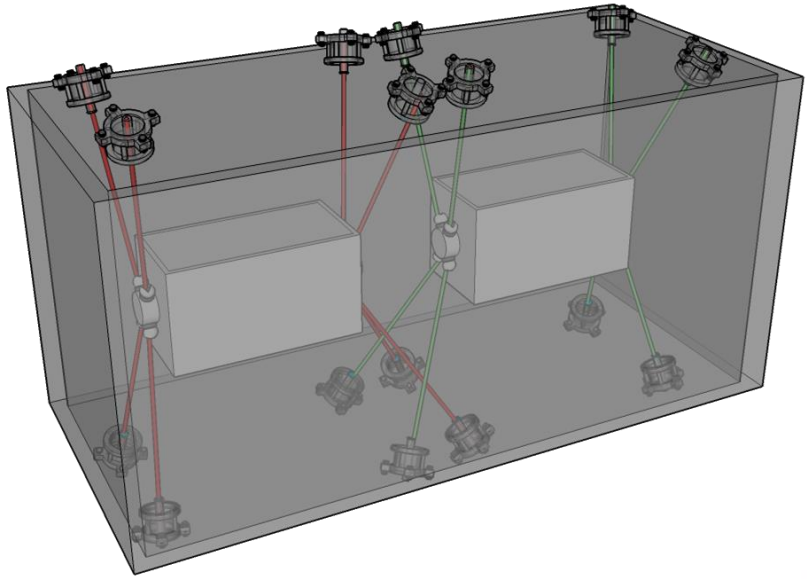


Crab Cavities:
Alignment update
From SPS prototype to HL-LHC

Vivien RUDE
Mateusz SOSIN

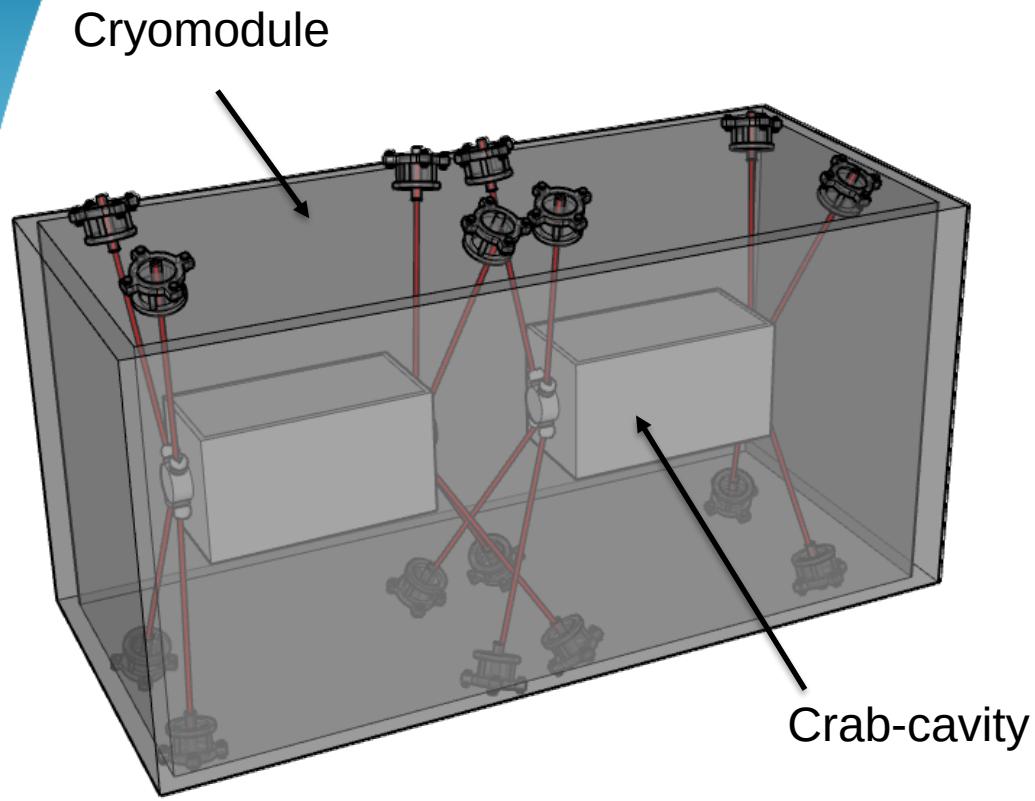
2021-10-20

11th HL-LHC Collaboration Meeting

Outline :

- PART 1 : Introduction
  - Internal monitoring
  - External monitoring
  - Configuration of internal monitoring
  - Monitoring system : Multi-target FSI
  - Accuracy
- PART 2 : SPS prototype
  - Uncertainty by Degrees of Freedom
  - Follow-up before LS2 (2018-2019)
  - Follow-up after LS2 (since October 2020)
- PART 3 : SPS-RFD prototype (HL-LHC Crab-cavities)
  - Simulation (RFD prototype)
  - Main modifications (From SPS prototype to HL-LHC)
  - Integration

Internal monitoring



Environment :

- Temperature : 1.9 K (Cryogenics conditions)
- Vacuum : 10-6 mBar
- Radiation : TID ~1 MGy / 4000 fb-1

Accuracy :

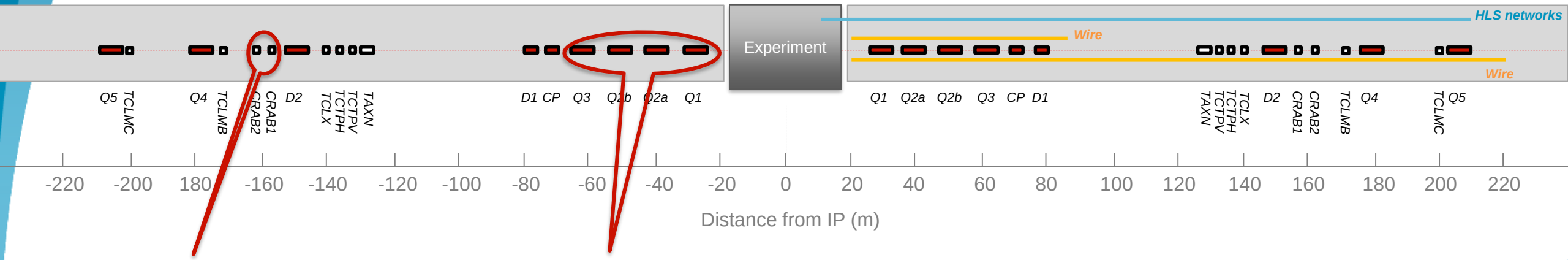
- 0.1 mm w.r.t. cryomodule

LHC
- Considered the position of inner component inside cryomodule → **stable during the whole life cycle**

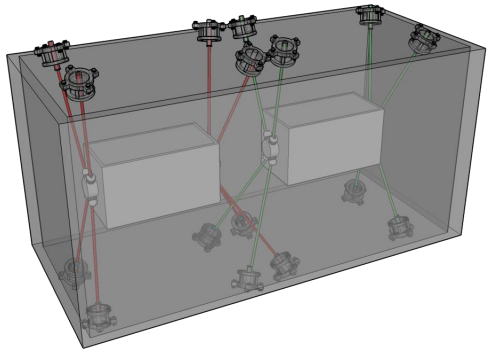
HL-LHC
- Follow the position of the cavities inside the cryomodule→ internal monitoring in harsh conditions

Internal monitoring

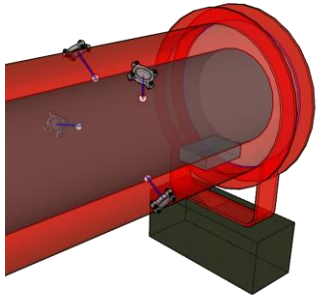
External monitoring

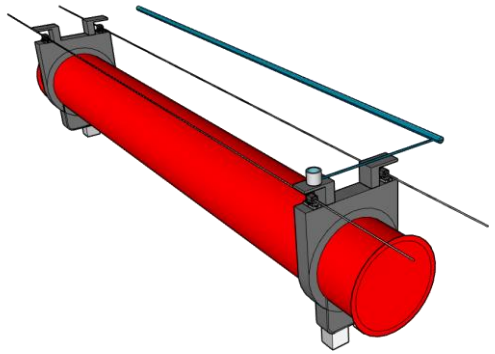


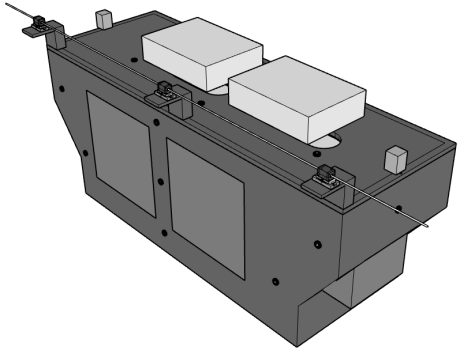
Crab1, Crab2



Q1, Q2a, Q2b, Q3







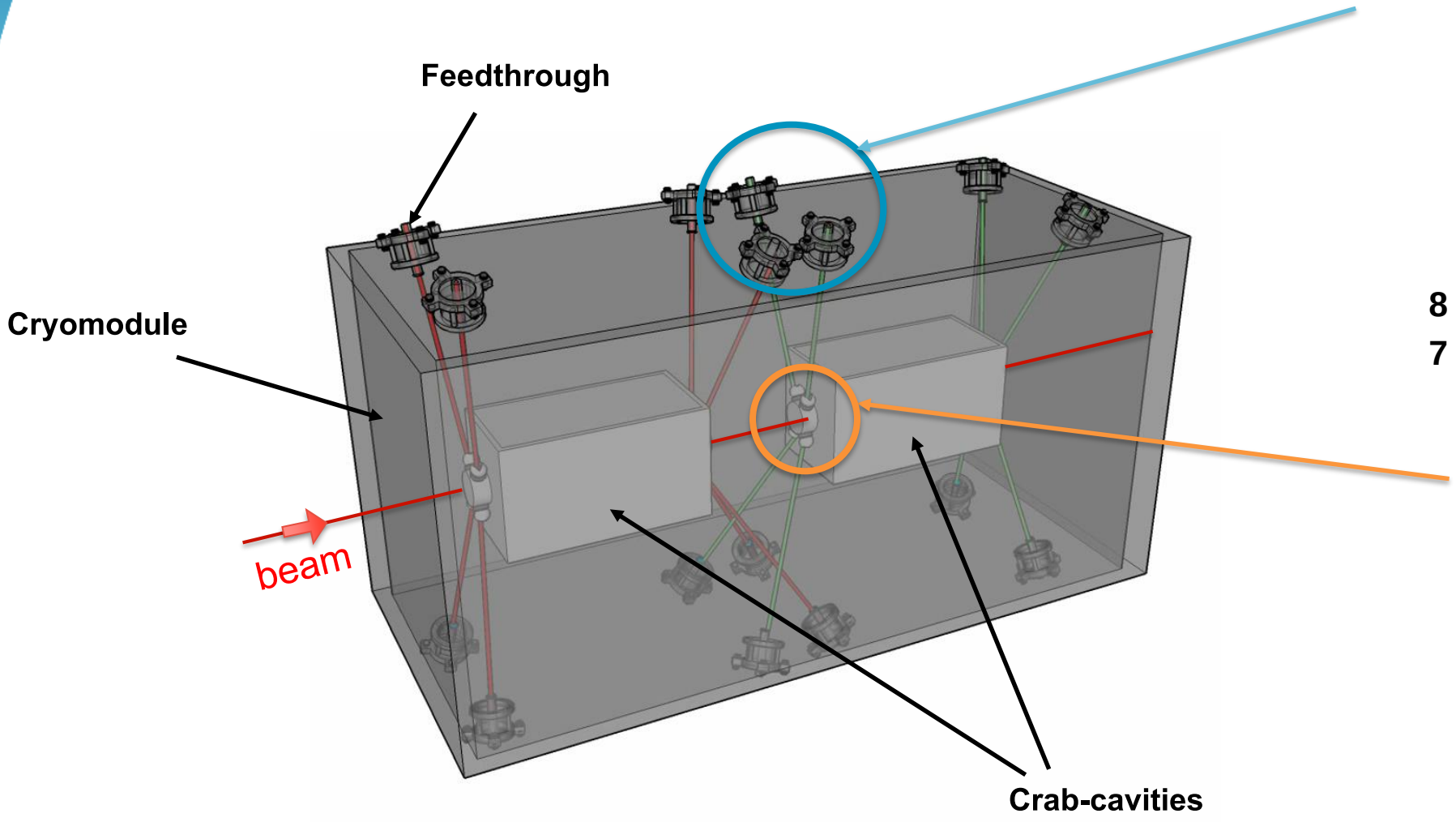
CERN-ACC-2015 and TDR

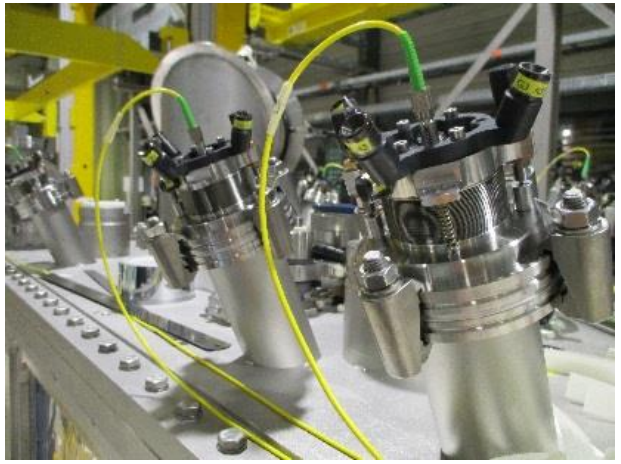
- Position of the components cryostat along one side of the tunnel : +/- 0.1 mm
- Position of the components cryostat along one side of the tunnel w.r.t the other side : +/- 0.15 mm

FRAS : Full Remote Alignment System (EDMS 2166298)

11th HL-LHC Collaboration Meeting, CERN - 19-22 October 2021 (19-22 octobre 2021): Summary and Update on the FRAS implementation · Indico

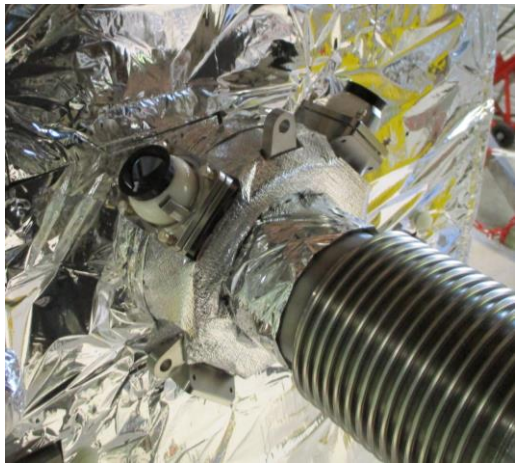
Configuration





8 FSI distances by Cavity

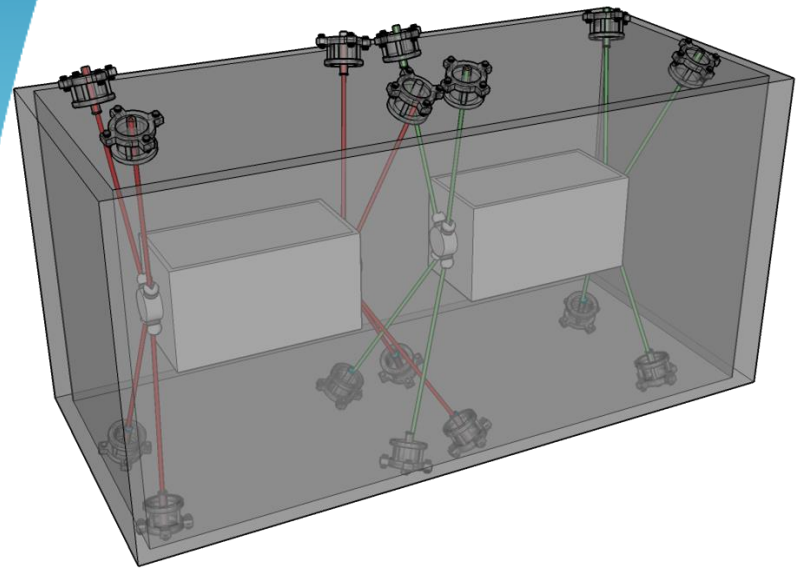
7 Degrees of Freedom by Cavity

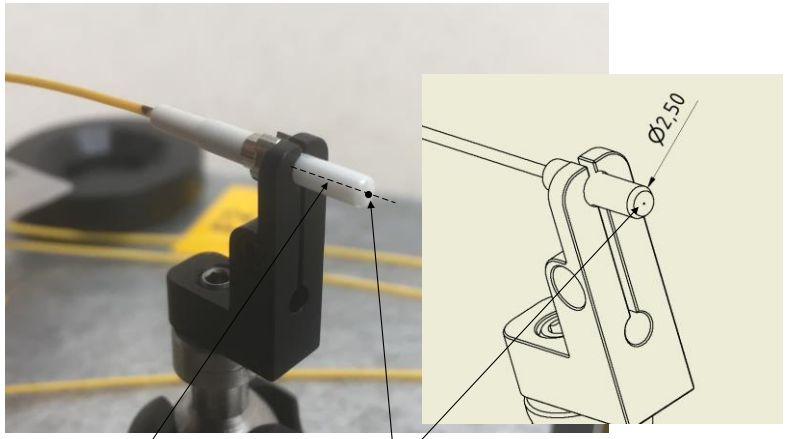


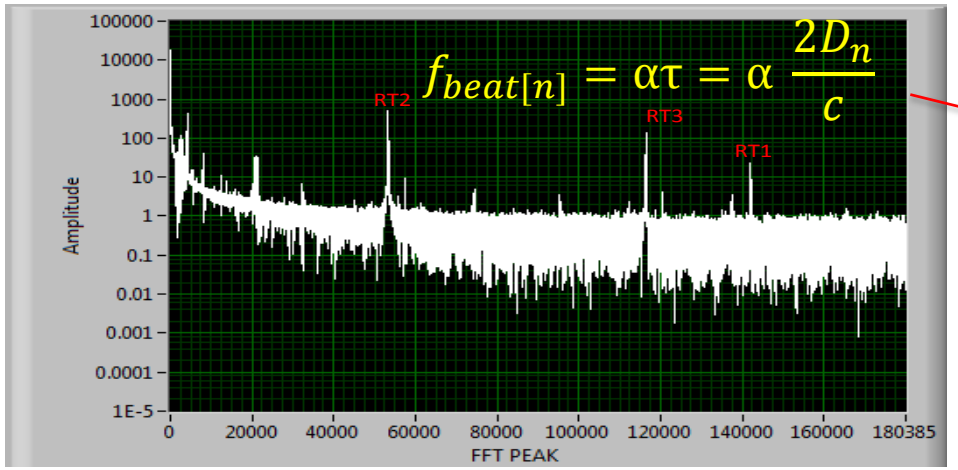
- Vacuum : 10^{-6} mbar
- Temperature : 1.9 K

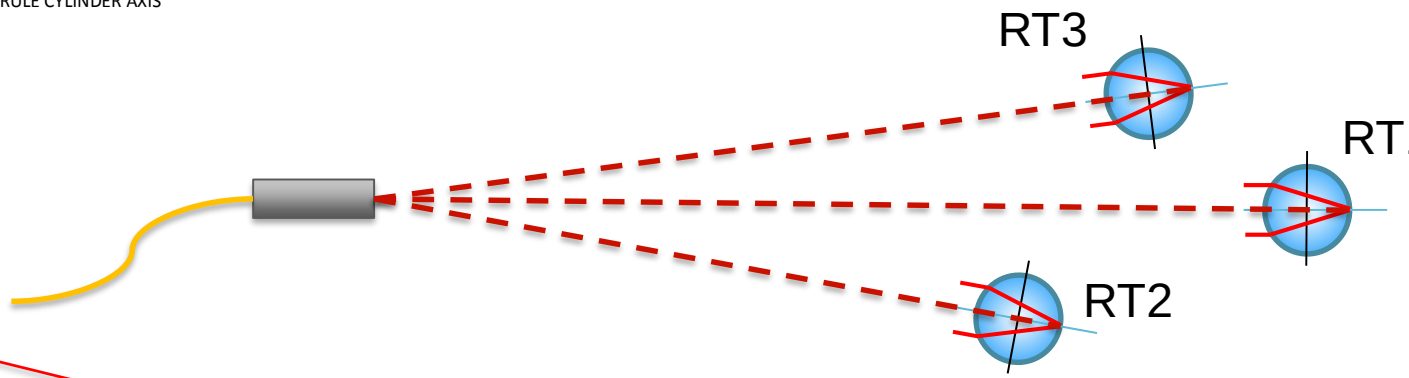
Multi-target Frequency Scanning Interferometry (FSI)

n=2









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

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

c – speed of light;

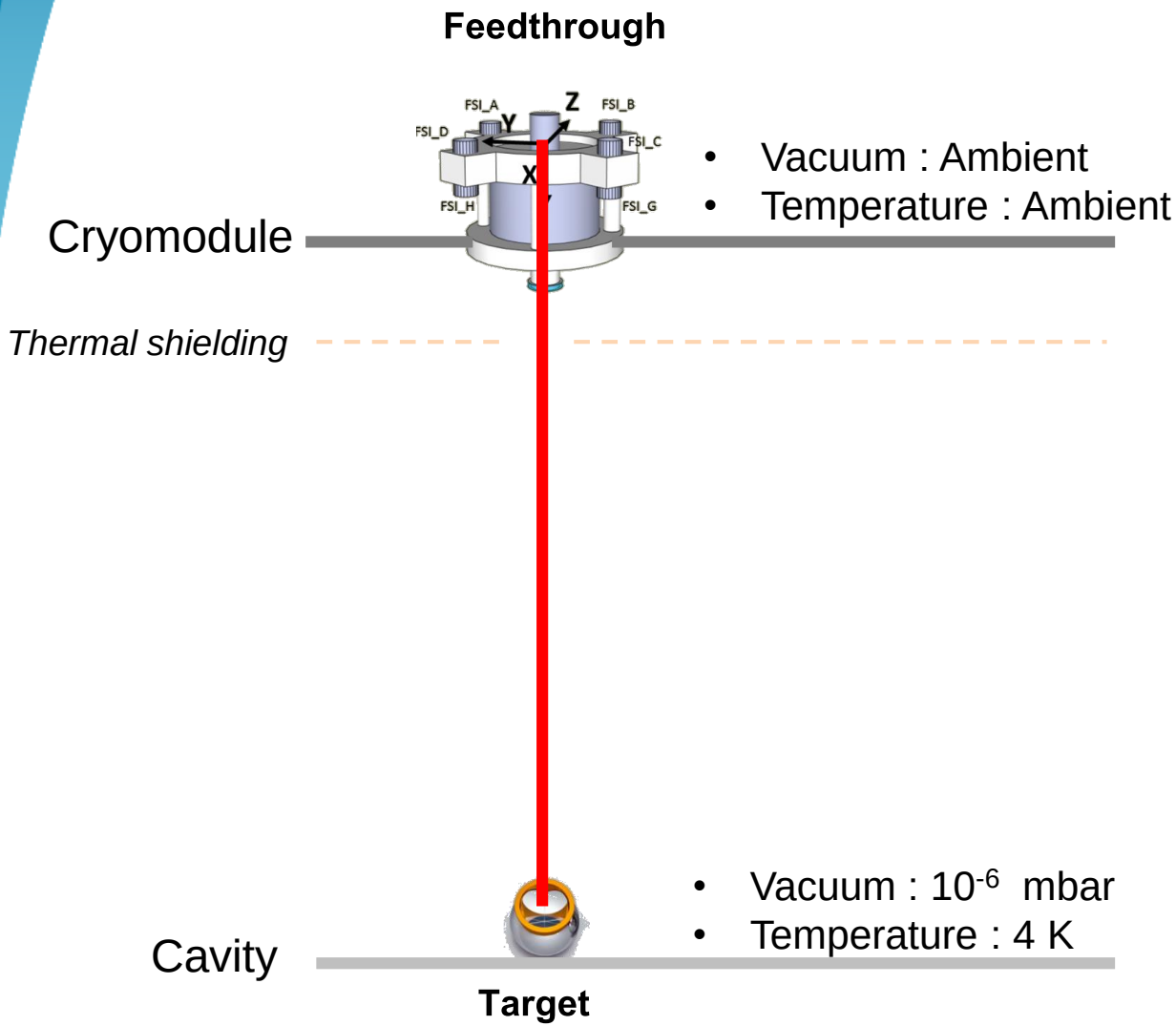
n – refractive index of light transmission medium;

τ – time of flight of laser to the target

from Mateusz Sosin

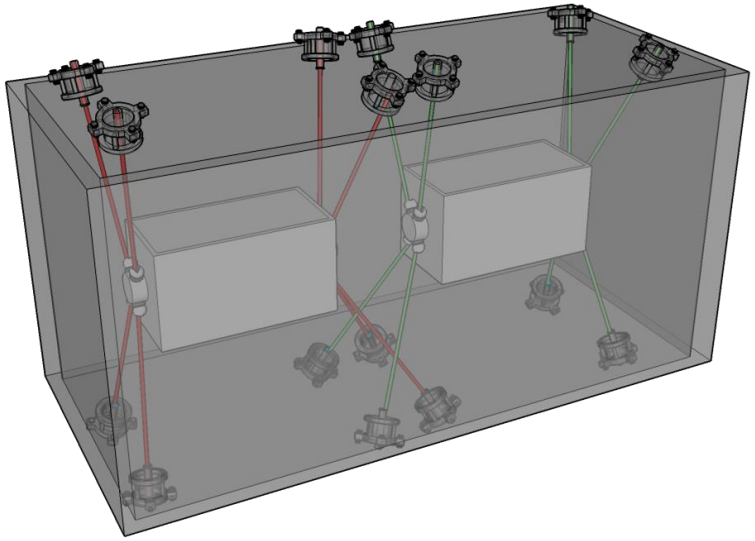
20.10.2021

A-priori accuracy



- Vacuum : Ambient
- Temperature : Ambient

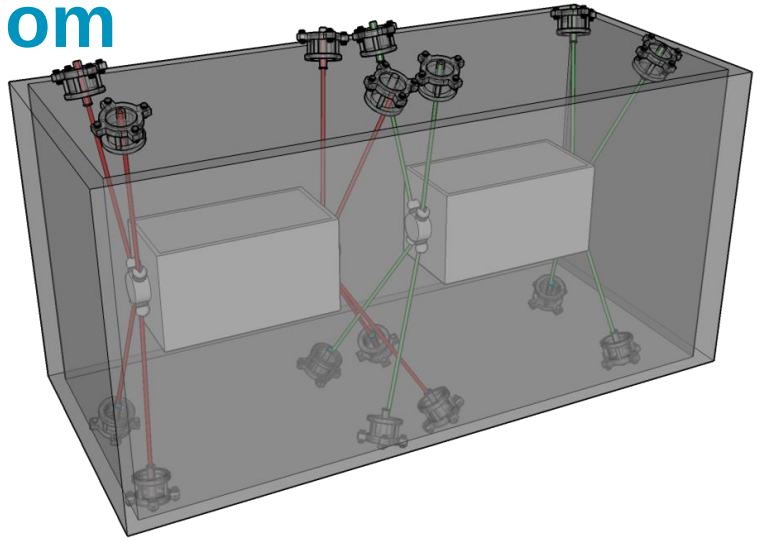
- Vacuum : 10^{-6} mbar
- Temperature : 4 K

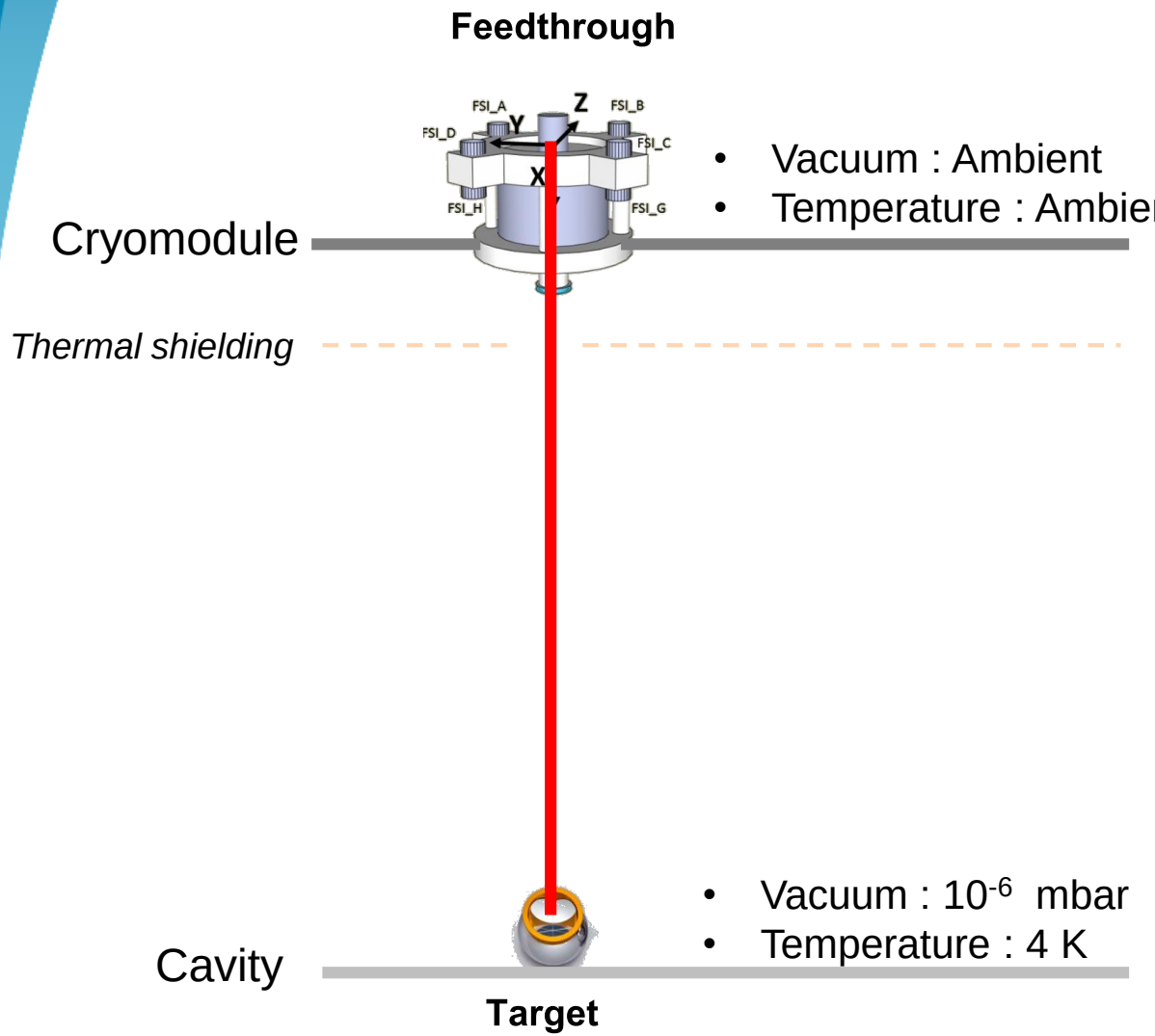


Sensors	Estimated Accuracy
Internal FSI	**20µm**

PART 2 : SPS prototype

Uncertainty by Degrees of Freedom





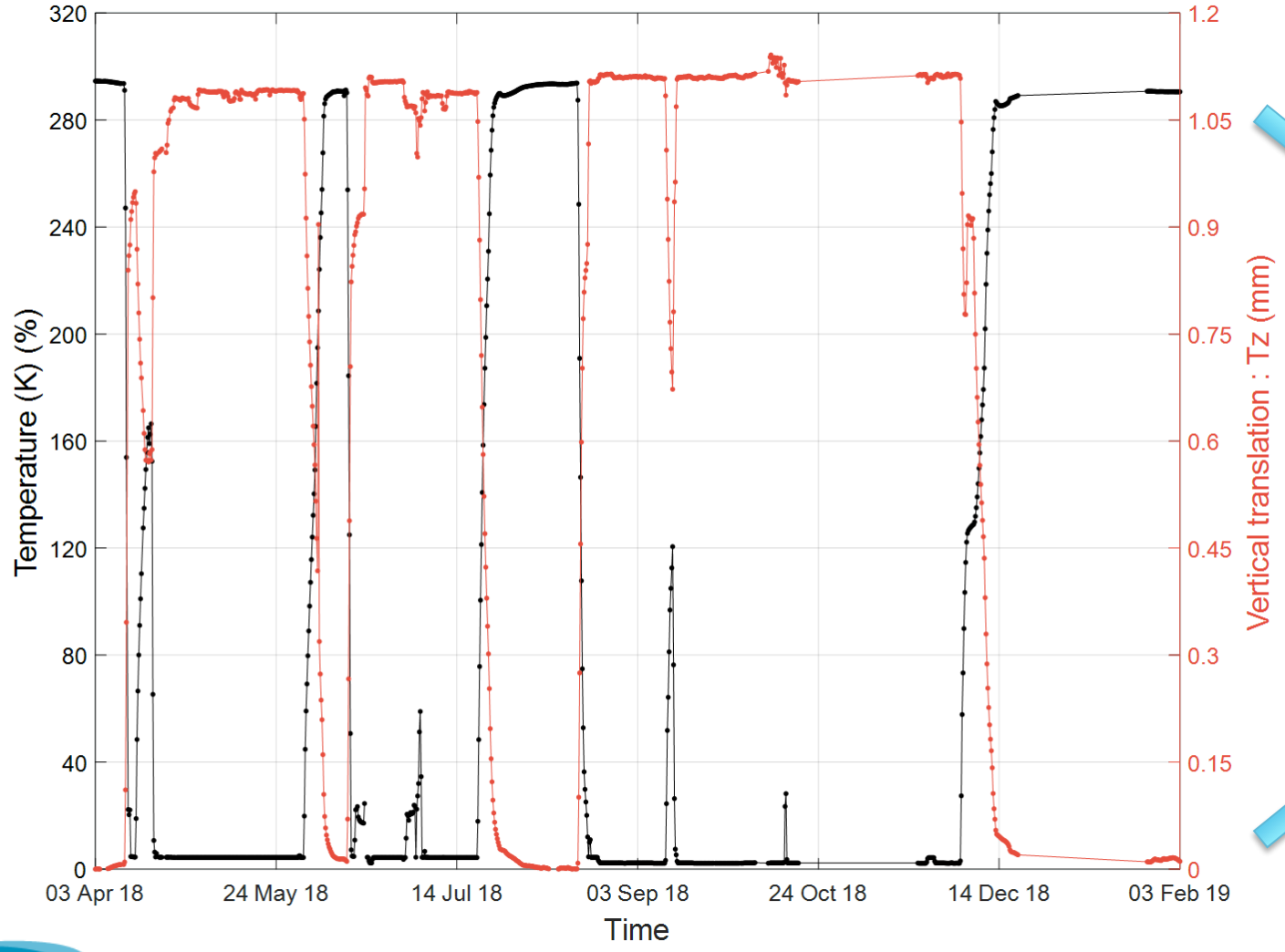
- Vacuum : Ambient
- Temperature : Ambient

- Vacuum : 10^{-6} mbar
- Temperature : 4 K

Parameter	Uncertainty (1σ)
Tx (radial)	+/- 25 µm
Ty (longitudinal)	+/- 45 µm
Tz (vertical)	+/- 10 µm
Rx (pitch)	+/- 30 µrad
Ry (roll)	+/- 150 µrad
Rz (yaw)	+/- 70 µrad
Scale	+/- 60 ppm

Follow-up before LS2

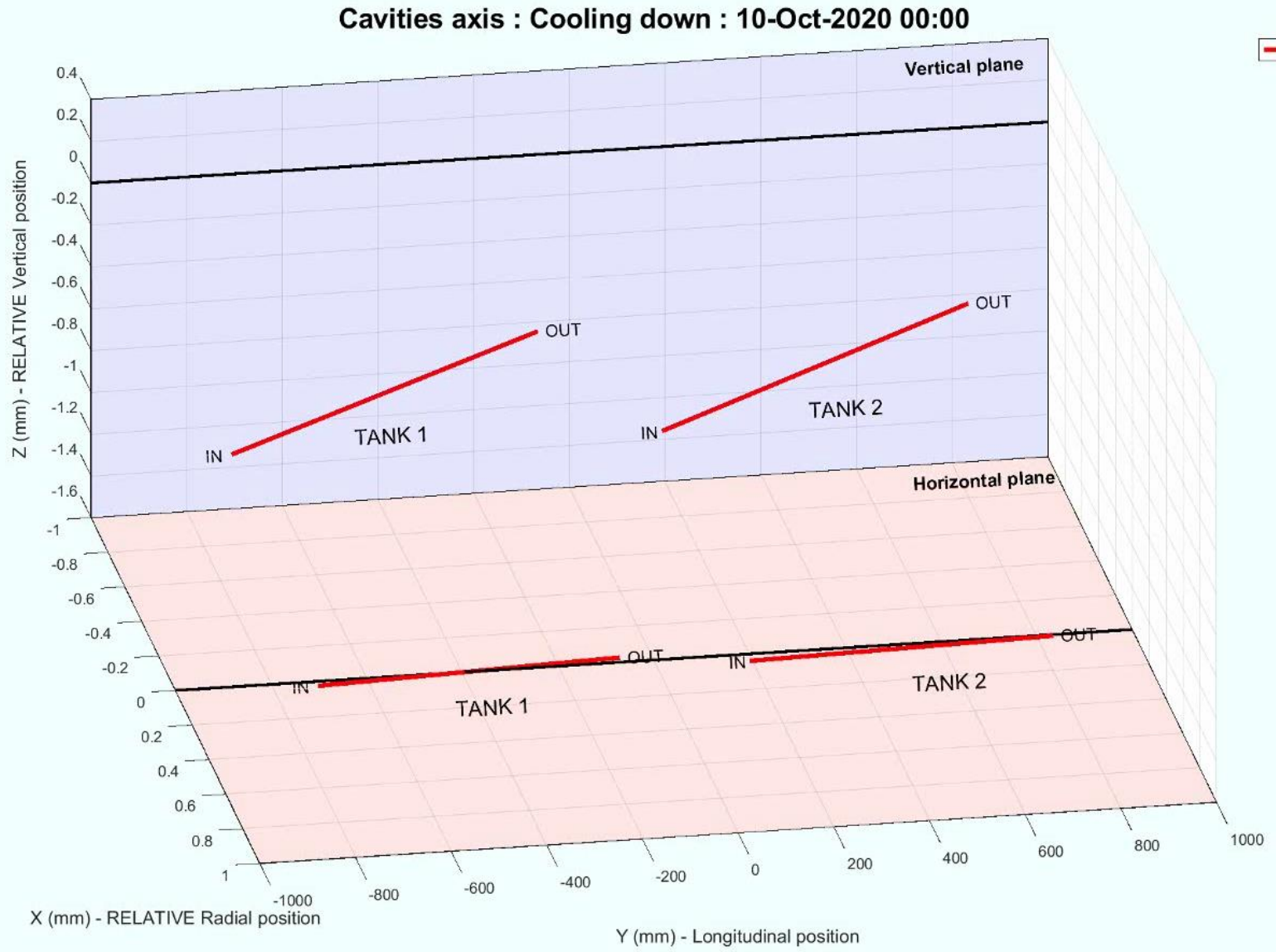
Since April 2018, the monitoring of the Crab-cavities worked correctly.

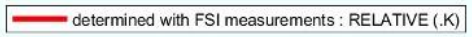


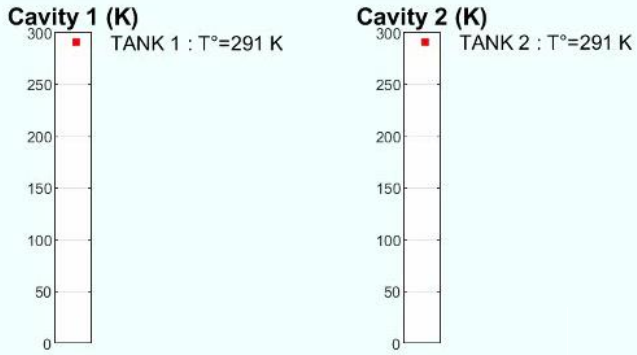
Repeatability of several heat-up and cool down sequences :

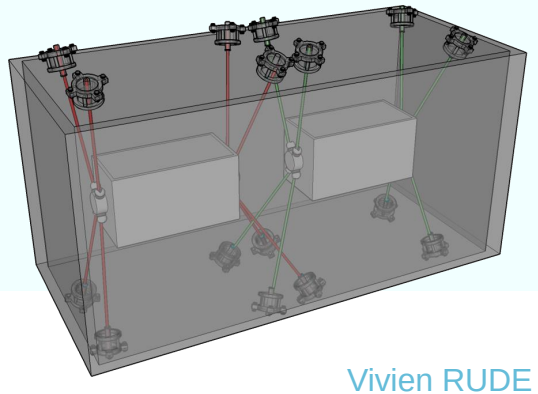
→ Below 20 µm

Follow-up after LS2

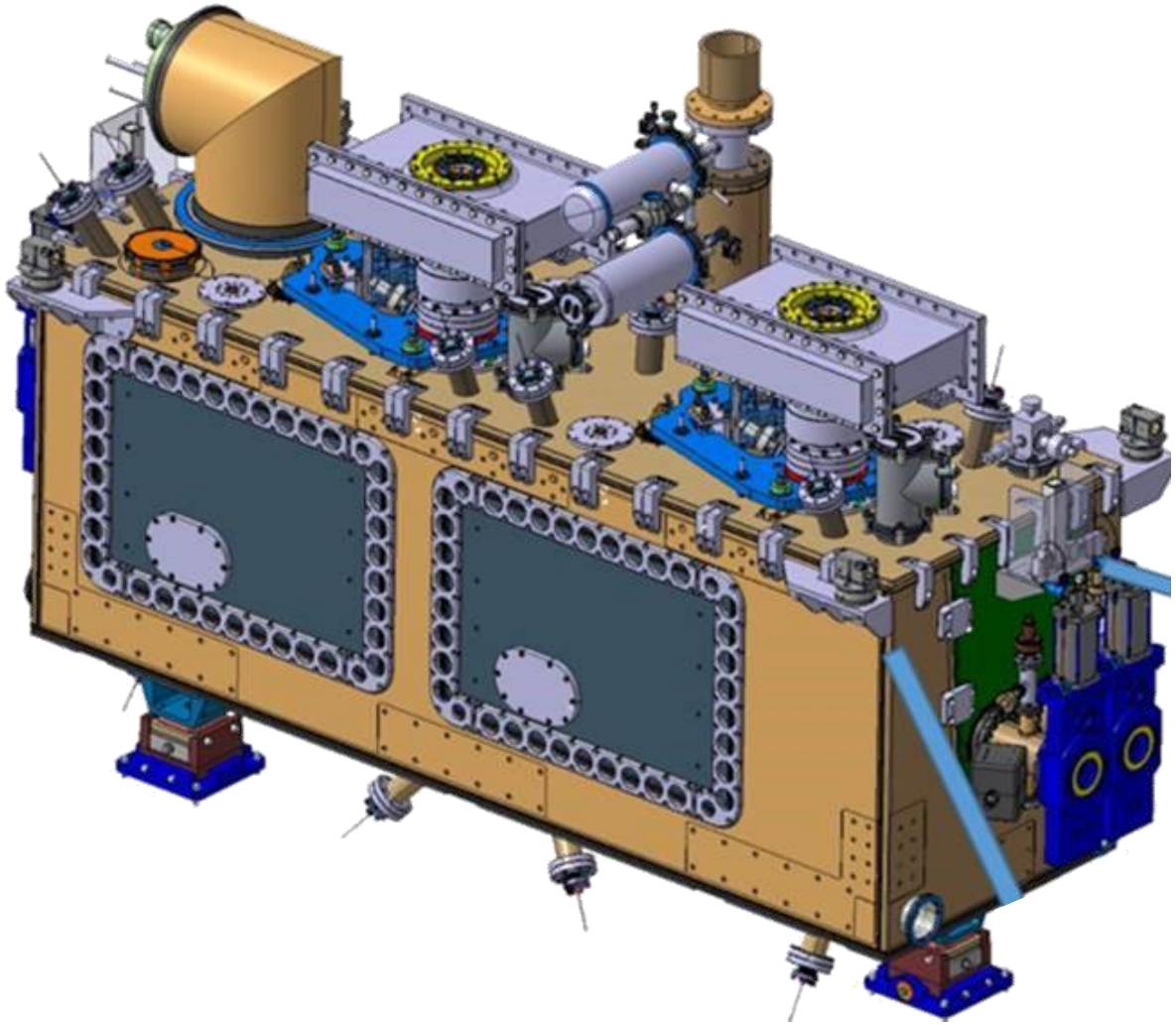




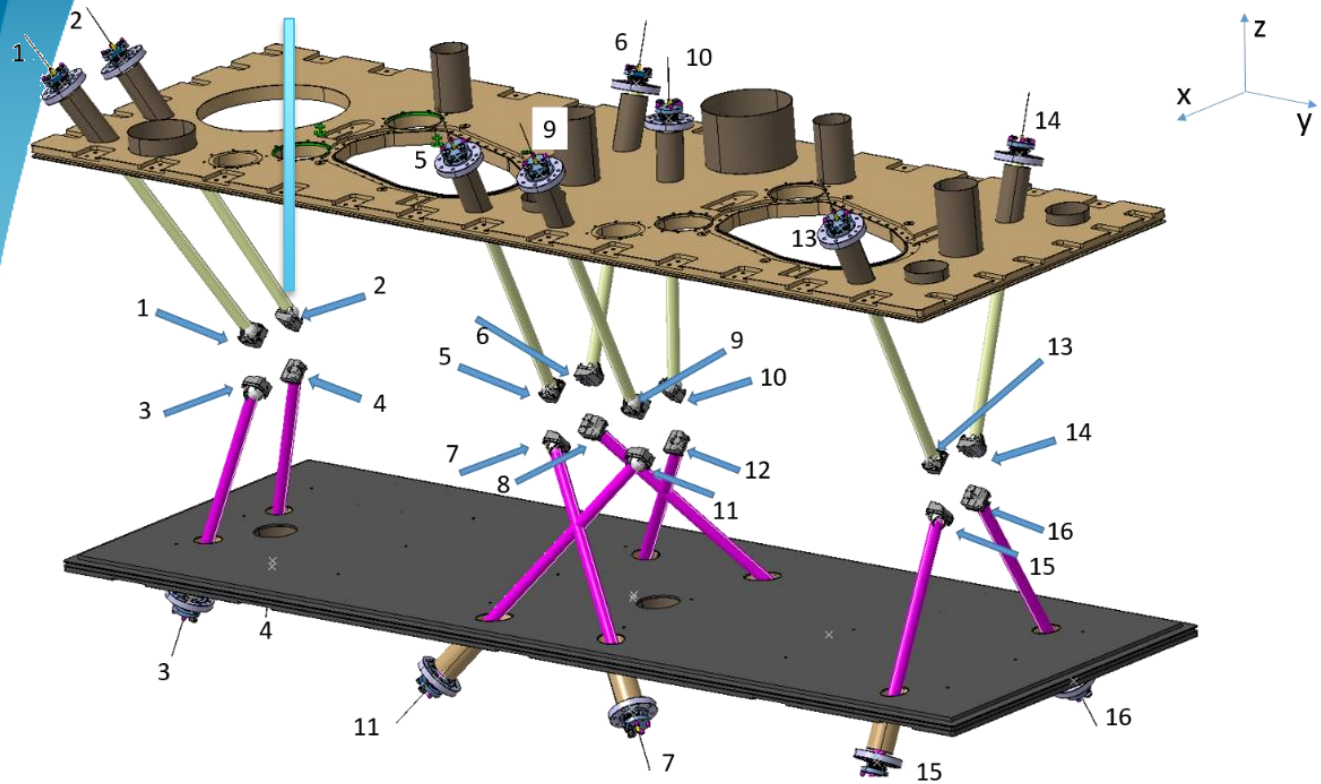




PART 3 : SPS-RFD prototype (HL-LHC Crab-cavities)



Simulation for RFD prototype → Towards HL-LHC



σ(A priori FSI distance) = 0.020 mm

TANK	GOAL (1σ)
Tx (mm) Radial	**< 0.083 mm**
Ty (mm) longitudinal	
Tz (mm) vertical	**< 0.083 mm**
Rx (mrad)	**< 0.300 mrad**
Ry (mrad)	**< 1.700 mrad**
Rz (mrad)	**< 0.300 mrad**
Scale (ppm)	

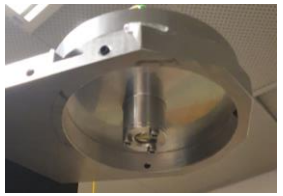
7 D.O.F.

TANK 1	Precision (1σ)
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

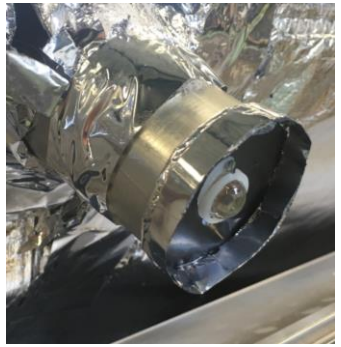
7 D.O.F.

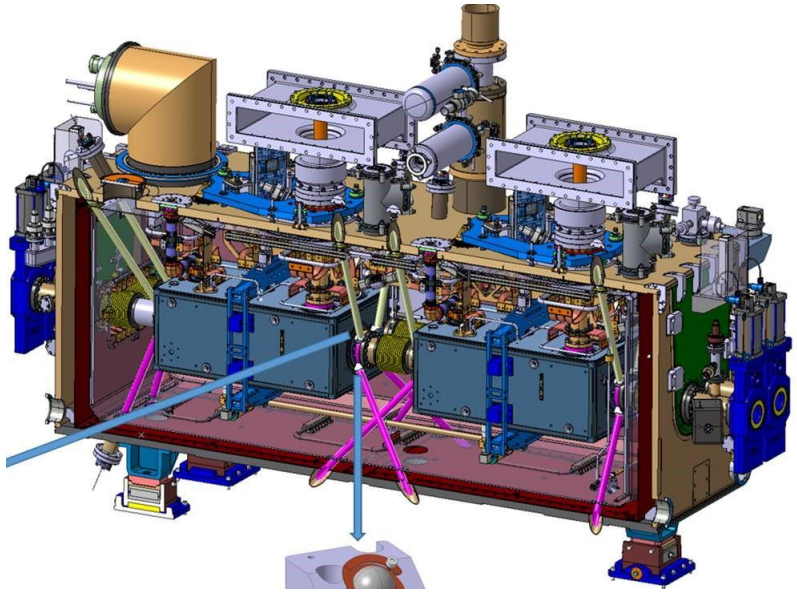
TANK 2	Precision (1σ)
Tx (mm) Radial	0.021
Ty (mm) longitudinal	0.077
Tz (mm) vertical	0.011
Rx (mrad)	0.023
Ry (mrad)	0.180
Rz (mrad)	0.047
Scale (ppm)	101

Main modification w.r.t. SPS prototype

	SPS Prototype	HL-LHC
Targets	 Corner Cube Reflector 1.5 inch = 38.1 mm	 Glass Sphere 0.5 inch = 12.7 mm
Feedthrough	 Tip/Tilt adjustment	  No adjustment

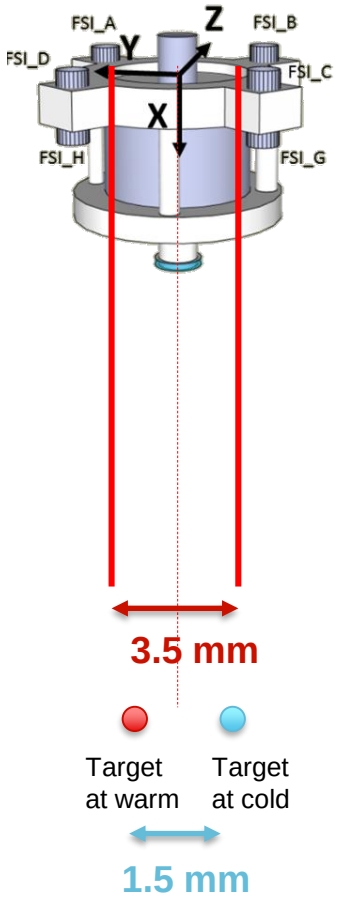
Already tested in a dipole

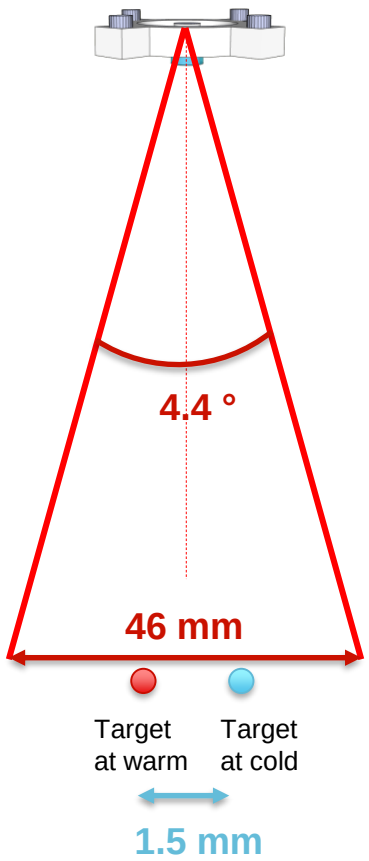




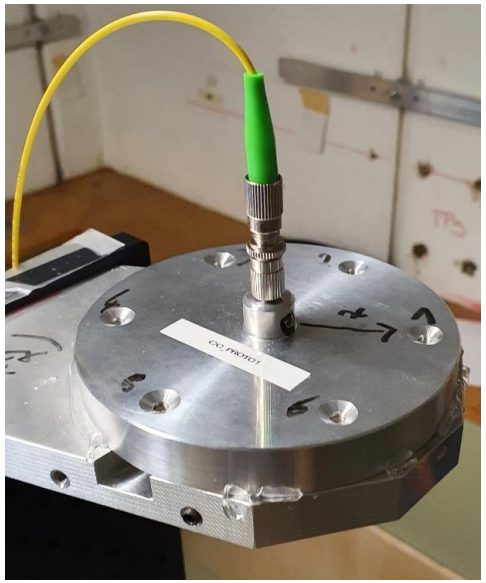
Main modification w.r.t. SPS prototype

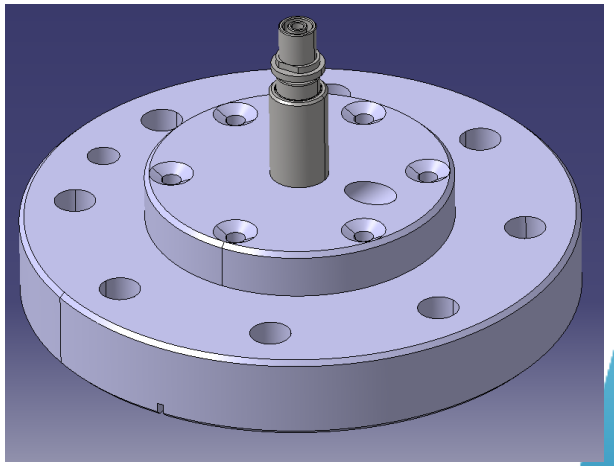
	SPS Prototype	HL-LHC
Lens	Convergent Tip/Tilt adjustment	Divergent No adjustment



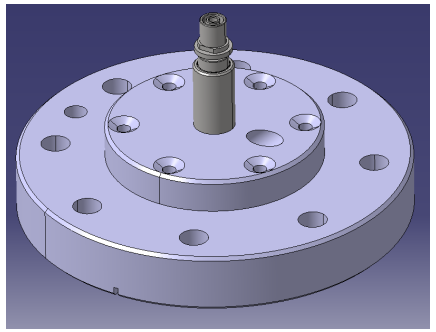


Dist = 600 mm

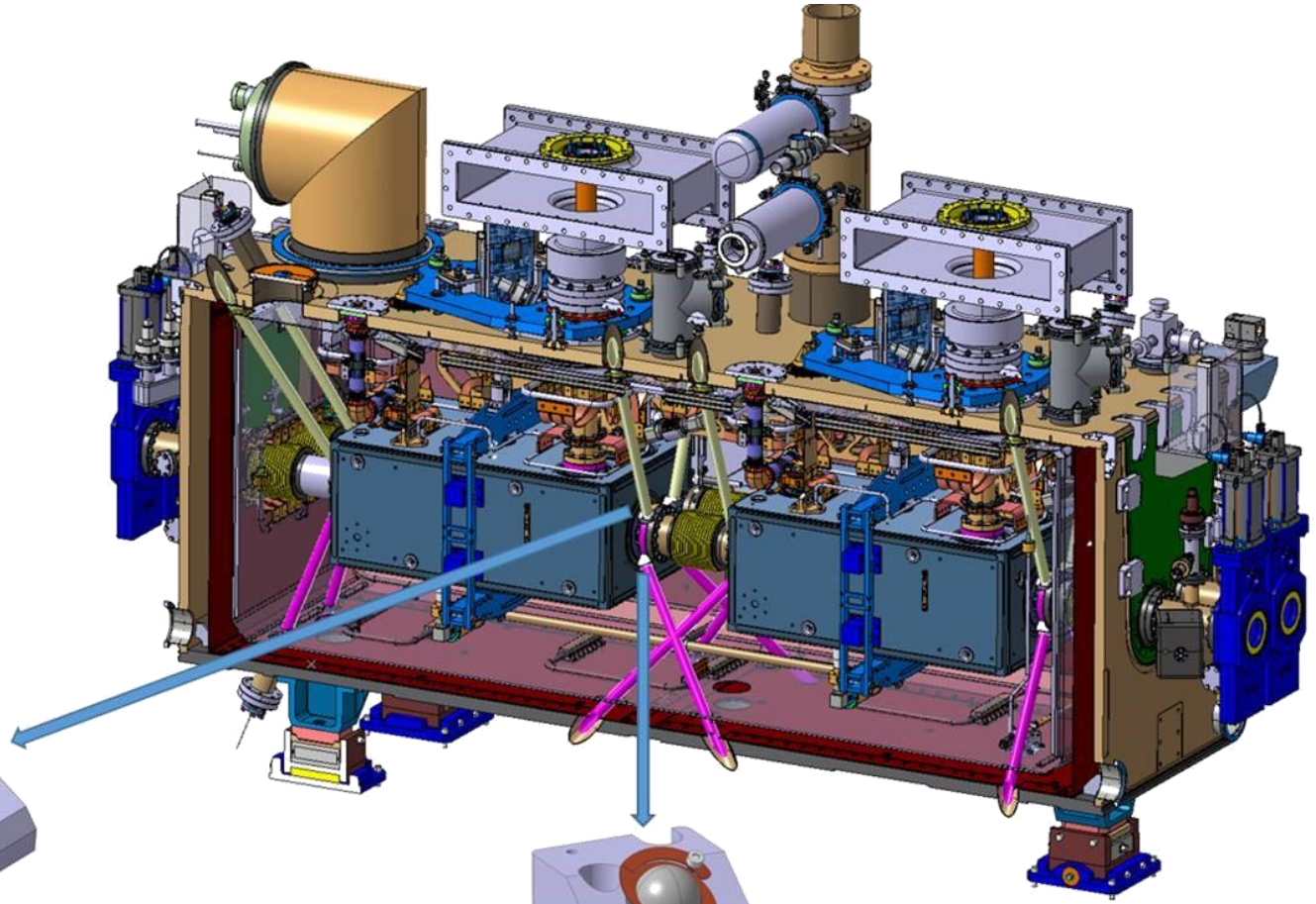




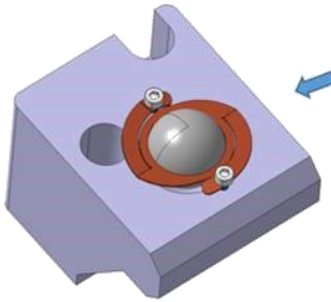
Integration / design status (Internal monitoring)

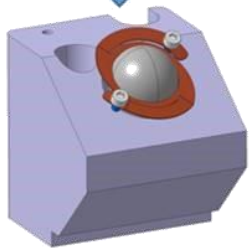


FSI targets assembly
ST1408969_01



ST1407441_01



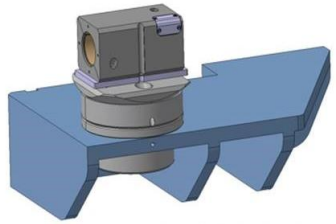


ST1408926_01

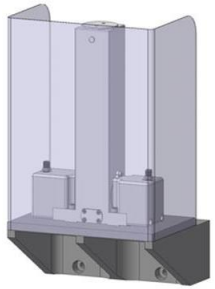
- FSI heads and target supports – preliminary design is ready
- Prototypes tests ongoing

Integration / design status (External monitoring + motorisation)

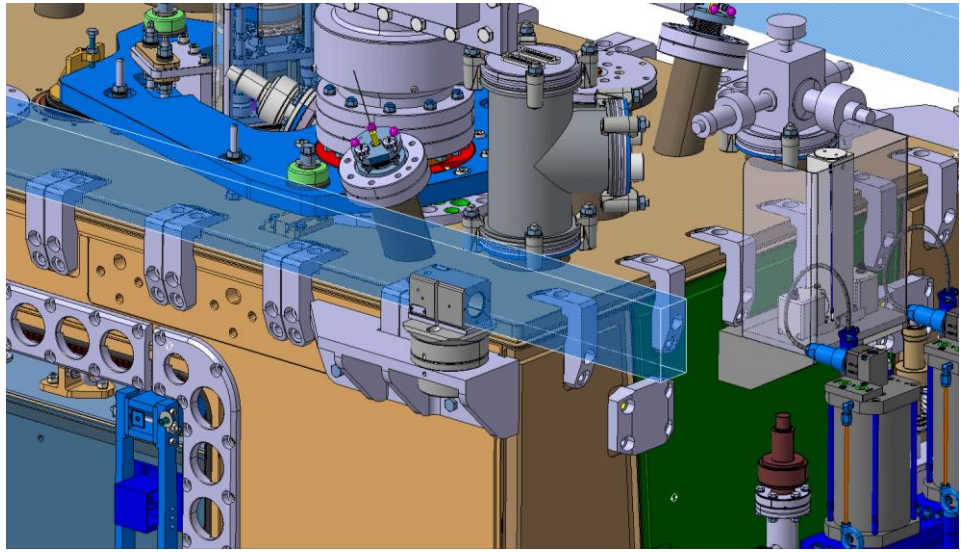
3 WPS
2 Inclinometers

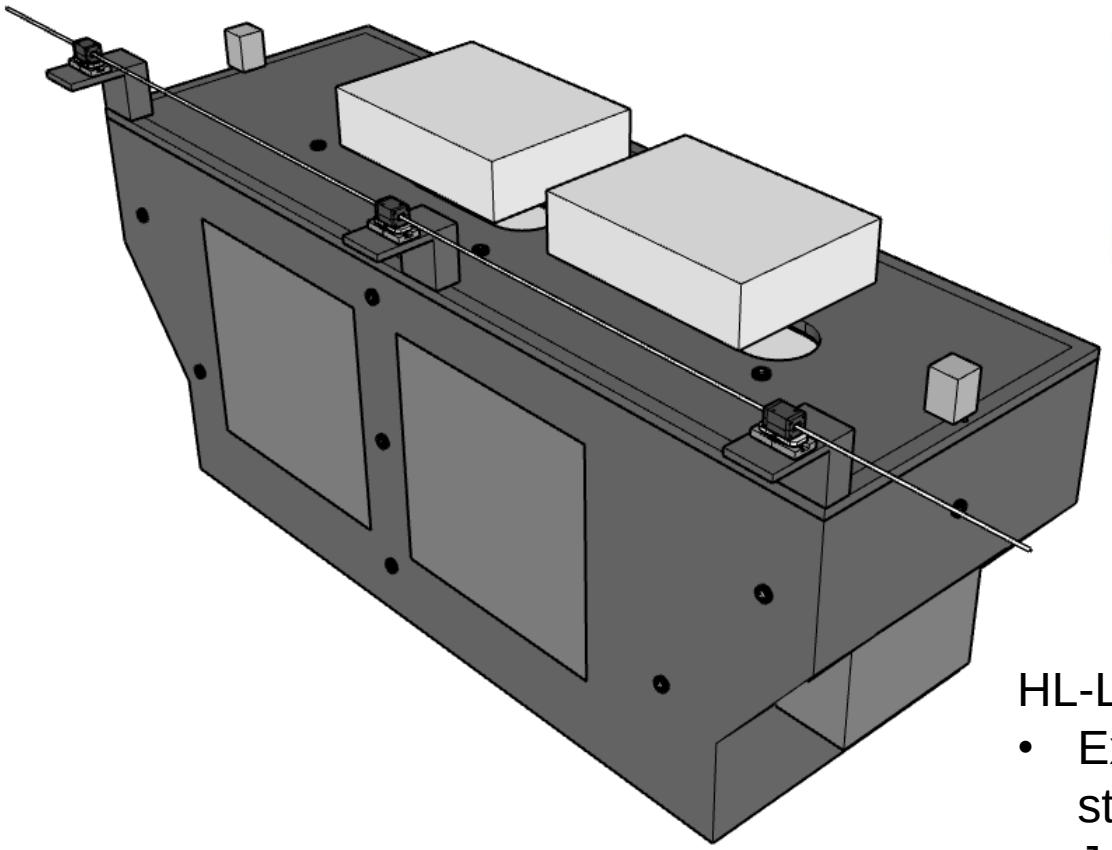


ST1397346_01



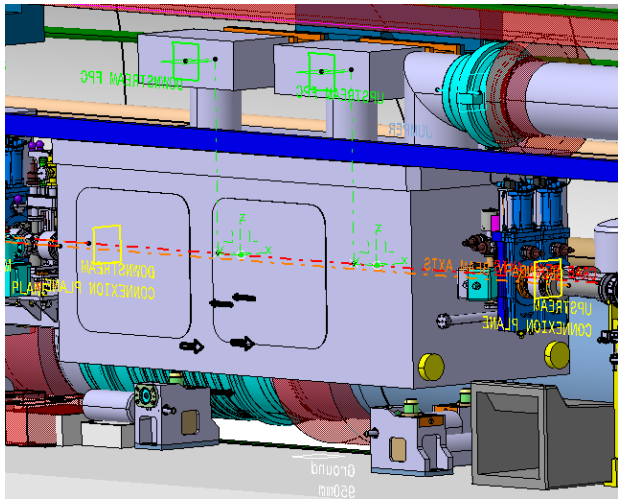
ST1385376_01





HL-LHC:

- External sensors - integration study finished
- Jacks integration - ongoing

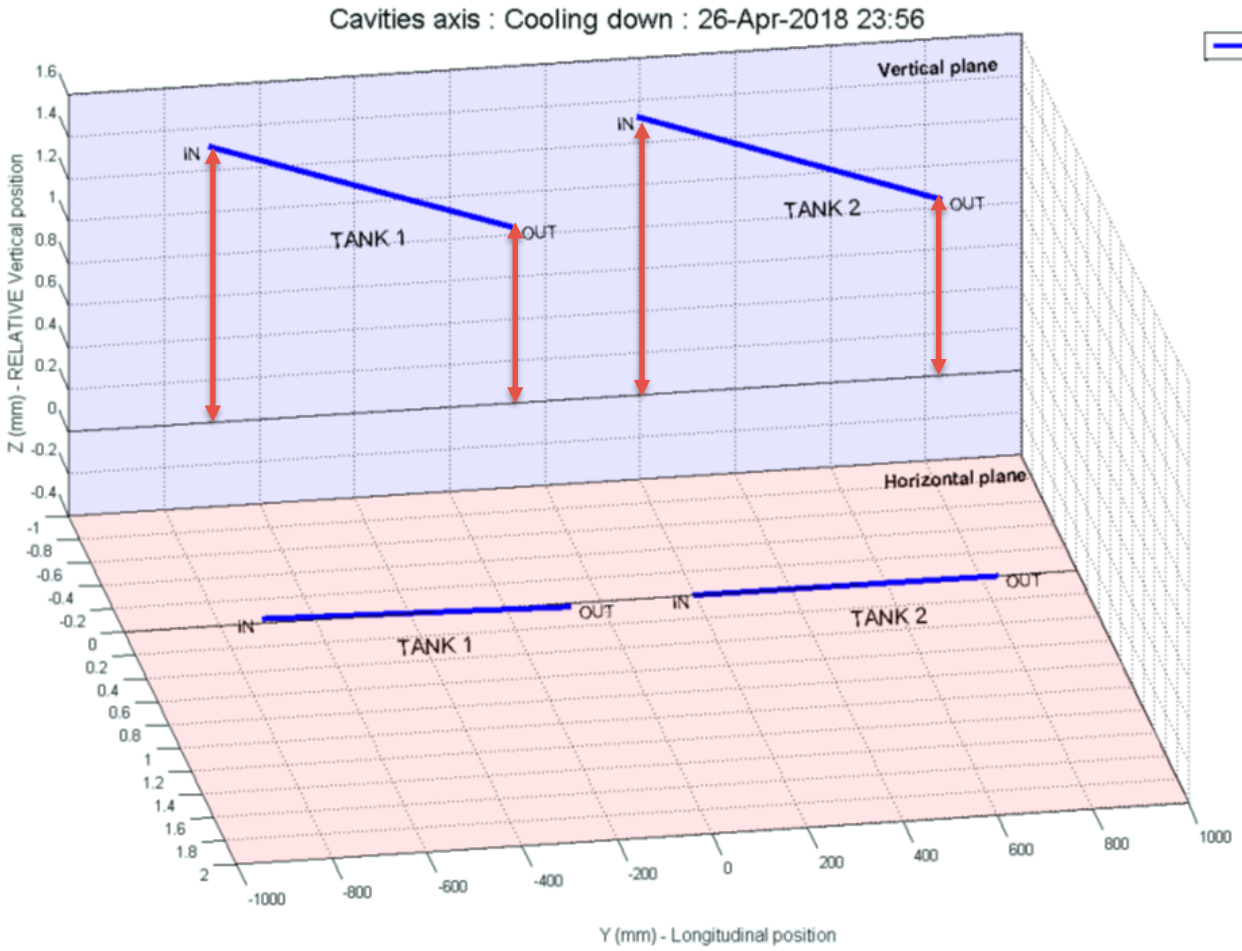


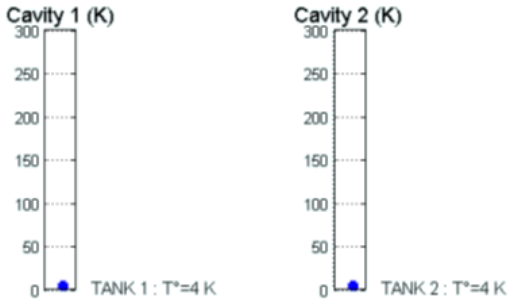
Conclusion for HL-LHC configuration (Crab-cavities)

- Internal monitoring : Measurement uncertainty of FSI monitoring system
  - Simulation done for RFD prototype
  - For HL-LHC : future improvement
- Internal monitoring : targets
  - Supports and Glass spheres validated and integrated
- Internal monitoring : feedthroughs
  - Test on FSI head prototype : ongoing
- External monitoring
  - Space reservation studied for WPS and inclinometers
  - Test on WPS and inclinometers : ongoing

SPARE

Thermal contraction : From 293 K to 4 K





CONTRACTION	Cav 1		Cav 2	
	IN (mm)	OUT (mm)	IN (mm)	OUT (mm)
Simulation	1.097	0.678	1.097	0.678
SM18	1.321	0.843	1.295	0.832
SPS	1.310	0.834	1.320	0.835

FSI : Frequency Scanning interferometry

Absolute distance measuring interferometric technique

Measures phase changes in a measurement and reference interferometer as frequency is scanned

- $\Delta Phase\ (meas.) = \frac{2\pi}{c} * L_M * \Delta\nu$
- $\Delta Phase\ (\ ref.\ ) = \frac{2\pi}{c} * L_R * \Delta\nu$

$$\frac{\Delta Phase\ (meas.)}{\Delta Phase\ (\ ref.\ )} = \frac{L_M}{L_R}$$

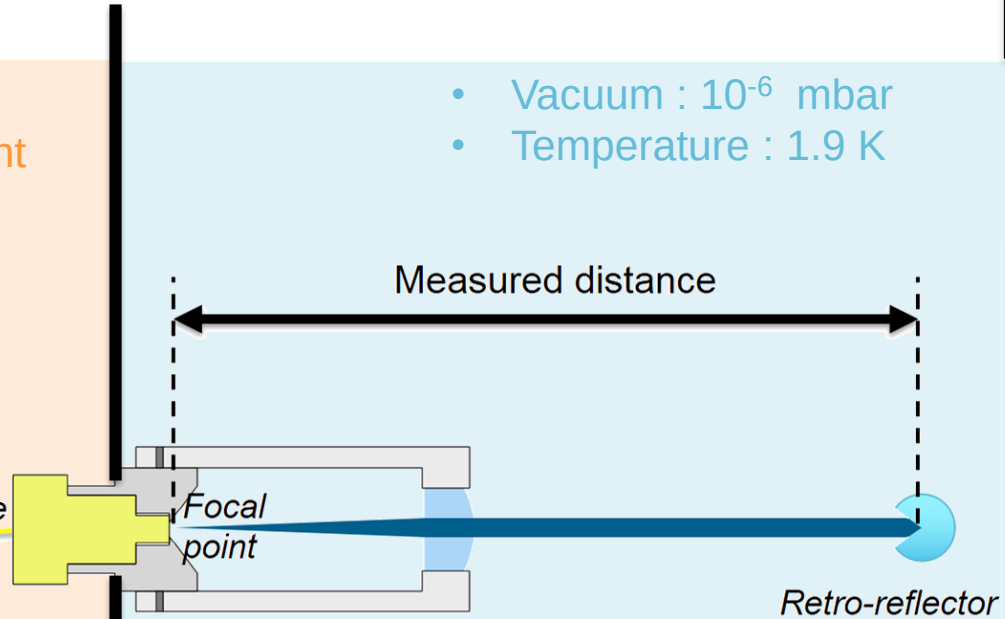
Vacuum Vessel

- Vacuum : Ambient
- Temperature : Ambient

Reference interferometer

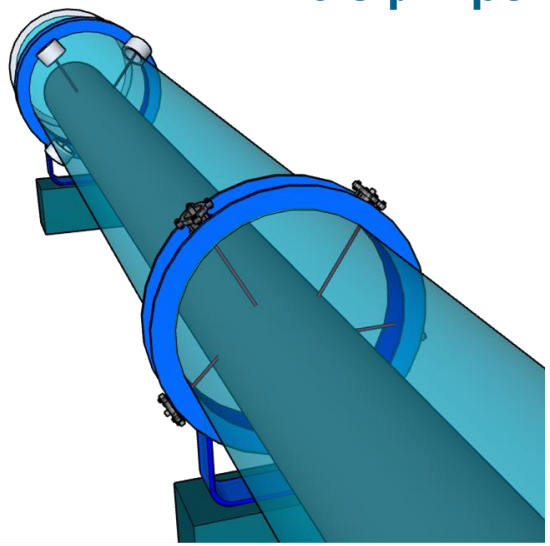
Optical fibre

- Vacuum : 10^{-6} mbar
- Temperature : 1.9 K



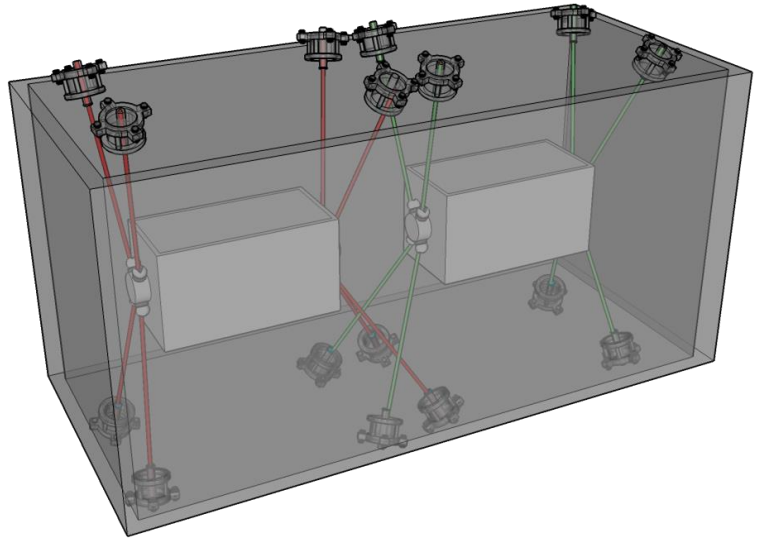
Measurement interferometer

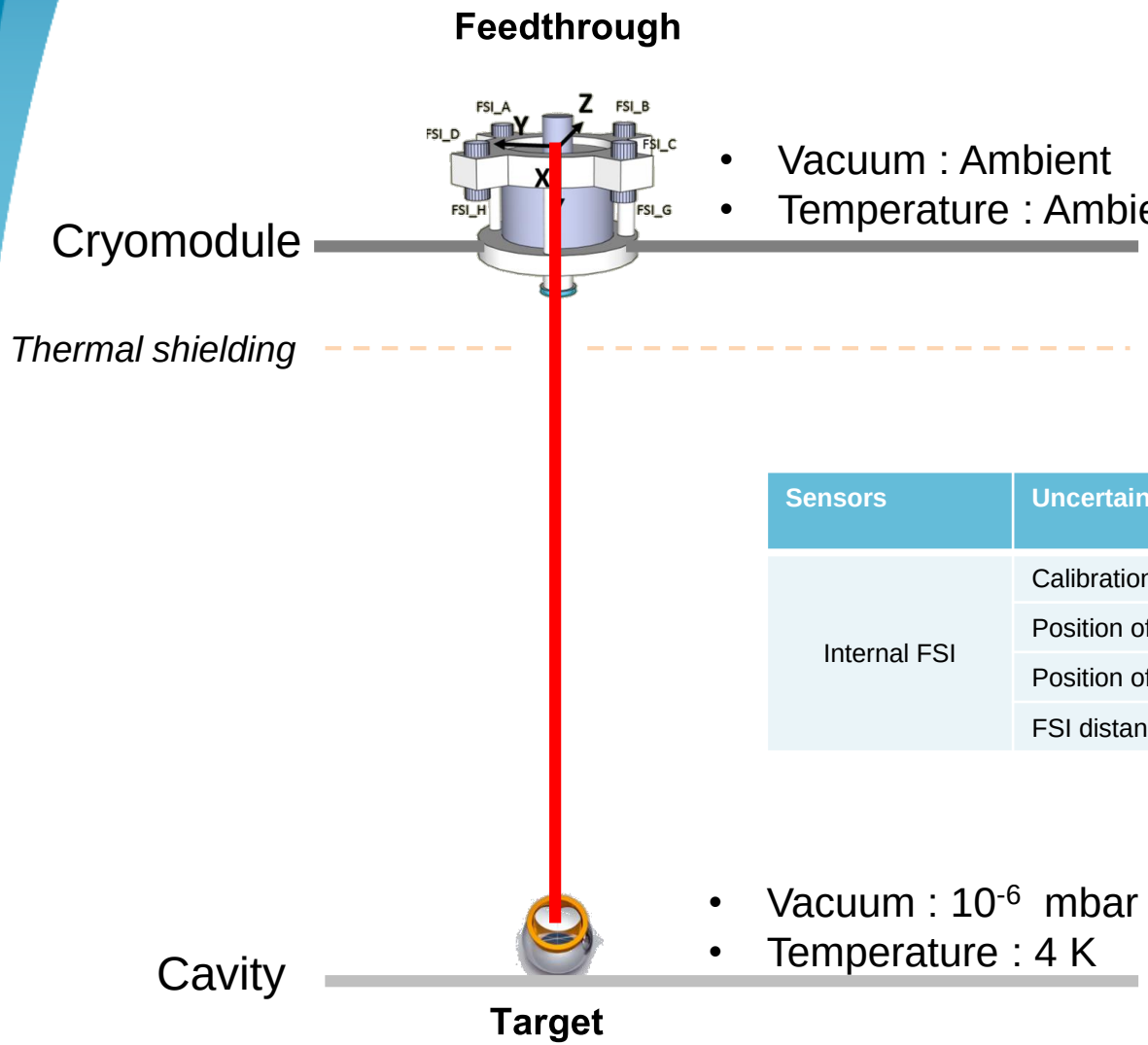
Accuracy : 0.5 µm per meter



Absolute distance : deduced from the ratio of the phase change between the 2 interferometers by frequency scanning

A-priori accuracy





- Vacuum : Ambient
- Temperature : Ambient

- Vacuum : 10^{-6} mbar
- Temperature : 4 K

Sensors	Uncertainty	Value	Estimated Accuracy
Internal FSI	Calibration of Feedthrough (FSI Head)	10 µm	**20µm**
	Position of the Feedthrough (FSI Head) in the framework of the vacuum vessel	15 µm	
	Position of the target in the framework of the cold mass	10 µm	
	FSI distance	few µm	

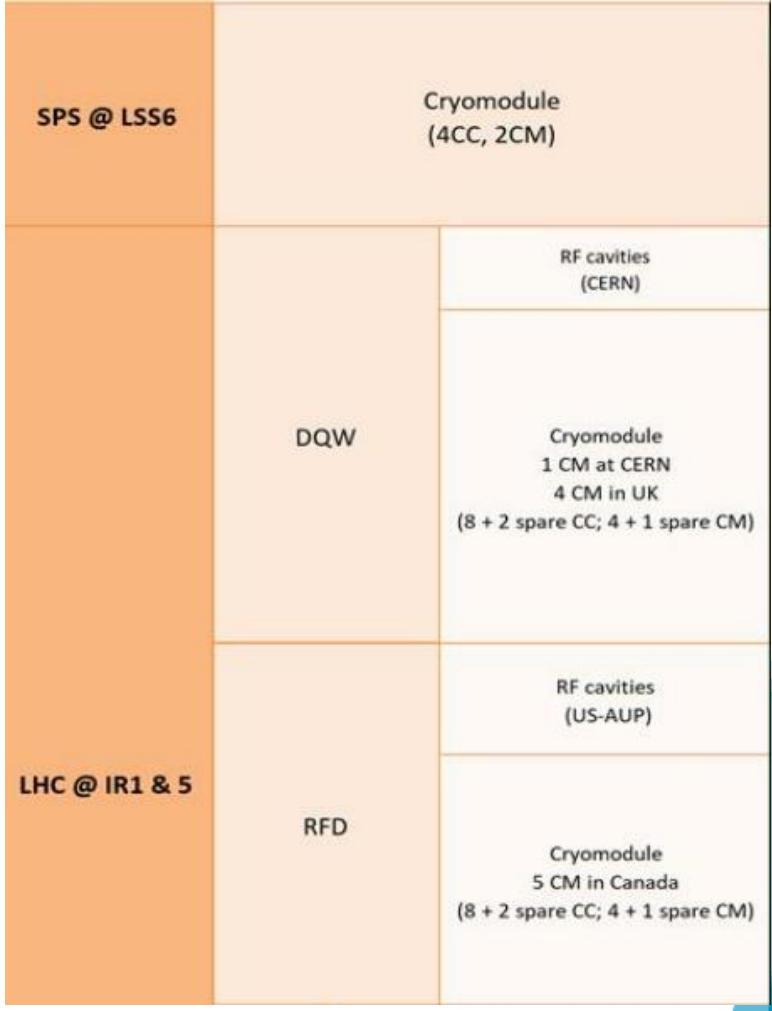
Internal monitoring CRAB-CAVITIES (2021-09-06 news)

DQW (for CMS) :

- No proto
- 5 LHC series (4 UK, 1 CERN) → 2023 to 2025

RFD (For Atlas):

- 1 proto : RFD TCM0 (CERN + UK) → 2021/2022 → Tested in SPS
- 5 LHC series (5 Canada)



- **RFD proto :**
  - → CERN : 2 Cavities→ Done
  - → CERN : 2 Helium TANKs → Summer 2021
  - →UK : Assembly : autumn 2021 to Winter 2021
  - →UK : Validation at cold condition (70K) : Winter 2021 to Spring 2022
  - →CERN SM18 : Validation at cold condition (1.9K) : Spring 2022 to Autumn 2022 → Workflow in progress
  - →CERN SPS : Installation in SPS accelerator : Dec 2022

- 17 FSI heads (Crab-cavities Heads) have to be assembled, calibrated and sent (Mateusz, Vivien) for RFD proto