PROCEEDINGS OF SCIENCE

Performance of the CMS Tracker during Run 3

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Daina Leyva Pernia[a] and Maryam Bayat Makou[a,*] for the CMS collaboration

[a] *Deutsches Elektronen Synchrotron (DESY), Notkestraße 85, Hamburg, Germany*

E-mail: daina.leyva.pernia@desy.de, maryam.bayat.makou@desy.de

The current CMS silicon tracker consists of two tracking devices: the inner pixel and the outer strip detectors. The tracker occupies the region around the center of CMS, where the LHC beams collide, and therefore, operates in a high-occupancy and high-radiation environment produced by the particle collisions within the LHC tunnel.

This article provides an overview of the excellent performance of the CMS silicon tracker during the ongoing Run 3 data-taking period. It discusses the behavior of local observables, such as hit reconstruction efficiency, their response to the accumulated integrated luminosity, and the precision achieved in aligning the detector components.

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*Speaker

1. The CMS tracker detector

Comprising 1856 silicon pixel detector modules and 15 148 silicon strip detector modules, the CMS tracker [1, 2] plays a crucial role in physics research. The Pixel detector, located closest to the interaction point, is particularly susceptible to radiation damage. Its modules are arranged in four cylindrical layers around the beampipe and three endcap disks on each side of the detector. It is surrounded by the Silicon Strip detector, which features ten cylindrical layers and twelve endcap disks. Together, they deliver robust tracking and contribute with a pivotal role in CMS vertex reconstruction. This article highlights the remarkable performance attained in the face of challenging conditions during the Run 3 LHC data-taking period, including managing up to 62 interactions per beam crossing.

2. Tracker detector performance during Run 3

2.1 Pixel detector performance

Being the closest component to the interaction point, the Pixel detector is much more likely to suffer from radiation damage effects. These can lead to inefficiencies or instabilities, impacting the data quality. Consequently, during the second LHC Long Shutdown (LS2) period, from 2018 to 2022, the Pixel detector was extracted for a series of improvements and refurbishments [3]. This includes the installation of a whole new pixel barrel layer to replace the one nearest to the interaction point and the repair of modules and electronics in the other layers and disks. A measure of its performance during the present data-taking period is shown in Fig. 1 (left), showing the hit efficiency with instantaneous luminosity during Run 3 [4]. The distribution exhibits rather stable performance, which slightly deteriorates towards larger instantaneous luminosity for all layers, with the layer one efficiency being the most affected. This is mostly caused by the saturation of the readout buffer in the chips [5]. The improvements in preparation for Run 3 allowed for a hit efficiency higher than 96% at 22×10^{33} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. A summary of the hit efficiency in the barrel layers for the delivered integrated luminosity in Run 3 is shown in Fig. 1 (right). Here again, Layer 1 efficiency decreases rather rapidly with accumulated radiation. The effect can be partially recovered by increasing the application voltage for the sensors and through continuous calibrations [6], which can be seen as the discontinuities where the efficiency increases rapidly in the figure.

2.2 Silicon Strip detector performance

The integrity of the strip detector is essential for data-taking. The stability during Run 3 can be seen in the fraction of bad module components trend with the integrated luminosity, reflecting the integrity of its components to maintain an excellent tracking performance. This trend is shown in Fig. 2 for 2022 and 2023 proton-proton collisions [7], showing a rather stable trend, with a fraction of active channels of about 96%. The jumps at 205 fb^{-1} are caused by the recovery of a cooling loop on the endcap region. Furthermore, some of the module power supplies in the Tracker Inner Disks were turned off during 2023 because of technical issues with the Front-End Drivers after 245 fb^{-1}[7]. As can be seen, the trend returned to usual values after the power to the modules was restored. Overall, no major issues have affected data quality.

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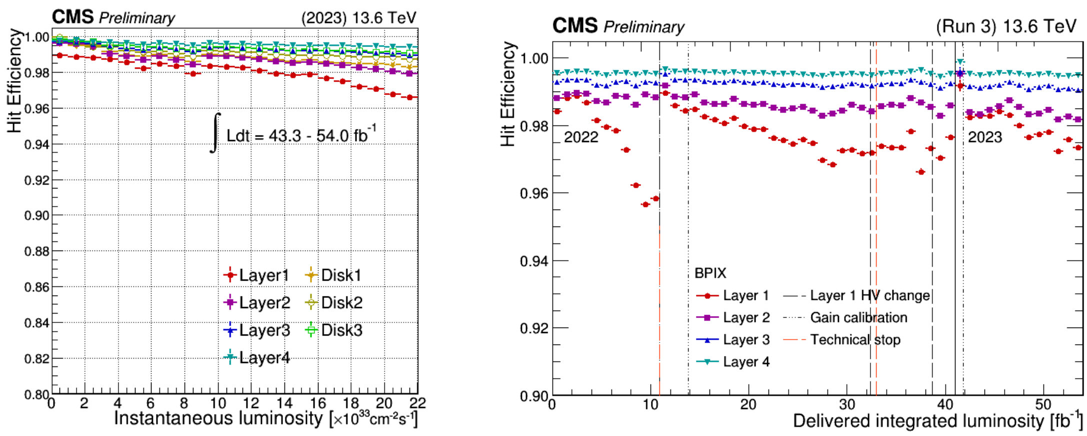

Figure 1: Pixel detector Hit Efficiency vs Instantaneous Luminosity during data-taking runs in May and June 2023 (left) and vs delivered integrated luminosity during Run 3 (right).

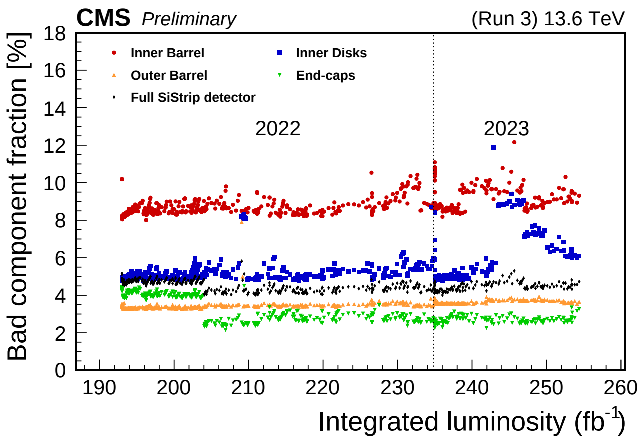

Figure 2: Evolution of fraction of modules flagged as bad vs delivered integrated luminosity during Run 3.

2.3 Tracker alignment performance

A feature of the CMS tracker detector is its outstanding hit resolution, of about 10 μm. However, after installation, a mechanical alignment can only yield a precision on the position and orientation of the modules of about 0.1 mm [8]. Furthermore, it has been observed that changes in the conditions, like magnet cycles and temperature changes, as well as the long-term exposure to a high-radiation environment, can cause real or apparent movements of the detectors [8, 9]. To improve the precision of the knowledge of the component's geometry, a track-based alignment approach, relying on the minimization of the sum of squares of normalized track-hit residuals, is performed. This process allows us to obtain changes to alignment parameters, which describe the geometrical location of the components.

After the technical stop at the end of 2022 and the beginning of 2023 (Year End Technical Stop or YETS), significant movements were expected as explained before. To overcome this, alignment geometries were iteratively derived using cosmic rays and proton-proton collision data at 900 GeV and 13.6 TeV, as data became available [10]. The performance achieved, continuously improving the mean and reducing the width of the track hit residuals to guarantee the accuracy for data-taking, is shown in Fig. 3.

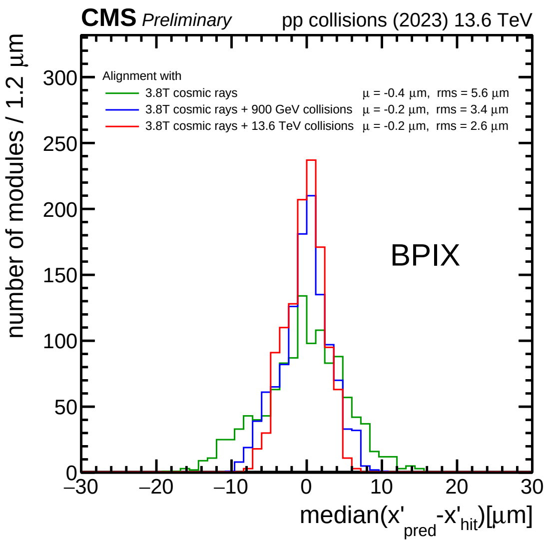

Figure 3: Distribution of median residuals in the local x coordinate on the barrel pixel detector according to alignment geometries derived iteratively in 2023.

3. Summary

The CMS tracker system plays a critical role in data-taking, enabling precise reconstruction of charged particle positions and momenta, even under the challenging conditions of Run 3, with a peak pileup of about 62 interactions per beam crossing. This article has discussed the performance of the Pixel and Silicon Strip detectors during Run 3, highlighting the continuous efforts to maintain exceptional performance and the role of the Tracker alignment in ensuring high-quality data.

References

[1] CMS collaboration, "The CMS experiment at the CERN LHC", *Journal of Instrumentation* **3** (2008) S08004.

[2] CMS collaboration, "Development of the CMS detector for the CERN LHC Run 3", 2309.05466.

[3] L.O.S. Noehte and on behalf of the Tracker Group of the CMS collaboration, "CMS Phase-1 pixel detector refurbishment during LS2 and readiness towards the LHC Run 3", *Journal of Instrumentation* (2022) .

[4] CMS Collaboration, "Pixel Detector Performance in early 2023", CMS-DP-2023-041, https://cds.cern.ch/record/2865842, (2023).

[5] T.A. Vami for the CMS Collaboration, “Calibration and performance of the CMS pixel detector in LHC Run 2”, Proceedings of 7th Annual Conference on Large Hadron Collider Physics — PoS(LHCP2019) https://doi.org/10.22323/1.350.0010, (2019).

[6] CMS Collaboration, “Pixel Detector Performance in Run 3”, CMS-DP-2022-067, https://cds.cern.ch/record/2844889, (2022).

[7] CMS Collaboration, “CMS Silicon Strip Tracker Performance in 2023”, CMS-DP-2023-040, https://cds.cern.ch/record/2865841, (2023).

[8] CMS Collaboration, “Strategies and performance of the CMS silicon tracker alignment during LHC Run 2”, *Nucl. Inst and Meth. A* **1037** (2022) 166795.

[9] A.V. Barroso for the CMS Collaboration, “Tracker Alignment in CMS: Interplay with Pixel Local Reconstruction”, Proceedings of Science — PoS(Pixel2022), arXiv:2303.16642, (2023). 10.22323/1.350.0010.

[10] CMS Collaboration, “Tracker alignment performance in early 2023”, CMS-DP-2023-039, https://cds.cern.ch/record/2865840, (2023).

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