Study of TrackerMuon Residuals

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Context

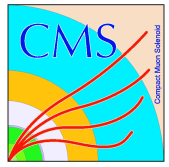
- Alignment relative to the tracker is based on tracker-tracks propagated into the muon system
- Currently, we do that by re-fitting GlobalMuons with no weight in the muon hits
- This feature is also useful for physics analyses, so there's a standard tool for doing it: TrackerMuons

  (note: our refitted-GlobalMuons method predates TrackerMuons)

GlobalMuons vs. TrackerMuons

GlobalMuons	TrackerMuons
1. Build StandAloneMuons, 2. look for matching tracker-tracks	For each tracker-track, look for matching segments
Result is one long track	Result is a collection of "matches"
Easy to re-fit the track to see the effect of a new alignment	Must rebuild whole collection from scratch to test a new alignment

Why look at TrackerMuons?



- Should yield the same results as refitted-GlobalMuons, but it's a completely different technical path

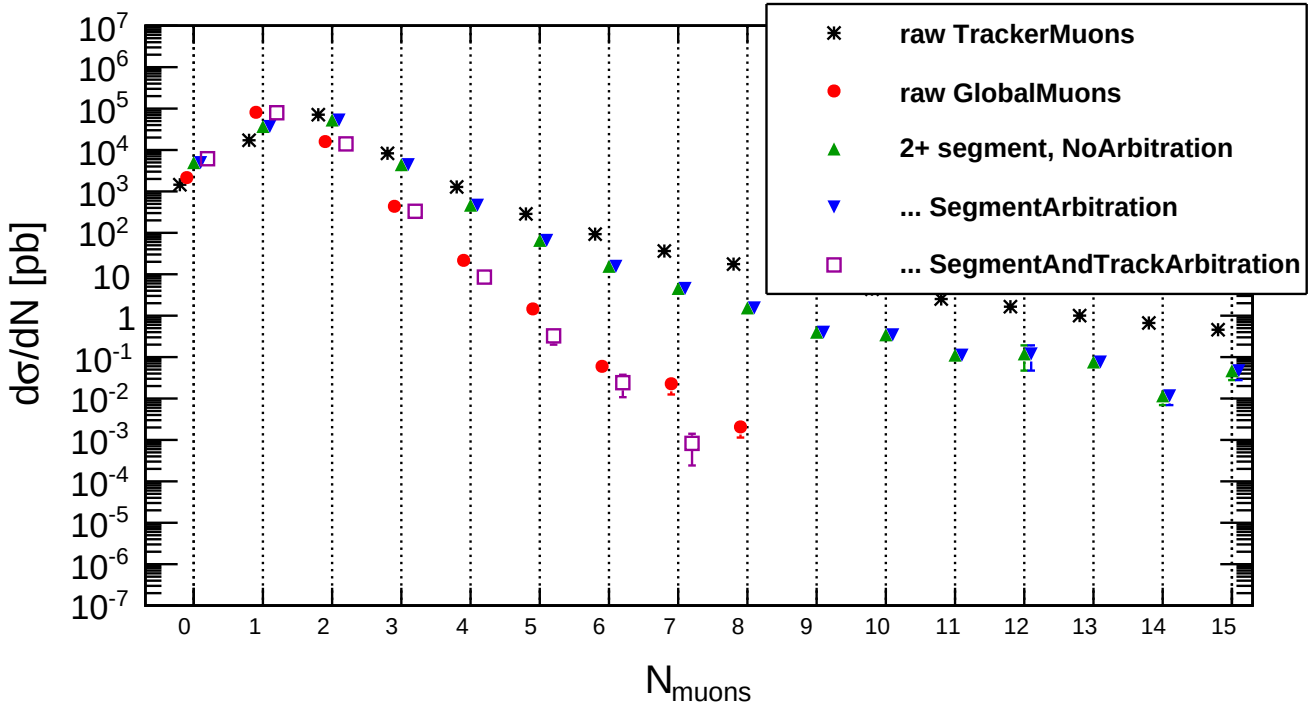
  If we had done this sooner, we would have caught the RPC-hit bias
- By-product of an analysis I'm working on that uses TrackerMuons
- Track-based alignment infrastructure could be updated to use TrackerMuons, but there are so many technical complications that there would have to be a strong reason for it

Dataset: 2.1 pb^{-1} of collisions

- In this talk, I'll be showing residuals from collisions, not cosmic rays
- Ideally, we'd only want to swap one thing at a time: GlobalMuons $\rightarrow$ TrackerMuons, cosmics $\rightarrow$ collisions, or high-momentum $\rightarrow$ low-momentum, but I'm swapping all three
- Hopefully the gaps will be filled in soon

TrackerMuon backgrounds

- TrackerMuons are built in an inclusive way: it is *essential* to reject background with offline cuts
- Sufficient cuts for high-momentum ($p_T > 5$ GeV/c) muons: require at least 2 segments to be *exclusively* matched to the track
- TrackerMuons with 2 "arbitrated" (exclusive) segments (purple) recover purity of GlobalMuons (red) in inclusive muon background MC



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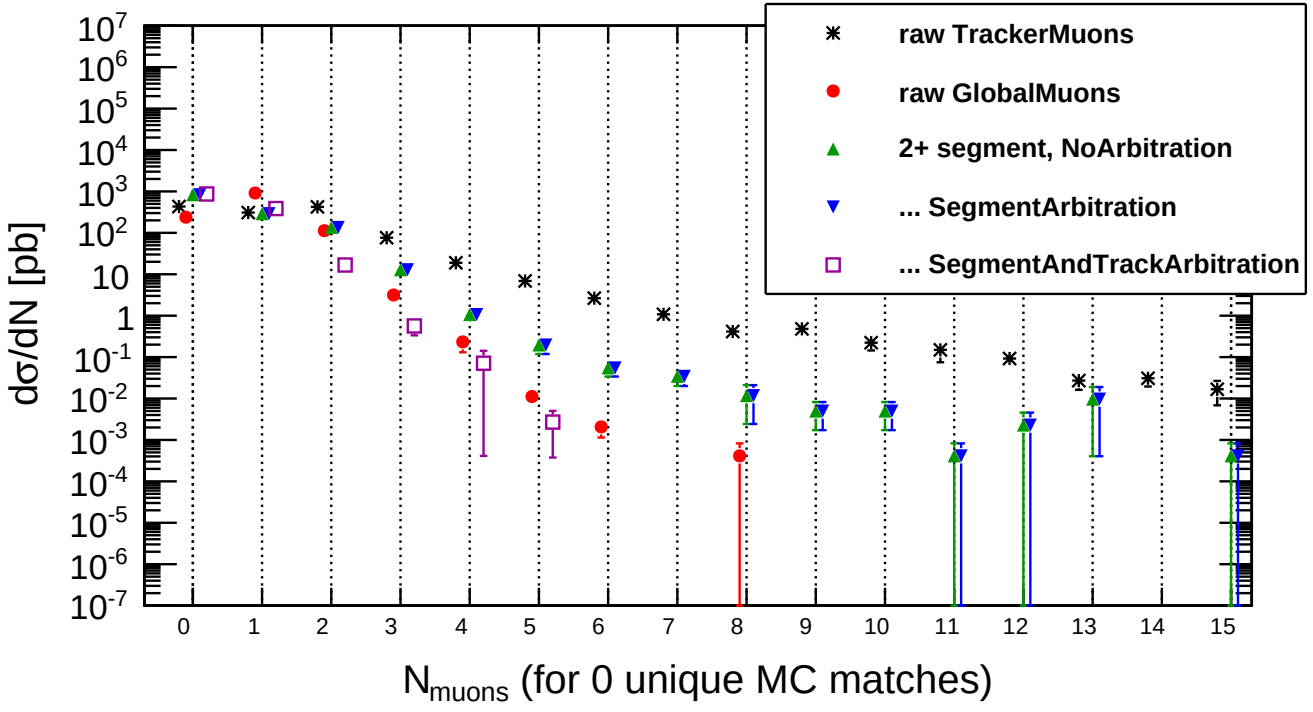
- Number of reconstructed muons for 0 generator-level muons



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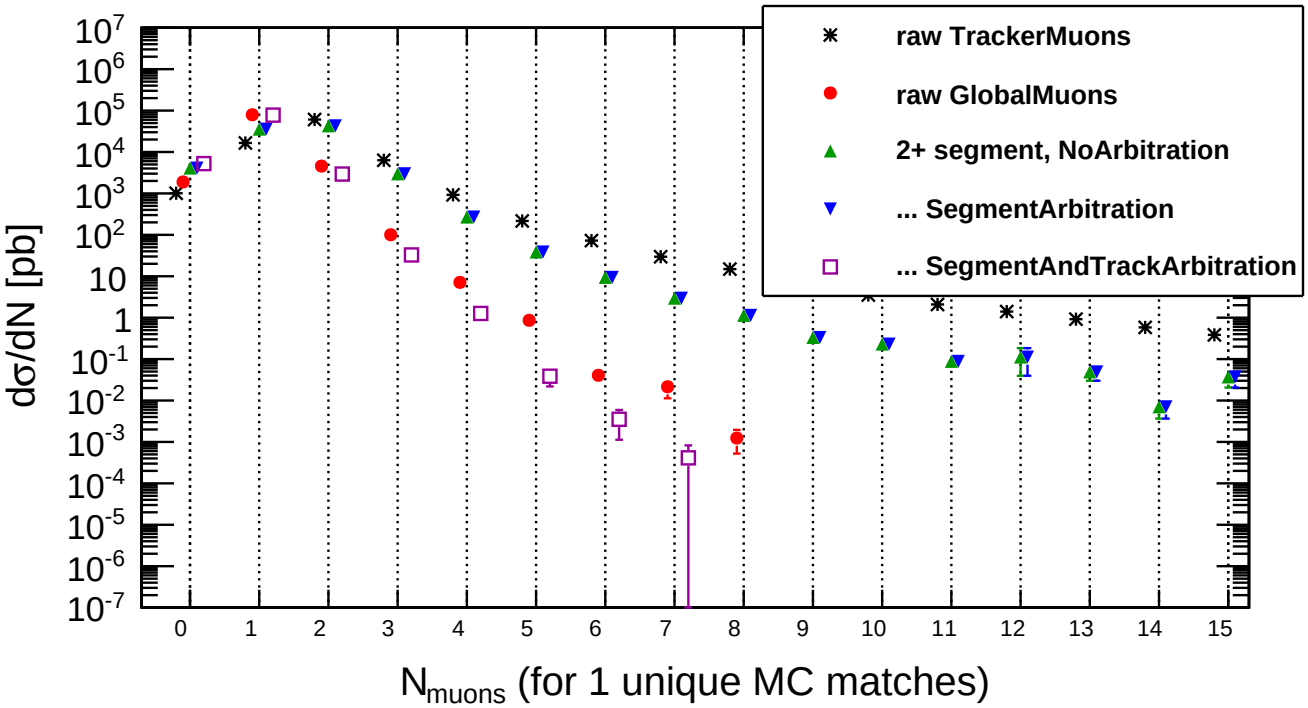
- Number of reconstructed muons for 1 generator-level muon



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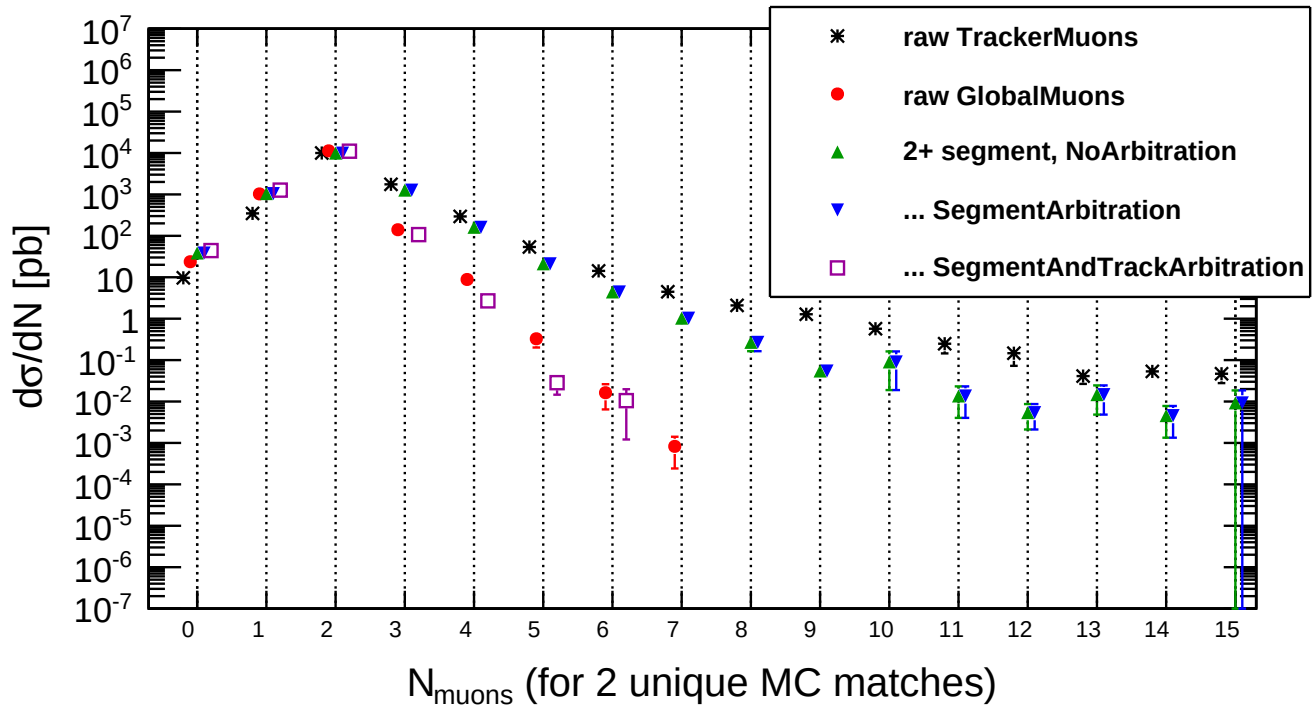
- Number of reconstructed muons for 2 generator-level muons



TrackerMuon backgrounds

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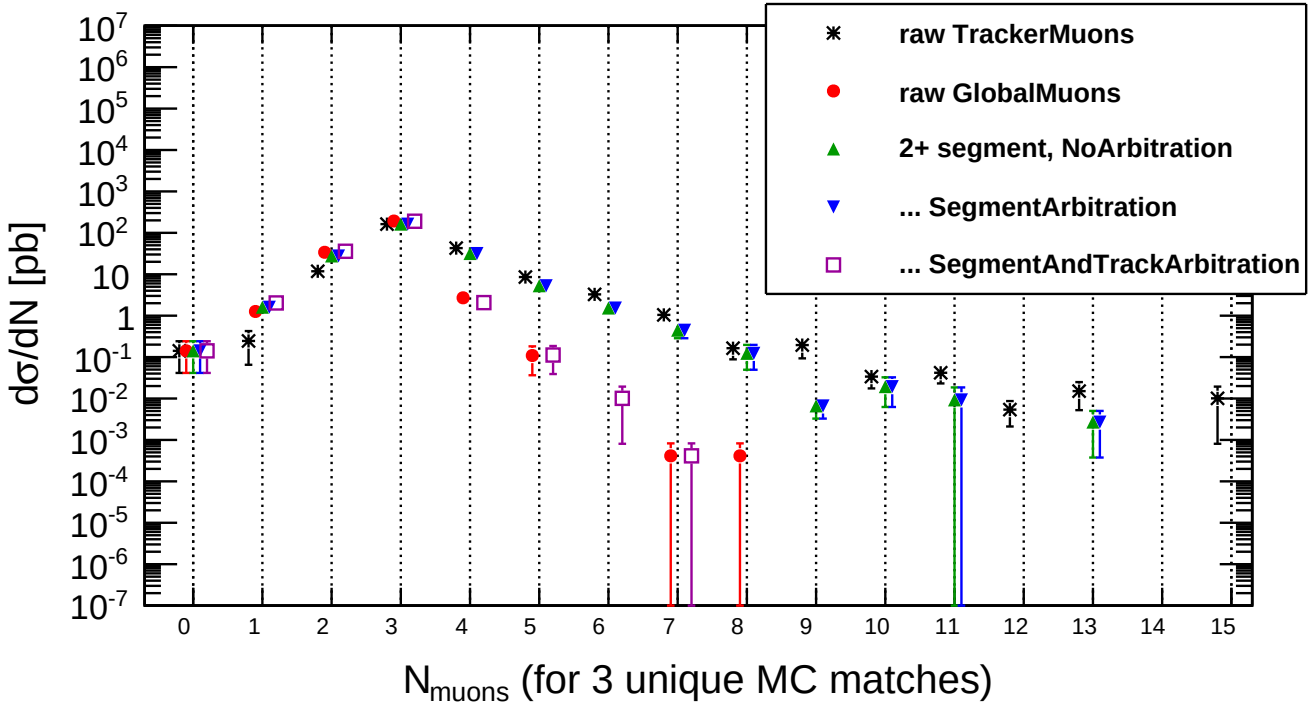
- TrackerMuons with 2 "arbitrated" (exclusive) segments (purple) recover purity of GlobalMuons (red) in inclusive muon background MC
- Number of reconstructed muons for 3 generator-level muons



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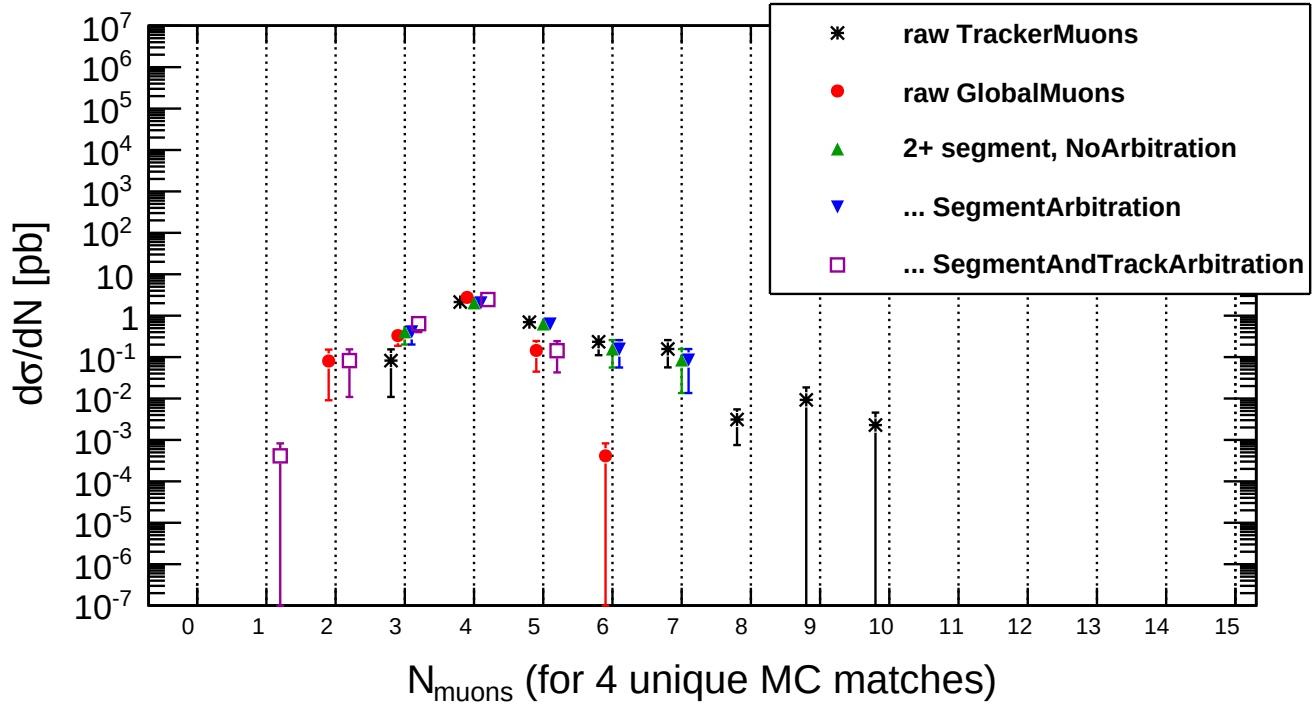
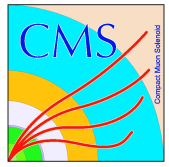
- Number of reconstructed muons for 4 generator-level muons



Avoid trigger bias



- Since triggers are tighter in collisions data than they are in cosmics, it is important to make sure that the trigger requirements are not sculpting the muon distributions
- The method I used in this study:

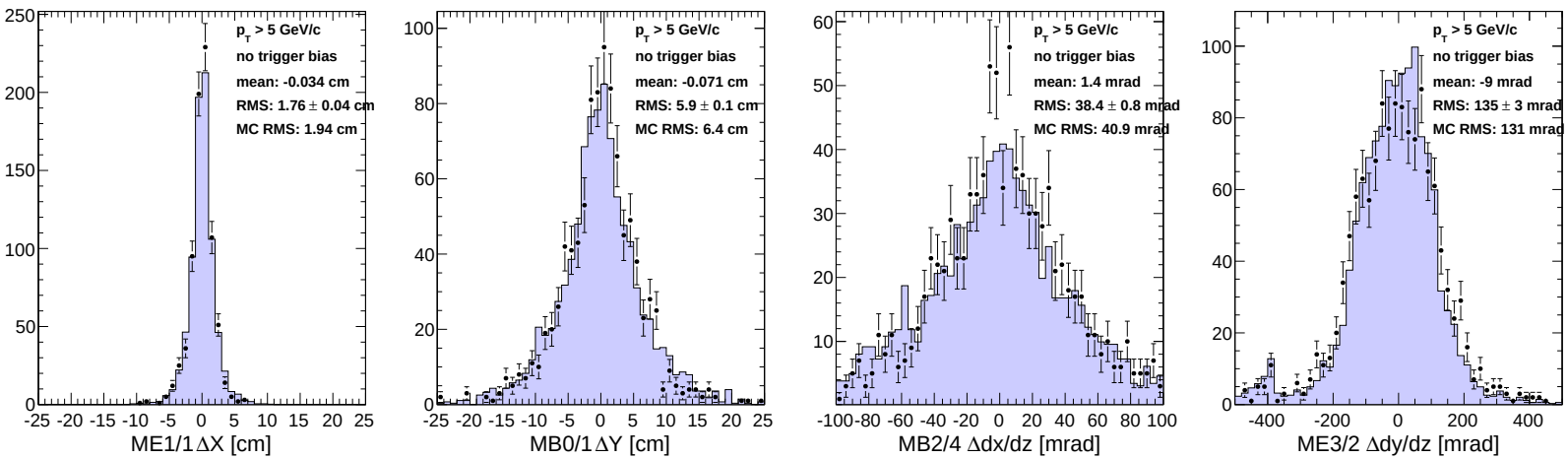
  trigger = HLT_Mu9 (lowest unprescaled single-μ trigger)
  triggerable muon = muon with $p_T > 11$ GeV/c, $|\eta| < 2.1$

  if passed trigger **and** number of triggerable muons > 0 **then**
  for loop over muons **do**
  if number of triggerable muons $= 1$ **and** this muon isn't it **then**
  include this muon in plots! (case 1)
  else if number of triggerable muons > 1 **then**
  include this muon in plots! (case 2)
  end if
  end for
  end if

- Every event we look at has at least two muons in it

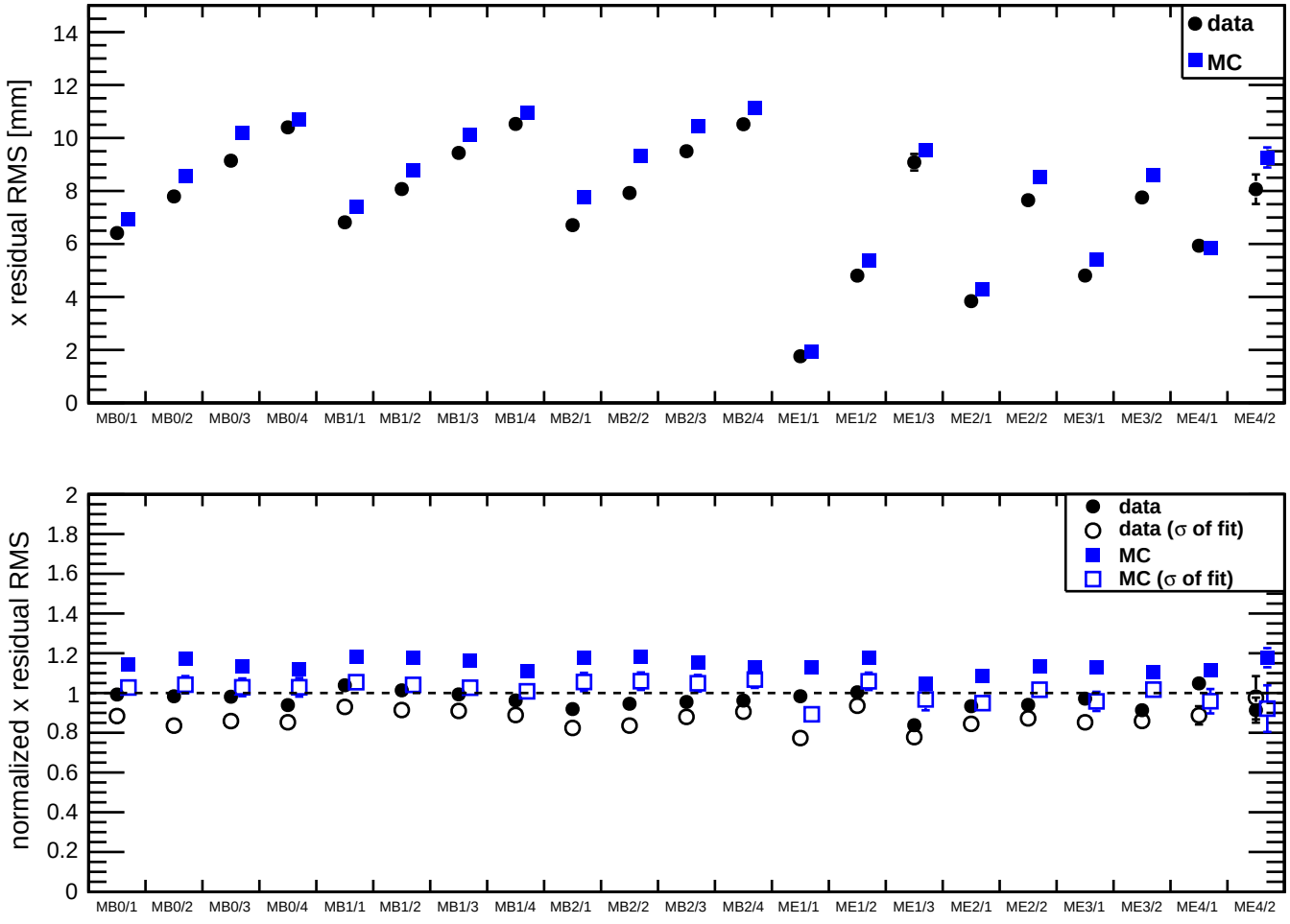
Residuals per ring of chambers

- Not enough statistics to bin residuals by chamber
- Bin by rings of identical chambers
  - barrel wheels 0, ± 1, ± 2 in stations 1, 2, 3, 4
  - endcap stations 1/1, 1/2, 1/3, 2/1, 2/2, 3/1, 3/2, 4/1, 4/2
- Additionally require the muons to share a vertex with $P_{\text{vertex}} > 1\%$ (reduces backgrounds from decays-in-flight)
- Muons are mostly from double-semileptonic decays ($b \to c \to s$ with both $W \to \mu\nu$) and dimuon resonances (J/ψ)
- Re-fit PromptReco with the latest alignment in 3_8_2
- Examples (points are data, shaded blue/grey is Monte Carlo):



Summary plots

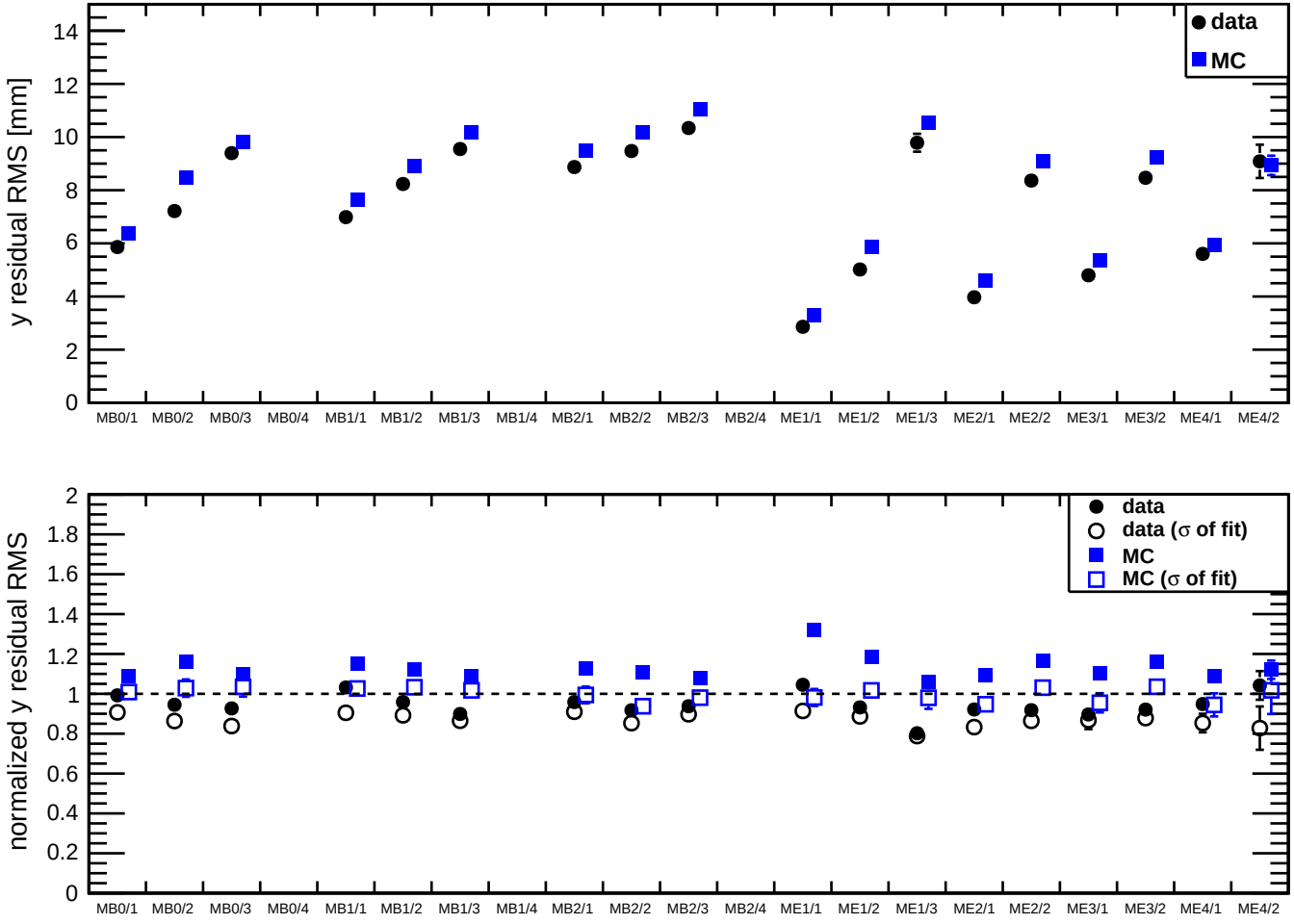
- MC is a little wider than the data everywhere
- MC has STARTUP conditions re-tracked with IDEAL alignment: could be the influence of mis*calibrated* hits?



Summary plots

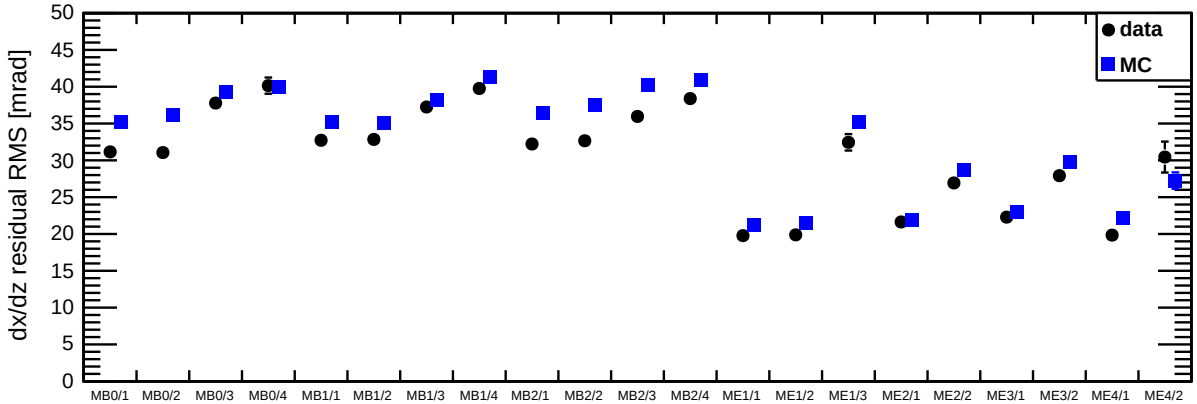
- Same for y
- Compared with standard RelVals (similar results):

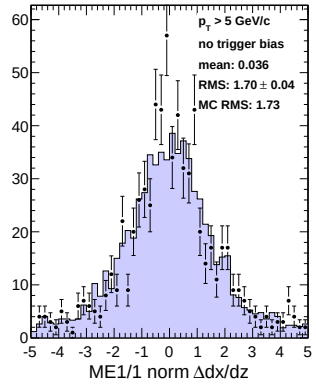
http://cmsdoc.cern.ch/cms/Physics/muon/CMSSW/Performance/RecoMuon/MuonIdentification/

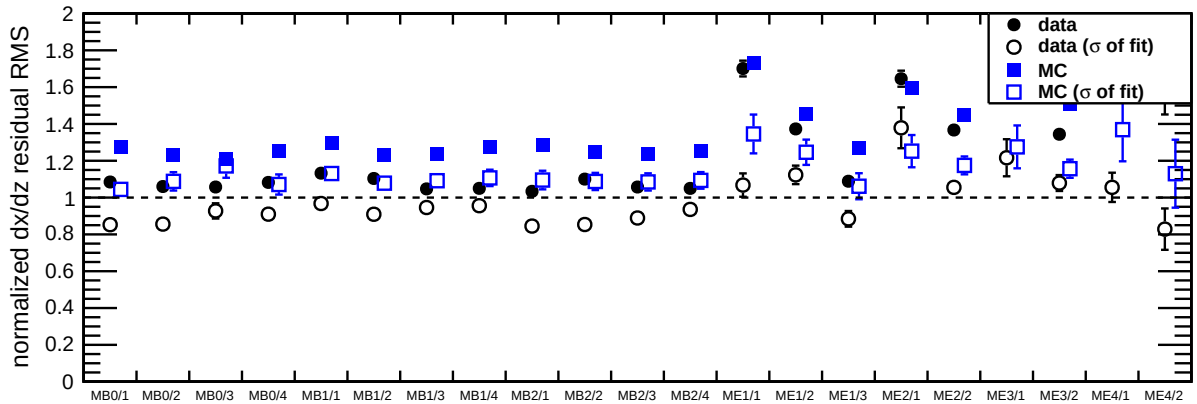


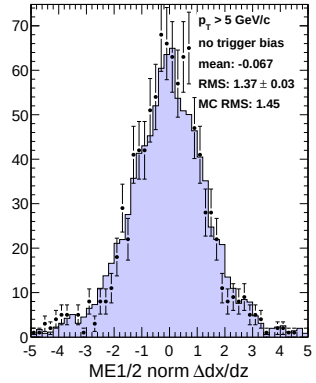
Summary plots

- Endcap normalized $\Delta\frac{dx}{dz}$ distributions have tails (RMS $> \sigma$)
- δ_{ϕ_y} (directly related to $\Delta\frac{dx}{dz}$) has not been aligned in the endcap
- But this pattern is reproduced in MC— doesn't seem like misalignment is the problem



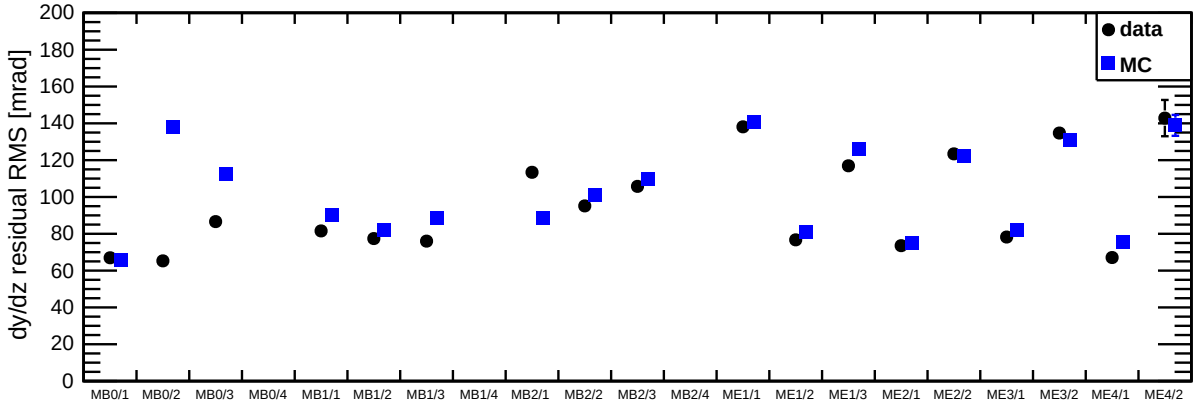


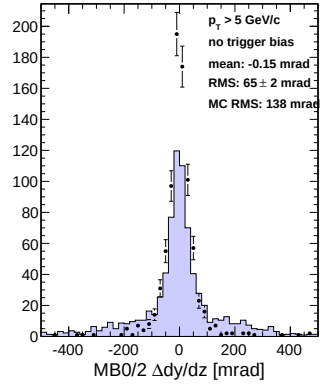


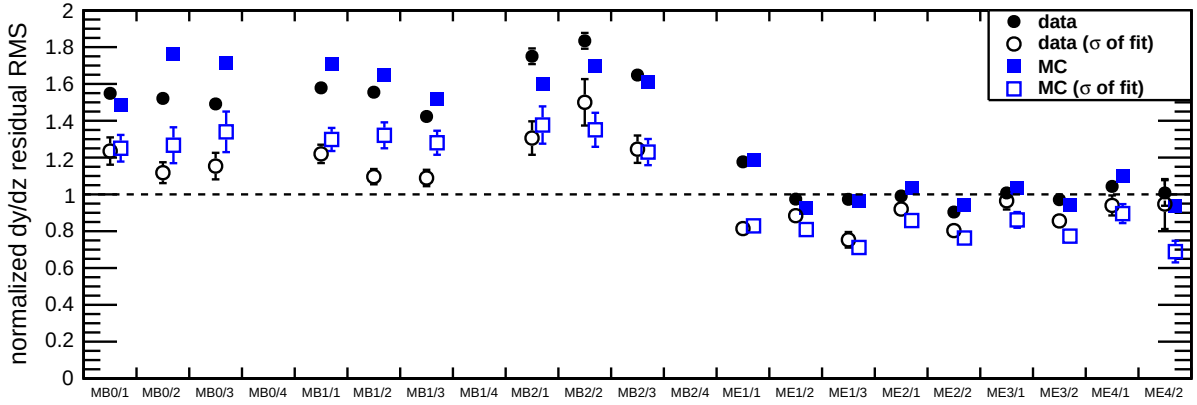


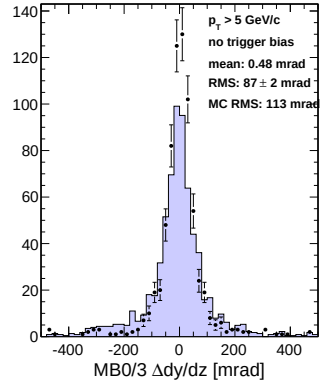
Summary plots

- The same can be said for dy/dz in the barrel
- Discrepancy in MB0/2 and MB0/3: MC has large tails. . . ?



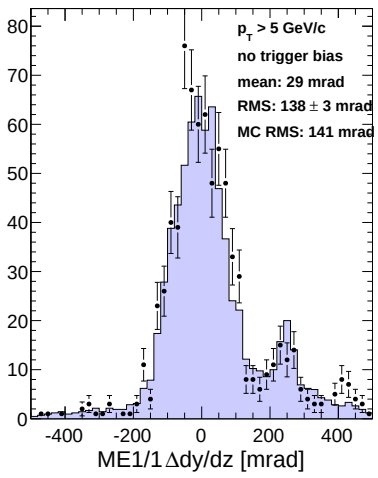


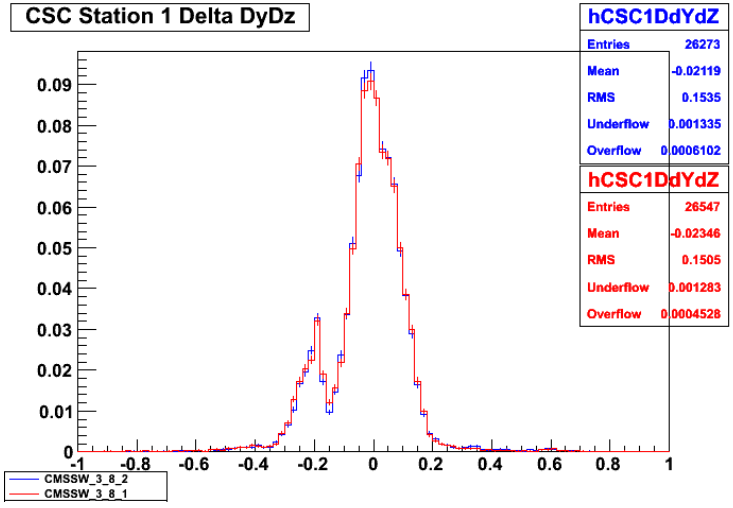




Summary plots

- Oddity in endcap: discrete peaks in $\Delta\frac{dy}{dz}$ residuals, reproduced by Monte Carlo and observed in standard RelVal plots (right)
- Could be related to granularity of CSC wire-groups?
- Note: we never use Δy or $\Delta\frac{dy}{dz}$ in CSC alignment because of the granularity of wire-groups



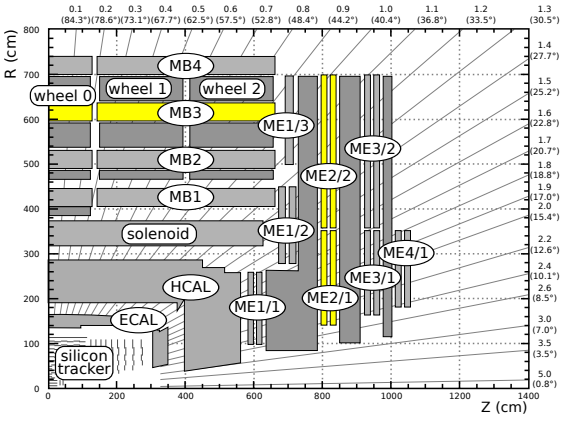


Full set of plots

- All of the individual residuals plots with data/MC overlays are in the backups

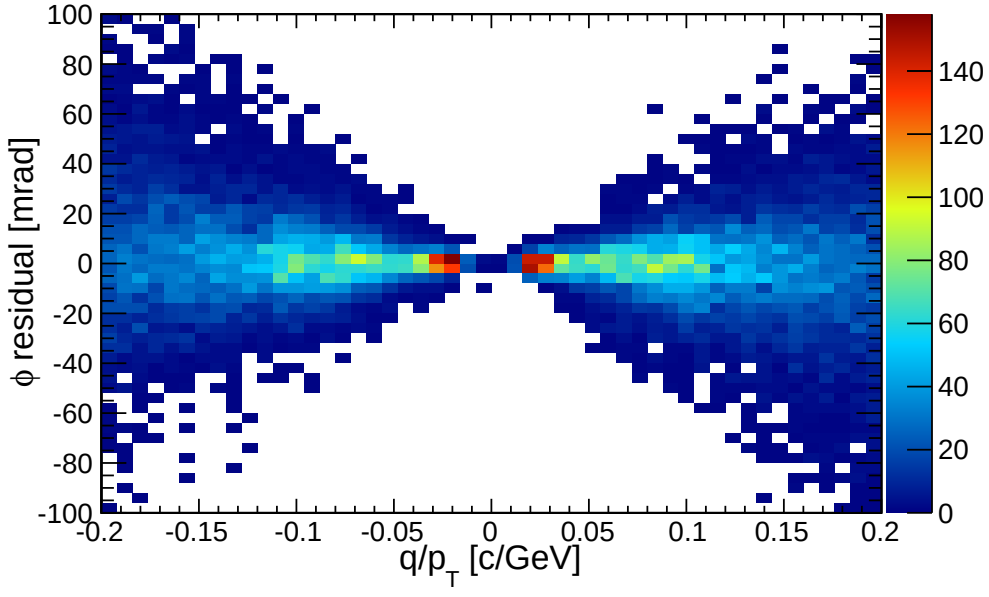
Dependence on momentum

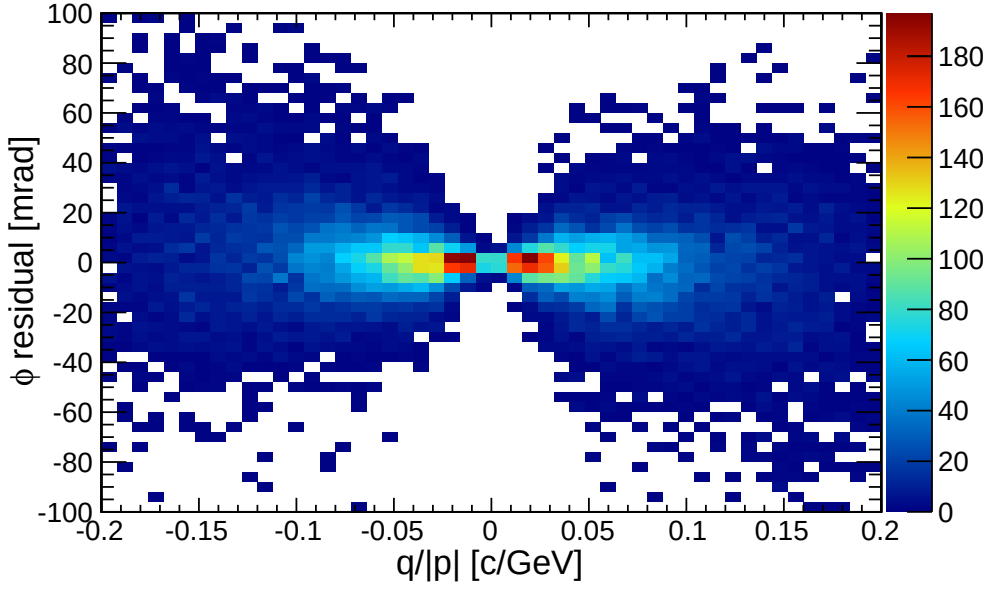
- Plot $\phi = x/R$ residuals from MB3 and ME2



(one representative residual per track)

- Width of residuals distribution scales roughly as $1/|p|$, cut at $1/p_T < 0.2\ c/\text{GeV}$
- Any biases in the mean are much smaller than the width of the distribution



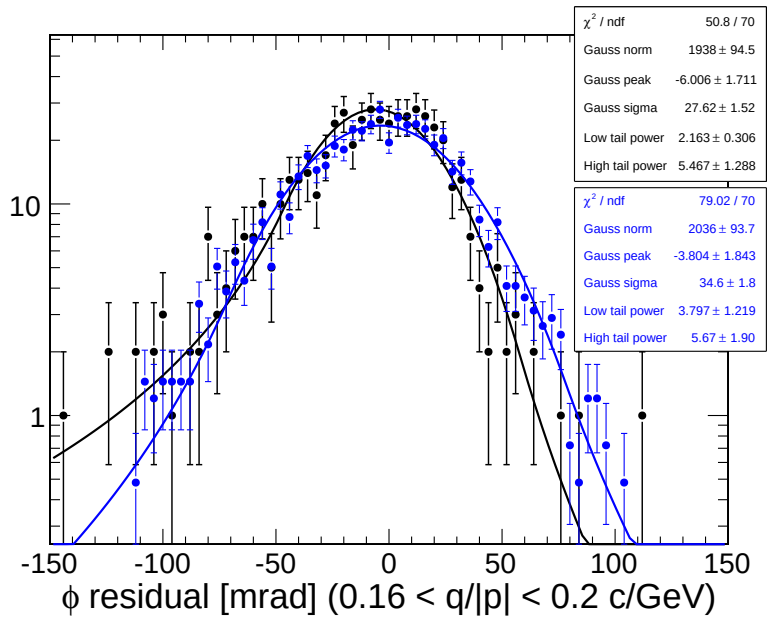


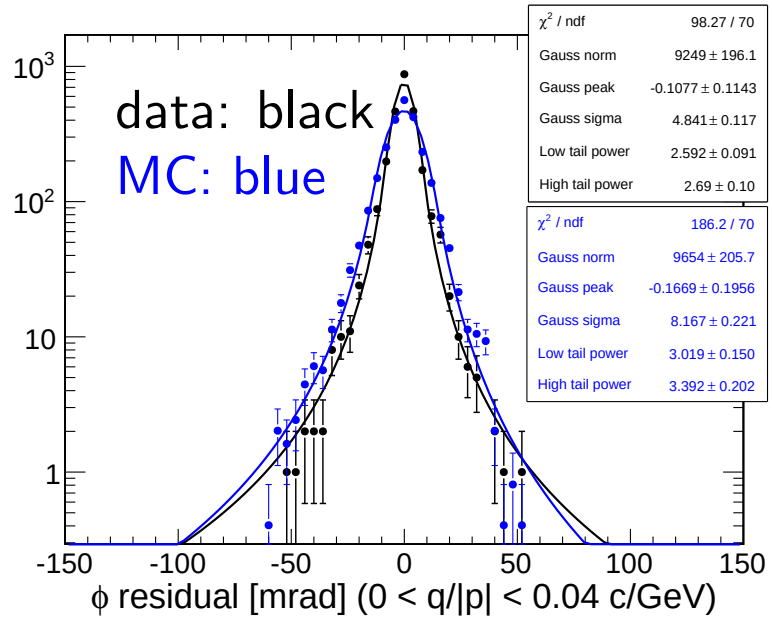
Dependence on momentum

- To quantify bias in the Gaussian part of the residuals peak (not the tails), fit distributions in momentum bins to

$$p(x) = \begin{cases} A\exp\left(-(x-x_0)^2/(2\sigma^2)\right) & |x-x_0| < m \\ B/|x|^{p_1} & (x-x_0) > m_1 \\ C/|x|^{p_2} & -(x-x_0) < -m_2 \end{cases}$$

where A, B, C, m_1, and m_2 are chosen to make the function continuous and differentiable (like alignment fit)

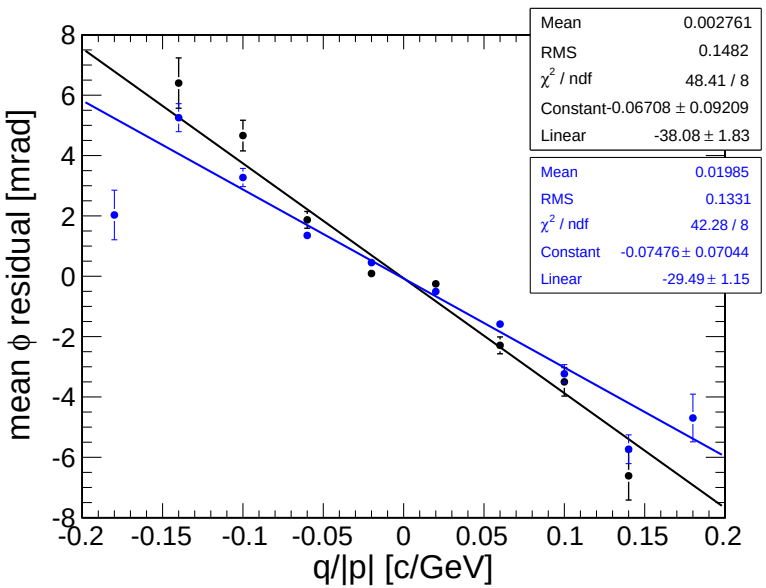




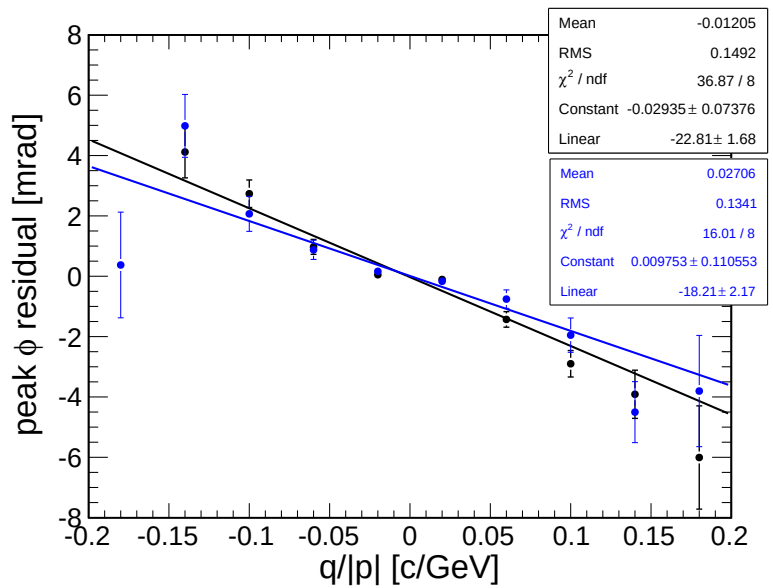
Dependence on momentum

- There is a trend in residuals vs. inverse momentum that is partly in the tails, partly in the Gaussian peak of the distribution
- Black: data, blue: Monte Carlo

Mean of each bin vs. $q/|p|$

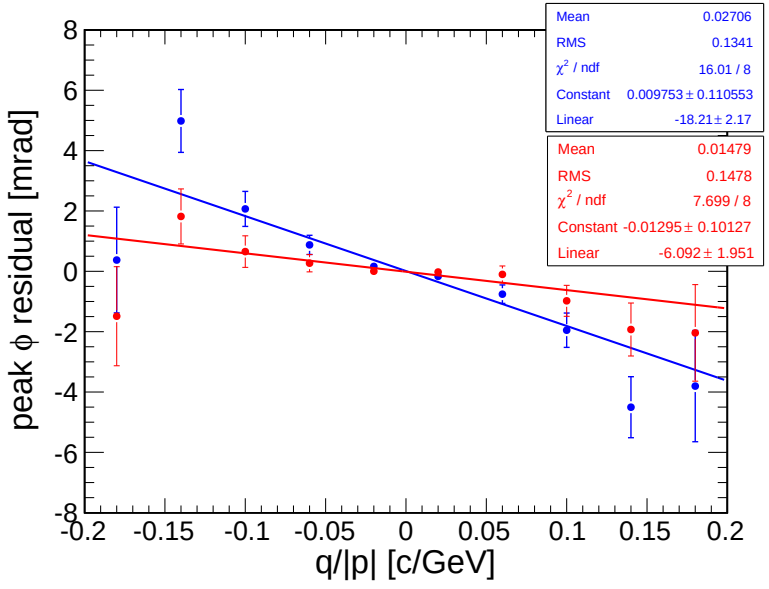


Fitted peak of each bin vs. $q/|p|$



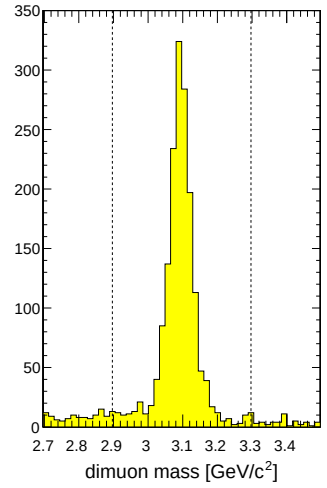
Dependence on momentum

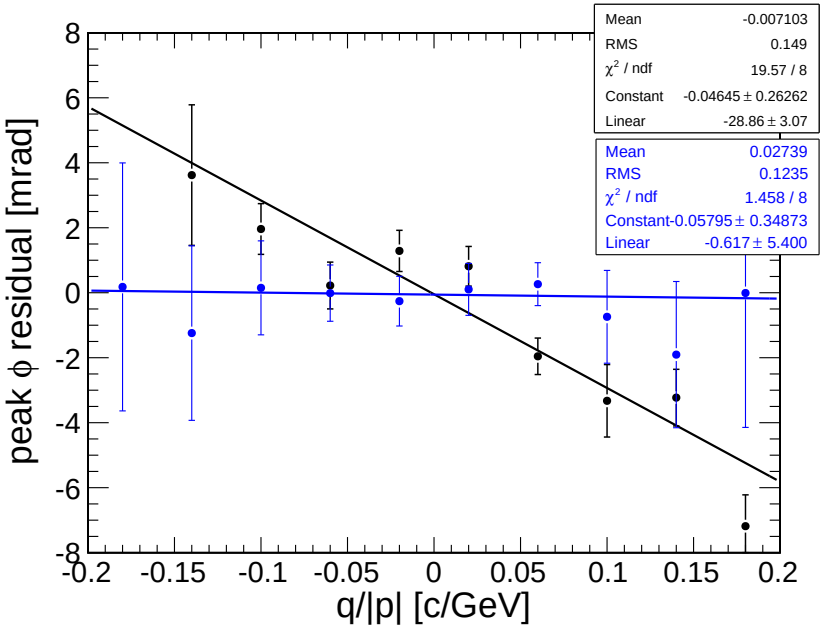
- However, decays-in-flight can bias the residuals distribution in exactly this way
- In Monte Carlo, we can ask that none of the muons come from a $\pi^{\pm}$ or $K^{\pm}$ decay
- Blue: the MC you saw on the previous page, red: same with no decays-in-flight

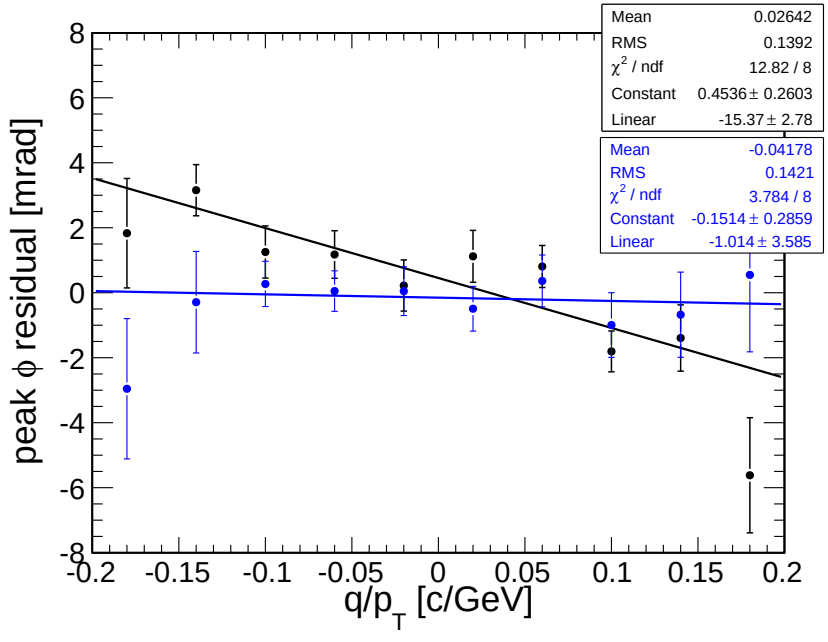


Dependence on momentum

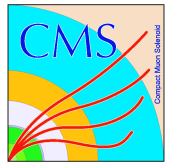
- To suppress decays-in-flight in data, we require muons to come from a J/ψ (± 0.2 GeV/c^2; right)
- We are left with a bias in data but not Monte Carlo: about 15% of the width of the 5 GeV/c distribution
- Do we see the same in GlobalMuon cosmic rays?
- Black: data, blue: Monte Carlo







Conclusions



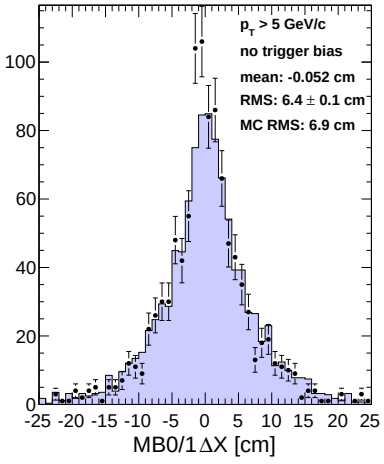
- TrackerMuons provide a conceptually similar but technically different implementation of the tracker-to-muon propagation we use in muon alignment

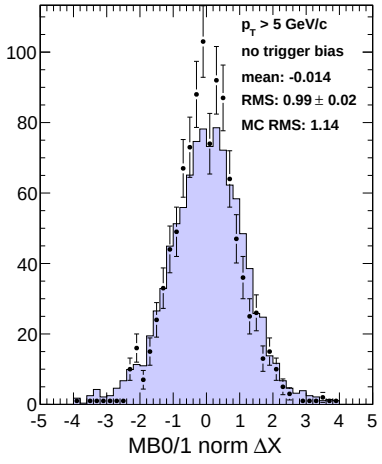
- TrackerMuon residuals are pretty similar to what we would expect and pretty similar to Monte Carlo predictions

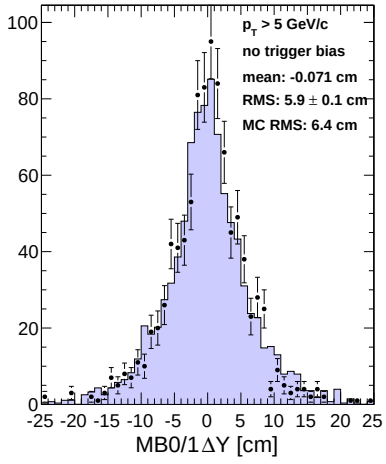
- How do the observed biases compare with what we see from GlobalMuon cosmic rays?

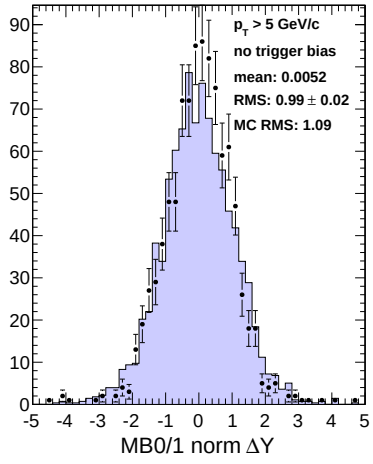
  (Since my talk is after Pablo's, I suppose we would know the answer by now. . .)

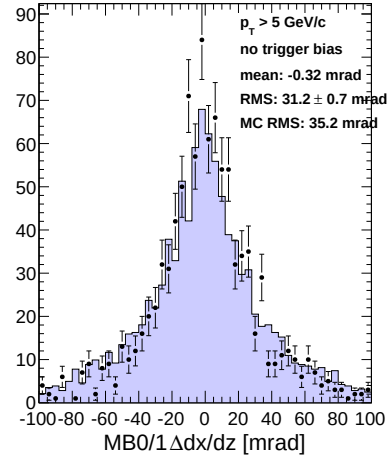
MB0/1

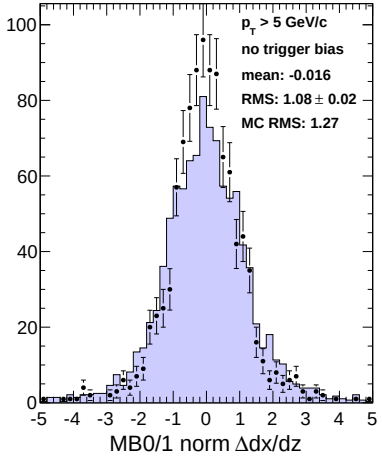

p_T > 5 GeV/c
no trigger bias
mean: -0.052 cm
RMS: 6.4 ± 0.1 cm
MC RMS: 6.9 cm
MB0/1 ΔX [cm]

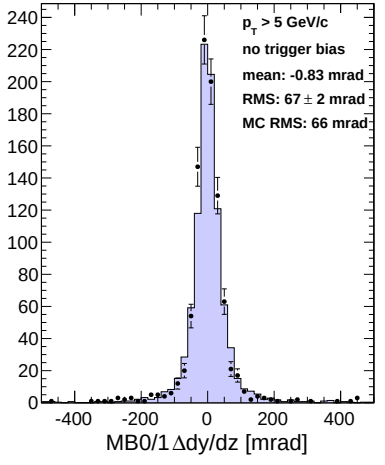

p_T > 5 GeV/c
no trigger bias
mean: -0.014
RMS: 0.99 ± 0.02
MC RMS: 1.14
MB0/1 norm ΔX

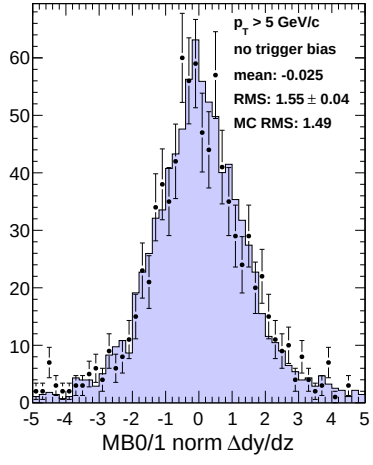

p_T > 5 GeV/c
no trigger bias
mean: -0.071 cm
RMS: 5.9 ± 0.1 cm
MC RMS: 6.4 cm
MB0/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.0052
RMS: 0.99 ± 0.02
MC RMS: 1.09
MB0/1 norm ΔY

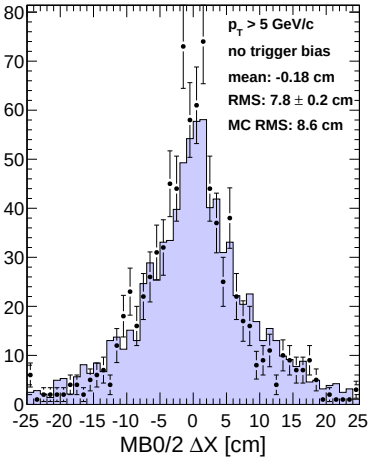

p_T > 5 GeV/c
no trigger bias
mean: -0.32 mrad
RMS: 31.2 ± 0.7 mrad
MC RMS: 35.2 mrad
MB0/1 Δdx/dz [mrad]

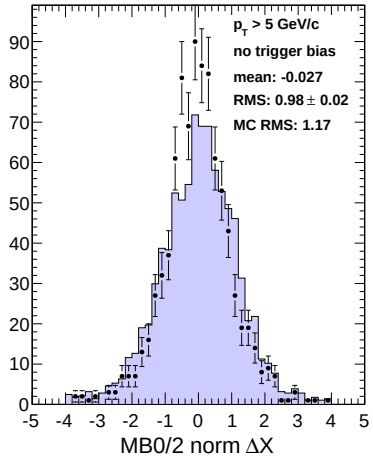

p_T > 5 GeV/c
no trigger bias
mean: -0.016
RMS: 1.08 ± 0.02
MC RMS: 1.27
MB0/1 norm Δdx/dz

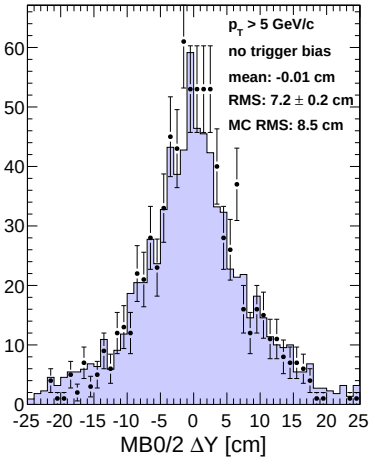

p_T > 5 GeV/c
no trigger bias
mean: -0.83 mrad
RMS: 67 ± 2 mrad
MC RMS: 66 mrad
MB0/1 Δdy/dz [mrad]

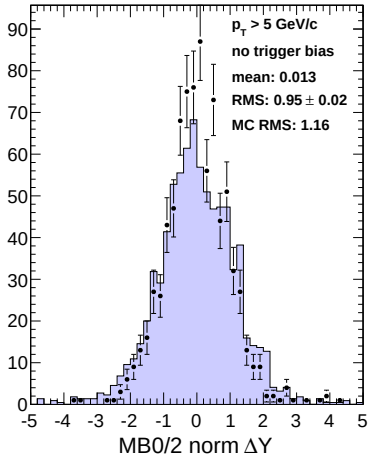

p_T > 5 GeV/c
no trigger bias
mean: -0.025
RMS: 1.55 ± 0.04
MC RMS: 1.49
MB0/1 norm Δdy/dz

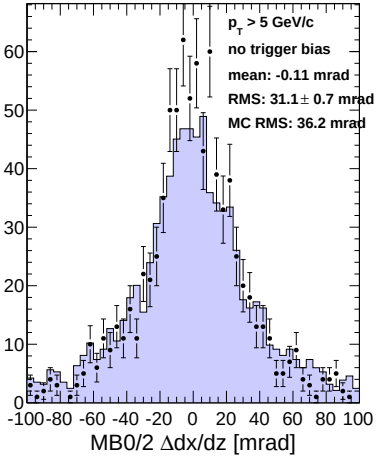
MB0/2

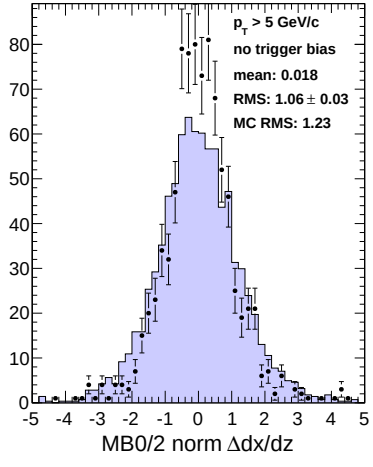

p_T > 5 GeV/c
no trigger bias
mean: -0.18 cm
RMS: 7.8 ± 0.2 cm
MC RMS: 8.6 cm
MB0/2 ΔX [cm]

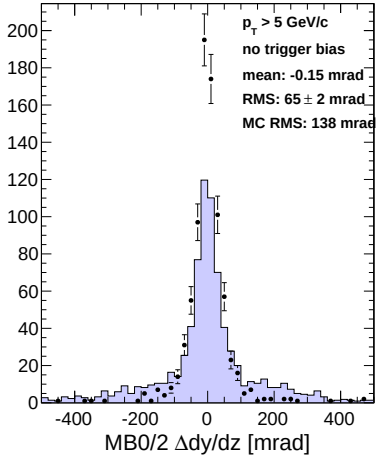

p_T > 5 GeV/c
no trigger bias
mean: -0.027
RMS: 0.98 ± 0.02
MC RMS: 1.17
MB0/2 norm ΔX

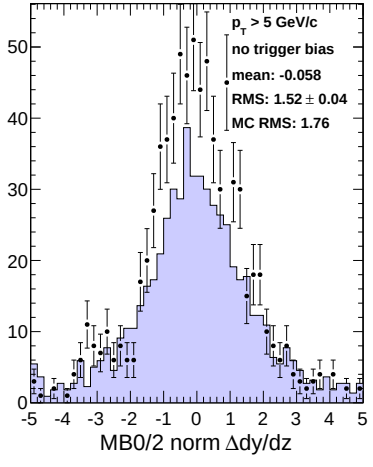

p_T > 5 GeV/c
no trigger bias
mean: -0.01 cm
RMS: 7.2 ± 0.2 cm
MC RMS: 8.5 cm
MB0/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.013
RMS: 0.95 ± 0.02
MC RMS: 1.16
MB0/2 norm ΔY

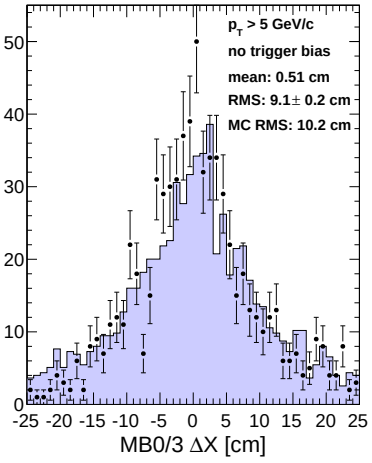

p_T > 5 GeV/c
no trigger bias
mean: -0.11 mrad
RMS: 31.1 ± 0.7 mrad
MC RMS: 36.2 mrad
MB0/2 Δdx/dz [mrad]

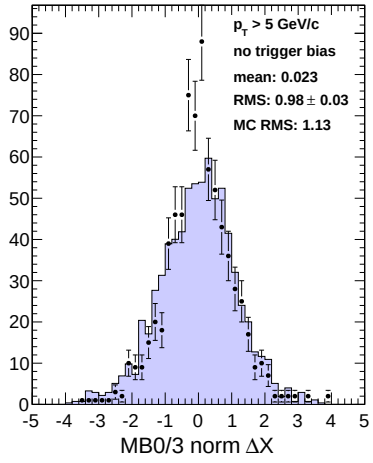

p_T > 5 GeV/c
no trigger bias
mean: 0.018
RMS: 1.06 ± 0.03
MC RMS: 1.23
MB0/2 norm Δdx/dz

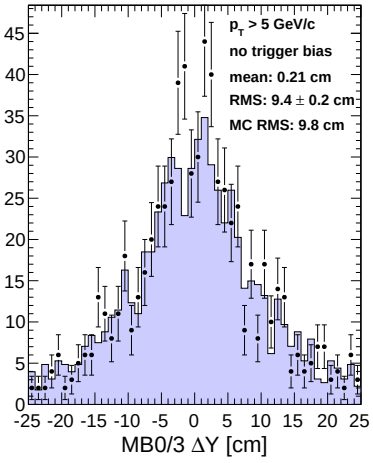

p_T > 5 GeV/c
no trigger bias
mean: -0.15 mrad
RMS: 65 ± 2 mrad
MC RMS: 138 mrad
MB0/2 Δdy/dz [mrad]

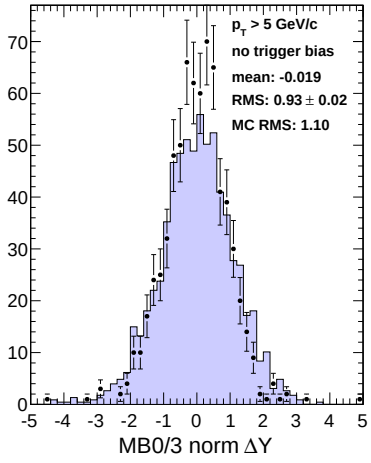

p_T > 5 GeV/c
no trigger bias
mean: -0.058
RMS: 1.52 ± 0.04
MC RMS: 1.76
MB0/2 norm Δdy/dz

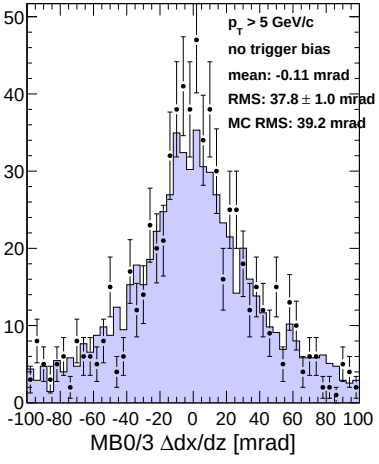
MB0/3

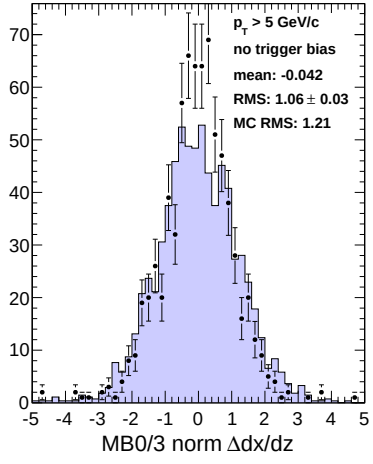

p_T > 5 GeV/c
no trigger bias
mean: 0.51 cm
RMS: 9.1 ± 0.2 cm
MC RMS: 10.2 cm
MB0/3 ΔX [cm]

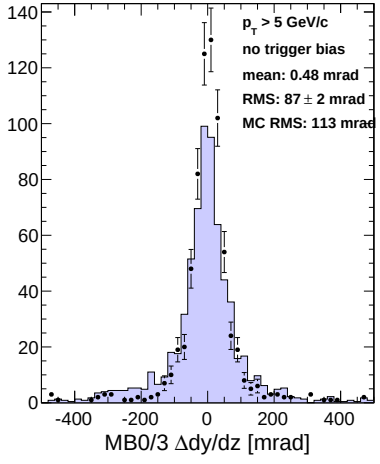

p_T > 5 GeV/c
no trigger bias
mean: 0.023
RMS: 0.98 ± 0.03
MC RMS: 1.13
MB0/3 norm ΔX

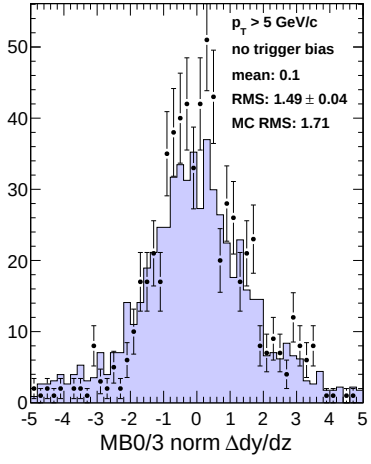

p_T > 5 GeV/c
no trigger bias
mean: 0.21 cm
RMS: 9.4 ± 0.2 cm
MC RMS: 9.8 cm
MB0/3 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.019
RMS: 0.93 ± 0.02
MC RMS: 1.10
MB0/3 norm ΔY

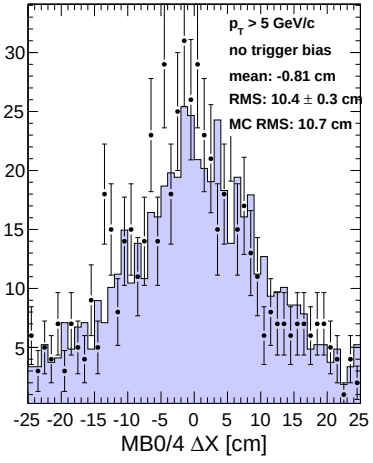

p_T > 5 GeV/c
no trigger bias
mean: -0.11 mrad
RMS: 37.8 ± 1.0 mrad
MC RMS: 39.2 mrad
MB0/3 Δdx/dz [mrad]

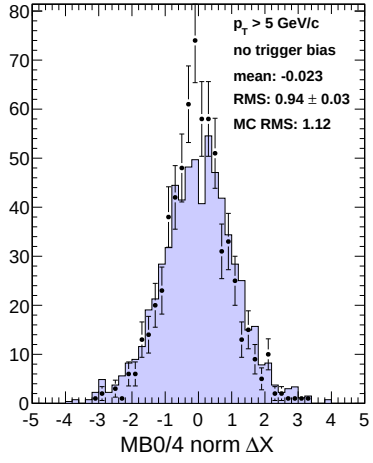

p_T > 5 GeV/c
no trigger bias
mean: -0.042
RMS: 1.06 ± 0.03
MC RMS: 1.21
MB0/3 norm Δdx/dz

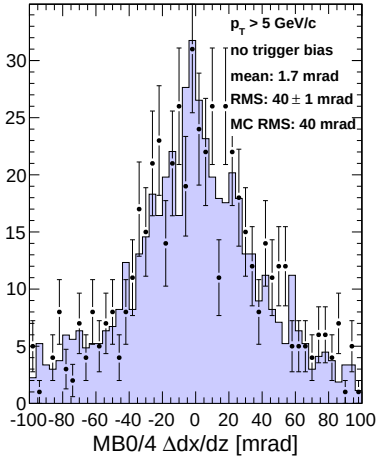

p_T > 5 GeV/c
no trigger bias
mean: 0.48 mrad
RMS: 87 ± 2 mrad
MC RMS: 113 mrad
MB0/3 Δdy/dz [mrad]

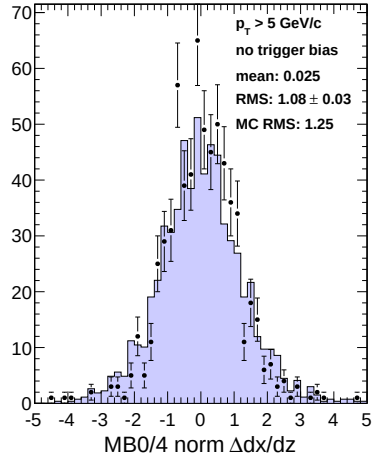

p_T > 5 GeV/c
no trigger bias
mean: 0.1
RMS: 1.49 ± 0.04
MC RMS: 1.71
MB0/3 norm Δdy/dz

MB0/4

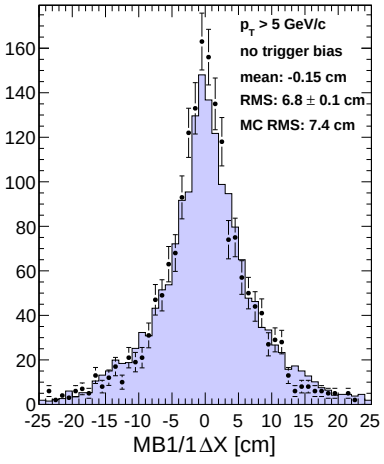

p_T > 5 GeV/c
no trigger bias
mean: -0.81 cm
RMS: 10.4 ± 0.3 cm
MC RMS: 10.7 cm
MB0/4 ΔX [cm]

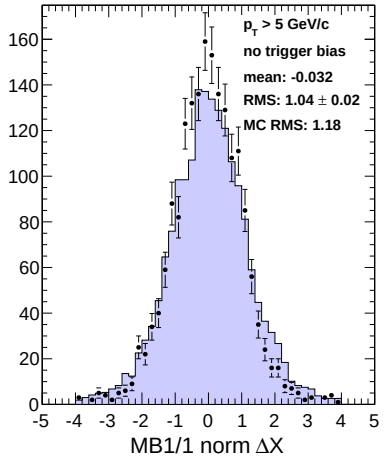

p_T > 5 GeV/c
no trigger bias
mean: -0.023
RMS: 0.94 ± 0.03
MC RMS: 1.12
MB0/4 norm ΔX

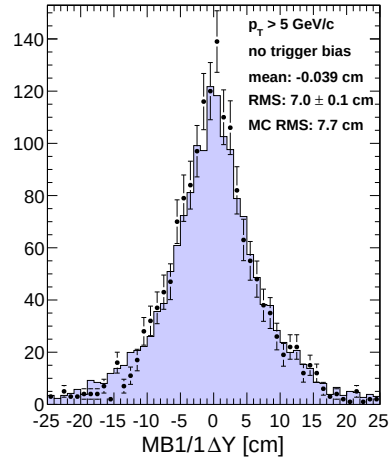

p_T > 5 GeV/c
no trigger bias
mean: 1.7 mrad
RMS: 40 ± 1 mrad
MC RMS: 40 mrad
MB0/4 Δdx/dz [mrad]

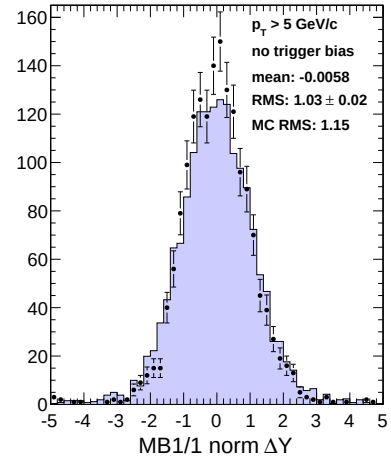

p_T > 5 GeV/c
no trigger bias
mean: 0.025
RMS: 1.08 ± 0.03
MC RMS: 1.25
MB0/4 norm Δdx/dz

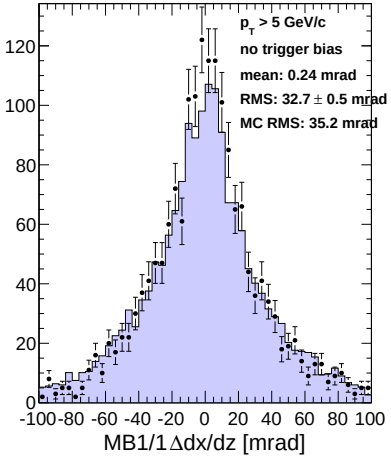
MB1/1

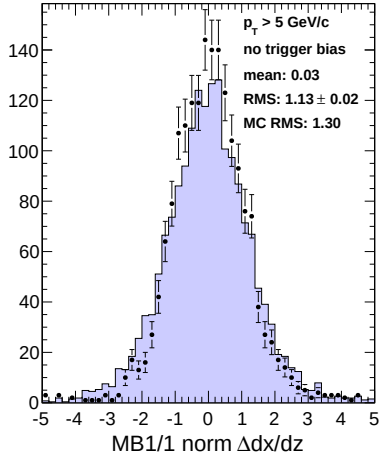

p_T > 5 GeV/c
no trigger bias
mean: -0.15 cm
RMS: 6.8 ± 0.1 cm
MC RMS: 7.4 cm
MB1/1 ΔX [cm]

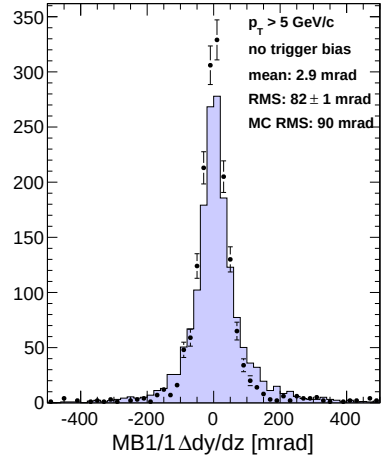

p_T > 5 GeV/c
no trigger bias
mean: -0.032
RMS: 1.04 ± 0.02
MC RMS: 1.18
MB1/1 norm ΔX

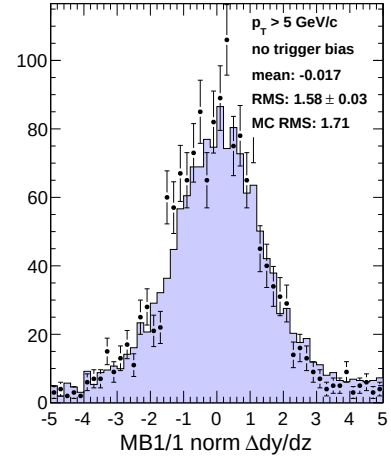

p_T > 5 GeV/c
no trigger bias
mean: -0.039 cm
RMS: 7.0 ± 0.1 cm
MC RMS: 7.7 cm
MB1/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.0058
RMS: 1.03 ± 0.02
MC RMS: 1.15
MB1/1 norm ΔY

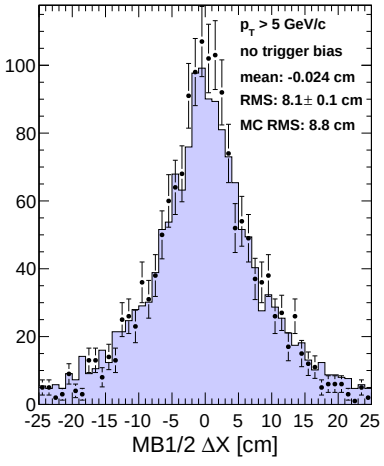

p_T > 5 GeV/c
no trigger bias
mean: 0.24 mrad
RMS: 32.7 ± 0.5 mrad
MC RMS: 35.2 mrad
MB1/1 Δdx/dz [mrad]

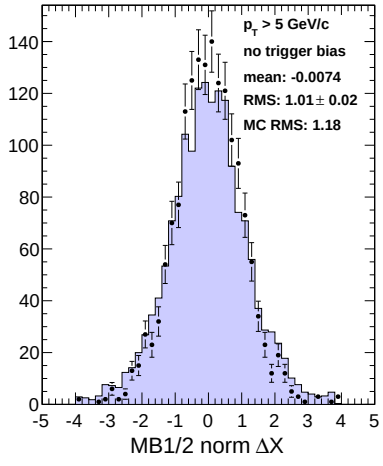

p_T > 5 GeV/c
no trigger bias
mean: 0.03
RMS: 1.13 ± 0.02
MC RMS: 1.30
MB1/1 norm Δdx/dz

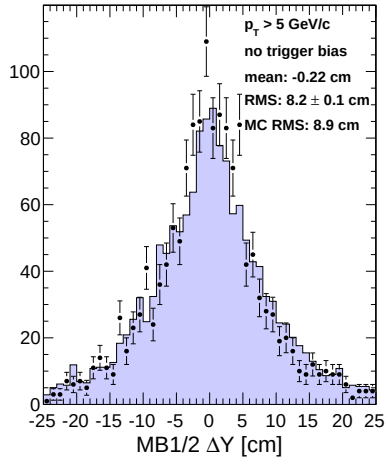

p_T > 5 GeV/c
no trigger bias
mean: 2.9 mrad
RMS: 82 ± 1 mrad
MC RMS: 90 mrad
MB1/1 Δdy/dz [mrad]

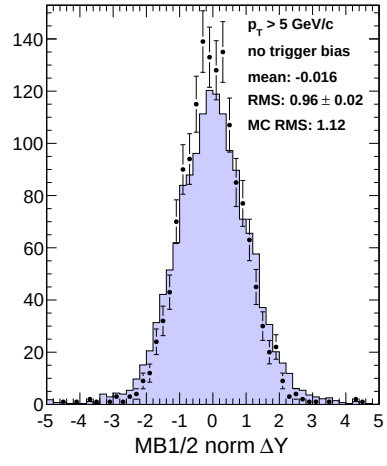

p_T > 5 GeV/c
no trigger bias
mean: -0.017
RMS: 1.58 ± 0.03
MC RMS: 1.71
MB1/1 norm Δdy/dz

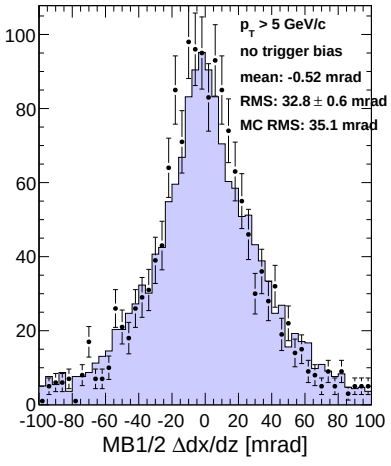
MB1/2

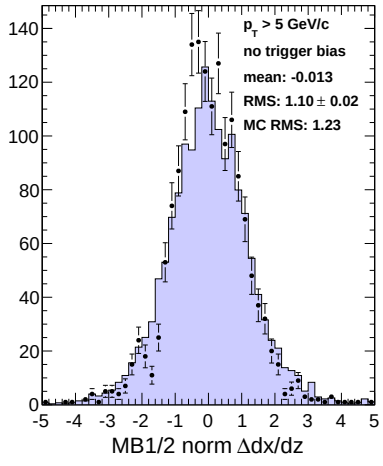

p_T > 5 GeV/c
no trigger bias
mean: -0.024 cm
RMS: 8.1 ± 0.1 cm
MC RMS: 8.8 cm
MB1/2 ΔX [cm]

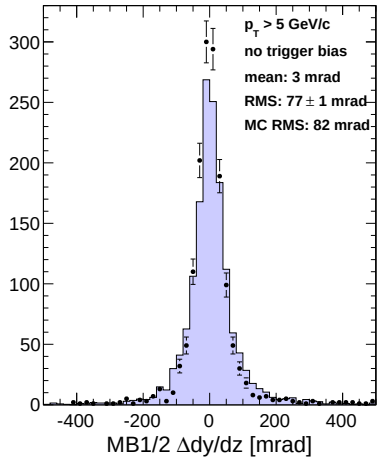

p_T > 5 GeV/c
no trigger bias
mean: -0.0074
RMS: 1.01 ± 0.02
MC RMS: 1.18
MB1/2 norm ΔX

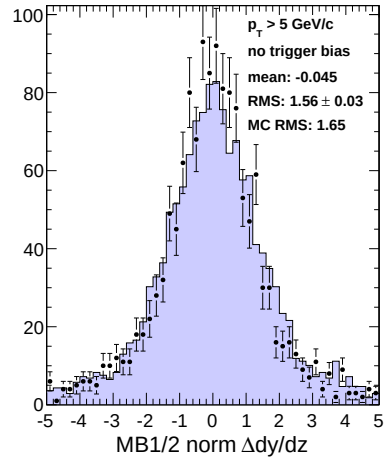

p_T > 5 GeV/c
no trigger bias
mean: -0.22 cm
RMS: 8.2 ± 0.1 cm
MC RMS: 8.9 cm
MB1/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.016
RMS: 0.96 ± 0.02
MC RMS: 1.12
MB1/2 norm ΔY

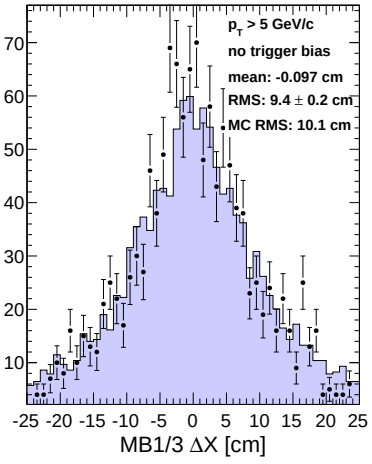

p_T > 5 GeV/c
no trigger bias
mean: -0.52 mrad
RMS: 32.8 ± 0.6 mrad
MC RMS: 35.1 mrad
MB1/2 Δdx/dz [mrad]

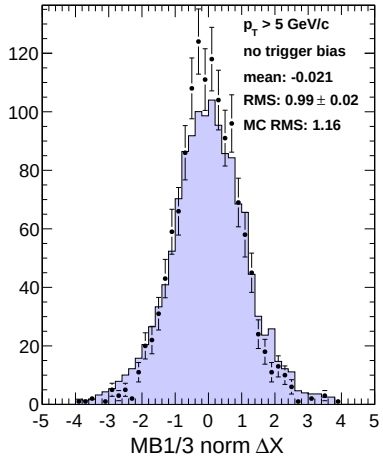

p_T > 5 GeV/c
no trigger bias
mean: -0.013
RMS: 1.10 ± 0.02
MC RMS: 1.23
MB1/2 norm Δdx/dz

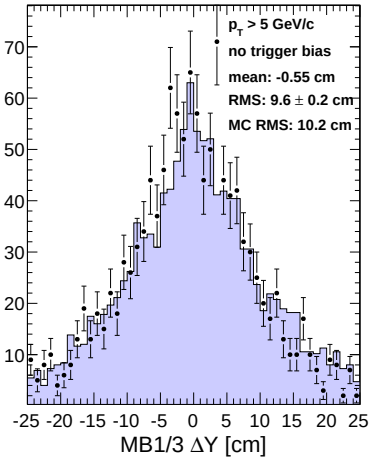

p_T > 5 GeV/c
no trigger bias
mean: 3 mrad
RMS: 77 ± 1 mrad
MC RMS: 82 mrad
MB1/2 Δdy/dz [mrad]

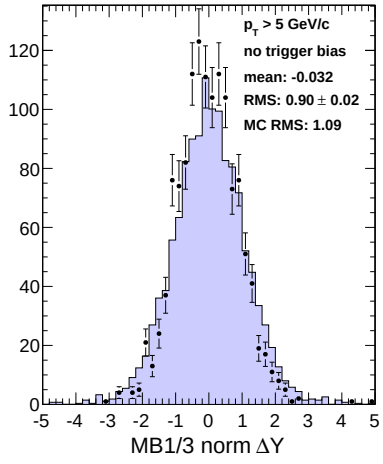

p_T > 5 GeV/c
no trigger bias
mean: -0.045
RMS: 1.56 ± 0.03
MC RMS: 1.65
MB1/2 norm Δdy/dz

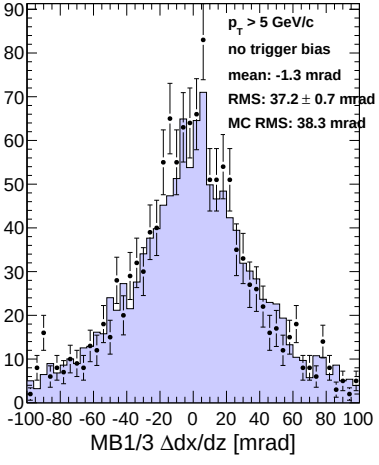
MB1/3

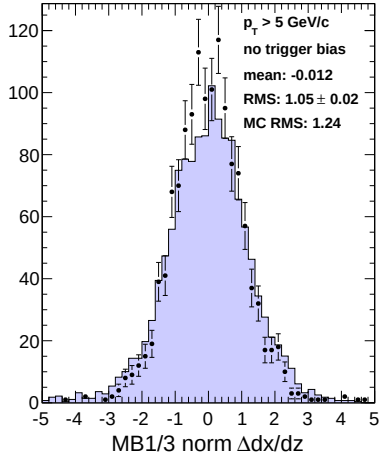

p_T > 5 GeV/c
no trigger bias
mean: -0.097 cm
RMS: 9.4 ± 0.2 cm
MC RMS: 10.1 cm
MB1/3 ΔX [cm]

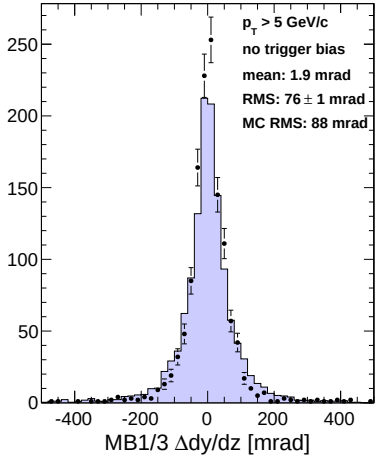

p_T > 5 GeV/c
no trigger bias
mean: -0.021
RMS: 0.99 ± 0.02
MC RMS: 1.16
MB1/3 norm ΔX

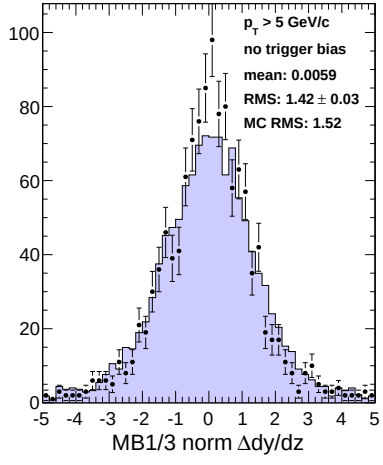

p_T > 5 GeV/c
no trigger bias
mean: -0.55 cm
RMS: 9.6 ± 0.2 cm
MC RMS: 10.2 cm
MB1/3 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.032
RMS: 0.90 ± 0.02
MC RMS: 1.09
MB1/3 norm ΔY

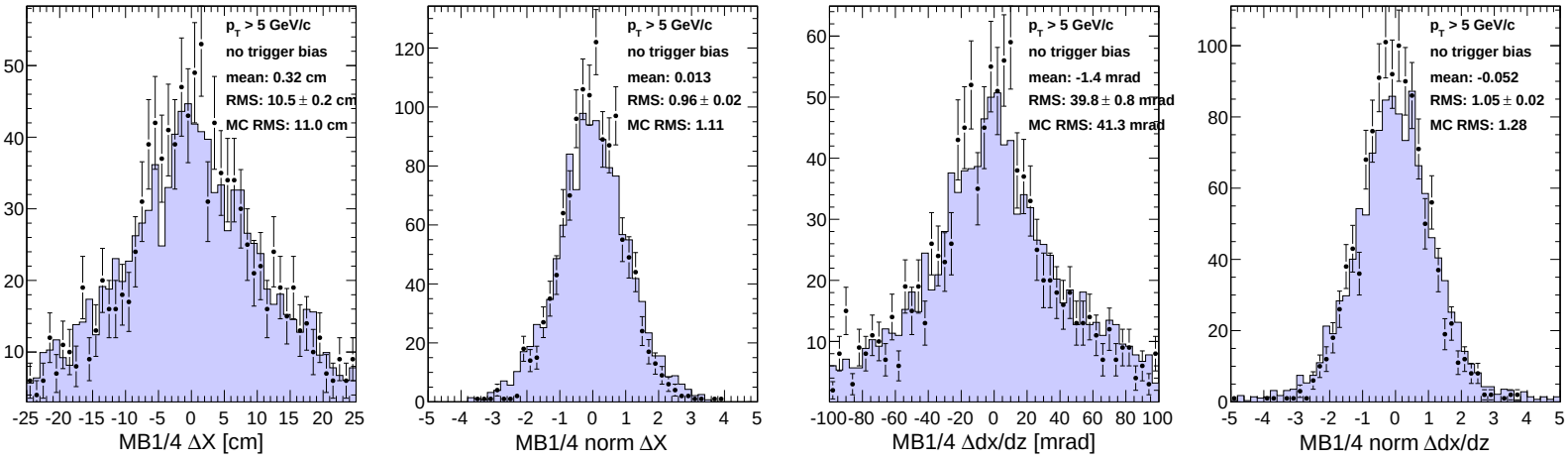

p_T > 5 GeV/c
no trigger bias
mean: -1.3 mrad
RMS: 37.2 ± 0.7 mrad
MC RMS: 38.3 mrad
MB1/3 Δdx/dz [mrad]


p_T > 5 GeV/c
no trigger bias
mean: -0.012
RMS: 1.05 ± 0.02
MC RMS: 1.24
MB1/3 norm Δdx/dz

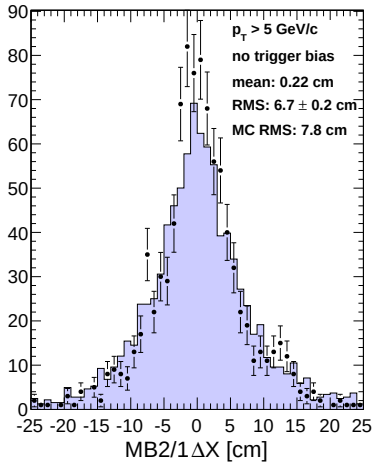

p_T > 5 GeV/c
no trigger bias
mean: 1.9 mrad
RMS: 76 ± 1 mrad
MC RMS: 88 mrad
MB1/3 Δdy/dz [mrad]

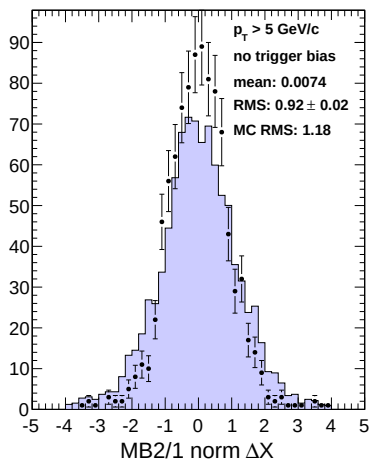

p_T > 5 GeV/c
no trigger bias
mean: 0.0059
RMS: 1.42 ± 0.03
MC RMS: 1.52
MB1/3 norm Δdy/dz

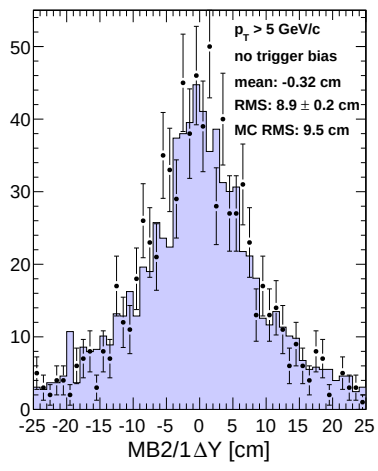
MB1/4

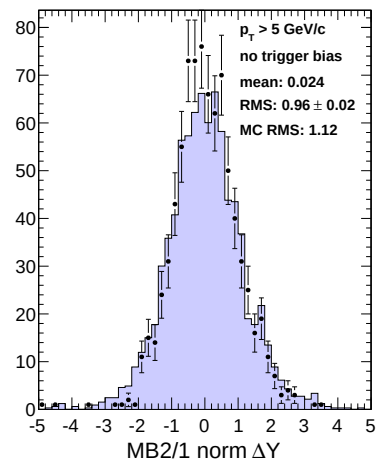

p_T > 5 GeV/c
no trigger bias
mean: 0.32 cm
RMS: 10.5 ± 0.2 cm
MC RMS: 11.0 cm
MB1/4 ΔX [cm]
p_T > 5 GeV/c
no trigger bias
mean: 0.013
RMS: 0.96 ± 0.02
MC RMS: 1.11
MB1/4 norm ΔX
p_T > 5 GeV/c
no trigger bias
mean: -1.4 mrad
RMS: 39.8 ± 0.8 mrad
MC RMS: 41.3 mrad
MB1/4 Δdx/dz [mrad]
p_T > 5 GeV/c
no trigger bias
mean: -0.052
RMS: 1.05 ± 0.02
MC RMS: 1.28
MB1/4 norm Δdx/dz

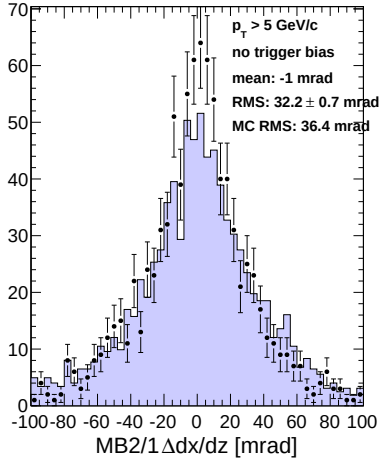
MB2/1

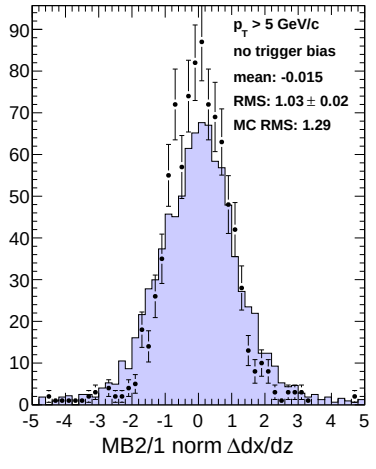

p_T > 5 GeV/c
no trigger bias
mean: 0.22 cm
RMS: 6.7 ± 0.2 cm
MC RMS: 7.8 cm
MB2/1 ΔX [cm]

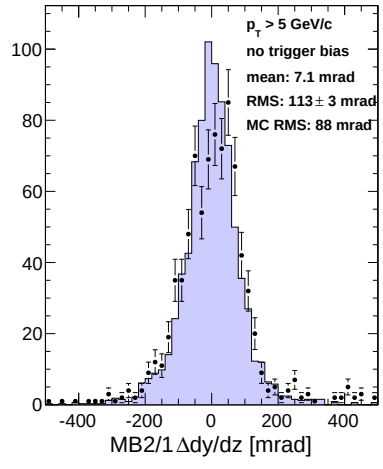

p_T > 5 GeV/c
no trigger bias
mean: 0.0074
RMS: 0.92 ± 0.02
MC RMS: 1.18
MB2/1 norm ΔX

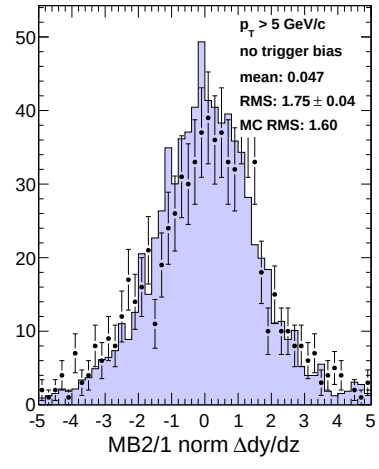

p_T > 5 GeV/c
no trigger bias
mean: -0.32 cm
RMS: 8.9 ± 0.2 cm
MC RMS: 9.5 cm
MB2/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.024
RMS: 0.96 ± 0.02
MC RMS: 1.12
MB2/1 norm ΔY

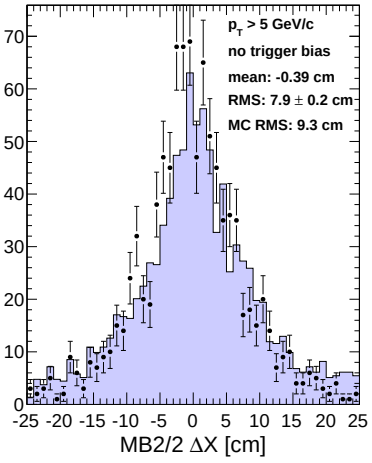

p_T > 5 GeV/c
no trigger bias
mean: -1 mrad
RMS: 32.2 ± 0.7 mrad
MC RMS: 36.4 mrad
MB2/1 Δdx/dz [mrad]

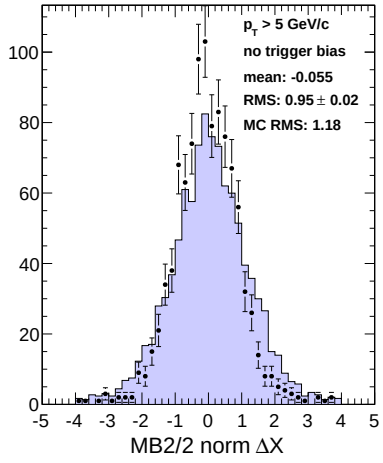

p_T > 5 GeV/c
no trigger bias
mean: -0.015
RMS: 1.03 ± 0.02
MC RMS: 1.29
MB2/1 norm Δdx/dz

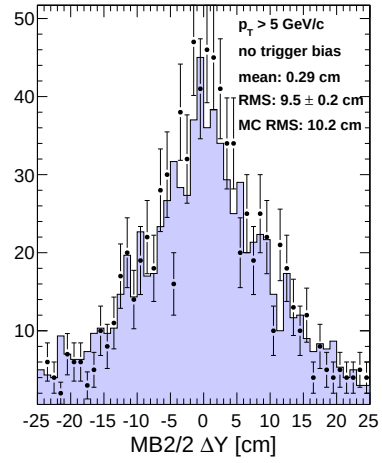

p_T > 5 GeV/c
no trigger bias
mean: 7.1 mrad
RMS: 113 ± 3 mrad
MC RMS: 88 mrad
MB2/1 Δdy/dz [mrad]

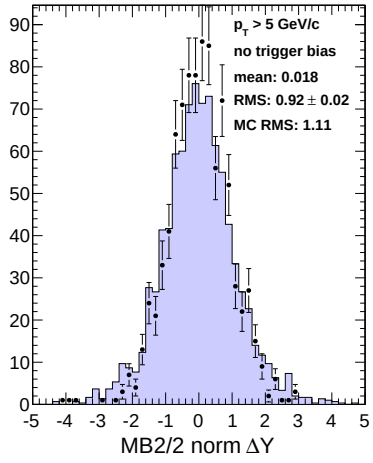

p_T > 5 GeV/c
no trigger bias
mean: 0.047
RMS: 1.75 ± 0.04
MC RMS: 1.60
MB2/1 norm Δdy/dz

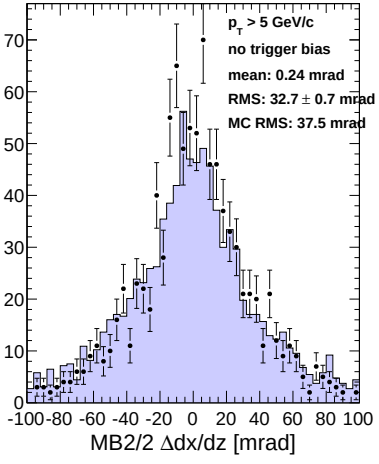
MB2/2

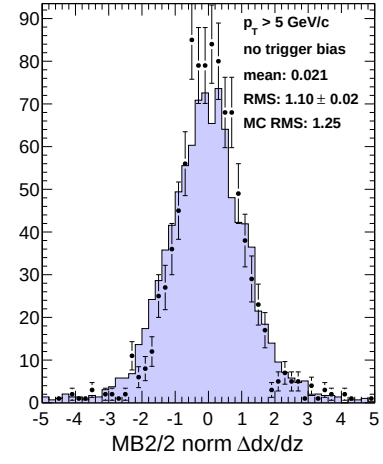

p_T > 5 GeV/c
no trigger bias
mean: -0.39 cm
RMS: 7.9 ± 0.2 cm
MC RMS: 9.3 cm
MB2/2 ΔX [cm]

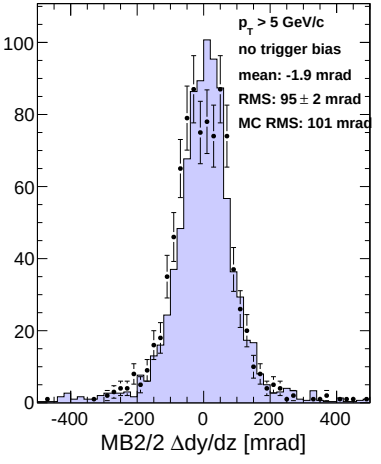

p_T > 5 GeV/c
no trigger bias
mean: -0.055
RMS: 0.95 ± 0.02
MC RMS: 1.18
MB2/2 norm ΔX

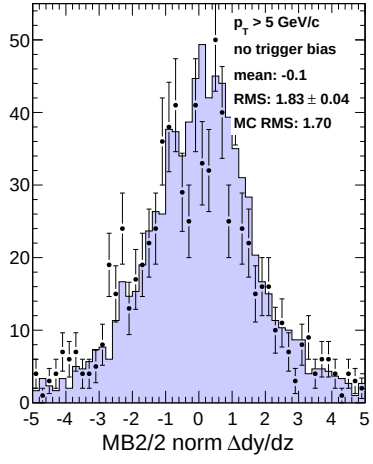

p_T > 5 GeV/c
no trigger bias
mean: 0.29 cm
RMS: 9.5 ± 0.2 cm
MC RMS: 10.2 cm
MB2/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.018
RMS: 0.92 ± 0.02
MC RMS: 1.11
MB2/2 norm ΔY

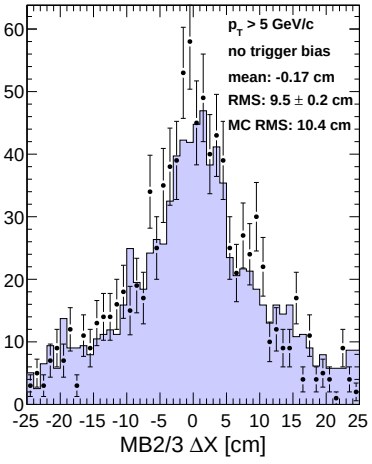

p_T > 5 GeV/c
no trigger bias
mean: 0.24 mrad
RMS: 32.7 ± 0.7 mrad
MC RMS: 37.5 mrad
MB2/2 Δdx/dz [mrad]

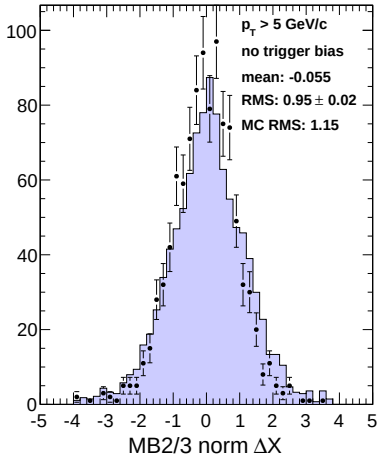

p_T > 5 GeV/c
no trigger bias
mean: 0.021
RMS: 1.10 ± 0.02
MC RMS: 1.25
MB2/2 norm Δdx/dz

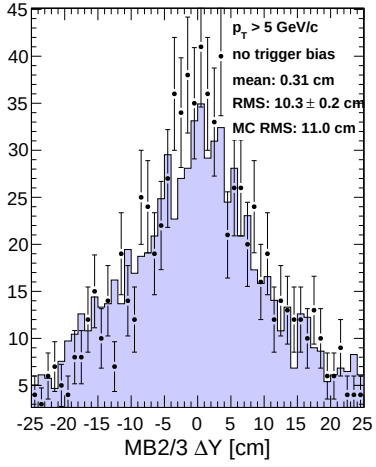

p_T > 5 GeV/c
no trigger bias
mean: -1.9 mrad
RMS: 95 ± 2 mrad
MC RMS: 101 mrad
MB2/2 Δdy/dz [mrad]

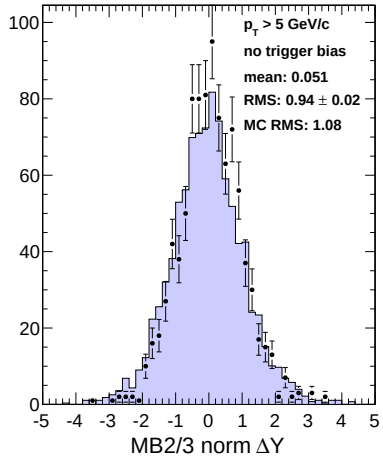

p_T > 5 GeV/c
no trigger bias
mean: -0.1
RMS: 1.83 ± 0.04
MC RMS: 1.70
MB2/2 norm Δdy/dz

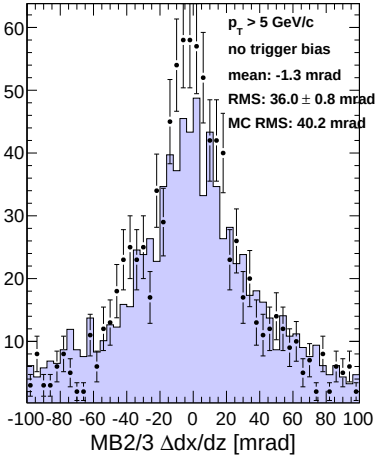
MB2/3

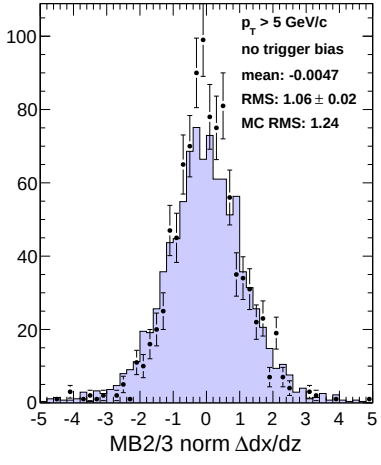

p_T > 5 GeV/c
no trigger bias
mean: -0.17 cm
RMS: 9.5 ± 0.2 cm
MC RMS: 10.4 cm
MB2/3 ΔX [cm]

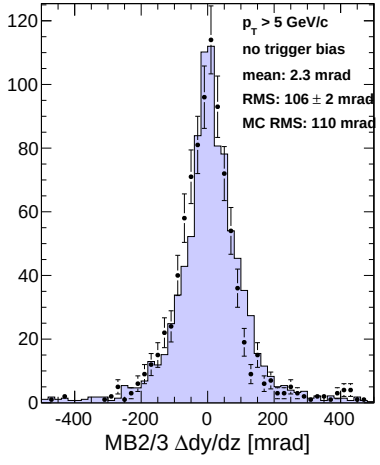

p_T > 5 GeV/c
no trigger bias
mean: -0.055
RMS: 0.95 ± 0.02
MC RMS: 1.15
MB2/3 norm ΔX

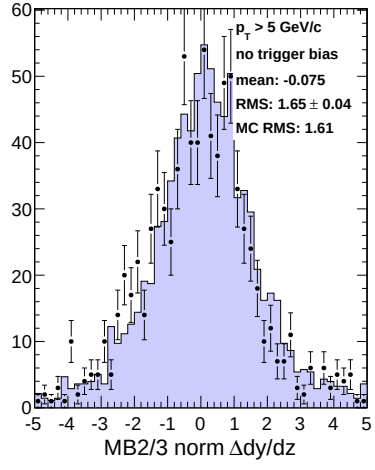

p_T > 5 GeV/c
no trigger bias
mean: 0.31 cm
RMS: 10.3 ± 0.2 cm
MC RMS: 11.0 cm
MB2/3 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.051
RMS: 0.94 ± 0.02
MC RMS: 1.08
MB2/3 norm ΔY

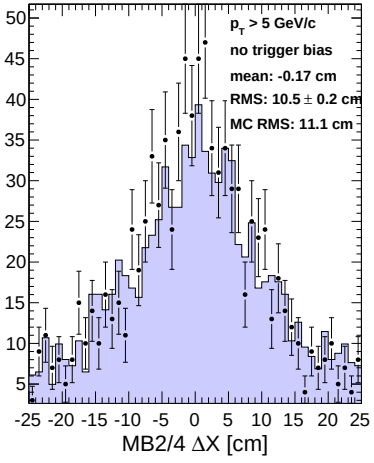

p_T > 5 GeV/c
no trigger bias
mean: -1.3 mrad
RMS: 36.0 ± 0.8 mrad
MC RMS: 40.2 mrad
MB2/3 Δdx/dz [mrad]

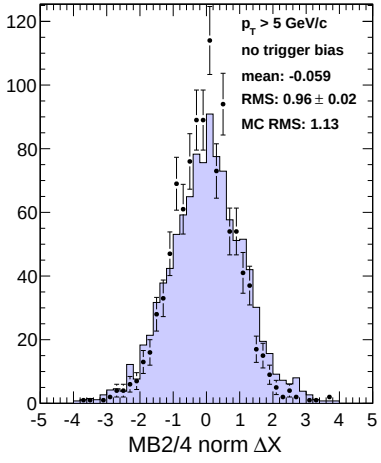

p_T > 5 GeV/c
no trigger bias
mean: -0.0047
RMS: 1.06 ± 0.02
MC RMS: 1.24
MB2/3 norm Δdx/dz

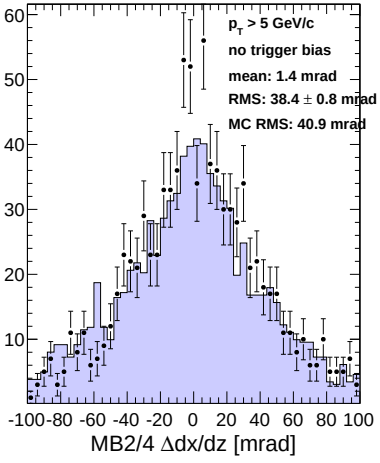

p_T > 5 GeV/c
no trigger bias
mean: 2.3 mrad
RMS: 106 ± 2 mrad
MC RMS: 110 mrad
MB2/3 Δdy/dz [mrad]

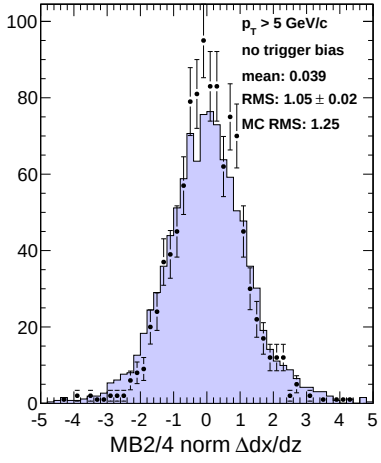

p_T > 5 GeV/c
no trigger bias
mean: -0.075
RMS: 1.65 ± 0.04
MC RMS: 1.61
MB2/3 norm Δdy/dz

MB2/4

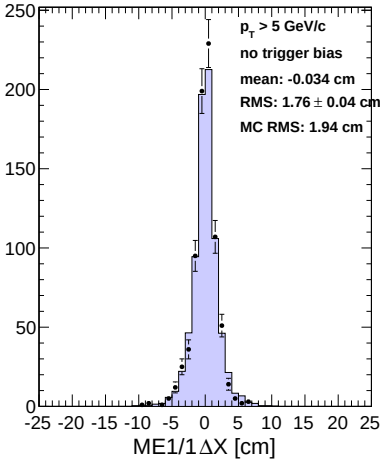

p_T > 5 GeV/c
no trigger bias
mean: -0.17 cm
RMS: 10.5 ± 0.2 cm
MC RMS: 11.1 cm
MB2/4 ΔX [cm]

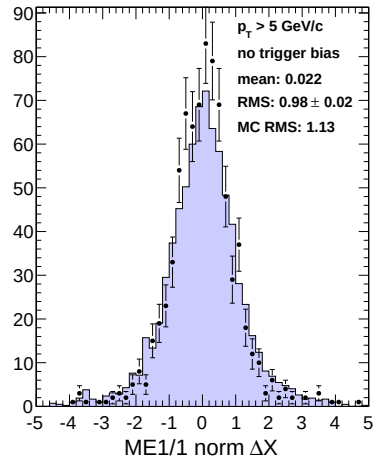

p_T > 5 GeV/c
no trigger bias
mean: -0.059
RMS: 0.96 ± 0.02
MC RMS: 1.13
MB2/4 norm ΔX

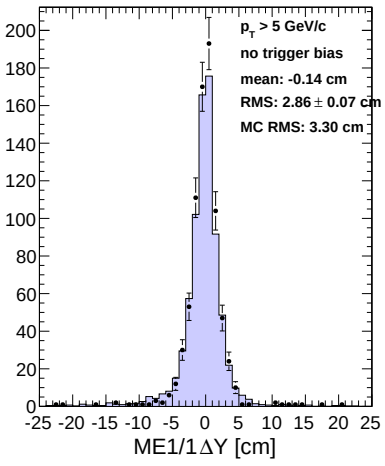

p_T > 5 GeV/c
no trigger bias
mean: 1.4 mrad
RMS: 38.4 ± 0.8 mrad
MC RMS: 40.9 mrad
MB2/4 Δdx/dz [mrad]

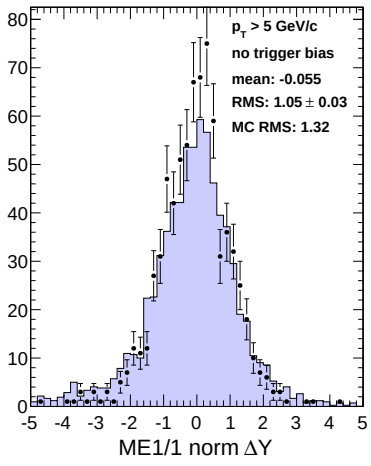

p_T > 5 GeV/c
no trigger bias
mean: 0.039
RMS: 1.05 ± 0.02
MC RMS: 1.25
MB2/4 norm Δdx/dz

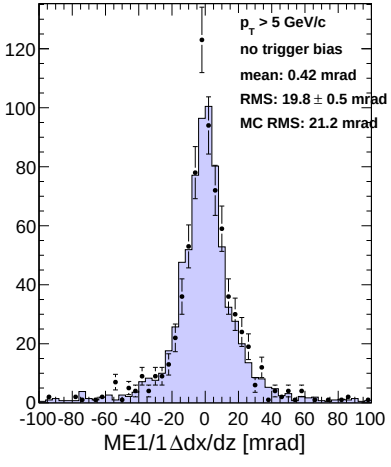
ME1/1

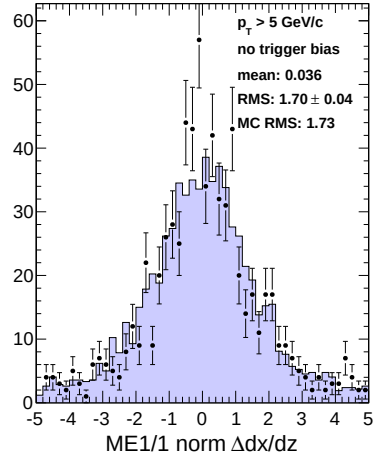

p_T > 5 GeV/c
no trigger bias
mean: -0.034 cm
RMS: 1.76 ± 0.04 cm
MC RMS: 1.94 cm
ME1/1 ΔX [cm]

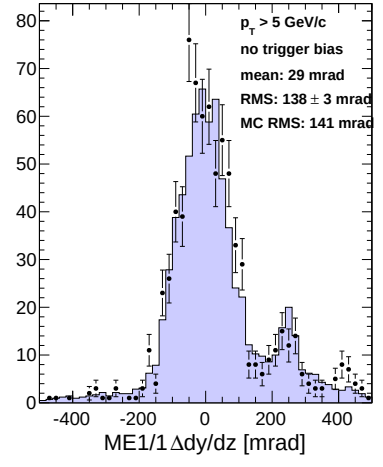

p_T > 5 GeV/c
no trigger bias
mean: 0.022
RMS: 0.98 ± 0.02
MC RMS: 1.13
ME1/1 norm ΔX

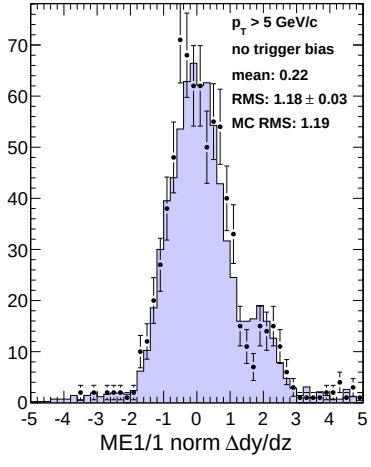

p_T > 5 GeV/c
no trigger bias
mean: -0.14 cm
RMS: 2.86 ± 0.07 cm
MC RMS: 3.30 cm
ME1/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.055
RMS: 1.05 ± 0.03
MC RMS: 1.32
ME1/1 norm ΔY

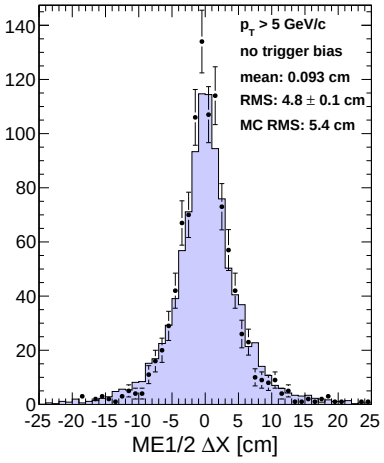

p_T > 5 GeV/c
no trigger bias
mean: 0.42 mrad
RMS: 19.8 ± 0.5 mrad
MC RMS: 21.2 mrad
ME1/1 Δdx/dz [mrad]

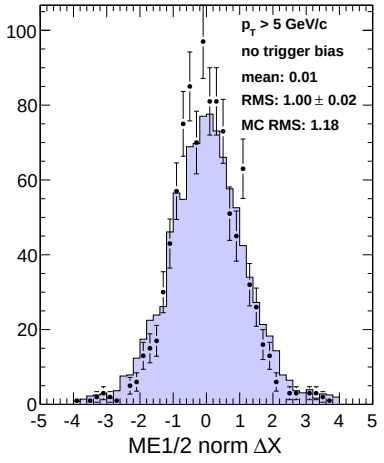

p_T > 5 GeV/c
no trigger bias
mean: 0.036
RMS: 1.70 ± 0.04
MC RMS: 1.73
ME1/1 norm Δdx/dz

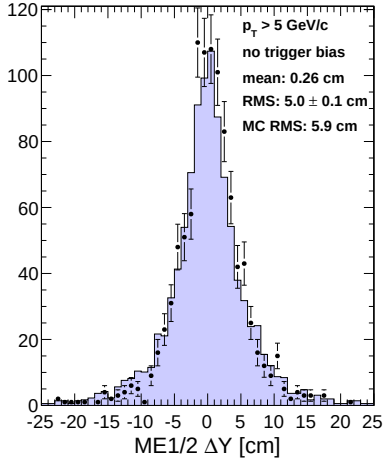

p_T > 5 GeV/c
no trigger bias
mean: 29 mrad
RMS: 138 ± 3 mrad
MC RMS: 141 mrad
ME1/1 Δdy/dz [mrad]

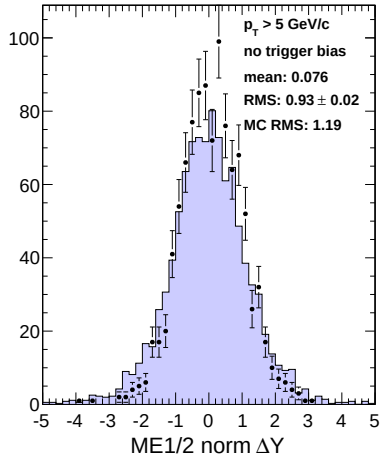

p_T > 5 GeV/c
no trigger bias
mean: 0.22
RMS: 1.18 ± 0.03
MC RMS: 1.19
ME1/1 norm Δdy/dz

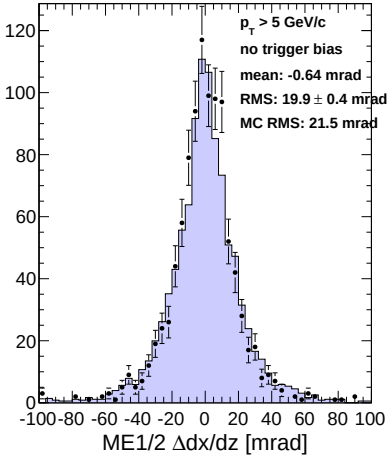
ME1/2

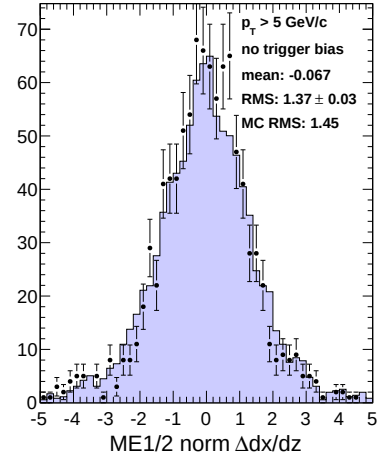

p_T > 5 GeV/c
no trigger bias
mean: 0.093 cm
RMS: 4.8 ± 0.1 cm
MC RMS: 5.4 cm
ME1/2 ΔX [cm]

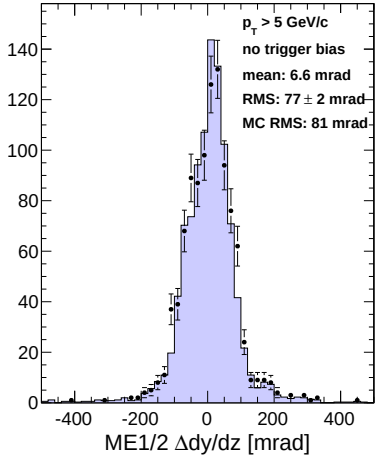

p_T > 5 GeV/c
no trigger bias
mean: 0.01
RMS: 1.00 ± 0.02
MC RMS: 1.18
ME1/2 norm ΔX

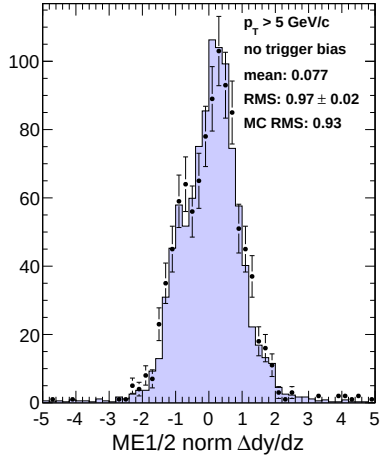

p_T > 5 GeV/c
no trigger bias
mean: 0.26 cm
RMS: 5.0 ± 0.1 cm
MC RMS: 5.9 cm
ME1/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.076
RMS: 0.93 ± 0.02
MC RMS: 1.19
ME1/2 norm ΔY

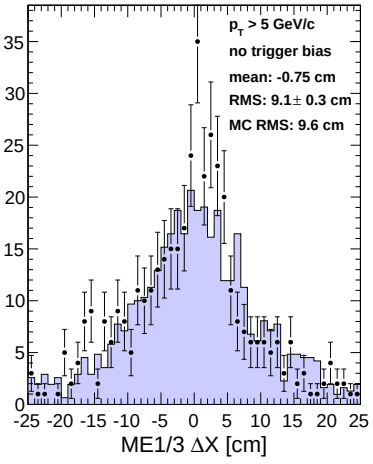

p_T > 5 GeV/c
no trigger bias
mean: -0.64 mrad
RMS: 19.9 ± 0.4 mrad
MC RMS: 21.5 mrad
ME1/2 Δdx/dz [mrad]

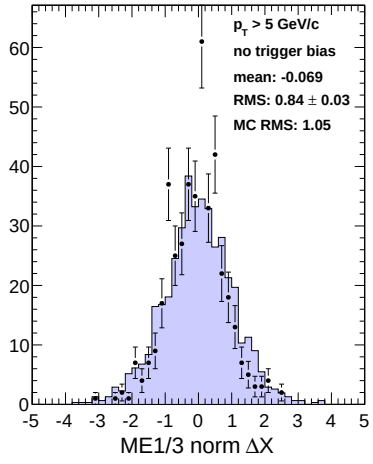

p_T > 5 GeV/c
no trigger bias
mean: -0.067
RMS: 1.37 ± 0.03
MC RMS: 1.45
ME1/2 norm Δdx/dz

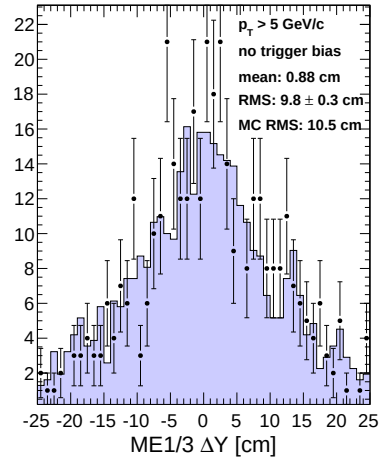

p_T > 5 GeV/c
no trigger bias
mean: 6.6 mrad
RMS: 77 ± 2 mrad
MC RMS: 81 mrad
ME1/2 Δdy/dz [mrad]

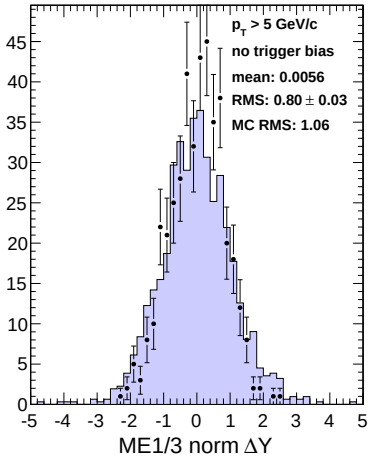

p_T > 5 GeV/c
no trigger bias
mean: 0.077
RMS: 0.97 ± 0.02
MC RMS: 0.93
ME1/2 norm Δdy/dz

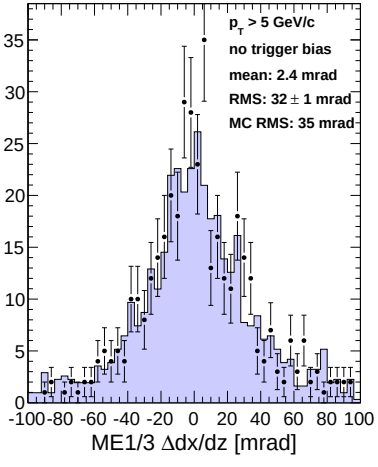
ME1/3

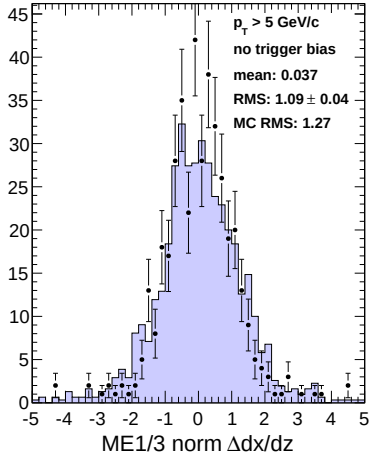

p_T > 5 GeV/c
no trigger bias
mean: -0.75 cm
RMS: 9.1 ± 0.3 cm
MC RMS: 9.6 cm
ME1/3 ΔX [cm]

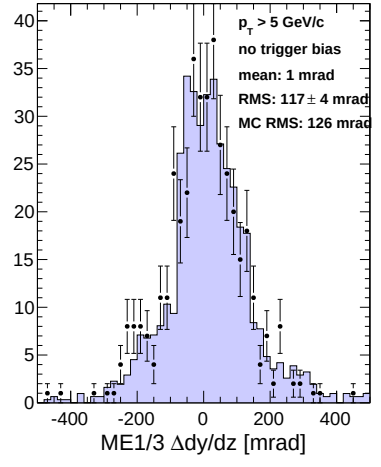

p_T > 5 GeV/c
no trigger bias
mean: -0.069
RMS: 0.84 ± 0.03
MC RMS: 1.05
ME1/3 norm ΔX

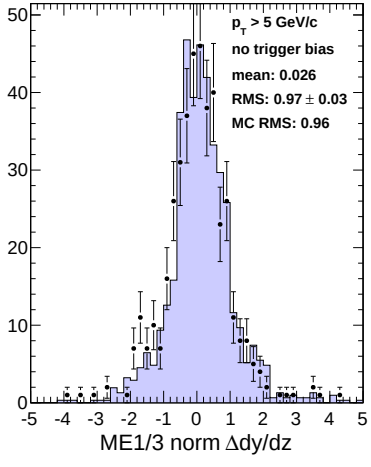

p_T > 5 GeV/c
no trigger bias
mean: 0.88 cm
RMS: 9.8 ± 0.3 cm
MC RMS: 10.5 cm
ME1/3 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.0056
RMS: 0.80 ± 0.03
MC RMS: 1.06
ME1/3 norm ΔY

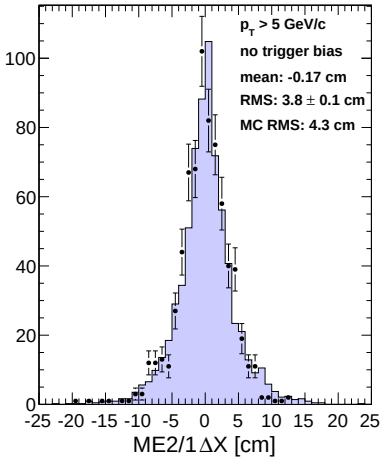

p_T > 5 GeV/c
no trigger bias
mean: 2.4 mrad
RMS: 32 ± 1 mrad
MC RMS: 35 mrad
ME1/3 Δdx/dz [mrad]

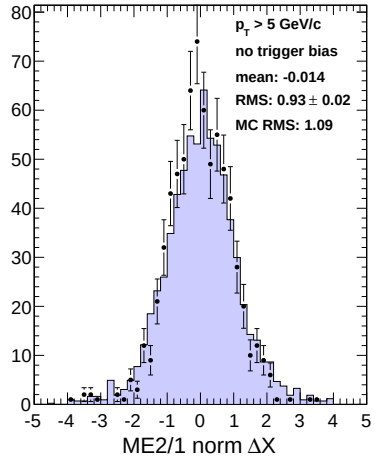

p_T > 5 GeV/c
no trigger bias
mean: 0.037
RMS: 1.09 ± 0.04
MC RMS: 1.27
ME1/3 norm Δdx/dz

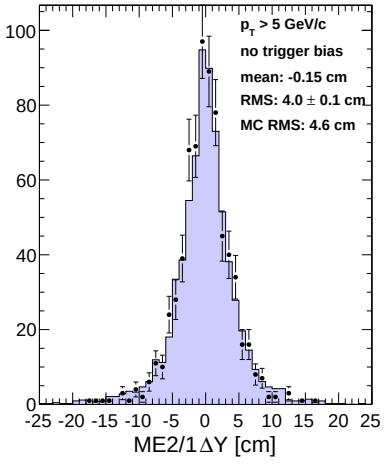

p_T > 5 GeV/c
no trigger bias
mean: 1 mrad
RMS: 117 ± 4 mrad
MC RMS: 126 mrad
ME1/3 Δdy/dz [mrad]

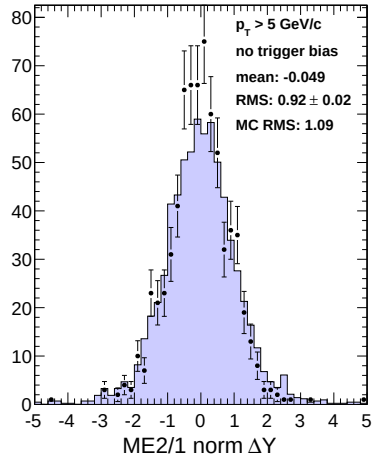

p_T > 5 GeV/c
no trigger bias
mean: 0.026
RMS: 0.97 ± 0.03
MC RMS: 0.96
ME1/3 norm Δdy/dz

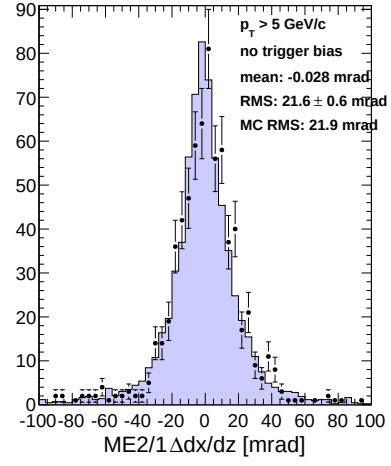
ME2/1

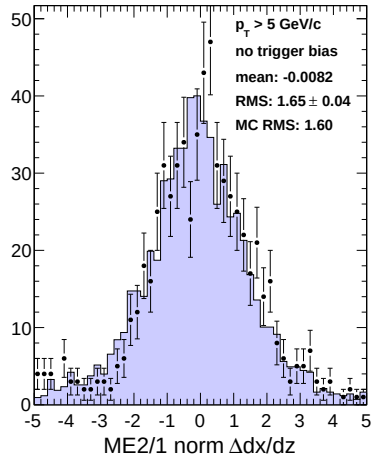

p_T > 5 GeV/c
no trigger bias
mean: -0.17 cm
RMS: 3.8 ± 0.1 cm
MC RMS: 4.3 cm
ME2/1 ΔX [cm]

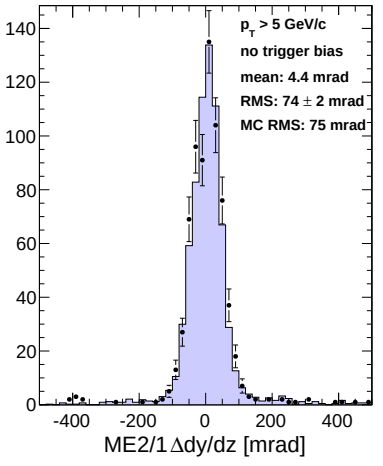

p_T > 5 GeV/c
no trigger bias
mean: -0.014
RMS: 0.93 ± 0.02
MC RMS: 1.09
ME2/1 norm ΔX

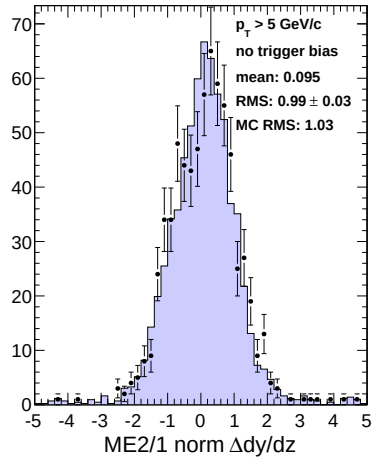

p_T > 5 GeV/c
no trigger bias
mean: -0.15 cm
RMS: 4.0 ± 0.1 cm
MC RMS: 4.6 cm
ME2/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.049
RMS: 0.92 ± 0.02
MC RMS: 1.09
ME2/1 norm ΔY

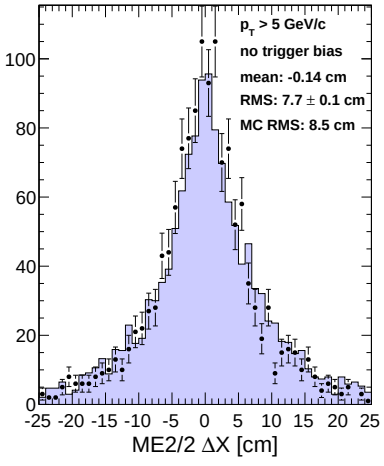

p_T > 5 GeV/c
no trigger bias
mean: -0.028 mrad
RMS: 21.6 ± 0.6 mrad
MC RMS: 21.9 mrad
ME2/1 Δdx/dz [mrad]

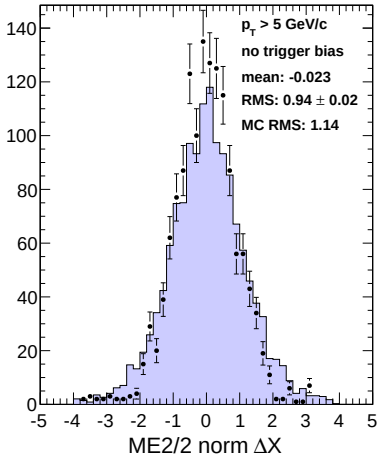

p_T > 5 GeV/c
no trigger bias
mean: -0.0082
RMS: 1.65 ± 0.04
MC RMS: 1.60
ME2/1 norm Δdx/dz

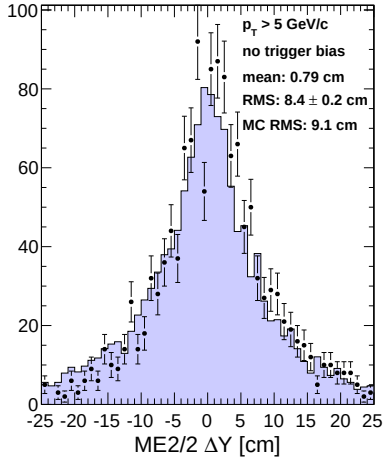

p_T > 5 GeV/c
no trigger bias
mean: 4.4 mrad
RMS: 74 ± 2 mrad
MC RMS: 75 mrad
ME2/1 Δdy/dz [mrad]

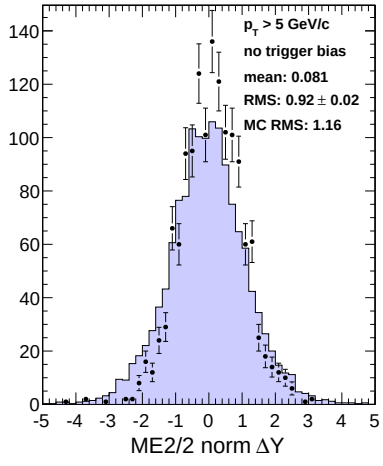

p_T > 5 GeV/c
no trigger bias
mean: 0.095
RMS: 0.99 ± 0.03
MC RMS: 1.03
ME2/1 norm Δdy/dz

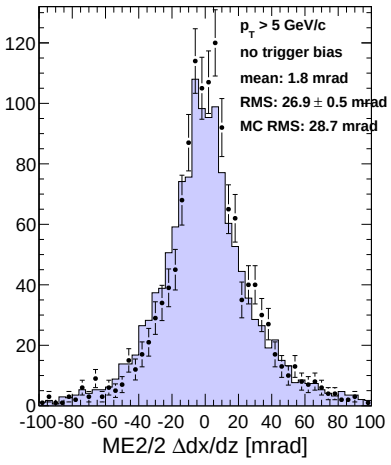
ME2/2

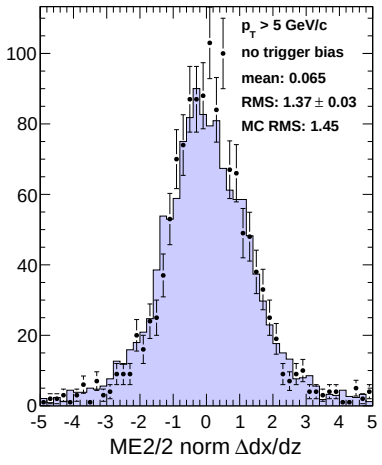

p_T > 5 GeV/c
no trigger bias
mean: -0.14 cm
RMS: 7.7 ± 0.1 cm
MC RMS: 8.5 cm
ME2/2 ΔX [cm]

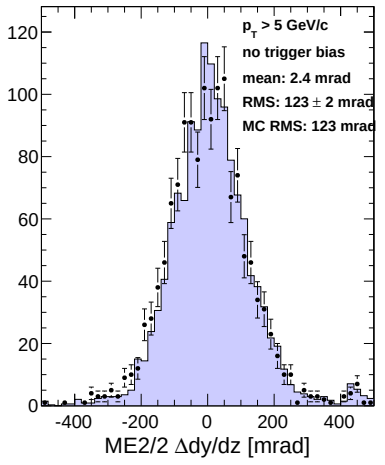

p_T > 5 GeV/c
no trigger bias
mean: -0.023
RMS: 0.94 ± 0.02
MC RMS: 1.14
ME2/2 norm ΔX

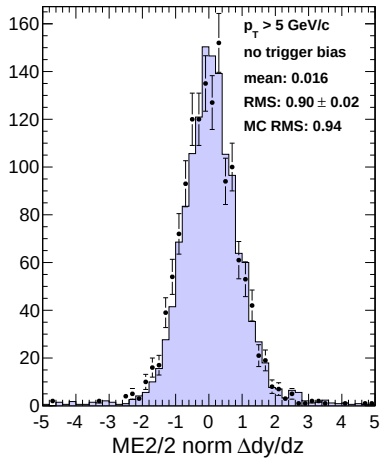

p_T > 5 GeV/c
no trigger bias
mean: 0.79 cm
RMS: 8.4 ± 0.2 cm
MC RMS: 9.1 cm
ME2/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.081
RMS: 0.92 ± 0.02
MC RMS: 1.16
ME2/2 norm ΔY

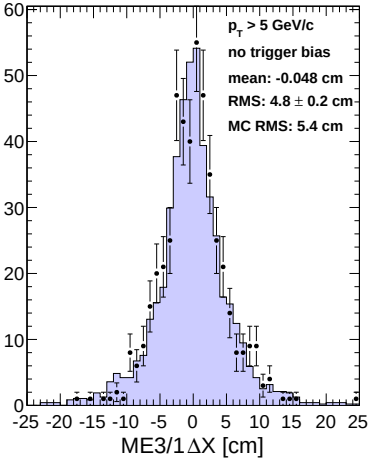

p_T > 5 GeV/c
no trigger bias
mean: 1.8 mrad
RMS: 26.9 ± 0.5 mrad
MC RMS: 28.7 mrad
ME2/2 Δdx/dz [mrad]

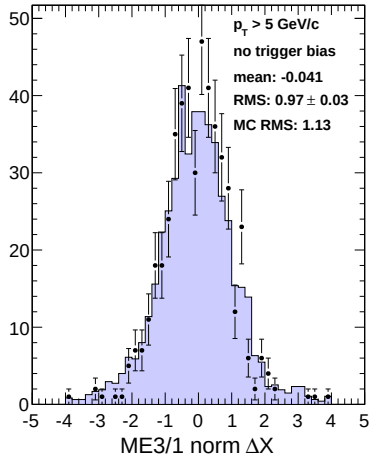

p_T > 5 GeV/c
no trigger bias
mean: 0.065
RMS: 1.37 ± 0.03
MC RMS: 1.45
ME2/2 norm Δdx/dz

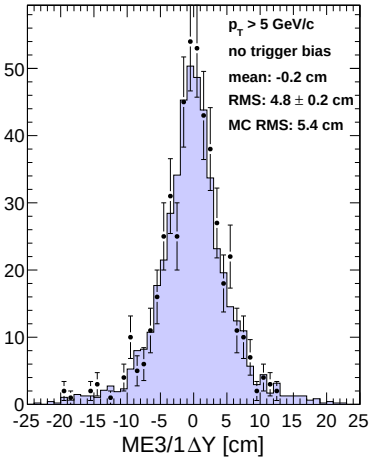

p_T > 5 GeV/c
no trigger bias
mean: 2.4 mrad
RMS: 123 ± 2 mrad
MC RMS: 123 mrad
ME2/2 Δdy/dz [mrad]

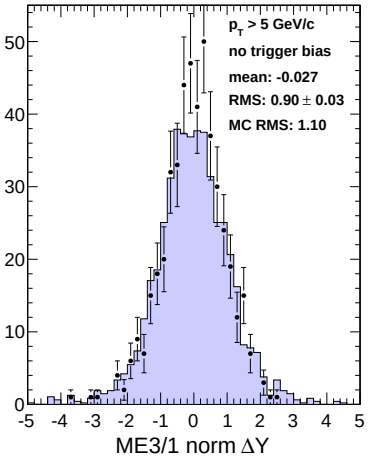

p_T > 5 GeV/c
no trigger bias
mean: 0.016
RMS: 0.90 ± 0.02
MC RMS: 0.94
ME2/2 norm Δdy/dz

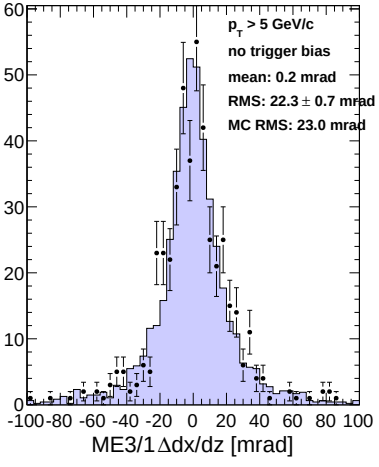
ME3/1

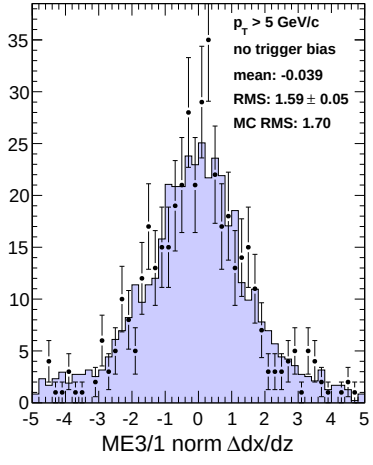

p_T > 5 GeV/c
no trigger bias
mean: -0.048 cm
RMS: 4.8 ± 0.2 cm
MC RMS: 5.4 cm
ME3/1 ΔX [cm]

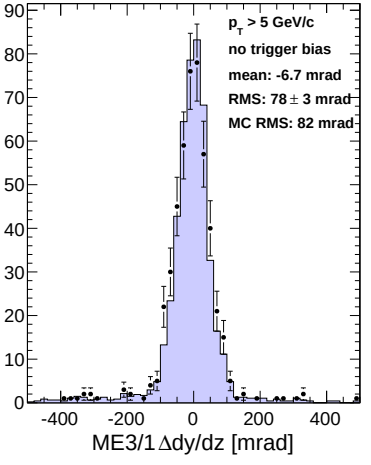

p_T > 5 GeV/c
no trigger bias
mean: -0.041
RMS: 0.97 ± 0.03
MC RMS: 1.13
ME3/1 norm ΔX

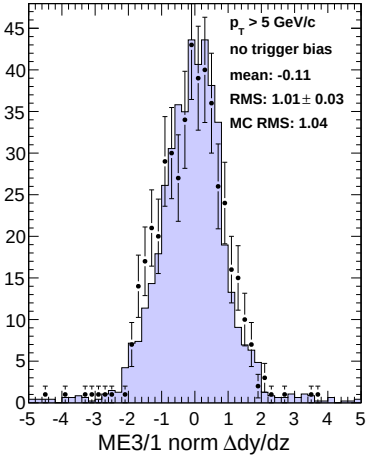

p_T > 5 GeV/c
no trigger bias
mean: -0.2 cm
RMS: 4.8 ± 0.2 cm
MC RMS: 5.4 cm
ME3/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.027
RMS: 0.90 ± 0.03
MC RMS: 1.10
ME3/1 norm ΔY

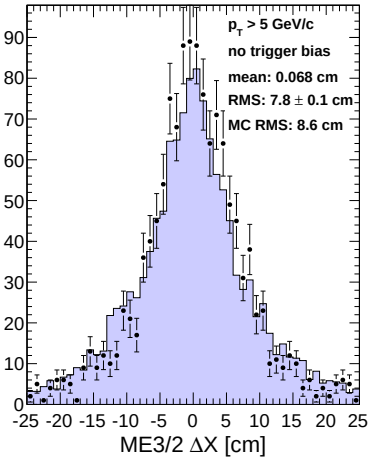

p_T > 5 GeV/c
no trigger bias
mean: 0.2 mrad
RMS: 22.3 ± 0.7 mrad
MC RMS: 23.0 mrad
ME3/1 Δdx/dz [mrad]

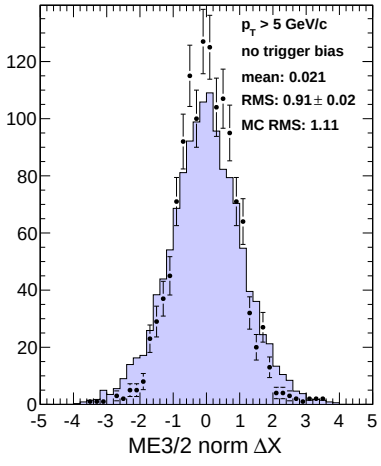

p_T > 5 GeV/c
no trigger bias
mean: -0.039
RMS: 1.59 ± 0.05
MC RMS: 1.70
ME3/1 norm Δdx/dz

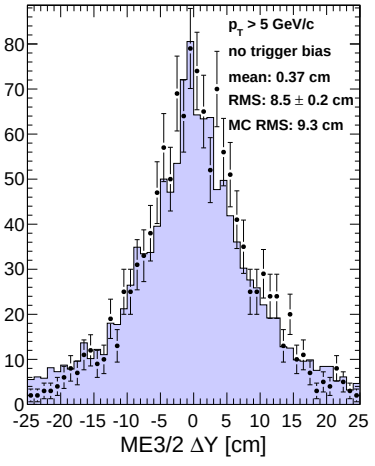

p_T > 5 GeV/c
no trigger bias
mean: -6.7 mrad
RMS: 78 ± 3 mrad
MC RMS: 82 mrad
ME3/1 Δdy/dz [mrad]

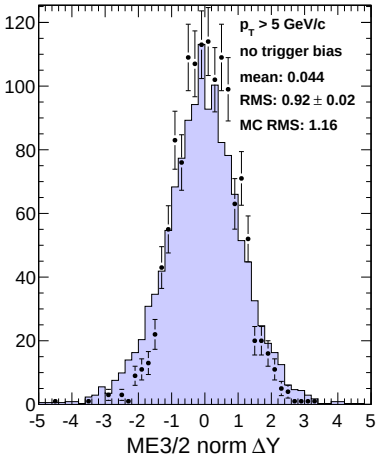

p_T > 5 GeV/c
no trigger bias
mean: -0.11
RMS: 1.01 ± 0.03
MC RMS: 1.04
ME3/1 norm Δdy/dz

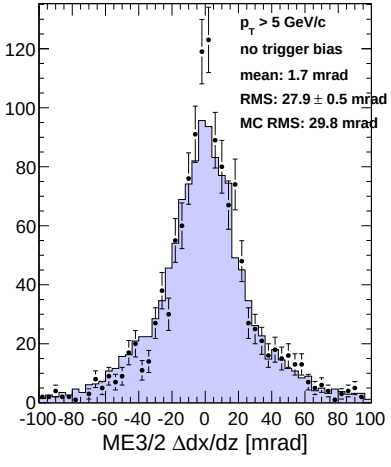
ME3/2

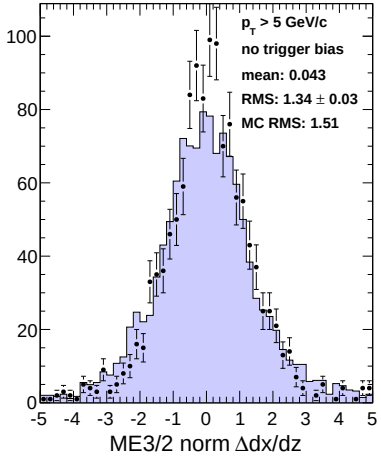

p_T > 5 GeV/c
no trigger bias
mean: 0.068 cm
RMS: 7.8 ± 0.1 cm
MC RMS: 8.6 cm
ME3/2 ΔX [cm]

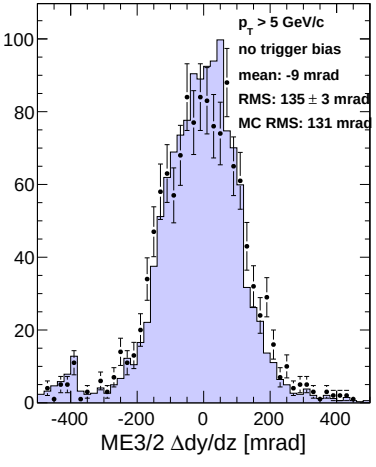

p_T > 5 GeV/c
no trigger bias
mean: 0.021
RMS: 0.91 ± 0.02
MC RMS: 1.11
ME3/2 norm ΔX

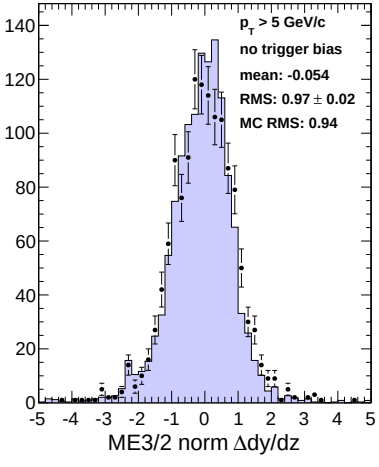

p_T > 5 GeV/c
no trigger bias
mean: 0.37 cm
RMS: 8.5 ± 0.2 cm
MC RMS: 9.3 cm
ME3/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.044
RMS: 0.92 ± 0.02
MC RMS: 1.16
ME3/2 norm ΔY

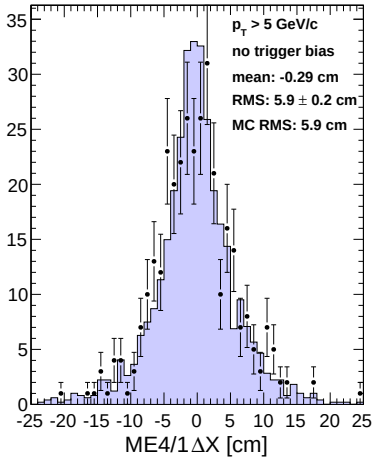

p_T > 5 GeV/c
no trigger bias
mean: 1.7 mrad
RMS: 27.9 ± 0.5 mrad
MC RMS: 29.8 mrad
ME3/2 Δdx/dz [mrad]

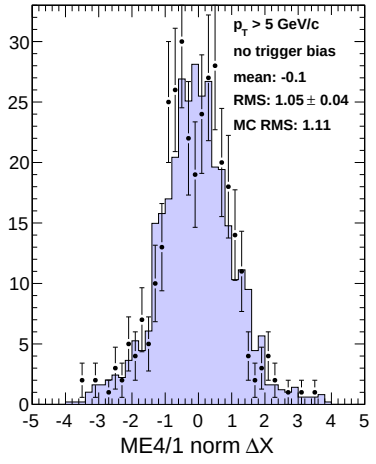

p_T > 5 GeV/c
no trigger bias
mean: 0.043
RMS: 1.34 ± 0.03
MC RMS: 1.51
ME3/2 norm Δdx/dz

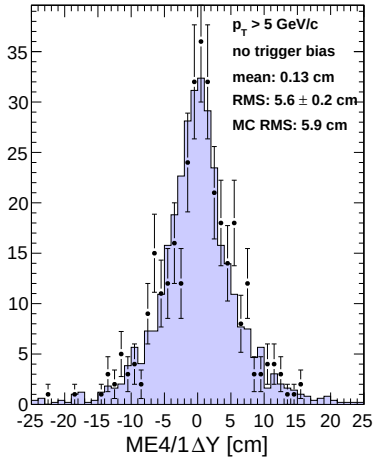

p_T > 5 GeV/c
no trigger bias
mean: -9 mrad
RMS: 135 ± 3 mrad
MC RMS: 131 mrad
ME3/2 Δdy/dz [mrad]

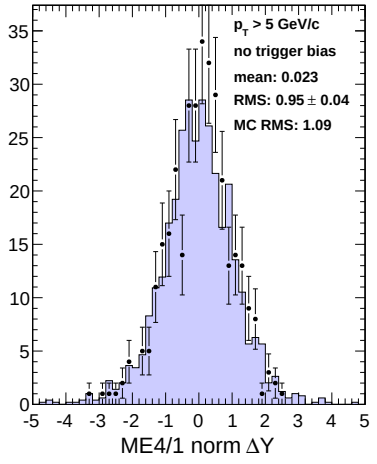

p_T > 5 GeV/c
no trigger bias
mean: -0.054
RMS: 0.97 ± 0.02
MC RMS: 0.94
ME3/2 norm Δdy/dz

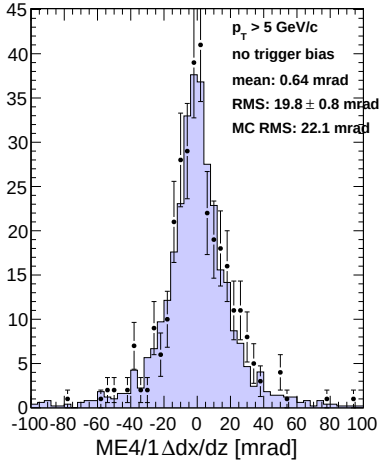
ME4/1

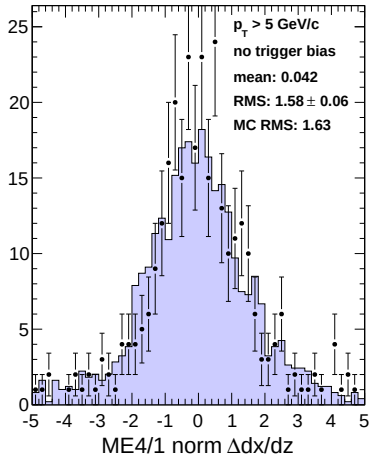

p_T > 5 GeV/c
no trigger bias
mean: -0.29 cm
RMS: 5.9 ± 0.2 cm
MC RMS: 5.9 cm
ME4/1 ΔX [cm]

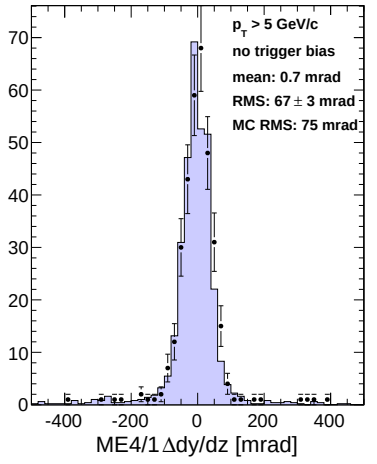

p_T > 5 GeV/c
no trigger bias
mean: -0.1
RMS: 1.05 ± 0.04
MC RMS: 1.11
ME4/1 norm ΔX

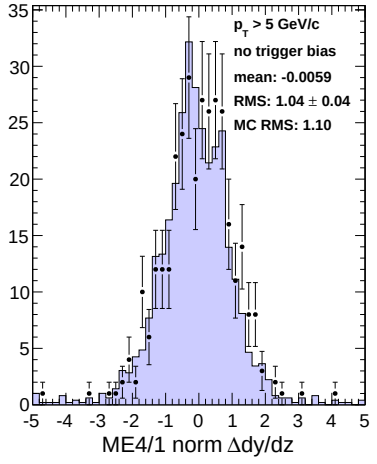

p_T > 5 GeV/c
no trigger bias
mean: 0.13 cm
RMS: 5.6 ± 0.2 cm
MC RMS: 5.9 cm
ME4/1 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: 0.023
RMS: 0.95 ± 0.04
MC RMS: 1.09
ME4/1 norm ΔY

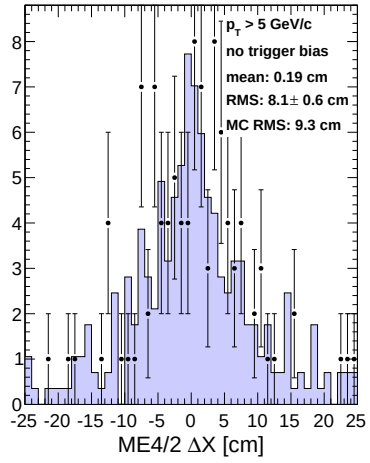

p_T > 5 GeV/c
no trigger bias
mean: 0.64 mrad
RMS: 19.8 ± 0.8 mrad
MC RMS: 22.1 mrad
ME4/1 Δdx/dz [mrad]

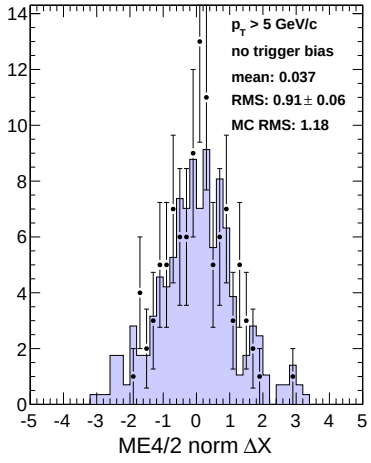

p_T > 5 GeV/c
no trigger bias
mean: 0.042
RMS: 1.58 ± 0.06
MC RMS: 1.63
ME4/1 norm Δdx/dz

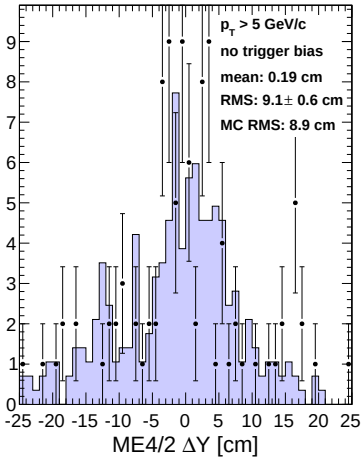

p_T > 5 GeV/c
no trigger bias
mean: 0.7 mrad
RMS: 67 ± 3 mrad
MC RMS: 75 mrad
ME4/1 Δdy/dz [mrad]

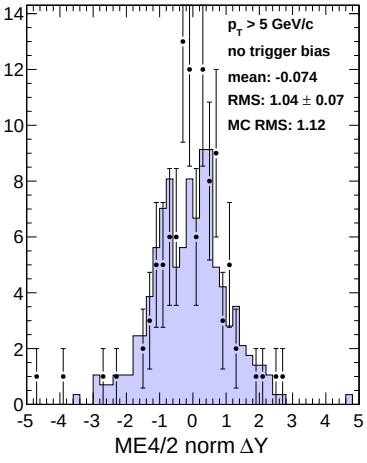

p_T > 5 GeV/c
no trigger bias
mean: -0.0059
RMS: 1.04 ± 0.04
MC RMS: 1.10
ME4/1 norm Δdy/dz

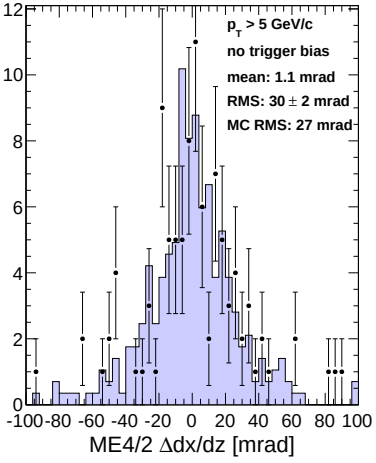
ME4/2

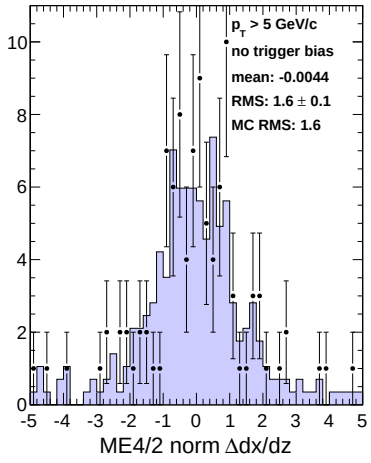

p_T > 5 GeV/c
no trigger bias
mean: 0.19 cm
RMS: 8.1± 0.6 cm
MC RMS: 9.3 cm
ME4/2 ΔX [cm]

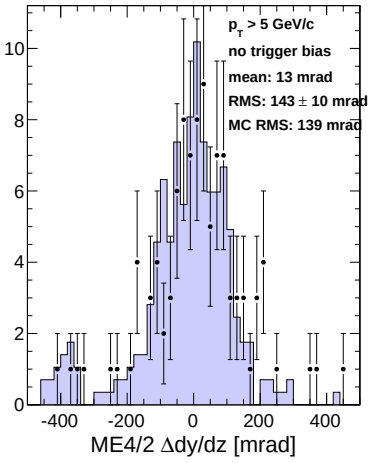

p_T > 5 GeV/c
no trigger bias
mean: 0.037
RMS: 0.91± 0.06
MC RMS: 1.18
ME4/2 norm ΔX

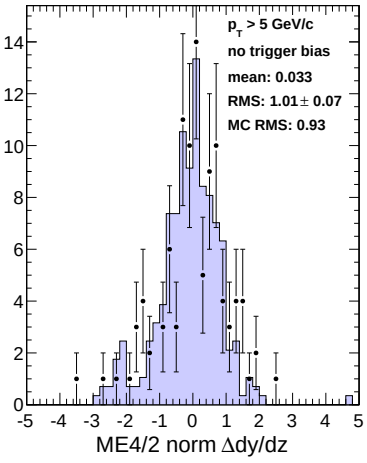

p_T > 5 GeV/c
no trigger bias
mean: 0.19 cm
RMS: 9.1± 0.6 cm
MC RMS: 8.9 cm
ME4/2 ΔY [cm]


p_T > 5 GeV/c
no trigger bias
mean: -0.074
RMS: 1.04 ± 0.07
MC RMS: 1.12
ME4/2 norm ΔY


p_T > 5 GeV/c
no trigger bias
mean: 1.1 mrad
RMS: 30 ± 2 mrad
MC RMS: 27 mrad
ME4/2 Δdx/dz [mrad]


p_T > 5 GeV/c
no trigger bias
mean: -0.0044
RMS: 1.6 ± 0.1
MC RMS: 1.6
ME4/2 norm Δdx/dz


p_T > 5 GeV/c
no trigger bias
mean: 13 mrad
RMS: 143 ± 10 mrad
MC RMS: 139 mrad
ME4/2 Δdy/dz [mrad]


p_T > 5 GeV/c
no trigger bias
mean: 0.033
RMS: 1.01± 0.07
MC RMS: 0.93
ME4/2 norm Δdy/dz