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Status of the CMS Silicon Strip Tracker and commissioning results

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ABSTRACT

The main subsystems of the CMS Silicon Strip Tracker were assembled together in a dedicated large clean room at CERN prior to their installation in the CMS collision hall. Following the integration of the Tracker a long commissioning period took place, during which up to 15% of the silicon modules were operated and read out simultaneously at different temperatures. Some of the achievements of the commissioning phase are discussed in details like Tracker noise performance, signal-to-noise measurements, and hit reconstruction efficiency. The Tracker was inserted in CMS in December 2007 and the commissioning of the full Tracker started. A description of the commissioning procedure followed at CMS and the actual status of the Tracker are presented.

1. Introduction

In order to study the physics of particles and forces at the smallest distances, accelerators are used to collide particles with great energy while detectors provide information on the characteristics of the collisions.

The Large Hadron Collider (LHC) is world's largest and most powerful particle accelerator. One of the detectors built to study the LHC proton–proton collisions is the Compact Muon Solenoid (CMS) (Ref. [1]). This general-purpose detector was designed for a wide range of physics goals, including: the discovery of Higgs boson, elucidation of the electroweak symmetry breaking mechanism, and the search for physics beyond the Standard Model. In order to achieve these goals, all detector subsystems are required to perform optimally.

2. CMS Tracker

With about 200 m^2 of active silicon area, 5.8 m long and a diameter of 2.5 m, the CMS Tracker is the largest Silicon Strip Tracker (SST) ever built for high energy physics experiments. The SST consists of four major subsystems, shown in Fig. 1. The 16 half cylinder shells which form the Inner Barrel (TIB) complemented by the Inner Disks (TID)—formed of 18 rings—cover the $20\,\text{cm} < r < 55\,\text{cm}$ and $|z| < 110\,\text{cm}$ region. The Outer Barrel (TOB) is formed of 688 rods covering approximately $55\,\text{cm} < r < 120\,\text{cm}$, and the same z range as the Inner part. The 2×144 petals representing the two End Caps (TEC) complete the pseudorapidity coverage up to $|\eta| \sim 2.5$. The silicon detectors used at SST are made of one (thin—320 μm in the inner region) or two (thick—500 μm in the outer region) daisy chained silicon sensors (Ref. [2]). In addition, some layers and rings are equipped with back-to-back modules, where the sensors in one set of modules are rotated by 100 mrad with respect to the sensors in the normal (axial/radial) set. These stereo combinations provide z information for barrel detectors and r information for disks.

At the design luminosity the detector will observe 10^9 inelastic interactions per second. This leads to a number of formidable experimental challenges. The radiation hardness is absolutely necessary because of the high particle fluency. Is is necessary to cool the sensors down to $-20\,^\circ\text{C}$ to reduce the damage in silicon due to the radiation. The density of the hits is very large and, therefore, a correct track reconstruction is almost impossible without a high granularity in the detector layers. The short time between bunch crossings, 25 ns, also has major implications for the design of the readout and trigger systems (Ref. [2]).

The quality of the construction and the performance of the components contained within the Tracker are of vital importance and must be thoroughly evaluated under realistic conditions before operation at LHC.

3. Tracker integration facility

The SST construction proceeded during 2006 and 2007, tasks being distributed throughout much of the world. The final assembly of the Tracker was carried out in March 2007 in a large, specially constructed, clean room at CERN: the Tracker Integration Facility (TIF). This facility was instrumented with a significant fraction of the final infrastructure and services needed to operate, control and read out a sector of the Tracker that corresponds to 15% (on the $+z$ side) of the entire detector.

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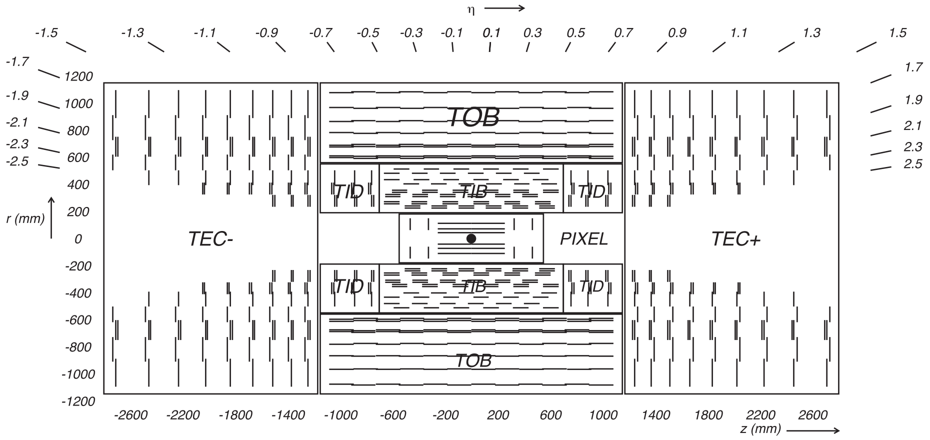

Fig. 1. CMS Tracker Layout.

The detector was commissioned and operated from March to July 2007 at the TIF, a period referred to as the Sector Test, during which about 5 million cosmic ray events were recorded. The slice of the Tracker selected for the Sector Test was chosen in order to include portions of all subsystems, to have a good match with the segmentation of the cooling, control, and readout systems, and to provide a good acceptance for cosmic muons. During the Sector Test, practical experience with the operation of the systems (Data Acquisition, Data Quality Monitoring, Control, Safety, Cooling etc.) was achieved.

The test progressed in an incremental way, beginning with testing parts of the subsystems, then proceeding to a test of the barrel systems, and finally incorporating one endcap. A local chiller was used for the Sector Test and this did not have the cooling capacity of the cooling plant installed at the experiment. The lowest coolant temperature achieved during the Sector Test was $-15\,^{\circ}$C (Ref. [2]), whereas the design specification is $-25\,^{\circ}$C. The temperatures measured at the cooling tubes proved to be very stable, with variations of less than $0.1\,^{\circ}$C. The temperature of the silicon modules depends directly on the temperature of the coolant.

In order to understand the efficiency and alignment of the Tracker modules, a cosmic ray trigger was implemented in the TIF. The trigger design was constrained by space above and below the Tracker; in particular clearance below the Tracker restricted the amount of material that could be used to filter low energy cosmic muons. A layer consisting of 5 cm thick lead bricks was used for this purpose. Six scintillators were placed above the Tracker, in a fixed position; below the Tracker there was initially only one scintillator mounted on a movable support structure; later a further set of four scintillators were added to increase the trigger acceptance. The trigger rates ranged from 3.5 Hz in the initial configuration up to 6.5 Hz in the final configuration. Since the Data Acquisition software (DAQ) was limited to about 3 Hz by the Front End Driver board (FED), however, a trigger veto was implemented to keep the rate under that level.

Some of the achievements of this commissioning phase related to the noise performance, hit reconstruction and signal characterization are described below.

3.1. Noise performance

The noise of a Tracker module is a function of the input capacitance at the APV25, which in turn is dominated by the silicon strips (128 strips/APV). Thus, one expects a linear dependence of the noise on the length of the silicon strip for all modules.

The pedestal and noise studies are part of the calibration of the detector. Pedestals were measured before physics runs on daily basis. For a good reconstruction of the particle trajectory it is important to know the missing and noisy strips.

An important step in these analyzes is applying the gain correction factor. This can be different for each pair of APVs connected to the same fiber. The height of the APV synchronization pulse (known as the tick mark) depends on the operating voltage for each module, but it is also highly dependent on the fiber response. The tick mark height was used in some TIF studies to calculate the gain correction factor. There is a limitation though imposed by the different module operating voltages for different layers. An alternative method for correcting the gain is to apply a scale factor based on the mean noise of the 256 channels corresponding to each fiber.

Faulty channels were studied both from the perspective of badly behaving modules or missing fibers and of individual bad channels. Missing pairs of APVs in the data invariably correspond to broken fibers. Modules with known problems or which were badly behaving were removed, either from the DAQ or from the data analyzes. The resulting fraction of missing modules was at the 0.5% level. The number of missing fibers in the Tracker was at the 0.1% level. The number of individual dead channels (see Table 1) is very constant among several runs for all subdetectors, showing that the identification of these channels is clear and stable: the majority of the dead strips (70%) were flagged in all runs (Ref. [2]). The noisy components is instead subject to fluctuations in particular for TOB and TID. On the other hand, only a small fraction of the noisy strips were consistently noisy throughout the Sector Test.

Stability of noise performance was studied by taking pedestal and noise runs at different times and temperatures of the coolant (from $+15$ to $-15\,^{\circ}$C) when the Tracker was running in stable conditions. For constant coolant temperature, the noise is stable to better than 0.5%. Most importantly, the noise decreases with the decreasing temperature as expected from the module qualification studies made on the APV25 performance.

Fig. 2 shows the noise is proportional to the strip length, within the statistical uncertainty, as expected from the laboratory tests. The mean of the noise shows differences for the same strip length, but different module geometries. In the real data, effects such as temperature changes can also give rise to significant differences of the noise, even for sensors of the same length. A very simple digitization model was constructed in order to obtain a linear parametrization of the noise as a function of the sensor length. The model is in fairly good agreement with measurements from the Sector Test, although there is a significant deviation for modules with long sensors.