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Performance of the CMS pixel detector from the first LHC collisions

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Abstract

In 2009 and 2010, the LHC has delivered a relatively large amount of collision data that were successfully used to improve the understanding of the CMS pixel detector response. The results from data/simulation comparisons based on hit-by-hit measurements as Lorentz angle, hit resolution and charge collection are reported. In addition event-by-event observations related to the hit multiplicity in the pixel detector are discussed.

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Performance of the CMS pixel detector from the first LHC collisions

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In 2009 and 2010, the LHC has delivered a relatively large amount of collision data that were successfully used to improve the understanding of the CMS pixel detector response. The results from data/simulation comparisons based on hit-by-hit measurements as Lorentz angle, hit resolution and charge collection are reported. In addition event-by-event observations related to the hit multiplicity in the pixel detector are discussed.

1. Introduction

The CMS pixel detector [1] plays a significant role in track seeding, identification and reconstruction of primary vertices as well as secondary vertices from long-lived particles produced by LHC p-p collisions [2]. The detector includes a central barrel (BPIX) and two forward (FPIX) regions. The BPIX contains 48 million $100 \times 150 \mu\text{m}^2$ pixel cells distributed on three 53-cm-long layers placed radially at 4.4, 7.3 and 10.2 cm from the beam axis. Each layer is composed of ladders made of 8 modules. A full module contains 66560 pixels, read by sixteen read-out chips (ROC) [3]. In the FPIX, two pairs of disks are placed at $z = \pm 34.5$ and ± 46.5 cm and contain 18 million pixel cells. The covered pseudo-rapidity range is $|\eta| < 2.5$, matching the acceptance of the surrounding silicon strip tracker.

2. Hit-by-hit properties: charge collection, Lorentz angle and hit resolution

Charged particles produced by collisions interact with the sensors, creating electron-hole pairs. The combined presence of the electric field and 3.8T magnetic field generated by the CMS solenoid result in a drift of the electrons to one or several pixels. The charge is read out by the ROCs, allowing the reconstruction of the hit positions used for the tracking. The modeling of detector response is therefore crucial and involves accurate simulation of the analog response of the pixels (electrons to ADC count), of the Lorentz

deflection and read-out thresholds [4]. In addition the correct adjustment of gains and pedestals for the 66 million channels is required.

In this section the main hits-based measurements are reviewed by comparing data with the simulation [5–8] (MC). Three results are presented: the charge collection, the Lorentz angle and the intrinsic hit resolution. A more detailed presentation is given in [9].

The hits [10] formed by a collection of adjacent pixels above a given charge threshold are characterized by the total charge or by the “normalized” charge, i.e. total charge corrected for the particle path length through the sensor. The latter has the virtue of being able to provide a distribution independent on the particle impact angle. The normalized hit charge distribution in the BPIX is shown in Figure 1(a) and was obtained using hits belonging to tracks with a minimum momentum of 2 GeV/c. Using a Vavilov fit [12] to the distributions, the relative most probable value (width) difference between data and simulation is approximately 2% (5%). In the FPIX this value is 4% (15%). This demonstrates a fair agreement between simulation and data.

The Lorentz angle θ_{LA} affects the hit position resolution and is sensitive to the sensor bias voltage V_{bias} , the temperature and the B-field, since these quantities affect the drift of the electrons in the $r - \phi$ plane. It is thus relevant to monitor θ_{LA} , also because of its evolution in time with sensor irradiation. Two methods were successfully used to measure θ_{LA} . First, the “grazing angle” method (GA) [14] uses tracks with shallow an-

Figure 1. (a): Normalized cluster charge in BPIX from data (dots) and MC (solid line). (b): Linear fit of the electron drift over depth with the 0.9 TeV data, for $T \sim 14^\circ\text{C}$, $V_{bias}=150\text{V}$, $B=3.8\text{T}$.

gles with respect to the z axis. The electron drift distance is determined with respect to the depth of electron-hole production in the sensor, using the track angle. By averaging over a large number of tracks, θ_{LA} is extracted from the slope of the linear fit made over the drift length. Second, the “minimal hit size” method (MHS), previously used with the 2008 cosmic ray data [13,14], determines the angle for which the hit size is smallest in the $r-\phi$ plane, which corresponds to θ_{LA} . The GA result is given in Figure 1(b), where the fit over the electron drift with respect to creation

depth gives $\tan \theta_{LA}^{data,GA} = 0.3985 \pm 0.0005(\text{stat})$ for $T \sim 14^\circ\text{C}$, $V_{bias}=150\text{V}$, $B=3.8\text{T}$ and shows a good agreement with the value for MHS: $\tan \theta_{LA}^{data,MHS} = 0.409 \pm 0.002(\text{stat})$. Both results are consistent with the simulation that gives $\tan \theta_{LA}^{MC,GA} = 0.4006 \pm 0.0005(\text{stat})$ and $\tan \theta_{LA}^{MC,MHS} = 0.411 \pm 0.005(\text{stat})$ respectively.

In order to measure the intrinsic hit resolution σ_{hit} , a method which exploits overlapping modules in the BPIX is used. Tracks traversing the overlap regions of two modules in a single layer are identified. The expected hit position in $r-\phi$ plane (x_{pred}) and in the z direction (z_{pred}) is then estimated on both modules from track extrapolation, removing the layer under study. The difference between the two predicted positions $\Delta x, z_{pred}$ and the difference between the reconstructed position $\Delta x, z_{hit}$ are calculated. The double difference $\mathcal{D} = \Delta x, z_{hit} - \Delta x, z_{pred}$ distribution is then computed and fitted with a Gaussian. Finally the intrinsic hit resolution σ_{hit} is estimated using $\sigma_{hit}^2 = \sigma_{\mathcal{D}}^2 - \sigma_{\Delta_{pred}}^2$ where $\sigma_{\Delta_{pred}}$ is evaluated for each overlap site as the mean of the distribution of errors, taken from the trajectory extrapolations.

The hit resolution estimation was made with tracks with $p_T > 2.5 \text{ GeV}/c$ and by selecting overlapping sites with at least 20 tracks. In the $r-\phi$ direction, the data and MC (including PIXELAV prediction [6]) results are $\sigma_{hit} = 12.7 \pm 2.3 \mu\text{m}$ and $14.1 \pm 0.5 \mu\text{m}$, respectively. Along the z axis the corresponding values are $28.2 \pm 1.9 \mu\text{m}$ and $24 \pm 0.5 \mu\text{m}$, respectively. This demonstrates a very good agreement between data and simulation.

3. Event-based observations: hit multiplicity

The measurements discussed in the previous section confirm that hit reconstruction in the CMS pixel detector is well understood. In the following the comparison of hit multiplicity (HM) for both data and MC is discussed, for which there are many potential sources of discrepancies. Of particular interest are the collisions modeling, the detector simulation and the presence of beam background events.

In the case of the collisions simulation, the shower type/scale and the tuning of underlying events contribute principally to the number of charged particles emitted from the interaction point (IP) and in particular the number of soft particles looping in the tracker, generating therefore many hits. A second potential source of discrepancy is related to the presence of secondary particles resulting from the interaction between sensors and incoming particles. This effect is clearly observed for instance in the FPIX where the density of charged particles emitted from the IP is expected to be similar in each disks of the same z side. Finally, beam background events observed from the very first LHC runs are characterized by large occupancy tails, hence their importance in the HM study. More detailed discussions, in particular the possibility to monitor and efficiently suppress these events within physics sample are in [15].

Using beam background events suppression, the HM was measured for the whole pixel detector and compared to the simulation. The agreement, in terms of the mean of the distribution, is better than approximately 92% at 0.9 TeV and 86% at 7 TeV. This overall very good agreement is confirmed with the comparison of hit multiplicities at the level of the layers/rings in BPIX and disks in FPIX. In order to further improve the description of data by the simulation, intense studies focused on the parameterization of event generators like PYTHIA [7] are ongoing. This is illustrated in Figure 2, where the HM distribution is shown for several different parameterizations of PYTHIA and for the 7 TeV data.

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Figure 2. Pixel hit multiplicity distribution for data (dots) compared different Pythia tunes: MC-AT [16], MC-P8 [8], MC-D6T [7], MC-DW [17].

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