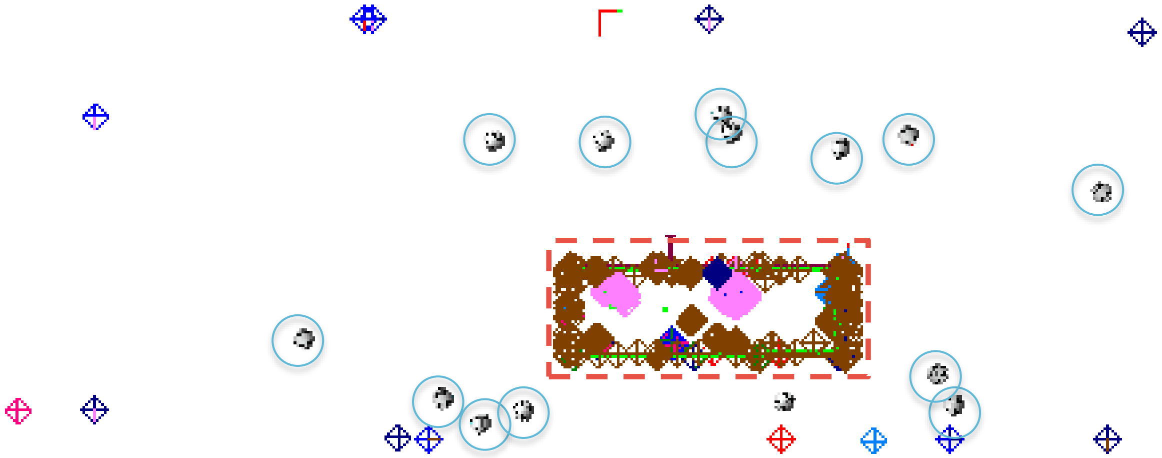


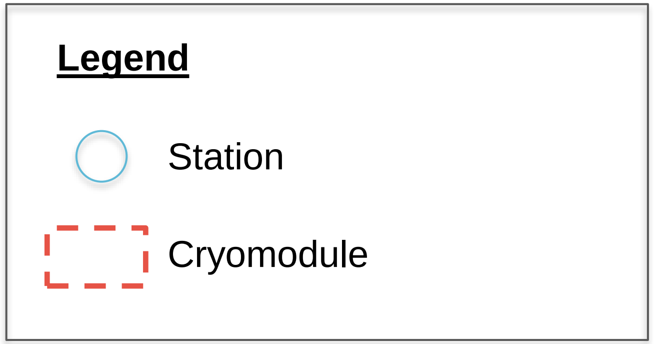
Legend

Station

Cryomodule

	Step	
Part 6 : cold test at STFC or Triumf	12	*Measurement ambient pressure*
		Measurement under vacuum
		Measurement at cold





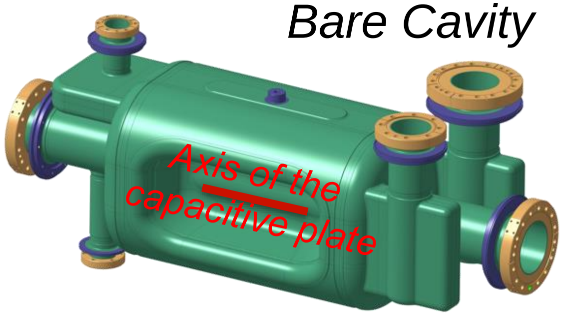
Thank you for your attention

SPARE

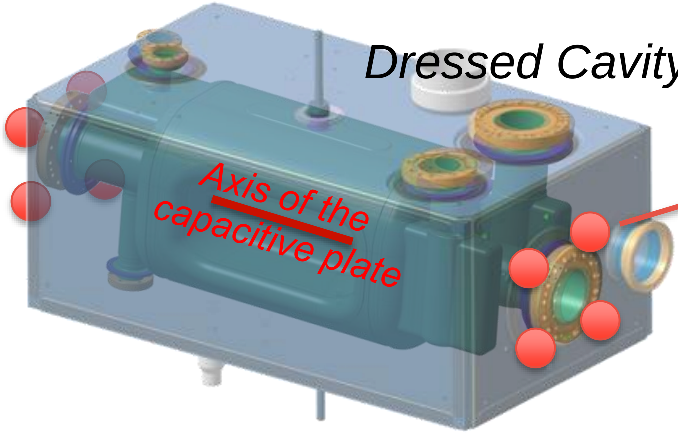
Alignment Objective n°1 : Fiducialisation

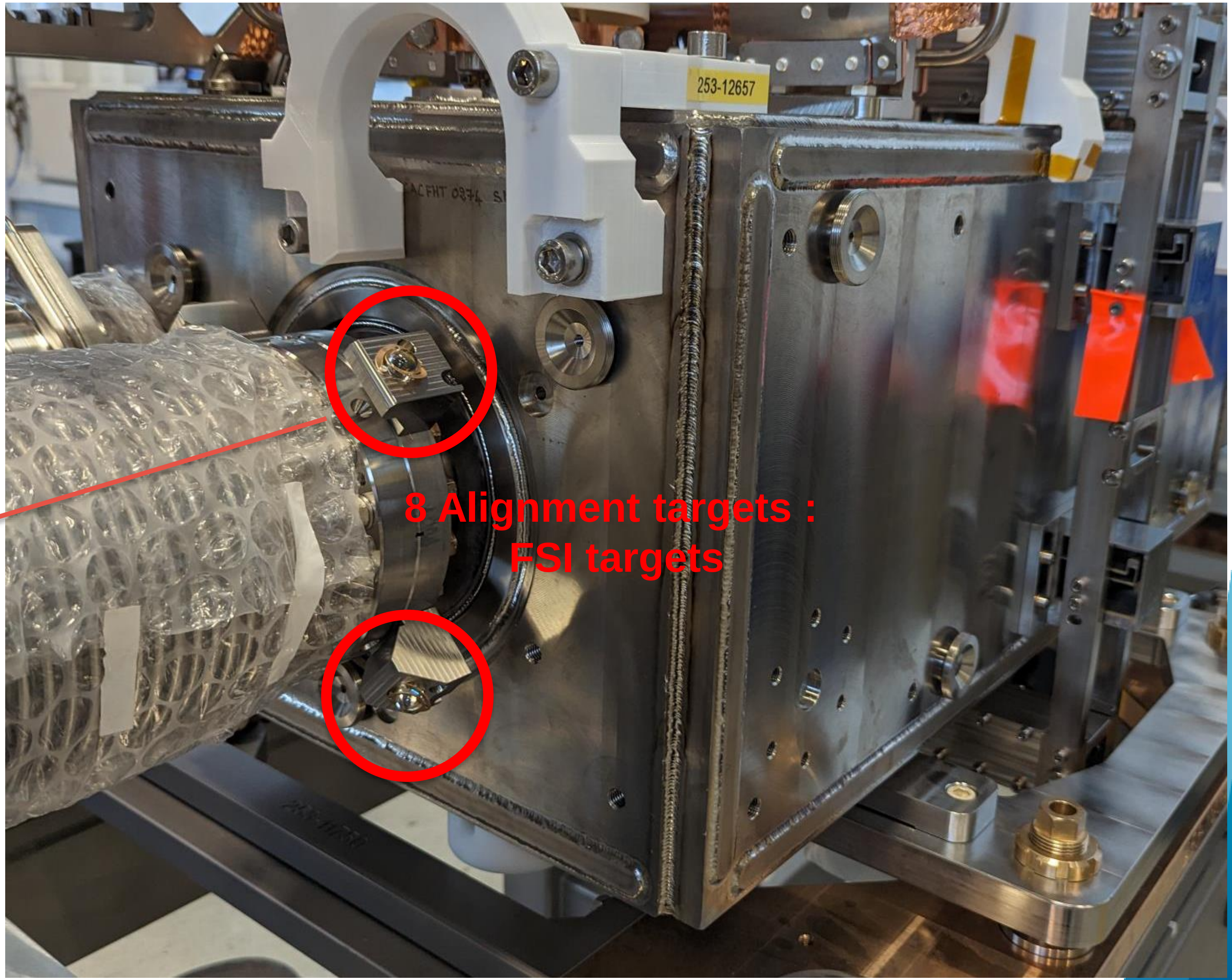
Cavity radio frequency axis → Approximated to mechanical axis of the capacitive plate

Bare Cavity



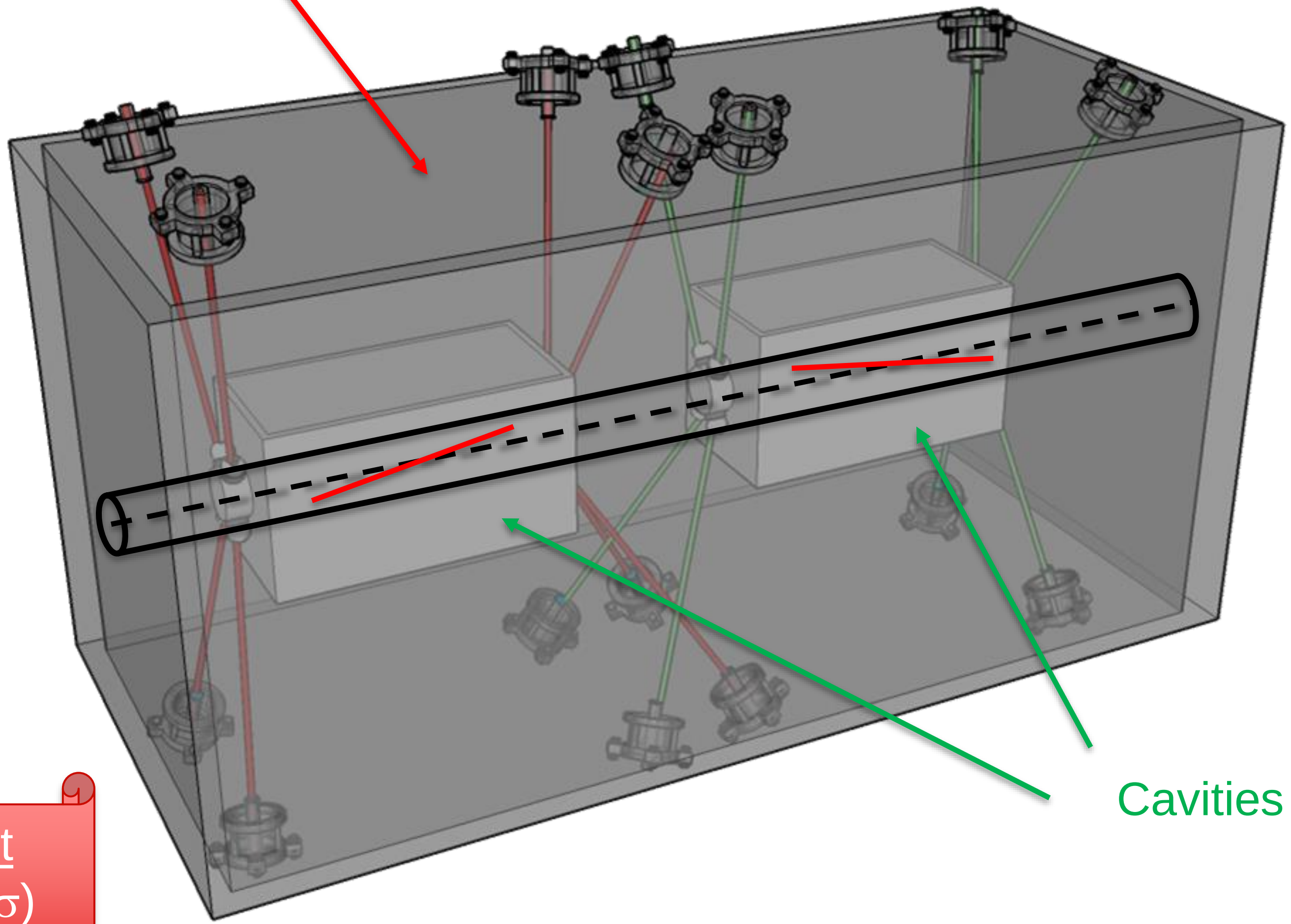
Dressed Cavity





Alignment requirement
Position : 50 µm (1σ)
Roll : 100 µrad (1σ)

Alignment Objective n°2 : Internal monitoring

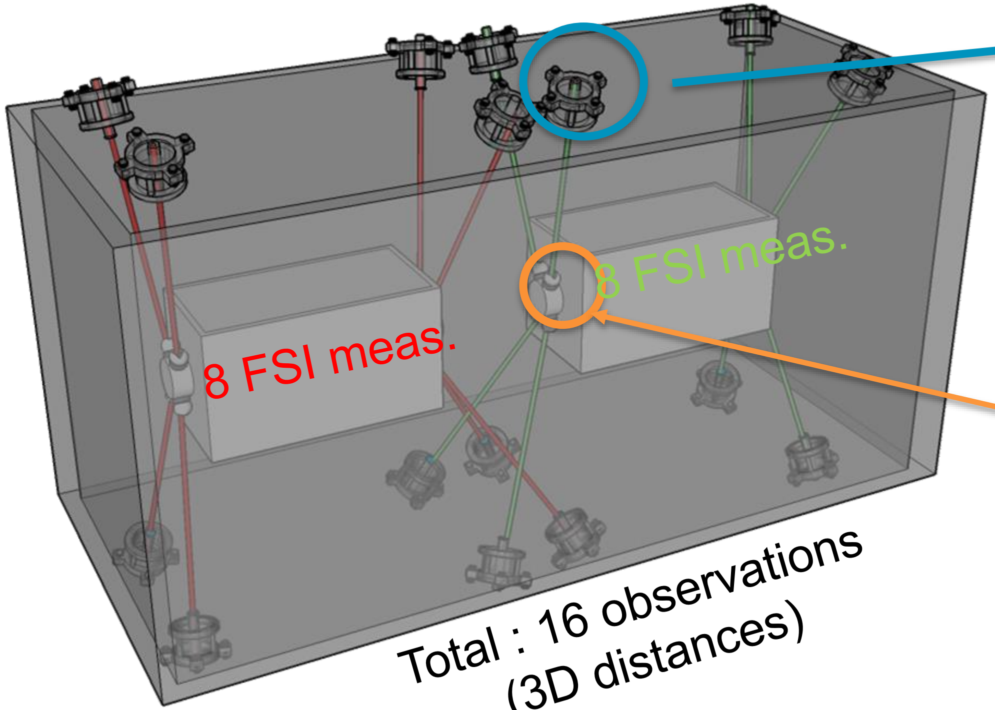


<u>Alignment requirement</u>
Position : < 100 µm (1σ)
Roll : < 400 µrad (1σ)

Internal monitoring : Configuration

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

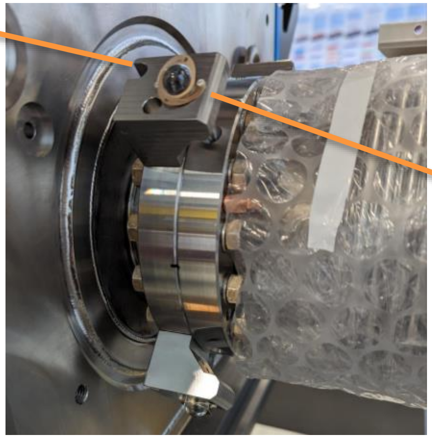
Largest standard uncertainties	Uncertainty (1σ)
Position of the FSI Sensor in the framework of the cryomodule	40 µm
Position of the FSI target in the framework of the crab-cavity	<15 µm

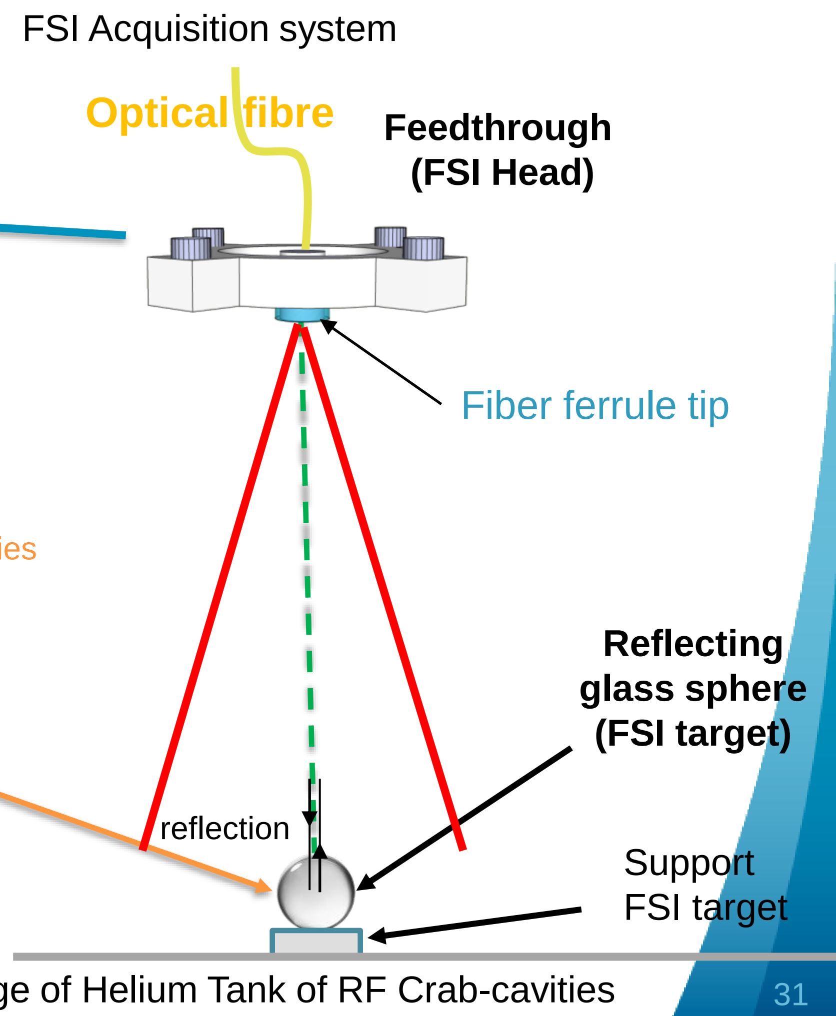


Total : 16 observations
(3D distances)

FSI Head (sensor)
on the Cryomodule

FSI target
on the flange of Helium TANK of the cavities





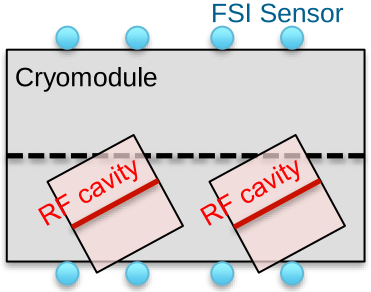
Internal monitoring : Challenges and prerequisites

Ambient pressure
Measurement + Adjustment

The position of the FSI sensors w.r.t. cryomodule must be measured with an accuracy of less than 40 microns.

All adjustments should be carried out at ambient pressure.

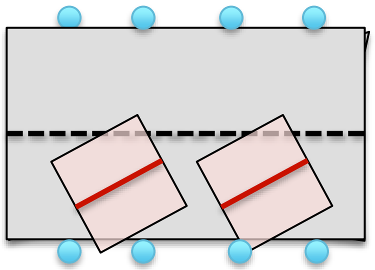
ANTICIPATION : The position of the cavities should be at their nominal position at warm with an accuracy of less than 40 microns.



Under vacuum
Anticipation

Anticipation of the Deformation of the outer envelope with an accuracy of less than 40 microns
(deformation up to 1.2 mm)

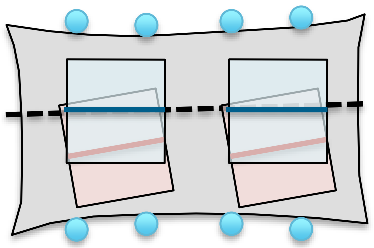
Anticipation of the Movement of the cavities :
(Complex movement up to 0.4 mm
6 DOF)



Cooling down
Anticipation

Anticipation of the Deformation of the outer envelope with an accuracy of less than 40 microns
(deformation up to 0.1 mm)

Anticipation of the Movement of the cavities :
(Complex movement up to 1.2 mm
7 DOF)



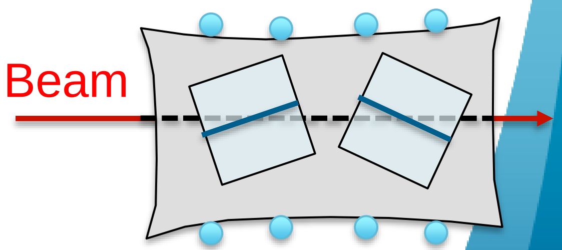
The position of two cavities should be determined **at cold** at less than 0.1 mm (1sigma)

The position of two cavities **at cold** should be aligned **at less than 0.1 mm** (1sigma)

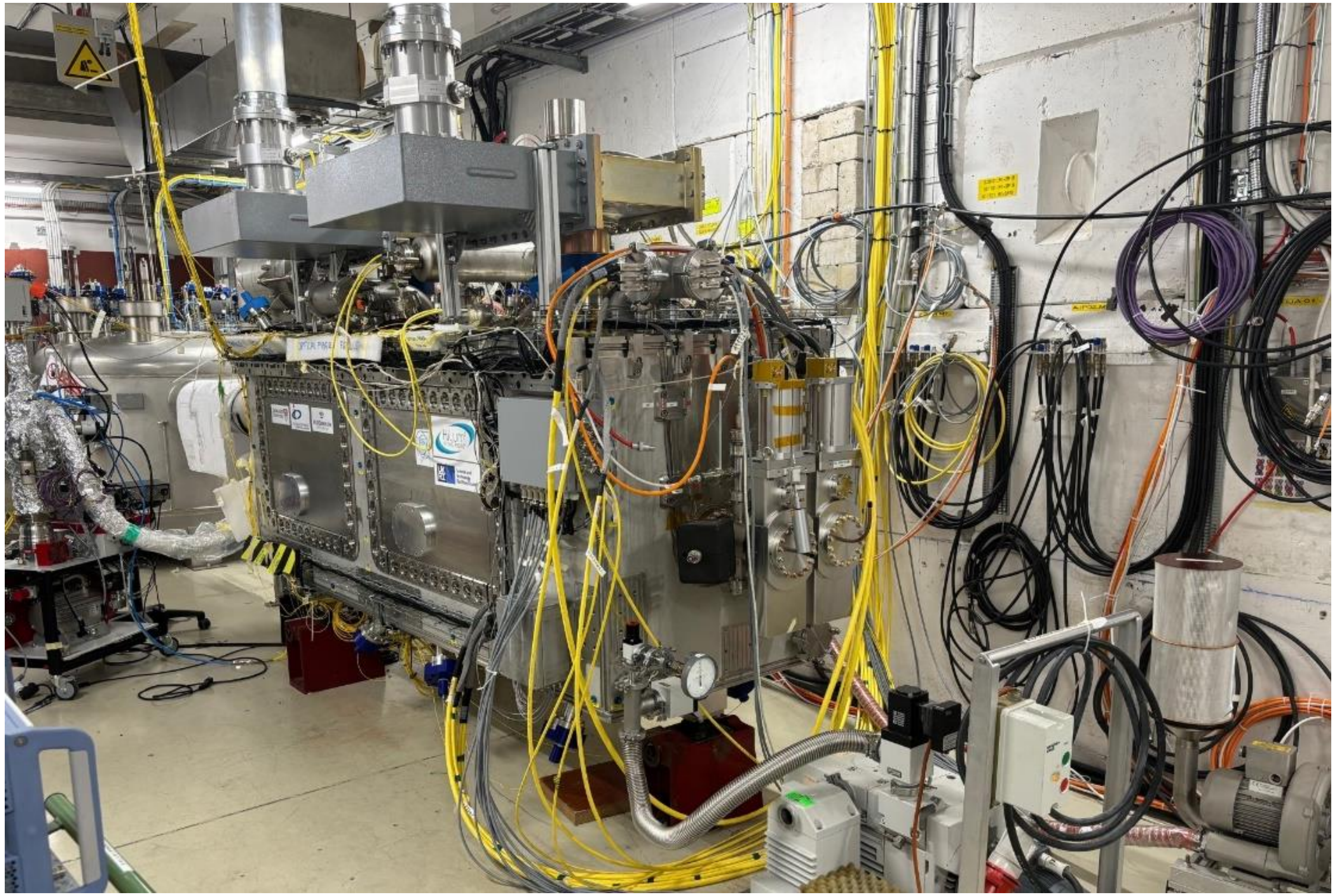
Two inner components

Non compensable misalignment on the external envelope

No possibility to adjust



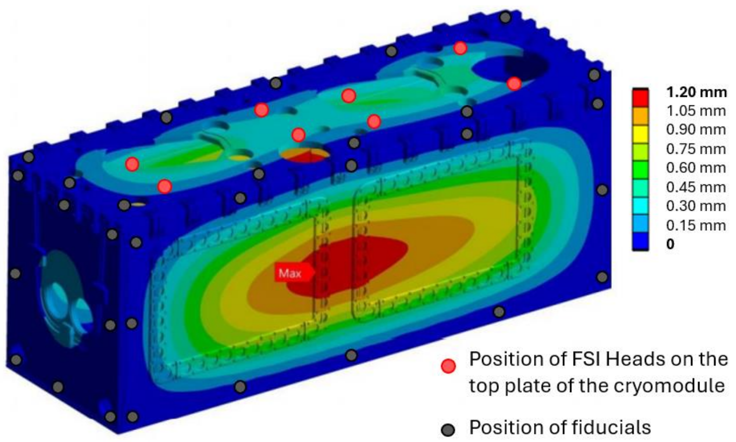
Alignment analysis of the RFD prototype during cold test at CERN

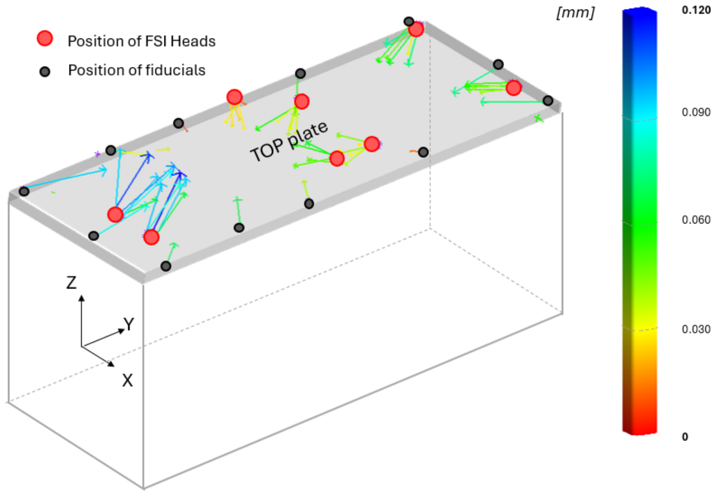


Deformations of the cryomodule (due to pumping and cooling down)

No deformation was observed on the edge of the top plate during pumping.

During cooldown, the top plate observed a thermal contraction due to thermal convection between the thermal screen and the top plate --> not expected but repeatable--> Can be anticipated





Ambient pressure ⟷ Under vacuum: Max deformation : 1.20 mm

Under vacuum ⟷ Cold: Max deformation : 0.12 mm

Ambient pressure

Shape Repeatability For 3 cycles :

- Maximum dispersion : 67 µm
- Average dispersion : 18 µm

Shape of the cryomodule at ambient pressure Repeatable at +/- 0.040 mm (RMS)

Under vacuum

Shape Repeatability For 3 cycles :

- Maximum dispersion : 57 µm
- Average dispersion : 16 µm

Shape of the cryomodule under vacuum Repeatable at +/- 0.040 mm (RMS)

Cold

Shape Repeatability For 3 cycles :

- Maximum dispersion : 68 µm
- Average dispersion : 17 µm

Shape of the cryomodule at cold Repeatable at +/- 0.040 mm (RMS)

Relative Motions of the cavities due to vacuum and cooling down (cycle 3)