The Compact Muon Solenoid Experiment
Conference Report

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CMS Tracker Performance and Readiness for LHC Run II

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Abstract

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CMS Tracker Performance and Readiness for LHC Run II

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Abstract

The CMS Tracker performance during LHC Run I is reviewed. The latest results of both pixel and strip detectors following the first LHC long shutdown (LS1) are then presented. Results from detector calibration and commissioning, together with a description of operations and repairs done during LS1, will be shown.

Keywords: Tracking detectors, CMS, Strip and pixel detectors

1. Introduction

The Compact Muon Solenoid (CMS) is a general-purpose detector operating at the Large Hadron Collider (LHC) at CERN. CMS successfully collected data during the first p-p collisions run at LHC (Run I), with a center of mass energy of $\sqrt{s} = 7$ and 8 TeV. In 2012, during the so called Long Shutdown 1 (LS1), LHC was stopped for the upgrades needed in order to reach a center of mass energy of $\sqrt{s} = 13$ TeV, and has been restarted again in June 2015 for the second data taking period (Run II).

The CMS tracker [1] is a large silicon detector with cylindrical symmetry and with a total sensitive area of $\sim 200 \text{ m}^2$. In the CMS coordinate system the z axis coincides with the beam direction, ϕ is the azimuthal angle and the pseudorapidity is $\eta = -\ln \tan(\theta/2)$, where θ is the polar angle.

Figure 1: Pictorial view of a tracker slice in the r - z plane. Pixel modules are shown in red, single-sided strip modules are depicted as black thin lines and strip stereo modules are shown as blue thick lines.

The tracker is composed of two sub-detectors immersed in a 3.8 T magnetic field produced by an external solenoidal magnet. Referring to figure 1, the innermost detector, closest to the beam pipe, is the pixel detector, while the outer detector is the strip detector. The pixel detector has a sensitive area of 1.1 m^2

and is segmented into 66 million pixels of size $100 \mu\text{m}$ in the $r\phi$ plane and $150 \mu\text{m}$ along the z axis. The detector comprises three layers in the barrel region and two endcap disks at each side of the barrel. The strip sub-detector is composed of 9.6 million silicon strips with a varying pitch from 80 to $205 \mu\text{m}$. The silicon tracker has 10 layers in the barrel region, four in the inner barrel (TIB) and 6 in the outer barrel (TOB). It also has two endcaps, each one made up of 3 inner disks (TID) and 9 outer disks (TEC). To provide 3-dimensional information, several layers in the barrel and in the endcap have stereo modules with two silicon strip modules mounted back-to-back and rotated by 100 mrad with respect to each other.

2. Tracker developments during LHC Long Shutdown 1

During LS1 the CMS strip detector has been upgraded in order to operate at lower temperatures with respect to the $+4^\circ\text{C}$ operation temperature of Run I. A lower cooling plant set point is needed in order to reduce those radiation damage induced effects that have a temperature dependence, such as the increase of the leakage current and the long-term increase of the depletion voltage (also called reverse annealing) [2]. To prevent humidity formation inside the detector, the tracker volume has been fully sealed and a new dry gas plant has been installed in order to provide the tracker with the needed amount of dry gas. It was verified that the tracker is able to operate at -20°C with a sufficient safety margin, but the operating temperature for Run II has been chosen to be -15°C in order to reduce mechanical stresses.

During LS1 also the pixel detector has been extracted to repair damaged channels.

3. Tracking in CMS

Tracking in CMS is an iterative procedure based on the Kalman filter [3]. Each track is reconstructed following four different steps. In the first step (*seeding*) initial track candidates are obtained using the hits in the innermost layers (pixel

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triplets, pixel pairs, etc.). The aim of the second step (*pattern recognition*) is to search for hits in the outer layers which could be associated to the initial track, reconstructing the particle trajectory. Then a fit of the trajectory using its associated hits is performed, providing an estimate of the track parameters (*fitting*). Finally (*selection*) tracks are selected based on quality requirements.

Figure 2: Tracking efficiency after each iteration of the tracking procedure as a function of track p_T (left) and production radius (right), computed using a simulated $t\bar{t}$ MC sample with an average pile-up (PU) of 20.

These steps are repeated during several iterations, searching initially for tracks that are easy to find, e.g. high p_T tracks using pixel layers as initial seeds, and removing the hits associated to the reconstructed track after each iteration, in order to reduce the combinatorial complexity of the procedure. The last iterations aim to reconstruct displaced tracks using pixel and strip layers, or strip layers only, as initial seeds. The reconstruction efficiency after each iteration as a function of track p_T and production radius, i.e. the distance in the transverse plane between the production point of the particle and the beam axis, is shown in figure 2.

4. Challenges in Run II and tracking developments

In a realistic pile-up scenario for Run II, the maximum average number of pile-up events will be around 45 for a bunch crossing period of 25 ns. The high pile-up is the main challenge in Run II, because of the large increase in tracker occupancy. The main issue will be caused by out of time pile-up which will provide an increase of the strip detector occupancy of 45% and an increase of 5% in the pixel detector at 25 ns bunch crossing period, leading finally to an increase of the computational time per iteration needed for tracking. Moreover the pixel detector will be affected by a dynamic inefficiency due to the overflow of buffers in the read-out chips, providing a lower hit finding efficiency in the pixel detector at large instantaneous luminosities. The problem will be solved when the pixel detector will be exchanged in the Year End Technical Stop 2016/2017.

Several tracking improvements have been developed for Run II, either aiming to improve tracking computing time performances or physics object reconstruction efficiency. For what concerns the timing-oriented developments, a new algorithm has been developed to replace strip-seeded steps based on a χ^2 cut from a straight line fit of three points in the rz plane. In this way half of the seeds are rejected, but the same number of

tracks is reconstructed, finally resulting in a total time reduction of $\sim 40\%$. The second development goal is to mitigate timing and fake rate increase due to out of time pile-up. This improvement is based on a cluster charge cut which removes clusters due to out of time events. These events are in fact characterized by a low collected charge, since they are induced by tracks (loopers) that deposit charge not in time with respect to the sampling window. For what concerns the physics-oriented developments, two new iterations were added to recover muon reconstruction efficiency, which was found to decrease at high pile-up, and also another iteration fully dedicated to the reconstruction of high p_T jets.

Figure 3: Track reconstruction efficiency as a function of η (top left) and production radius R (top right), and fake rate as a function of η (bottom).

In figure 3 are reported the performance simulations of Run I and Run II tracking with nominal pile-up and bunch crossing conditions, calculated using a $t\bar{t}$ MC sample. The results show that the Run II tracking performance is comparable to the performance under Run I conditions regarding prompt and displaced tracks efficiency. The fake rate is slightly higher for Run II tracking but only in the central region of the tracker.

5. Conclusion

The CMS tracker is in very good shape and is ready to operate in LHC Run II. The Run II tracking performance is comparable to the one in Run I, in spite of a much more challenging environment.

References

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