Performance of CMS Track-Based Muon Alignment in Run2

CMS Collaboration
Contact: cms-muon-DPGO@cern.ch

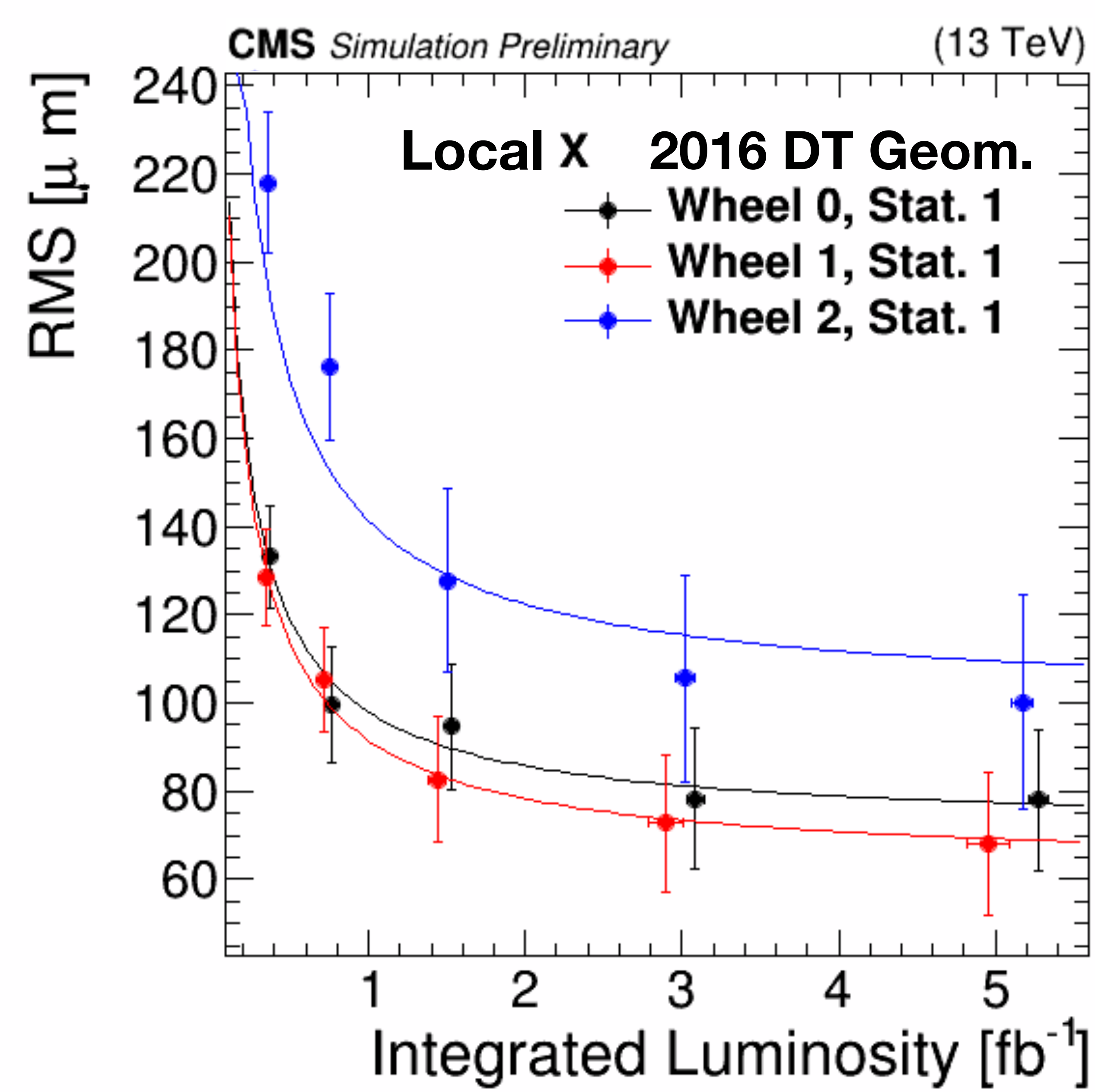
Abstract

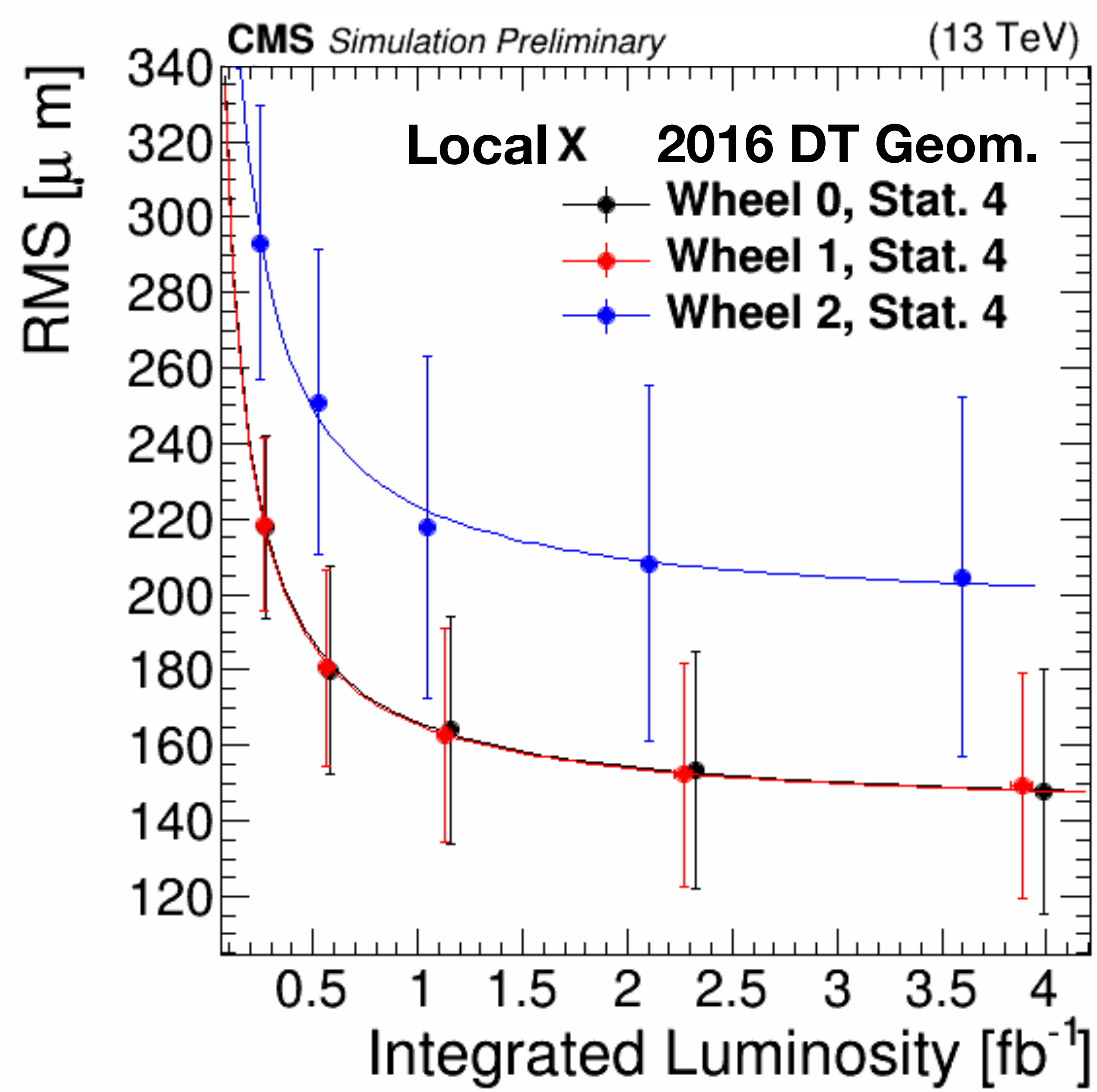
The alignment of the CMS muon detector is critical to maintaining accurate position determination of muon hits, thereby affecting momentum resolution and the sensitivity of physics analyses involving muons in the final state. Muon track data from both the muon system and the inner tracker is used to perform a multidimensional fit on the misalignment degrees of freedom. The performance of this track-based alignment algorithm is validated by using muons in Z boson decays and evaluating the alignment's accuracy in reconstructing the mass peak. Chamber alignment accuracies on the order of 100 µm are achieved and alignment performance is presented using Run 2 data.

Introduction

- Muon alignment accuracy
    - CMS simulation study of muon alignment accuracy with 2016 DT geometry
- Physics validation with legacy geometry
    - Di-muon mass and width
- CSC alignment
    - 2018 CSC residual: $\Delta r\phi$ distribution by global ϕ
    - 2018 CSC displacement: comparison of CSCs position
    - Physics validation of 2016 CSC alignment
- Dataset
    - Inclusive muon datasets used in this study are collected at the beginning of the 2016 (5.44 fb-1), 2017 (4.79 fb-1), and 2018 (3.60 fb-1) runs in proton-proton collisions at 13 TeV

Accuracy



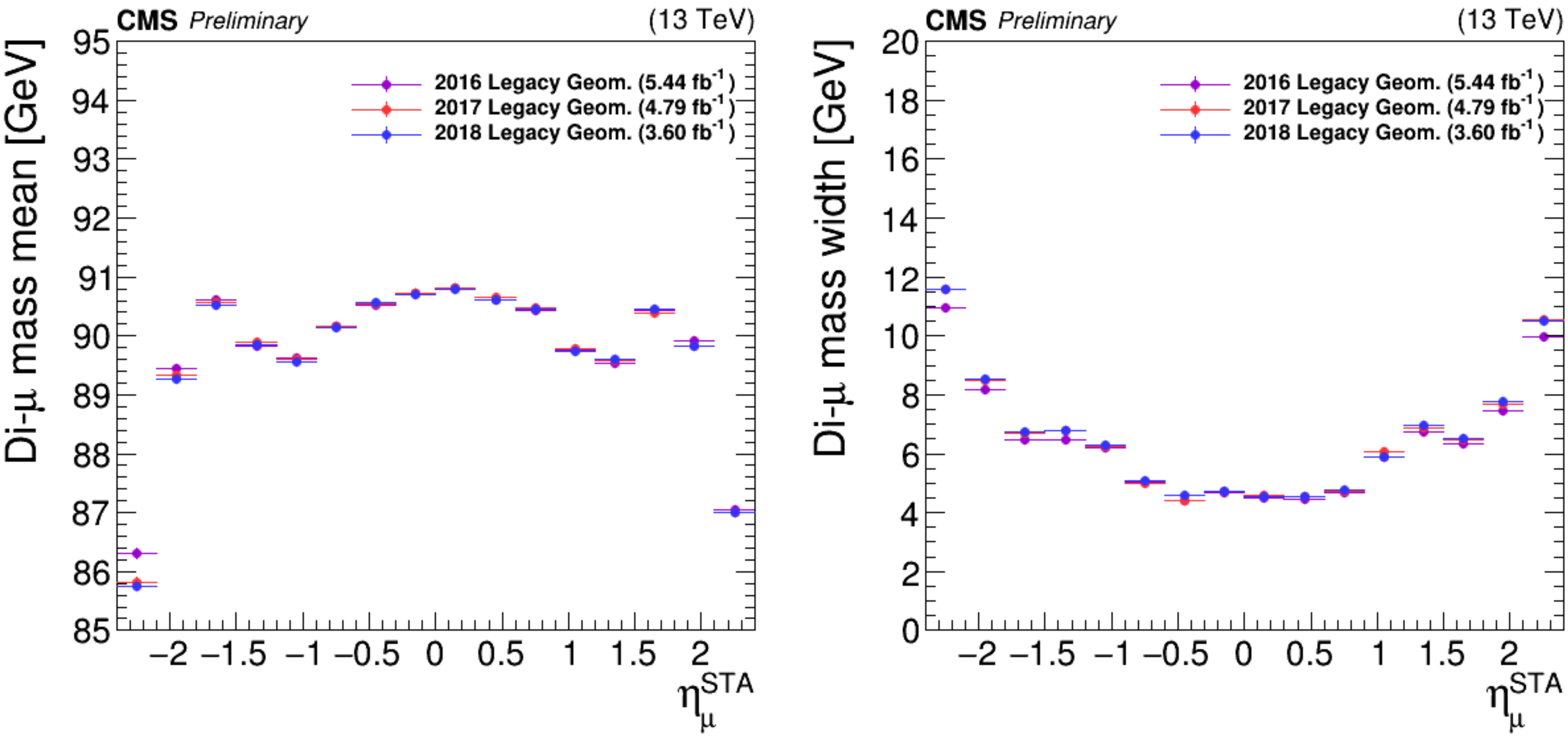


RMS values of alignment variable distributions in local X in the CMS track-based muon alignment (TBMA) procedure on DT chambers as a function of the integrated luminosity of pp collisions. This indicates 2 fb^{-1} or larger luminosity is a requirement for TBMA. Each error bar includes systematics uncertainties, such as chamber-to-chamber deviation. The alignment accuracy depends on the detector location (wheels and stations for DT) and six alignment valuables (δx, δy, δz, $\delta\phi_x$, $\delta\phi_y$, and $\delta\phi_z$ for DT). Here δx is the most sensitive in the p_T resolution, and the best alignment accuracies are obtained from chambers in the central region (Wheel 0 and +/-1).

Physics Validation

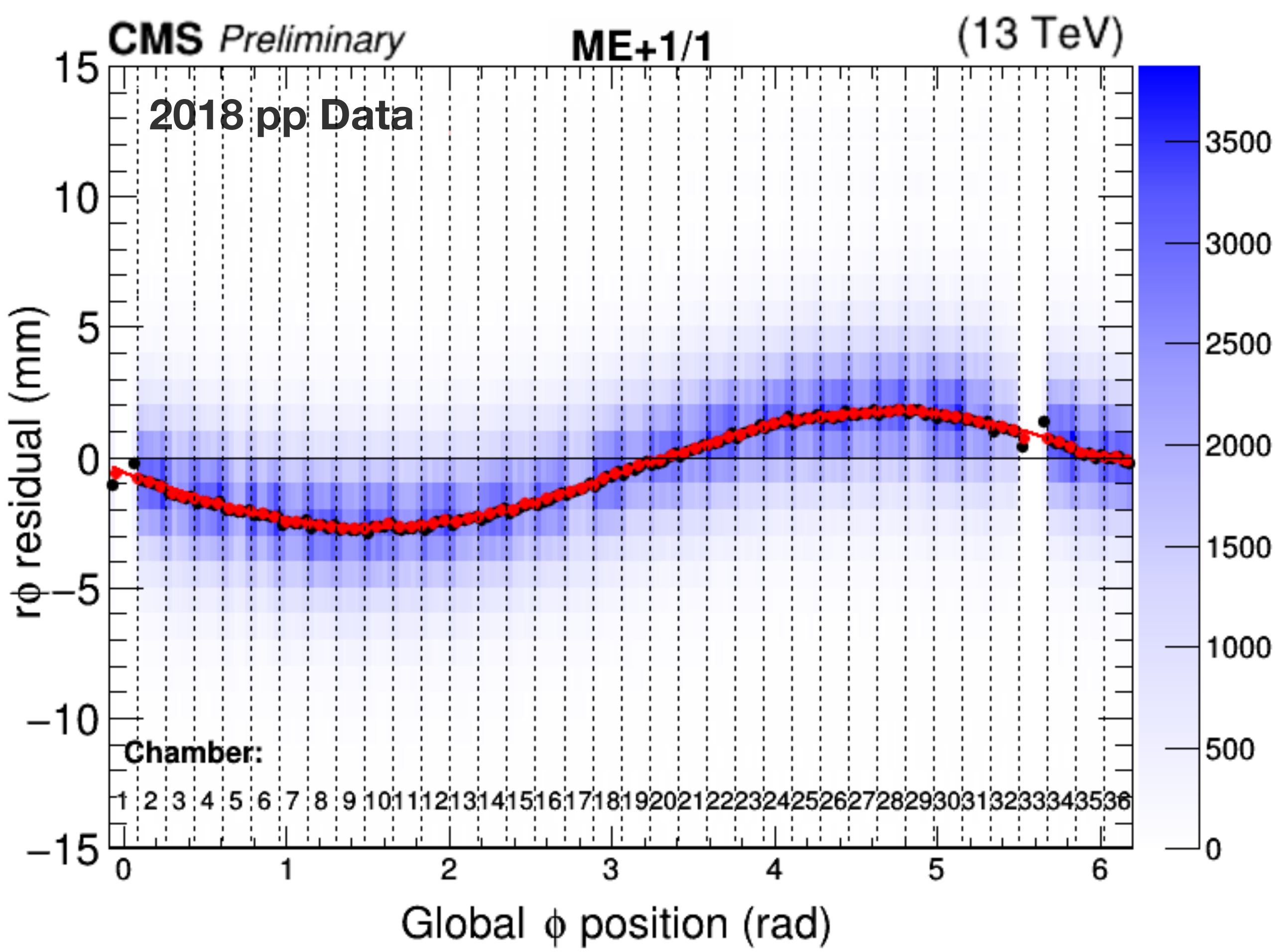
- Muon alignment physics validation datasets:
  - Data collected at the beginning of the 2016 (5.44 fb^{-1}), 2017 (4.79 fb^{-1}), and 2018 (3.60 fb^{-1}) proton-proton collision runs
- Only muons reconstructed as global muons (details in MUO-16-001) are used in the study. They consist of tracks reconstructed independently in the inner tracker (tracker tracks) and in the muon system (standalone muon tracks, STA), as well as of a combined track refit using information from both detectors (global muon tracks, GLB).
- Muon selection:
  - Global muon
  - $|\eta_{\mu}^{\text{inner-track}}| < 2.4$
  - $p_{\mathrm{T}\mu}^{\text{inner-track}} > 30$ GeV
- Di-muon invariant-mass plots:
  - Computed selecting opposite-charge muon pairs satisfying muon selection
  - Use either muon track information from:
    A. The STA track fit for one muon and the GLB track fit for the other muon
    B. The GLB track fit for both muons
  - Results are also plotted as functions of the eta or phi of the STA (A.) or GLB (B.) muon fit
  - In the case in A., STA muon fit corresponds half of the times to q=+1 and half of the times to q=-1 muons
- Muon p_{T} resolution plots:
  - Computed for every muon satisfying the muon selection
  - Measuring metric: $q/p_{\mathrm{T\ STA}} - q/p_{\mathrm{T\ GLB}}$
- The above metrics are sensitive to the STA fit performance, which depends on muon alignment

Di-muon Mass

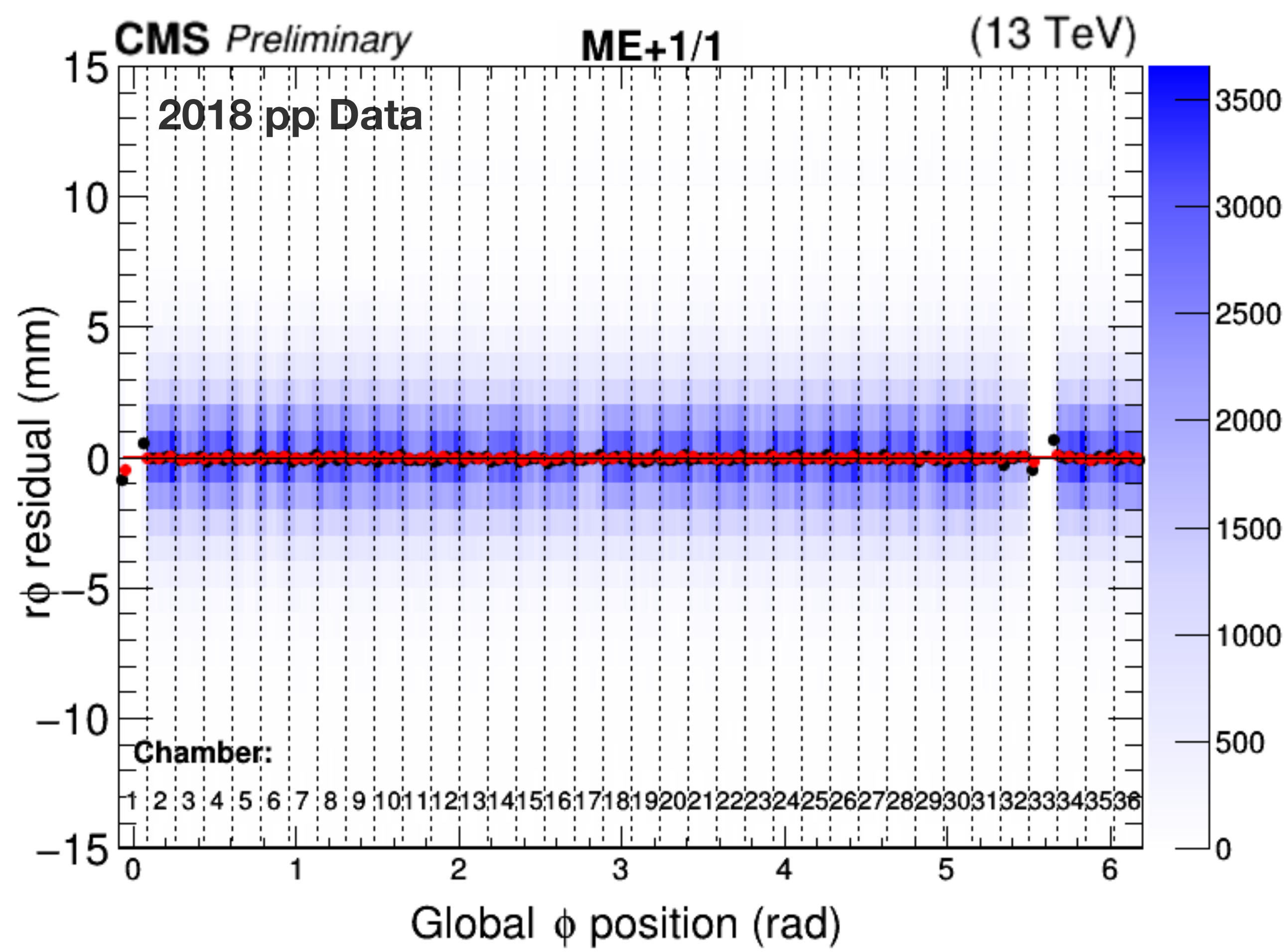


Validation of Run2 legacy muon alignment using di-muon (**GLB + STA**) mass distributions for $Z \rightarrow \mu\mu$ event candidates. Left: Di-muon mass (mean and width values from Gaussian fit) as a function of the standalone muon η. Right: Di-muon mass width as a function of the standalone muon η. High η (endcap) region is unstable and sensitive to operating conditions. Since one di-muon leg is STA, there is scale bias (a 1% scale bias in barrel and a up to 5% bias in the endcap [MUO-10-004]).

2018 CSC Residual



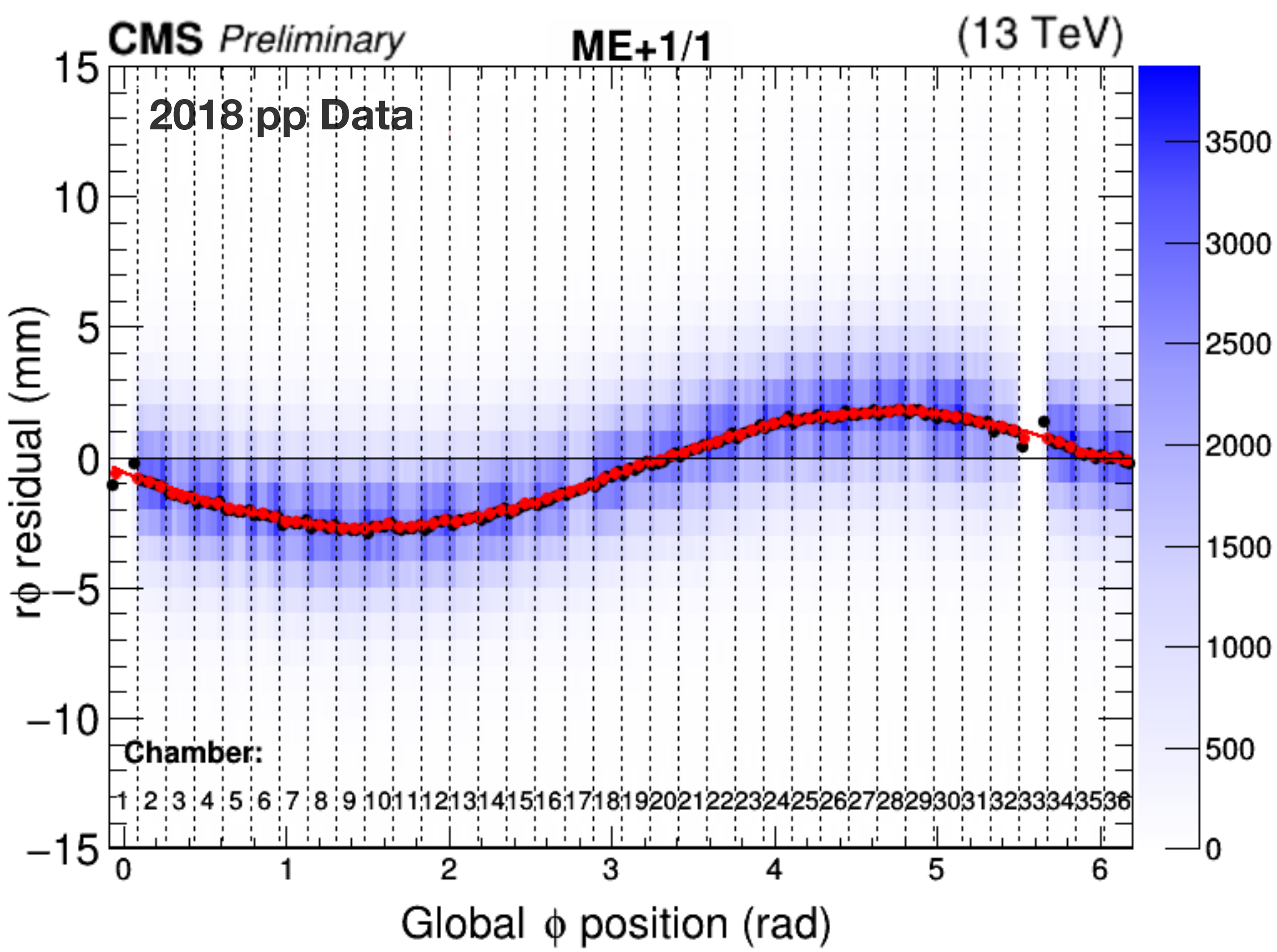
Before Alignment



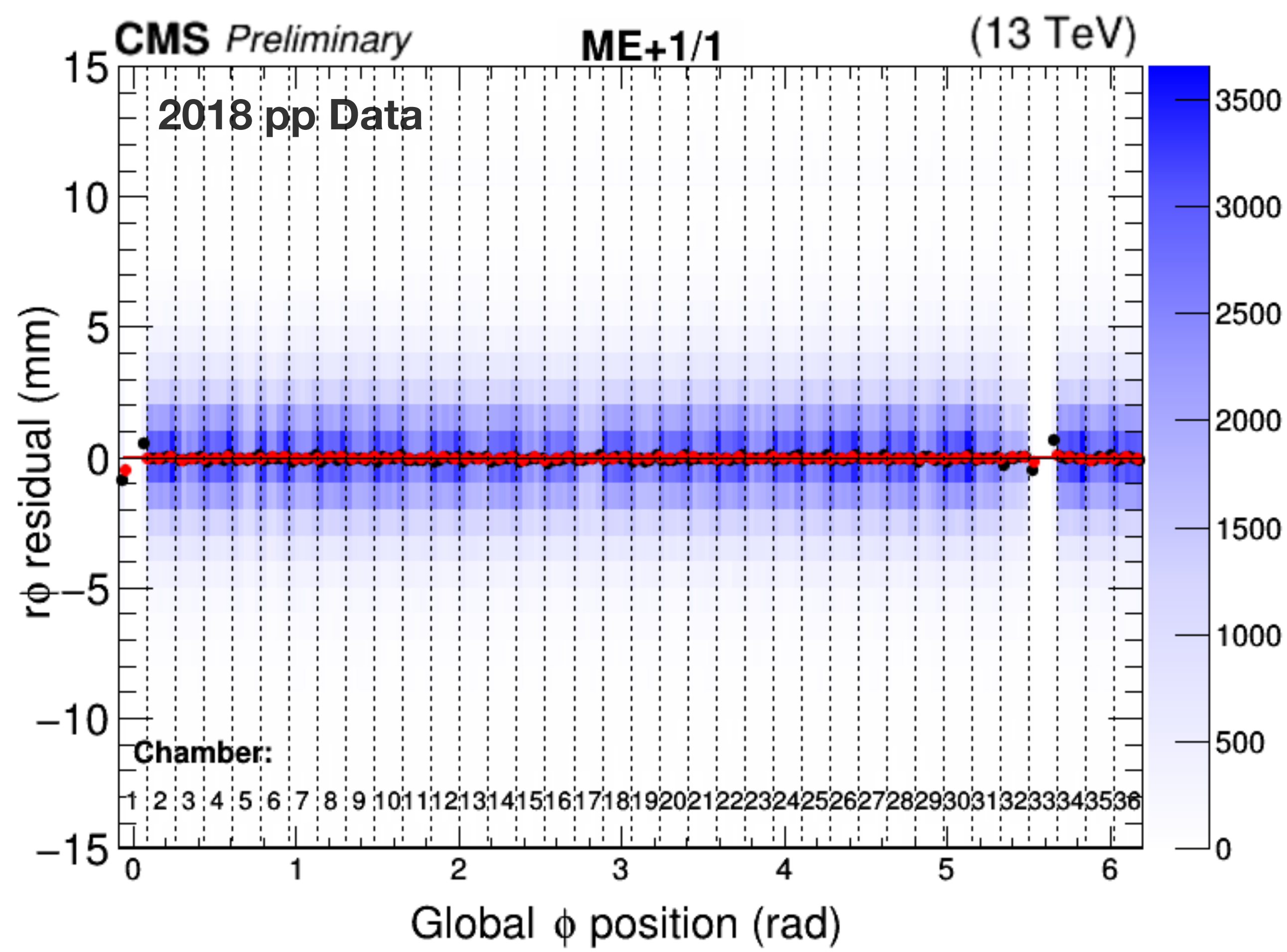
After Alignment

Residual on $r\phi$ as a function of global ϕ for the first ring on the first disk of CSC chambers in the positive endcap (ME+1/1). On the left, the residual distribution has a sinusoidal trend due to the misalignment of the CSC disk. On the right, the residual distribution is centered around zero after the initial geometry has been corrected. The residual means (red), medians (black), and distributions (blue heat map) are shown shown before alignment (left) and after alignment (right).

2018 CSC Residual Fit Results



Before Alignment

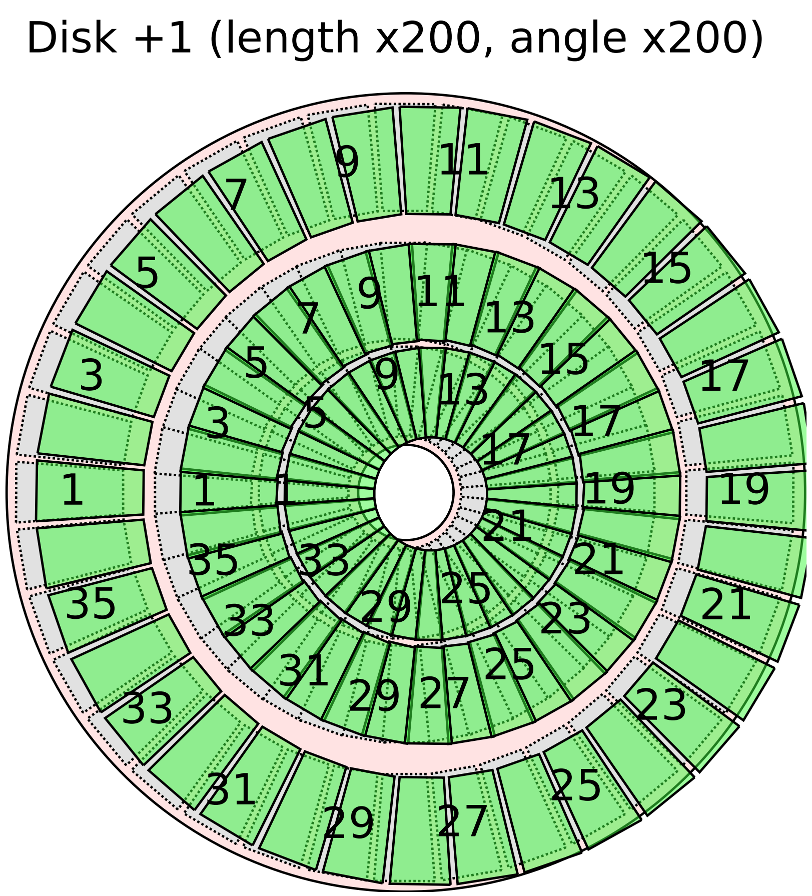


After Alignment

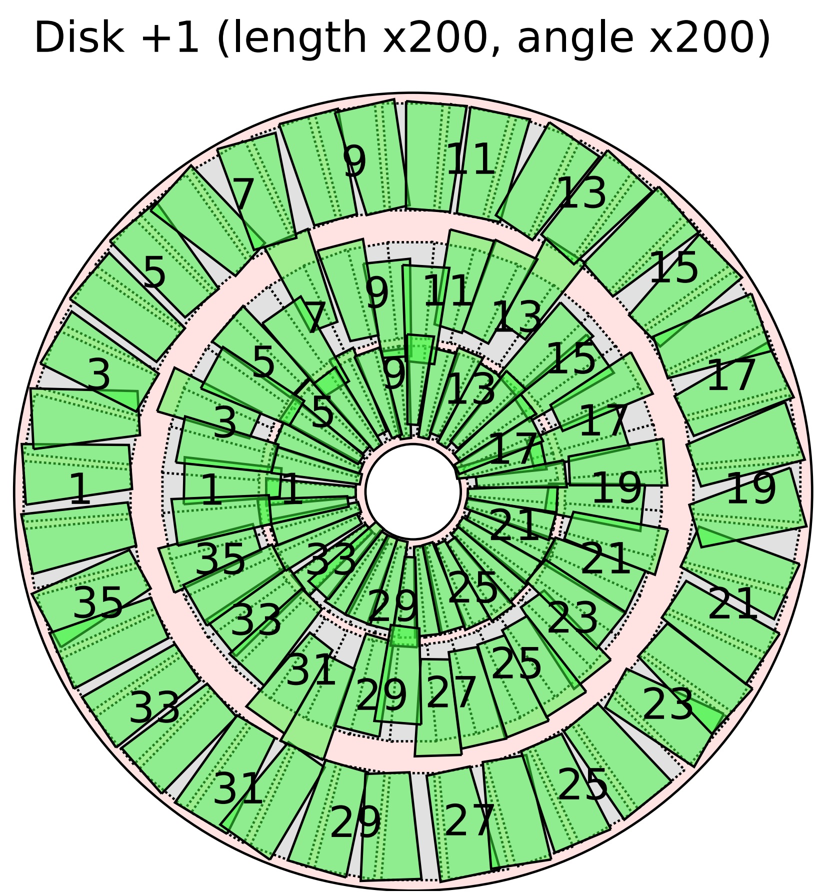
$$c_0 + c_1 \cdot \sin\phi + c_2 \cdot \cos\phi$$

	Before alignment	After alignment
c_0	-0.542 ± 0.001	-0.005 ± 0.001
c_1	-2.275 ± 0.002	0.005 ± 0.002
c_2	-0.378 ± 0.002	-0.000 ±0.002

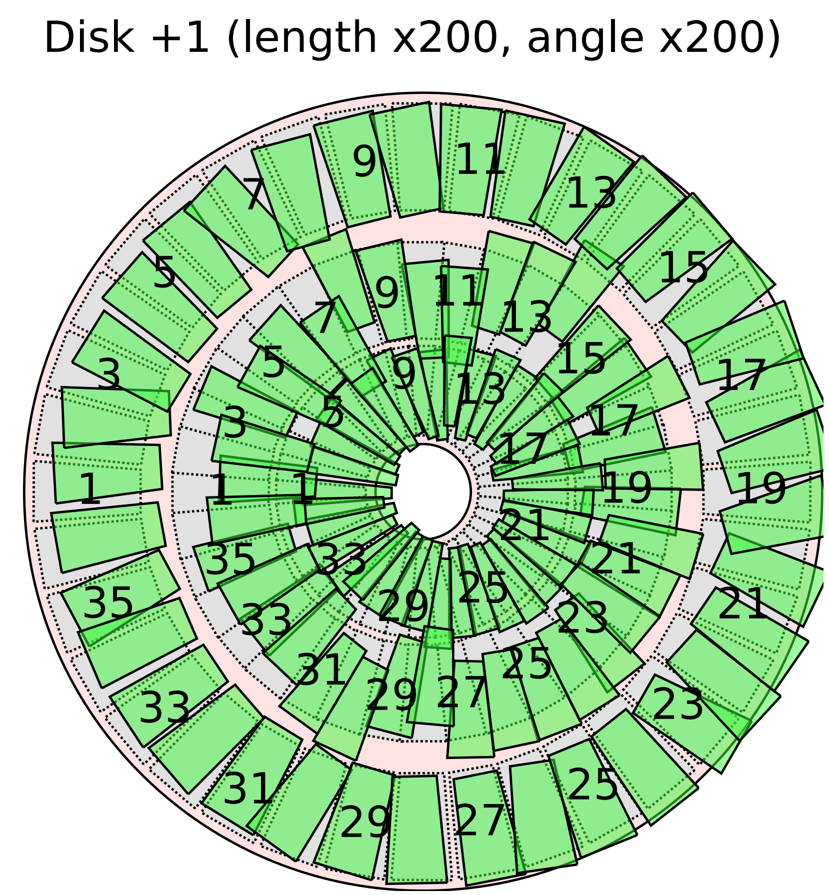
2018 CSC Displacement



Step1: disk level



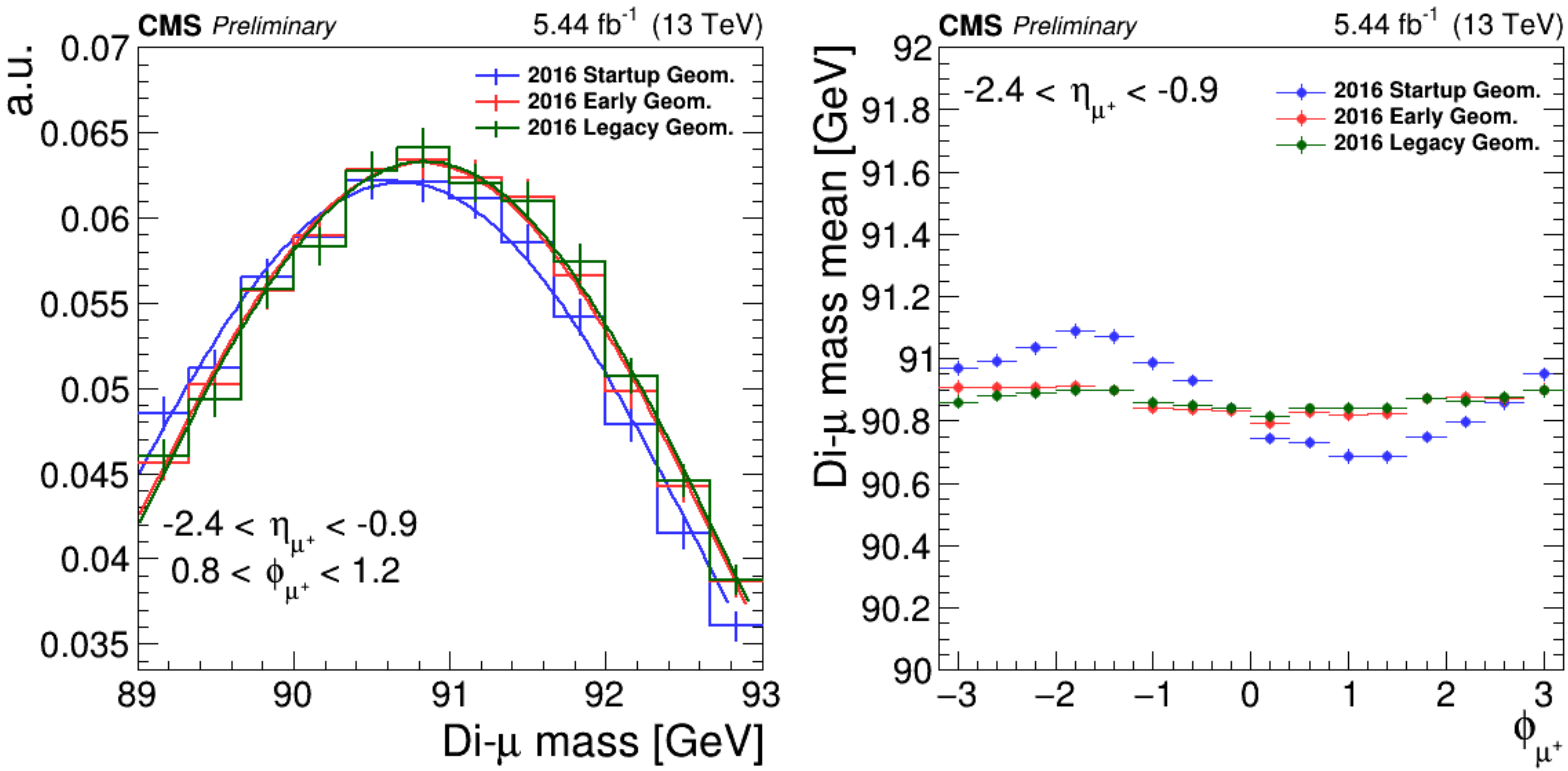
Step2: chamber level



Step1+Step2

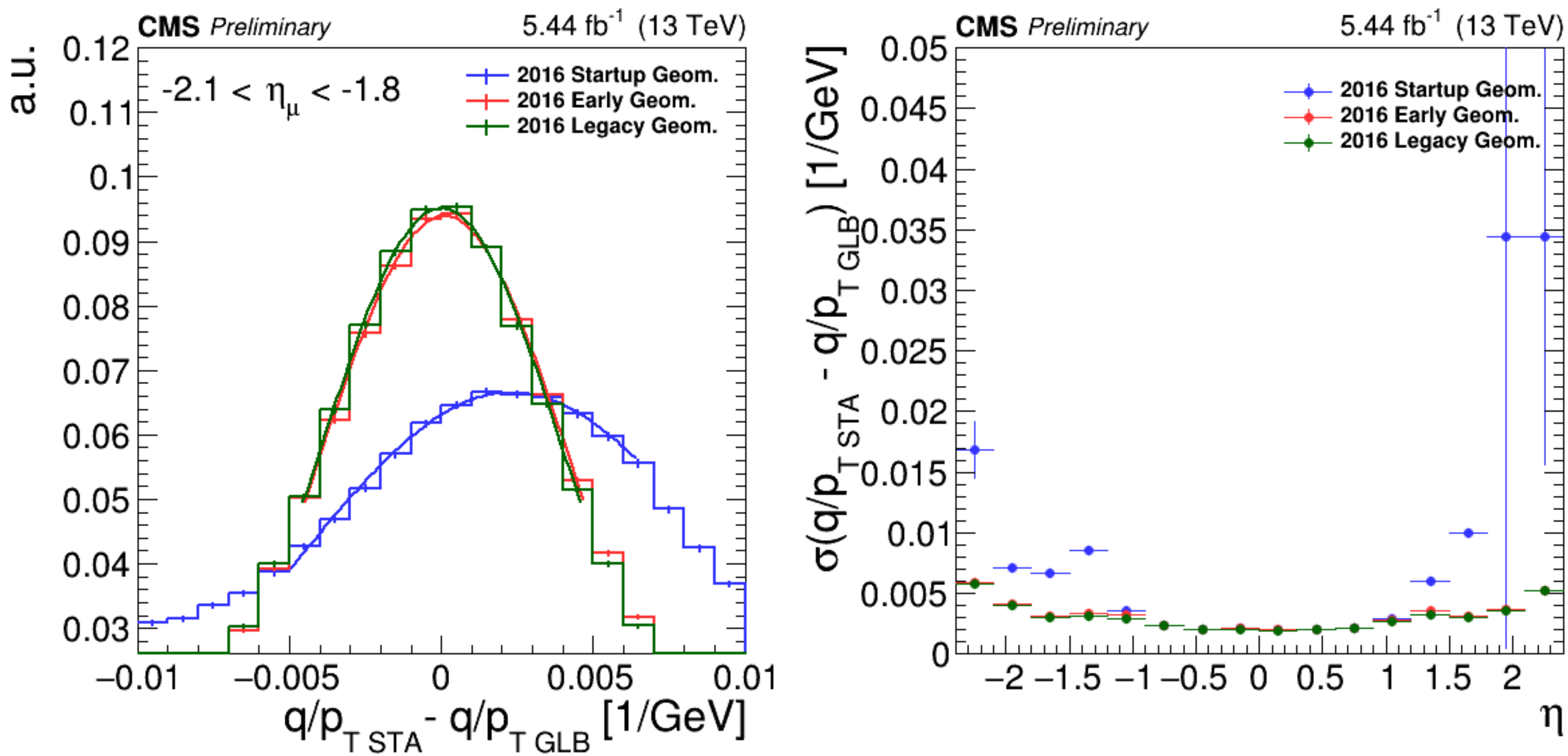
A two-step process of aligning the CSC is used after the endcaps have been opened, shown for ME +1/1: a disk-level alignment (left) followed by a chamber-level alignment using the disk-level alignment as the new reference geometry (middle). The final comparison (right) shows the sum of both alignment's chamber movements with respect to the 2018 startup geometry. Linear and angular chamber displacements are exaggerated 200-fold.

2016 CSC Di-μ Mass



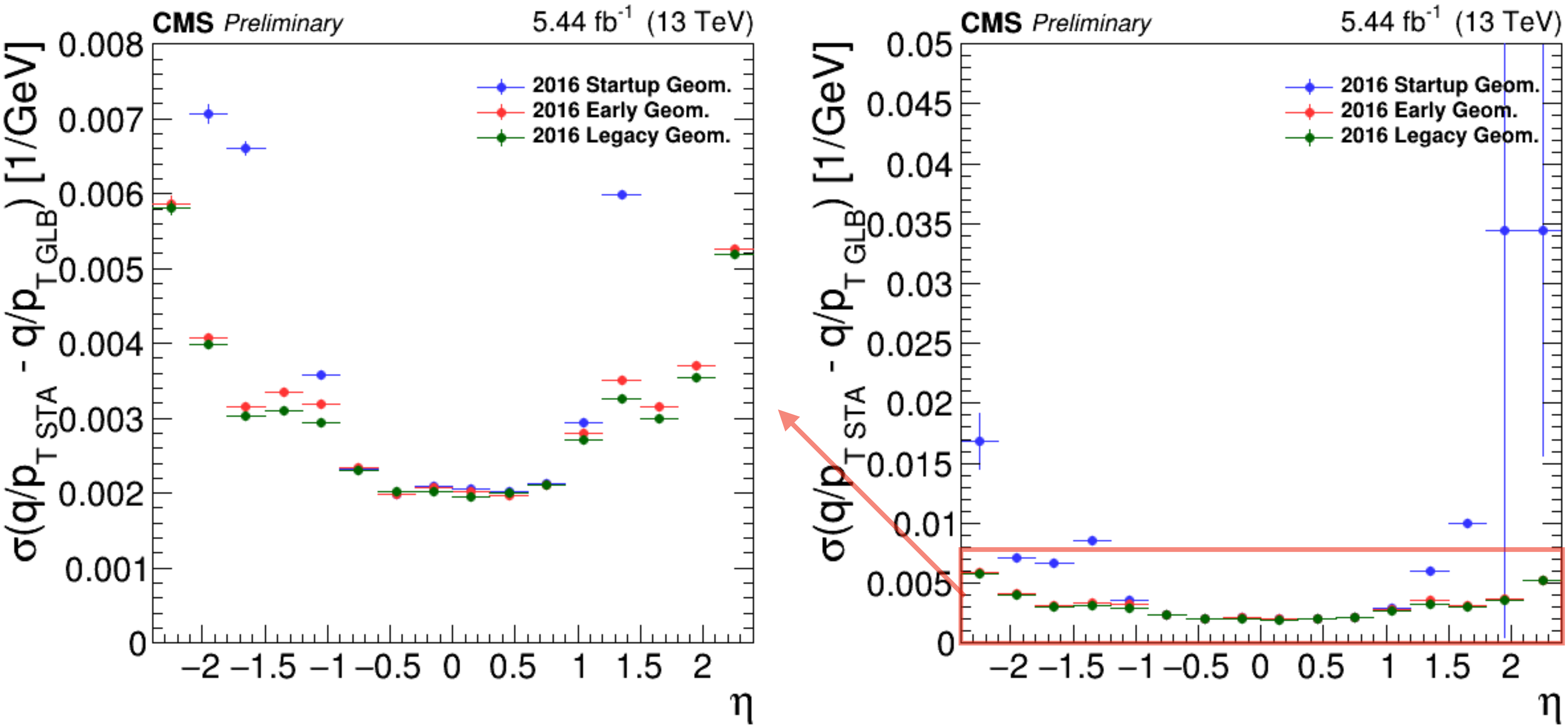
Left: Di-muon mass (both GLB) distributions for muons between $0.8 < \phi_{\mu^+} < 1.2$ rad and $-2.4 < \eta_{\mu^+} < -0.9$. Right: Mean value of the di-muon mass distribution vs ϕ_{μ^+} for $-2.4 < \eta_{\mu^+} < -0.9$. The improvements in the CSCs after the track-based muon alignment are visible. All entries are using the same up-to-date tracker geometry.

2016 CSC $p_{T\mu}$ Resolution



Left: Resolution in p_T distributions for muons between $-2.1 < \eta < -1.8$. Right: resolution in p_T mean vs. η. The improvements in the CSCs after the track-based muon alignment are visible.

2016 CSC $p_{T\mu}$ Resolution (Closeup)



Resolution in p_T mean vs. η (left: Y-axis range is 0 to 0.008).