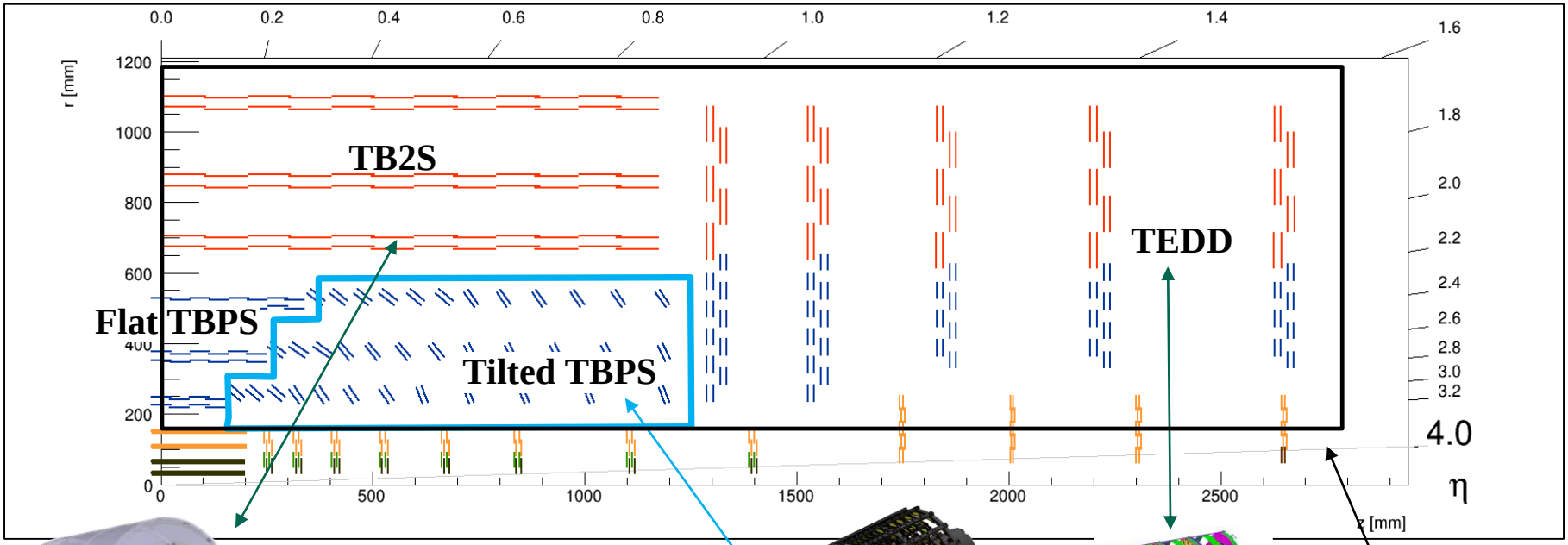
Tilted TBPS Ring Mechanics for CMS Tracker Upgrade Phase II

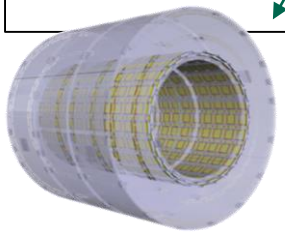
- Introduction
- Al-CF Anomalies
- Al-CF Investigation
- Ring Production

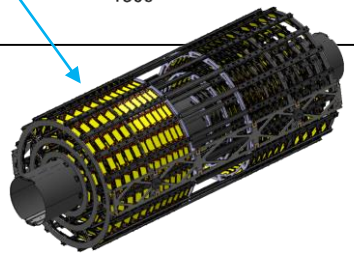
09 June 2022
https://indico.cern.ch/event/853861/

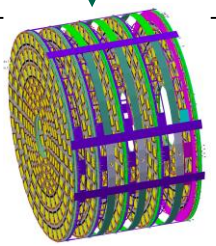
Speaker : Pierre Rose (CERN)
Main contributors : EP-DT group (CERN)

Introduction – CMS – Outer Tracker Description

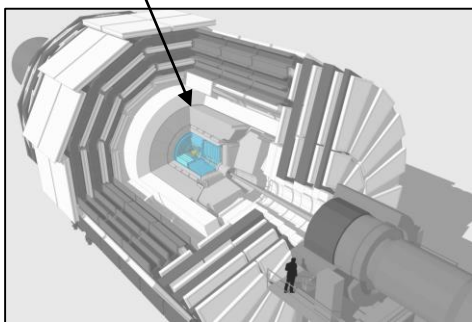




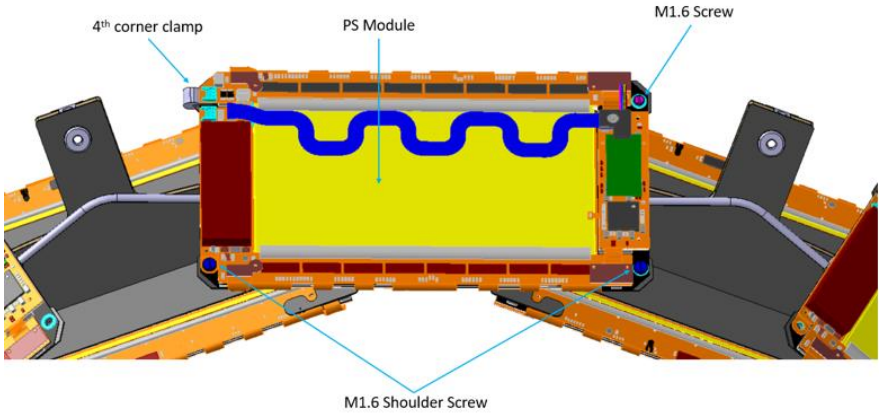


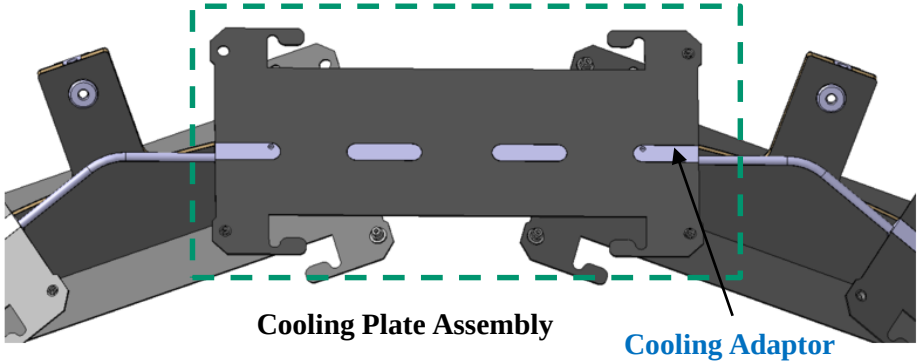


- Existing CMS Tracker will be replaced by a completely new one in LHC LS3 (2025)
- Will use new Module types capable of selecting high momentum tracks (>2-3 GeV)
  And innovant light-weight structures as the TBPS Tilted Rings.
- See Kamil Cichy's talk in Cornell University (2019)
  "*Prototyping of 'tilted' Rings and design of global structures and assembly sequence for the TBPS*"
  https://indico.cern.ch/event/775863/

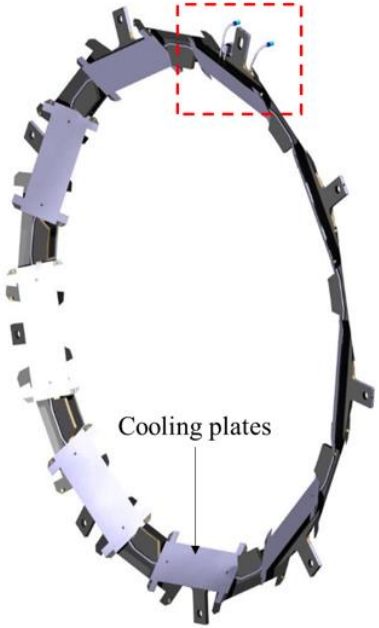


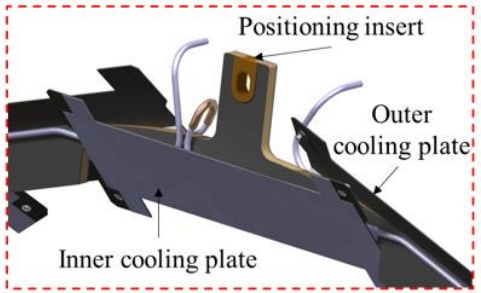
Introduction – CMS – Outer Tracker Description

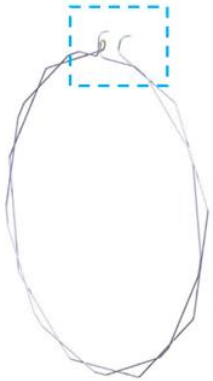


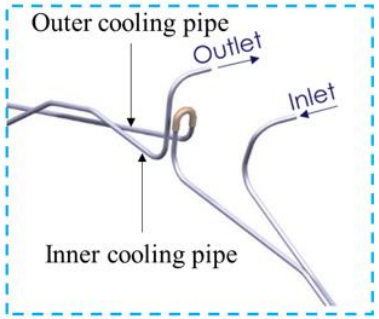


Anomalies reported in this presentation









TBPS Tilted Rings:

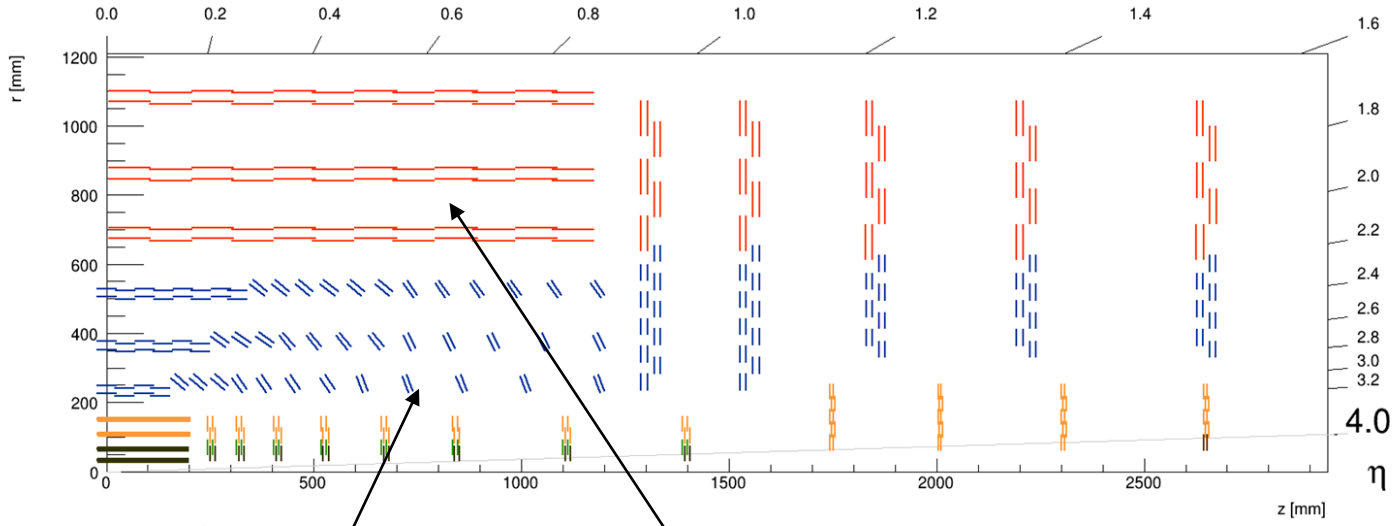
3 layers (Ø600 – Ø850 – Ø1150)

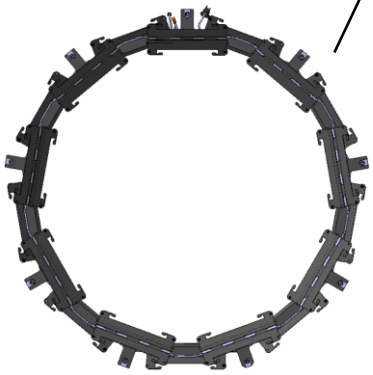
12 Rings per layer per end

72 Rings in total, of 8 different types

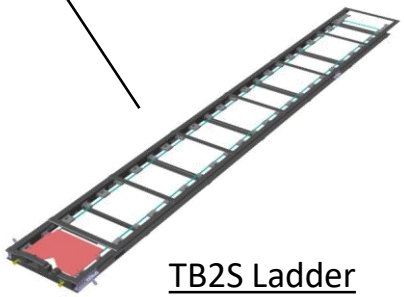
Component	Material
Sandwich Plate Ring	M55J/DT120 carbon-fibre/epoxy + Airex R82.80
Cooling Plate	K13D2U/EX-1515 carbon-fibre/cyanate ester
Cooling Adaptor	**Al-CF 4ppm**
Cooling Pipe	Stainless steel 316L
Cooling Pipe conn.	Cu-Ni 70/30
Cooling U-tube	Cu
Positioning inserts	PEI

Introduction –
Al-CF components inside the Outer Tracker

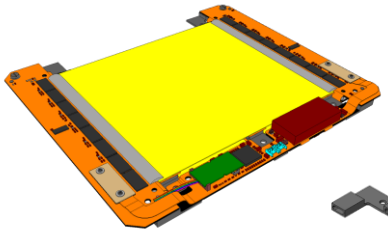




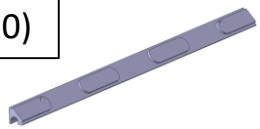
TBPS Ring
Cooling Adaptors (x1920)

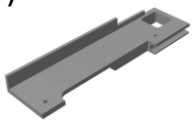


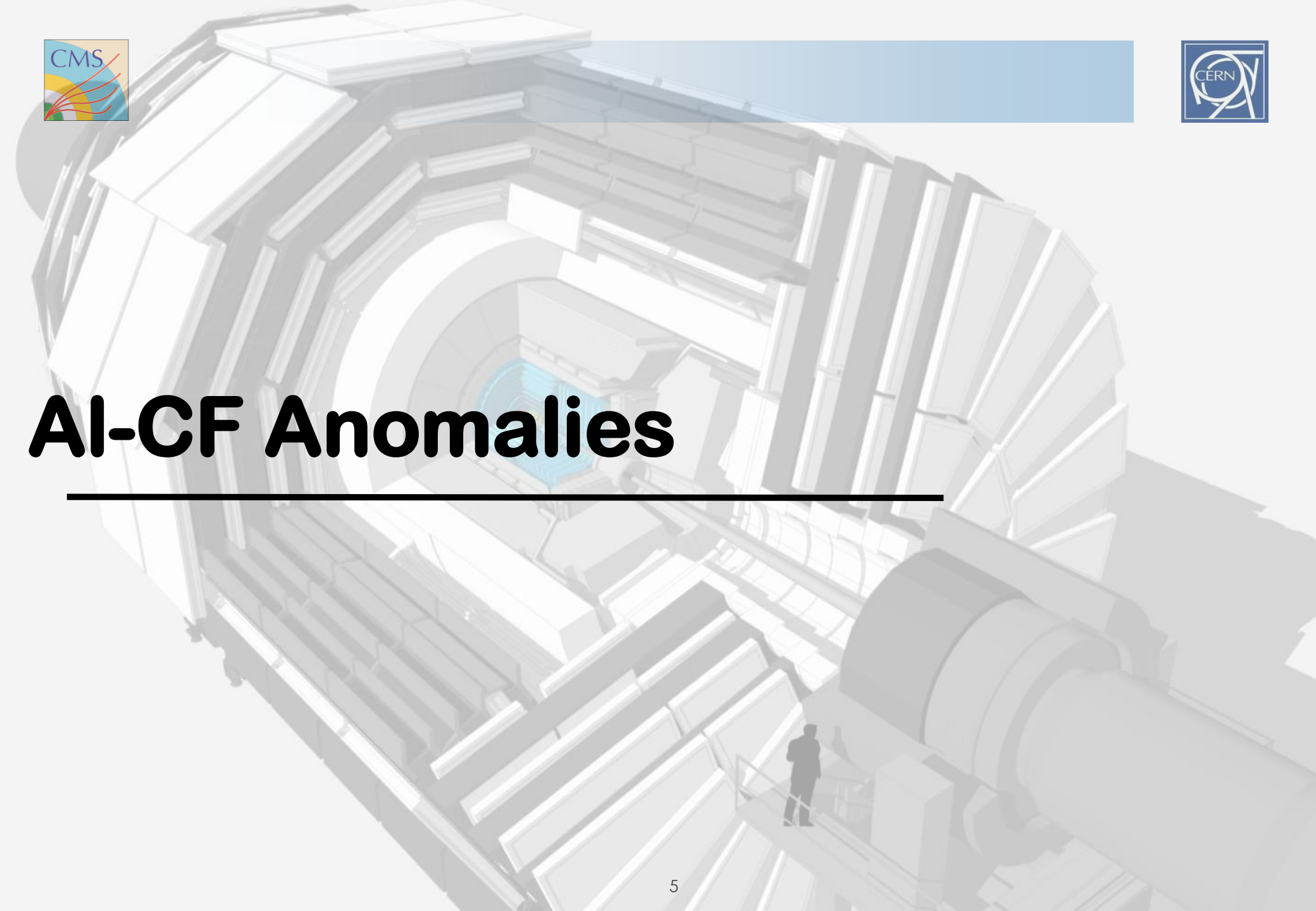
TB2S Ladder
Special Inserts
at Module #1 (x368)



2S Modules
Spacers (x15216)







AI-CF Anomalies

Al-CF Anomalies – Al-CF Material

- Al-CF material from a Manufacturer (here called “MA”) has been used since the beginning of the CMS OT developments ~2012.

- Second Manufacturer (here called “MB”) proposes Al-CF since ~2018 with “nominally same” material properties as MA.

- Manufacturing process for material production is different:
  MA : *Induction Melting Process => Casted Al-CF*
  MB : *Sintering Process => Sintered Al-CF*

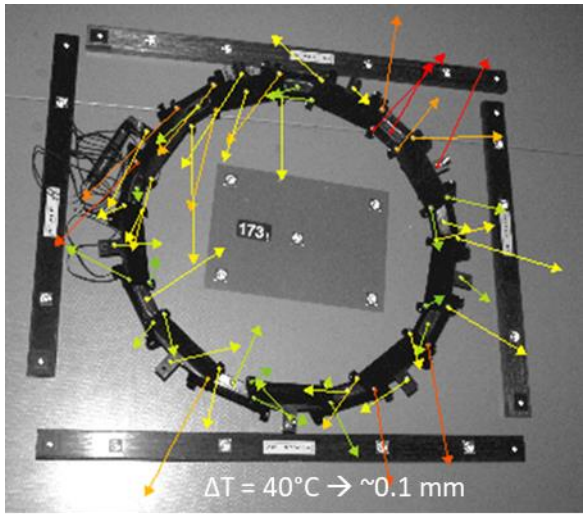
- *MA* delivers Round disk shapes – not ideal for our use, early deliveries contained Al veins, but this aspect has been solved – They are considering to produce rectangular blocks.

- *MB* delivers rectangular blocks – ideal for use and no veins

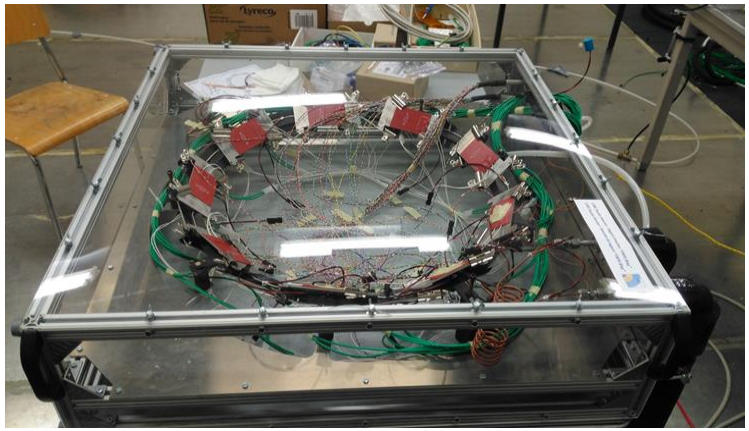
Al-CF Anomalies – TBPS Ring Prototyping -2019

Full-size TBPS Ring prototype was successfully made and tested in 2019, and validated the design, manufacturing method and material choices (including Al-CF material)

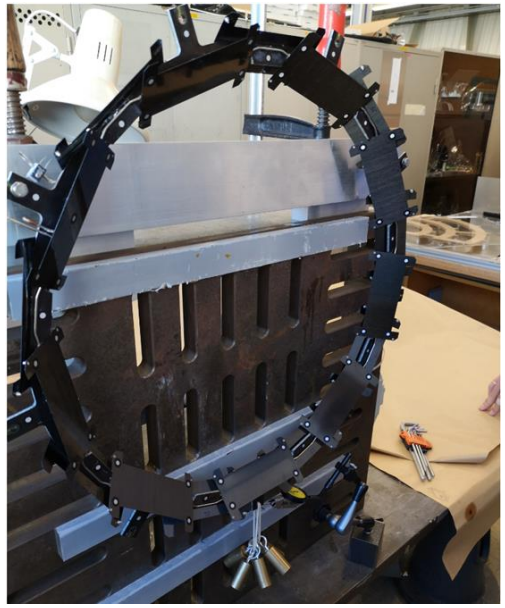
Casted Al-CF was used (from MA)



Deformation at D40◦C



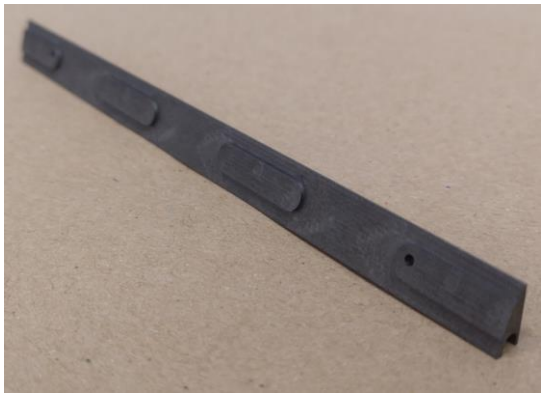
Thermal test using dummy modules



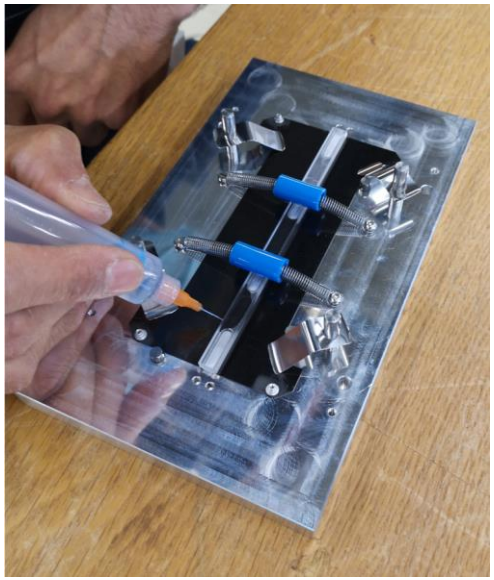
Mechanical load measurements

- Geometry within specifications
- Cooling performance validated
- Deformations due temperature change: < 100 µm after ΔT of 40°C.
- Deformation under mechanical load: 65 µm under 1 kg (2-point support, full load concentrated in one point).
- Electrical continuity : 25-230 Ω between module supporting Cooling plates.

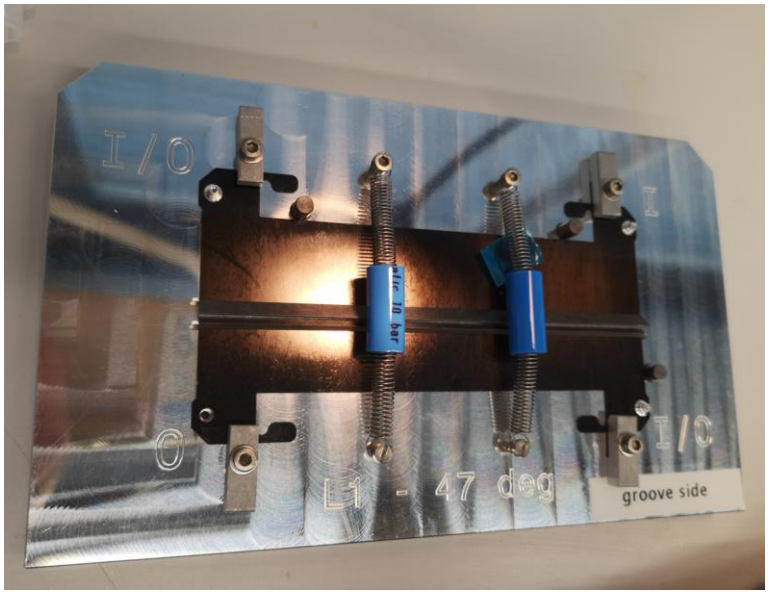
Al-CF Anomalies – TBPS Ring Production – 2021



Sintered Al-CF cooling adaptor



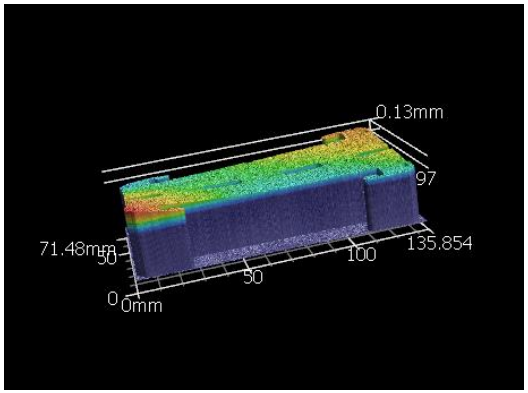
Cooling Plate gluing jig

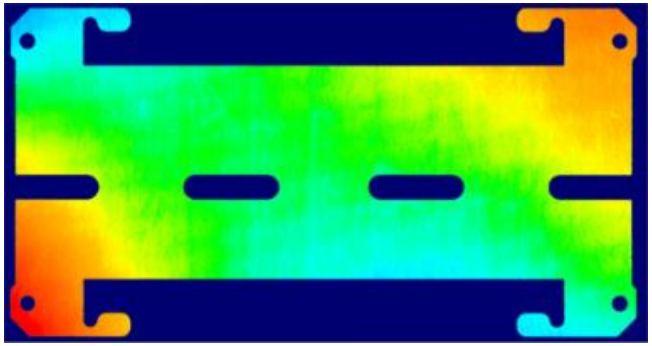


Cooling Plate Assembly

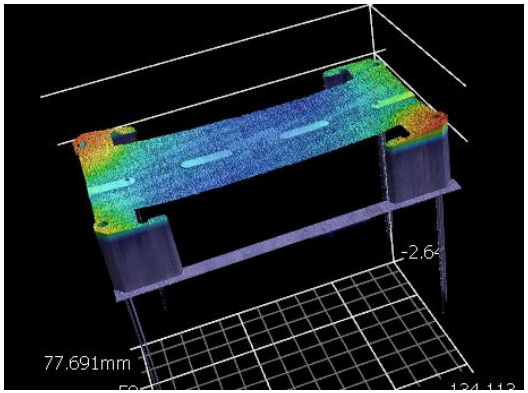
- Design of the Cooling Adaptor was updated by adding 4 pads to increase the thermal efficiency of the cooling assemblies
- The assemblies were made in July 2021
- Cooling Plate Gluing Jigs are used for both Inner and Outer Cooling Plate assemblies
  *- CF Cooling Plate (Five plies of 120 gsm K13D2U/EX1515 UD carbon-fibre / cyanate ester prepreg laminated to ~0.5 mm thick flat plates with [0, 90, 0, 90, 0] layup) + Sintered Al-CF Cooling Adaptor made from **MB material** + Al Inserts*
- Polytec EP 601-LV glue used
- 48h of curing at laboratory Temperature: ≈25°C with ≈50% Rh
- 22 Cooling Plate assemblies were glued for the Layer 1 Ring (nominal : 18)

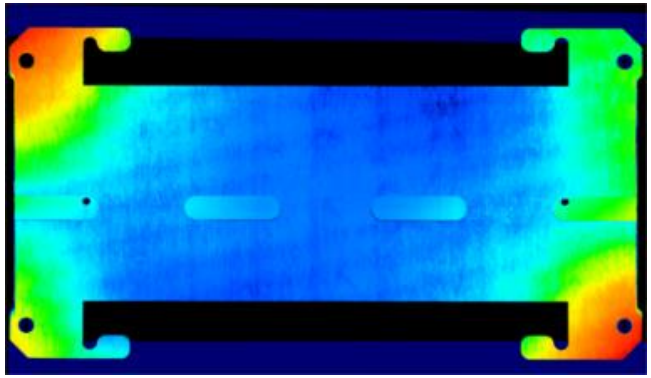
Al-CF Anomalies – TBPS Ring Production – 2021





	Height difference	Max. height	Min. height	Max.-Min.
	mm	mm	mm	mm
Total	0.000	0.133	-0.068	0.201
Max.	0.000	0.133	-0.068	0.201
Min.	0.000	0.133	-0.068	0.201
Ave.	0.000	0.133	-0.068	0.201
Std. DV	0.000	0.000	0.000	0.000
3 Sigma	0.000	0.000	0.000	0.000
Area1	0.000	0.133	-0.068	0.201

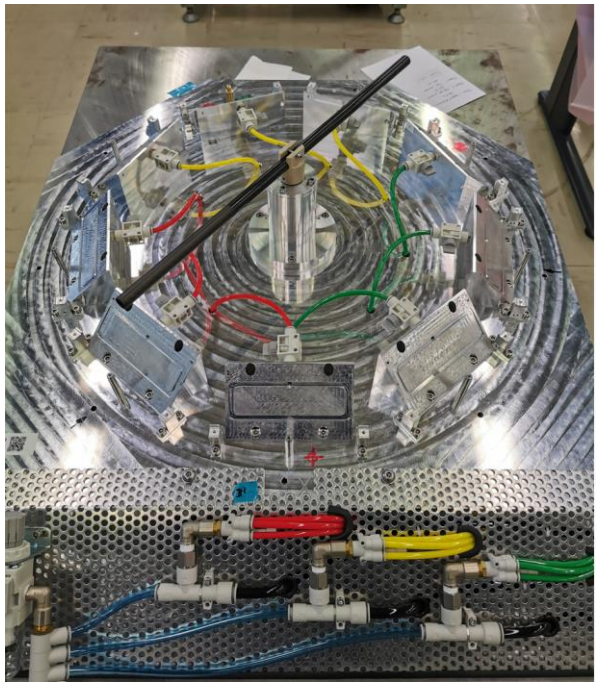




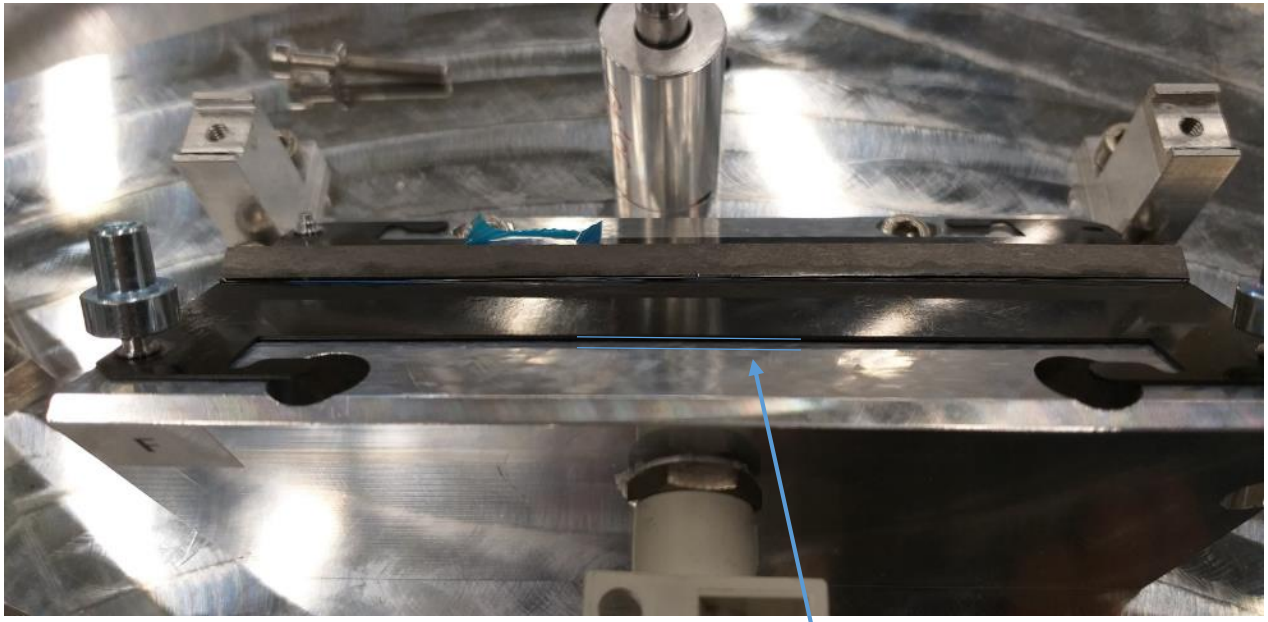
	Height difference	Max. height	Min. height	Max.-Min.
	mm	mm	mm	mm
Total	0.000	0.113	-0.058	0.171
Max.	0.000	0.113	-0.058	0.171
Min.	0.000	0.113	-0.058	0.171
Ave.	0.000	0.113	-0.058	0.171
Std. DV	0.000	0.000	0.000	0.000
3 Sigma	0.000	0.000	0.000	0.000
Area1	0.000	0.113	-0.058	0.171

- Flatness of every Cooling Plate was measured with Laser VR Keyence microscope in July 2021 before and after the gluing with the Al-CF adaptor (from MB)
- Plate flatness measured to between 120 µm and 200 µm both for single Cooling Plates as for Cooling Plate + Al-CF Adaptor assemblies
- All the assemblies were stored in a cupboard in a lab with no thermal/humidity control from July to October, with temperatures from +18°C to +35°C, as the lab air-conditioning was off (due Covid reasons)

Al-CF Anomalies – TBPS Ring Production – 2021



L1 - Inner Assembly jig



Before 0.17mm

- In parallel, the Assembly Jigs were produced and adjusted, and delay occurred on the delivery of the Sandwich Plate Rings
- Finally, the Ring production "started" at the end of October 2021 (3 months after the gluing of the cooling plate assemblies)
- But the cooling plate assemblies were not as flat as before ! Factor 2 of deflection was observed on all the cooling plate assemblies
- A bi-metallic effect was observed, but why did it occur now ? (and was never observed before (2019))
- The assemblies are not as stable as we thought
- **Influence of the humidity ? Or influence of the design itself ?** (Casted Al-CF cooling adaptors didn't have the 4 pads)
- Problem with the CF cooling plate ? Problem with the Temperature ? Some other problem that we cannot imagine ?

Al-CF Investigation

Al-CF Investigation – Al-CF behavior

- Temperature change (CTE) was quickly removed as a potential source of the deformation problem. Changing the temperature of the Cooling Plate assembly within 10°C range did not lead to any measurable deformations

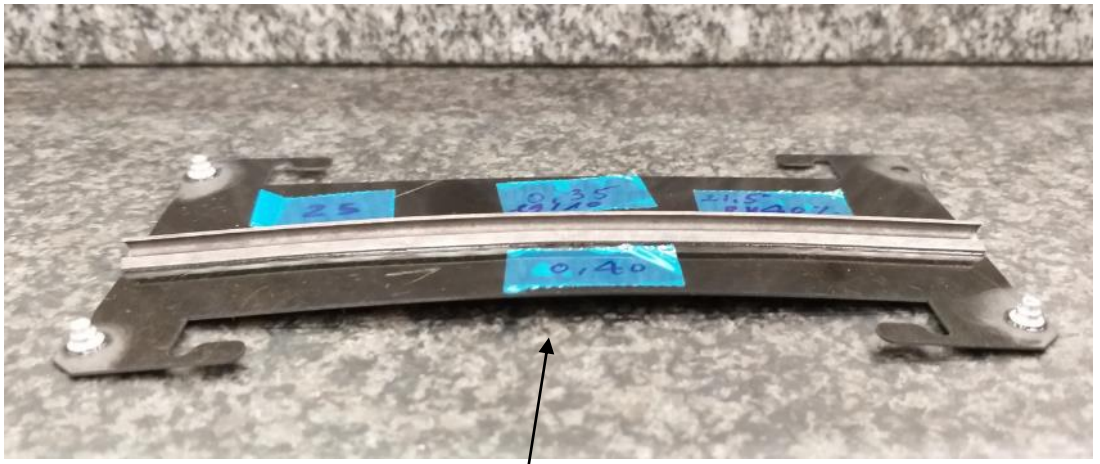
- **Humidity influence ?**

A 1st test was done on a Cooling Plate Assembly with Sintered Al-CF (From MB)

Test conditions:

- Temperature: 70°C
- Humidity: 100%
- Time: 60 hours (weekend)

CP assembly inside a sealed bag with water



Deflection of 3.2mm !

Al-CF Investigation – Al-CF behavior

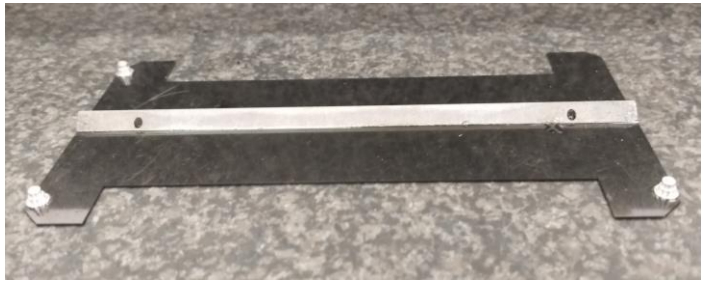
- **Humidity influence ?**

A 2nd test was done with a MB Cooling plate assembly and a MA one (glued 3years ago)

Test conditions:

- Temperature: 70°C
- Humidity: 100%
- Time: 18 hours

Sintered Al-CF (MB): Deformation from 0.35mm to 0.80mm



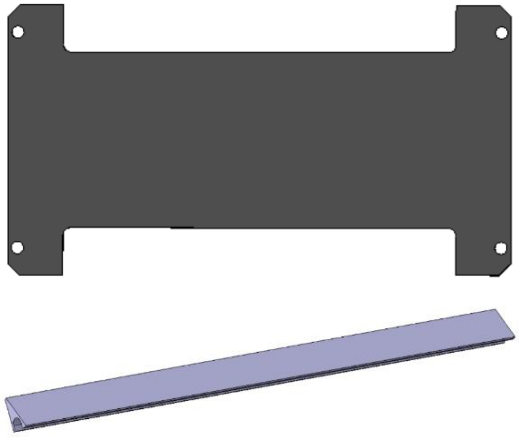
Casted Al-CF (MA): No visible deformation

- It seems that the moisture affects only the Sintered Al-CF,
  but as the Al-CF adaptor geometries in the two assemblies are not the same, could the source be the geometry ?

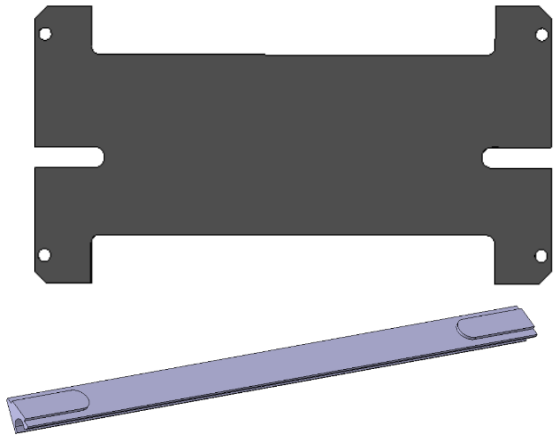
Al-CF Investigation – Al-CF behavior

- **Geometry influence ?**

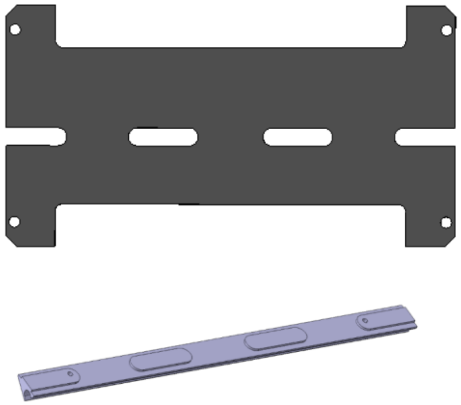
Tests were performed using 6 Casted and 6 Sintered Al-CF assemblies, with 3 different geometrical designs (number of notches).



Design #1, no notched



Design #2, 2 notches



Design #3, 4 notches

Test conditions:

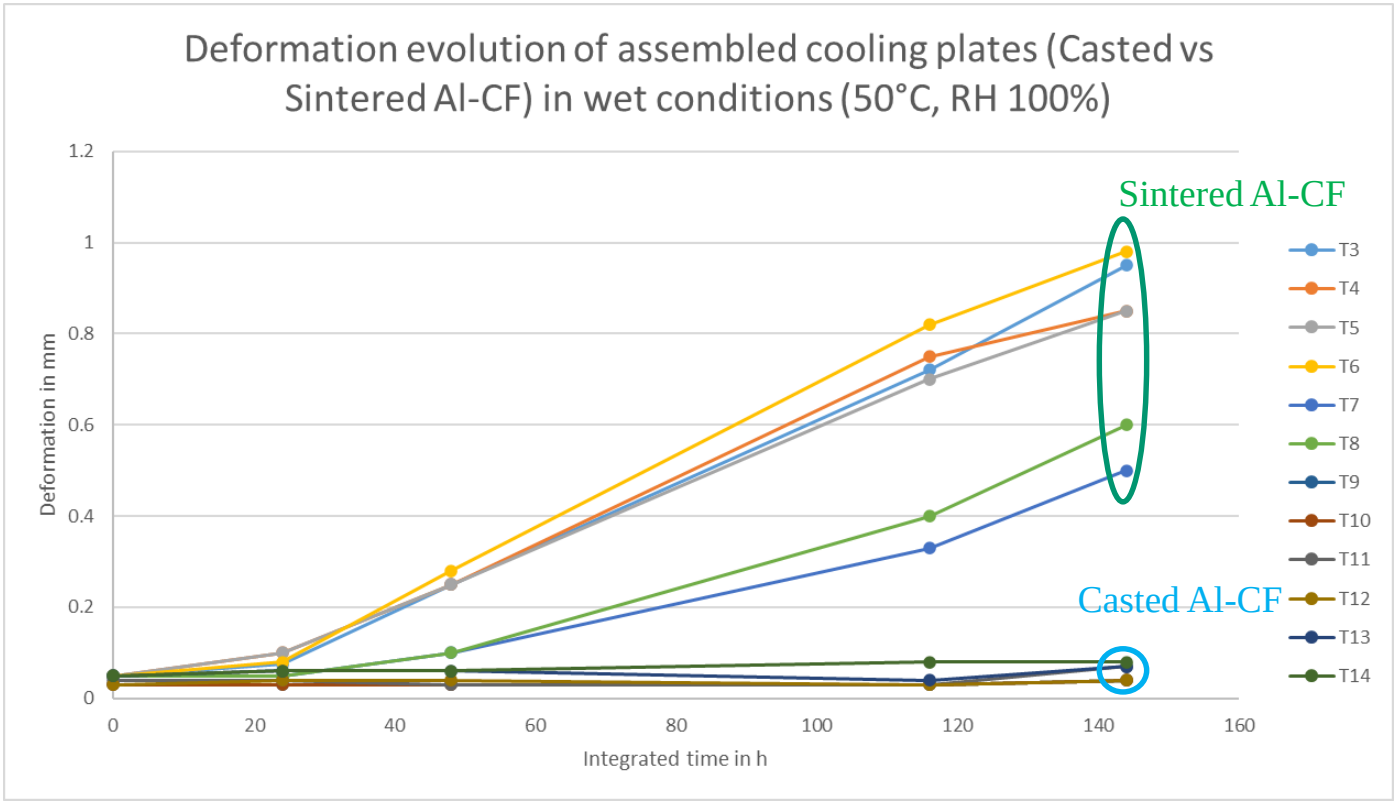
- 50°C and 100% RH for days.

AL/CFMaterial	Plate #	# of notches
Sintered Al-CF MB	T3	2
	T4	2
	T5	4
	T6	4
	T7	0
	T8	0
Casted Al-CF MA	T9	0
	T10	0
	T11	2
	T12	2
	T13	4
	T14	4

Al-CF Investigation – Al-CF behavior

➢ **Geometry influence ?**

Tests were performed using 6 Casted and 6 Sintered Al-CF assemblies, with 3 different geometrical designs (number of notches).

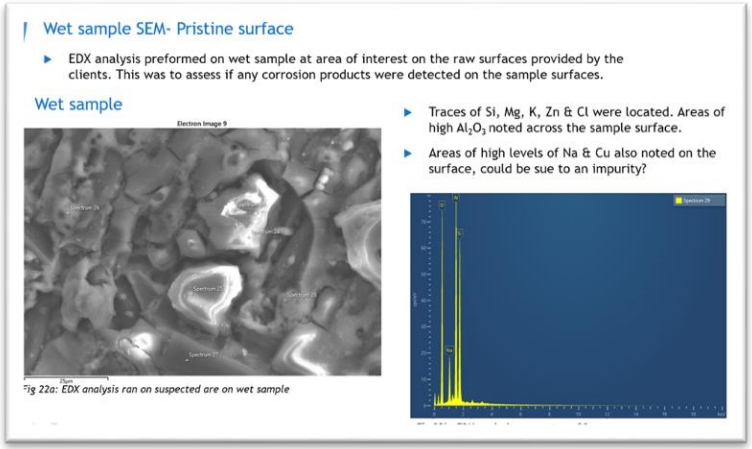


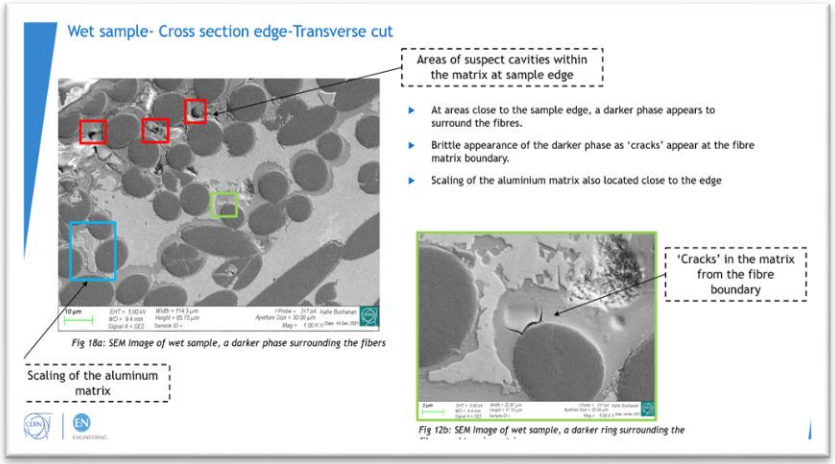
- There is no direct correlation between deformation and design (presence or absence of notches)
- The bi-metallic effect is directly due to the Al-CF material itself, and visible only with the Sintered material.

Al-CF Investigation – Material Inspection

- Samples that had been exposed to high level of humidity were analyzed at the EN-MME-MM group at CERN (Materials, Metrology and Non-Destructive Testing)

- The samples were test with EDX analysis (Energy Dispersive X-Ray) and SEM (Scanning Electron Microscope)





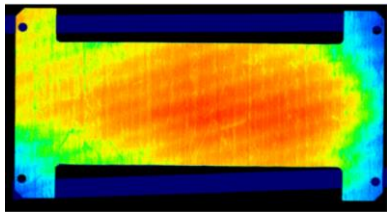
- Their conclusion: *"observed degradation of the MB wet sample the underwent extreme condition is understood to have **extreme moisture sensitivity** due to degradation induced by active galvanic corrosion phenomenon happening between the carbon fibre and aluminium matrix. This may be related to the more open structure due to the fabrication route of powder metallurgy"*
  "MA samples has slight breakdown on the outer surface of the pristine sample and not in the bulk material of the wet sample"

- *Contact persons : katie.elizabeth.buchanan@cern.ch Stefano.Sgobba@cern.ch*

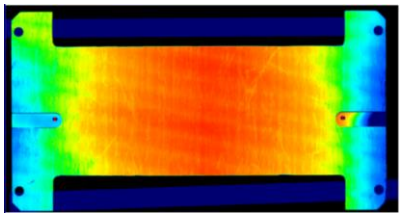
Al-CF Investigation – Coating Measurements

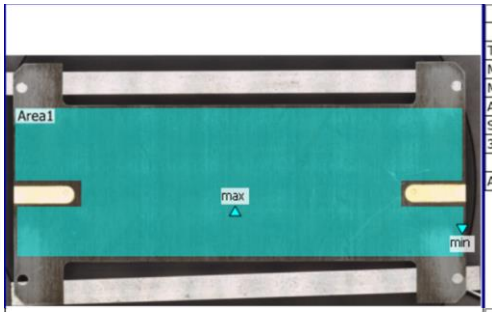
- MB was informed about this moisture issue with their Sintered material
- They proposed to “protect” the material by adding a coating on the adaptors as they usually coat all the pieces they sent to electronic consumers.
- They propose to perform more moisture tests with coated adaptors (with coating of 12µm of Ni and 0.2µm of Au)
- 6 samples were produced, and the 3 best parts were tested
- 3 cooling plate assemblies were done with flatness below 100µm

Sintered Al-CF coating adaptors

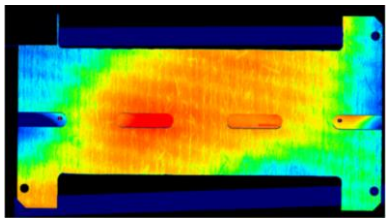


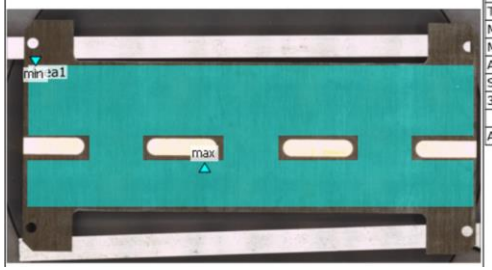
	Height difference	Max. height	Min. height	Max.-Min.
	mm	mm	mm	mm
Total	0.000	0.024	-0.045	0.069
Max.	0.000	0.024	-0.045	0.069
Min.	0.000	0.024	-0.045	0.069
Ave.	0.000	0.024	-0.045	0.069
Std. DV	0.000	0.000	0.000	0.000
3 Sigma	0.000	0.000	0.000	0.000
Area1	0.000	0.024	-0.045	0.069





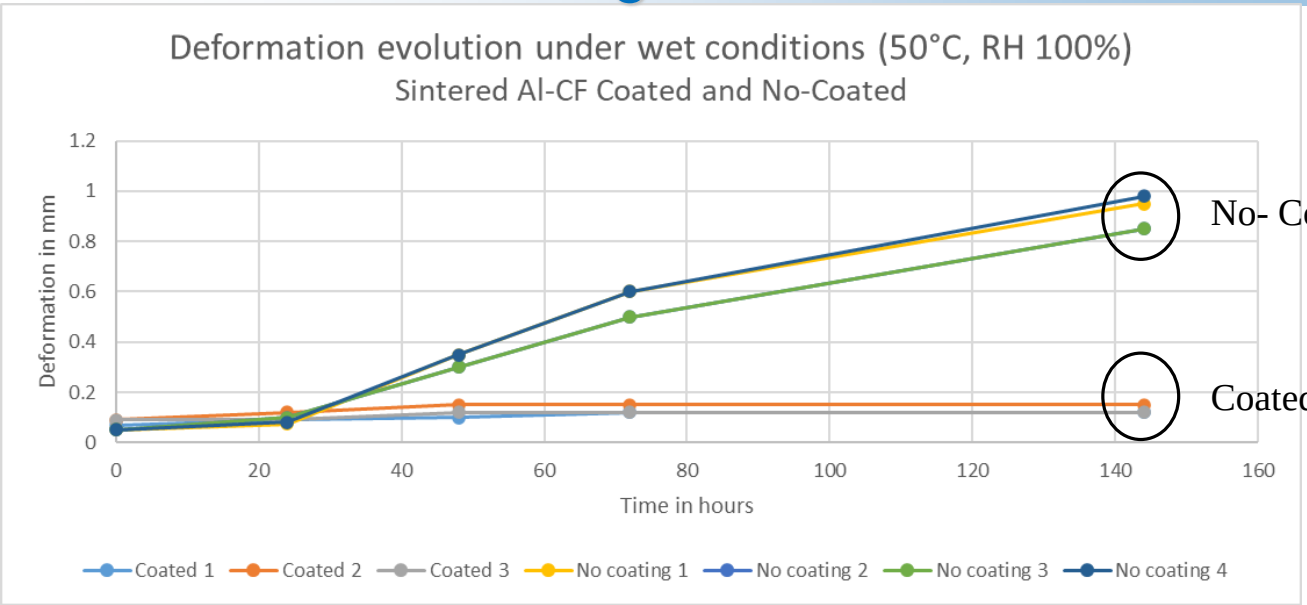
	Height difference	Max. height	Min. height	Max.-Min.
	mm	mm	mm	mm
Total	0.000	0.031	-0.061	0.093
Max.	0.000	0.031	-0.061	0.093
Min.	0.000	0.031	-0.061	0.093
Ave.	0.000	0.031	-0.061	0.093
Std. DV	0.000	0.000	0.000	0.000
3 Sigma	0.000	0.000	0.000	0.000
Area1	0.000	0.031	-0.061	0.093





	Height difference	Max. height	Min. height	Max.-Min.
	mm	mm	mm	mm
Total	0.000	0.025	-0.057	0.082
Max.	0.000	0.025	-0.057	0.082
Min.	0.000	0.025	-0.057	0.082
Ave.	0.000	0.025	-0.057	0.082
Std. DV	0.000	0.000	0.000	0.000
3 Sigma	0.000	0.000	0.000	0.000
Area1	0.000	0.025	-0.057	0.082

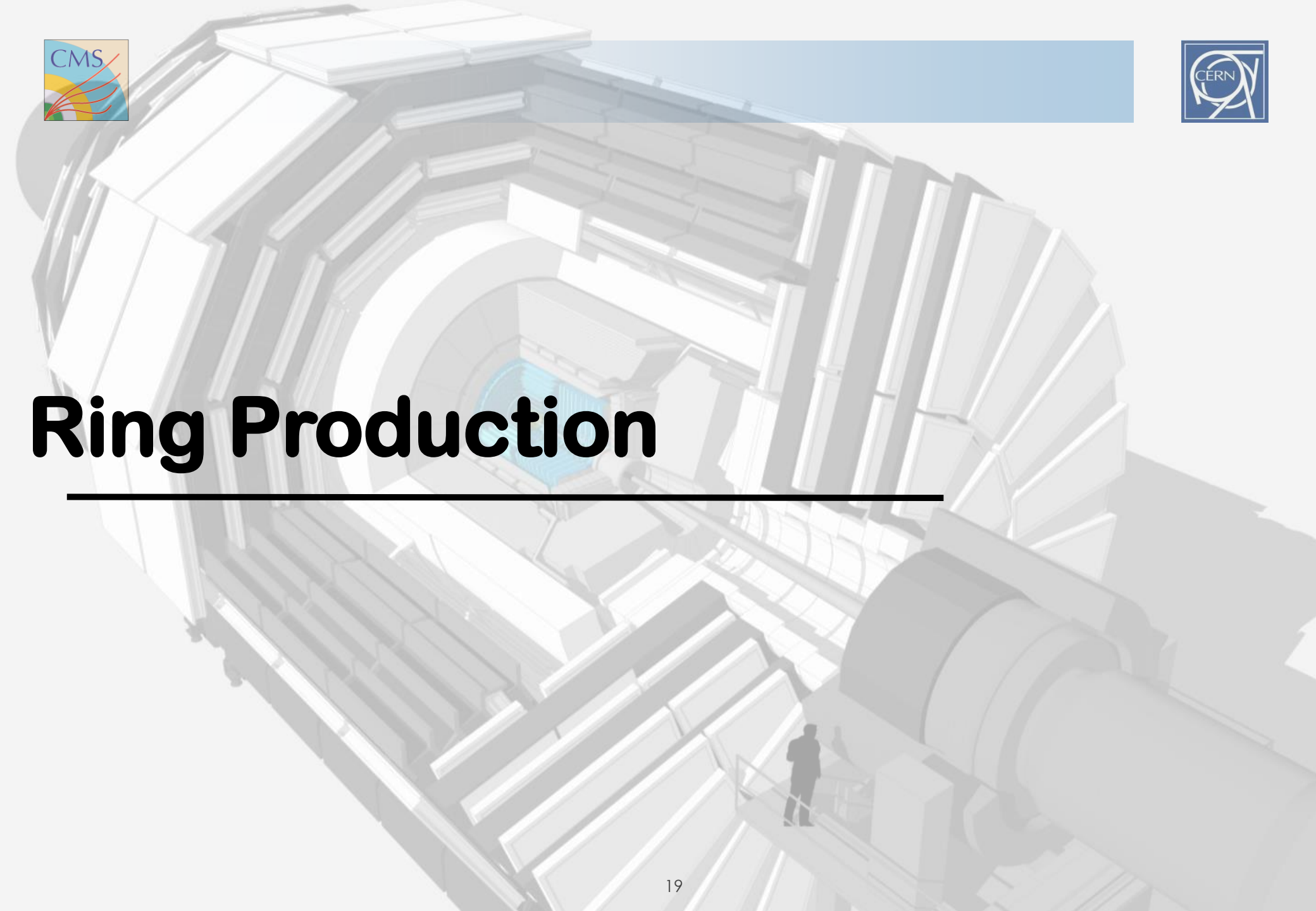
Al-CF Investigation – Coating Measurements



- Coating does protect the pieces from the moisture absorption effect.
- Coated pieces are acceptable for TBPS Ring production but do increase the radiation length of the parts by 15%.
- EN-MME-MM did analysis too :

Al/CF Powder metallurgy Ni-Au coated samples

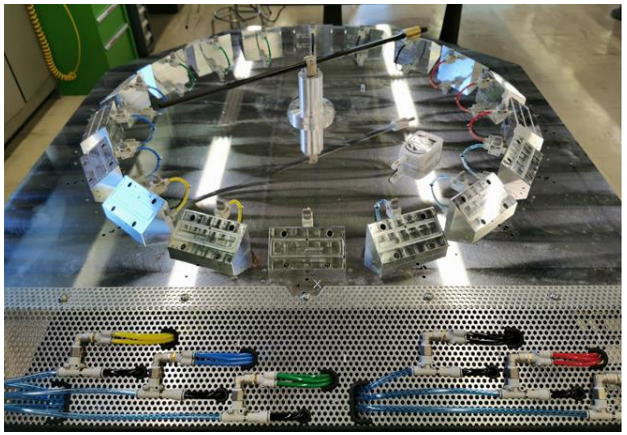
- Effective coating application: good wetting and adherence both to the Al matrix and to the fibres
- Continuous coating: no breakages were found
- Coating impervious to moisture: no corrosion events identified, even for the Ni-Au Coated - Extreme environment sample



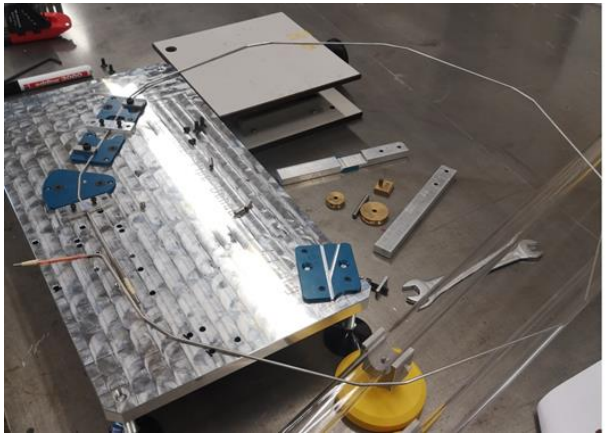
Ring Production

Ring Production – Ring Assembly Building

Ring Assembly Zone



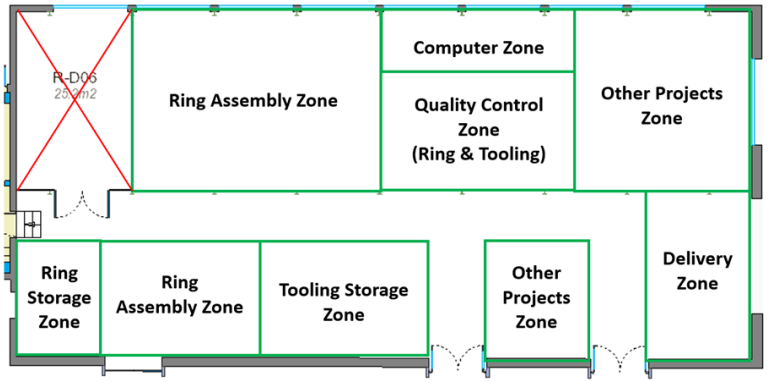
Layer 3 Ring Assembly Jig

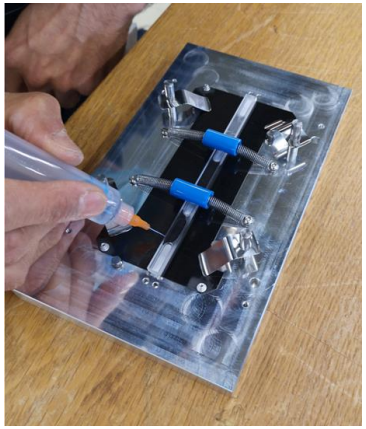


L1 – Pipe Bending Jig

- The Tilted TBPS mechanics is constructed in CERN EP-DT facilities.
- Temperature controlled space (288 m2) has been setup in 2021 and is the key facility for high-precision assembly gluing operations. The facility benefits of high-precision machining workshop, laboratory and office spaces in the same building cluster

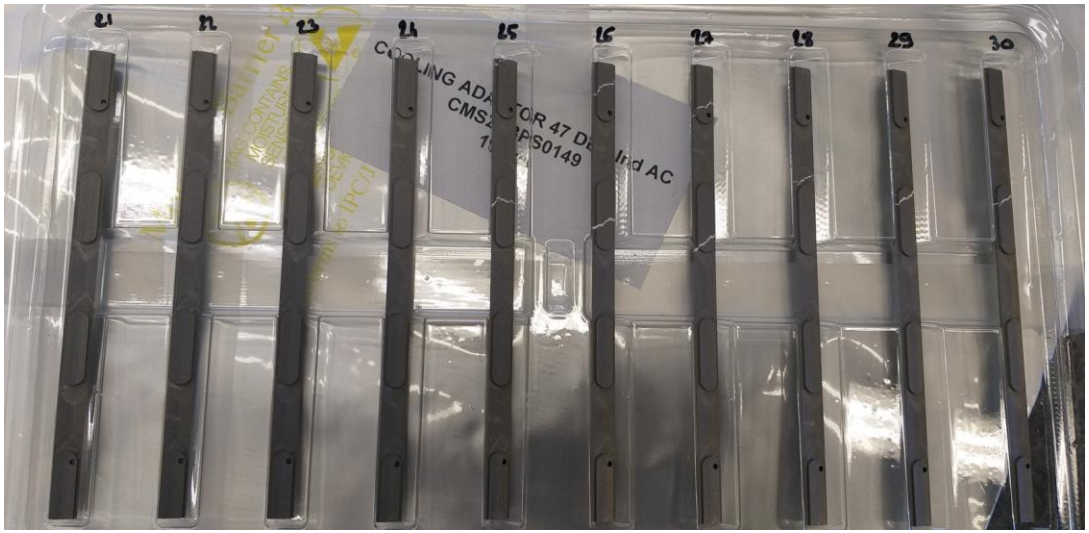
Ring Production Building layout





Cooling Plate Assembly Jig

Ring Production – Ring L1-47°

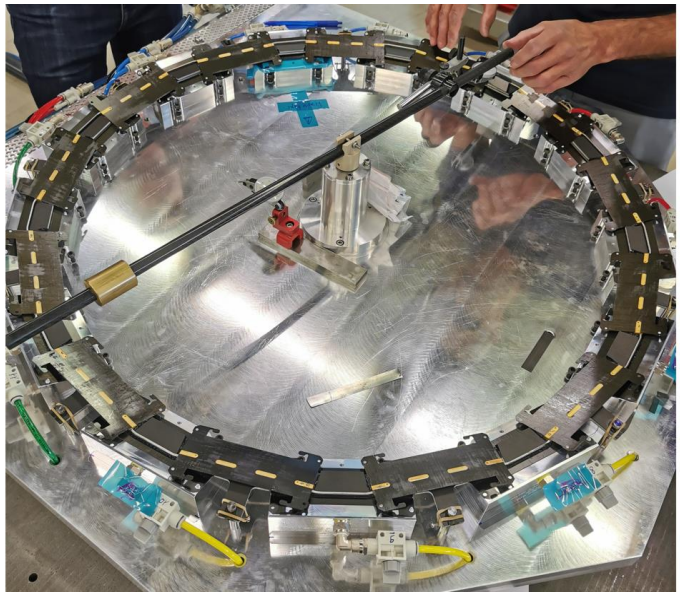


Casted Al-CF Cooling Adaptor

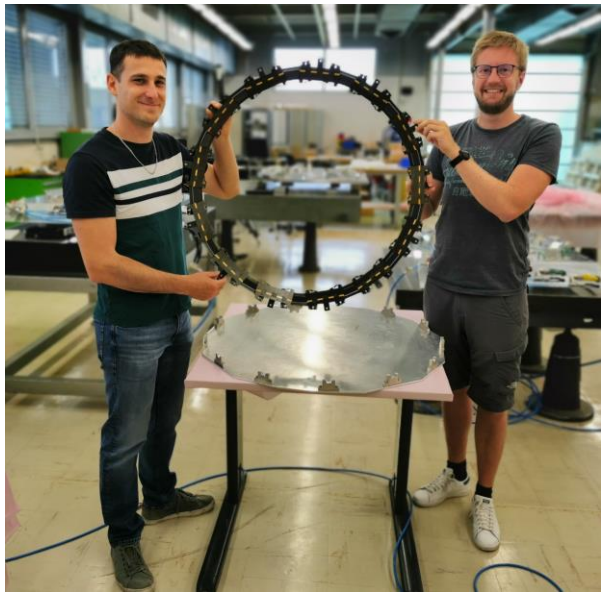
L1-47° Ring

- For the 1st Ring L1-47°, Casted adaptors have been machined and installed in the Ring
- Ring assembly was OK, pressure tested, metrology tested
- Currently thermal tested, preliminary results look fine.

Ring Production – Ring L2-68°



L2-68° Outer Assembly jig with Ring



L2-68° Ring

L2-68° Ring – on metrology machine

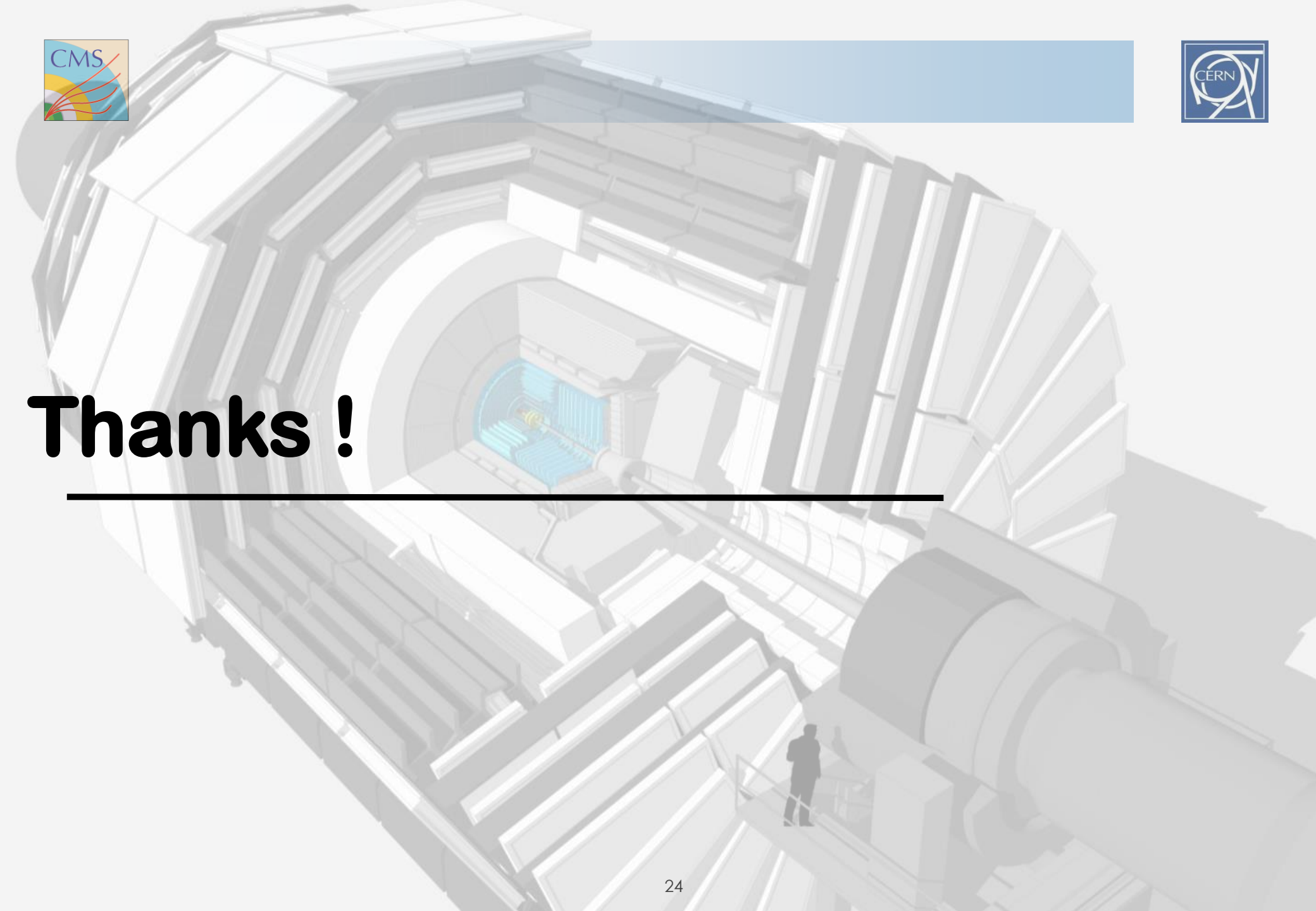
- For the 2nd Ring L2-68°,Sintered coated Al-CF adaptors have been machined and used
- Ring assembly was OK, Cooling Plates assemblies behaved as expected.
- Currently at the metrology lab

Conclusion

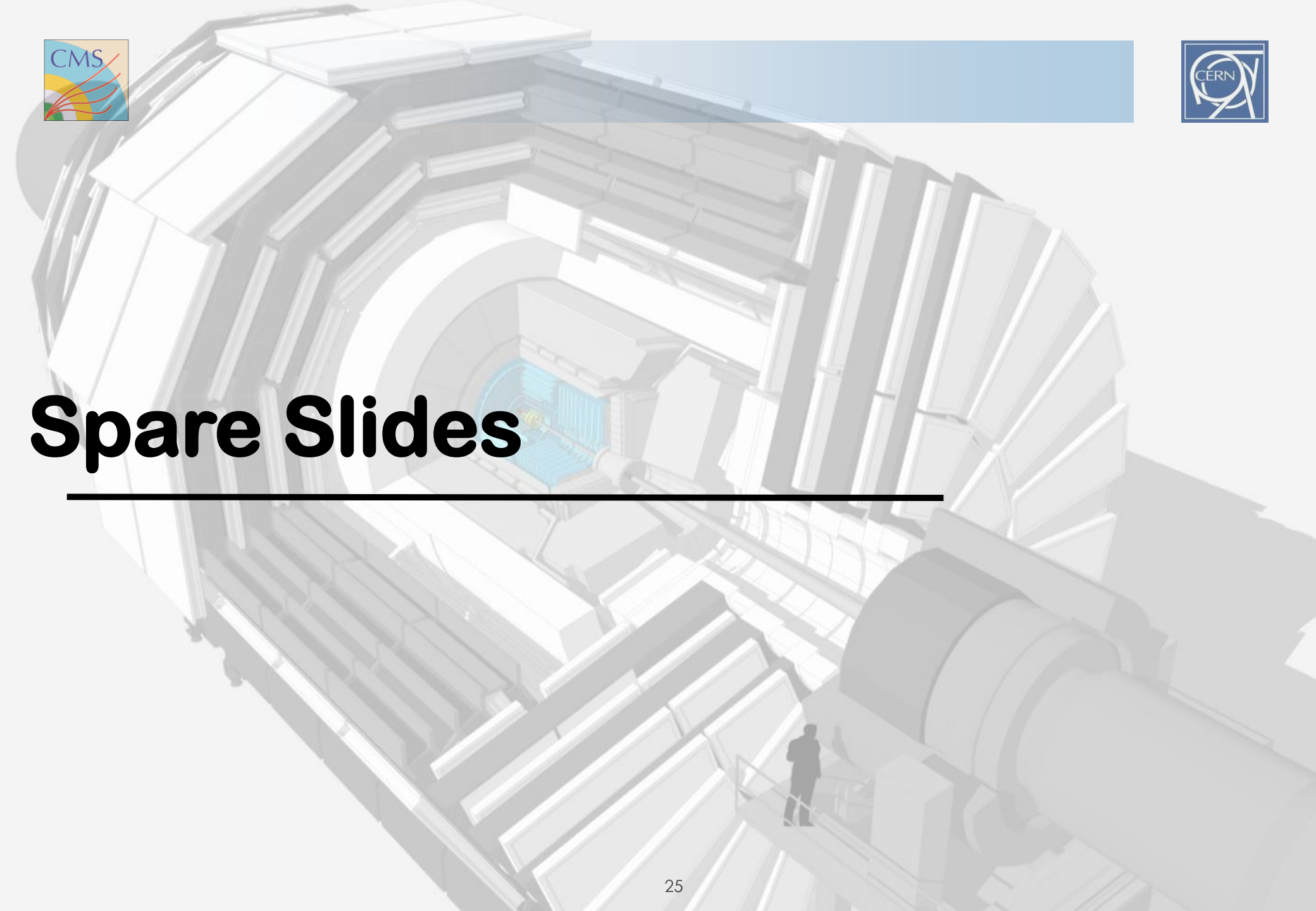
- Discovery of the moisture effects on Sintered Al-CF at the beginning of the Ring Production. Material behaviour now better understood and considered in the further production plans

- Controlled lab conditions (+22°C and Rh<60%) seem to have no effect (at least in the time period of few months) for the Sintered Al-CF material, but any excursions to higher humidity levels must be avoided

- TBPS Ring pre-production now started with 2 Rings assembled (Layer 1 and Layer 2) and the first Ring Layer 3 Ring due this summer. Need to ramp-up production to full speed (1 Ring per week) by spring 2023.



Thanks !

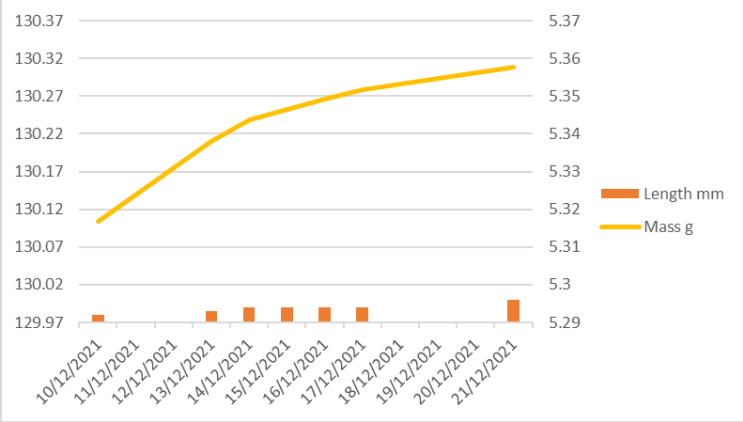


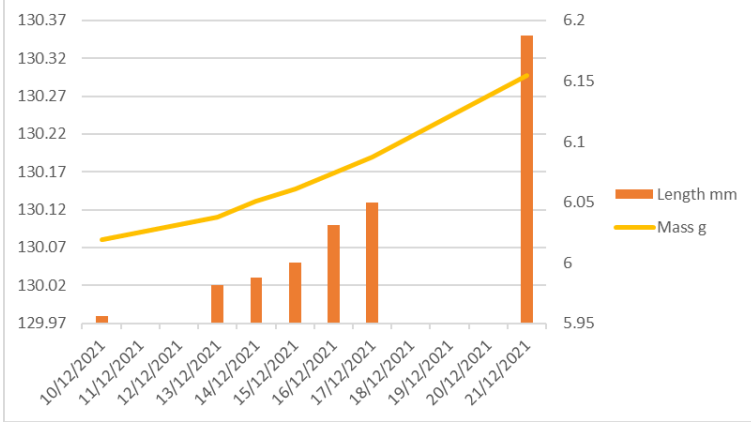
Spare Slides

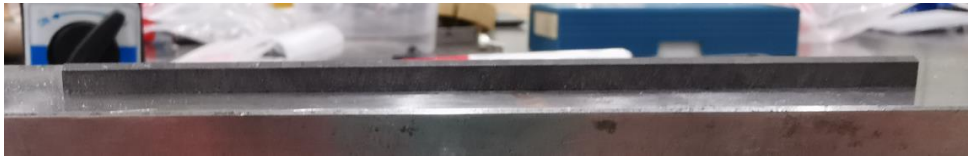
Al-CF behavior

Casted Al-CF (MA)					
Date	Length mm	Temp °C	Condition	Mass g	Deflection
10/12/2021	129.98	25	Ambient	5.3168	0
11/12/2021		25	Oven		
12/12/2021		25	Oven		
13/12/2021	129.985	25	Oven	5.3379	
14/12/2021	129.99	25	Oven	5.3437	
15/12/2021	129.99	25	Oven	5.3465	
16/12/2021	129.99	25	Oven	5.3492	0.08
17/12/2021	129.99	25	Oven	5.3518	0.09
21/12/2021	130	25	Oven	5.3577	

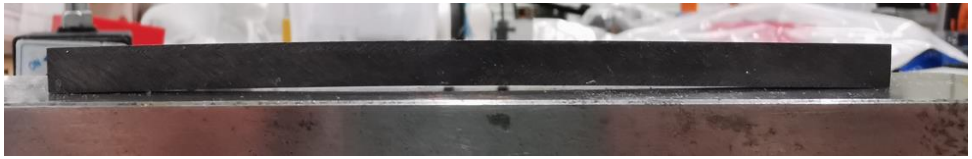
Sintered Al-CF (MB)					
Date	Length mm	Temp °C	Condition	Mass g	Deflection
10/12/2021	129.98	25	Ambiante	6.0189	0
11/12/2021		25	Oven		
12/12/2021		25	Oven		
13/12/2021	130.02	25	Oven	6.0379	
14/12/2021	130.03	25	Oven	6.0506	
15/12/2021	130.05	25	Oven	6.0611	0.55
16/12/2021	130.1	25	Oven	6.0737	0.75
17/12/2021	130.13	25	Oven	6.0875	0.85
21/12/2021	130.35	25	Oven	6.1547	







Casted Al-CF piece on 15/12/2021



Sintered Al-CF piece on 15/12/2021

- The “raw” materials acting differently on wet conditions (50°C – 100% RH) – 11days
- Casted Al-CF +0.015% of length , +0.8% of mass
- Sintered Al-CF +0.285% of length, +2.2% of mass