The CMS Silicon Strip Tracker: from integration to start-up

V. Ciulli*

Università and INFN Firenze,
via G. Sansone 1, Sesto F. (FI), 50019, Italy
**E-mail: vitaliano.ciulli@fi.infn.it*

The CMS Silicon Strip Tracker (SST) integration has been completed. After an extensive period of testing with cosmic muons the detector is ready for the final installation inside the CMS magnet. This paper will review the integration procedures and the tests completed to ensure that SST performs according to specifications.

Keywords: CMS, Tracker, Silicon, Microstrip, Integration, Commissioning

1. Introduction

The CMS tracker is the largest silicon microstrip detector ever designed. Consisting of three main sub-assemblies, Tracker Inner Barrel and Disks (TIB/TID), Tracker Outer Barrel (TOB) and Tracker End Caps (TEC), it is 5.5 m long and is 2.4 m in diameter (Fig. 1). The total detector surface is an unprecedented 200 m^2 with more than 15000 detector modules such as that shown in Fig. 2.

The CMS solenoid provides a homogeneous magnetic 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 Refs. 1 and 2.

2. Integration procedures

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. The mechanical

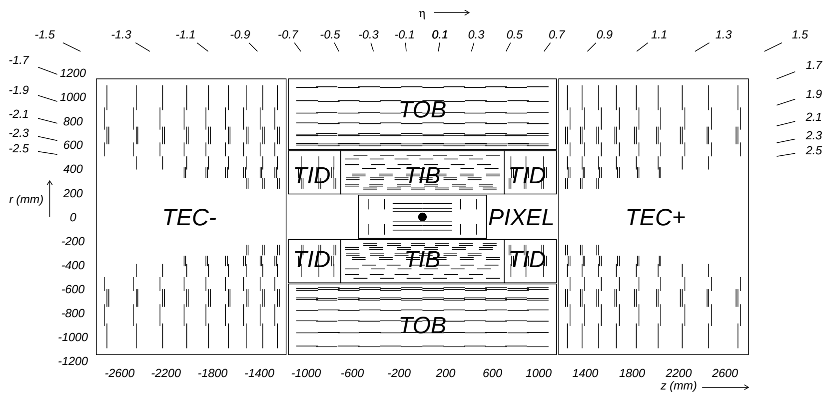

Fig. 1. Schematic cross section of the CMS tracker. Each line represents a detector module. Double lines indicate back-to-back modules which deliver stereo hits.

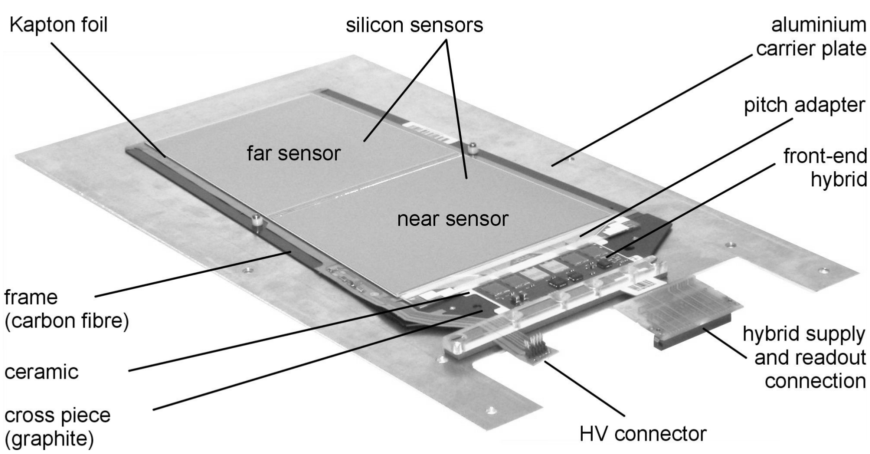

Fig. 2. Picture of a TEC module. The other three sub-assemblies use similar pieces for integration. The main difference with TIB modules is the use of two sensors instead of one (TIB modules are smaller). Roughly 15000 of these modules are integrated in the CMS SST.

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. A TOB rod with 12 modules is shown in Fig. 3. 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).

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.

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. In general

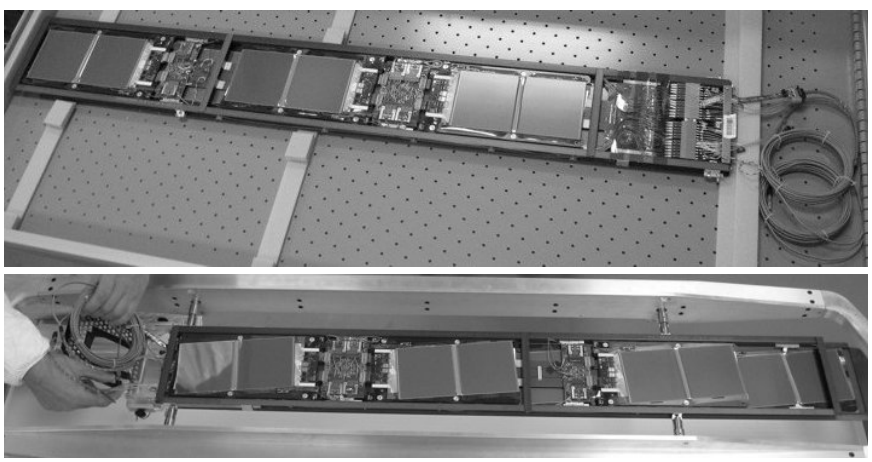

Fig. 3. A TOB rod completed with 12 modules. The top picture shows the $r\phi$ side where the strips are parallel to the beam axis. The bottom picture shows the stereo side, with strips rotated by 0.1 rad to measure the z coordinate along the beam axis.

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.

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.

Once ready, TIB and TEC were shipped to CERN and integrated with TOB, assembled on site, in the Tracker Integration Facility (TIF). The complexity of the final integration of the three sub-detector is evident from the channel and service densities shown in Tab. 1.

Table 1. Channels density in the detector volume and service area for the different tracker subsystems. Density on service area is a relevant parameter only for TIB and TOB, due to their access through the barrel end-flanges. For TEC and TID services instead do not have access problems.

	# of channels	Volume [m^3]	Channel Density [$\times 10^6$ m^{-3}]	Service Area [m^2]	Ch. Density on Serv. Area [$\times 10^6$ m^{-2}]
TIB	1 787 904	0.82	2.2	1.6	1.11
TID	565 248	0.5	1.1		
TOB	3 096 576	5.9	0.52	5.7	0.54
TEC	3 866 624	11	0.35		

The tracker will be transported to the experimental area and inserted into CMS in November. Meanwhile, services deployement in the cavern is ongoing. A great care is applied to test each single cooling pipe, cable or fibers ribbon, since it would be difficult, if not impossible, to repair a faulty one after tracker insertion.

3. Tests with cosmic muons

A period of commissioning of the full CMS experiment with cosmic muons is foreseen between December 2007 and the LHC start-up next year. Several tests of this kind were already done in the past. Among them, two were particularly important for the quality and the amount of data they provided: the Magnet Test and Cosmic Challenge (MTCC) and the Slice Test at the TIF.

3.1. *Magnet Test and Cosmic Challenge*

In the summer of 2006, the CMS collaboration took advantage of the magnet commissioning tests and of the partial installation of some of the subdetectors in the above ground hall to do the MTCC. A fraction of all subdetectors (with the exception of the pixel systems) was operated with an up-to 4 T magnetic field delivered by the superconducting solenoid and read out with a downscaled, final design global data acquisition system (DAQ). Cosmic muon triggering was provided by the Level-1 trigger electronics of the muon detectors. The tracker front-end chip, the APV25,[3] was operated in "slow" read-out mode, because cosmic muons are not synchronous with 40 MHz read-out design. As shown in Fig. 4, the cluster signal in the TIB for different latency values was consistent with a CR-RC shape. The timing constant of 50 ns was in agreement with APV specifications.

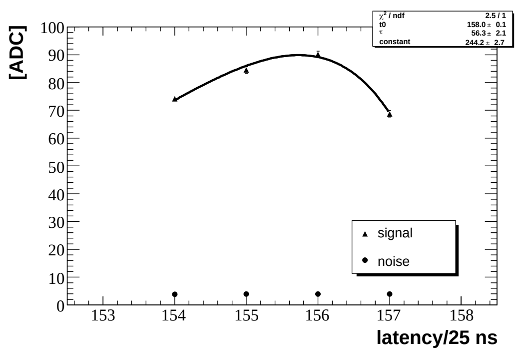

Fig. 4. Cluster charge and noise in TIB modules for different latency at MTCC. Sampling time is delayed as latency decrease.

Despite the fact that the MTCC tracker setup represented only about 1% of the final system, most of the selected hardware and software systems were prototypes of the final versions. The MTCC, therefore, offered the unique opportunity of testing the performance of the tracker in the presence of the 4 T magnetic field. No increase was observed in the strip noise because of the magnetic field or interference with other subdetectors. The Lorentz drift of the charge carriers in the silicon was measured using reconstructed tracks. The Fig. 5 shows the fit to the cluster width versus the track incident angle: the minima correspond to the drift direction of the charge carriers without and with magnet on. The results are in agreement with values expected for holes in silicon detectors.[4]

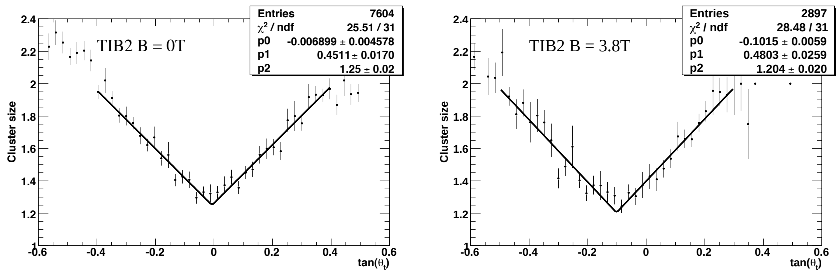

Fig. 5. Cluster width vs track incident angle, without (left) and with (right) 3.8 T magnetic field.

3.2. *Slice Test at TIF*

Once the integration was completed in the TIF, a slice of about 90^o of the plus side was connected to power units, cooling and control and read-out electronics. Plastic scintillators were laid above and below the tracker to provide the trigger for cosmic muons. A layer of lead 5 cm thick on top of ground scintillators filtered the very low momentum muons, hence reducing the effect of multiple scattering for the triggered ones.

About 5 million events were collected in four months of operations. Different conditions where tested, including changing the temperature of the cooling fluid from 15°C to −15°C. To prevent condensation and ice formation, which could have seriously damaged the system, the tracker was enclosed in a sealed volume flushed with dry air. Temperature sensor and humidity probes on the cooling manyfolds and inside the tracker volume provided a constant monitoring of the dew point for the Detector Safety System. Furthermore, 150 thermistors and humidity sensors on the modules were read-out by the Detector Control System and also sent to the Safety System, in particular to avoid overheating and consequent damage of the hybrids.

The quality of data collected was excellent. About one event out of ten was reconstructed online, providing immediate feedback about the system behaviour. Overall more than 90% of the runs were considered good for further analyses.[5] Figure 6 shows the stability over time and temperature variations of signal-to-noise values for the three subsystems. The numbers of dead and noisy strips were found to be at per mil level, as obtained at the end of subsystems integration. Hence, no evidence of any degradation of the performance because of the final assembly was found.

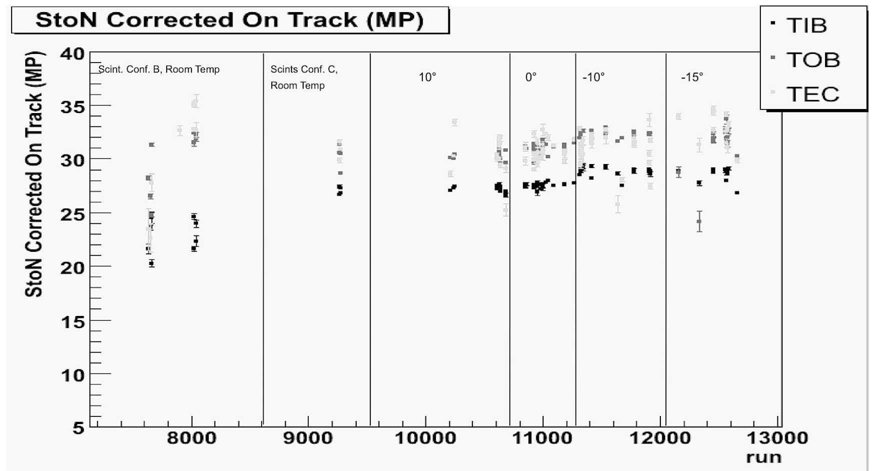

Fig. 6. Signal-to-noise values for the three subsystems during the slice test at TIF. In the first period a non-optimal latency value was used.

4. Conclusions

The construction of the CMS Silicon Strip Tracker is approaching completion. So far the quality of the detector has been nothing short of exceptional. The SST fully meets design specifications. Still it remains to be seen how it will interact with the rest of the CMS environment, but all tests done showed no relevant interferences with external sources of noise. This author is confident that the excellent quality achieved will be maintened throughout the installation and commissioning process.

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