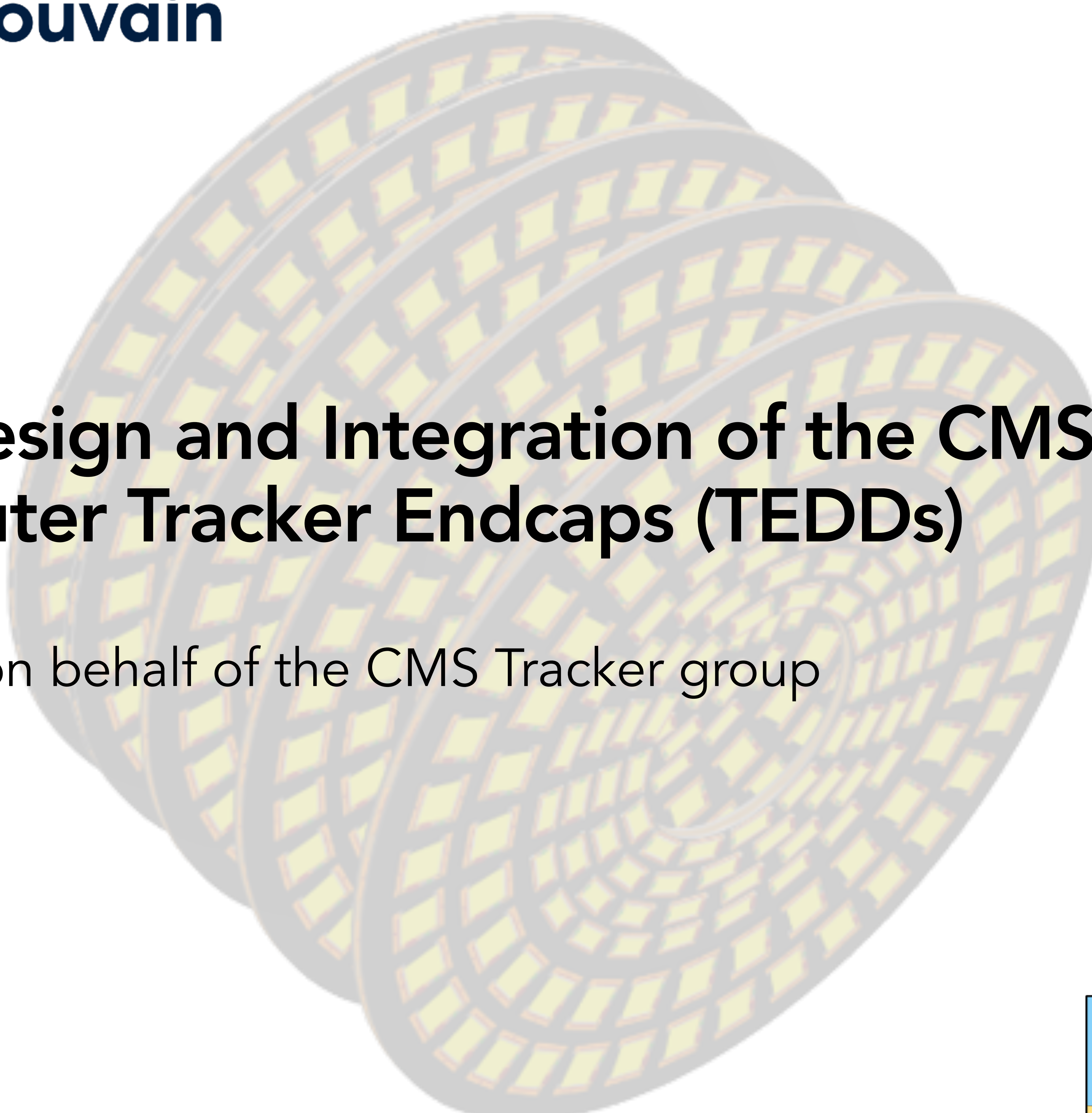
Services Design and Integration of the CMS Phase 2 Outer Tracker Endcaps (TEDDs)



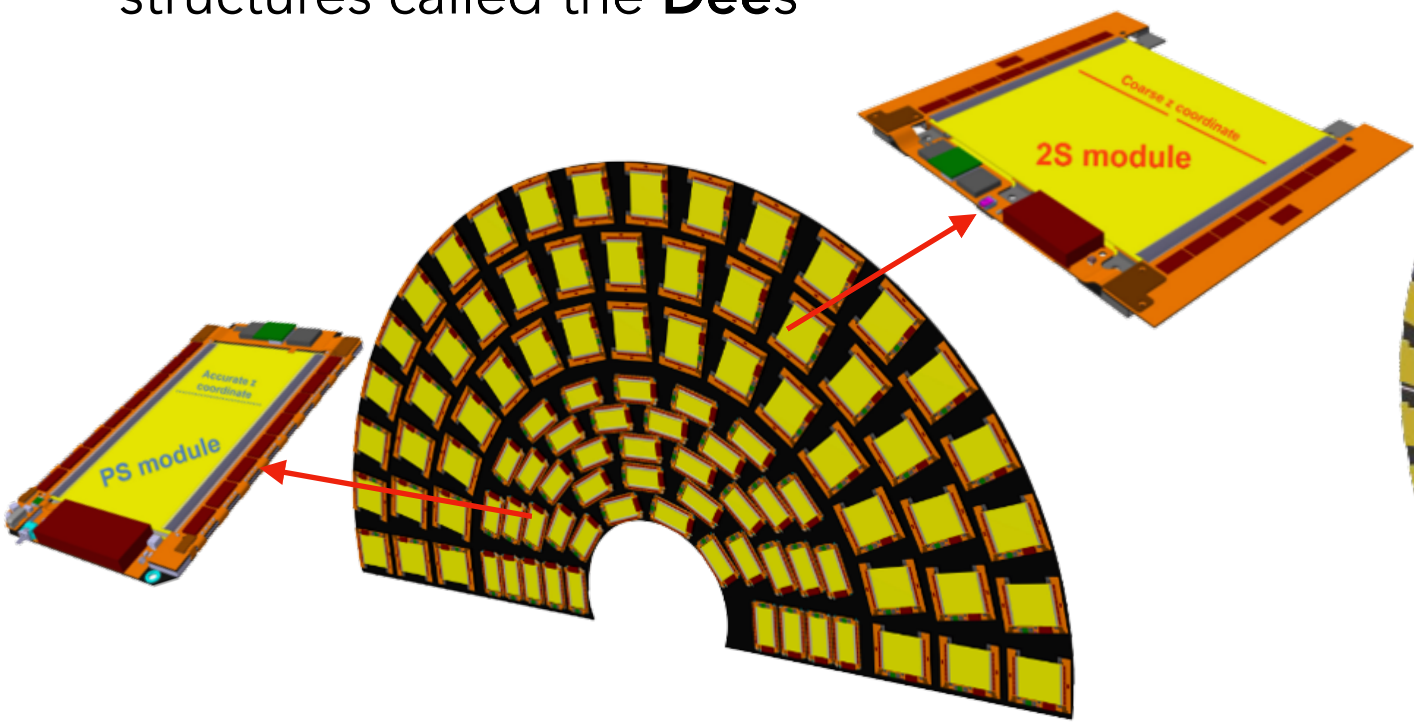
Suat Donertas on behalf of the CMS Tracker group

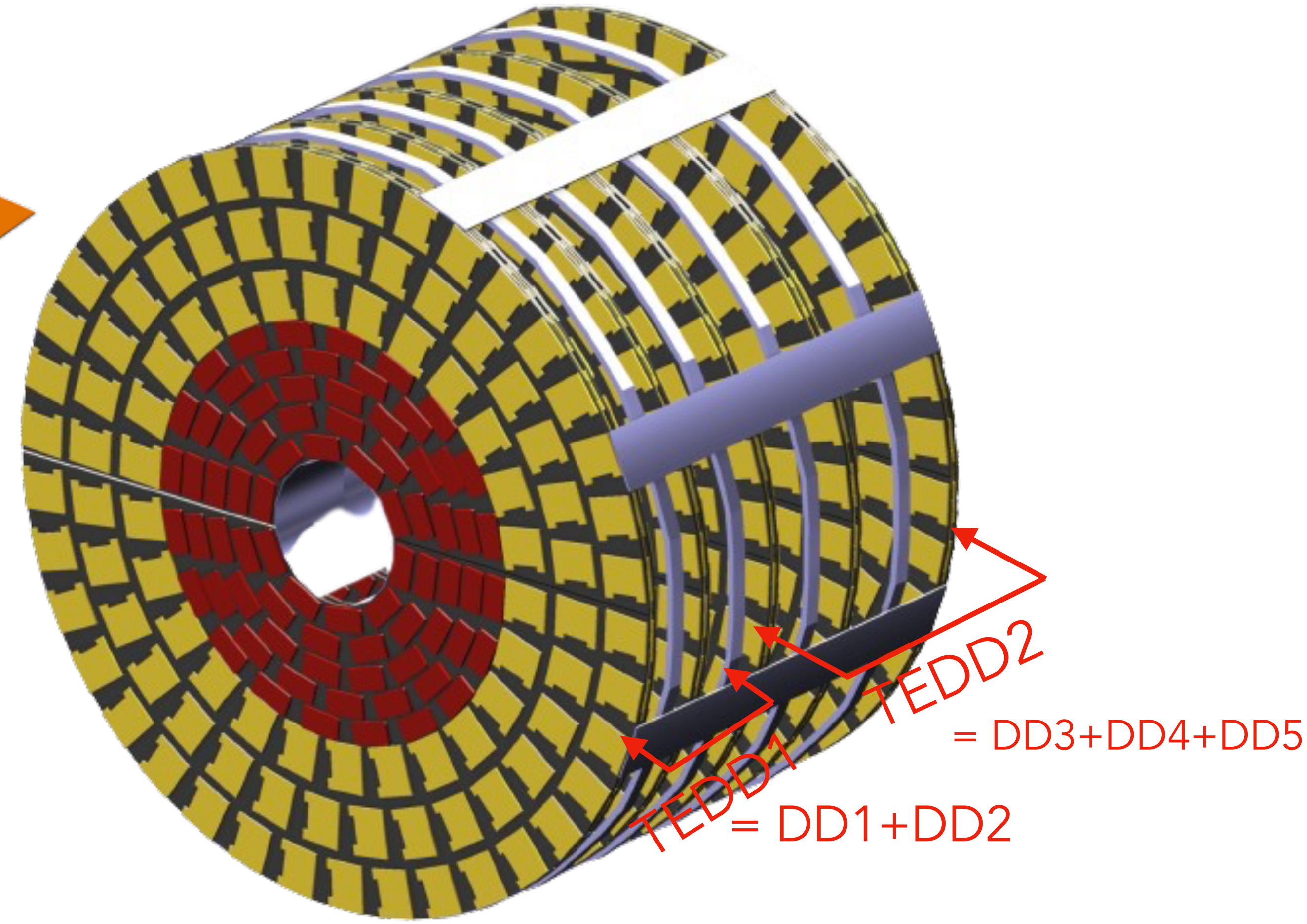
01 June 2023

FTDM 2023

TEDD Design Recap

- **T**racker **E**ndcap **D**ouble **D**isks: consist of ten double-disks: consist of four half-disk structures called the **Dee**s

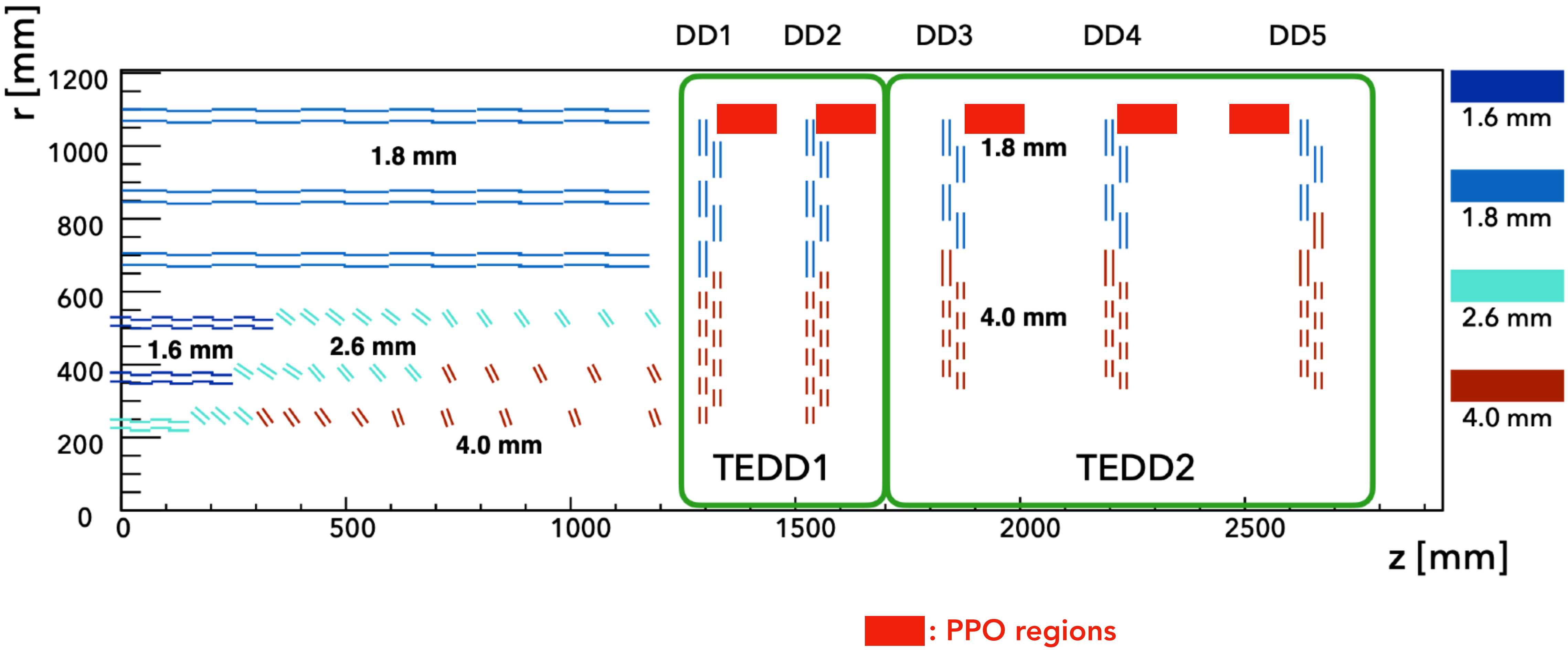




- The services (power cables, optical fibres and cooling pipes) are in two segments:
  - Transverse: Routed within each Dee from the modules to connection patch panels ("PP0") located at the Dee periphery
  - Longitudinal: Routed along the TEDD periphery and out from the CMS Tracker volume

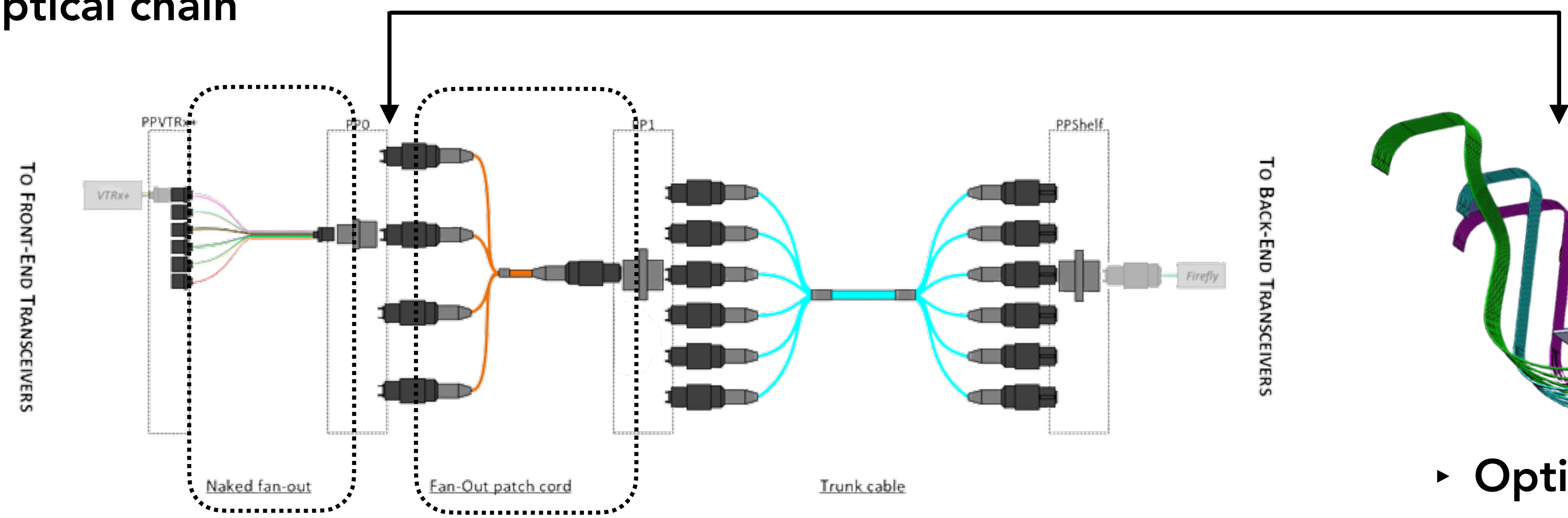
TEDD Design Recap

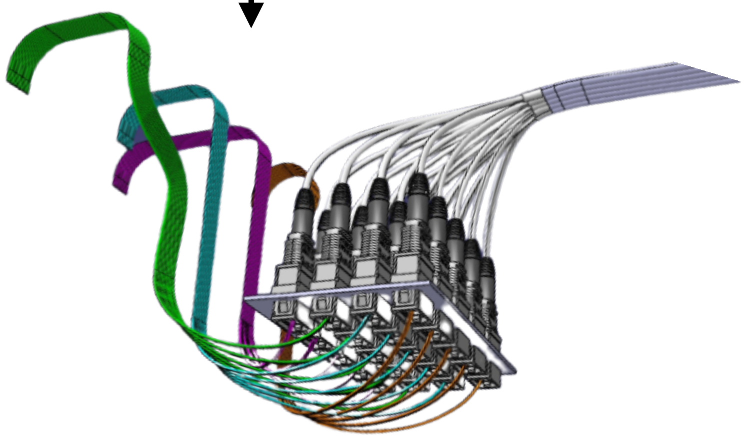
- **T**racker **E**ndcap **D**ouble **D**isks: consist of ten double-disks: consist of four half-disk structures called the **Dee**s



TEDD Design Recap: Optical/Electrical Chain

- **Optical chain**

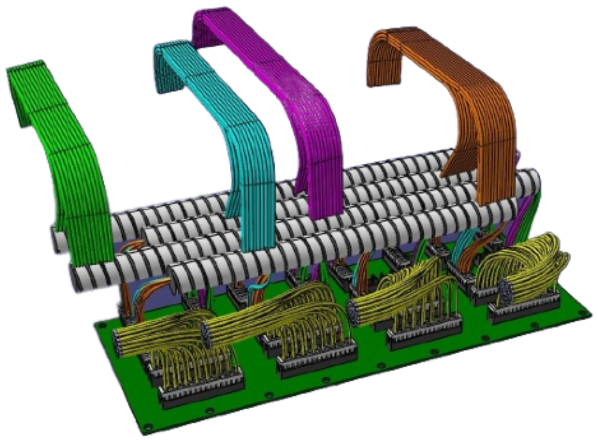




- **Optical PP0**

  - 15 cm (12 cm) optical pigtail for the PS (2S) module
  - Pigtail is mated with a naked fanout (MT to MT) —> then MT to MTP at PP0 level

- **Electrical chain**
  - Initially a long pigtail directly connected at the PPO
  - Recent update: a short pigtail instead
  - ePP0 in two variants: either three or four power groups



- **Electrical PP0**

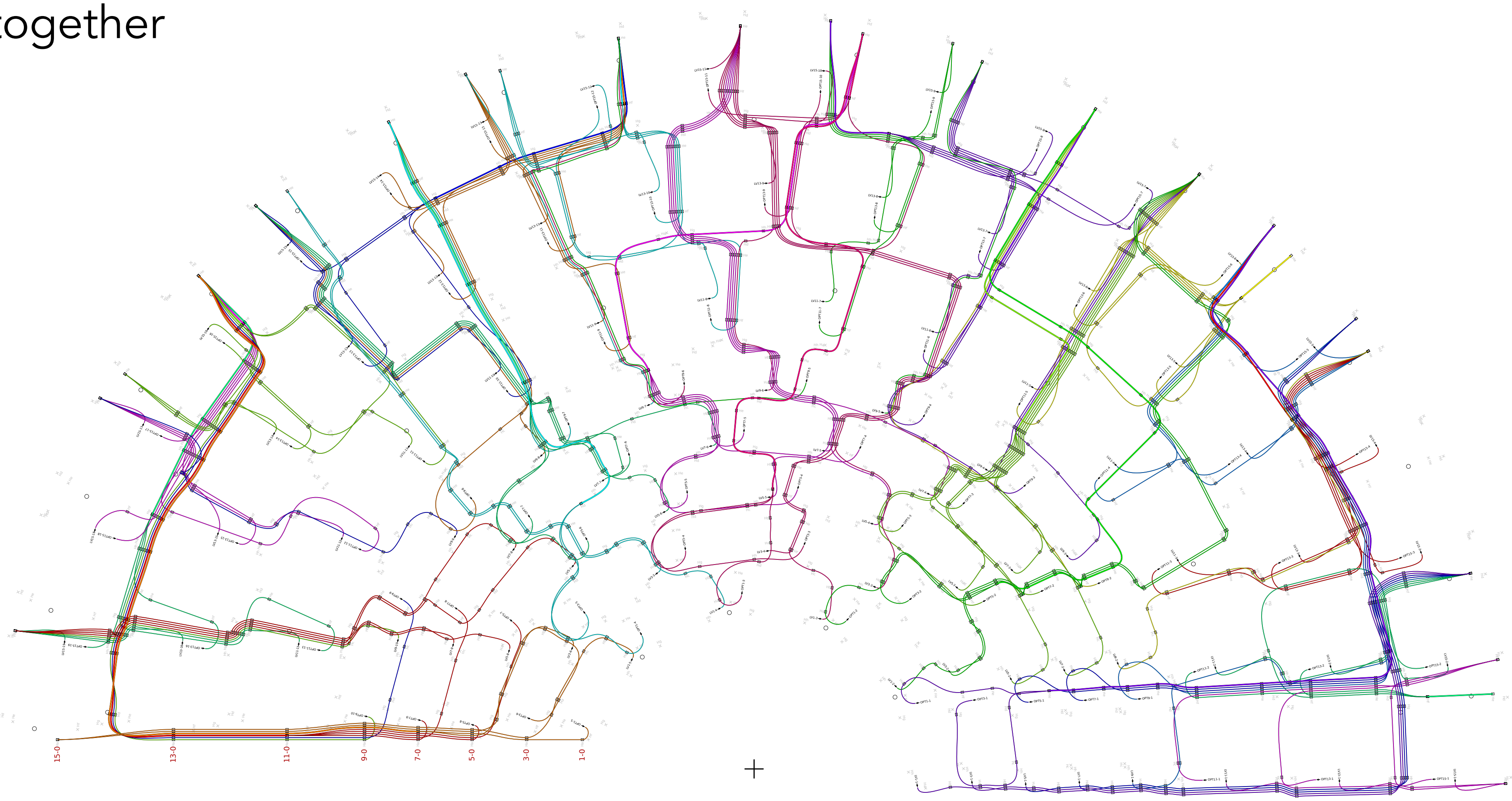
Services Design: Transverse Services: Methodology

- Imposed by the L1 trigger design —> optical groups and service channel mapping
- 16 different Dee layouts emerge (for one full endcap)
- Routing of the optical services —> more constrained
  - Minimum bending radius (12 mm), avoiding excessive clustering or crossing
- Routing of the power services —> rather straightforward
  - LV and HV are routed together

1

Drawing the Dee layout imposed by L1, routing (scripting the routing) the services from modules to PP0 and exporting the drawings as vector graphics

LaTeX, tikz/pgf

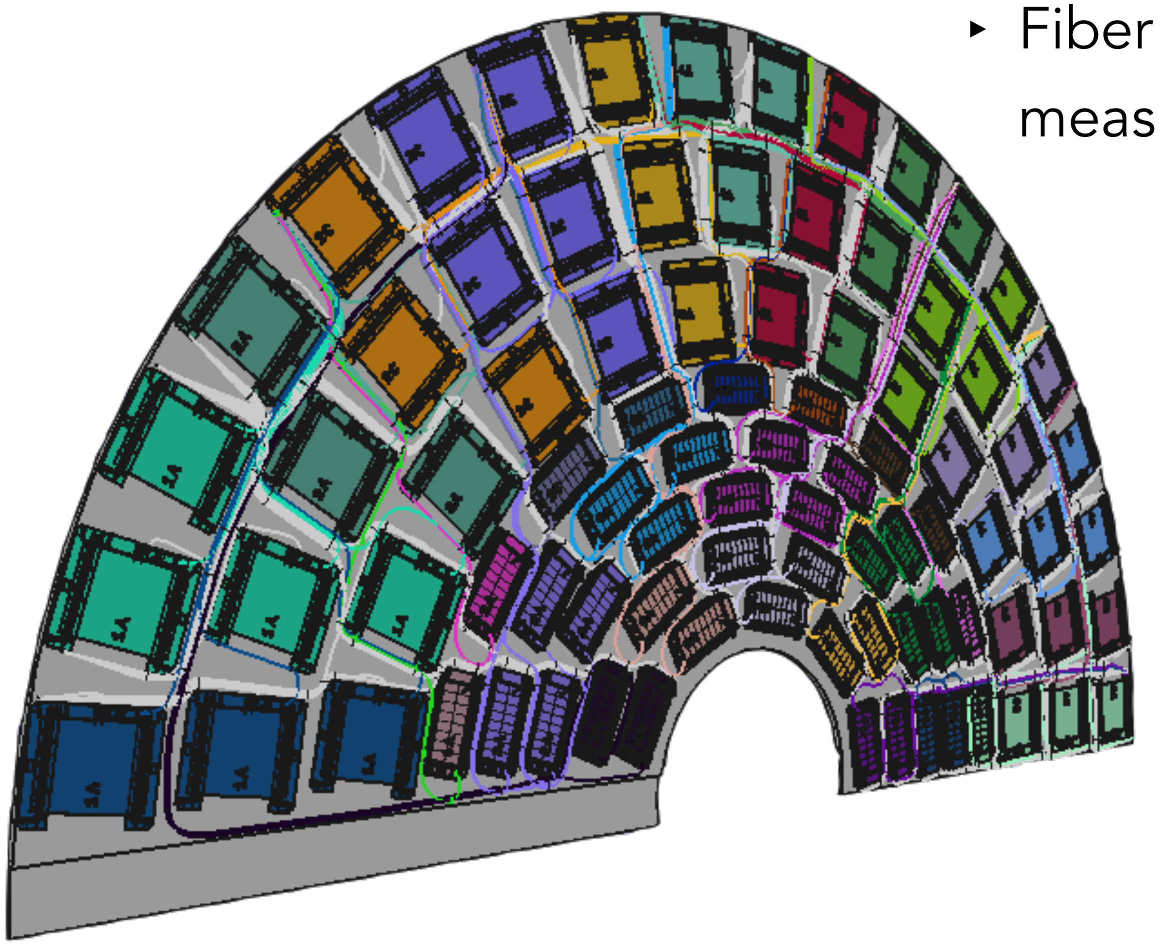


Services Design: Transverse Services: Methodology

2

Importing the vector graphics on FreeCAD for 3D visualization and analysis of the cabling

FreeCAD, python

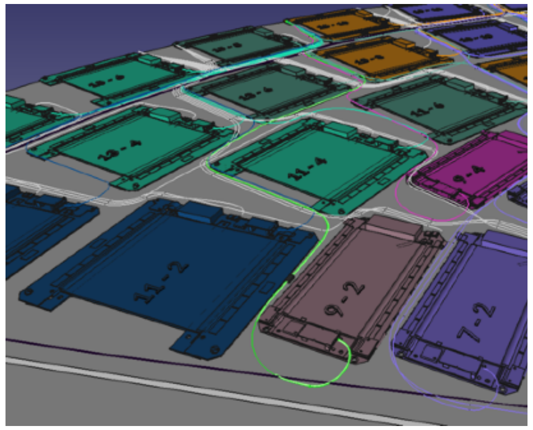


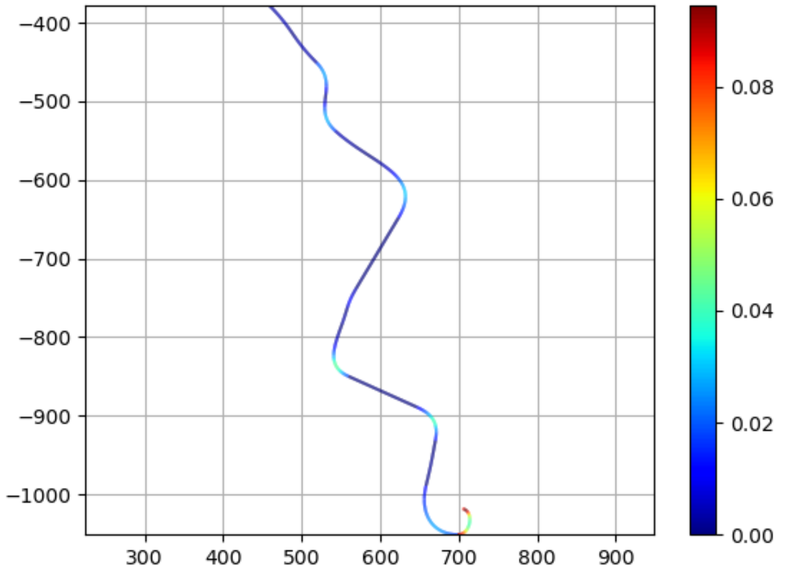
- Optical pigtail length check
- Curvature check
- Fiber and cable length measurement

- Finally, the two steps were iterated over 16 different Dee layouts

Services Design: Transverse Services: Analysis

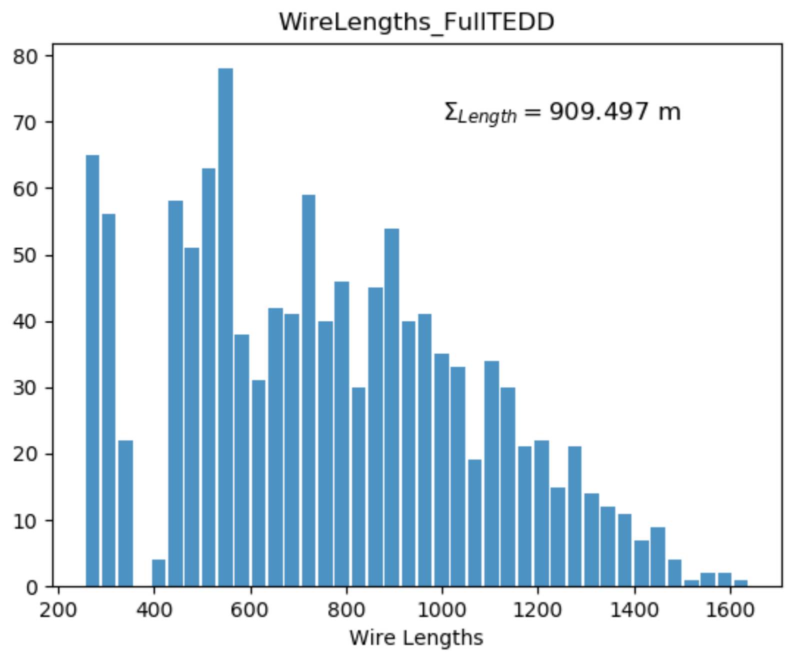
- Customised tools through python macros allow
  - Optical pigtail length check
  - Curvature check for the fibers
  - Fiber and cable length measurement

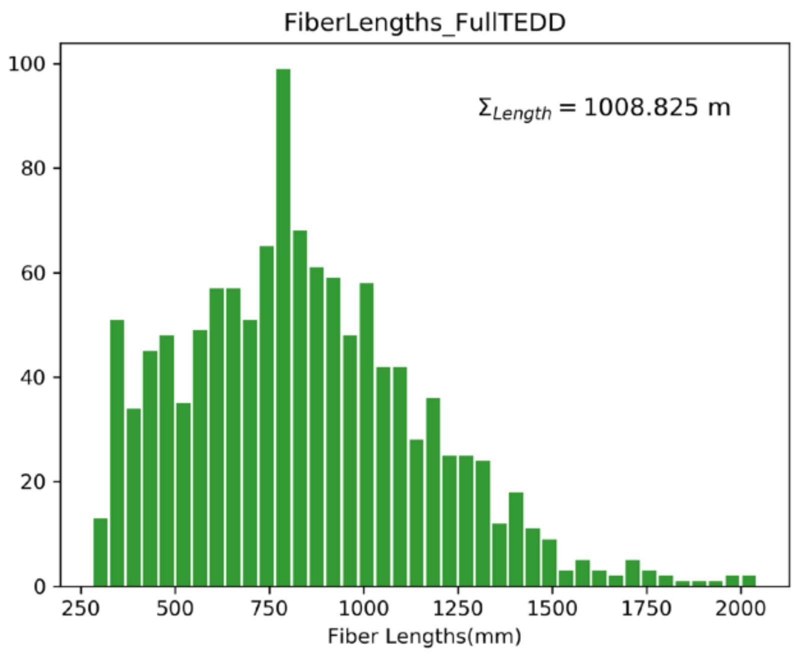




Curvature of the highlighted fibre at every point along its path, large curvatures correspond to small bending radii

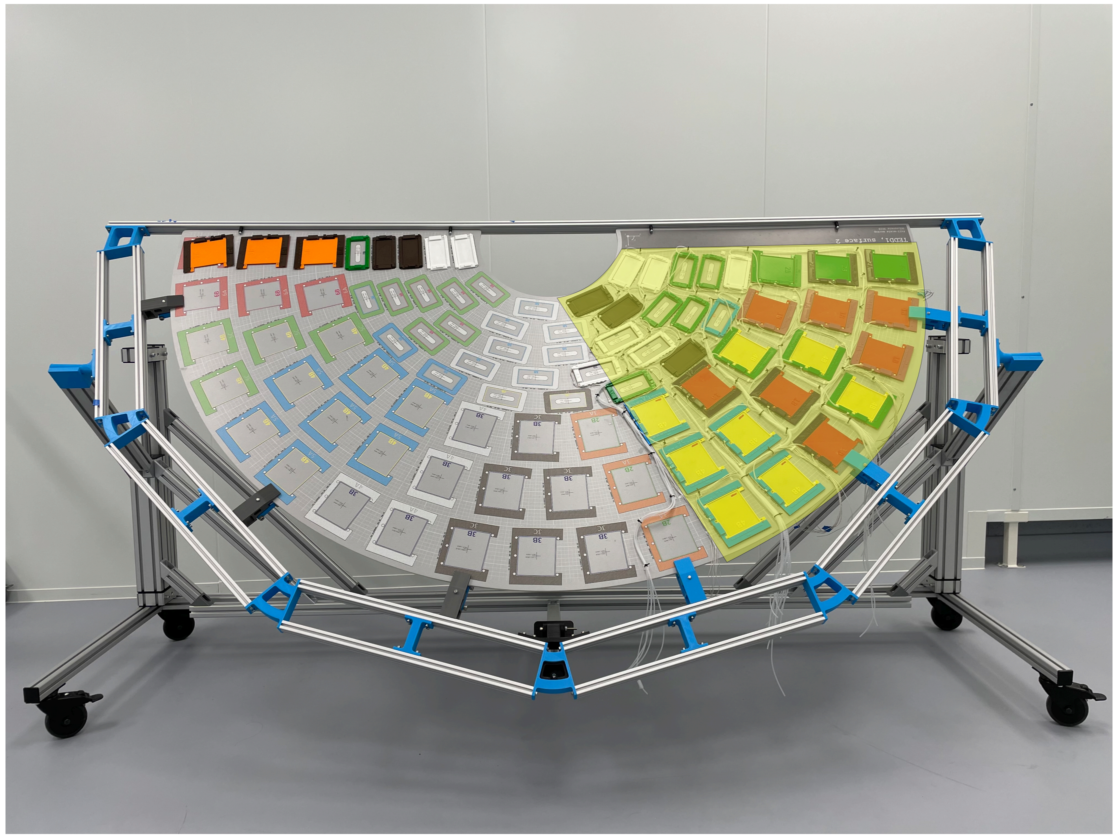
- 16 dees were analysed via FreeCAD tools
  - Pigtail lengths were compatible
  - Curvature considerations were easily justified for all cases and validated with the mockup
  - Total length for fibers and power cables (done only for HV or LV, not both)

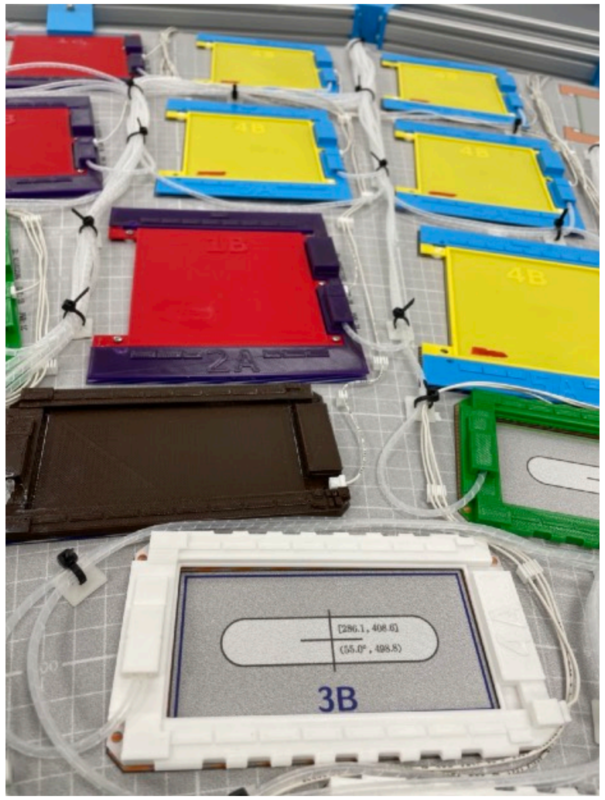


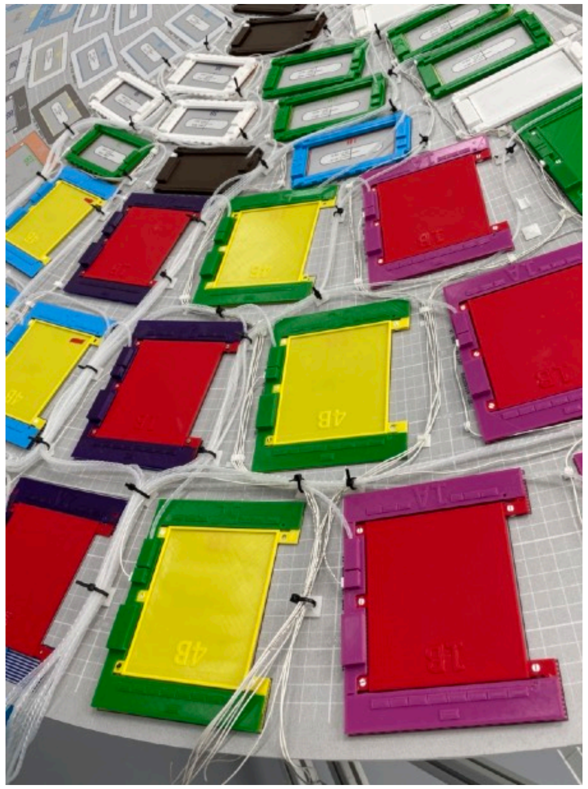


Services Design: Transverse Services: Validation

- Mockup partially installed with 3D printed (simplified) modules used for :
  - Validation of the population on the dee surface (especially the busy spots)
    - Studying the fixation options
  - Validation of the curvatures
  - Validation of the length measurements
  - Validation of the dee periphery population (connection to PP0)





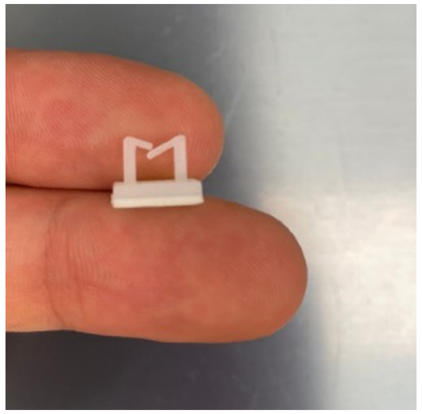


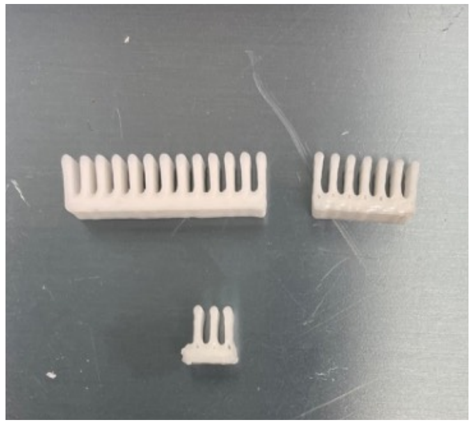
- The integration table shown is a temporary solution

- Spiral tubes as fiber substitutes, 24AWG dummy cables as wire substitutes

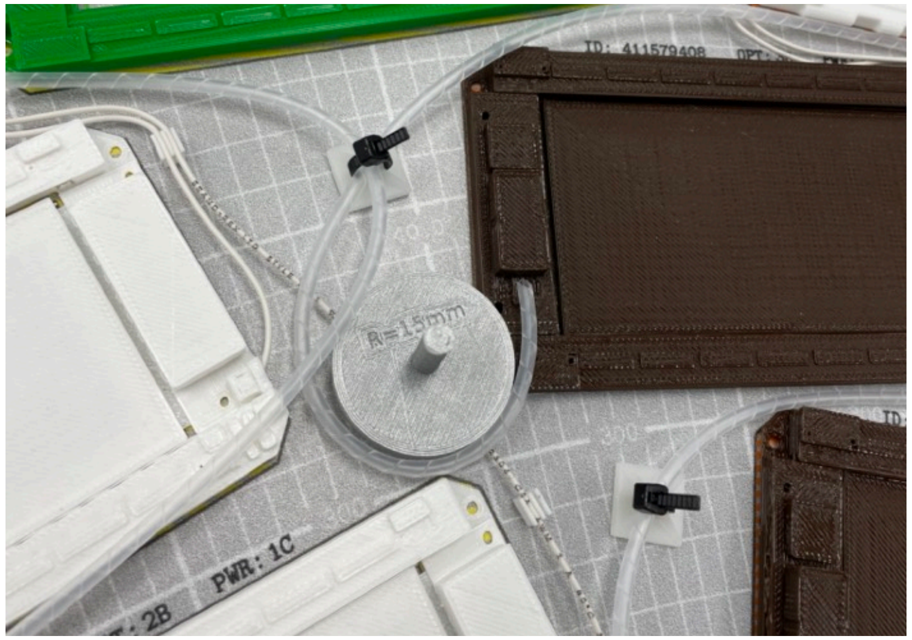
Services Design: Transverse Services: Validation

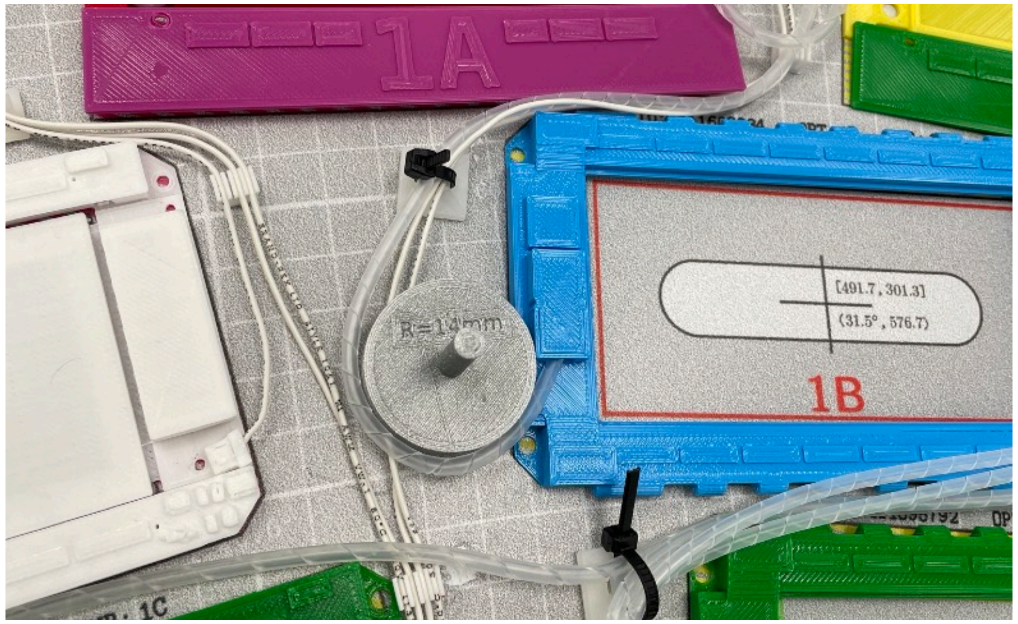
- The ongoing validation studies shown so far:
  - Busy spots —> can be best handled by the choice of wire/fiber holders
    - Tested options include





  - Curvature —> the highest concern was at the module exit, justified with the mockup

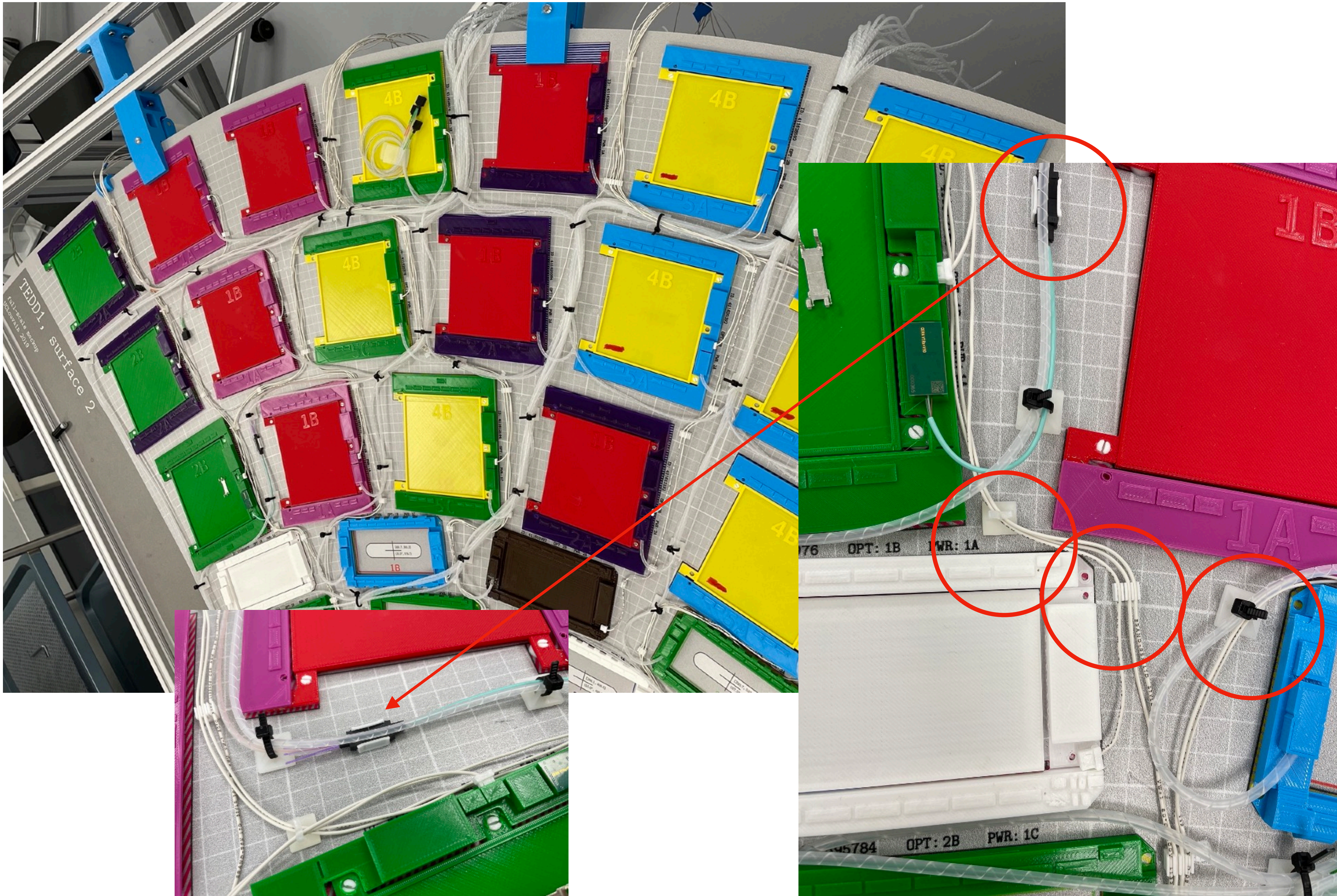




  - Population at the Dee exit —> mockup equipped with 3D printed PP0, studies ongoing

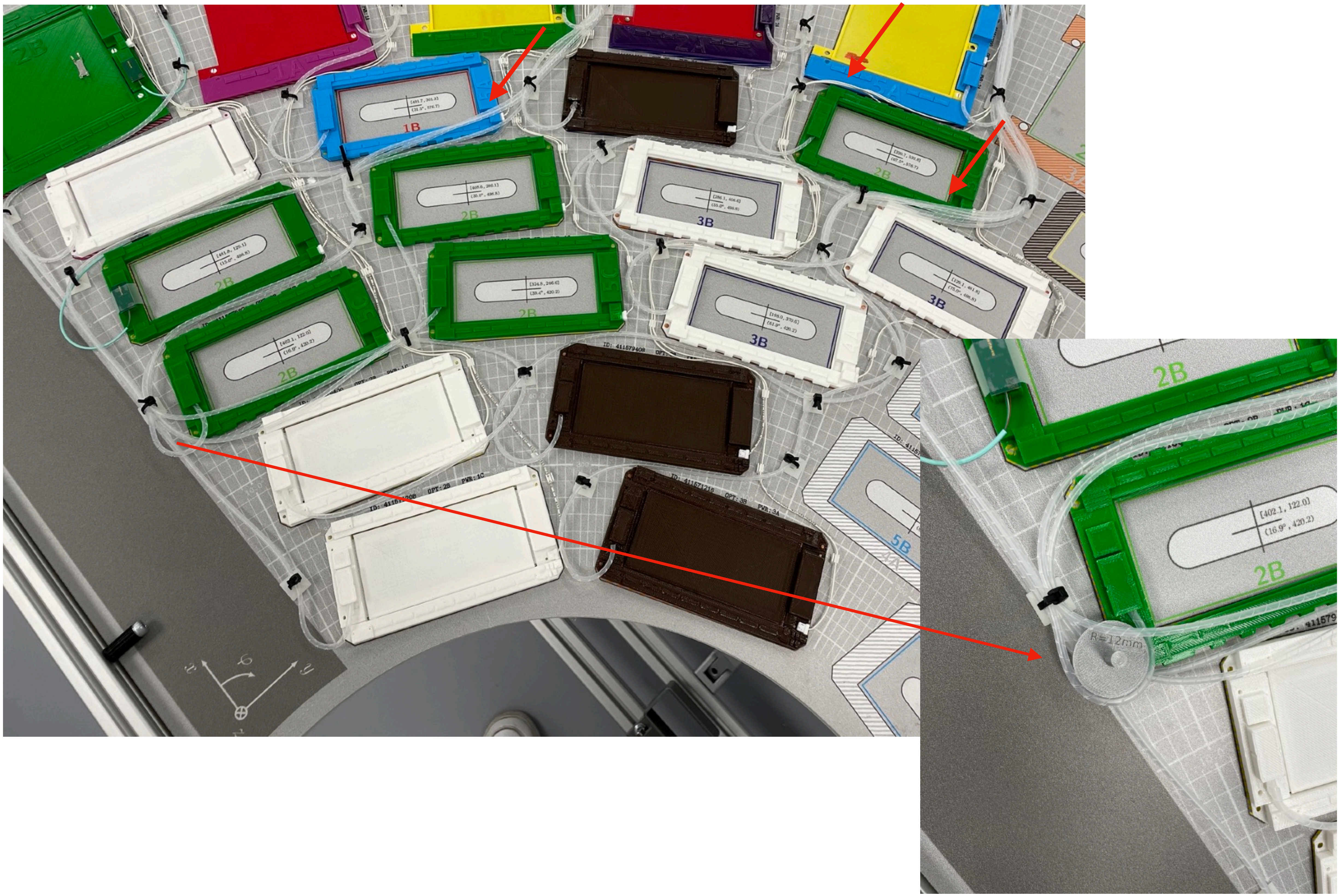
Close up look into the installed mockup

- **2S region**



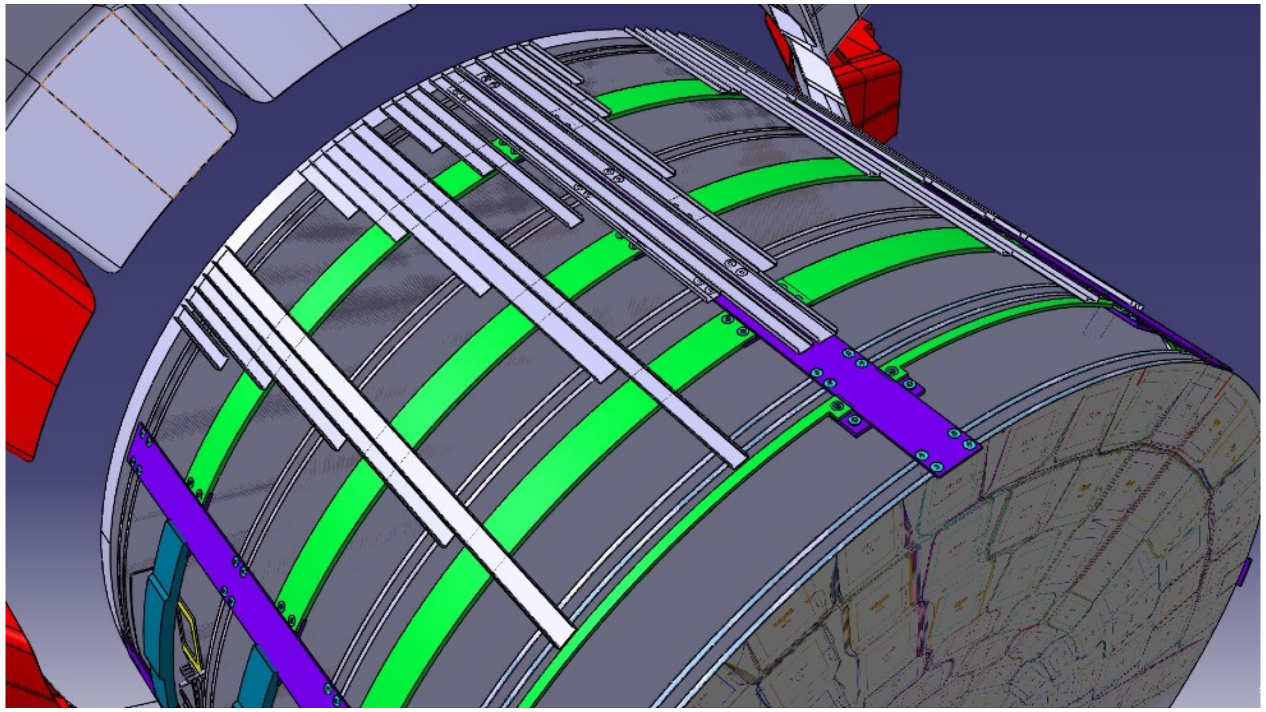
Close up look into the installed mockup

- PS region

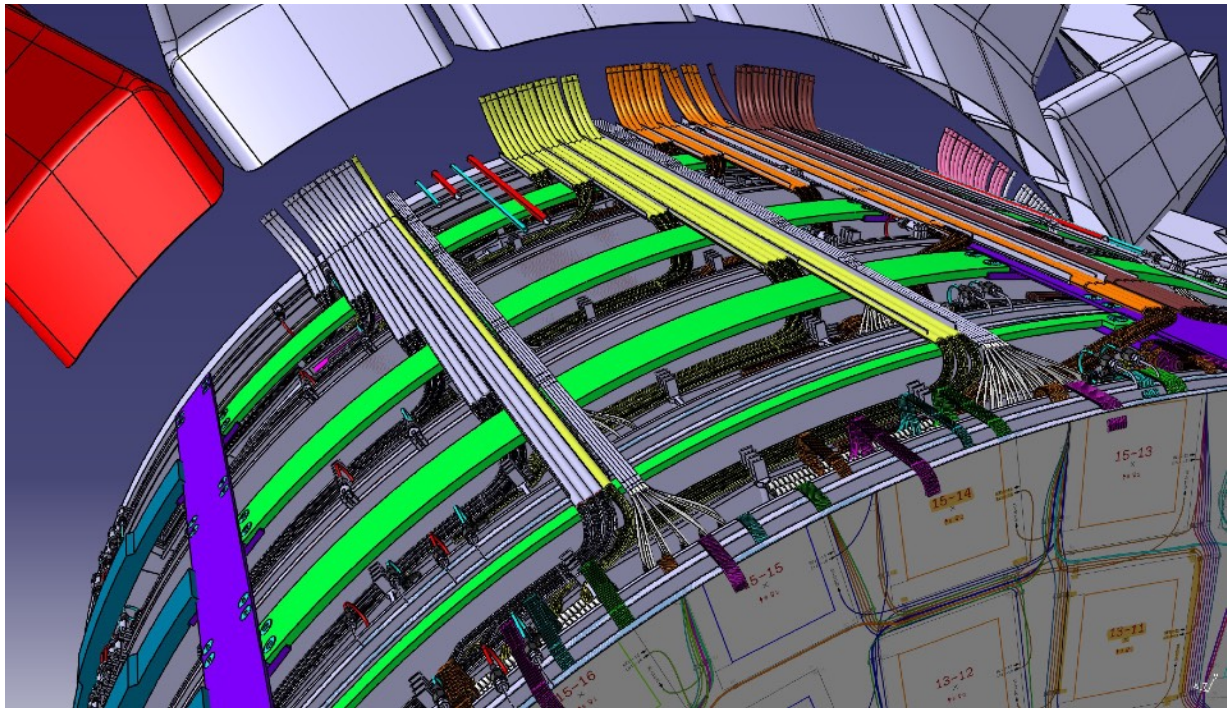


Longitudinal Services

- Maintained in the TEDD service volume by plastic gutters and straps, will likely be 3D printed out of radiation hard plastic (Accura 25)
  - Each guide will house three to four cables, clipped to the beams of the TEDD superstructure
- Lightweight structure while allowing for design flexibility
- Longitudinal services consist of:
  - Rugged fanouts (for the optics),
  - Multi-service cables regrouping LV and HV for one power group (for the power cables)



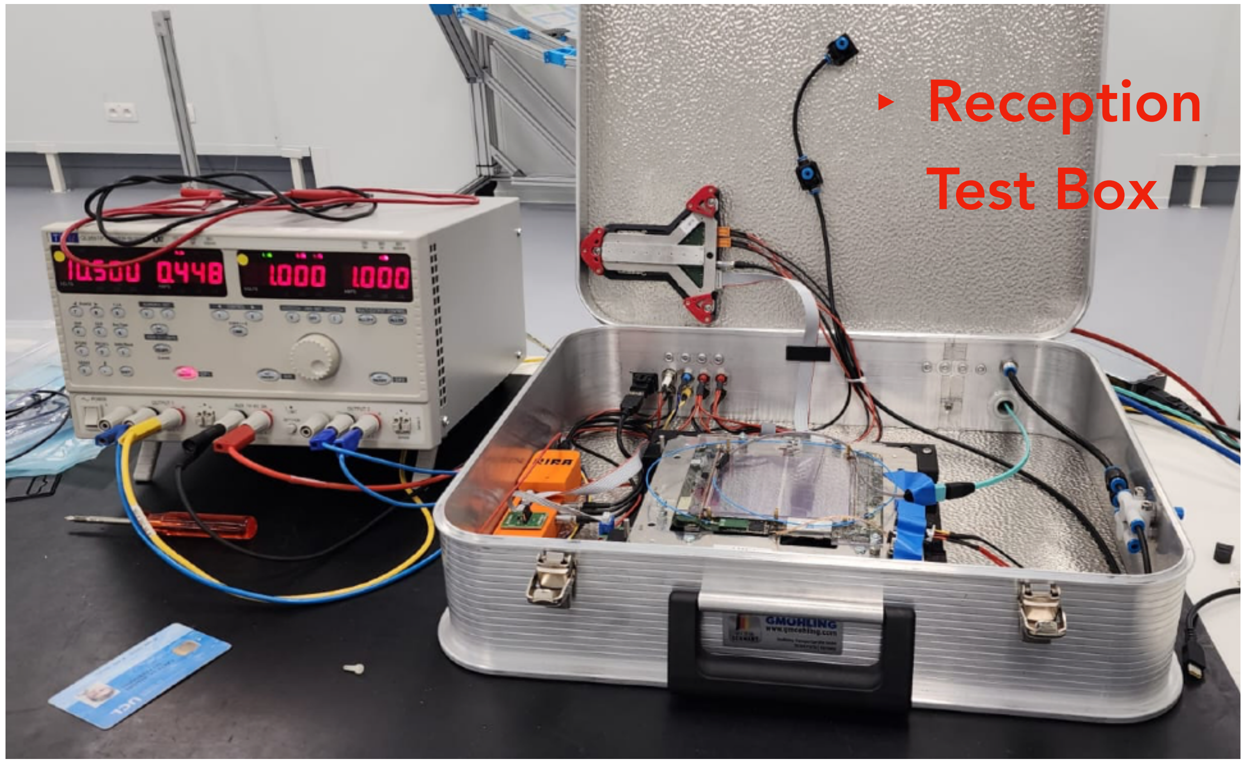
- **Guides installed on the TEDD straps**



- **Longitudinal services running on the guides**

Services Tests: Full Test Chain during TEDD production

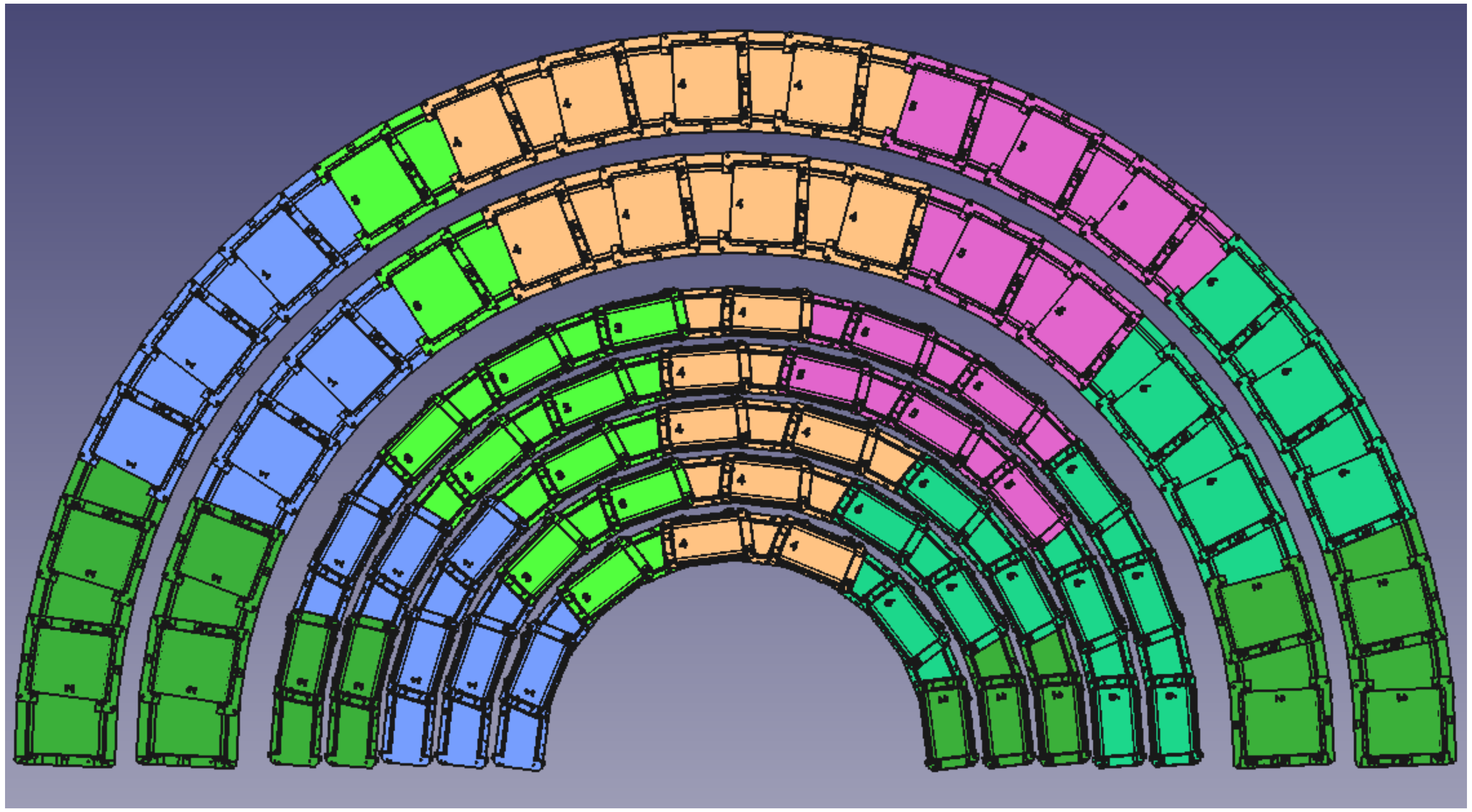
- Before installation on the Dees each module is carefully tested
  - Reception test with the reception test box
    - Testing of module functionality upon reception
  - Burn-in of the received modules
    - Quality assurance of module functionality with active cooling
- Once installed on the Dee, then:
  - Single module test on integrated Dee
    - Connectivity test (optics+power)
    - Optical power measurement
    - Pedestal/Noise scan ?
  - Sector test of the integrated dee



Test Procedures: Testing of the Dee in Sectors

- Once integrated, the Dees will be subjected to a quality assurance test, with active cooling
- Use of temporary patch panels, tPPO and tPP1
- Sector division (into 6 sectors, similar to cooling loops) required, testing a full Dee in one go in the assembly facility will not be possible due limitations in available hardware

- Sectors obtained by imposing:
  - Two cooling loops deployed at a time,
  - Maximum of 10 LV cables
  - Total cooling power of 300 W
  - Similar heat load between two used loops



- **Division of one Dee into six sectors for testing, with each colour corresponding to one sector**

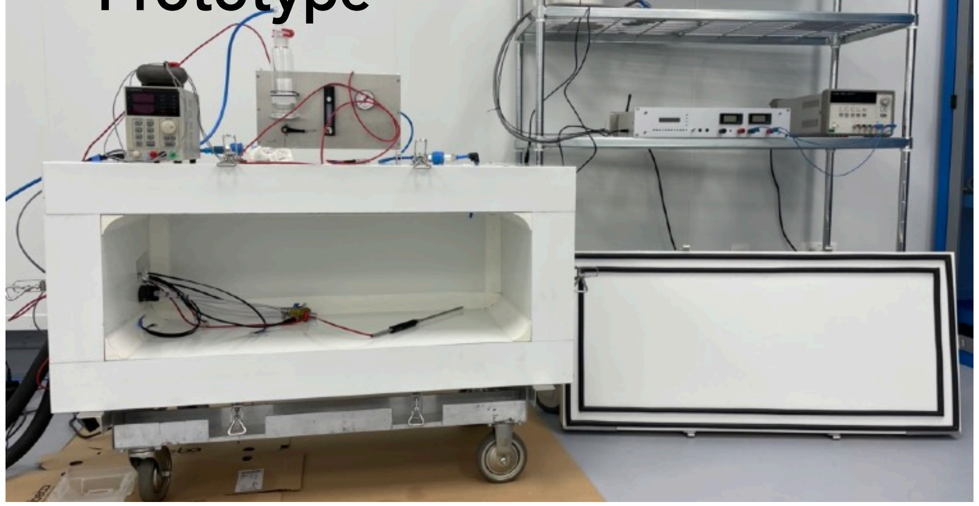
Test Procedures: Sector Test Setup

- The components of the sector test infrastructure are
  - CAEN SY4527 mainframe coupled to 5x8-channel LV and 4x12-channel HV PSUs
  - Julabo FP-52 high power chiller (oil-based fluid)
  - MARTA CO2 cooling plant (evaporative CO2)
  - Donaldson Ultrapac air dryer
  - DAQ components: μTCA crate with FC7s
- Switch box: dedicated electrical switching matrix
  - Testing series of modules individually while limiting the amount of recabling needed
  - Allows the operator to switch between one module to another within the same power group, as well as from one power group to another

Test Procedures: Sector Test Setup: Louvain Cold Box

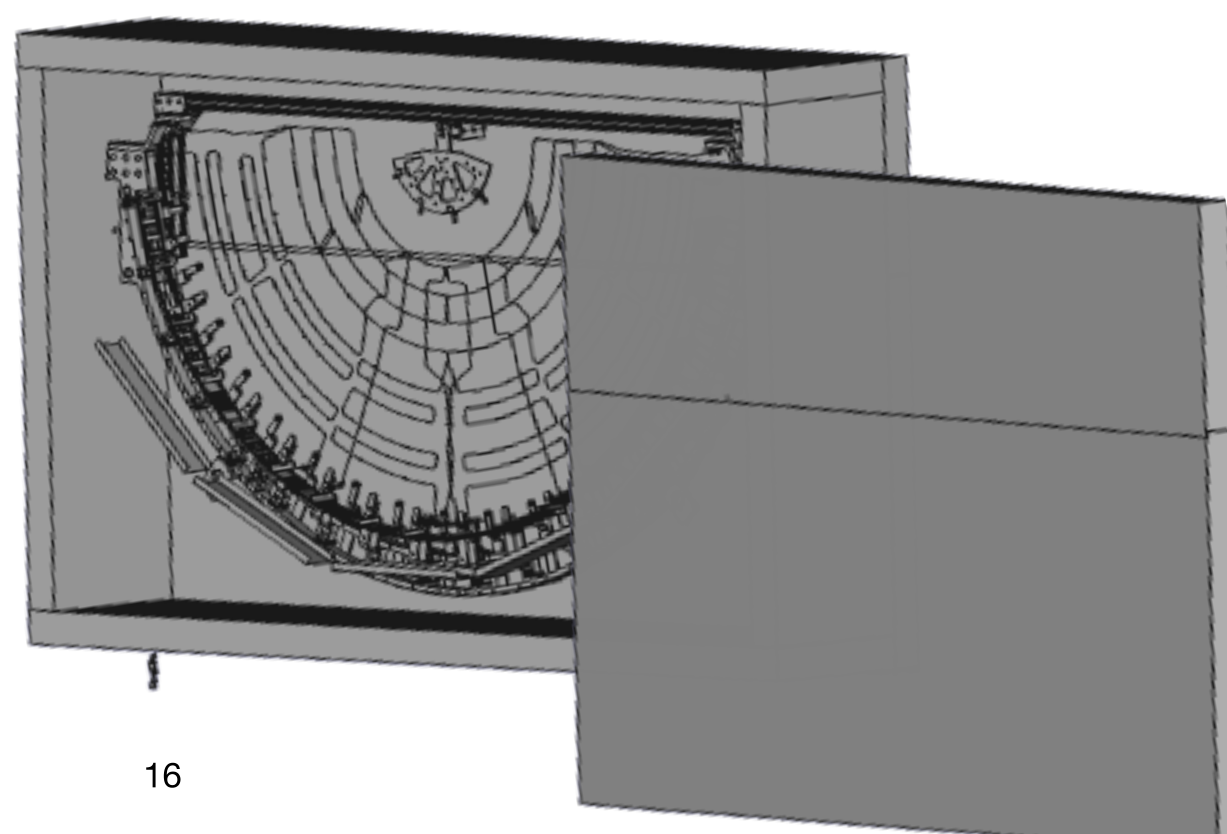
- Each collaborator is designing their own solution for the cold box
  - Louvain cold box will be assembled on-site from commercially available insulation panels
- The first prototype was assembled and tested in Louvain
  - Validation of material choice, the assembly procedure, and thermal insulation performance

- **Prototype**



- Takes about ~1h to go to -30C with active cooling and flush of dry air
- Made of polyurethane foam, same material as the original design
- Assembly procedure validated

- **CAD view of the final design**



- The dee goes in vertical position with a support frame for tPPOs
- Removable front panel with magnetic lock

Conclusions

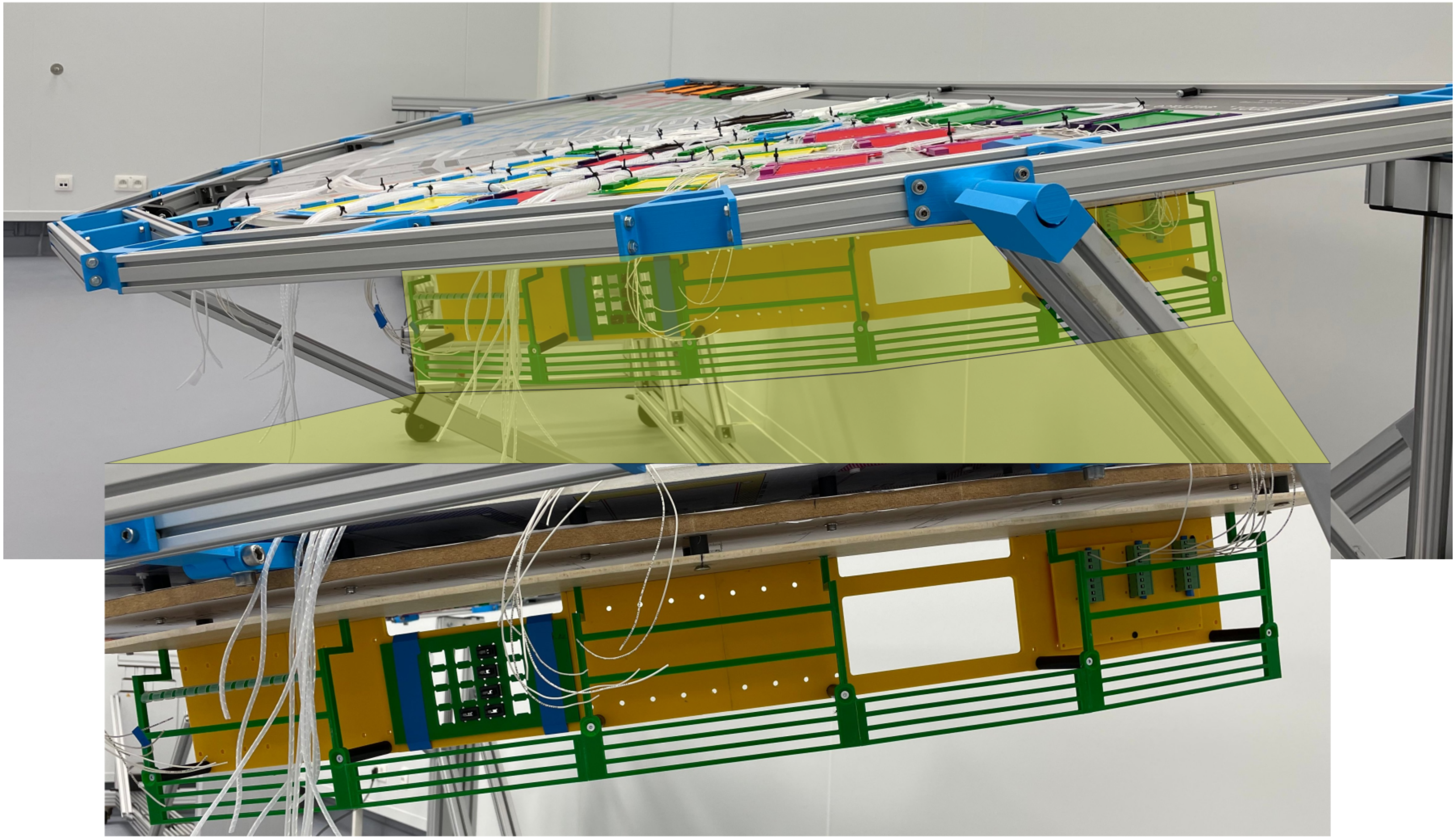
- Services design and laying down the services (integration) is a multi constrained task
  - Validation of the length measured via freeCAD is in good agreement with the mockup measurements
    - Difference in measured length was ~1 cm on avg
  - Among the fixation options, m-shaped clamp and the cable tie performed the best as it can bundle together much more cable/fiber load
  - Whereas the comb like 3D printed option was also very performant for power cables
  - Deciding on fixation locations is not trivial
    - Inserts, distance to the module (in case the fiber/cable touches the module or not)
- Challenging and exciting times around the corner

Next steps

- Transverse services
  - Further validation studies on fixation options and positions on the dee surface
  - Validation of the population of the dee periphery — need to redo the length measurement to see if the agreement holds
- Integration test at DESY in June 5th to 9th
  - Pre-integration test for a single sector, equipped with modules
- Assembly of the cold box according to the final design

PPO region validation

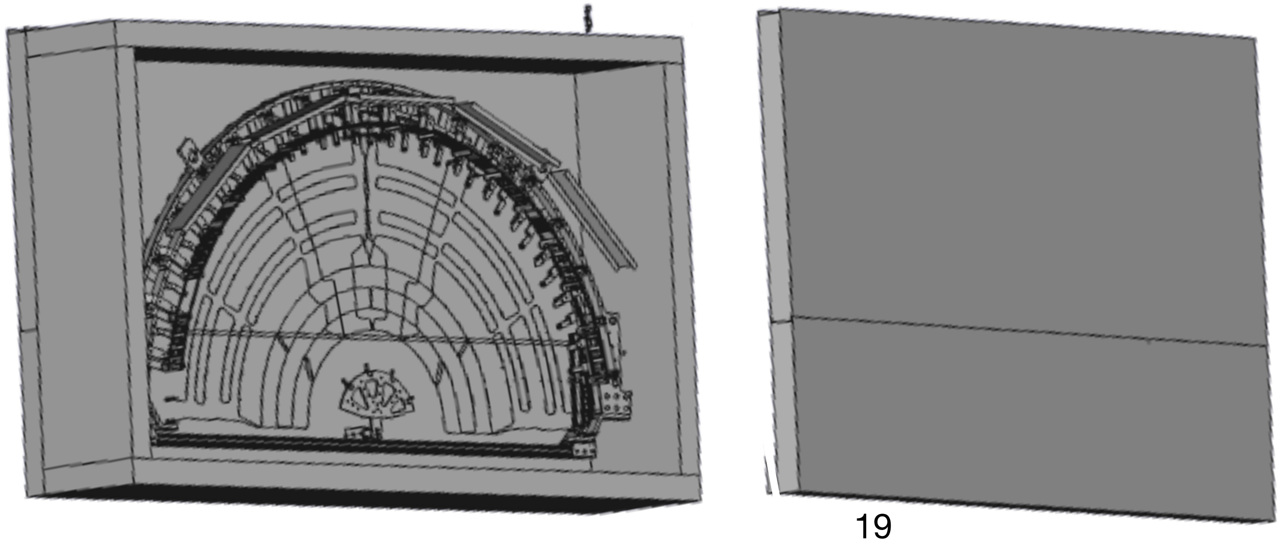
BACKUP



Test Procedures: Sector Test Envisaged Steps

BACKUP

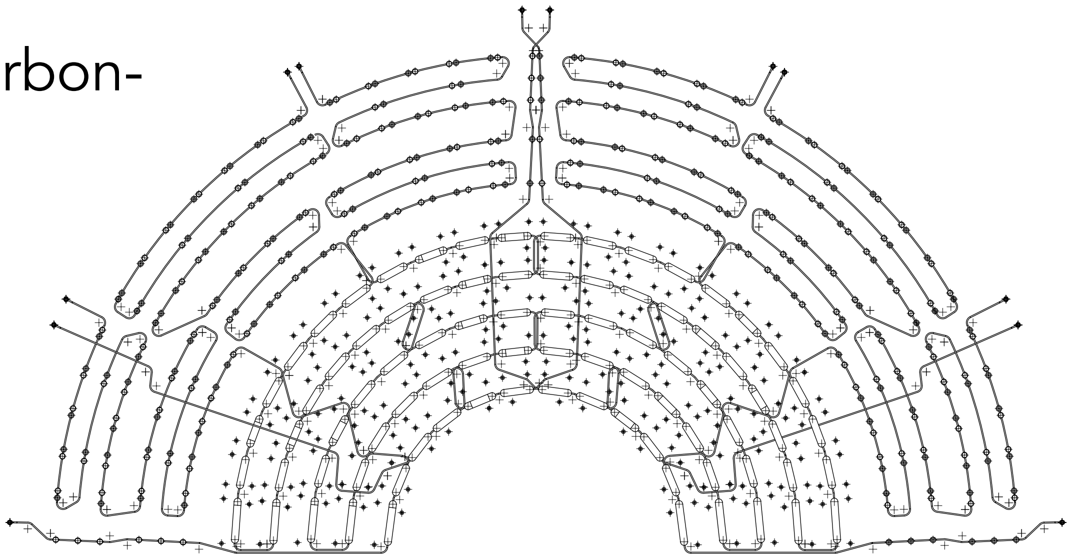
1. Installation the dee in the cold box; full connectorization; securing the door; vacuum pumping the cooling loops.
2. Connectorization of one test sector at the level of the tPP1s.
3. Flushing the cold box using dry air.
4. Cooling the cold box and dee to −35C.
5. Testing the modules.
6. Flushing the liquid CO2 contained in the cooling loops back into the MARTA tank.
7. Re-cabling at the tPP1s and switching cooling manifold for the next sector (no thermal cycling or additional vacuum pumping needed).
8. Testing the modules.. . .
9. Once all sectors have been tested, heating the cold box to room temperature.
10. Opening the box and moving the dee into safe storage (if all tests successful), or replacing failed modules and repeating the test



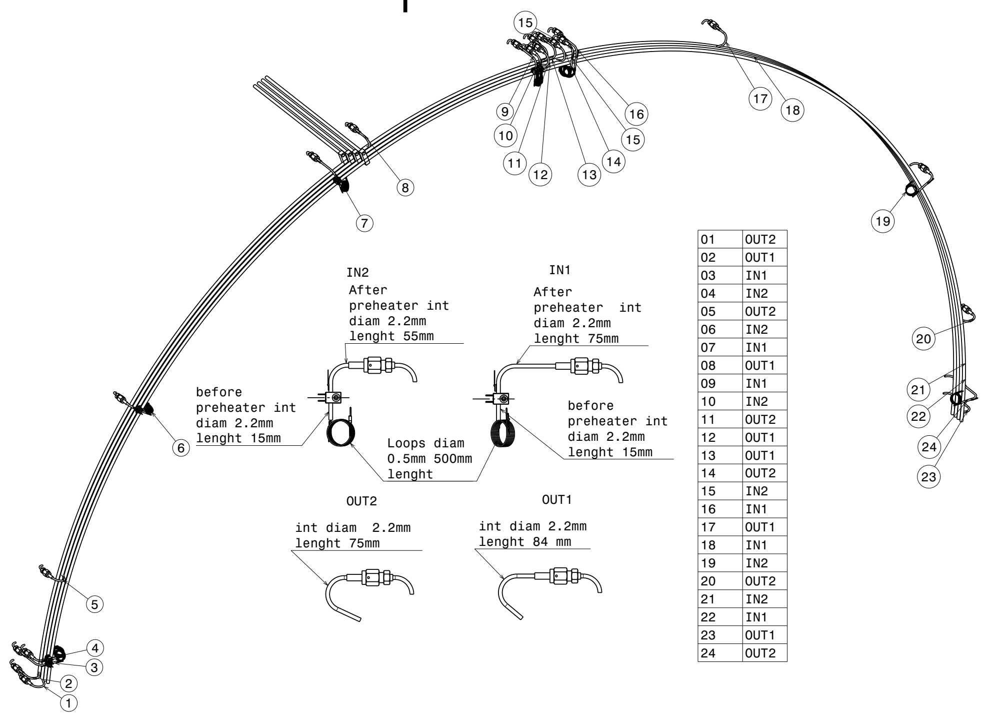
Cooling

BACKUP

- Each dee hosts 6 cooling loops, placed inside the Dee’s carbon-fibre + foam sandwich structure
- Evaporative CO_2 cooling
- Cooling loops of a pair of adjacent dees are connected to a cooling manifold —> from here, a single pair of cooling line runs to the proper service channel

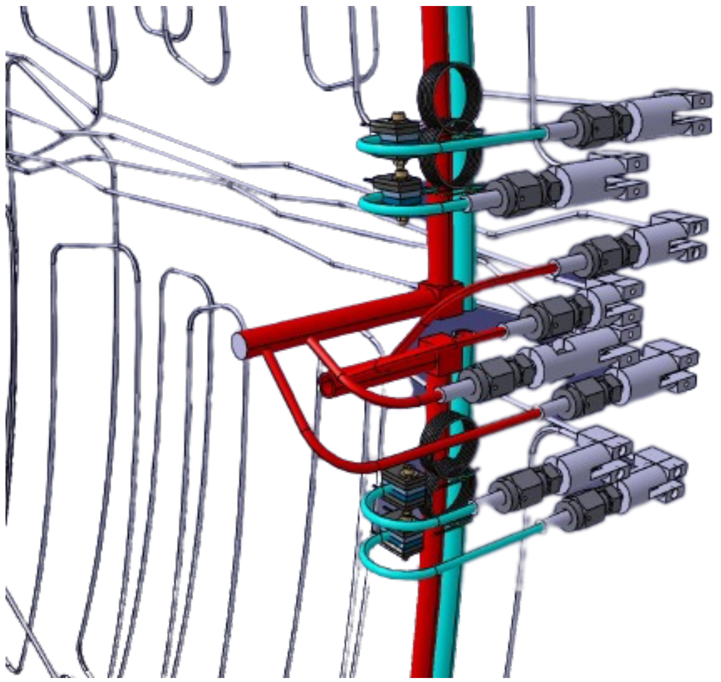


- Cooling manifolds shaped as an arc, placed parallel to the edge of one dee
  - Two pairs of manifolds per double disk, connecting either the inlets or the outlets of a pair of dees



01	OUT2
02	OUT1
03	IN1
04	IN2
05	OUT2
06	IN2
07	IN1
08	OUT1
09	IN1
10	IN2
11	OUT2
12	OUT1
13	OUT1
14	OUT2
15	IN2
16	IN1
17	OUT1
18	IN1
19	IN2
20	OUT2
21	IN2
22	IN1
23	OUT1
24	OUT2

- **Cooling manifold concept**



- **CAD view of a cooling manifold connected at the junction of a top and a bottom dee**