The CMS Silicon Strip Tracker: experience in integration and commissioning [1]

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Abstract

The CMS Silicon Strip Tracker (**SST**) is now in its final installation phase. All the various sub-sections are now at CERN and are either undergoing final assembly or being tested with cosmic rays. The CMS schedule foresees to lower the whole SST by summer 2007 so that it can be cabled and be ready in time for the first beams provided by the LHC. The fruitful completion of this project (ongoing now for more than ten years) will be thanks to an enormous effort by hundreds of people from many institutions in the design and construction phase of the detector. Yet it is now that the biggest effort is needed in bringing all pieces together and ensuring that they work to specification, in other words: integration and commissioning. This paper will focus on some of the points that have come up during integration of the sub-assemblies and some of the issues that have had to be addressed to ensure that the SST performs according to specifications.

Key words: CMS; Tracker; Silicon; Integration; Commissioning; Microstrip

1. Introduction

The CMS tracker is the largest silicon microstrip detector ever designed. Consisting of three main sub-assemblies, TIB/TID (Tracker Inner Barrel, Tracker Inner Disks), TOB (Tracker Outer Barrel) and TEC (Tracker End Caps), it is 5.4 m long and is 2.4 m in diameter, see Figure 1. The total detector surface is an unprecedented 210 m^2 with more than 15000 detector modules such as that shown in Figure 2. Power and control signals are not distributed individually to these modules, instead they are grouped in so-called control rings so as drastically reduce the number of cables and fibres fed to the SST.

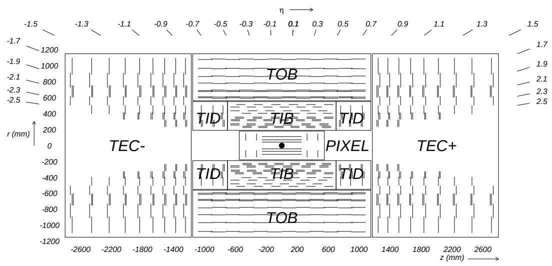

Fig. 1. Schematic cross section of the CMS tracker. Each line represents a detector module. Double lines indicate back-to-back modules which deliver stereo hits.

The CMS solenoid provides a homogeneous mag-

[1] The material for this article is taken from the talk the author gave at the Vertex 2006 conference
[2] On behalf of the CMS collaboration.

netic field of 4 Tesla over the full volume of the tracker. The tracker is operated at or slightly below $-10°$C. At the LHC design luminosity of 10^{34} cm^{-2} s^{-1} there will be on average about 1000 particles from more than 20 overlapping proton proton interactions traversing the acceptance of the tracker for each bunch crossing, i.e. every 25 ns. A detailed description of the SST is given in references (1; 2).

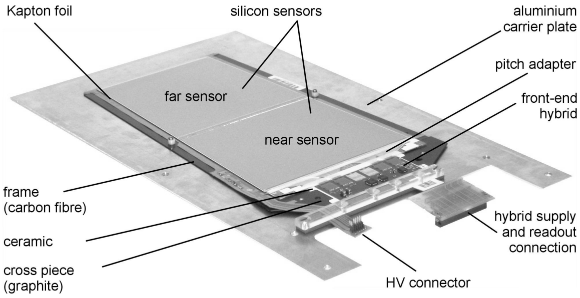

Fig. 2. Picture of a TEC module. The other three sub--assemblies use similar pieces for integration. The main difference with TIB modules is the use of two sensors instead of one (TIB modules are smaller). Roughly 15000 of these modules are integrated in the CMS SST.

2. Integration procedures.

2.1. *Introduction*

Even though the SST is an all-silicon device with the same front-end electronics (FEE) and same type of auxiliary chips, it is essentially three independent sub-detectors put together as a single assembly. We underline some of the main differences for which, in some cases, no explanation can be found except historical separation of the groups involved. These differences in the construction of the three parts have also translated into different integration procedures [3].

[3] Building the TIB/TID, TOB and TEC were three relatively independent communities or consortia based in Italy, CERN-USA, Europe(-Italy) respectively

2.2. *Mechanics and cooling circuits*

The mechanical support structures for all three sub-assemblies are made from carbon fibre. In the case of TOB and TEC the silicon detector modules are first integrated in rods (containing 12 modules) or petals (containing either 23 or 28 modules). These are later integrated in the actual TOB or TEC. Rods and petals are self contained units which have all the electrical and cooling services for the silicon detector modules. The TIB/TID on the other hand has no intermediate structure and modules are assembled directly on shells or disks (up to 150 modules at a time).

The cooling circuits have also been implemented with different materials. The TIB for instance used aluminum (Figure 3) while the TOB used a CuNi(70/30) alloy and the TEC titanium. These different choices have in turn implied different problems for each system. For example it was very difficult to have a reliable soldering of the thin aluminum tubes used by TIB. Only very experienced soldering specialists were able to efficiently perform this operation. On the other hand aluminum has the lowest impact on the material budget of the tracker while being an excellent heat conductor.

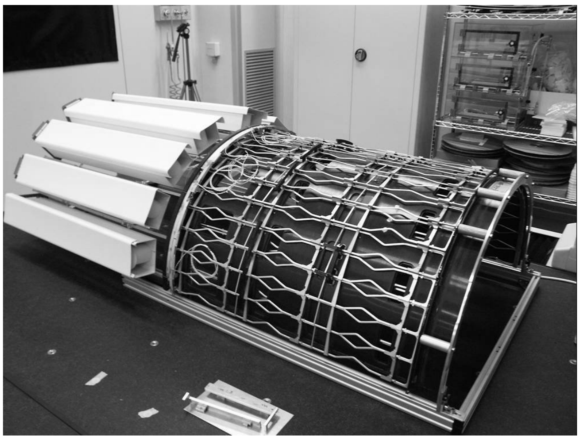

Fig. 3. Aluminum cooling circuits installed on one of the TIBs carbon fibre shells. Detector modules are subsequently mounted directly on the cooling ledges which also provide precision reference insets.

Notwithstanding the different implementations, all cooling circuits were fully tested by the three consortia following similar criteria, namely an initial high pressure test (20 bars) with air, followed by a test at nominal working temperature ($-25°$C) with the coolant fluid and finally a leak test with helium after mounting on the carbon structures (rods, petals or shells).

2.3. *Integration sequence*

2.3.1. *Introduction*

All three detectors followed a similar sequence of integration steps, the basic tenet of the integration paradigm being an in depth test at all levels so as not to rework integrated structures. Thus all the required pieces arrived at the integration facilities having already undergone extensive testing and burn-in procedures.

Counting everything, from tiny screws to inserts to cable holders to hybrids etc., the number of pieces needed was of the order of 10^5. The logistics governing the flow of these objects was a major undertaking in itself. Very often there were stoppages and/or bottle necks because of mislaid or defective components.

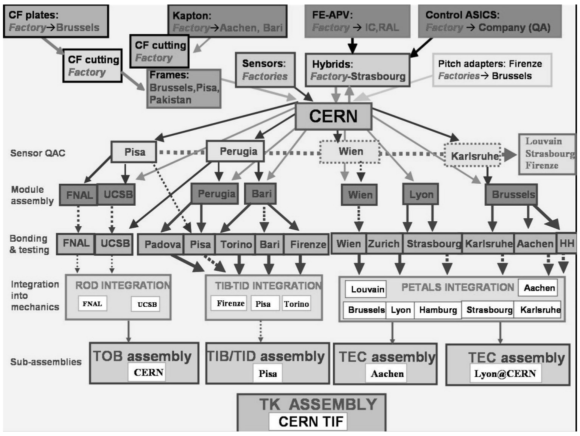

Fig. 4. Production chart for the SST parts together with some of the institutes where these parts were produced. Arrows define the part flow from the basic pieces at the top to the fully assembled SST at the Tracker Integration Facility (TIF) at CERN.

This reflects the excessive fragmentation of production activities (shown in Figure 4) which effectively made it very difficult to implement an efficient and fast problem messaging service.

2.3.2. *Electrical services*

The first integrated objects are optical hybrids which transform the electric analog outputs of the Front End Electronics (FEE) to their corresponding optical signals, and the interconnect boards which supply power, bias voltages and control signals to the detector modules. All these components arrive at the integration facilities having already been tested. Also the Clock Control Unit Modules (CCUMs) are integrated on the interconnect boards at this stage. In Figure 5 a TIB shell is shown with these components installed on it.

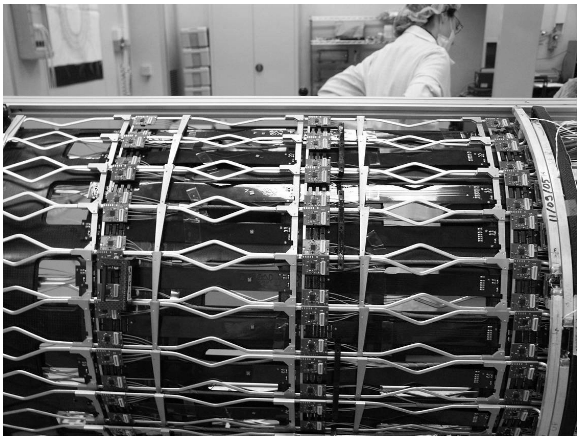

Fig. 5. First phase of integration for a TIB shell (TOB and TEC have a similar sequence). Evident in the picture are the Analog Opto Hybrids (AOHs) and the kapton interconnect boards. Fibres (green) are routed along the cooling loops to temporary holders fixed to the end flanges.

A test is made at this point of the interconnect boards and CCUs, before installing the actual modules. Apart from an electrical connection test which checks for short circuits and similar, the CCUMs are also checked for correct signal decoding and response. Once the tests are completed the partially assembled structure (be it rod, petal or shell) is ready to accept the detector modules.

2.3.3. *Detector module integration*

Apart for the great care used in fixing the modules to the structures, this part of the integration really consists of an exhaustive electrical test of the integrated structure itself.

Modules are fixed by hand with special tooling to the precision insets on cooling loops. Once a rod or petal is fully equipped tests are made on electrical connectivity, control signal response and finally noise characterization. For the TIB, since the number of modules in a shell is huge, the connectivity tests are made each time a single interconnect board is fully equipped while the noise characterization is made at the level of a full control ring. It is very important at this stage that the tests

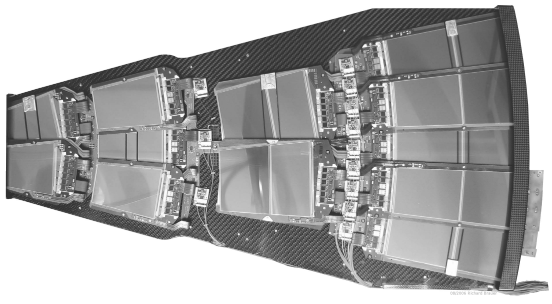

Fig. 6. TEC front petal assembled with the detector modules. This structure is tested extensively before being assembled together with its back counterpart in one of the TEC disks.

are made in a standardized way and that the results are placed in an easily retrievable storage so that they can be used for future comparisons during the tracker lifetime. Thus the use of databases has been a constant leit motif of the whole tracker construction. Specifically for the integration a connection database was established which kept track of where the components were placed and to what they were connected. This information is instrumental also in the subsequent performance tests where the connection information is needed in setting up the data acquisition. Plots summarizing these results are shown in figure 8 were the noise distribution for all the strips of all the modules belonging to an integrated half-shell is shown. In general the number of dead/noisy channels for all three sub-structures is at the per mil level, an amazing achievement which testifies to the care placed in handling all components during the integration phase.

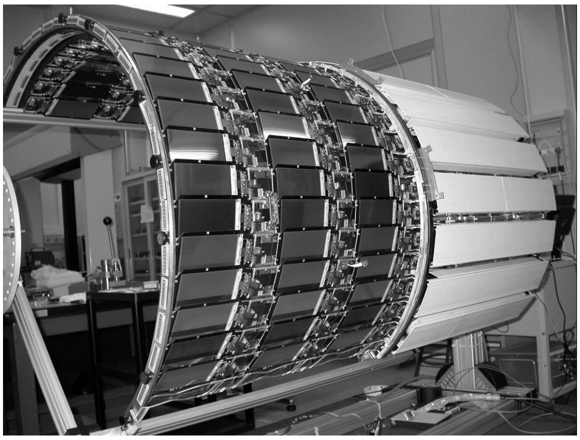

Fig. 7. An assembled TIB half-shell with the detector modules.

In order that the information is accessible in a user friendly way many client programs were developed. Once again the three consortia chose to have its own version. Still all clients in the end gave immediate access to the wealth of information stored, along with up to date status and clickable plots and history of the components used.

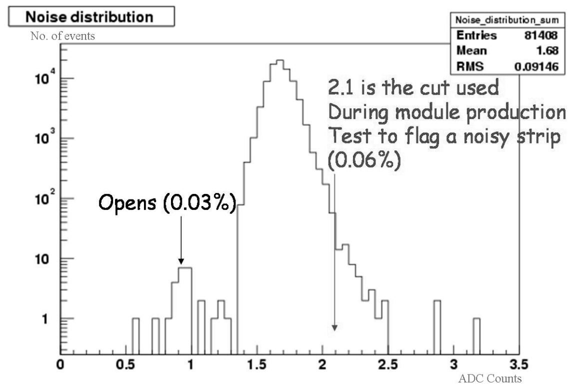

Fig. 8. Noise distribution for all strips belonging to an integrated TIB half-shell(Layer 4 backward, 159 detector modules).

Rods and petals were also separately tested at cold temperatures. For TIB special procedures were made because of the size of the structure to be tested. A climate chamber of a large enough dimension was equipped with a chiller and sufficient electronics to service a TIB half-layer. Besides functioning as a final test facility for TIB before shipment to CERN, it was extensively used by the TIB community to investigate grounding and shielding issues, as discussed in the next section.

3. Noise and grounding issues

Whether in a dedicated facility (such as the TIB) or during integration and then later on the assembled sub-detectors (TEC and TOB) all had to face system issues concerning noise and reliability of operation. In fact many problems were encountered and solved during integration. Problems that had not previously surfaced became evident when a large number of detectors were read-out in one go. For example a dedicated power supply system had been developed for the tracker (3) which then had to have minor modifications installed because of instabilities observed during integration testing.

However the main issues have always been noise pick-up and stability of the system when more than one control ring was being read-out at the same time. Of course the fact that the SST is a synchronous machine ticking with the 40MHz LHC clock has greatly reduced the impact of stray pick-ups. Nevertheless for example in figure 9 a plot

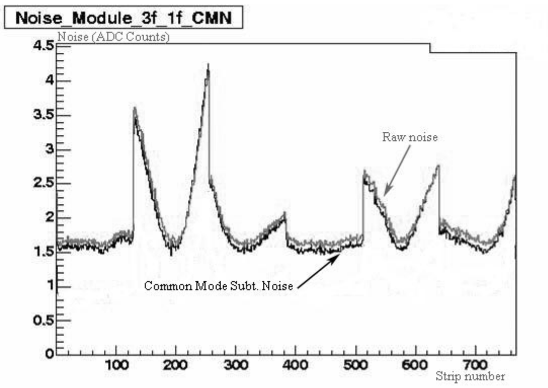

Fig. 9. Noise vs strip distribution for a TIB module acquired during a burn-in run. The winged structure was later associated to a random 20 MHz pick-up originating from the CCUM module. A revamped grounding scheme for the modules eventually solved the problem.

is shown of the noise distribution for one detector module during one of the final burn-in tests in which an anomalous interference is evident.

In the end these kinds of effects were either eliminated or greatly reduced by grounding all modules to the cooling structures which provide the only metal in the SST. The carbon fibre (4) itself was also connected to the cooling manifolds. The control ring electronics (CCUMs and Digital Optohybrids) was also connected at well defined points to the manifolds and thin copper rings have been used to distribute the grounding to all elements of the SST (very sparse and very thin so as to minimise material budget impact). Thin shields have also been used to effectively screen out high speed switching devices. The end result is a spectacular noise distribution for strips along the whole SST. The same distributions as that shown in Figure 10

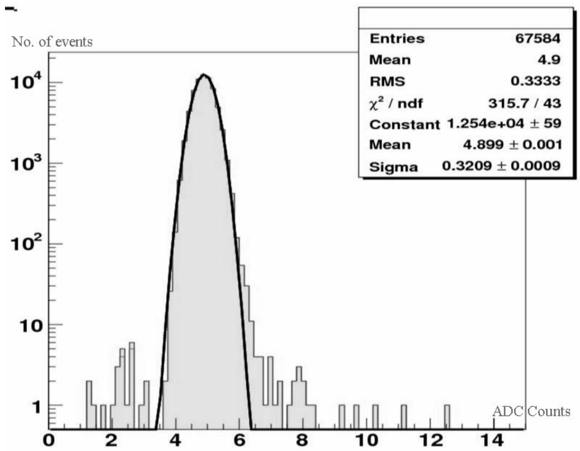

Fig. 10. Noise distribution for the TIB layer 3 shell at $-10°$C.

have been obtained for TOB and TEC. Grounding schemes are similar between the three sub-detectors with small differences due to the different mechanical structures.

In general the SST will rely on a good general ground at the experiment end while the power supply modules themselves will be floating. All the other signals, whether controls, triggers or data from the detector are optically decoupled. This avoids having ground loops running across the entire detector hall picking up noise from stray sources. Power cable shields which are another potential source of problems are terminated just outside the detector volume on the service distribution patch panels.

4. Conclusions

All the sub-assemblies of the CMS Silicon Strip Tracker are now at CERN. In the CERN Tracker Integration Facility, see Figure 4, the TIB, TOB and TEC detectors are undergoing final tests, cabling and checkouts before final assembly inside the tracker support tube.

So far the quality of the sub-detectors has been nothing short of exceptional. Still it remains to be seen how the three will interact with each other and with the rest of the CMS environment. This author is confident that the performance obtained so far will not be easily deteriorated. The adopted grounding schemes are robust and the many problems that have cropped up during the integration phase have been understood and robust solutions have been found.

References

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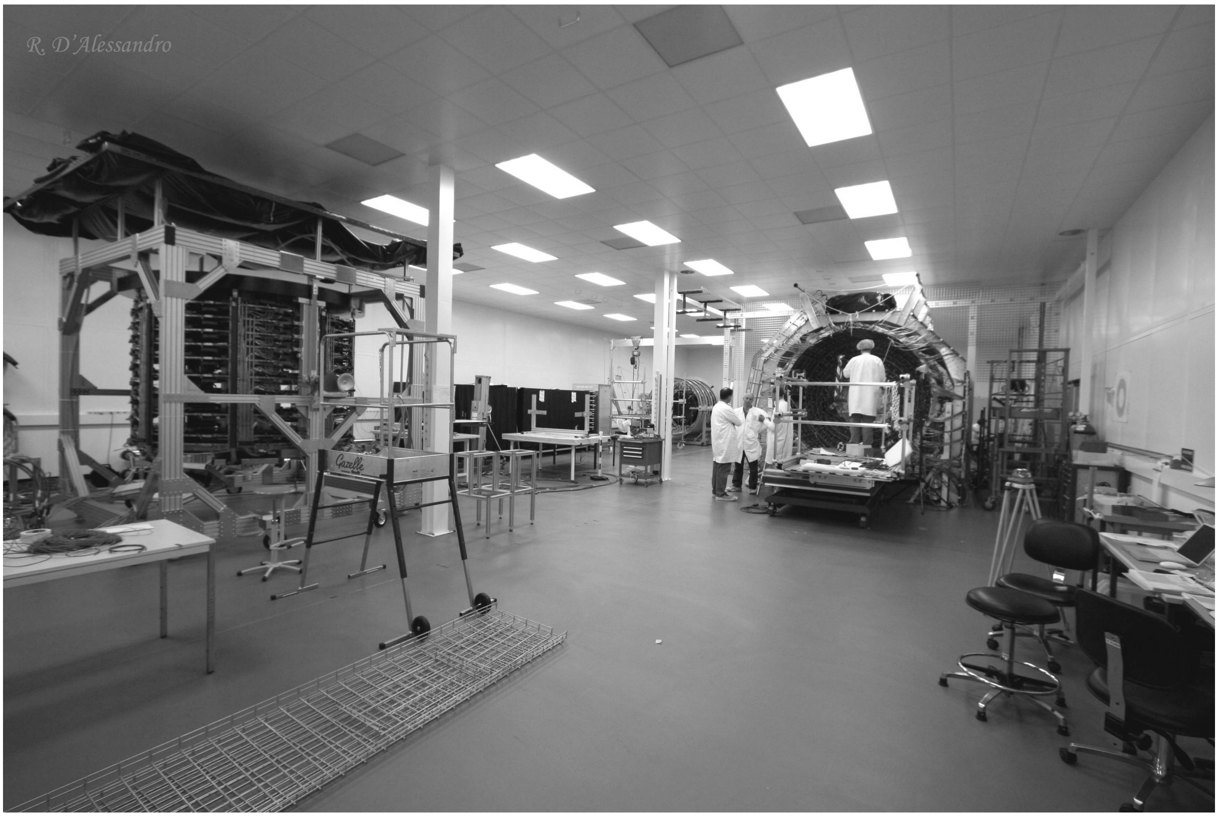

Fig. 11. Assembly hall (TIF) where the three tracker sub detectors undergo final cabling and tests before being inserted in the tracker support tube. TEC assembly is in the foreground at left, TOB at the right (inside the support tube) while TIB is at the back on the left.