Prototyping, Integration and Assembly of the CMS Phase-2 Outer Tracker Endcap

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on behalf of the CMS collaboration

Forum on Tracking Detector Mechanics
Cornell University, 20.06.2019

Overview

- Introduction to the CMS Phase-2 tracker endcap (TEDD = Tracker End Cap Double-Disks)
- Dee prototyping at DESY and IPNL
- Dee production quality control
- Integration and assembly

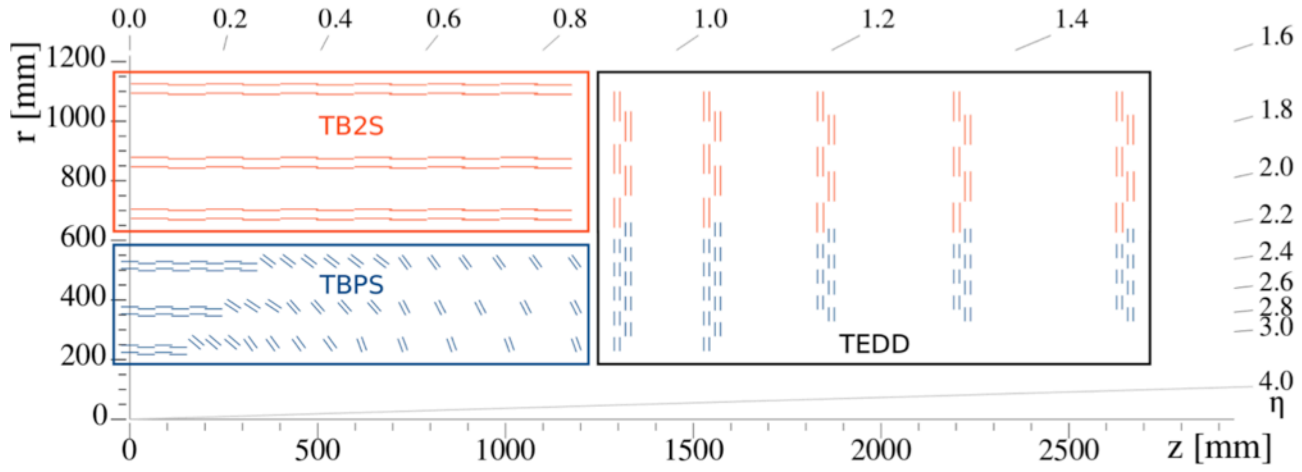
New CMS Tracking Detector

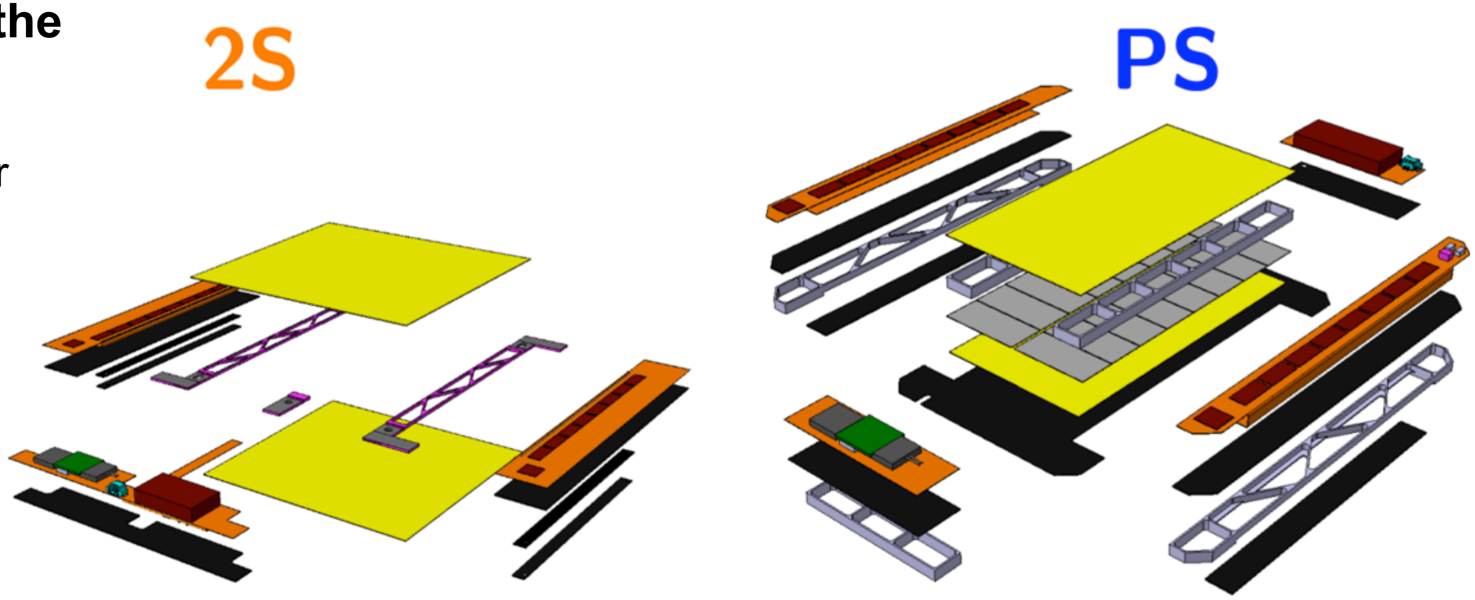
The HL-LHC will put challenging demands on the new tracker system

- High radiation ➟ Radiation hard sensors
- High pileup ➟ Increased sensors granularity
- Tracker input to CMS trigger system upgrade ➟ New modules with Pt sensitive trigger output

A new tracking detector is needed to meet the challenges

- 2 module types (2S & PS) with on-module trigger capability
- 6 Barrel layers (3 in TB2S & 3 in TBPS)
- 2 end-caps (TEDD) with 5 Double-Disks each

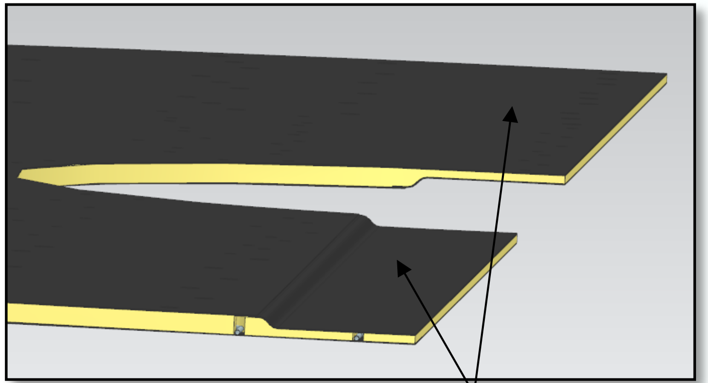




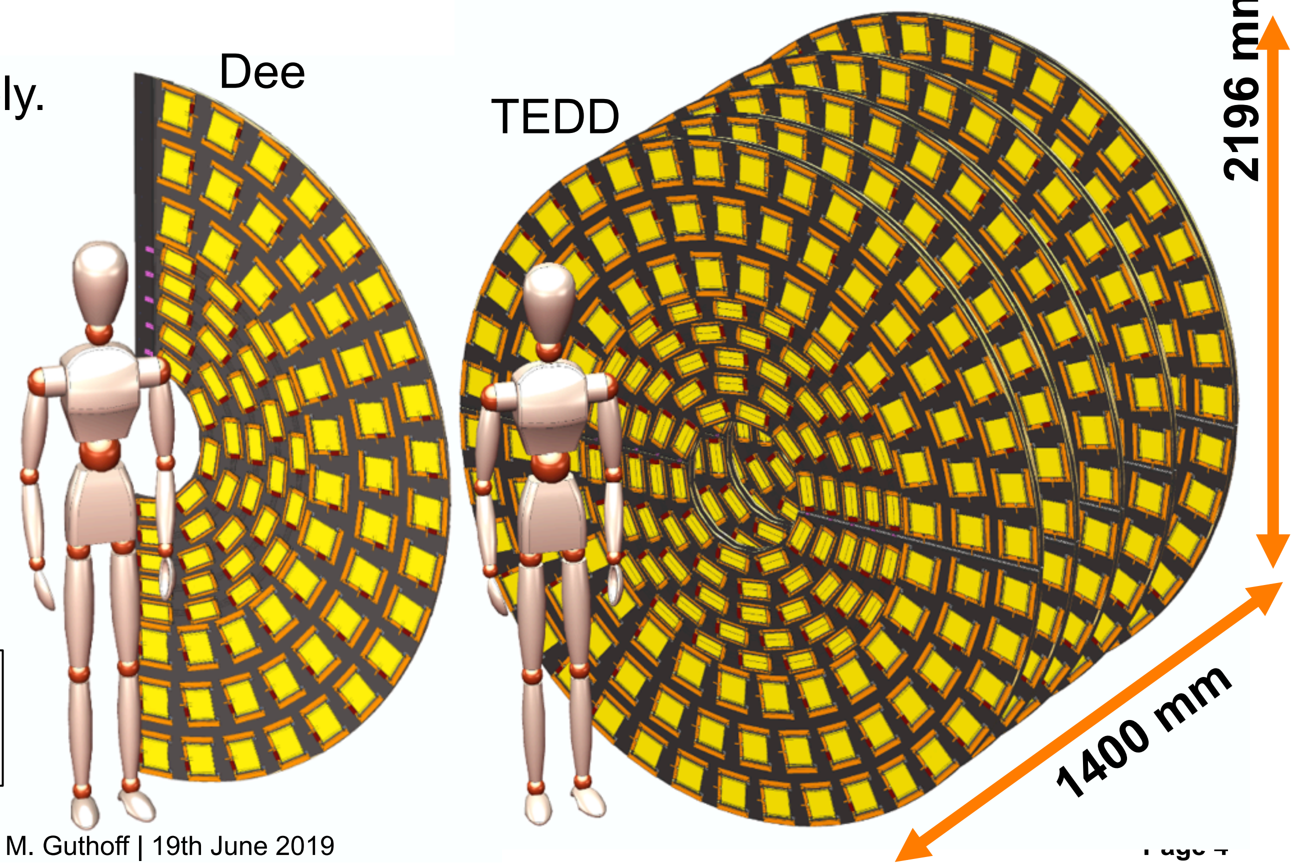
TEDD Elements

- The **Dee** is the main element of the TEDD mechanics
  - A half disk of highly integrated CFRP sandwich with embedded inserts, cooling elements and pipes
- Exploiting symmetries: Minimizing number of different types of parts.
- A step on the straight edges for Dee to Dee assembly.
- 6 cooling sectors per Dee (wedge shaped)

• Two Dees	➠	Disk
• Two Disks	➠	Double Disk
• Five Double-Disks	➠	TEDD

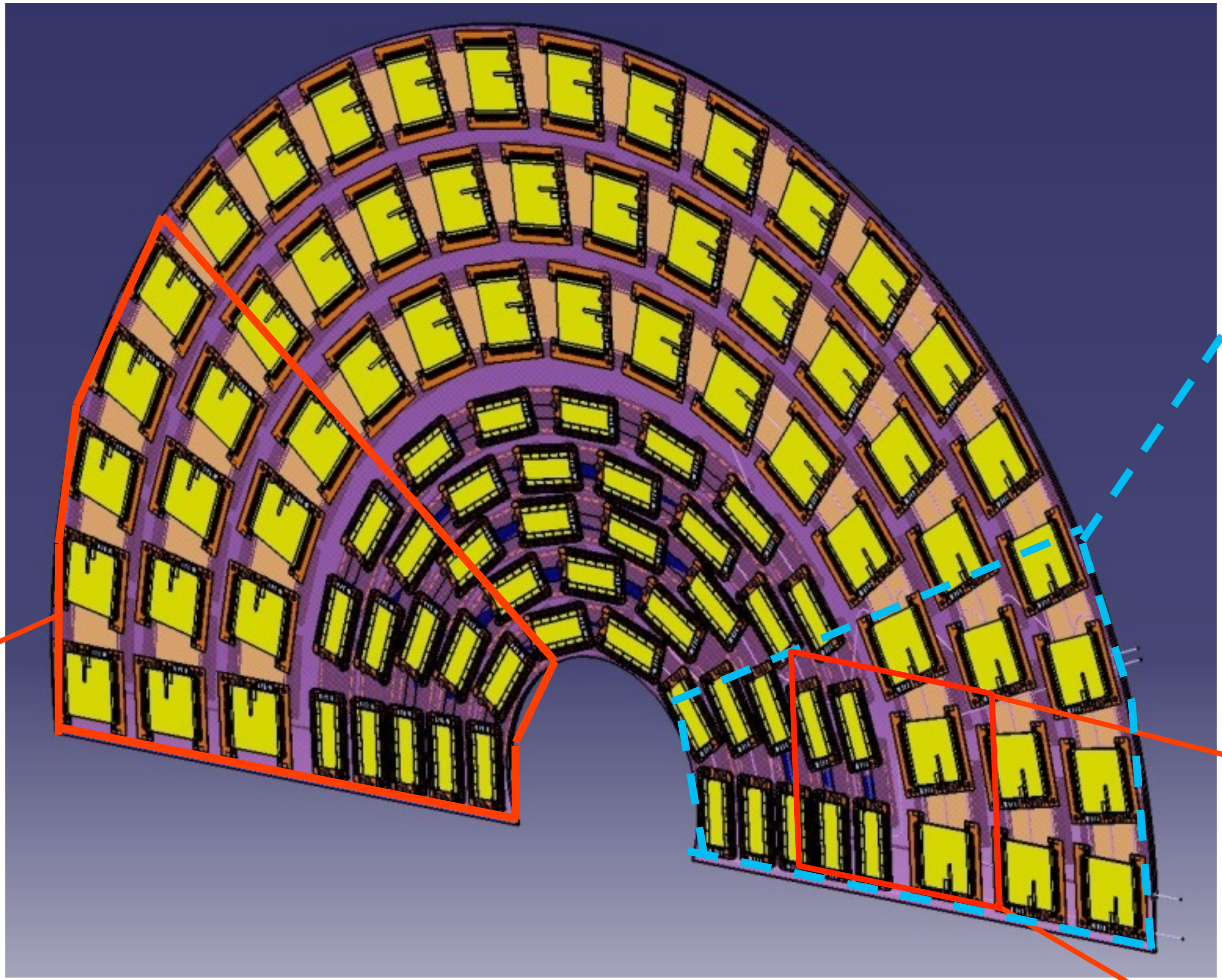


Edge steps to combine Dees (on opposite sides due to symmetry)



Dee prototyping

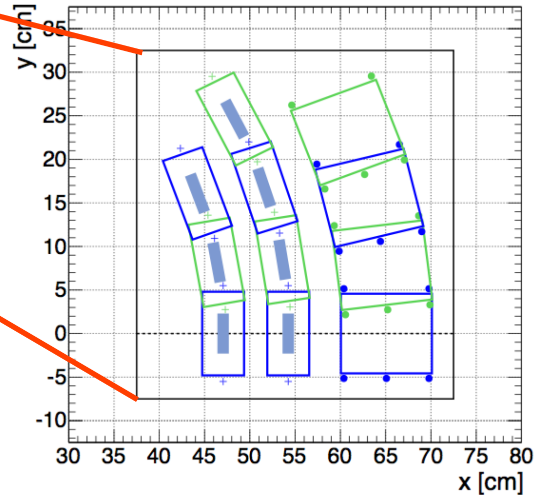
Dee Prototyping



DESY Prototype
one entire cooling sector
currently being build

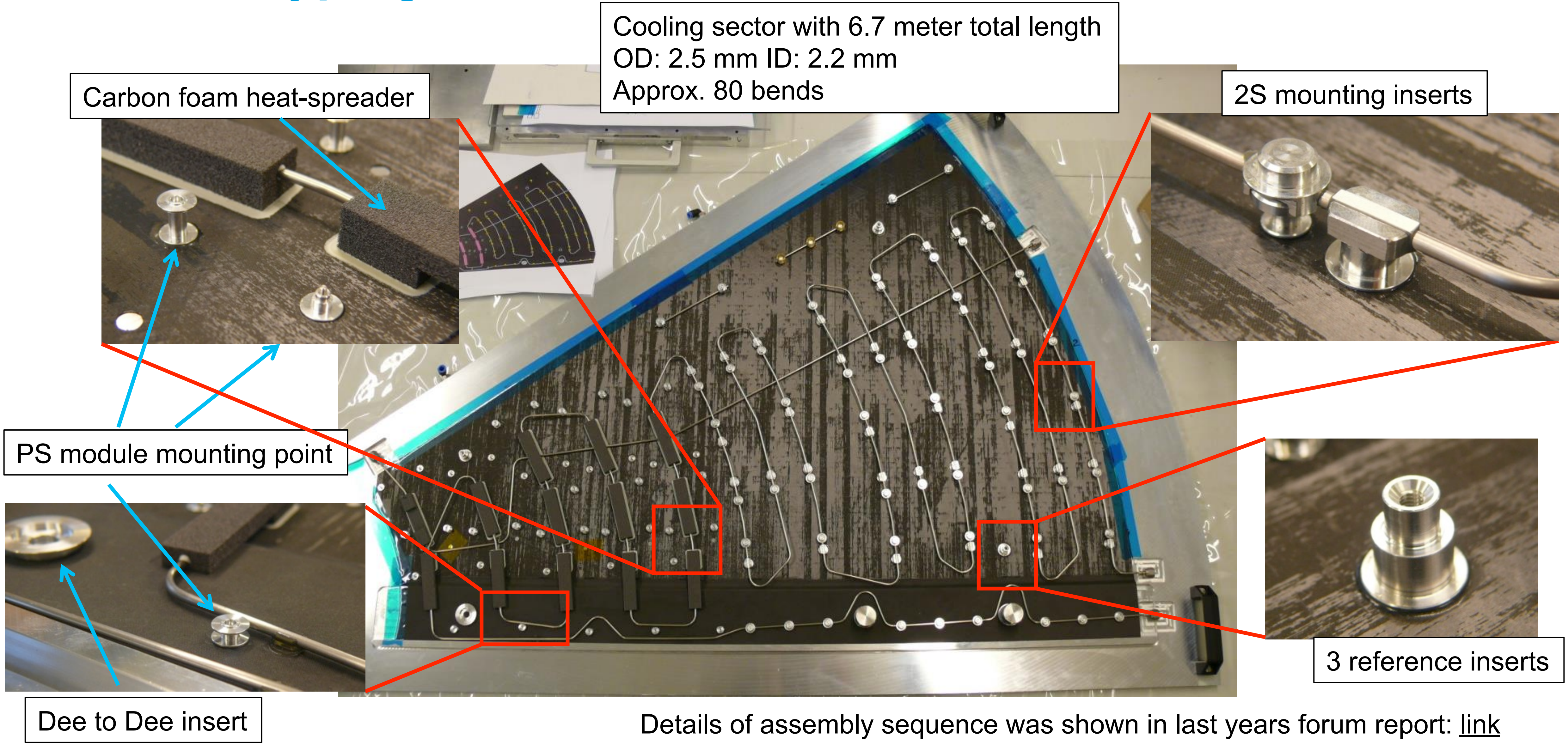
Lyon Prototype
two cooling sectors

DESY Prototype
35 x 40 cm



- Taking place in two institutes: IPNL (Lyon) and DESY (Hamburg)
- Both institutes are planning to build a full size prototype this year.
  - Currently assembly procedure developed in parallel, but will converge for final production.

Dee Prototyping at DESY



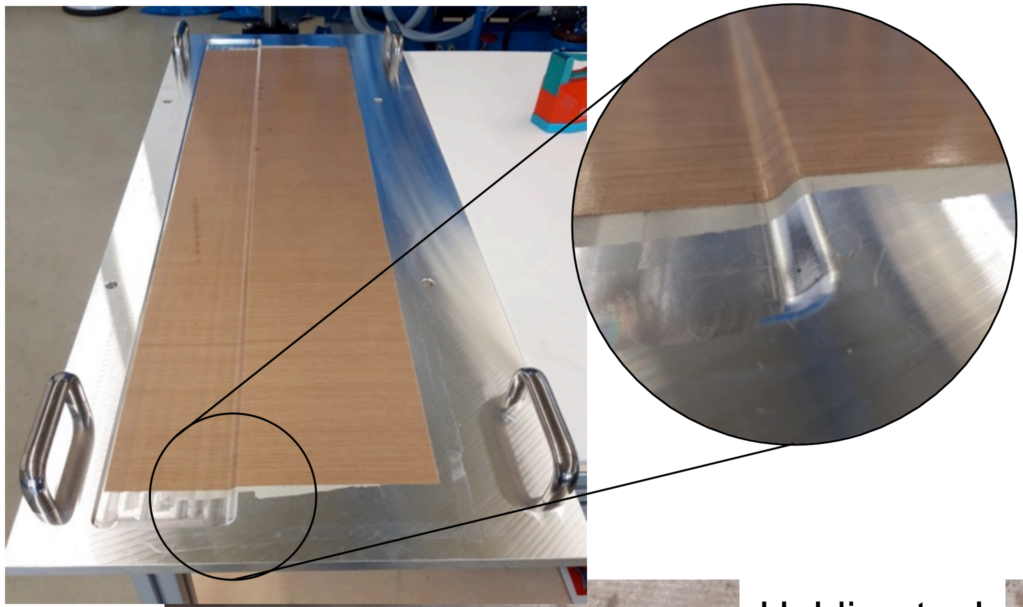
Details of assembly sequence was shown in last years forum report: link

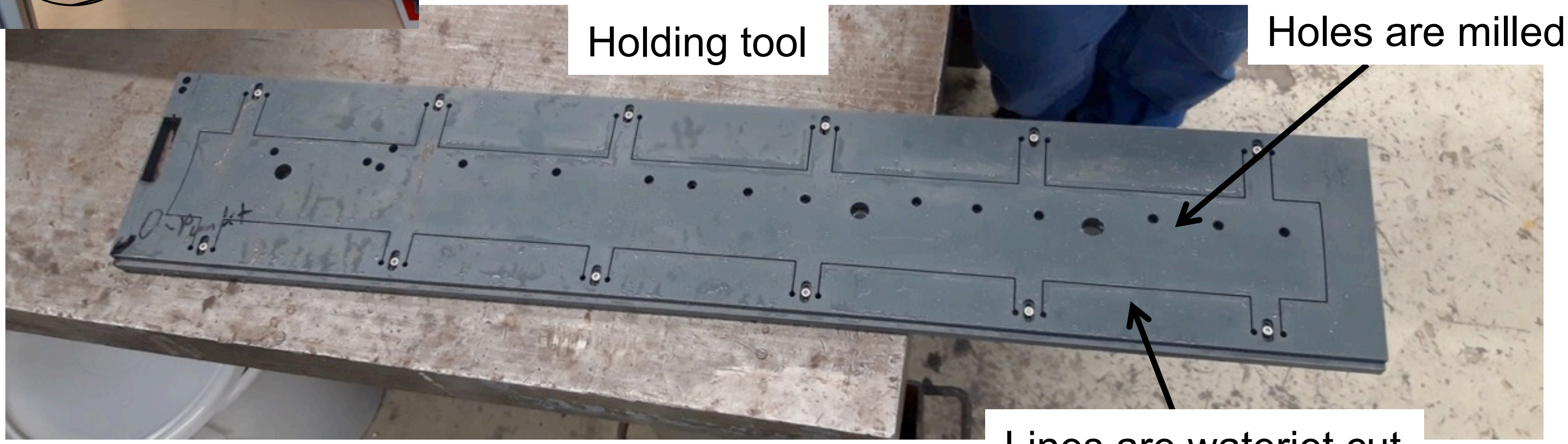
Prototyping at DESY

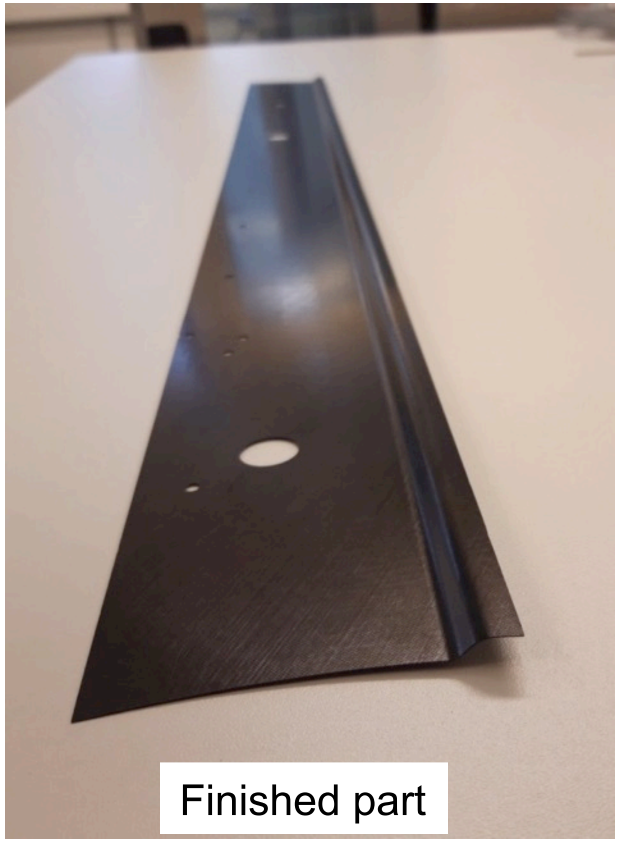
Production of CFRP face sheet with step

Production steps:

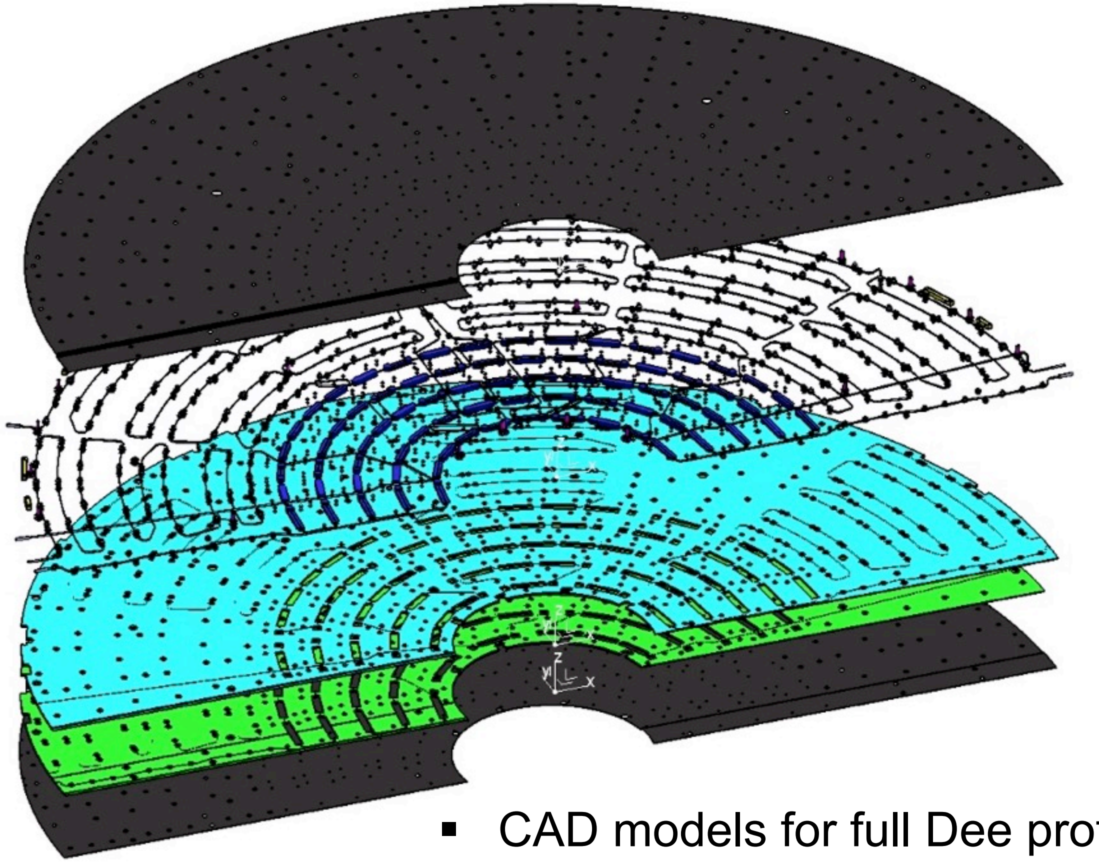
- Carbon fiber: NGF YS-95A (epoxy resin, UD prepreg)
- Layup: [60/-60/0]s
- Cured at 120°C, 4h, 3bar in vacuum bag
- Sandwiched between plastic plates for machining:
  - Holes milled by CNC machine
  - Edges cut by water jet
- Ears cut off by hand







Lyon Full Dee Prototype



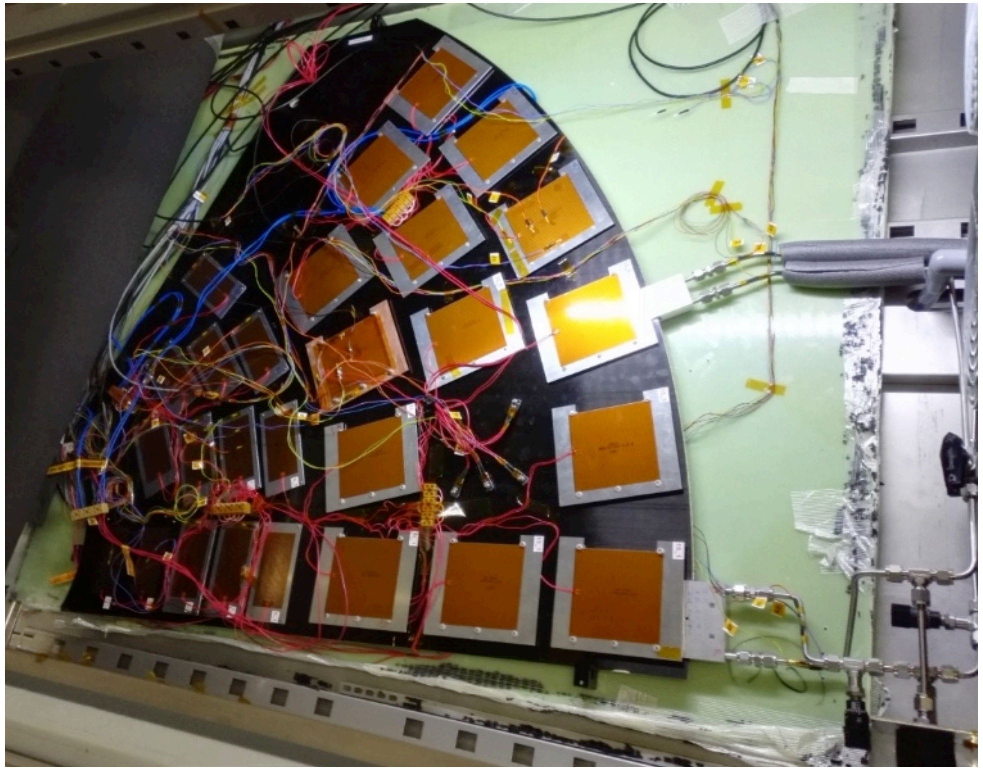
Nick Lumb
Thierry Duspasquier
IPNL

Gluing jig for pipes, inserts and carbon foam

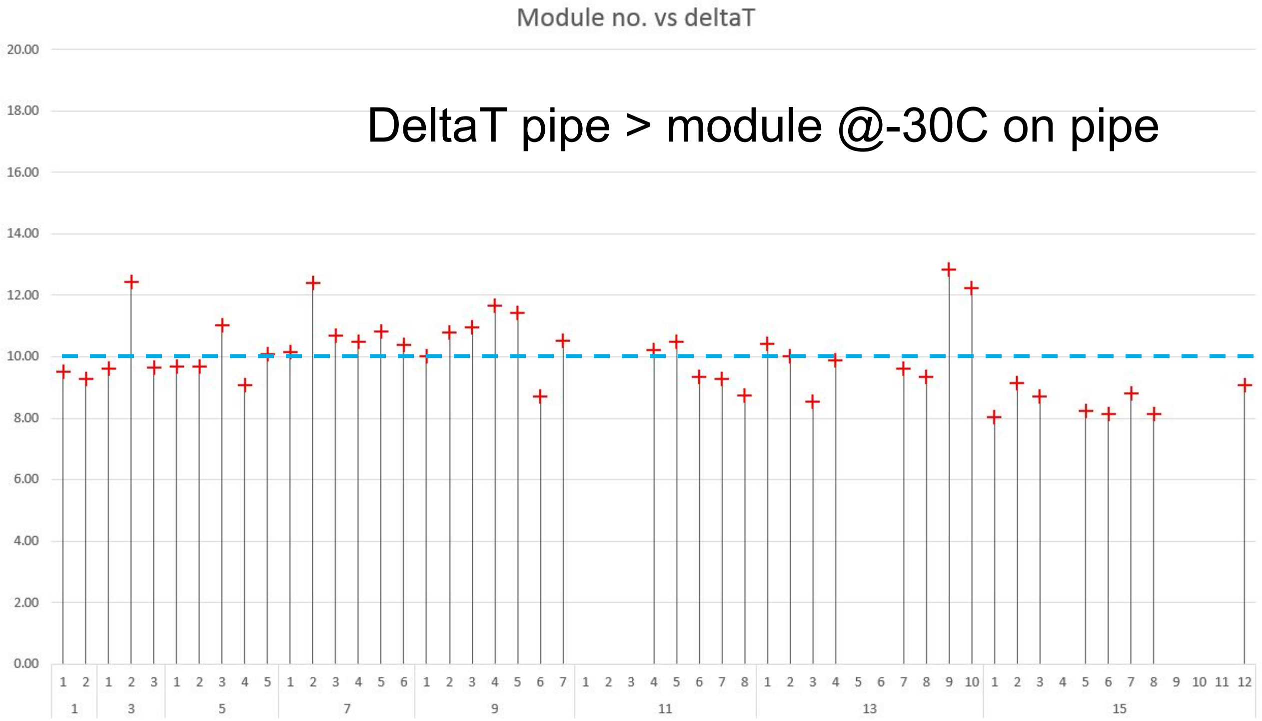
- CAD models for full Dee prototype finalized
- All parts are available or ordered
- Gluing will start as soon as we receive the jigs
- Production together with industry partners
- Aim to have prototype completed by ~September, tested by year end.

Dee production quality control

Thermal Testing at Lyon



Nick Lumb, IPNL



PS modules 2S modules

Fridge installation:

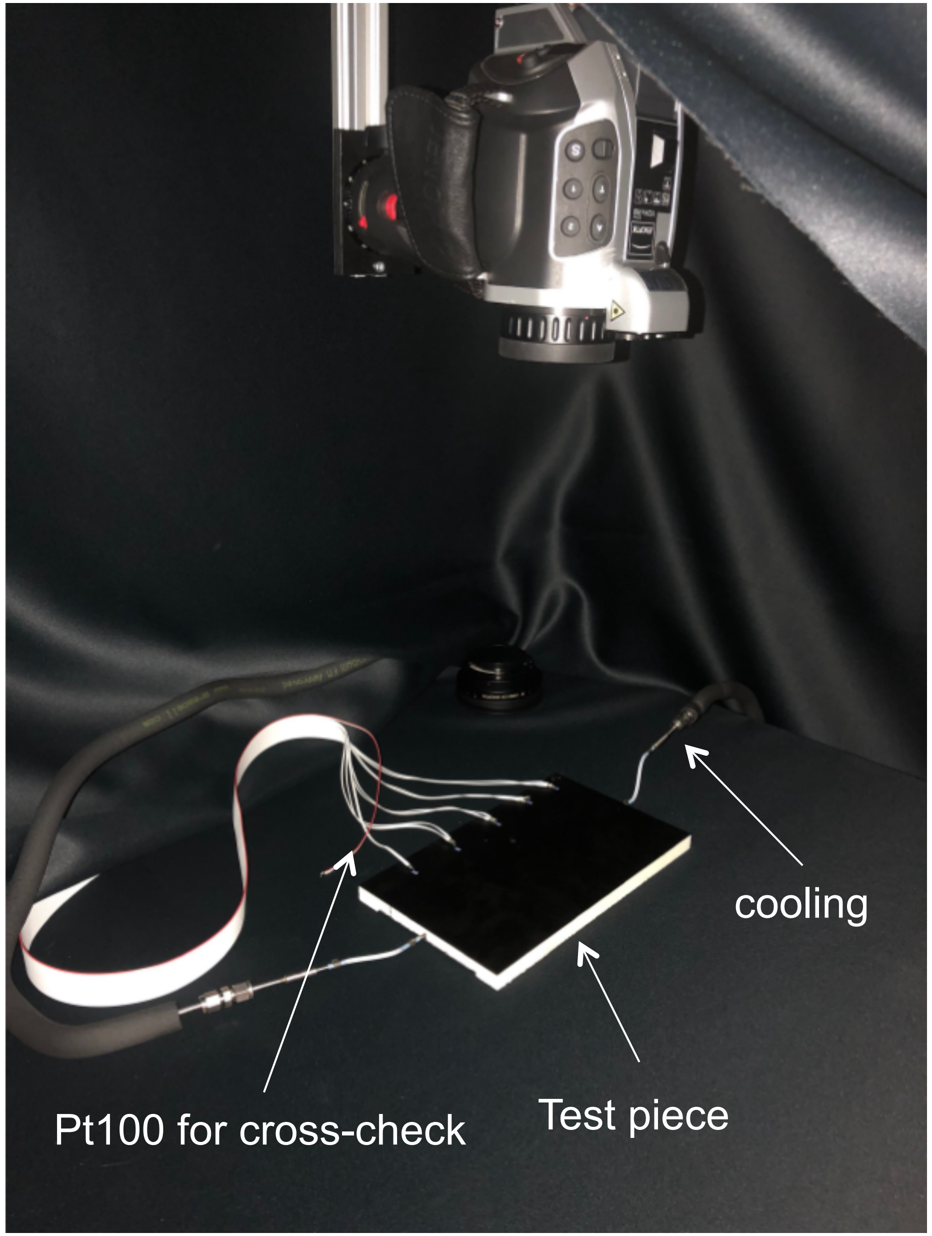
- Aluminium PS and 2S dummy modules
- Equipped with heating foils and pt100 sensors

Reliable measurement but time consuming in final production

Infrared Imaging at DESY

Setup and Test piece

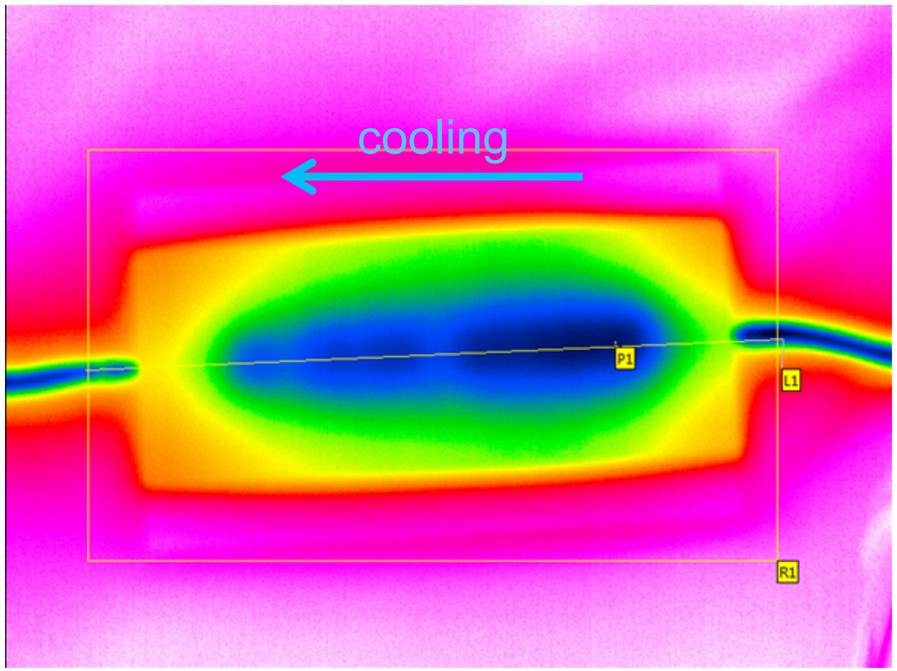
- Camera: InfraTec VarioCAM HD research 900
  - Up to 2,048 x 1,536 IR pixels
  - Standard lense (30 mm focal distance).
- Black fabric cover to minimize reflections and external IR ray
- External cooling supply (coolant: Novec™ 7100, in final setup: CO_2)
- Measurement of temperature on surface while cooling.
  - Heating for thermal gradient by ambient air.
  - Warm spots indicate bad thermal contact.
- Test piece with defective gluing is used to study sensitivity with this method.

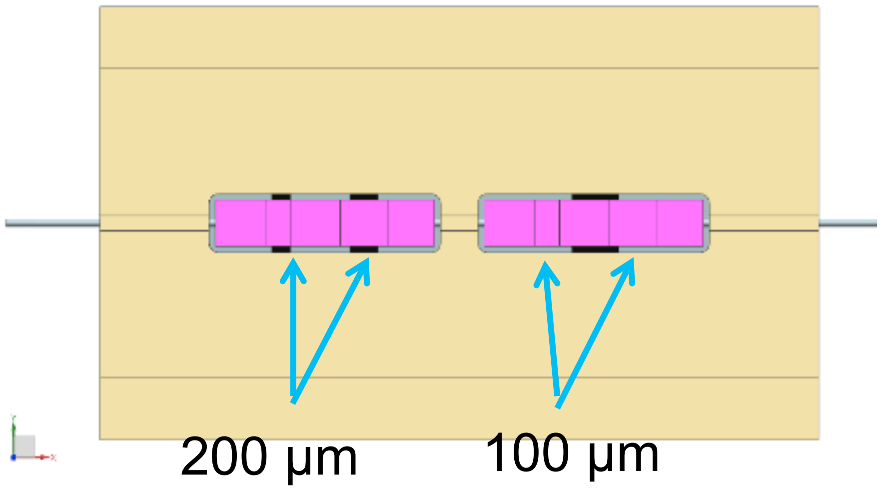


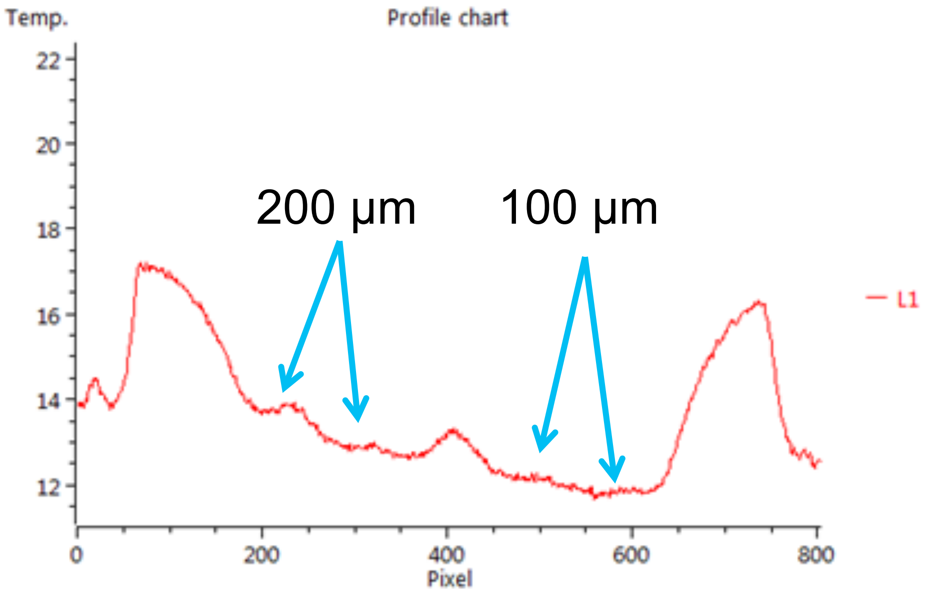
Infrared Imaging

Results

- Test piece with two PS module carbon foam cooling blocks.
- Grooves in carbon foam (100 µm & 200 µm)
- 200 µm step easily visible.
- Method not sensitive for 100 µm step.



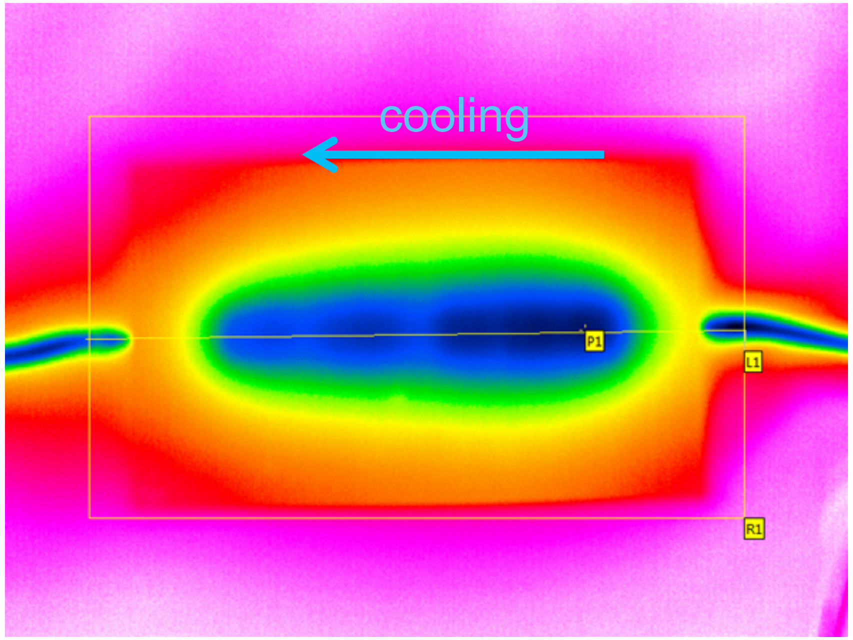


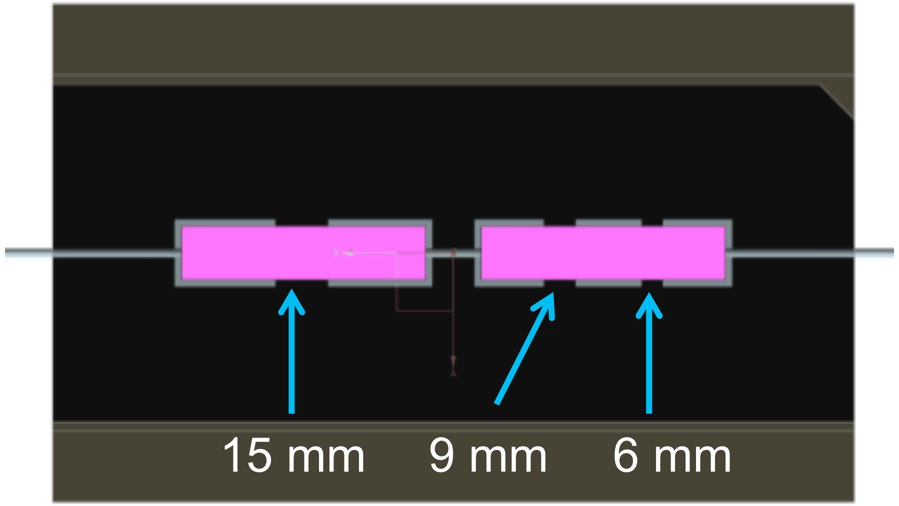


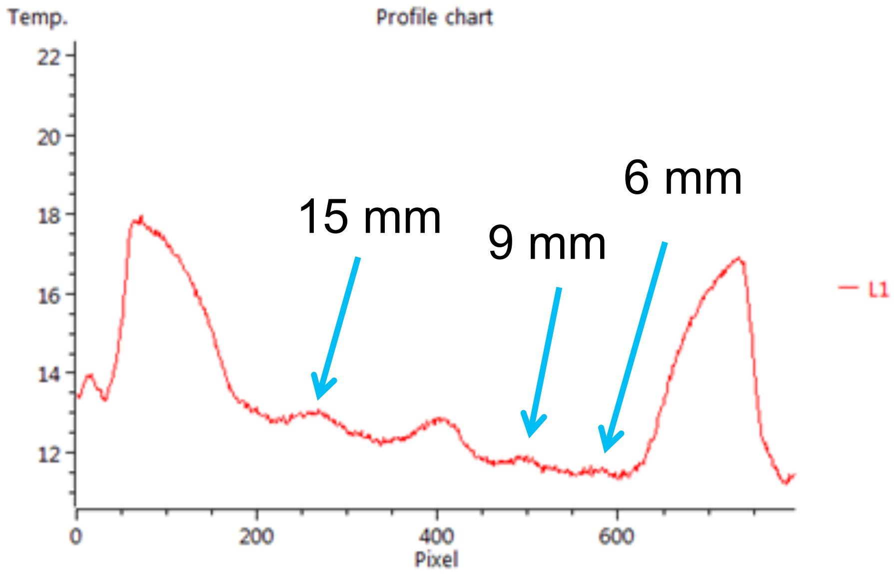
Infrared Imaging

Results

- Flat carbon foam piece, but areas without adhesive.
- 15 mm adhesive gap easily visible
- Method not sensitive enough for gaps smaller than 9 mm.



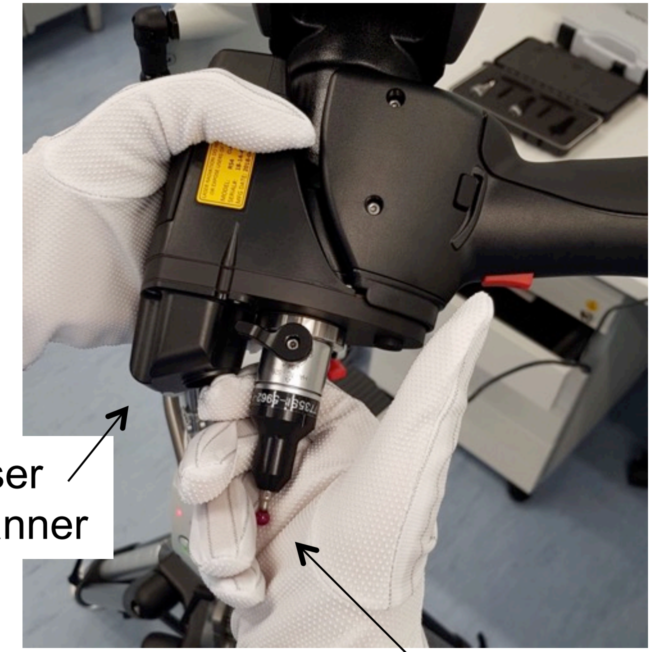


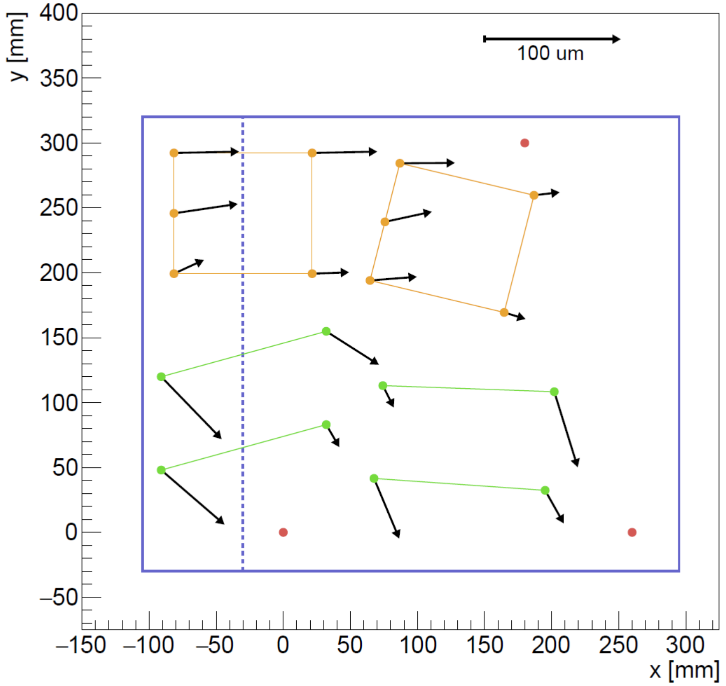


Metrology

Setup and Results

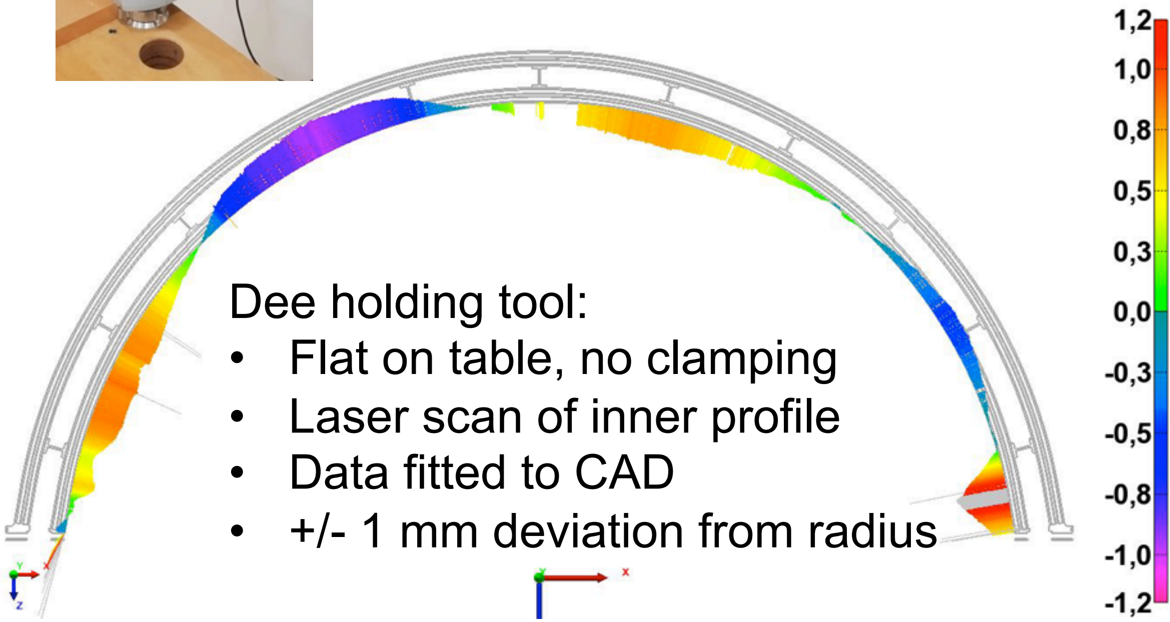
- All mechanical TEDD components should be checked with metrology.
- **Tactile probing:** e.g. Dee insert positions.
- **Laser scanner:** e.g. envelope of mechanical components





40 x 35 cm Prototype:

- Measurement of module mounting inserts
- Comparison with CAD model
- Deviations are within specifications



Dee holding tool:

- Flat on table, no clamping
- Laser scan of inner profile
- Data fitted to CAD
- +/- 1 mm deviation from radius

Cooling pipe

Pressure Test and Ovalisation

- Pipe raw material in rings
- Stainless steel 1.4301
- Bending done in industry

Vacuum braising of end sleeve, to be done at CERN and DESY.

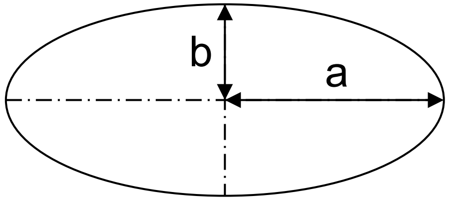
Pressure Test:

- 160 bar required
- Test up to 400 bar.
- Theoretical damage at approx: 700 bar

Pattern plate for QA of bending

Ovalisation from beding:

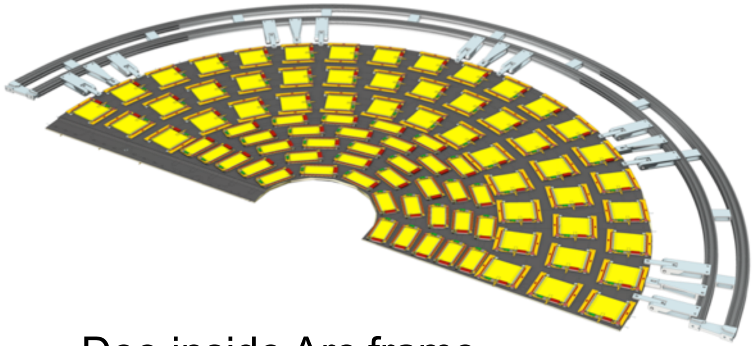
Area 93.5% of ideal shape measured at highest bending angle



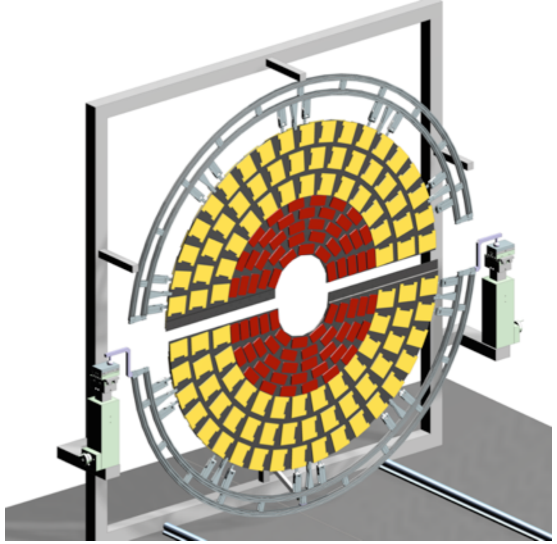
Module integration and TEDD assembly

TEDD Assembly Concept

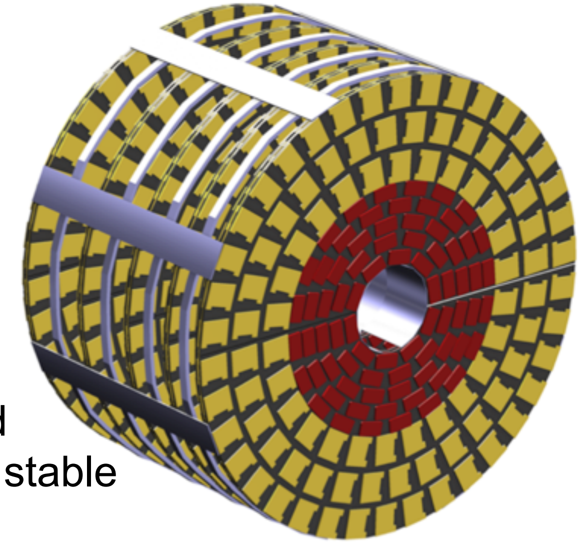
- Challenge: Endcap reaches mechanical stability only when all parts are connected.
  - Individual Dees are fragile and need mechanical support.
  - Arc frame will be used to support Dee during **all integration steps** and **transport between institutes**.
- Dedicated assembly stations for:
  - Double disk assembly
  - TEDD assembly



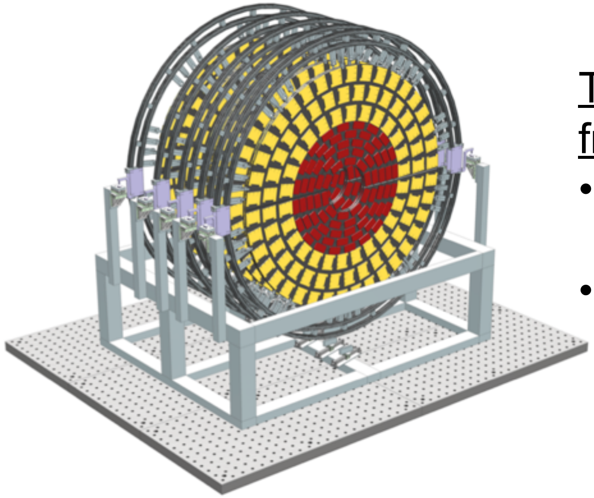
Dee inside Arc frame
- Installation of modules
- Thermal treatment
- Cold test
- Transport



Disk and double disk assembly
- Relative alignment of Dees
- Installation of patch panels and cooling manifold



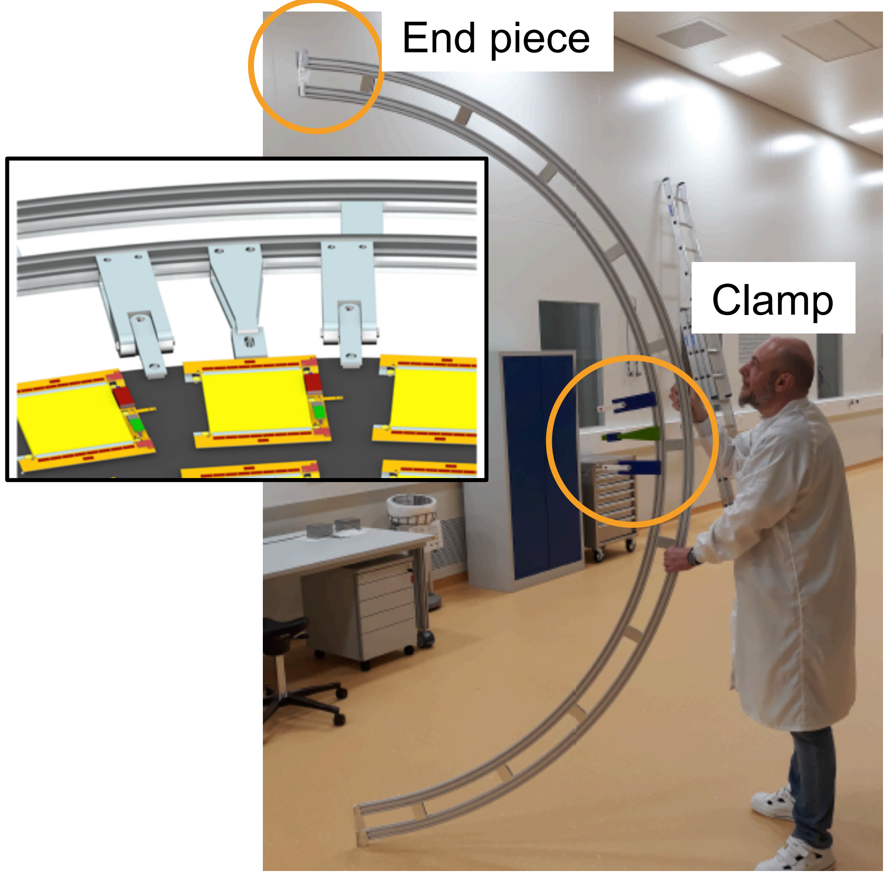
Final detector
- Outer Skeleton installed
- Only now mechanically stable

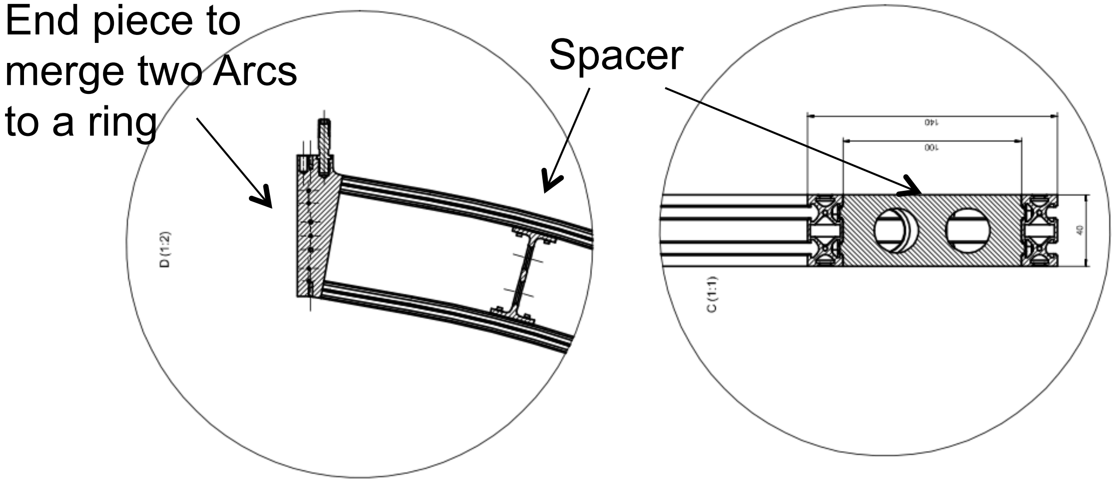


TEDD assembly frame
- Alignment of double disks
- Installation of support skeleton and services

Arc frame (Dee support)

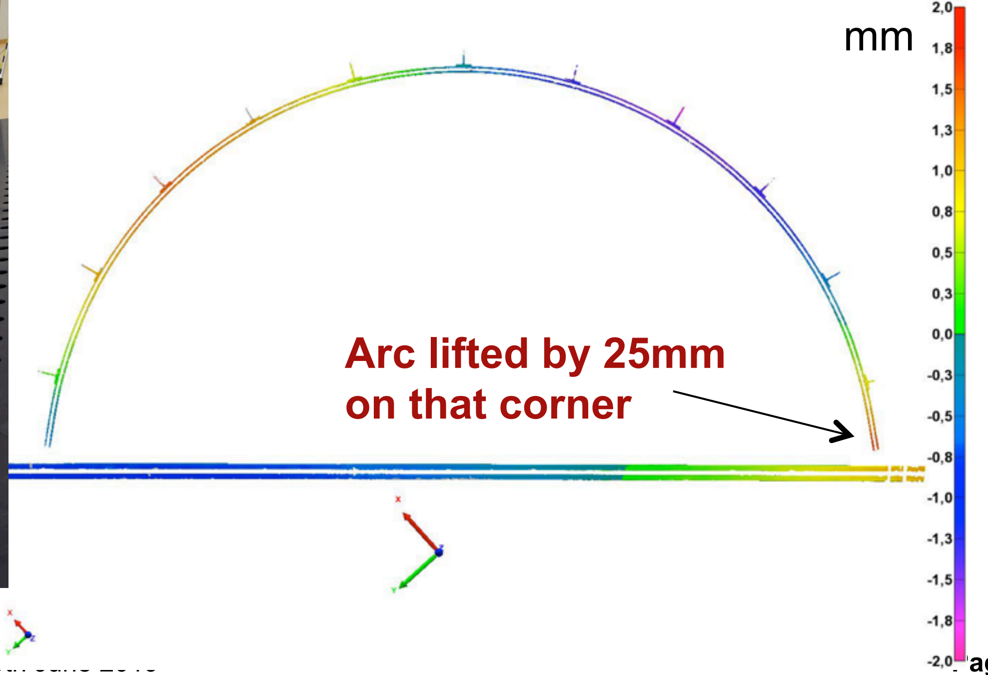
- Requirements:
  - Support of Dee, minimal deformation of Dee in all operations.
  - Combines to form a ring without stress on disk.
    - End pieces need to be aligned precisely wrt Dee.
  - Connects to all production stations like module mounting, disk assembly, storage etc.
  - Holds temporary patch panels.
- Prototype build from bent Aluminium profiles.
  - Two profiles linked with spacers for radial stiffness.
  - Current baseline design 40mm wide. (Initial 20mm prototype was too floppy.)
  - Connection piece between both ends with support of Arc in the center.





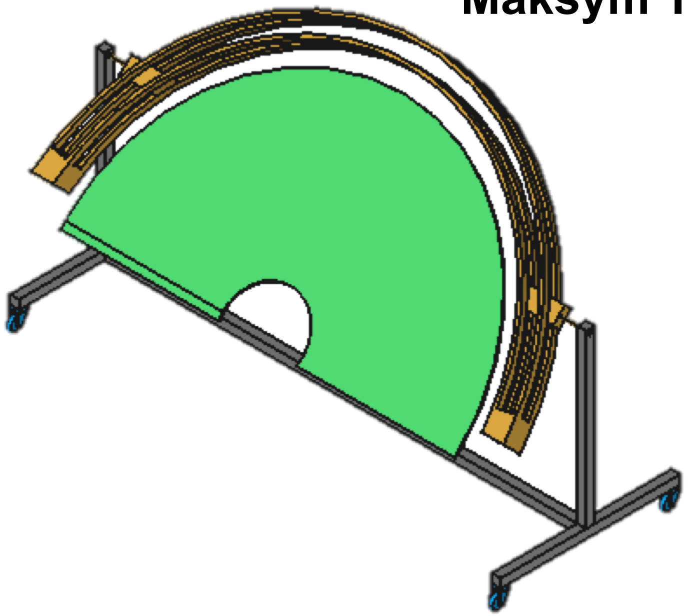
Arc frame stability

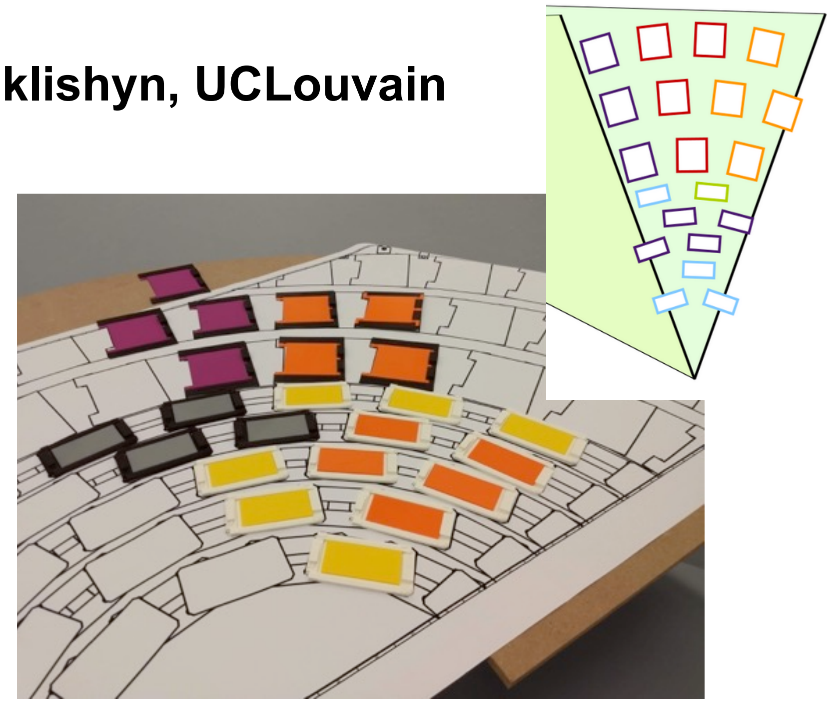
- Test of stiffness:
  - Lift Arc on one end (by 25mm) to simulate worst case scenario
  - Laser scan of Arc placed flat and lifted.
  - Difference shows deformation due to sagging.
- Arc suffers 7-8 mm deformation.
- Addition of bar connecting both ends -> Sagging reduces to about 3 mm.
- Further optimization of Arc frame geometry ongoing to optimize: Stiffness, precisions and weight.

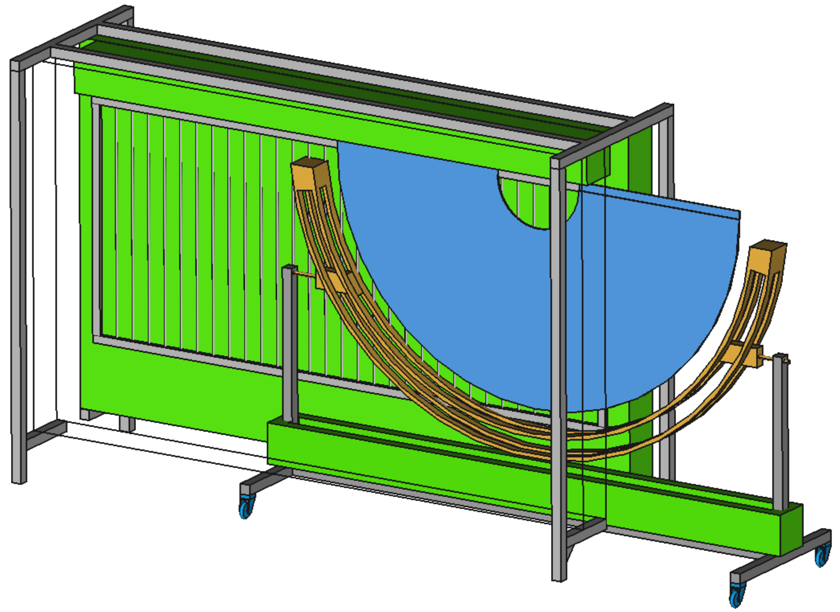


Module integration, hot/cold oven, transport

Maksym Teklishyn, UCLouvain







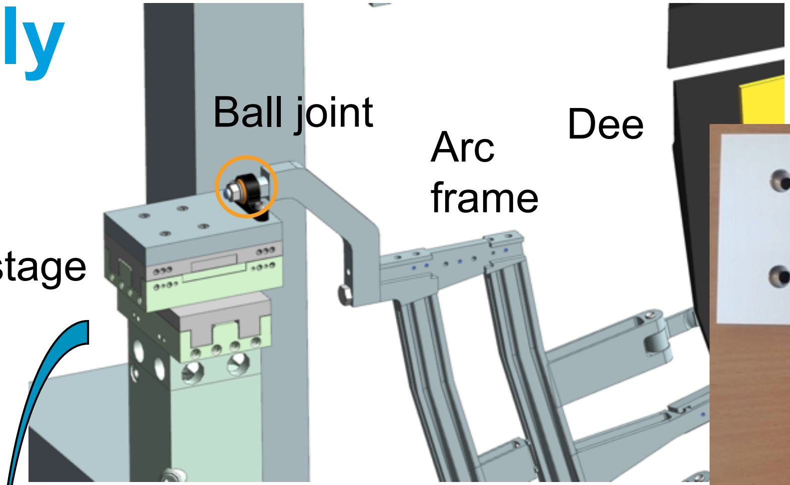
Module installation station
- Facilitates comfortable access to all module locations.
- Rotation mechanism allows vertical, horizontal and tilted installation

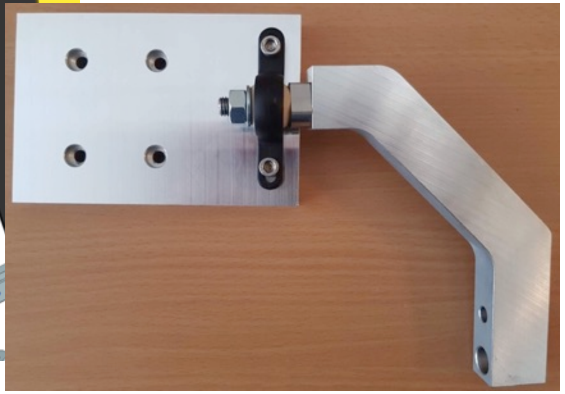
Mockup installation
- Test of installing dummy modules on wooden mockup.
- Plan to assemble one 30°-sector with modules, cables and patch panels.
- Particularly cabling of PS modules will be tricky due to uneven pattern.

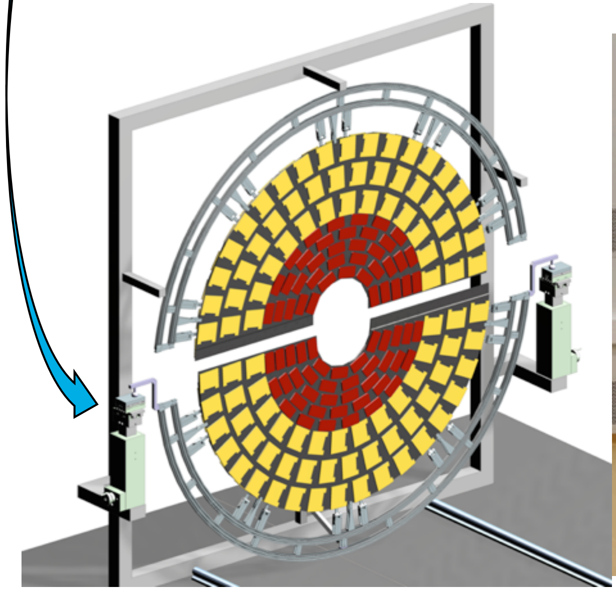
Phase change and cold test box:
- Can take one Dee (incl. Arc)
- Heat up for phase change thermal interface material.
- Cooling, electrical and optical connections routed to outside.
- Cool down for test of thermal connection module to support structure.

Disk and double disk assembly

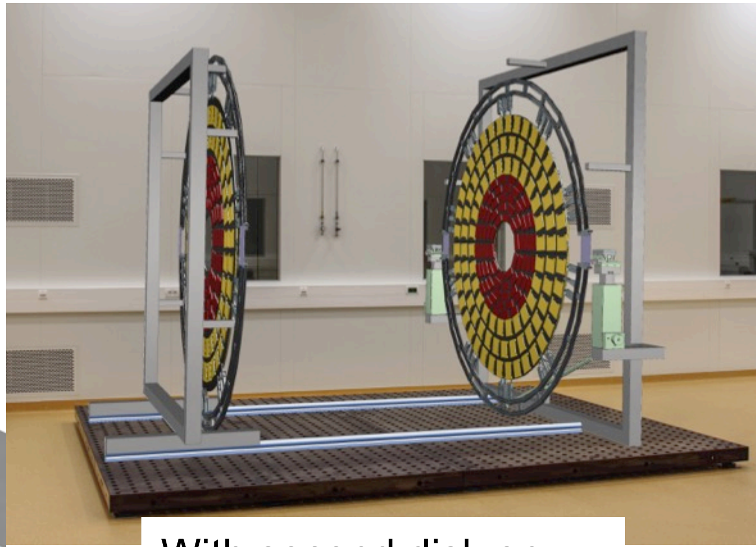
- Dee to Dee alignment
  - Upper Dee is fixed to frame
  - Lower Dee rests on linear X/Y/Z stages
  - Match 6 dimensional position based on metrology measurement
- Arc frames are combined to form support ring.
- Disk to disk alignment.
  - Assembled disk is picked up by service frame
  - Assembly of second disk, stays on stages
  - Installation of spacers
  - Relative alignment of both disks.
- Disks and Arc frames are combined
- Installation of patch panels, cooling manifold.
- Full checkout (verify connections)







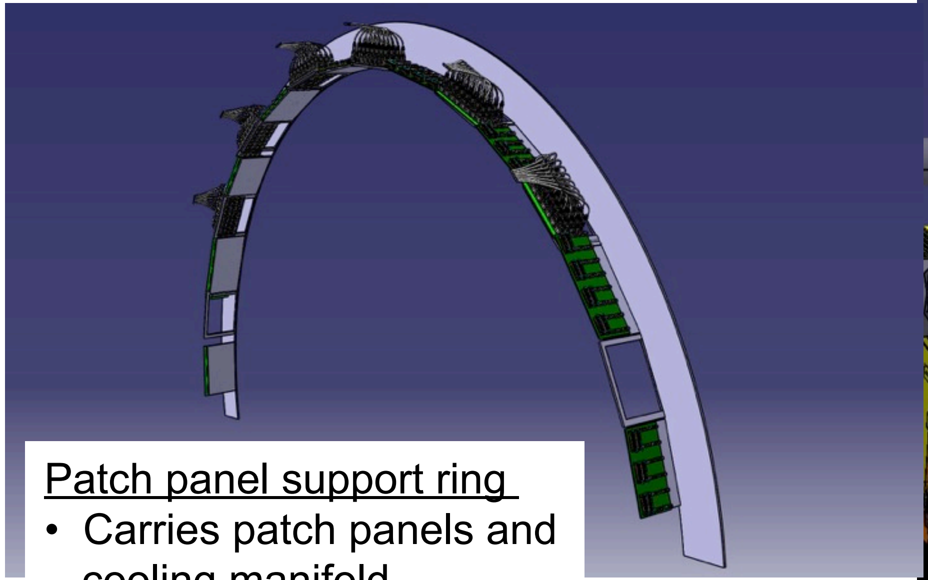
Disk assembly frame



With second disk on service frame.

Details on mechanical and service design

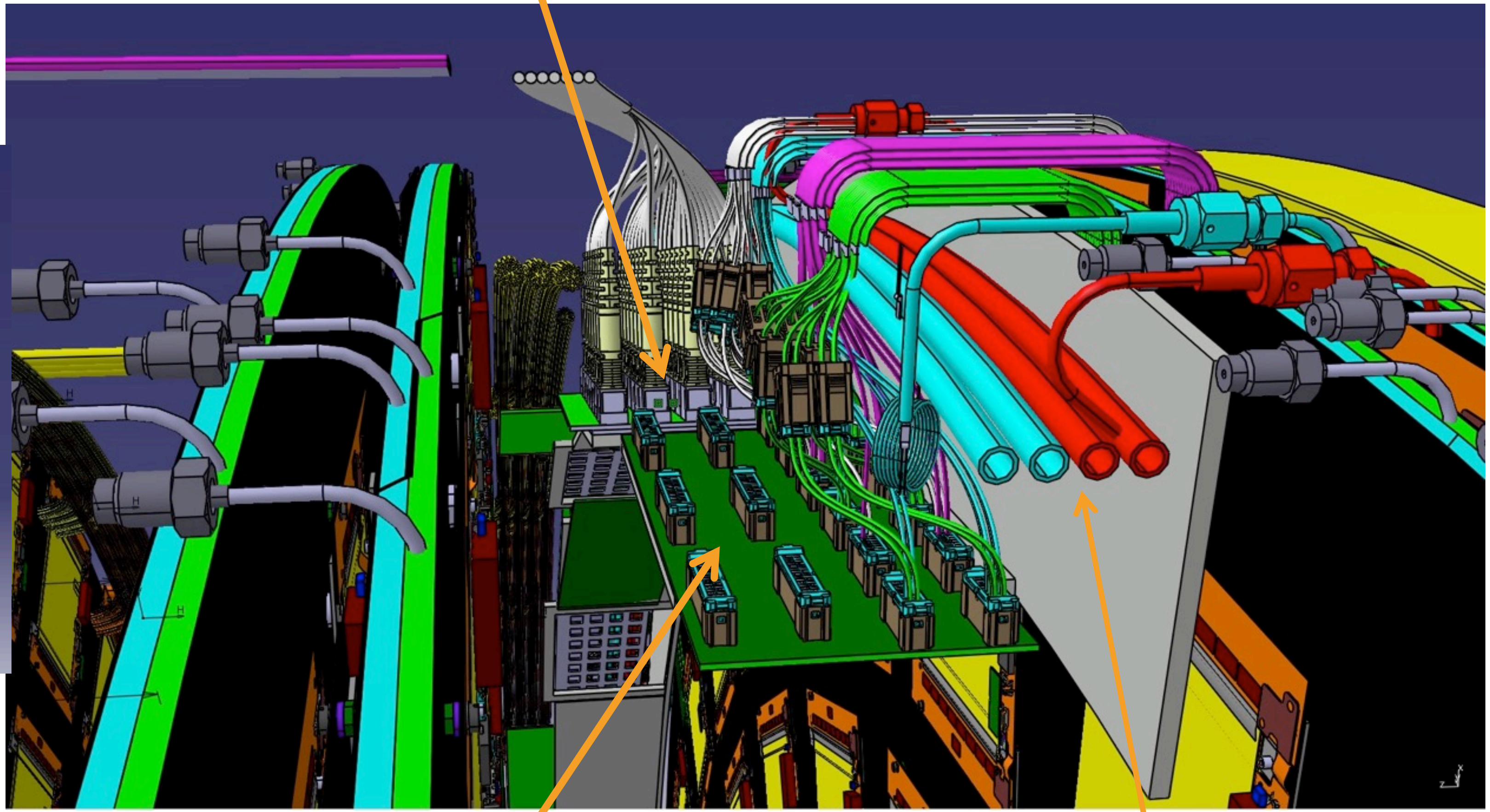
Service design ongoing at UCLouvain, pictures by Nicolas Szilasi



Patch panel support ring

- Carries patch panels and cooling manifold
- Important also for mechanical stability and Dee to Dee connection.

Optical patch panel



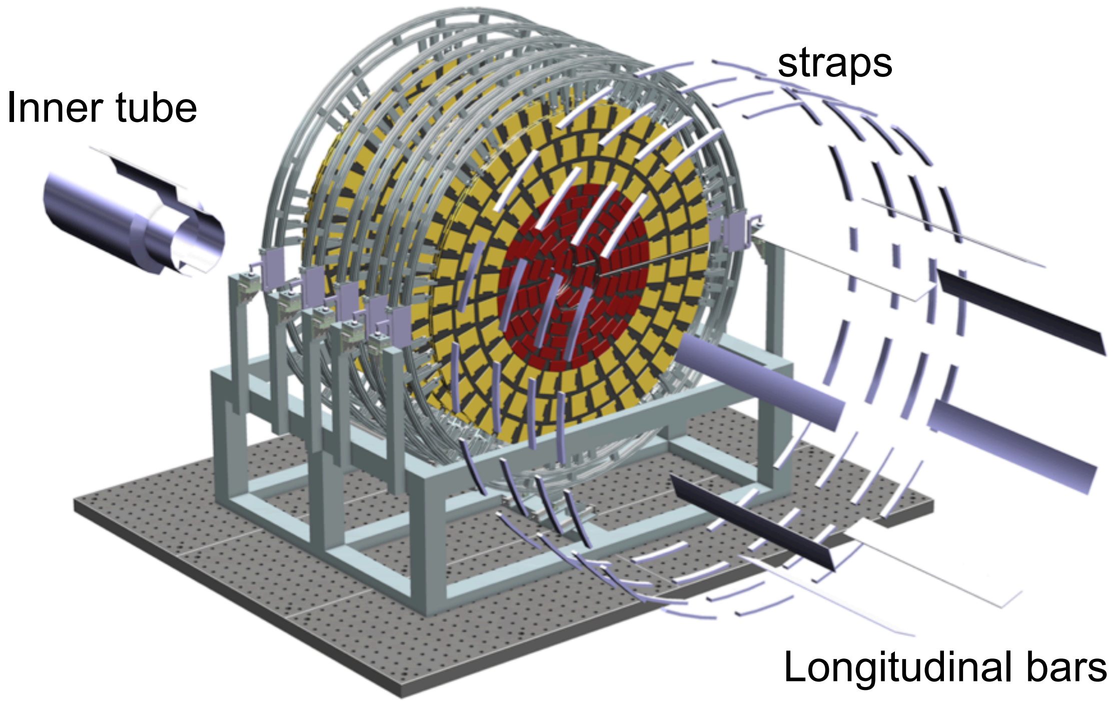
Electrical patch panel

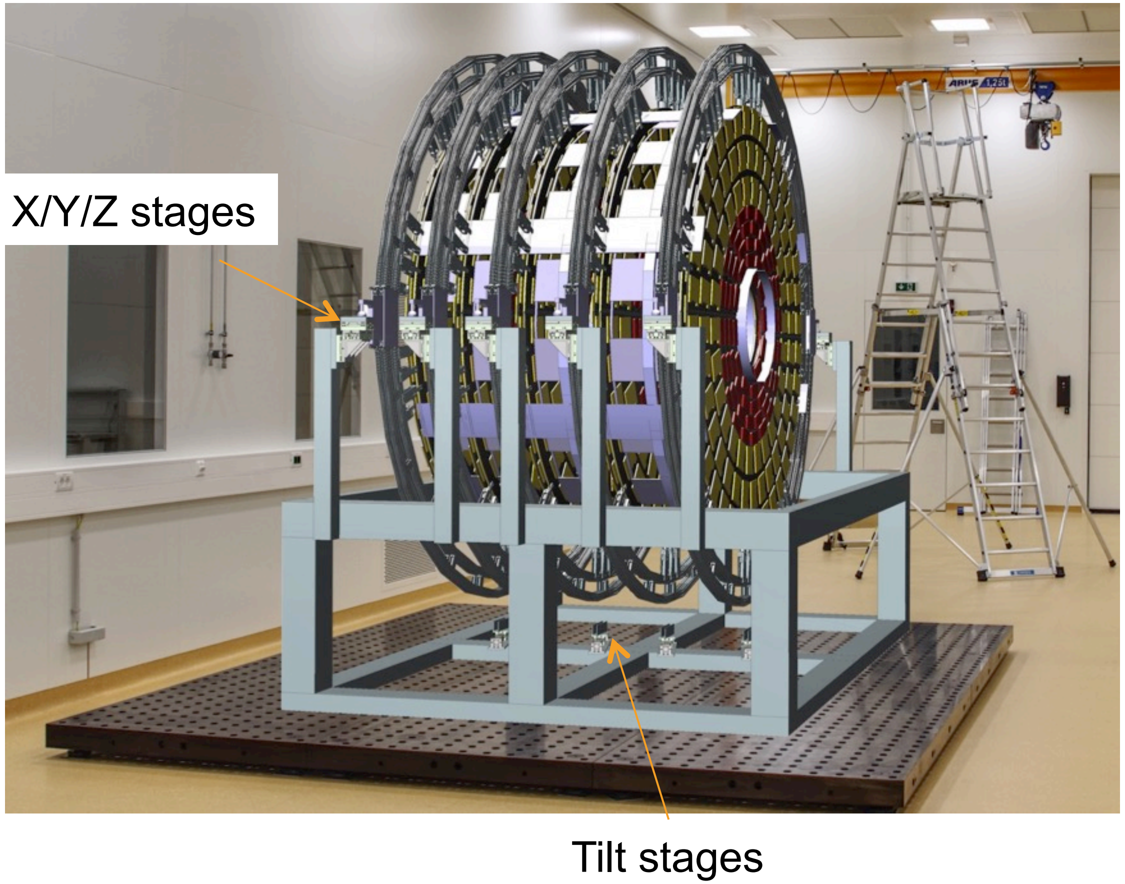
Cooling manifold

TEDD assembly I

- Alignment of all double-disks. (Each resting on linear stages)
- Installation of inner tube and longitudinal bars (no straps yet)
  - Must not introduce stress/movement

➢ TEDD has reached intrinsic stability

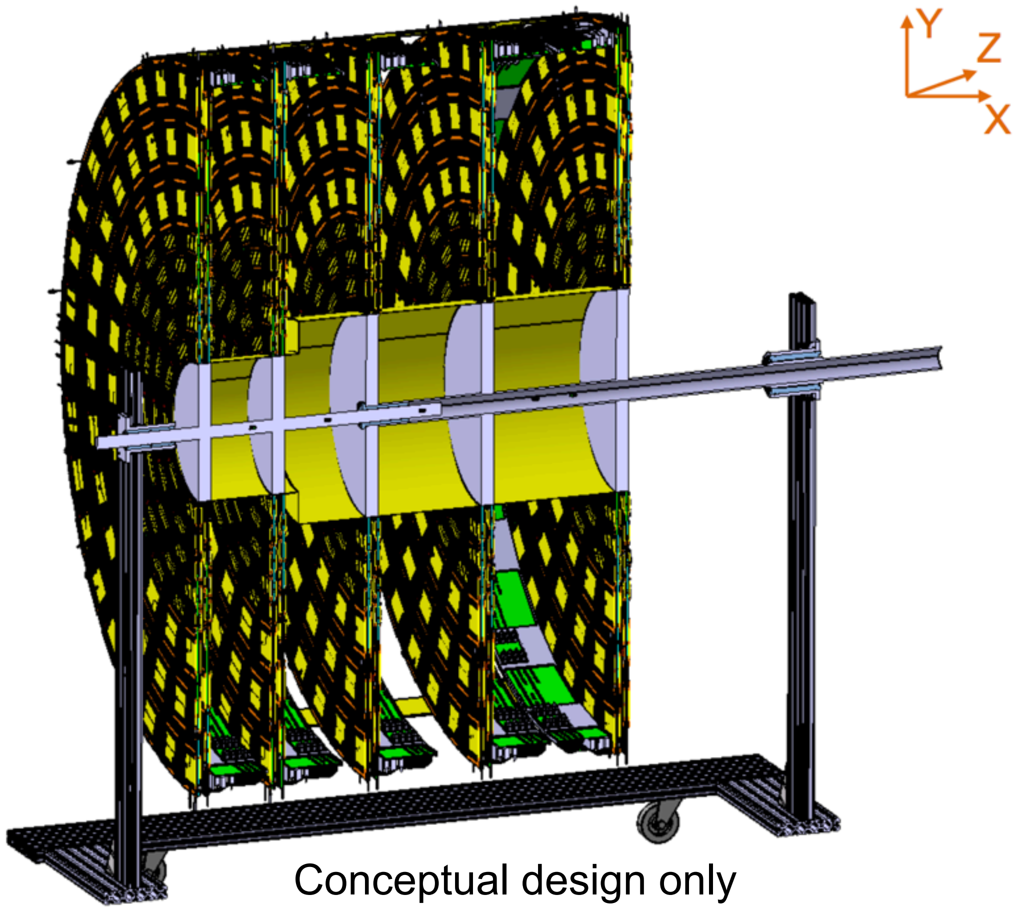




TEDD assembly II

- Install **rotation mechanism**: insert “plug” in inner tube.
  - Each disk is individually supported
- Load transfer to rotation mechanism
  - Remove upper Arcs (TEDD rests in lower Arcs)
  - Lift rotation mechanism until it carries weight.
  - Remove lower Arcs.
- Install services and straps.
  - Needs rotation of TEDD to reach all sides.
  - Order of installation to be studied based on services design.
- Assemble transport carriage around TEDD for shipment.

Pierre Dené, IPNL

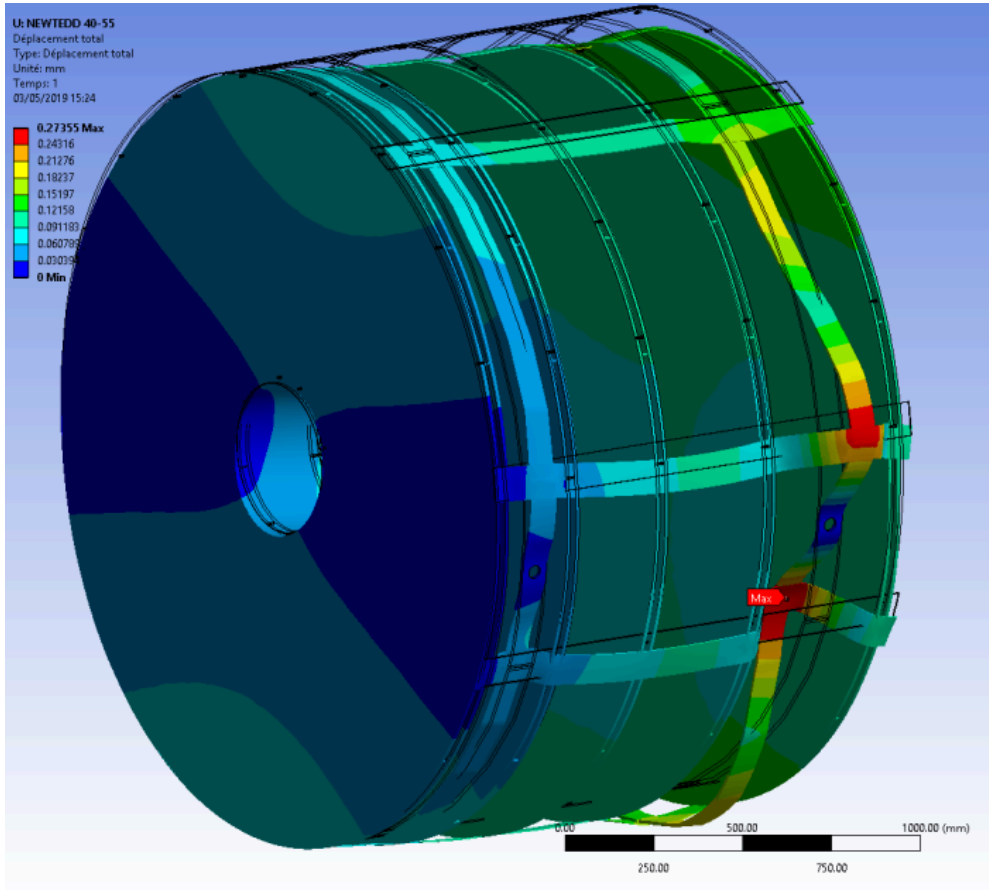


Conceptual design only

TEDD mechanical stability

- FEM simulation to predict deformation of TEDD from its weight.
- Studies to optimize optimize skeleton geometry.
  - Original 12-bar proposal was reduced to 8 bars with optimized position (**30°-55°-40°**)
  - Deformation: max. **280 µm**, module displacement: **140 µm**.
  - Planned to study position of strap rings to optimize access to patch panels.

Emilie Schibler, IPNL



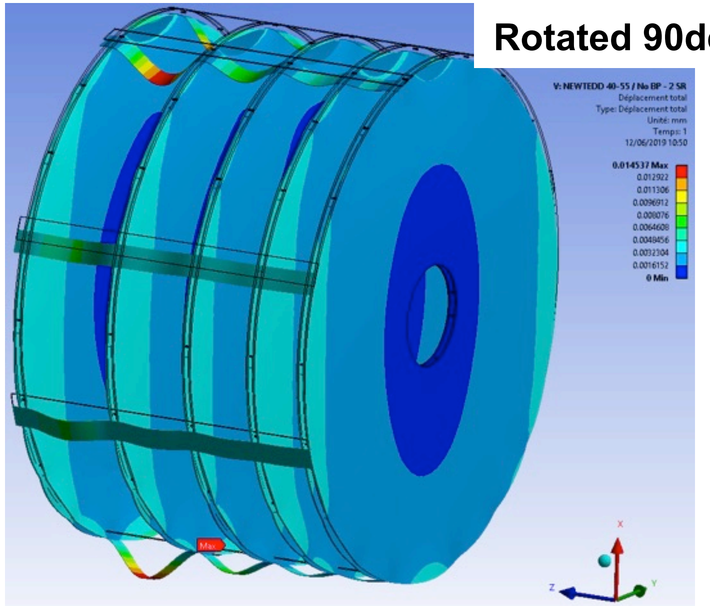
TEDD stability during service installation

Emilie Schibler, IPNL

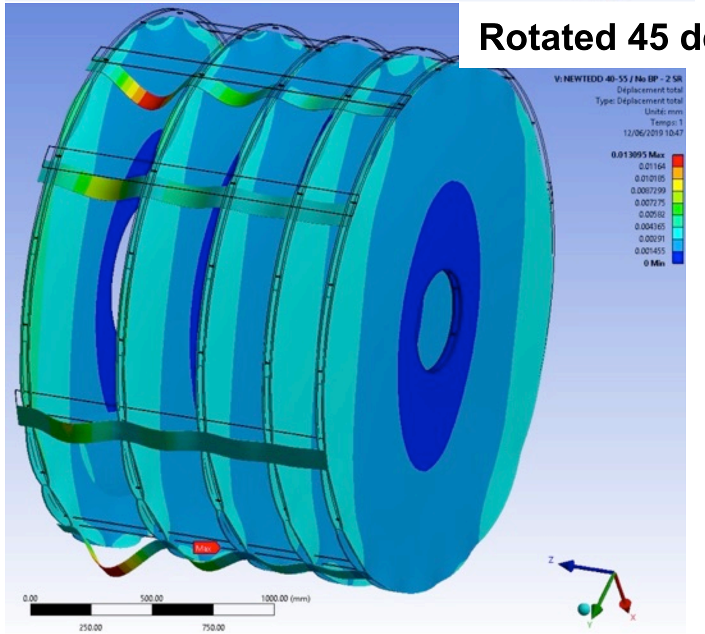
- Simulation stability in the situation when lifting TEDD by the rotation mechanism.
  - Lifted by inner tube, no straps, no services
- Check of different orientations to simulate rotation.
- Maximum displacement < 20 um.
- Lifting TEDD by inner tube creates little stress on disks.
  - Disk deformation when held by normal mounting points mostly due to stress from straps and bars.

➢ **Lifting TEDD by rotation mechanism without straps is possible.**

Rotated 90deg



Rotated 45 deg



Summary

- Final TEDD design well on track, service design ongoing.
- Dee prototyping ongoing to finalize design and improve production process.
  - Full size prototypes available soon.
- Dee QA testing procedures are being established.
- Dee integration tooling design and integration procedure under development.
- Disk and TEDD assembly procedure defined and tooling prototypes under preparation.
- Mechanical stability of final TEDD and during assembly verified.

Thank you

Contact

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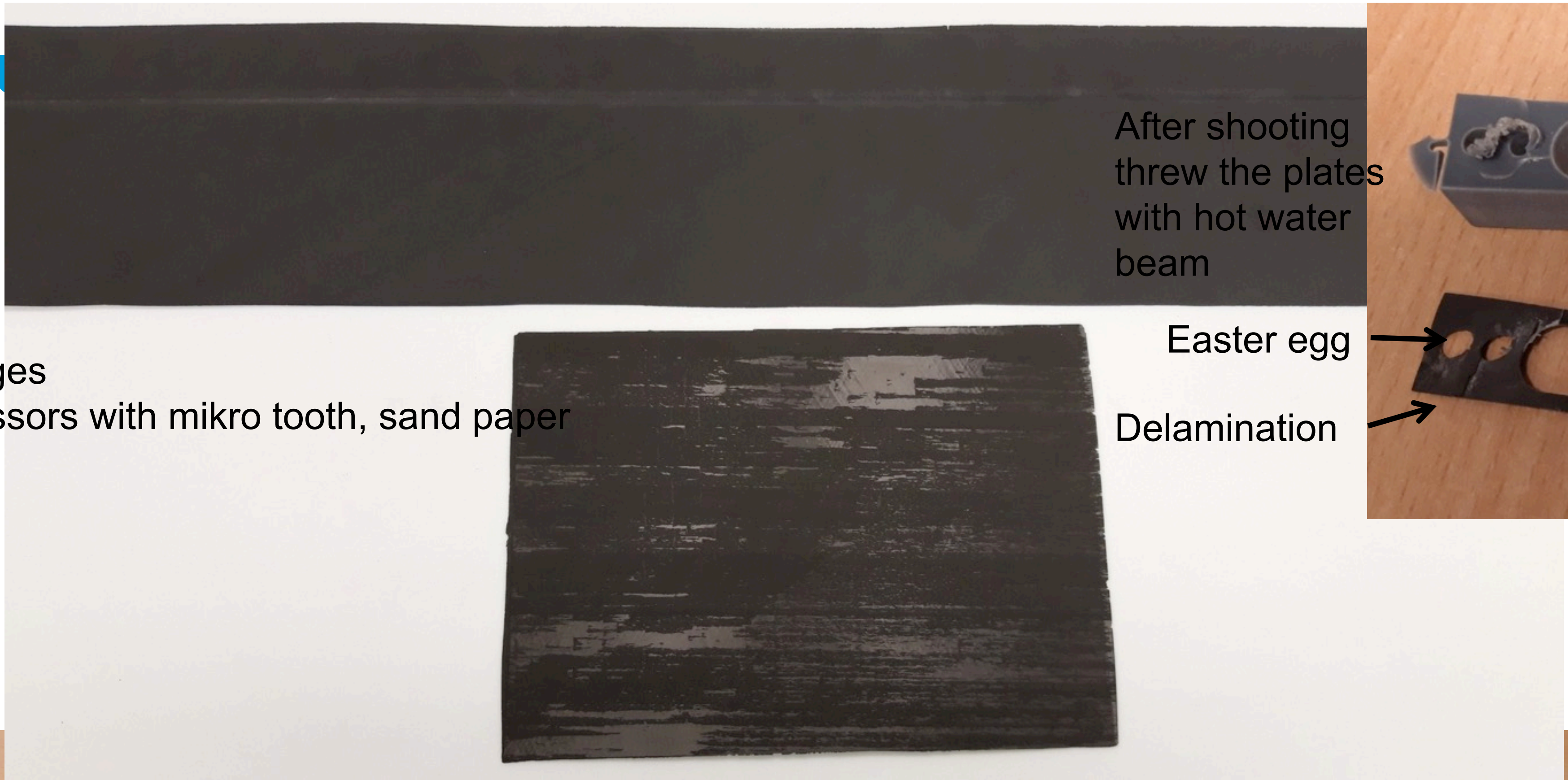
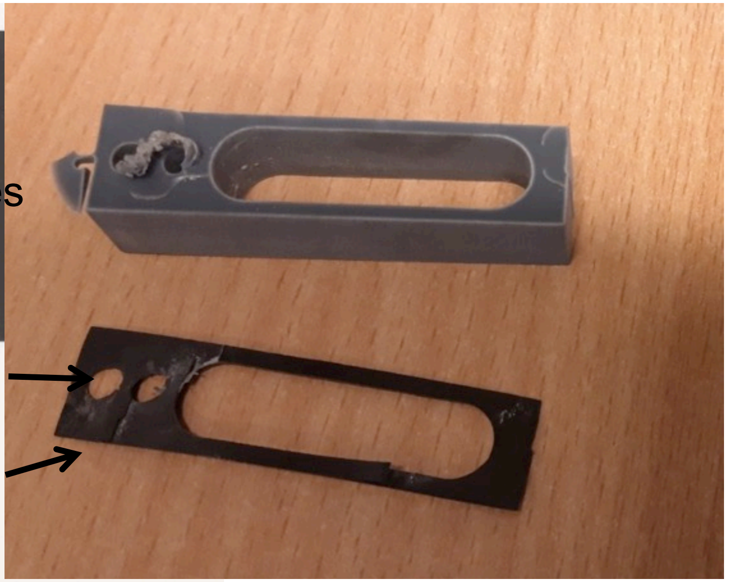
Backup

Back u



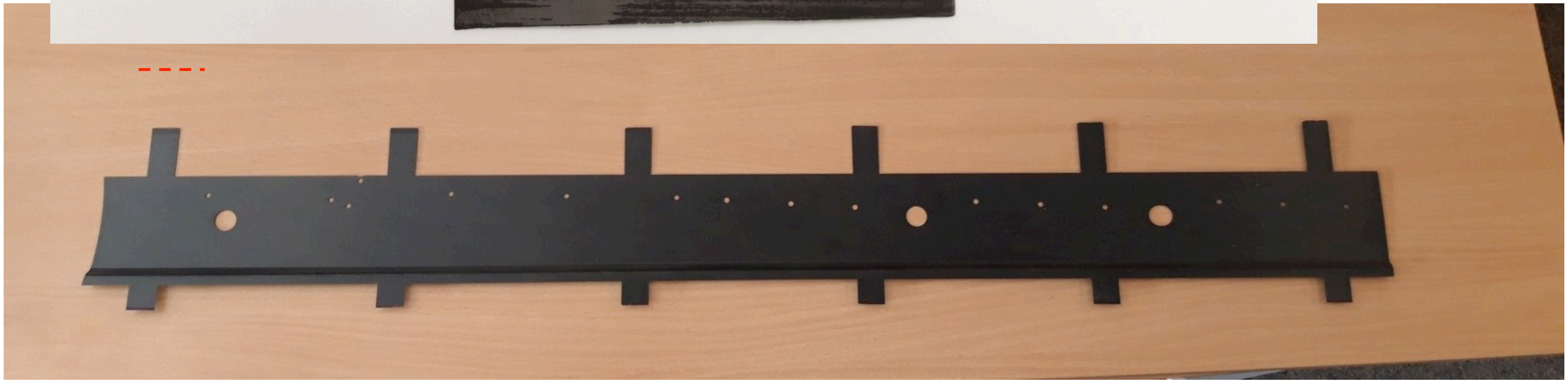


After shooting threw the plates with hot water beam

Easter egg

Delamination

Cut of edges
Tools: scissors with mikro tooth, sand paper



DESY TEDD Prototyping