CMS-Phase2 Upgrade of the Inner Tracker: TBPX service flanges

INFN *(National Institute for Nuclear Physics)*

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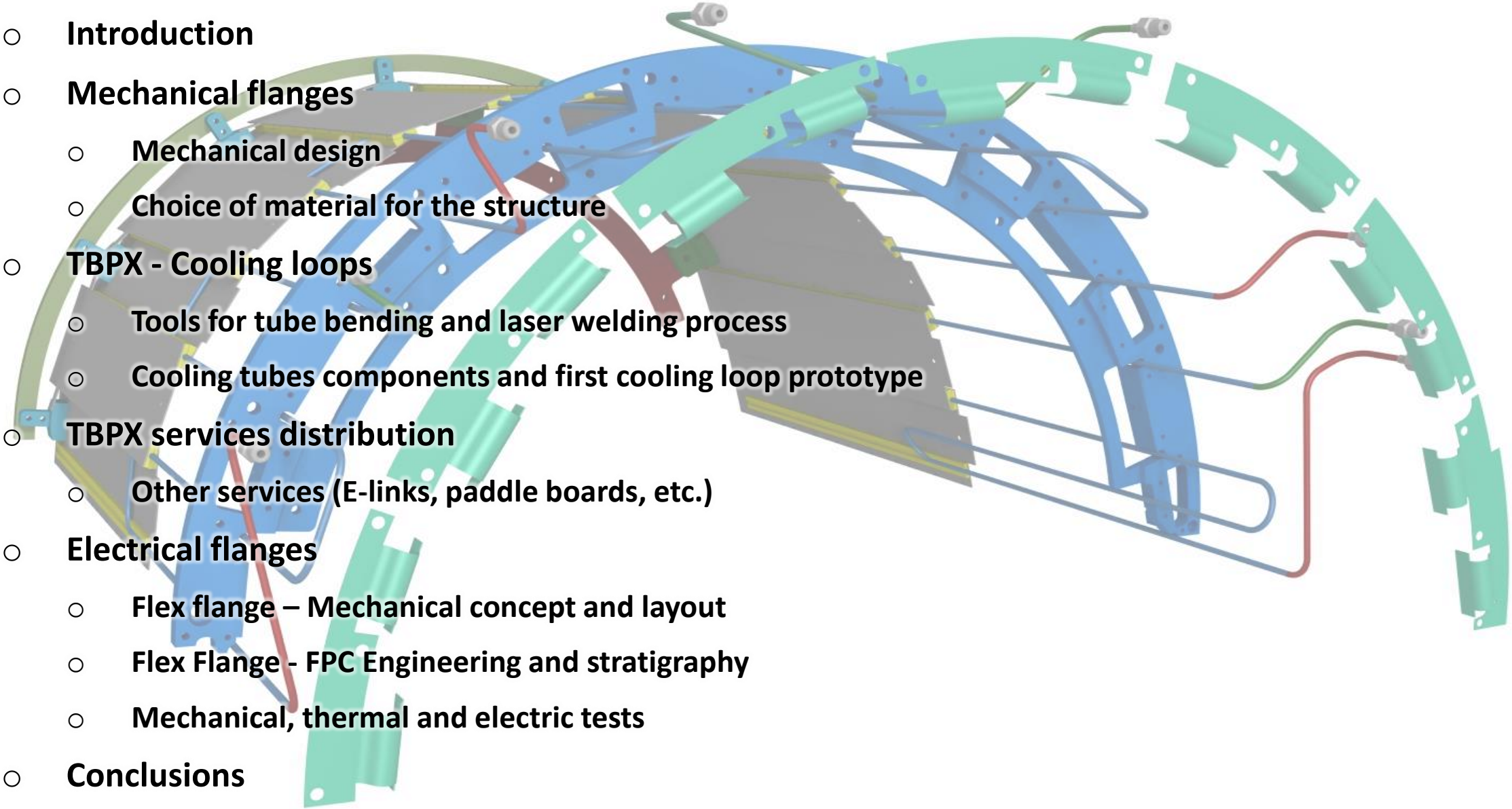
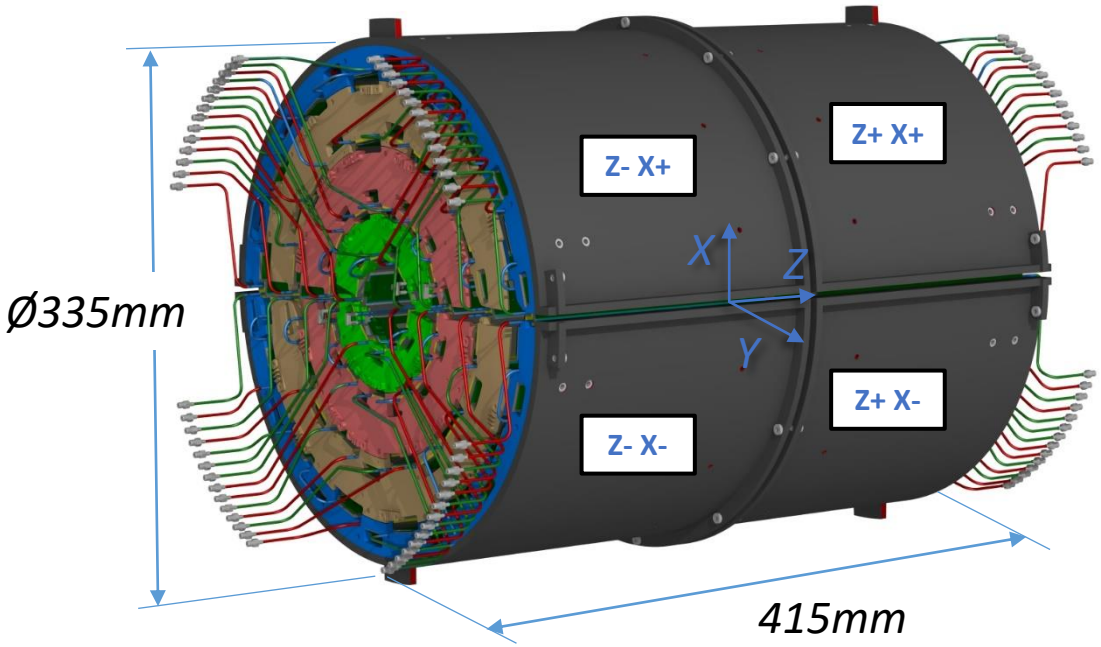
on behalf of the Tracker group

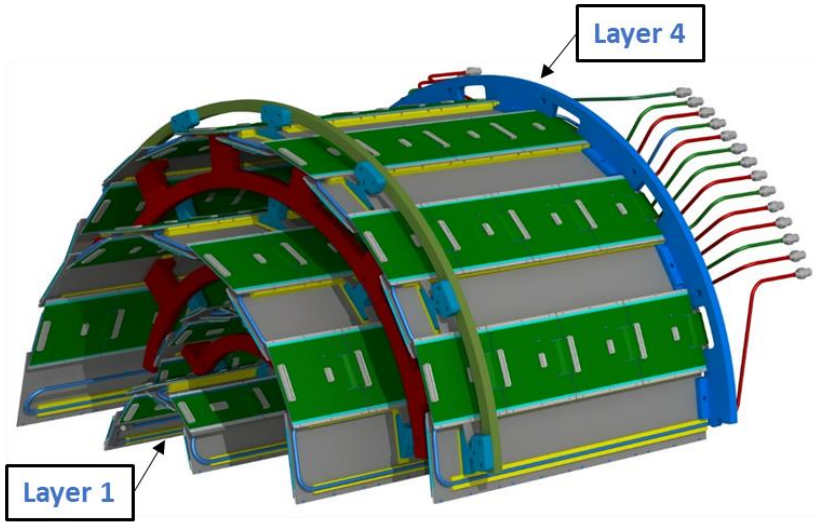
Overview

- Introduction
- Mechanical flanges
  - Mechanical design
  - Choice of material for the structure
- TBPX - Cooling loops
  - Tools for tube bending and laser welding process
  - Cooling tubes components and first cooling loop prototype
- TBPX services distribution
  - Other services (E-links, paddle boards, etc.)
- Electrical flanges
  - Flex flange – Mechanical concept and layout
  - Flex Flange - FPC Engineering and stratigraphy
  - Mechanical, thermal and electric tests
- Conclusions



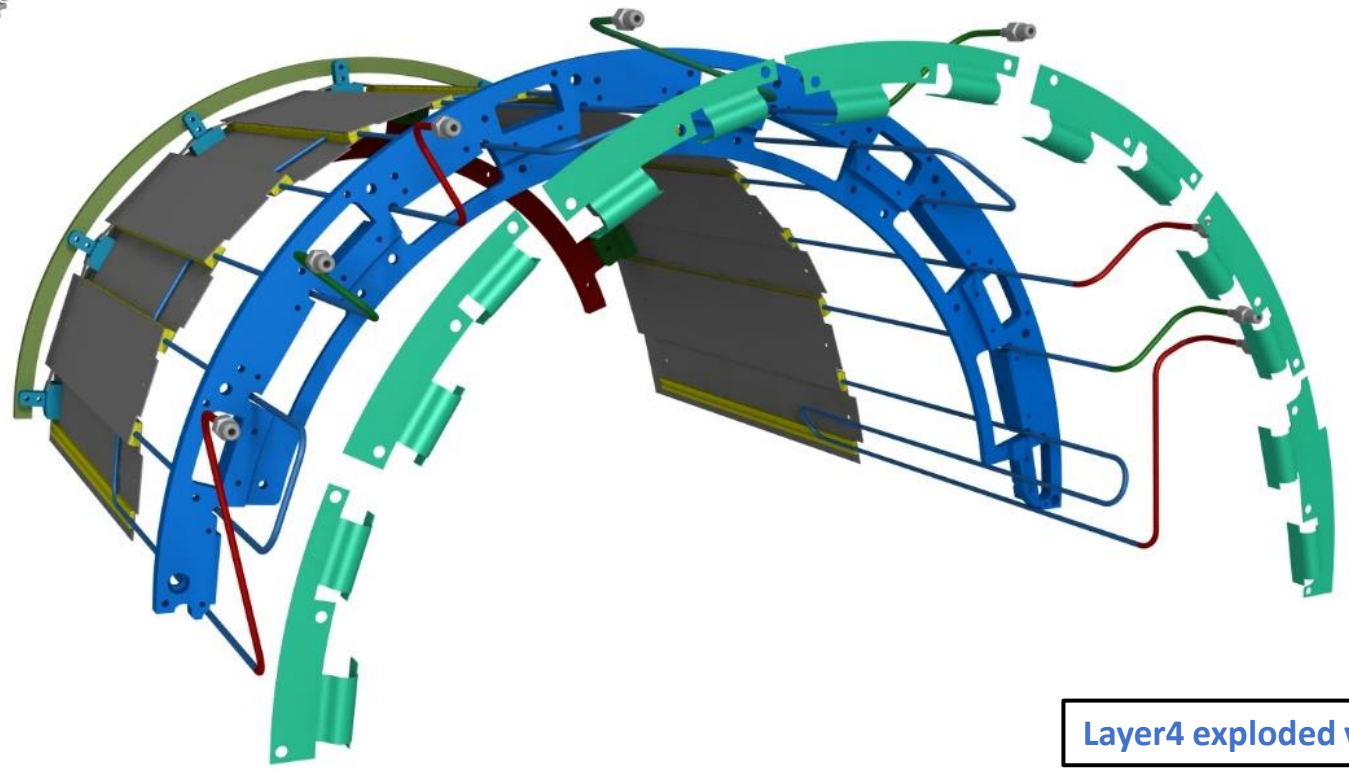
CMS-Phase2 TBPX





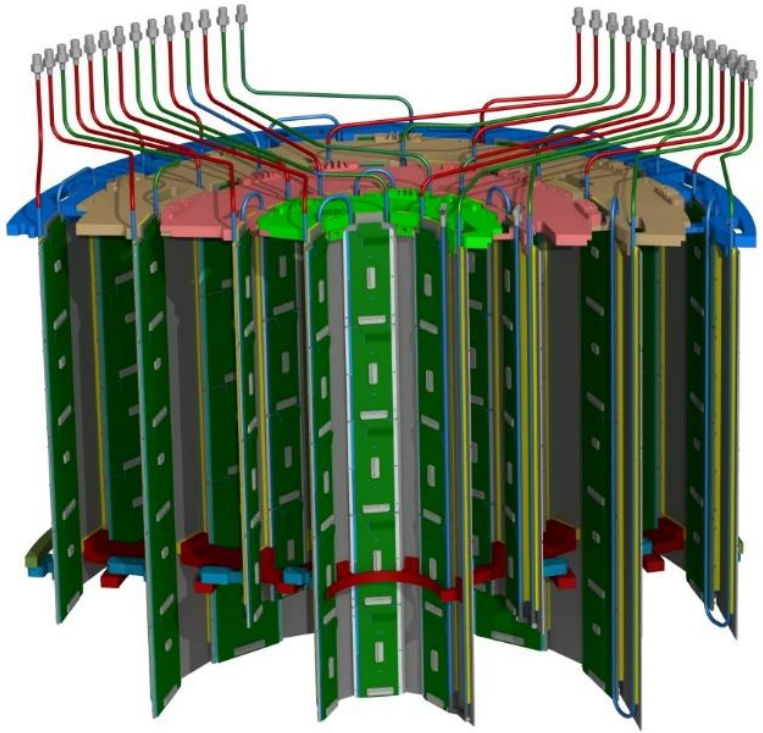
Tracker Barrel Pixel detector (TBPX):

- the central innermost part of the *Inner Tracker* (IT)
- it is made out of four cylindrical layers
- Layers are composed of ladders, structural elements in carbon fiber, on which the silicon modules are positioned, supported by mechanical flanges

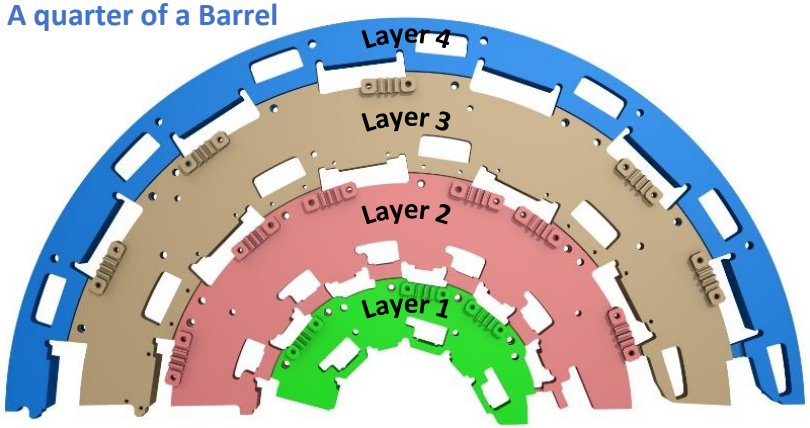


Layer4 exploded view

Mechanical flange – Mechanical design



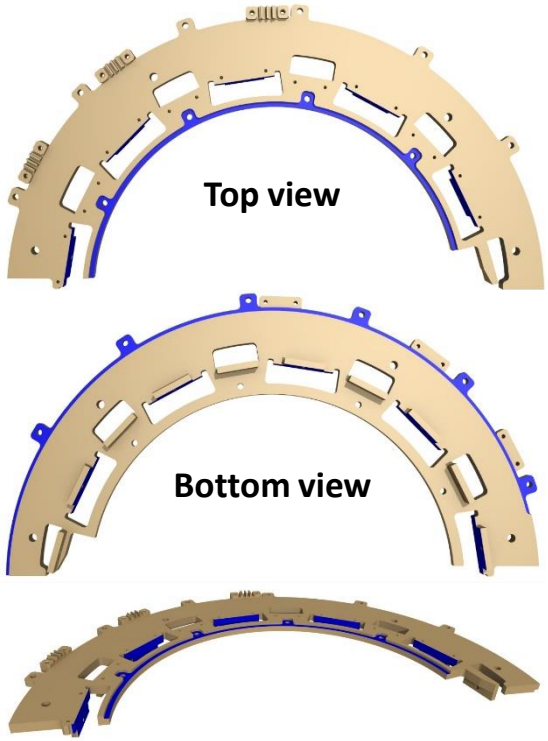
A quarter of a Barrel



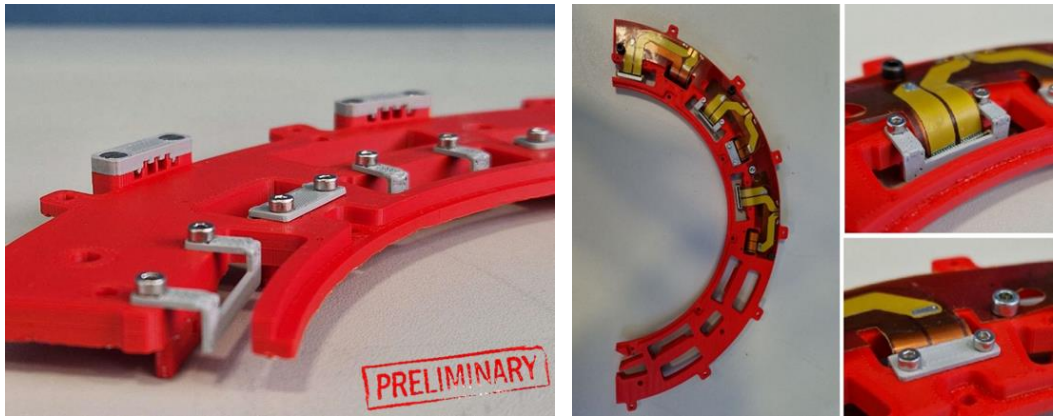
The mechanical flanges play an essential role for the module supports position and for the several services distribution.

- They allow the assembly of the four cylindrical layers with a precise positioning of each ladder, the structural support of the modules.
- Many efforts are being employed for the complex design, the feasibility study and the manufacturing process.

Mechanical Flange for Layer 3



- Serial Power & High Voltage clamps single piece with flange
- Support flange prototypes made in Turin by 3D printing (**ABS**)
- Connector clamps made in ABS
- Clamps integrated with the flange support and the flexible circuit (check the assembly procedure and define the drawings)

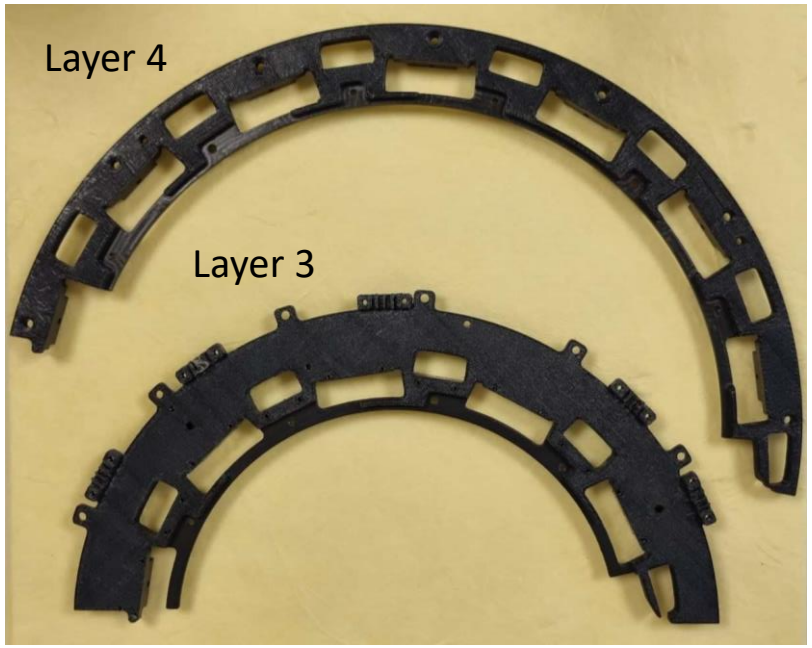


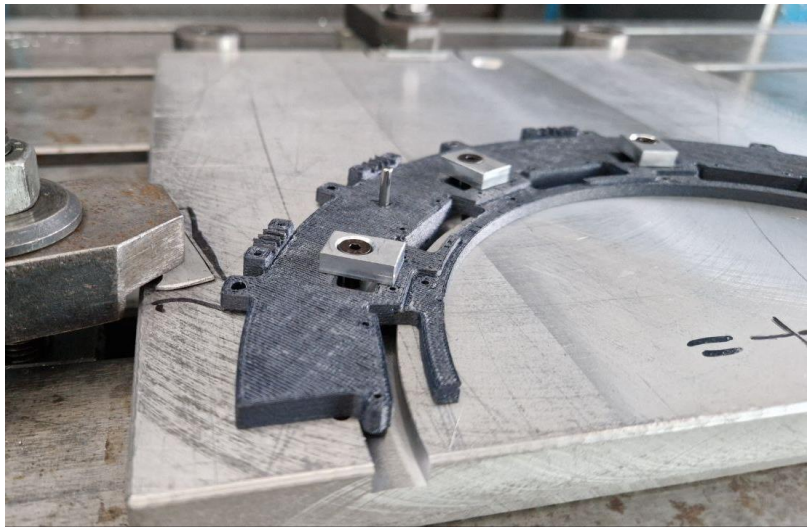
Mechanical flange – Choice of material (1)

Investigated different materials for the production of the flanges, evaluating standard PEEK, carbon PEEK and other innovative composite materials (PPS+CF).

Comparison between mechanical flanges in different materials:

1. **ABS flanges** → Production of first prototypes for the validation of the final geometry
   - **Printed in the INFN-TO workshop**
2. **Carbon PEEK flanges** → mechanical test of connection between two adjacent flanges
   - Components produced by an Italian company specialized in PEEK 3D printing
   - Material: Carbon PEEK (PEEK + 10% chopped carbon fiber)
     - Carbon PPEK instead of traditional PEEK to reduce internal stresses/deformations
   - 3D printed parts achievable in **medium tolerance class** (ISO 2768 –mK)
   - Implement surface roughness and dimensional tolerances with mechanical reworking
   - Production cost: **270 €/flange**
   - Production time: **Days**
   - **Two finished pieces, printed and machined, for layers 3 and 4**
   - **Mechanical test ongoing**
   - **Material irradiation test on schedule at Sandia (with 50x50x5mm samples)**





Mechanical flange – Choice of material (2)

Investigated different materials for the production of the flanges, evaluating standard PEEK, carbon PEEK and other innovative composite materials (PPS+CF).

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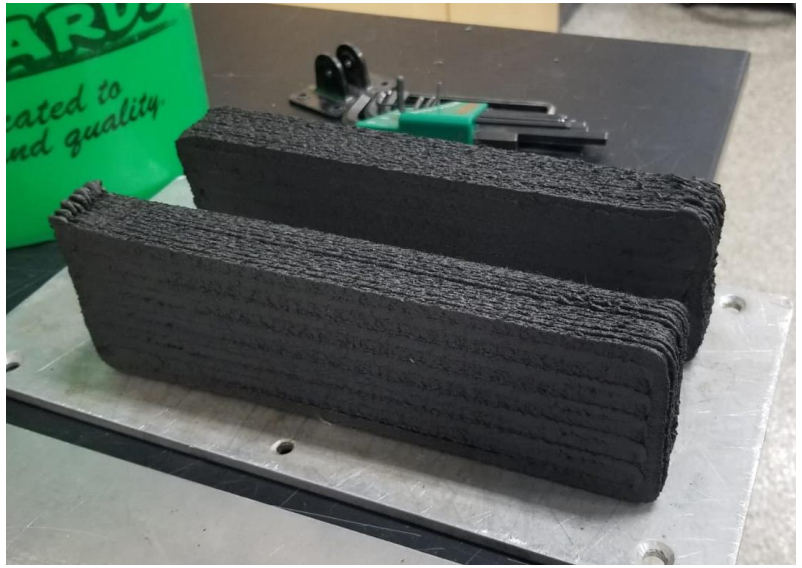
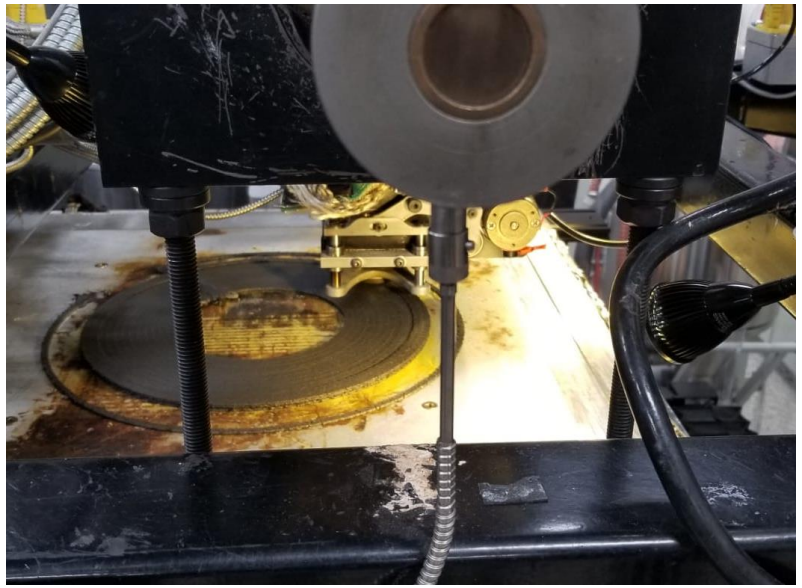
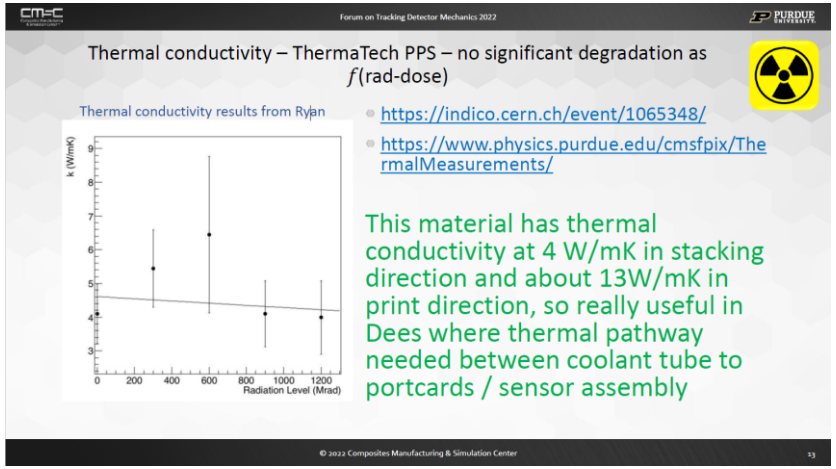
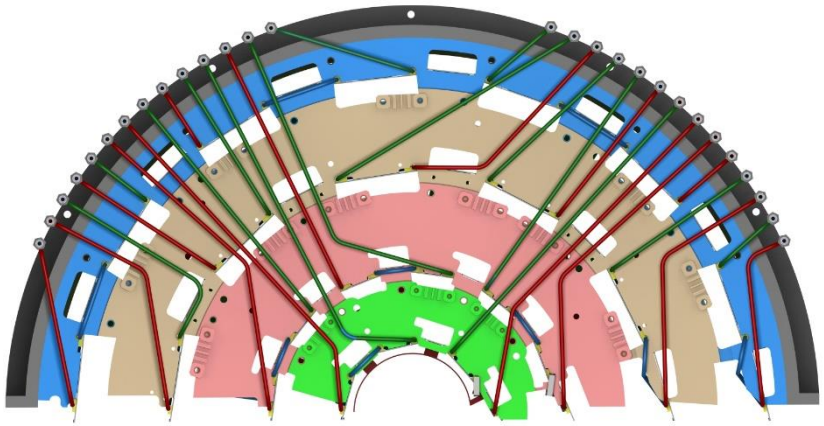
3. **PPS+CF** → Higher thermal conductivity coefficient → Evaluate its thermal benefits
   - https://indico.cern.ch/event/853861/contributions/4841274/
   - **Thermally conductive PPS+CF which has the thermal properties as 4 W/mK in stacking direction and about 13 W/mK in print direction**
   - ThermaTech PPS – **no significant degradation as f(rad-dose)**
   - **Block of material already printed by the Purdue lab**
   - **Flanges will be machined at the INFN-Pisa workshop**

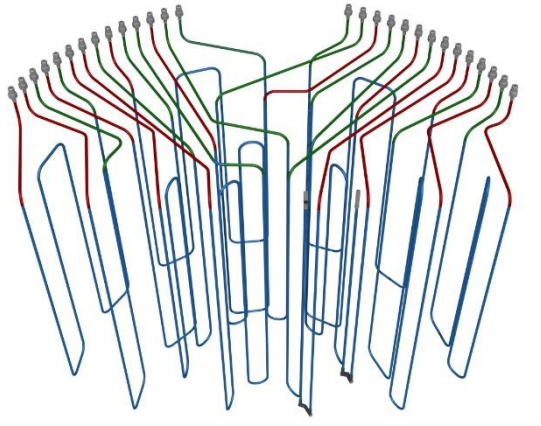


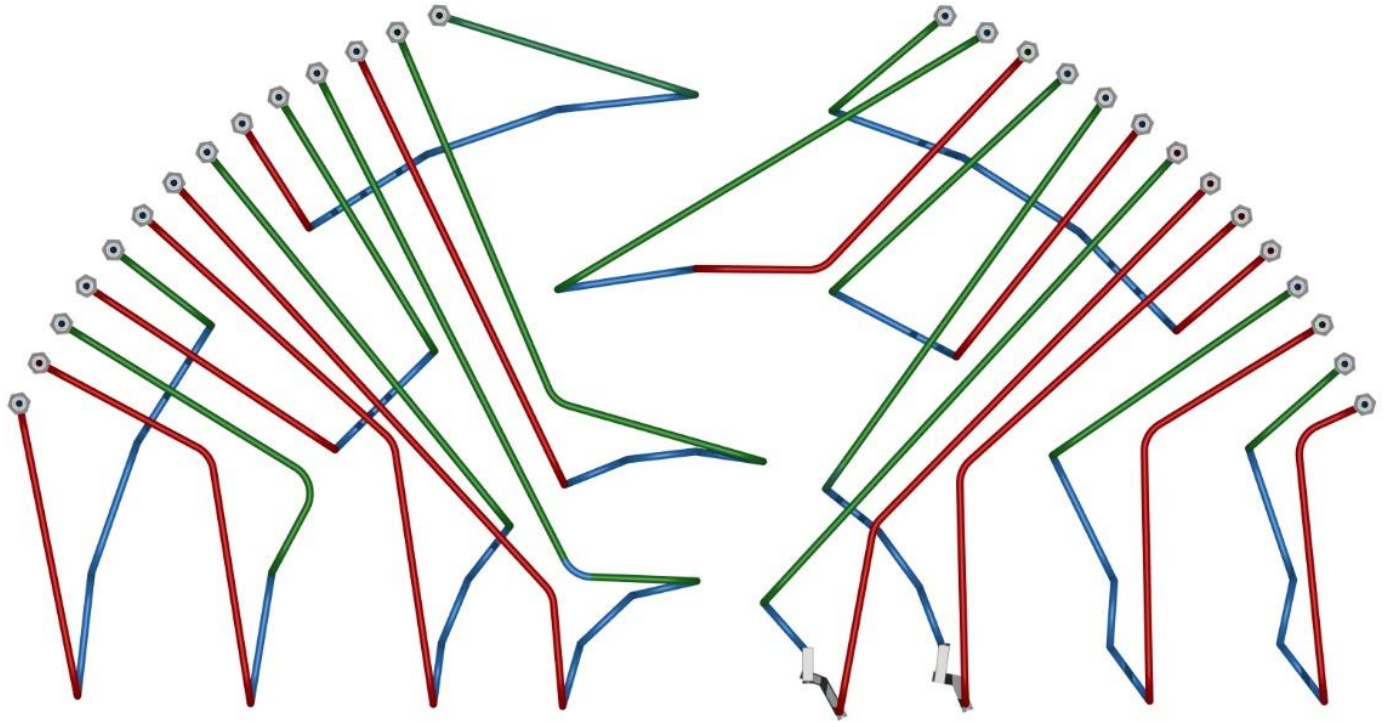




Cooling tubes: bending process + tools





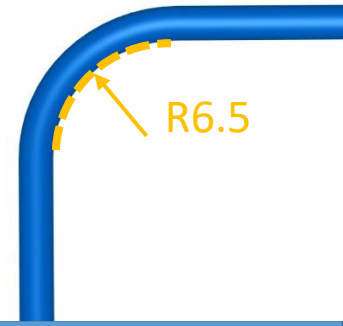


Tube purchase

- Company: **SWISS-TUBE LN Industries SA**
- Round tube (SS, AISI 316L, ID 1.6 – OD 1.8)
- Ø est. : 1.80 ± 0.02mm
- Ø int. : 1.6mm
- Wall: 0.10 ± 0.01

Cooling loops design

- 14 cooling loops for each quarter of a barrel
- Each cooling loops is different from the others
- Min radius 6.5mm for all curves
  - ➢ Where not possible → U-shaped inserts



Cooling tubes: bending process + tools

Bending

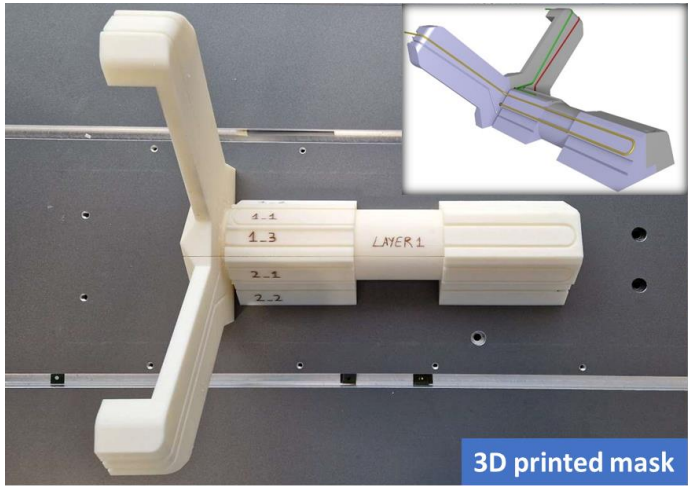
- Company: **Huber+Suhner**

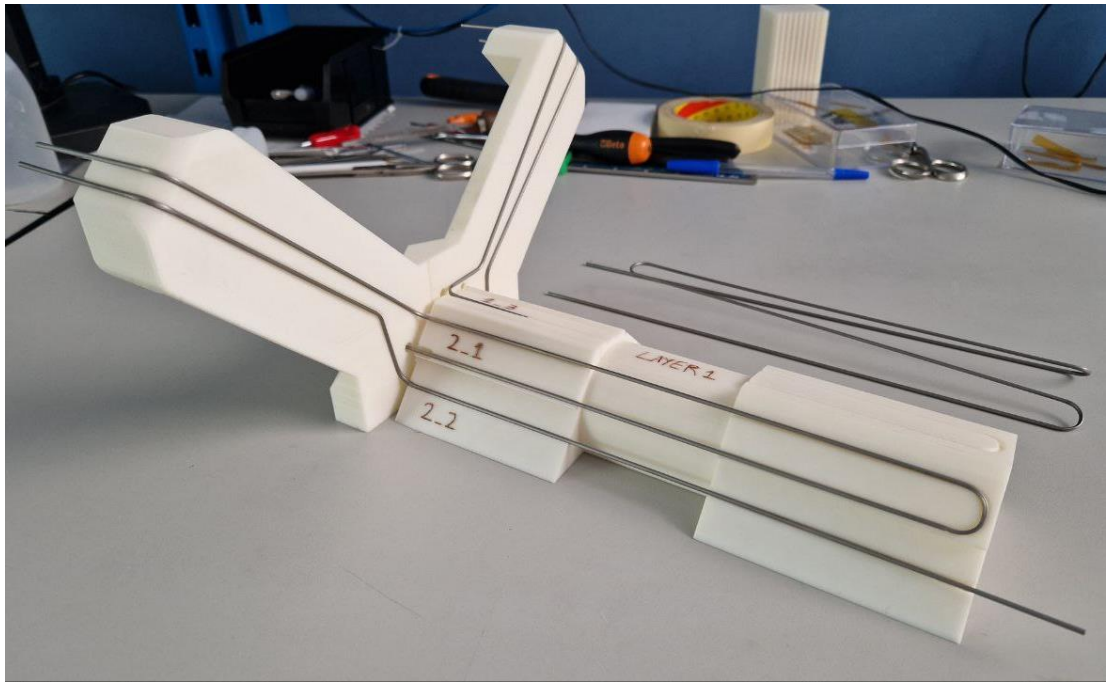
(experience with the CMS-Phase 1, not for our small diameters)

- Minimum bending radius **6.5mm**

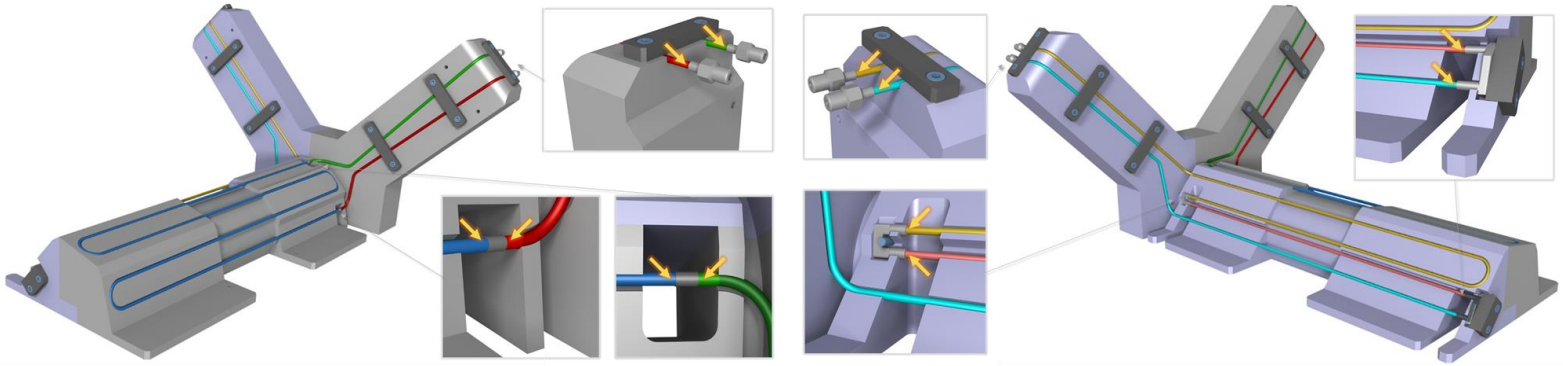
3D printed tools

Dedicated bending check tool for each TBPX cooling loop

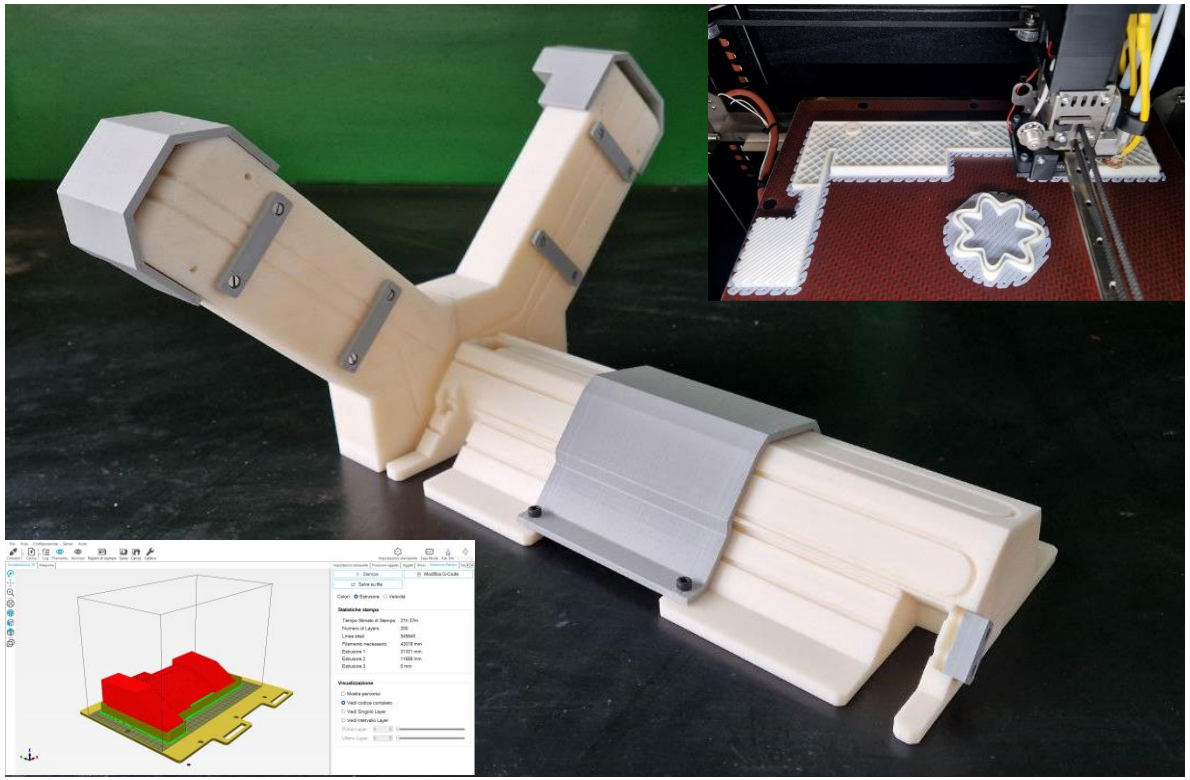


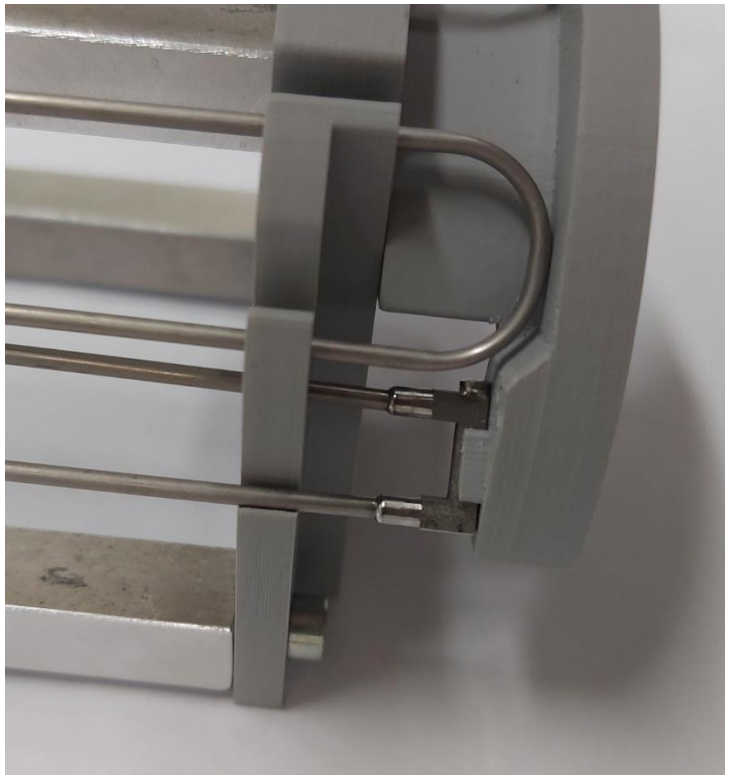


Cooling tubes: laser welding process + tools

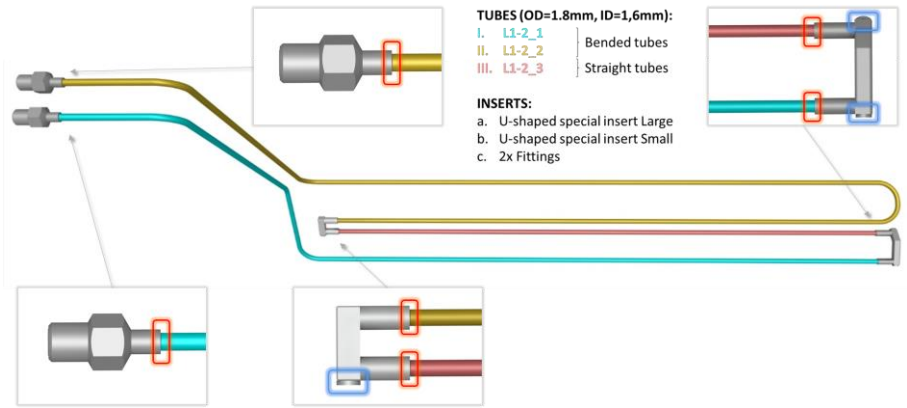


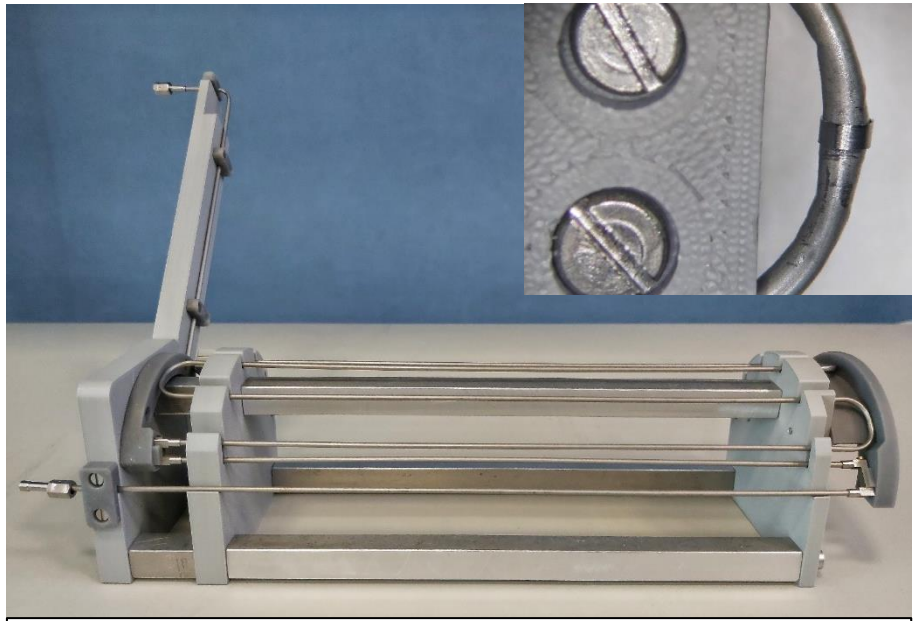
- Tools agreed with the laser soldering company (**Createch AG – Langenthal**)
- ABS - 3D printed tool with grooves for the tubes
- Through windows in welding areas, to allow access
- Clamps to hold the components in place
- Protective cover of the cooling loop during transport





Cooling tubes components and first prototype





First cooling loop prototype (layer 1) - Already bended /soldered

Cooling loop components:

- Fittings produced
- Special inserts produced
- External Rings in production

Cooling loops:

- Geometry agreed with the company for bending
- Final drawings completed

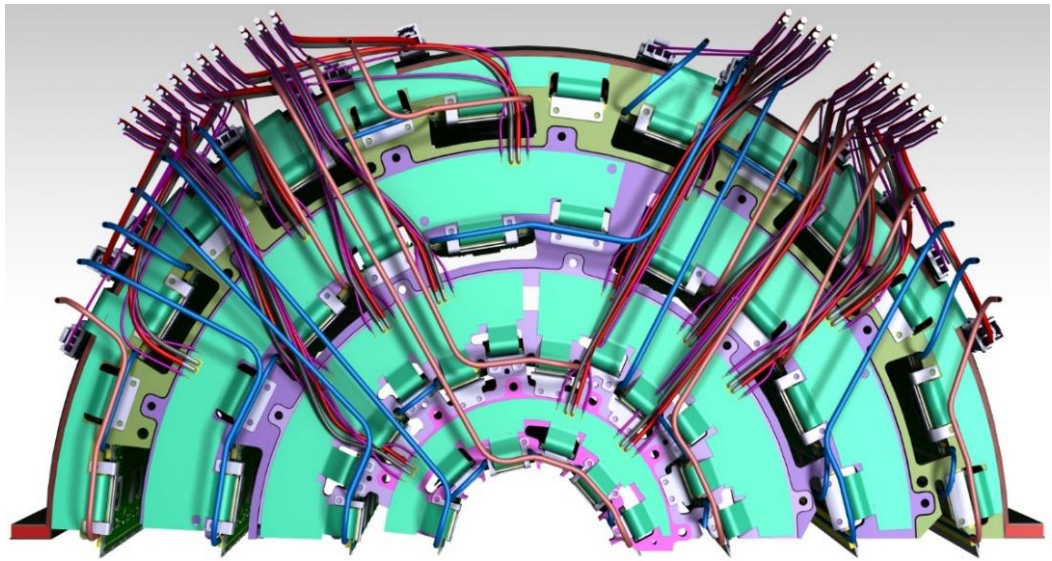
Cooling loop prototype (layer 1):

- First prototype ready
- **Mechanical/assembly test ongoing**
- **Pressure test (at 200 bar) done by the laser welding company**

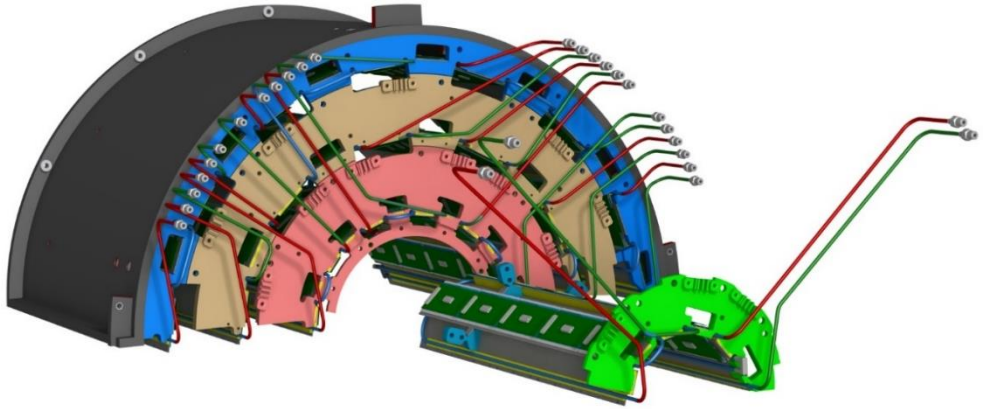
Fittings

Special inserts for R < 6.5mm	
Type 1: 3D printed	**Type 2: Machined**

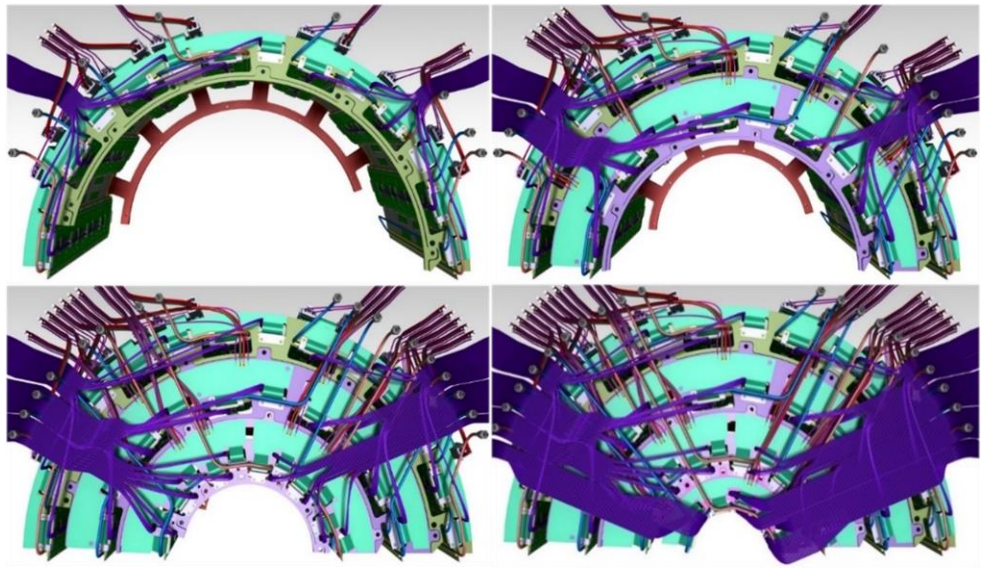
TBPX services distribution



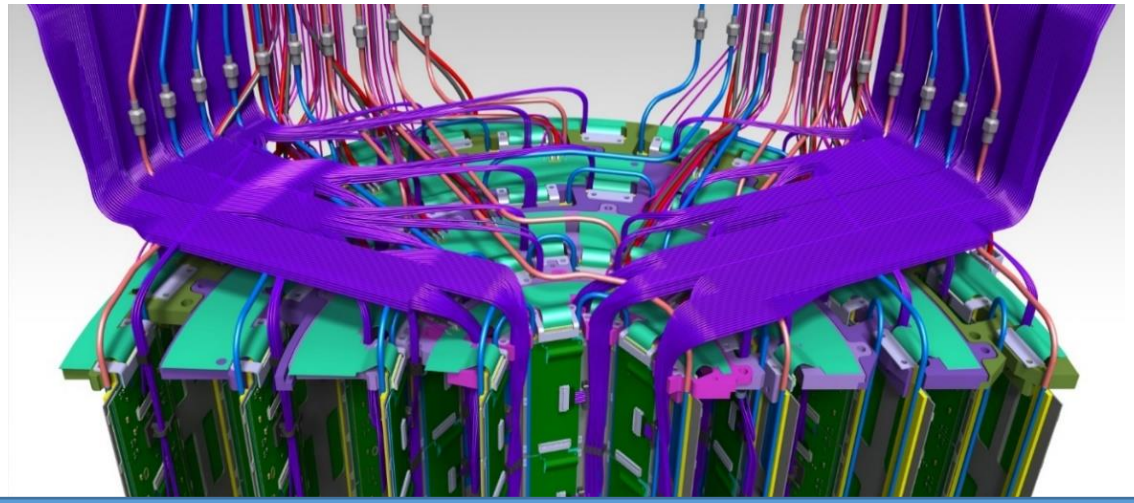
- From the SC windows, services reach their FPCs (previously soldered)
- SP and HV run between the electrical flange and the cooling tubes



The design will offer the possibility to exchange degraded parts, in particular the modules of the first layer (estimated replacement after 5 years of works)

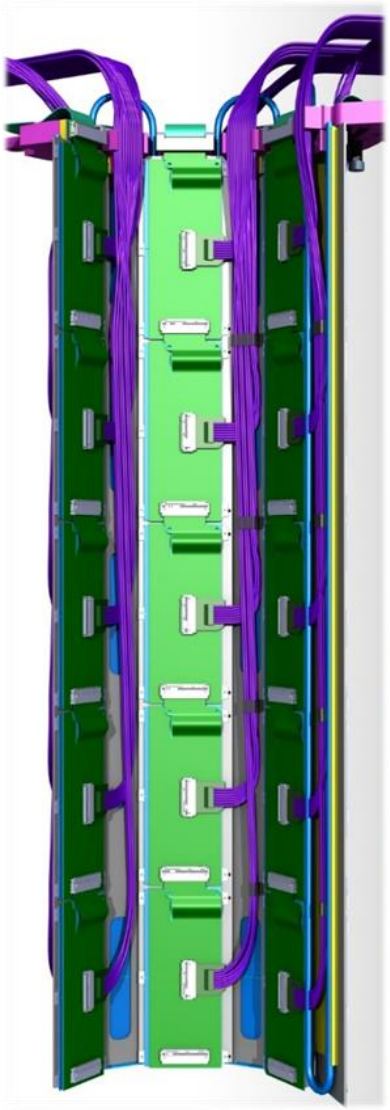


Services routing has been designed taking into consideration the entire TBPX assembly procedure, which involves the coupling of the layers starting from the outermost layer (Layer4), up to the innermost layer (Layer1).

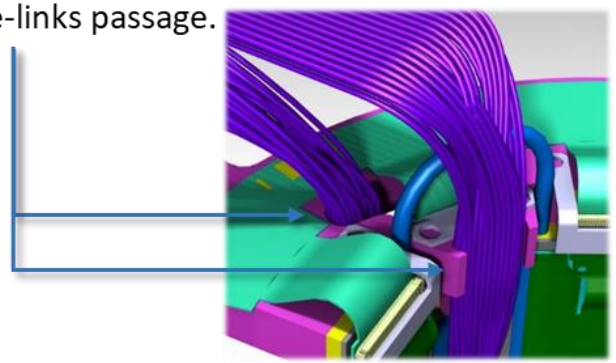


Other services (E-links, paddle boards, etc.)

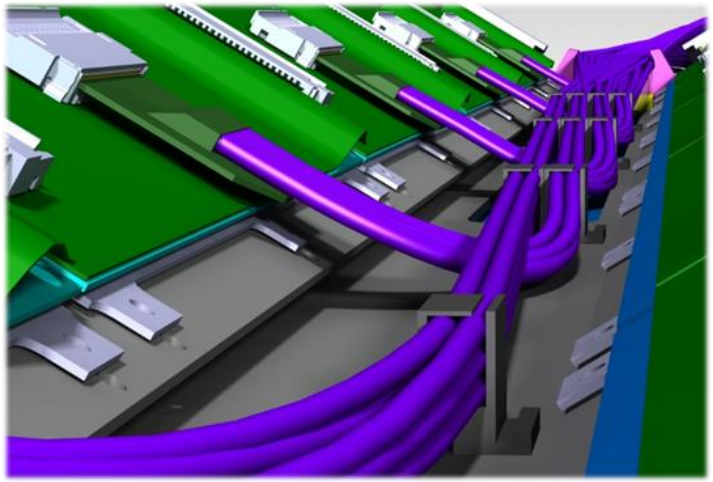
E-Links: Example of Layer 1 routing



Dedicated windows in the mechanical flange for e-links passage.



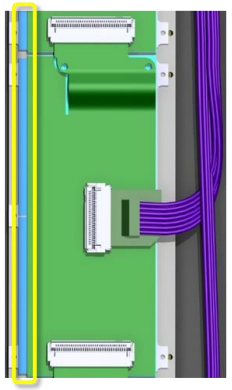
E-links run along the back of the adjacent ladders → dedicated clamps have been provided to hold the wires in place and avoid breaking wire bonding

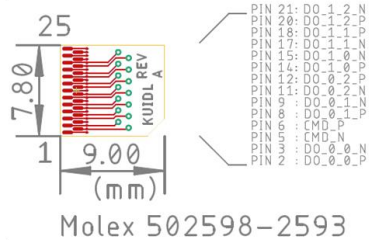


Paddle Boards (for e-Links) → final design defined

25 position TBPX croc

- **7 E-links** arrive at each Module of **Layer 1**
- **3 E-links** arrive at each Module of **Layer 2**





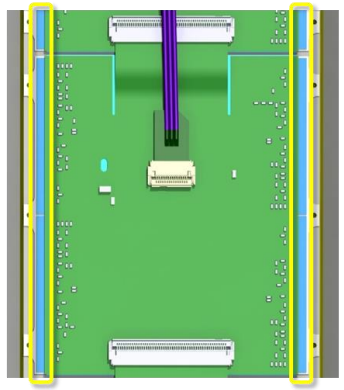
Molex 502598-2593

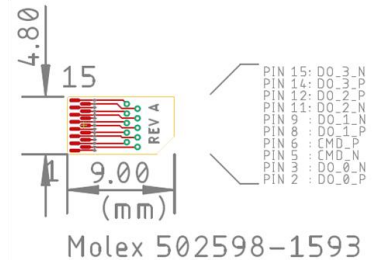
Example: layer1 module

Wire bonding areas

15 position TBPX croc

- **3 E-links** arrive at each Module of **Layer 3**
- **2 E-links** arrive at each Module of **Layer 4**



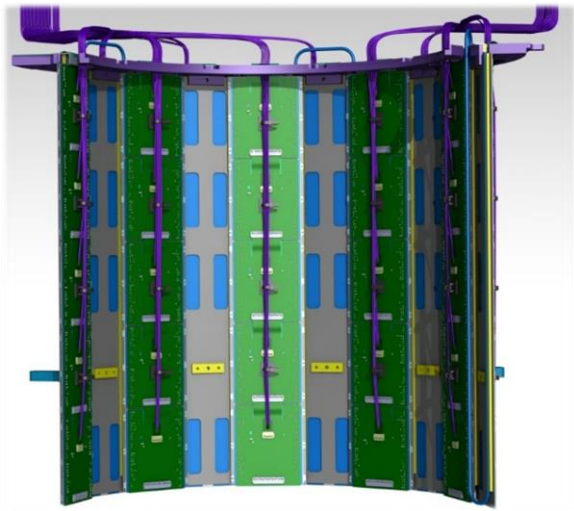


Molex 502598-1593

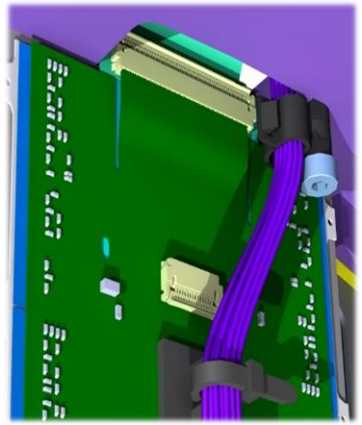
Example: layer3 module

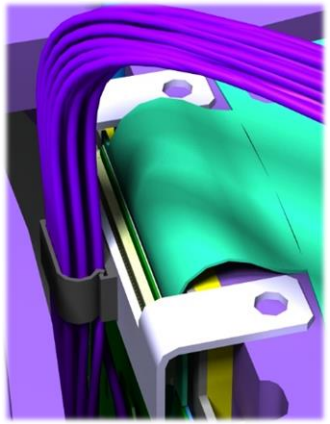
Wire bonding areas

E-Links: Example of Layer 3 routing

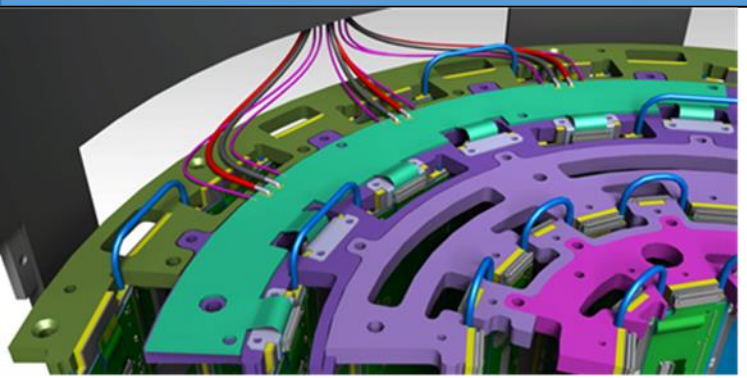


Clamps to take e-links in position and avoid to reach the wire bonding



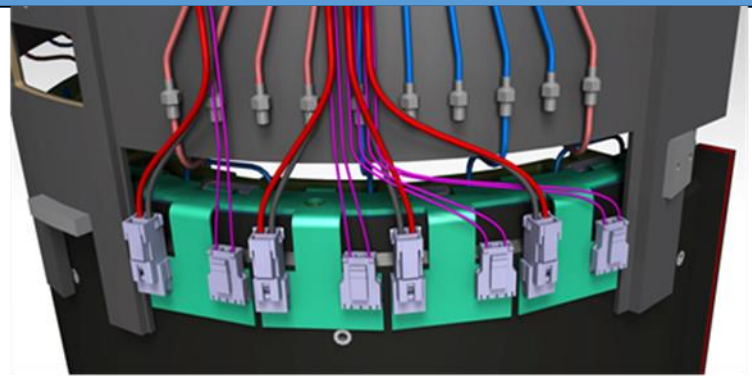


Flex flange: Mechanical concept and layout



SOLUTION FOR LAYER 1, 2 & 3

To solve the bending radius problems and to make the series connection between adjacent ladders, we use a flexible printed circuit with several pigtails (to reach the ladders module) and services soldered directly on it.

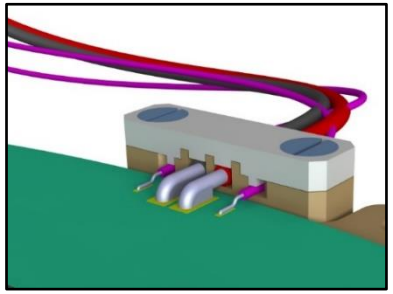


SOLUTION FOR LAYER 4

In this case, the solution proposed does not solve the bending radius problems, because we are too close to the windows of the external cylinder. To solve this, appropriate FPC-pigtails and wire-to-board connectors are used.

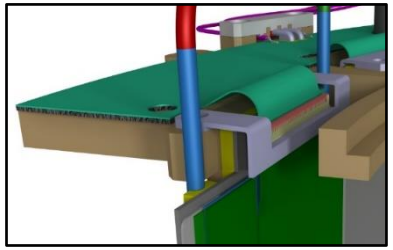
Clamps for SPs and HVs

- Keep services in place
- Follow the bending of the wires
- Do not damage welds during handling
- Do not stress solder pads and tracks



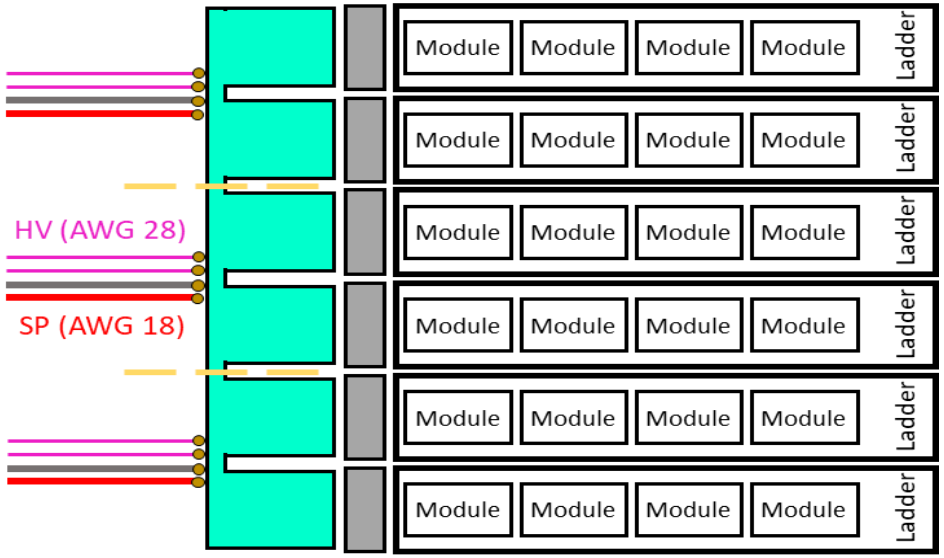
Clamps for pigtails and connectors

- L-shaped clamps fixed on the flange
- Different for internal/external ladders
- Properly sized pigtails
- Extra length to respect the min bend



FPC production planning

- **Start studying TBPXFL_3Z+w2, one of the circuits of layer 3**, for two reasons:
  - unlike layer 4 which has connectors for services, the other innermost layers have direct soldering between services and flexes → need to verify this kind of process
  - layers 3 and 4 have a double current compared to layers 1 and 2 → Critical case
  - **First Aluminum FPC prototype produced (4x flex) and tested**
- **Next step is to verify also the feasibility of the Layer 4 flexes**, which are different from others
  - Connectors for SP (serial power) and HV (high voltage) cables chosen and purchased
  - **Studies ongoing** in strong collaboration with the electronic CERN workshop



Flex flange: Engineering and stratigraphy

FLEXES PRODUCTION PROCEDURE

1. Mechanical drawings made by INFN
2. Engineering process made by Artel
3. Production process made by the CERN workshop

FPC PROPERTIES

- Double sided Aluminium flex
- 100um Al both sides
- coverlay both sides
- Ni/Au plating on all the connections
- 100um rigidizers below the connectors
- Connector assembly on both sides

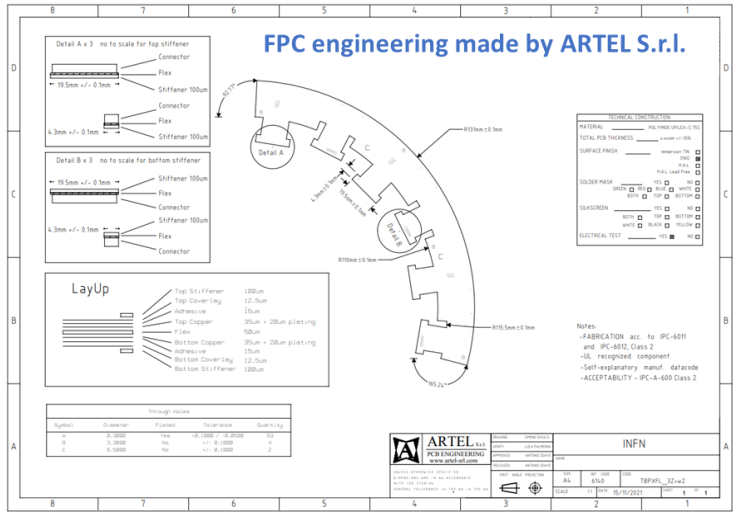
MATERIAL: EN AW-1050A (Aluminum 99.5%)

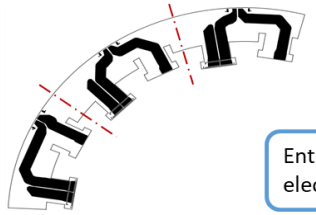
RESULTS

- **Good ductility (easy to bend)**
- **The flex maintain very well the given bend**

TESTS

- **Mechanical & thermal tests ongoing in Turin**
- **Electrical test ongoing at CERN, INFN-Pisa and INFN-Perugia**

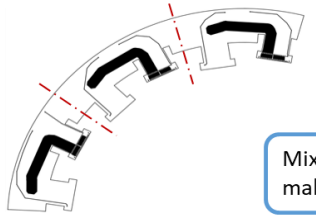




Top layer (tracks)

- SP_IIN
- SP_GND

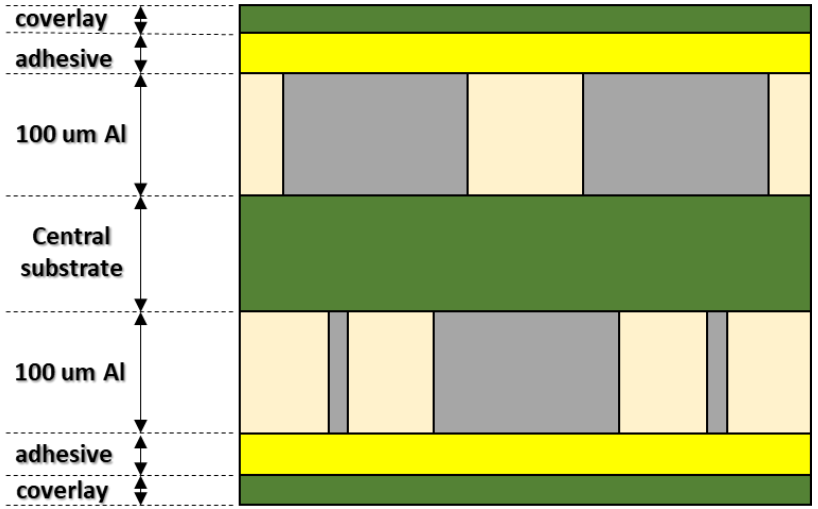
Entire polymide substrate, segmented into N electrically separated sub-parts (N = pairs of ladders)

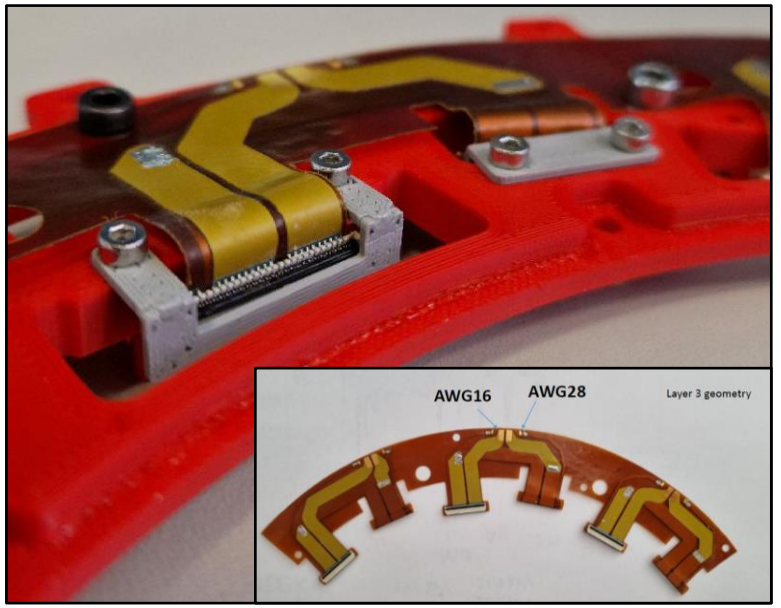


Bottom layer (tracks)

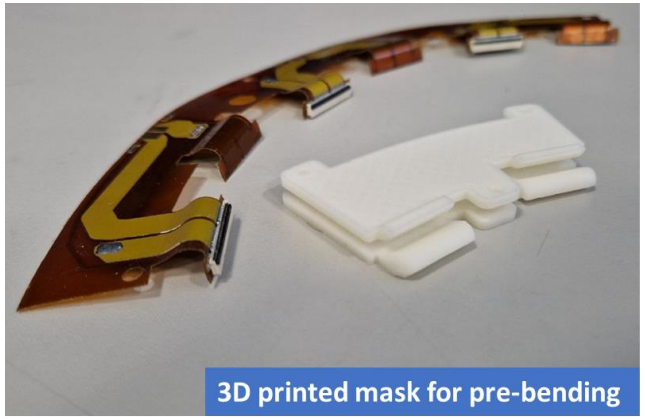
- SP_IRET
- HV_1
- HV_2

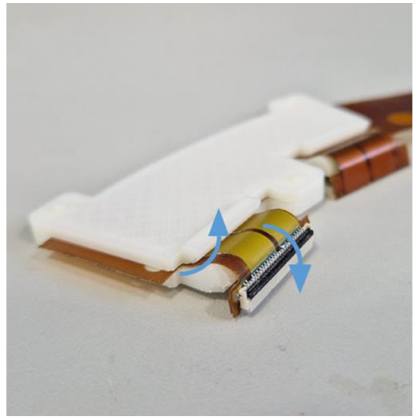
Mixed layers (SP and HV) to optimize the tracks and make the most of the circuit geometry

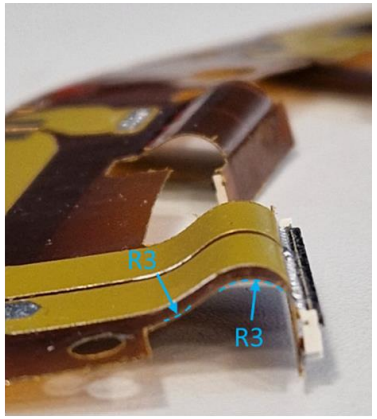




Flex flange: Tools for mechanical tests

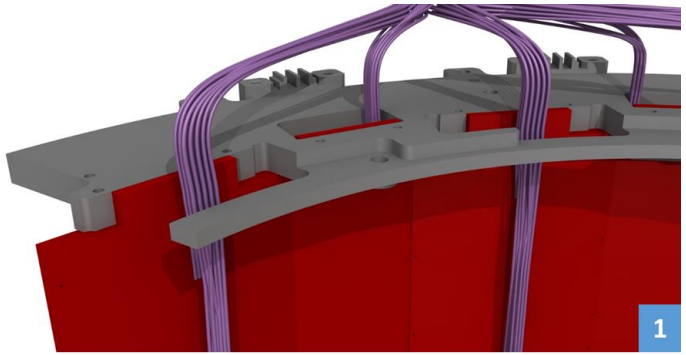


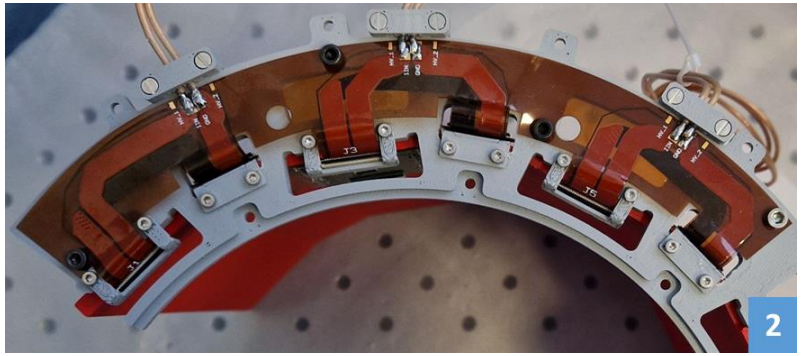


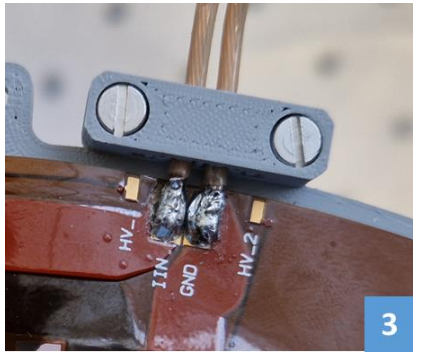


Pre-bending tool for pigtail

- The aluminum flex produced at cern has the ideal ductility for our application
- Waiting to carry out bending tests on the aluminum flexes produced by Artel
- Design of a bending tool also for module pigtail (currently pre folded by hand)







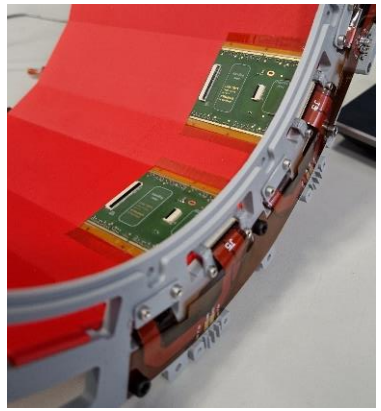
Flexes assembly procedure

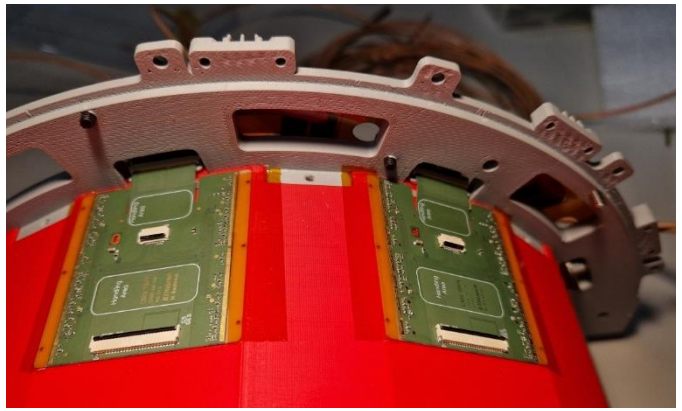
1. The e-links run within the dedicated windows
2. Place the flex on the mechanical flange and fix using 4x screws (M3)
   - ➢ Flex already pre-bended and CCA wires already soldered on the flex
3. Add the wires clamp → Avoid stresses and delaminations on the flex
4. Add the other clamps (to fix the connectors of the flex's pigtails)

Observation & Conclusions:

- ❖ Validation of pre-bending tool
- ❖ Verification of the module assembly procedure
- ❖ Direct soldering of the CCA wires on the flex verified
- ❖ Clamps for SPs and HVs work well → Avoid stress on flex

Flex flange: Mock-up for module assembly

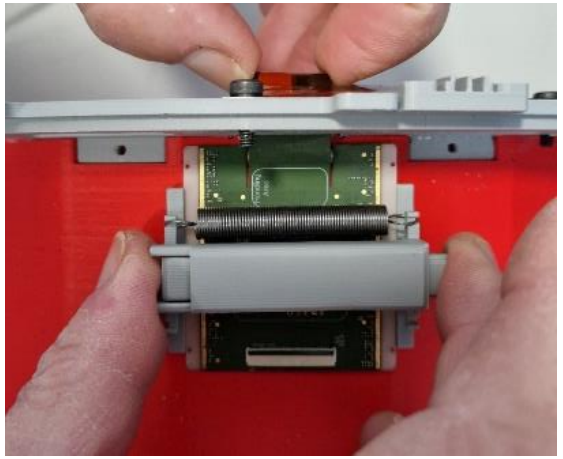


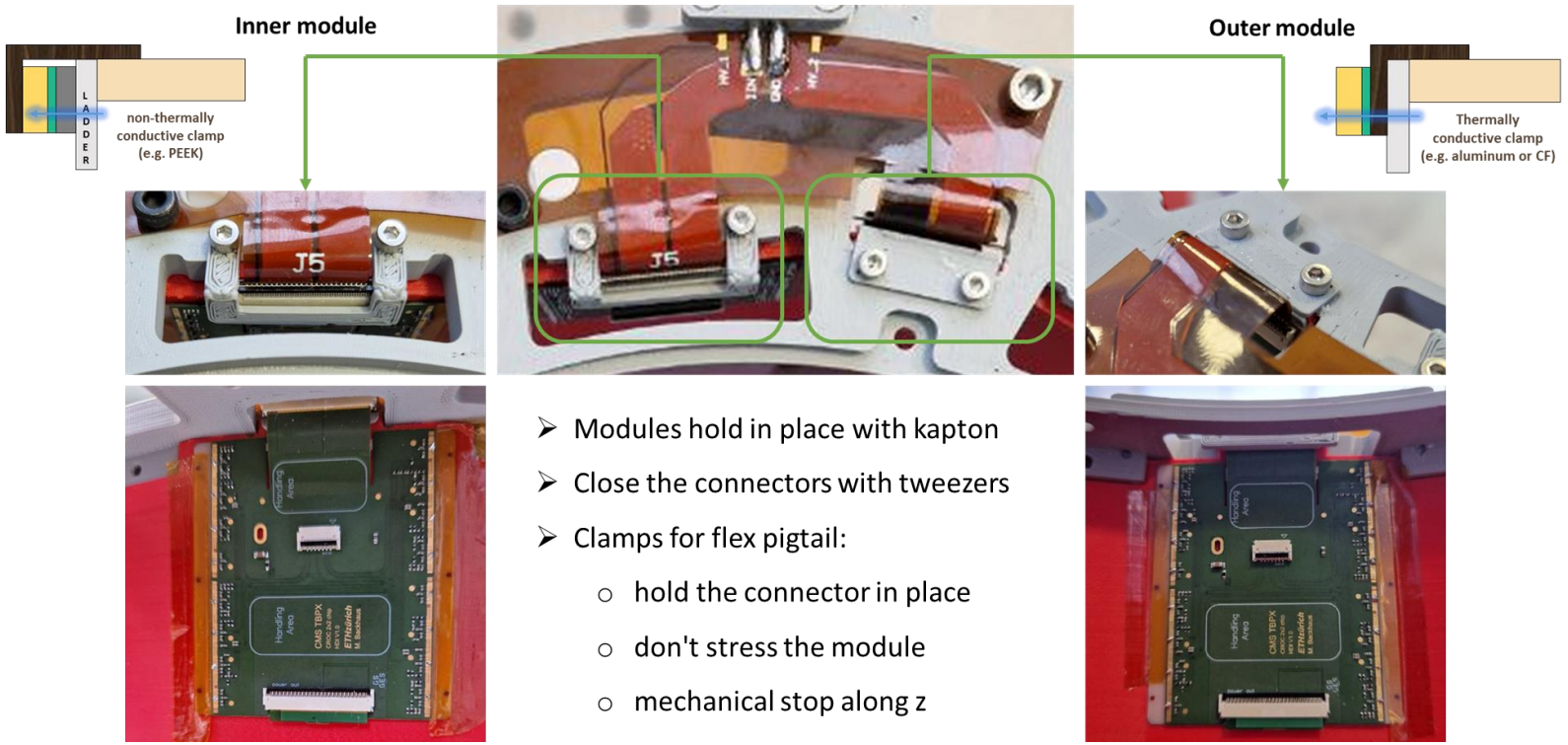


Mock-up for layer 3

- Check the connection between flex and the head modules into support flange windows
- Verify the module assembly procedure
- **Tests are ongoing with TBPX dummy modules**

NEXT STEP: design special tools to open and close Molex connectors safely (don't stress the actuator)





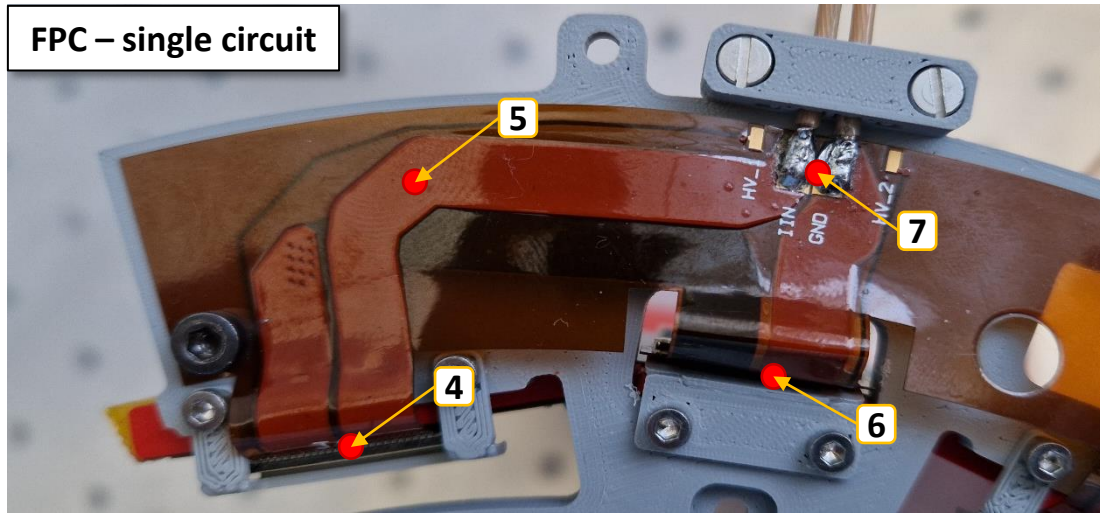
- Modules hold in place with kapton
- Close the connectors with tweezers
- Clamps for flex pigtail:
  - hold the connector in place
  - don't stress the module
  - mechanical stop along z

Observation & Conclusions:

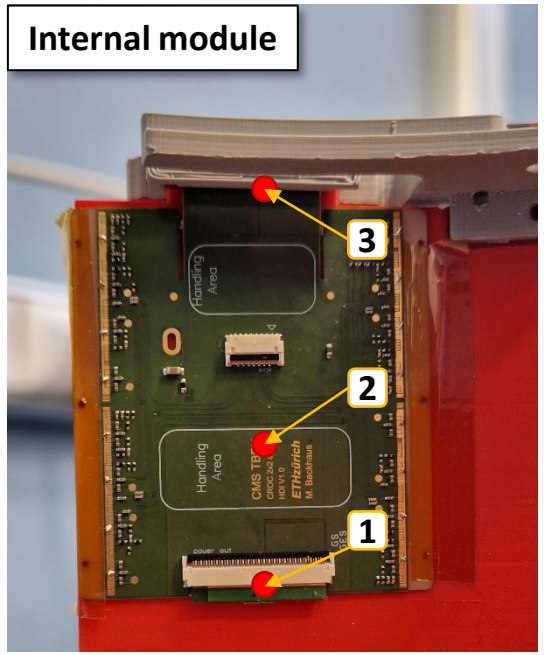
- Validation of module holders
- Feasibility of the coupling between modules and flex into the mechanical flange windows

Flex flange: Electrical and thermal tests (1)

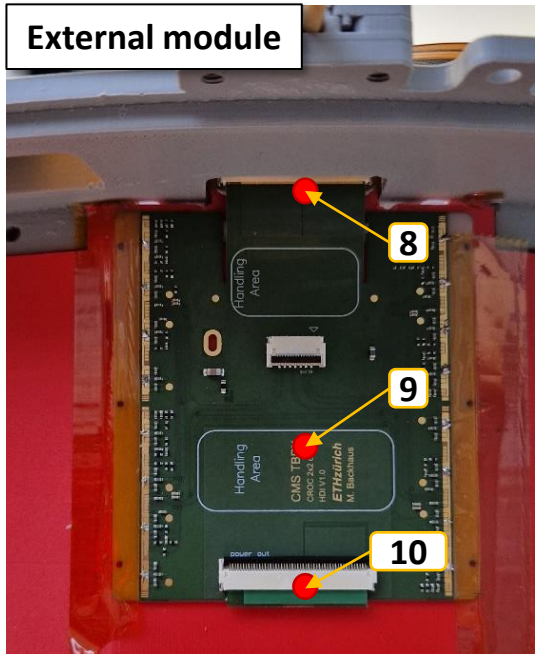
FPC – single circuit

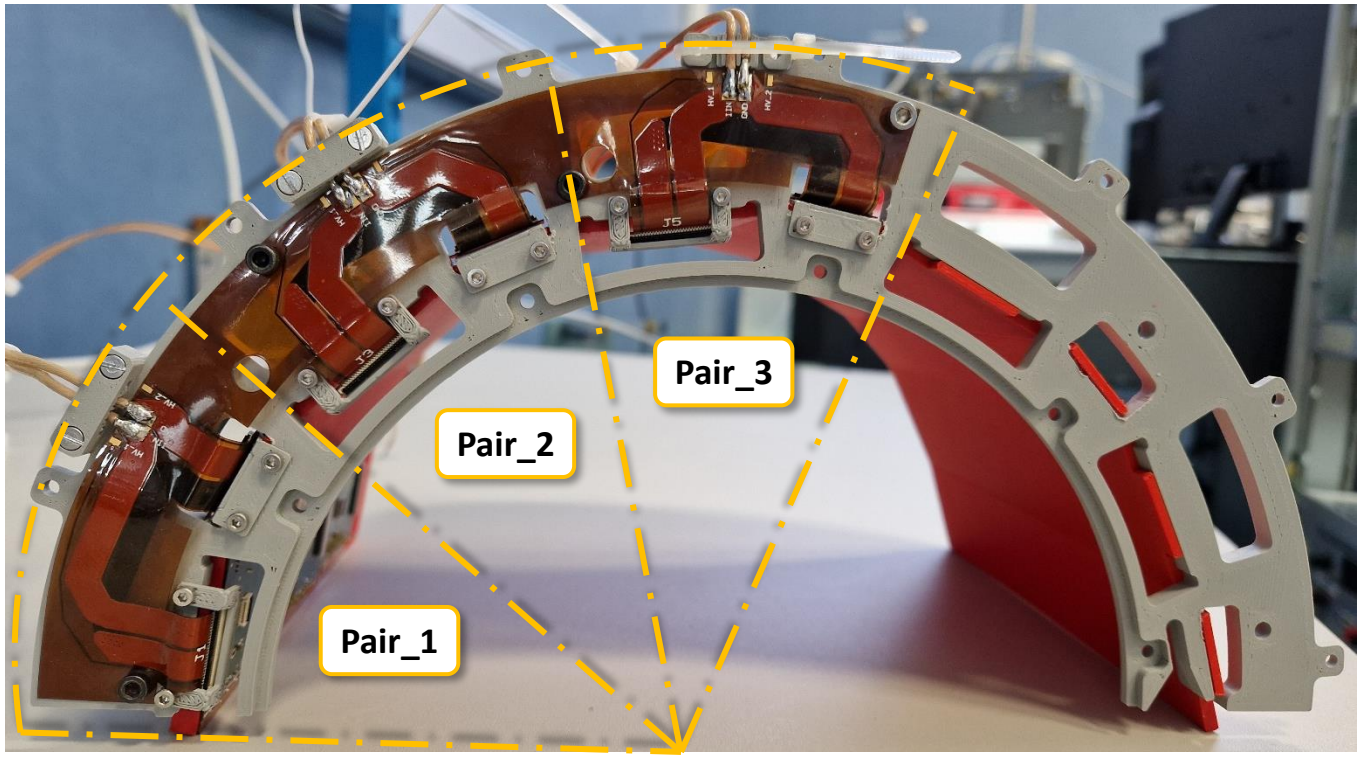


Internal module



External module

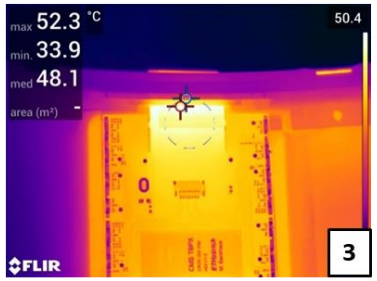


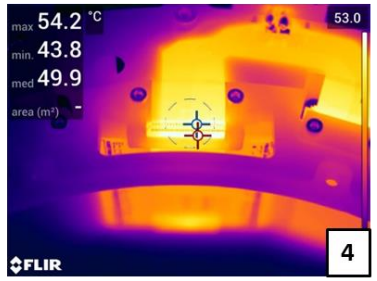


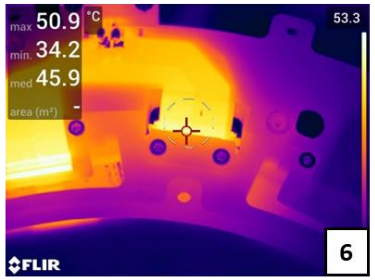
TBPX – flexes Thermal Test

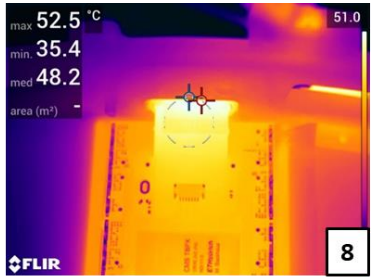
- Place the flex on the mechanical flange (3D printed in ABS)
- 2x TBPX dummy module with module cap (to close the circuit)
- Measure the temperature with a thermal imaging camera (10 points)
- **Goal: estimate the temperature rise of the flex fed with a current of 8A**

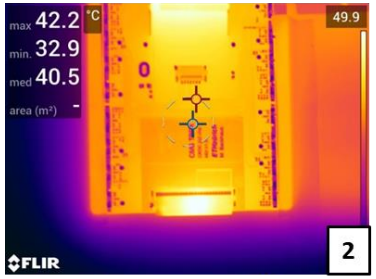
Flex flange: Electrical and thermal tests (2)

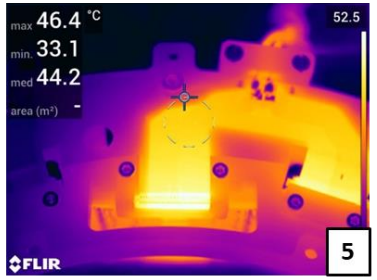


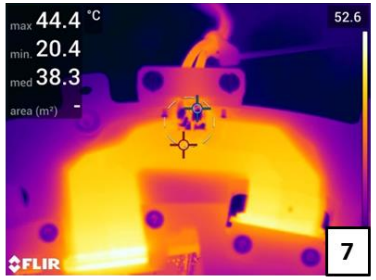


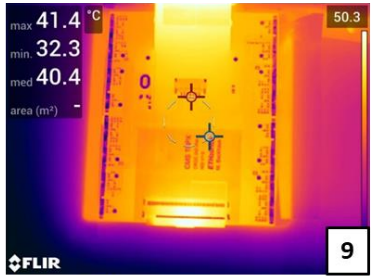


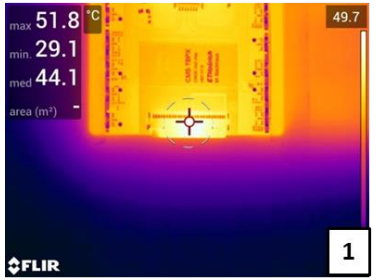






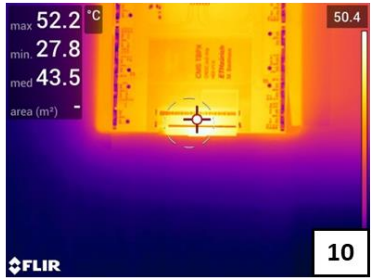


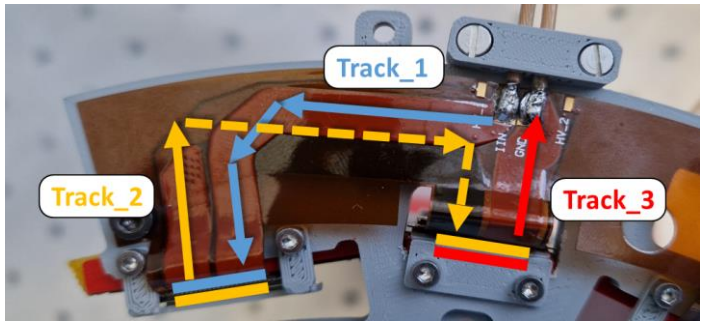




Test conditions:

- Using the same modules (internal and external)
- Flex fed with a current of 8A (Layer 3)
- Circuit powered for one hour
- Tests carried out at $T_{room} \approx 19°C$





The electrical path of the Serial Power is composed by 3 tracks (Track_1, Track_2 and Track_3)

	Aluminum Flex (CERN)					
	Pair_1		Pair_2		Pair_3	
Photo n.	T [°C]	T [°C]	T [°C]	T [°C]	T [°C]	T [°C]
1	51,5	52,7	52,8	51,8	53,0	52,8
2	42,2	43,0	43,3	42,0	43,7	42,0
3	54,6	55,2	55,1	56,2	55,1	55,1
4	57,1	56,7	57,6	59,1	55,5	56,5
5	50,3	49,5	48,9	49,3	48,0	47,2
6	53,7	53,1	55,2	55,8	53,5	53,0
7	44,2	44,2	46,8	46,8	44,4	45,4
8	55,9	56,3	59,5	59,6	55,2	57,2
9	41,9	41,4	42,5	42,3	42,1	41,6
10	52,9	52,4	53,1	52,4	52,6	51,7

Observations and Conclusions:

- The highest thermal gradients are at the level of flex connectors
- Without dedicated cooling and using a non-thermal conductive material for the flange, the temperature gradient wrt ambient temperature is about 30-35 degrees: test with cold tube planned

Conclusions

- **Good communications between the various IT groups** (TBPX, TFPX and TEPX)
  - Work in strong collaboration for the realization of the various interfaces between the tracker detectors
- **Mechanical flanges** → Study of new technologies/materials to lower temperatures
- **Cooling tubes** production is a very complex procedure → CAD design - bending process - laser welding
  - 3D printer allows to reduce costs and production times of the several tools needed for each layer
- **Electric flanges** → Thanks to the cern workshop we have produced prototypes
  - the minimum quantities required, a dedicated design (the several layer flexes are different) and the necessary good ductility are not achievable by other companies specialized in fpc production
- **Routing of the numerous TBPX services** → All of required specifications and constraints have been satisfied
- **The importance of 3D printed** → Prototypes and several tools made in ABS
  - Obtain prototypes quickly
  - Print custom assembly/placement templates
  - Speed up the mechanical drawings finalization

Conclusions

Thanks for your attention!