



Vancouver, 24 Sept. 2023

Status report on internal monitoring on Q3 (Collaboration : FERMILAB / CERN)

Vivien RUDE

2023-09-27

On behalf :

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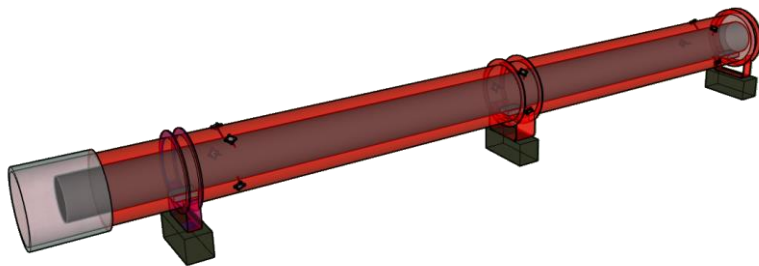
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Andreas HERTY

Vincent BARBARROUX

Michel NOIR

Roberto FERNANDEZ BAUTISTA

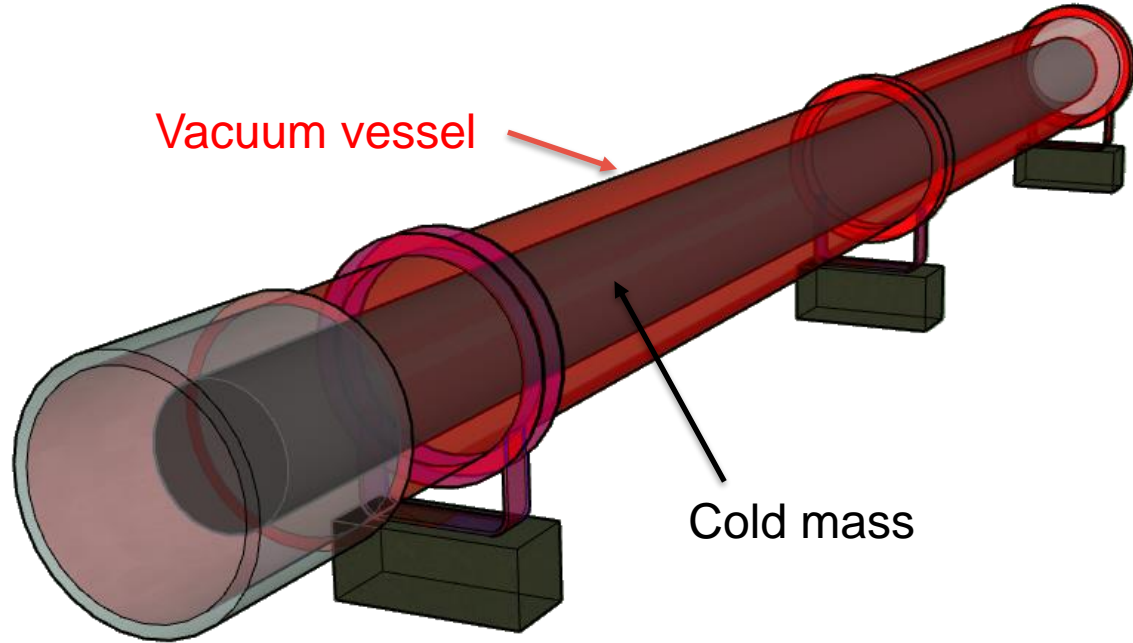


Outline

- Alignment objective for HL-LHC internal monitoring
 - Internal monitoring
 - Low Beta Quadrupole configuration
 - Alignment requirement
 - Alignment simulation for Low Beta Quadrupoles
- Q3 (Survey tasks : FERMILAB - CERN collaboration)
 - Determination of the mechanical and magnetic axis
 - FSI targets installation
 - FSI heads installation
 - FSI validation
 - Alignment control before cooling down
 - First Cooling down Results
 - Second Cooling down Results

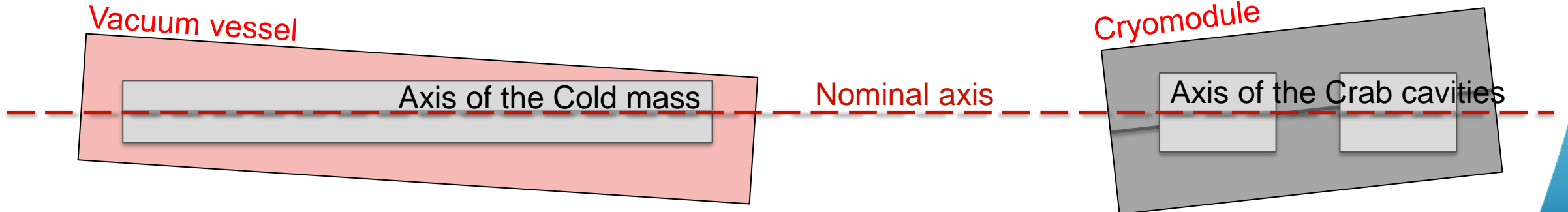
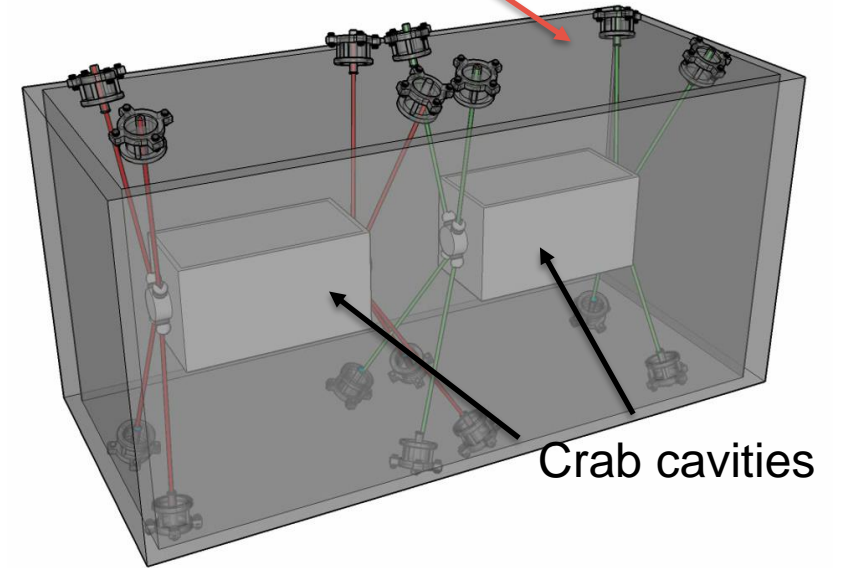
Internal monitoring for “special” components

Q1, Q2a, Q2b, Q3



Crab-Cavities

Cryomodule

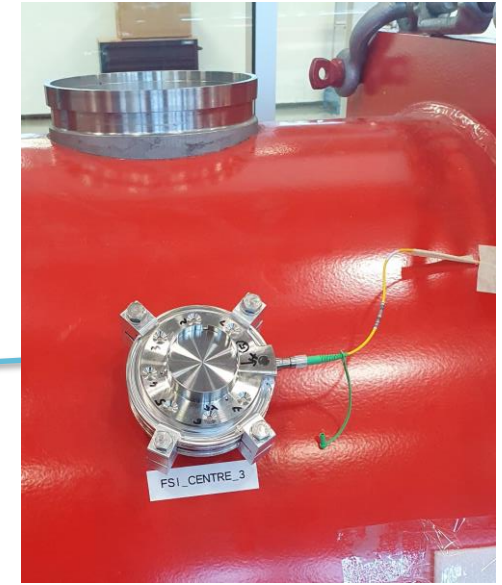
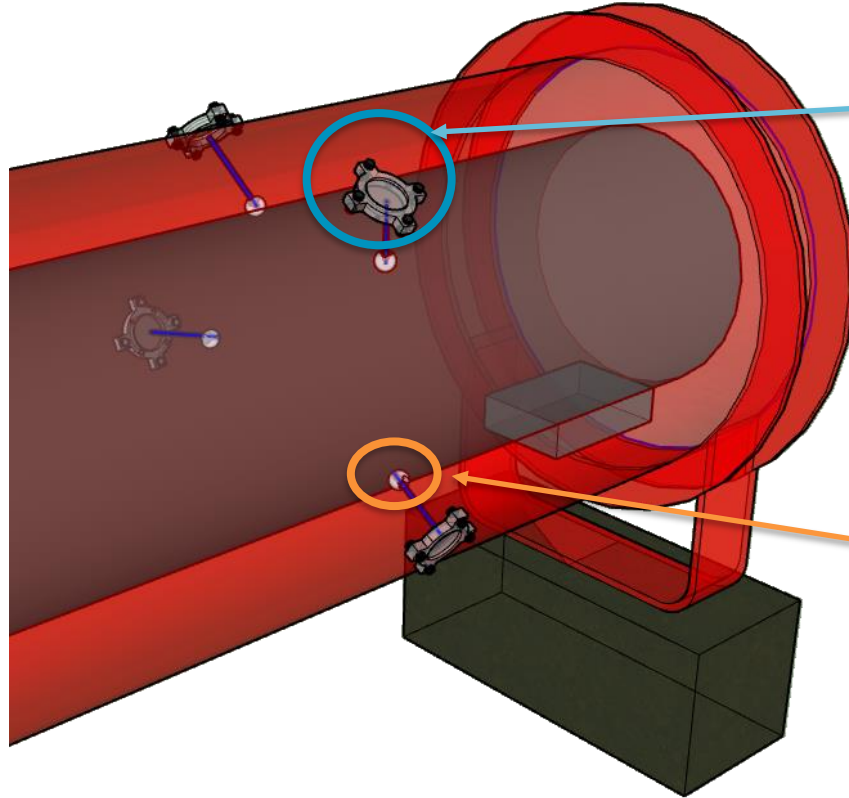


Internal monitoring : Configuration

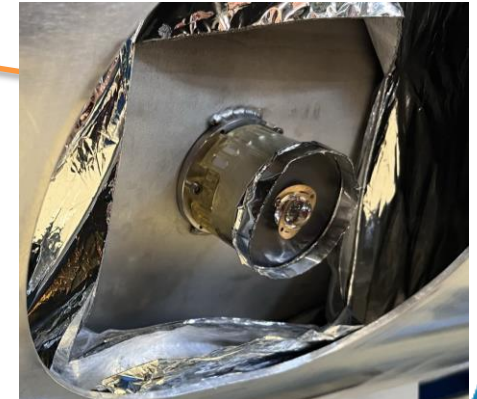
FSI Head (sensor) on the vacuum vessel

- **FSI : Frequency Scanning interferometry**

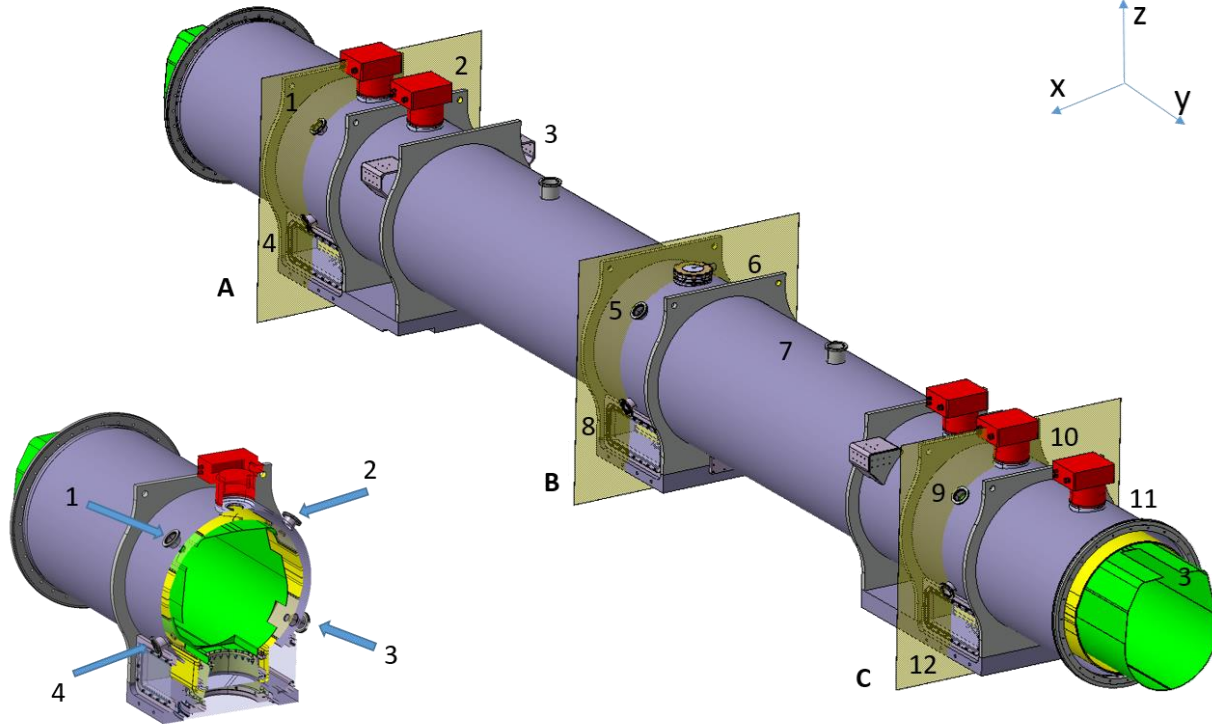
→ Absolute distance measuring interferometric technique



FSI target on the cold mass



Alignment requirement (at cold)



Cold Mass	GOAL (1σ)
Tx (mm) Radial	< 0.1 mm
Ty (mm) longitudinal	
Tz (mm) vertical	< 0.1 mm
Rx (mrad)	
Ry (mrad)	
Rz (mrad)	
Scale (ppm)	

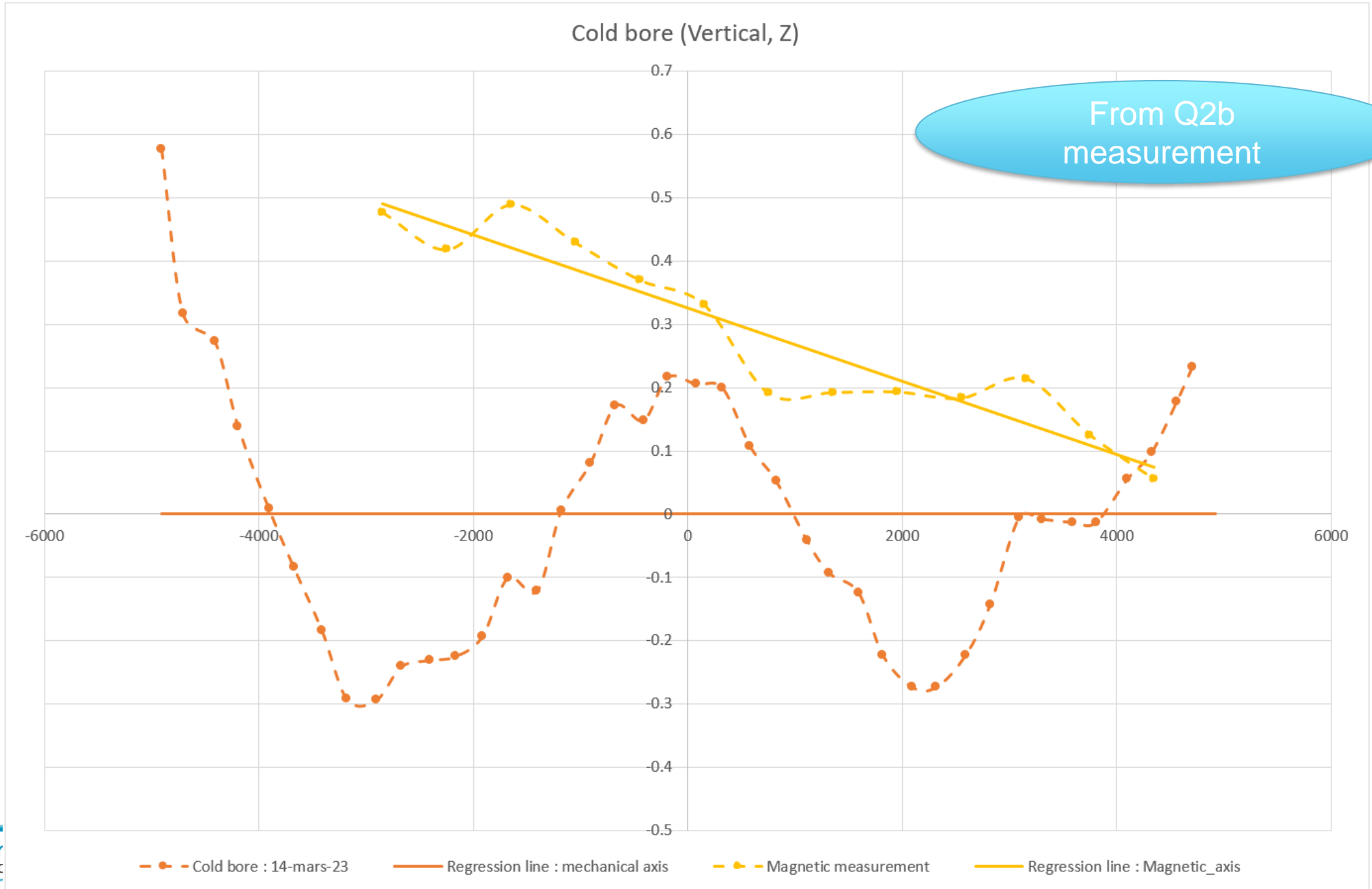
σ (A priori FSI distance) = 0.040 mm

Position of the Cold Mass inside the cryostat	Accuracy (1σ)
Tx (mm) Radial	0.031
Ty (mm) longitudinal	0.020
Tz (mm) vertical	0.027
Rx (mrad)	0.009
Ry (mrad)	--
Rz (mrad)	0.012
Scale (ppm)	7

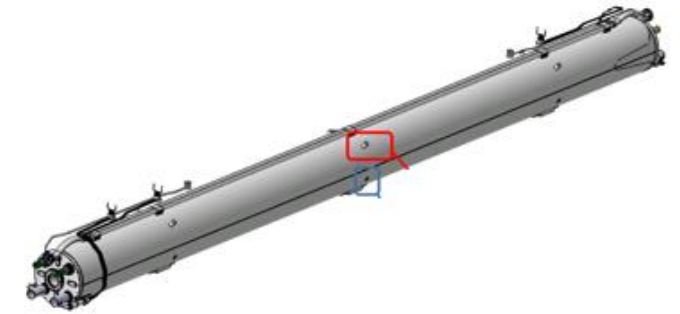
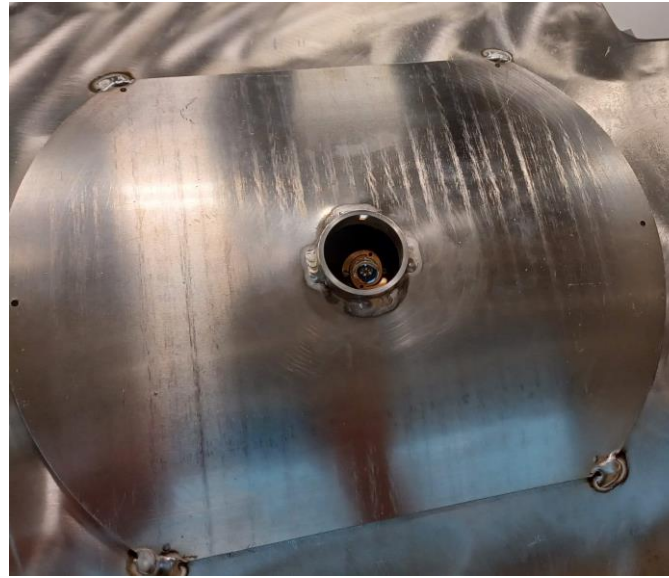
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Determination of mechanical and magnetic axis of the cold mass at warm



Installation of FSI targets



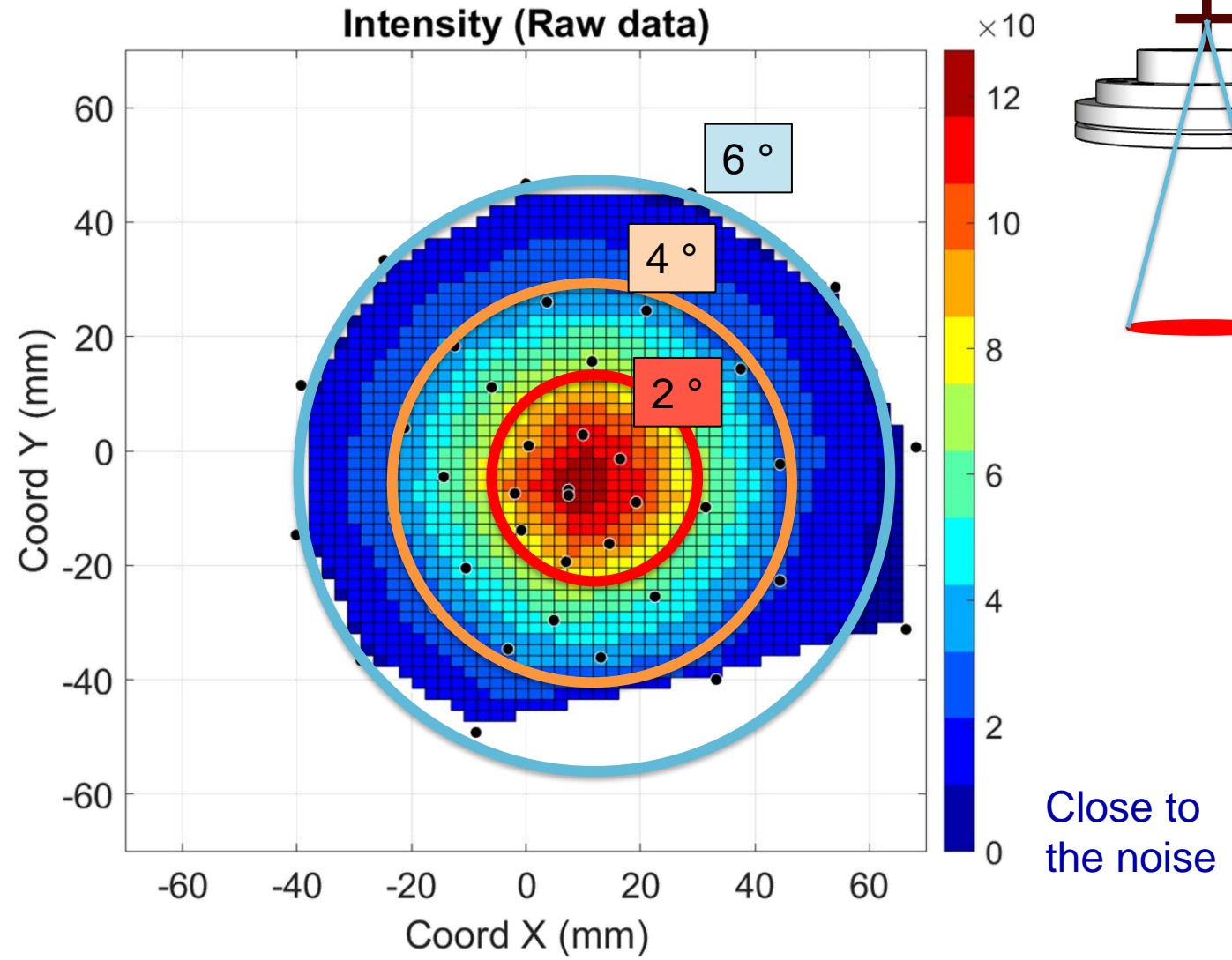
Targets position
Difference to nominal

	ΔX (mm)	ΔY (mm)	ΔZ (mm)
FSI_IP_1	-0.4	-0.1	-0.8
FSI_IP_2	-1.2	-0.5	-0.8
FSI_IP_3	-0.1	-0.4	0.6
FSI_IP_4	0.3	-0.1	0.4
FSI_Center_1	0.9	-0.4	-0.5
FSI_Center_2	-0.8	-0.9	-1.3
FSI_Center_3	-0.3	0.0	0.9
FSI_Center_4	1.5	-0.4	-0.2
FSI_NIP_1	0.6	0.0	-0.5
FSI_NIP_2	-0.8	-0.2	-0.9
FSI_NIP_3	-0.2	0.2	1.0
FSI_NIP_4	0.4	-0.3	0.3

Difference < 2 mm

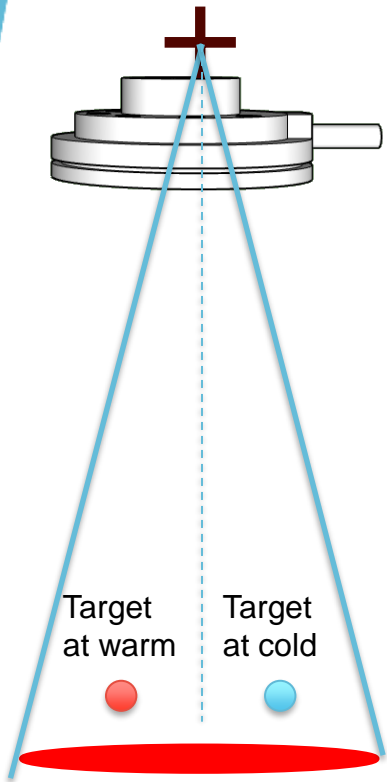


Installation of FSI heads

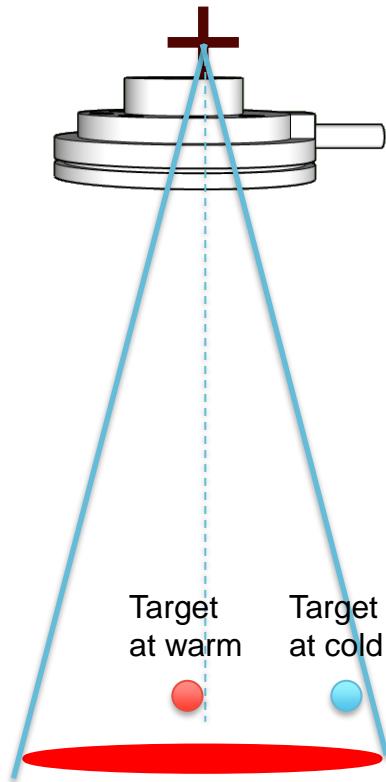


Validation of FSI visibility between sensor and target at warm and at cold

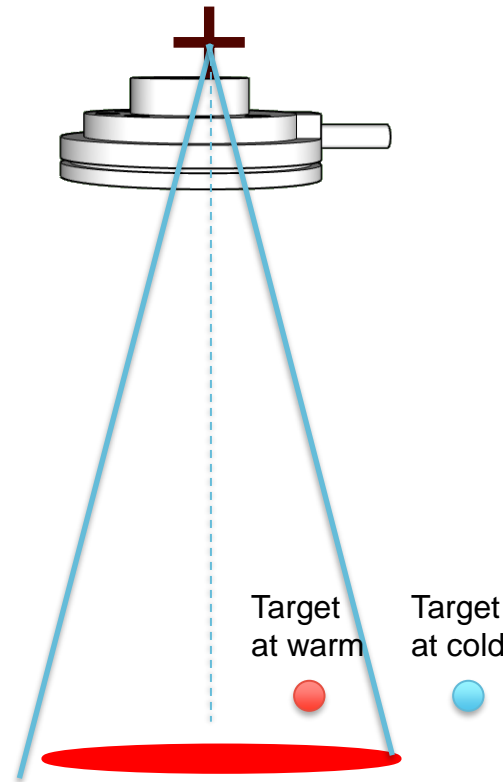
Objective



Acceptable



NOT Acceptable



Orientation at warm
R-head

	Rx (°)	Ry (°)
IP1	0.6	1.8
IP2	-0.4	0.9
IP3		
IP4	0.3	1.7
Center1	-0.3	0.2
Center2	0.4	0.3
Center3	0.3	0.0
Center4		
NIP1	0.3	1.7
NIP2	-0.5	1.5
NIP3		
NIP4	0.1	1.7

Orientation at cold
R-head

	Rx (°)	Ry (°)
IP1	0.1	-1.2
IP2	-0.4	-2.2
IP3		
IP4	0.4	-1.3
Center1	-0.1	0.2
Center2	0.7	0.3
Center3	0.7	0.0
Center4		
NIP1	0.1	-1.3
NIP2	-0.5	-1.7
NIP3		
NIP4	0.1	-1.4

Objective



$\alpha < 2^\circ$

Acceptable



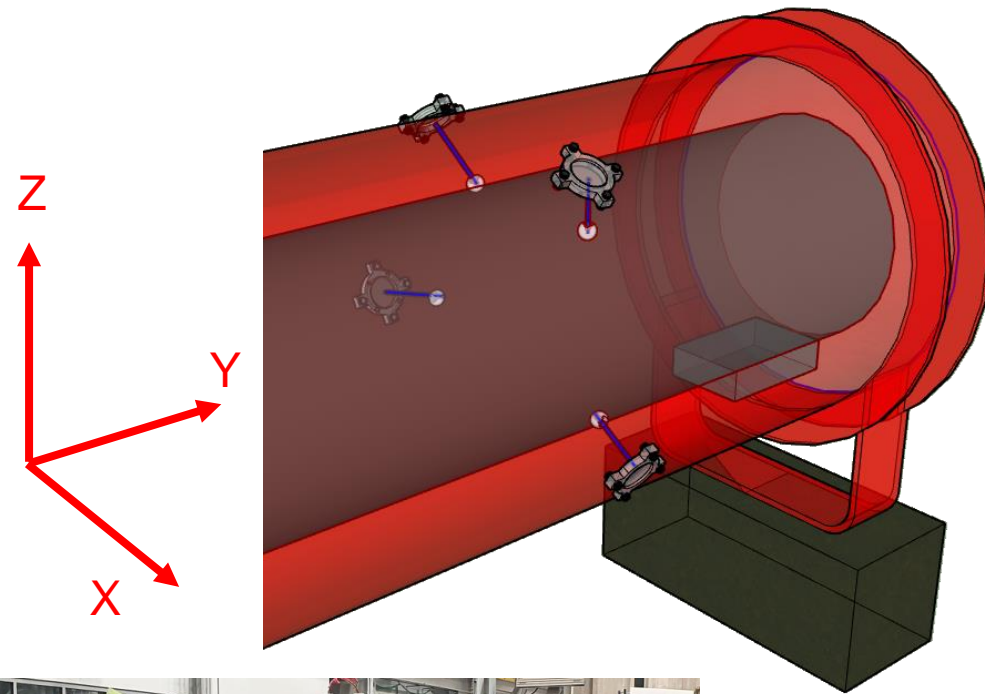
$2^\circ < \alpha < 4^\circ$

Not acceptable



$\alpha > 4^\circ$

Position of the cold mass inside the cryostat at warm (FSI versus laser Tracker)



Position of the cold mass inside the vacuum vessel

Intercomparison

Laser Tracker

FSI

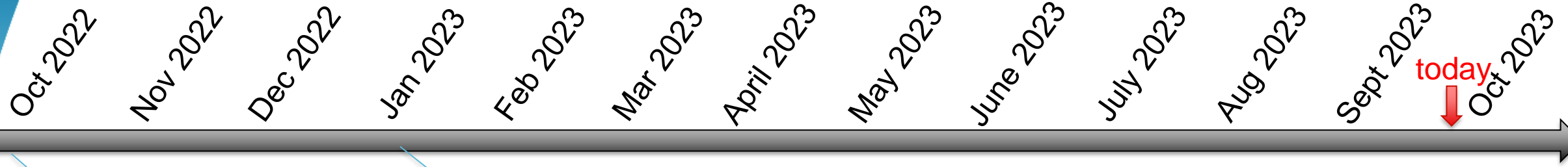
From Laser Tracker
2022-09-29

From FSI
2022-10-04

	Axe	Value (mm)	Value (mm)	Difference (mm)
IN NIP side	X (mm) radial	1.656	1.637 +/- 0.030	-0.019
	Y (mm) longitudinal	0.074	0.149 +/- 0.060	0.075
	Z (mm) vertical	-54.114	-54.141 +/- 0.030	-0.027
OUT IP side	X (mm) radial	-1.740	-1.734 +/- 0.030	0.006
	Y (mm) longitudinal	9500.002	9499.990 +/- 0.060	-0.012
	Z (mm) vertical	-54.032	-54.039 +/- 0.030	-0.007



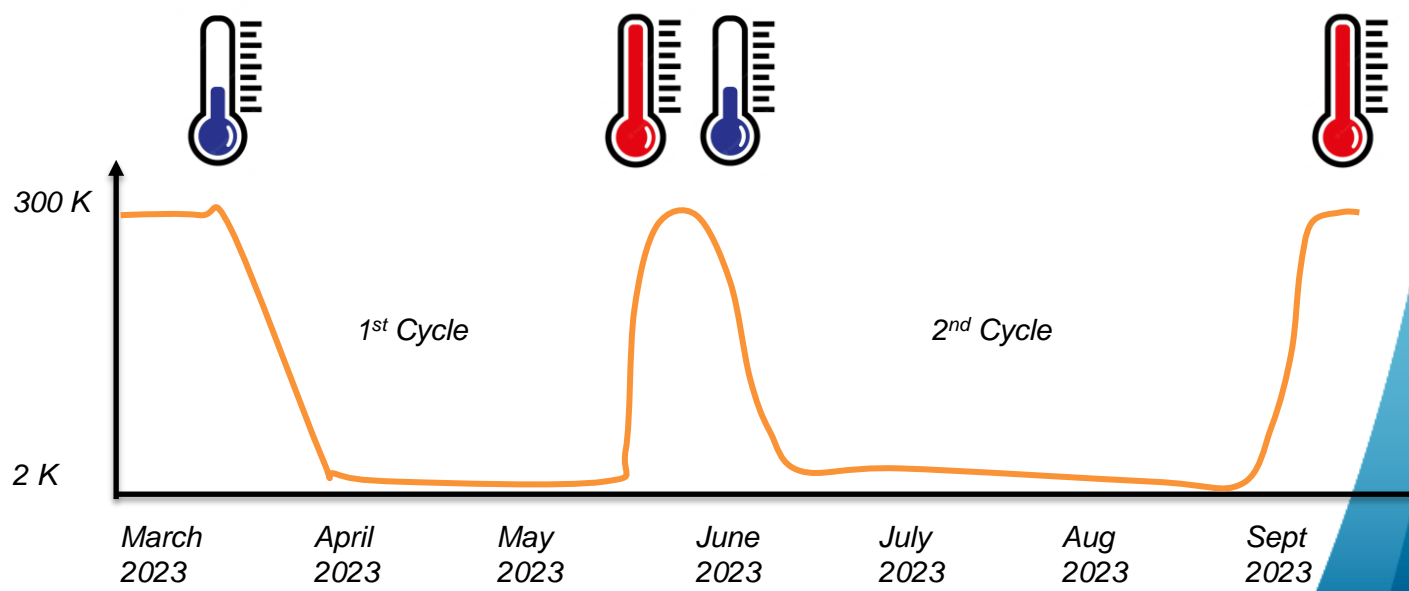
Schedule



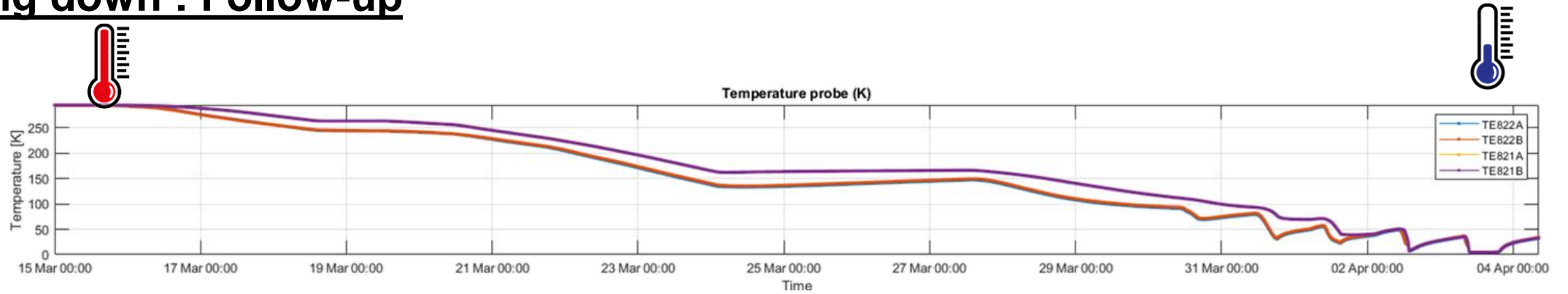
Installation of FSI system + FSI heads

Transfer to IB1 building

Cooling down / Warm up 1 and 2

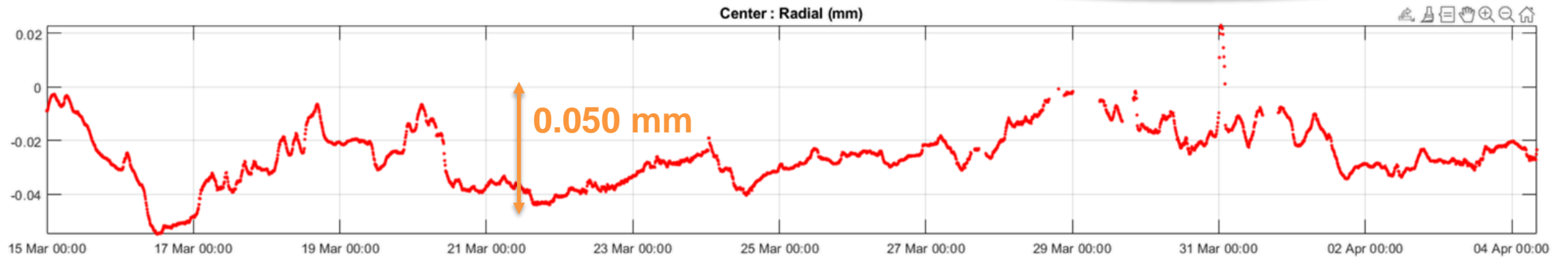


Cooling down : Follow-up

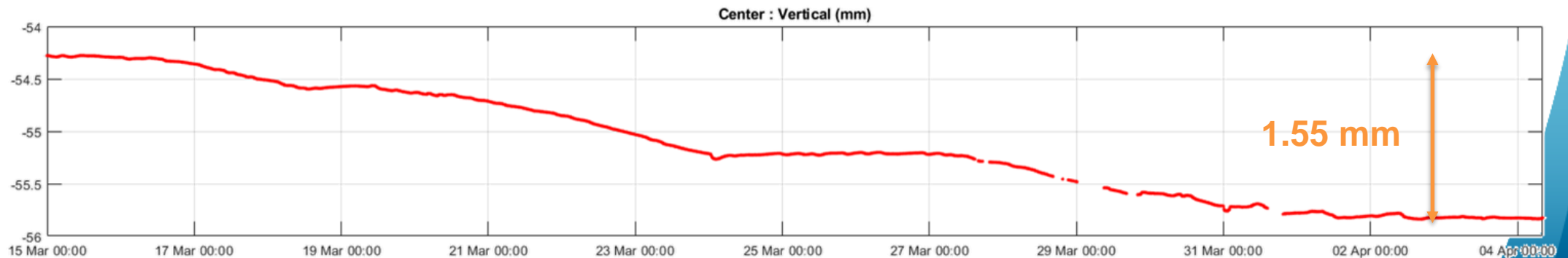


Temperature [K]

Accuracy : +/- 0.030 mm



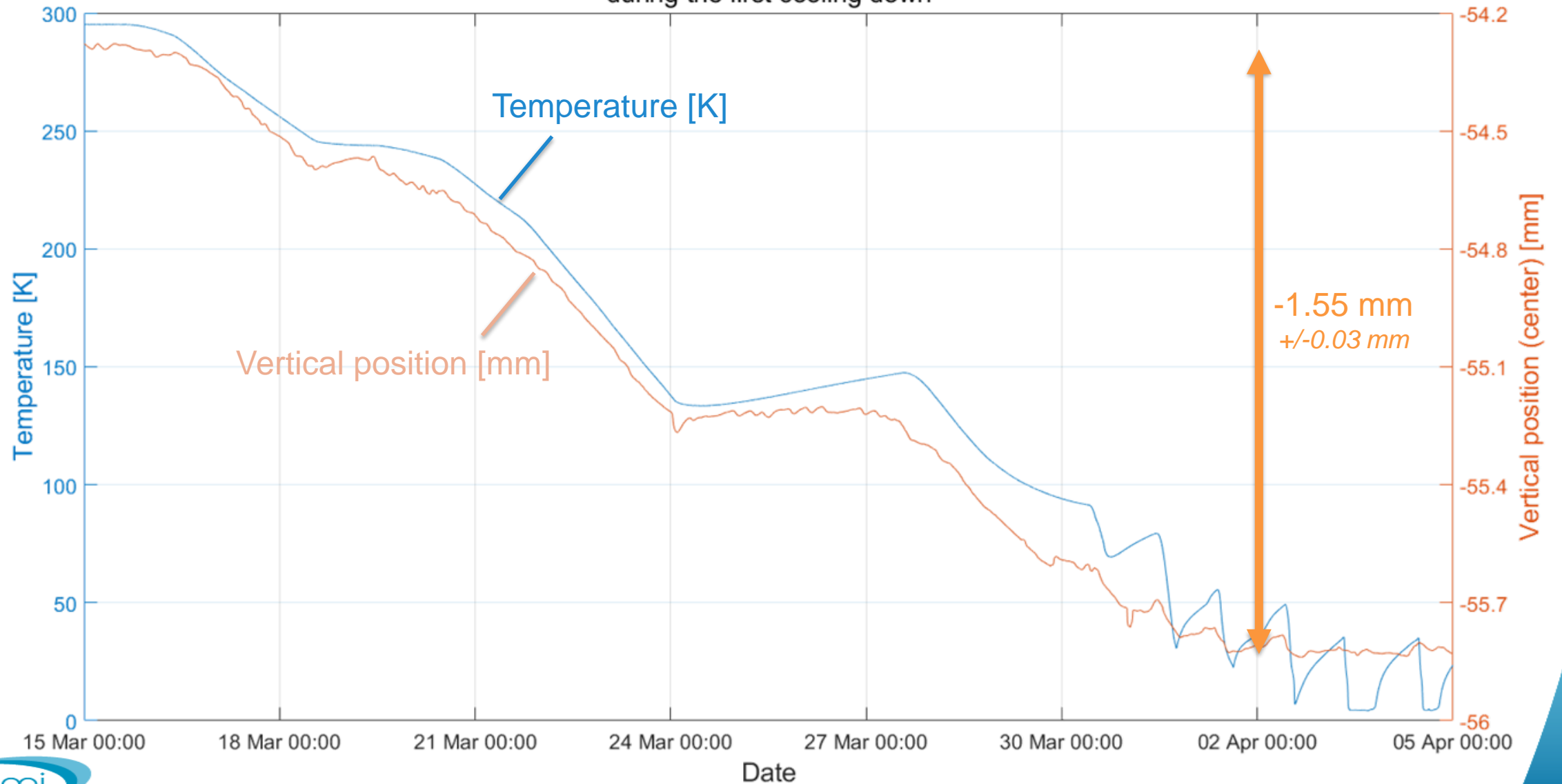
Radial Position [mm]



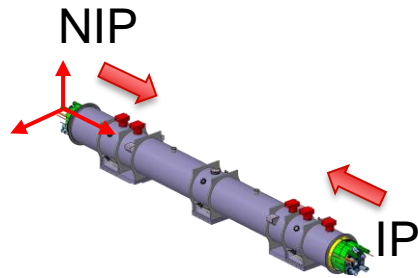
Vertical Position [mm]

Cooling down : Correlation between temperature and Vertical position

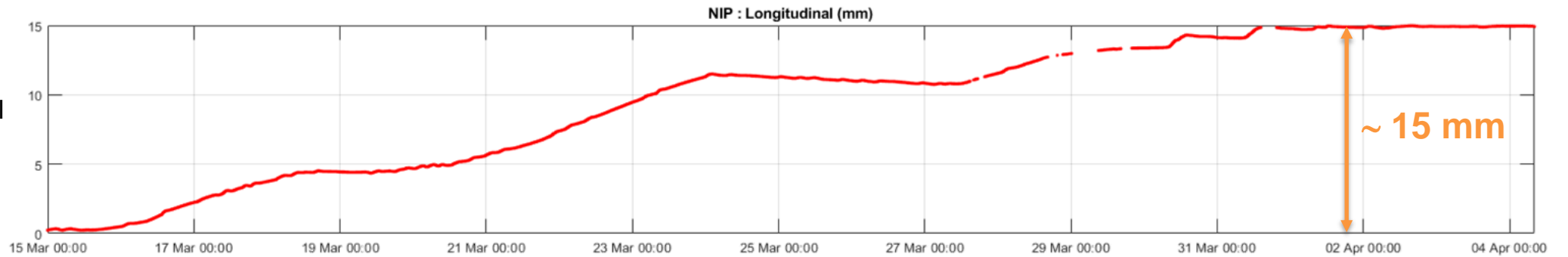
Vertical position of the cold mass inside the vacuum vessel during the first cooling down



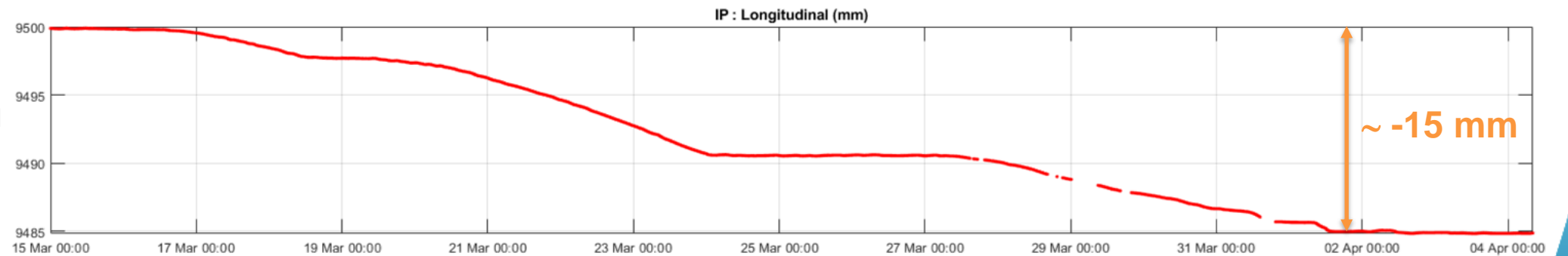
Longitudinal Accuracy
(at the extremities) :
 ± 0.060 mm



NIP side
Longitudinal
Position
[mm]



IP side
Longitudinal
Position
[mm]



Position Repeatability

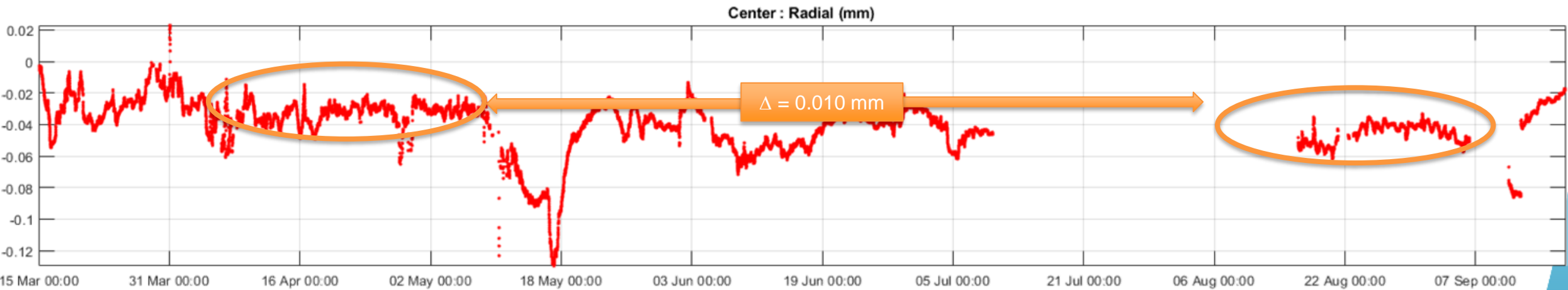
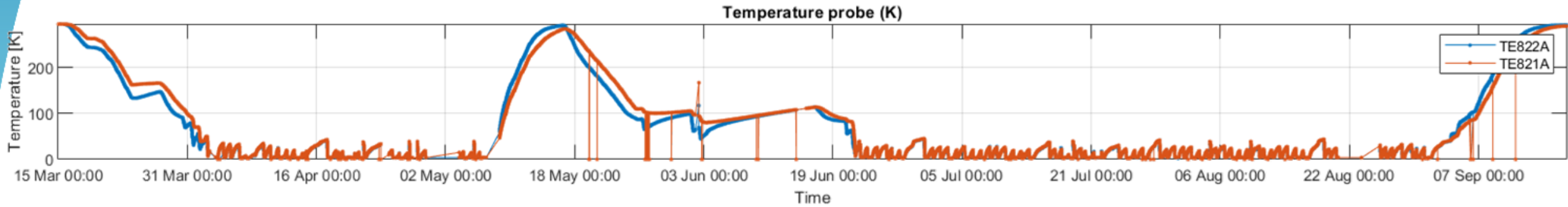
- First cooling down
- Second cooling down

Cooling down : Radial motion

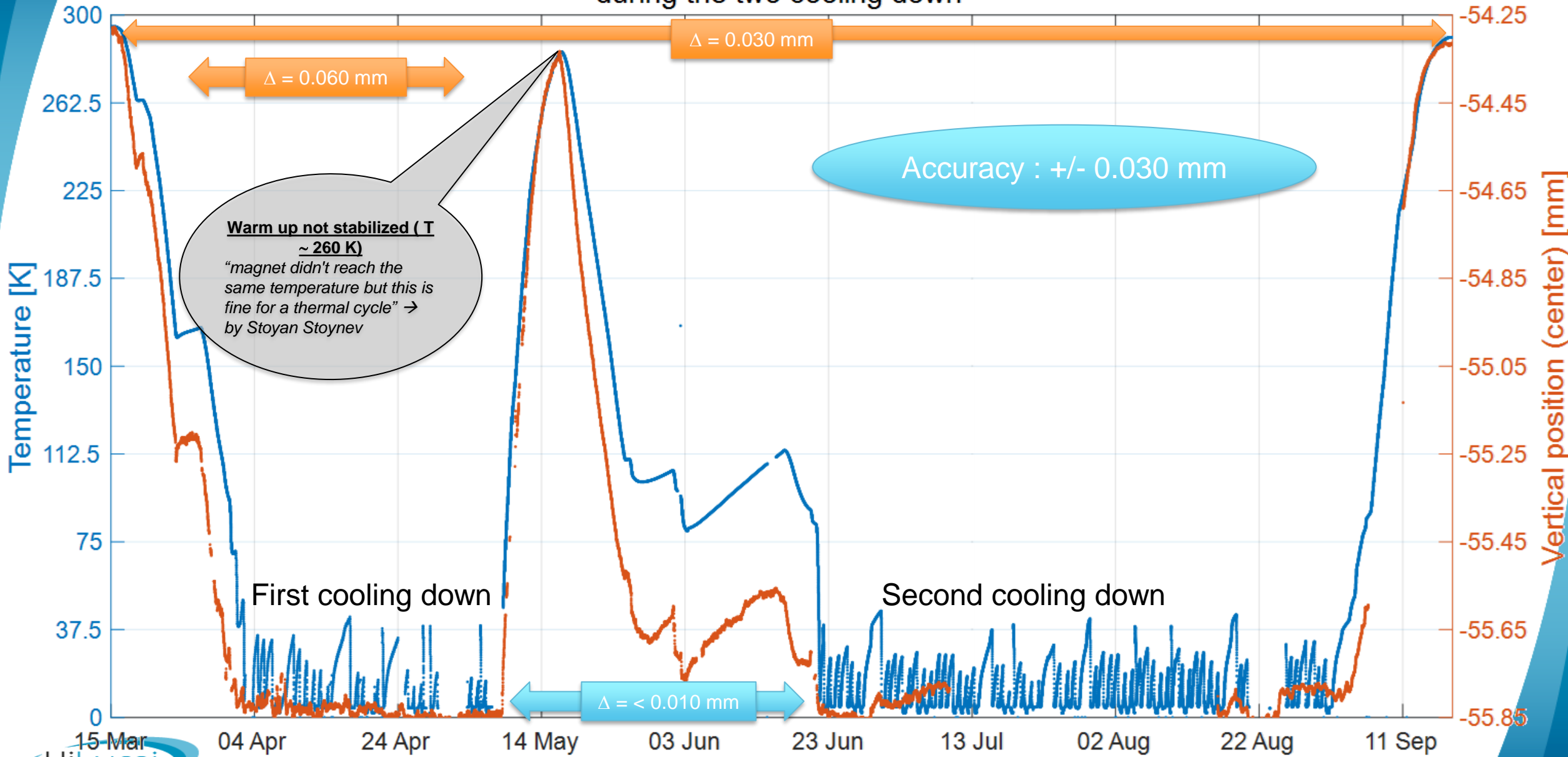
Accuracy : +/- 0.030 mm

First cooling down

Second cooling down



Vertical position of the cold mass inside the vacuum vessel during the two cooling down

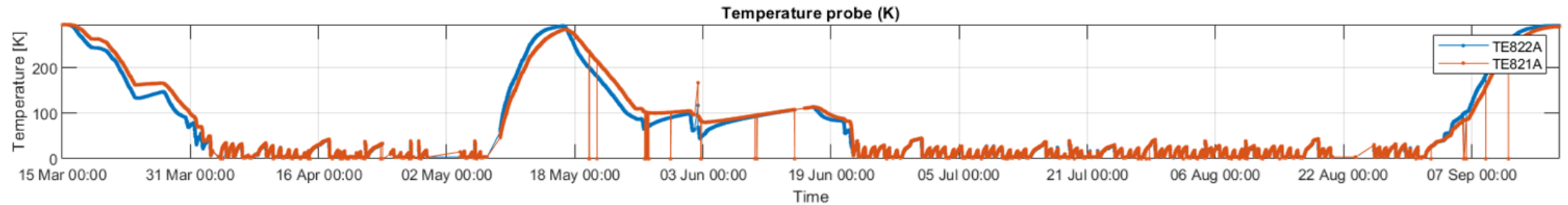


Cooling down : Longitudinal contraction

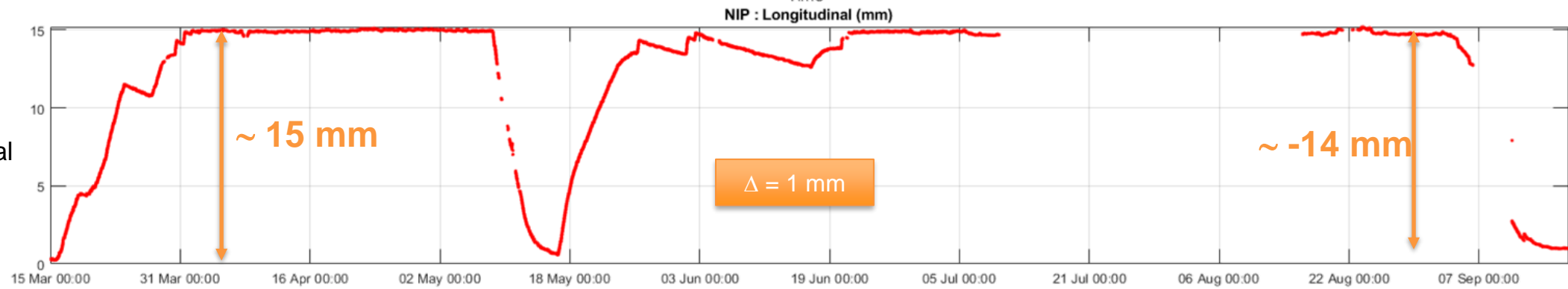
Longitudinal Accuracy
(at the extremities) :
 $\pm 0.060 \mu\text{m}$

First cooling down

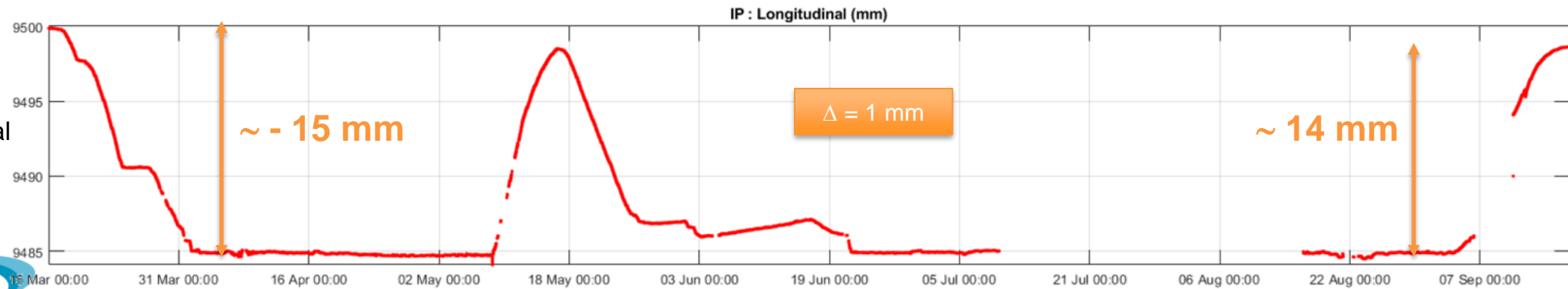
Second cooling down



NIP side
Longitudinal
Position
[mm]



IP side
Longitudinal
Position
[mm]

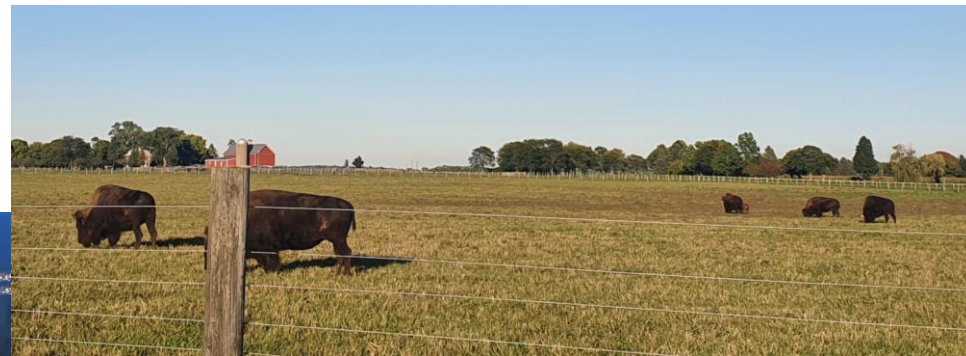


Conclusion

Q3 will soon return to CERN !!

Many thanks to FERMILAB team :

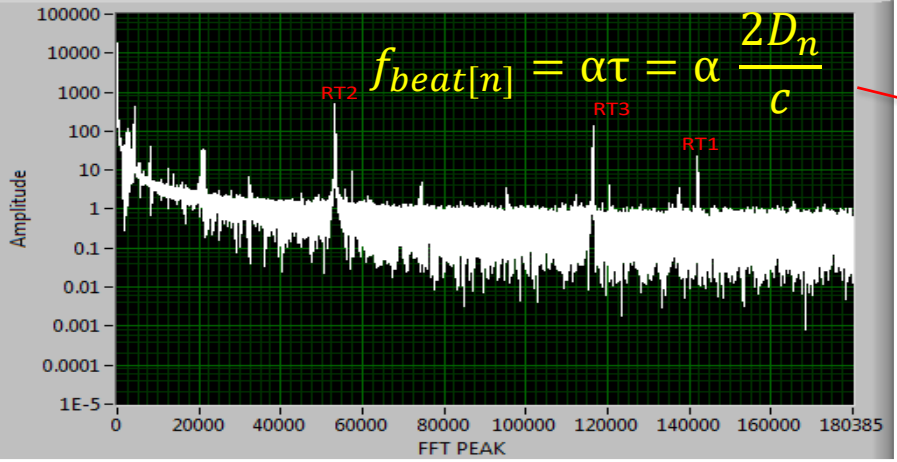
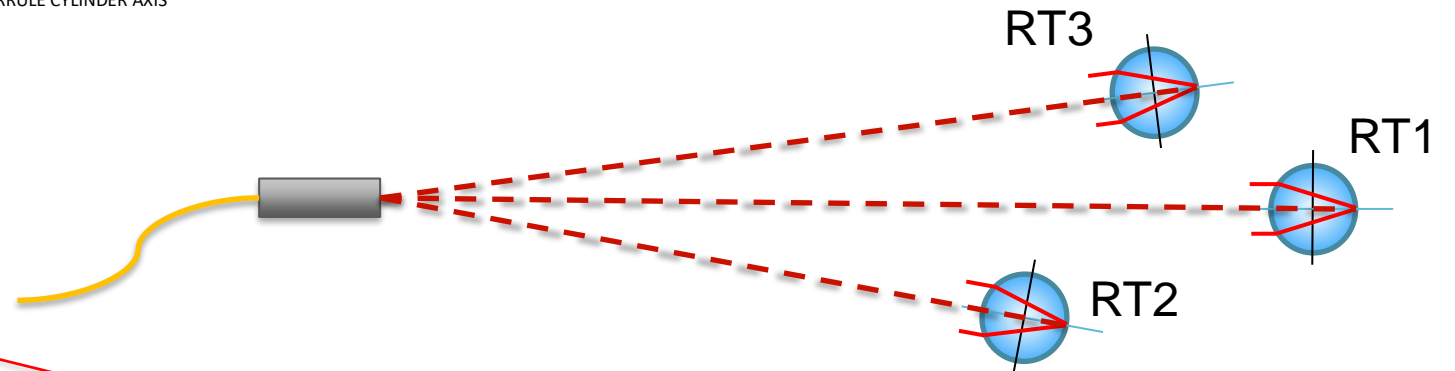
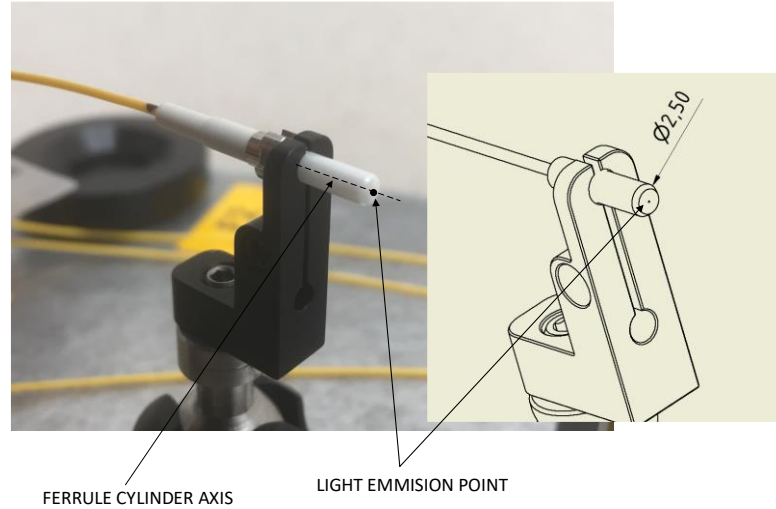
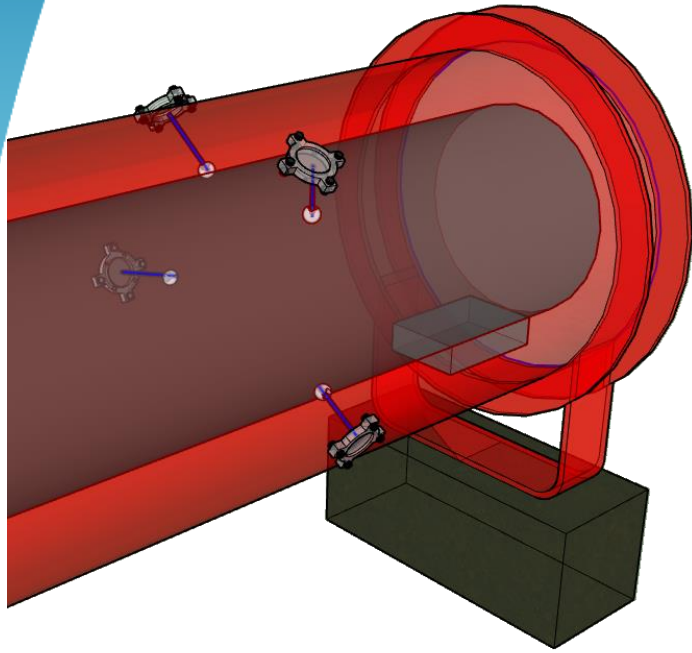
- Roger
- Guram
- Stoyan
- Chuck
- Thomas
- Brian
- Matt
- Sandor
- ...



Thank you for your attention

Multi-target FSI

$n=2$



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

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