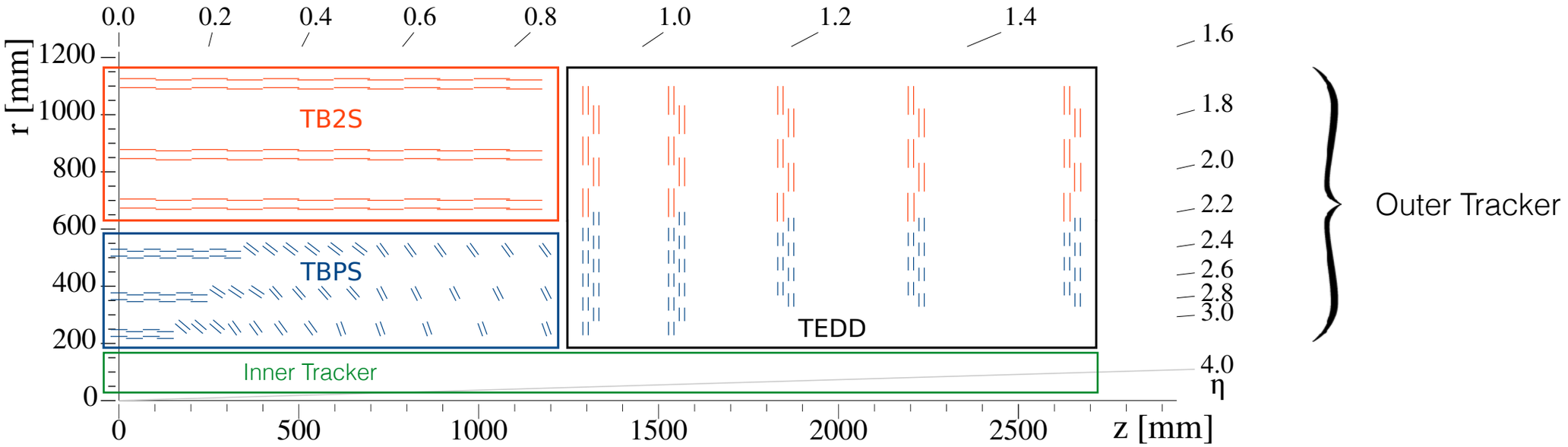
# Mechanical support structure of the CMS Phase-2 Outer Tracker Barrel (TB2S)

J.-L. Agram , on behalf of the CMS Collaboration

*Forum on Tracking Detector Mechanics, 8-10 June 2022*

- Some mechanical aspects of the TB2S
- The TB2S support structure preparation

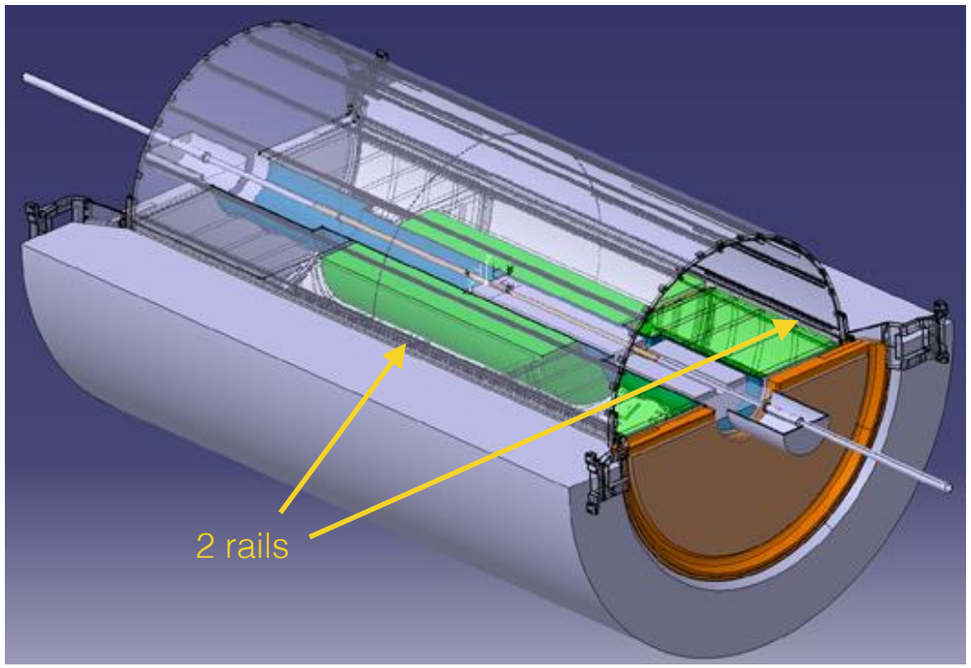
# Phase 2 CMS Tracker




- Focus on Outer Tracker
- Comparison with current tracker layout:
  - ~ same volume
  - Less layers, some tilted elements
  - Not only strips sensors
- 2 types of modules:
  - 2S sensors: 2 Strips (5 cm long) in a row
  - PS sensors: Pixel-Strips (1.5-2.4 cm long)

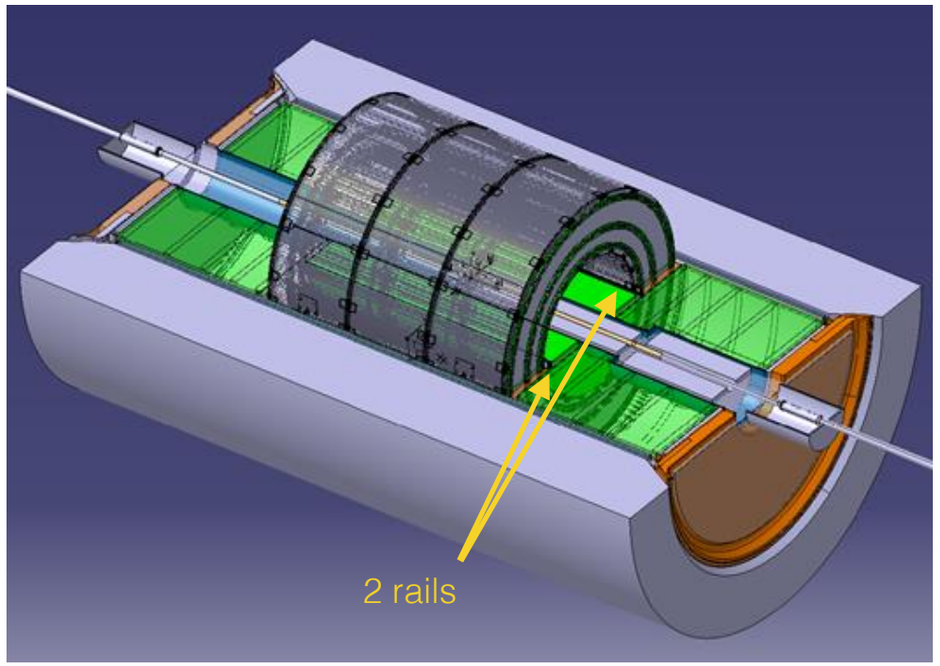
# TB2S environment

Outer Tracker Support Tube:



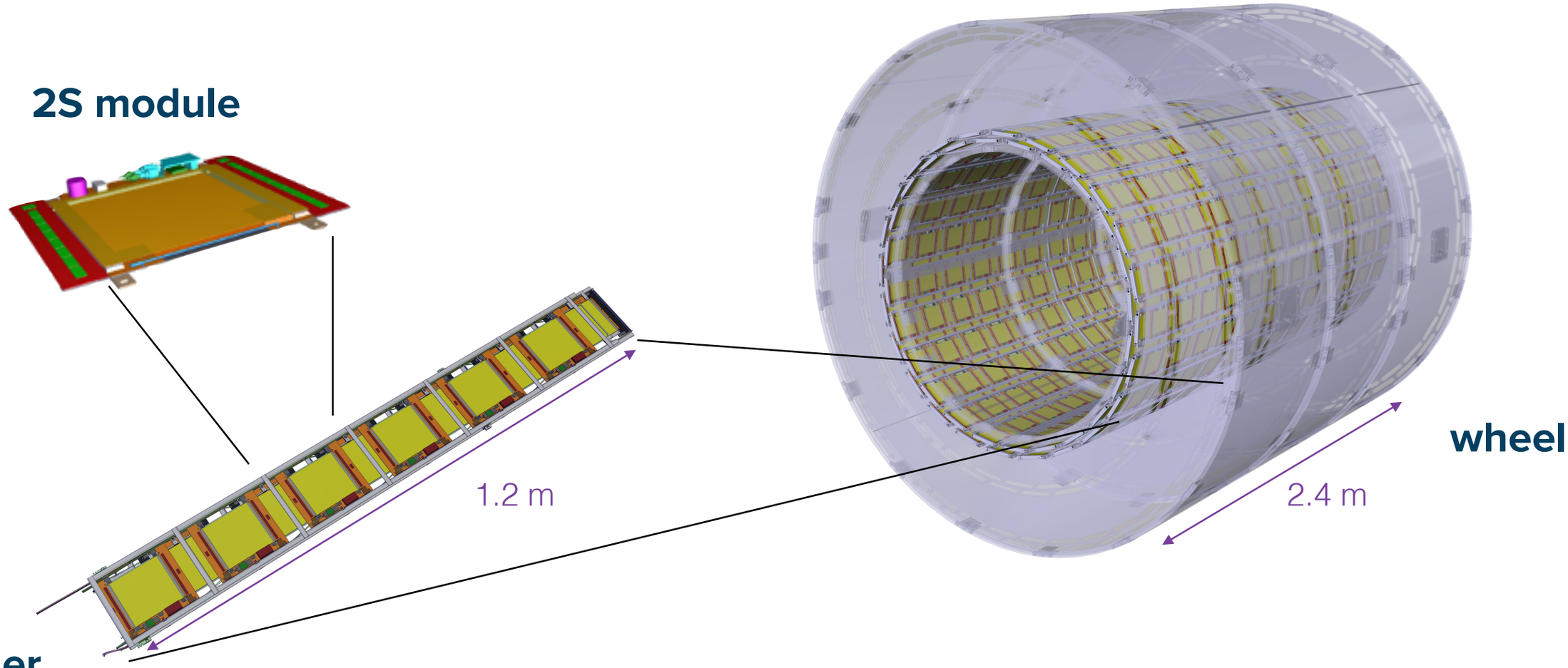

- Delimiting the tracker volume
- Closing space for air tightness
- Supporting TB2S and TEDD on 2 rails
- Barrel Timing Layer (BTL) detectors fixed in the inside of the support tube

TB2S:

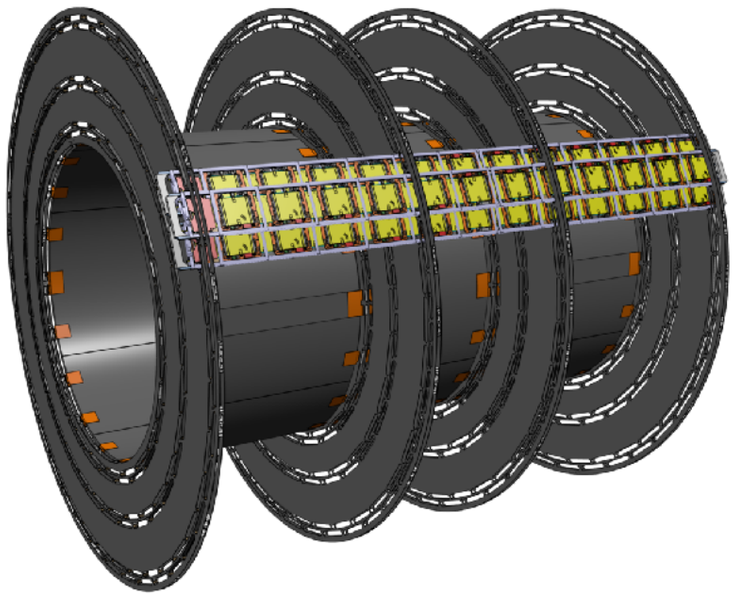



- Holding 2S modules
- Supporting TBPS on 2 rails. TBPS itself supporting the central section of the inner tracker

# TB2S mechanics



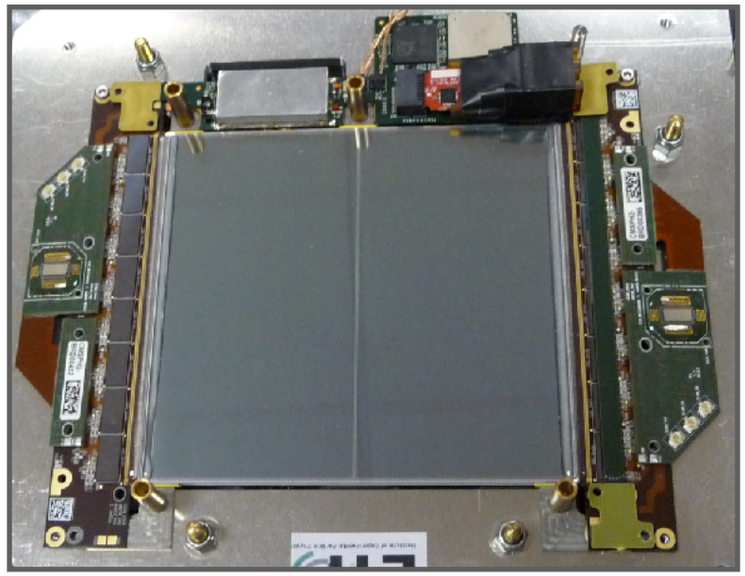

- 12 modules per ladder (6 on each sides with overlap)
- 368 ladders on 3 layers and 2 sides



# Ladders integration

## Modules:

(USA, Germany)

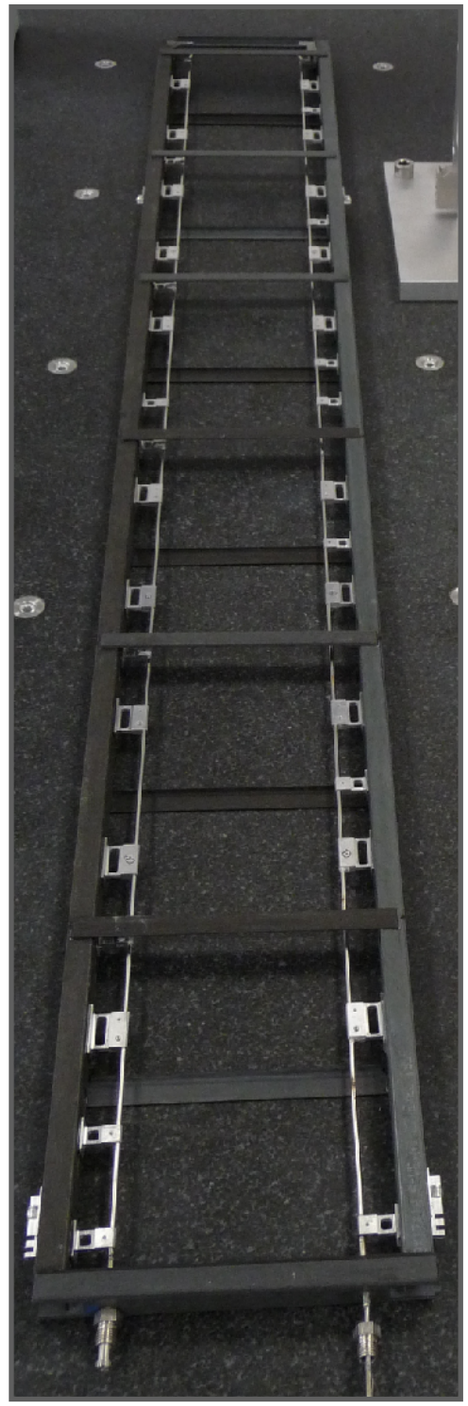


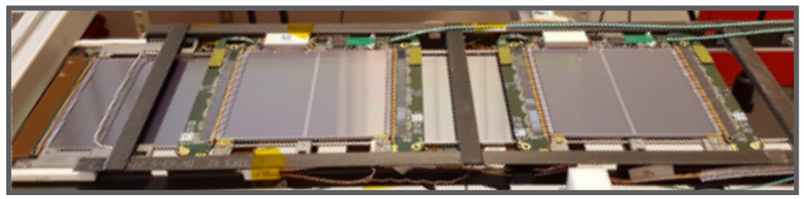
- 2S silicon sensors
- Mechanical support
- Service + front-end hybrids

## Ladders:

(Pakistan)

- Carbon fiber frame
- Modules inserts
- Cooling tube





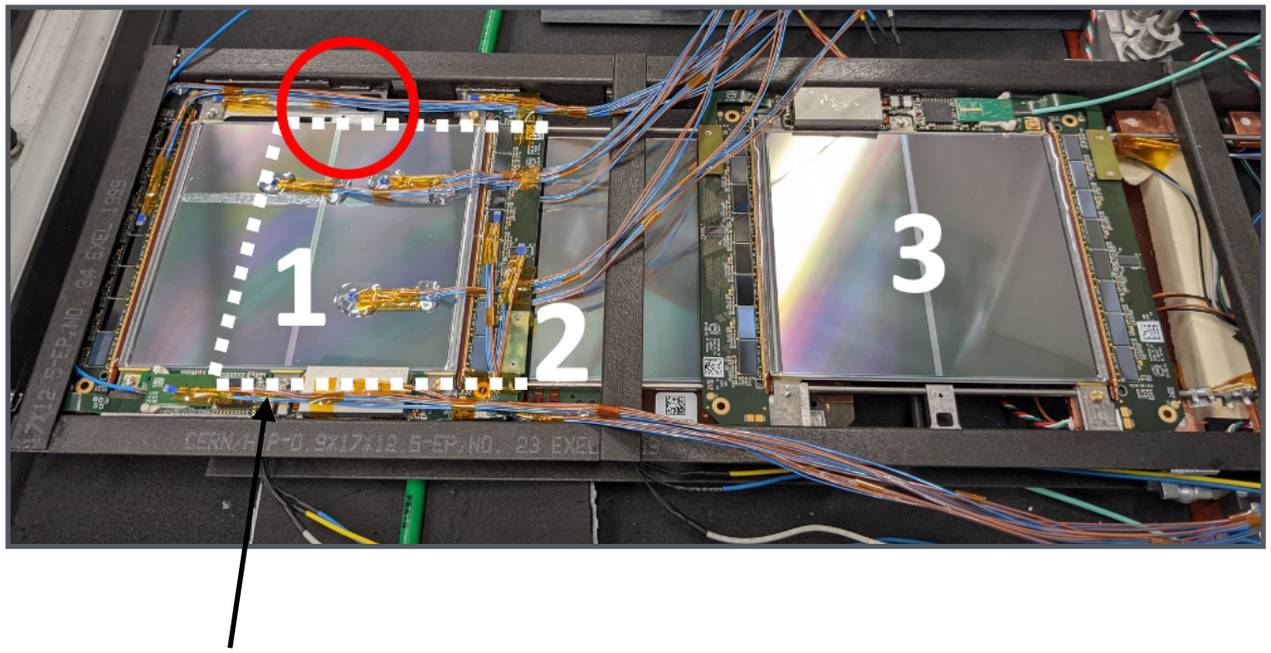
## Integration:

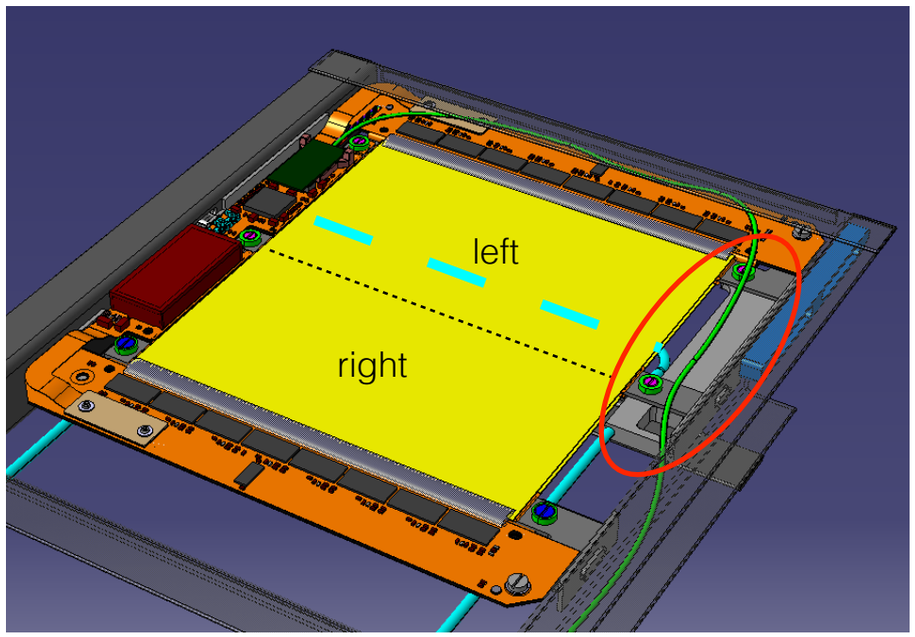
(France, India)

- Reception tests (geometrical, functional)
- Mounting
- Ladder tests at +20 and -30°C

# Integration test on a $CO_2$ cooled ladder

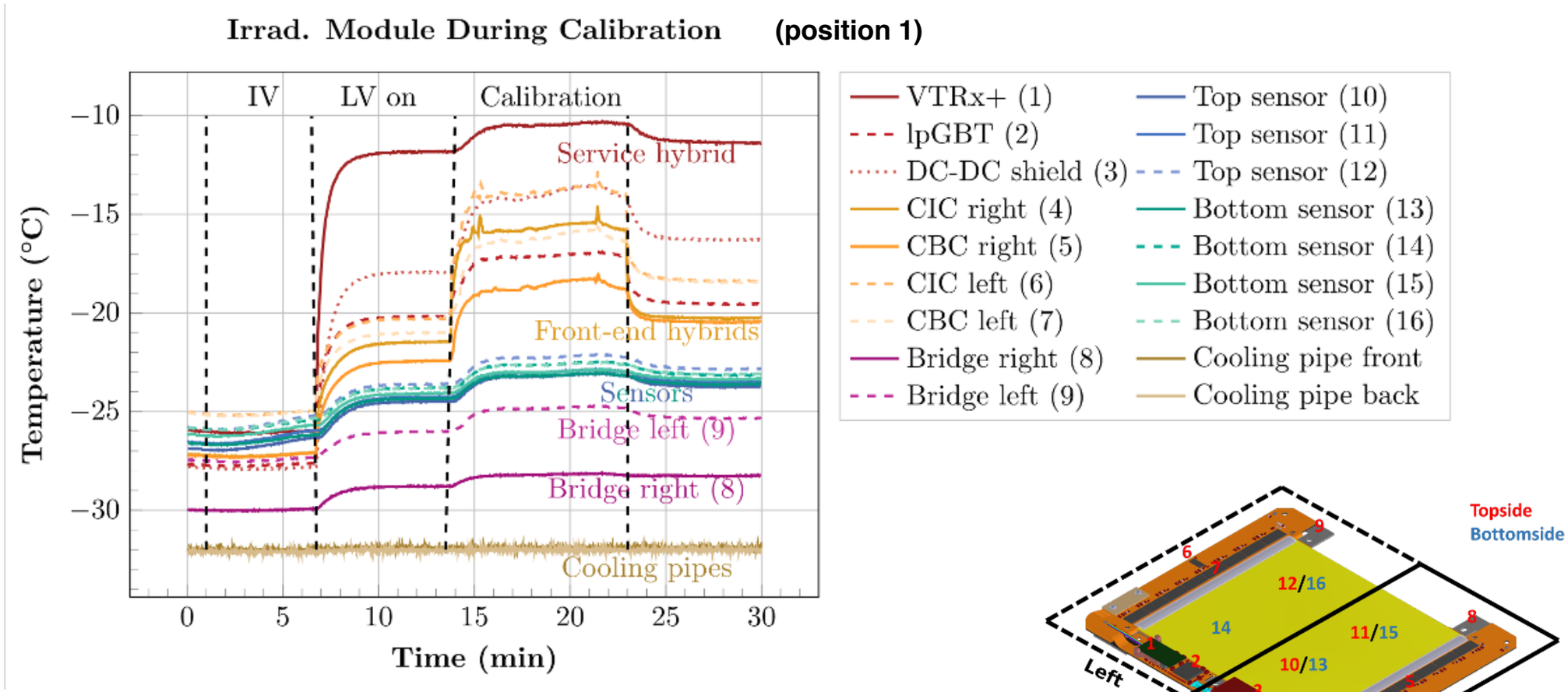
- In aluminium test-box in cold room at CERN
  - Ladder cooled with CO2
  - Test-box flushed slightly with dry air
- Three functional modules mounted on ladder:
  - 1 irradiated on position 1 and 2 non-irradiated modules
  - Position 1 is particular:
    - overlap of Z+ and Z- ladders -> less space for inserts for cooling contact
    - Thinner and longer inserts at the extremity
- Heating resistors at the other places




- <u>Test of cooling performance:</u>
  - 16 temperature probes on the irradiated module
  - Monitoring of voltages and currents

# Temperature measurements:







- Calibration period with the highest consumption
- Temperature asymmetry due to long inserts (6th cooling point missing)
- Effect mainly on hybrids, much lower on sensor

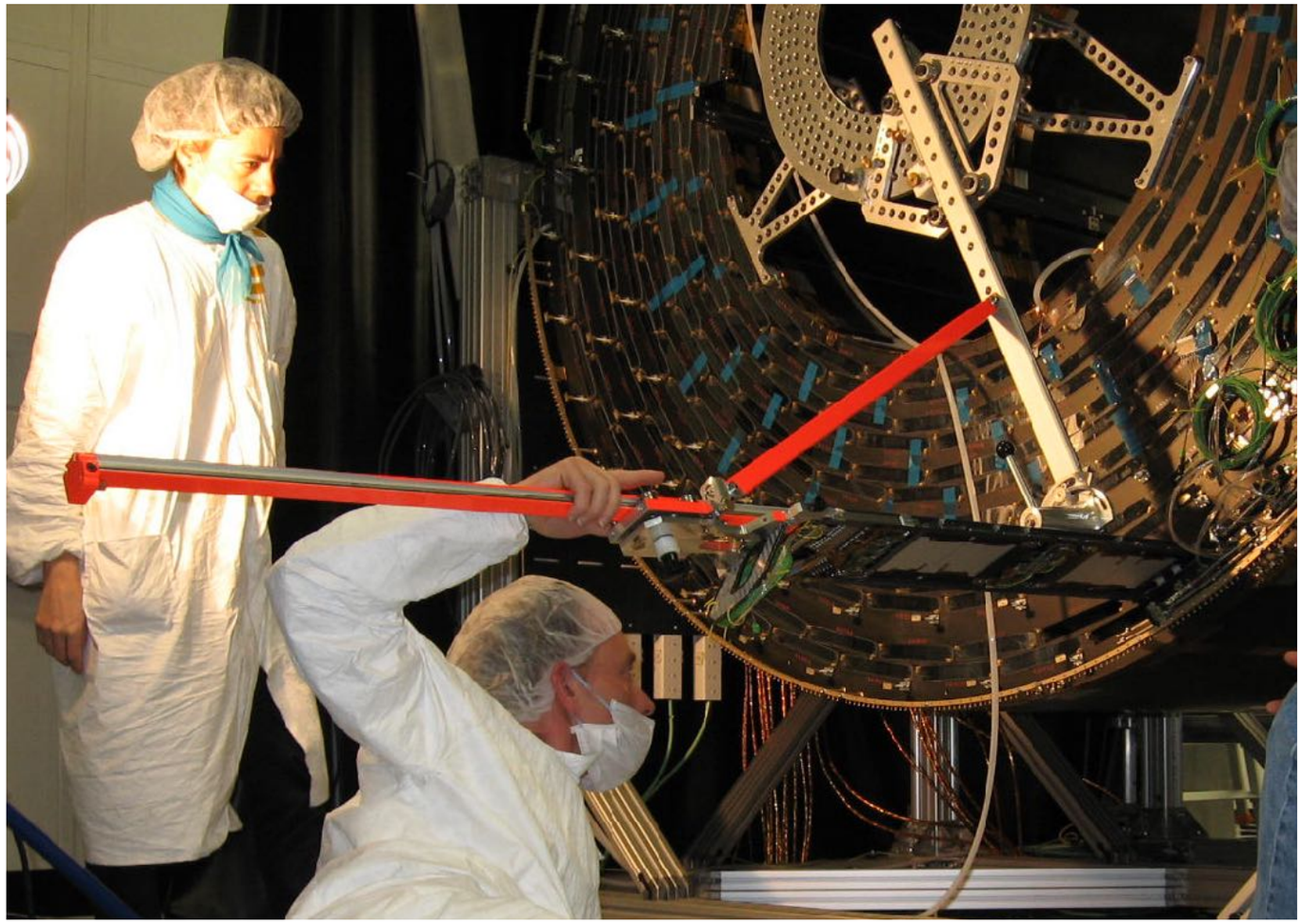
Variations of $CO_2$ cooling set value:

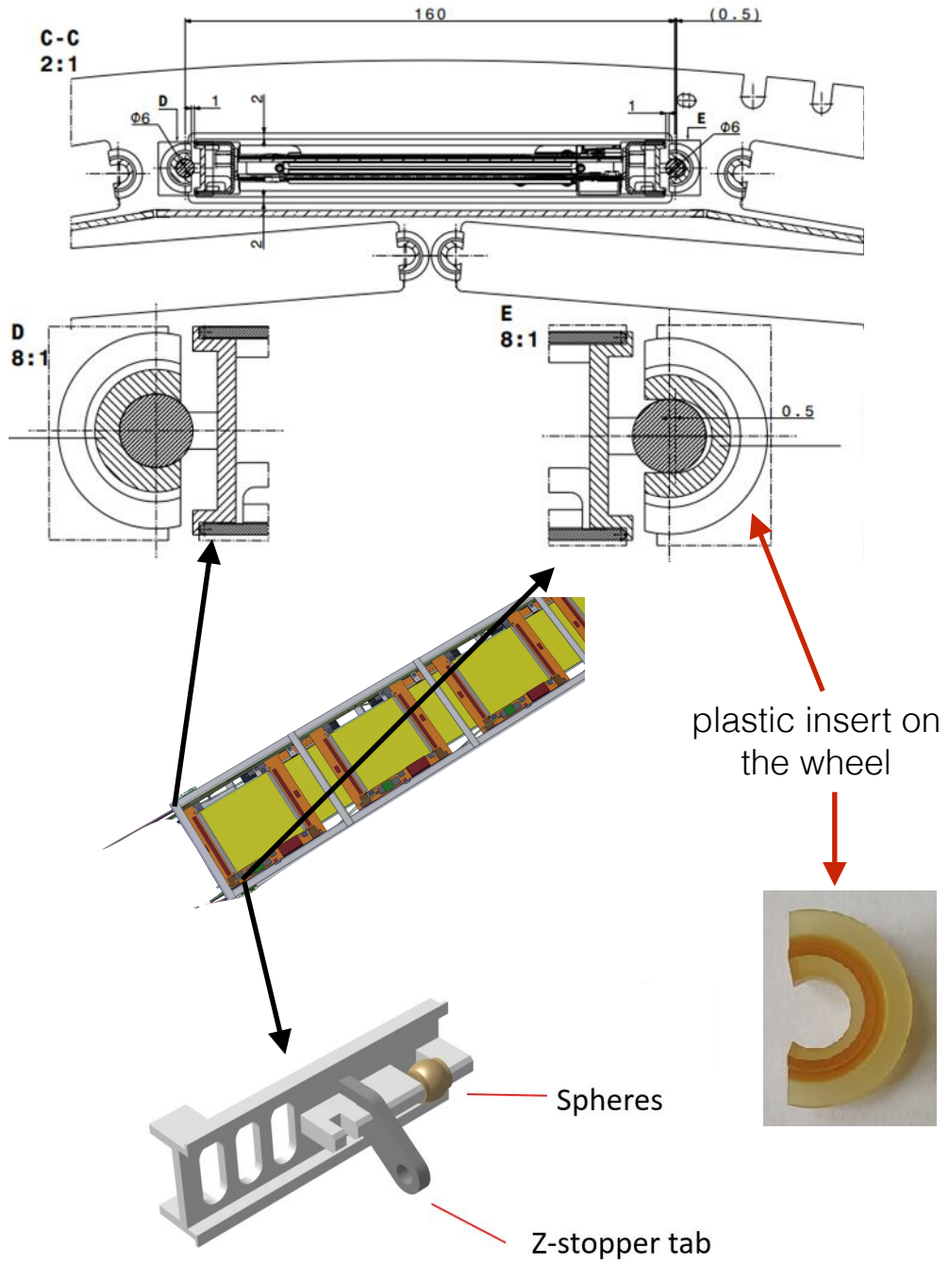
- No thermal runaway observed below -18°C
- Potential convection contribution

See Lea Stockmeier poster about the integration test

# Ladders insertion

Current tracker installation in 2006:





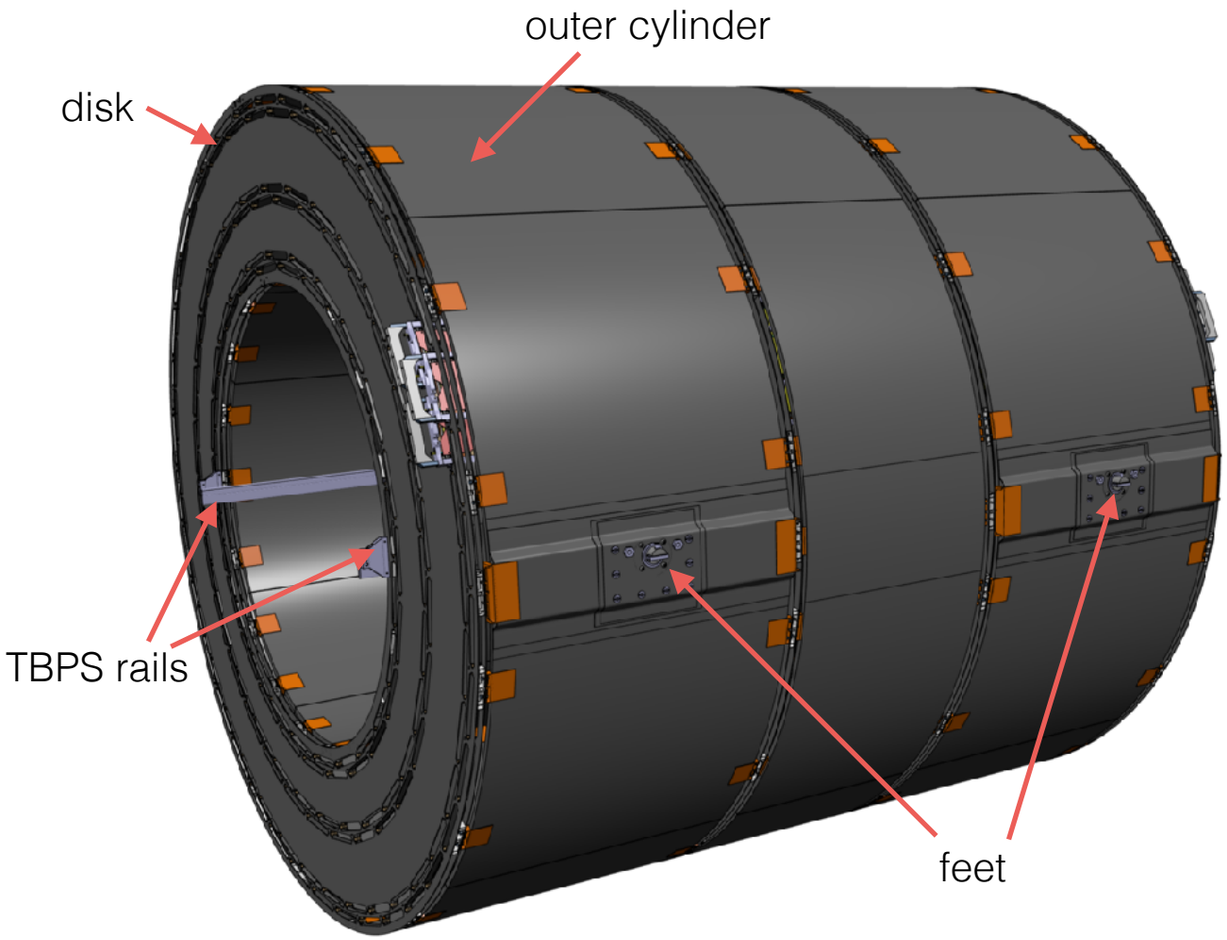

- Dedicated tool for guiding ladder insertion (in preparation)
- Ladders positioned by spheres on their sides inserted in plastics inserts glued on the disks

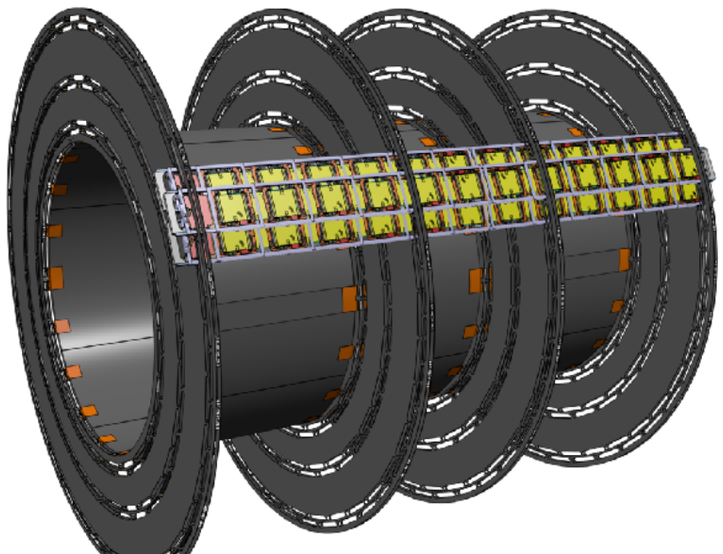
# TB2S wheel preparation

Design, prototyping, construction preparation

(France, CERN)

# TB2S wheel design



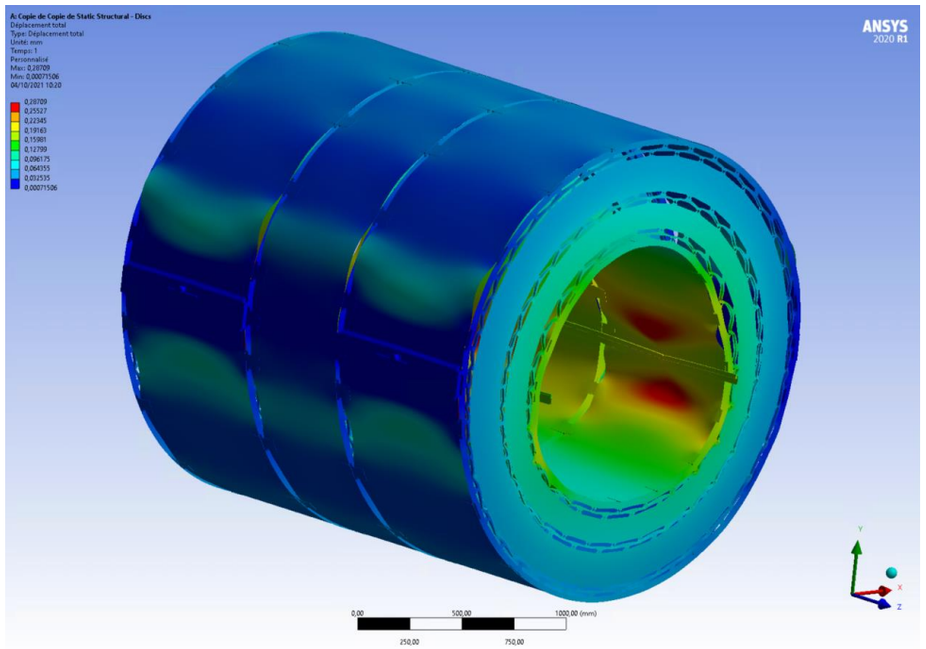



Elements:

- 4 disks (carbon fiber) for ladders positioning
- Disks linked by inner and outer cylinders (carbon fiber)
- 2 rails in the inside for TPBS supporting
- 4 feet for supporting the wheel on the support tube rails

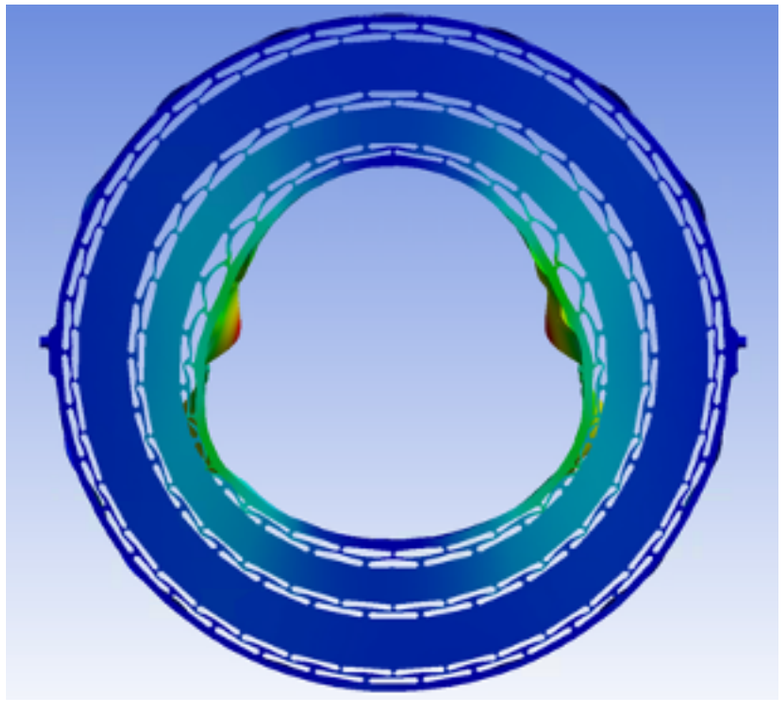
- Similar structure than for the current TOB (Tracker Outer Barrel)
- Differences with TOB:
  - 3 layers instead of 6
  - Timing Layer detectors between tracker and its support tube
- Equipped TB2S + TBPS + IT load : 1t on 4 feet

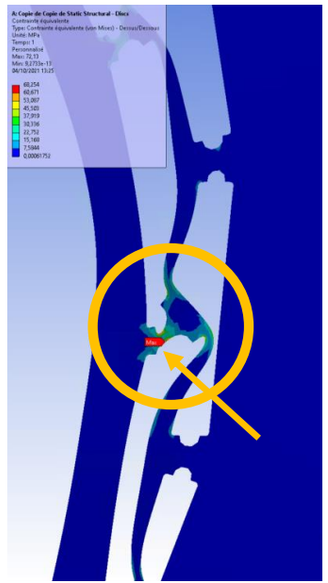
# Wheel FEA simulation




- Full wheel simulation with final geometry
- Large model with many elements (~2000) and connections (~1000)
- For disks: using carbon fiber composite planes with Young modulus = 78 GPa
- Realistic load case:
    - 150 daN corresponding to disks and cylinders mass
    - 180 daN of ladders load on inserts on disks
    - 570 daN of TBPS + inner tracker on the inner rails Waves magnitude up to 0.3mm
- Waves magnitude up to ~0.1 mm. Largest deformation on the cylinders that does not affect sensors position. Only the half at ladders positions.
- Small stress: max. Von Mises stress : <30 MPa. To be compared for example with the tensile strength of the disks ~350MPa (from tensile test)

**Total displacement**



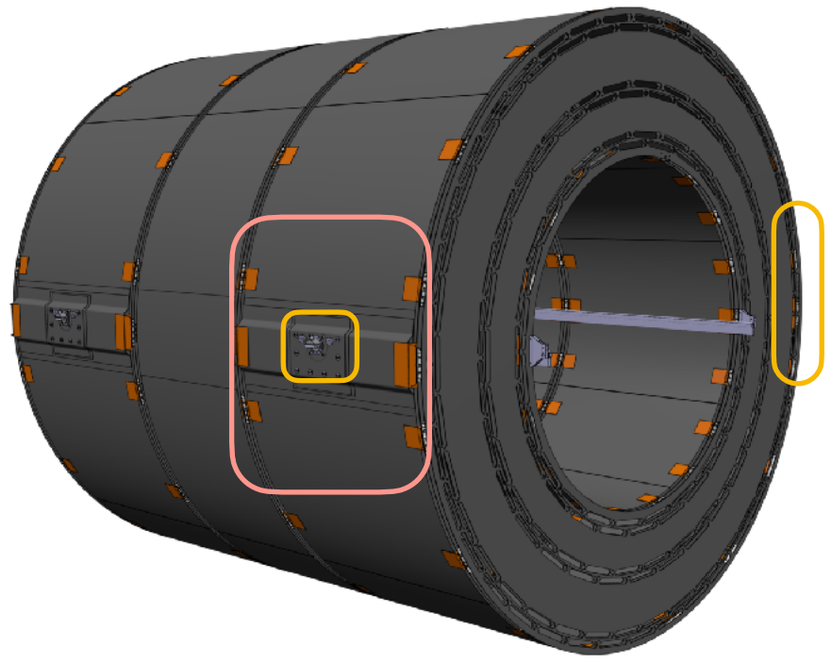


**max. stress location**

# Prototyping

Current tracker can be considered as the proof of feasibility → avoid a costly full size prototype

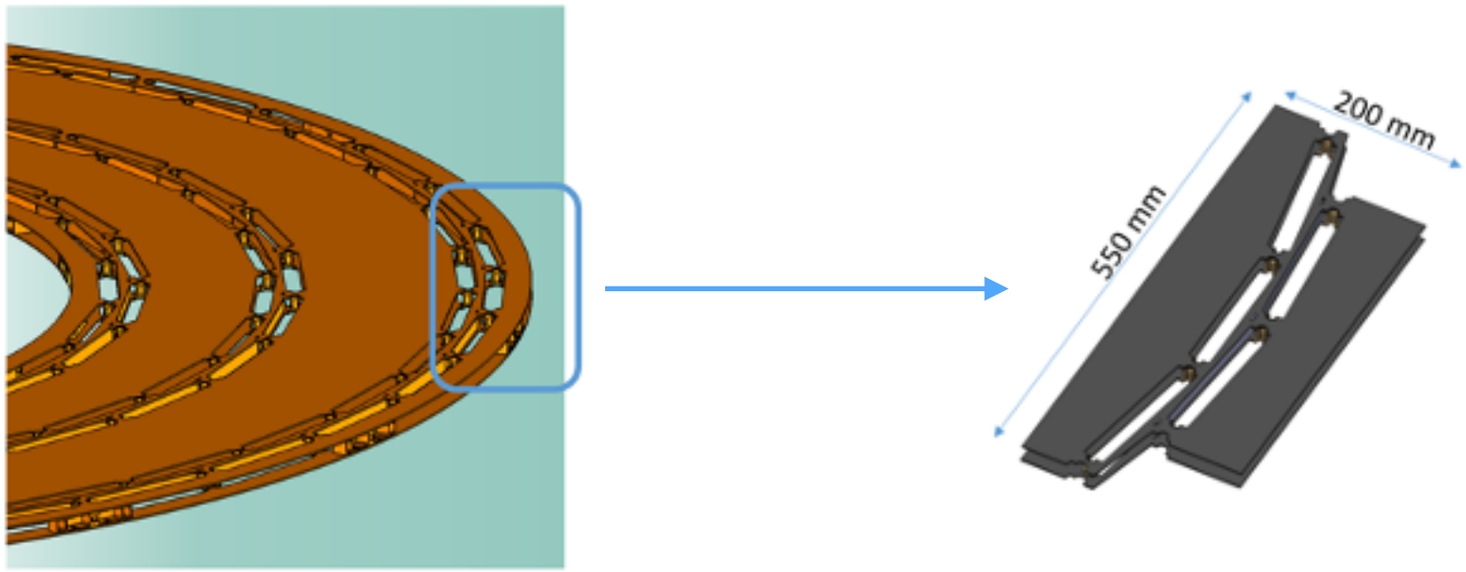
Focusing on the particular parts with evolutions.



- In the disks:
  - Closer ladder positions in some layers → less material
  - Use of composite with cyanate ester resin instead of epoxy
- Around the feet:
  - Larger distance between rail and wheel → reinforced region around the feet due to BTL
  - New geometry of foot + use of Ti for one element

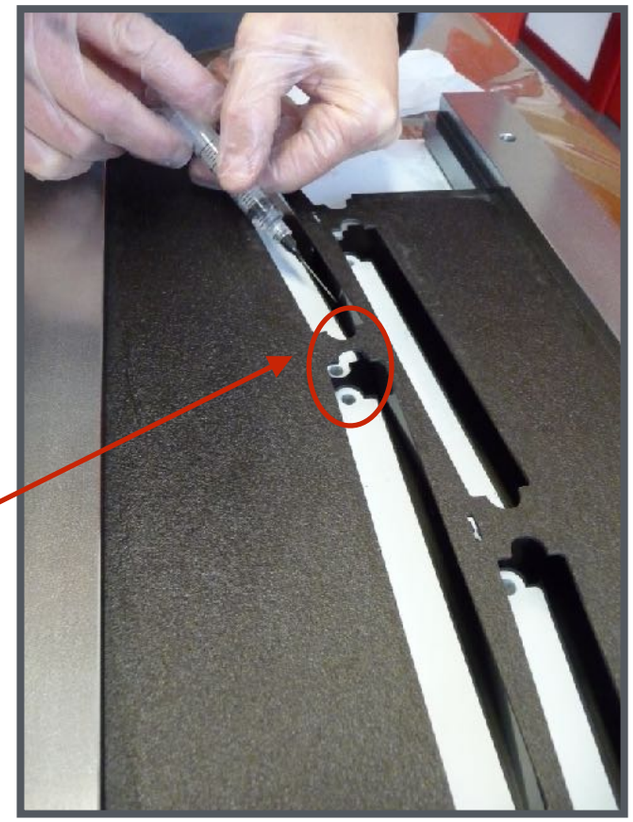
Prototypes tested and comparison made with FEA, for gaining in confidence on the full size wheel predictions.

# Disk sub-part prototype



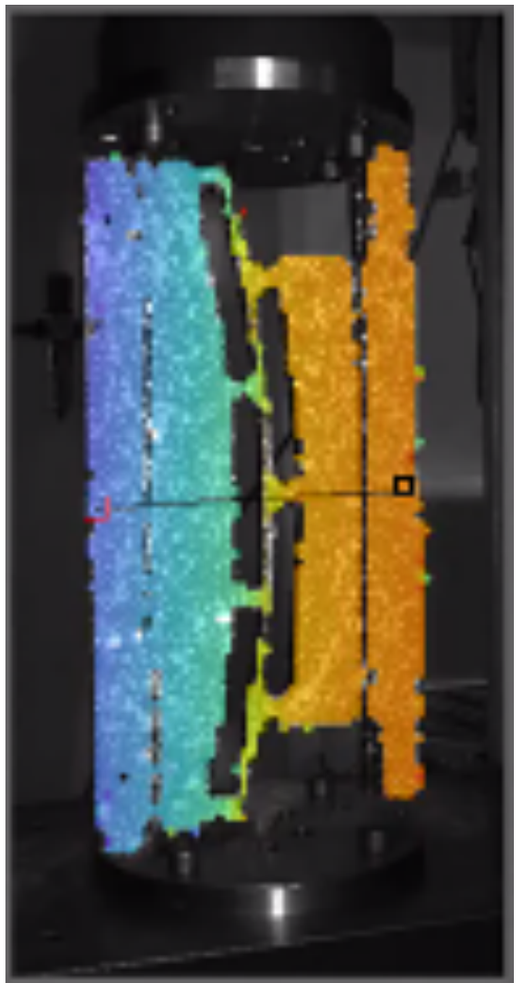

- Disk composition:
  - 2 planes separated by spacers and glued
  - 1 plane : 2mm thick, 12 plies of unidirectional carbon fibers in 4 different directions

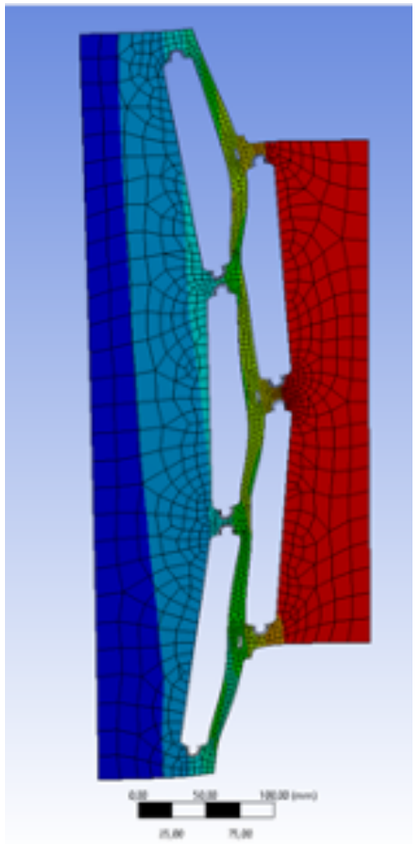
- Purpose of prototype:
  - Test of a new composite material (M55J fiber + cyanate ester resin)
  - Check strength of region with few material between ladders
  - Compare with simulation
  - Train with the procedure of gluing (on jig)



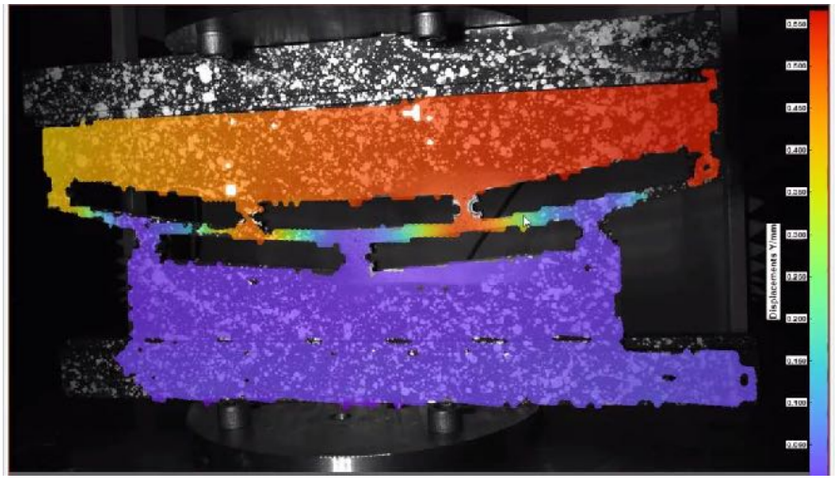
- Traction tests:
  - Made at CERN Mechanical and Materials Engineering laboratory
  - Test followed with image correlation technique (spraying painting and following movement of spots) giving a map of displacements/deformations.
  - Few cycles up to 250kg (much more than in future structure) in 2 directions
  - Vertical position (side of a disk)
    - Max displacement ~0.3mm (measured by optical monitoring). In agreement with FEA predictions.

Colors representing the Y displacement



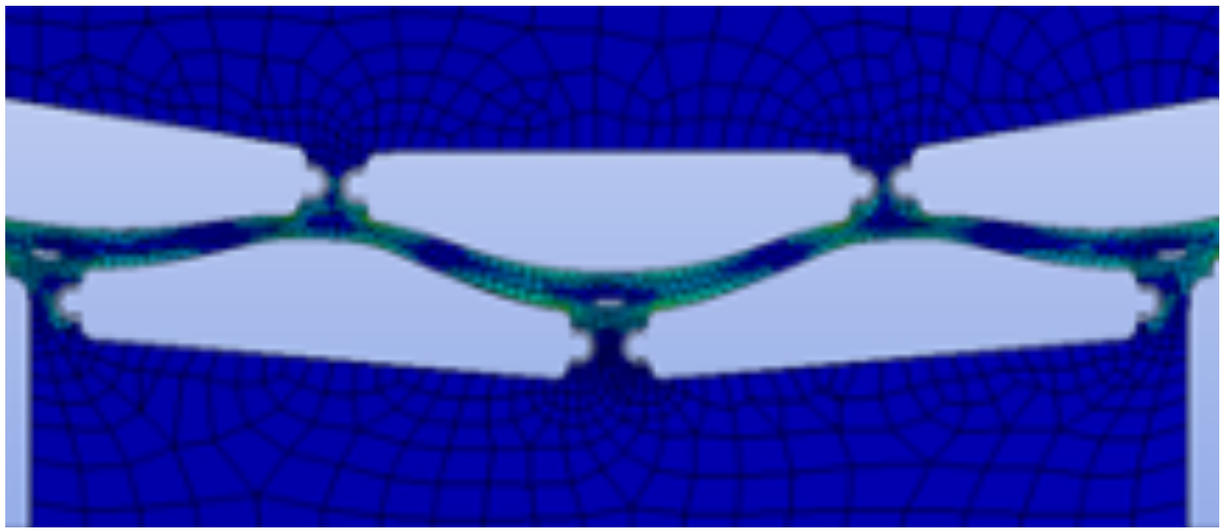


- Horizontal position (bottom or top of a disk)
  - Displacement ~twice larger than in vertical position as predicted
  - One cycle in focusing on the region with the inserts where the constraints are expected to be the largest.

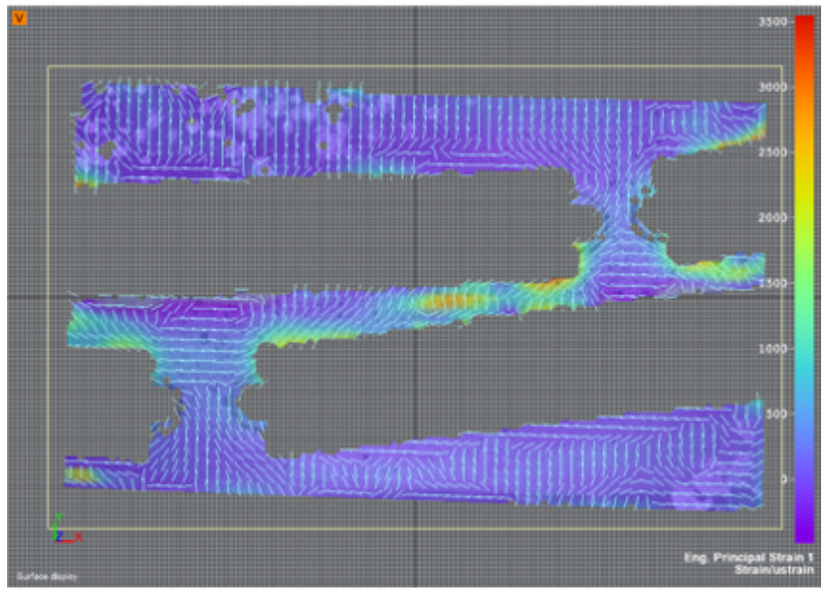


Measured Y displacement

Deformations from FEA



Deformations from measurements




(only qualitative comparison of deformations)

- Tests conclusions:
  - No break, quality of materials and gluing is good
  - Observed displacements close to FEA predictions -> confidence in FEA for larger pieces
  - Design confirmed

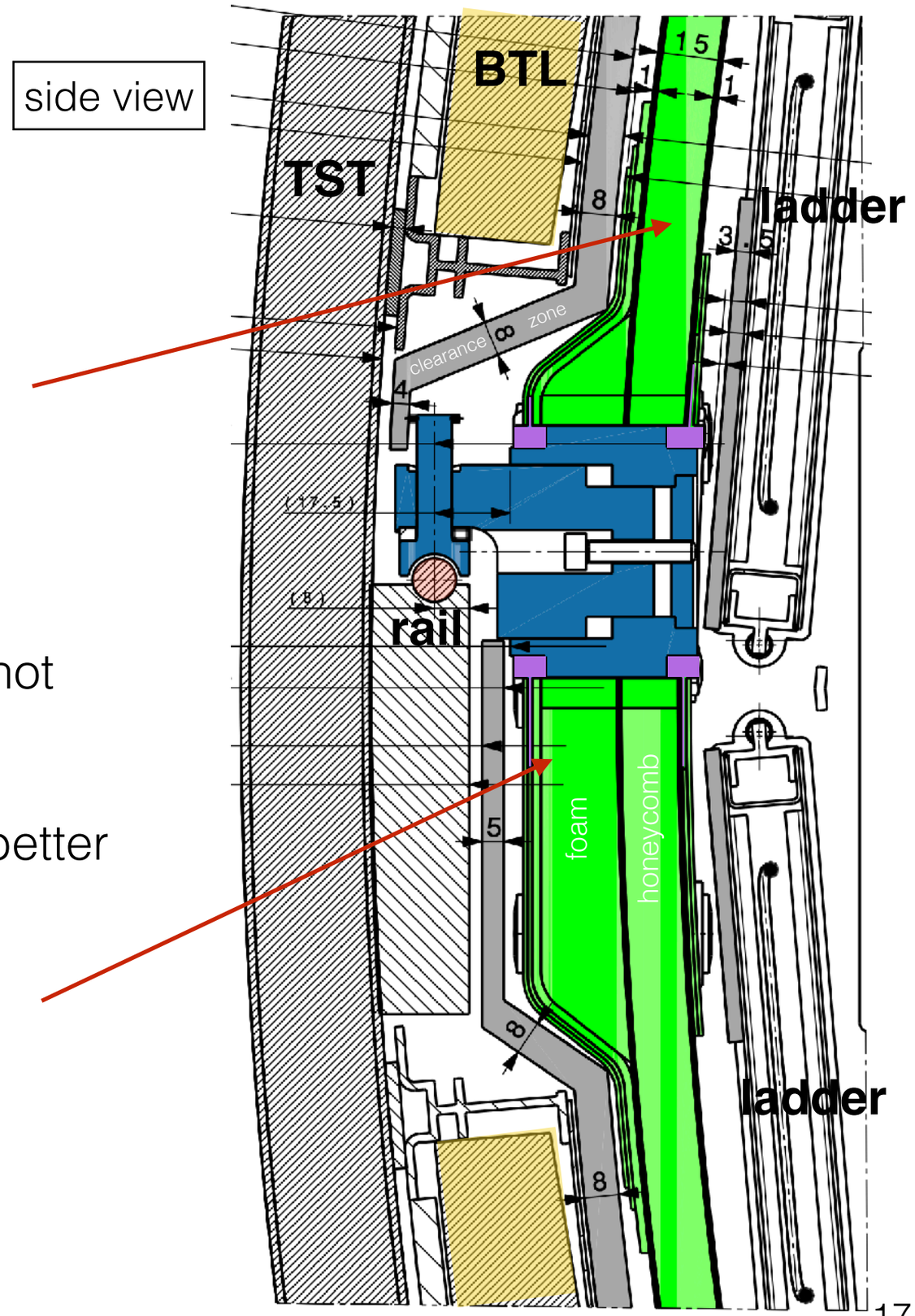
# Reinforced region

Cylinder:

- Thickness of 15mm for the outer cylinder
- Honeycomb structure between 2 carbon fiber sheets of 1mm thickness (8 plies)

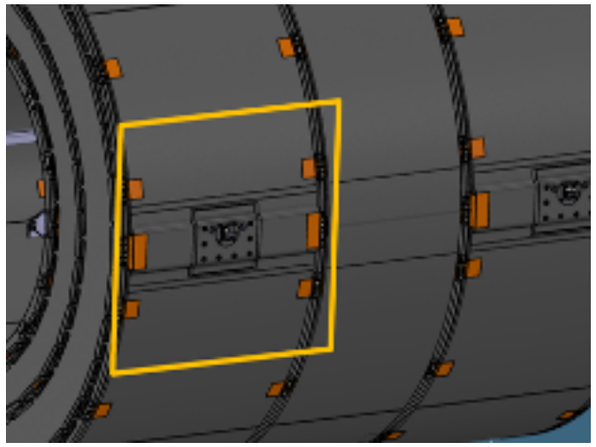
Reinforcement:

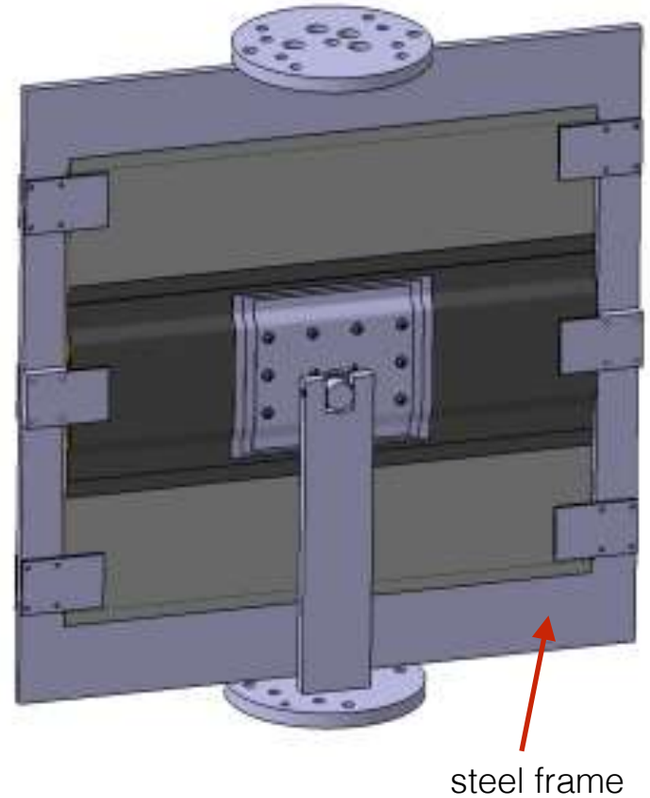
- Due to the Barrel Timing Layer the cylinder is not very close to the support tube
- Fill the distance between cylinder and rail for better maintaining of the foot
- Made of 2 planes in Titanium around the foot shoulder, foam, additional carbon fiber layers, screws to avoid delamination

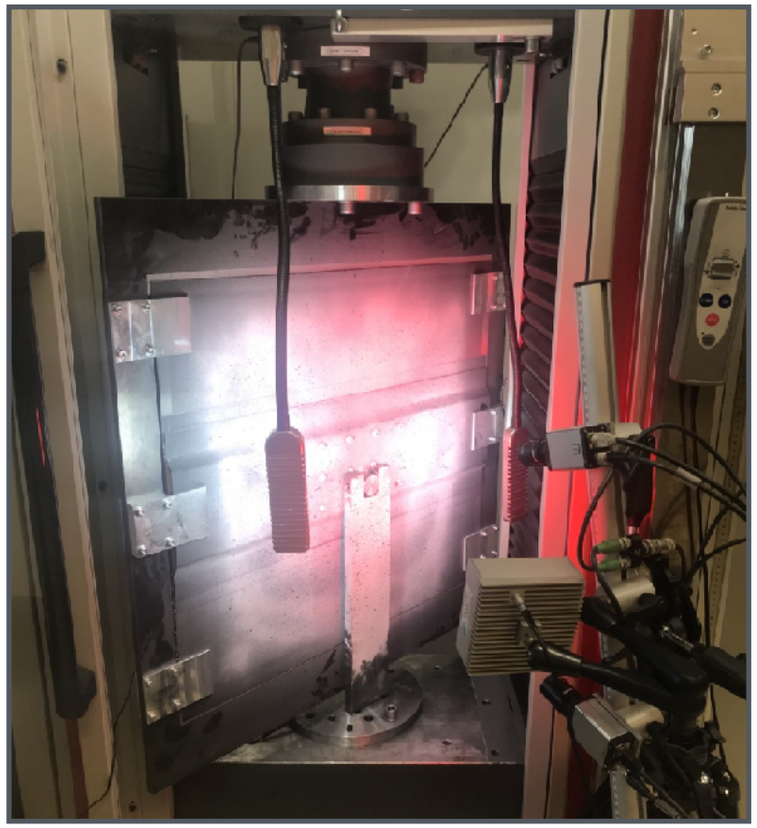


# Reinforced region prototype

- Purpose of prototype:
  - Validate design
  - Test assembly of this more complex part
- Prototype:
  - Flattened design for ease of preparation and testing
  - Mounted on a steel frame
  - Simplified foot in the hub : a rod with same degrees of freedom
  - Produced by a company
- Tested under traction at CERN
  - With optical stereo monitoring

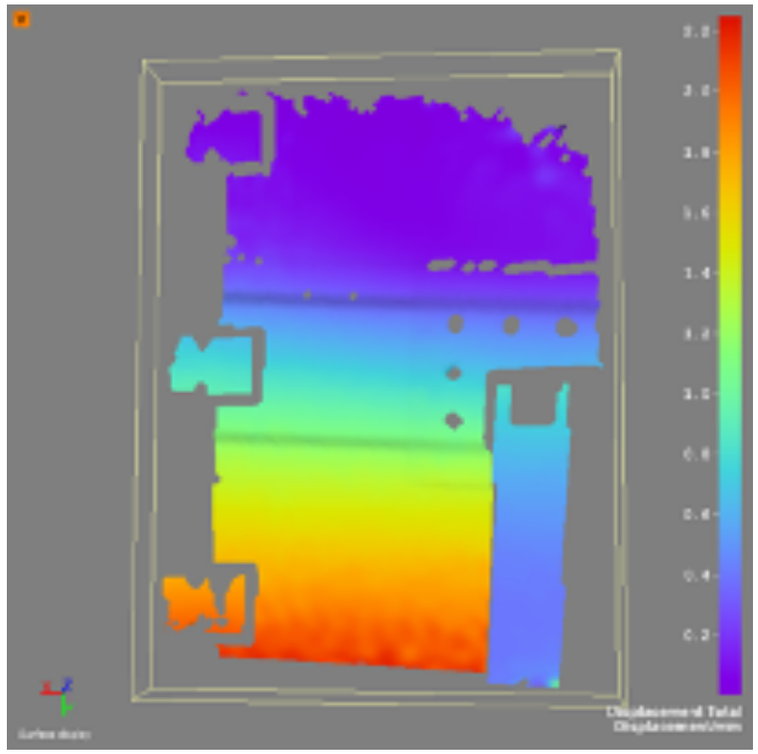




- Traction tests:
  - Several cycles of increasing load
  - Measurements made at 500kg
  - Went up to 1t (load of the full barrel tracker on a single foot) ! No break, no noise.

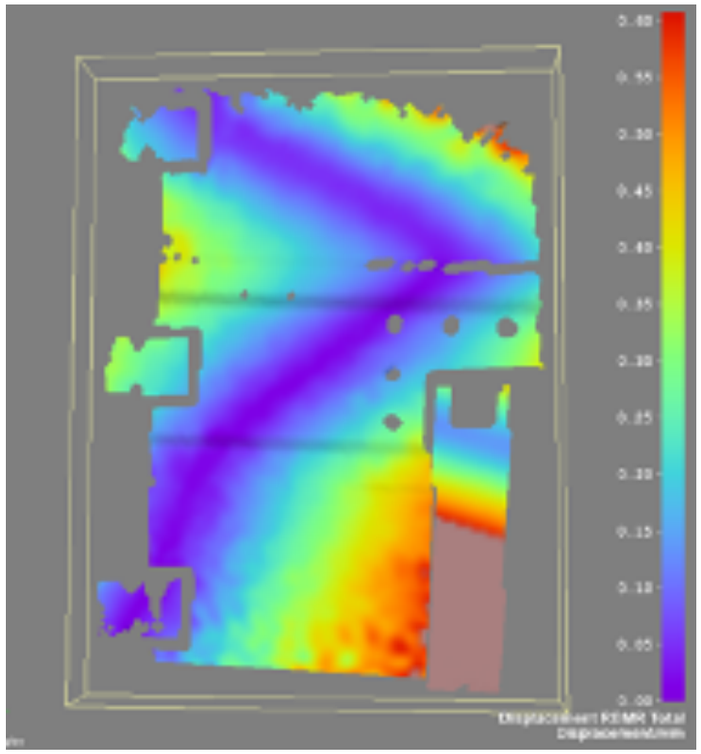
- Observed displacement:



2.2mm

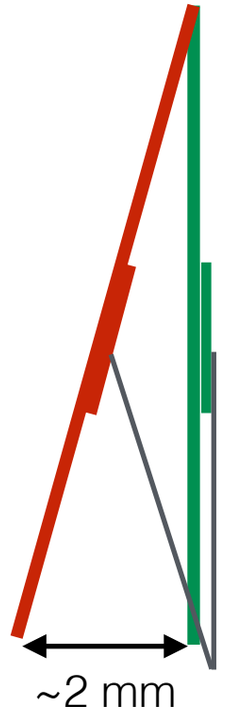
Total displacement

Global displacement due to steel frame elasticity



0.6mm

Total displacement with rigid body motion removed




side view:
- green : standby position
- red : position at maximum load

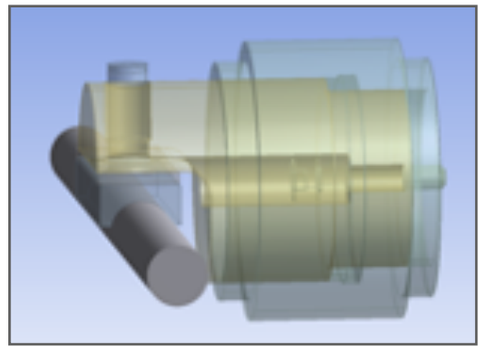
- Comparison with FEA:

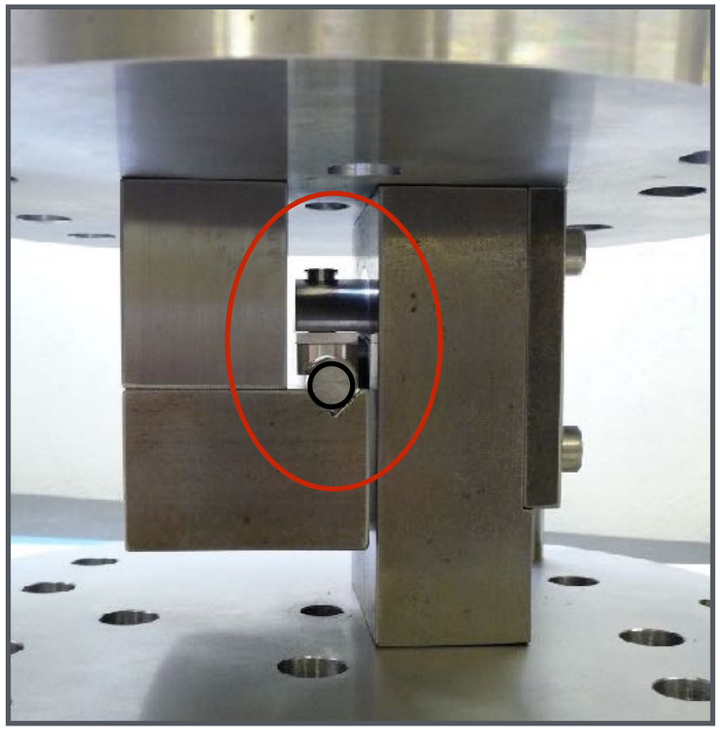
  Similar magnitude. Global displacement half than observed.
  Close value of local displacement.

# Foot prototype

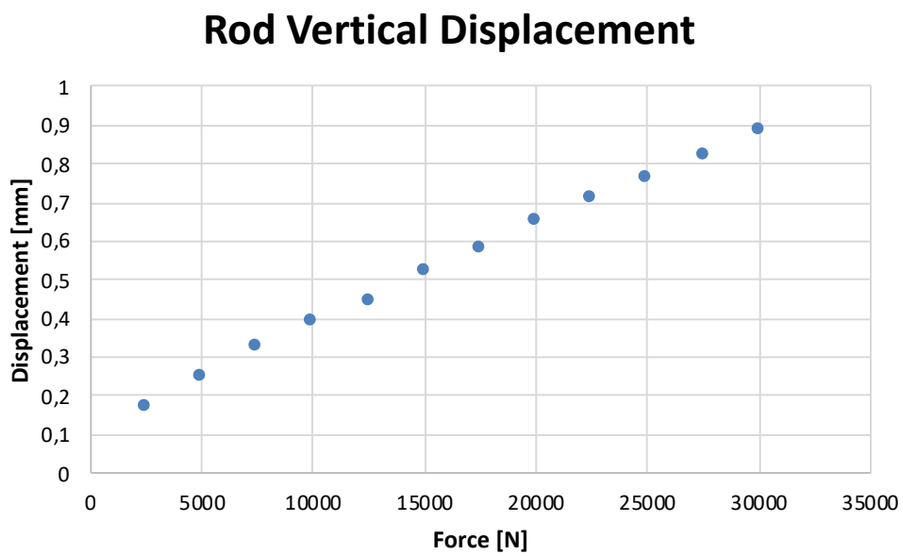
Reminder: fully equipped central tracker ~1t on 4 feet

- Doing a prototype because:
  - New geometry with respect to TOB foot (longer arm)
  - New material: one critical piece in titanium instead of alu
  - Train the people who will do the final pieces (@lab)
  - Test behaviour under traction





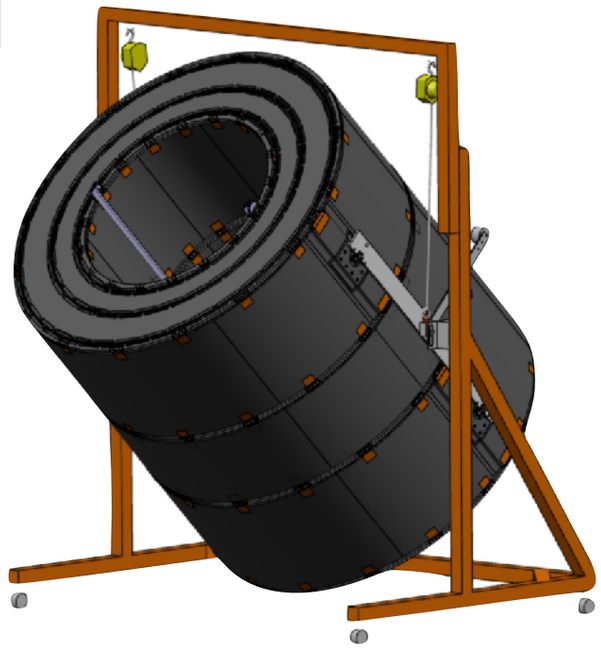
- Test:
  - Did cycles of load. Went up to 3t without problem (still in elastic regime)
  - Displacement <0.2mm under standard load (250kg, on 4 feet). FEA estimations are 0.03mm but without gaps between pieces or plasticisation
  - Geometry not optimised in term of material (outside of tracker), preferred strength and safety

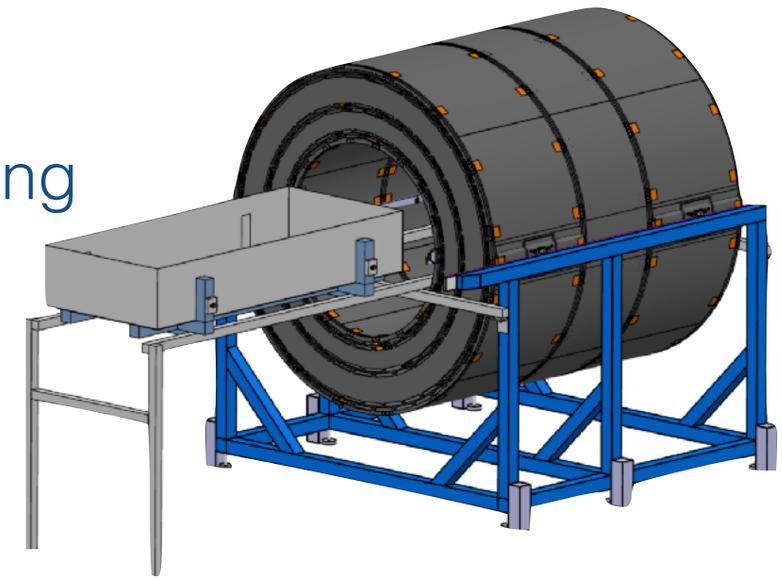


# Construction process

- Construction on a flat table
  - Serves as jig for ladders positions (plastic inserts) → in a room with air temperature regulation
  - Flat table for disks gluing, cylinders connectors gluing, wheel assembly
  - Adaptation of the flat table used for the current tracker
- Rotation of the structure for loading test on horizontal position

Current tracker construction in 2006:





# Outline

- Presented TB2S mechanics
- Design is ready
- Validated with tests on prototypes
- Start the process of elements ordering

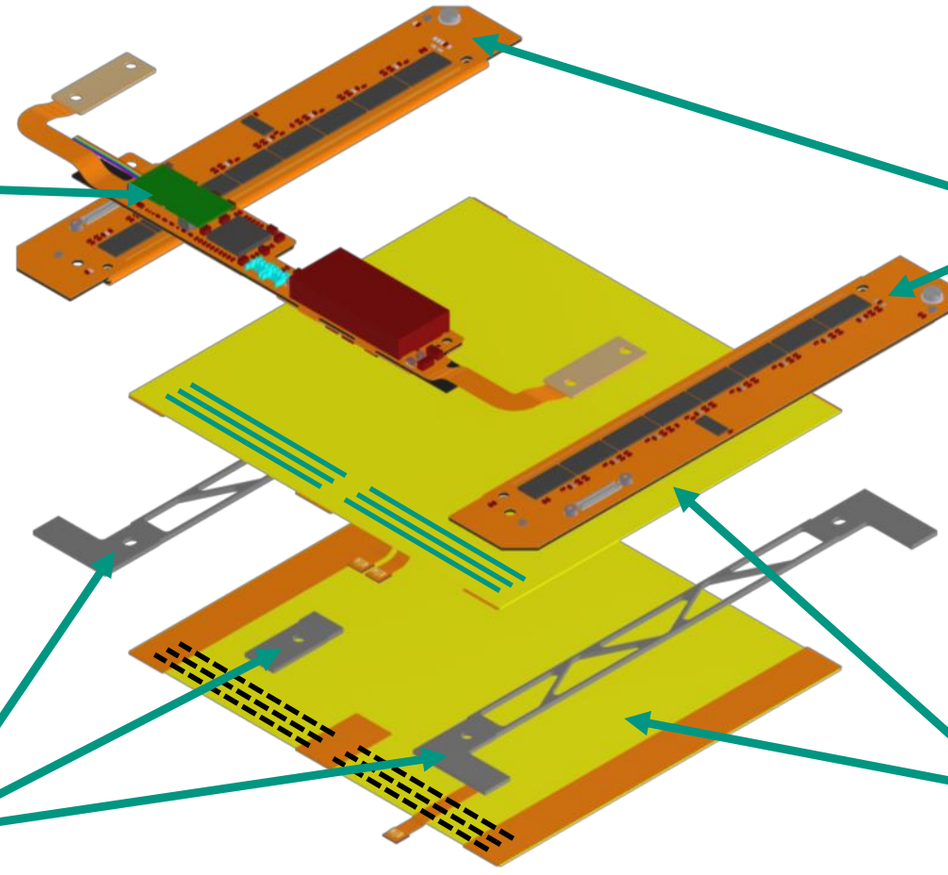
# Back-up

# The 2S Module

**Service Hybrid**

Powering

Data transmission



**2 Front-end Flex Hybrids**

8 CMS Binary Chips each

1 Concentrator Chip each

Connected to both sensors

**Spacer**

Carbon fiber
reinforced aluminium

Mechanical fixation / cooling

**2 Silicon Strip Sensors**

2 x 1016 strips (5cm) each

Back-to-back