Commissioning the CMS Pixel Detector with Cosmic Rays

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The pixel detector of the Compact Muon Solenoid (CMS) experiment consists of three barrel layers and two endcap disks at each side of the barrel section. The detector was installed in summer 2008, commissioned with the readout chip internal pulse generator, and used in cosmic ray trigger data taking in a 3.8 T magnetic field. Despite the excellent detector performance some problems arose after installation. In about a year we went through a complete and important sequence of steps that go from the insertion of the detector in CMS, calibration, running, extraction, maintenance, to the re-insertion, re-calibration and final running. Currently 98.6% of the whole pixel detector is fully functional and results on detector performance are found to be in line with the design specifications.

1 Introduction

The CMS experiment [1] is designed to explore physics at the TeV energy scale exploiting the proton-proton collisions delivered by the Large Hadron Collider (LHC) [2]. The new energy frontier that is going to be attained by LHC requires the experiments to gather as much information as possible from each collision. To achieve such a challenging goal in the innermost, radiation hostile region, the high-precision and low-background tracking of CMS is based on the pixel detector [1].

2 Threshold, noise distributions and overall status

The thresholds are controlled at pixel level using two 8-bit DACs per ROC plus one 4-bit trim value per pixel. The readout thresholds and noise are measured by means of threshold scans.

Table 1: Mean noise and mean threshold for both barrel and endcap regions.

	Mean noise	RMS	Mean threhsold	RMS
Pixel barrel	141 e^-	35 e^-	3829 e^-	416 e^-
Pixel endcap	85 e^-	26 e^-	2941 e^-	237 e^-

The threshold is the value of injected charge where the efficiency is 50%. The noise is measured as the RMS of the curve. In Tab. 1 are reported the mean noise and mean threhsold, together with the their RMS value, for both barrel and endcap regions. The current detector status is: pixel barrel has ∼99% of working channels; pixel endcap has ∼97% of working channels (it's not at 99.5% because after re-insertion we experienced a bandwidth reduction on the analog output for some modules).

3 Cosmic ray data analysis

Approximately 85,000 tracks traversing the pixel detector volume were reconstructed with the Combinatorial Track Finder (CTF) algorithm in the 3.8 T field. For this set of tracks the average number of pixel hits is 3.01, for a total of about 257,000 clusters reconstructed in the pixel system. Pixel clusters are formed from adjacent pixels with a charge above the readout threshold. Both side and corner adjacent pixels are included in the cluster and a cut of 5,000 electrons is applied to the total charge. The cluster is projected along the sensitive directions by summing the charge collected in the pixels with the same coordinate. Residual charge miscalibration due to the pixel-to-pixel variation of the charge injection capacitor is modeled in the Montecarlo simulation. Figure 1 shows the simulated and measured cluster charge corrected for the track incident angle. To emulate the acceptance expected from collisions, tracks with angles in the transverse plane larger than 12° from normal are excluded from the study. Clusters are required to include at least two pixels and those with edge pixels are excluded from the sample. Finally, events with more than one cluster in the same sensor are excluded.

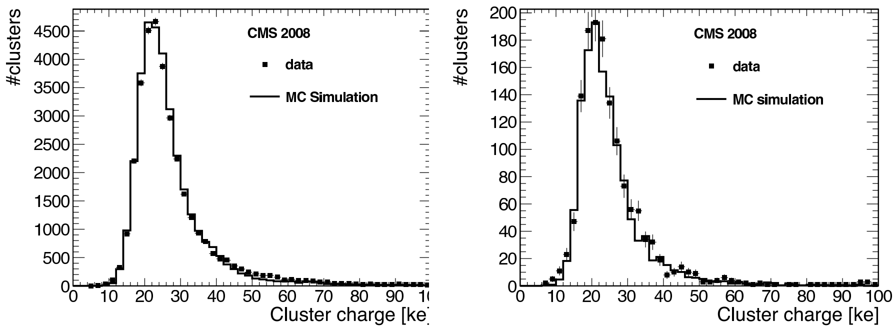

Figure 1: Charge distribution in kiloelectrons (ke) for clusters larger than one pixel measured with the barrel and endcap pixel detector in the first and second plot respectively. The data points show the measurement with cosmic rays and the solid line the simulation.

The residual distributions are measured as a function of the impact angles and cluster charge and a Gaussian fit is performed in each bin. The contributions to the width of the residual distribution are the track extrapolation error, the detector intrinsic resolution and multiple scattering contribution. The track extrapolation error is the largest contribution and includes the uncertainties due to residual misalignment of the sensors used in the trajectory extrapolation with respect to the measured sensor. Figure 2 shows the width from the Gaussian fit of the residual distribution as a function of the α and β angles and total cluster charge. For tracks normal to the sensor plane the Gaussian sigma is about 30 μm and 65 μm along the local x and y coordinates, respectively. The width strongly depends on the cluster charge and impact angles.

The intrinsic detector position resolution is measured using tracks traversing overlapping sensors in the barrel layers. Tracks passing through two overlapping modules in the same layer are used to compare the hit position with the expected position from the track trajectory. The difference in local hit position (ΔX_{hit}) of the track predictions is much more precisely known than the individual predicted positions. The double difference is formed by taking the difference between the hit position difference and the predicted position difference (ΔX_{pred}).

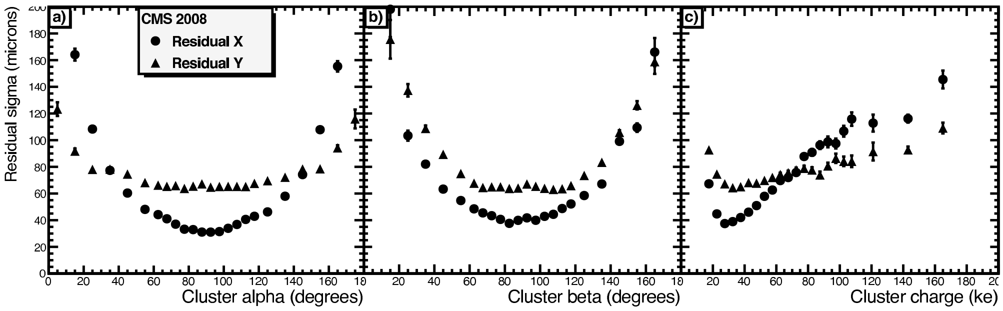

Figure 2: Pixel hit residuals as function of the transverse and longitudinal impact angles and cluster charge in kiloelectrons. The full circles correspond to the transverse coordinate and the full triangles to the longitudinal coordinate. Tracks have a momentum larger than 10 GeV/c. Impact angles of 90° correspond to normally incident tracks.

The width of this double difference distribution is insensitive to translational misalignment of the overlapping modules. The double difference widths are fit with a Gaussian and the uncertainty from the tracking prediction are subtracted to recover the hit resolution on the position difference. With the assumption of equal resolution for each of the modules in the overlap, the final fit values for the resolution for a single module is 18.6±1.9 μm along x and 30.8±3.2 μm along y. Events with the same range of impact angles as in the measured sample have been simulated in detail. The residual distributions are obtained comparing the true and reconstructed hit positions. A Gaussian fit to the simulated residual distribution gives a RMS of 22.1±0.2μm and 28.5±0.1μm along the x and y coordinates, respectively. The simulated values agree well with the measurements.

4 Conclusions

After installation in July 2008, the CMS Silicon pixel detector was rapidly commissioned and then operated in a month-long cosmic ray trigger run in October 2008. About 94% of the forward disks and 99% of the central barrel were included in this commissioning cosmic ray run. Online charge calibration permitted comparison of charge measurements with expectations from simulation, showing good agreement for charge distributions. Using tracks intersecting overlapping modules, hit resolutions of 20 μm $(r - \phi)$ and 30 μm (z) are extracted from the small statistics available in the barrel detector. These results are in line with the expectations presented in Ref. [3]. Currently 98.6% of the whole pixel detector is fully functional. The thresholds are close to the minimum achievable. With the first data taken with the beam it is planned to time-align the different portions of the pixel detector with respect to the beam collisions and improve the spatial alignment.

References

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[3] CMS Collaboration, *CMS physics: Technical design report,* CERN-LHCC-2006-001 (2006).