Design and prototyping of support mechanics with integrated cooling for the Endcaps of the CMS Tracker Upgrade

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on behalf of the CMS Collaboration

Forum on Tracking Detector Mechanics 2021

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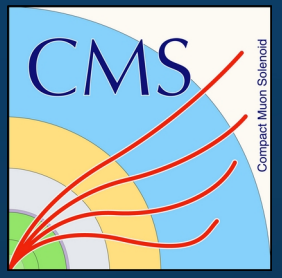
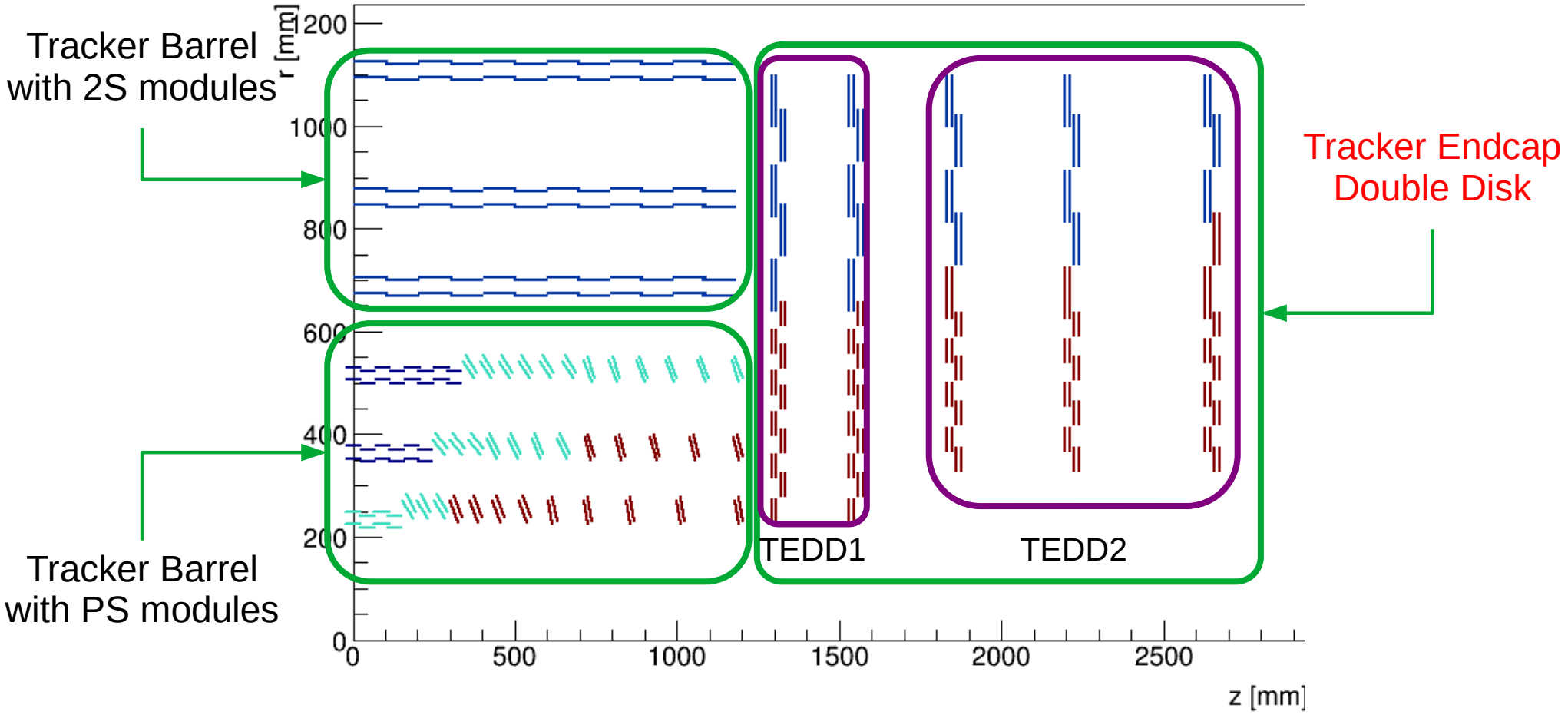


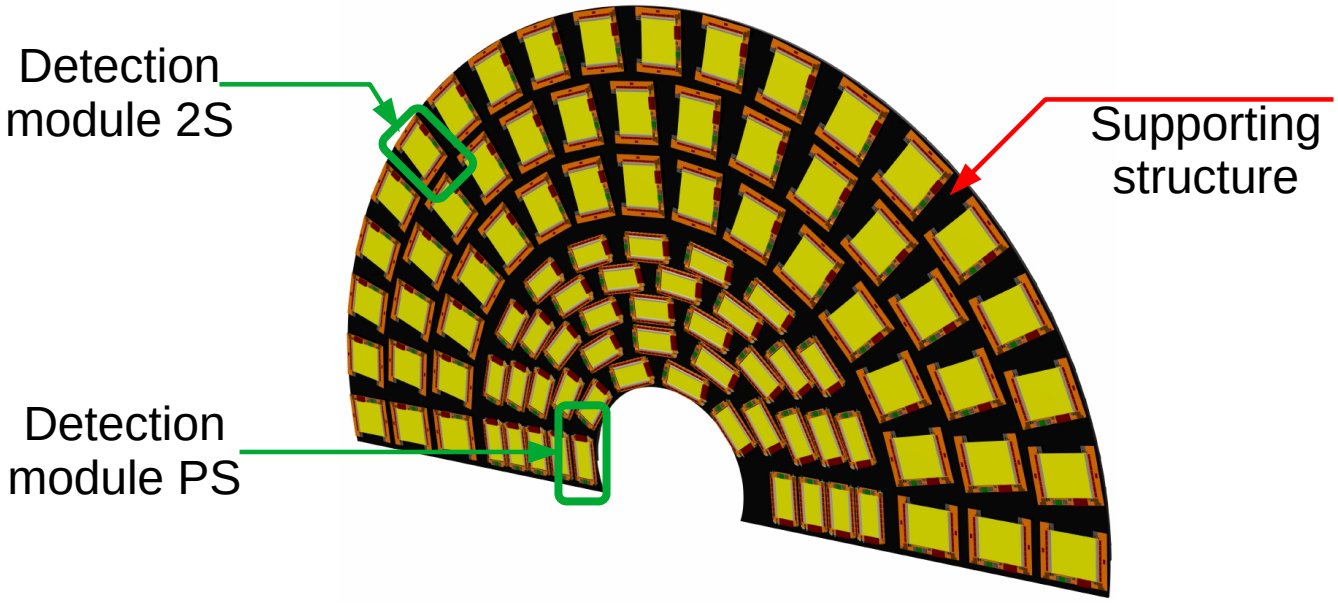
Upgraded CMS Outer tracker

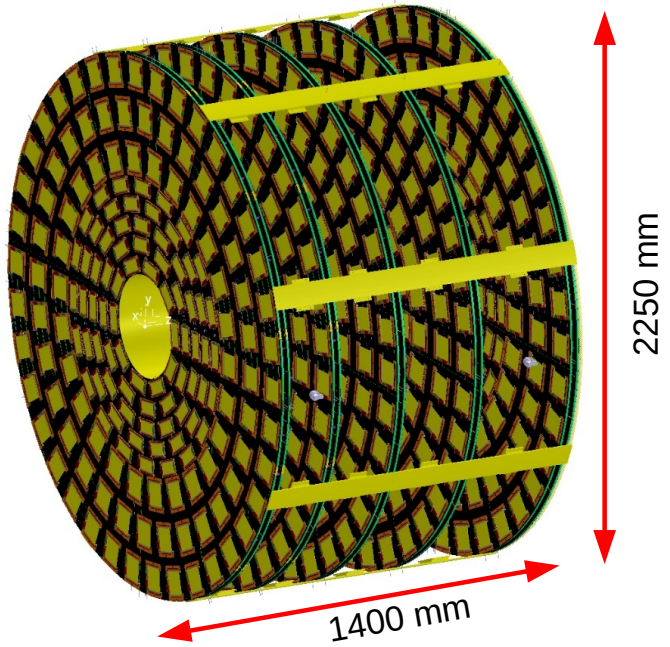
- Upgraded CMS Outer Tracker will be composed of 3 sub-detectors: **TBPS**, **TB2S** and **TEDD** (Tracker Endcap Double-Discs)



Tracker Endcap Double Disk

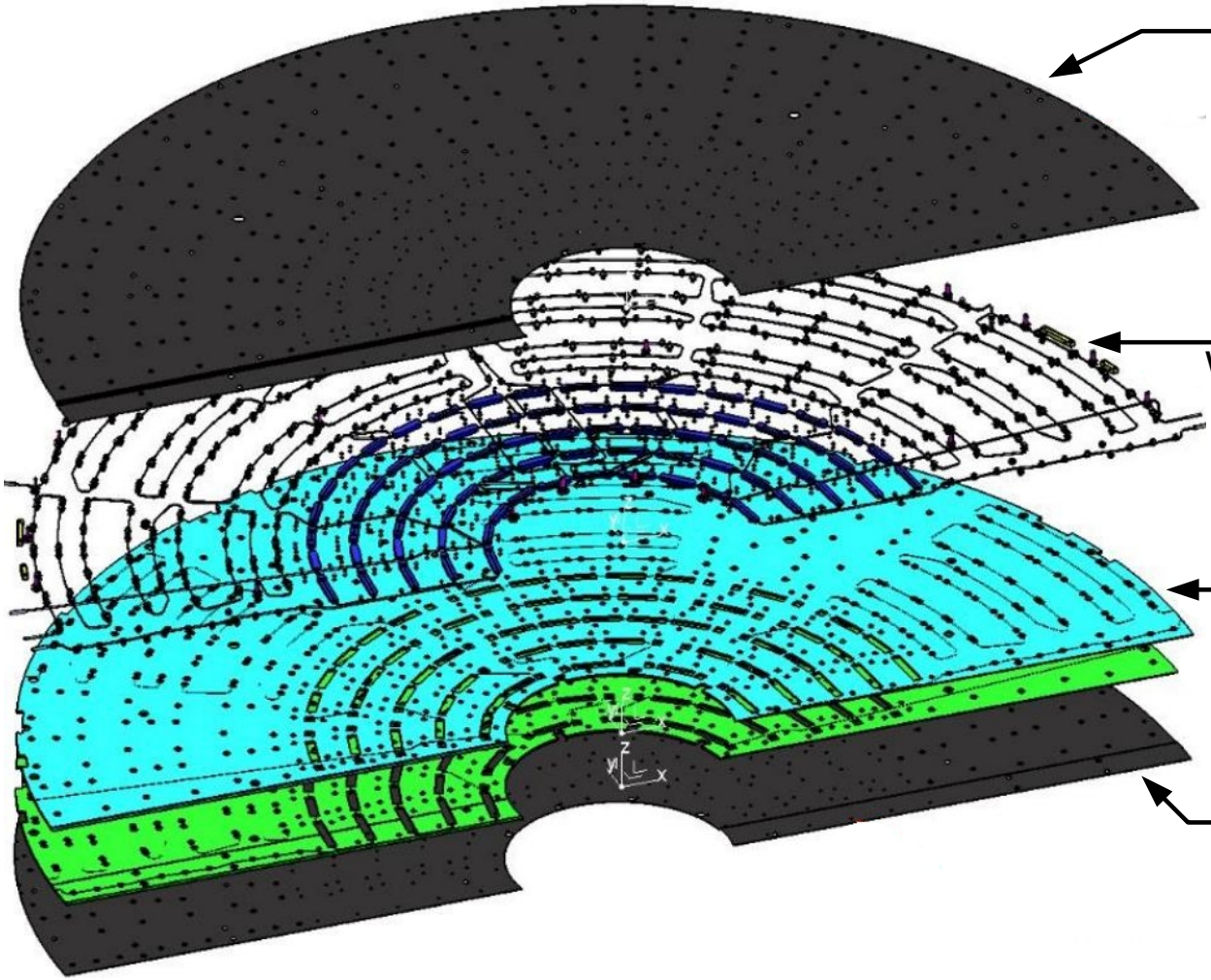
- **TEDD = Tracker Endcap Double Disk**
- A **Dee** is the fundamental element of the TEDD
- Made in composite material, each Dee has a semi-circular shape providing mechanical support and cooling for the detection modules
- Two Dees form a Disk; two Disks form a Double Disk (TEDD=10 Double Disks)





- Two slightly different types of Double Disk (TEDD1 vs TEDD2): different size and number of modules, but same mechanical concept

Dee composition



Top carbon fiber skin
with holes for inserts
0.4 mm

6 cooling circuits equipped
with carbon foam and metallic
inserts
2.5 mm OD

Filler layers (Airex)
2 x 4.5 mm

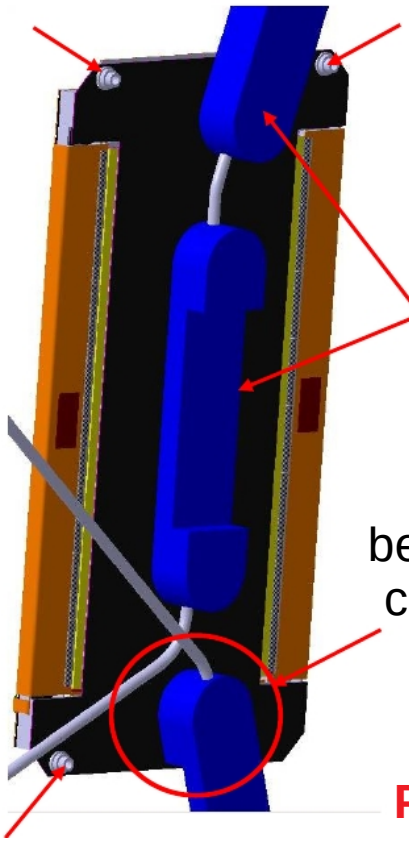
Bottom carbon fiber skin
with holes for inserts
0.4 mm

Total thickness = 9.8 mm

Detection modules on Dee

- Two types of Si modules will be mounted on the Dee:

Pixel-Strip (PS)



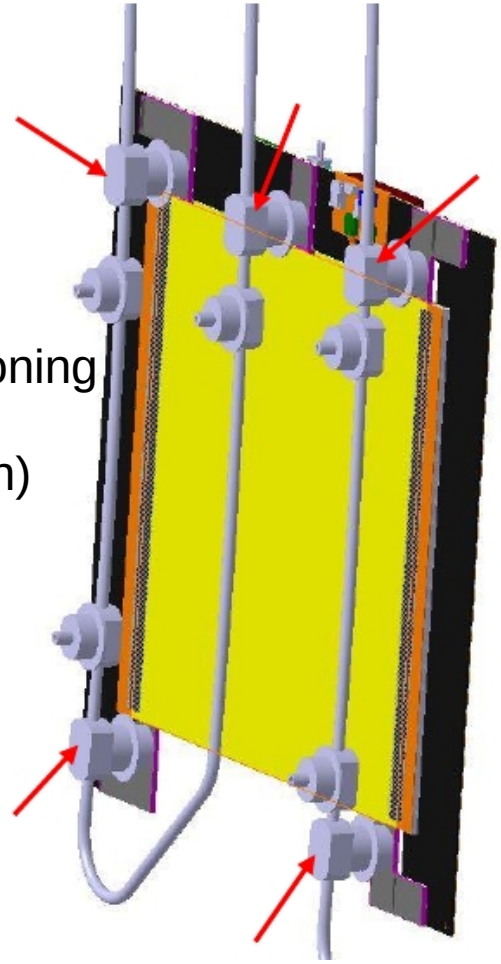
High thermal conductivity carbon foam in contact with carbon fiber

Thermal contact between modules and carbon fiber assured using Thermal Interface Material

Power consumption up to 12 W

3 Al positioning inserts (4 in final production)

Strip-Strip (2S)

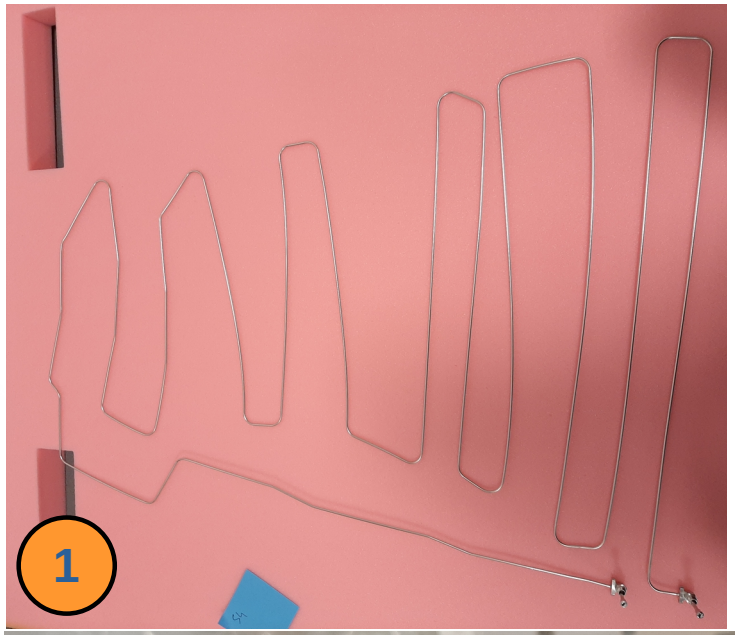


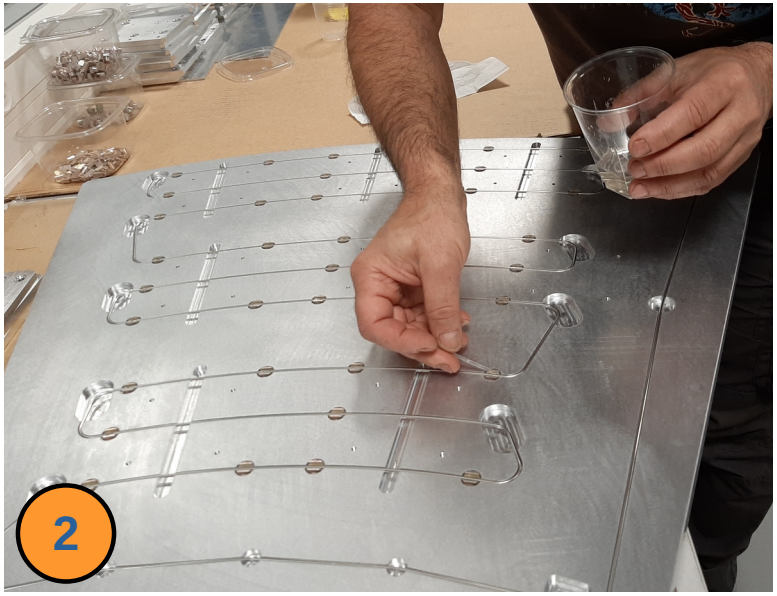
5 Al cooling and positioning insert per module (6 in final production)

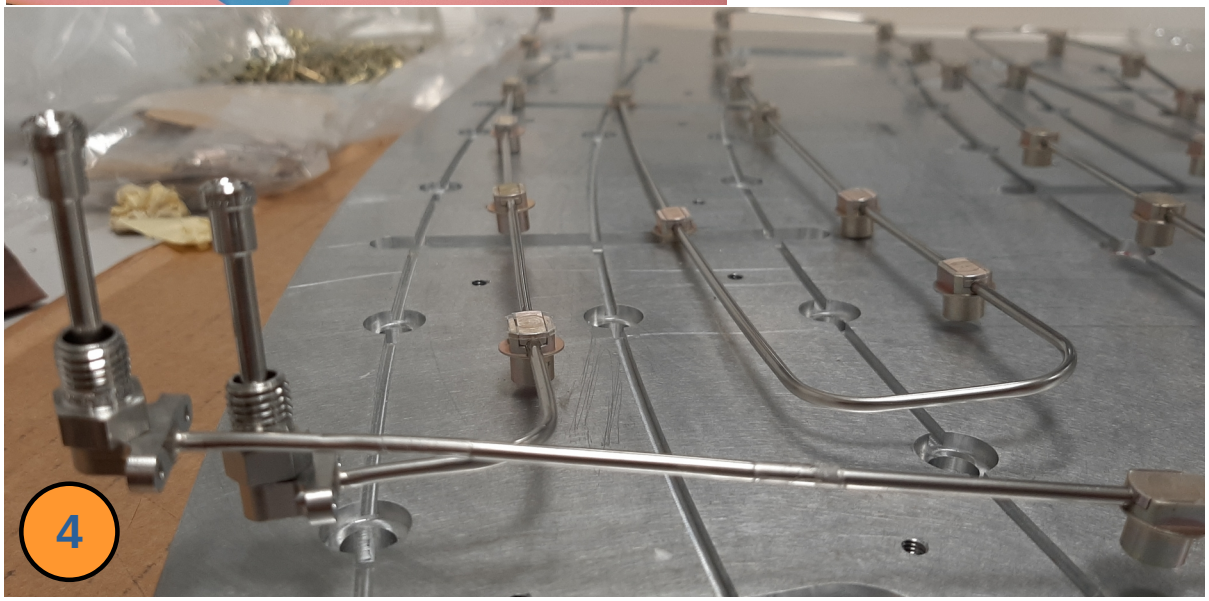
Power conumption up to 7.4 W

Dee assembly procedure

Dee assembly procedure

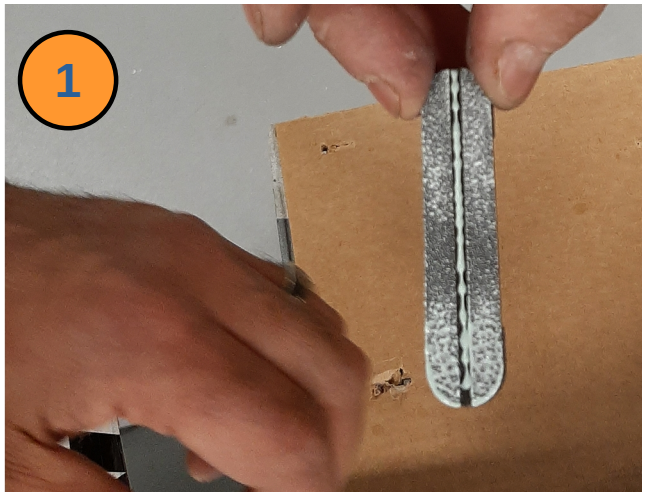


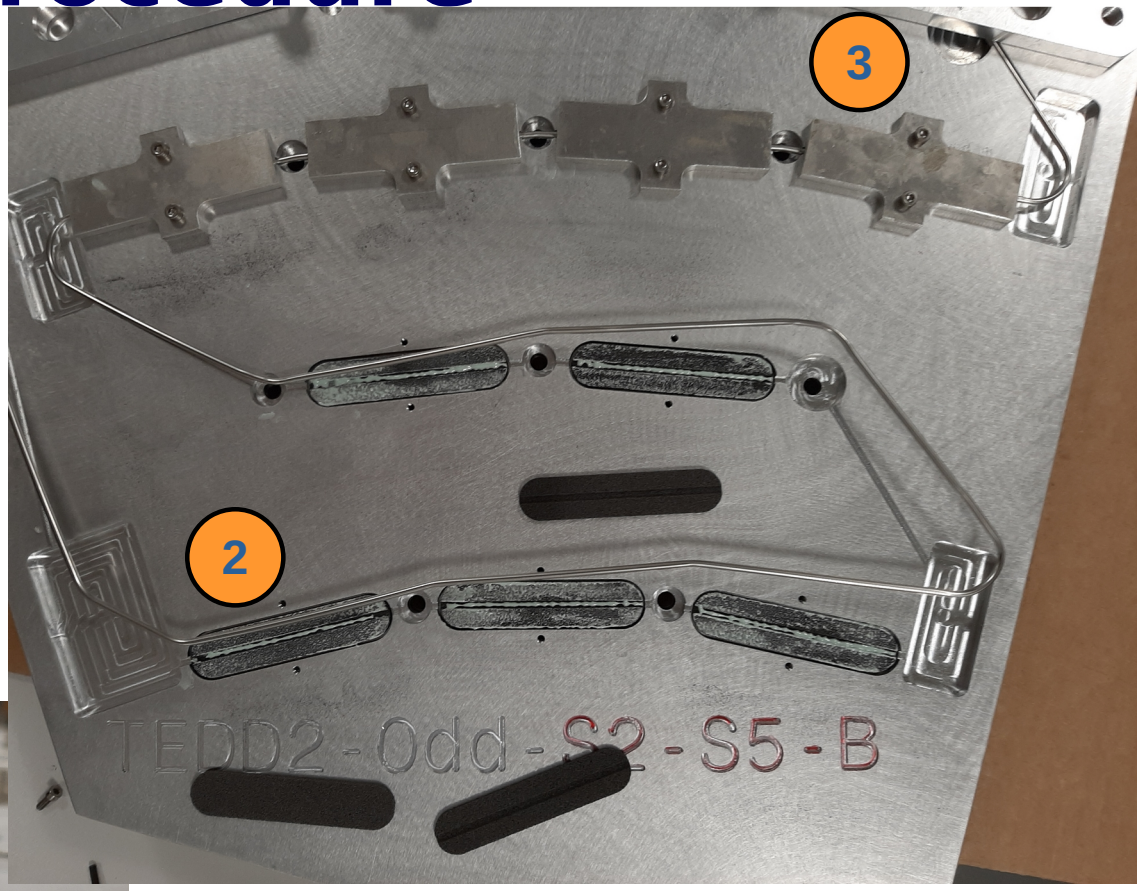


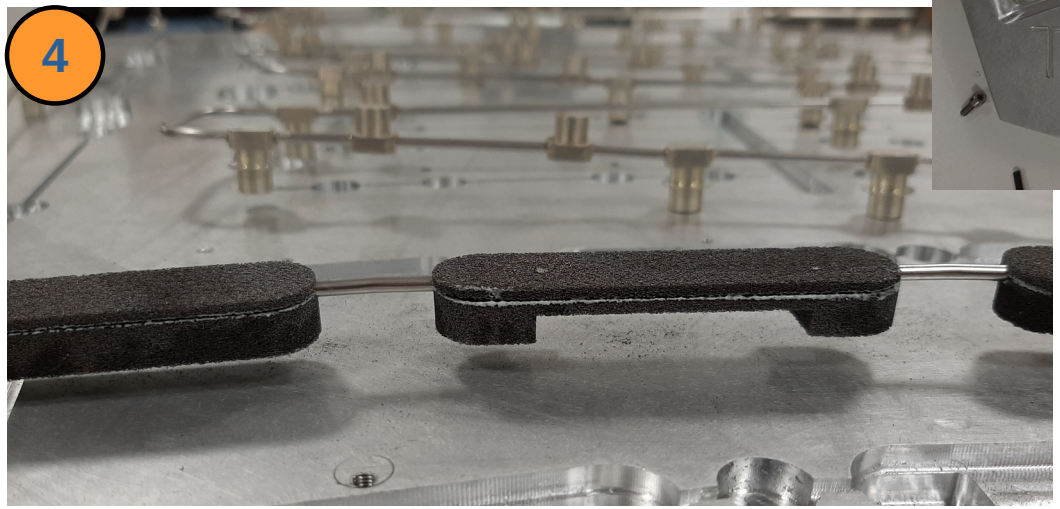


1. Bare cooling pipes arrive from CERN after connectors brazing/welding
2. 2S inserts are glued to the pipe (Araldite 2011) with the aid of a jig
3. Curing time is approximately 2 days
4. Final results after pipe extraction

Dee assembly procedure

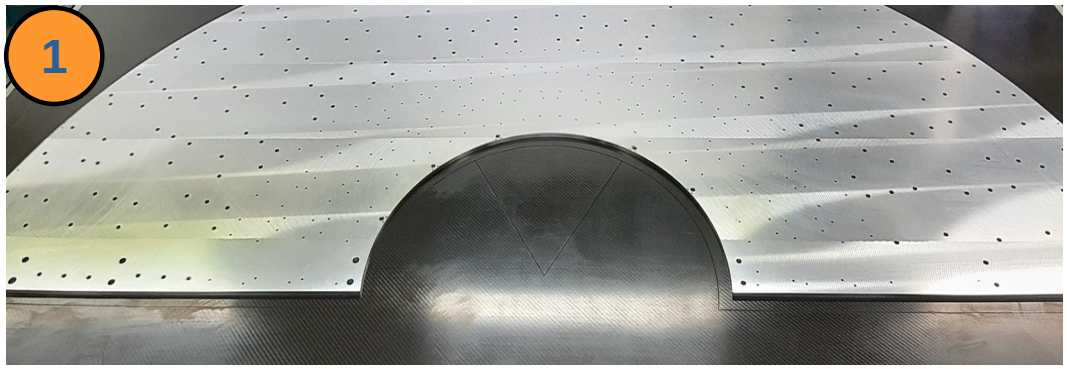


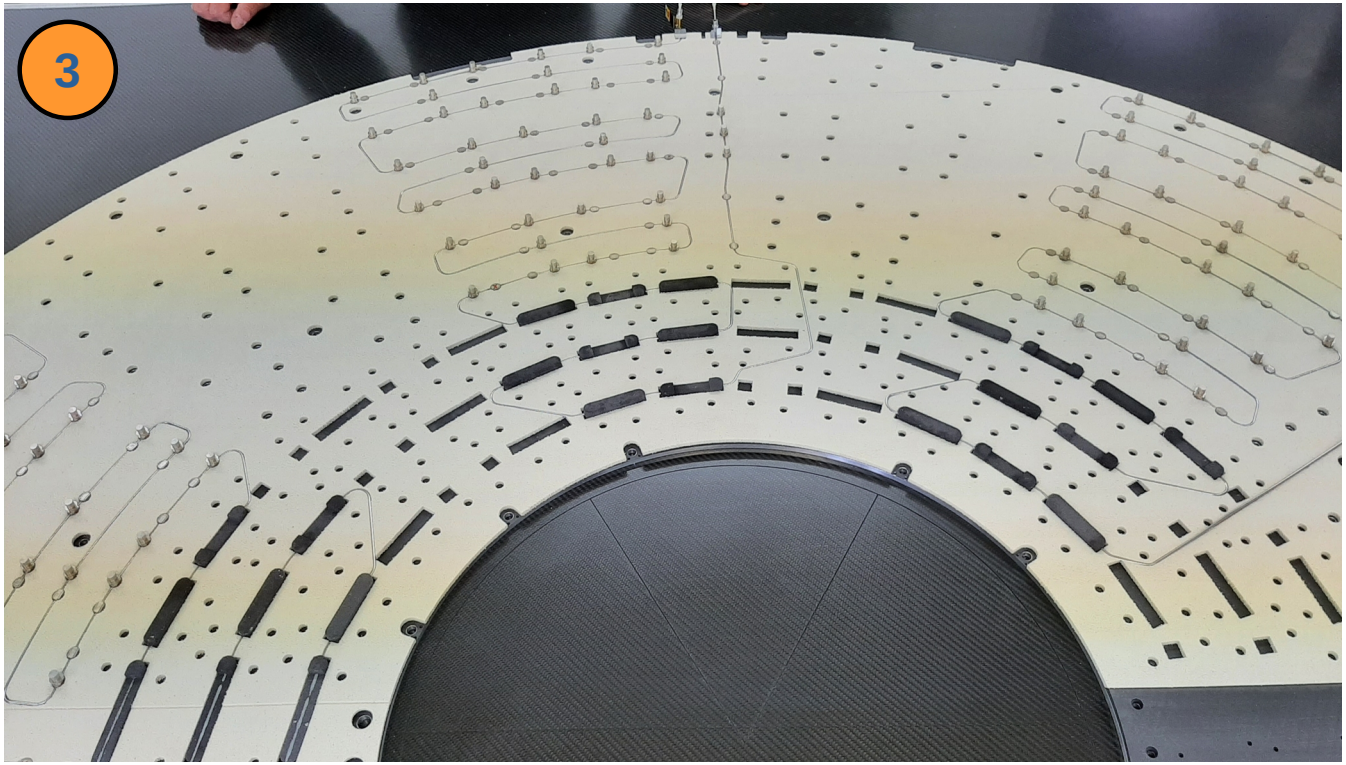




1. Glue EA9396 AERO + 25% boron nitride is applied to the carbon foams
2. Carbon foams are glued to the pipe with the aid of a jig
3. Curing time is approximately 2 days
4. Final results after pipe extraction

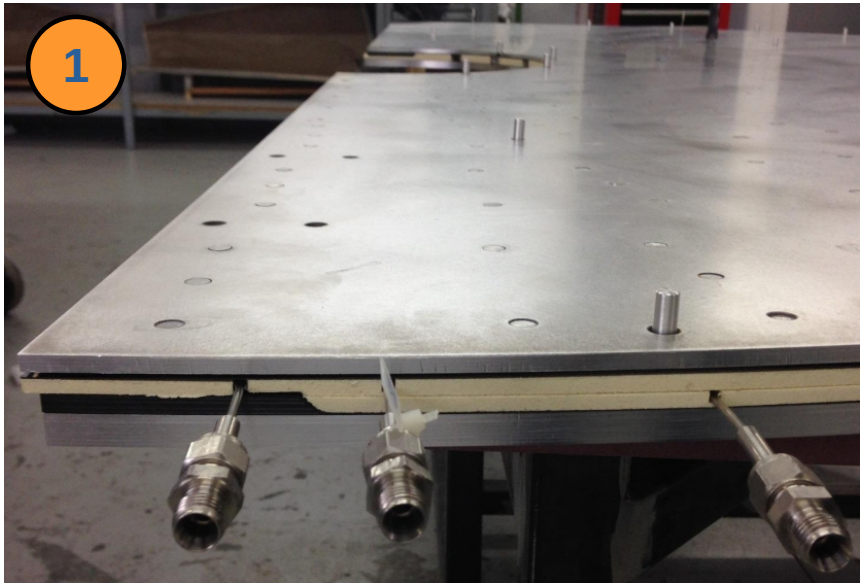
Dee assembly procedure





1. Bottom jig is used to constrain all elements during Dee assembly
2. Bottom carbon fiber is piled up
3. Fillers, cooling pipes and inserts are added

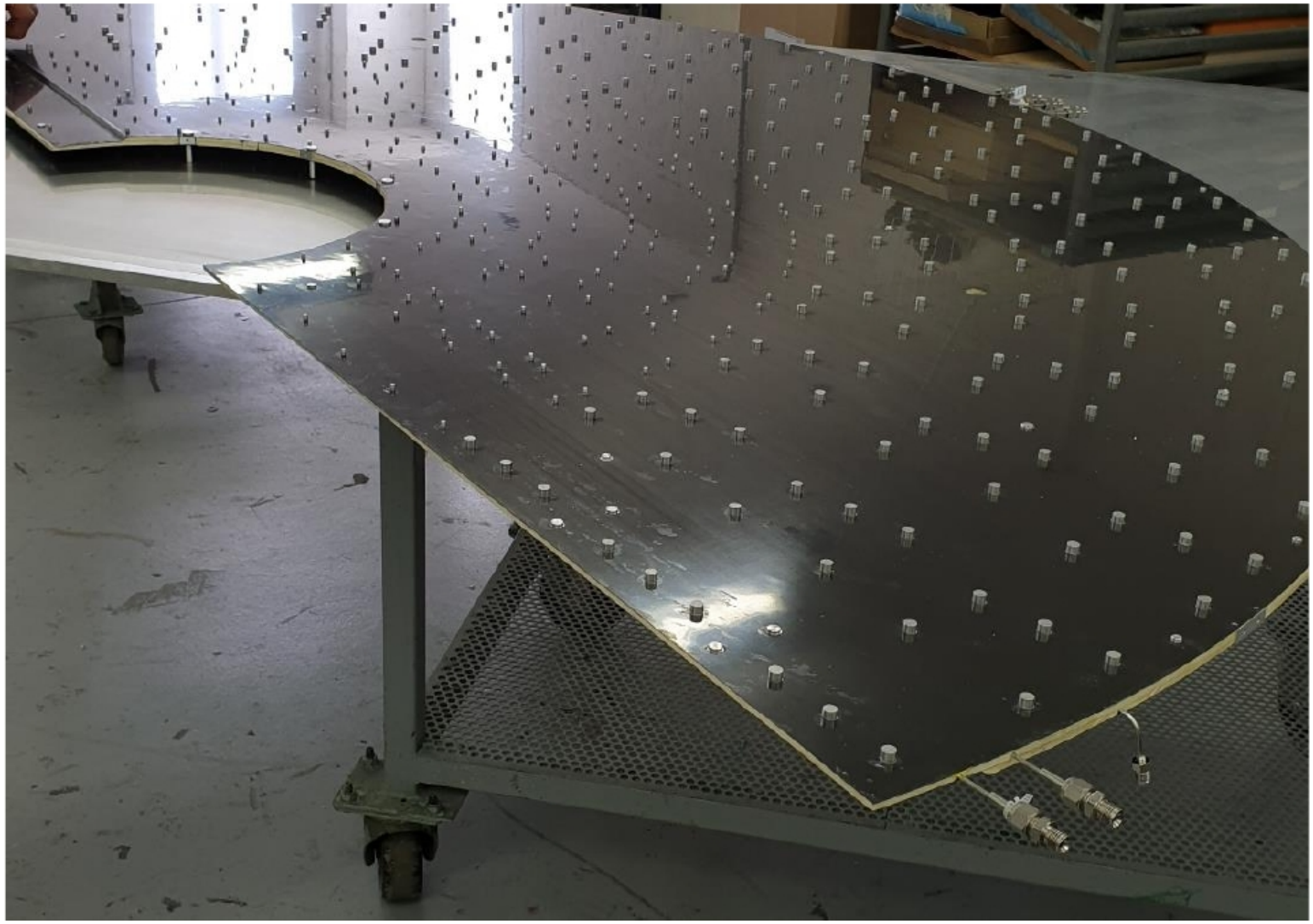
Dee assembly procedure



1. Top carbon foam and top jig are the final elements to be piled up

2. 3. Dee is now ready for vacuum and for 24h in autoclave at 2 bar, 30 °C

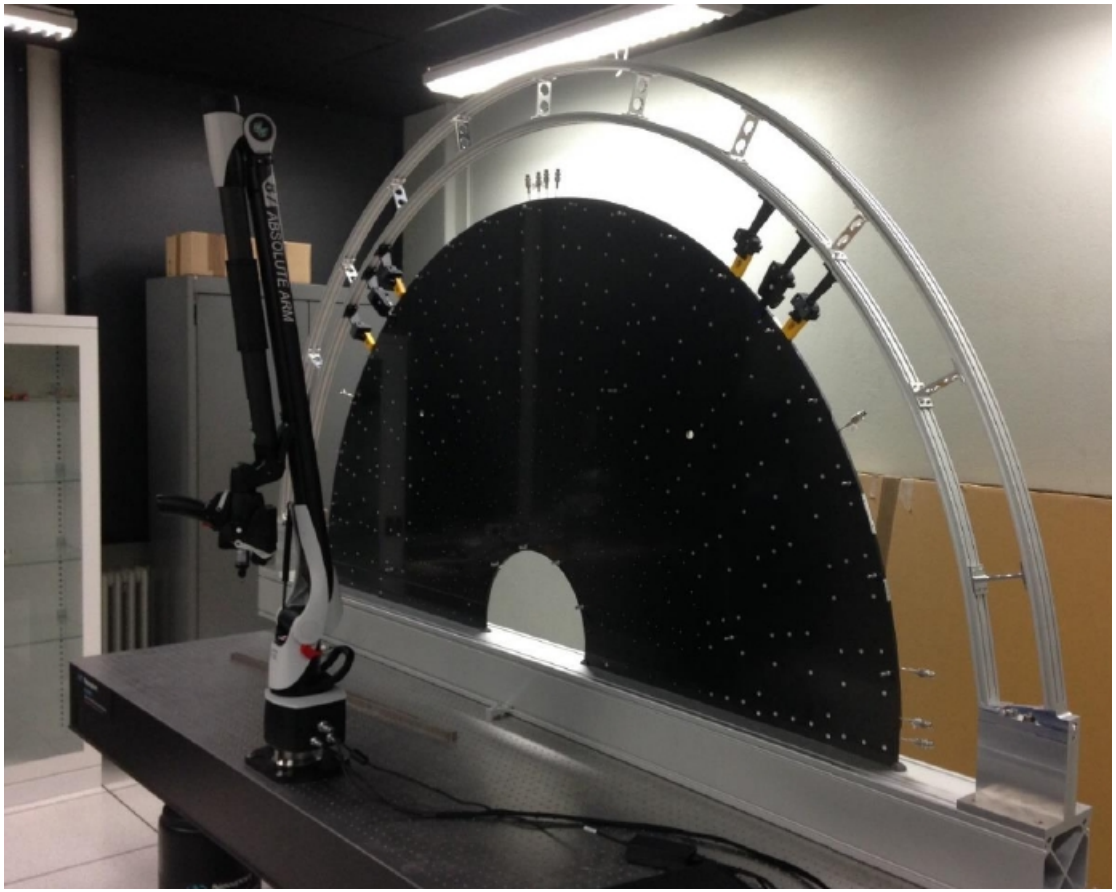
Final results



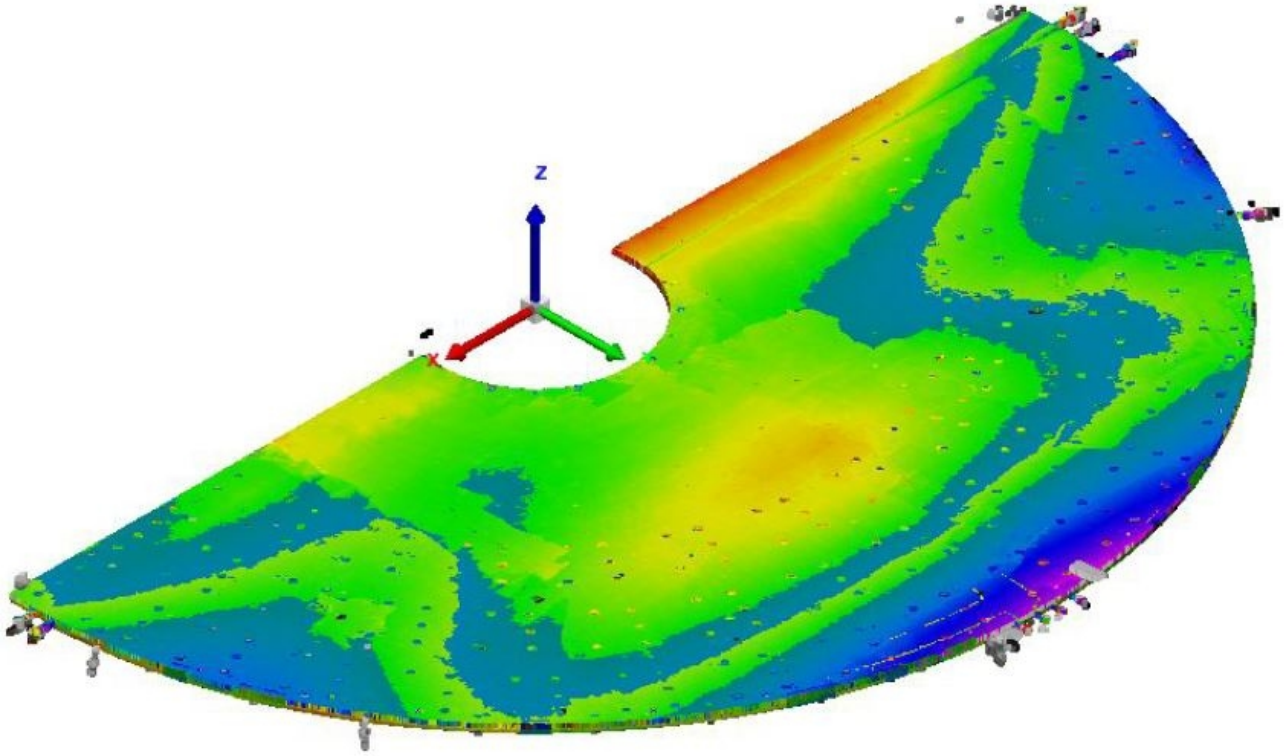
Mechanical validation

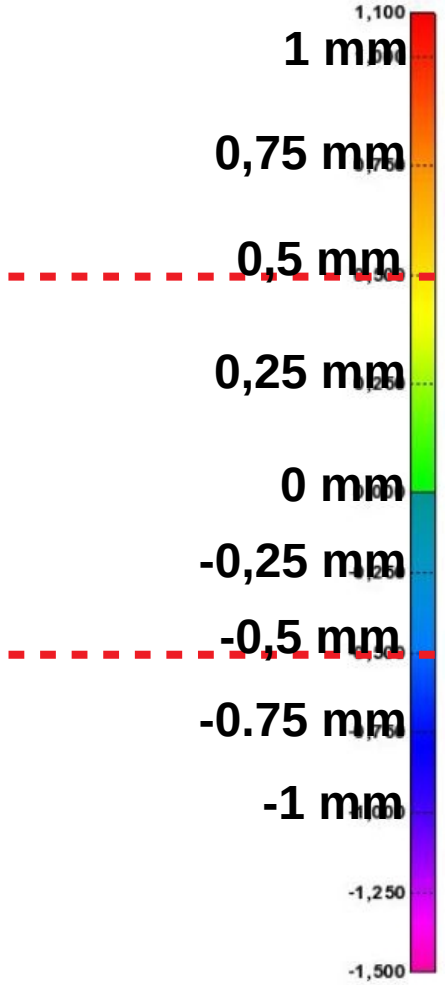
Metrology setup

- Dee suspended vertically in an arc frame
- Hexagon 7-axis measurement arm used:
  - laser scanning head
  - 3 mm silicon nitride tip
- Mechanical validation includes:
  - Global and local flatness
  - module displacement parallel to the surface
  - Dee inner and outer radii



Global flatness

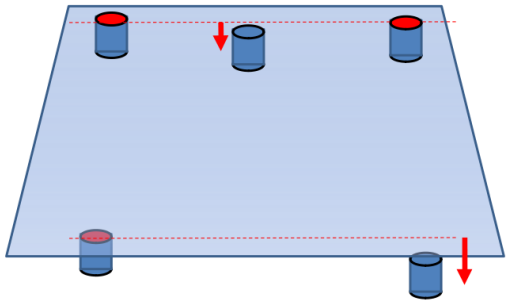


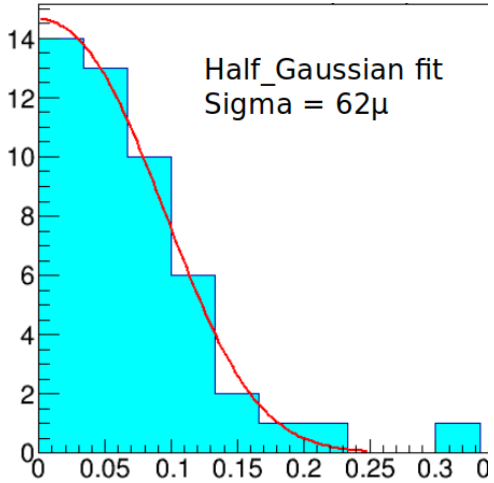


- Flatness measured with laser
- Within $\pm$ 0.5 mm throughout the surface, except the edges

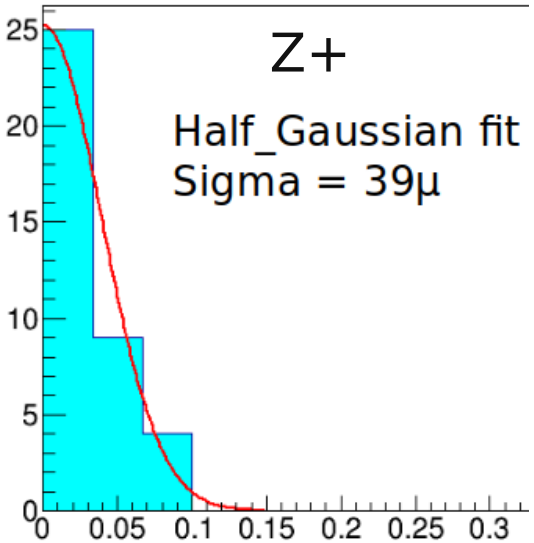
PS and 2S mounting flatness

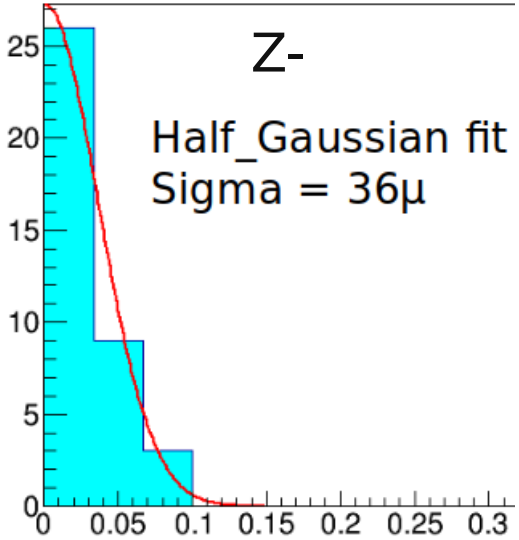
- Fit plane to the 3 highest points → measure largest deviation from plane among the remaining two
- Flatness of 2S within 200 µm





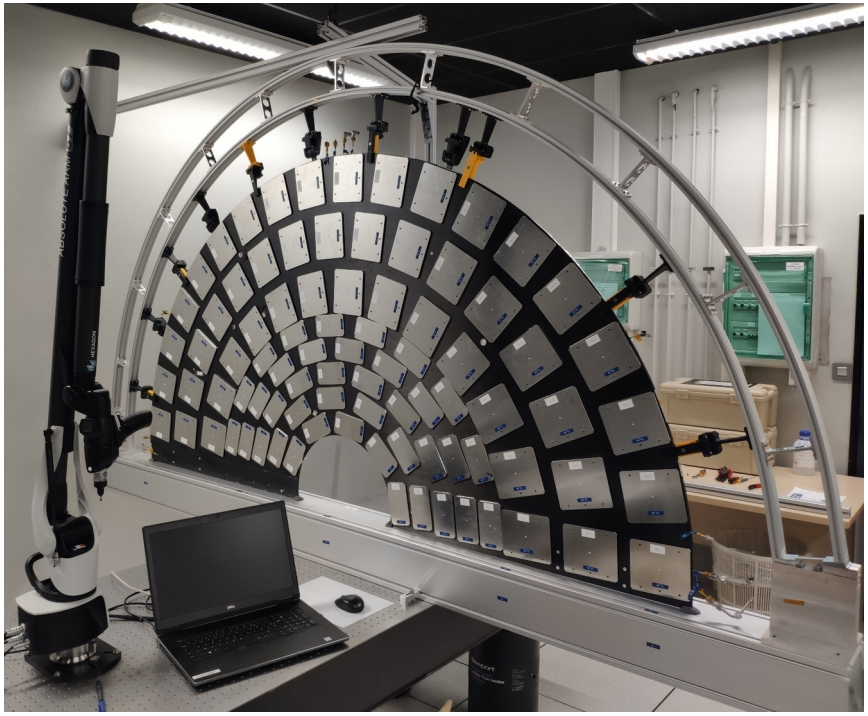
- Flatness of PS within 100 µm (½ of 2S module surface area)

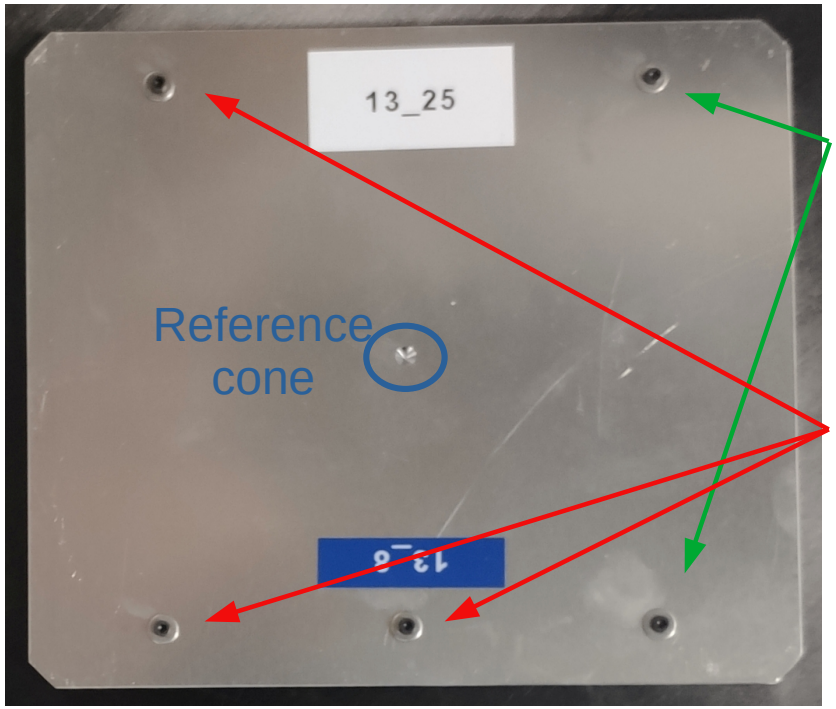




Measurement points

- High precision dummy modules are used to verify insert position module by module
- A cone present on each dummy module is touched by the tip → module displacement parallel to the Dee surface is calculated





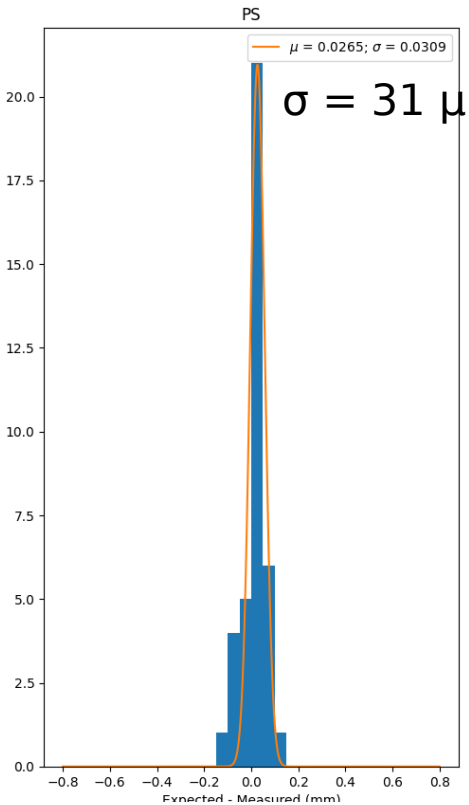
- For future Dees, a second cone is being added on all dummy modules, providing rotation information

Modules displacement

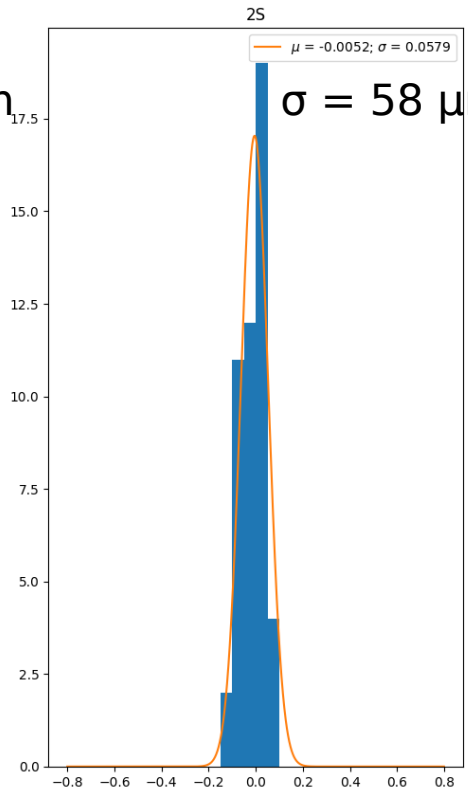
- Similar results for PS and 2S: most of the modules are within ±150 µm displacement along the two axes parallel to Dee

ΔX

PS

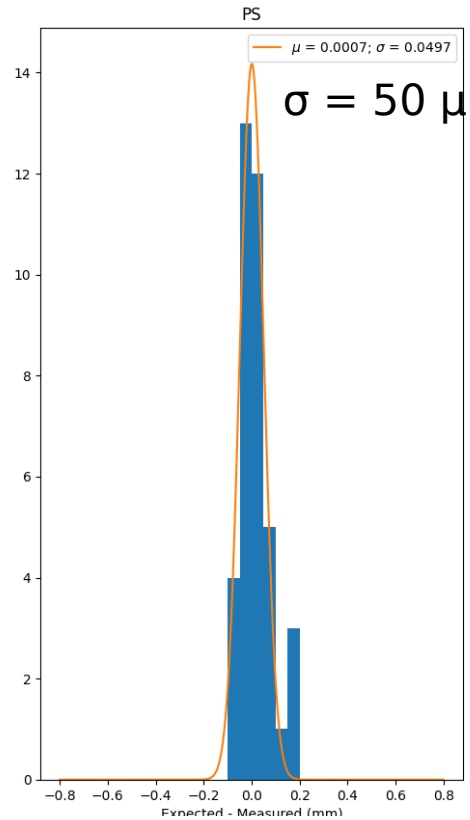


2S

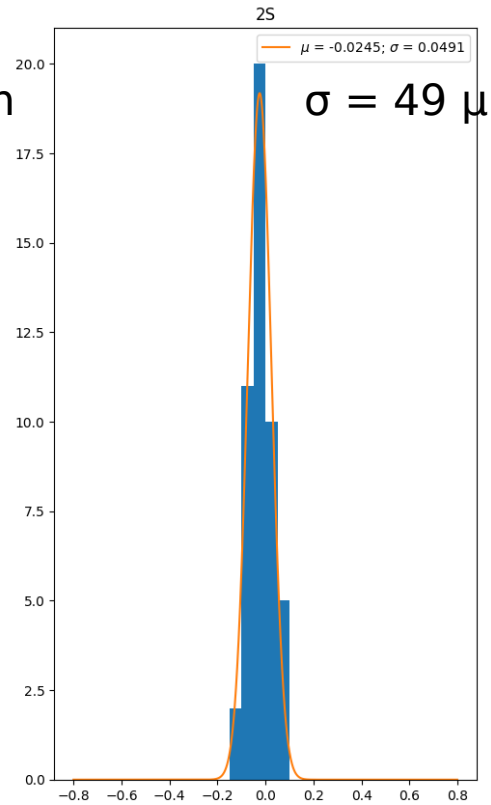


ΔY

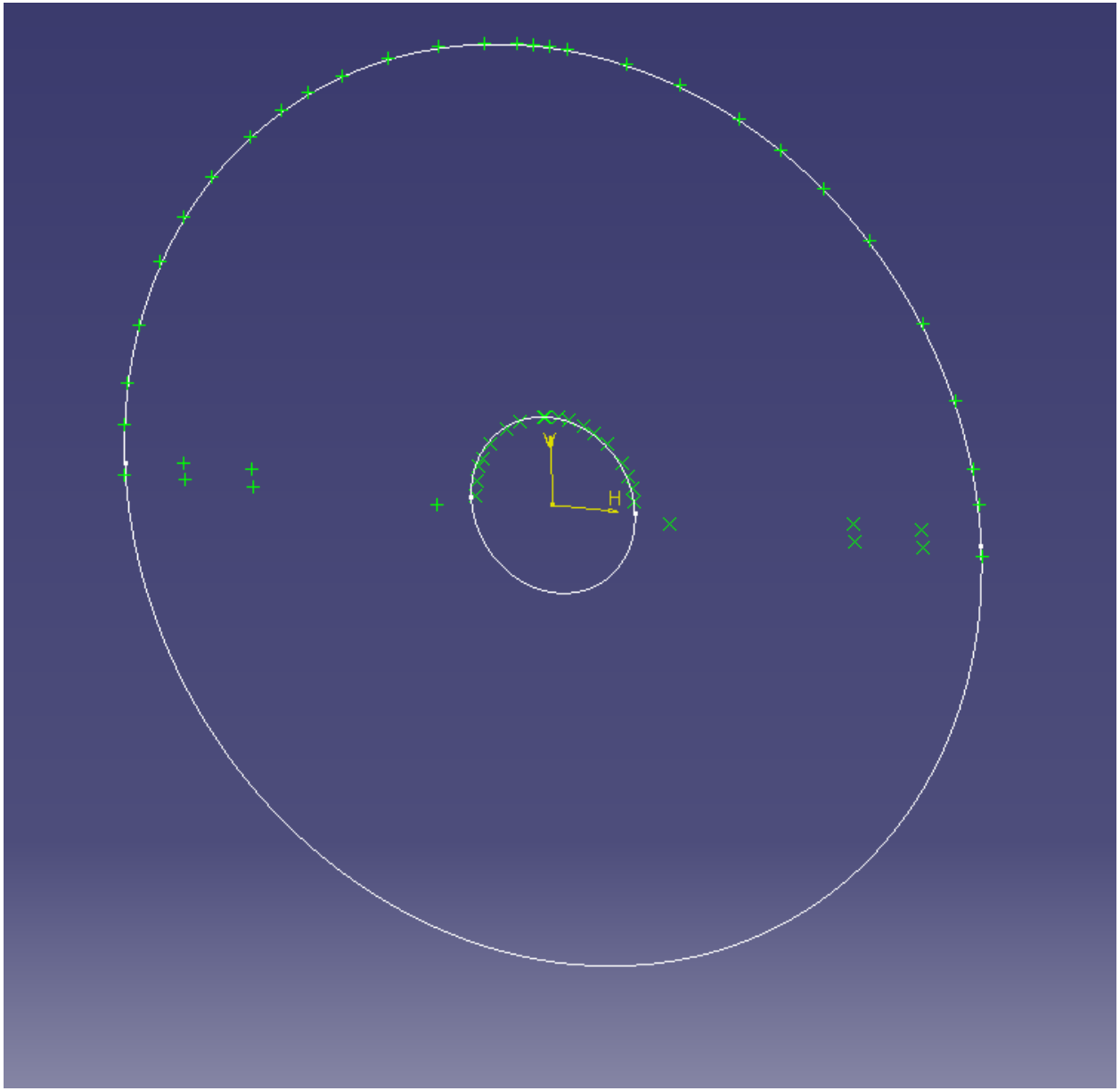
PS



2S



Inner and outer radii



- Average outer radius 1125.6 $\pm$ 0.13 mm (nominal = 1125.0)
- Average inner radius 214.5 $\pm$ 0.10 mm (nominal = 215.0)
- Difference due to the carbon-fiber glued on the inner and outer sides (0.4 mm)

Thermal validation

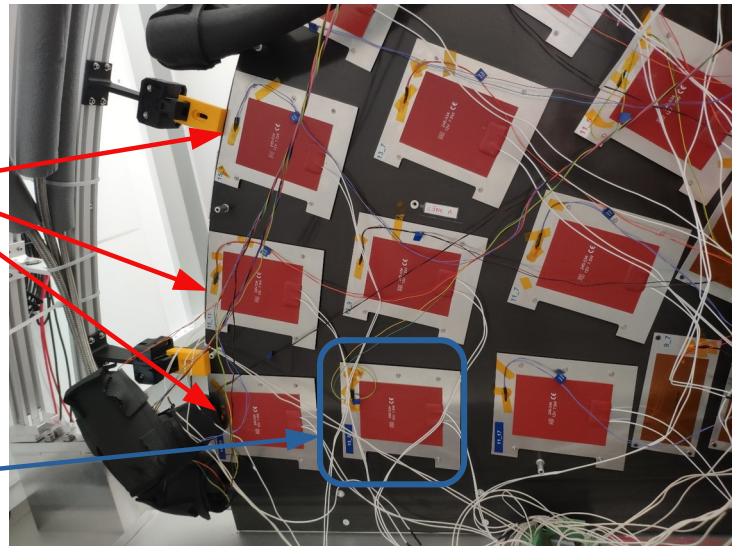
Thermal test setup at Lyon

- Dee suspended vertically in an arc frame
- Biphase CO_2 at -30 °C circulates in up to 4 cooling circuits
- Environmental temperature set at -20 °C
- Dry air is injected
- Temperature monitoring and data recording done with LabVIEW program

Dummy modules

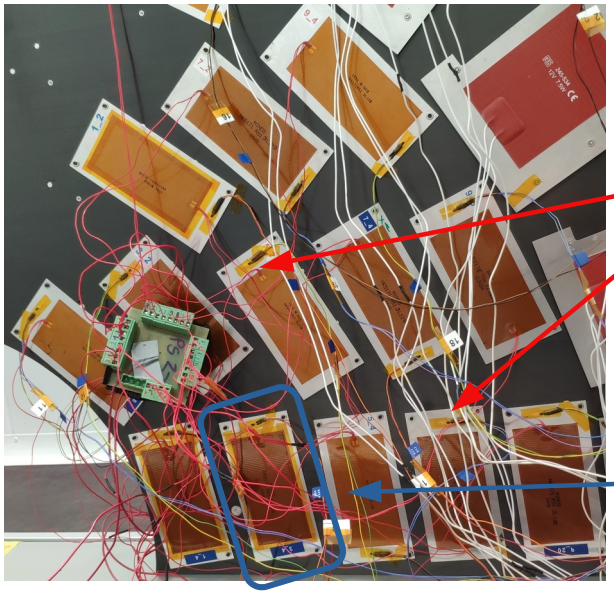
- Metallic fake modules with realistic foot-prints are equipped with heating foils to simulate the heat dissipation produced by electronics

PS



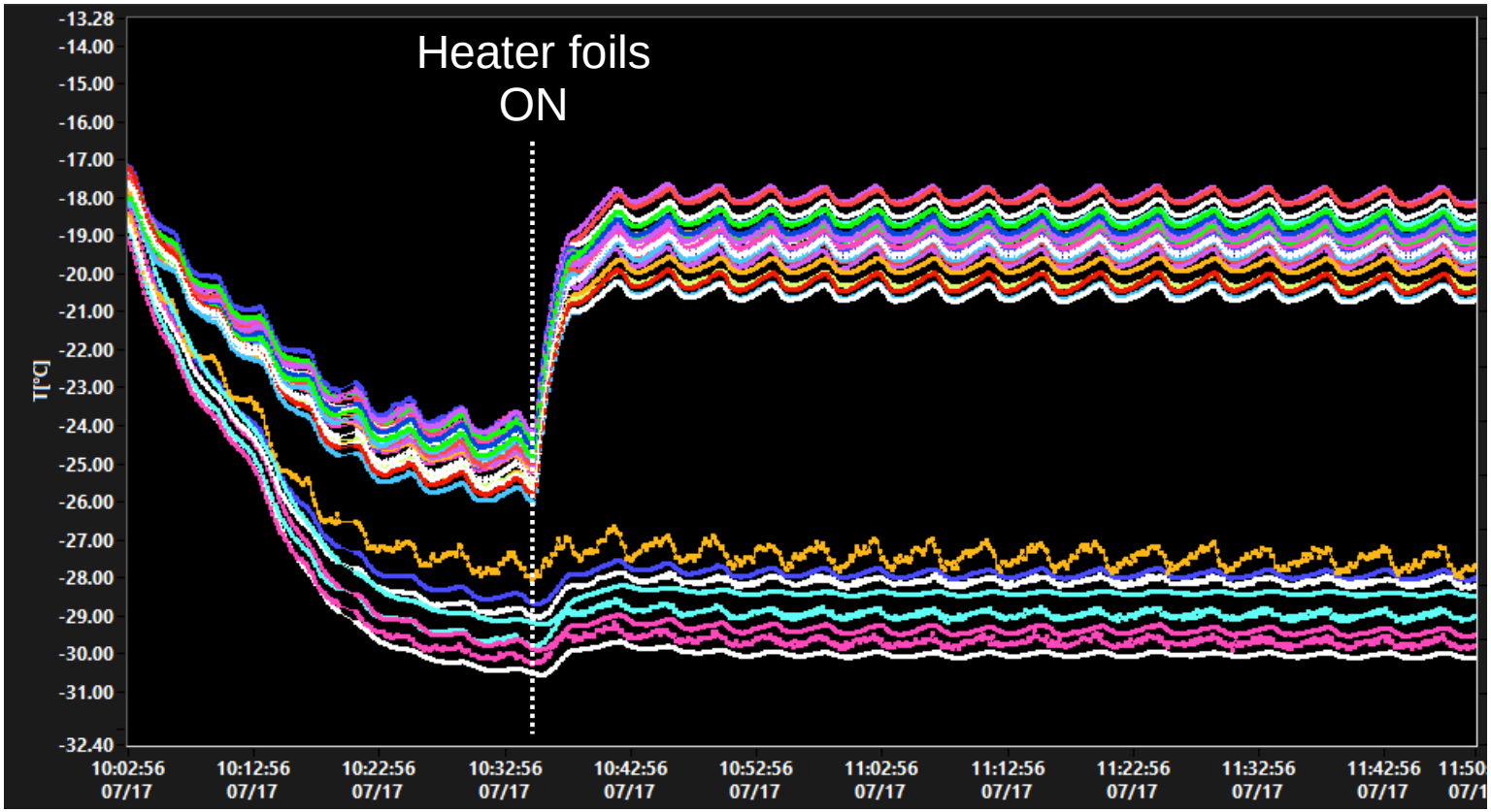
- One PT100 per module
- 5 x M1.6 fixation screws on inserts, 16 cN·m torque.
- Heat transfers through the 5 Al inserts

2S



- 1 to 5 PT100 per module depending on the test
- 3 x M1.6 fixation screws on inserts, 6 cN·m torque.
- Heat transfers through c-skin and c-foam (thermal paste applied)

Raw temperature trend

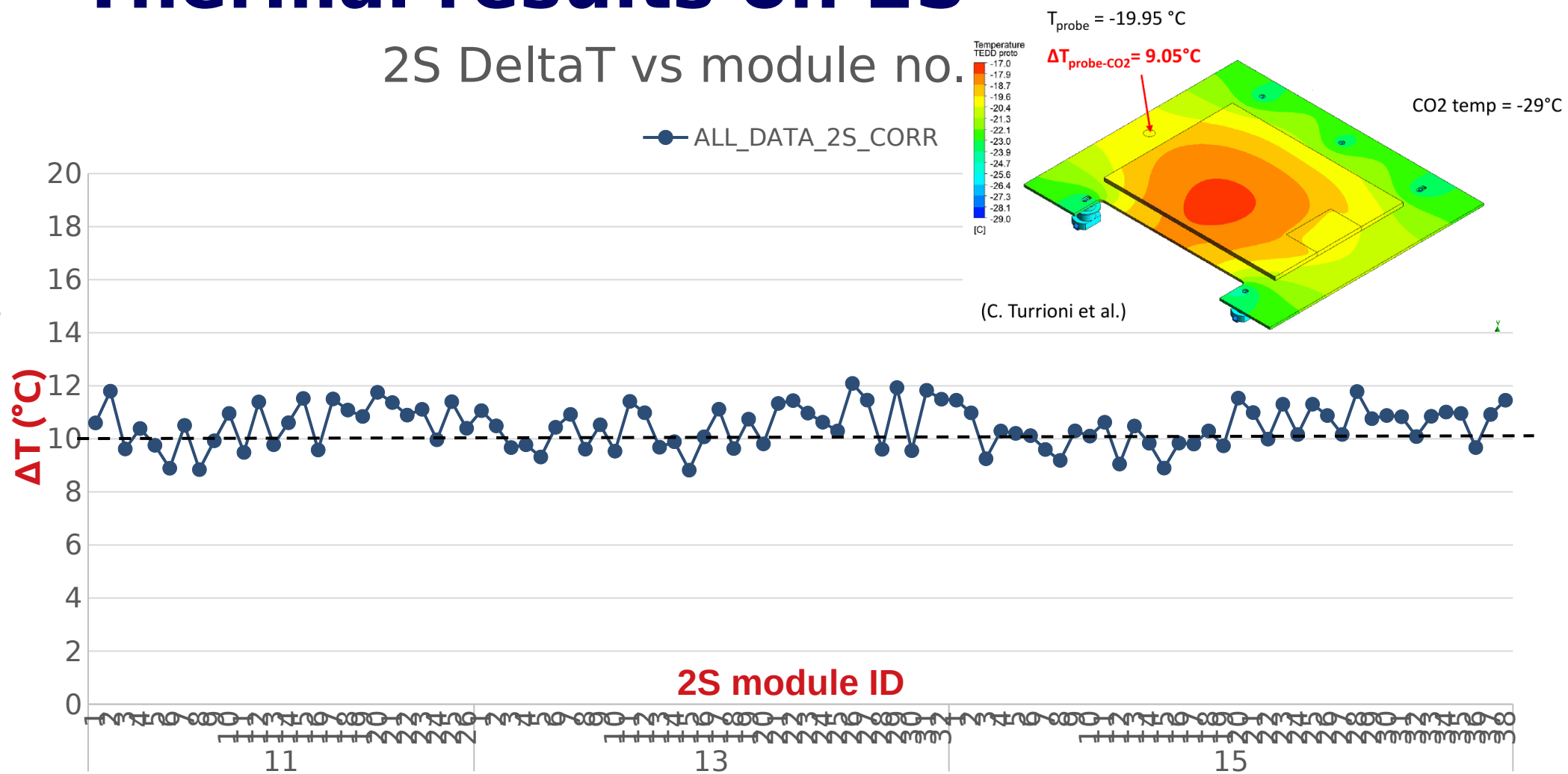


PS and 2S temperature

CO_2 temperature

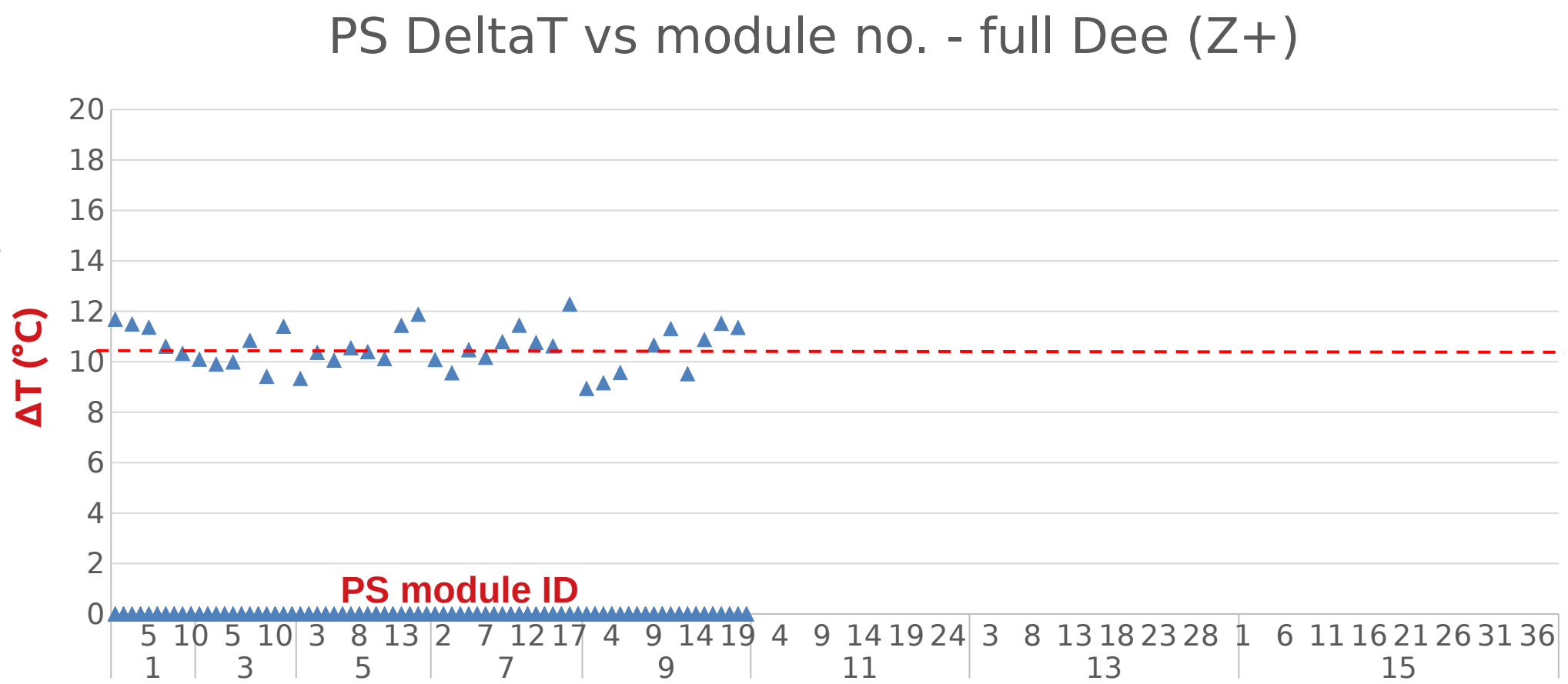
- Oscillations due to cold chamber ON/OFF cycle
- ΔT: temperature on module – CO_2 temperature
- Temperature on module corrected for variation in heater foil resistance
- CO_2 temperature extrapolated at each module location

Thermal results on 2S



- Summary of the ΔT measured for all 2S modules on Dee prototype
- Average ΔT = 10.5 °C, simulation results (C. Turrioni et al.) agree to best performing modules

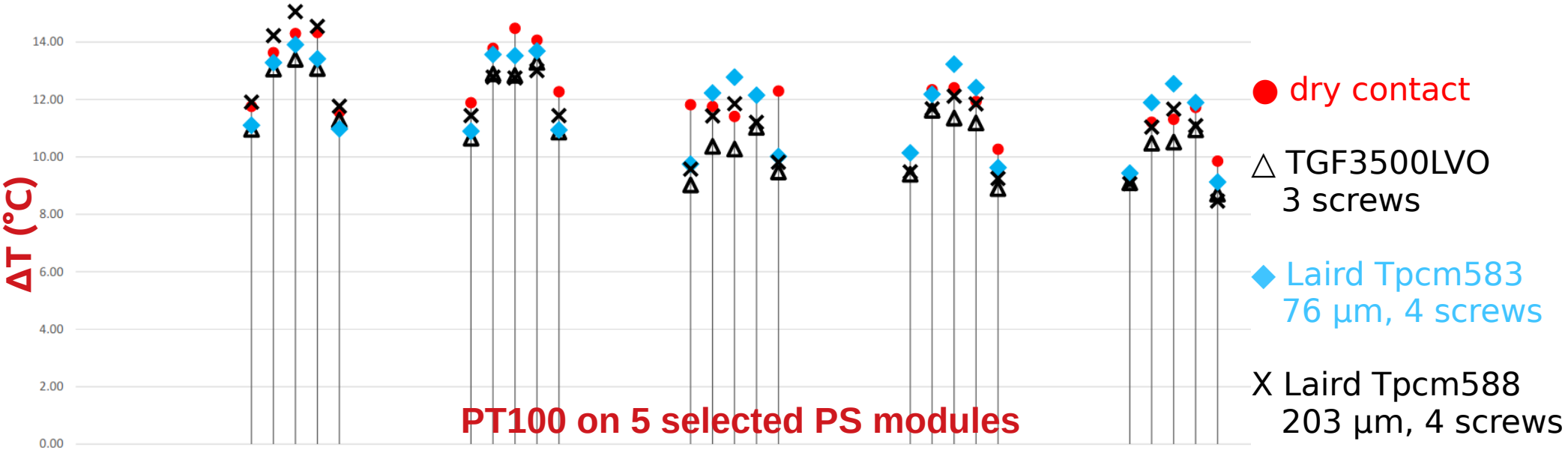
Thermal results on PS



- Summary of the ΔT measured for all PS modules on Dee prototype
- Average ΔT = 10.6 °C, simulation from C. Turrioni et al. (9.2 °C) agree to best performing modules

Thermal results on PS

- A more detailed study has been performed on PS modules:
  - several thermal interface material used
  - adding a 4th screw to increase contact with surface
  - up to 5 PT100/module to have a better control of the temperature
- Conclusions:
  - 4th screw doesn't improve the result
  - different thermal pastes give similar performance

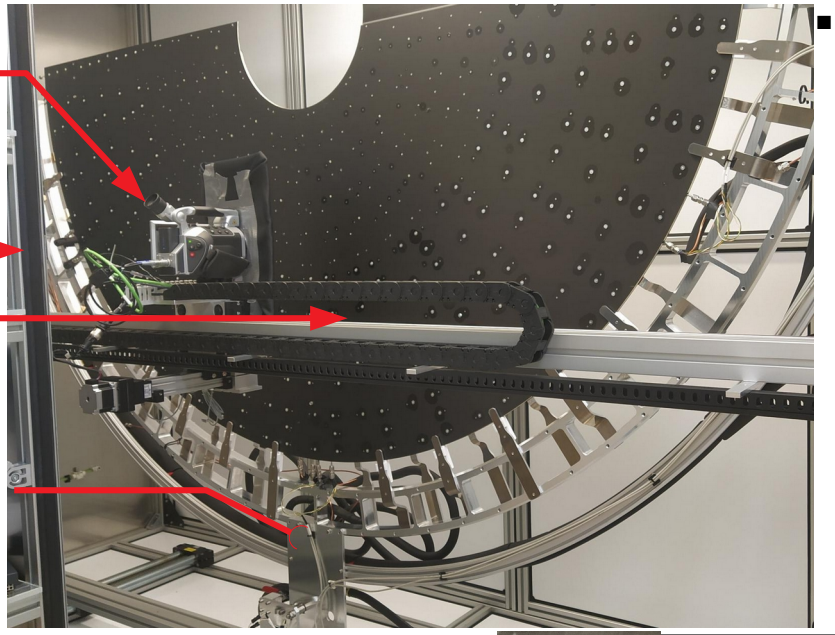


Infrared measurements at DESY

IR camera

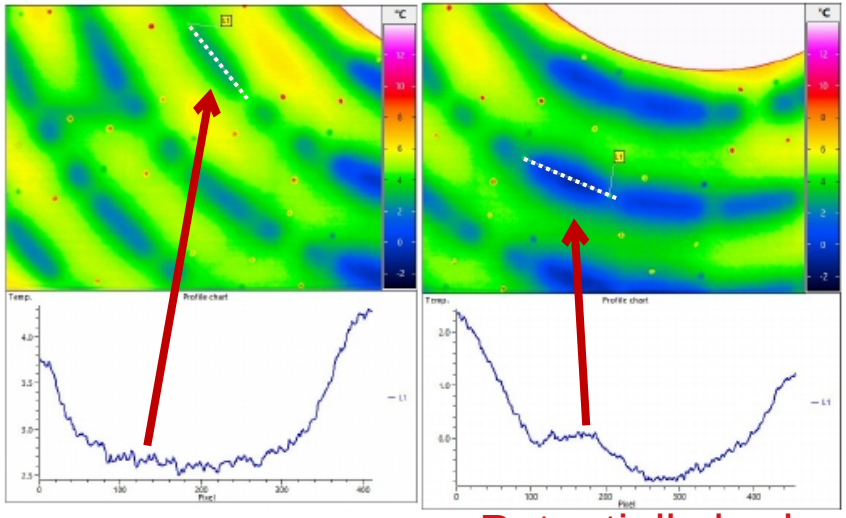
Moving stages (horizontal and vertical)

Cooling distribution to all sectors (Novec 7100)



- Setup in operation and working well
- Improvements planned:
  - Cooling fluid T measurement
  - IR lamp and heat laod
  - Results quantification and automated analysis

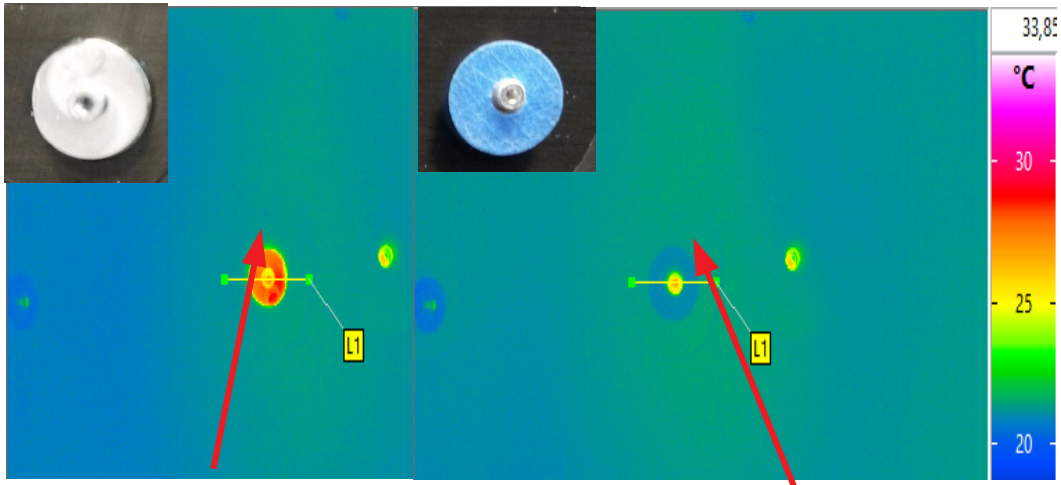
C-foam measurement



Good

Potentially bad (further study needed)

2S inserts measurement



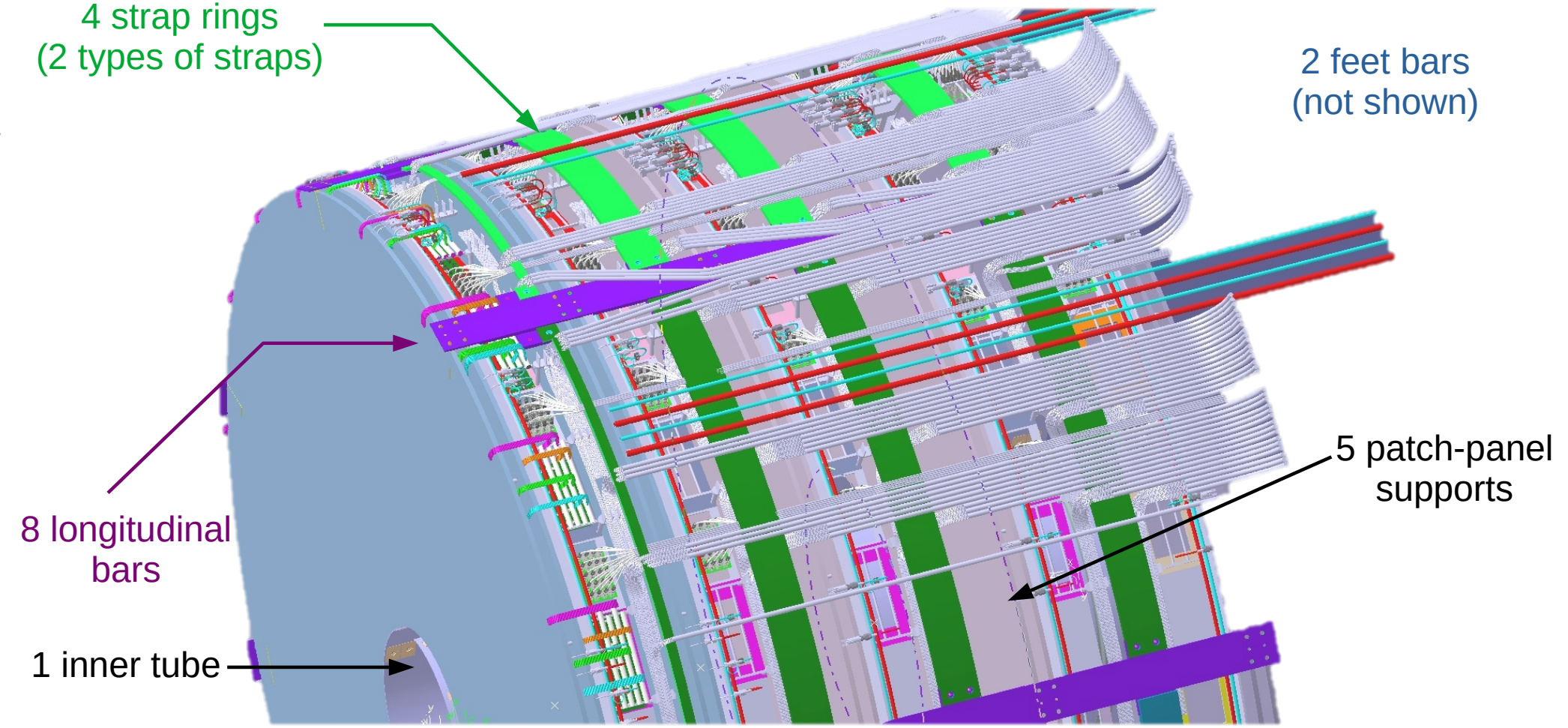
Bare insert has problematic reflection → measurement impossible

Reflection mitigated with tape on insert

Superstructure

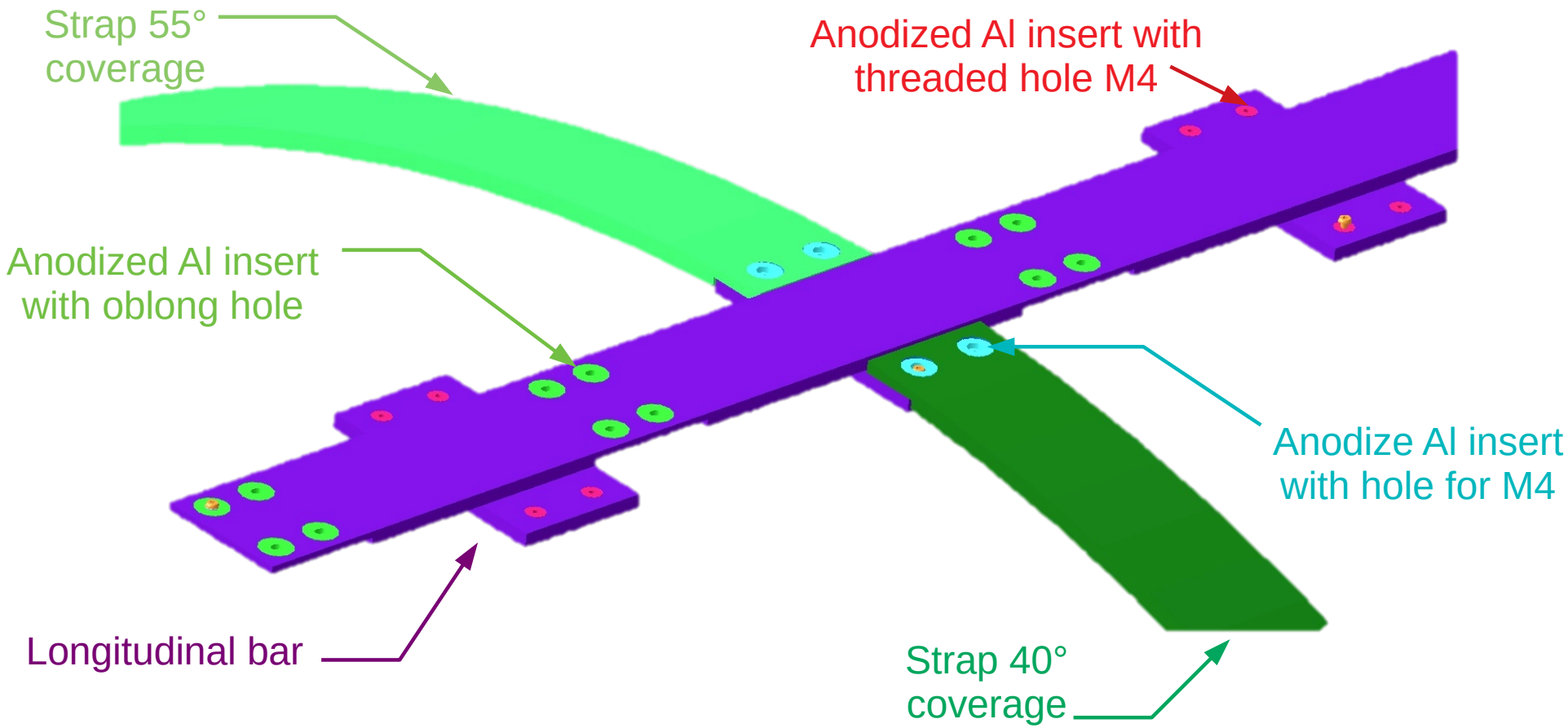
Mechanical requirement

- A set of carbon fiber pieces is also being designed to position the Double Disks and to give strength to the whole TEDD structure.



Bars and straps

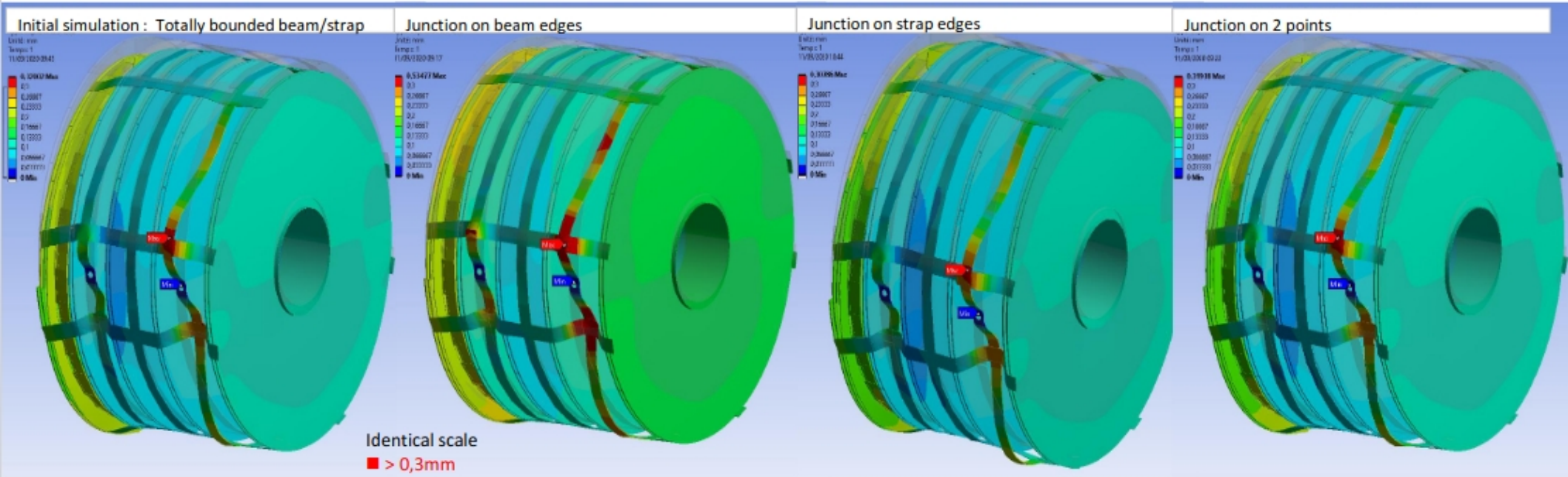
- Now working on precise design of junctions and choice of material
- Bars and straps finalized ad ready for prototype production



- A French company has been contacted to perform a tensile test to qualify and validate the junctions.

FEA simulations

- Many FEA simulations have been carried out to optimize the design of several element composing the superstructure



Initial simulation : Totally bounded beam/strap	Junction on beam edges	Junction on strap edges	Junction on 2 points
320 µm (228 for disks)	535 µm (257 for disks)	308 µm (224 for disks)	319 µm (225 for disks)
36 Mpa	53 Mpa	35 Mpa	36 Mpa
Ideal connection	Not presentative	Too much fixed	Close to reality

- Max 320 µm of deformation expected with the chosen design

Conclusions and outlook

- Dee general design completed, now working on details to improve mechanical and thermal conduction quality
- Metrology measurements show good results. All companies involved in the production and assembly chain are able to respect the tolerances imposed. Further measurements are foreseen (module rotation and other inserts position).
- Thermal tests show 1-1.5 °C of average difference compared to simulations with local deviations up to 3 °C, for PS and 2S modules.
- An alternative method using IR has been prepared at DESY.

- An improved Dee is currently under production and will be ready for test by June
- First prototype elements of the superstructure will be ready in Autumn

Backup