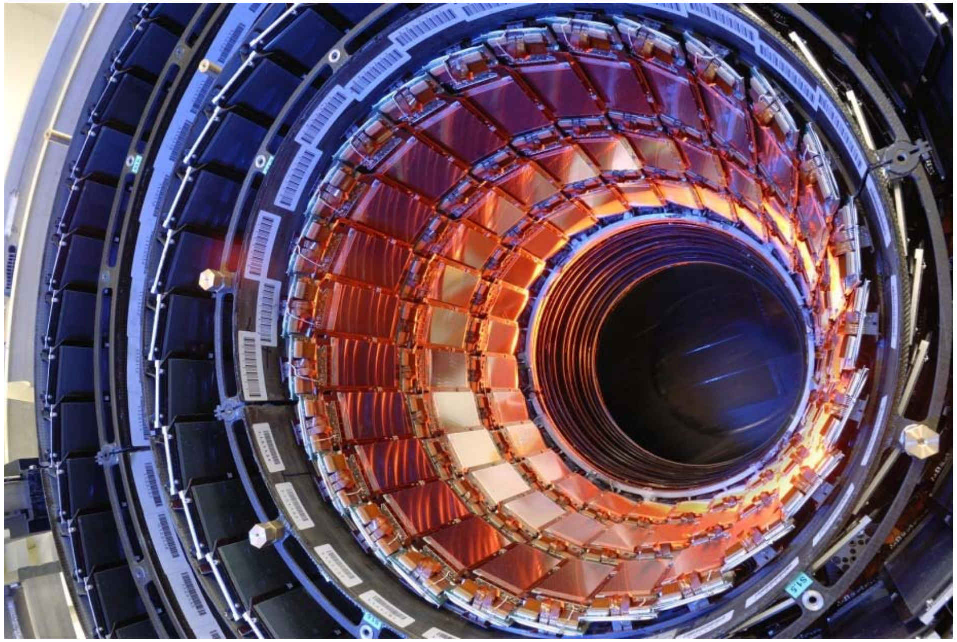
3-4 July 2012 CERN
Forum on Tracking Detector Mechanics



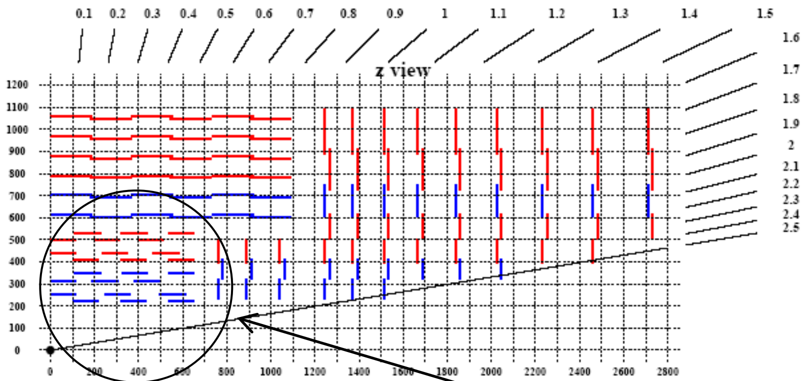
The construction of CMS-TIB at Pisa: what we learned

A.Basti

Outline:

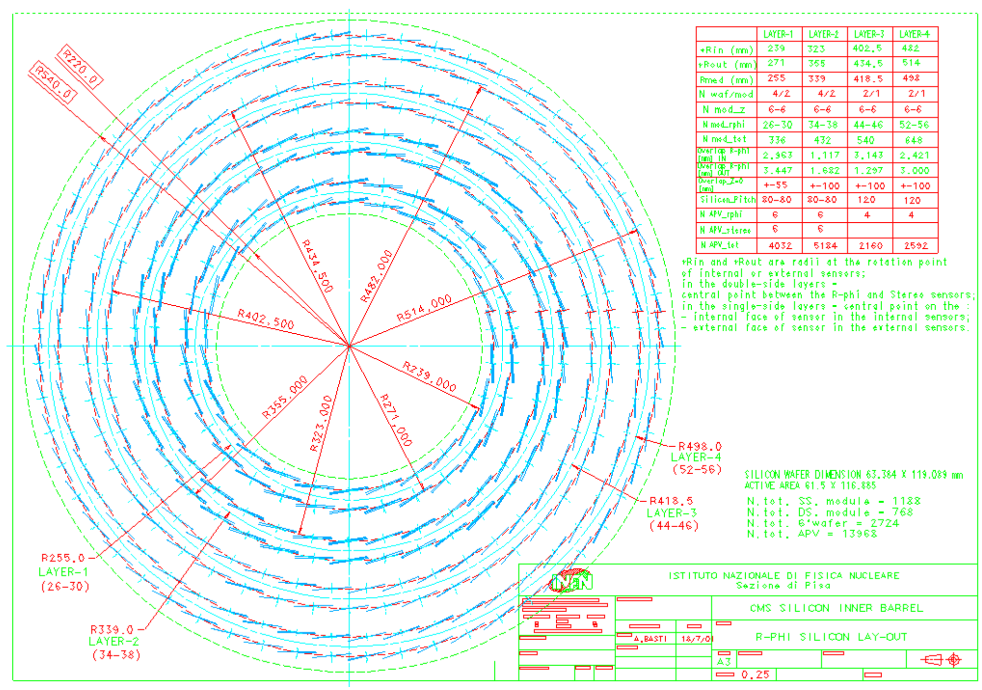
- CMS-TIB Layout.
- Main design constraints.
- Construction of TIB carbon fiber structural parts.
- Mounting of TIB precision elements.
- TIB modules assembly.
- TIB layers integration.
- TIB-TID integration.
- General remarks.
- Conclusion.

CMS-TIB Layout



TIB

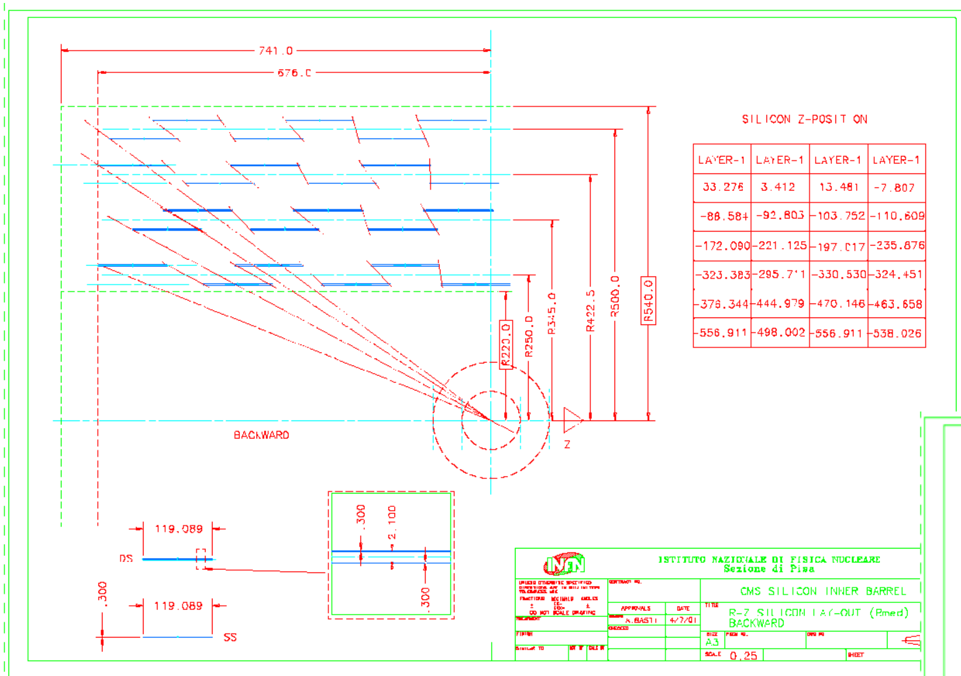
- •A very large structure.
- Divided in two parts (backward and forward) to optimize the spaces for services.
- Four silicon layers (four track hits).
- Min radius 220 mm.
- Max radius 540 mm.
- Half length 725 mm.
- 1188 Single Sided Modules.
- 768 Double Sided Modules.
- Temperature of silicon about -10 C.



	LAYER-1	LAYER-2	LAYER-3	LAYER-4
*Rin (mm)	239	323	402.5	482
*Rout (mm)	271	355	434.5	514
Rmed (mm)	255	339	418.5	498
N waf/mod	4/2	4/2	2/1	2/1
N mod_z	6-6	6-6	6-6	6-6
N mod_rphi	26-30	34-38	44-46	52-56
N mod_tot	336	432	540	648
Overlap R-phi [mm] IN	2.963	1.117	3.143	2.421
Overlap R-phi [mm] OUT	3.447	1.682	1.297	3.000
Overlap_Z=0 [mm]	+-55	+-100	+-100	+-100
Silicon_Pitch	80-80	80-80	120	120
N APV_rphi	6	6	4	4
N APV_stereo	6	6		
N APV_tot	4032	5184	2160	2592

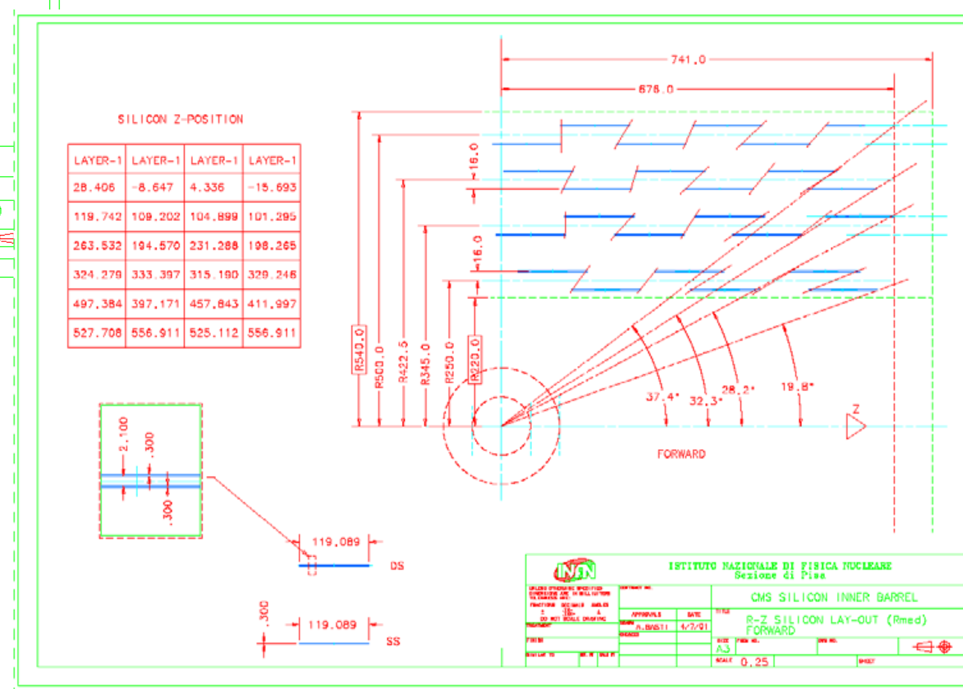
TIB Forward/Backward
R - phi silicon layout

CMS-TIB Layout



TIB Backward
R - z silicon layout

TIB Forward
R - z silicon layout



Main design constraints

• For each parts (backward and forward), we decided to build a support structure made of four cylinders, connected together to obtain two single objects (no space for other solutions like TOB).

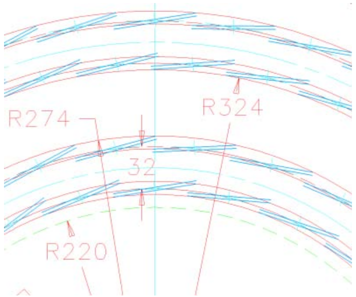
• The two parts needed to penetrate in the middle to cover with the silicon modules the region of z =0.

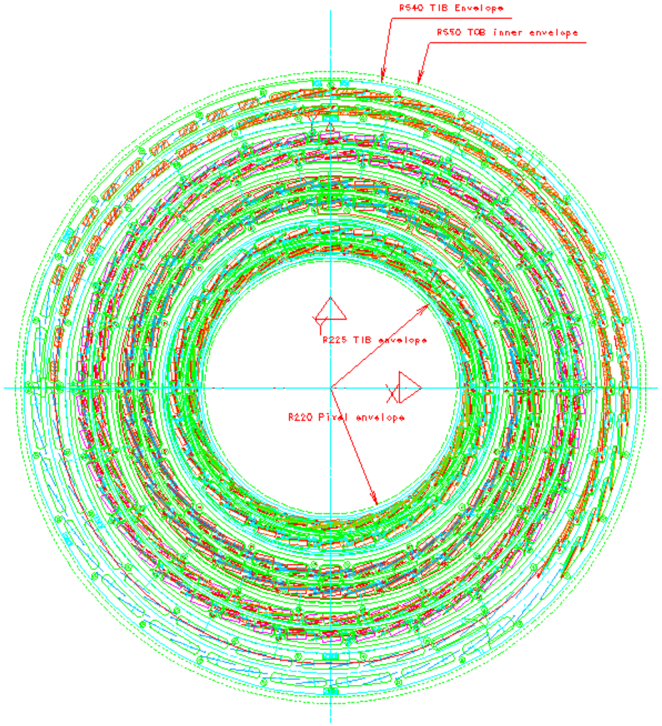
• The silicon modules had needed to be mounted in a precise and stable way on both parts of the cylinders (outside and inside).

• The cylinders had needed to be very light structures (to minimize the budget material).

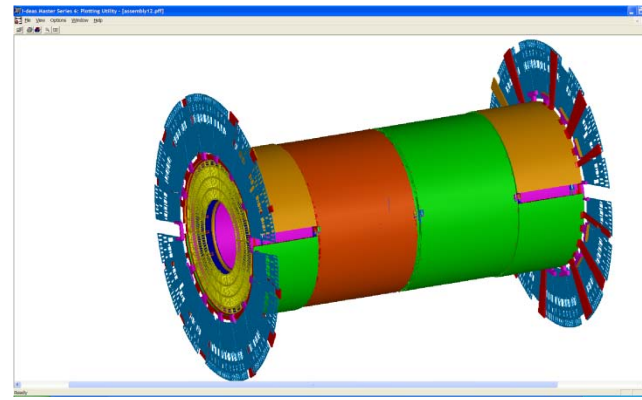
• The position of silicon modules had needed to be fixed with an accuracy less than 100 micron and their positions needed to be stable with the time.

• The silicon modules had needed to be cooled to reach, in the working condition, about -10 C on silicon surface.





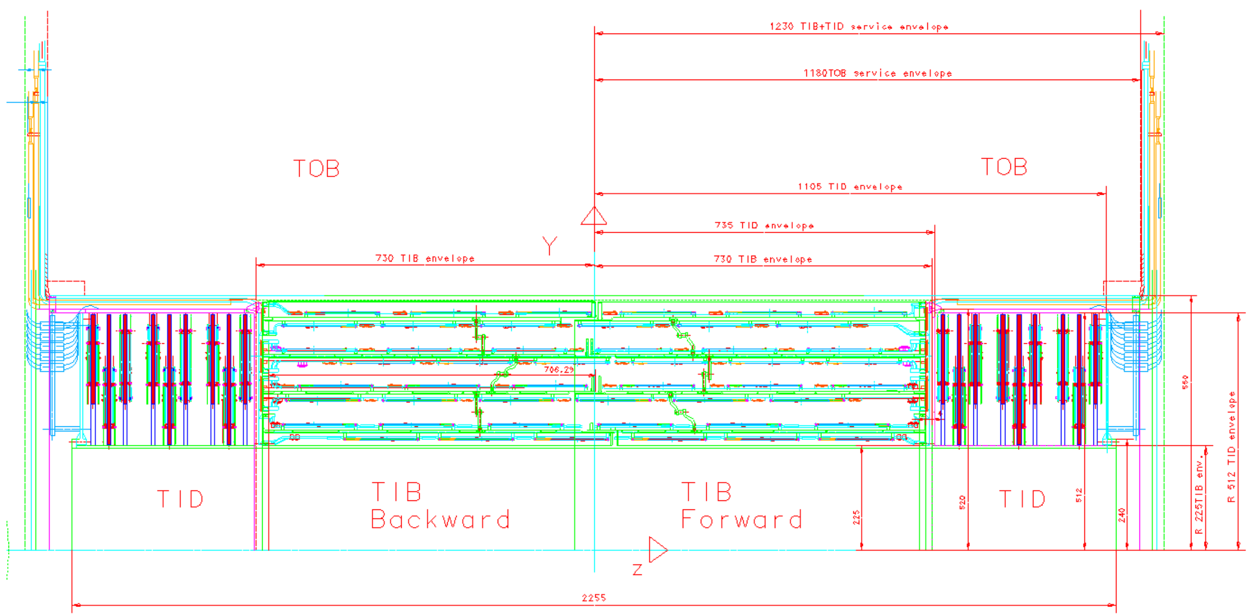
Main design constraints



- We had needed to take in account the space for electronic, power-on and read-out, of the modules .

- The services had needed to go out through the radial space between the TID and TOB to the front of TOB faces.

- The total structure had needed to be inserted inside the TOB part of CMS tracker.



Construction of TIB structural parts

• All support cylinders were built in carbon fiber (T300 fiber for end-flanges, M46J for all other pieces, 950.1 space approved epoxy as matrix).

• Each cylinder was built gluing together several parts (skins , flanges and ribs).

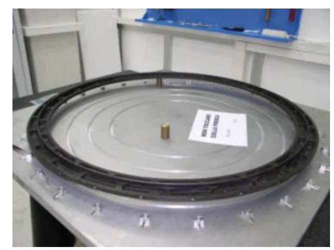
• To obtain the precision requirements an external company produced only the skins and parts in carbon fiber.

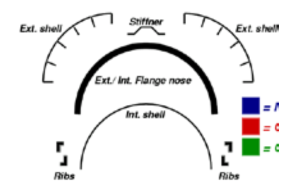
• In the INFN-Pisa workshop we machined the moulds to produce all these parts and we carefully checked them during the design and production.

• After the lamination, in the INFN-Pisa Lab. all CF skins and parts were glued together with the help a tool designed and produced only for this scope (tool type-1).

• On all structures we also glued precision aluminum inserts , with special masks to fix their positions.

• At the end, we machined by hand the extra areas and we covered with dilute glue all edges and corners.





Construction of TIB structural parts

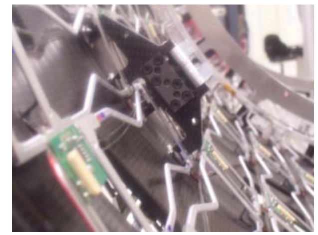
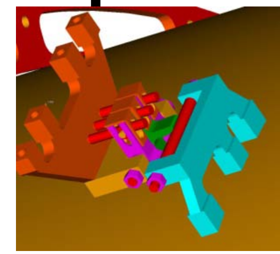
• Each cylinder was built to allow the opening of it in the middle plane, in a precision and accessible way (for that scope we used the longitudinal “ribs”).

• The cylinders were connected one to each other at the end-flanges with some plates and inside, between the modules, with the help of special features, called “pillars”.

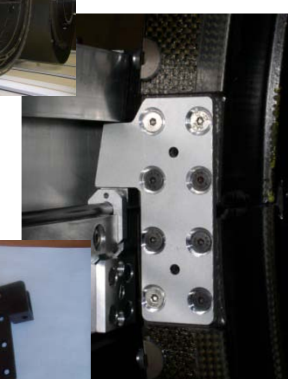
• Special pieces (“feet”) were designed and mounted on the end-flange and end-ring of the external cylinder (layer_4) to allow to install and support the structure inside the internal rails of TOB.

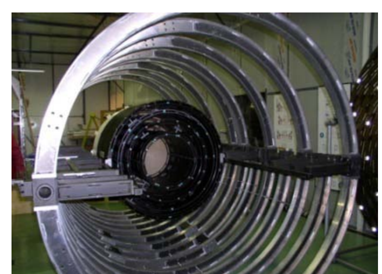
• After the production, the two TIB structural parts were assembled and tested inside a special structure called “Cradle”.

• The Cradle was designed and built to allow the assembly of TIB, the integration between TIB and TID, the transport to Geneva and finally the installation of it inside the TOB.





Mounting of TIB precision elements

• On top of cylinders we glued some precision elements to allow to mount the silicon modules and to cool them.

• These pieces, called ledges, were in the contact with the cooling tubes.

• They fixed the planes, with the right angle and radius, on which the modules were rigid bolted.

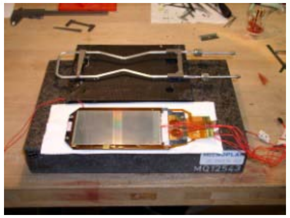
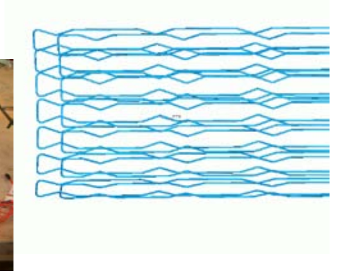
• The positions of the ledges defined the positions of the modules with respect to the reference system of CF structure.

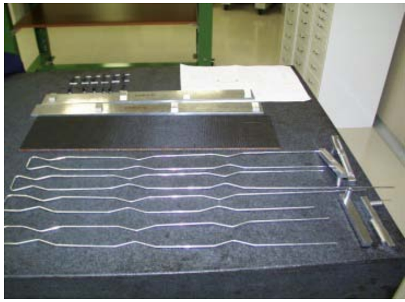
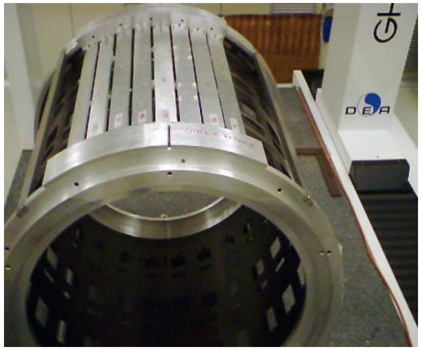
• The cooling tubes were prepared and leak tested before, they were also welded together to obtain cooling loops.

• The ledges were glued to cooling tubes before and then on CF structures.

• All these operations were made with the help of a special tool (tool type-2) designed and built for this scope.



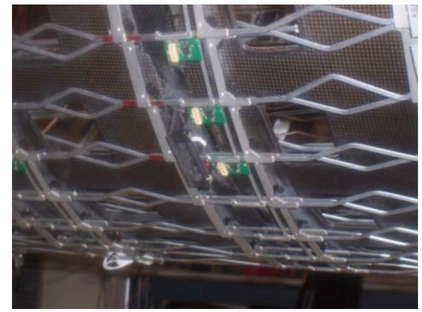



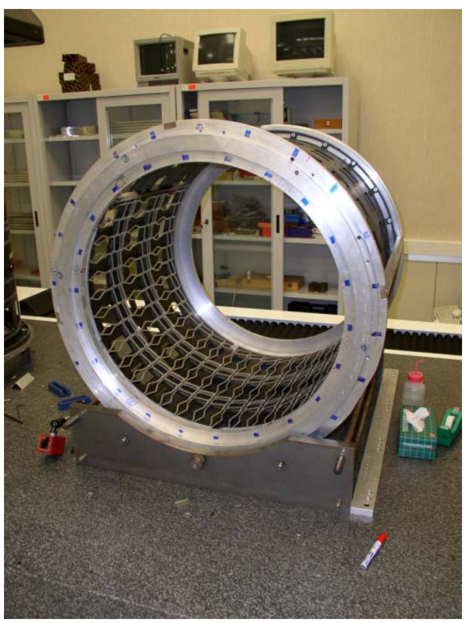

Mounting of TIB precision elements

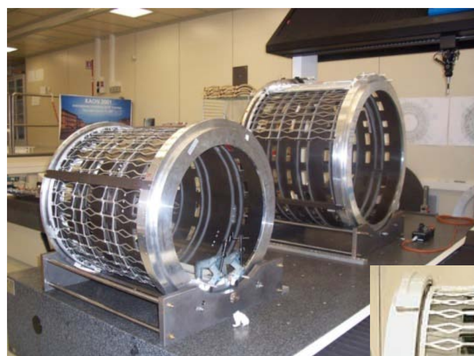
- The tools were accurately checked before the use.

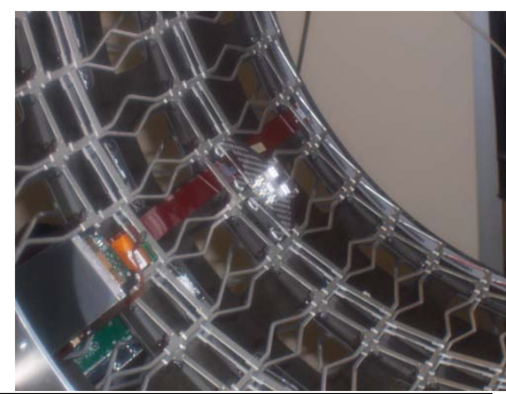
- These precise gluing operations were made under a big CMM to check carefully the positions of the ledges before the curing of the glue.

- The operations were made inside the Pisa clean rooms.

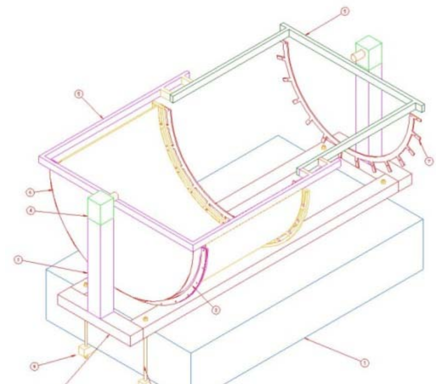


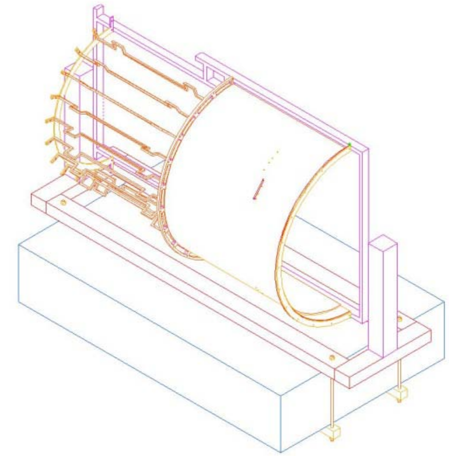






TIB modules assembly





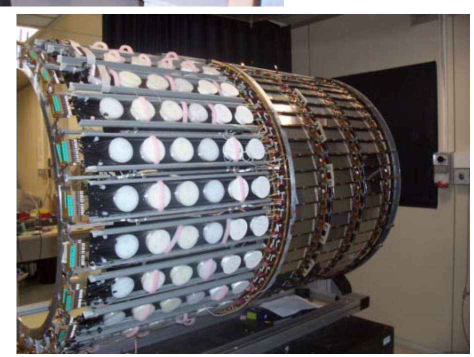
• After the gluing of precision parts, the CF cylinders were ready to mount the silicon modules and all the electronic services needed for the right work of them (optical hybrids, mothecables, DOM etc..)

• The space between the modules was very small and the silicon modules were also fragile to handle.

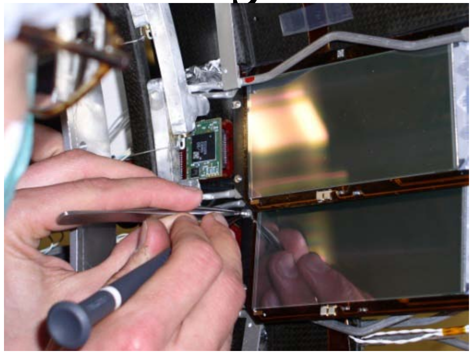
• A tool to hold the half cylinders and to rotate them was built.

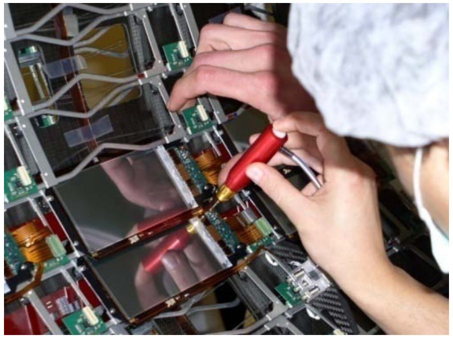
• A special frame to hold the optical fibers was also built, this remained connected to each half cylinder until the layers integration.

• Inside Pisa clean-room we collected all TIB silicon modules produced (in several places in Italy) and here all were assembled.



TIB modules assembly

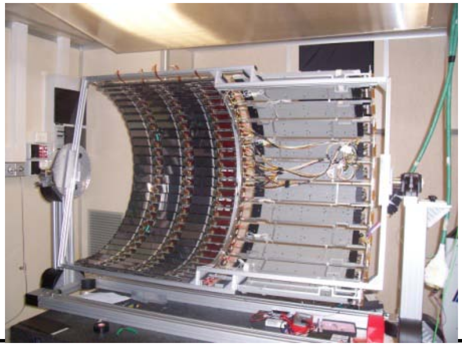




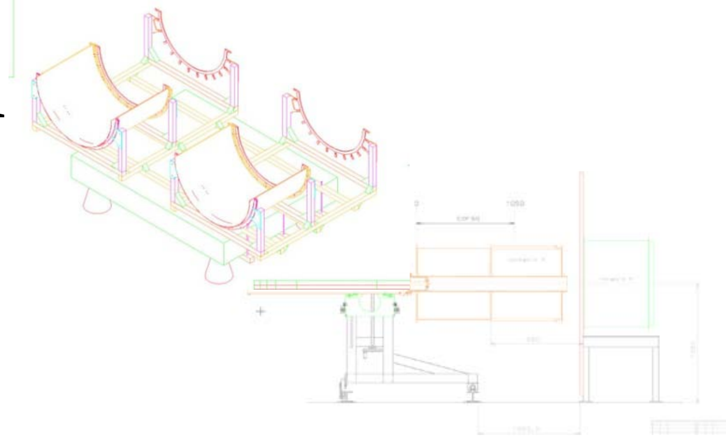
- The modules were mounted by hand, but a special tool to handle and tighten the small screws (M1) with the right torque was used.

- The modules were mounted in rows and each string was carefully tested individually at room temperature before go ahead.

- At the end of mounting, each half layer was thoroughly tested at nominal temperature (-10C) for an extended period; (fluid was circulated in all cooling loops; power and control was on for all cooling loops); read-out was performed on one cooling loop at a time. The test was performed in a temperature and humidity controlled environment).



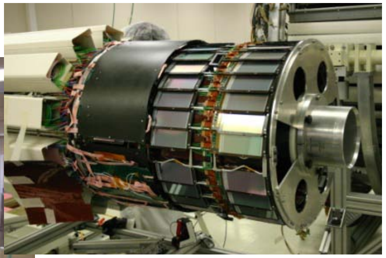
TIB layers integration

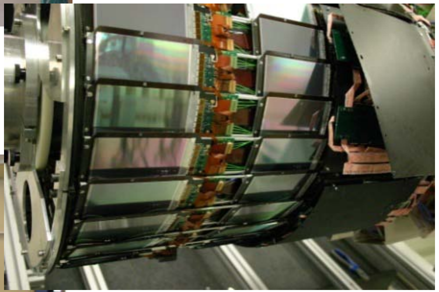


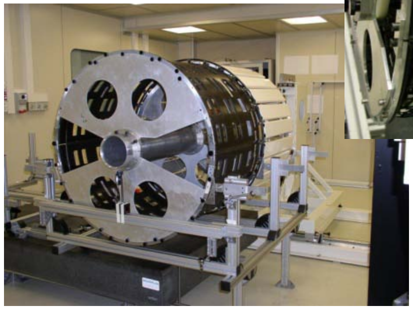
• After the burn-in, each half silicon layer (= half cylinder full of modules) was ready to be assembled in the final structure.

• That was also a very delicate and risky phase and it also was made in the Pisa clean-room.

• A special machine was designed and built to do that.
• The machine allowed:
  • to close the two half cylinders, to obtain the complete layer,
  • put these layers one inside the other, to obtain the final structure,
  • move them in safety conditions inside the clean-room.

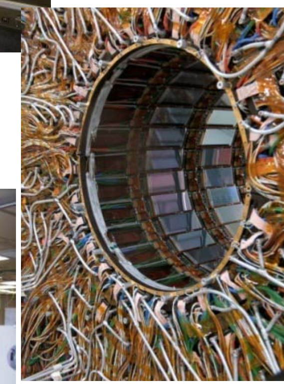


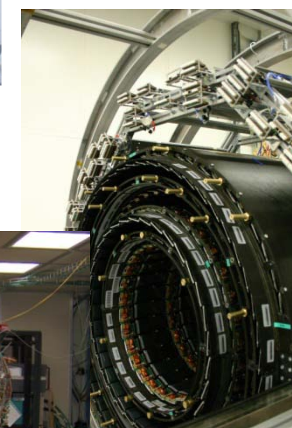
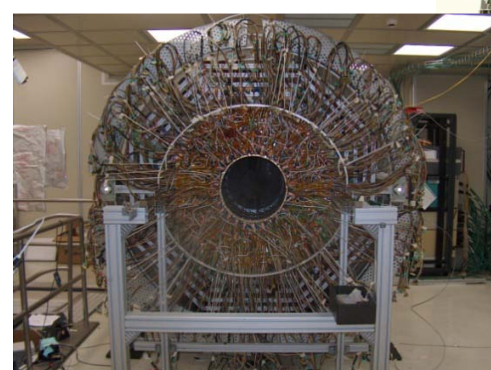




• In this machine we had a special head that could travel along two rails with a long, movable and rigid shaft; the shaft could take the half cylinder from the inside (but only at the level of end-flange and end-ring with some plate) and safety move it inside the clean-room.

TIB layers integration

- At the beginning the two half-cylinders were seated on a structure upon a granite table then they were put one on top of the other with the help of the machine to obtain the cylinder.

- After that the cylinders were ready to be assembled.

- We decided to put soon all layers inside the Cradle.
- On front of it we put a temporarily plate to hold the services during these operations in clean-room.

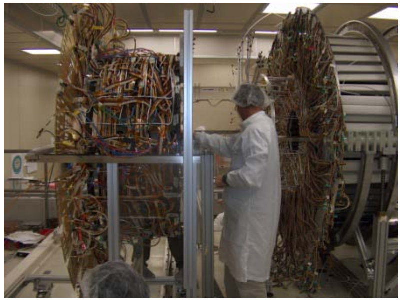
- We started from the layer_4 that had the feet to support and to slide inside the TOB rails, then we put the other layers, in order, one inside the other.

- Each time we put a cylinder inside the Cradle we dismounted the cable holder connected to it and we put all the services on front of cradle plane, to have enough space to insert the following layer inside.

- This operation was repeated four time and at the end we obtained the TIB forward (and then backward) ready.

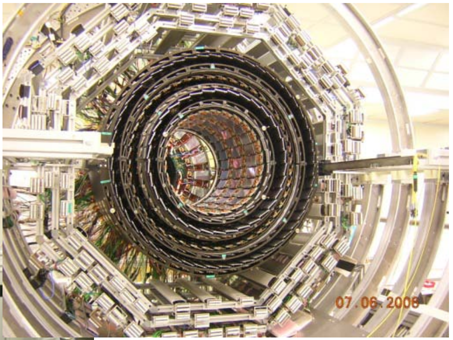
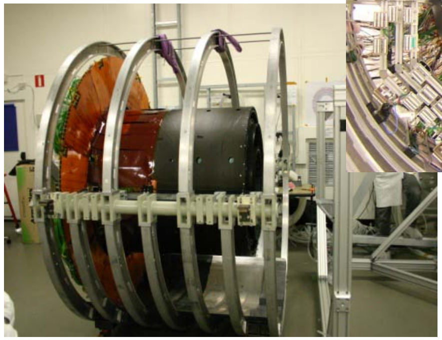
TIB-TID integration


• The last phase was to integrate the TIB with the TID disks. The TID disks were built separately but in the same clean-room, using the same general equipment: to measure them (big CMM), to do the electrical test of the modules and for the burn-in in a cold condition.

• The TID disks were integrated inside a cylinder (the Service Cylinder) that also allowed to manage the services of TIB and TID.

• In front of the Service Cylinder we had a set of plates ("margherita") where we put the connectors of power cables and optical fibers and the connections for the cooling manifolds.

• Also this operation was made inside the clean room with the help of special structures to hold the objects.

• At the end, the TIB+TIB system with all services was put inside the Cradle ready to be transported to Cern.

General remarks

• A lot of people was involved in the project starting from the first design phase (physicists, engineer and technicians). It was a work of a team.

• No design work was made outside the Pisa labs.

• Small amount of work was assigned to external firms, and the works made by these firms were always done under control of an engineer from INFN-Pisa (lamination of CF parts, production of big tools etc..).

• A lot of energy was spent in the first phase of design, and we need to take in account that in this period there were a lot of uncertainties and necessary objects were unknown, in special way in the electronic aspects correlated with the working of silicon modules.

• Several prototypes were produced in Pisa before the final TIB design, some of them were very different from the final object built, but all has been usefully; in special way to learn how to manage with the production of big and precise objects in CF and how to work with silicon modules.

• A lot of tools have been designed and produced.

General remarks

• The design of these tools was always made from people that were involved in the project and the person that designed the tool sometime, apart to control its production, used it during the assembly phases.

• The engineers, involved in the project, have worked, in the design phase, with the physicists to define the things and then with the technicians inside the clean-rooms during the assembly phases.

• The structural CF parts were also precise components. We always glued precision inserts on structural parts with the help of special masks; all the gluing were made at room temperature, the objects were carefully checked and measured after the assembly phases.

• All precision gluing, the modules assembly, the layers integration and final junction with the TID and Service Cylinder have been made in the same place (Pisa clean rooms) that allowed us to avoid a lot of risks due to the packing and transport and to reduce the handling of all objects.

• In the Pisa clean-rooms a big CMM was available to measure with precision all the objects. With this machine we were able to measure also the bigger tools that we used and we were able to perform all precision gluing under this machine.

• All the most precision operations were made by hand, but to hold the biggest objects it was necessary to build some structures or machines to help the people that did these operations.

General remarks

- We had only an accident during the mounting of the modules in which we broke one module mechanically and we needed to replace it.

- The space assigned for services in the design was underestimate.

- During the module assembly, we found that some extra electronic cards were needed and we also discovered that cables and connectors were bigger then the prevision.

- In the final assembly we found a lot of problems to fill with all cables/fiber and tubes the space left for this purpose.

- At the end, if we take in account the material budget, the weight of all mechanics parts has been overestimated with respect to the electronic parts.

- Integrate the cooling system in the mechanics was not been a easy job, a lot of tubes have to be produced, bended, welded and finally glued to the CF structure (and all of them were manual operations).

- The space available for the cooling connectors turned out to be also very small due to number and dimensions of fibers, cables and connectors.

Conclusions

- The construction of CMS-TIB at Pisa was a very long and difficult job (about ten years if we take in account the first design phases).

- The INFN strongly supported us with the infrastructure (big clean-rooms) , the machines (CMM) and the personal to do the work, in the better way.

- The design and construction of TIB in Pisa was a very new experience.

- Some people had participated to the construction of small silicon tracker in the past (CDF, Aleph, BABAR, ISL), but in same cases in Pisa we produced only the silicon modules or only the support structure (but with dimensions very small compared to this).

- No other so big and complicated structure in carbon fiber was build before in Pisa.

- Such amount of silicon modules has never been installed and tested before at Pisa.

Conclusions

- We learned how to produce carbon fiber structures with big dimension and the precision requests of one silicon tracker.

- We learned how to manage with the production and assembly of a large number of silicon modules.

- Finally we learned how to manage with a big number of services (mechanical and electrical).