



Crab-cavities monitoring system validation and first cool down results

Vivien RUDE

2017-12-18

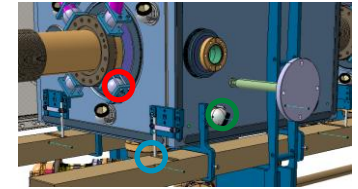
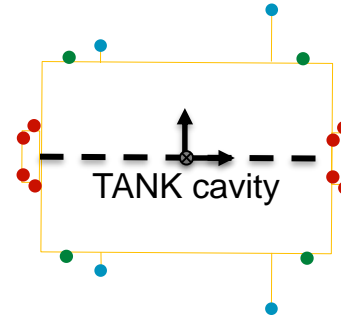
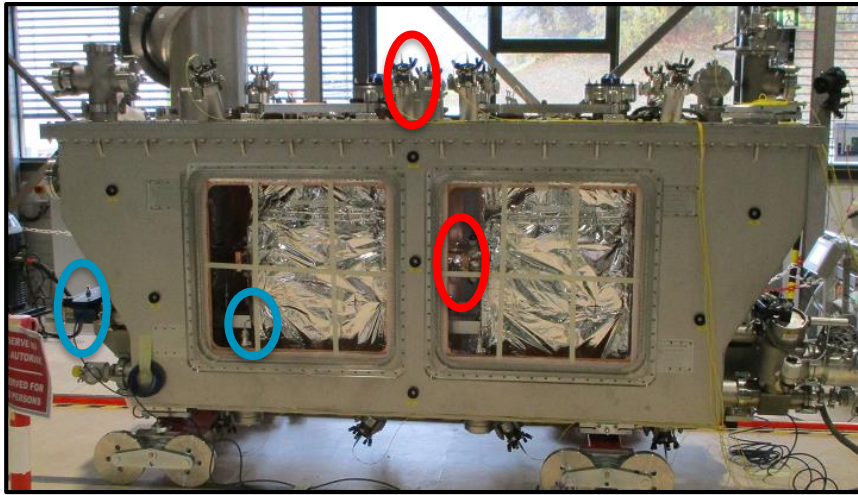
On behalf of :

- Thibault Dijoud
- Mateusz Sosin
- H el ene Mainaud Durand
- Mathieu Duquenne
- Anna Zemanek

Outline

- Alignment monitoring systems (FSI, BCAM, Laser Tracker)
- Results at ambient T, P (Cryomodule OPEN)
- Results under vacuum
- Cooling down / Warm up
- Results at 4K
- Simulation vs measurements (thermal contraction)
- Conclusion

FSI / BCAM / Laser Tracker measurements



- FSI targets
- BCAM targets
- Laser tracker targets

FSI
(absolute distances)

BCAM
(Angle measurements)

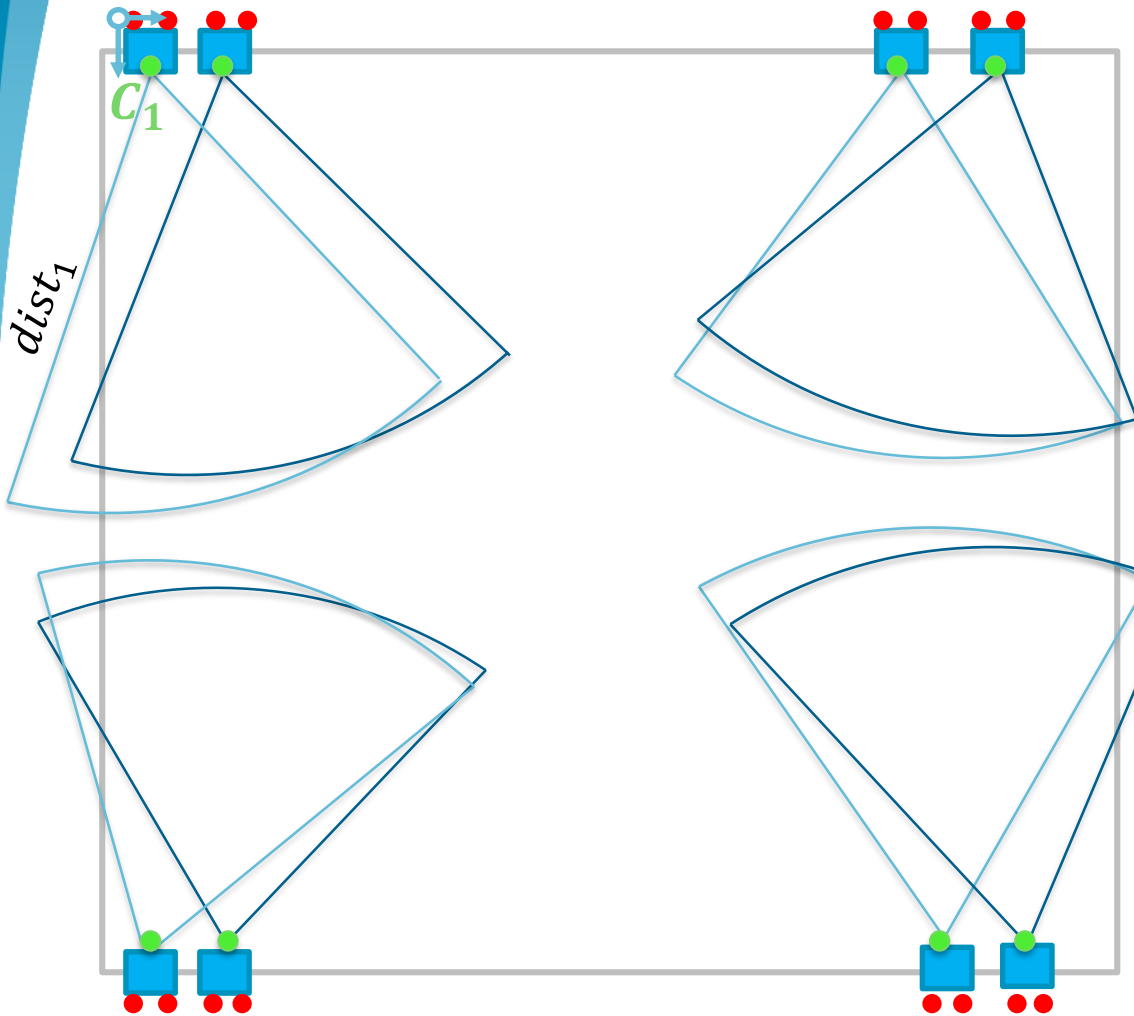
Laser Tracker
(Angles and distances measurements)



FSI alignment strategy

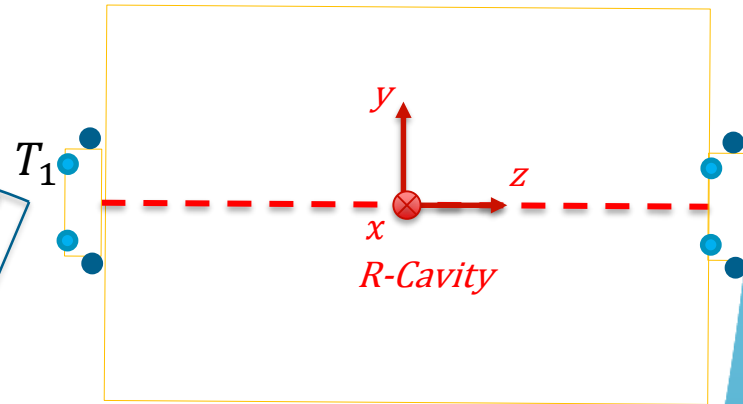
$$Dist_i = \sqrt{(X_{C_i} - X_{T_i})^2 + (Y_{C_i} - Y_{T_i})^2 + (Z_{C_i} - Z_{T_i})^2}$$

R-FSI 1



$$\begin{pmatrix} X_{T_i} \\ Y_{T_i} \\ Z_{T_i} \end{pmatrix} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + [R]^* \begin{pmatrix} x_{T_i} \\ y_{T_i} \\ z_{T_i} \end{pmatrix}$$

R-general *R-cavity*



R-general

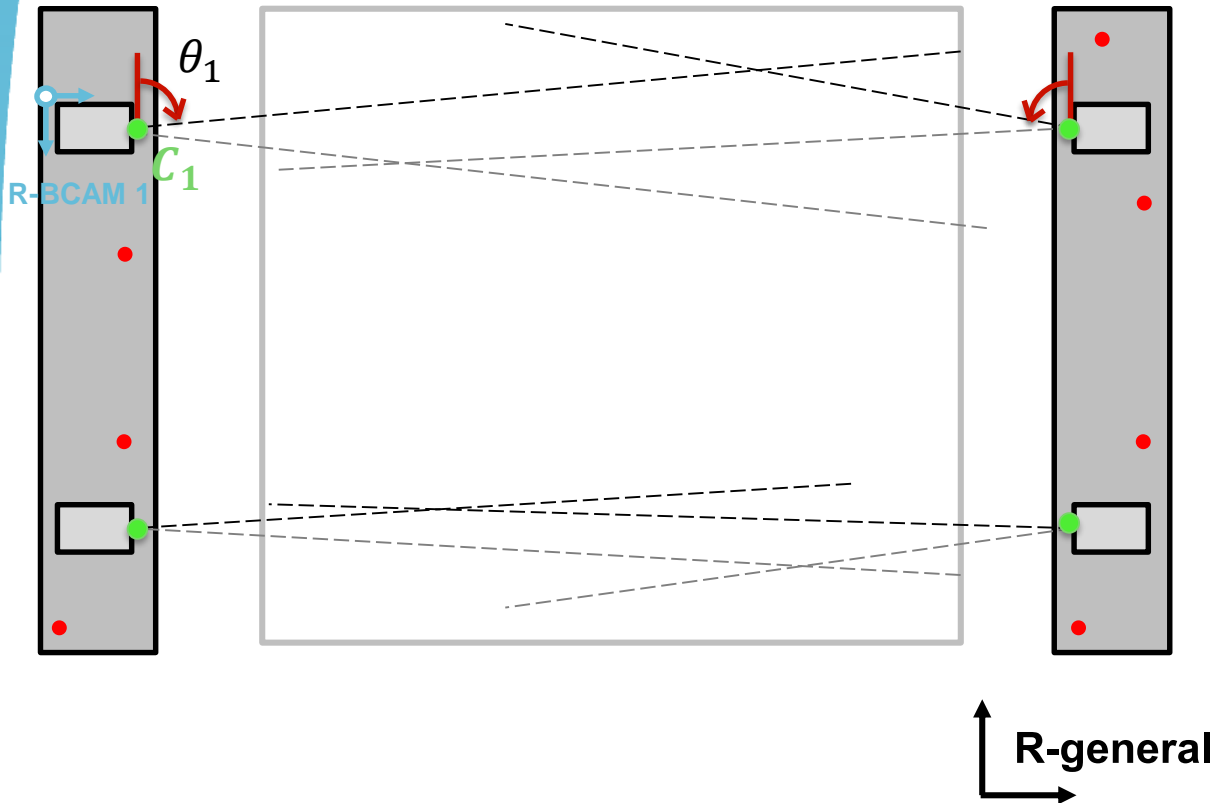


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BCAM alignment strategy

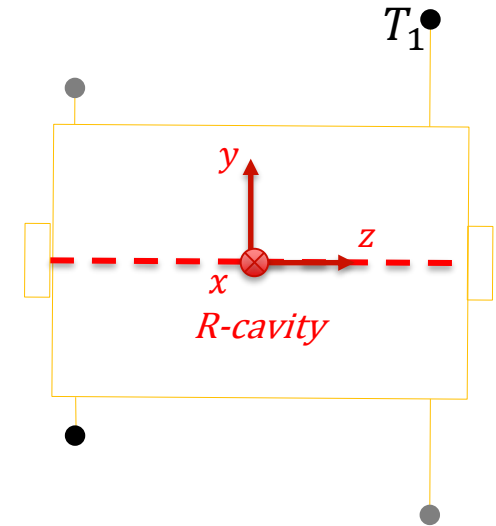
$$\theta_i = \tan^{-1} \frac{(X_{C_i} - X_{T_i})}{(Z_{C_i} - Z_{T_i})}$$

$$\varphi_i = \tan^{-1} \frac{(Y_{C_i} - Y_{T_i})}{\sqrt{(Z_{C_i} - Z_{T_i})^2 + (X_{C_i} - X_{T_i})^2}}$$

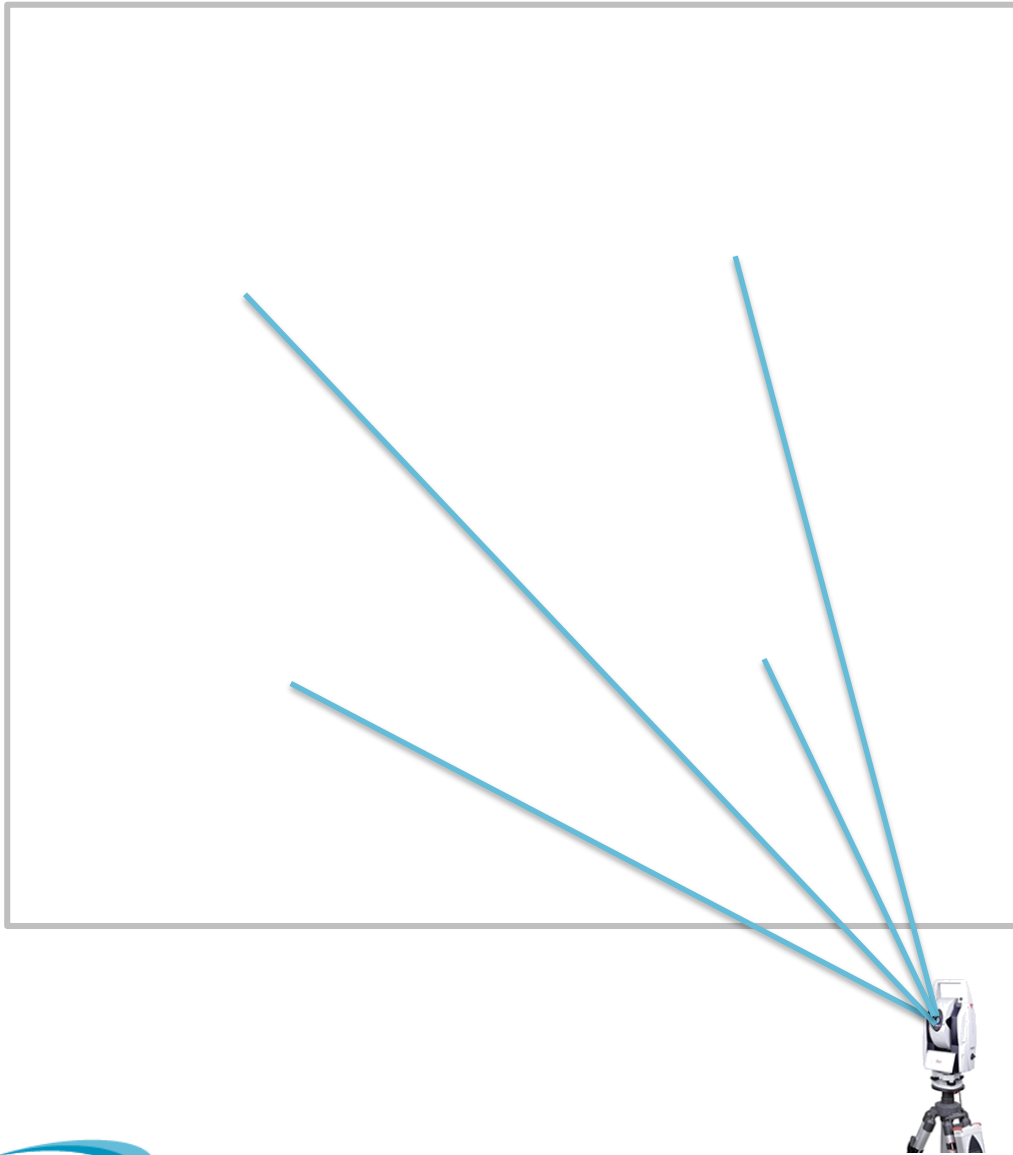


$$\begin{pmatrix} X_{T_i} \\ Y_{T_i} \\ Z_{T_i} \end{pmatrix} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + [R]^* \begin{pmatrix} x_{T_i} \\ y_{T_i} \\ z_{T_i} \end{pmatrix}$$

R-general *R-cavity*

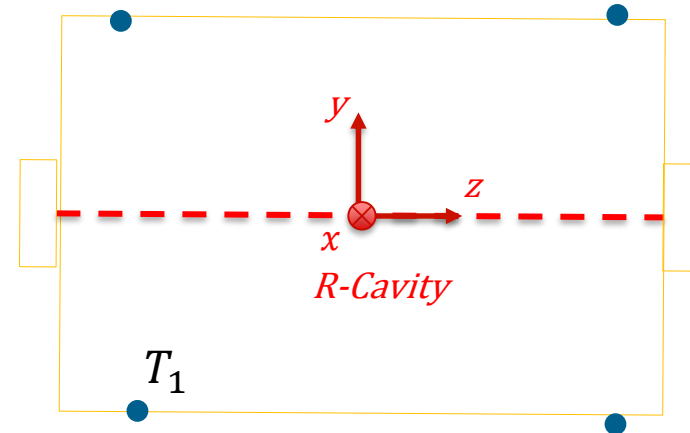


Laser Tracker alignment strategy

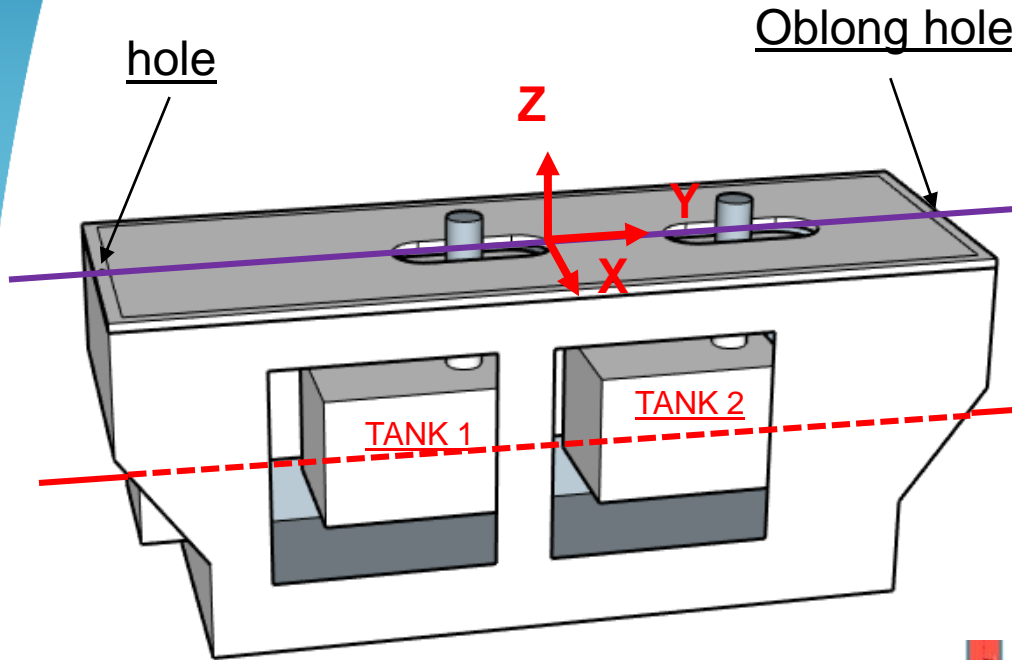


$$\begin{pmatrix} X_{Ti} \\ Y_{Ti} \\ Z_{Ti} \end{pmatrix} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + [R] \begin{pmatrix} x_{Ti} \\ y_{Ti} \\ z_{Ti} \end{pmatrix}$$

R-general *R-cavity*

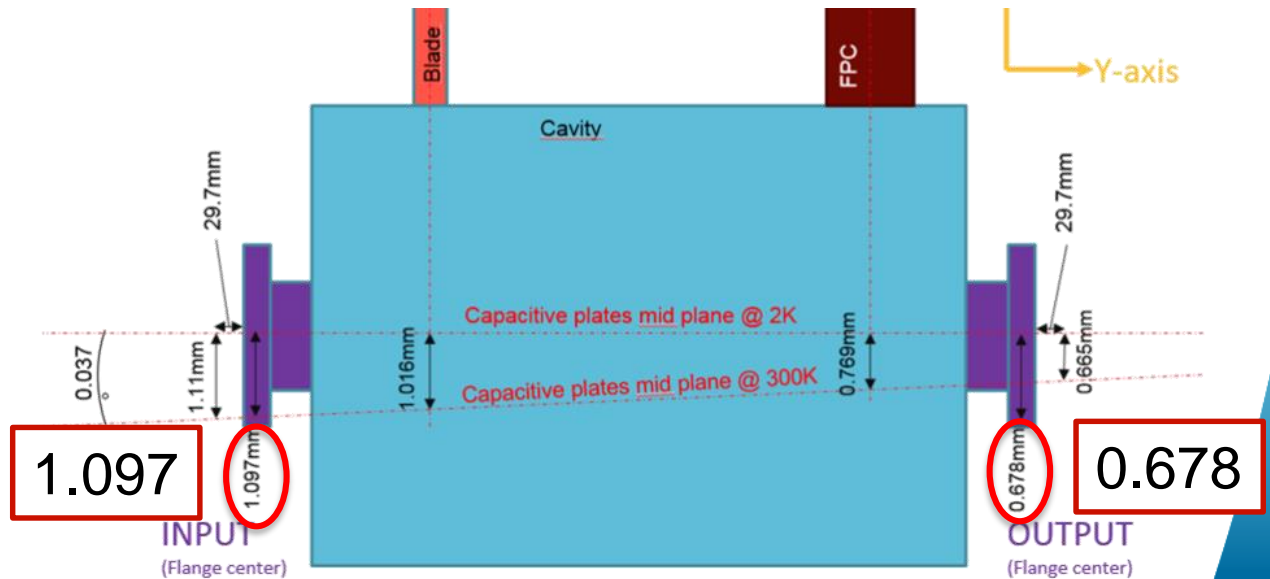


Nominal position of the cavities



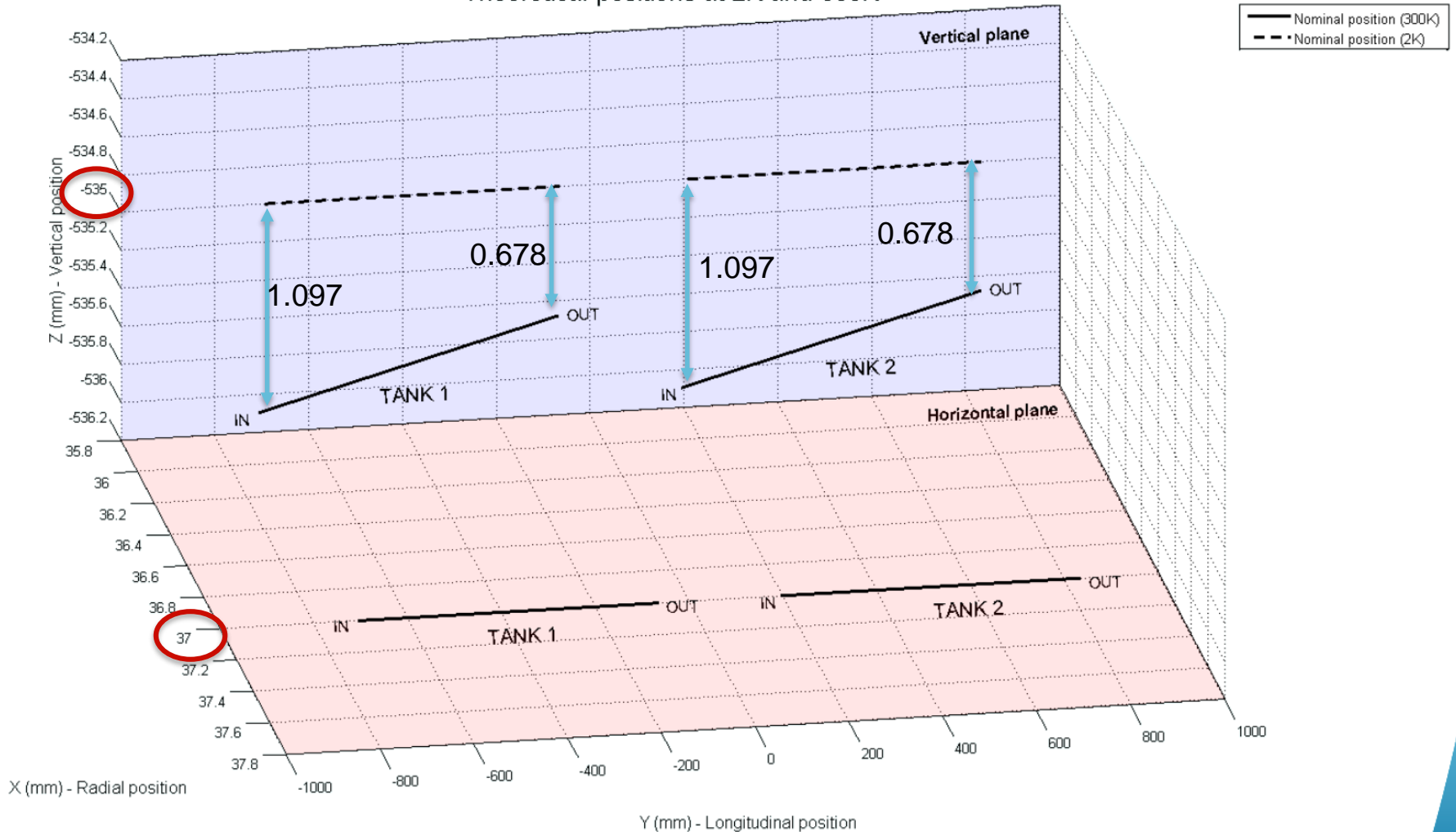
$$\left\{ \begin{array}{l} \Delta X = 37 \text{ mm} \\ \Delta Z = -535 \text{ mm} \end{array} \right.$$

T. Capelli

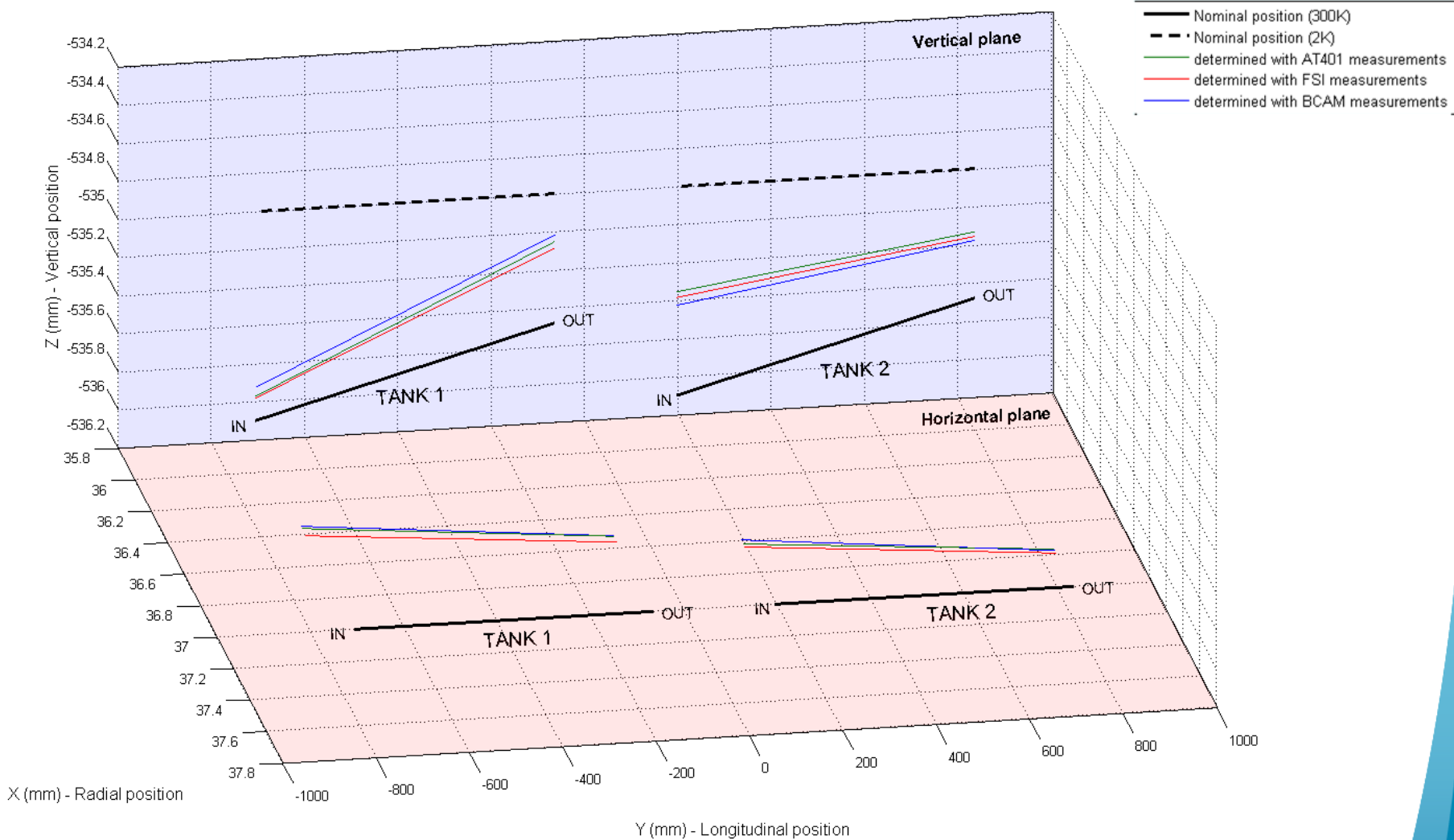


Nominal position of the cavities

Theoretical positions at 2K and 300K



Ambient conditions (T°, P)



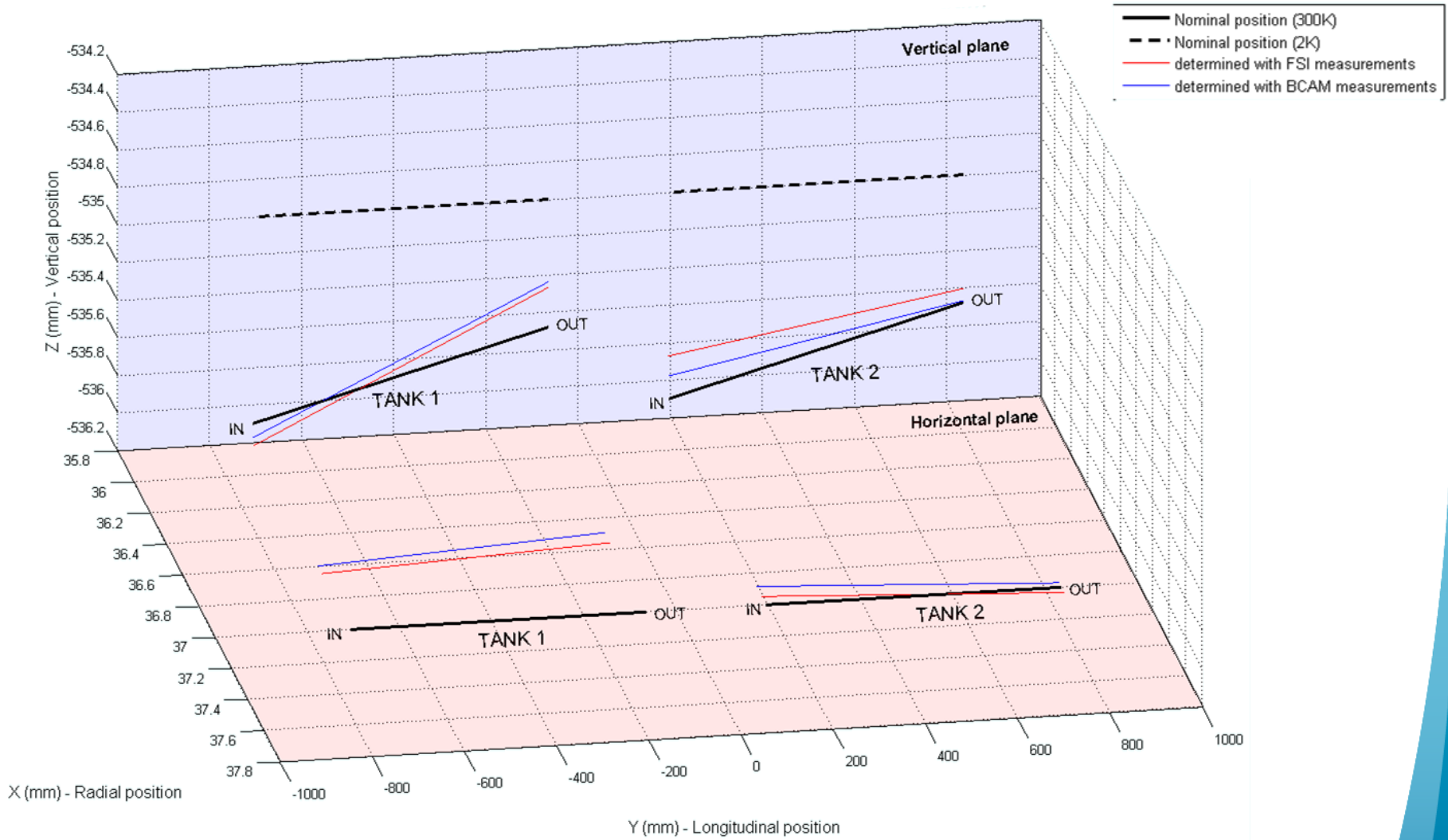
Differences between :

- Laser Tracker measurements
- FSI measurements
- BCAM measurements



• +/- 35 μm

Under vacuum



Differences between :

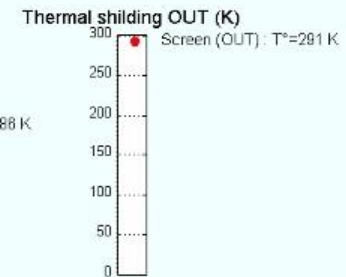
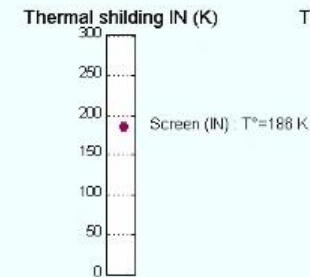
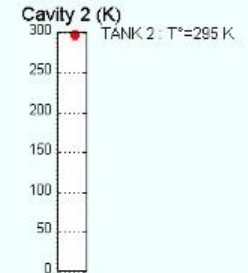
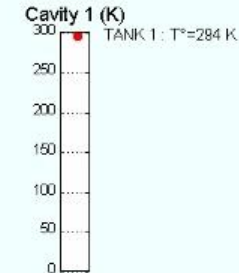
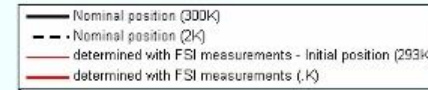
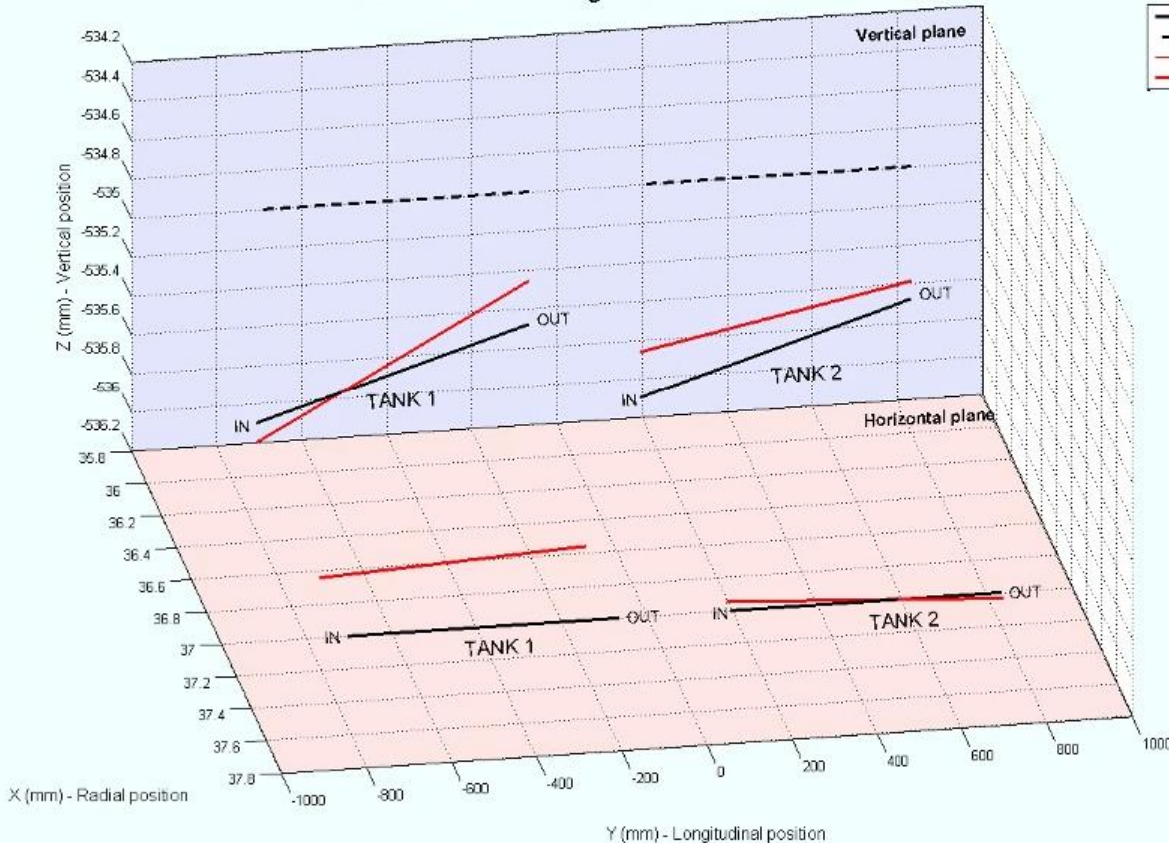
- FSI measurements
- BCAM measurements



• +/- 50 μm

Cooling down / Warm up

Cavities axis : Cooling down : 30-Nov-2017 09:47

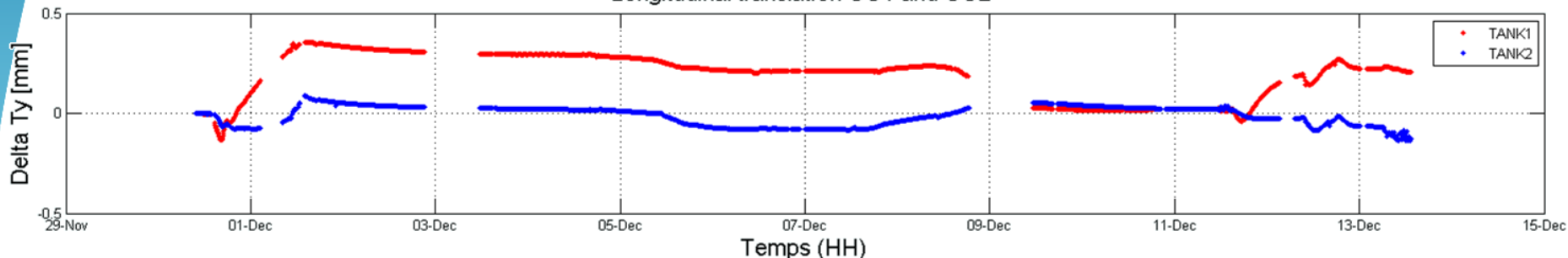


- 30 Nov ½ → 07 Dec ½ : Cooling down of the Cavities to 4 K (Thermal shielding : 50 K)
- 07 Dec ½ → 11 Dec ½ : Warming up to 300 K
- 11 Dec ½ → 13 Dec ½ : Cooling down of the Cavities to 4 K (Thermal shielding : 50 K)

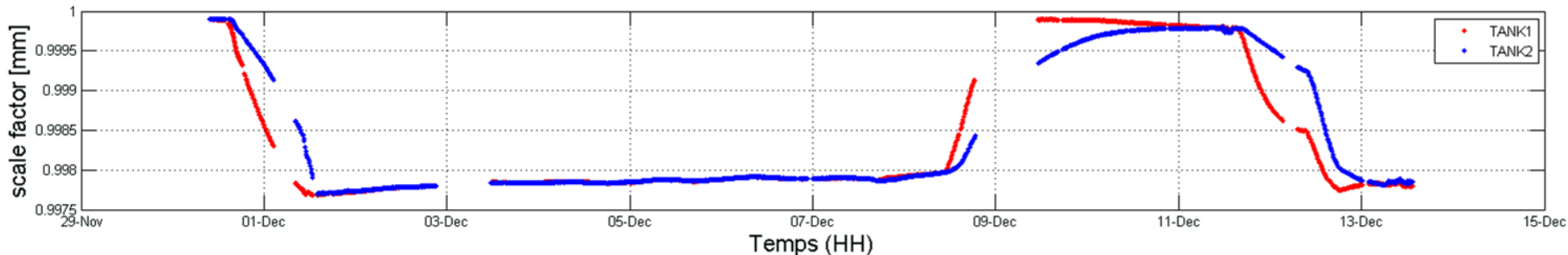
- **Repeatability (Cooling down / Warm up) : +/- 10 μm**

Cooling down / Warm up

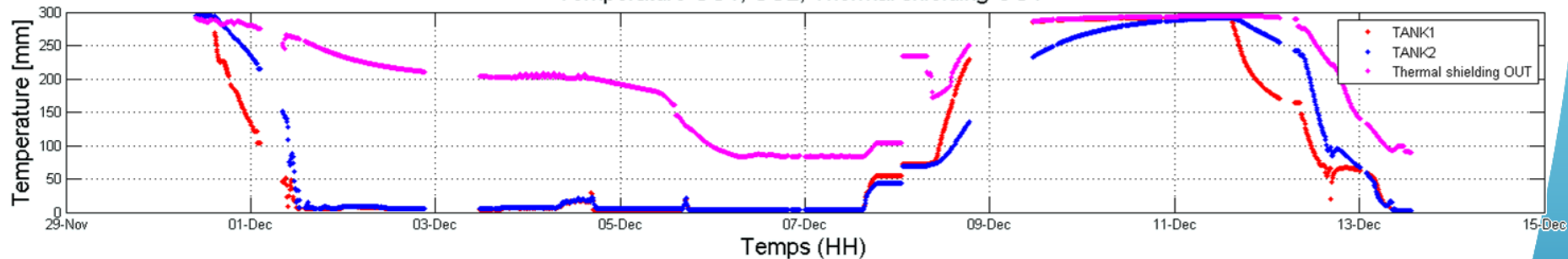
Longitudinal translation CC1 and CC2



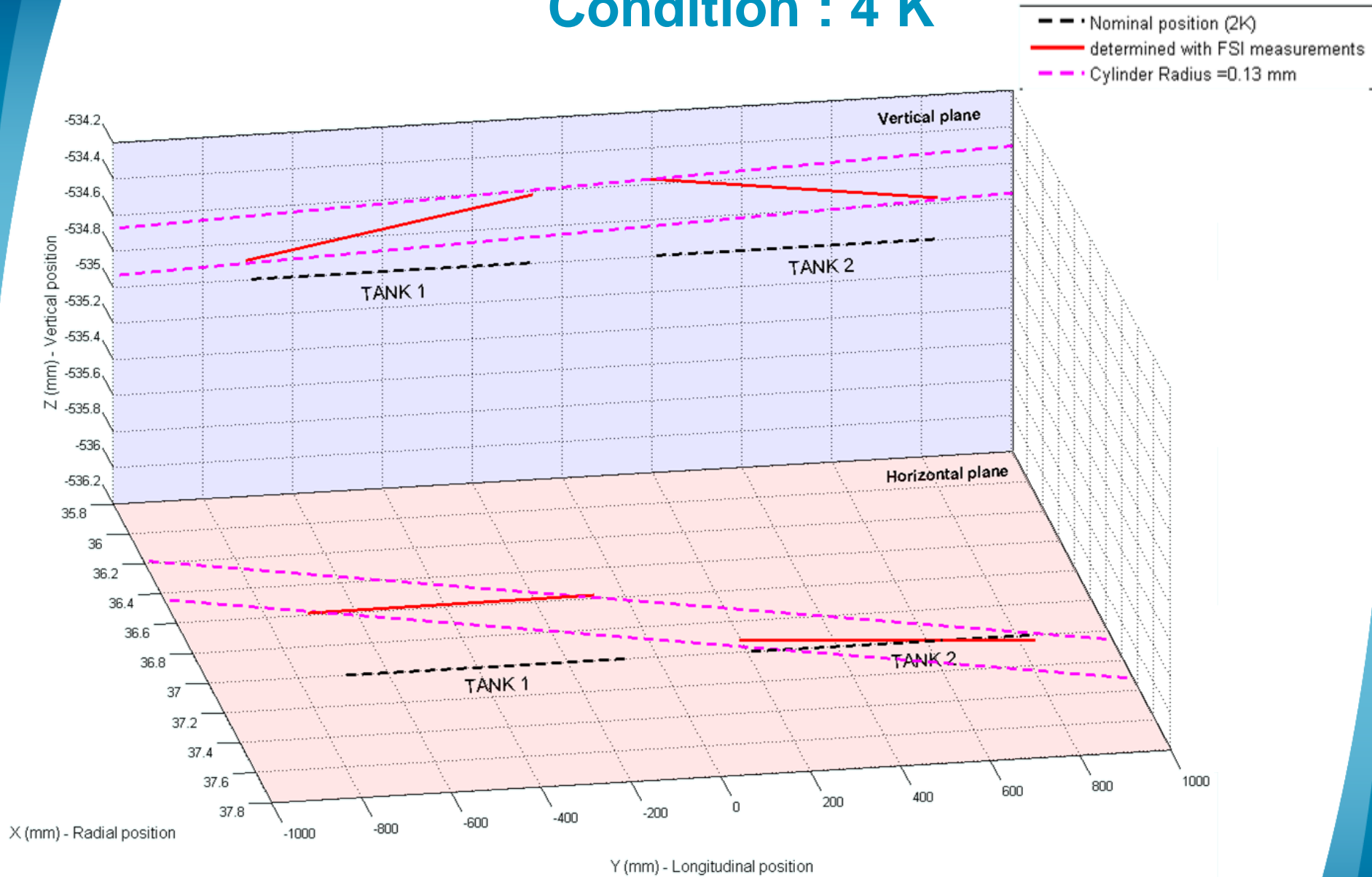
Scale factor CC1 and CC2



Temperature CC1, CC2, Thermal shielding OUT

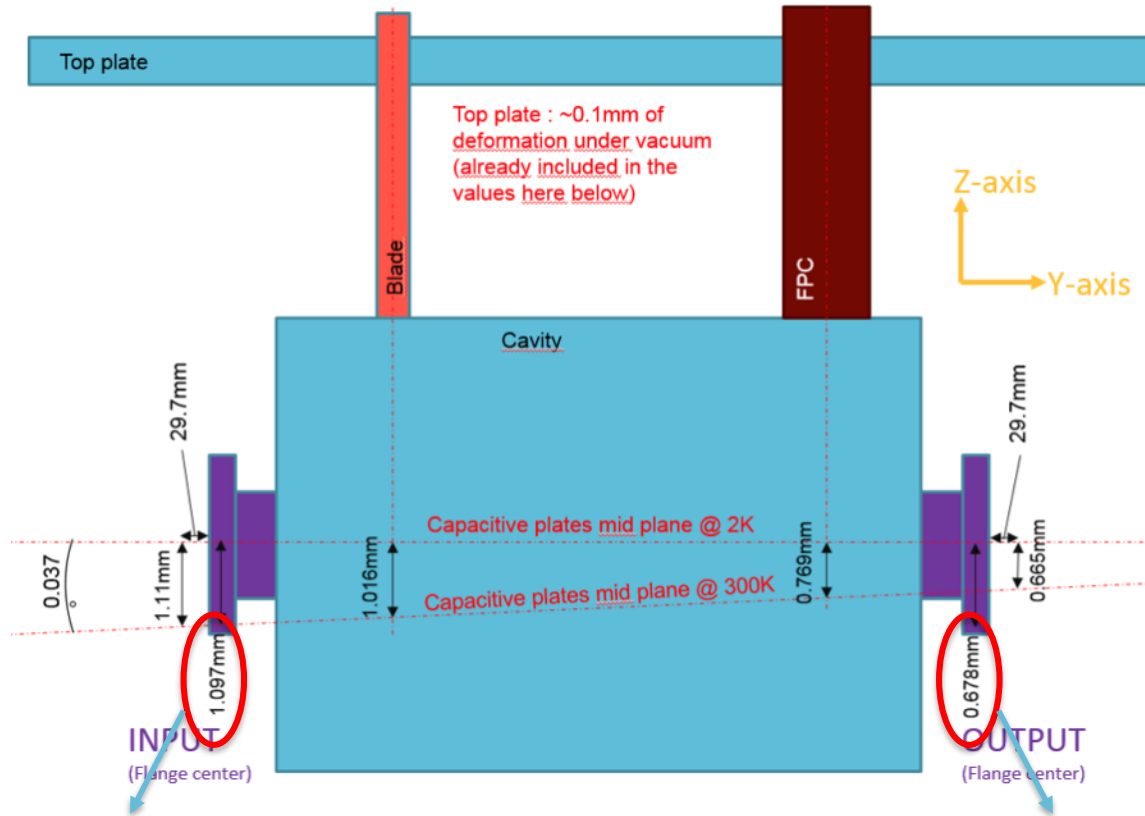


Condition : 4 K



• Alignment between the 2 cavities : Radius = 0.13 mm

Thermal contraction (simulation vs measurements)



Theoretical :
1.097 mm
1.321 → TANK 1
1.295 → TANK 2

+19%

+23%

Theoretical :
0.678 mm
0.843 → TANK 1
0.832 → TANK 2

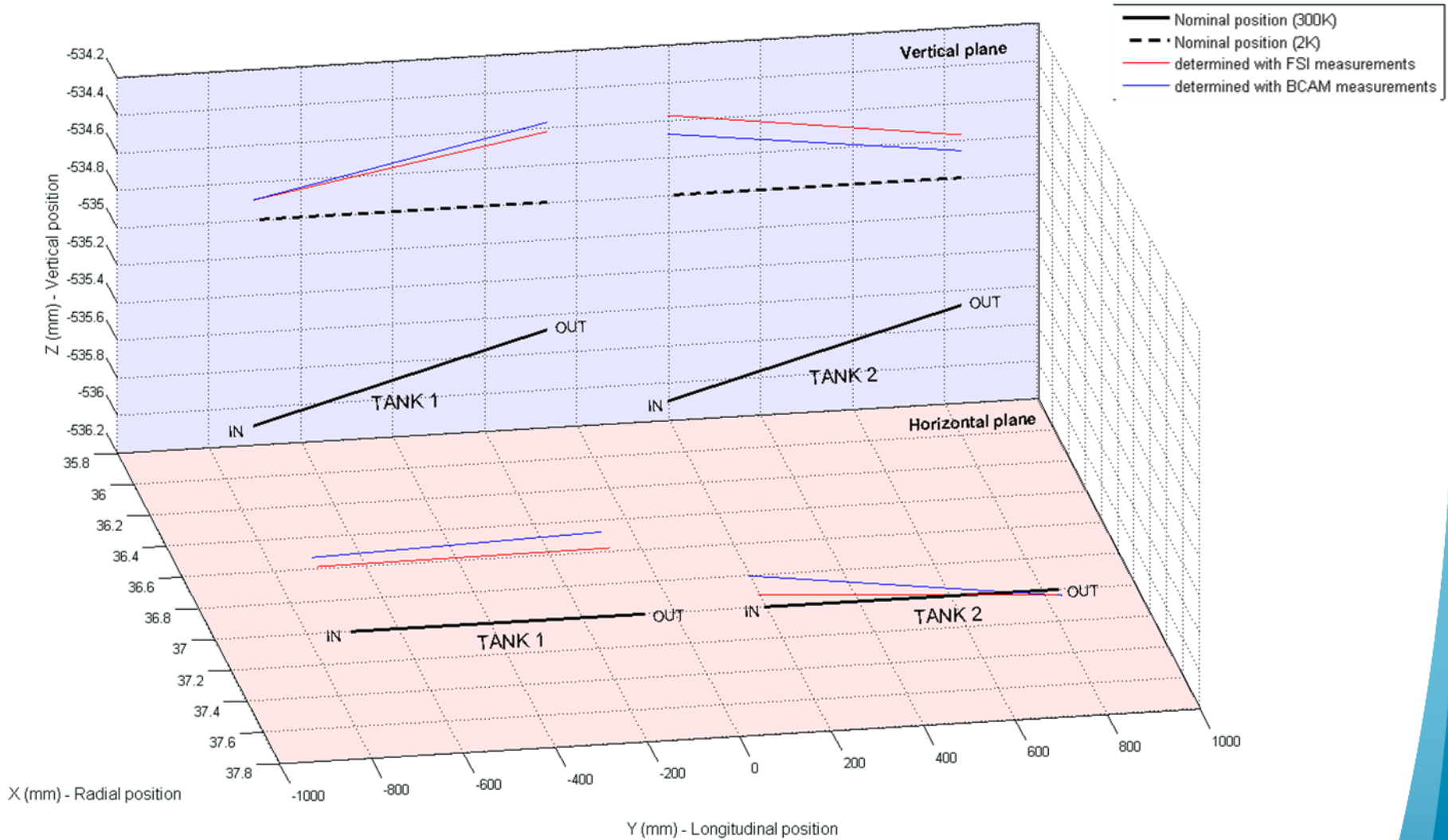
Conclusion

- FSI, BCAM and Laser Tracker measurements are coherent ($\pm 60 \mu\text{m}$)
- Cooling down / Warm up : 2 cycles \rightarrow Repeatability below $10 \mu\text{m}$
- Thermal contraction : Difference between measurements and simulation : + 21%
- Distance to nominal position : $400 \mu\text{m}$
- 2 K : the position of 2 cavities include in cylinder with a radius of $130 \mu\text{m}$

Thank you for your attention

SPARE

Condition : 4 K



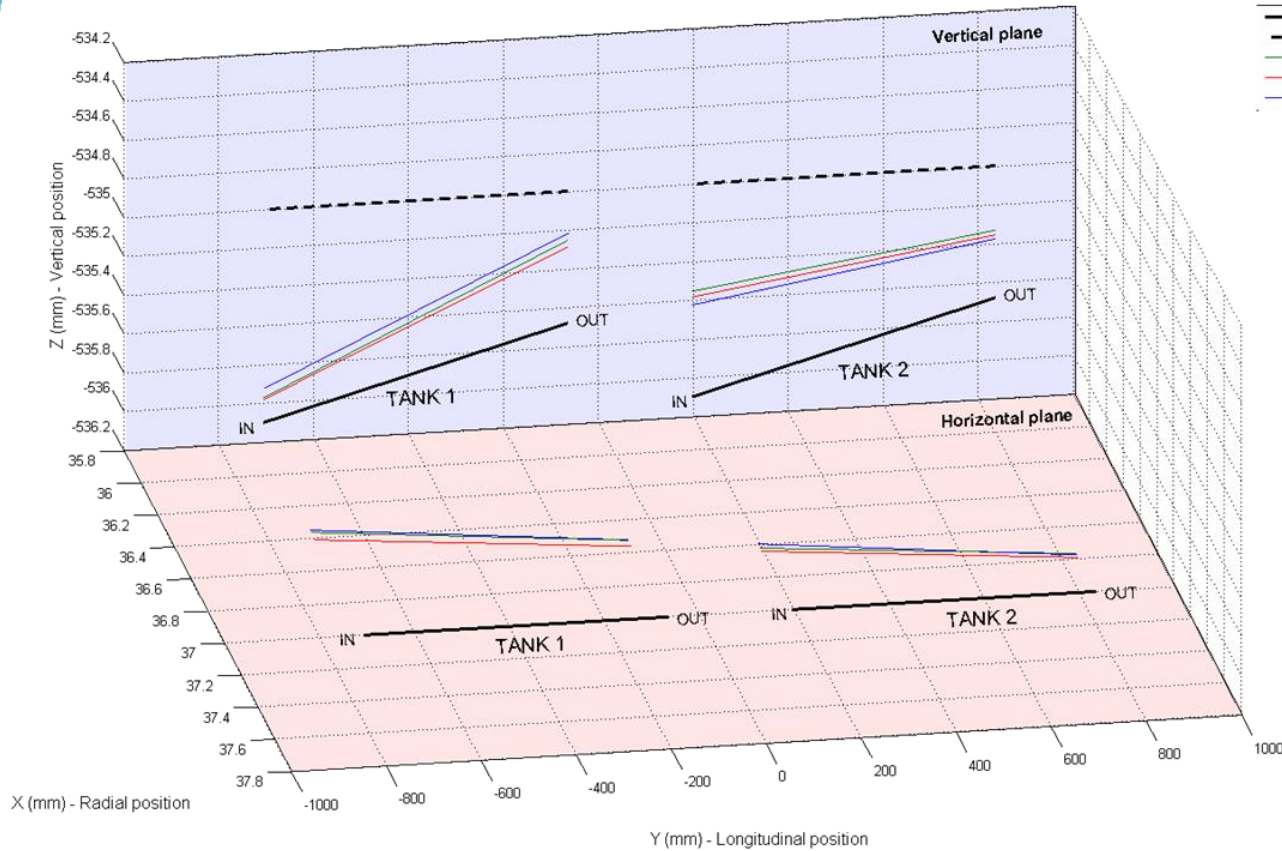
Differences between :

- FSI measurements
- BCAM measurements



• +/- 60 μm

Cavities axis : room temperature (293 K) and ambient pressure



- Nominal position (300K)
- - - Nominal position (2K)
- determined with AT401 measurements
- determined with FSI measurements
- determined with BCAM measurements

AT401 measurement

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X-Radial (mm)	36.361	36.523	36.618	36.763
Y-Longitud (mm)	-706.039	-66.037	193.690	833.693
Z-Vertical(mm)	-535.969	-535.251	-535.553	-535.331

FSI measurement

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X-Radial (mm)	36.407	36.560	36.637	36.788
Y-Longitud (mm)	-706.017	-66.019	193.721	833.746
Z-Vertical(mm)	-535.978	-535.284	-535.583	-535.354

BCAM measurement

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X-Radial (mm)	36.347	36.520	36.592	36.772
Y-Longitud (mm)	-705.735	-65.571	193.993	833.920
Z-Vertical(mm)	-535.922	-535.216	-535.624	-535.375

AT401 measurement Accuracy

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X Accuracy (mm)	0.013	0.013	0.015	0.014
Y Accuracy (mm)	0.012	0.012	0.014	0.014
Z Accuracy(mm)	0.014	0.015	0.016	0.015

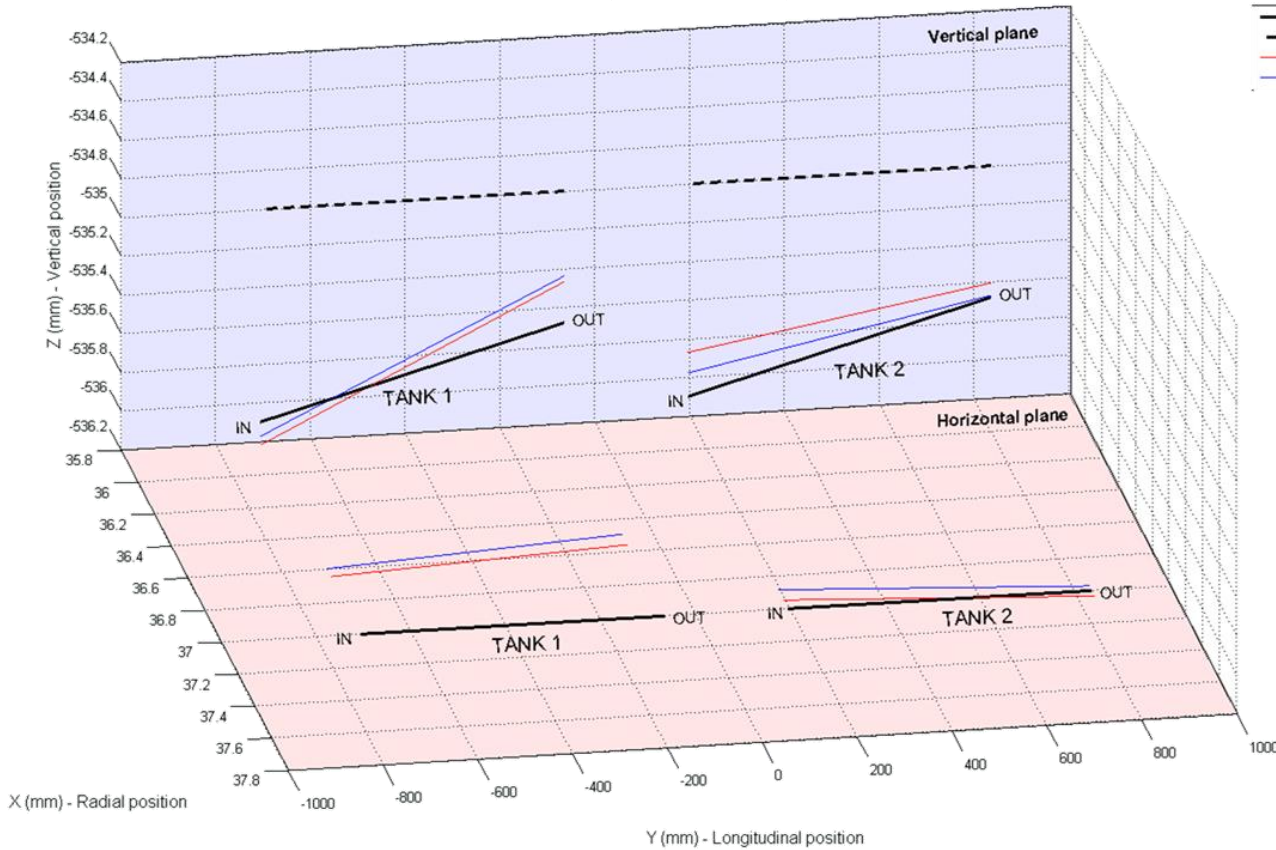
FSI measurement Accuracy

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X Accuracy (mm)	0.044	0.044	0.050	0.050
Y Accuracy (mm)	0.039	0.039	0.044	0.044
Z Accuracy(mm)	0.019	0.019	0.022	0.021

BCAM measurement Accuracy

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X Accuracy (mm)	0.045	0.049	0.052	0.052
Y Accuracy (mm)	0.966	0.961	1.051	1.051
Z Accuracy(mm)	0.048	0.046	0.055	0.053

Cavities axis : room temperature (293 K) and under vacuum



— Nominal position (300K)
 - - - Nominal position (2K)
 — determined with FSI measurements
 — determined with BCAM measurements

FSI measurement

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X-Radial (mm)	36.641	36.555	36.946	37.034
Y-Longitud (mm)	-706.092	-66.006	193.637	833.727
Z-Vertical(mm)	-536.216	-535.466	-535.870	-535.604

BCAM measurement

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X-Radial (mm)	36.592	36.490	36.882	36.971
Y-Longitud (mm)	-705.590	-65.471	193.782	833.597
Z-Vertical(mm)	-536.170	-535.436	-535.976	-535.668

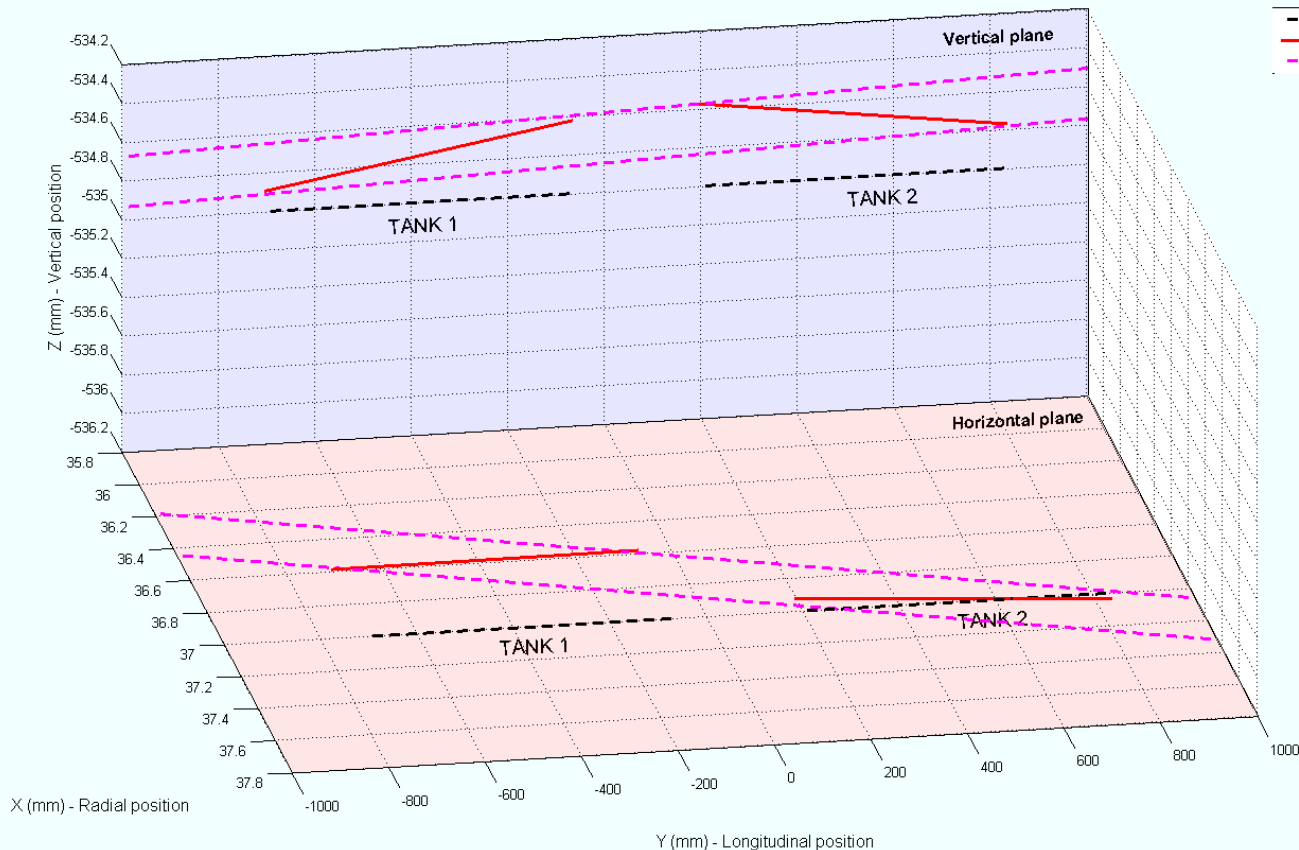
FSI measurement Accuracy

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X Accuracy (mm)	0.044	0.044	0.044	0.044
Y Accuracy (mm)	0.039	0.039	0.039	0.039
Z Accuracy(mm)	0.019	0.019	0.019	0.019

BCAM measurement Accuracy

	TANK 1 - IN	TANK 1 - OUT	TANK 2 - IN	TANK 2 - OUT
X Accuracy (mm)	0.048	0.047	0.050	0.051
Y Accuracy (mm)	1.000	0.998	1.056	1.052
Z Accuracy(mm)	0.047	0.048	0.056	0.054

Cavities axis : 4 K



- - - Nominal position (2K)
 — determined with FSI measurements
 - - - Cylinder Radius = 0.13 mm

FSI measurement

	TANK1 - IN	TANK1 - OUT	TANK2 - IN	TANK2 - OUT
X-Radial (mm)	36.582	36.574	36.922	37.036
Y-Longitud (mm)	-705.125	-66.474	194.219	832.871
Z-Vertical(mm)	-534.895	-534.623	-534.575	-534.772

FSI measurement Accuracy

	TANK1 - IN	TANK1 - OUT	TANK2 - IN	TANK2 - OUT
X Accuracy (mm)	0.044	0.044	0.044	0.044
Y Accuracy (mm)	0.039	0.039	0.039	0.039
Z Accuracy(mm)	0.019	0.019	0.019	0.019