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The CMS Silicon Strip Tracker performance using cosmic ray data

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Abstract

The CMS Silicon Strip Tracker is the largest tracking system based on silicon detector technology ever built for high energy physics experiment. It consists of 24244 single-sided micro-strip sensors for a total active area of 198 m^2 and about 10 million readout channels. The SST was installed inside CMS in December 2007, commissioned during summer 2008 and then it participated along with other CMS subdetectors in several cosmic muon data taking runs. The commissioning strategy, operational experience and detector performance results will be presented.

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1 Introduction

The Silicon Strip Tracker (SST) of the Compact Muon Solenoid (CMS) experiment [1] is the largest tracking system based on silicon detector technology ever built for high energy physics experiment. This large and complex detector consists of four main subsystems: the central region is covered by the Inner Barrel (TIB) and the Outer Barrel (TOB), which are composed of four and six cylindrical layers respectively. The forward regions are covered by the Inner Disks (TID) consisting of three disks on each side of the barrel region and the End-Caps (TEC) composed of nine disks per side to complete the pseudorapidity coverage up to $|\eta| \sim 2.5$.

The SST is instrumented with 15148 single-sided modules for a total active area of 198 m^2 and 9.3 million readout channels. Each module is made of a carbon or graphite fibre frame supporting the silicon sensor and the readout electronics. Four barrel layers and three rings of end-cap disks are equipped with double-sided modules which consist of two single-sided modules glued back-to-back with a stereo angle of 100 mrad between the strips to provide also z information for barrel detectors and r information for disks.

Modules are based on single-sided p^+ strips on n-bulk sensors with two different thickness, 320 μm for the innermost layers and rings and 500 μm to instrument the region far from the interaction point. Fifteen types of sensors [2] with different strip pitch and length are used in the SST to ensure good cluster reconstruction, a single strip occupancy below 1% and a good two-hit resolution when operating at the full LHC luminosity [3]. More details on the layout and performance of the CMS tracker can be found in [4].

Different SST subsystems were assembled in a dedicated facility at CERN in March 2007, partially tested during the summer and finally installed inside CMS in December 2007. After completing the connection of services, the detector was commissioned and then operated within the full CMS experiment during cosmic data taking.

This paper describes the commissioning procedure, the operational experience and some relevant results on detector performance using cosmic muon data.

2 The SST commissioning

Before starting physics data taking, a complex procedure was performed to optimally configure, synchronize and calibrate the SST readout channels. The basic element of the readout system is the APV25 [5] front-end chip where the analogue signal is amplified, shaped and buffered. The analogue data are converted to optical signals via Analogue Opto Hybrids (AOH) and transmitted through fibres to the Front-End Driver (FED) board [6]. The FEDs digitize data, apply pedestal and noise subtraction, and perform a fast cluster finding. After receiving a trigger signal, FEDs forward processed data to the central DAQ system.

The distribution of slow control commands, clock and trigger signals is managed by the Front End Controller (FEC) boards [7]. The signals from FECs are transmitted via optical links to digital opto-hybrids and then distributed to Communication and Control Units (CCU) which are organised in a token ring structure. Each CCU provides clock, trigger and communication to the front-end electronics and receives monitoring data provided by the Detector Control Unit chips on each module.

The SST commissioning was done in parallel on four different partitions: TIB/TID, TOB, TEC+, TEC-. This procedure consists of several steps which provide information about the connections and optimize the parameters of the readout electronics. First, two runs are needed to establish the connection between the control system, the power supply and readout systems. The results of these steps are used also to identify any missing or faulty connections. After checking the connections, an internal timing run is performed to synchronize all the channels. The next step is the tuning of the signal, which includes the optimization of AOH settings and the tuning of the APV pulse shape. A pedestal run is then performed biasing the modules at 300 Volts to evaluate the pedestals and noise for each APV and store the measured values in the online database. The final step is the latency scan which is required to synchronize the tracking system with the LHC clock.

The commissioning procedure was successfully completed in a short time and the overall quality of the tracking system is excellent. Table 1 shows the percentage of working modules for each SST partition. The low fraction of faulty hardware components proves the quality of the construction, integration and commissioning procedures.

Table 1: Fraction of working modules for each SST partition evaluated after the commissioning procedure

TIB/TID	TOB	TEC+	TEC-
96.6%	98.0%	99.2%	97.8%

During the shutdown, an intense activity is planned and already partially completed to recover a significant fraction of the faulty hardware components. Once this programme is completed, it is expected that about 99% of modules will be functioning for future data taking.

3 Cosmic data taking and SST operation

After completing the commissioning of each partition, the SST was included with the rest of CMS experiment for global data taking. During a five month period, more than 300 million cosmic events were collected with different experimental conditions. Moreover, for a period of twenty consecutive days, cosmic data were collected using a 3.8 T magnetic field.

This activity was intended to integrate the SST into the overall CMS DAQ system, provide experience in operating the SST and to study the performance in terms of cluster and track reconstruction.

The data taking period was also important for demonstrating the reliability of the operational procedures for slow control, safety, power, cooling system and data quality monitoring.

The SST safety and control systems were found to work well. The detector was monitored during operation and it was interlocked whenever required, for example, due to over-temperature, cooling plant failure, power cuts, or other alarm conditions.

Another important tool deployed during data taking was the Data Quality Monitoring (DQM), which is designed to assess detector performance and quickly identify any problem. The DQM system is based on monitorable elements which are filled by accessing information from different levels of the reconstruction, from raw data to fully reconstructed data. This tool was extensively used both online for fast detection of problems during data taking and offline during reconstruction to provide fast feedback on the quality of the data before the completion of detailed off-line analysis of data.

4 The SST performance

Data collected during CMS global runs were analysed to evaluate SST performance, such as cluster and track reconstruction, module hit efficiency and hit resolution. The results discussed here were achieved by analysing cosmic muon data collected with 3.8 T magnetic field.

The cluster reconstruction depends on the charge collection of the silicon sensors and the performance of the full electronics chain. The procedure used to reconstruct signals is based on a three-threshold algorithm that groups together adjacent strips whose collected charge pass a set of thresholds depending on the noise of the strips. Only clusters associated to a reconstructed track were considered and the total cluster signal was corrected for the incident angle of the cosmic muon. Table 2 summarizes the average value of the signal-to-noise ratio for all SST subsystems evaluated from the fit of the distribution with a Landau function: the perfomance is excellent and in good agreement with expectations from previous measurements [8].

Table 2: Signal-to-Noise ratio for all SST subsystems evaluated from the fit of the distribution with a Landau function.

	TIB	TID	TOB	TEC
S/N	25	28	31	30

The signal-to-noise ratio was also used to evaluate the stability of the SST during cosmic data taking. Figure 1 shows the Most Probable Value (MPV) for each SST subsystem computed for each run collected under stable operating conditions. A general stable trend can be observed for all subsystems, and the increase of the measured values for the last part of data taking is related to a correction of the optical fibre length that improved the cluster performance.

Track reconstruction was studied using three algorithms developed for cosmic ray data [9]: the Combinatorial Kalman Filter, the Road Search, and the Cosmic Track Finder. The first two are standard algorithms designed for proton-proton collisions and properly modified to reconstruct cosmic muons, while the third one is a dedicated algorithm for cosmic data taking.

All the algorithms consist of three steps: seed finding, pattern recognition,and track fitting. The first two steps are specific to the algorithm, while the final fit is the same for all of them.

The tracking efficiency was evaluated with different methods, all providing consistent results: the measured efficiency is at the level of 85%-90% with a maximum value around 95% for tracks crossing the central region of the tracking system. These preliminary results are satisfactory and agree well with Monte Carlo predictions.

The hit reconstruction efficiency is computed by reconstructing tracks excluding the information from the module

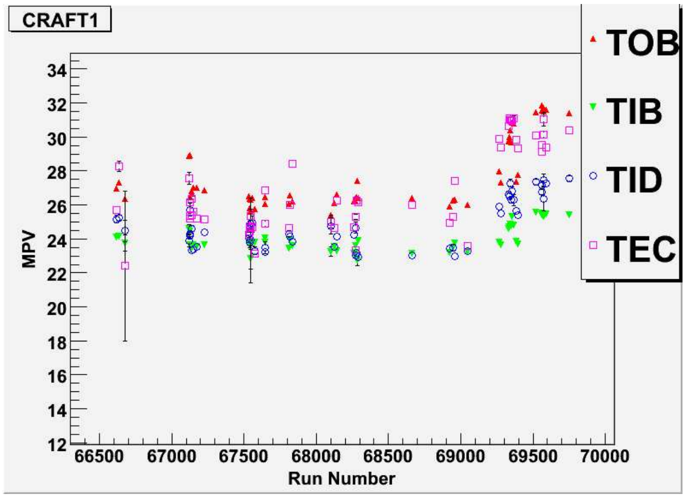

Figure 1: MPV as a function of the run number for each SST subsystem.

under study. The track trajectory is extrapolated to the considered module and the hit efficiency is then computed as the fraction of reconstructed hits found inside a fiducial sensitive area of the module to the total number of expected hits. The overall efficiency is higher than 99%, but some some regions with lower efficiency have been observed. The outcome of this analysis has been compared with results from offline studies and commissioning activities, indicating that almost all inefficiencies correspond to known hardware problems or failures that should be fixed in the shutdown period.

The hit resolution is estimated by comparing the measured hit position with the one predicted by track trajectory. This calculation is done considering only the regions where adjacent modules overlap to minimise the effect of multiple scattering and to reduce the effect of track extrapolation. Hit resolution changes with the sensor geometry since it depends on the strip pitch and silicon thickness which affect the charge sharing between adjacent strips. Four different geometries have been analysed: TIB12 (TIB34) represents modules with 320 μm thick sensors and 80 (120) μm strip pitch, TOB1-4 and TOB56 represents modules with 500 μm thick sensors and 183 (121) μm strip pitch. Figure 2 shows the hit resolution as a function of the track incident angle: for each sensor geometry, the minimum value is achieved at the angles corresponding to the optimal charge sharing. The results are excellent since the measured resolution is $\sim 20\mu$m for TIB and $\sim 40\mu$m for TOB which are fully compatible with the expectations.

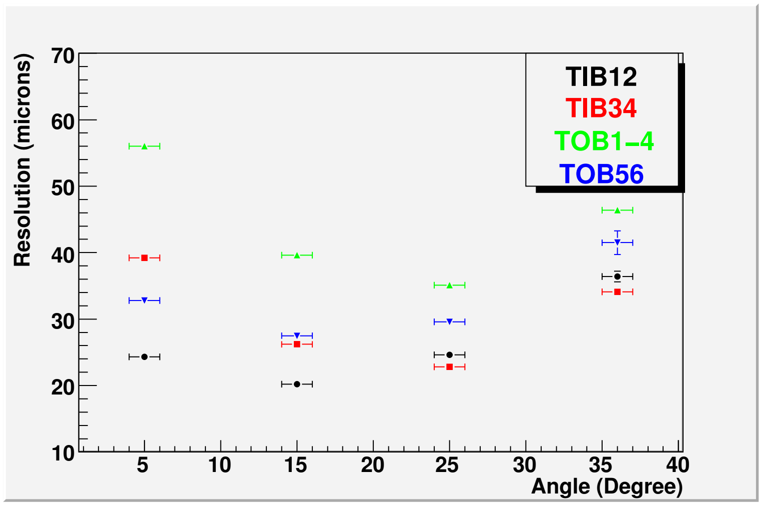

Figure 2: Hit resolution as a function of the track incidence angle for modules with different sensor geometries.

5 Conclusion

The Silicon Strip Tracker was integrated inside CMS experiment and the commissioning procedure was successfully completed with a working fraction of the detector close to 98%. The SST was then operated within the full CMS experiment during cosmic data taking for a five month period. The reliability of the operational procedure for the slow control, safety, power and cooling system, and data quality monitoring was proven. The performance of the SST has been studied using cosmic data and the results are excellent.

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