Performance of the current CMS pixel detector

Silvia Taroni for the CMS Collaboration

Abstract

The silicon pixel detector is the innermost component of the CMS tracking system. Based on the precise measurement of up to three unambiguous space points, it allows an effective pattern recognition even in the high track density environment of LHC collisions. In this contribution, we present the performance of the CMS pixel detector during the first LHC run. In particular, we present the hit efficiency, position resolution, and data-losses caused by the large LHC instantaneous luminosities.

Presented at IEEE-NSS-MIC-RTDS-2013 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference
Performance of the current CMS pixel detector
Silvia Taroni on behalf of the CMS Collaboration

Abstract—The silicon pixel detector is the innermost component of the CMS tracking system. Based on the precise measurement of up to three unambiguous space points, it allows an effective pattern recognition even in the high track density environment of LHC collisions. In this contribution, we present the performance of the CMS pixel detector during the first LHC run. In particular, we present the hit efficiency, position resolution, and data-losses caused by the large LHC instantaneous luminosities.

Index Terms—CMS, pixel detector.

I. INTRODUCTION

The CMS pixel detector is the innermost part of the CMS experiment [1], it has an active silicon area of \( \sim 1 \text{ m}^2 \) and it covers a pseudorapidity range up to \(|\eta| < 2.5\). The detector is composed of three layers in the barrel region (BPIX) and two end cap disks (FPIX) on either side of the interaction point. It uses n+ -in-n silicon sensors, 285 \( \mu \text{m} \) thick, having a pixel cell size of \( 100 \times 150 \mu \text{m}^2 \). It is composed of 66 million pixels, grouped into 1440 modules. During data taking, the bias voltage is 150 V for BPIX and 300 V for FPIX. It uses an analog readout via optical links which retains information about the absolute signal height and it employs an on-chip data sparsification to reduce the data volume to be shipped out. This detector has been in more or less continuous operation during the past years of data taking. During 2012, pixel operational issues accounted for only 9% of CMS downtime. Only 3.7% of the Read-Out Chips (ROCs) are unavailable for readout; the most common reason is that the ROC produces an incorrect pulse shape, which results in the signal being unidentified within the analog pulse train. One entire optical channel in the FPIX is lost due to a broken laser driver. Most of these unavailable channels are going to be recovered in the current LHC shutdown. During 2012, a total of 23.3 fb\(^{-1}\) of proton - proton collision data has been delivered of which 21.8 fb\(^{-1}\) have been recorded. This corresponds to a data taking efficiency of 93.6% which is higher than in 2011 despite the fact that the average pile up has been doubled.

A. Hit efficiency

Pixel hit efficiencies are determined by measuring missing hits on reconstructed tracks during LHC running. The efficiency for working ROCs is above 99% for all layers, as shown in figure 1. However, the module hit efficiency decreases as function of the instantaneous luminosity, as shown in figure 2, with the pixel modules in the innermost layer of the BPIX, layer 1, being affected the most. This is mainly caused by a dynamic inefficiency which increases with hit rate and originates from limitations in the internal buffering of the readout chip.

S. Taroni is with the Physik-Institut, Zurich University, Switzerland
B. Cluster size and charge

The high occupancy produces also an effect on the cluster proprieties. Figure 3 shows the average cluster size for the three layers of the barrel detector. For Layer 1 a small decrease is visible at high instantaneous luminosities: this is probably due to the loss of part of the cluster because of the limitation of the ROC internal buffering. This average size variation is one of the responsibles for the average cluster charge decrease (figure 4) at high instantaneous luminosity. The second, and probably the most important, is the temperature dependence of the gain calibration of the ROC: the higher occupancy increases the power consumption that causes an increase of the temperature of the ROC. The resulting effect is a change of the collected charge distribution most probable value (MPV) of $\sim 1000 \text{ e}^-$ for long runs.

II. Effects of radiation

The CMS pixel detector has been designed to be able to continue operation even after significant radiation damage. Nevertheless, there is the need to monitor the damage through studies of the leakage current and depletion voltage evolution. Changes to the analog current and threshold setting in each ROC, correlated with the integrated luminosity, have also been observed.

A. Depletion voltage

The depletion voltage is investigated by varying the bias voltage at which the detector is operated during the LHC operation and thus changing the charge collection and hit efficiency. The hit efficiency has been measured in such scan for particular channels. The hit efficiency measurement during a bias scan for layer 1 is shown in figure 5. The dependence of the voltage needed to have the 99% efficiency on the total integrated luminosity is shown in figure 6 where a minimum at 8-10 fb$^{-1}$ of integrated luminosity is clearly visible: layer 1 has been type inverted during 2012 data taking.

B. Lorentz angle and charge collection profile

The silicon sensors of the CMS tracker are operated in a 3.8 T magnetic field. Charges created by traversing ionizing particles inside the active sensor volume are deflected by the Lorentz force. The Lorentz angle, under which the charge drifts through the sensor, is strongly dependent on the mobility, which in turn depends on the electric field and on the radiation damage [2]. The Lorentz angle is measured from collision data using the grazing angle technique [3]; the behavior of
the tangent of the Lorentz angle as a function of the integrated luminosity is shown in figure 7. The dependence of the Lorentz drift on bias voltage is well visible in figure 8 where it is plotted as a function of the depth at which the charge is released in silicon: lowering the bias voltage, the curves become steeper and steeper. Using the data collected during a bias scan, the effect of radiation on charge collection has also been studied. Radiation damage produces a non-uniform electric field in the silicon bulk and the trapping of the carriers. These can be investigating studying the charge collected by a pixel as a function of the depth at which the charged is released in the sensor. A flat profile is expected for a non irradiated detector. Figure 9 shows the charge profile at the end of 2012: lowering the bias voltage, the importance of the carrier trapping increases reducing the absolute value of the average pixel charge and distorting the distribution at high depth, farer from the readout (n+ side). Nevertheless, this effects is correctly treated during data reconstruction. In this process, the pixel detector clusters are compared to templates for taking into account correctly non-working channels, Lorentz angle variations and radiation effects. This template are produced with PIXELAV [4] simulation and updated regularly according to the detector conditions and response. The model used for the reconstruction of data taken at the end of 2012 is shown in figure 10: it well describes real data at a bias voltage of
150 V.

C. Leakage current

Leakage current is measured in the pixel barrel, using readings from the high voltage power supplies, and compared to models of leakage current evolution due to radiation damage. In order to facilitate comparison between experiments, measured leakage currents are normalized to the area of instrumented silicon and extrapolated to 0 °C [5]. The leakage current averaged over each barrel layer is shown in figure 11 and 12, as a function of integrated luminosity and of time in 2011-12. The data are compared to a parameterization adding exponential and logarithmic terms [6], which accounts for accumulated damage and for annealing, whose input is the fluence as predicted by a model of the CMS detector implemented in the FLUKA program ([7], [8]). This model produced good agreement in shape with data but needed to be rescaled. The reason for these discrepancies in scale are under investigation, with possibilities including uncertainties in the operational temperature of the detector.

D. Pixel threshold

During the past data taking period, it has been observed that the pixel threshold increases with time (figure 13), necessitating optimization to not affect the data quality. A possible explanation is a change in the meaning of the DAC setting; this may have been caused by bulk damage in a diode used as a reference voltage within the ROC.

E. Hit resolution

The pixel detector is performing well in terms of resolution: only a small increase due to radiation damage can be observed (see figure 14). The hit resolutions are measured using the triplet method, in which tracks with 3 hits in the barrel are
Fig. 14. Transverse resolution as a function of integrated luminosity.

extrapolated to layer 2 using the layer 1 and 3 positions and angles. The residual in both $\phi$ and $z$ direction may then be measured; they are shown in figure 15 and 16. Hit resolutions may also be determined for tracks that contain multiple hits on the same layer due to overlapping regions; these yield consistent results.

III. CONCLUSION

The CMS pixel detector operated successfully in the whole data taking period. Only few channels were not in the readout because showing a distorted pulse shape or having a broken readout chain; maintenance work is ongoing to recover these channels. The effect of radiation has been continuously monitored and compared to models; studies are ongoing to understand the discrepancies. Nevertheless, the hit efficiency and resolution remains excellent.

REFERENCES