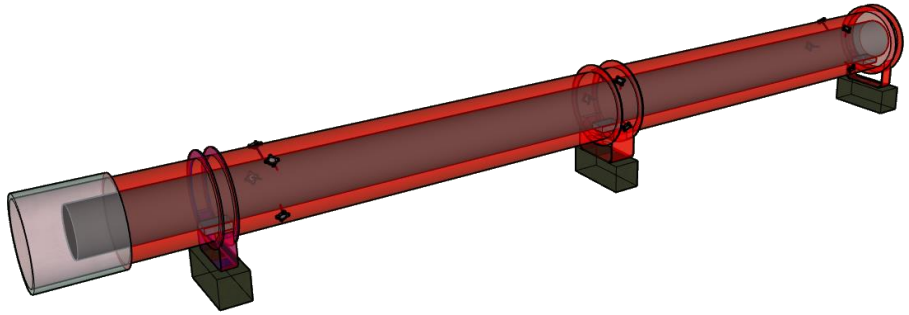

Alignment analysis on the low-beta quadrupoles during cold test

Vivien RUDE

2024-10-10

On behalf :

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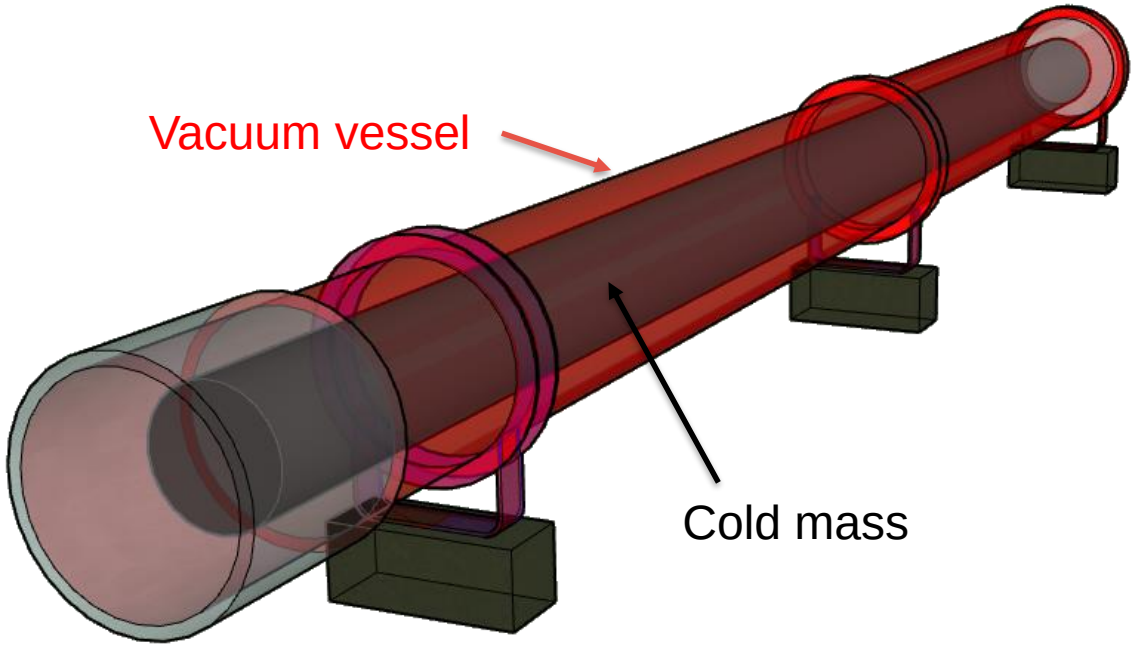
14th HL-LHC Collaboration Meeting, Genoa (Italy), 7-10 October 2024

Outline

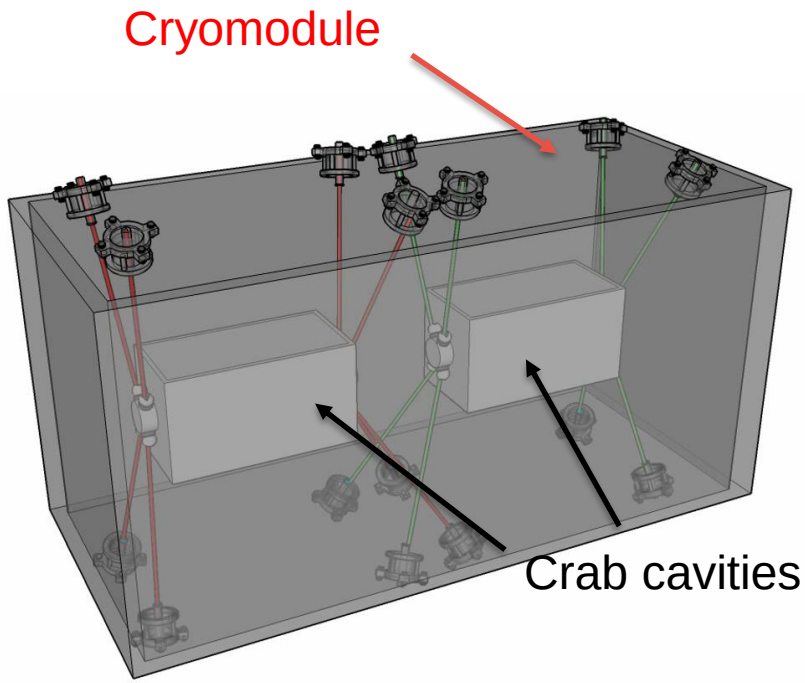
- Alignment Objectives (3 objectives)
- Internal monitoring configuration
- FSI measurements on different Q2
  - Impact of transport on alignment
  - Impact of pumping on alignment
  - Impact of cooling down on alignment
- FSI measurements on Q3 (at Fermilab and at CERN)
- Mechanical and magnetic axes behaviour during cooling down

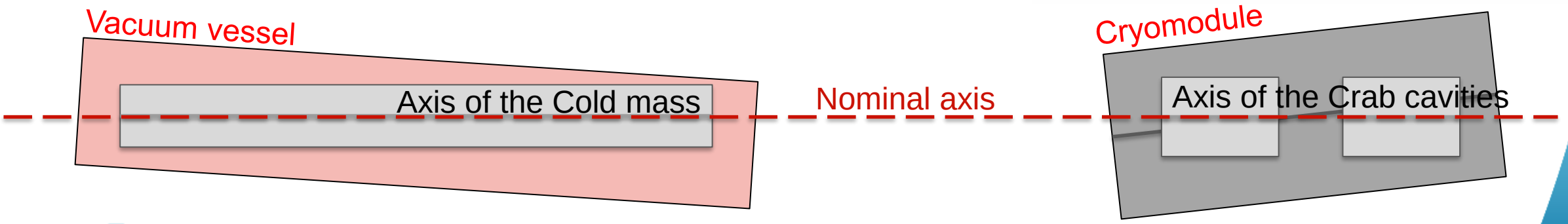
Internal monitoring for “special” components

Q1, Q2a, Q2b, Q3



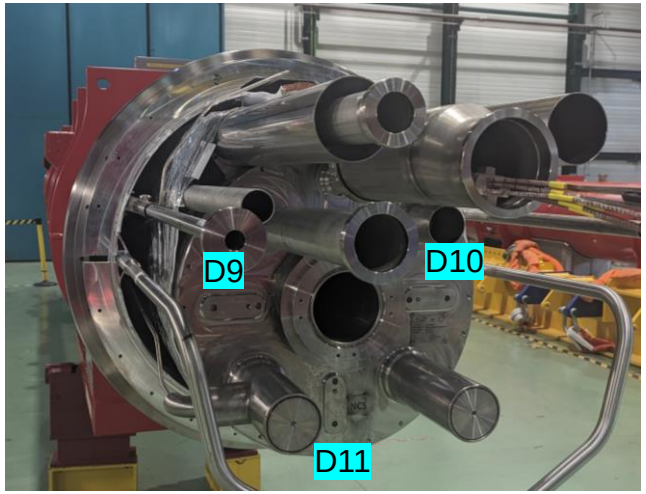
Crab-Cavities

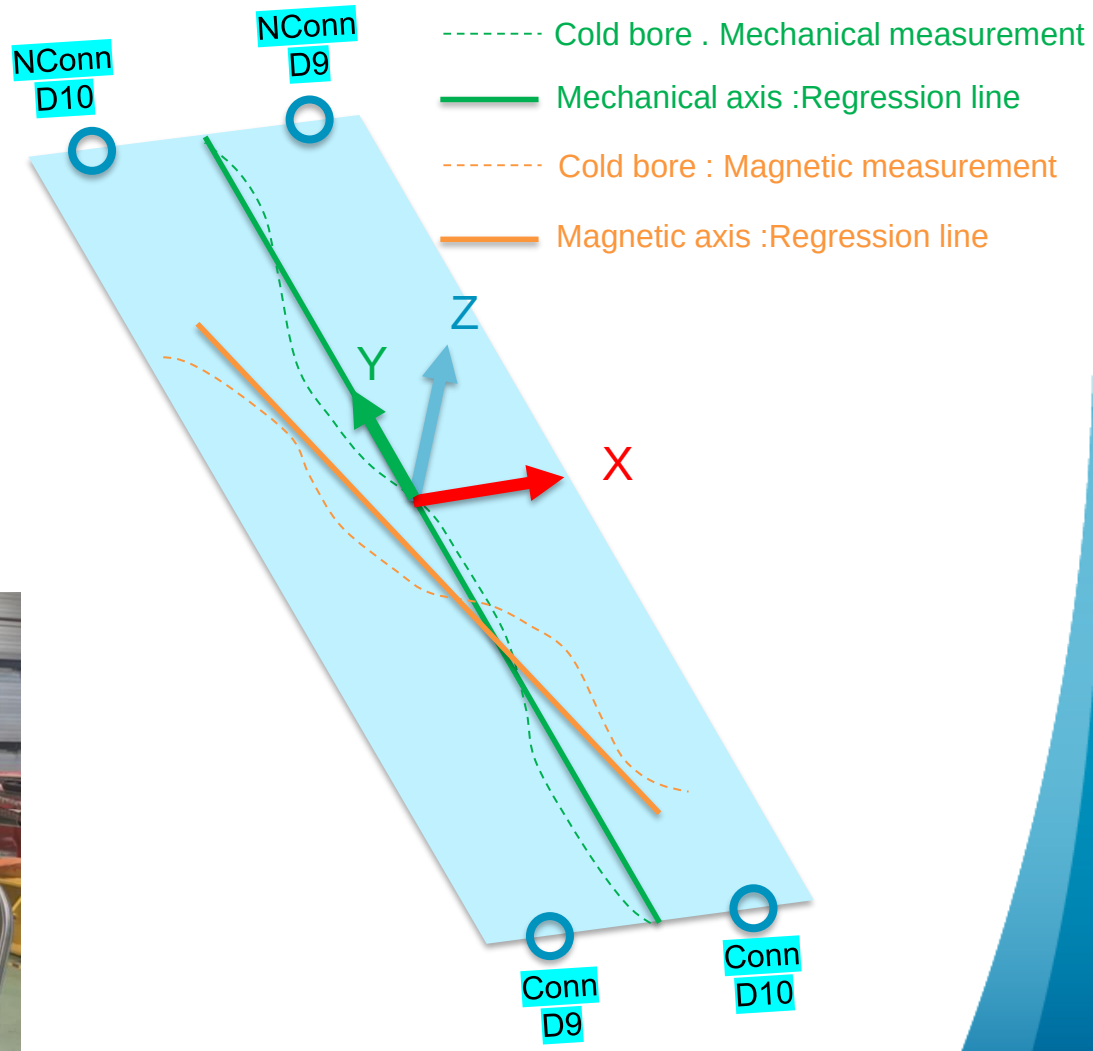




Mechanical Coordinate system

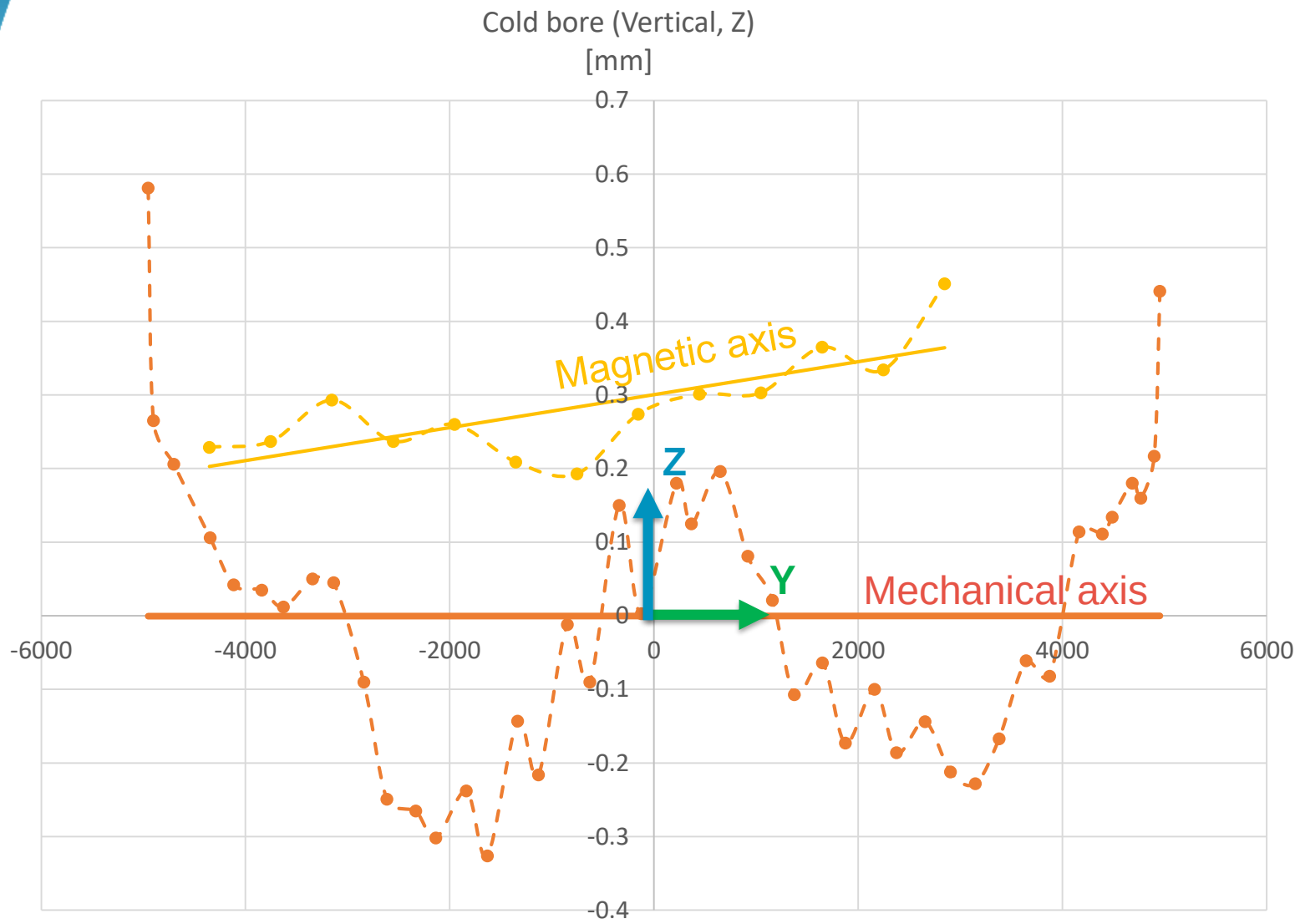
- *Primary axis : Y : Regression line corresponding to the mechanical cold bore axis (determined from mechanical mole)*
- *Secondary axis : Z : Normal vector of the plane [Conn-D9, Conn-D10, NConn-D9, NConn-D10]*
- *Origin : Projection of the central cold feet on Y axis*

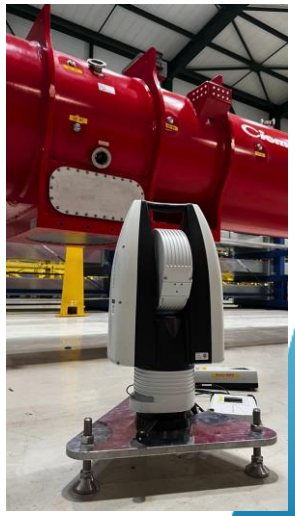




Alignment Objective n°1 : Fiducialisation

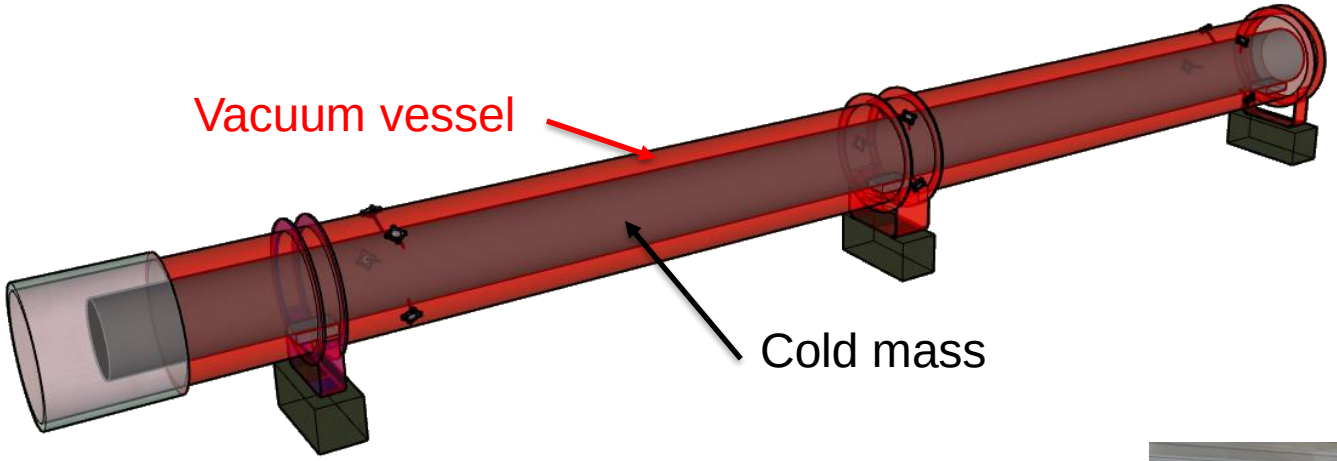
Alignment requirement
Position : 40 µm (1σ)

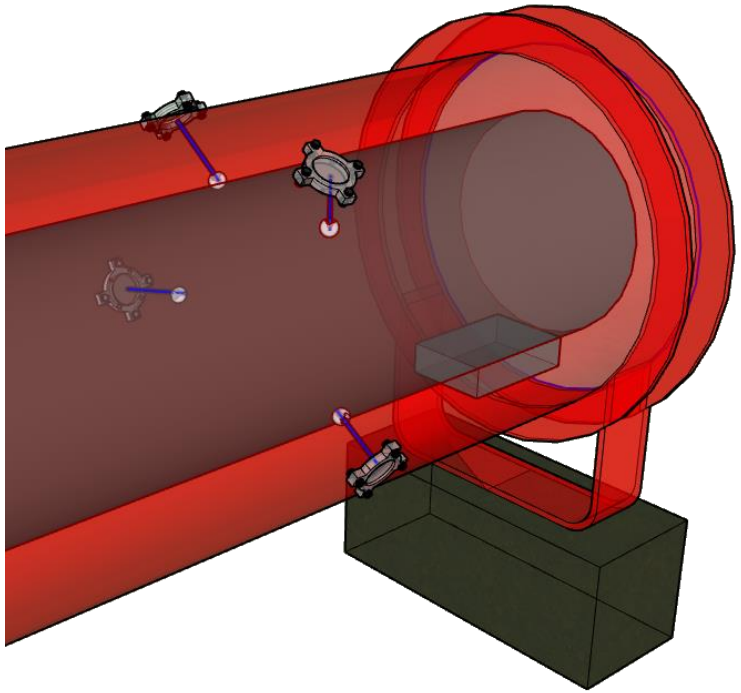


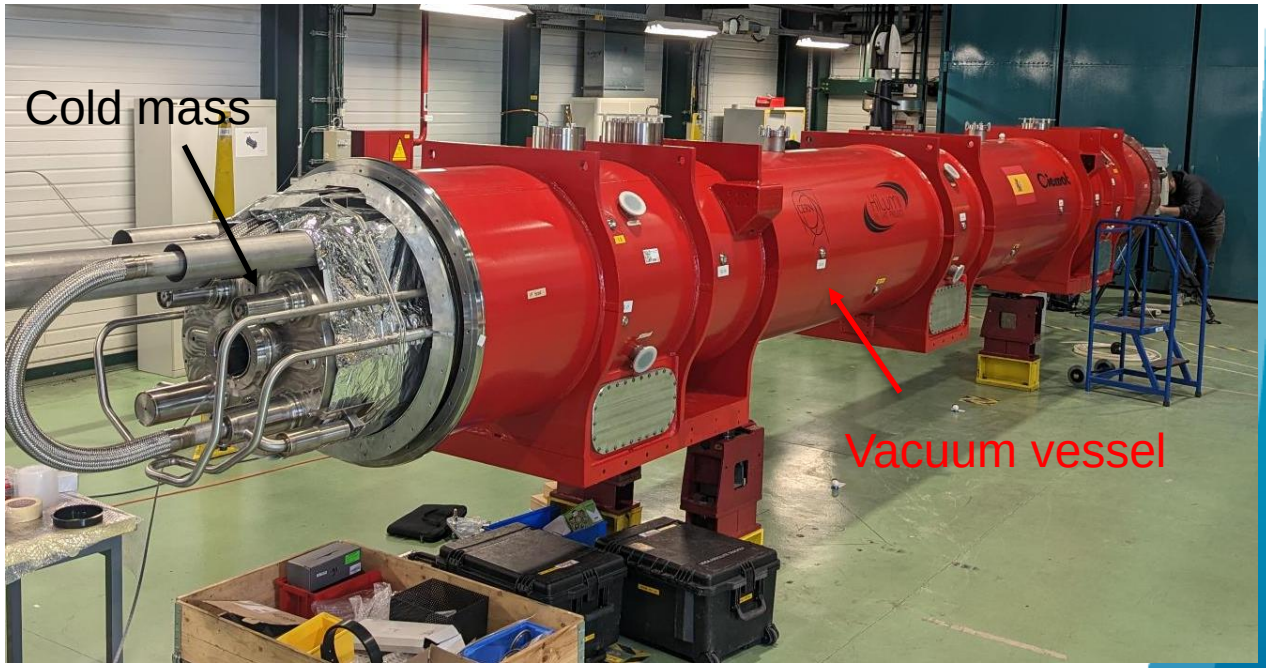


Alignment Objective n°2 : Internal monitoring

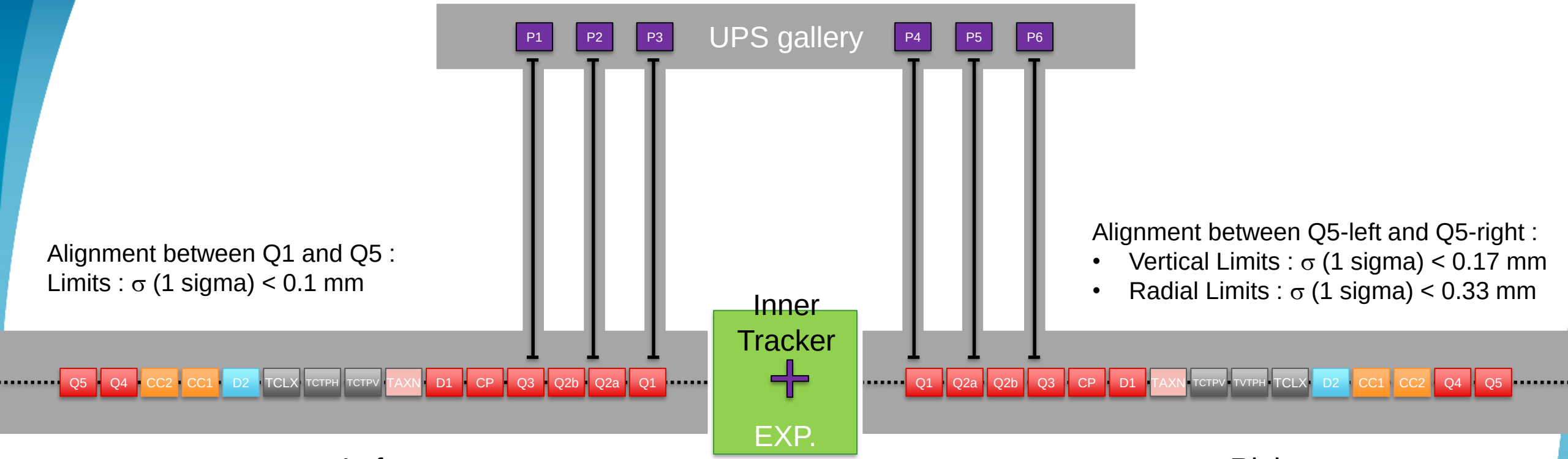
Alignment requirement
Position : < 100 µm (1σ)







Alignment Objective n°3 : External monitoring

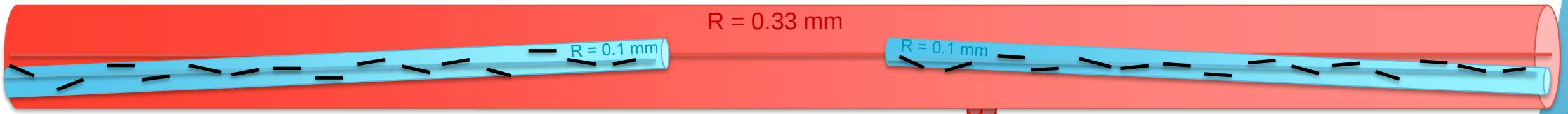


Alignment between Q1 and Q5 :
Limits : σ (1 sigma) < 0.1 mm

Alignment between Q5-left and Q5-right :
- Vertical Limits : σ (1 sigma) < 0.17 mm
- Radial Limits : σ (1 sigma) < 0.33 mm

Left

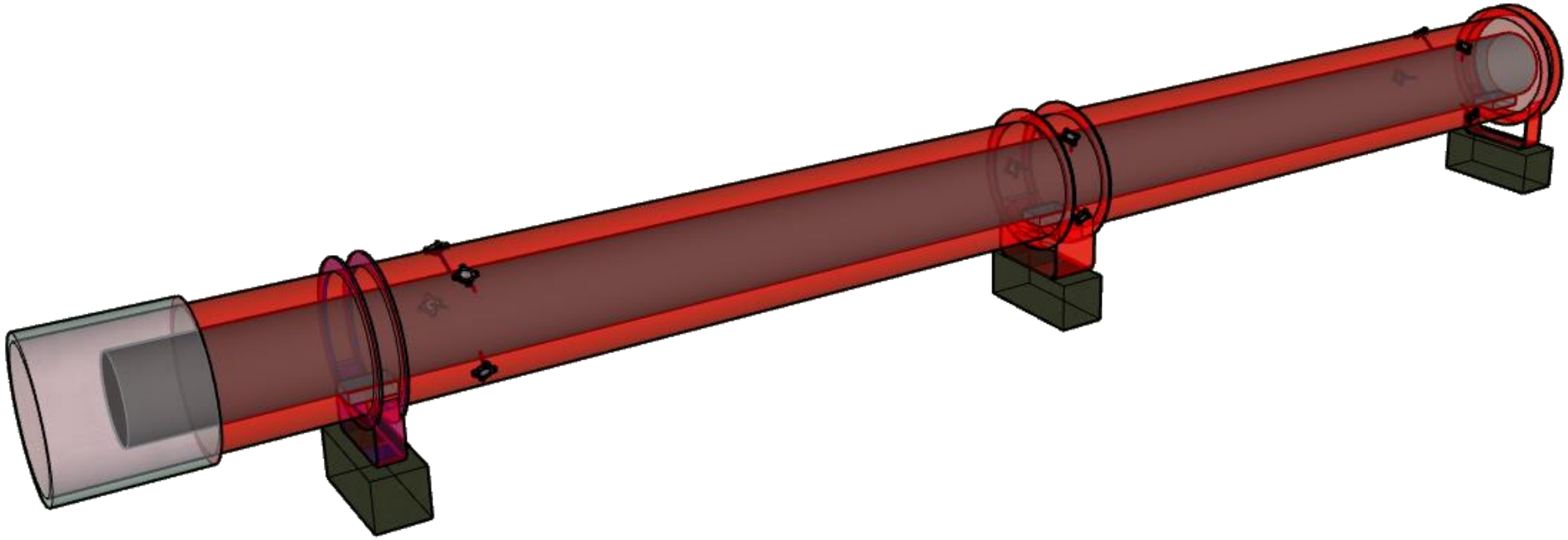
Right



Alignment requirement
- Align all the components per IP side : < 100 µm (1σ)
- Align all the components (Left and Right) : Vertical < 170 µm (1σ)
- Align all the components (Left and Right) : Radial < 330 µm (1σ)
- Roll : < 150 µrad (1σ)

Internal monitoring

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



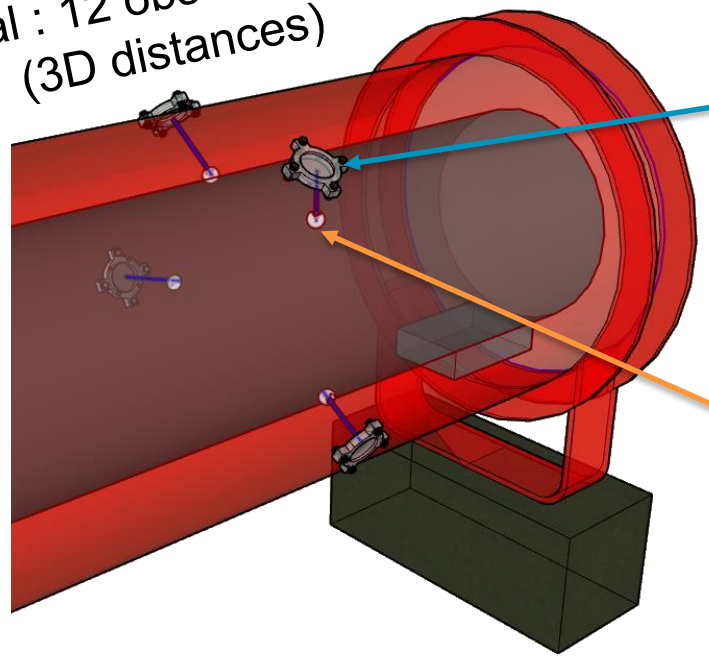
Internal monitoring : Configuration

- **FSI : Frequency Scanning interferometry**

  → Absolute distance measuring interferometric technique

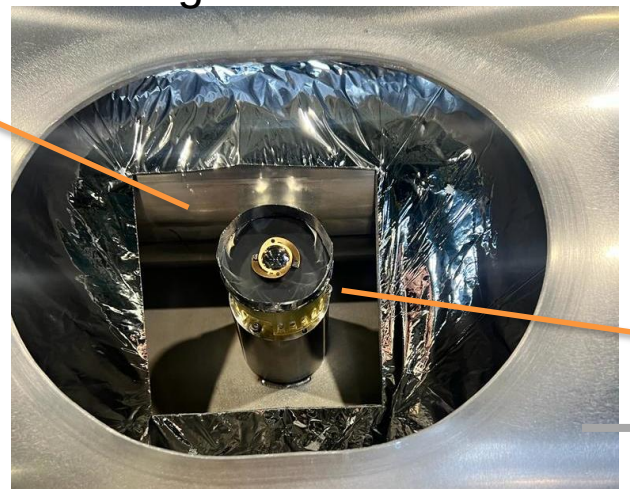
Largest standard uncertainties	Uncertainty (1σ)
Position of the FSI Sensor in the framework of the vacuum vessel	40 µm
Position of the FSI target in the framework of the cold mass	<15 µm

Total : 12 observations (3D distances)

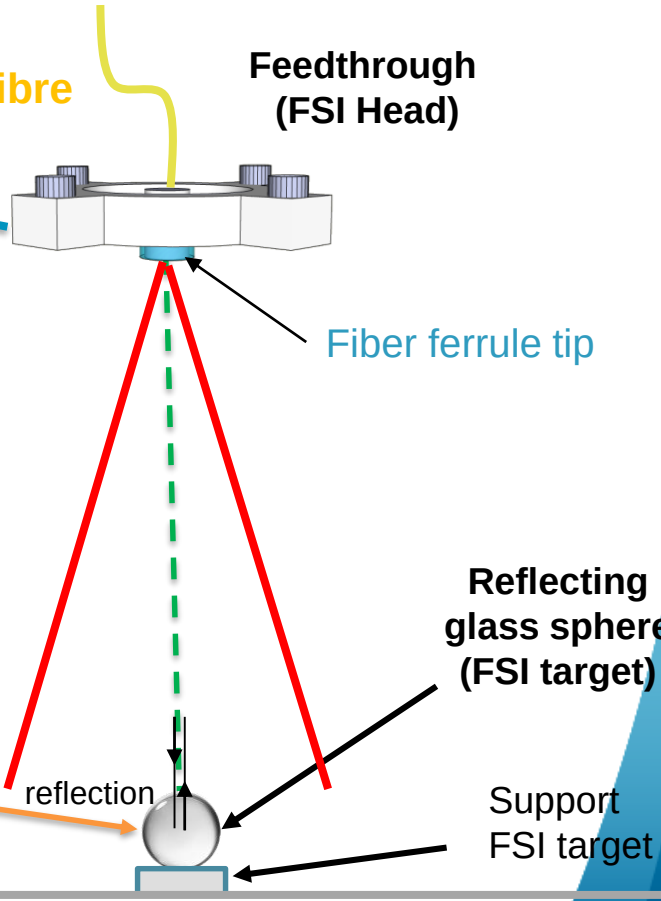


FSI Head (sensor)
on the vacuum vessel

FSI target on the cold mass

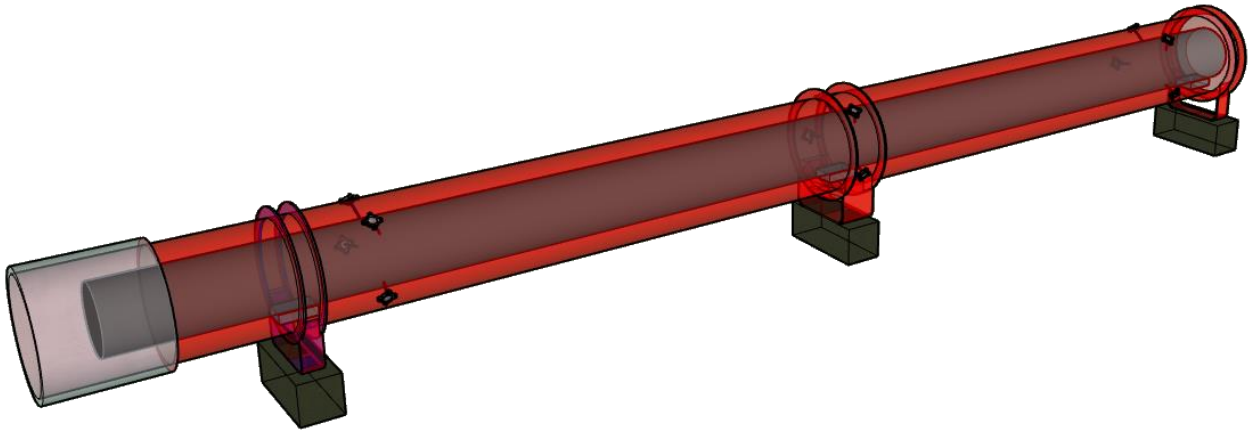


FSI Acquisition system



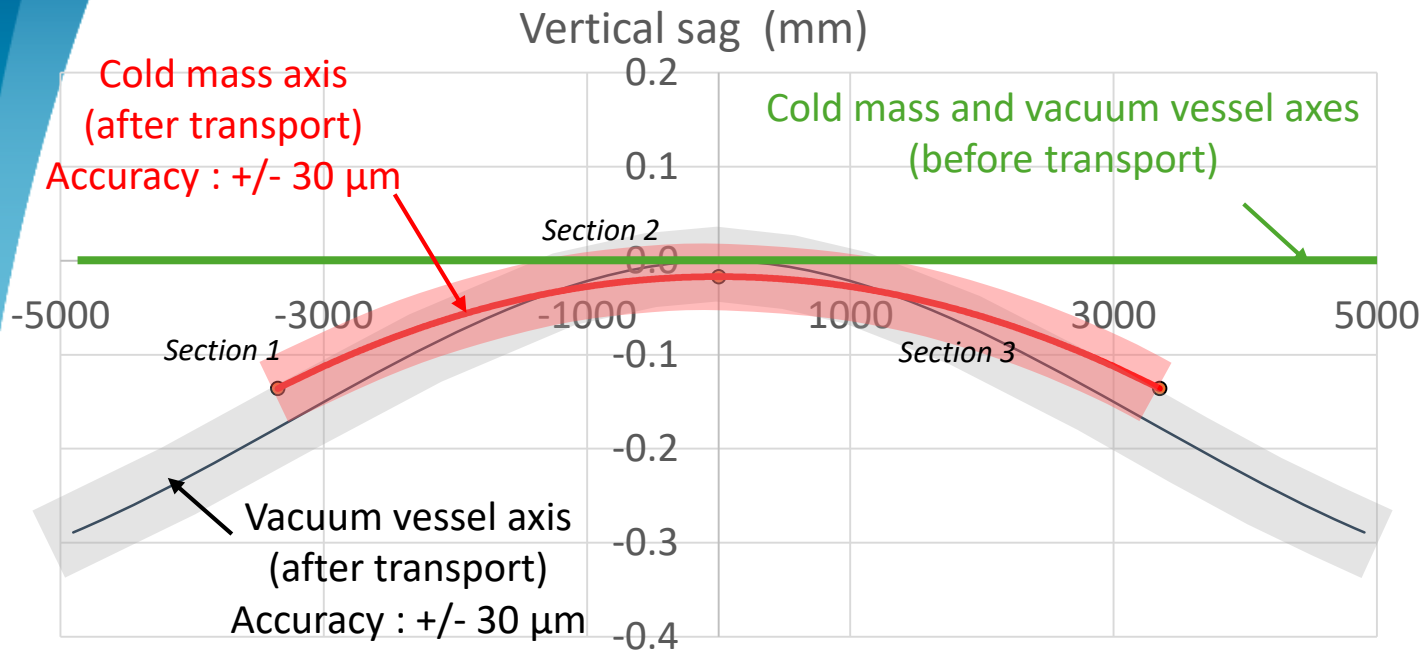
Alignment analysis of the Q2s during cold test at CERN

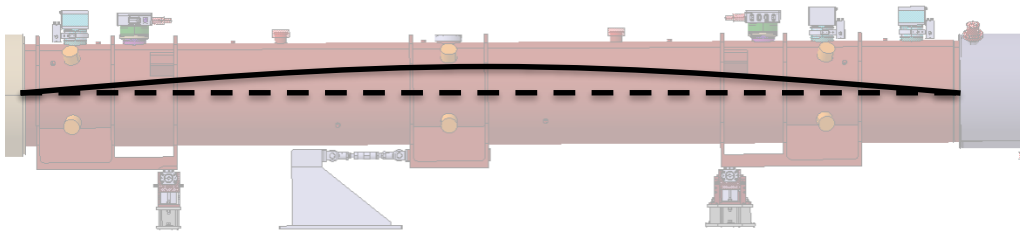
Measurement steps for Q2

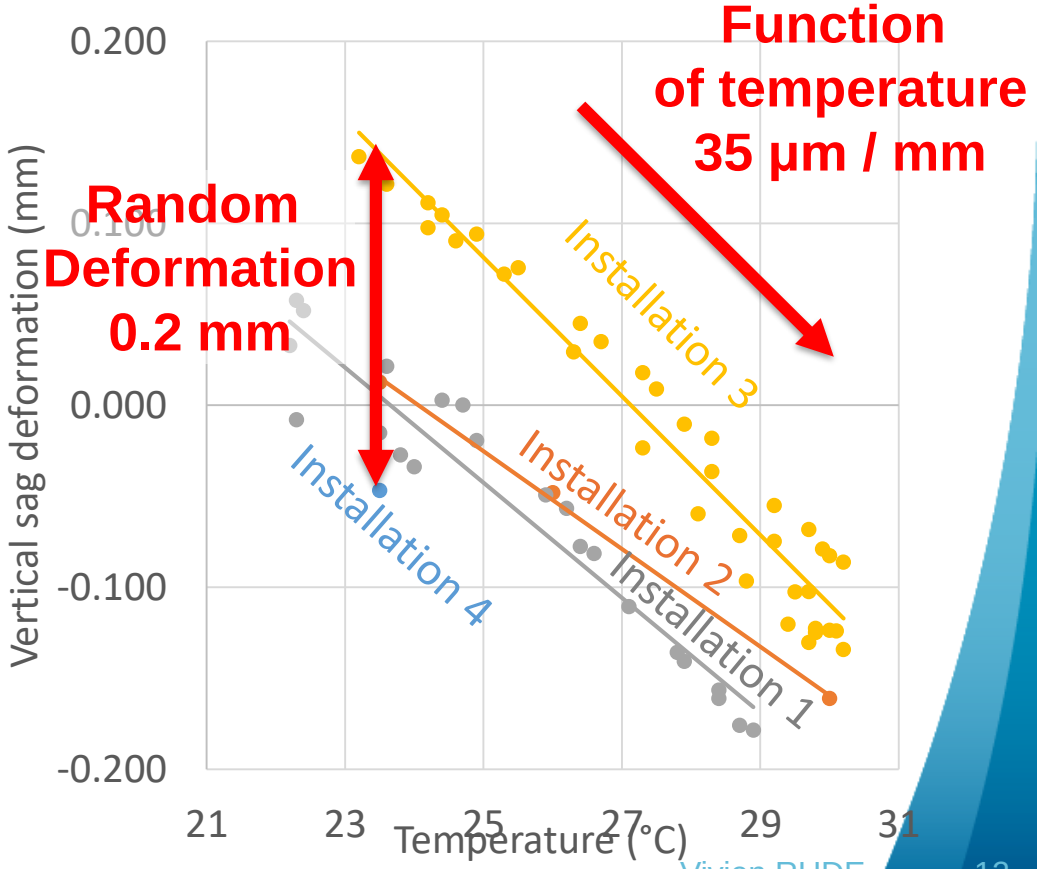


Fiducialisation	Transport	Ambient	Under vacuum	Cooling down
Place 1 : Fiducialisation bench		Place 2 : Cold test bench		
Mechanical measurement → mechanical mole measurement		Mechanical measurement → FSI meas.		
Magnetic measurement →rotating coil scanner		Magnetic measurement → single-stretched wire (SSW)		Magnetic measurement → single-stretched wire (SSW)

Impact of transport on vacuum vessel and cold mass shape







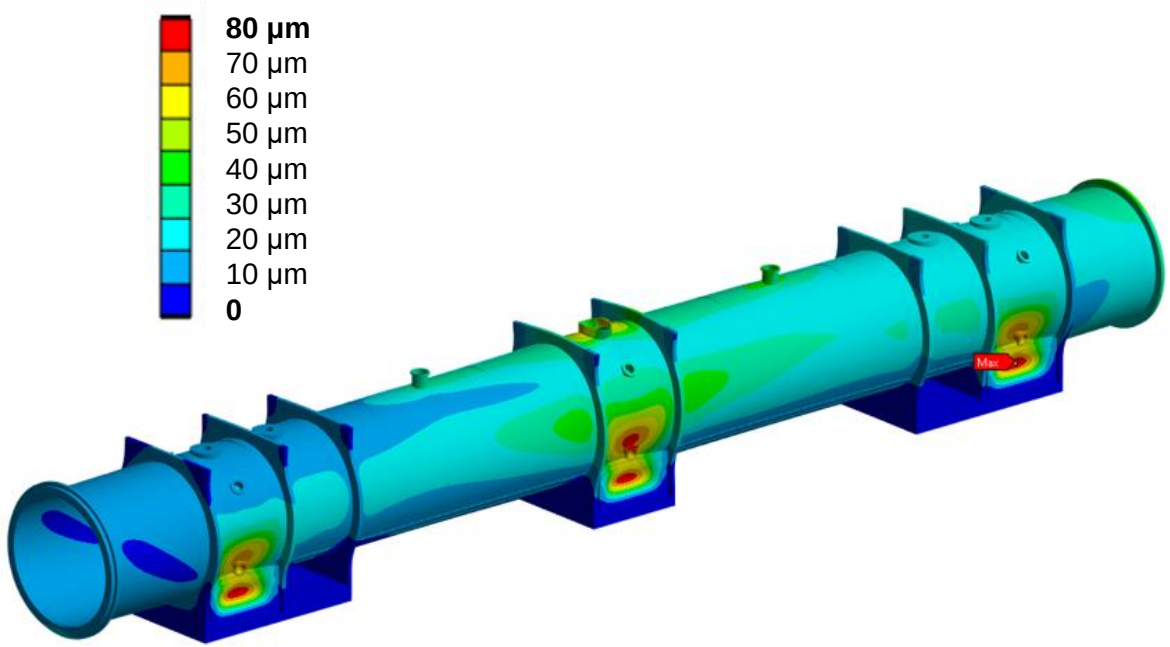
Impact of transport and external temperature :

- The shape (in vertical) of the vacuum vessel is influenced by transport and temperature changes
  → This can be modelized by a 2nd order polynomial
- The vertical slop of the cold mass is consistent with the vertical slope of the vacuum vessel

Impact of pumping on vacuum vessel and cold mass shape

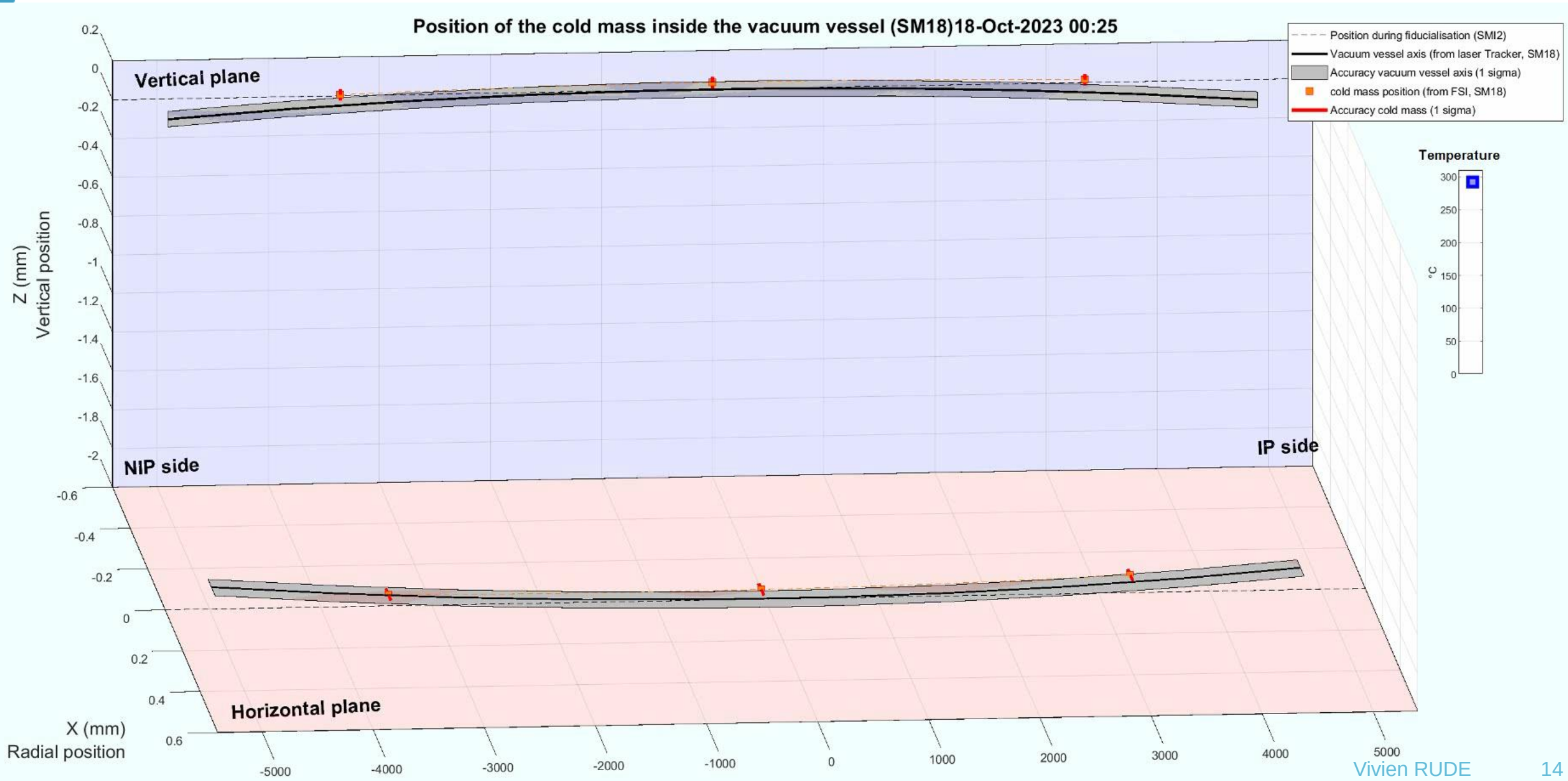
Impact of pumping :

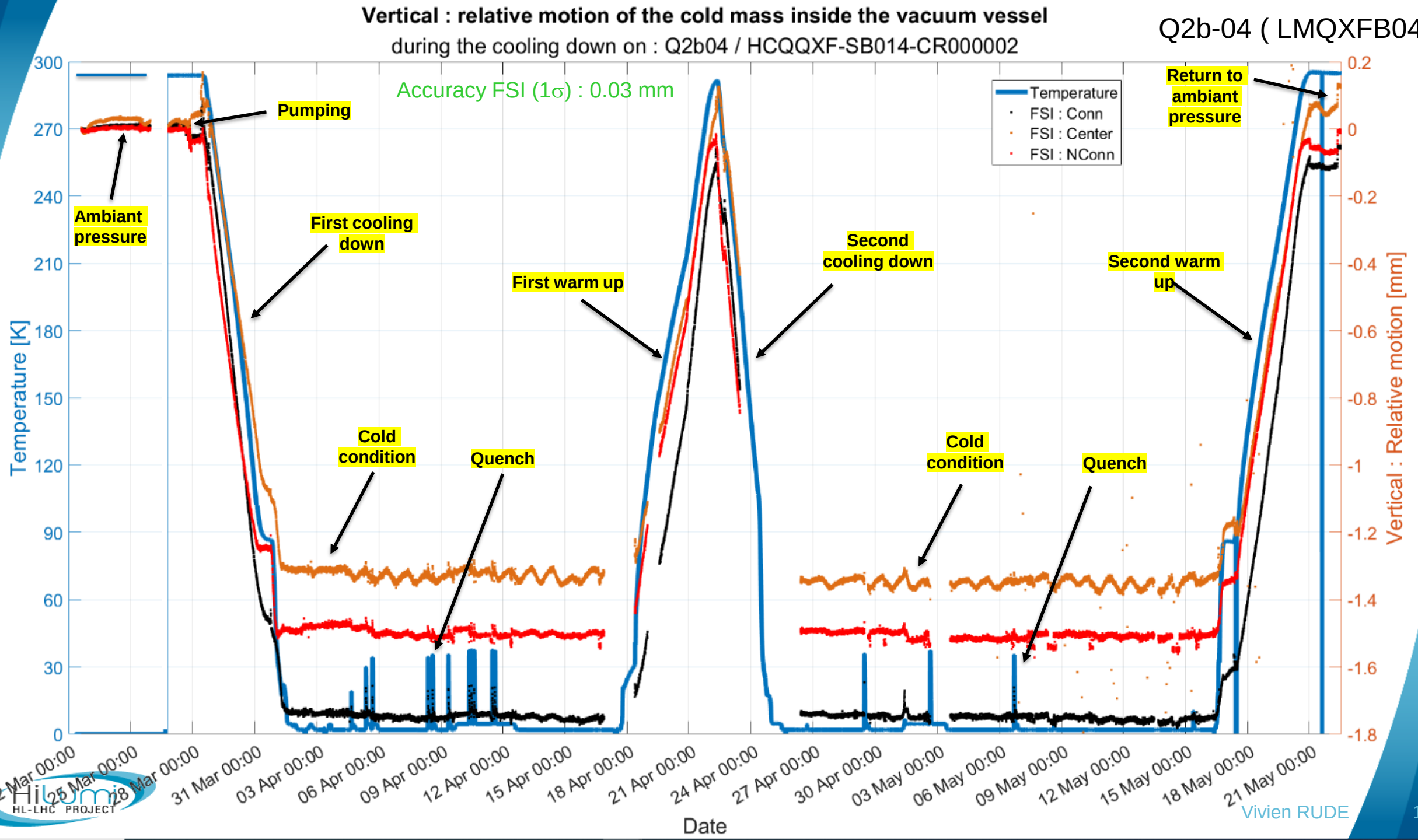
- The vacuum vessel's shape is distorted by pumping (up to 80 µm)
- This impact can be modelled and is repeatable
- Maximum difference between model and real observation is bellow 50 µm
- No significant movement of the cold mass inside the vacuum vessel



Impact of cooling down

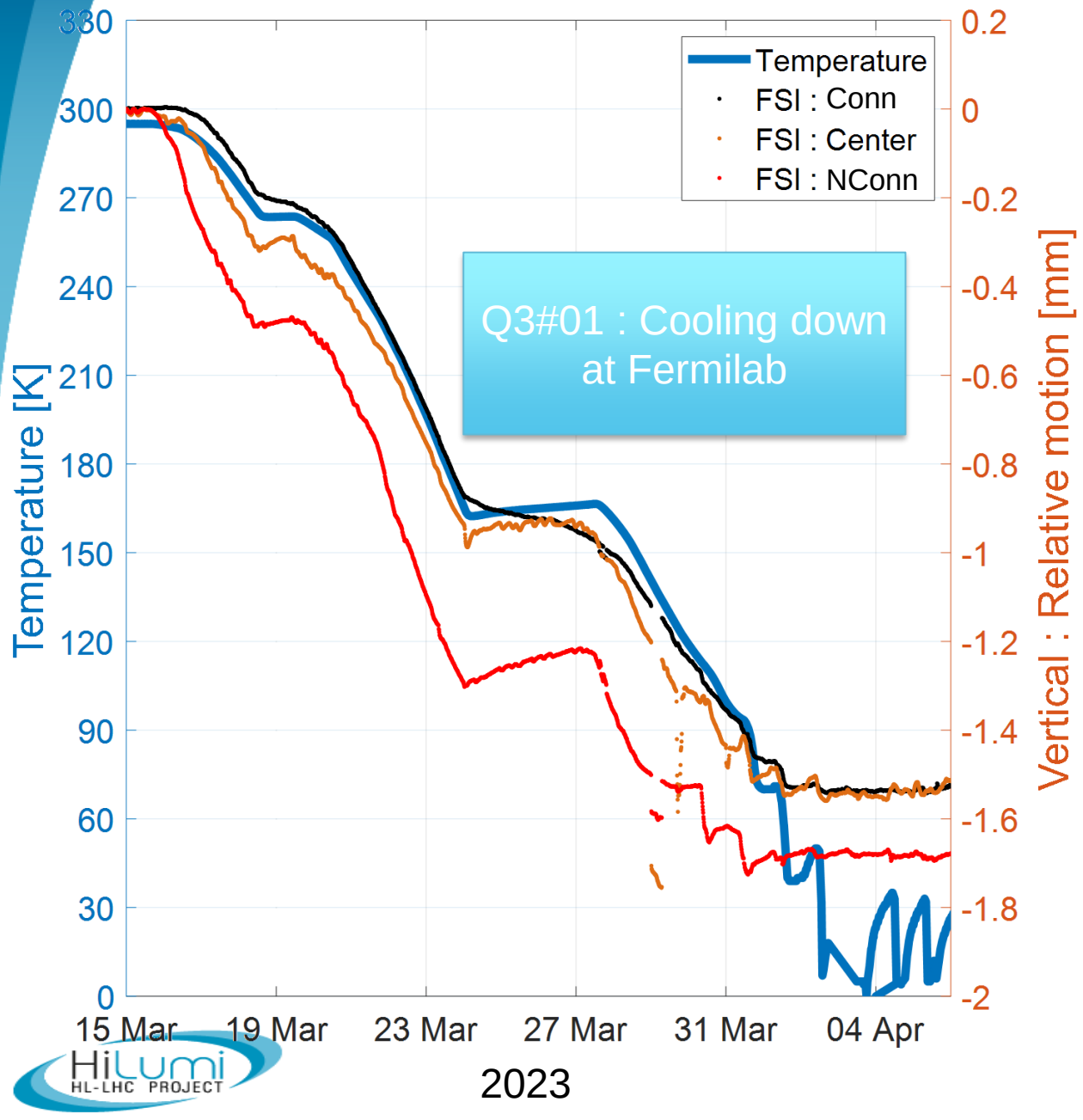
Q2b-P2 (LMQXFB01)

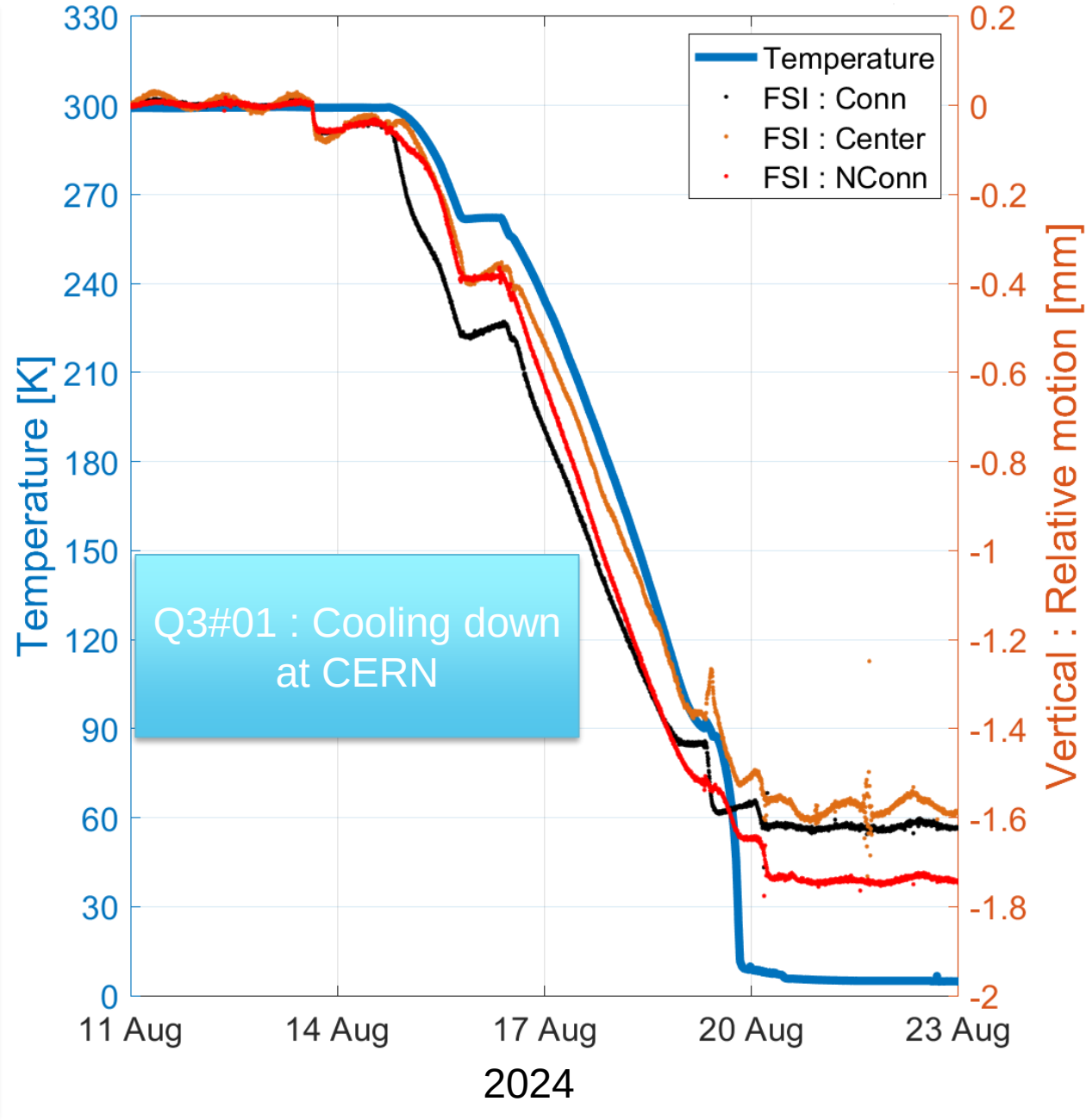



Vertical : relative motion of the cold mass inside the vacuum vessel
during the cooling down on : Q2b04 / HCQQXF-SB014-CR000002
Accuracy FSI (1σ) : 0.03 mm
Temperature
FSI : Conn
FSI : Center
FSI : NConn
Ambiant pressure
Pumping
First cooling down
Cold condition
Quench
First warm up
Second cooling down
Cold condition
Quench
Second warm up
Return to ambiant pressure
Temperature [K]
Vertical : Relative motion [mm]
Date
300
270
240
210
180
150
120
90
60
30
0
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
22 Mar 00:00
25 Mar 00:00
28 Mar 00:00
31 Mar 00:00
03 Apr 00:00
06 Apr 00:00
09 Apr 00:00
12 Apr 00:00
15 Apr 00:00
18 Apr 00:00
21 Apr 00:00
24 Apr 00:00
27 Apr 00:00
30 Apr 00:00
03 May 00:00
06 May 00:00
09 May 00:00
12 May 00:00
15 May 00:00
18 May 00:00
21 May 00:00

Cooling down at Fermilab and CERN

Mechanical measurements on Q3#01 at Fermilab and at CERN





HiLumi HL-LHC PROJECT

Mechanical and magnetic measurements

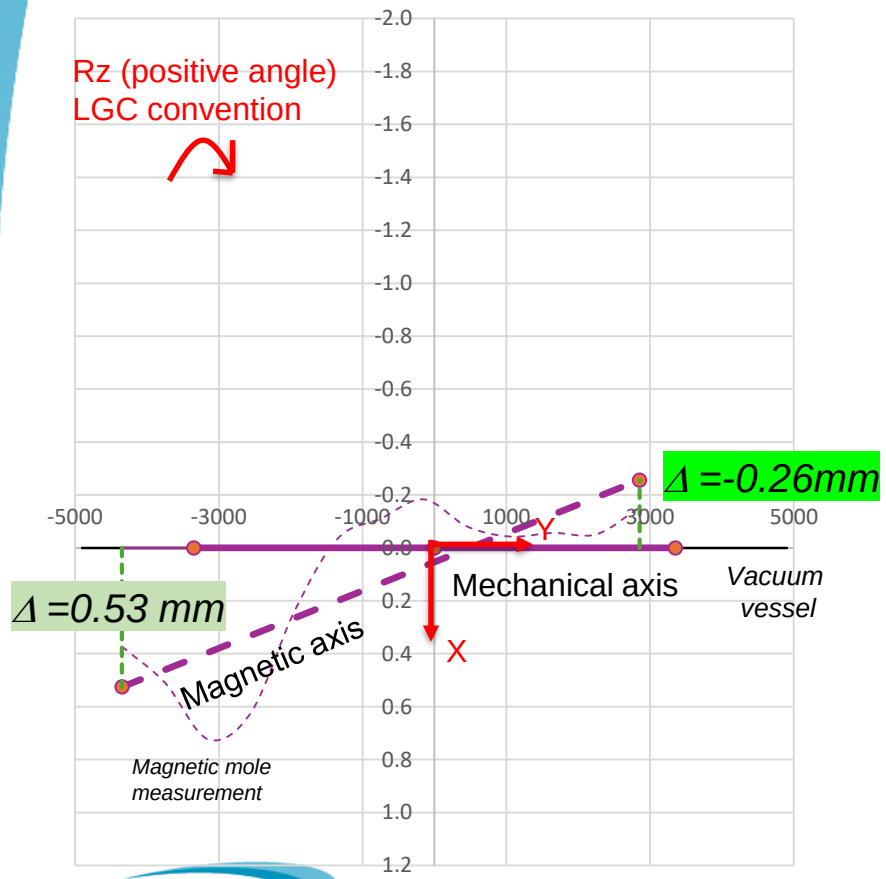
Mechanical and magnetic measurements at different steps

Mechanical measurement
→ mechanical mole measurement

Magnetic measurement
→rotating coil scanner

Fiducialisation : SMI2/B180 measurement

Radial measurement

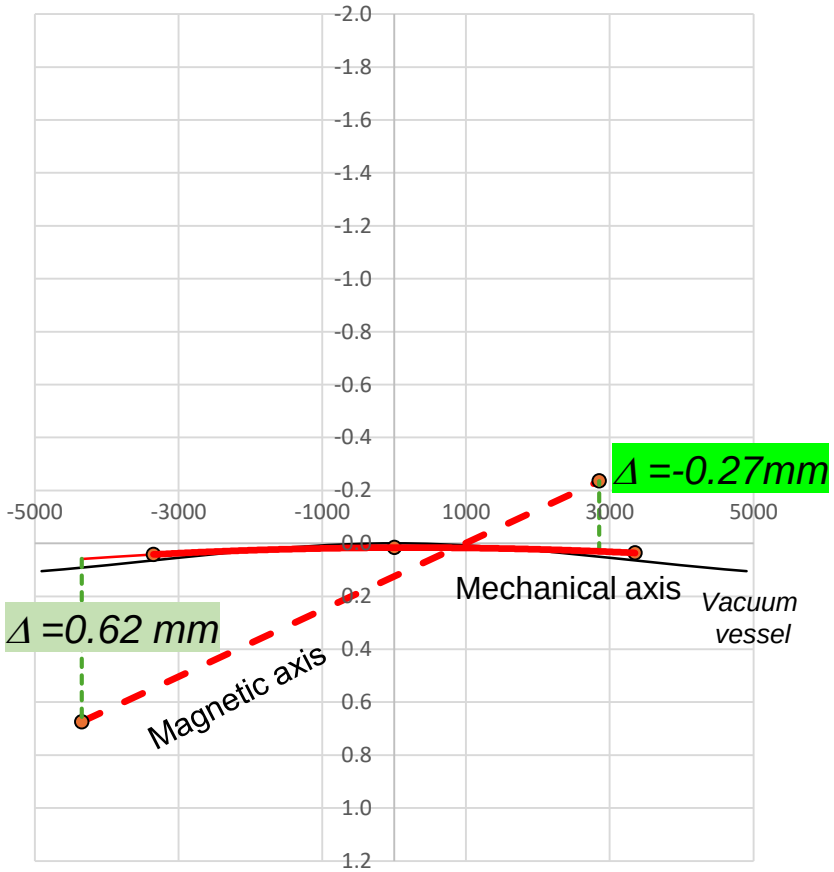


Mechanical measurement
→ FSI meas.

Magnetic measurement
→ single-stretched wire (SSW)

WARM Ambient pressure : SM18

Radial measurement

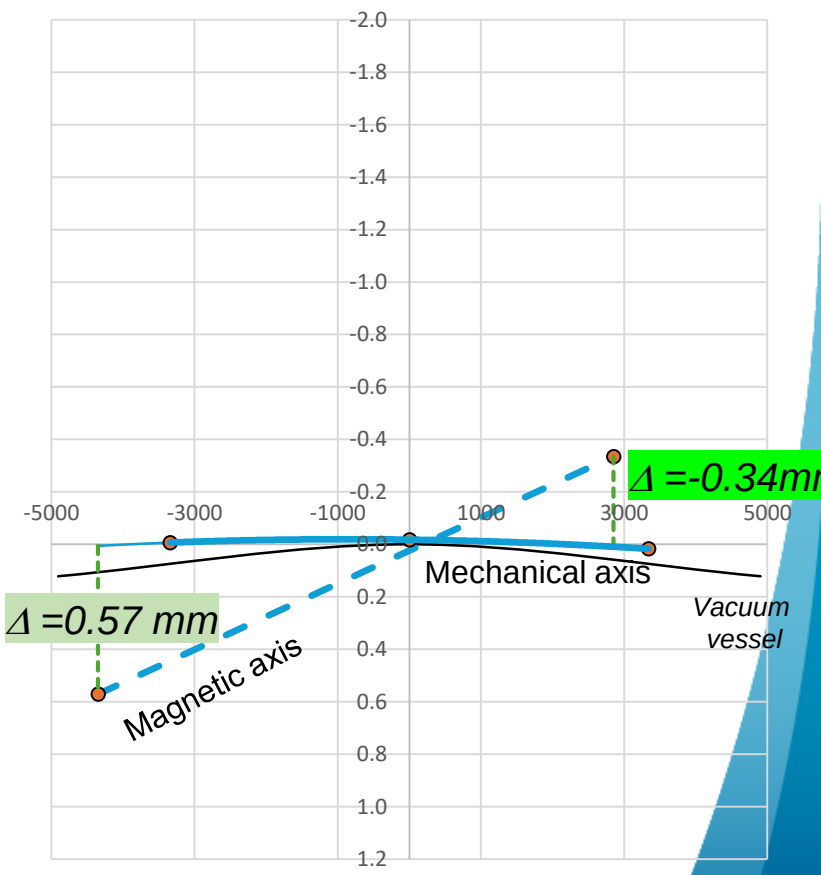


Mechanical measurement
→ FSI meas.

Magnetic measurement
→ single-stretched wire (SSW)

COLD : SM18

Radial measurement



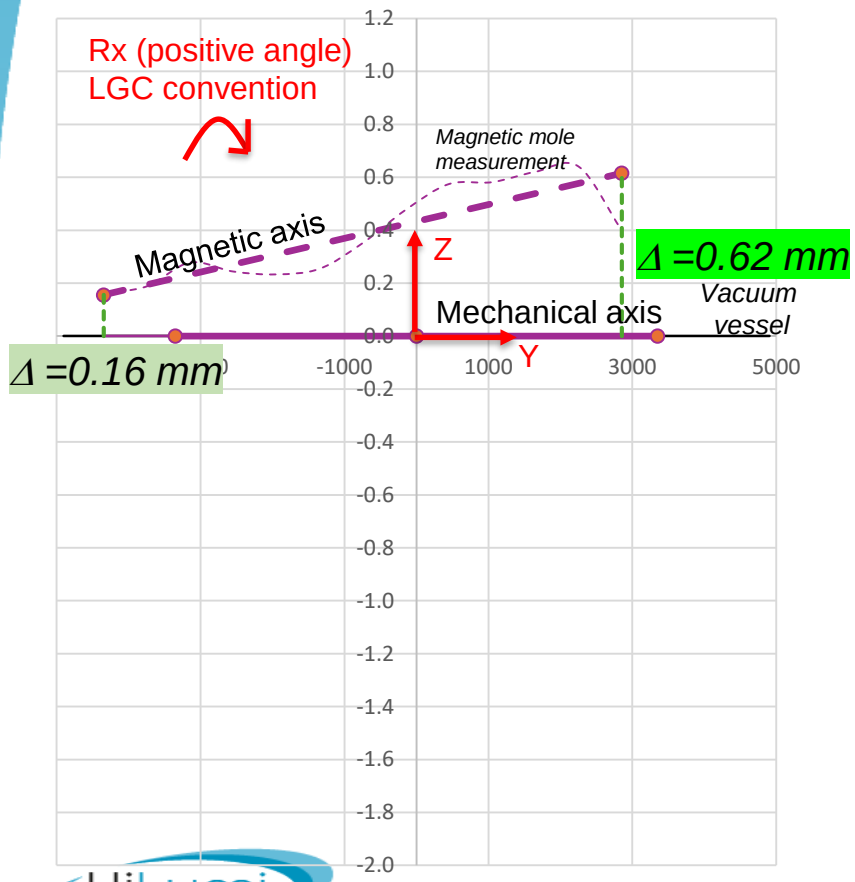
Q2a-P3 (LMQXFB02)

Mechanical and magnetic measurements at different steps

Mechanical measurement
→ mechanical mole measurement

Magnetic measurement
→rotating coil scanner

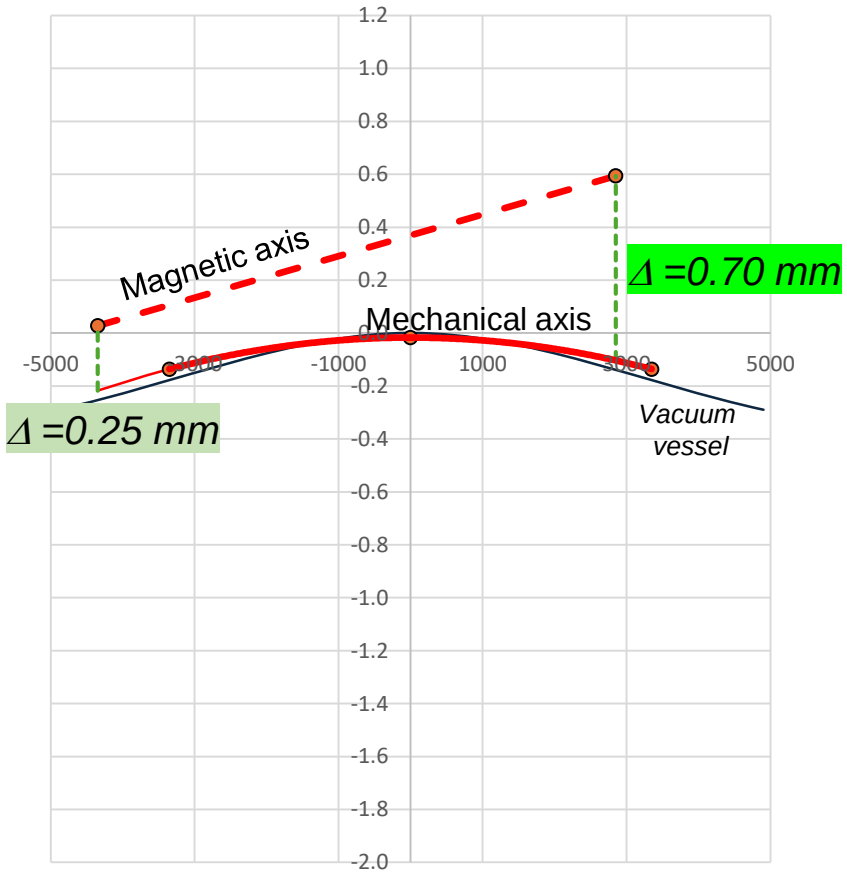
Fiducialisation : SMI2/B180 measurement
Vertical measurement



Mechanical measurement
→ FSI meas.

Magnetic measurement
→ single-stretched wire (SSW)

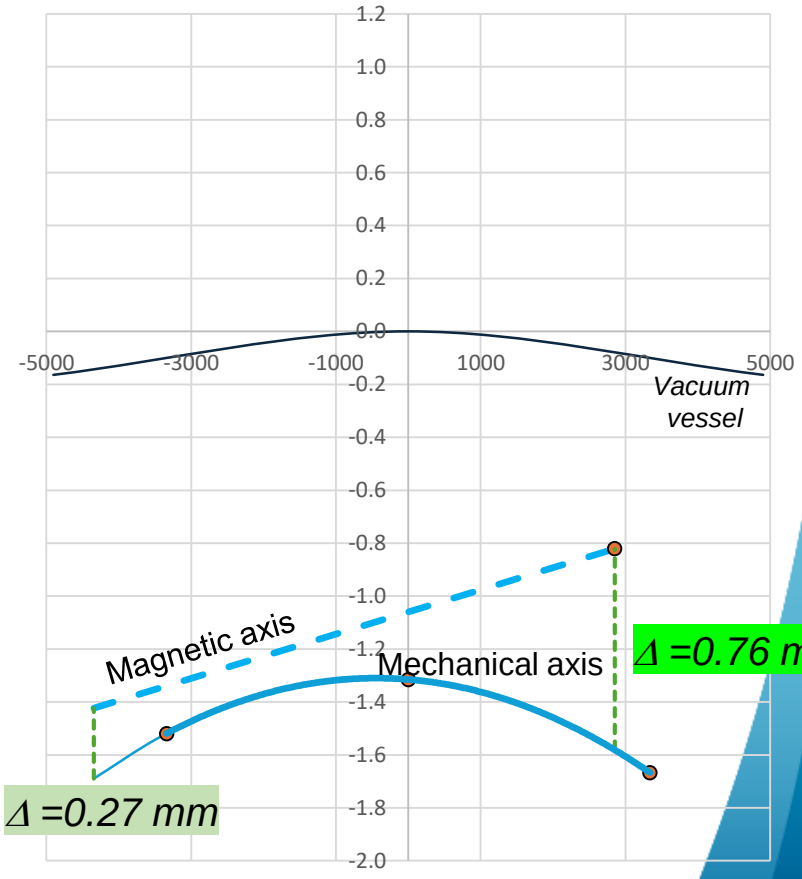
WARM Ambient pressure : SM18
Vertical measurement



Mechanical measurement
→ FSI meas.

Magnetic measurement
→ single-stretched wire (SSW)

COLD : SM18
Vertical measurement

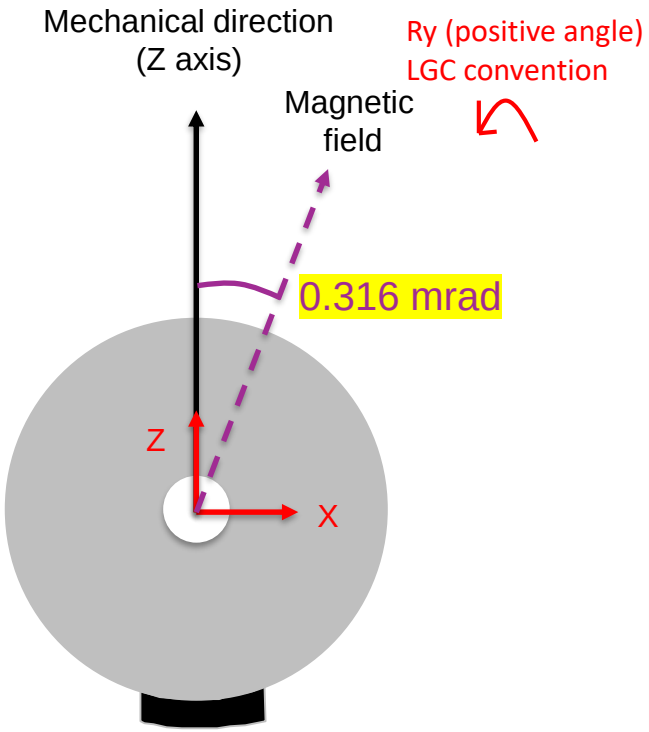


Q2a-P3 (LMQXFB02)

Mechanical and magnetic measurements at different steps

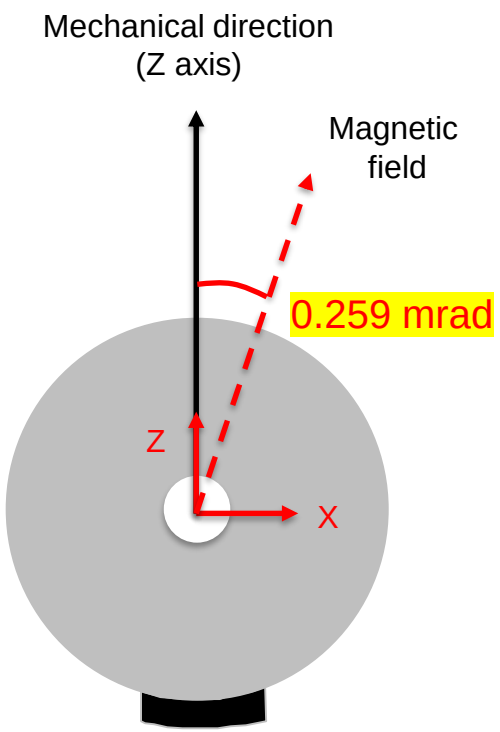
Q2a-P3 (LMQXFB02)

Fiducialisation : SMI2 measurement
Magnetic field



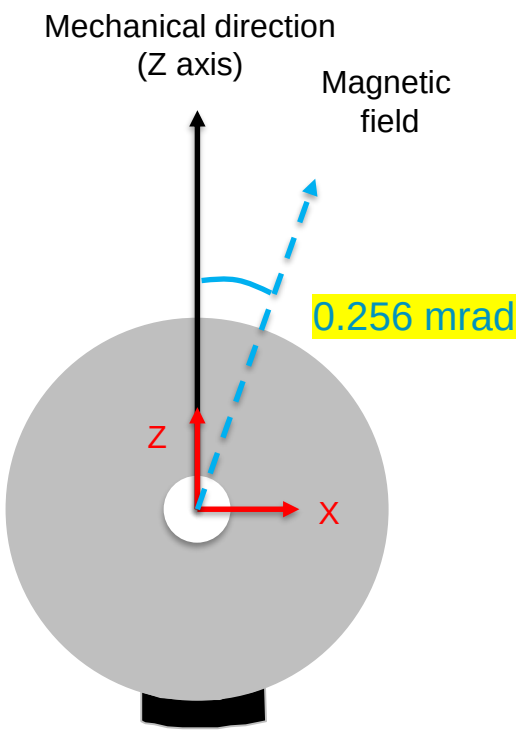
	LGC conv.
Delta Roll. (mrad) meca → magn	-0.316

WARM Ambient pressure : SM18
Magnetic field



	LGC conv.
Delta Roll. (mrad) meca → magn	- 0.259

COLD : SM18
Magnetic field



	LGC conv.
Delta Roll. (mrad) meca → magn	- 0.256

	Installation FSI targets	Cryostating	CERN Mechanical Fiducialisation	CERN Installation FSI Sensors	CERN Cold test Magnetic and mechanical measurement at cold
MQXFBP2	CERN	CERN			
MQXFBP3	CERN	CERN			
MQXFB03	CERN	CERN		Nov 2024	
MQXFB04	CERN	CERN			
MQXFB05	CERN	CERN			On going
MQXFA01	Fermilab	Fermilab			On going
MQXFA02	Fermilab	Fermilab	Dec 2024		

Conclusions

- Impact of transport on alignment

  The shape (in vertical) of the vacuum vessel and the cold mass is influenced by transport and temperature changes

- Impact of pumping on alignment

  The vacuum vessel's shape is distorted by pumping (up to 80 µm)

- Impact of cooling down on alignment

  The cold mass goes down of 1.5 mm in average (between 1.3 mm to 1.8 mm)

- Impact of quench on alignment

  Elastic deformations (0.6 mm in longitudinal, 0.2 mm in vertical)

- Mechanical and magnetic axes behaviour during cooling down

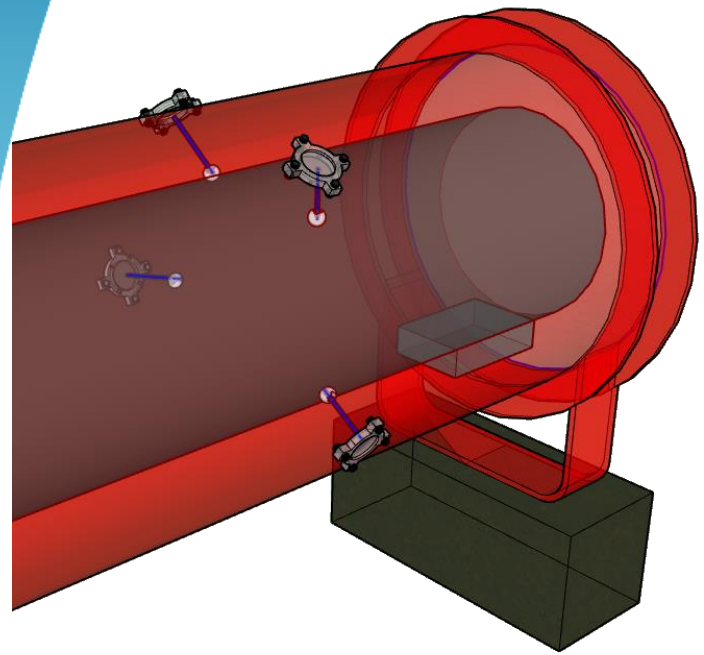
  Same behaviour

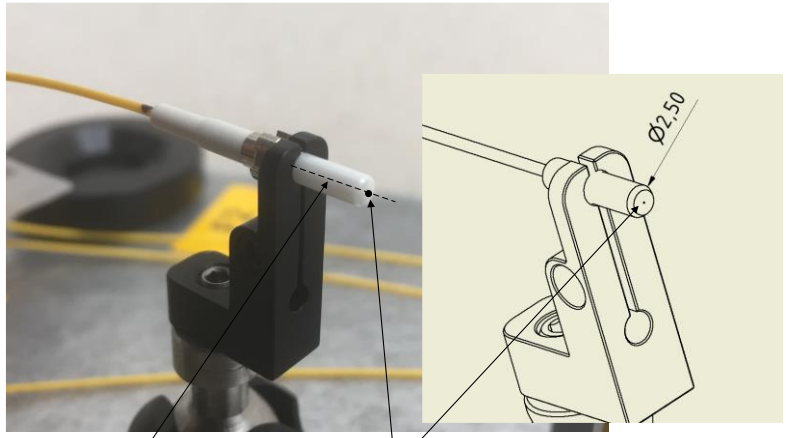
Thank you for your attention

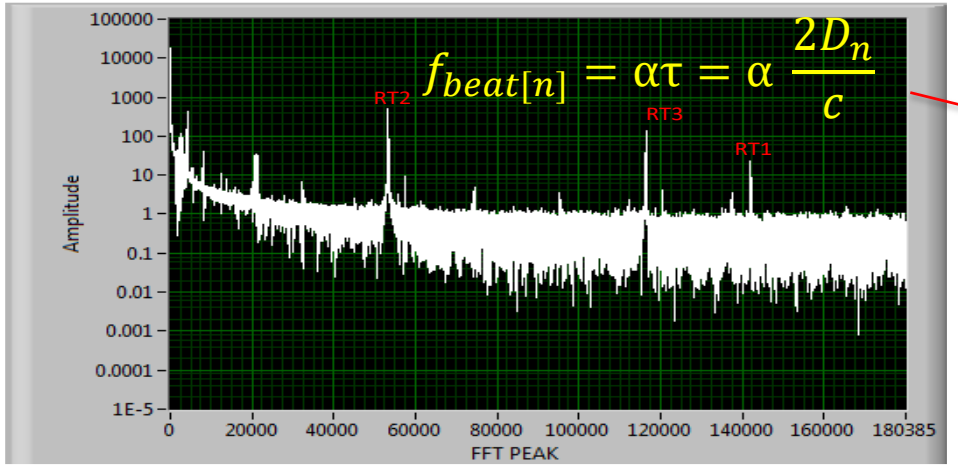
Spare

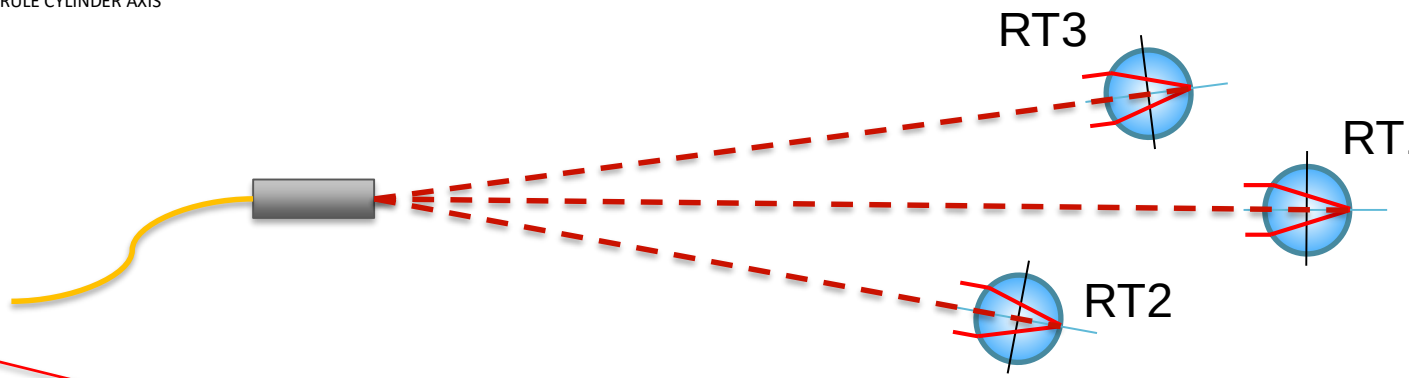
Multi-target FSI

n=2







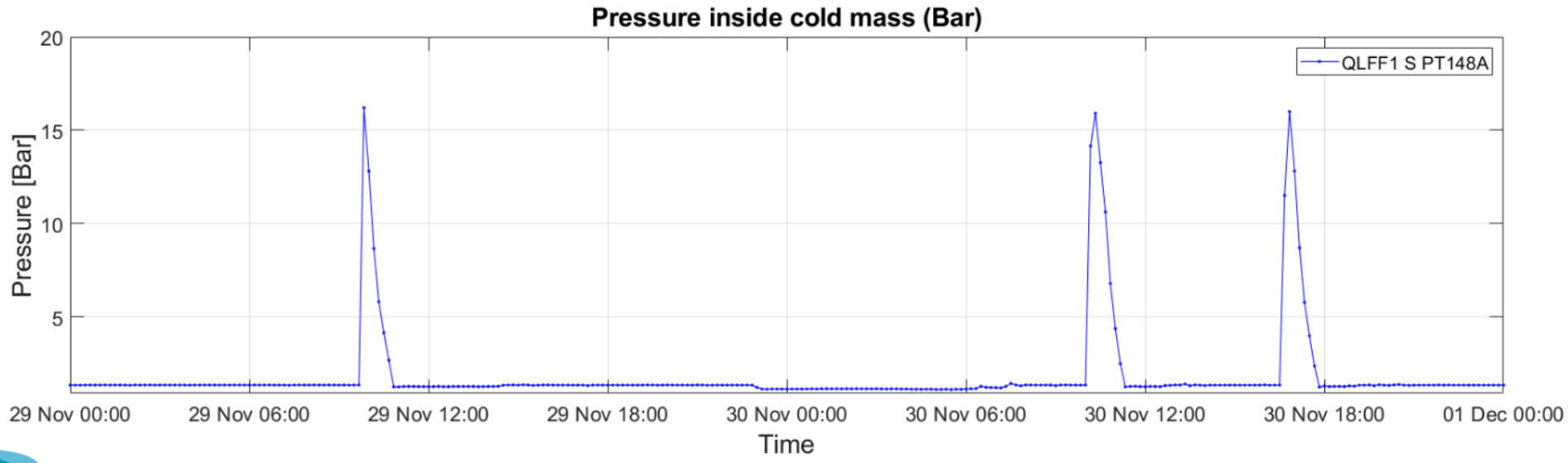


$$D_n = c \frac{f_{beat[m]}}{2\frac{d\nu}{dt}n}$$

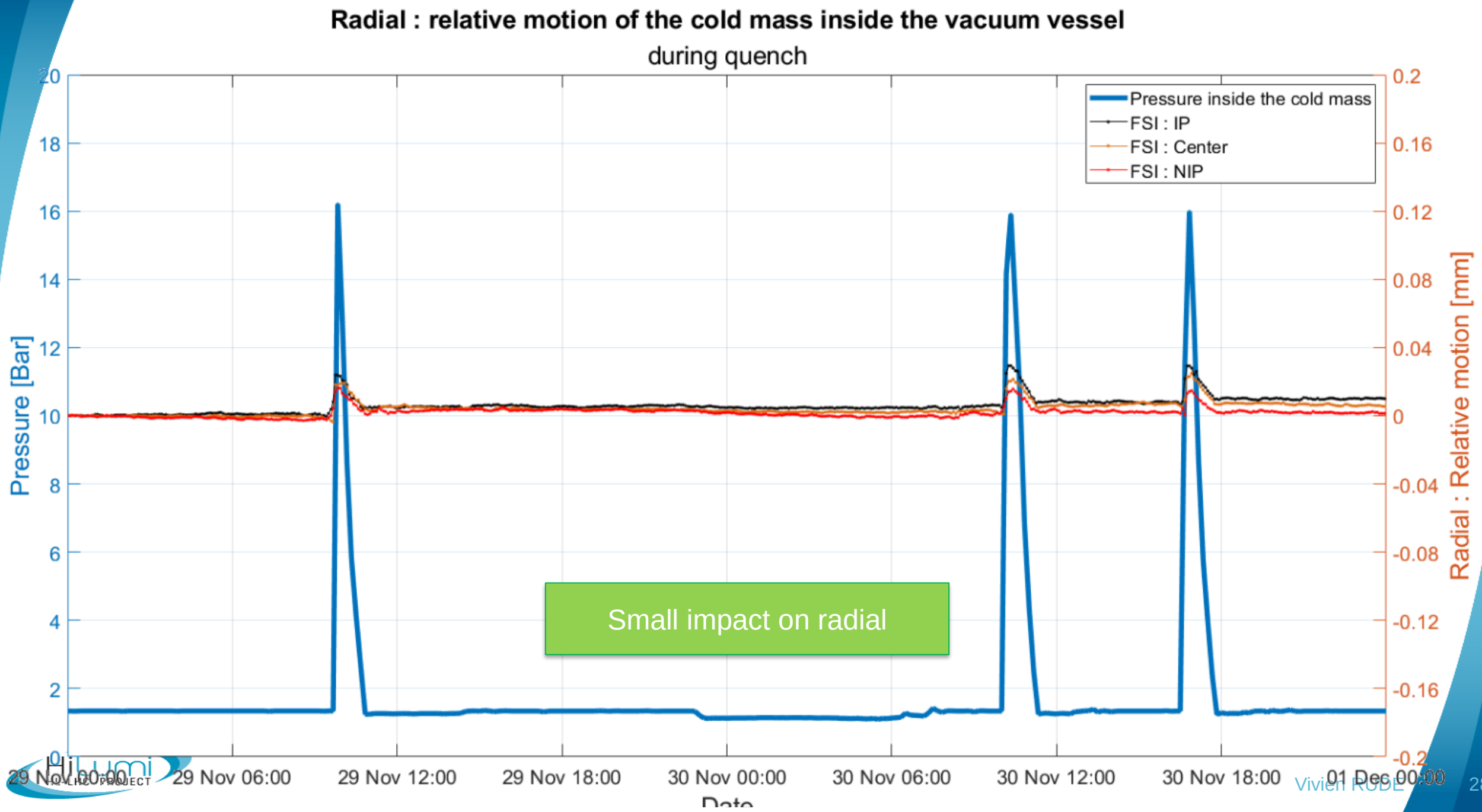
α – is a sweep rate of the laser ($\alpha = \frac{d\nu}{dt}$ - laser frequency change in time);
c – speed of light;
n – refractive index of light transmission medium;
τ – time of flight of laser to the target

from Mateusz Sosin

Impact of quench

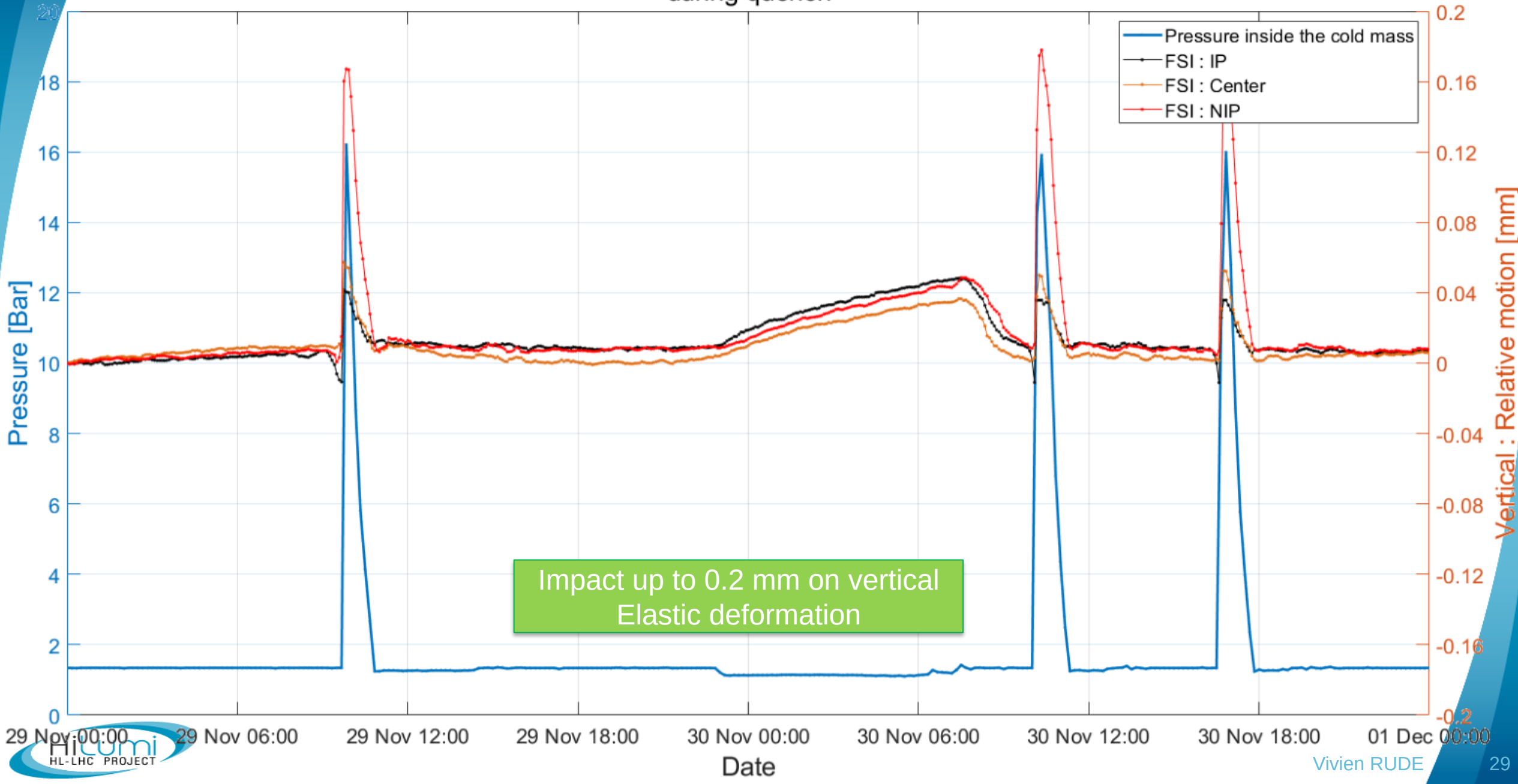


Accuracy FSI (1σ) : 0.03 mm



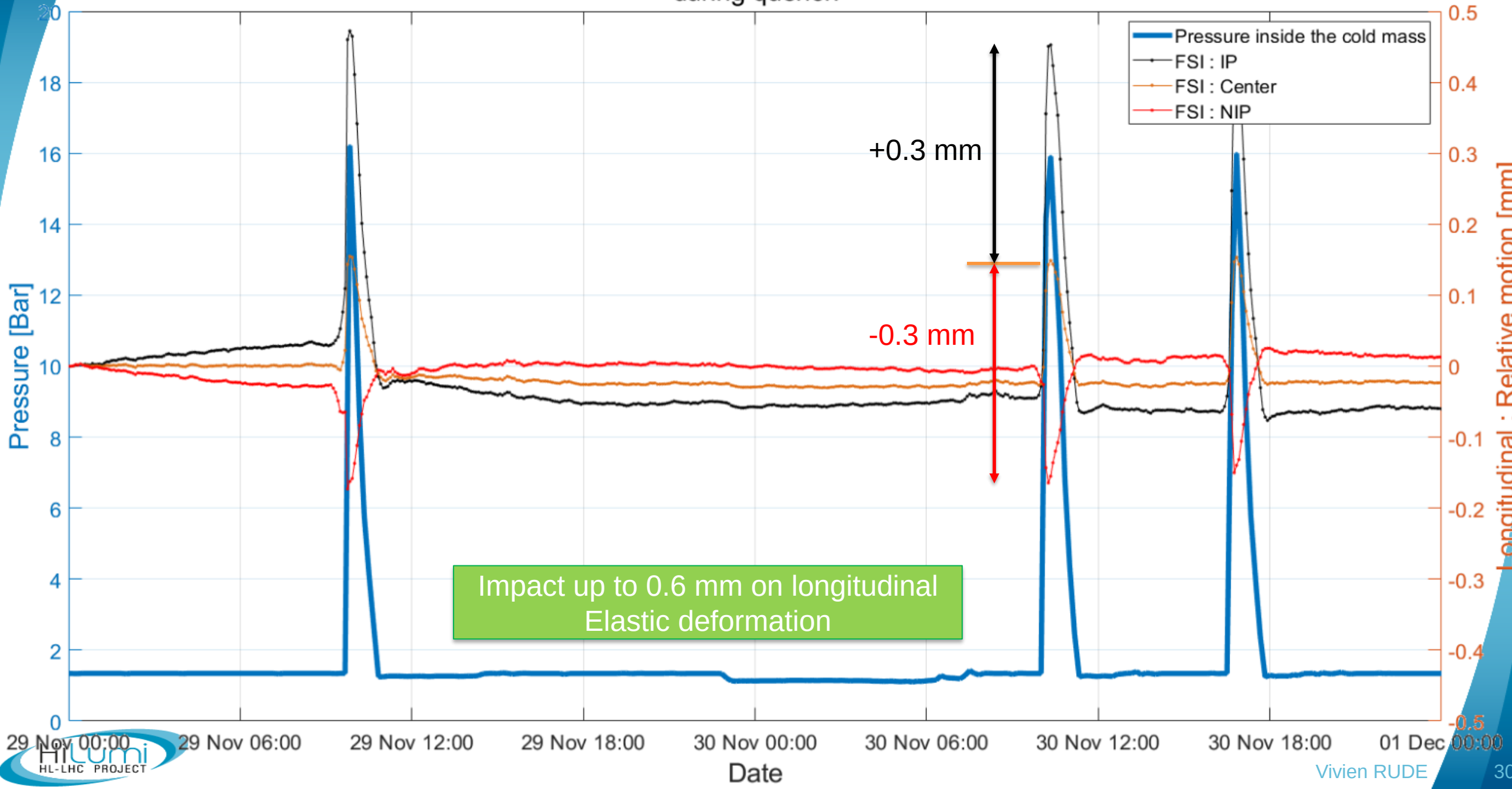
Vertical : relative motion of the cold mass inside the vacuum vessel during quench

Accuracy FSI (1σ) : 0.03 mm



Longitudinal : relative motion of the cold mass inside the vacuum vessel during quench

Accuracy FSI (1σ) : 0.1 mm



Our needs from Fermilab for Q1/Q3 (For Survey)

In the same coordinate system :

Coordinate systems

- *Primary axis : Y : Regression line corresponding to the mechanical cold bore axis (determined from mechanical mole)*
- *Secondary axis : Z : Normal vector of the plane [Conn-D9, Conn-D10, NConn-D9, NConn-D10]*
- *Origin : Projection of the central cold feet on Y axis*

Cold mass

- Reference points of the cold mass : D9, D10, D11 (Conn and NConn)
- Mechanical mole measurement in the cold bore
- Magnetic measurement with Rotating coil scanner
- Magnetic field direction

Vacuum Vessel

- Fiducials on the vacuum vessel