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The Compact Muon Solenoid Experiment

Conference Report

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The CMS GEM alignment with a new back-propagation method

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Abstract

The muon system of the CMS detector at CERN plays an important role for many searches of the physics phenomena within and beyond the standard model, in particular the Higgs boson discovery and observation of the Bs0 and B0 muon decays. The next phase of high luminosity LHC (HL-LHC) foresee an increase of the instantaneous luminosity in order to extend the discovery potential of the detector. In order to meet the increased particle rates and to ensure a robust and redundant system CMS is adding new detector layers in the forward region of the muon system. The endcap regions will be equipped with Gas Electron Multiplier (GEM) detectors and improved Resistive Plate Chambers (iRPC). The first of three GEM detector systems (called GE1/1) has been already installed and will operate during Run 3 of LHC starting this year. The alignment of the new detector is mandatory for correct muon transverse momentum assignment, thus for muon triggering and reconstruction. We report the status of a newly developed back-propagation method for GEM alignment to reduce the muon momentum dependence due to the multiple scatterings, compared to the standard alignment technique using muon tracks in the CMS tracker system. This new method significantly improves the relative GEM-CSC system alignment.

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The CMS GEM alignment with a new back-propagation method

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The muon system of the CMS detector at CERN plays an important role for many searches of the physics phenomena within and beyond the standard model, in particular the Higgs boson discovery and observation of the Bs0 and B0 muon decays. The next phase of high luminosity LHC (HL-LHC) foresee an increase of the instantaneous luminosity in order to extend the discovery potential of the detector. In order to meet the increased particle rates and to ensure a robust and redundant system CMS is adding new detector layers in the forward region of the muon system. The endcap regions will be equipped with Gas Electron Multiplier (GEM) detectors and improved Resistive Plate Chambers (iRPC). The first of three GEM detector systems (called GE1/1) has already been installed and will operate during Run 3 of LHC starting this year. The alignment of the new detector is mandatory for correct muon transverse momentum assignment, thus for muon triggering and reconstruction. We report the status of a newly developed back-propagation method for GEM alignment to reduce the muon momentum dependence due to the multiple scatterings, compared to the standard alignment technique using muon tracks in the CMS tracker system. This new method significantly improves the relative GEM-CSC system alignment.

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1. Introduction

The alignment of the CMS muon detector is critical to maintaining accurate position determination of muon hits, thereby affecting momentum resolution and the sensitivity of physics analyses involving muons in the final state. The high luminosity LHC (HL-LHC) will be a harsh environment of pp collisions and will require high-performance muon trigger and muon track reconstruction, especially in the endcap region. In order to maintain the trigger performance of the CMS muon system in the endcap region, the CMS collaboration has been developing a Gas Electron Multiplier (GEM) detector. The first of three GEM detector systems (called GE1/1) has been installed and will operate during Run 3 of LHC starting this year. It is crucial to perform an accurate alignment of GE1/1 chambers relative to CSC chambers for the measurement of the bending angle for muons at O(15) GeV at trigger level. We report a new technique to align GEM chambers by back-propagating CSC tracks, resulted in achieving the residuals are measured independently of muon momentum.

2. CMS Muon System

The CMS muon system is designed to be highly redundant to reconstruct muons, measure muon momenta and charge, and trigger the CMS readout system upon muon detection over a broad kinematic range in challenging conditions including multiple particle interactions per collision. The alignment of chambers in the muon detector system is one of the important operational tasks to ensure stable trigger performance during data taking and excellent muon reconstructions in a wide variety of physics analyses. The CMS muon system consists of three types of gaseous ionization chambers: drift tube chambers (DTs), cathode strip chambers (CSCs), and resistive plate chambers (RPCs). The DTs and CSCs measure an accurate position of the bending plane coordinate (measured as $R - \phi$ in the CSCs, where ϕ is the global azimuthal angle in cylindrical coordinates) while the RPCs are primarily designed to provide timing information for the muon trigger. Only the DTs and CSCs are considered for the track-based muon alignment.

A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [1].

3. Back-Propagation Method

The CMS track-based muon alignment (TBMA) [2] uses the CMS inner tracker tracks and propagates them to the muon system. The predicted hit positions in the muon chambers based on the tracks from the tracker are compared with the reconstructed muon hit positions. The residual between the positions are the input data for the muon alignment. The TBMA effectively minimizes the residuals with a multidimensional objective function. The new propagation method is implemented for the GEM alignment. The back-propagation method propagates the muon track from near CSC detectors. It has less scattering due to the short distance and aligns GEM relative to CSC detectors. Since the main purpose of the GEM detector is a measurement of the muon bending angle between GEM and CSC the new back-propagation method suit well for GEM-CSC alignment.

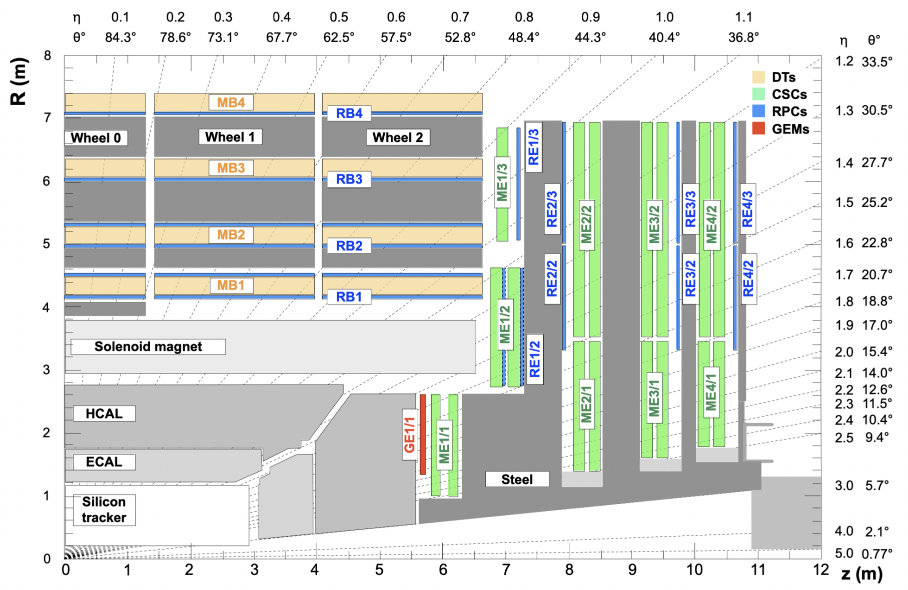

Figure 1: The CMS Muon System.

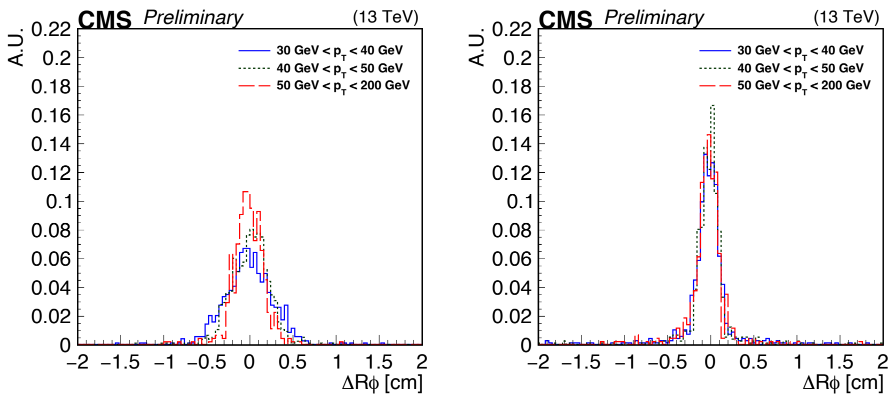

Figure 2: GEM demonstration [3] results to compare two propagation methodes. Residual ($\Delta R\phi$) distributions for muons ($p_{\mathrm{T}} > 30\,\mathrm{GeV}$) on Layer 2 of GE1/1 superchambers 27, 28, 29, 30 (after its alignment), relative to the inner tracker (left) and the ME1/1 chambers (right) in the minus endcap for the Run-2 data. The residuals with the CSC segment back-propagation show no p_{T}dependence as expected.

4. GEM Alignment Results with Cosmic ray muons

Exercise of the GEM-CSC alignment with cosmic ray muons collected by the CMS detector at 3.8 T has been performed with 3 DOF alignment. The results show a geometrical effect of cosmic ray muons. The GEM-CSC alignment results are limited due to the geometrical effect of the cosmic ray muons and statistics. However, this alignment procedure confirms the GEM-CSC alignment process is working properly.

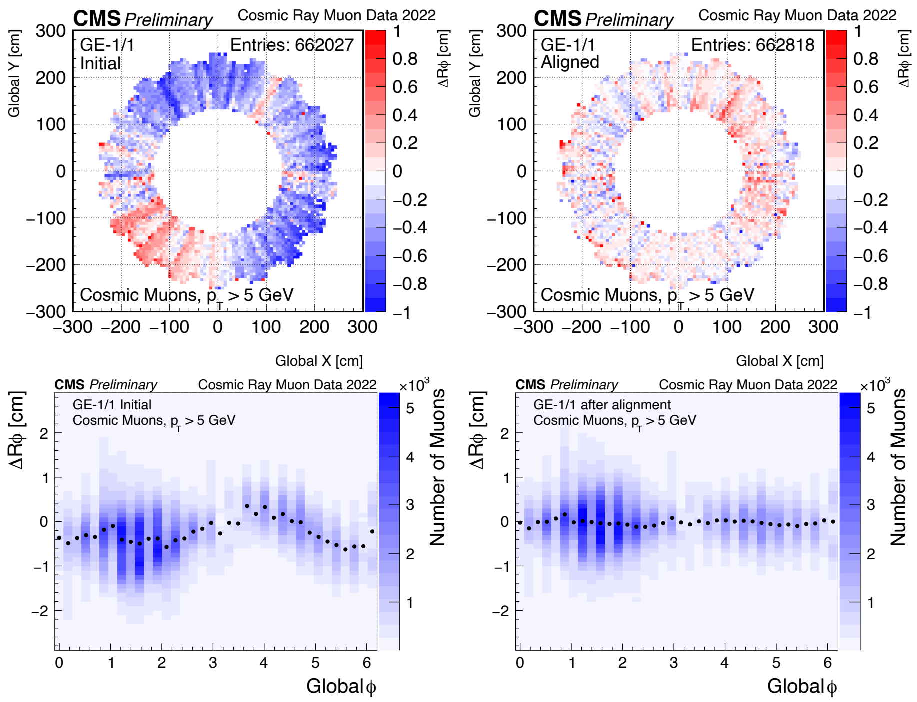

Figure 3: Residual ($\Delta R\phi$) distribution of before (top left) and after (top right) alignment for muons ($p_{\mathrm{T}} >$ 5 GeV) on GE1/1 superchambers. chambers at 3 and 9 o'clock (Global ϕ = 0 and π) show worse results due to statistics and non-Gaussian residual distributions due to a geometrical effect of cosmic ray muons. The mean values (black dot) and its distributions (blue heat map) of residuals are shown on GE1/1 superchambers before alignment (bottom left) and after alignment (bottom right). Chambers at 3 and 9 o'clock (Global ϕ = 0 and π) have non-Gaussian residual distributions due to a geometrical effect of cosmic ray muons. An alternating low and high muon entries are due to acceptance for muons on the short and long GEM chambers.

5. Summary

The new muon detector in the CMS forward muon system has been developed to improve the trigger and muon reconstruction. The alignment of GEM-CSC is important for the triggering with bending angle measurement. The GEM-CSC alignment requires relative align between two detector system, so we implement a new back-propagation method to reduce multiple scattering and get relative position between GEM and CSC. The comparison between a traditional tracker propagation method and a new back-propagation method shows that the last one reduces the muon dependency. The exercise of the GEM-CSC alignment with comic ray muons shows a limitation of the cosmic ray muons due to geometry effect but confirms the GEM-CSC alignment process works as expected.

References

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[2] CMS Collaboration, *Alignment of the CMS muon system with cosmic-ray and beam-halo muons*, *JINST* **5** (2010) T03020.

[3] M. Abbas et al., *Performance of a triple-GEM demonstrator in pp collisions at the CMS detector*, *JINST* **16** (2021) P11014 [2107.09364].