The Compact Muon Solenoid Experiment

Conference Report

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

22 June 2018 (v2, 28 June 2018)

Performance of the CMS Muon System in LHC Run-2

Carlo Battilana for the CMS Collaboration

Abstract

The CMS muon system has played a key role for many physics results obtained from the LHC Run-1 and Run-2 data. It presently consists of three detector technologies equipping different regions of the spectrometer. Drift Tube chambers (DT) are installed in the CMS muon system barrel, while Cathode Strip Chambers (CSC) cover the CMS end-caps; both serve as tracking and triggering detectors. Moreover, Resistive Plate Chambers (RPC) complement DT and CSC in barrel and end-caps respectively and are mostly used in the trigger. Finally, Gas Electron Multiplier (GEM) chambers are going to be installed in the muon spectrometer endcaps at different stages of the CMS upgrade programme. A slice test consisting of 10 GEM chambers is being presently operated in parallel to the rest of the muon spectrometer. The performance of the different muon detectors and the muon trigger, evaluated using data collected at 13 TeV centre-of-mass energy during the LHC Run2, will be presented in this report in all of its aspects.

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

Abstract

The CMS muon system has played a key role for many physics results obtained from the LHC Run-1 and Run-2 data. It presently consists of three detector technologies equipping different regions of the spectrometer. Drift Tube chambers (DT) are installed in the CMS muon system barrel, while Cathode Strip Chambers (CSC) cover the CMS end-caps; both serve as tracking and triggering detectors. Moreover, Resistive Plate Chambers (RPC) complement DT and CSC in barrel and end-caps respectively and are mostly used in the trigger. Finally, Gas Electron Multiplier (GEM) chambers are going to be installed in the muon spectrometer endcaps at different stages of the CMS upgrade programme. A slice test consisting of 10 GEM chambers is being presently operated in parallel to the rest of the muon spectrometer. The performance of the different muon detectors and the muon trigger, evaluated using data collected at 13 TeV centre-of-mass energy during the LHC Run2, will be presented in this report in all of its aspects.

Keywords: Gaseous detectors, Muon spectrometers, Performance of High Energy Physics Detectors, CMS

1. The CMS Muon System

The Compact Muon Solenoid (CMS) is a general purpose detector operating at the CERN LHC collider. Muons are part of the signatures of many analyses performed within the CMS physics programme. For this reason, CMS is equipped with a robust and redundant muon system [1] that performs efficient muon identification, improves the measurement of the transverse momentum (p_T) for muons with energies in the regime of $O(100)$ GeV/c and provides standalone trigger capabilities.

During the LHC Run-2, muons are triggered and reconstructed in CMS using three different types of gaseous detectors, positioned within the steel flux-return yoke of the magnet solenoid. Four stations of Drift Tubes (DT) chambers equip the barrel of the muon system, covering a pseudorapidity region up to $|\eta| < 1.2$. Similarly, the muon spectrometer's end-caps are equipped with four stations of Cathode Strip Chambers (CSC) which cover the $0.9 < |\eta| < 2.4$ range. Each DT (CSC) chamber is built of 8 (6) detector layers measuring the muon trajectory in the transverse plane. Both DT and CSC are used as tracking detectors and participate in the trigger. Additionally, 6 (4) layers of Resistive Plate Chambers (RPC) equip the muon system barrel (end-caps) covering up to $|\eta| < 1.8$ and are mostly used to improve the trigger robustness. Overall, the CMS muon spectrometer consists of 250 DT chambers, 540 CSC chambers and 1056 RPC chambers.

A slice test consisting of 10 chambers of Gas Electron Multiplier (GEM) detectors equips a fraction of the negative CMS end-cap. It is presently being operated to acquire installation and commissioning expertise in view of future upgrades [2].

2. The CMS Muon Detectors Performance

From the hits reconstructed within a single DT or CSC chamber, segments are built out of straight-line track fits. Moreover, hits from adjacent RPC strips are combined into clusters. The efficiency to reconstruct DT and CSC segments or RPC clusters is measured with a *Tag-and-probe* method [1]. Opposite-sign dimuon pairs, coming from the same interaction vertex, are selected out of a sample of events collected with a single-muon trigger. *Tags* are defined as reconstructed muons satisfying tight selection criteria that are geometrically matched with the trigger. *Probes* muons are selected using looser selection criteria, tuned case by case to avoid biases in the measurement. Track trajectories from probes are propagated to the muon stations. A chamber is considered efficient if a reconstructed segment (cluster) is found within a given geometrical window around the propagated probe track. A chamber-by-chamber map of the CSC segment reconstruction efficiency is presented in Fig. 1. In general, efficiency is above 95%, with few exceptions typically due to chambers affected by known hardware problems, either sporadic, or that need intervention to be repaired. Similar conclusions, documented respectively in [3] and [4], hold for DT and RPC.

The CMS muon reconstruction starts from single detector elements (i.e. inner tracker or RPC clusters and DT/CSC segments) and builds tracks in parallel in the inner tracker and in the muon spectrometer. Tracks built out of the two detector systems are then combined and refitted using algorithms that improve the measurement of the p_T of muons with energies of the order of a few hundreds GeV/c, with respect to the tracker-only fit. Figure 2 compares, for tracker-only and combined muon tracks, the RMS of relative q/p_T residuals, computed as the relative difference between the momentum measured from the upper and lower leg of cosmic ray muons crossing CMS. Only muons traversing the CMS pixel detector are used for this study, to mimic muon topologies from collisions. More details about

*Corresponding author

Email address: carlo.battilana@cern.ch (C. Battilana)

Figure 1: Efficiency (in percent) of each CSC chamber to provide a locally reconstructed track segment as measured with *Tag-and-probe* using 2017 data.

Figure 2: The RMS of the relative q/p_T residual as function of muon p_T for muons from cosmic rays. Results from the inner tracker measurement (red) are compared with the ones of combined muon system + inner tracker fits (black).

the analysis method are given in [1].

The CMS Level-1 trigger (L1T) [5], is a hardware system in charge of reducing the data collection rate from up to 40 MHz (the LHC bunch crossing frequency) to, at most, 100 kHz. It builds L1T muon tracks using solely information from the three muon detectors. As for offline reconstruction, CSC/DT trigger segments and RPC hits constitute the basic components upon which L1T muon tracks are built. Besides providing geometrical information, trigger segments and hits are also in charge of identifying the bunch-crossing of origin of muons crossing the spectrometer's chambers (BX ID). A thorough description of the CMS L1T is beyond the scope of this document. We therefore limit ourselves to highlight how DT and RPC information is combined in the barrel muon trigger to improve BX ID. Linear propagation of DT trigger segments from a DT chamber is performed looking for geometrically-compatible hits in neighbouring RPC chambers. If a match is found, a DT+RPC *super segment* is built and RPC BX ID information can be used to supersede the DT one. Figure 3 [6] shows how DT+RPC supersegments improve, in terms of BX ID, the performance of *DT-only* trigger segments.

3. Conclusion

This document briefly summarises the performance of the CMS muon system with data collected during the LHC Run-2.

Figure 3: A comparison showing the BX assignment distribution of local trigger primitives in the muon barrel for DT-only (red) or combined DT+RPC (black) trigger segments.

Results for local reconstruction efficiency are presented, the impact of the muon chambers on the measurement of the p_T of high energy muons is discussed and the use of muon detector information within the L1T is highlighted. Overall, the CMS muon system performs remarkably, and plays a crucial role in fulfilling the experiment physics programme.

References

- [1] CMS collaboration : Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV, JINST, DOI: 10.1088/1748-0221/13/06/P06015.
- [2] CMS collaboration : CMS Technical Design Report for the Muon Endcap GEM Upgrade, CERN-LHCC-2015-012 ; CMS-TDR-013.
- [3] CMS collaboration : Efficiency of the CMS Drift Tubes at LHC in 2017, CMS DP-2018/016.
- [4] CMS collaboration : RPC Detector Performance Results for 2016 and 2017, CMS DP-2018/001.
- [5] CMS collaboration : CMS Technical Design Report for the Level-1 Trigger Upgrade, CERN-LHCC-2013-011 ; CMS-TDR-12.
- [6] CMS collaboration : Performance of the CMS TwinMux Algorithm in late 2016 pp collision runs, CMS DP-2016/074.