The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

05 June 2018 (v4, 27 June 2018)

Performance and Operation of the CMS Phase 1 Pixel Detector

Lea Michaela Caminada for the CMS Collaboration

Abstract

The silicon pixel detector of the CMS experiment at the LHC provides high precision tracking in the region closest to the proton-proton collision point. It operates in a particularly harsh environment characterized by high track multiplicity and heavy irradiation which poses severe challenges to the detector design. At the beginning of 2017, the original pixel detector was replaced with an upgraded 4-layer pixel system to maintain the excellent tracking performance of CMS in view of the increasing luminosity scenario (up to $2.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ during Run 2 and 3). The CMS Phase 1 detector features a new readout chip to reduce the dynamic inefficiency at high rate as well as an additional innermost layer at a radius of 3 cm from the interaction point to improve the impact parameter resolution. I review the main design features of the CMS Phase 1 pixel detector and discuss its performance and the challenges in operation during the first year of data-taking in 2017. Furthermore, I report about the consolidation work performed during the LHC year end technical stop and the status of the Phase 1 pixel detector and re-commissioning toward operation in 2018.

Presented at *ELBA2018 14th Pisa meeting on advanced detectors*

Performance and Operation of the CMS Phase 1 Pixel Detector

Lea Caminada, on behalf of the CMS collaboration

*Labor für Teilchenphysik, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
Physik Institut, Universität Zürich, Winterthurerstrasse 190, 8057 Zürich, Switzerland*

Abstract

The silicon pixel detector of the CMS experiment at the LHC provides high precision tracking in the region closest to the proton-proton collision point. It operates in a particularly harsh environment characterized by high track multiplicity and heavy irradiation which poses severe challenges to the detector design. At the beginning of 2017, the original pixel detector was replaced with an upgraded 4-layer pixel system to maintain the excellent tracking performance of CMS in view of the increasing luminosity scenario (up to $2.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ during Run 2 and 3). The CMS Phase 1 detector features a new readout chip to reduce the dynamic inefficiency at high rate as well as an additional innermost layer at a radius of 3 cm from the interaction point to improve the impact parameter resolution. I review the main design features of the CMS Phase 1 pixel detector and discuss its performance and the challenges in operation during the first year of data-taking in 2017. Furthermore, I report about the consolidation work performed during the LHC year end technical stop and the status of the Phase 1 pixel detector and re-commissioning toward operation in 2018.

Keywords: Tracking detectors, Solid State Detectors, Silicon Pixel Detectors

1. Introduction

The CMS silicon pixel detector [1, 2] provides high-precision tracking in the region closest to the interaction point in a particularly harsh environment characterized by a high track multiplicity and heavy irradiation. In order to maintain the excellent performance of the CMS tracking system at higher instantaneous luminosities (up to $2.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ during LHC Run 2 and 3), the original pixel detector has been replaced with an upgraded system (Phase 1) during the extended LHC technical stop in winter 2016/17.

The CMS Phase 1 upgrade pixel system [3] consists of four barrel layers at radii of 3, 7, 11 and 16 cm and three disks on each side of the interaction region at a distance of 29, 40, and 52 cm. Compared to the original detector the Phase 1 pixel detector features important improvements: 1) Improved tracking robustness due to an additional barrel layer and endcap disks, 2) improved vertex resolution with the innermost layer and disk being placed closer to the beam, 3) improved hit efficiency at high luminosity due to faster readout electronics and 4) reduced material budget due to the adoption of a CO₂ cooling system and a lightweight mechanical structure made from advanced carbon fiber material.

This report reviews the performance of the CMS Phase 1 pixel detector during its first year of operation, the consolidation work performed at the end of the run to mitigate an unforeseen issue with the DCDC converters used in the power system as well as the current detector status and operation early 2018.

2. Performance during first year of operation

The installation of the CMS Phase 1 pixel detector has been completed at the beginning of March 2017 and after a period of commissioning and calibration, the detector recorded its first collision data at the end of May 2017.

The pixels are operated at a threshold of about 1800e⁻ for the outer barrel layers and the endcap disks with a noise of about 150e⁻. For the innermost barrel layer a different readout chip [4] is used to cope with the significantly higher hit rate (up to 600 MHz/cm²). Since a higher than expected noise level has been observed during operation, the threshold has been raised to 2600e⁻ for the innermost layer.

After installation, the detector working fraction was 95.7%. The losses were mainly caused by problems with individual readout and power groups. During the first months of operation a large effort was spent on detector commissioning. Oper-

Figure 1: Hit efficiency as a function of instantaneous luminosity for the original (left) and the Phase 1 upgrade (right) CMS pixel detector.

ational procedures were developed to optimize the detector performance. In particular automatized procedures to power cycle, reset and re-configure detector modules were implemented to mitigate SEU effects and dynamic inefficiencies.

The pixel hit resolutions measured in data match the expectation from simulations and are about $10\mu\text{m}$ and $30\mu\text{m}$ in the transverse and longitudinal direction, respectively. The dynamic inefficiency at high instantaneous luminosity is significantly reduced with respect to the original detector: While the hit efficiency in the first layer of the original detector dropped to 94% at an instantaneous luminosity of $1.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ (as measured in 2016), the innermost layer of the Phase 1 upgrade achieves a hit efficiency of more than 98%, despite being located at a smaller radius. The hit efficiency as a function of instantaneous luminosity of the Phase 1 upgrade detector is compared to the original detector in Figure 1.

The CMS Phase 1 pixel detector uses 1184 DCDC converters [5] to power the detector modules. During the last two months of operation in 2017, a failure of these components was observed amounting to 67 broken DCDC converters by the end of the run. In order to investigate the issue and ensure optimal performance during 2018, the pixel detector was extracted for repair during the year end technical stop 2017/18. While the issue has been traced to damage in a transistor inside the FEAST2 chip [6], the cause of the problem is still under investigation.

3. Consolidation work during LHC shutdown

As soon as data-taking in 2017 was over, the CMS detector was opened to allow for access to the pixel detector. The pixel detector has then been extracted and brought to a surface cleanroom for testing and repair.

As precaution all 1184 DCDC converters used in the pixel system were dismantled and replaced. Subsequently the functionality of all detector components was verified.

In the pixel detector system the granularity of the low voltage supply for the readout chips is larger than the granularity of the high voltage supply for the silicon sensor bias. Therefore some modules attached to broken DCDC converters were operated with high voltage on, but low voltage off. If the LV is off the pixel leakage can no longer flow through the preamplifier structure. Instead the current will flow through the sensor bias grid

building up a voltage difference at the input of the pixel preamplifier which can cause damage. The extent of damage depends on the amount of leakage current (and thus the pixel module position) and the time operated without LV. All affected modules that were accessible without disassembling the detector layers were replaced (6 modules in the innermost layer).

During 2017 some detector regions (4%) could not be operated due to issues with power or readout groups. These issues were investigated and fixed by either improving the connections or substituting problematic components. The consolidation work in the cleanroom was completed within about 3 weeks and the pixel detector was successfully reinstalled in February 2018. After a period of commissioning and calibration, the pixel detector was ready in time to record the first LHC collisions of 2018.

4. Performance during early 2018 collision data-taking

A detector working fraction of 97.8% has been established at the start of the run. This is an improvement compared to 2017 and the losses are dominated by modules operated downstream of broken DCDC converters that could not be replaced.

The operational procedures developed during 2017 allowed for a smooth startup and high data-taking efficiency. The performance of the DCDC converters is closely monitored and preventive measures have been put in place to mitigate potential losses. So far no new issues have occurred and the performance of the pixel detector is excellent.

5. Conclusion

The CMS Phase 1 pixel detector delivered high-quality physics data during its first year of operation. An issue with the FEAST2 chip used in the DCDC converter modules, required an unforeseen intervention during the year end technical stop 2017/18. Despite the very limited time available before the start of the next LHC run, all DCDC converters as well as 6 modules in the innermost layer could be replaced. The detector working fraction at the beginning of collision data-taking in 2018 is 97.8%. Detailed investigations of the DCDC converter issue are ongoing and crucial in view of many future upgrade projects at the LHC experiments which will rely on the same technology.

References

- [1] CMS Collaboration, JINST 3 (2008) S08004.
- [2] H. C. Kästli et al., Nucl. Instrum. Meth. A582 (2007) 724-727.
- [3] CMS Collaboration, CERN LHCC-2012-016.
- [4] A. Starodumov et al., JINST 12 (2017) C01078.
- [5] L. Feld et al., JINST 9 (2014) 01, C01048.
- [6] F. Faccio, REDW (2014) 7004569.