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The Compact Muon Solenoid Experiment

CMS Performance Note

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GEM-CSC Alignment using Muons in 13.6 TeV pp Collisions

CMS Collaboration

Abstract

An alignment of the triple-GEM chambers at ring1 of station1 in endcap (GE1/1) relative to the ME1/1 chambers is mandatory for triggering muons in the endcaps. A new GEM alignment technique with a back-propagation of ME1/1 muon segments was developed with cosmic ray muons (CMS DP-2022/028) and is tested for the first time using muons in 13.6 TeV pp collisions. The performance of the relative alignments between GE1/1 and ME1/1 chambers with three misalignment parameters are reported.

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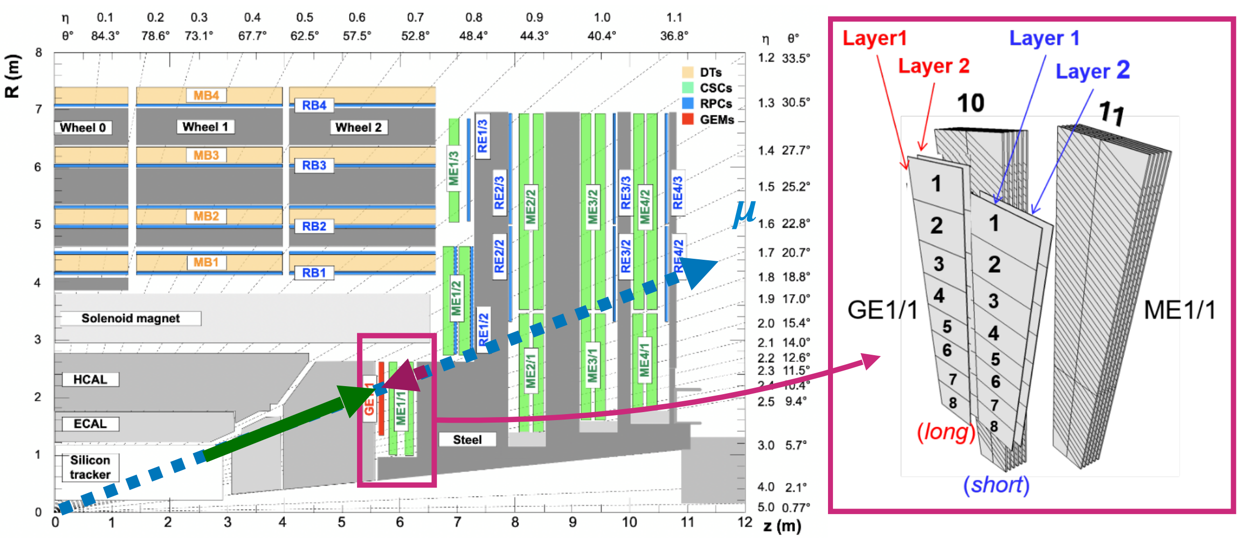
GE1/1 alignment using the ME1/1 segments (back-propagation)

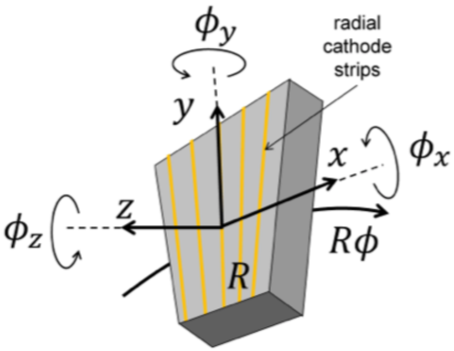


GE1/1: GEM Endcap Station1 Ring1

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

Each GE1/1 superchamber (SC), consisting of two triple-GEM detectors referred to as layer 1 and layer 2, covers Δφ = 10.15°. The SCs are arranged in a staggered configuration with an overlap of 0.075°, alternating in ϕ between a long version (1.55 < $|\eta|$ < 2.18) and a short version (1.61 < $|\eta|$ < 2.18). Each detector is segmented with eight η partitions ($i_\eta = 1$~8).

Each GE1/1 chamber must be aligned relative to the corresponding ME1/1 chamber. An alignment technique using back-propagation of the ME1/1 segments is developed with cosmic ray muons (CMS DP-2022/028). The GEM-CSC alignment is performed using muons ($p_T > 20$ GeV, $|\Delta R\phi|$ < 5 cm) in 13.6 TeV pp collisions.



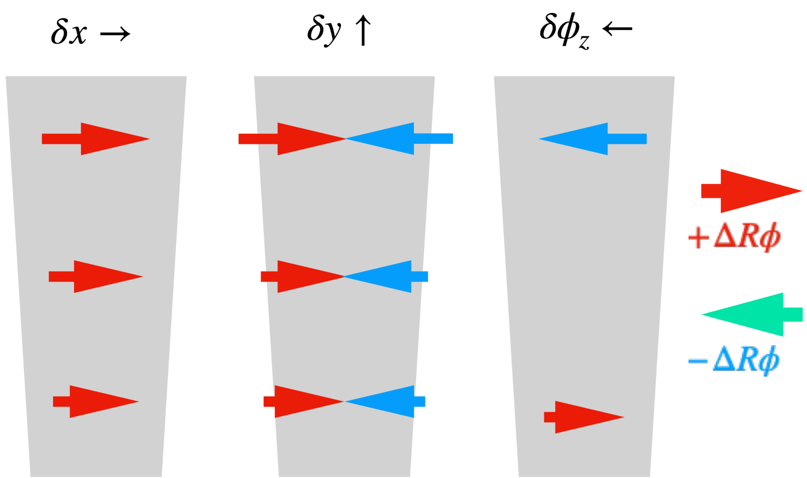
$$\begin{pmatrix} \Delta(R\phi) \\ \Delta y_o \\ \Delta \frac{d(R\phi)}{dz} \\ \Delta \frac{dy}{dz}_o \end{pmatrix} = \begin{pmatrix} 1 & \left[-\frac{x}{R} + 3\left(\frac{x}{R}\right)^3\right] & -\frac{dx}{dz} & -y\frac{dx}{dz} & x\frac{dx}{dz} & -y \\ 0 & 1 & -\frac{dy}{dz} & -y\frac{dy}{dz} & x\frac{dy}{dz}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

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

θ = strip angle of recHit

Δx = Xprediction - XrecHit

Δy = Yprediction - YrecHit



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 three 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.

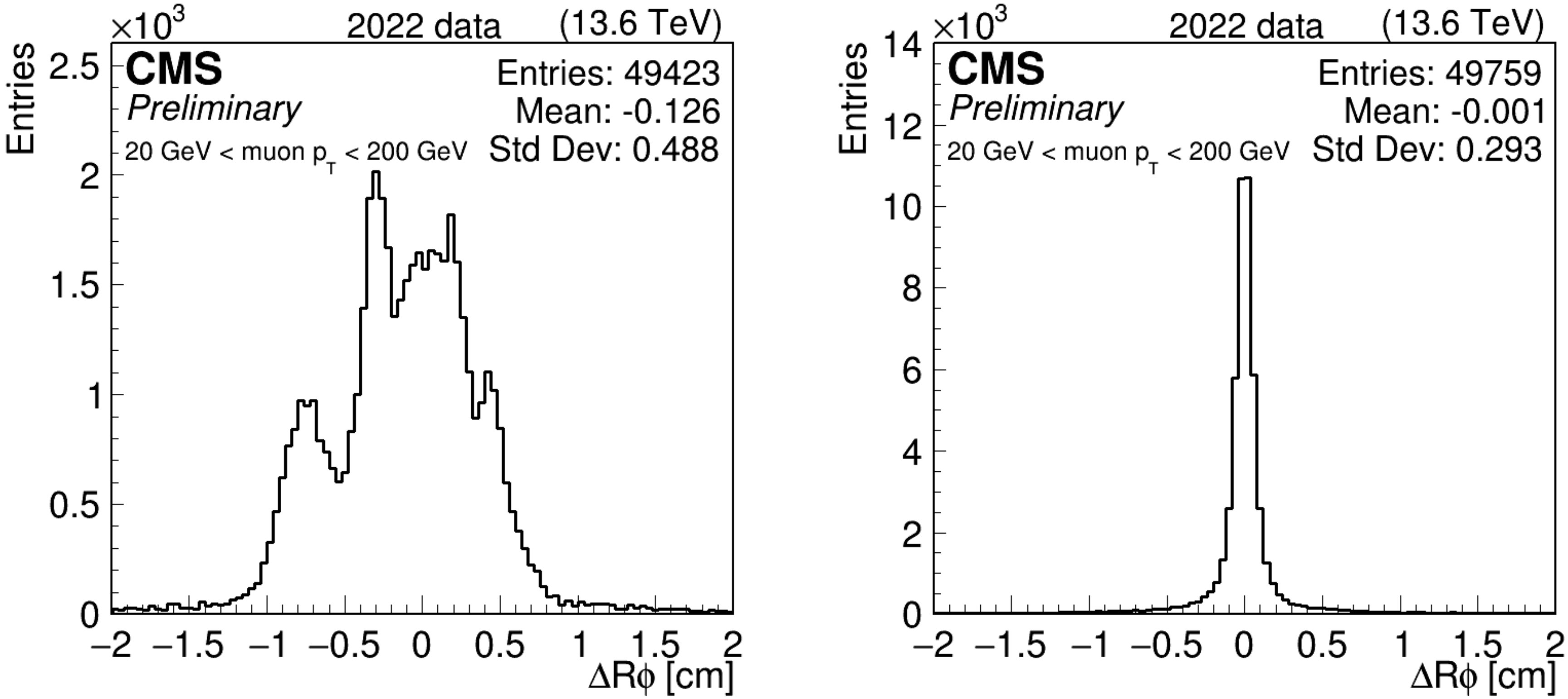


Figure 1: Residual ($\Delta R\phi$) distributions for muons ($p_T > 20$ GeV) on the GE1/1 superchambers relative to the ME1/1 chambers before (left) and after (right) the newly-developed back-propagation alignment (CMS DP-2022/028). An early stage of tracker geometry is used. A multi-peak structure of the residual distribution is due to four groups of mis-aligned chambers seen in Fig. 2. The values of the standard deviation are values from histograms. The standard deviation of the core part of the distribution after the alignment is 0.058 cm (580 μm) from double-Gaussian fit.

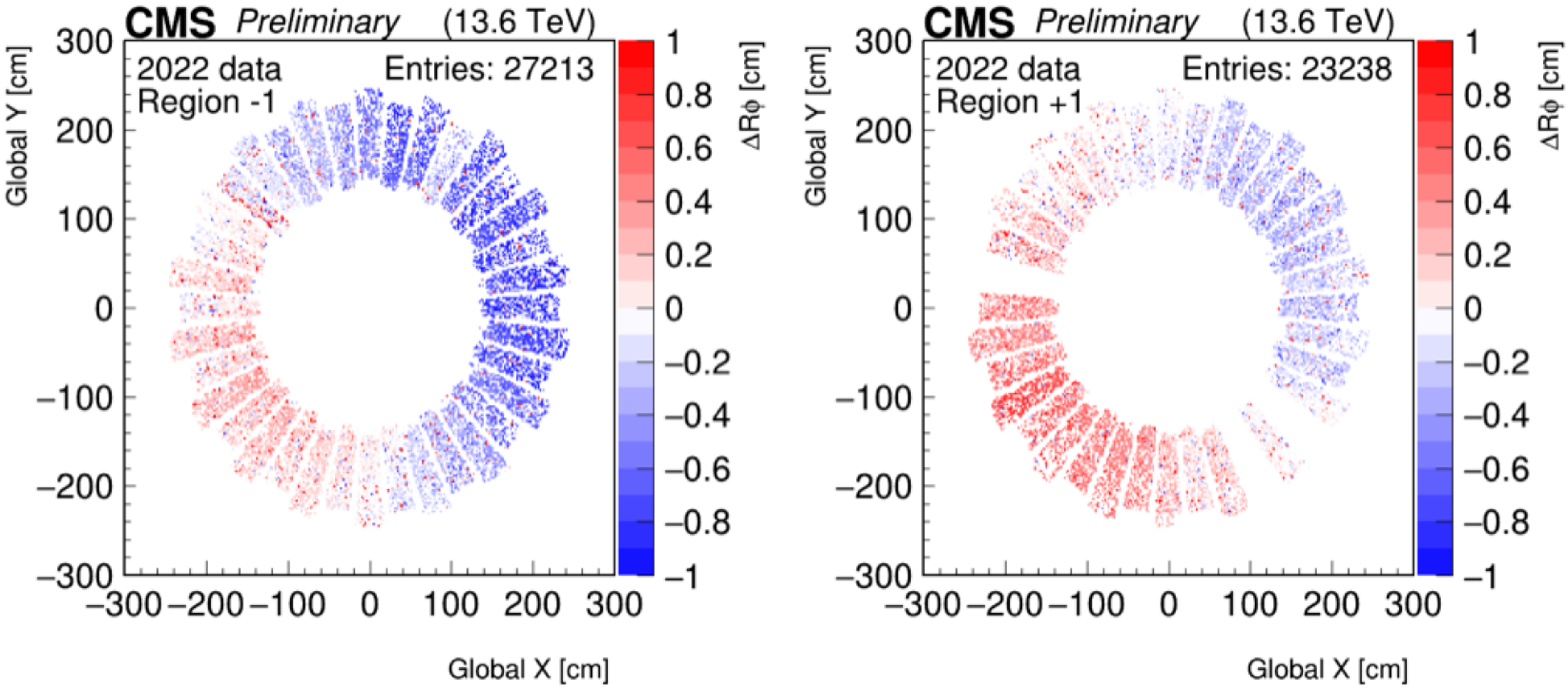


Figure 2a: Residual ($\Delta R\phi$) distribution map before alignment for muons (p_T > 20 GeV) on the GE1/1 superchambers in the minus (left) and plus (right) endcaps. Three GE1/1 chambers in the plus endcap are not shown, as the corresponding ME1/1 chambers were not read out.

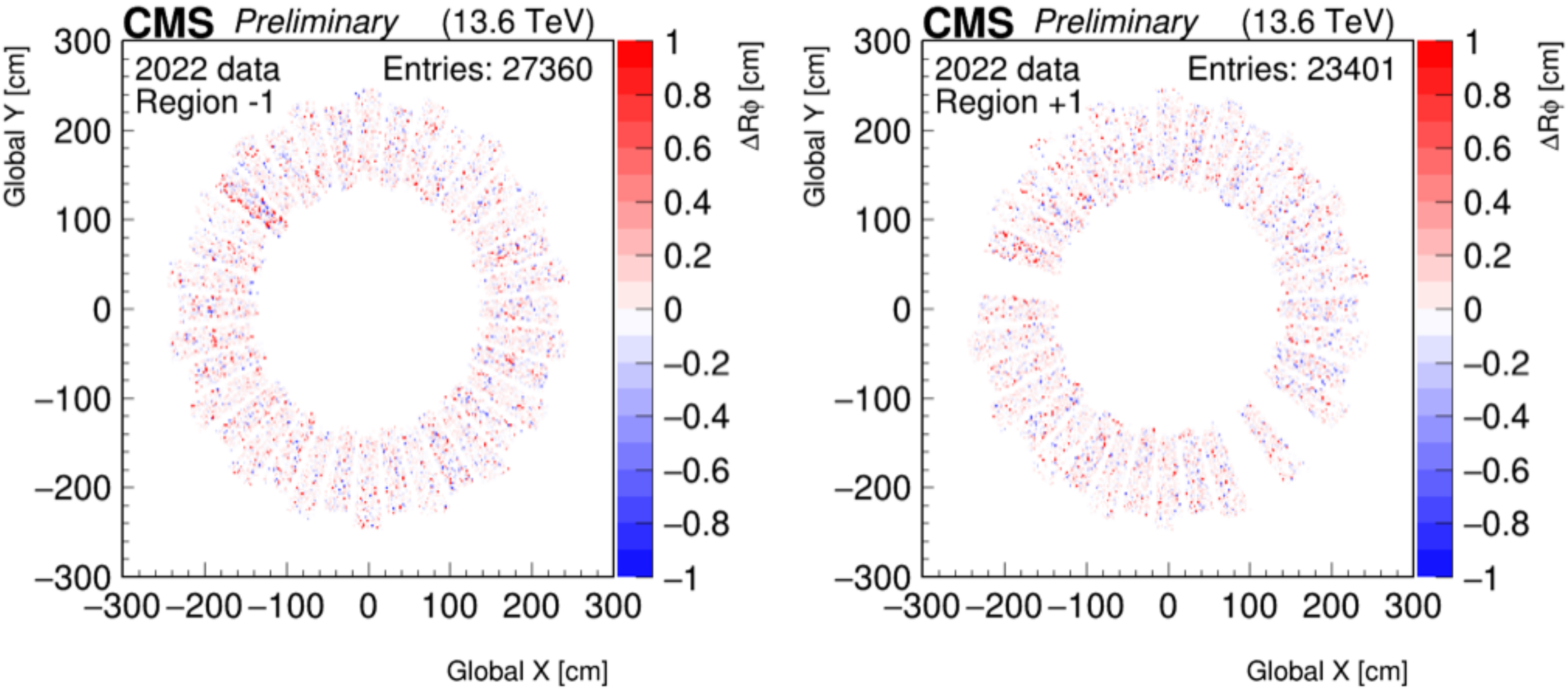


Figure 2b: Residual ($\Delta R\phi$) distribution map after alignment for muons (p_T > 20 GeV) on the GE1/1 superchambers in the minus (left) and plus (right) endcaps. Three GE1/1 chambers in the plus endcap are not shown, as the corresponding ME1/1 chambers were not read out.

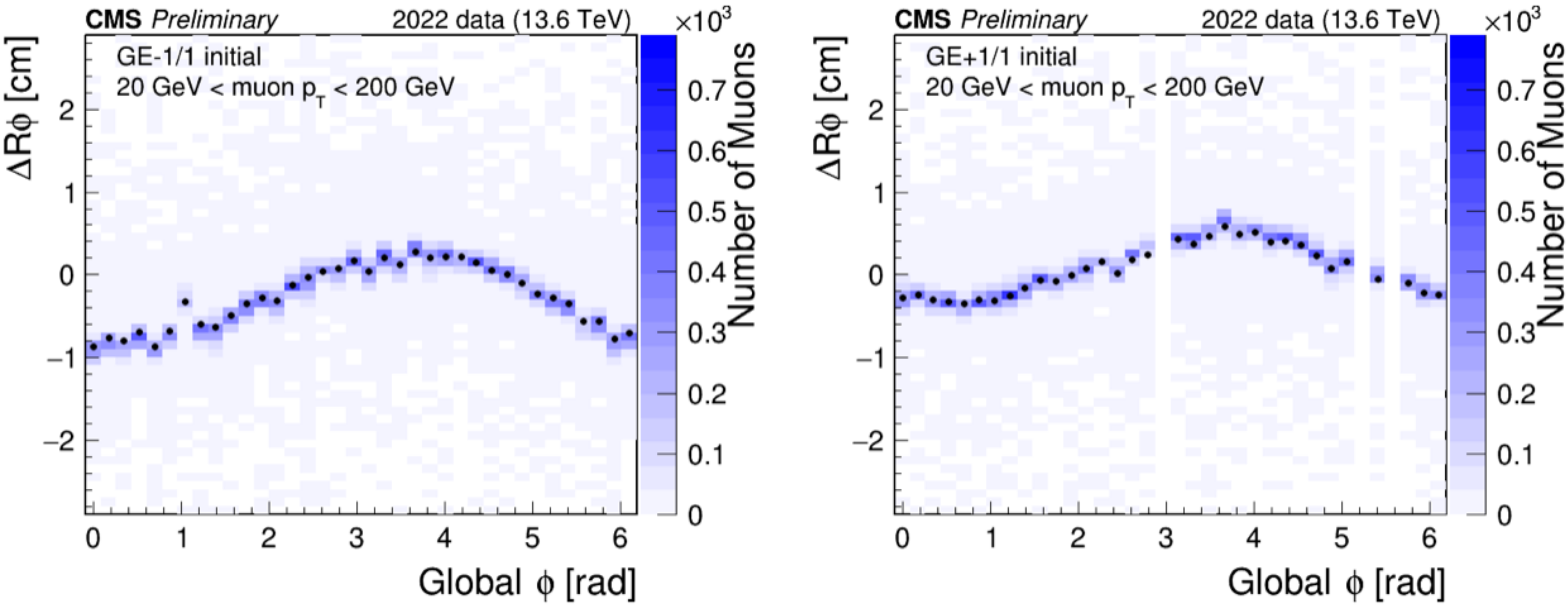


Figure 3a: The mean values (black dot) and its distributions (blue heat map) of residuals on the GE1/1 superchambers (before its alignment relative to the ME1/1 chambers) for muons in 13.6 TeV pp collisions in the minus (left) and plus (right) endcaps. Three GE1/1 chambers in the plus endcap are not shown, as the corresponding ME1/1 chambers were not read out. A group of chambers in the minus endcap in $0 < \phi \lesssim 1.5$ are $\Delta R\phi \sim -1$ cm correspond to the first peak in Fig. 1, while a group of chambers in the plus endcap in $0 < \phi \lesssim 1.5$ are $\Delta R\phi \sim -0.3$ cm to the second peak.

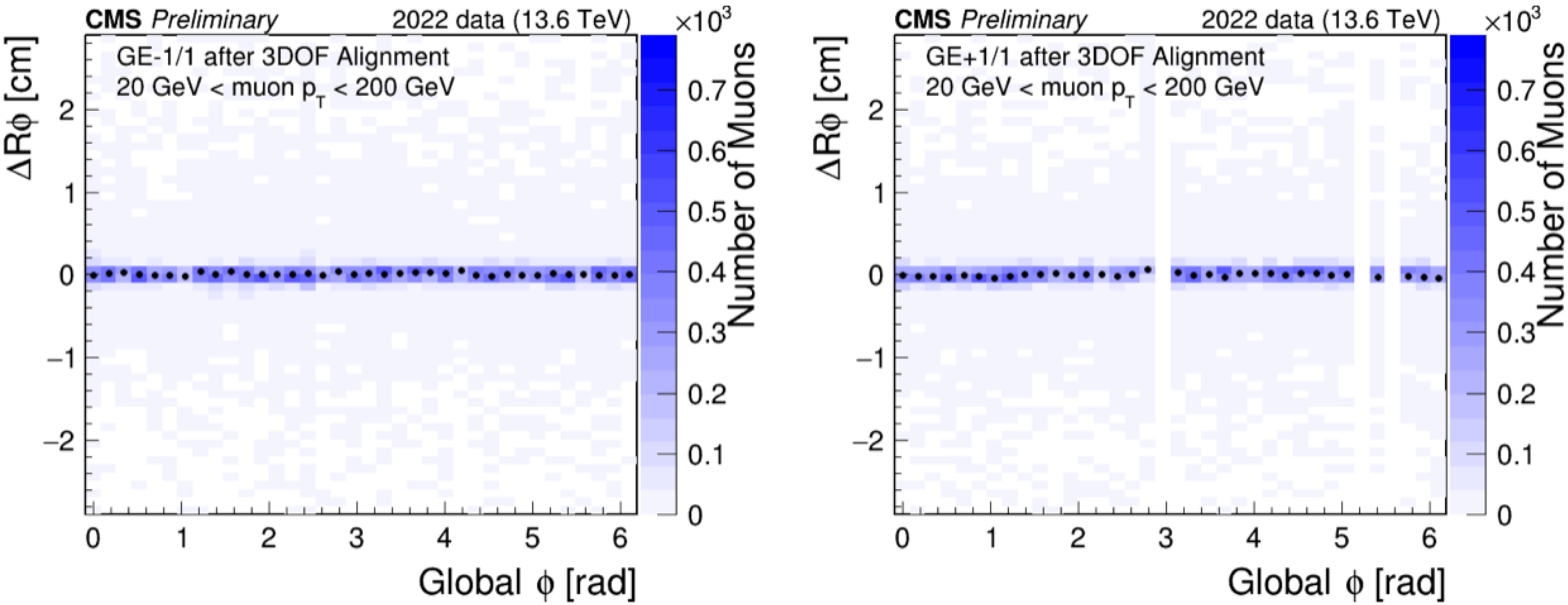


Figure 3b: The mean values (black dot) and its distributions (blue heat map) of residuals on the GE1/1 superchambers (after its alignment relative to the ME1/1 chambers) for muons in 13.6 TeV pp collisions in the minus (left) and plus (right) endcaps. Three GE1/1 chambers in the plus endcap are not shown, as the corresponding ME1/1 chambers were not read out.

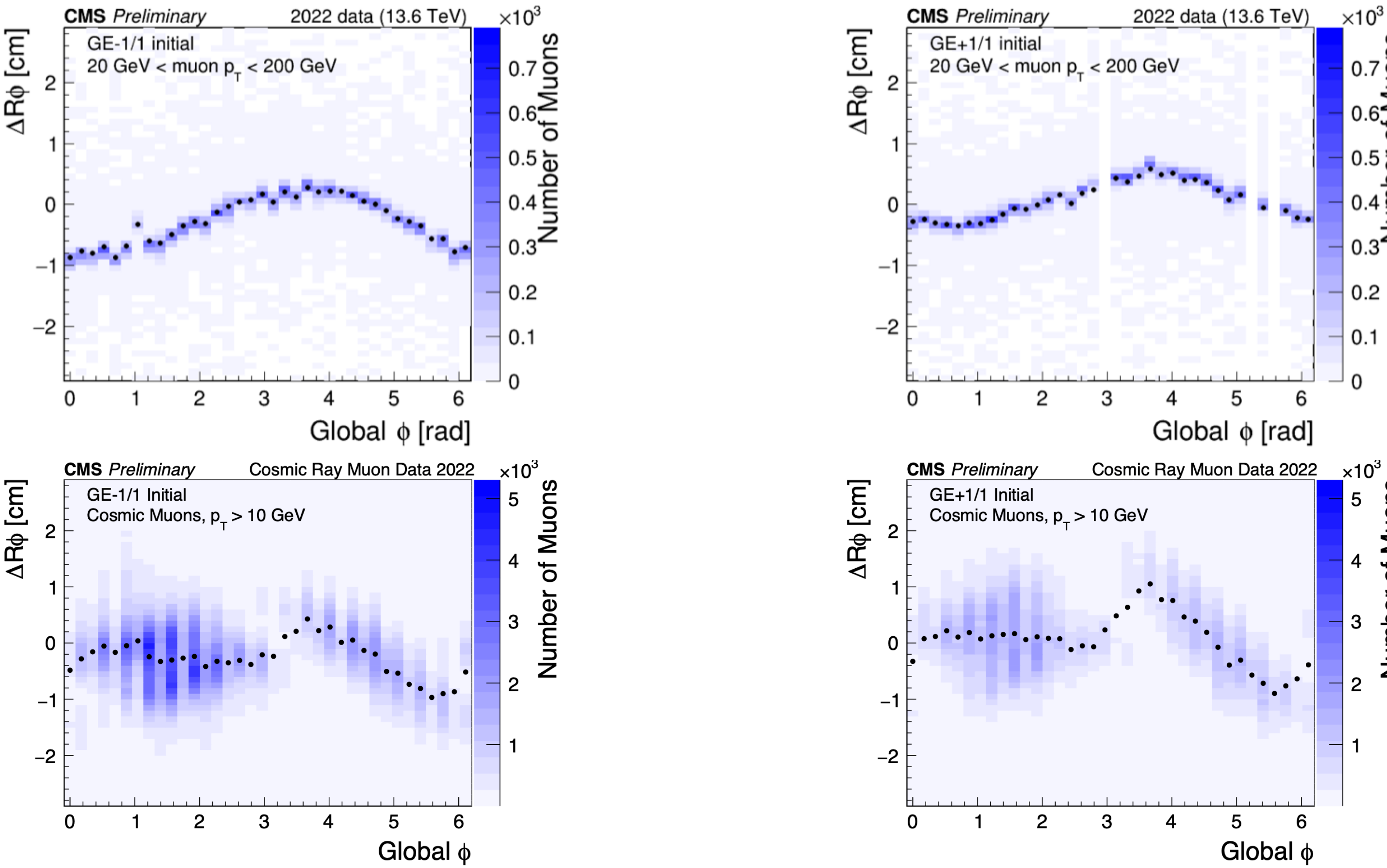


Figure 4: Comparison of the mean values (black dot) and its distributions (blue heat map) of GE1/1 residuals between pp collision data (top row) and cosmic ray muon data (bottom row) before its alignment relative to the ME1/1 chambers in the minus (left) and plus (right) endcaps. Note that larger distribution ranges for cosmic ray muon data, taken from CMS DP-2022/028, are because the ME1/1 segment reconstruction is not fully optimized for its tracks with lager incoming angles (i.e., not pointing back to the center of the detector).

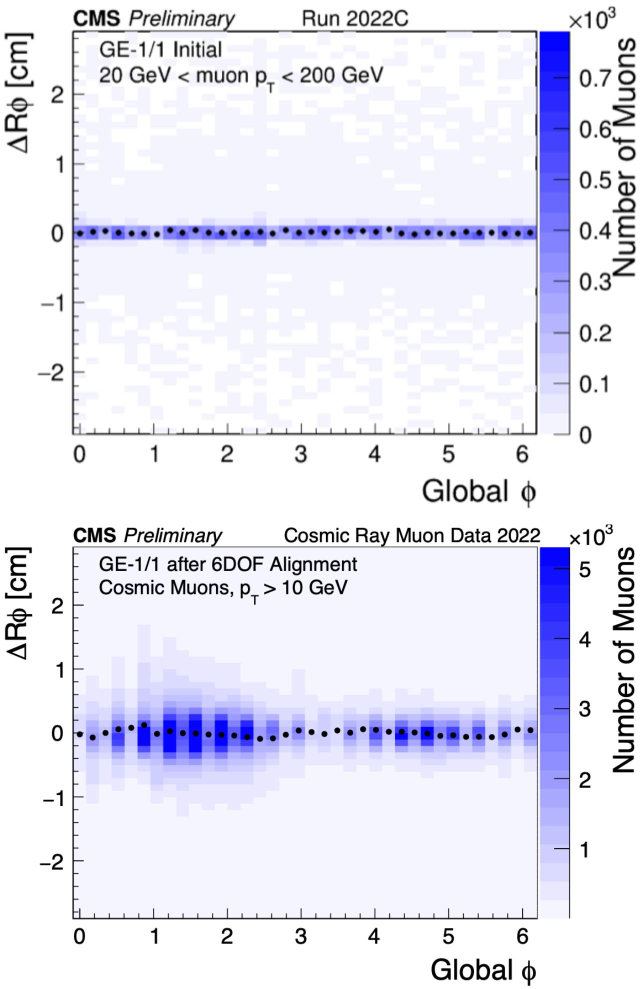


Figure 5: Comparison of the mean values (black dots) and its distributions (blue heat map) of GE1/1 residuals between pp collision data (top row) and cosmic ray muon data (bottom row) after its alignment relative to the ME1/1 chambers in the minus (left) and plus (right) endcaps. Note that results for cosmic ray muon data were obtained with 6DOF alignment instead of 3DOF. This is because the slope (dx/dz) in cosmic ray muons is not negligible (CMS DP-2022/028), while being small in pp collision data.