Precision assembly, examples from CERN projects

Composites workshop

29 February - 3 March 2016, LBNL

Antti Onnela
with contributions by Andrea Catinaccio, Neil Dixon, Corrado Gargiulo and Francisco Perez

CERN – Experimental Physics department – Detector Technologies group

https://conferences.lbl.gov/event/54/

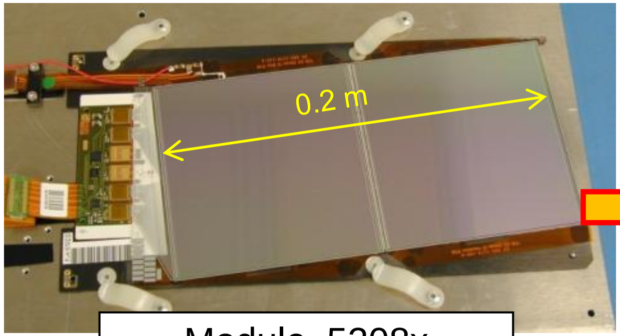
Examples taken from the following projects:

- CMS Tracker
- ATLAS TRT
- ALICE Inner Tracking System upgrade
- ATLAS Micromegas (New Small Wheel upgrade)

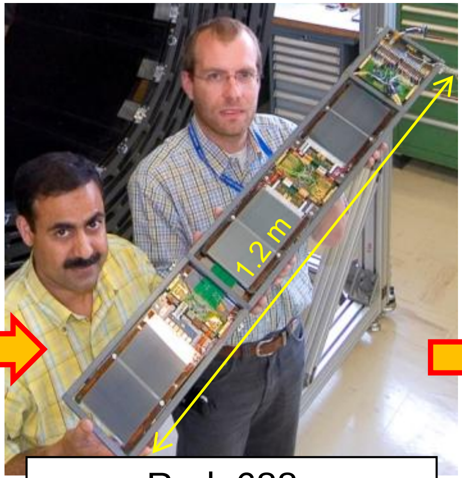
CMS Tracker Outer Barrel

Contact person: Antti Onnela

CMS TOB, Tracker Outer Barrel



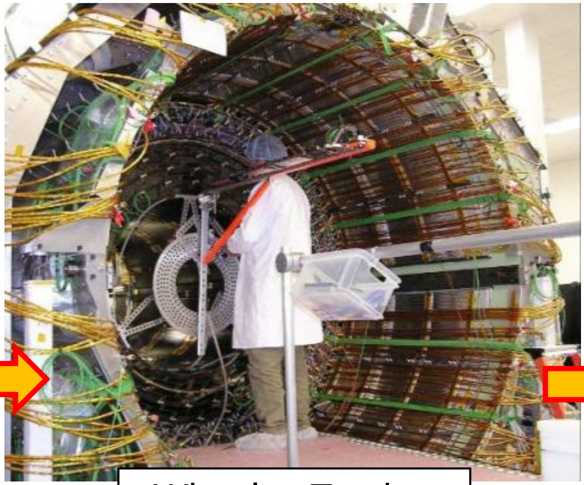
Module, 5208x
(34% of CMS Silicon Tracker)
Assembled in the U.S.



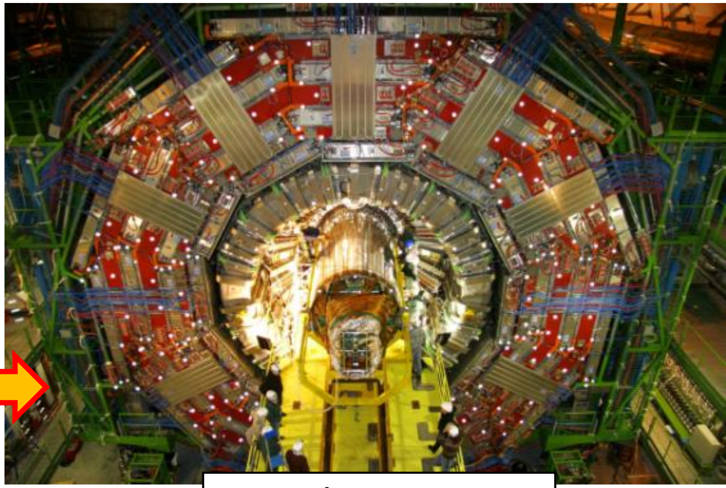
Rod, 688x
Finland, U.S., CERN

Wheel, 1x
CERN

Rod to Wheel

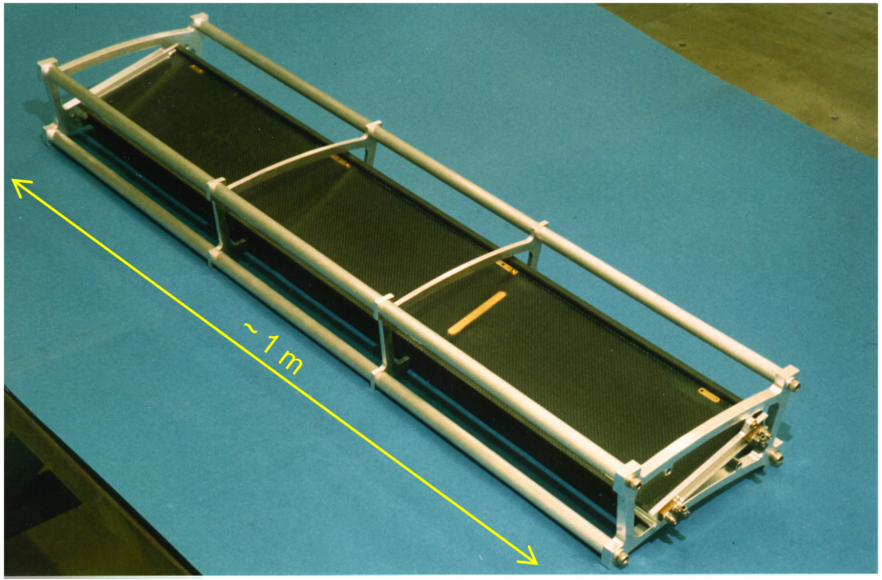


Wheel to Tracker

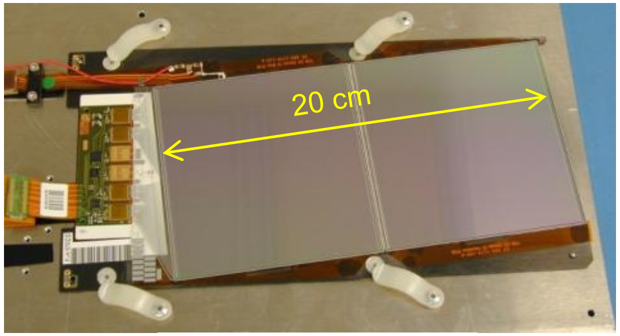


Tracker to CMS

TOB “Rods”



Purpose:
Support and cooling of Silicon detector modules. Module positioning to < 0.1 mm.

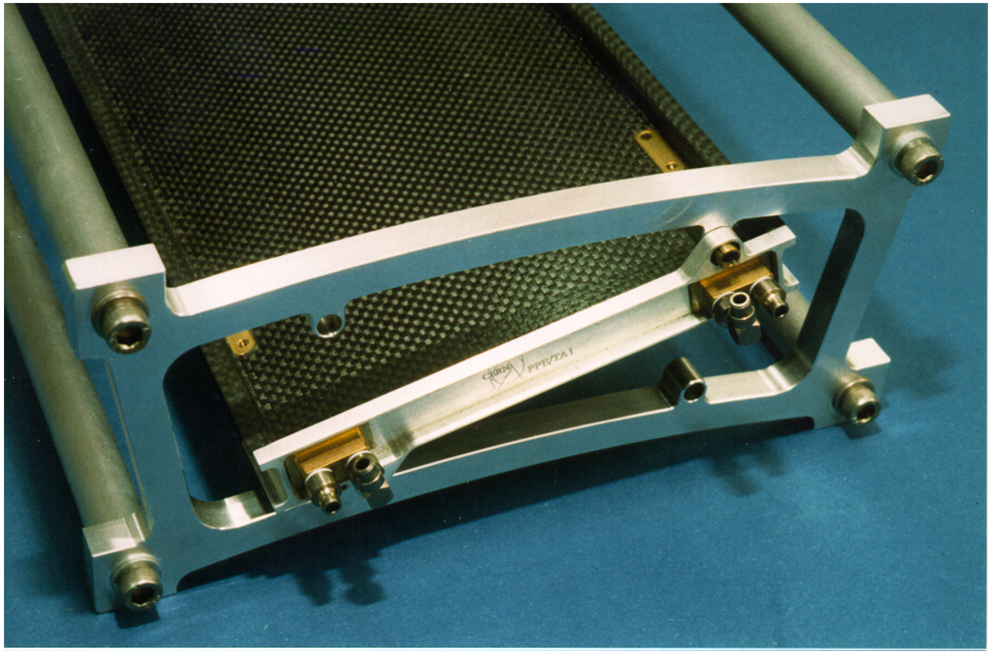


Silicon module

This early development version of a “Rod” was made of carbon-fibre skins + plastic foam core, with the cooling pipe and metallic inserts embedded to the sandwich structure.

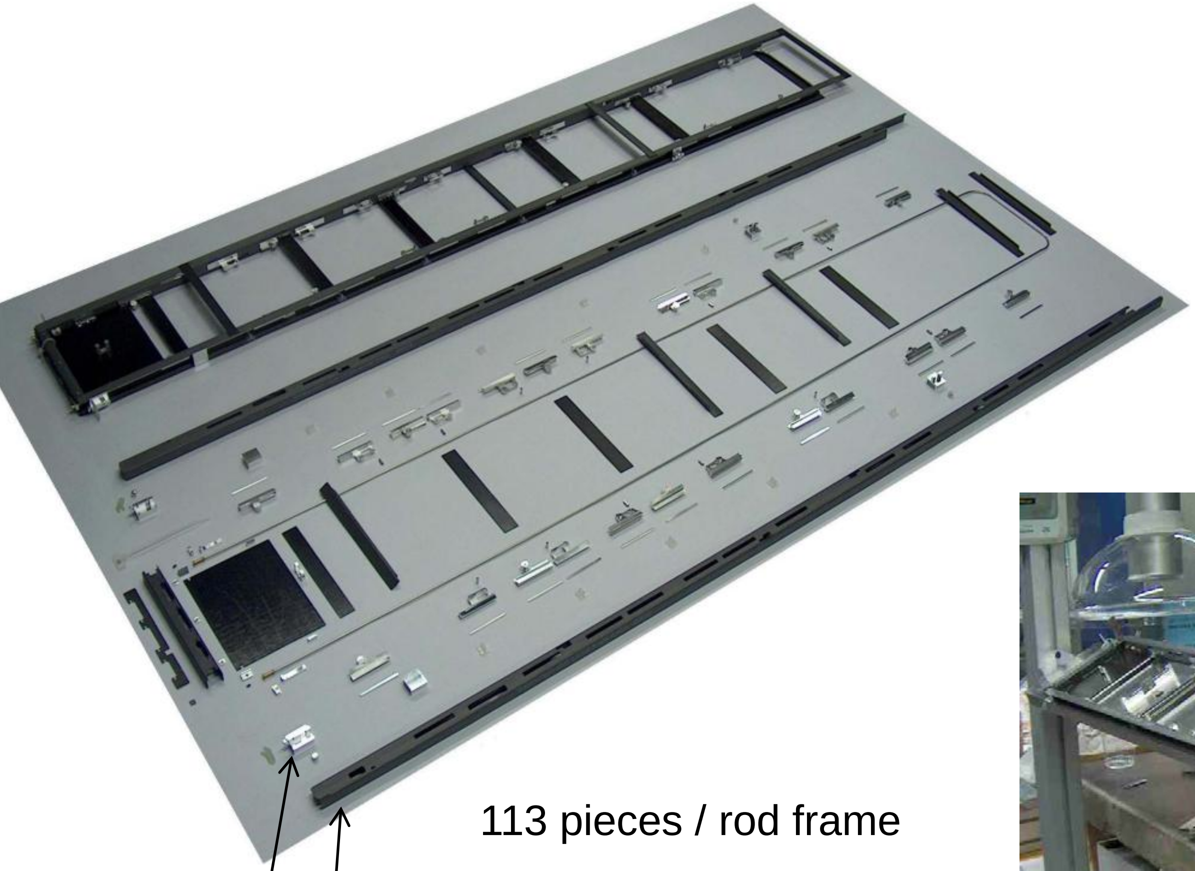
Module support inserts with over-thickness, machined to final dimensions in the assembly.

- → Use machining to reach high final precision.
- → But, supporting the light-mass structure during machining very difficult.
- → Doable by additional supports, shims and clamps, but time-consuming (measurements needed) and operator dependent.
- → Can be done for few pieces, but not for series of tens or hundreds.



TOB “Rods”

Chosen manufacturing and assembly method:
Produce “industrially manufacturable” components
and assemble them with room-temperature gluing on high-precision jigs.



Metallic inserts

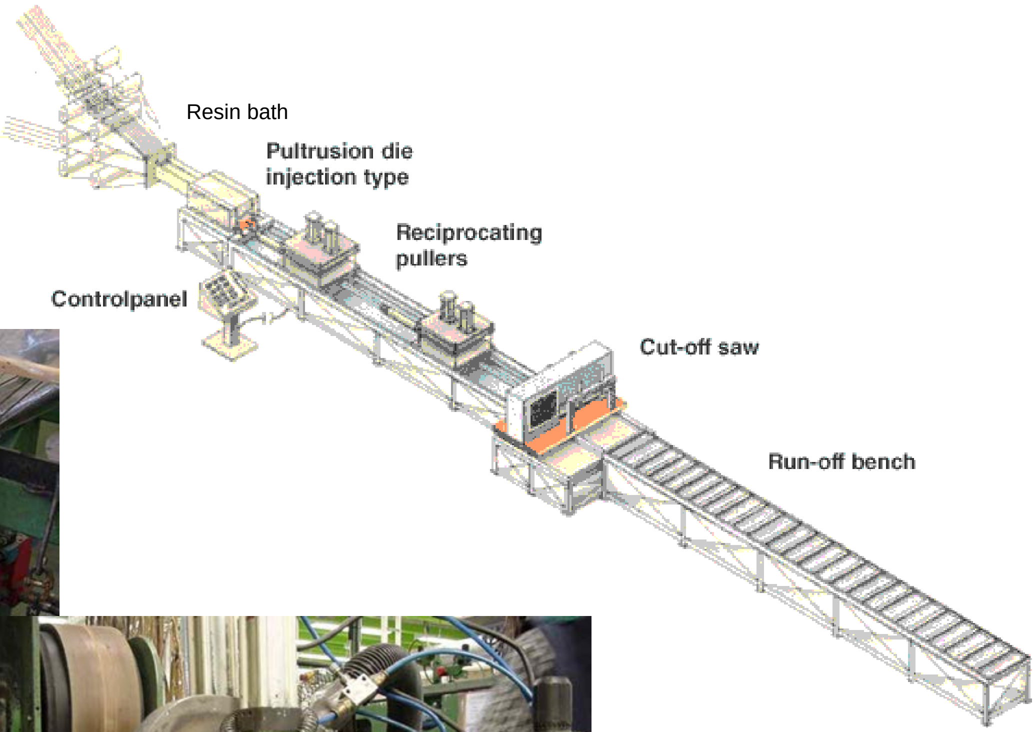
Carbon fibre pieces
in ~1 mm precision

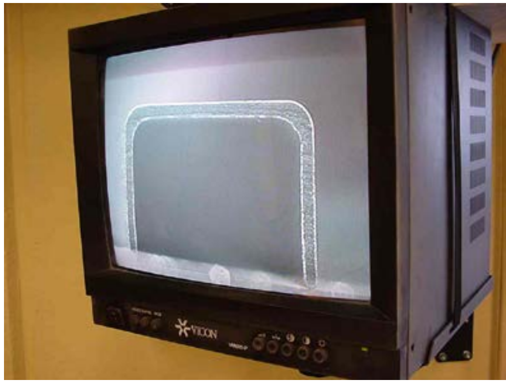
113 pieces / rod frame

760 rod frames in total
(688 needed + 72 spares)
= 85880 pieces in total !

1. Components placed stress-free on an accurate gluing jig
2. Capillary glue (Araldite 2020) added + room-temperature cure

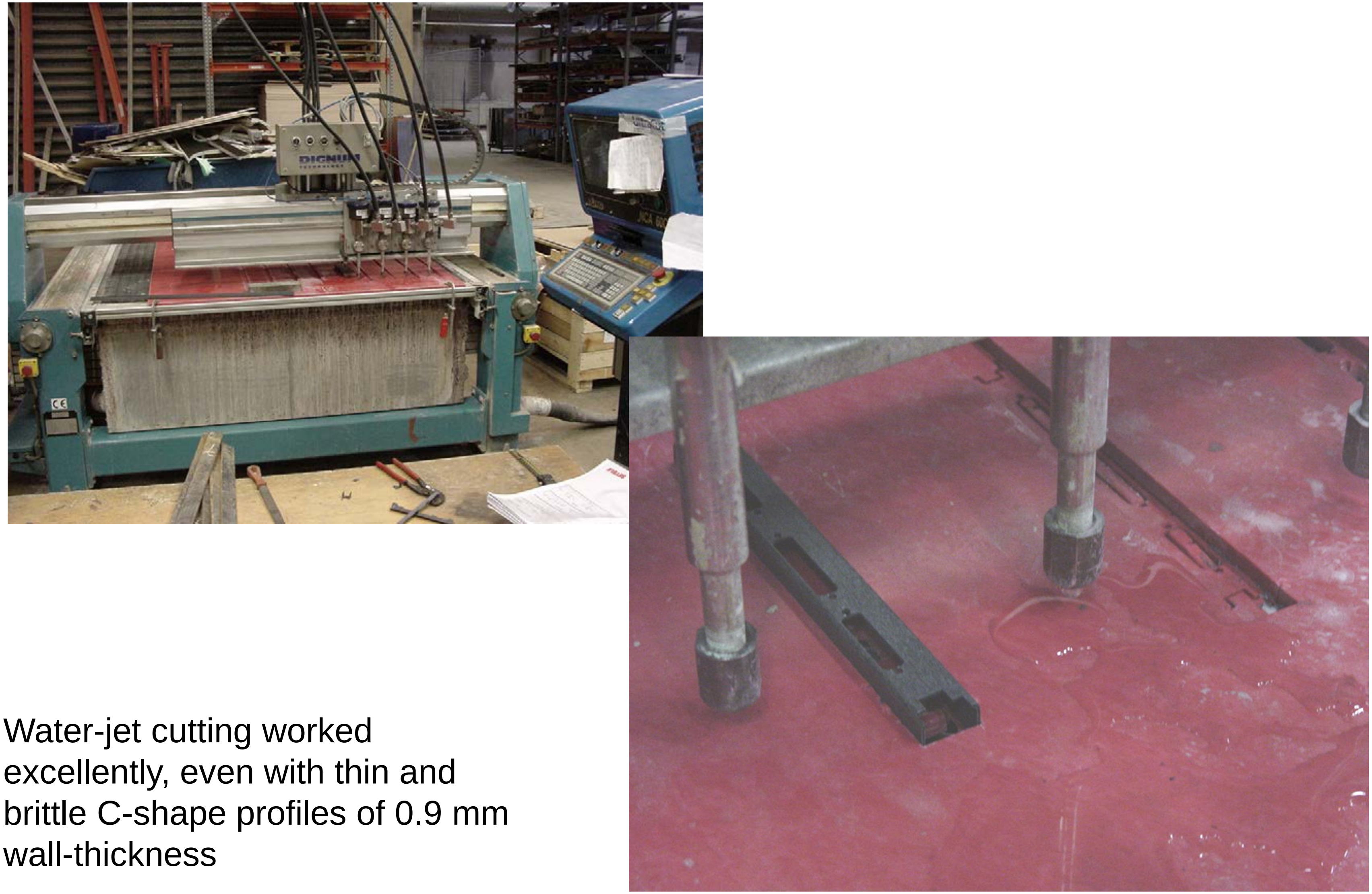
Industrial production of components





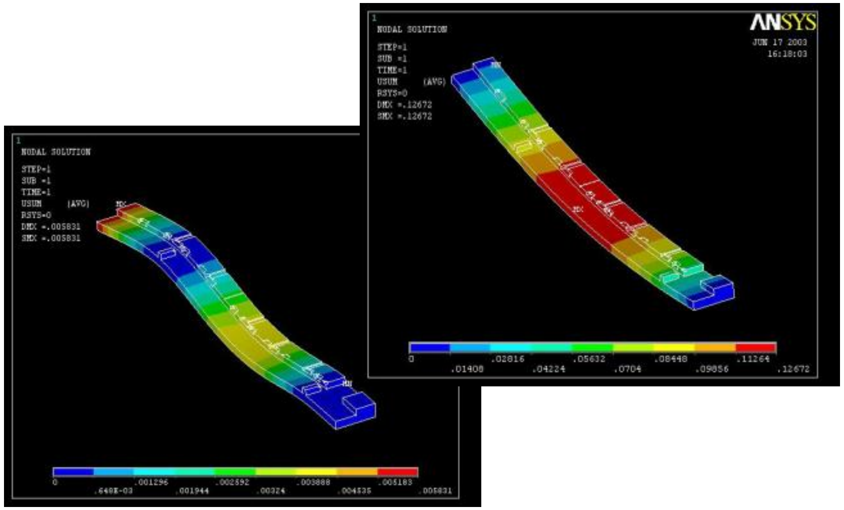
Pultrusion of C-profiles
in carbon-fibre/epoxy

Industrial production of components



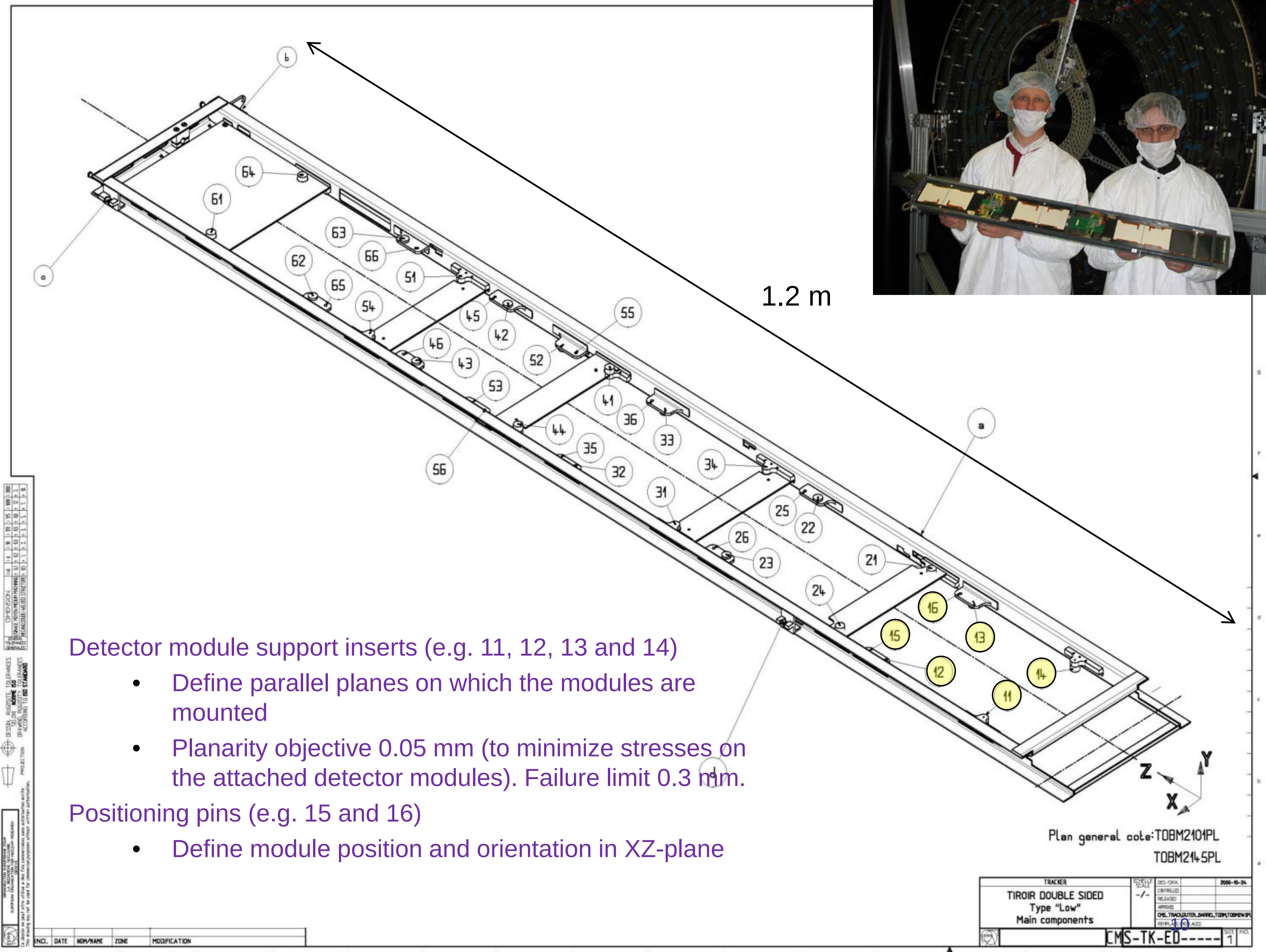
Water-jet cutting worked excellently, even with thin and brittle C-shape profiles of 0.9 mm wall-thickness

Assembly



Good tools, tested procedures and high-quality workmanship are essential.

756x in total



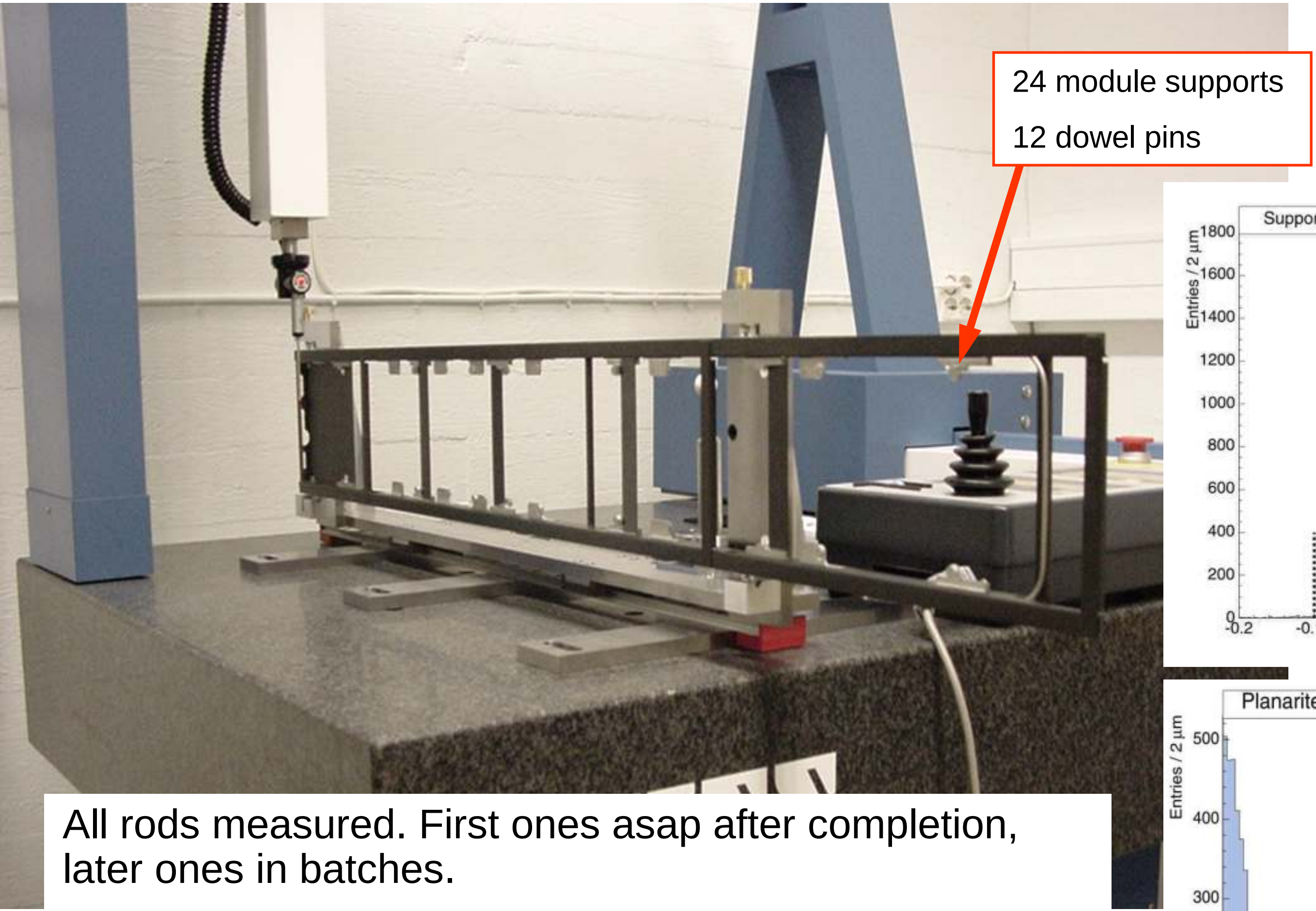
Detector module support inserts (e.g. 11, 12, 13 and 14)

- Define parallel planes on which the modules are mounted
- Planarity objective 0.05 mm (to minimize stresses on the attached detector modules). Failure limit 0.3 mm.

Positioning pins (e.g. 15 and 16)

- Define module position and orientation in XZ-plane

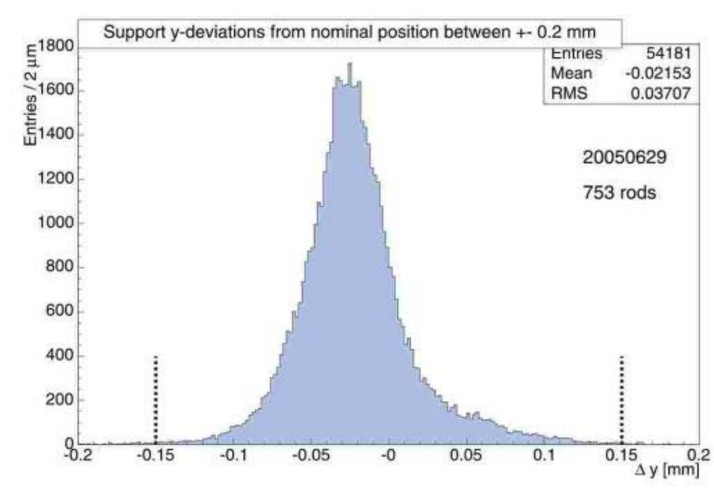
Measurements

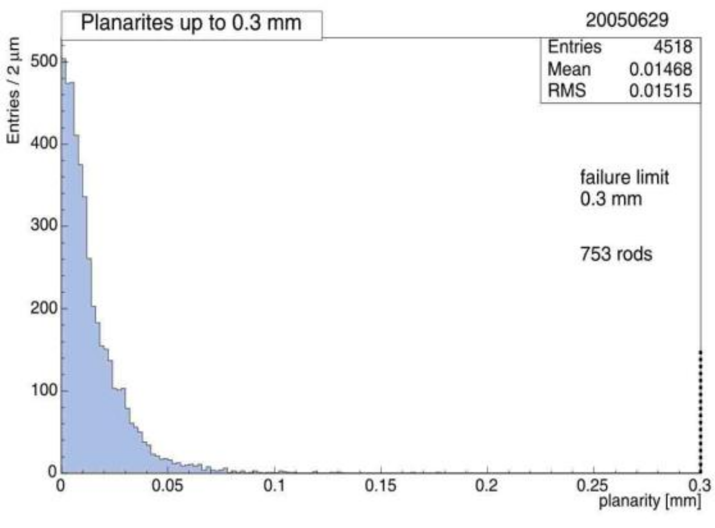


24 module supports

12 dowel pins

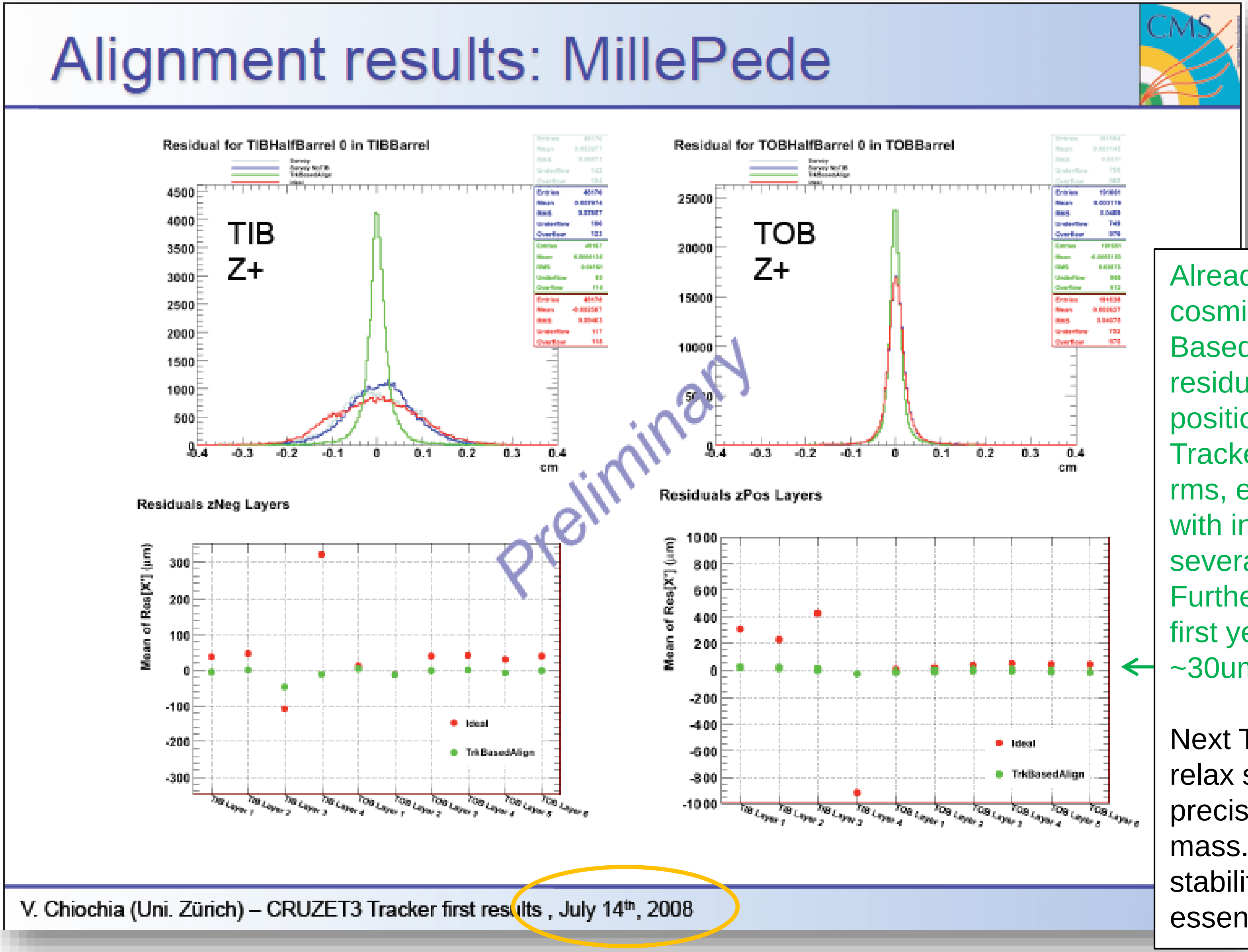
All rods measured. First ones asap after completion, later ones in batches.





Geometrical precision of the module supports and positioning dowel pins measured to be better than 50 µm (the initial requirement). 4% of assemblies found out of tolerances, and corrected (e.g. detach one insert with heat and replace/re-glue). Repairs are time-consuming.

Mechanical precision vs. Alignment with Tracks



Alignment results: MillePede

V. Chiochia (Uni. Zürich) – CRUZET3 Tracker first results , July 14th, 2008

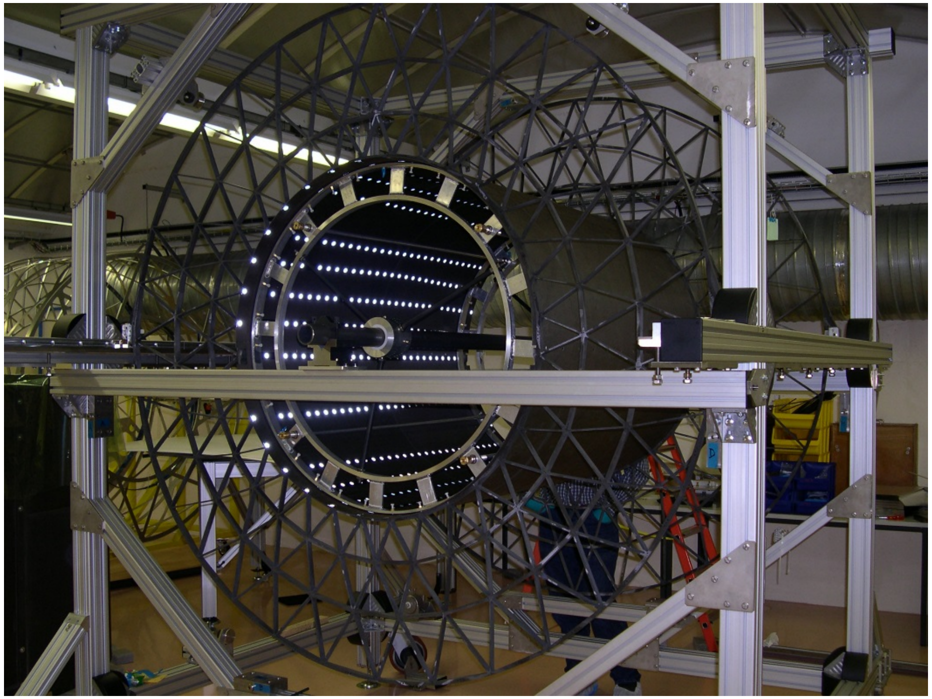
Already after first cosmic runs with Track Based Alignment the residuals for module positions within the full Tracker were at ~50um rms, even for layers with initial residuals of several hundred um. Further improved within first year of operation to ~30um.

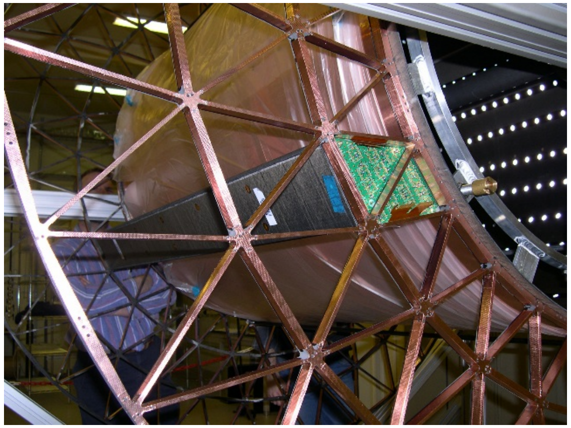
Next Trackers: May relax some of the precision if gaining in mass. However, stability remains essential.

ATLAS TRT Barrel Support Structure

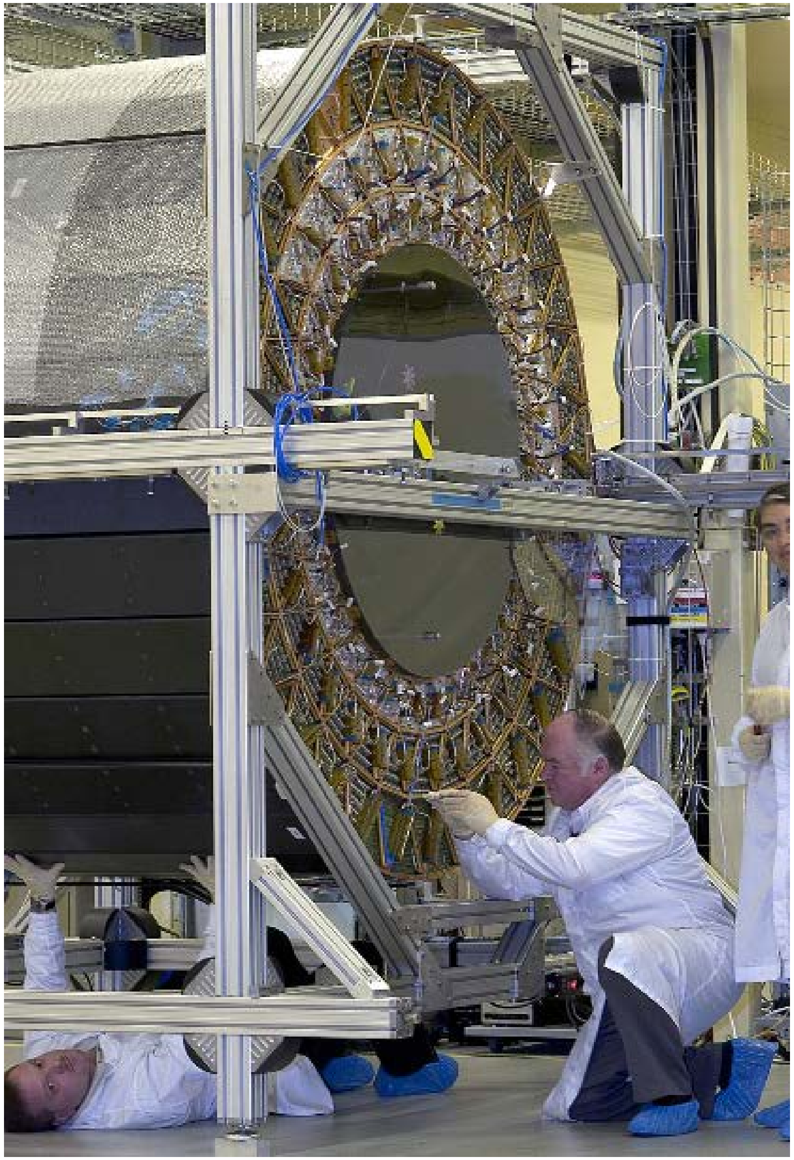
Contact persons: Andrea Catinaccio, Neil Dixon

ATLAS TRT Barrel Support Structure

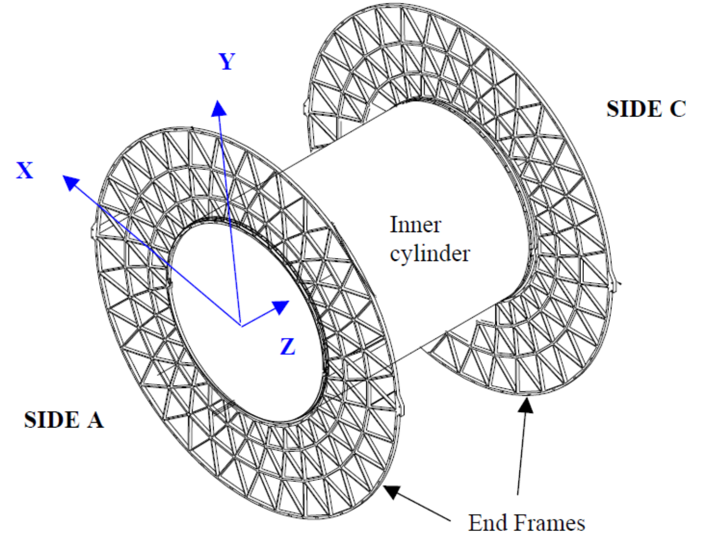




Length ~1.5 m,
Diam ~2.2 m.
Mass with
detectors ~700 kg.

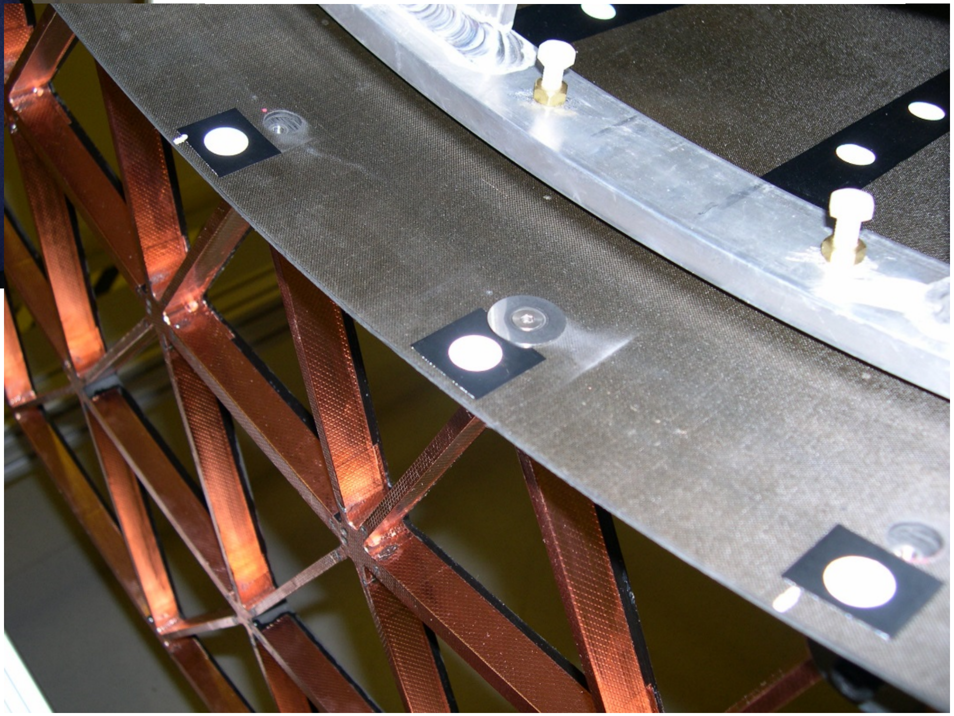


Alignment of the End Frames

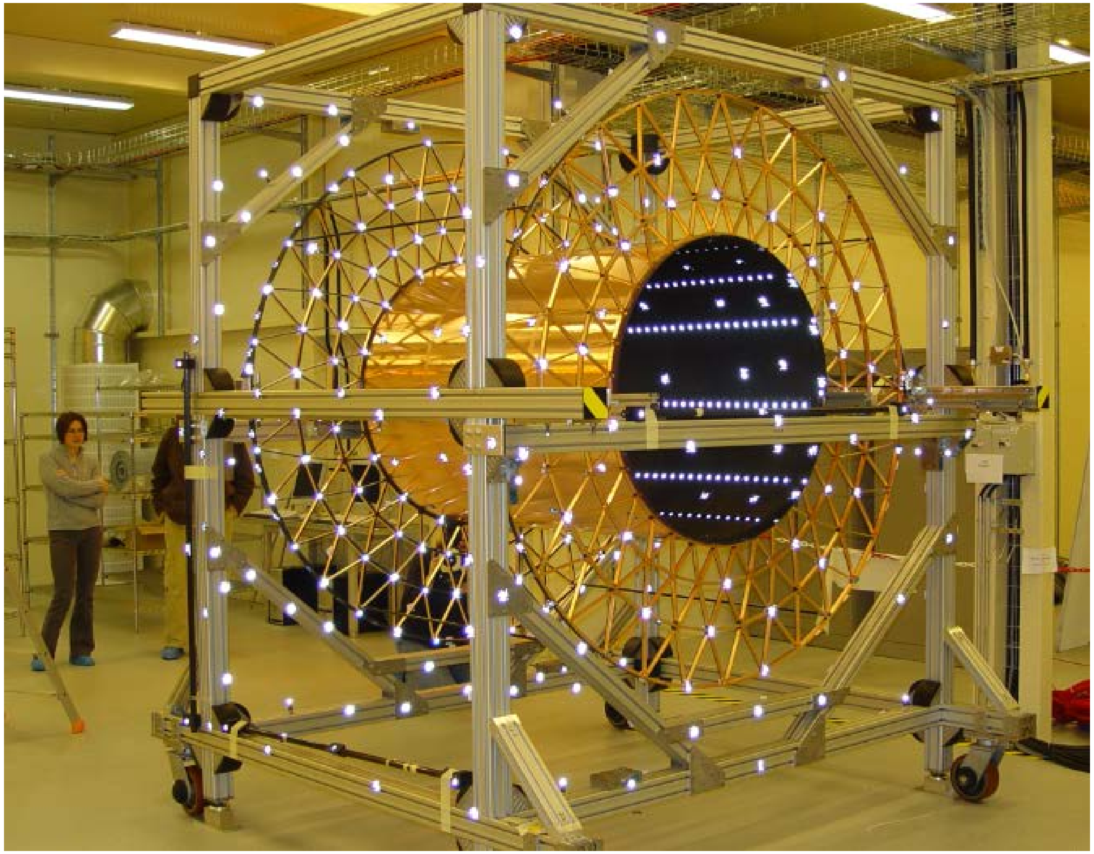


Measurements with a 3D measurement arm (Romer).

End Frames and Inner Cylinder aligned in a jig and attached with gap-filling glue and screws.



Control of the achieved precision



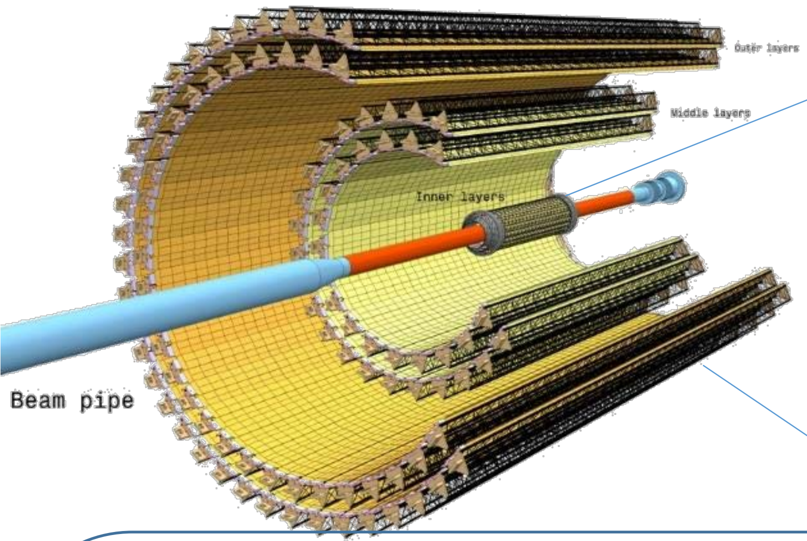
Photogrammetry measurements, Antje Behrens et al., CERN EDMS document 459653, 2004

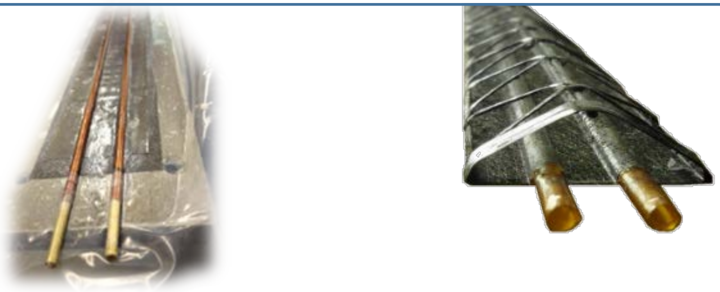
- Measurement of 70 reference points in the two end frames
- Photogrammetry measurement precision 0.06 mm.
- Nominal distance between opposite end points 1464 mm, measured distances max +0.48 mm, min -0.91 mm.
- Rotation of end frames (best fit of all points): 0.019 mrad
- Relative displacement of the two end frames (best fit of all points) 140 um in horizontal direction, 20 um in vertical direction.

ALICE Inner Tracking System upgrade

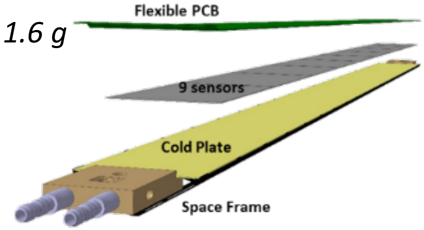
Contact person: Corrado Gargiulo

Base structure: Staves

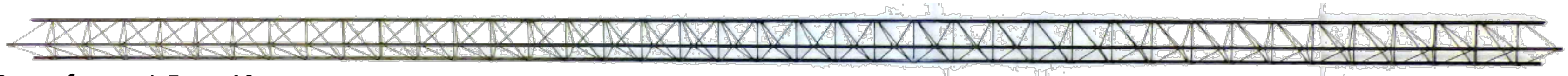




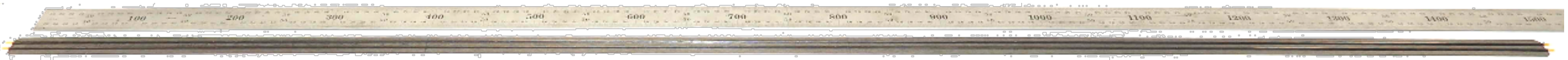
Spaceframe & Coldplate 0.29m, 1.6 g



3 inner layers



Spaceframe 1.5 m, 40 g



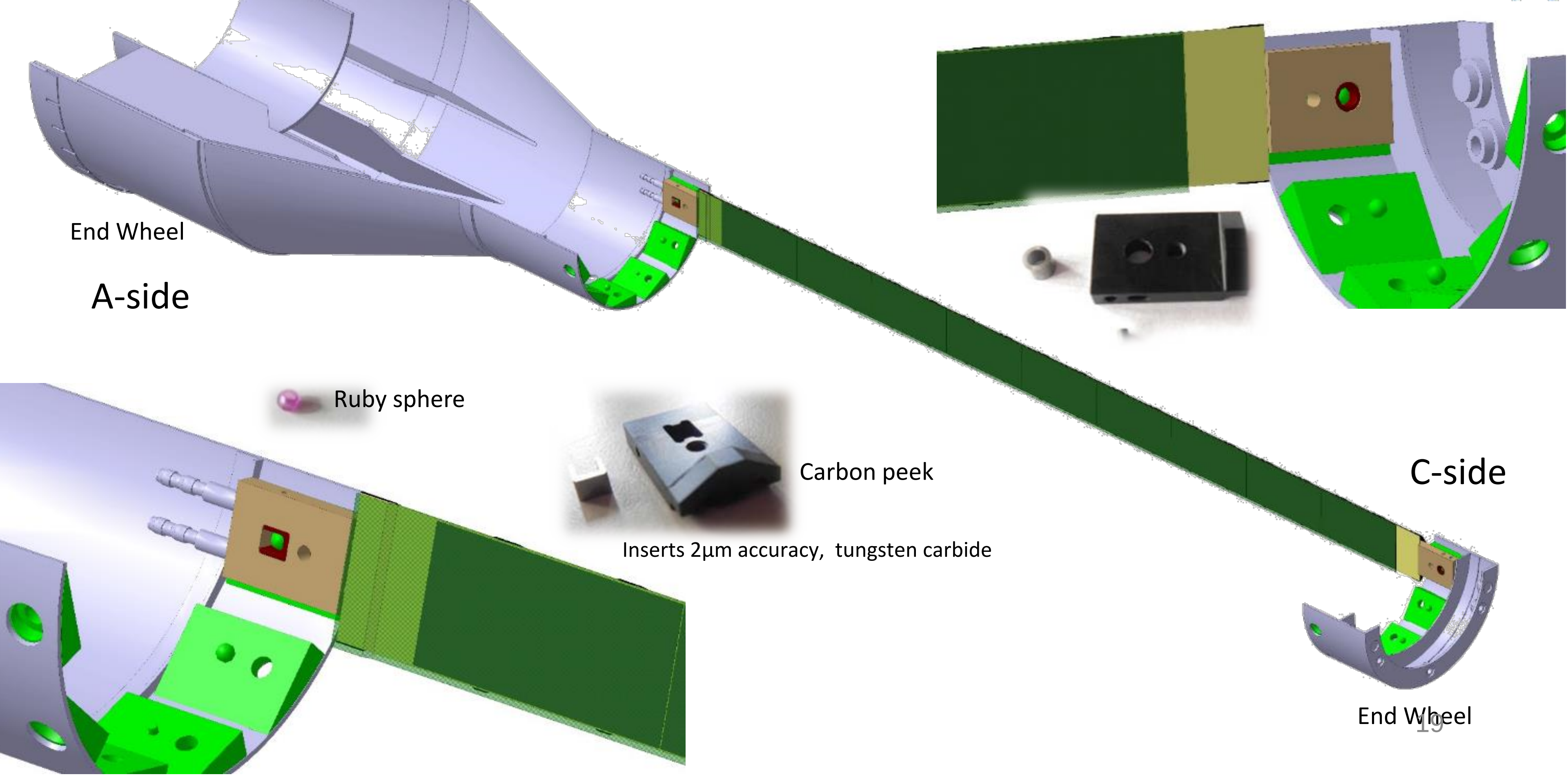
Coldplate 1.5m, 20 g

Spaceframe +2 Coldplates 1.5 m, 80 g

4 outer layers

Inner Barrel staves to layer configuratio

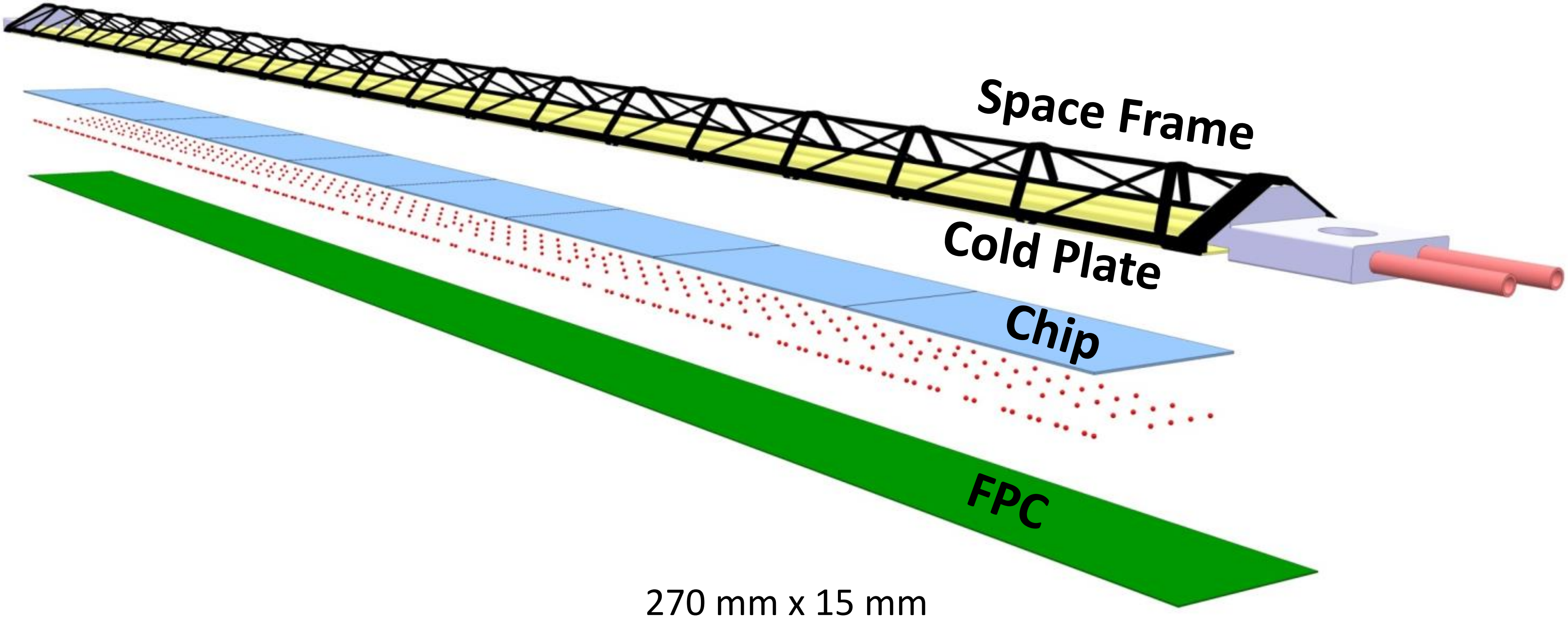
The stave is positioned on the end wheels reference planes by connectors at both extremities that engage a ruby sphere fixed in the reference plane. The Stave position is then blocked with a screw.



Inner Barrel Stave

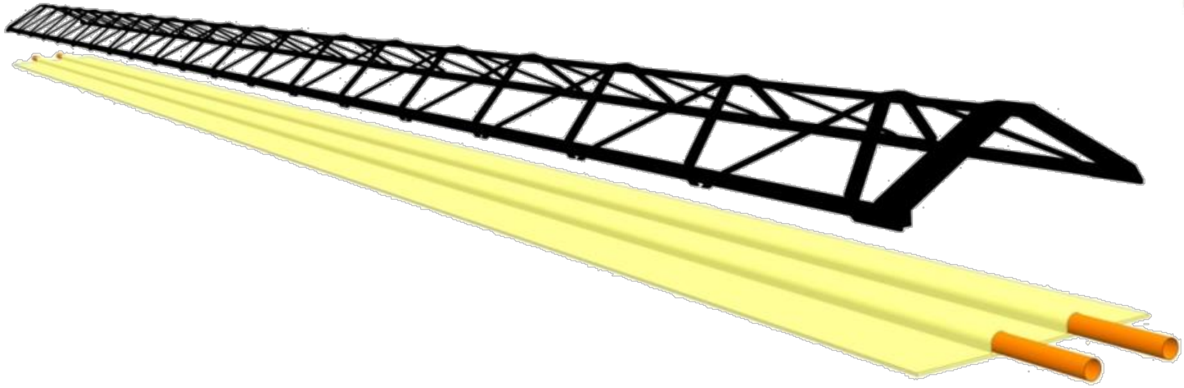
Space Frame: truss-like lightweight mechanical support structure based on composite material (carbon fibre).;

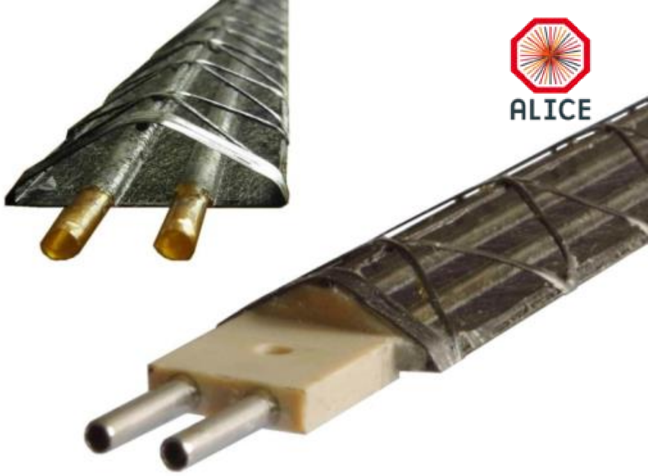
Cold Plate: a sheet of high-thermal conductivity carbon fibre with embedded polyimide cooling pipes, which is integrated with the Space Frame



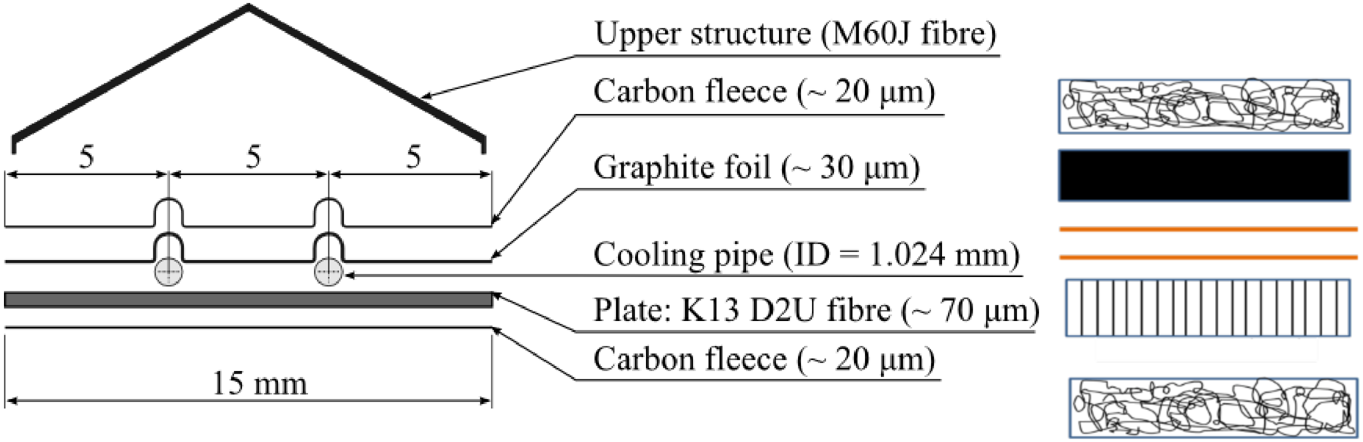
270 mm x 15 mm

Inner Barrel Stave





Transversal section:



Upper structure (M60J fibre)

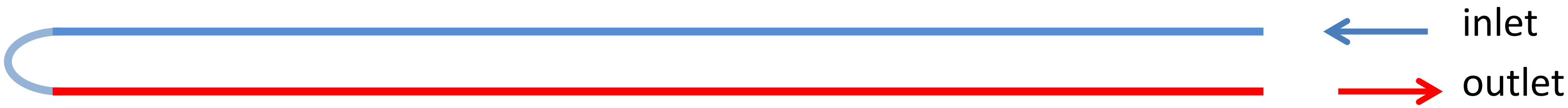
Carbon fleece (~ 20 µm)

Graphite foil (~ 30 µm)

Cooling pipe (ID = 1.024 mm)

Plate: K13 D2U fibre (~ 70 µm)

Carbon fleece (~ 20 µm)



inlet

outlet

1. Lamination and high temp cure of the cold plate
2. Cooling pipes glued to the cold plate at room temperature
3. Space frame wound around the package + room temperature cure

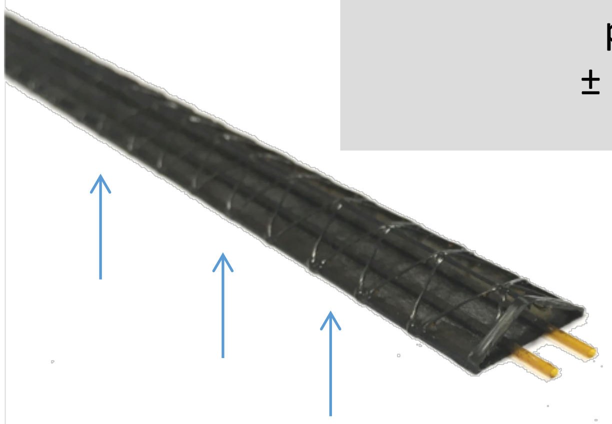
Production Process: parts separation

Cut and mould separation

~1.6 gram @290mm length

IB Spaceframe&Coldplate planarity

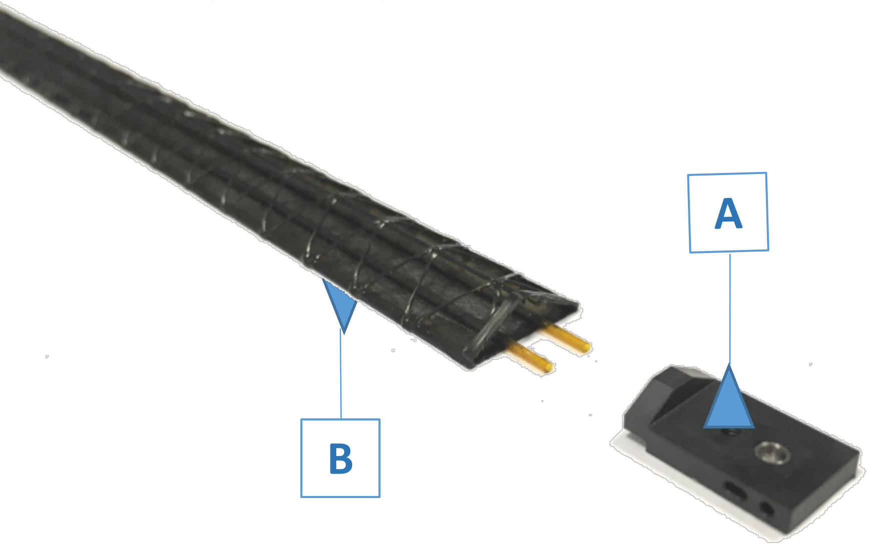
Layout and curing process optimization:
planarity achived
± 0,028 ÷ 0,040 mm



Planarity check of the coldplate where chips are glued

Part n#		MIN (mm)	MAX (mm)
1	7	-0.062	0.062
1	11	-0.036	0.053
1	12	-0.084	0.133
1	13	-0.103	0.067
1	14	-0.056	0.065
1	15	-0.088	0.070
1	16	-0.060	0.060
1	17	-0.049	0.083
1	**18**	**-0.028**	**0.035**
1	**20**	**-0.030**	**0.030**
1	**21**	**-0.039**	**0.039**
1	**23**	**-0.030**	**0.030**
1	**26**	**-0.040**	**0.040**
17a	1	-0.054	0.054
17a	2	-0.088	0.088
18a	1	-0.055	0.055
19	1	-0.052	0.052
19a	1	-0.063	0.063
20	1	-0.062	0.062
20	2	-0.069	0.069
20a	1	-0.144	0.144
20a	2	-0.053	0.053
20b	1	**-0.039**	**0.039**
21b	1	N/A	N/A

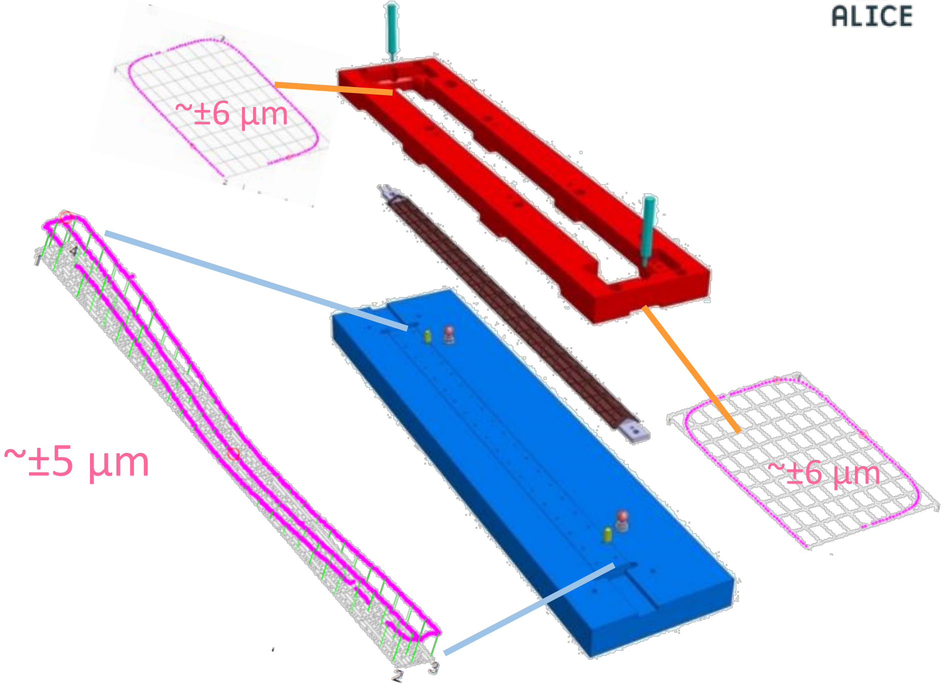
IB gluing connectors with Master jig

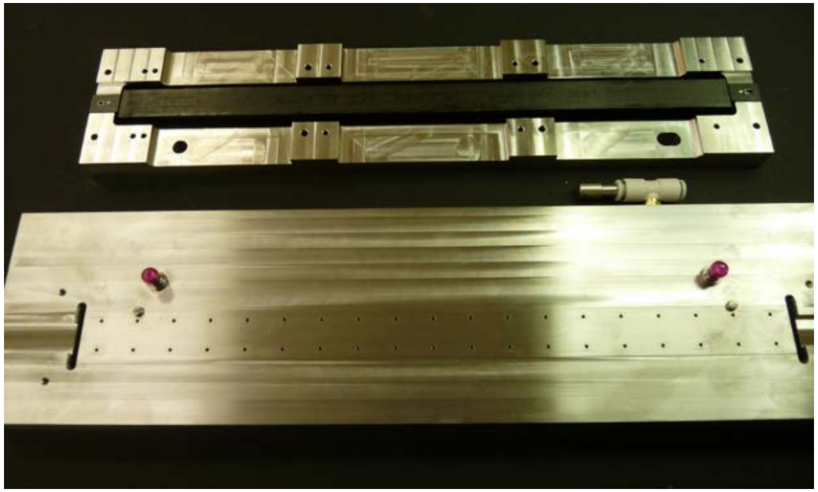


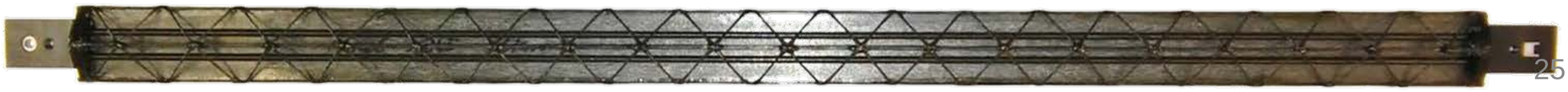
Inner Barrel stave mechanics is the assembly of

- CFRP Filament wound structure
- Carbon Peek connectors

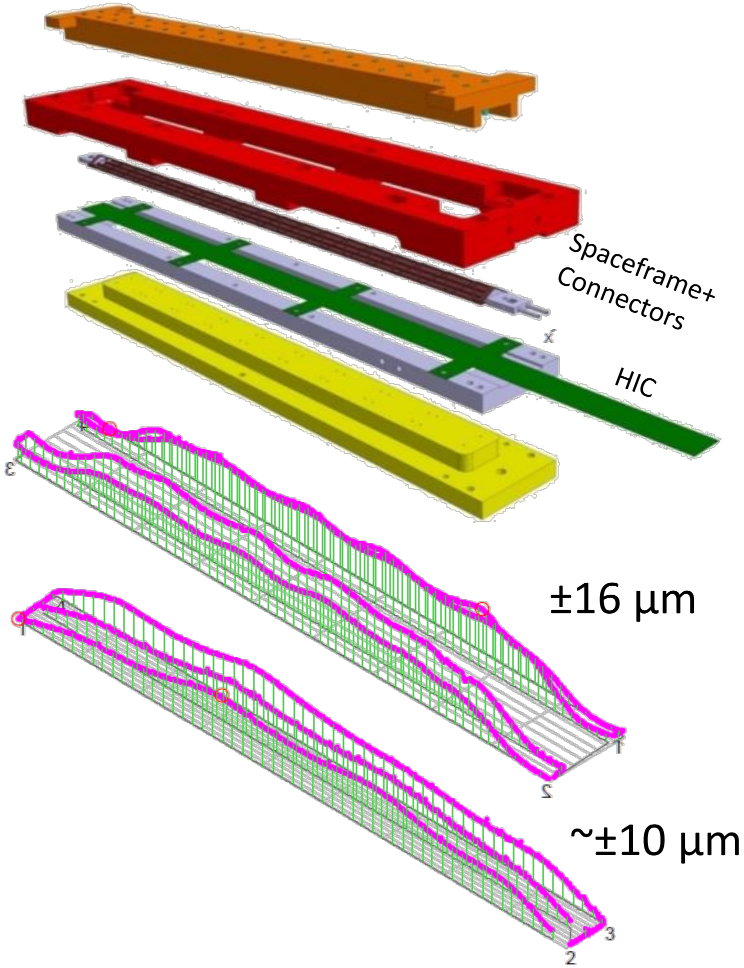
The carbon peek connectors provide the precise position of the stave

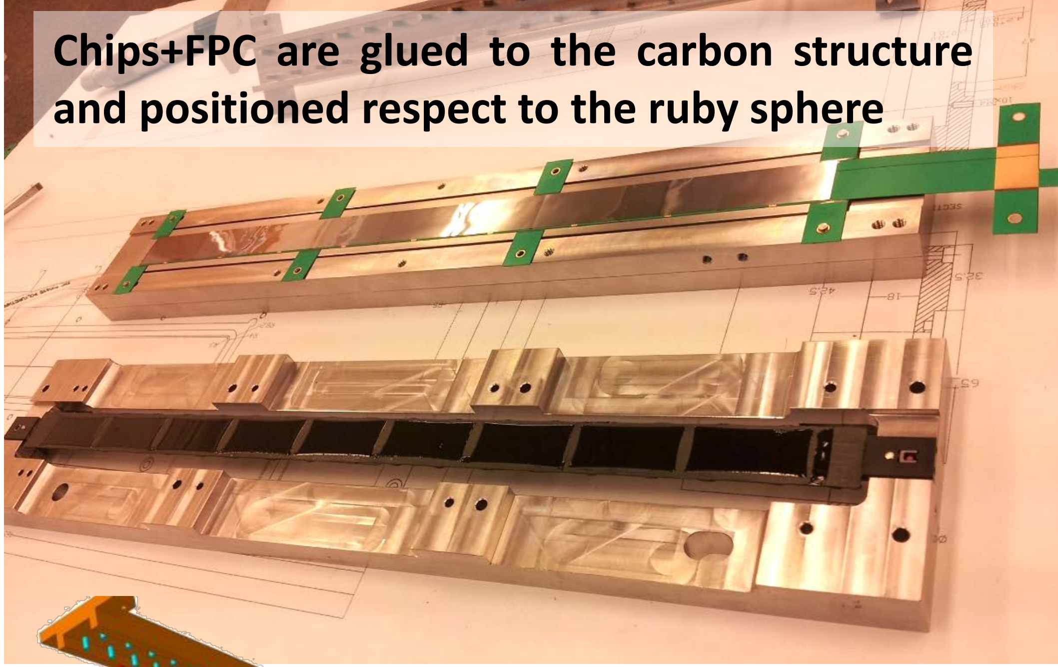




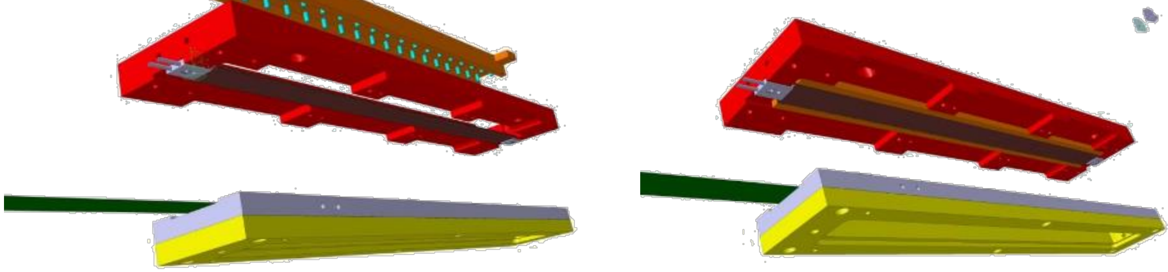


Space Frame & Cooling Plate + Chips & Flexible Printer Circuit

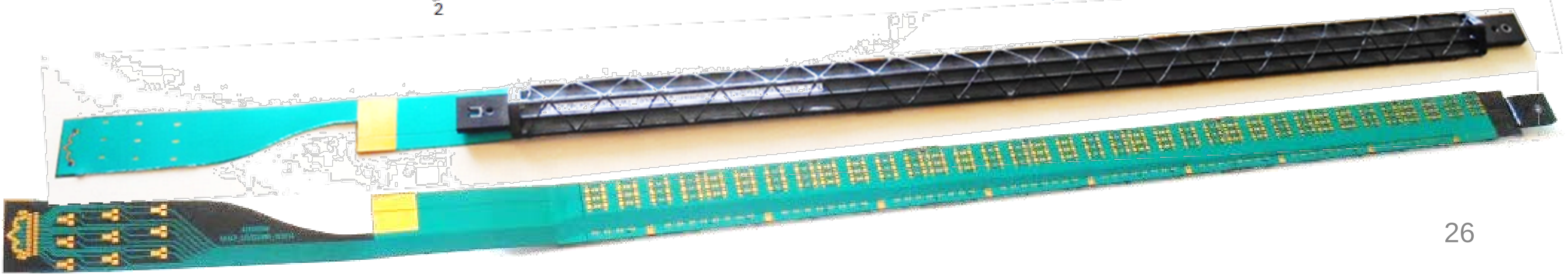




Chips+FPC are glued to the carbon structure and positioned respect to the ruby sphere

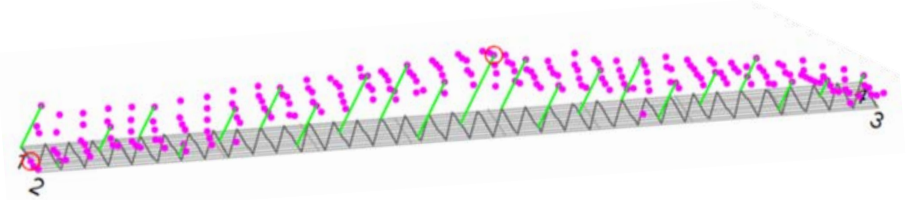


Inner Barrel stave is the assembly of
- mechanics
- Chip+FPC



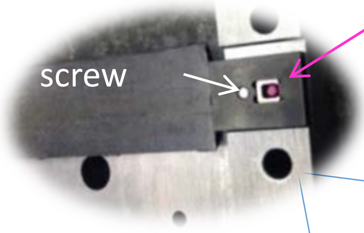
Assembly: SF&CP + HIC Gluing

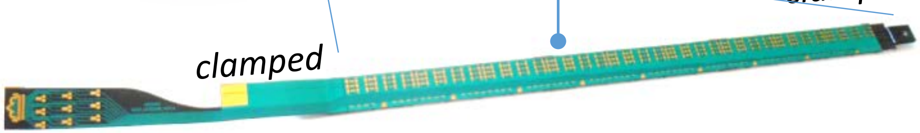
Before HIC gluing

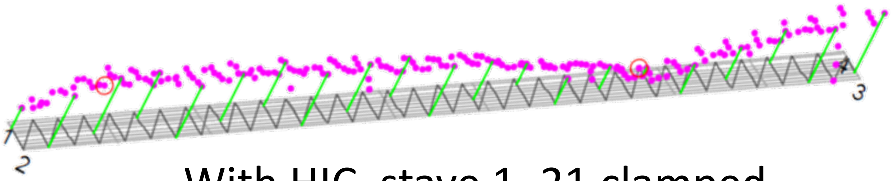


Spaceframe 1_21 (w/o connectors) free

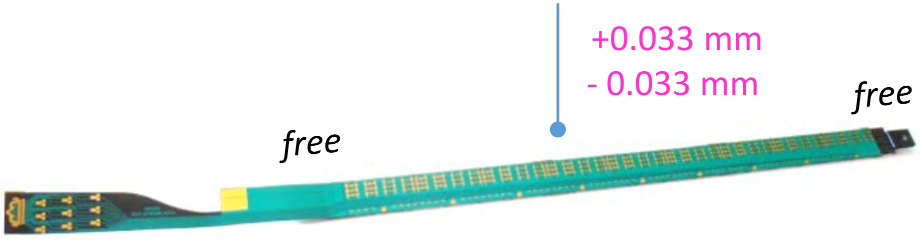
After HIC gluing

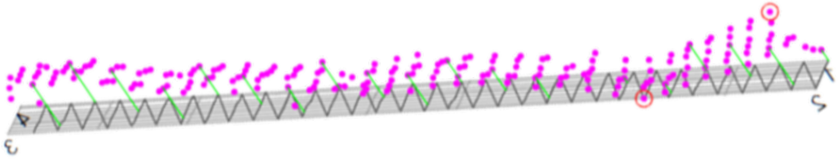






With HIC, stave 1_21 clamped



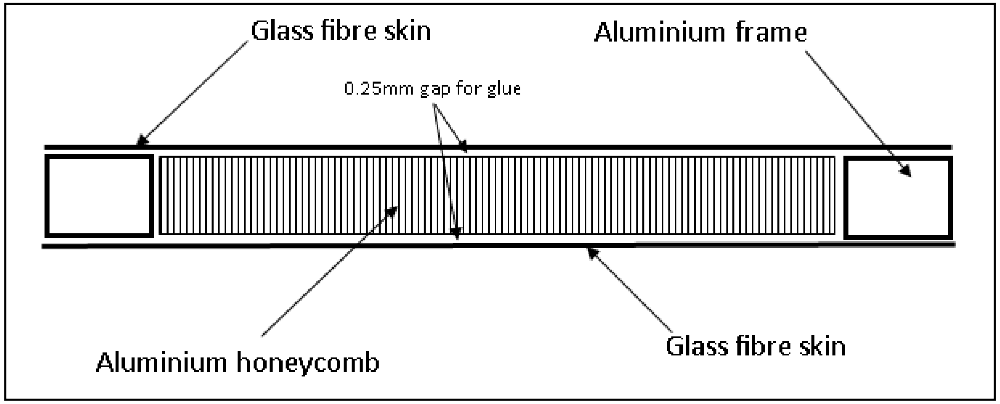


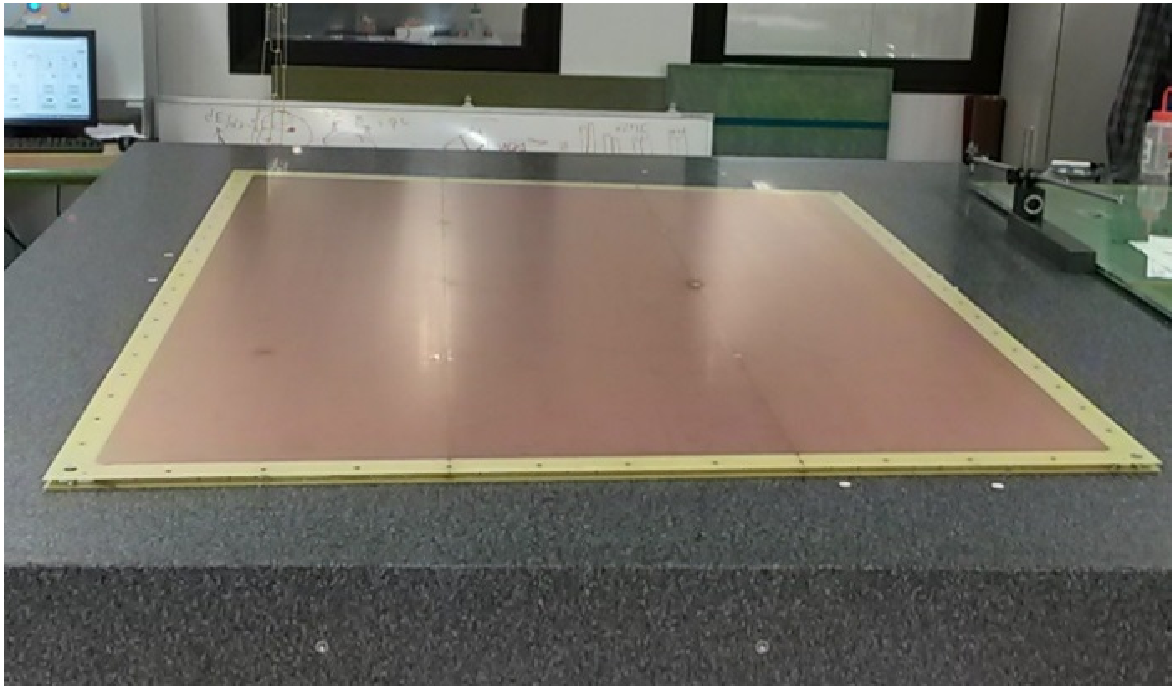
With HIC, stave 1_21 free

ATLAS Micromegas

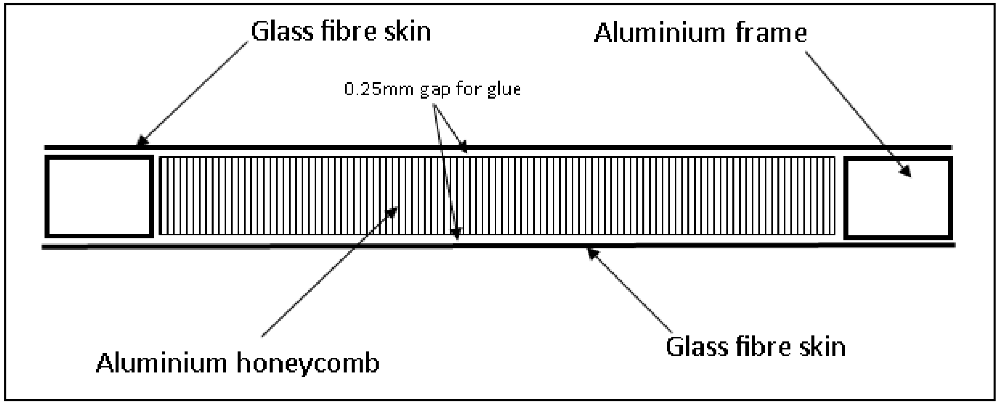
Contact person: Francisco Perez

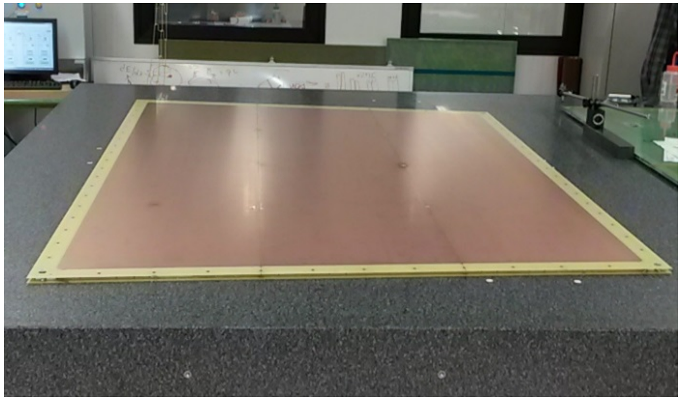
Micromega Drift Panel design

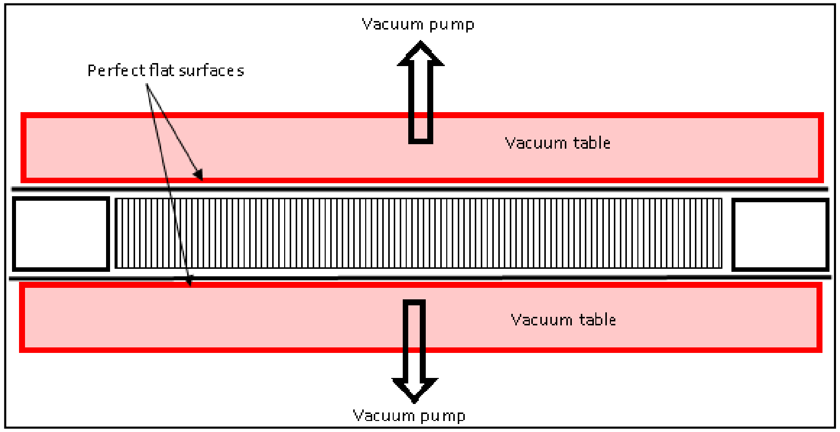




Micromega Drift Panel manufacture with vacuum tables

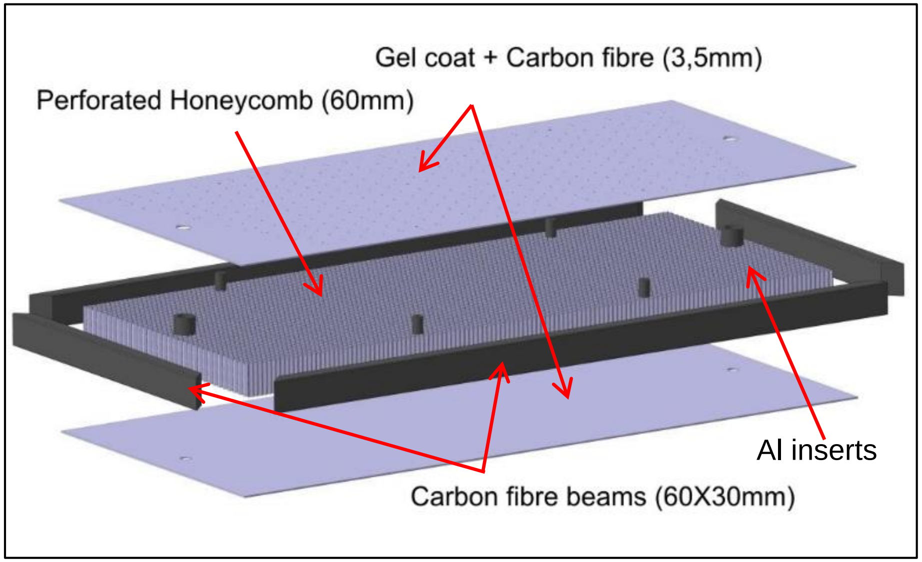






Lower Glass-fibre skin, honeycomb and alu frame assembled on the lower vacuum table.

Upper Glass-fibre skin held and lowered on the stack with the upper vacuum table.

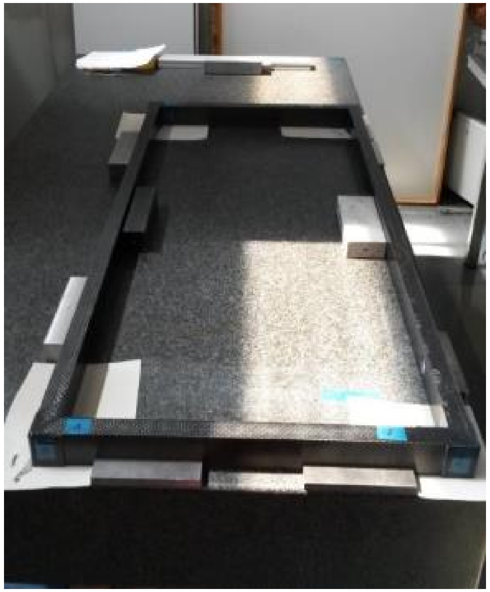


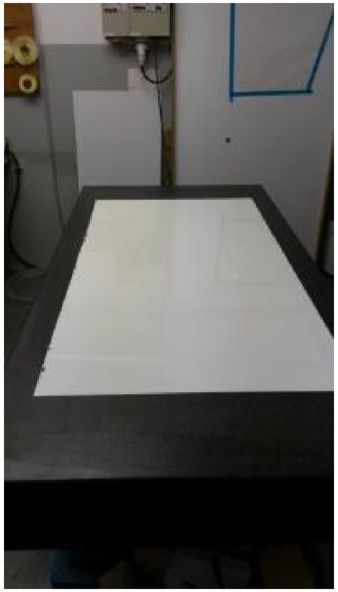
To make high-precision Panels the Vacuum tables must be flat, rigid and ‘porous’ for vacuum.

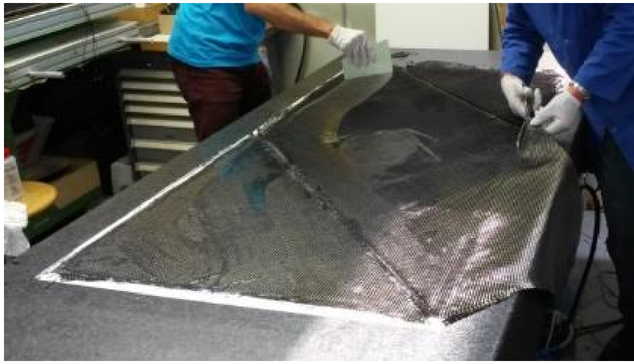
For handling the vacuum tables need to be light.

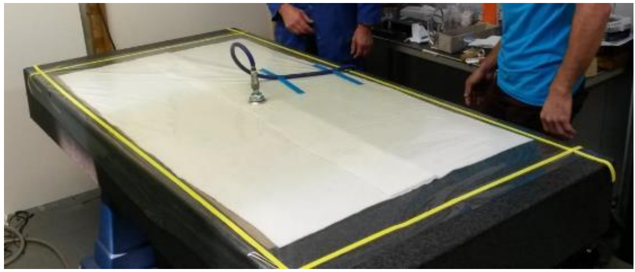
→ Use of a sandwich composite construction.

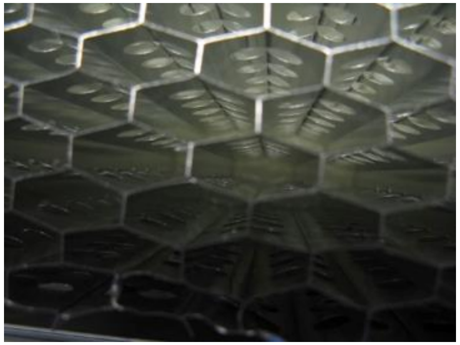
Smaller size proto of a Vacuum table



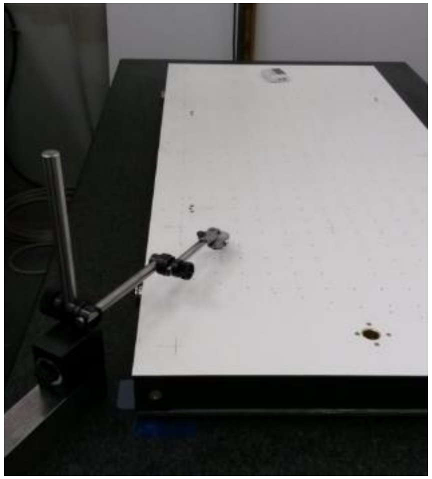








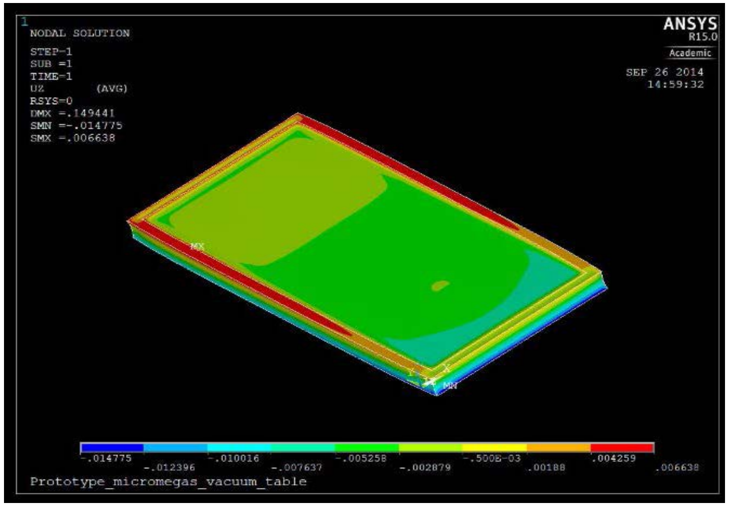
Perforated Al
honeycomb



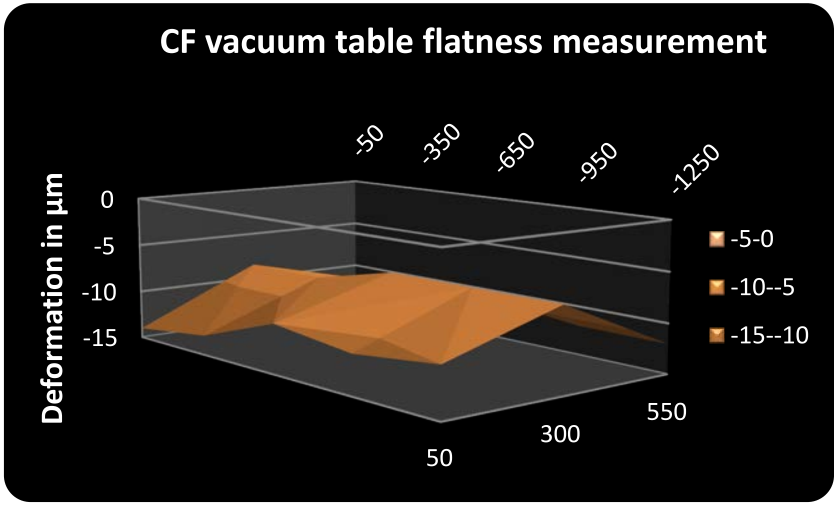
Flatness results for proto Vacuum table (1300X600X60mm)

- Calculated < 20µm
- No T effect ΔT=4°C

- Measured < 10µm
- No T effect ΔT=7°C

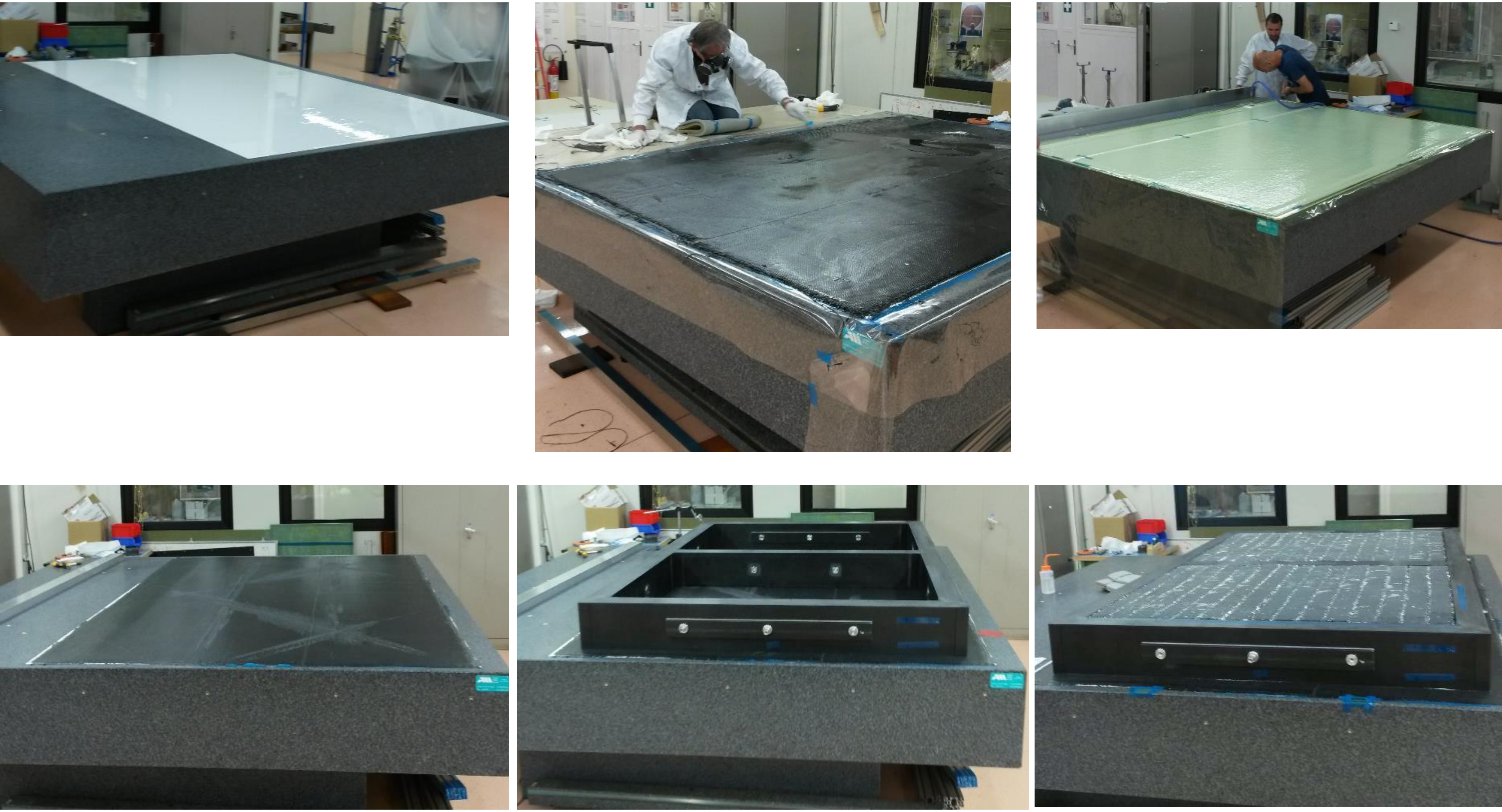


```
1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ        (AVG)
RSYS=0
DMX =.149441
SMN =-.014775
SMX =.006638
```



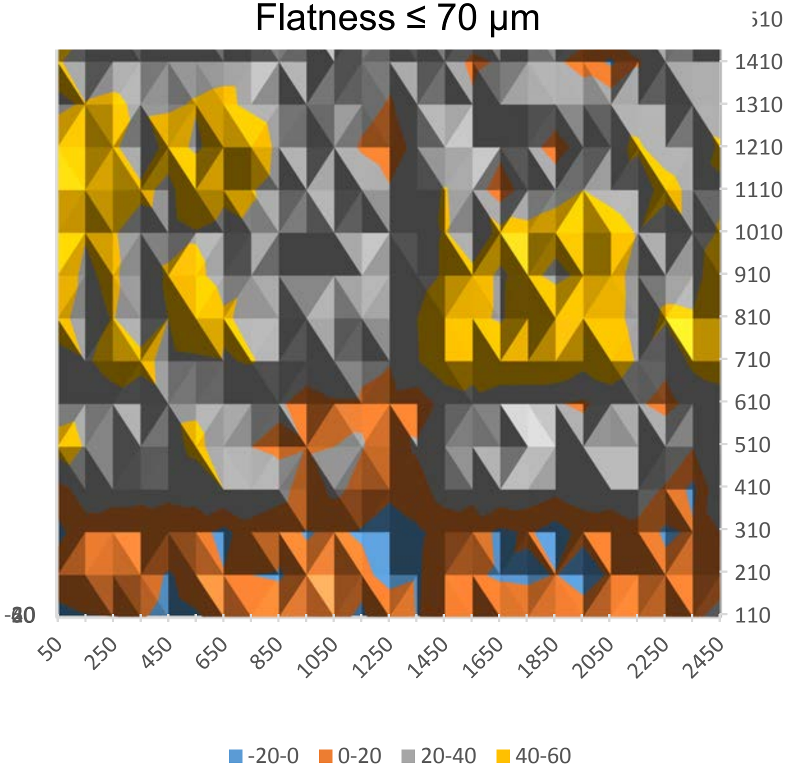
Results used for the design of the final size vacuum tables 2500X1600X200mm.

Manufacture of large size Vacuum tables

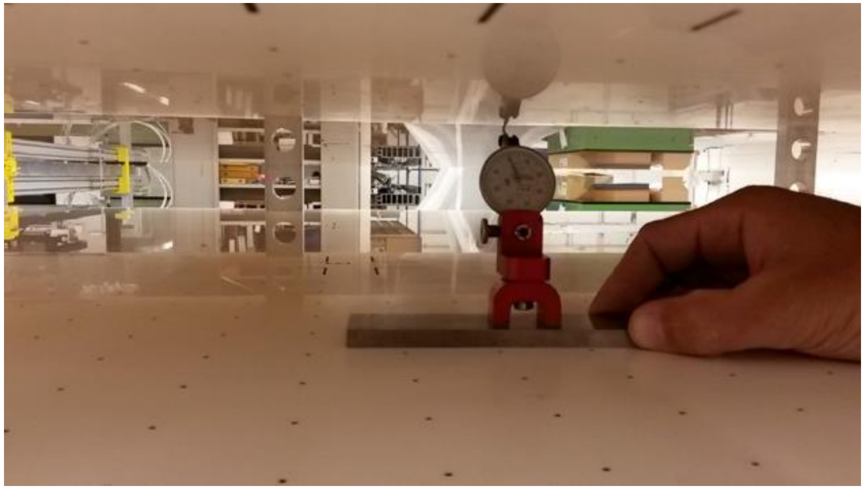


Obtained geometrical quality of the Vacuum tables

Measurement of Table 2
on 3 points of support with vacuum on
Flatness ≤ 70 µm



Tables 1 and 2
Lower table on 3 points of support
Upper table on 4 supports in corners.
Parallelism ≤ 100 µm

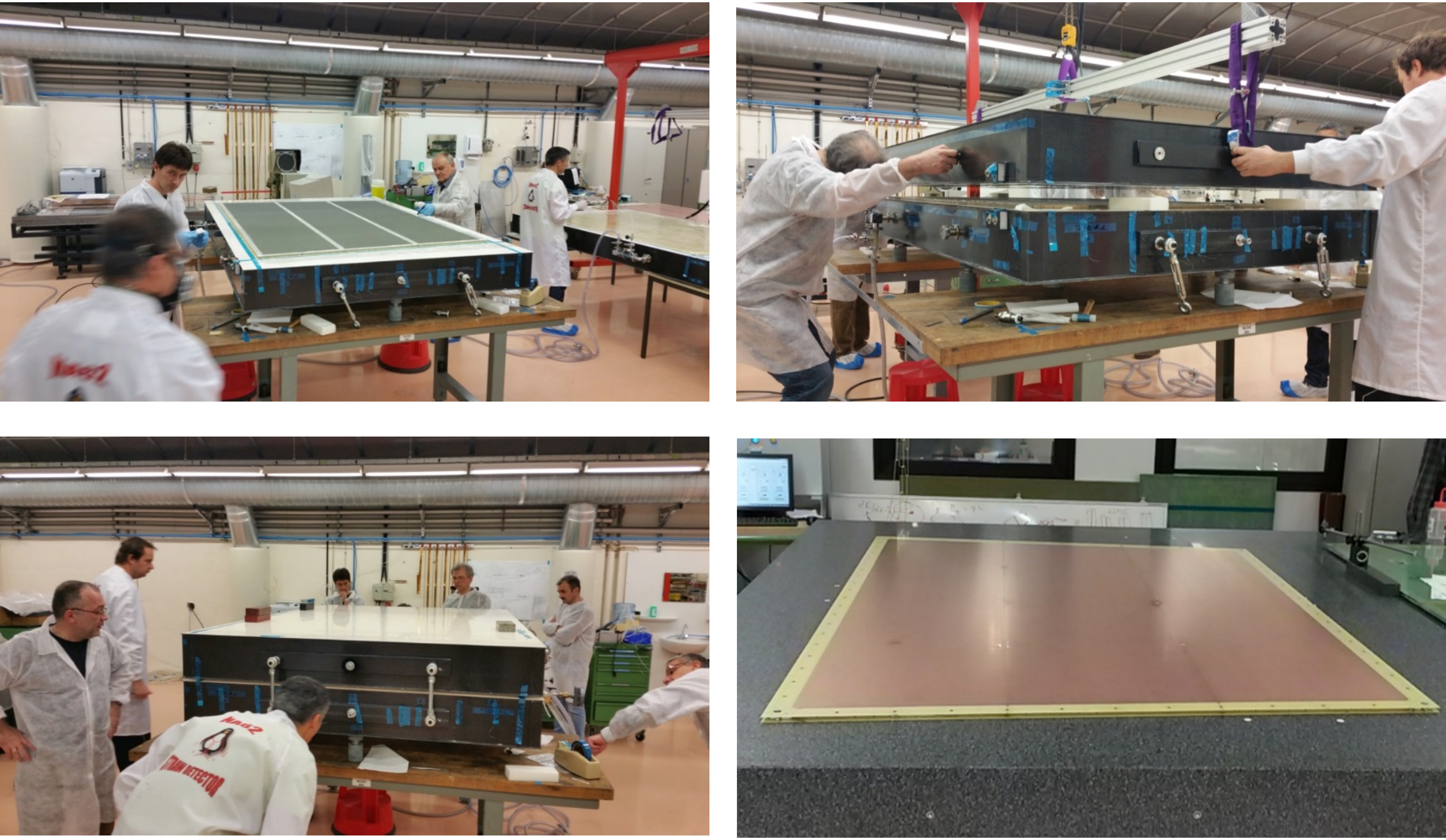


Complete set of Drift Panel assembly tooling

Gluing gantry machine

Drift Panel manufacture

Assembly of lower and upper part of a Drift Panel



Summary, some lessons

- A good way of producing high-precision assemblies is to use room-temperature gluing in precision jigs.
    - Well suited for light-mass assemblies
    - Glue joints can allow (depending on the joint design and gap-thicknesses allowed) use of components which are less precise than the final assembly.
- Machining to final precision requires the object to be sufficiently strong and rigid to support the machining loads. Not obvious in light-mass assemblies. Can be possible with proper (adjustable) support jigs, but is complex and time-consuming. Can be ok for few pieces, less for bigger series.
- Develop, prototype and test the manufacturing and assembly methods early – this needs to be an integral part of the design process early on.
    - Allow time for corrections and improvements in the manufacturing and assembly.
    - Warning: Often difficulties to scale-up from "home-made" prototypes to final "series production" done possibly in multiple sites, by different people, with logistic challenges, etc. Plan for such transitions and try to do them early enough...