Mechanics of MUonE tracking station

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on behalf of the MUonE collaboration

INFN-Pisa & CNR-INO & CERN

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II Muon Precision Physics Workshop (MPP2023)- 7/10 Nov 2023

Outline

- Introduction
- Mechanics
- Temperature
- Etalon
- Metrology
- Holografic aligment monitor (HAM)

Introduction

MUonE is an high precision tracking experiment. It requires:

- *light tightness*
- *humidity below a threshold (20%)*

} Required by the Pt-2S sensors

- *Stability* of the tracking sensors along the beam $\delta z < 10\ \mu m$

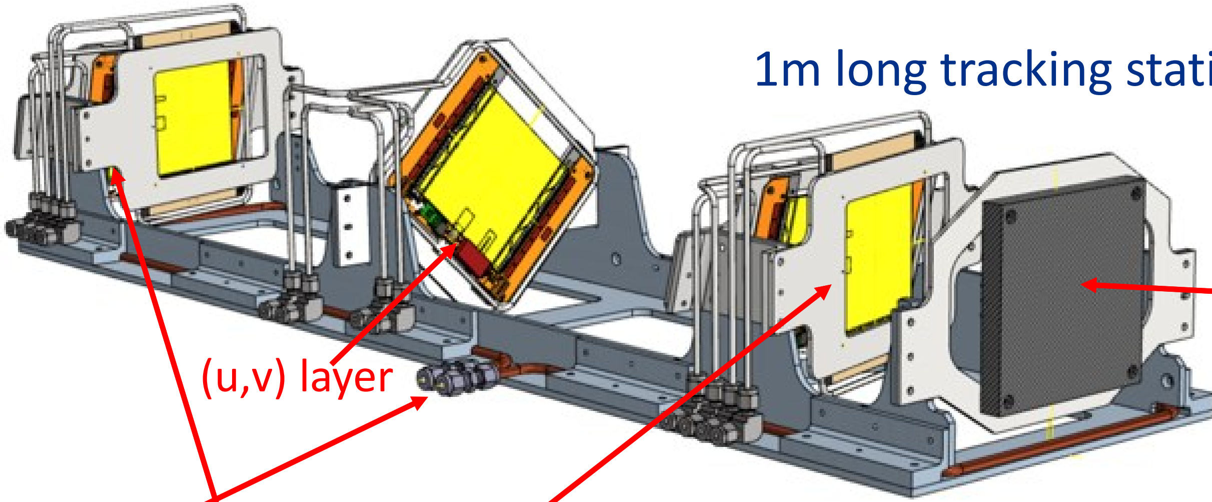
↓

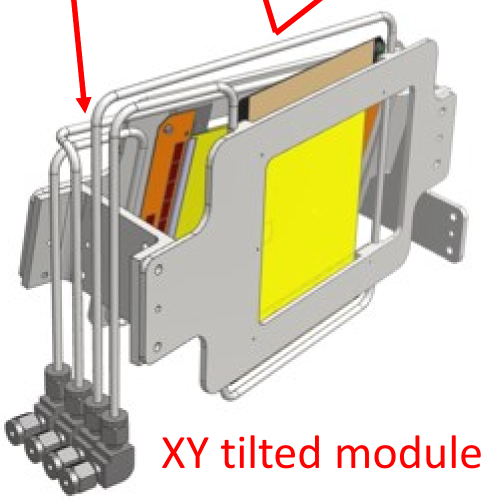
- ➢ Very stable temperature
- ➢ Low CTE material: → {
  - Invar (CTE = 1.2 ppm/K)
  - Glass/ceramic (Zerodur, 0.007 ppm/K)
  - Fiber carbon (- 0.1 ppm/K)
  - Aluminum is 24 ppm/K

Shape of the support

Tracker station mechanical design

1m long tracking stations; 3 layers of XY sensors

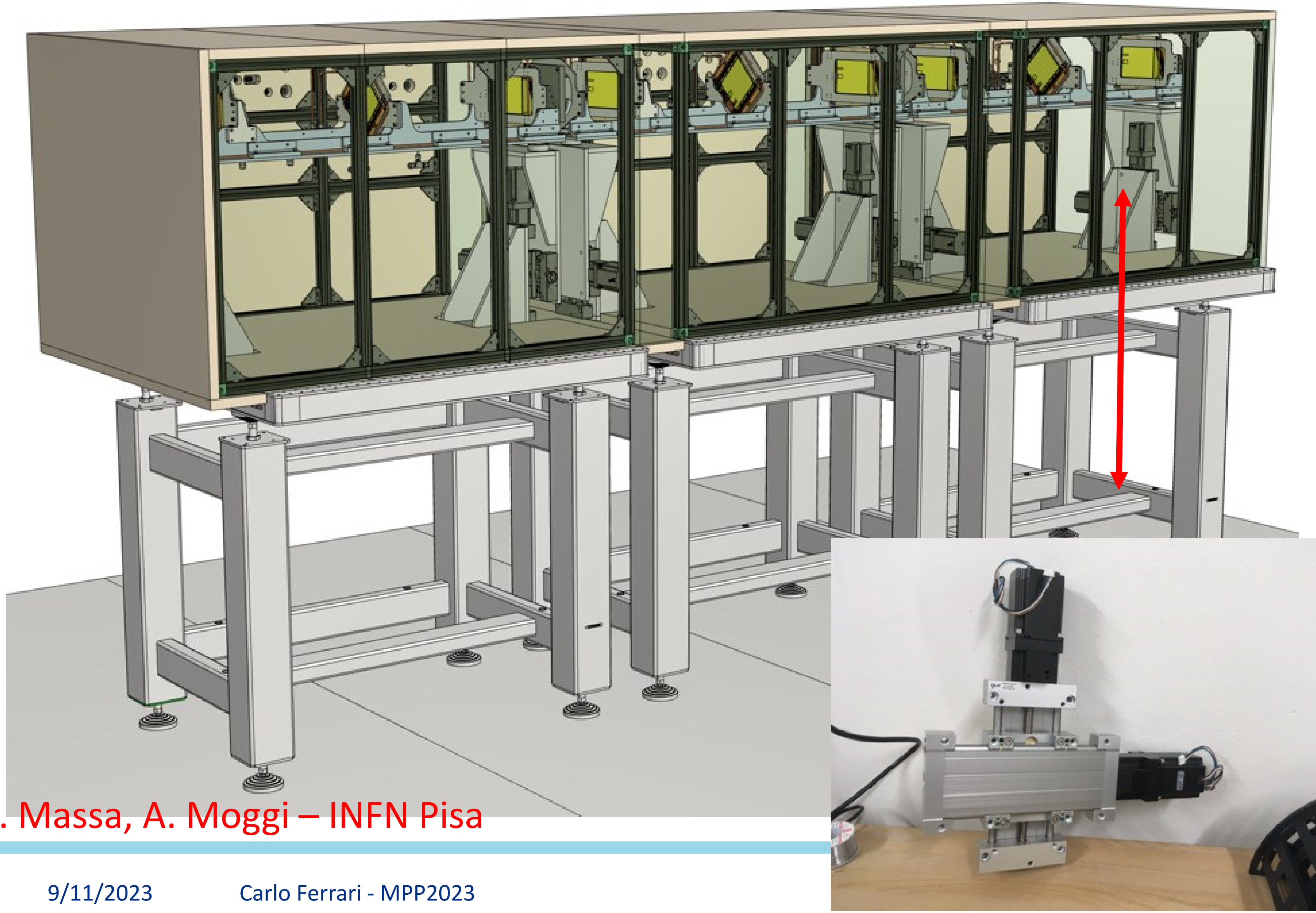




Requirement: very stable structure (< 10 μm)

- Based on Pt2S modules from CMS
- "tilt angle" to improve the hit resolution, (more complex fitting stage)
- Second module rotated to resolve ambiguities
- Module *stability* along the beam is $\delta z < 10\ \mu m$
- Structure with low thermal expansion coefficient (**Invar**, cte = $1.2 \times 10^{-6}\ K^{-1}$)
- Cooling circuit to control temperature and extract heat produced by the Pt2S modules (5W)
- *light tightness & humidity below a threshold (30%)*

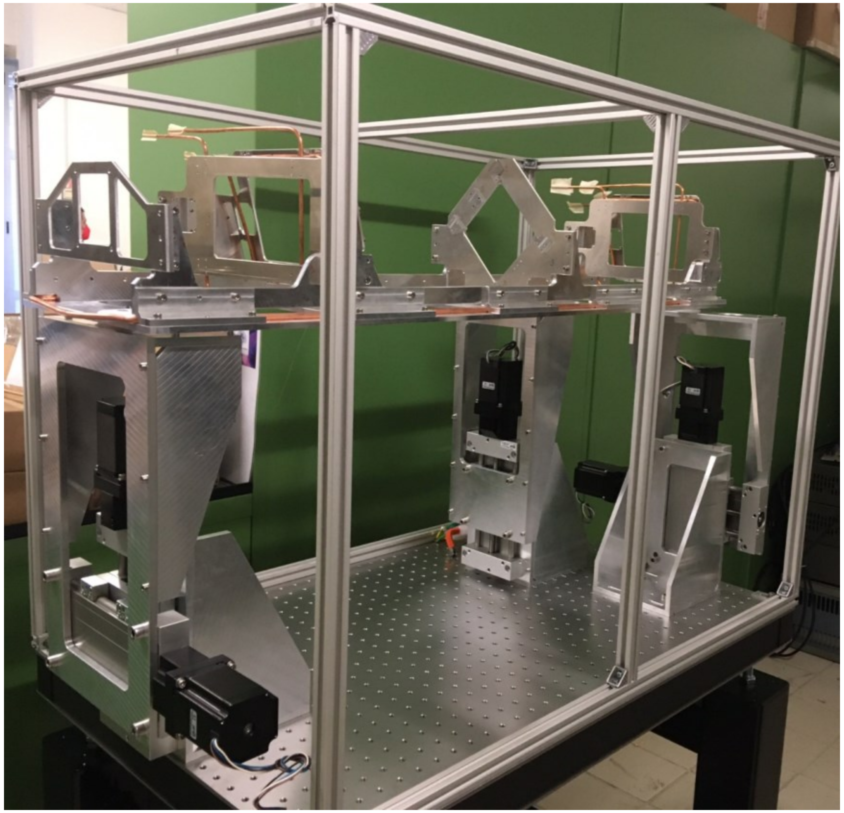
Tracker station mechanical design



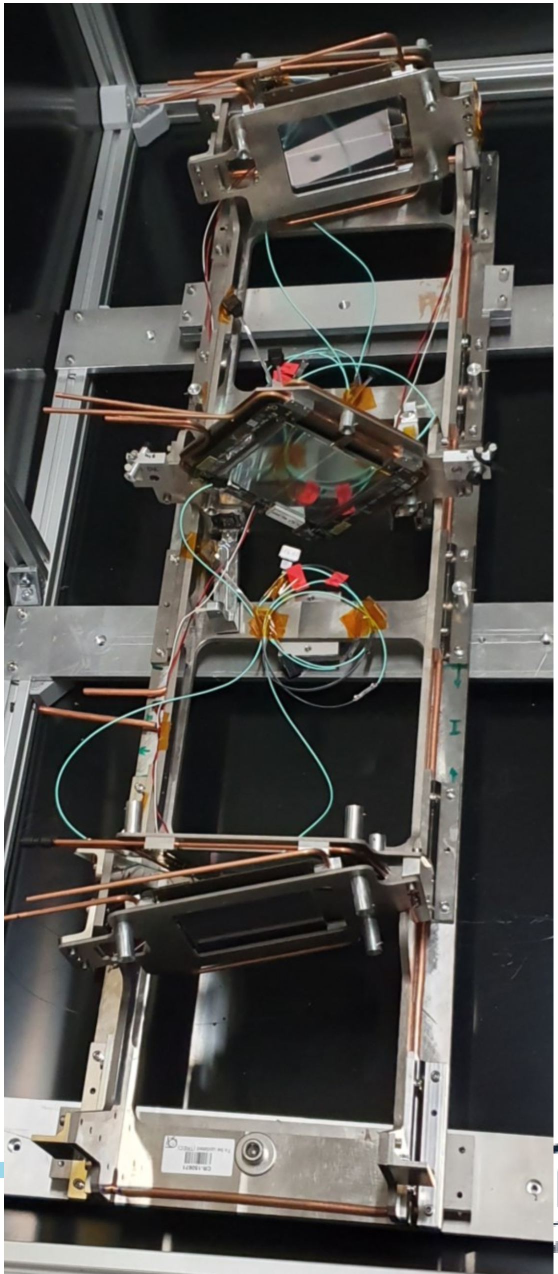
M. Massa, A. Moggi – INFN Pisa

Enclosure and aligment motors

- Stepper motors installed and tested (200 steps/revolution, 2 mm lead screw, 10 um steps, ± 26 mm stroke)



Station installed on M2 in June 2022



Invar

We built:

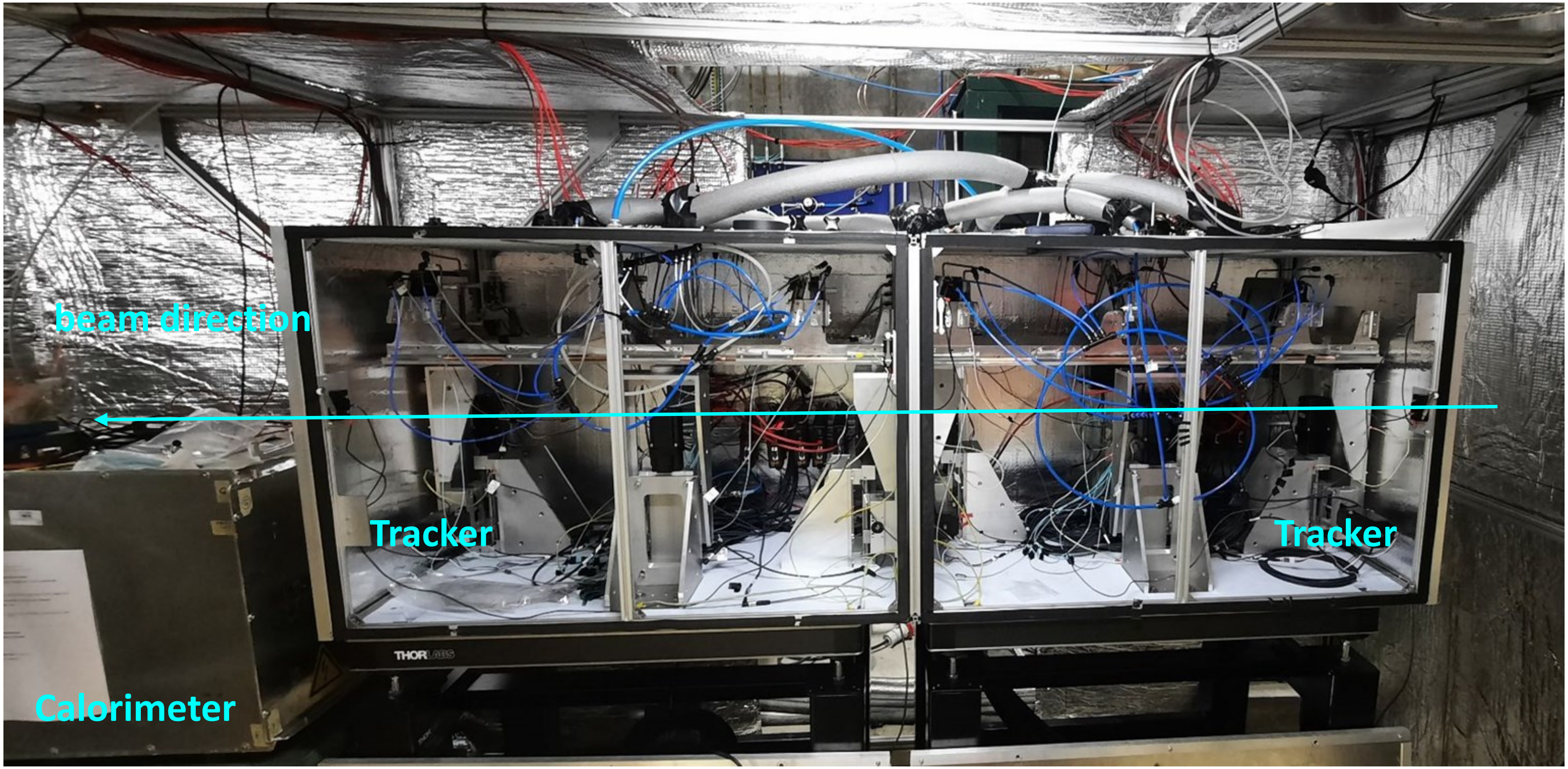
- two mock-up made of Aluminum in 2022
- three stations made of Invar in 2023

- Lesson learned about Invar:
- It is difficult to procure
- It is expensive
- it is hard to work in the workshop
- It is heavy (20 kg)
- **works well**

We are exploring the possibility of using carbon fiber (Liverpool)

The only problem that could arise concerns the rigidity of the structure (see subsequent slides)

Detectors setup, TB 2023



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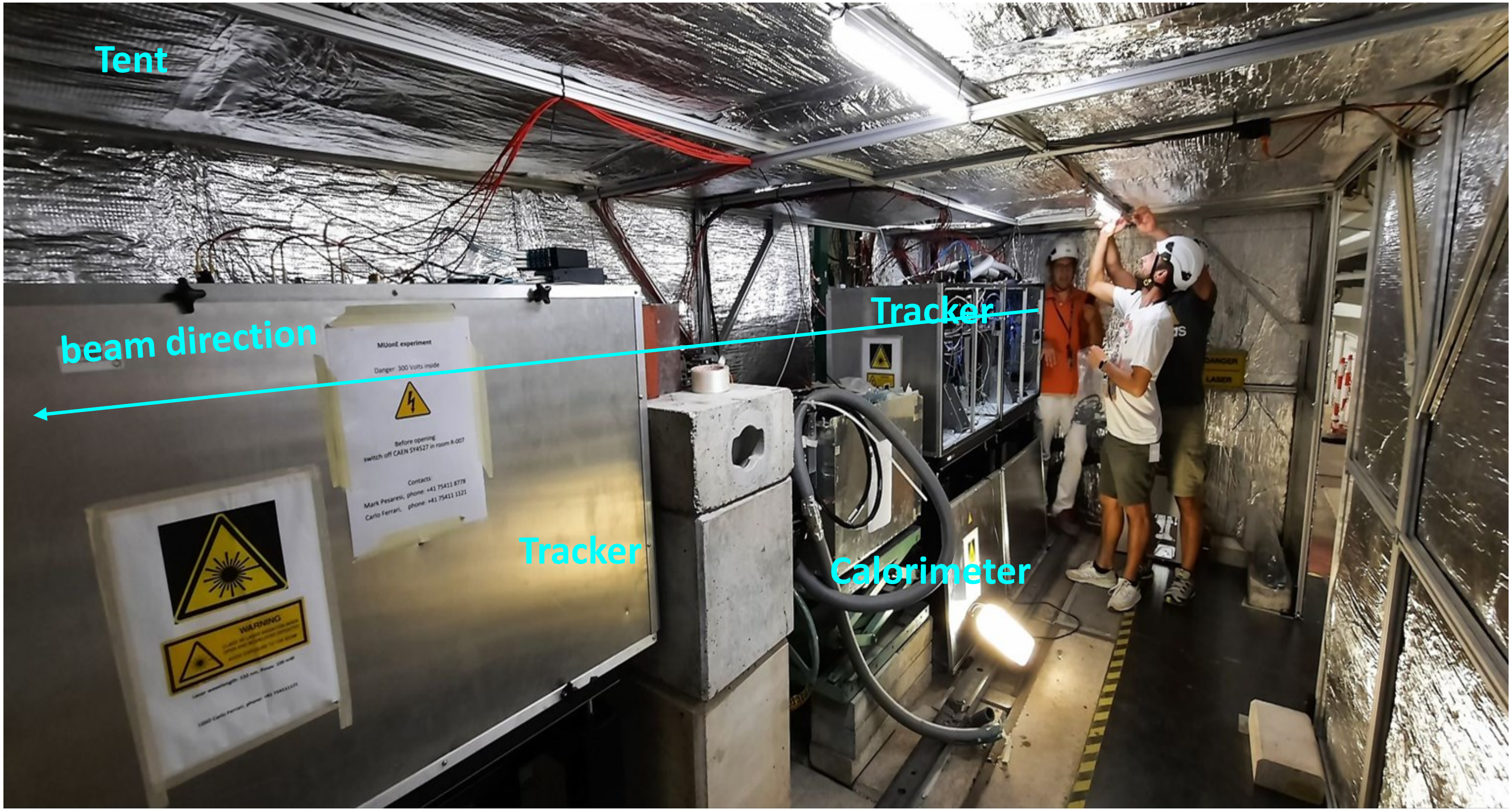
Detectors setup, TB 2023



The «tent»

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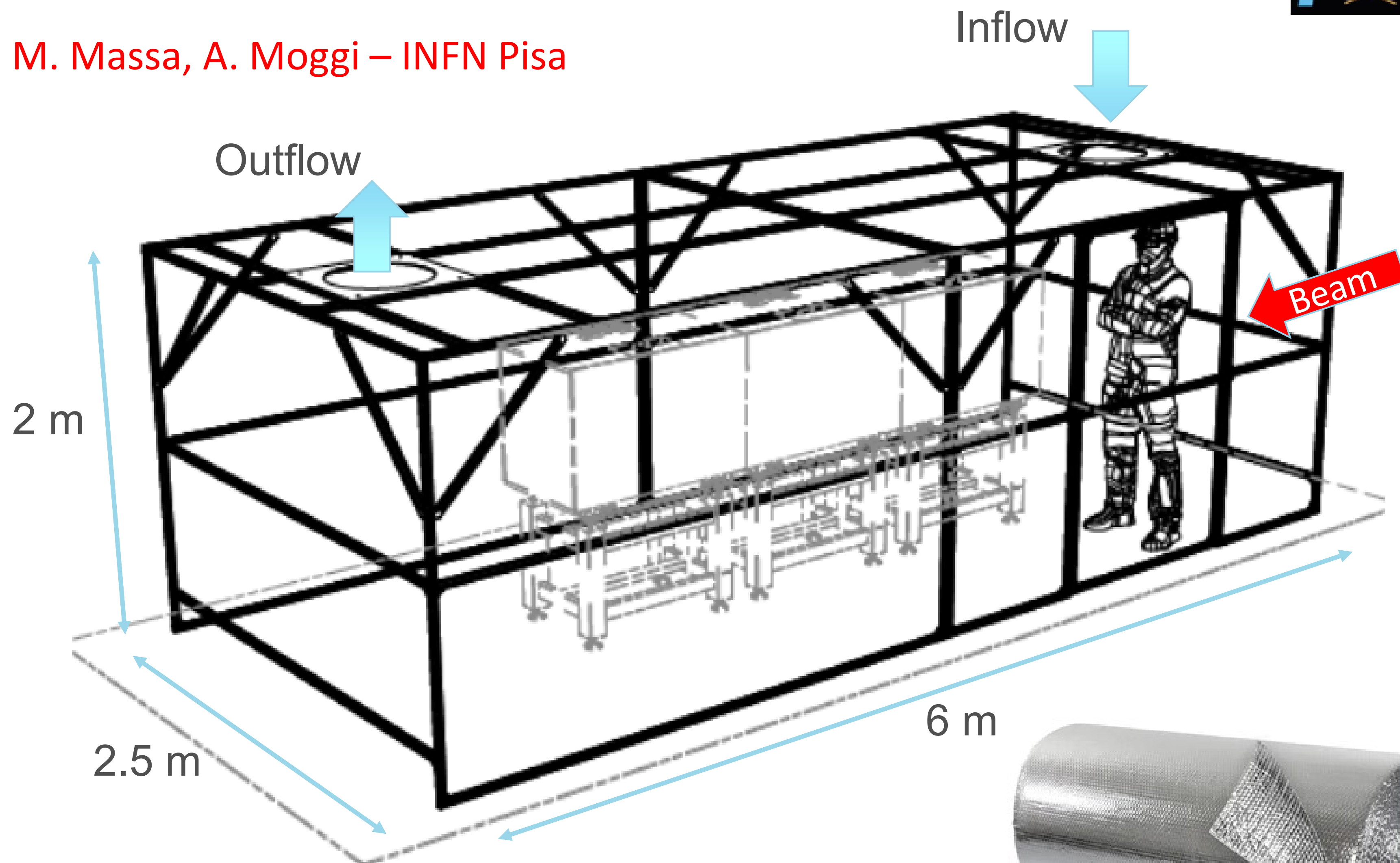
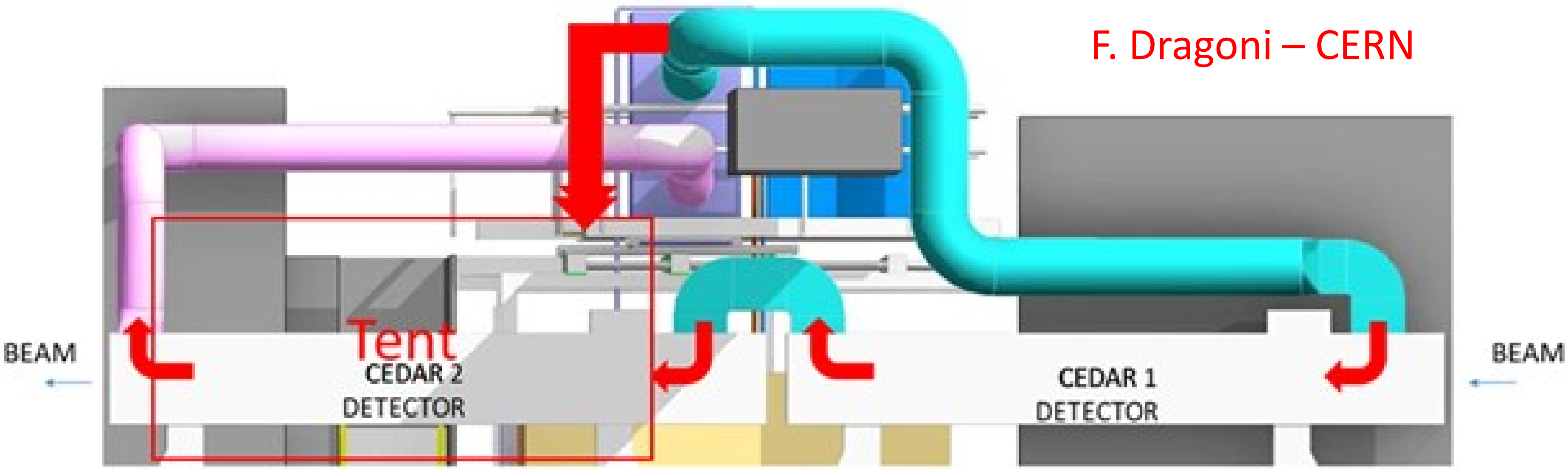


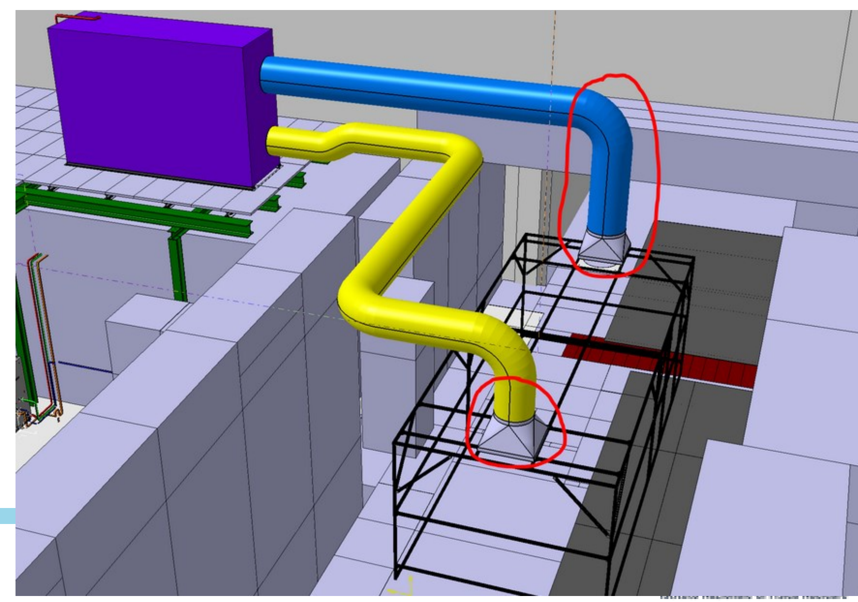
Insulating material: **Double Bubble Insulation**

The «tent»: The integration model

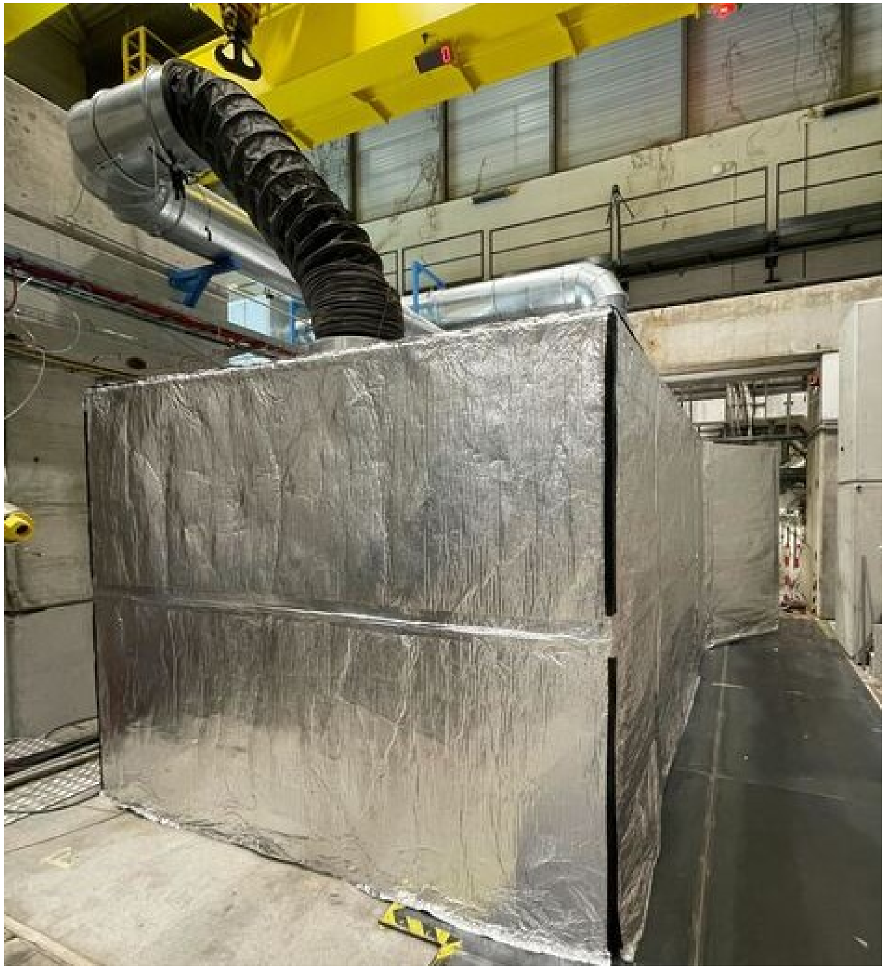
F. Dragoni – CERN



- Air T = 18 °C
- Mixing ventilation
- Duct modification
- C&V will take care of it



MUonE installation



Temperature

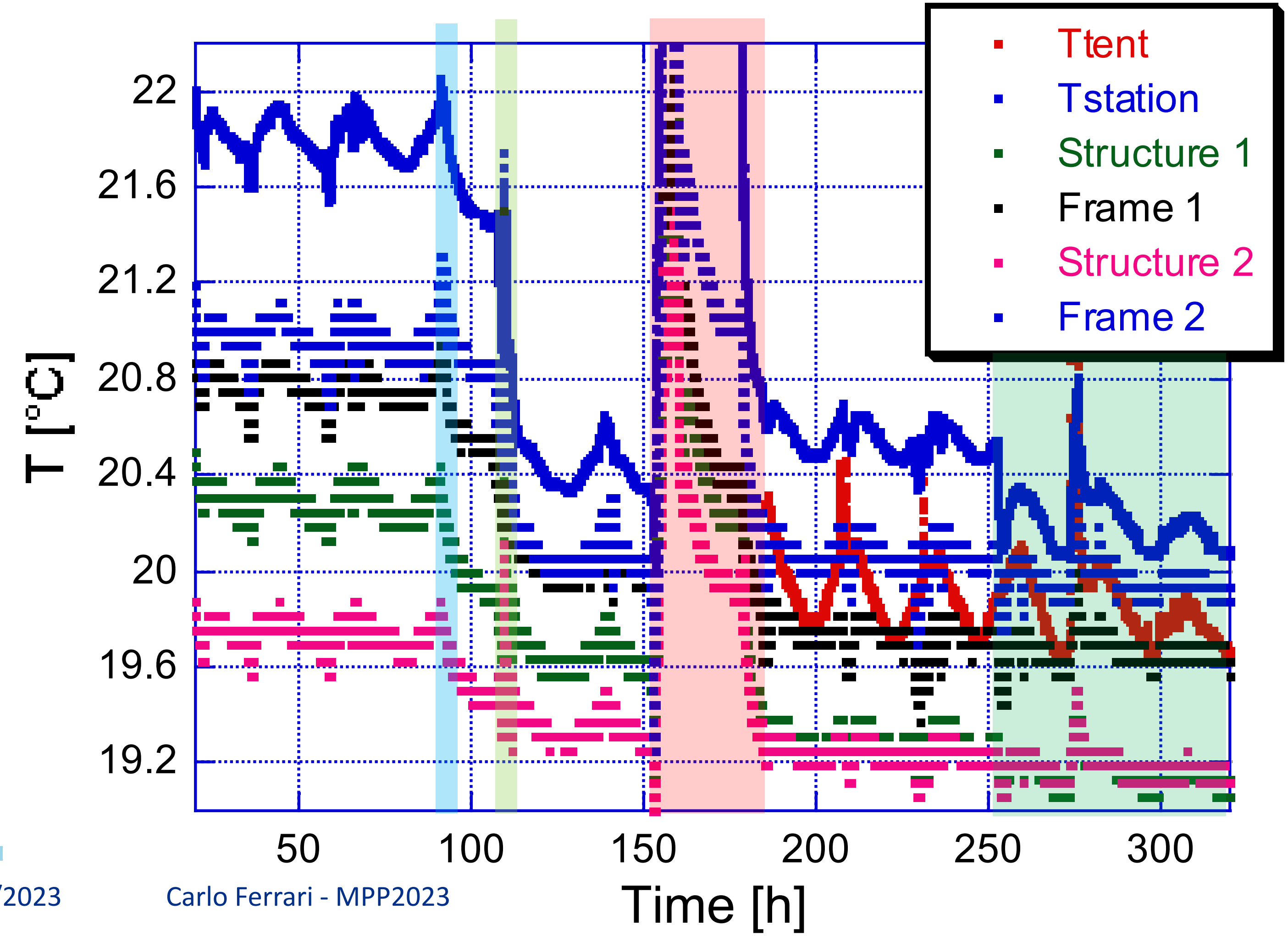
Starting point: Wednesday 31st Aug. Cooling started at 6pm (20 h)

Sunday 3th Sept (90.5 h): improved heat exchange on the dry air circuit

Monday 4th Sept: increased flow of cooling air (108h), access (110h), increased flow of dry air (112h)

Wednesday 6th Sept: Laser survey, flow to the calorimeter (155h)

Wednesday 13th Sept: Power supply Pt-2S OFF (250h), third station connected (270h)



Comments on temperature

The temperature of the structure is the result of a balance between various factors:

1) The AC at 18°C
2) the chiller at 18°C
3) modules releasing 5 W each
4) the dry air arriving at room T
5) the heat flux through the station walls which depends on the ambient/station temperature difference

Unfortunately, the AC is not dry air: the dry air is at room T

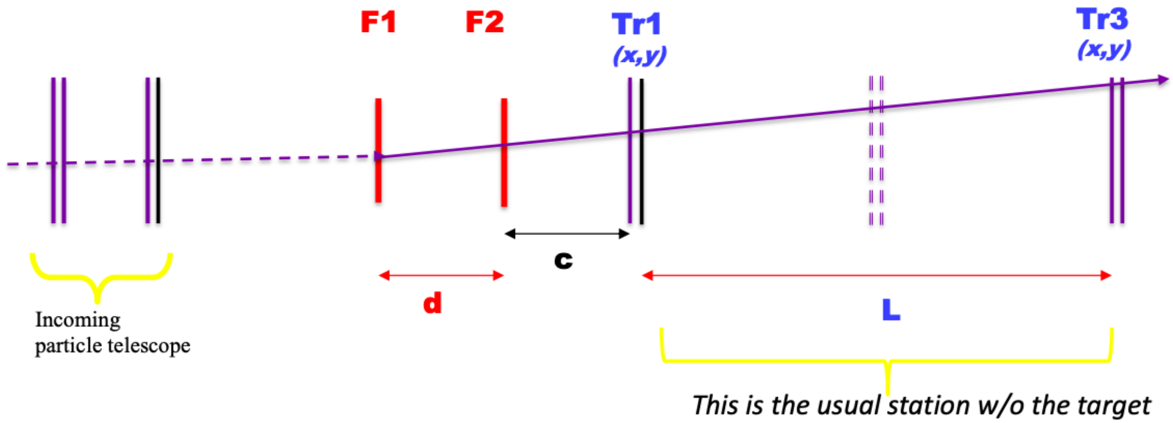
To mitigate this, dry air at ambient T go through a long pipe inside the tent before inserting it into the station, in order to thermalize it at 18°C.

Conclusions:

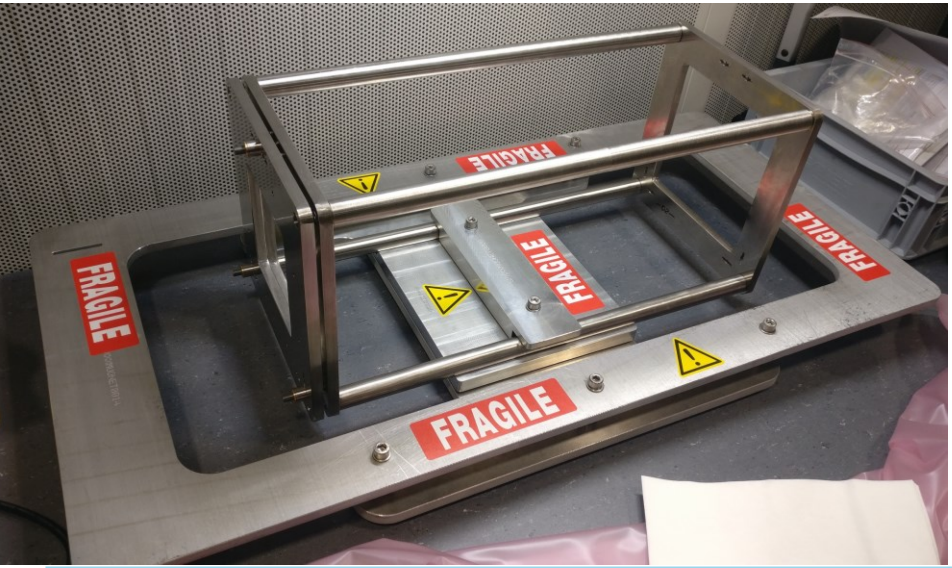
- Temperature of the frames are higher that that of the structure (as it should)
- The night/day fluctuation are visible in the plot
- Fluctuations in stable conditions are about 0.4 °C
- Temperatures are affected by the flows (both AC and dry air)
- AC flow and dry air flow can change the temperature by about 0.5 °C each

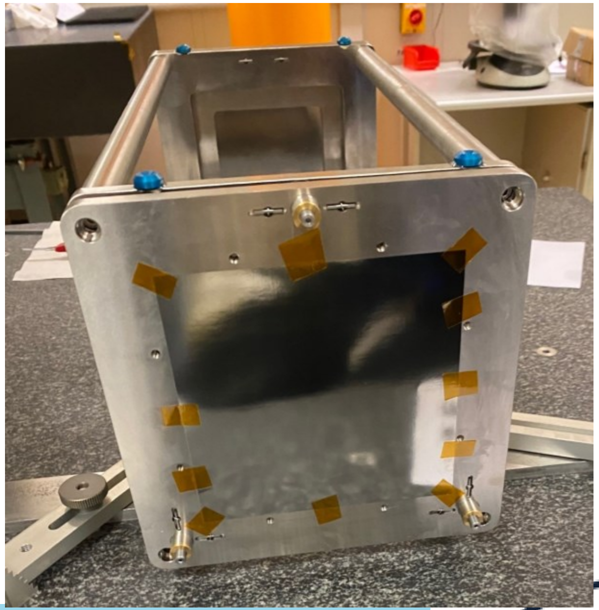
The Etalon device («Standard meter»)

It is proposed to use hadron interactions produced in two thin planes (of few micrometer) of tungsten, separated by a distance that can be measured to the required micron accuracy.



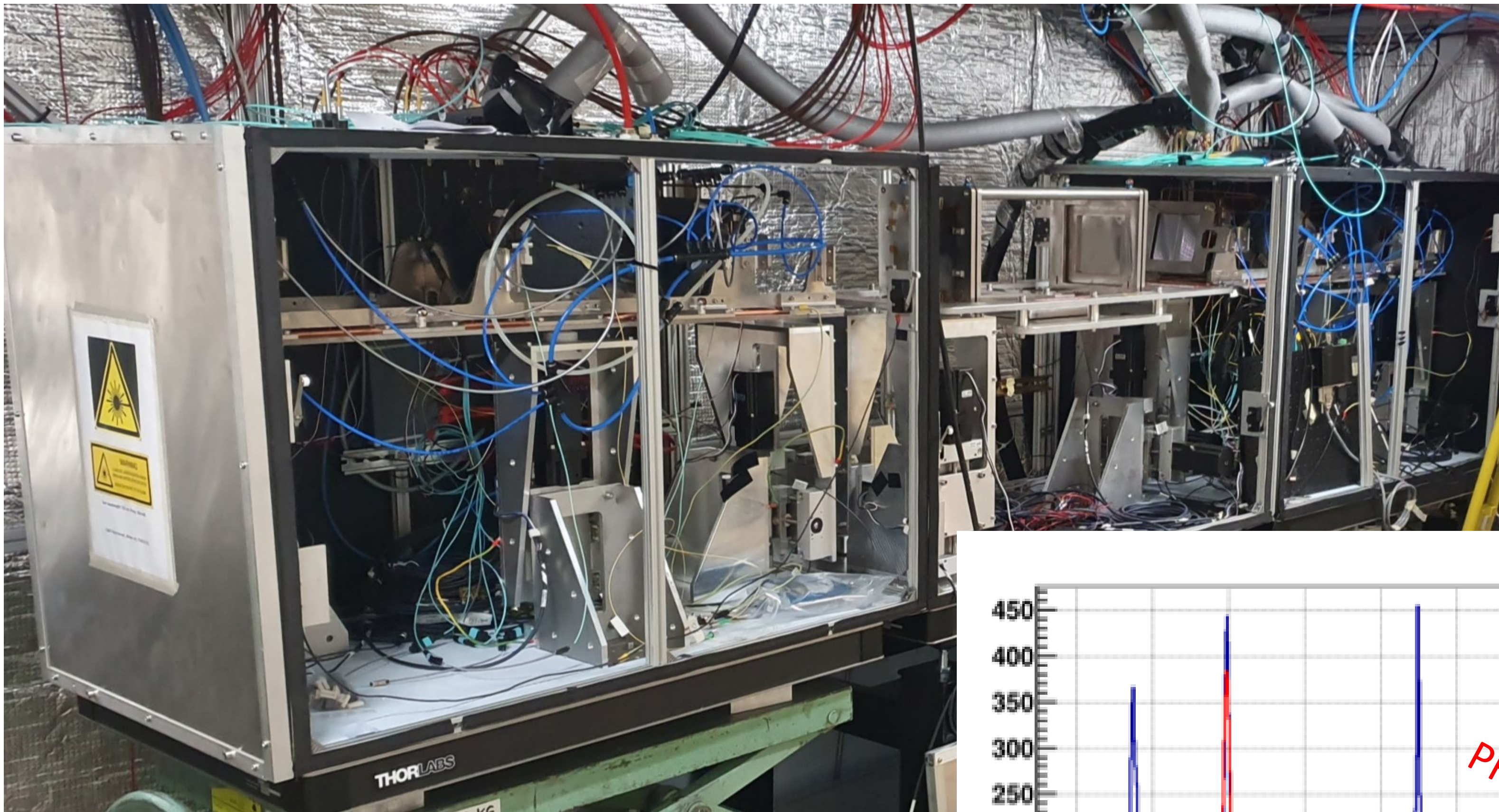
Etalon is developed by the CERN SY-STI-TCD group

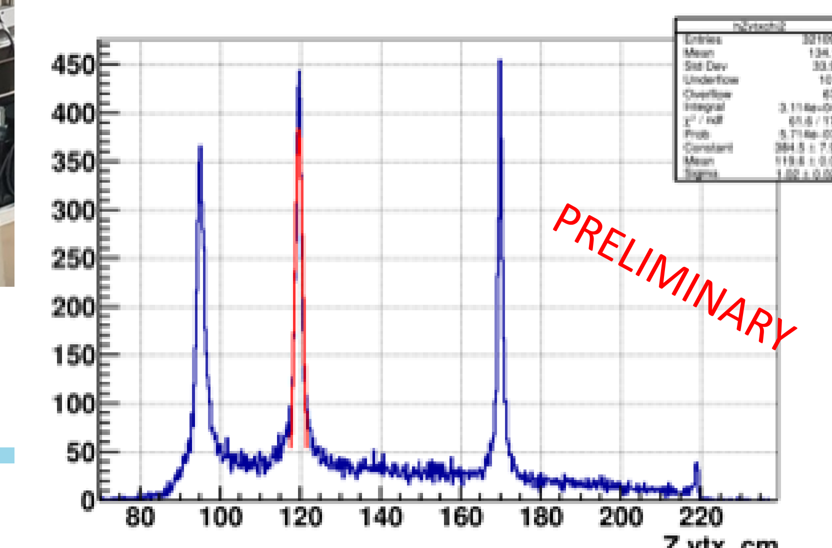




The Etalon device («Standard meter»)

Test beam on M2, Aug-Sept 2023, Pions





Laser survey

Measuring uncertainty:
100 µm

Two measurements (spheres on the main structure):

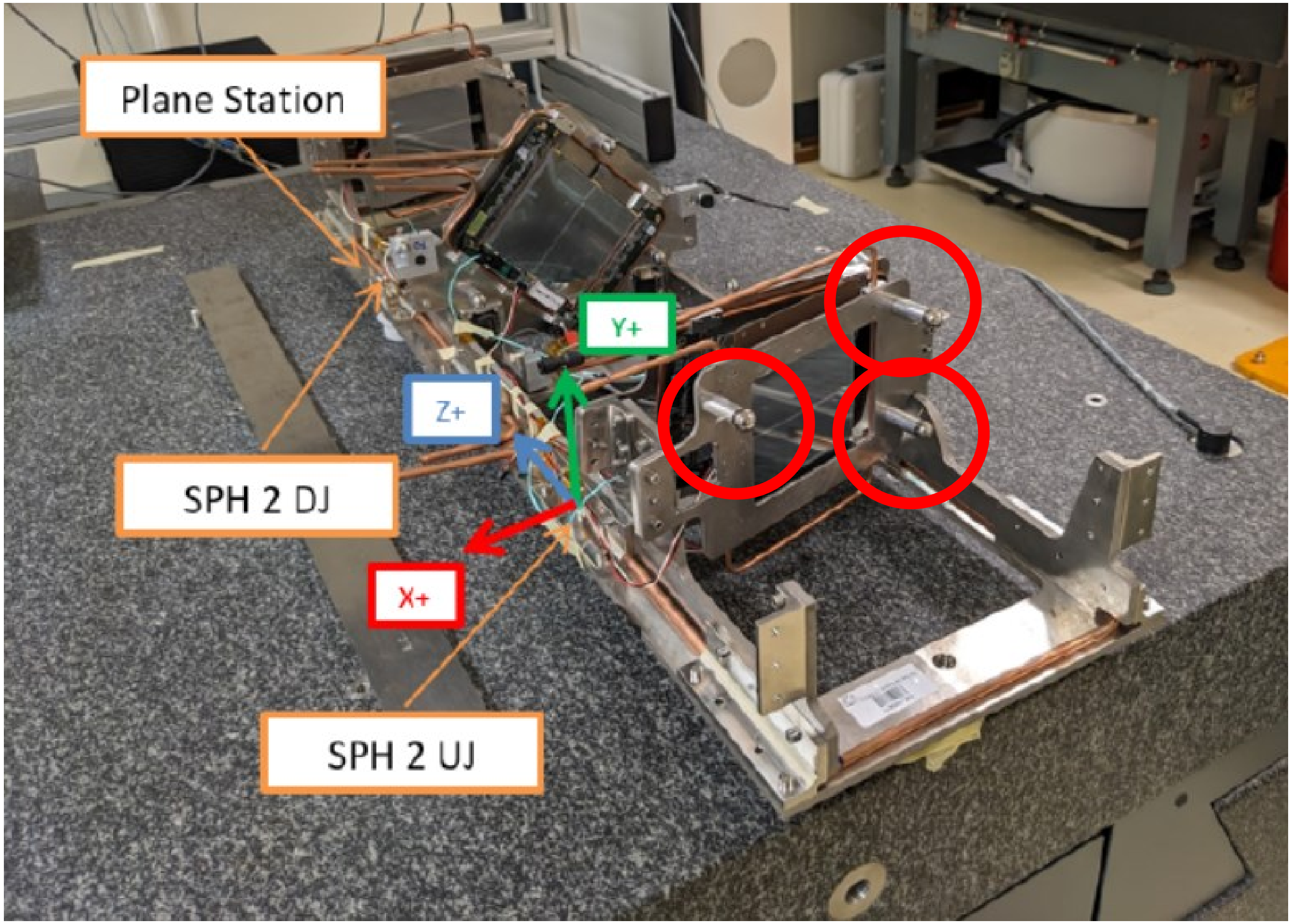
6/9/2023
ECAL + 2 stations

25/9/2023
Etalon + 2 stations

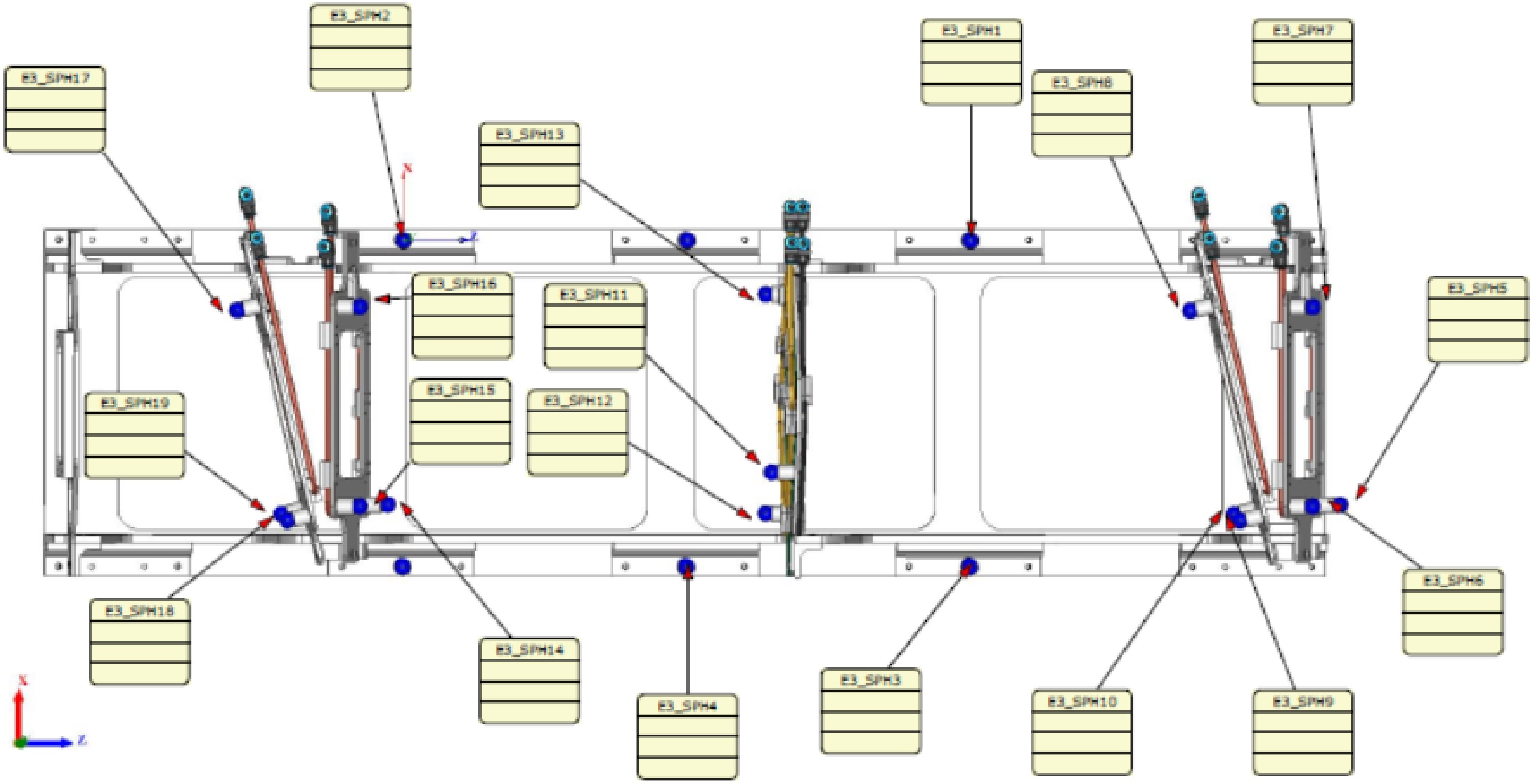
Metrology – 1 step

Metrology device:
Leitz PMM-C

Measuring uncertainty:
± (0.3µm + L/1000)

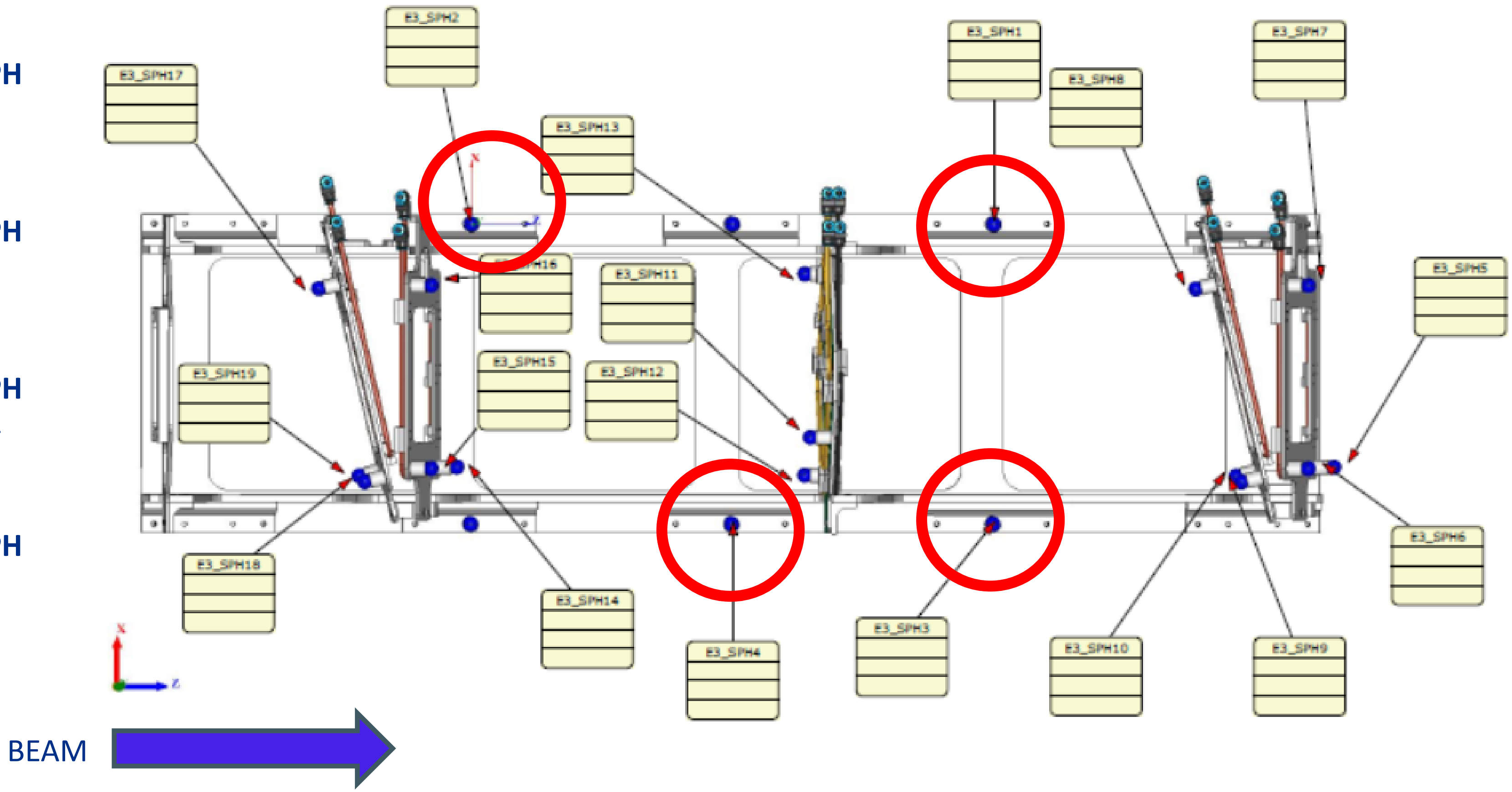


Fiducial markers (19 spheres)



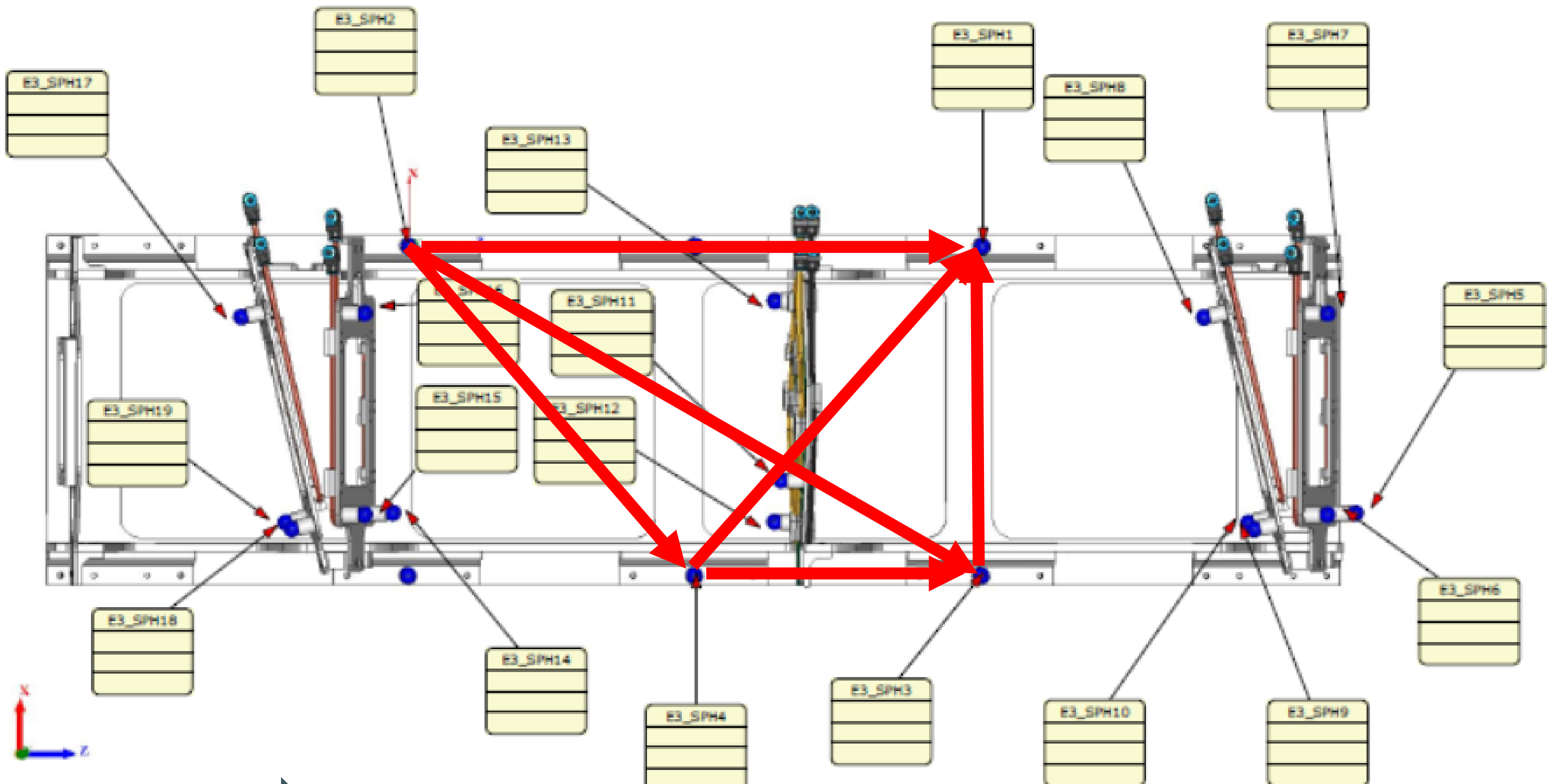
Metrology – spheres on the main structure

E3_SPH1 SPH
X 0.0000
Y -0.0074
Z 428.0351
E3_SPH2 SPH
X 0.0000
Y 0.0000
Z 0.0000
E3_SPH3 SPH
X -246.0054
Y 10.8511
Z 428.0057
E3_SPH4 SPH
X -245.8462
Y 10.7866
Z 213.9291



Metrology – distance between spheres

E3_SPH1 SPH
X 0.0000
Y -0.0074
Z 428.0351
E3_SPH2 SPH
X 0.0000
Y 0.0000
Z 0.0000
E3_SPH3 SPH
X -246.0054
Y 10.8511
Z 428.0057
E3_SPH4 SPH
X -245.8462
Y 10.7866
Z 213.9291



BEAM

Metrology – distance between spheres (mm)

Station 1

Laser Survey 1	Laser Survey 2		Metrology (Leitz PMM-	
428.022	427.995	-0.027	428.035	0.013
493.75	493.785	0.035	493.787	0.037
326.087	326.081	-0.006	326.071	-0.016
326.221	326.165	-0.056	326.187	-0.033
214.054	214.075	0.022	214.077	0.023
246.246	246.237	-0.009	246.245	-0.001

Station 2

Laser Survey 1	Laser Survey 2		Metrology (Leitz PMM-	
428.124	428.177	0.053	428.139	0.015
493.794	493.828	0.034	493.826	0.032
326.039	326.059	0.020	326.048	0.010
325.905	325.891	-0.014	325.873	-0.032
214.041	214.043	0.001	214.042	0.001
245.913	245.888	-0.025	245.908	-0.005

On the beamline — In the lab

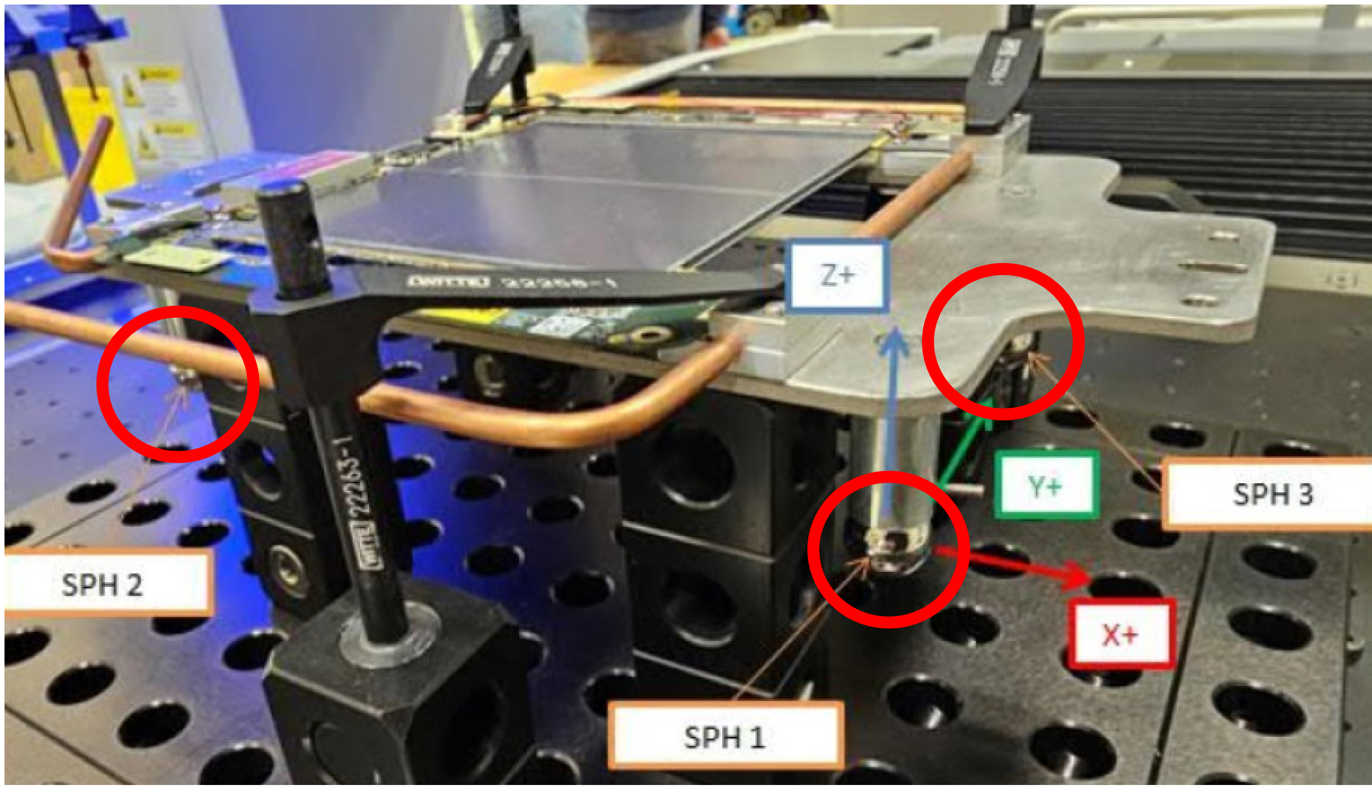
Laser survey measurements are consistent within 60 μm

Metrology measurement is between the two Laser survey measurements (or exceeding < 20 μm)

Metrology – step 2, the sensor

Metrology device:
ZEISS O-Inspect

Measuring uncertainty:
2.2 µm + L/150mm



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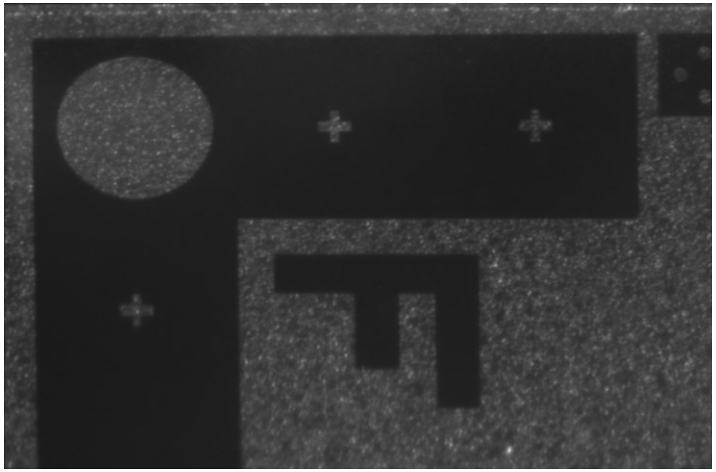
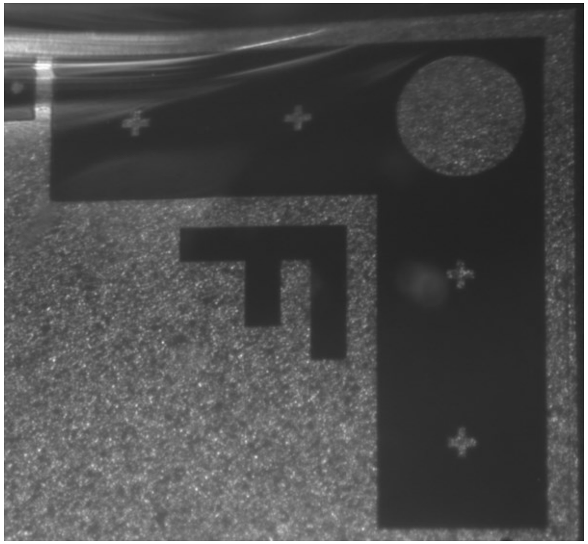
Metrology – distance between spheres





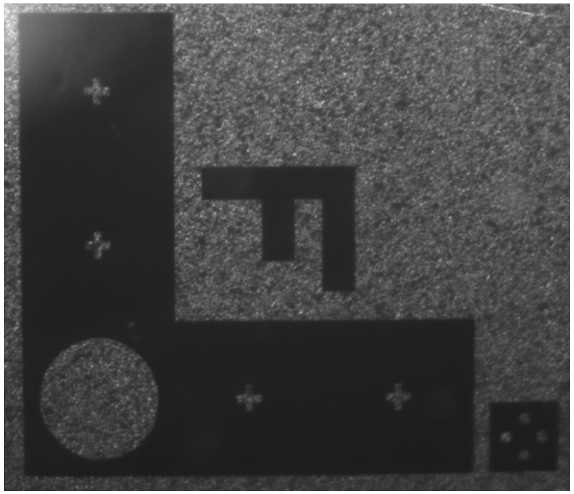
Valeur X_Cercle1 24,812
Valeur Y_Cercle1 104,928
Valeur Z_Cercle1 36,585

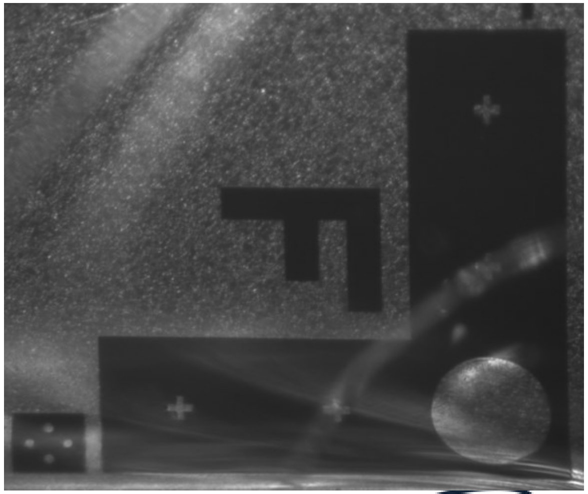
Valeur X_Cercle2 126,989
Valeur Y_Cercle2 105,148
Valeur Z_Cercle2 36,541

Valeur X_Cercle3 127,197
Valeur Y_Cercle3 11,313
Valeur Z_Cercle3 36,444

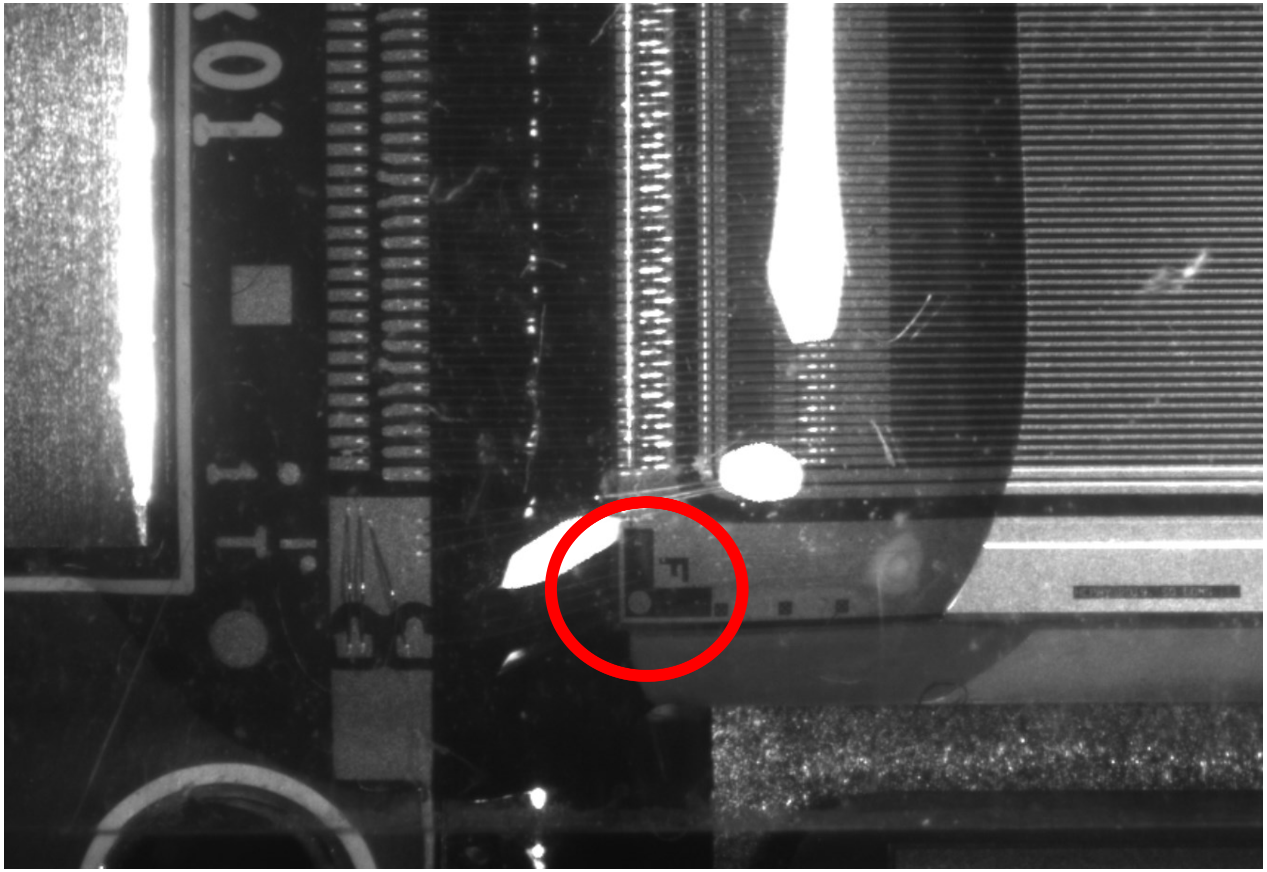
Valeur X_Cercle4 24,981
Valeur Y_Cercle4 11,107
Valeur Z_Cercle4 36,685

The sensors are in the XY plane, more or less





Metrology – drop of resin



Metrology – planes fit

The four points on each sensor are used to determine the sensor plane (see eq. below)
The distance of each point (mainly along Z axis) from the plane is shown in the table (mm):

The equation for a plane is: $ax + by + c = z$. So set up matrices like this with all your data:

$$\begin{bmatrix} x_0 & y_0 & 1 \\ x_1 & y_1 & 1 \\ & \cdots & \\ x_n & y_n & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} z_0 \\ z_1 \\ \cdots \\ z_n \end{bmatrix}$$

In other words:

$$Ax = B$$

Now solve for x which are your coefficients. But since (I assume) you have more than 3 points, the system is over-determined so you need to use the left pseudo inverse: $A^+ = (A^T A)^{-1} A^T$. So the answer is:

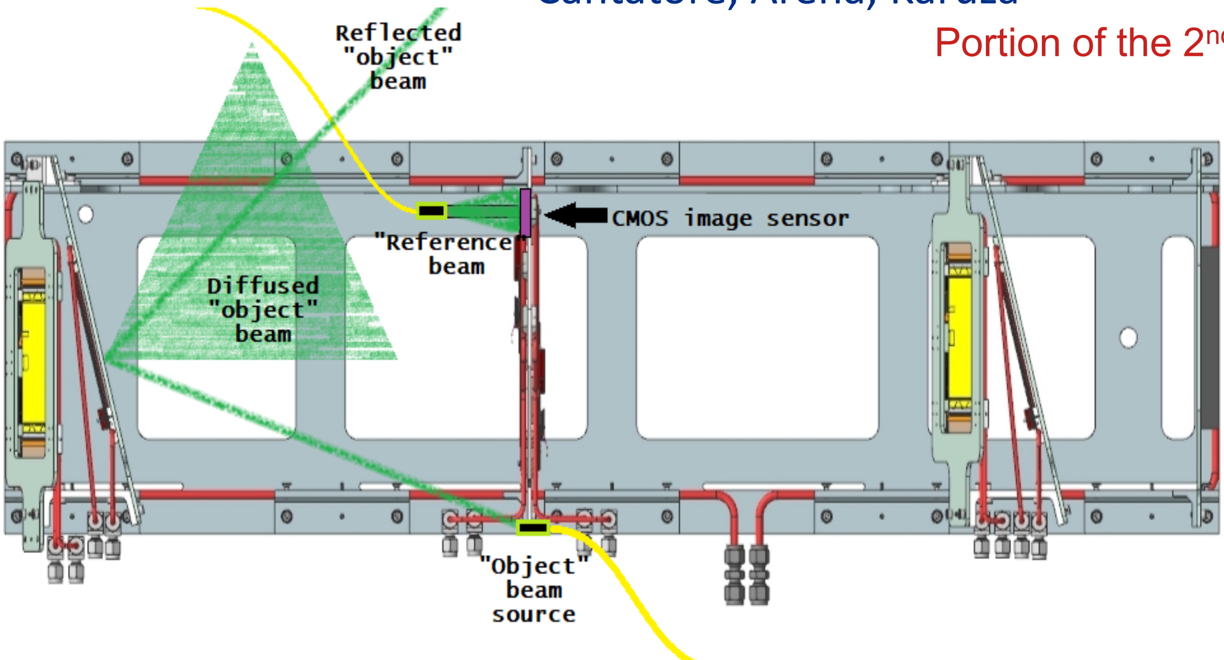
$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = (A^T A)^{-1} A^T B$$

This method fit the plane that minimizes the z distance

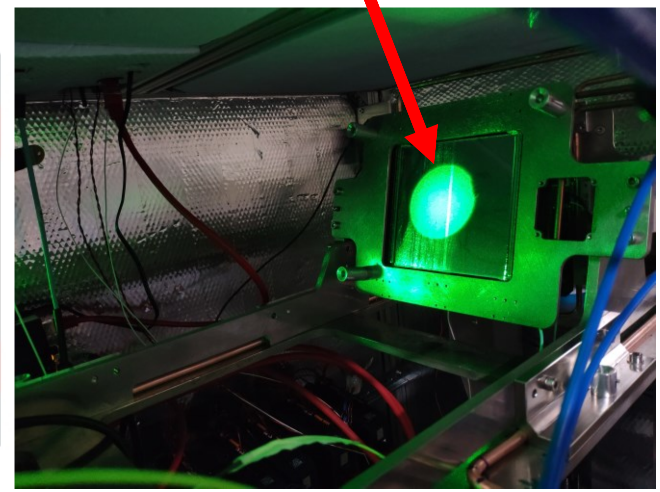
Residuals	Plane-center	Module names	
0.049	2.132E-14	PA1	Station 1
0.007	1.421E-14	PA2	Station 1
0.039	0	B3	Station 1
0.010	1.776E-15	B5	Station 1
0.016	7.105E-15	PAV1	Station 1
0.002	1.421E-14	FNL4	Station 1
0.069	2.131E-14	KIT1	Station 2
0.012	7.105E-15	BRN10	Station 2
0.064	3.553E-15	KIT_Nlato	Station 2
0.003	7.105E-15	KIT_N	Station 2
0.094	0	KIT2	Station 2
0.020	7.105E-15	BRN11	Station 2

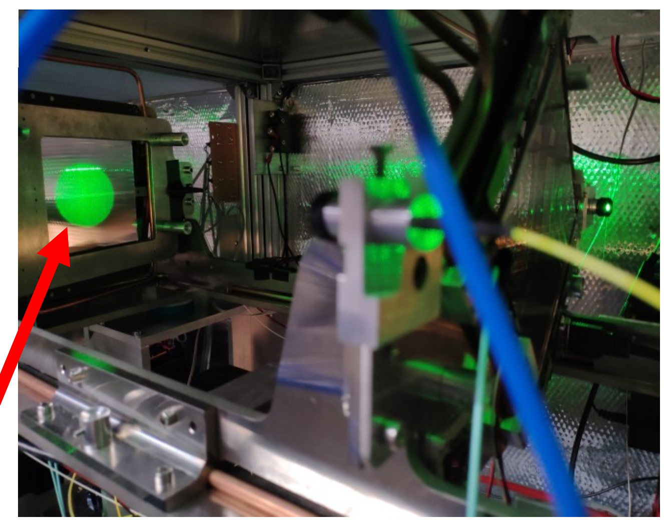
Holografic aligment monitor (HAM)

Cantatore, Arena, Karuza



Portion of the 2nd 2S Module illuminated/monitored





- 532 nm fiber-coupled laser system
- Tracking modules relative displacement monitor

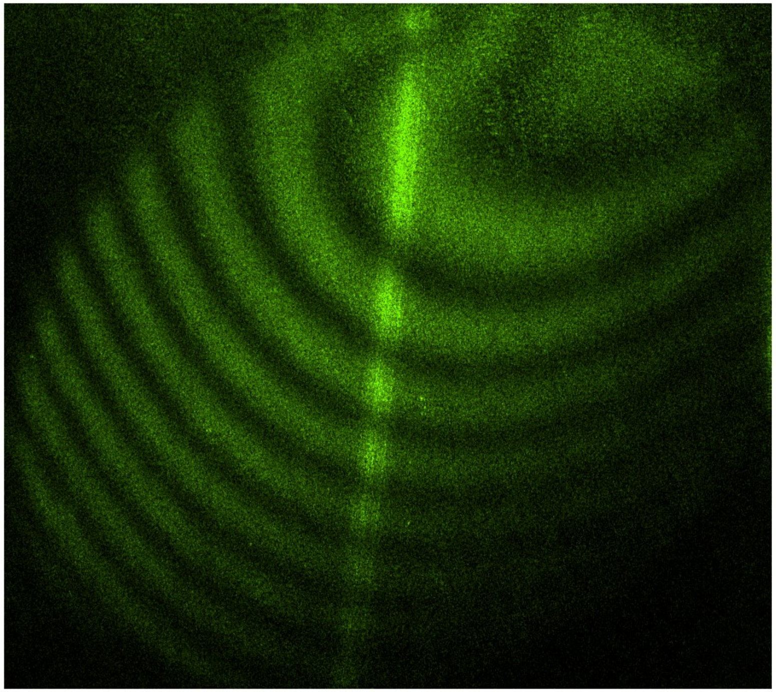
  (2nd and 5th modules in respect to the central tracking plane)
- ~ 0.25 micron resolution

Portion of the 5th 2S Module illuminated/monitored

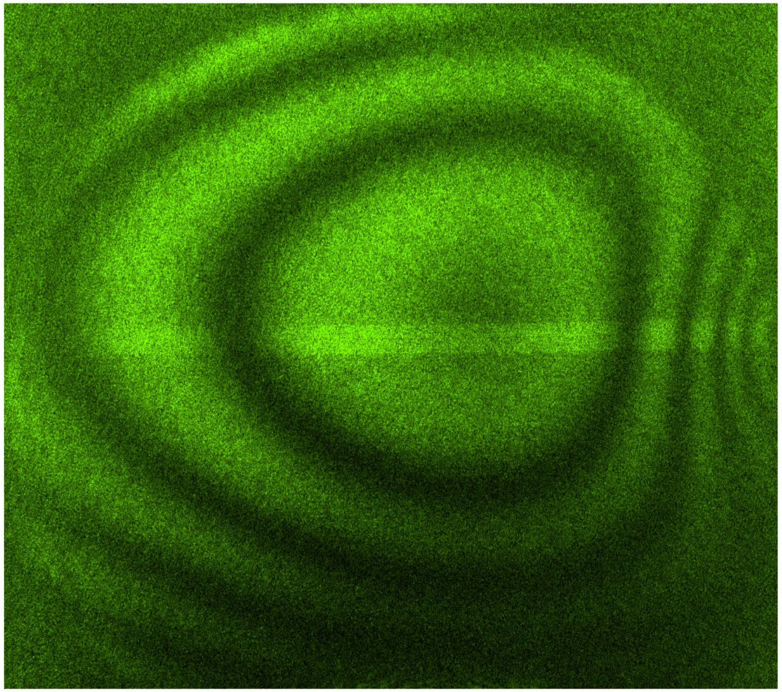
Holografic aligment monitor: TB results

Interferometric image after the installation of the C target on the 2nd station

Time-dependent interferometry (displacement at $\Delta t \approx 18$ h)



Module 2 Closer to target
relative displacement ~ 2.5 μm



Module 5
relative displacement ~ 1.2 μm

Conclusions

- the choice of invar for the mechanical structure involved a lot of work but the result was excellent (see HAM results)
- we hope to have a carbon fiber prototype for testing before the TDR is completed
- temperature management was complex and needs to be improved (flow regulator for dry air, active control?)
- the metrology of the system is very complicated. A reliable procedure still needs to be established (3D laser scan?).
- the current strategy for metrology has one fundamental flaw: it requires frame disassembly
- the laser survey is working very well

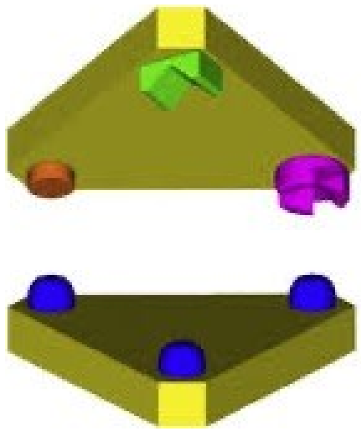
The end

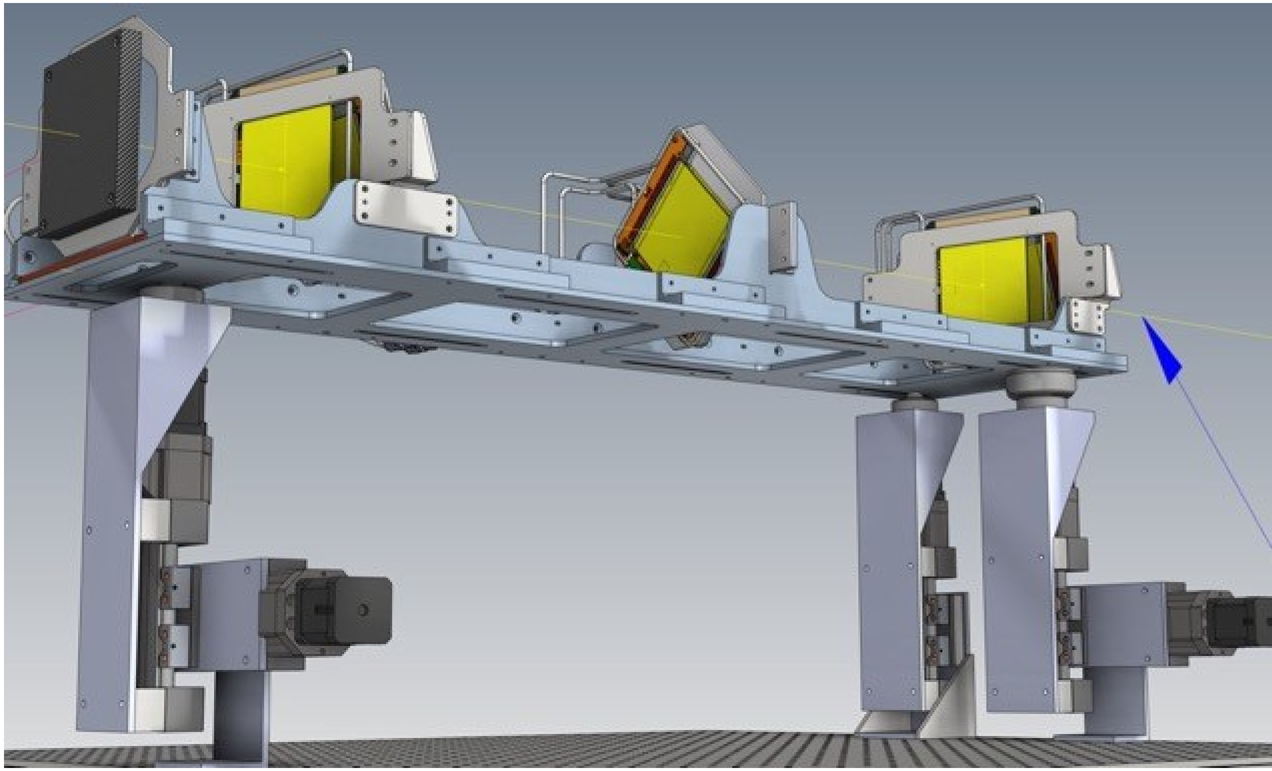
Tank you for your attention!

Spare

Kinematic aligment

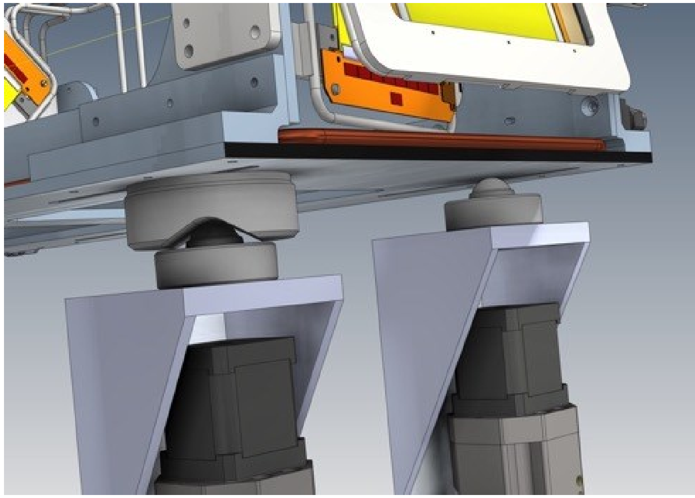
Invar structure and breadboard support have different thermal expansion coefficients





Spherical joint

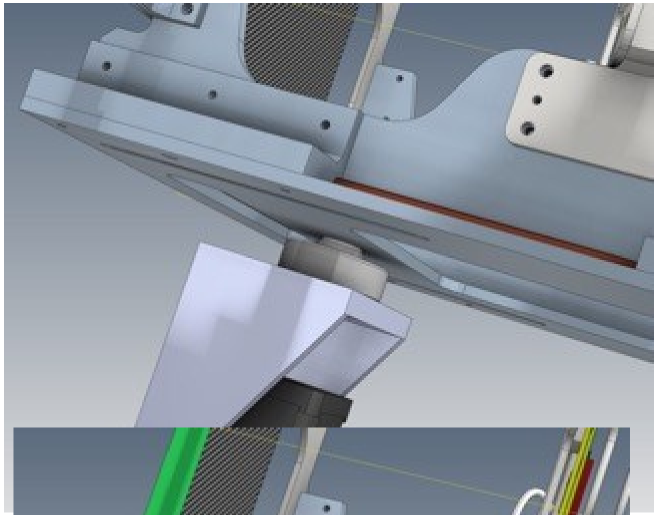
Downstream supports

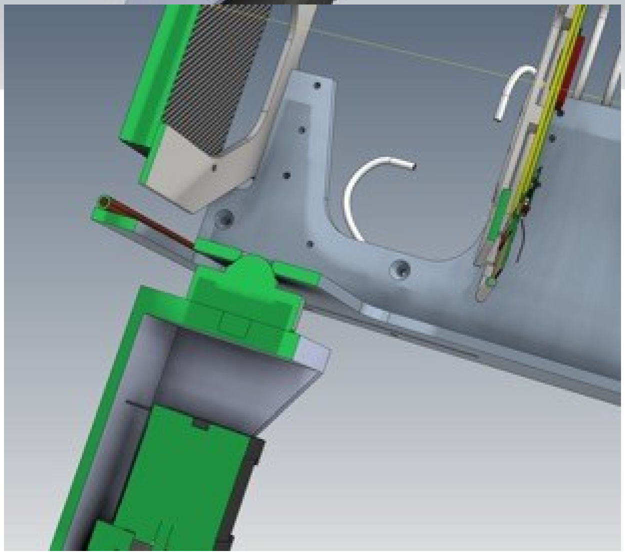


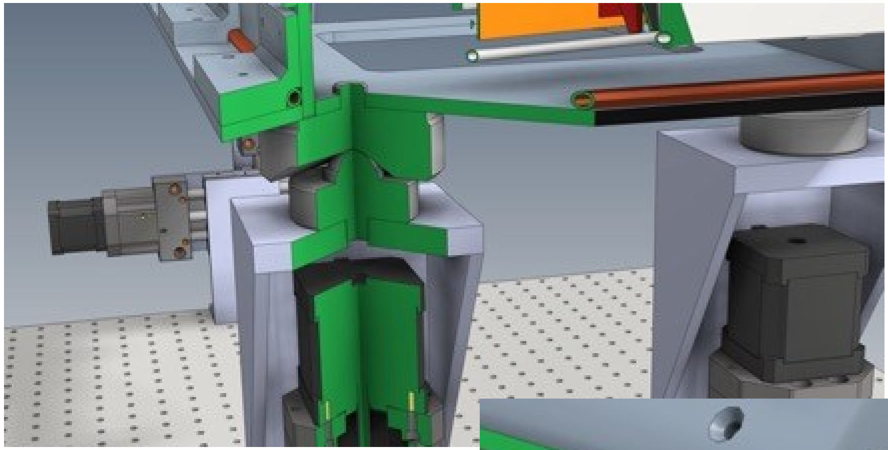
Upstream support

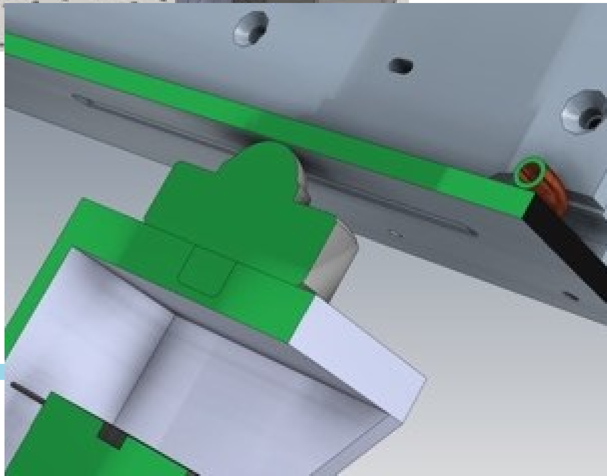
The sphere allows rotation

The translation is prevented



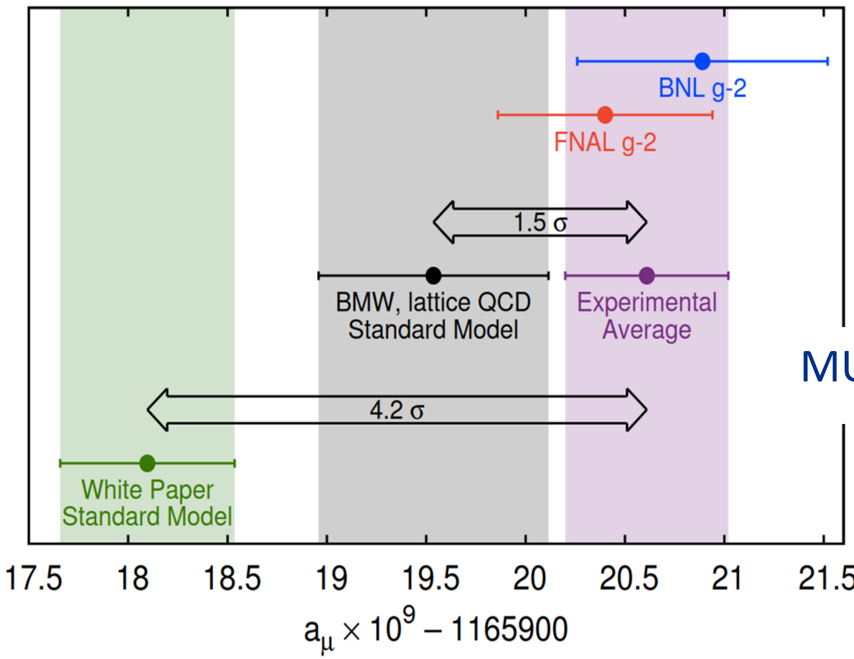






MUonE

Nel 2021 nuova misura di a_{μ}:

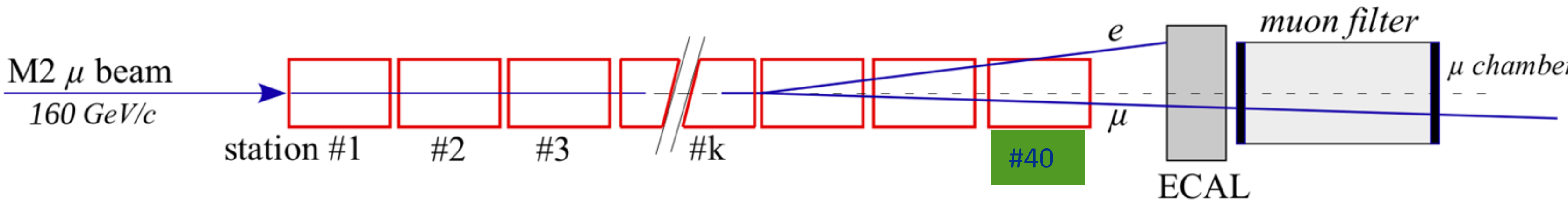


- Teoria: $a^{SM}_{\mu} = + a_{\mu}^{QED} + a_{\mu}^{EW} + a_{\mu}^{HAD}$
- Incertezza teorica dominata da a_{μ}^{HLO}
- Recentemente a_{μ}^{HLO} da "lattice calculations" (BMW20) in tensione con risultato dai canali e^+e^- (WP20)

MUonE propone di misurare al CERN :

$$a_{\mu}^{HLO} = \frac{\alpha_0}{\pi} \int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$

(spacelike approach)



Estrarre $\Delta\alpha_{had}(t)$ dallo «shape» della sezione d'urto differenziale dello scattering $e^- \mu^+ \rightarrow e^- \mu^+$

- 0.3% accuratezza statistica su a_{μ}^{HLO}
- LoI https://cds.cern.ch/record/2677471/files/SPSC-I-252.pdf

-C. M. Carloni Calame et al PLB 746 (2015) 325
-G. Abbiendi et al Eur.Phys.J.C 77 (2017) 3, 139

Slow control

PC (Win) is in the cage (R-007), with two Ethernet boards:

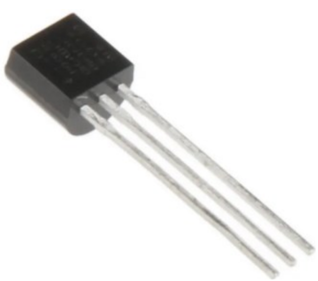
1) Connection to the CERN network
2) Connection to an hub

Hub connections:

1) CAEN crate (HV&LV power supply)
2) stepper motors controls (30 m cable to the station)

Slow control detectors/monitors:

1) Relative humidity (mod. SHT25: RH% + temperature)
2) Up to 255 T sensors (DS18B20+, 20 in hand, 6 installed)
3) Motors control
4) CAEN HV&LV

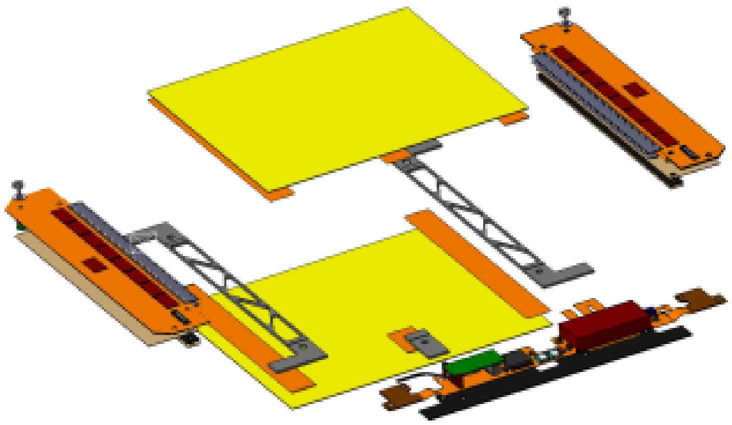


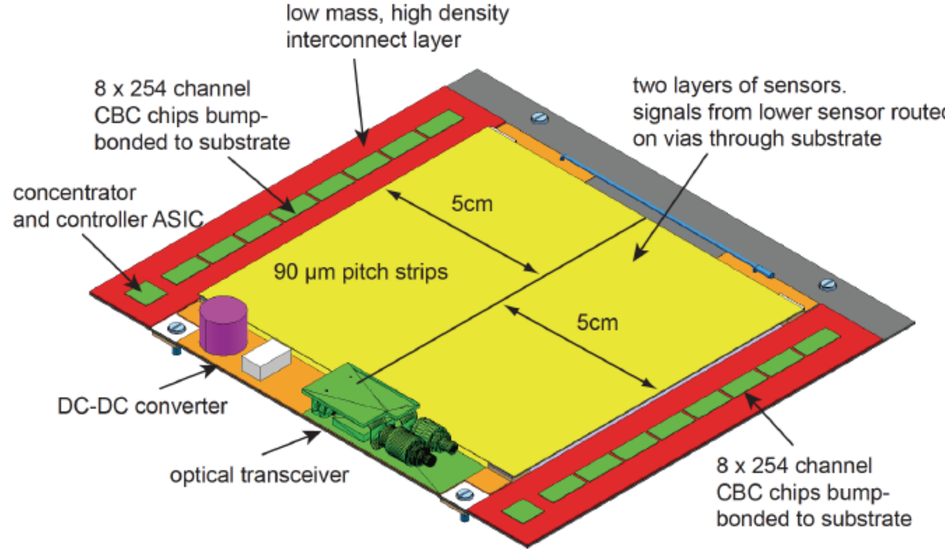
Log in local hard drive, 1 file/day, data saved every 60 sec

Tracker sensors

Pt-2S modules from CMS, assembled at INFN-Perugia

Two close-by planes of strips reading the same coordinate, providing track elements (stubs)





Large active area 10x10 cm^2
-> complete/uniform angular coverage with a single sensor
Good position resolution ~ 20µm
-> further improvable with a ~ 15° tilt around the strip axis and/or with effective staggering of the planes (with a microrotation)