The CMS GEM Alignment with a New Back-propagation Method

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Abstract

The next phase of high luminosity LHC (HL-LHC) foresees and increases 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 along with other upgrades. 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 in 2022. 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.

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 (Fig. 1-1). The high luminosity LHC (HL-LHC) will be a harsh environment of pp collisions and will require high-performance muon trigger (Fig. 1-2) and muon track reconstruction, especially in the endcap region. In order to maintain the performance of the CMS muon system, the CMS collaboration has been developing a Gas Electron Multiplier (GEM) detector for the endcap regions of the CMS muon system. GEM-CSC combined operation measures the bending angle at trigger level (Fig. 1-3), thus strongly reducing the rate of mis-measured.

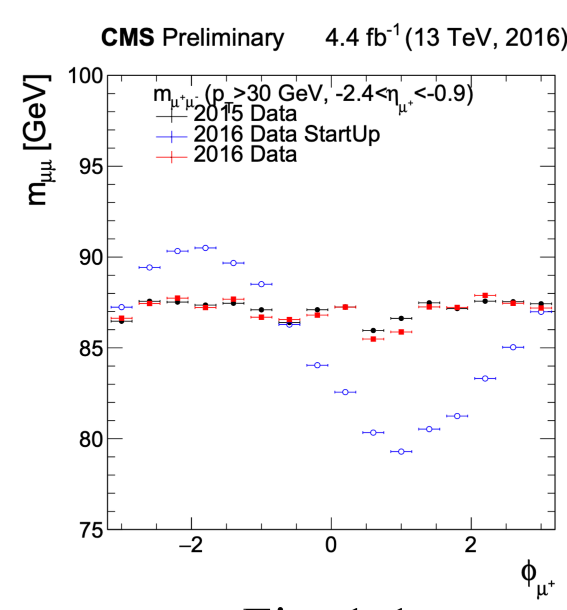


Fig. 1-1

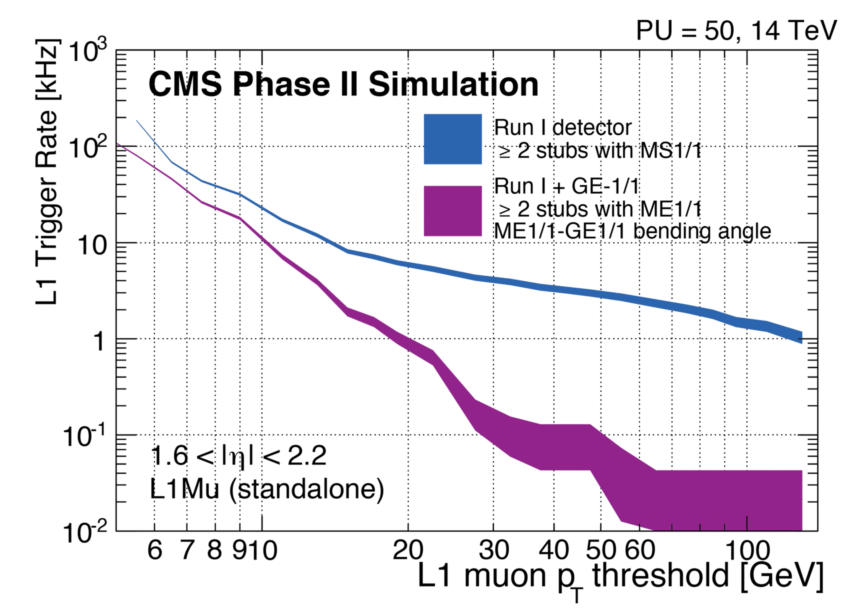


Fig. 1-2

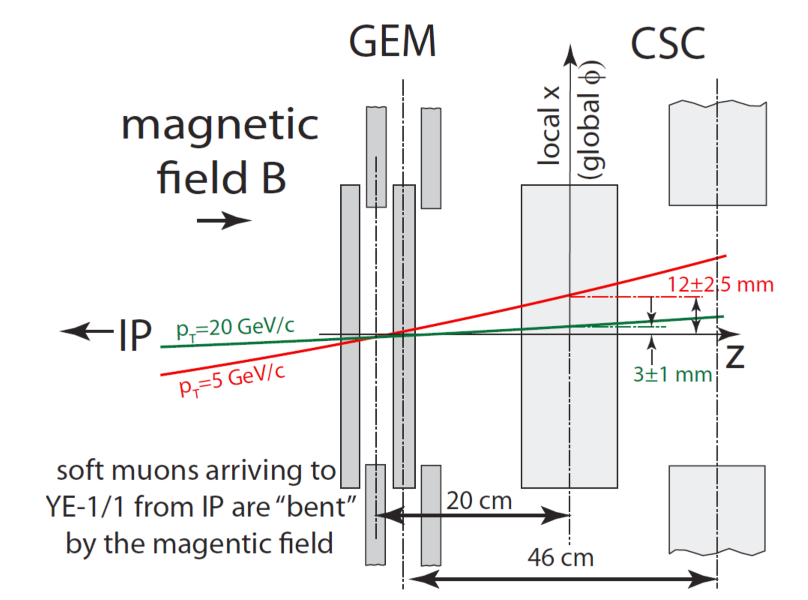
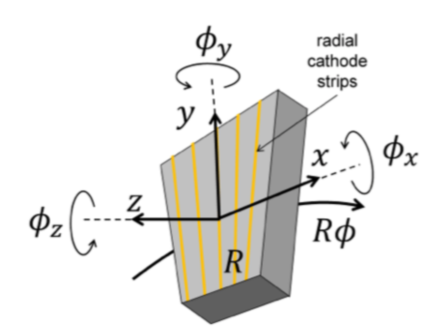


Fig. 1-3

Residual and Degree of Freedom

The GEM alignment algorithm treats each trapezoid chamber as a rigid body, and determine the misalignments in three degrees of freedom (DOF) using a residual ($\Delta R\phi$) between the measured position on the GEM chamber and the expected position by an external muon track. The cartoons show how each of the 3 basic misalignment (δx, δy, and $\delta\phi_z$) scenarios would be reflected in residuals measured on various locations of a GEM chamber in red ($+\Delta R\phi$) and blue ($-\Delta R\phi$) arrows.



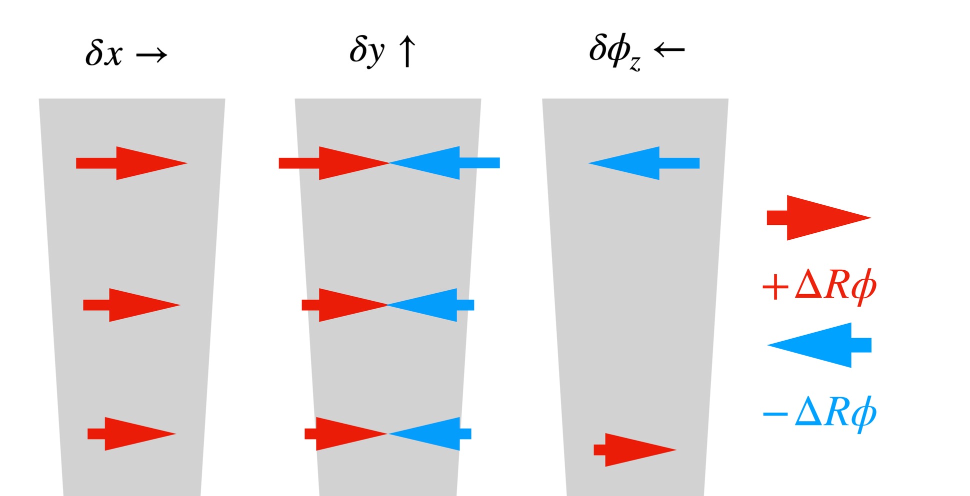
$\Delta R\phi = cos\theta \cdot \Delta x + sin\theta \cdot \Delta y$

θ: **strip angle of hit**

Δx: $X_{predition}$ - X_{hit}

Δy: $Y_{predition}$ - Y_{hit}

$$\begin{pmatrix} \Delta(R\phi) \\ \Delta y_o \\ \Delta\frac{d(R\phi)}{dz} \\ \Delta\frac{dy}{dz}_o \end{pmatrix} = \begin{pmatrix} 1 & \left[-\frac{x}{R}+3\left(\frac{x}{R}\right)^3\right] & -\frac{dx}{dz} & -y\frac{dx}{dz} & x\frac{dx}{dz} & -y \\ 0 & 1 & -\frac{dy}{dz} & -y\frac{dy}{dz} & x\frac{dy}{dz} & x \\ 0 & -\frac{1}{2R}\frac{dx}{dz} & 0 & \left[\frac{x}{R}-\frac{dx}{dz}\frac{dy}{dz}\right] & 1+\left(\frac{dx}{dz}\right)^2 & -\frac{dy}{dz} \\ 0 & 0 & 0 & -1-\left(\frac{dy}{dz}\right)^2 & \frac{dx}{dz}\frac{dy}{dz} & \frac{dx}{dz} \end{pmatrix} \begin{pmatrix} \delta x \\ \delta y \\ \delta z \\ \delta\phi_x \\ \delta\phi_y \\ \delta\phi_z \end{pmatrix}$$



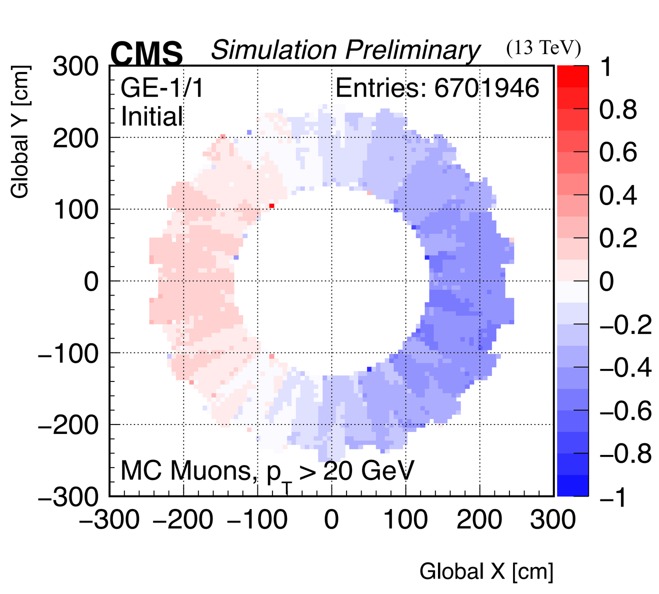


Fig. 2-1

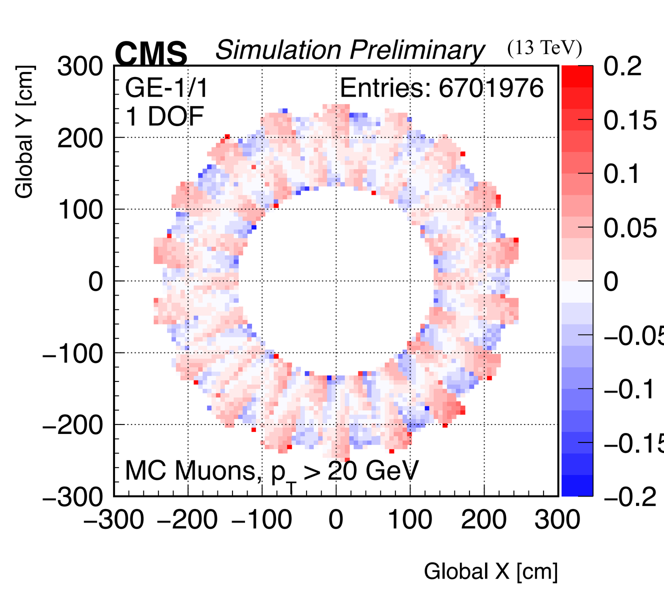


Fig. 2-2

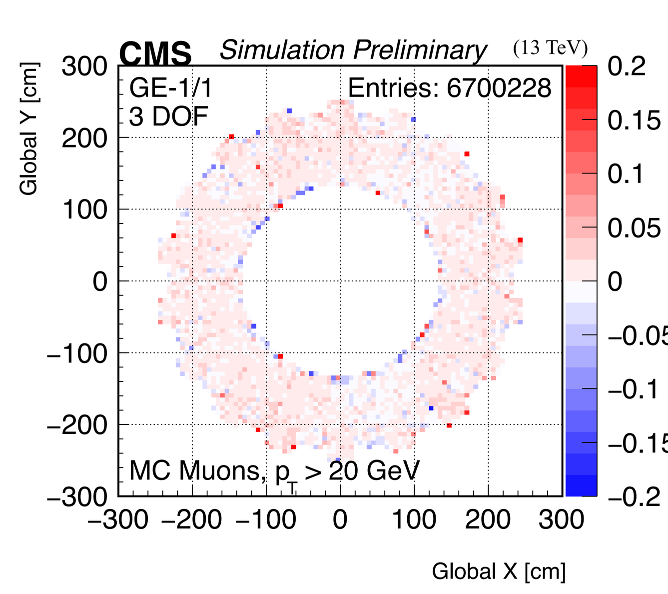
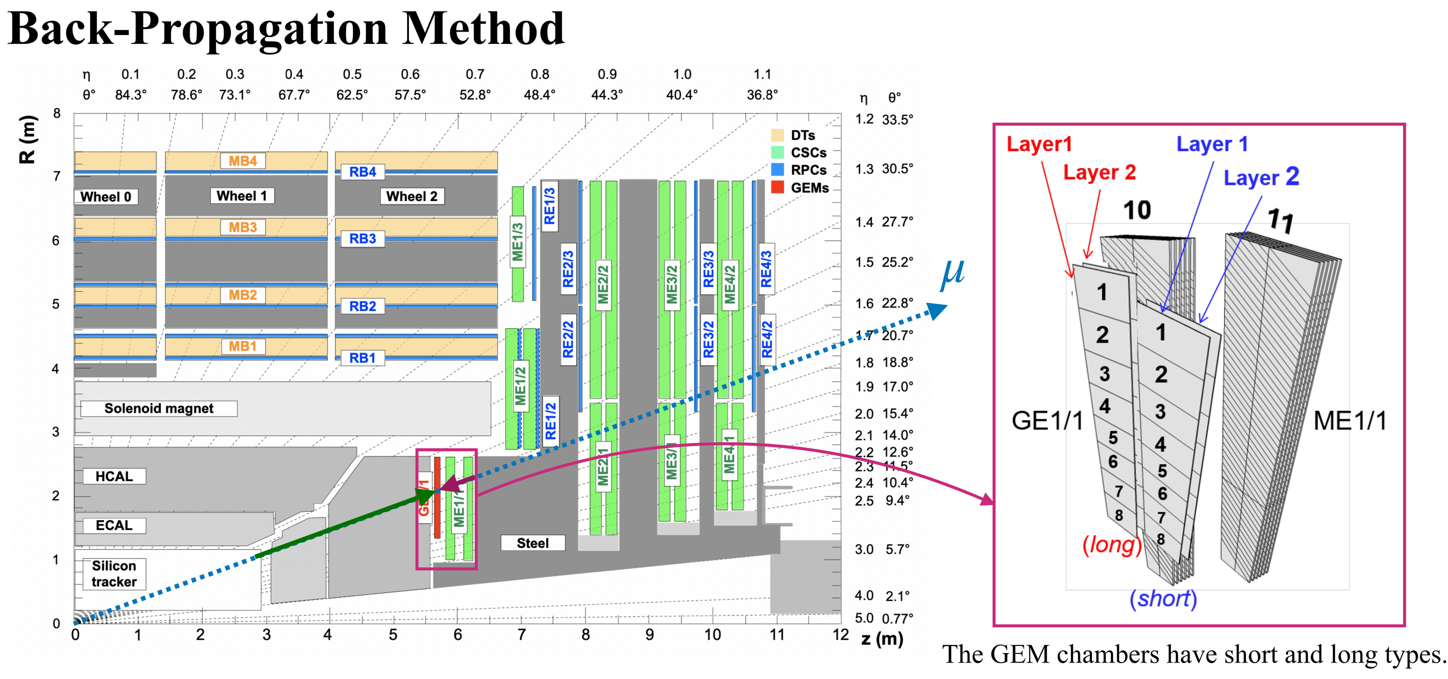


Fig. 2-3

1 DOF vs. 3 DOF MC Study

The residual ($\Delta R\phi$) distributions of the initial geometry (Fig. 2-1) of a realistic misalignment scenario are estimated from a Run2 CSC misalignment and after alignment using 1 DOF (Fig. 2-2, δx) and 3 DOF (Fig. 2-3, $\delta x, \delta y, \delta\phi_z$). A residual misalignment remains with 1 DOF alignment, but the alignment with 3 DOF reduces the misalignment. After 3 DOF alignment, the residual distributions are not perfectly zero due to the statistical fluctuations.

Back-Propagation Method



The GEM chambers have short and long types.

- **Inner Tracker propagation: pass heavy material budget, reference position is inner tracker**
- **Back-propagation: less scattering, reference position CSC**

GEM Demonstrator Results

Residual ($\Delta R\phi$) distributions for muons ($p_T > 30$ GeV) on Layer 2 of GE1/1 superchambers 27, 28, 29, 30 (after its alignment), relative to the inner tracker (Fig. 3-1) and the ME1/1 chambers (Fig. 3-2) in the minus endcap for the Run-2 data. The residuals with the CSC segment back-propagation show no p_T dependence as expected.

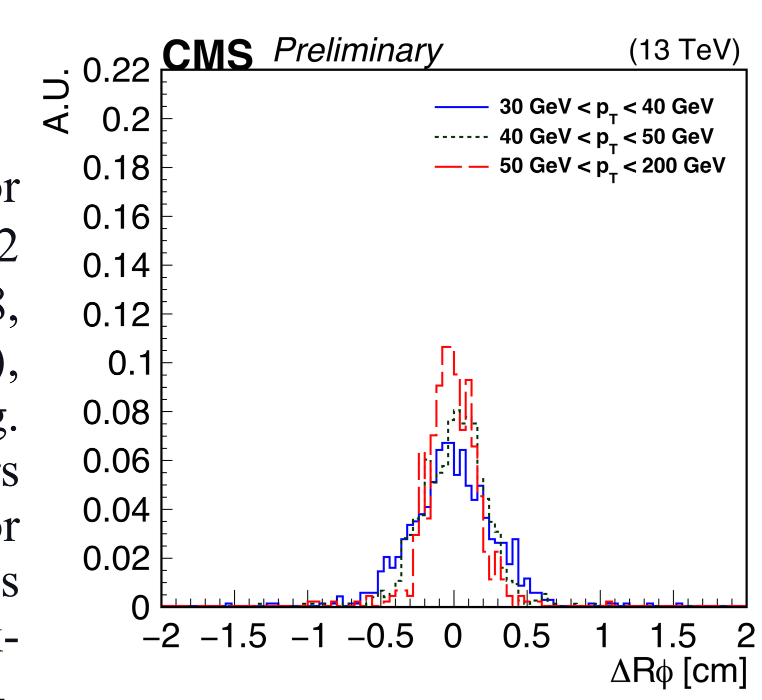


Fig. 3-1

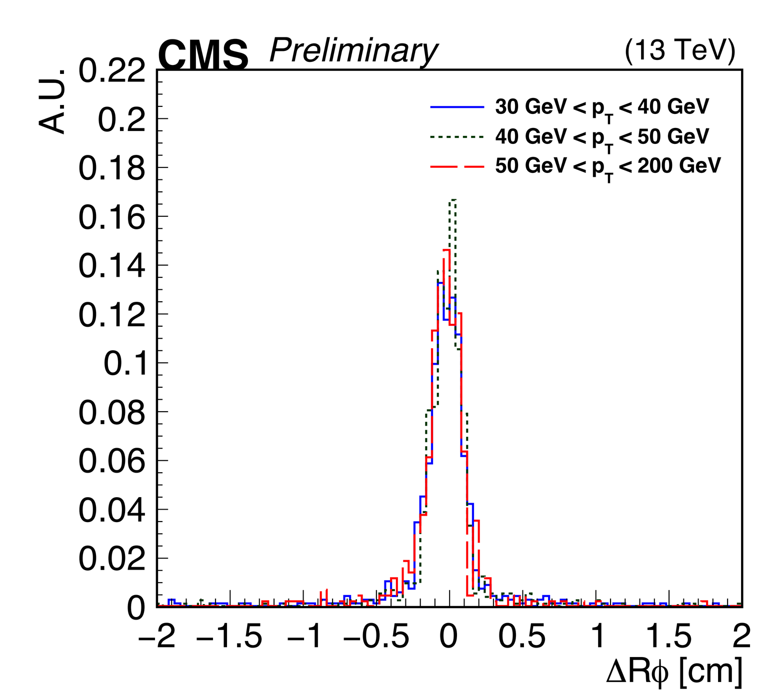


Fig. 3-2

Cosmic Ray Muons

An 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 GEM-CSC alignment results are limited due to geometrical effects of cosmic ray muons and low statistics. However, this alignment procedure confirms the GEM-CSC alignment process is working properly.

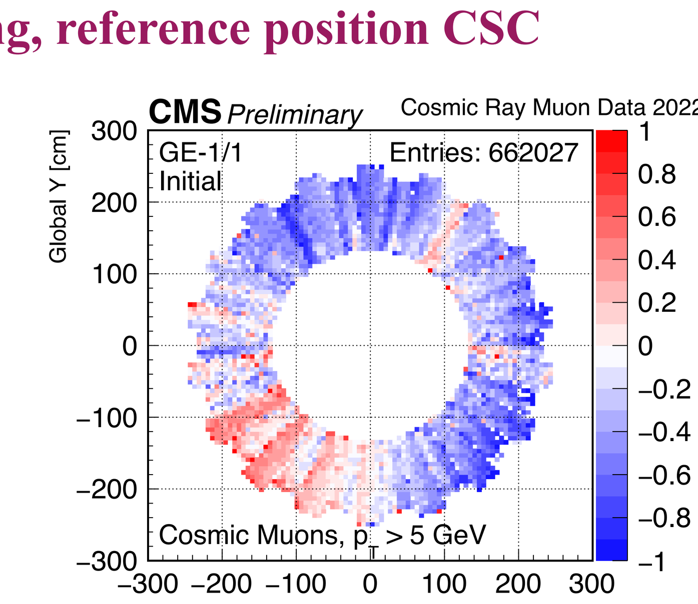


Fig. 4-1

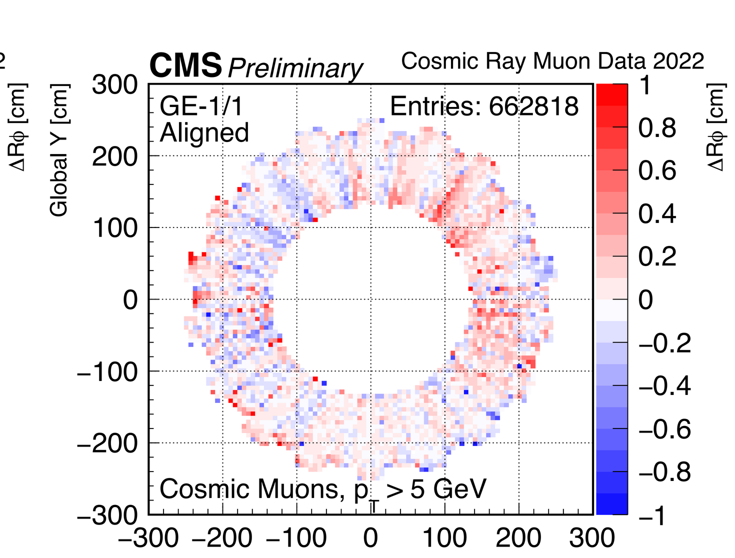


Fig. 4-2

Residual ($\Delta R\phi$) distribution of before (Fig. 4-1) and after (Fig. 4-2) alignment for muons ($p_T > 5$ GeV) on GE1/1 superchambers. chambers at 3 and 9 o'clock (Global $\phi = 0$ and π) show worse results due to statistics and non-Gaussian residual distributions due to a geometrical effect of cosmic ray muons.

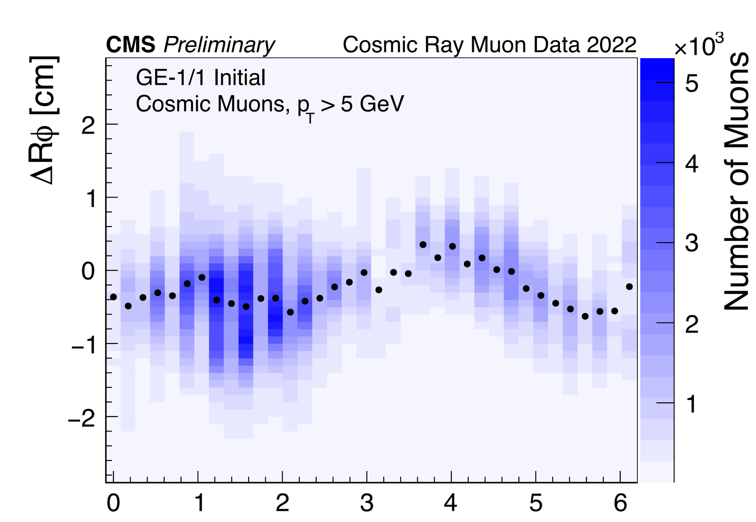


Fig. 5-1

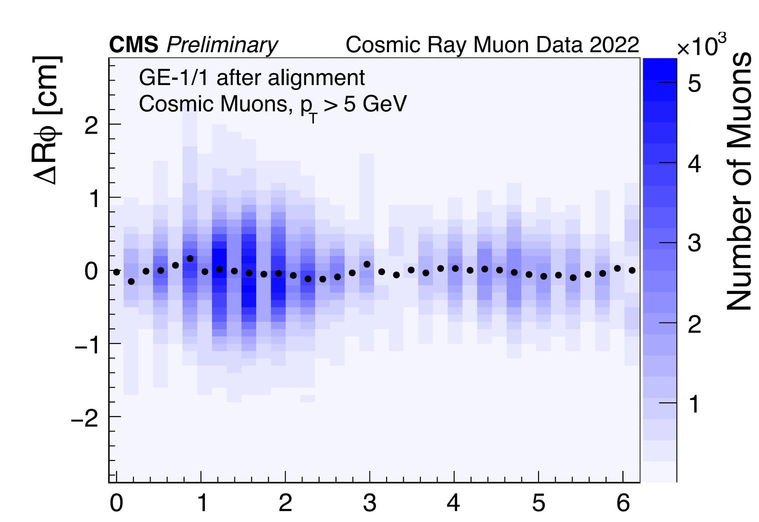


Fig. 5-2

The mean values (black dot) and its distributions (blue heat map) of residuals are shown on GE1/1 superchambers before alignment (Fig. 5-1) and after alignment (Fig. 5-2). Chambers at 3 and 9 o'clock (Global $\phi = 0$ 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.

Summary

The new GEM detector in the CMS forward muon system has been developed to improve the trigger and muon reconstruction. The trigger system will use the GEM-CSC bending angle to discriminate on muon, therefore the alignment of GEM-CSC is extremely important. The GEM-CSC alignment requires a 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 the new back-propagation method reduces the muon p_T 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.