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The CMS Silicon Strip Tracker (SST), consisting of 9.6 million readout channels from 15148 modules and covering an area of 198 square meters, needs to be precisely calibrated in order to correctly reconstruct the events recorded. Calibration constants are derived from different workflows, from promptly reconstructed events with particles as well as from commissioning events gathered just before the acquisition of physics runs. The performance of the SST has been carefully studied since the beginning of data taking: the noise of the detector, data integrity, signal-over-noise ratio, hit reconstruction efficiency and resolution have been all investigated with time and for different conditions. In this paper we describe the reconstruction strategies, the calibration procedures and the detector performance results from the latest CMS operation.

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CMS Silicon Strip Tracker Performance

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Abstract

The CMS Silicon Strip Tracker (SST), consisting of 9.6 million readout channels from 15 148 modules and covering an area of 198 square meters, needs to be precisely calibrated in order to correctly reconstruct the events recorded. Calibration constants are derived from different workflows, from promptly reconstructed events with particles as well as from commissioning events gathered just before the acquisition of physics runs. The performance of the SST has been carefully studied since the beginning of data taking: the noise of the detector, data integrity, signal-over-noise ratio, hit reconstruction efficiency and resolution have all been investigated as a function of time and for different conditions. In this paper we describe the reconstruction strategies, the calibration procedures and the detector performance results from the latest CMS operation.

Keywords: CMS, tracker, silicon detector, calibration, commissioning

1. Introduction

The Large Hadron Collider started to provide collisions at 7 TeV in 2010. The LHC experiments began their in-situ commissioning already well before in particular using cosmic muons and then the first collisions at 900 GeV and 2.36 TeV at the end of 2009. Since the beginning of 2010, a lot of data have been collected and used to calibrate the different sub-detectors and to estimate their performance. This presentation is devoted to the commissioning and performance of the CMS tracker.

2. The CMS Silicon Strip Tracker

2.1. Structure design

The CMS experiment uses a right-handed coordinate system, with the origin at the nominal interaction point, the x axis pointing to the centre of the LHC ring, the y axis pointing up (perpendicular to the LHC plane) and the z axis along the anticlockwise-beam direction. The distance from the beam pipe r is measured in the xy plane.

The CMS tracking detector (figure 1) is made of two sub-systems located in the inner part of the CMS detector inside the super-conducting solenoid which provides a magnetic field of 3.8 T. The closest part from the beam pipe is the pixel detector surrounded by the strip detector, both using silicon sensors. This presentation concentrates on the second element.

The Silicon Strip Tracker (SST) [1] is structured in two barrels, called TIB (Tracker Inner Barrel) and TOB (Tracker Outer Barrel), made of a total of 10 layers. The barrels are closed by wheels grouped in four parts, two TIDs (Tracker Inner Disks) with three wheels per side and two TECs (Tracker End Cap) with 9 wheels per side. The whole SST has a diameter of 2.4 m and a length of 5.5 m, being the largest silicon detector ever built with an active area of 198 m^2. Its acceptance ranges over a region in pseudo-rapidity $|\eta| < 2.5$.

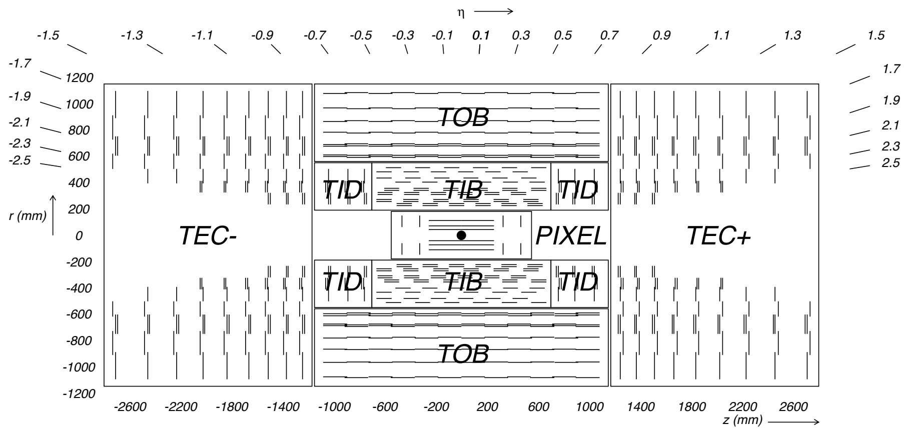


Figure 1: Longitudinal view of the tracker structure.

2.2. Sensors

The basic pieces which compose this detector are the modules. There are a total of 15 148 modules in the entire SST. Each of them holds one or two silicon sensors of n-type bulk with p+ doped strips. Depending on the layer the sensor thickness is 320 or 500 μm. The pitch depends on the distance from the beam pipe and varies between 80 and 205 μm in order to balance low occupancy and good resolution. Some layers of the tracker are double-sided with sensors glued back-to-back with a 100 mrad tilt for a bi-dimensionnal measurement. For each sensor, a front-end electronic card is connected to the 512 or 768 strips for the analog readout of the signal.

2.3. Electronic readout

The main element of the readout is the APV25 chip [2] for pre-amplification, fast shaping, sampling, buffering and sending the information of 128 strips in an analogue frame. The chip can work in two modes. The peak mode with a CR-RC pulse shape is mainly used for cosmic data. In this mode only one sample corresponding to the maximum of the signal is taken. This mode has a good signal-over-noise ratio but its rise time is 50 ns. As a consequence for collisions a second mode called deconvolution mode with a shorter signal shape is used. It is obtained from a combination of three samples of the CR-RC shape. Disadvantages of this mode are its sensitivity to timing and its higher noise.

Informations from the chip are sent via optic link to FED (Front End Driver) processing boards for digitization and application of a Zero-Suppression algorithm. The algorithm substracts pedestals and the common noise baseline. Special measurements are done in absence of collisions with random and low frequency trigger to extract and store values of pedestals and noise (respectively mean and width of signals) for each strip.

2.4. Energy deposit reconstruction

From the information of each single strip an algorithm is used offline to reconstruct clusters and hits. Clusters are groups of neighbouring strips reconstructed with the “3 thresholds algorithm”. The clustering starts from strips with a signal higher than three times its noise (measured in dedicated runs). Neighbours with a signal higher than two times their noise are added. Finally the group is kept if its charge is higher than 5 times its noise computed as the quadratic sum of its strips noise values. The cluster position is computed from the centroid of the signal heights of its strips. A cluster with its position information is called a hit, the basic element used by the tracking algorithm.

3. Detector commissioning

Commissioning [3, 4, 5, 6] started with a checkout of the cabling of the readout chain and powering system and a checkout of module position in the tracker. It was followed by a tuning of the laser gain used for the optical links, a tuning of the APV pulse shapes and an adjustment of the APV analogue baseline to optimize the FED ADC dynamic range. Further crucial steps are detailed in the following.

3.1. Timing

Trigger, timing and slow control commands are sent by the FEC (Front End Controller) to the APV chip. Time adjustment is an important step as a shift would give a lower signal value. The synchronization is done first between all the modules using dedicated pulses, called tick-mark, sent by the APV chips at regular intervals. Then a global latency scan is done in steps of 25 ns in order to synchronize the tracker with the central trigger. Finally fine delay scans [7] with 1 ns steps are done per detector layer. The variation of the signal height with the delay is shown in figure 2.

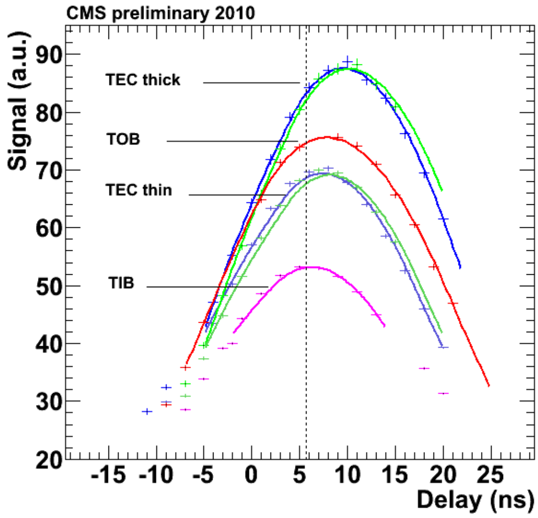


Figure 2: Variation of signal height with delay during fine delay scans done in 2010. The dashed line represents the working point determined in december 2009, measuring the timing of the TOB partition only.

3.2. Gain calibration

The gain of the chip is calibrated in several steps. The first one is a calibration using the same tick-mark as the one used for timing adjustment. The gain is tuned in a way that the tick-mark height amounts to 640 ADC counts. This tuning takes into account differences coming from the readout chain but does not consider differences at the sensor level. For this purpose the particle energy deposits are used. The charge of clusters belonging to a particle track is corrected for the particle path length in the sensitive layer of the sensor. The charge is normalized to 300 ADC counts which is the expected value for a minimum ionizing particle given a calibration of 270 electrons per ADC count. Figure 3 shows the effect of this last calibration on the charge distribution for each sub-part of the SST.

3.3. Lorentz angle correction

Due to the magnetic field, the drift direction of charge carriers inside the silicon depletion zone is tilted by a certain angle, called Lorentz angle. This effect is maximal in the barrel where the magnetic field is orthogonal to the electric field inside the sensor. It results in a systematic shift of the cluster position. Studying the cluster width as a function of the crossing angle of particles, one can extract the value of the Lorentz angle [8]. Indeed for this given angle, the width is minimal. It is then possible to derive the position shift and correct for it. From measurements done with cosmic particles, the lorentz angle tangent is 0.07±0.02 in the TIB and 0.09±0.01 in the TOB. It results in position shifts in the order of 10 and 20 μm, respectively.

4. Detector performance

4.1. Signal-over-noise ratio

The signal-over-noise ratio (S/N) is a sensitive variable useful for detector monitoring. For this purpose, the S/N is computed for clusters from tracks and corrected for path length. The most probable values obtained in standard

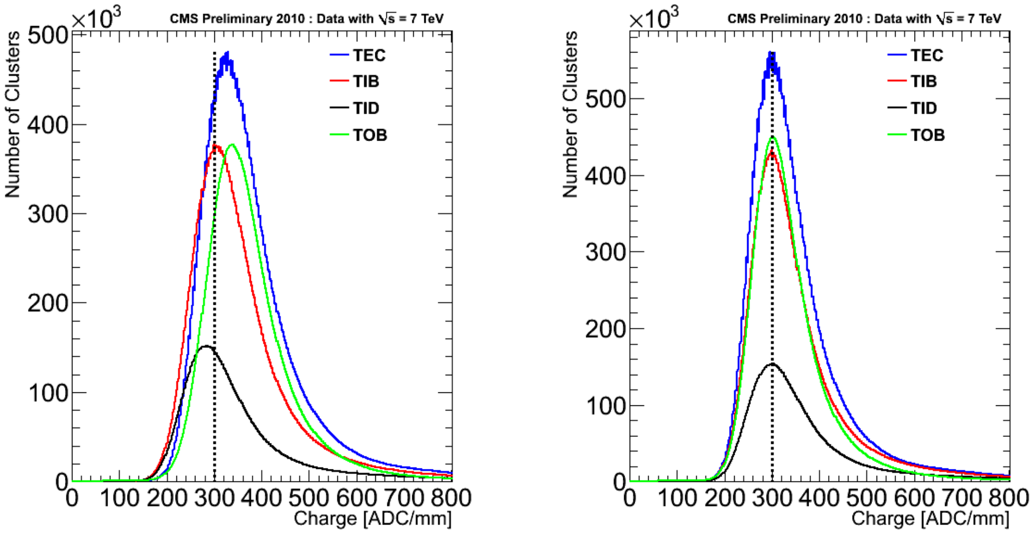


Figure 3: Cluster charge distributions corrected for particle path length in each SST sub-system. On the left, only the tick-mark correction is applied, while on the right side the correction based on particle hits is applied in addition.

conditions for each sub-system are given in table 1. The value depends on the sensor thickness as can be seen in the table for TOB and one of the TEC parts, where the sensors are thicker than in the rest of the tracker.

TIB	TID	TOB	TEC+ thin	TEC+ thick
19.4	18.5	22.5	19.4	23.9

Table 1: Most probable value of the charge distribution in each of the tracker sub-systems.

4.2. Module efficiency

The overall fraction of channels in operation is 98.1%. The efficiency of the working modules has been measured in the following way using tracks of high purity. For a studied layer, tracking is redone without using the hits from the layer. Then the extrapolation of the tracks through the layer is used to identify the crossed module and it is checked whether a hit is found or not. The results are given at the module level and done once per week. Any unexpected evolution will help to spot eventual problems. Figure 4 shows the module efficiency for each layer in two cases: when all modules or when only working modules are taken into account. The first series of points helps to follow the fraction of working modules per layer.

4.3. Hit resolution

The hit resolution has been measured in data in using overlapping parts of modules. Tracking is redone without the layer considered. Then the position difference of hits in overlapping modules is compared with the difference of predicted positions by extrapolation of tracks through the layer. This method is less sensitive to track extrapolation errors than a direct comparison between predicted and observed position. Results are shown in figure 5 for different layers as the hit resolution depends on pitch size. It also depends on cluster width related to the particle incidence angle.

4.4. Energy loss

The main purpose of the tracker is obviously track reconstruction, but its wide linear range allows energy loss measurements too [9]. Knowing the path length through the sensitive layer and the associated charge measured, the

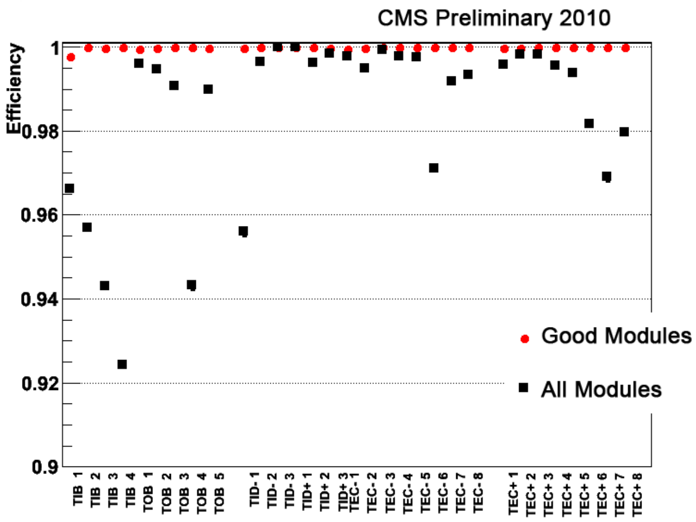


Figure 4: Summary of average module efficiency per layer. Efficiency is evaluated in checking modules crossed by tracks.

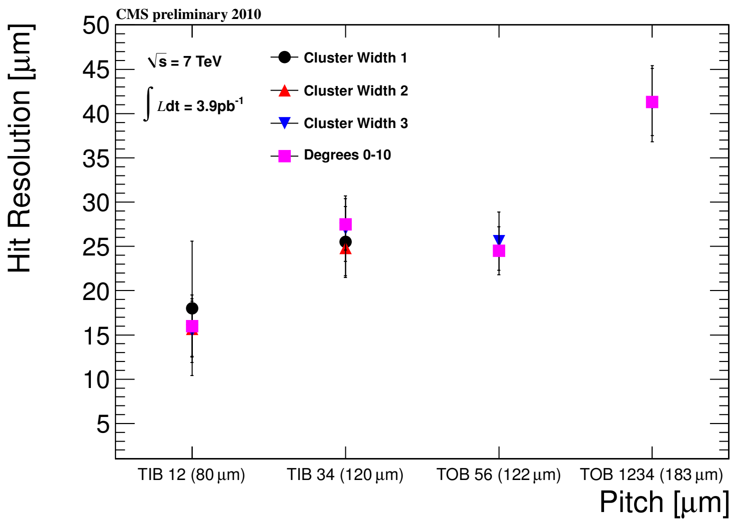
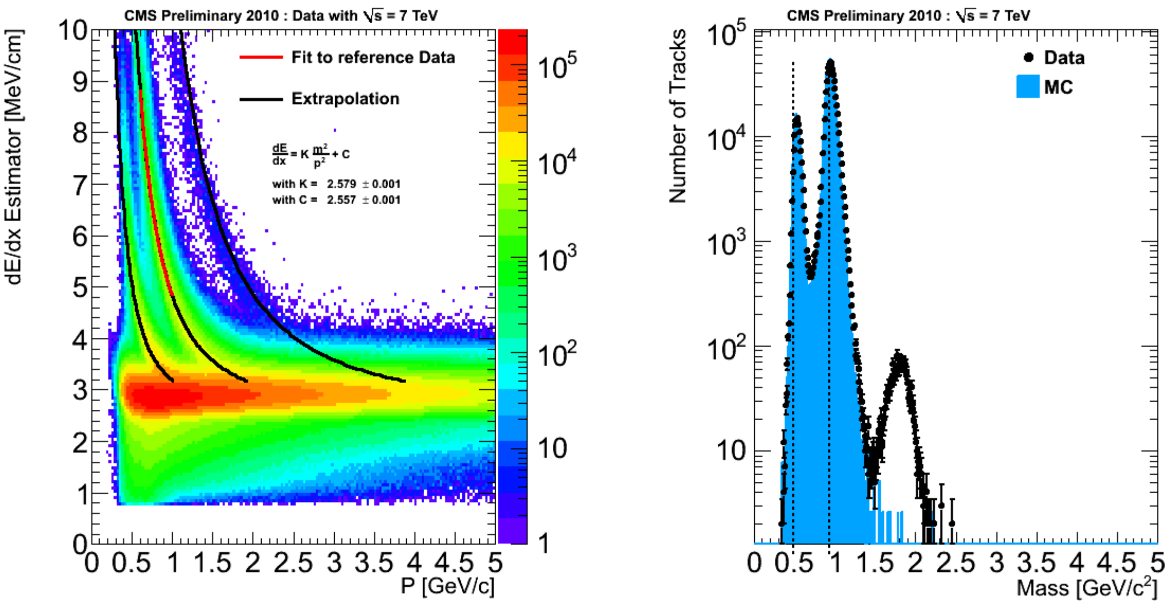


Figure 5: Hit resolution for different SST layers. The resolution has been computed using clusters selected for their track direction or their width in number of strips.

dE/dx variable can be obtained. For low momentum, it is then possible to distinguish charged particles types. In figure 6 an estimator of the energy loss as a function of particle momentum is illustrated . One can clearly see trails from kaons, protons et deuterons (from left to right, i.e. lighter to heavier). Data are fitted for protons with the function $\frac{dE}{dx} = K\frac{m^2}{p^2} + C$, where K and C are free parameters. By inverting the equation, one can extract the mass of the other particles. This is shown in the right part of figure 6. Simulation is in good agreement with data, except that deuterons are not simulated by PYTHIA. This estimator is useful to identify particles for low mass resonance reconstruction [9] and also for the search of new heavy stable charged particles [10].



(a) (b)

Figure 6: (a) Distribution of the dE/dx estimator as a function of the particle momentum. Data are fitted using protons with a momentum in the 0.7-1.0 GeV/c range. (b) Distribution of the reconstructed mass from momentum and dE/dx informations for data and simulations. Dashed lines represent the known kaon and proton masses.

5. Conclusion

The silicon strip tracker shows good performance. The working fraction, S/N, efficiency, resolution and energy loss measurement have been presented. All of this information is useful for tracking and finally for physics analyses. Many known low mass resonances have been reconstructed [9] with correct mass and good precision, showing the good tracking performance. The LHC detectors are preparing now for nominal beam conditions with 25 ns bunch crossing and higher pile-up.

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