Alignment of each endcap using beam-halo muons

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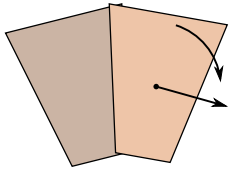
Overview

This is a long story involving two new alignment techniques. Here it is in reverse order:

4. To investigate possible barrel twist by anchoring transfer lines to multiple disks in each endcap...
3. I have produced an alignment of each endcap from beam-halo tracks, rather than tracks from the tracker (also a good cross-check for Vadim)
2. To get sensible extrapolations of segments from one station to the next, we need to know the ϕ_y angles of the chambers...
1. So I first aligned *only the* ϕ_y *angles* using collisions-TrackerMuons from the tracker.

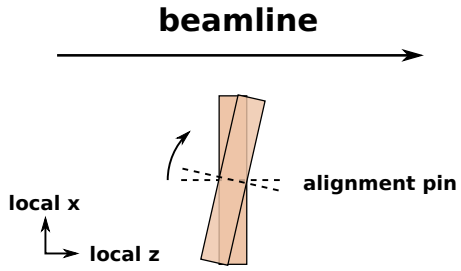
The pre-alignment from the tracker (1) is not introducing a twist into the endcap because "twist" is ϕ_z vs. z, not ϕ_y.

Classes of alignment parameters



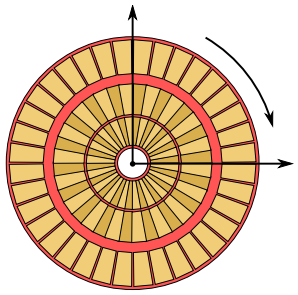
Alignment of chambers in the same disk relative to one another (local x, φz)

Beam-halo + PG (+ SLM?)



φy chamber alignments (unaligned values are all zero)

Collisions muons from tracker (beam-halo not sensitive enough)

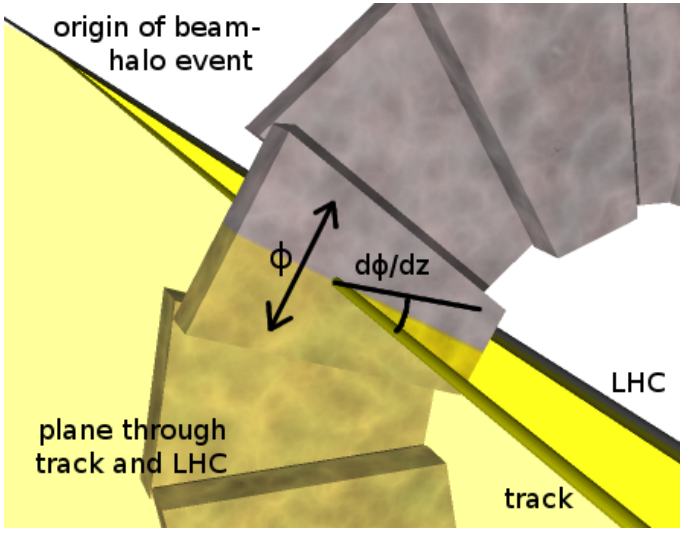


Alignment of whole disks (global x, y, φz), relative to the tracker or not

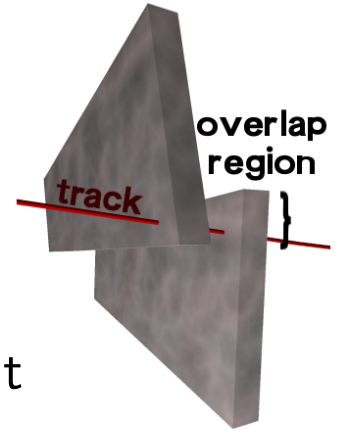
Straight-through beam-halo or muons from the tracker

- $(x, r\phi)$ can be considered separate from ϕ_y, though both can affect some types of residuals (making it difficult to determine how much of a residuals bias is local x and how much is ϕ_y)
- Disk-scale alignment can be considered separate from individual-chamber alignment, though both affect muons from the tracker
- The logical flow of solving the dependencies goes left-to-right, and the first step (chamber alignment from beam-halo) is already done

History of ϕ_y alignments



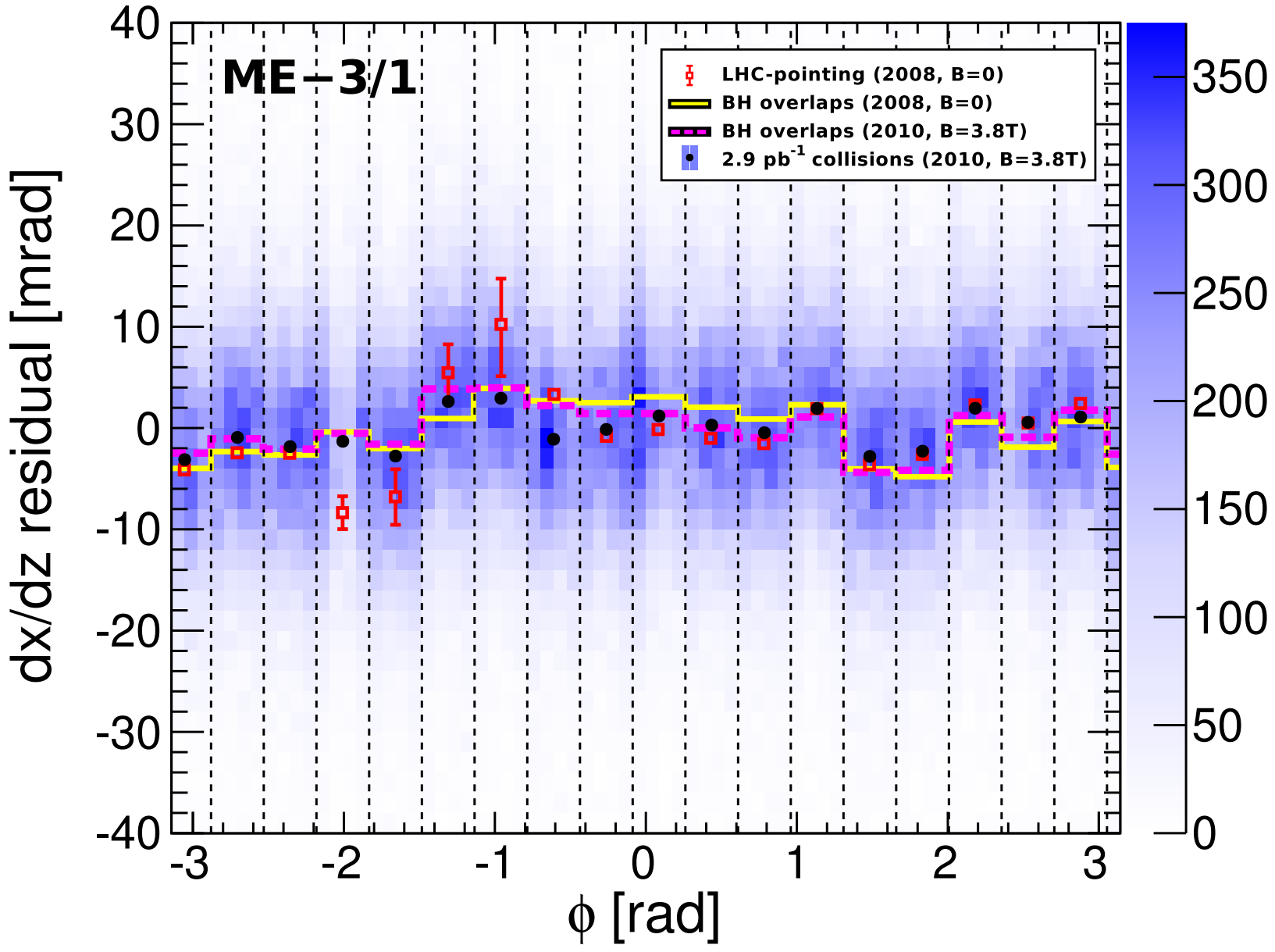
- ϕ_y was the first parameter we attempted to measure with beam-halo, by assuming that straight muon tracks originate somewhere along an infinitely long, straight LHC beampipe
- These assumptions are too strong, and the method doesn't work with $\vec{B} \neq 0$



- ϕ_y can in principle be measured with beam-halo overlaps, but the resolution is poor (determined from the width of the corresponding residuals distribution)
- ϕ_y was fixed to zero in the 2010 beam-halo alignment
- Measuring ϕ_y with collisions muons from the tracker is completely straight-forward: just look for an angular difference between propagated muon and segment
- Analysis with 2.9 pb^{-1} of $|\vec{p}| > 30$ GeV/c TrackerMuons; *ϕ_y only*

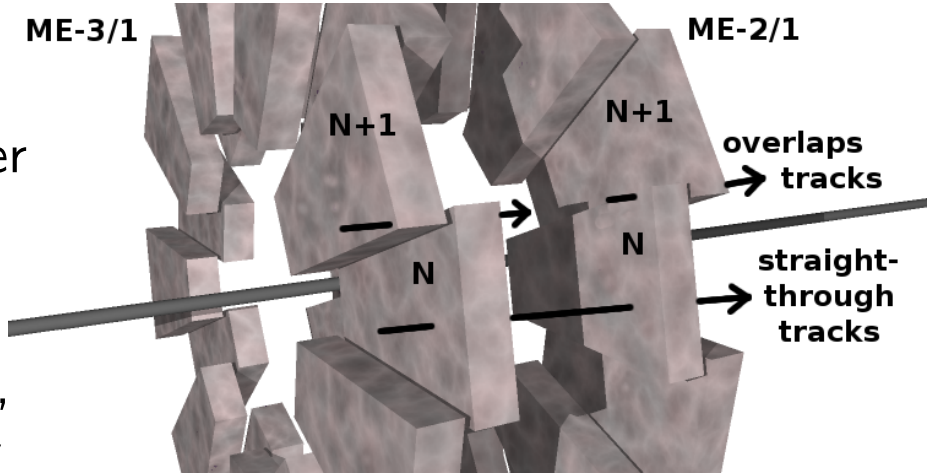
ϕ_y alignment results (example)

See backup slides for complete results

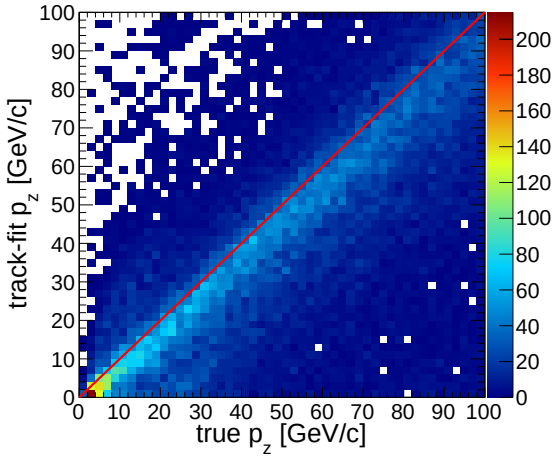


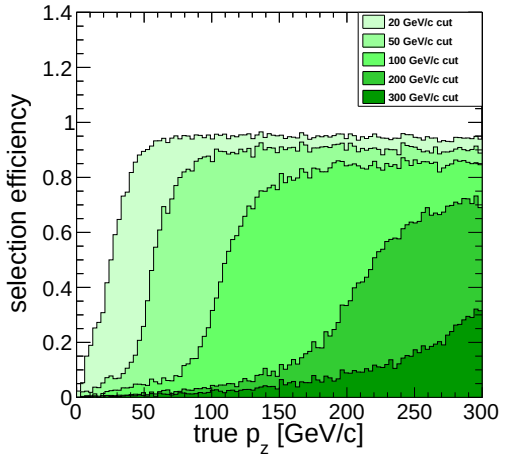
Disk alignment with beam-halo

- Beam-halo overlaps can only align chambers within the same ring to one another
- Straight-through tracks can align disks to one another in the same endcap, but resolution is smeared by transit through the steel yoke



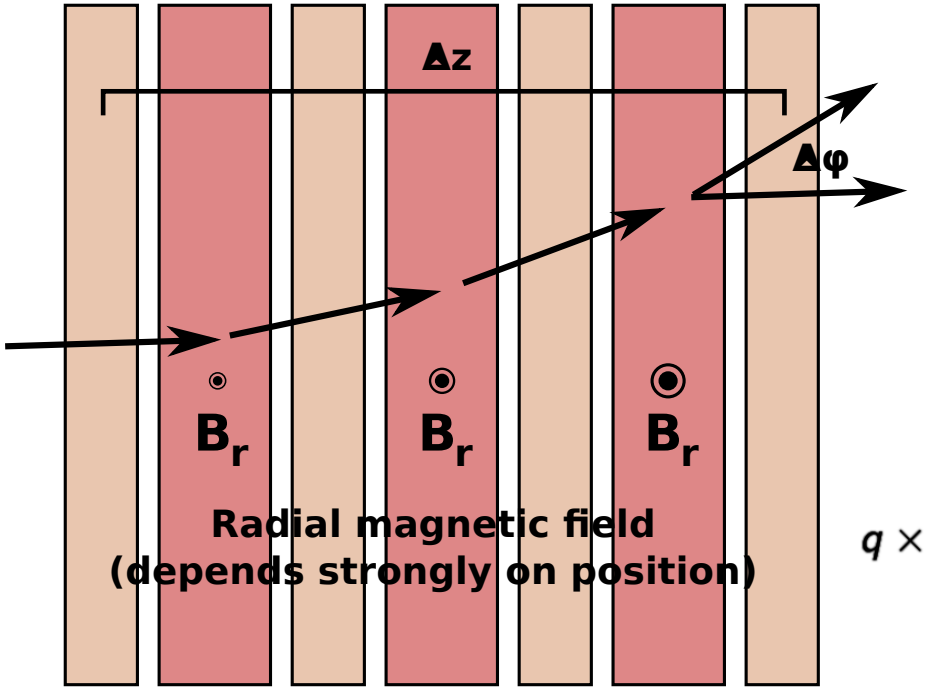
- It will be essential to select high-momentum beam-halo muons
- Though beam-halo is parallel to the axial field, it is influenced by the radial component of the magnetic field, which is large in the endcaps
- MC study of track-fit's discriminating power:





Track-fit alternative

- The momentum measurement from the standard track-fit depends on the positions of the disks, which is exactly what we want to align
- To avoid a circular dependence, we can take advantage of the fact that muon chambers measure position and direction:
  - measure momentum with the change in direction
  - align the positions

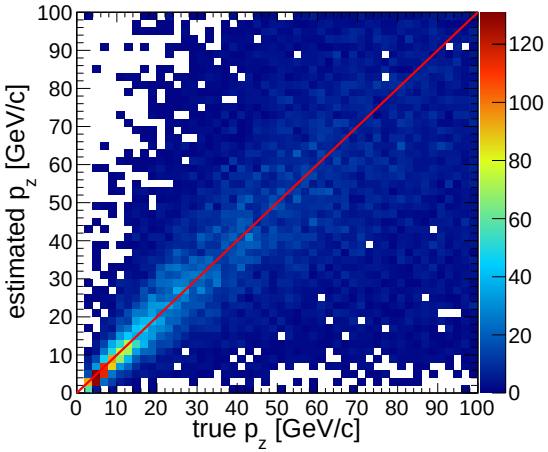


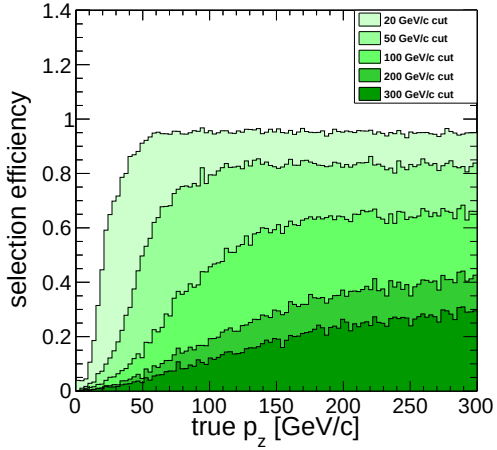
track changes entrance angle (φy, a.k.a. dx/dz)

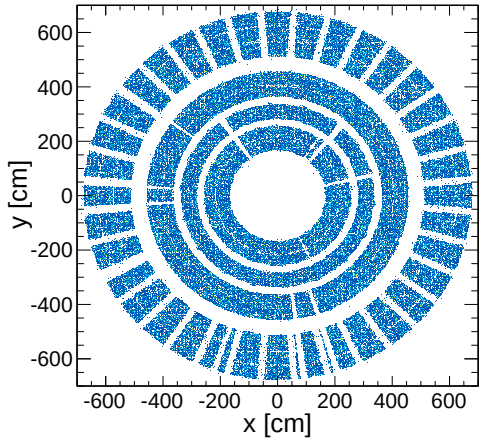
(ignore changes in position which are influenced by x, y, φz alignment)

$$q \times p_z = \frac{B_r}{330 \text{ cm T/GeV}} \frac{\Delta z}{\Delta \phi}$$

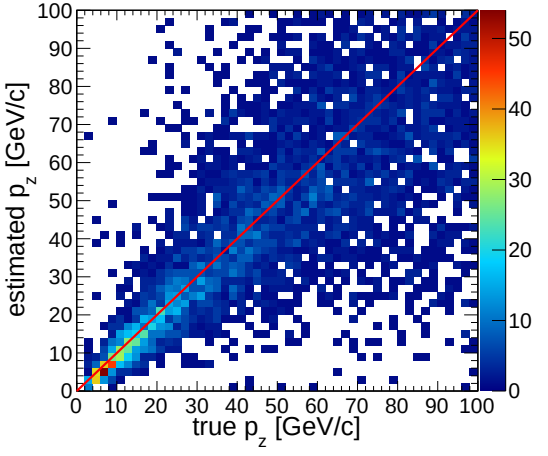
p_z estimated from ME1, 2, 3:

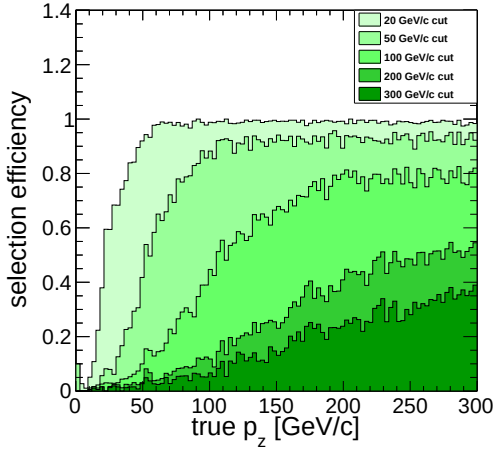


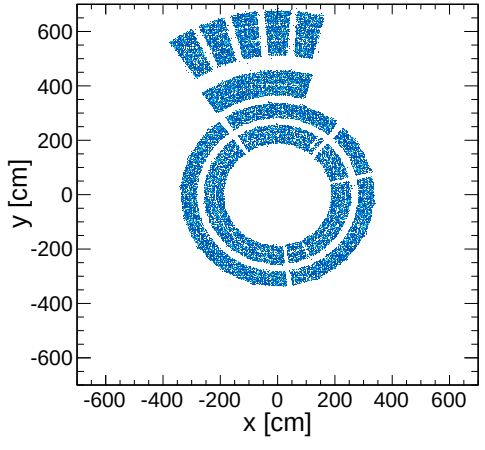




p_z estimated from ME1, 2, 3, and 4:



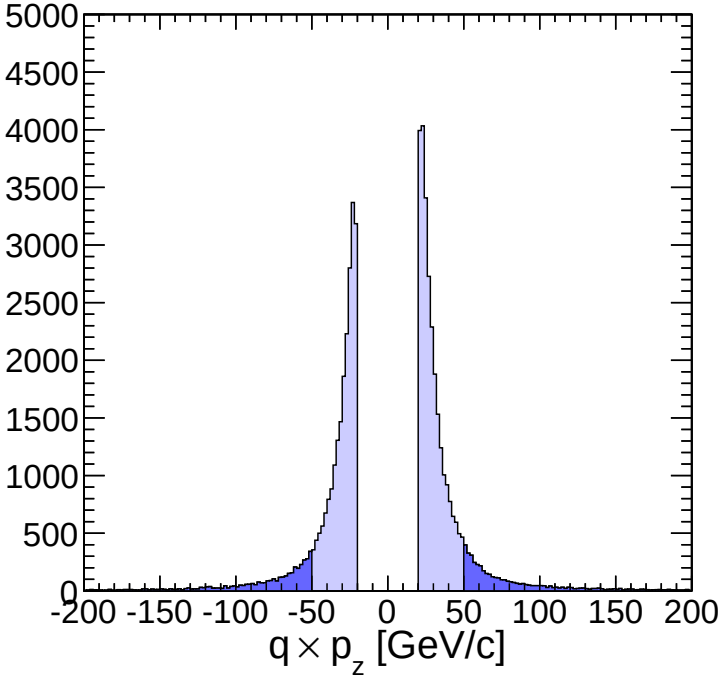




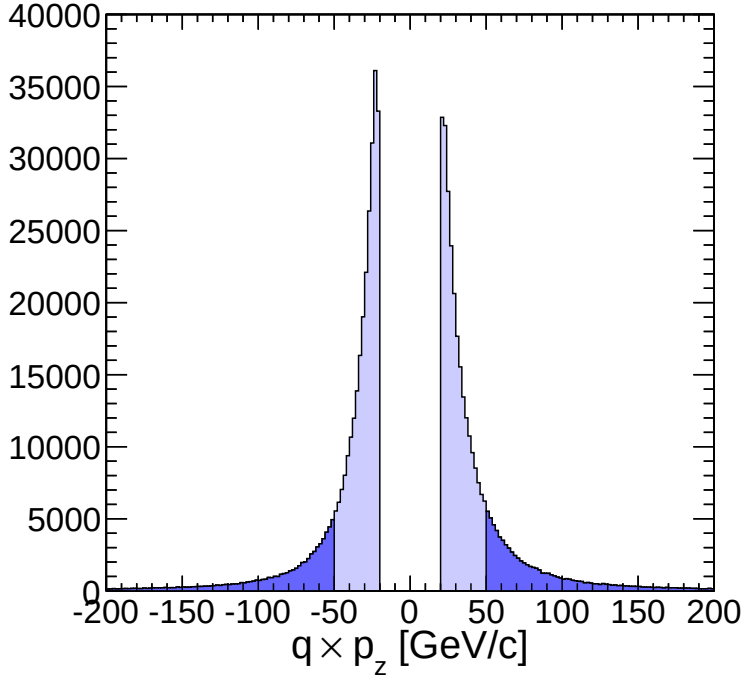
We'll cut at 50 GeV/c, using the 4-station estimate only when aligning ME4/1 and 4/2

Beam-halo datasets

LHC Tertiary Collimator Triplet test
(Mar 10, 2010: 130434 and 130445)



Beam-halo collected during collisions
(Jun 10–Sep 1, 2010: 137437–144431)



- All plots of TCT and during-collisions look consistent, though during-collisions has an order of magnitude more data (important when applying a tight momentum cut)

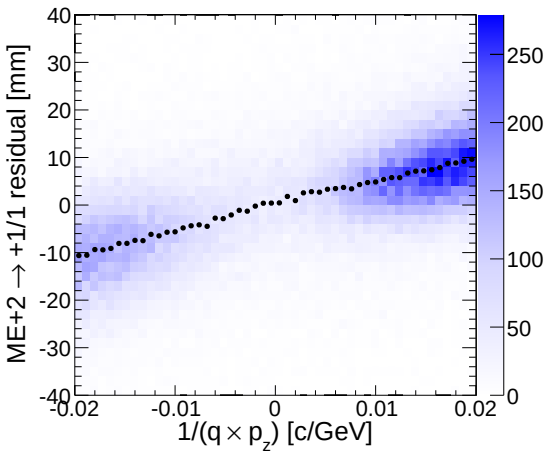
(Note that tracks have "CZ" symmetry: we can't tell a westward-bound muon from an eastern-bound antimuon)

Beam-halo disk alignment

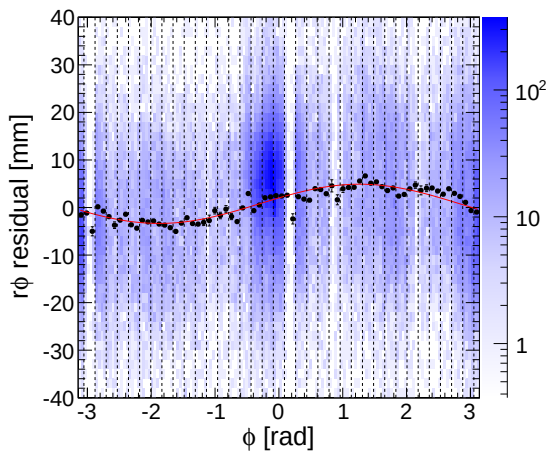
- After applying high momentum cut (nearly parallel segments), linearly extrapolate segment from one disk to another and compare position ($r\phi$ residual)
- Residuals depend linearly on $1/(q \times p_z)$ because we're not taking track-curvature into account: linearly fit to get infinite-momentum limit in each ϕ bin
- This is an example from ME+2 $\rightarrow$ ME+1/1 (strong $\vec{B}$-field)

(see backup for all plots)

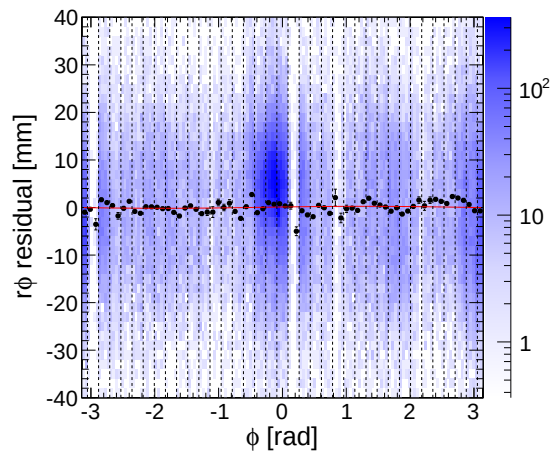
linear dependence on $1/(q \times p_z)$



$c_0 + c_1 \sin\phi + c_2 \cos\phi$ before alignment



flat distribution after alignment



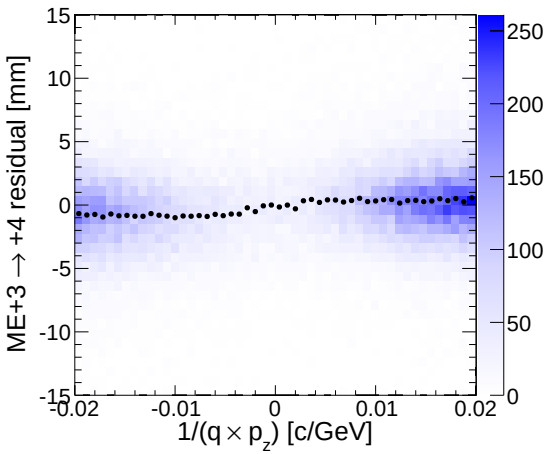
Note: color scale (number of hits) is logarithmic

Beam-halo disk alignment

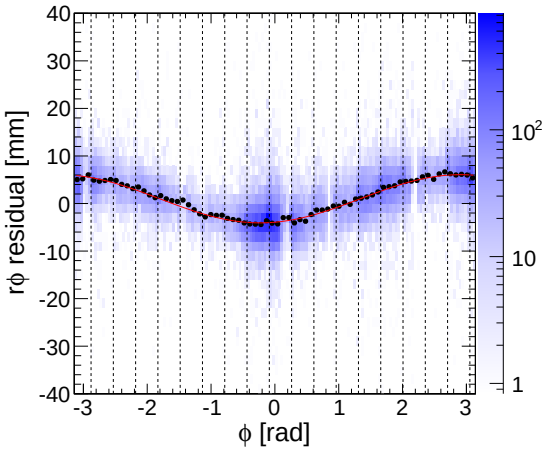
- After applying high momentum cut (nearly parallel segments), linearly extrapolate segment from one disk to another and compare position ($r\phi$ residual)
- Residuals depend linearly on $1/(q \times p_z)$ because we're not taking track-curvature into account: linearly fit to get infinite-momentum limit in each ϕ bin
- This is an example from ME+3 $\rightarrow$ ME+4 (weak $\vec{B}$-field)

  (see backup for all plots)

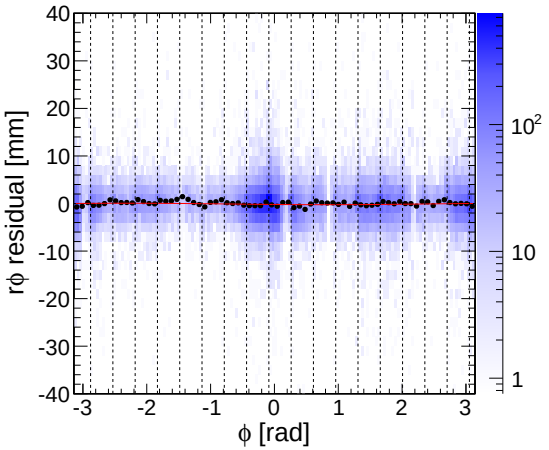
linear dependence on $1/(q \times p_z)$



$c_0 + c_1 \sin\phi + c_2 \cos\phi$ before alignment



flat distribution after alignment

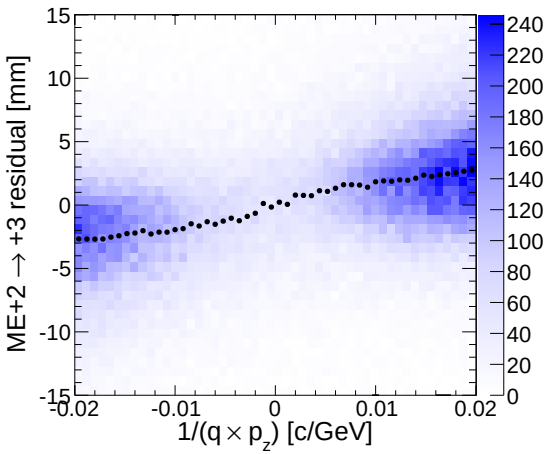


Note: color scale (number of hits) is logarithmic

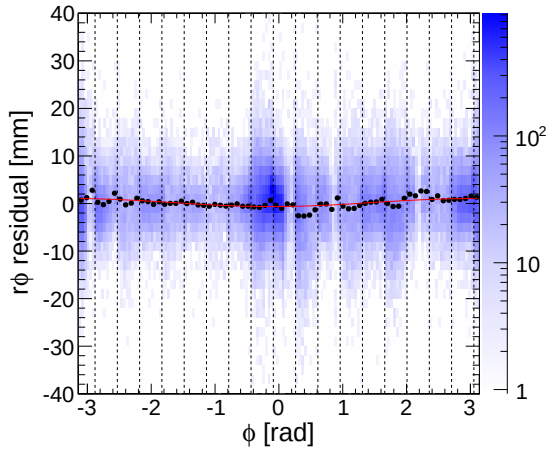
Beam-halo disk alignment

- After applying high momentum cut (nearly parallel segments), linearly extrapolate segment from one disk to another and compare position ($r\phi$ residual)
- Residuals depend linearly on $1/(q \times p_z)$ because we're not taking track-curvature into account: linearly fit to get infinite-momentum limit in each ϕ bin
- This is an example from ME+2 $\rightarrow$ ME+3: same disk, should be zero (see backup for all plots)

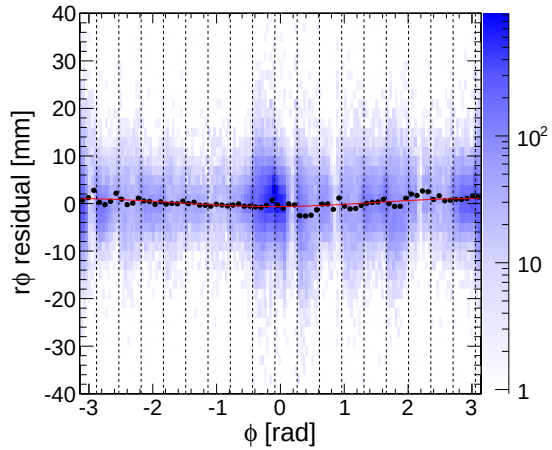
linear dependence on $1/(q \times p_z)$



$c_0 + c_1 \sin\phi + c_2 \cos\phi$ before alignment



same distribution; not aligned

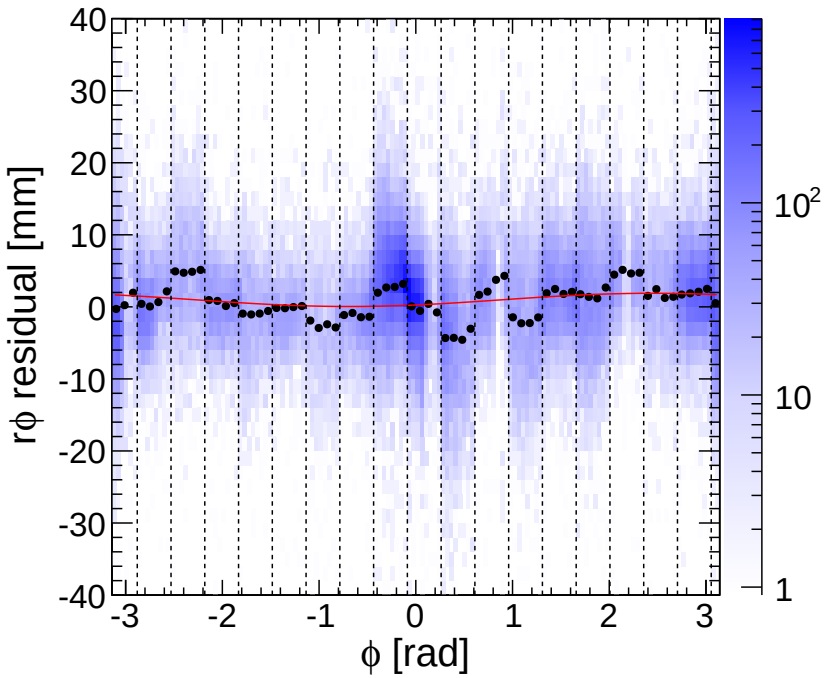


Note: color scale (number of hits) is logarithmic

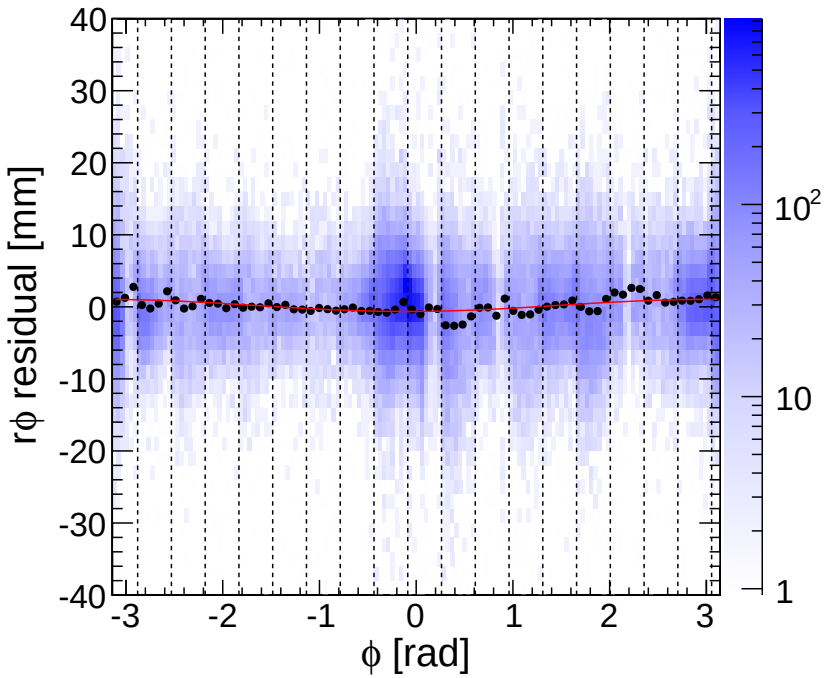
Importance of ϕ_y pre-alignment

- Extrapolations from one disk to the next have a rather large lever arm; getting the initial chamber orientation wrong by 1 mrad means >1 mm errors in the next disk (more than 1 meter apart)
- Discontinuities in the residuals imply a chamber-by-chamber error
- Remember that ϕ_y was aligned using a different method (tracker-to-muon chambers) on different muons (from collisions)

ME+2 $\rightarrow$ +3 without ϕ_y alignments



ME+2 $\rightarrow$ +3 with ϕ_y alignments



Disk alignment results

Corrections (relative to ideal) from beam-halo collected during collisions

	x (mm)	y (mm)	ϕ_z (mrad)
ME+1/1	3.933 ± 0.080	-1.242 ± 0.052	-0.411 ± 0.023
ME+1/2	3.564 ± 0.105	-0.727 ± 0.081	0.408 ± 0.020
check $+2 \to +3$	0.085 ± 0.035	0.837 ± 0.024	-0.085 ± 0.009
ME+4/1	1.196 ± 0.038	4.838 ± 0.028	-0.474 ± 0.010
ME−1/1	-1.701 ± 0.079	-1.787 ± 0.052	-0.797 ± 0.023
ME−1/2	-0.395 ± 0.108	-0.787 ± 0.086	-0.675 ± 0.020
check $-2 \to -3$	0.178 ± 0.035	-0.379 ± 0.025	-0.037 ± 0.009
ME−4/1	-2.117 ± 0.038	0.230 ± 0.027	-0.449 ± 0.010
Same for TCT	x (mm)	y (mm)	ϕ_z (mrad)
ME+1/1	3.568 ± 0.278	-0.293 ± 0.241	-0.496 ± 0.095
ME+1/2	3.824 ± 0.343	-0.580 ± 0.341	0.378 ± 0.076
check $+2 \to +3$	-0.353 ± 0.109	1.097 ± 0.112	-0.054 ± 0.037
ME+4/1	0.752 ± 0.102	4.939 ± 0.098	-0.473 ± 0.031
ME−1/1	0.161 ± 0.366	-1.555 ± 0.303	-0.148 ± 0.122
ME−1/2	-0.325 ± 0.876	-0.743 ± 0.557	-1.038 ± 0.197
check $-2 \to -3$	-0.135 ± 0.162	-0.792 ± 0.137	0.111 ± 0.048
ME−4/1	-2.399 ± 0.138	0.119 ± 0.114	-0.402 ± 0.038

Conclusions

- Two new measurements for endcap alignment:
  - ϕ_y of chambers (which had to wait for collisions, but interestingly enough agrees with the "LHC pointing" method that required so many assumptions)
  - global x, y, ϕ_z of disks, *independently* of the standard tracker-to-muon chamber method
- This will provide a cross-check for the standard procedure, but also gives us two aligned endcaps for anchoring transfer lines, to check for a barrel twist
  - remember that the position of one endcap relative to the other is not constrained, nor is either endcap relative to the tracker
  - location of constants: `/afs/cern.ch/user/p/pivarski/public/OCT7_CSC_beamhalo-PG-collisionsphiy-straightthrough-diskXYphiZ.db`

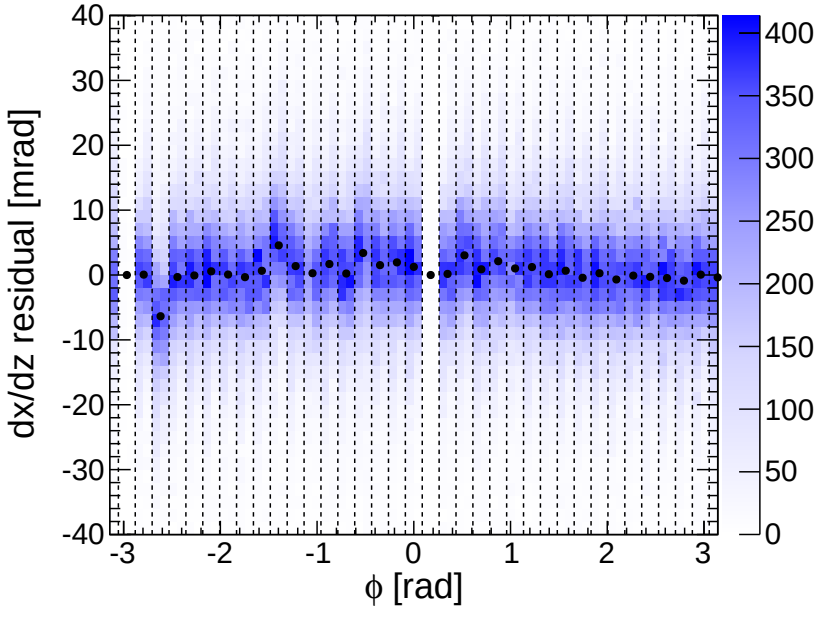
BACKUP

- ϕ_y alignment plots
- beam-halo disk alignment plots

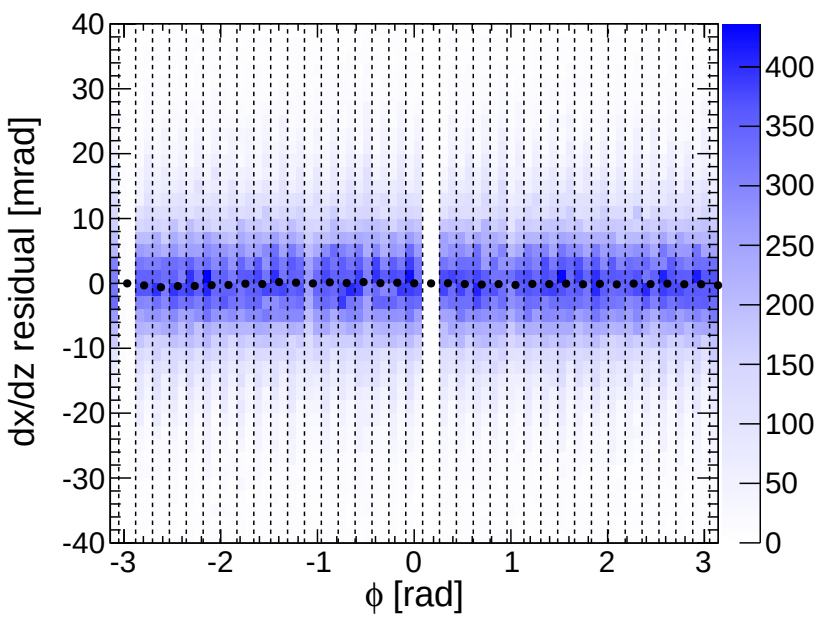
All of the ϕ_y alignment results

ME+1/1 (a and b)

Before



After (1 iteration)

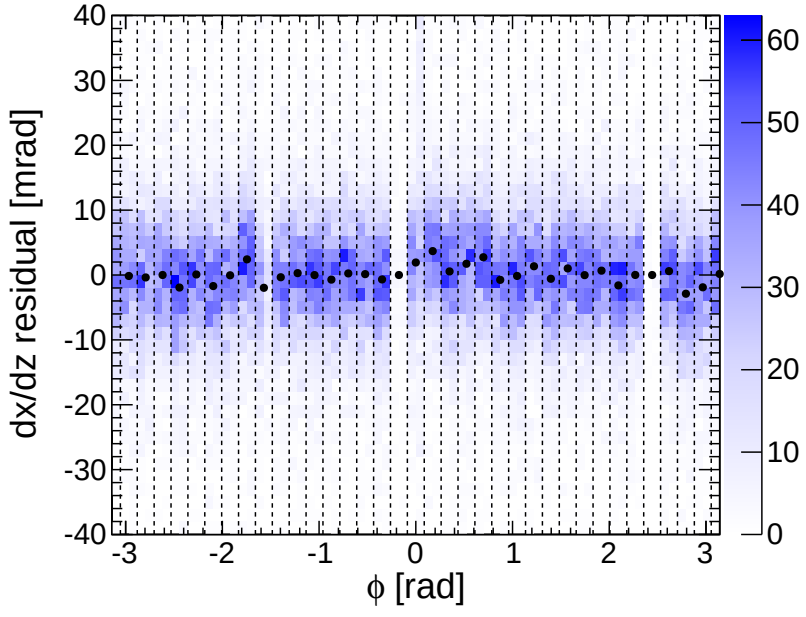


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

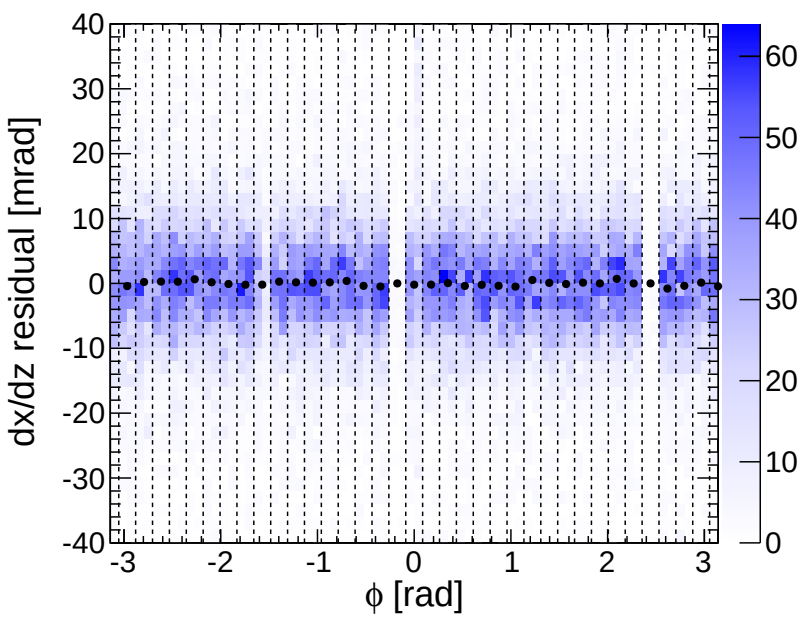
All of the ϕ_y alignment results

ME+1/2

Before



After (1 iteration)



- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
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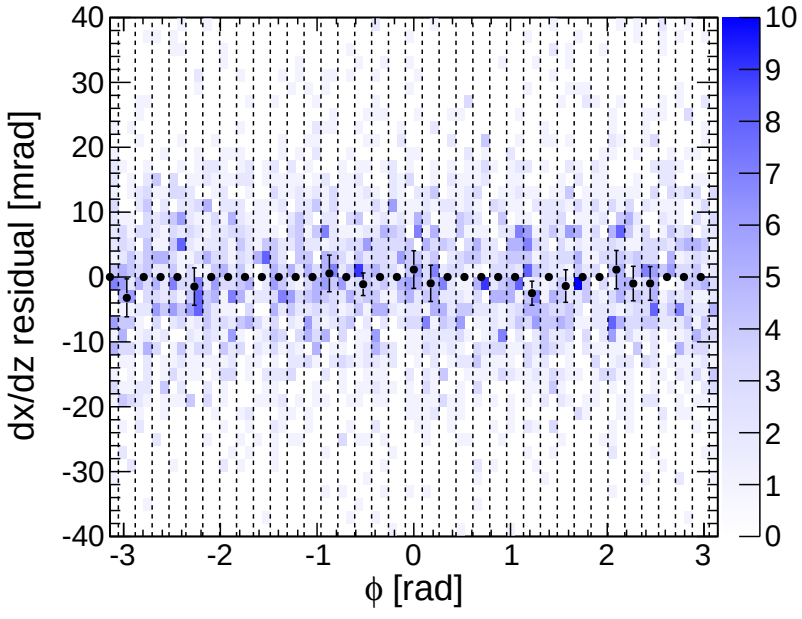
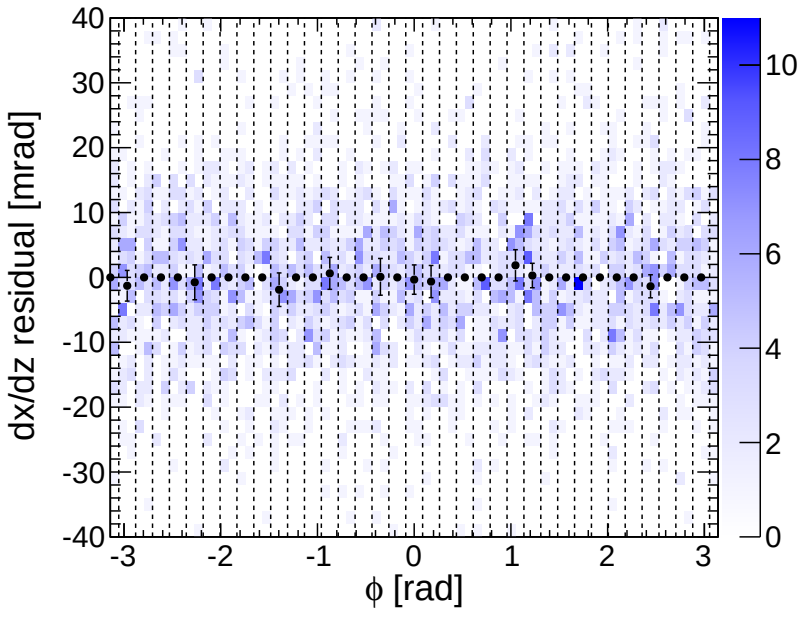
All of the ϕ_y alignment results

ME+1/3

Before



After (1 iteration)



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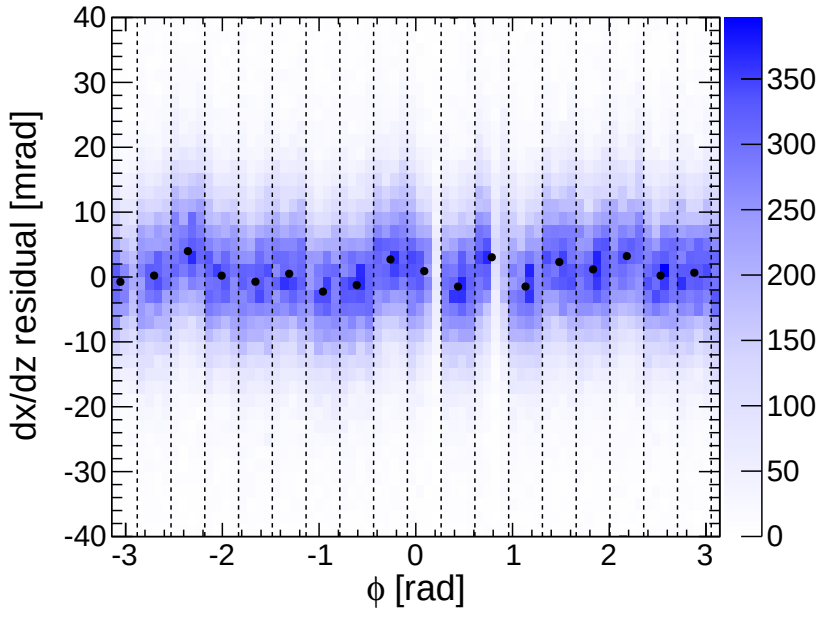
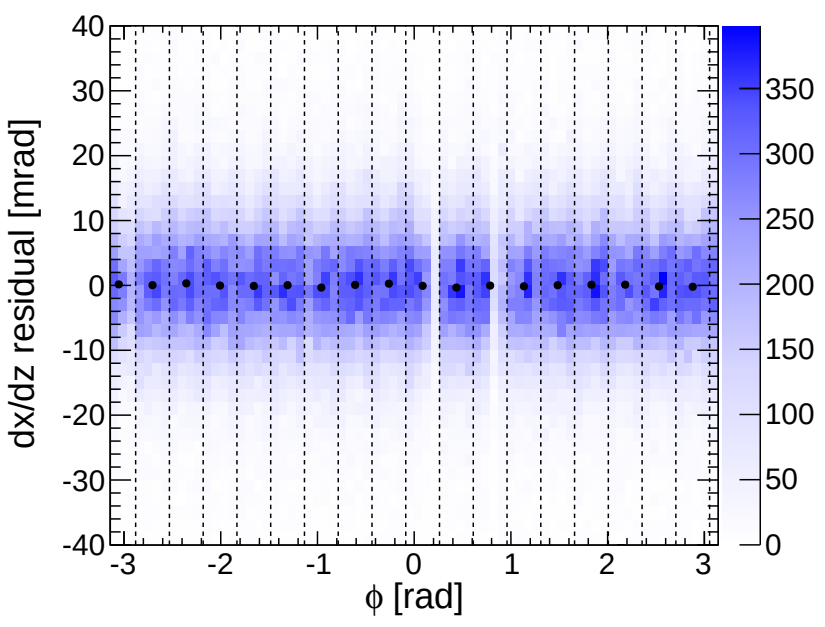
All of the ϕ_y alignment results

ME+2/1

Before



After (1 iteration)



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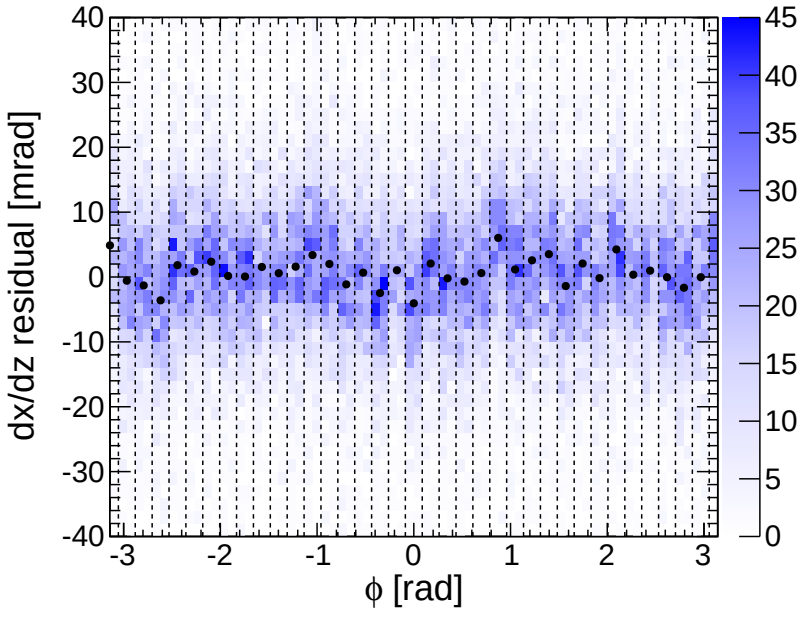
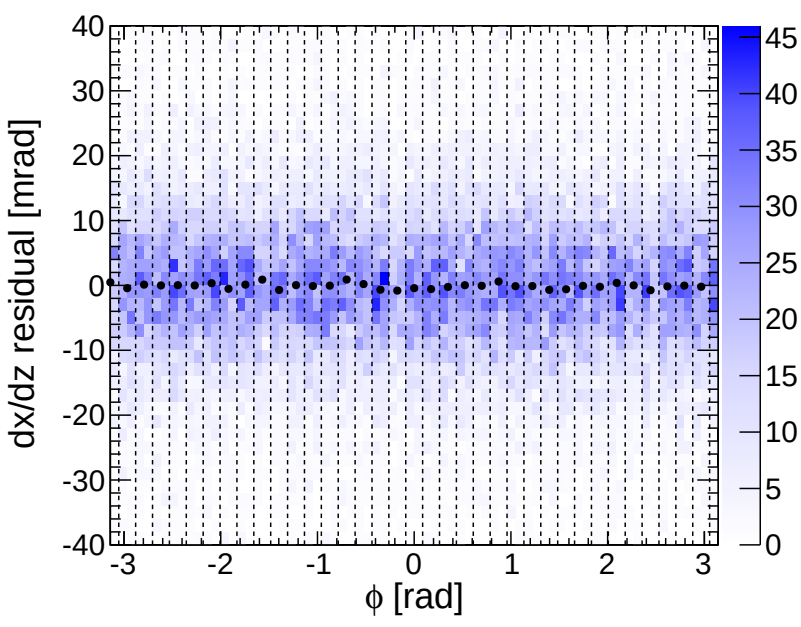
All of the ϕ_y alignment results

ME+2/2

Before



After (1 iteration)

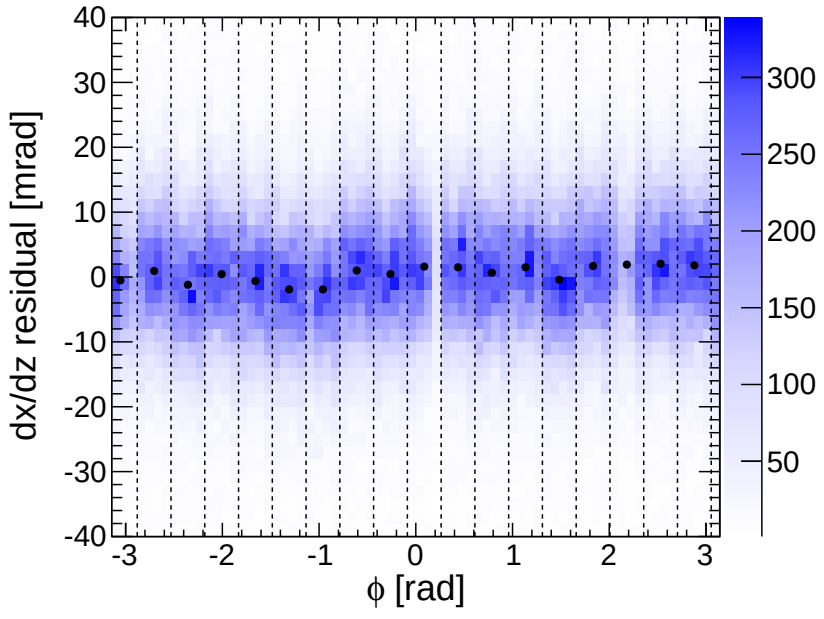


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

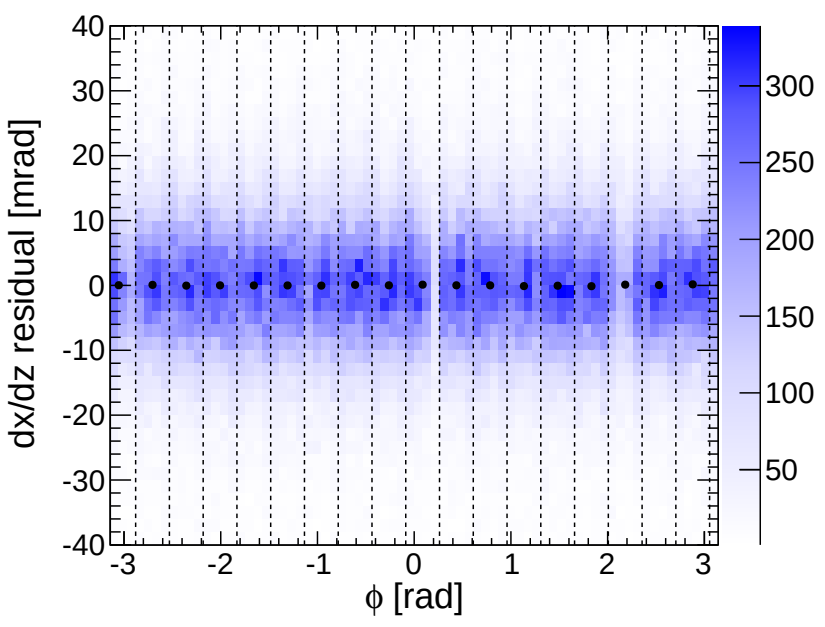
All of the ϕ_y alignment results

ME+3/1

Before



After (1 iteration)

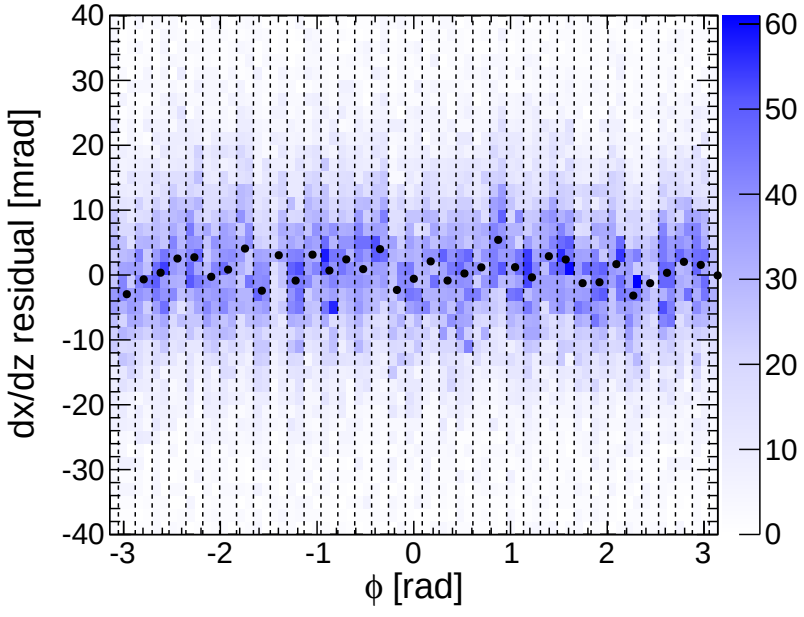


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

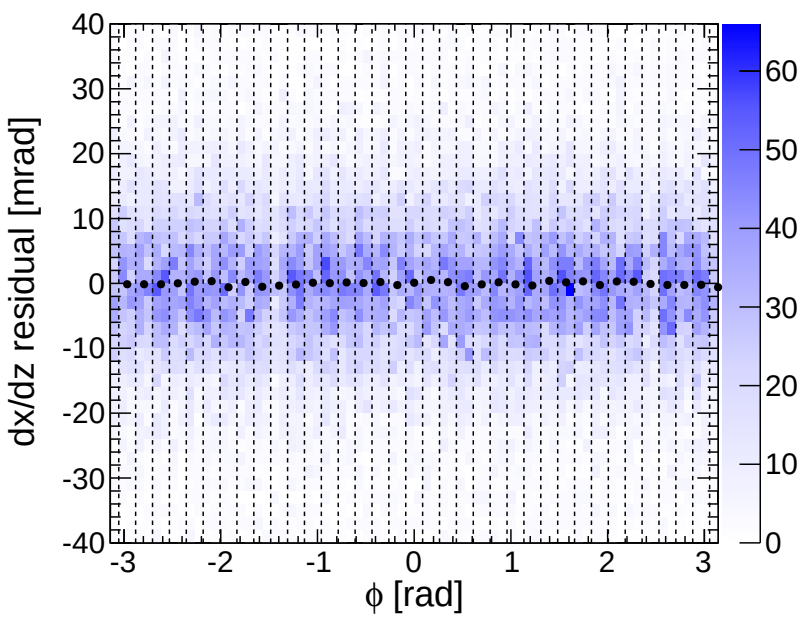
All of the ϕ_y alignment results

ME+3/2

Before



After (1 iteration)

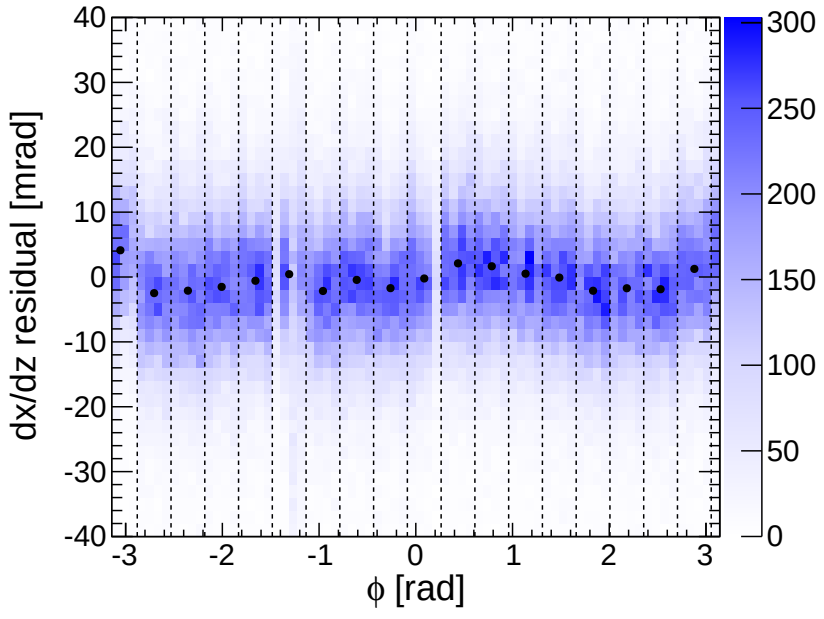


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

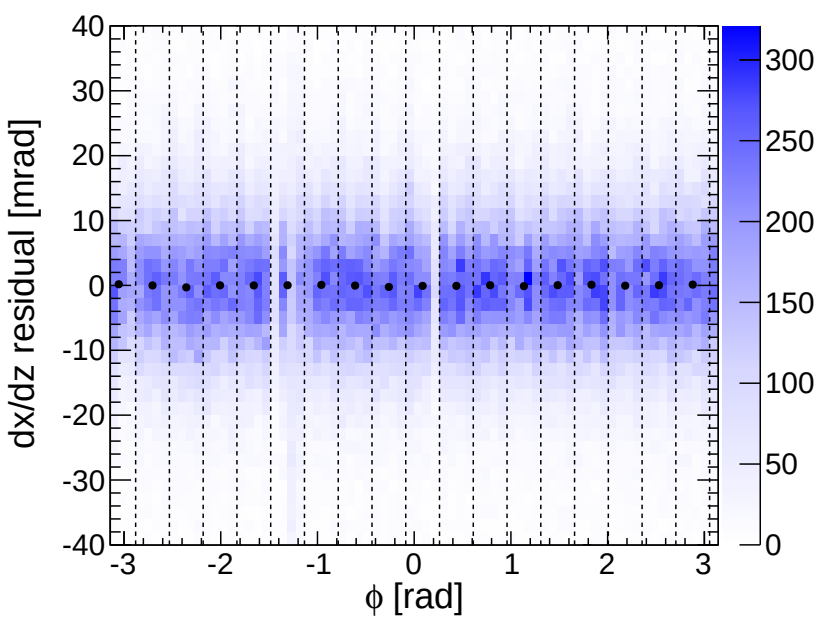
All of the ϕ_y alignment results

ME+4/1

Before



After (1 iteration)

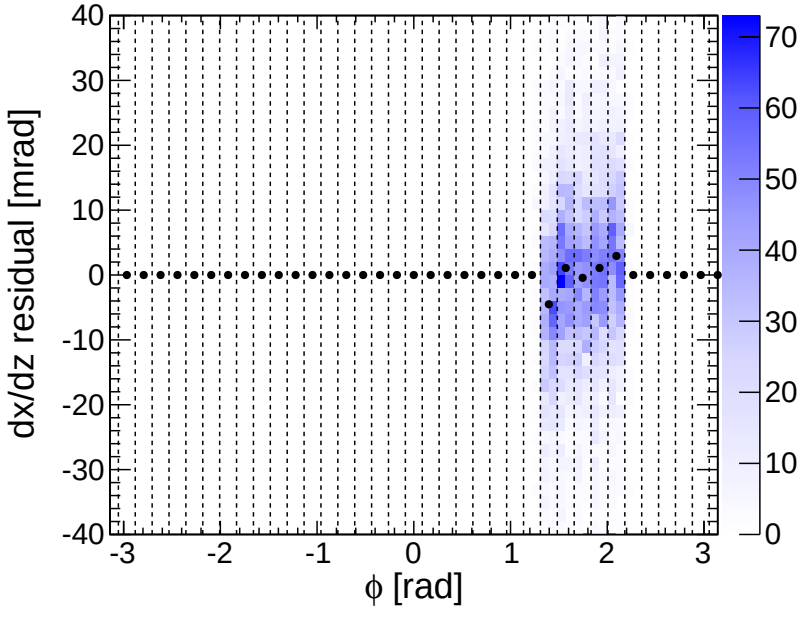


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

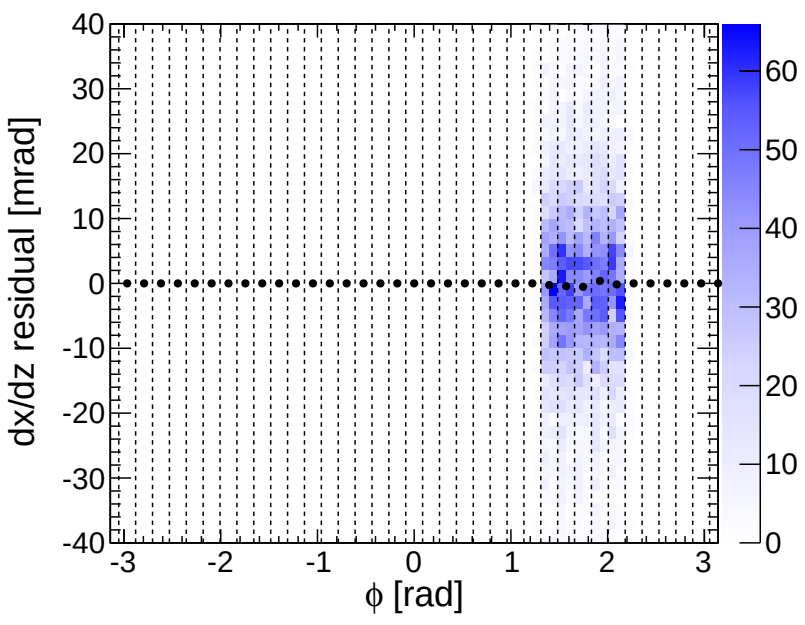
All of the ϕ_y alignment results

ME+4/2

Before



After (1 iteration)

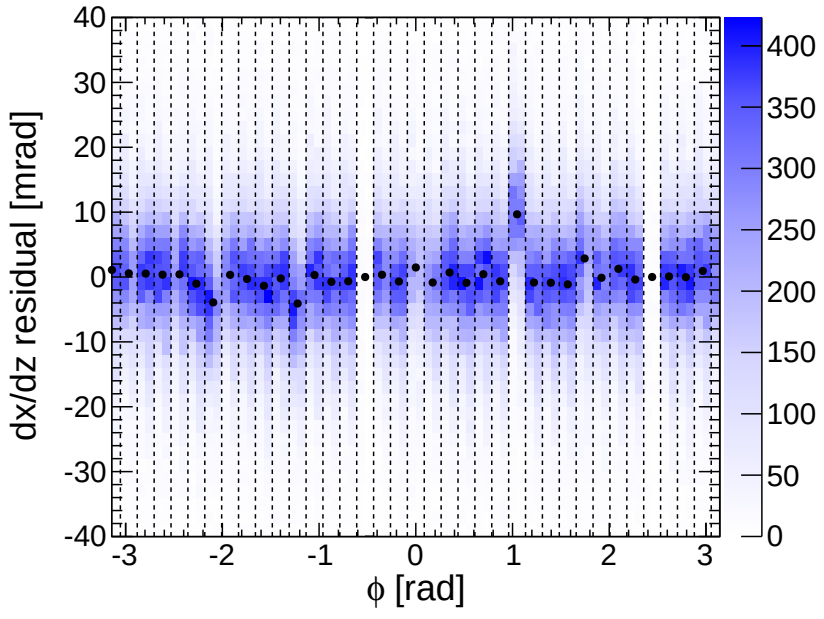


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

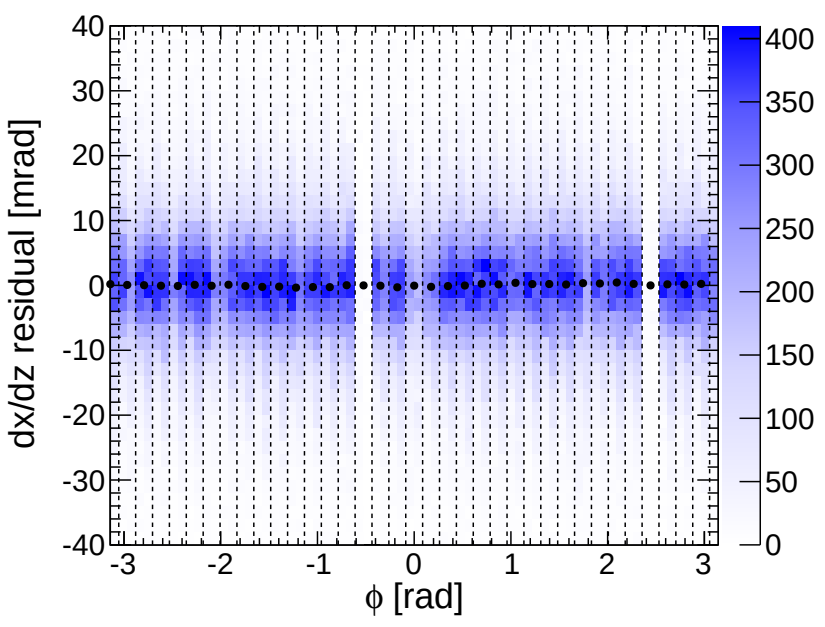
All of the ϕ_y alignment results

ME−1/1 (a and b)

Before



After (1 iteration)

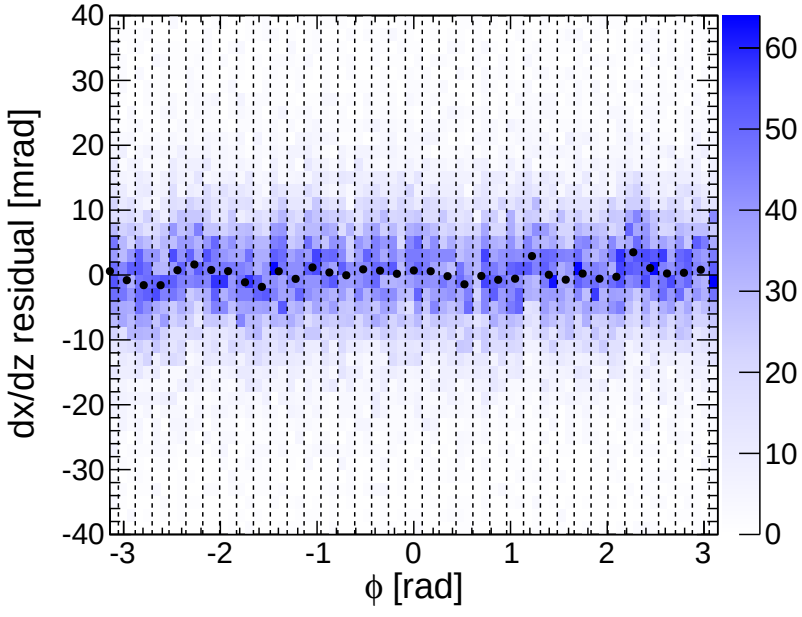


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

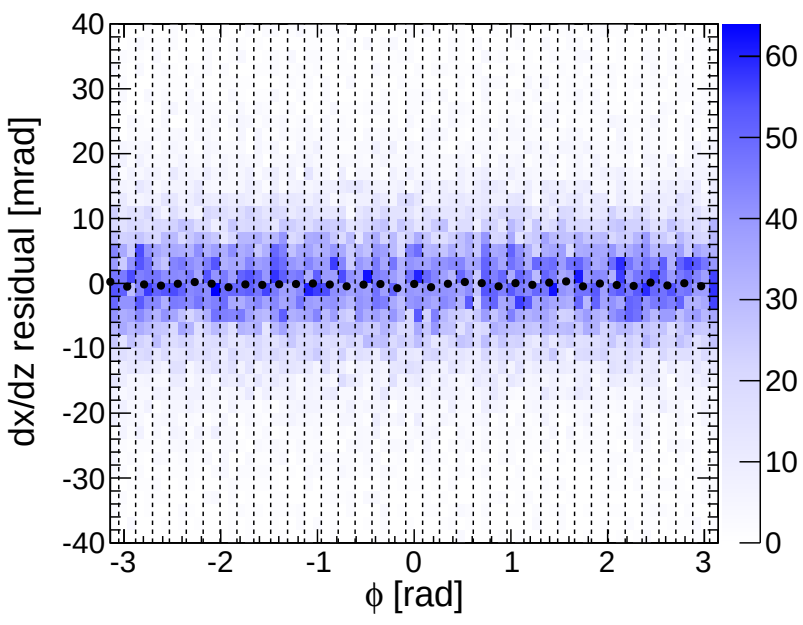
All of the ϕ_y alignment results

ME−1/2

Before



After (1 iteration)

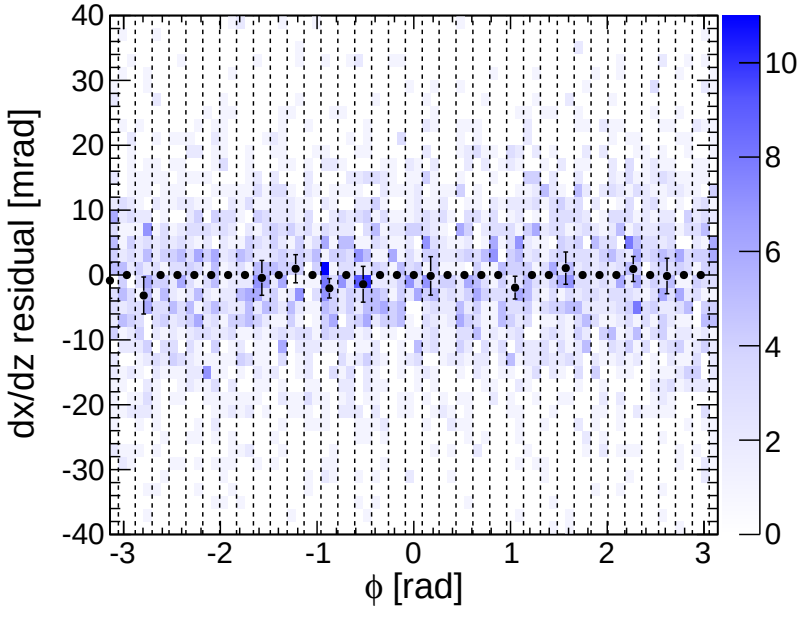


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

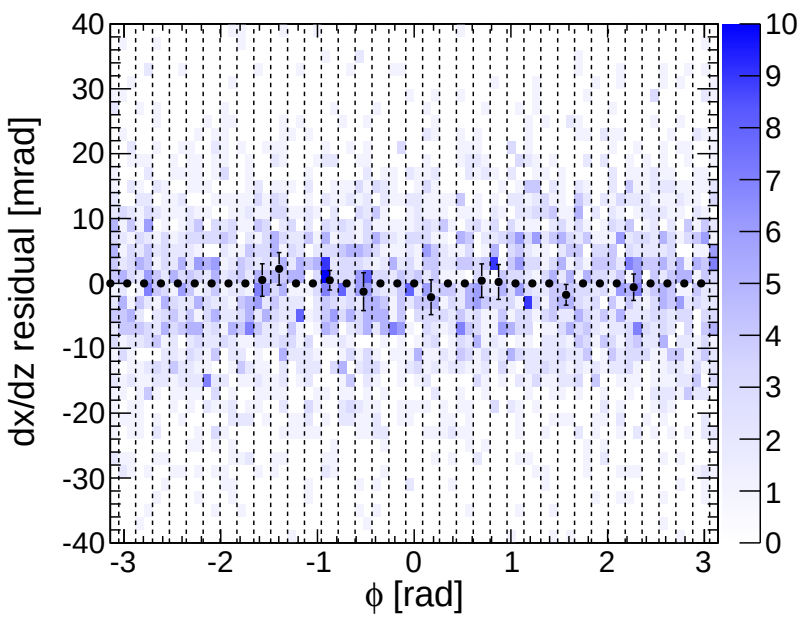
All of the ϕ_y alignment results

ME−1/3

Before



After (1 iteration)

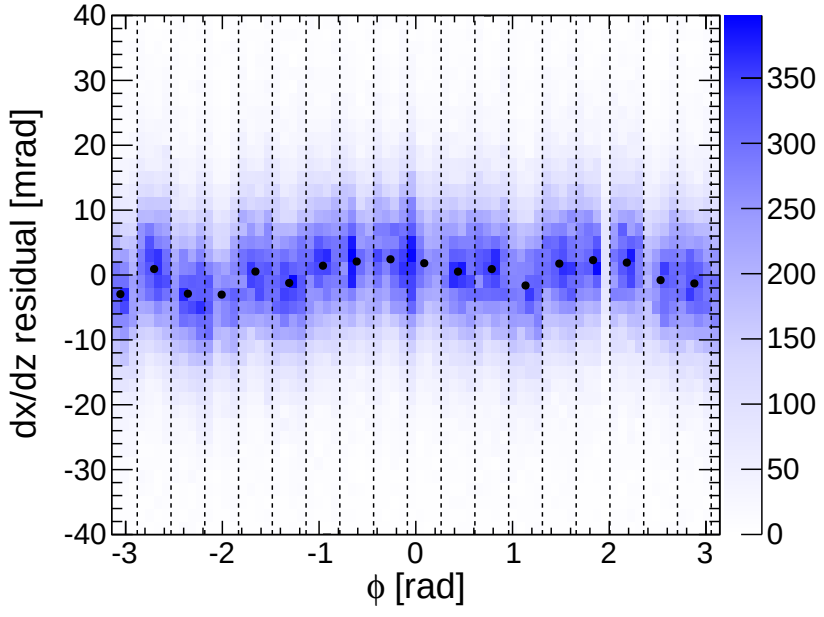


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

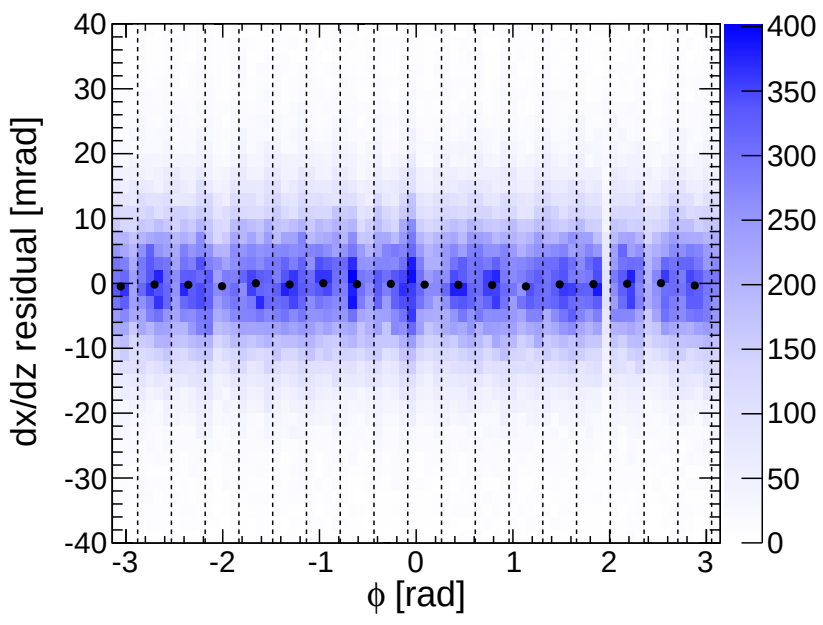
All of the ϕ_y alignment results

ME−2/1

Before



After (1 iteration)

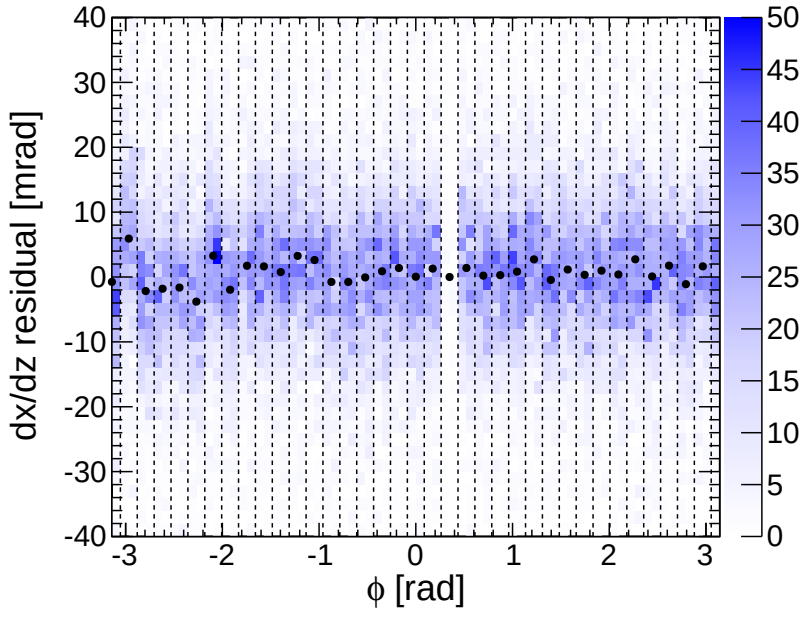


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

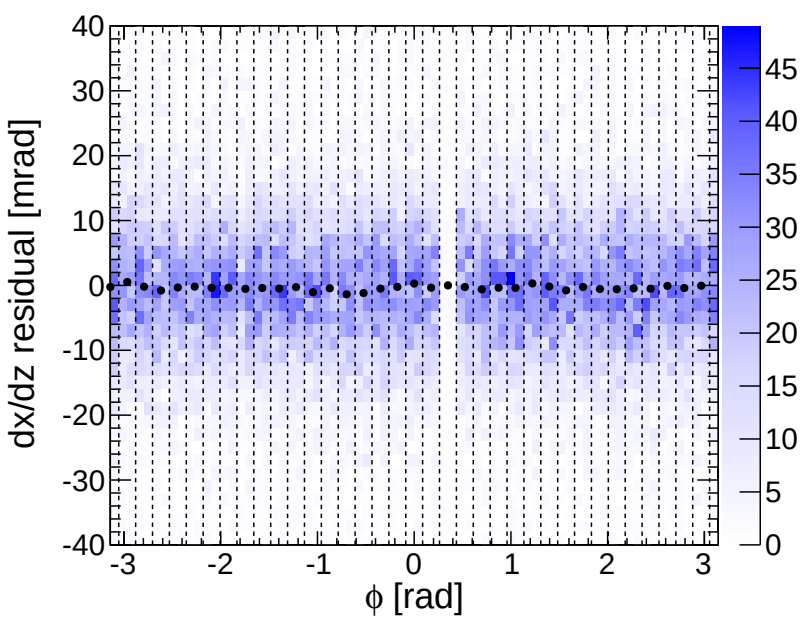
All of the ϕ_y alignment results

ME−2/2

Before



After (1 iteration)

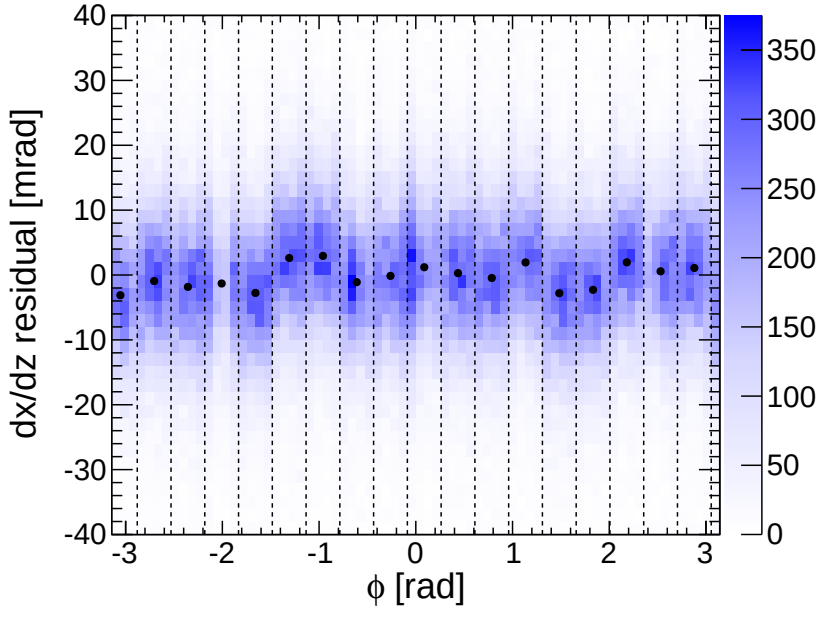


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

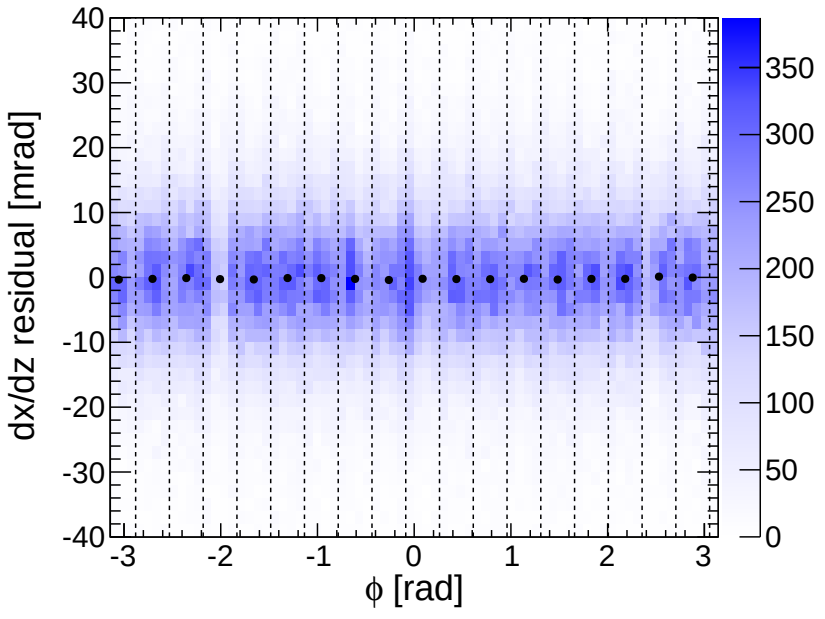
All of the ϕ_y alignment results

ME−3/1 (also shown on page 5)

Before



After (1 iteration)

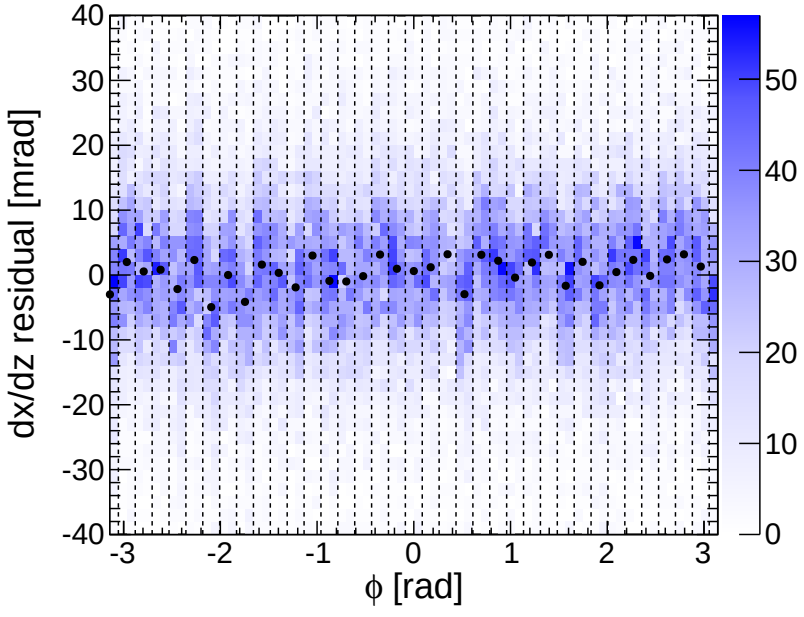


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

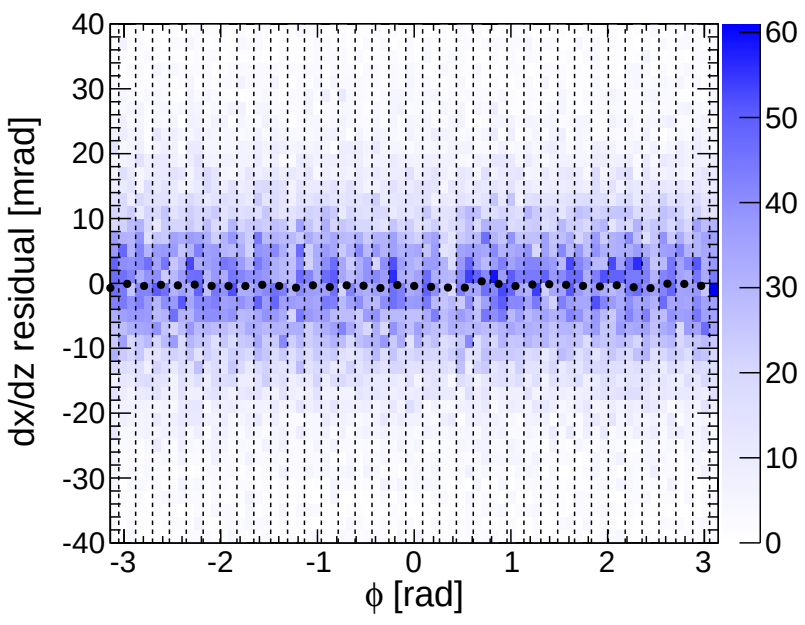
All of the ϕ_y alignment results

ME−3/2

Before



After (1 iteration)

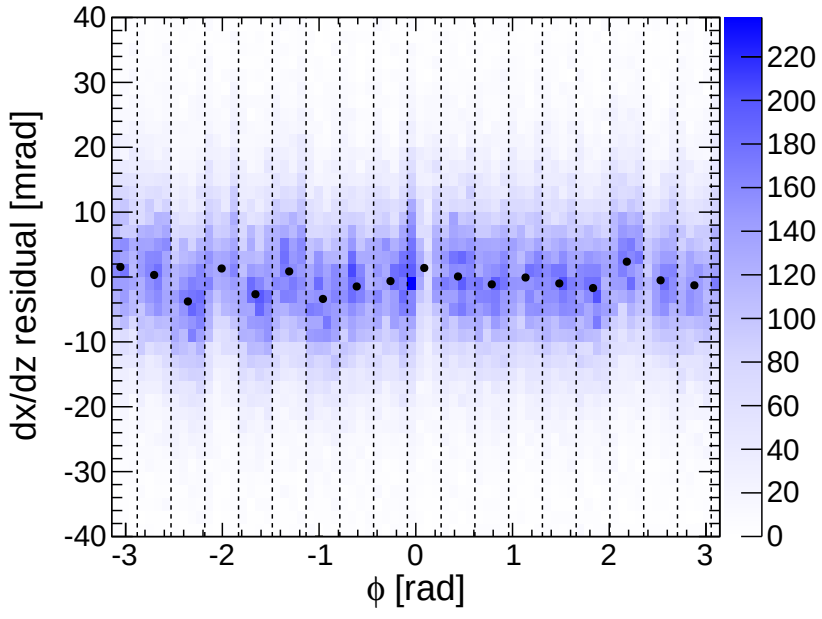


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

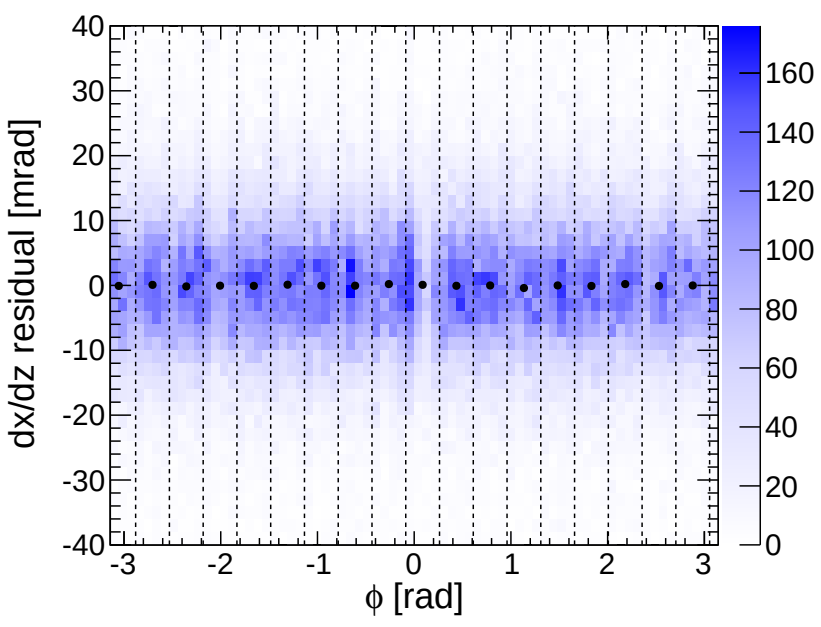
All of the ϕ_y alignment results

ME−4/1

Before



After (1 iteration)

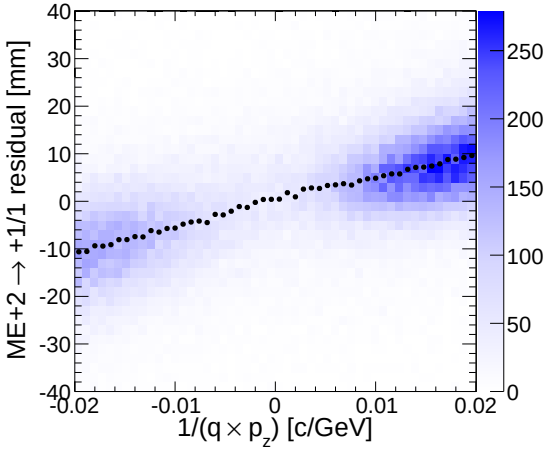


- Blue background is the dx/dz residuals distribution vs. ϕ from TrackerMuons; dashed lines are the chamber boundaries
- Black points are the actual corrections (zero if fewer than 30 hits or uncertainty is larger than 3 mrad), derived from a Gaussian fit from $-2\times$RMS to $2\times$RMS

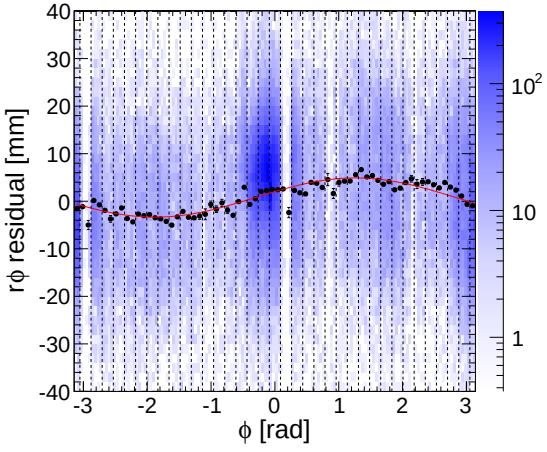
All of the beam-halo results

ME+2 → ME+1/1 (a and b)

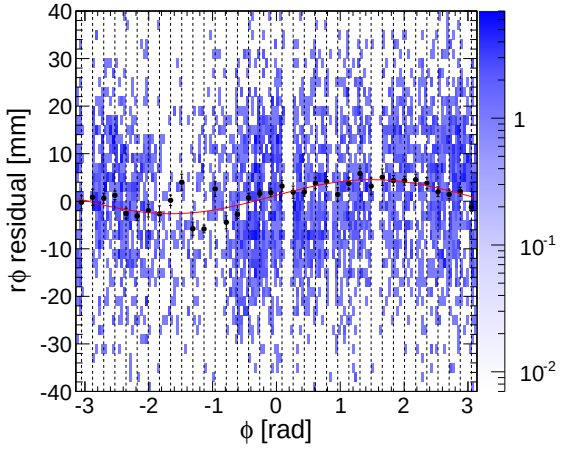
vs. momentum (aligned)



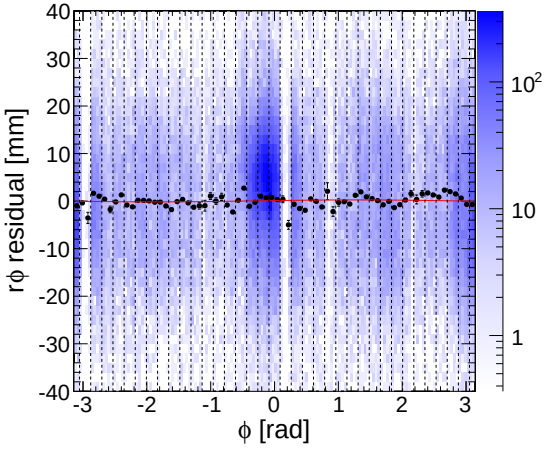
vs. ϕ (unaligned)



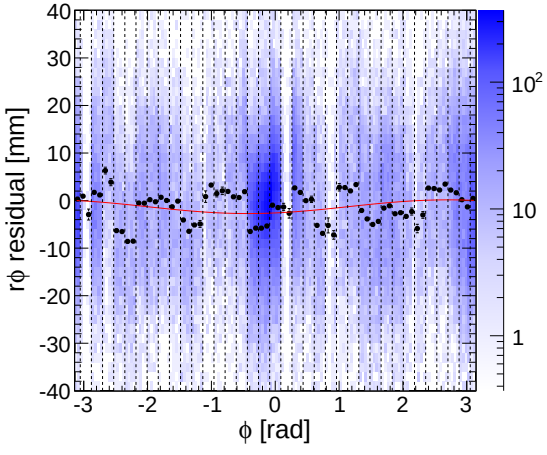
TCT (unaligned)



vs. ϕ (aligned)



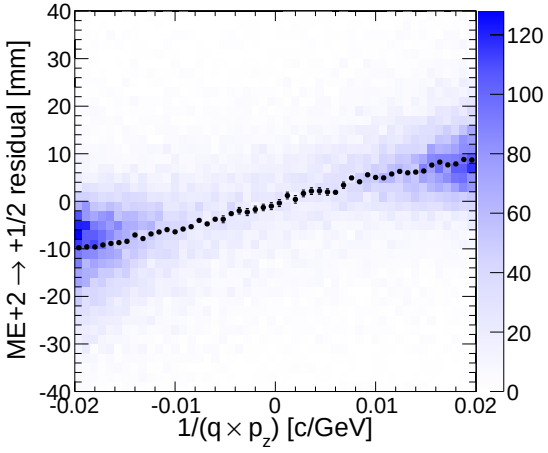
without ϕ_y alignment



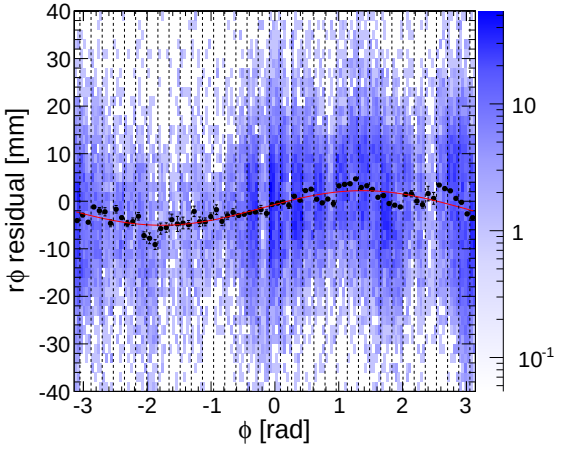
All of the beam-halo results

ME+2 → ME+1/2 and 1/3

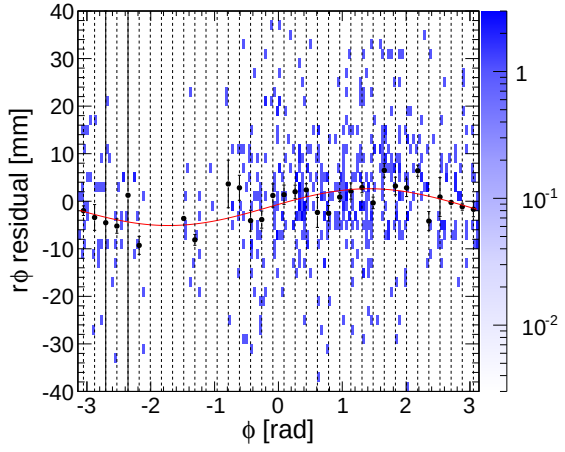
vs. momentum (aligned)



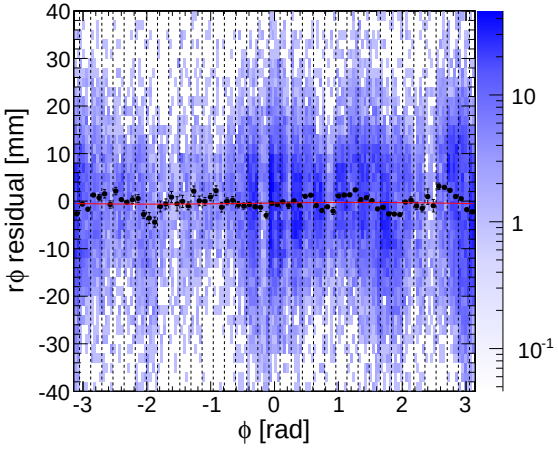
vs. ϕ (unaligned)



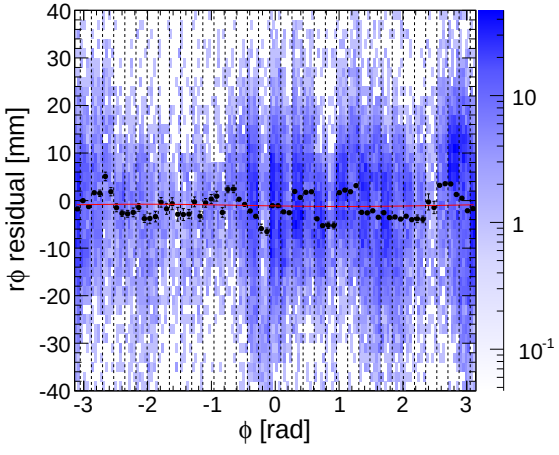
TCT (unaligned)



vs. ϕ (aligned)



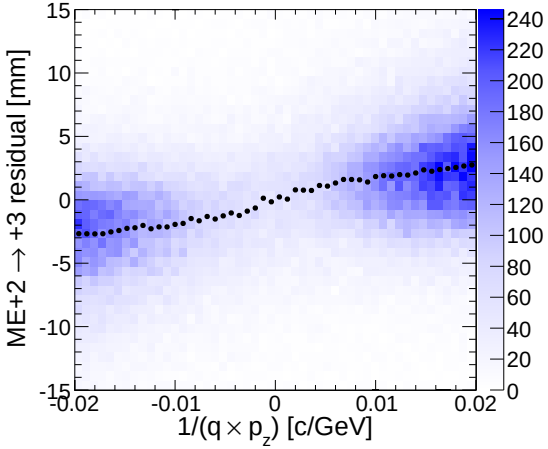
without ϕ_y alignment



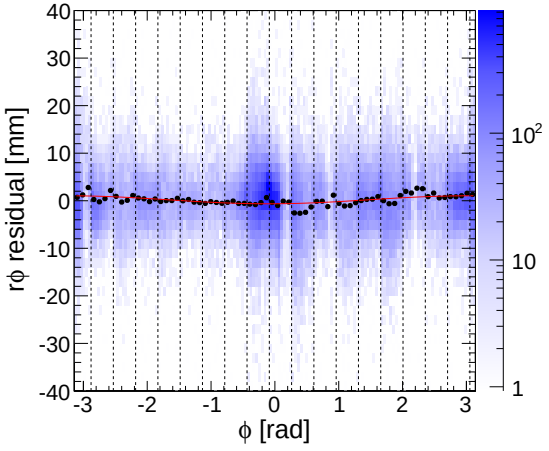
All of the beam-halo results

ME+2 → ME+3

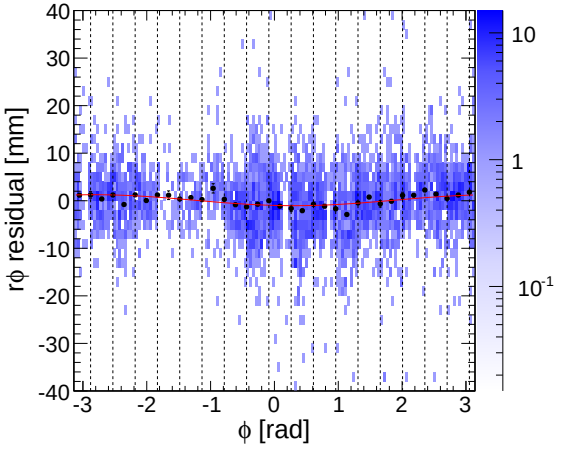
vs. momentum (aligned)



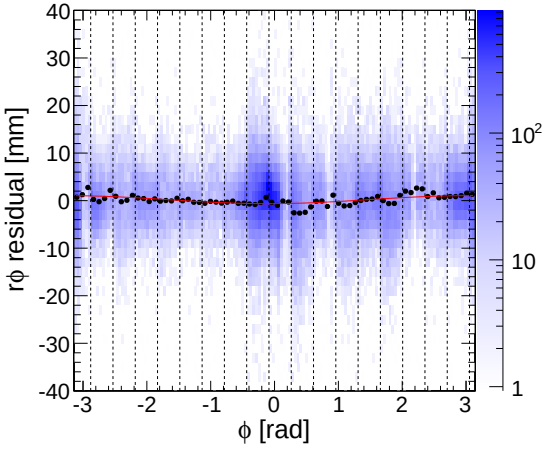
vs. ϕ (unaligned)



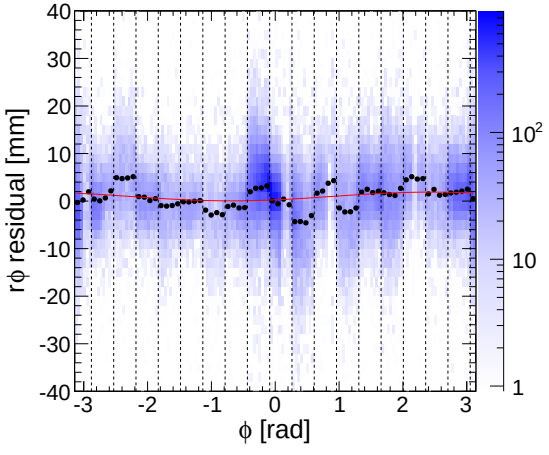
TCT (unaligned)



vs. ϕ (aligned)



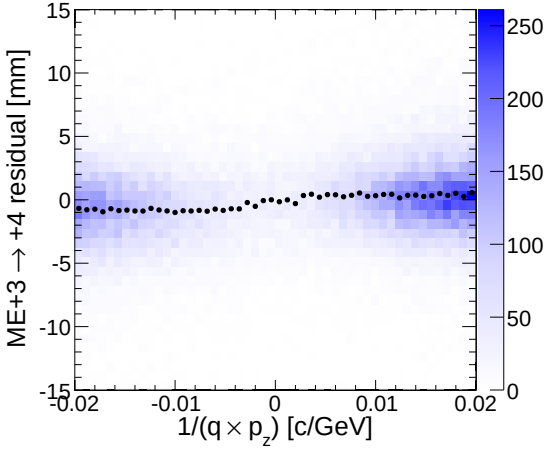
without ϕ_y alignment



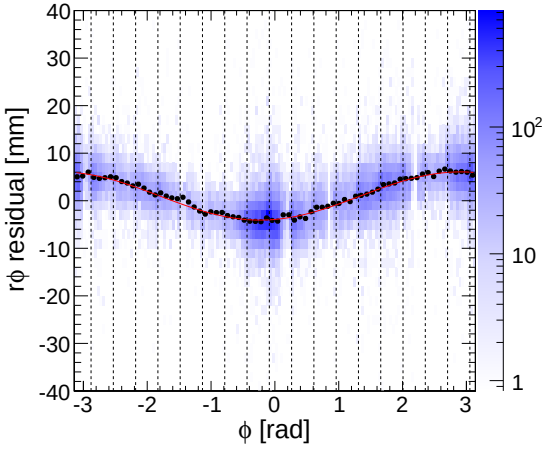
All of the beam-halo results

ME+3 → ME+4

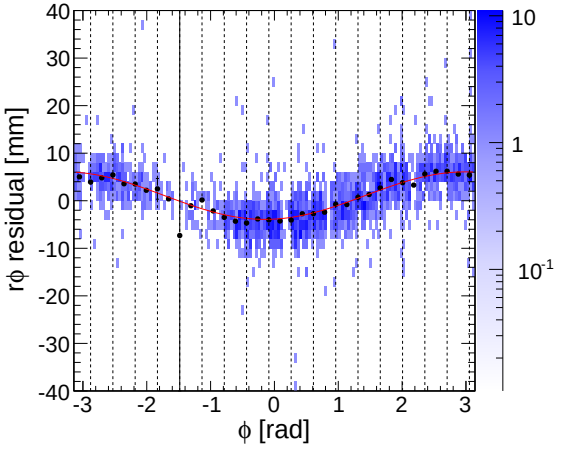
vs. momentum (aligned)



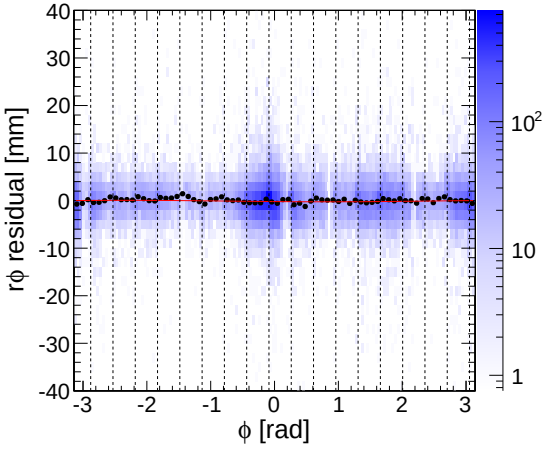
vs. ϕ (unaligned)



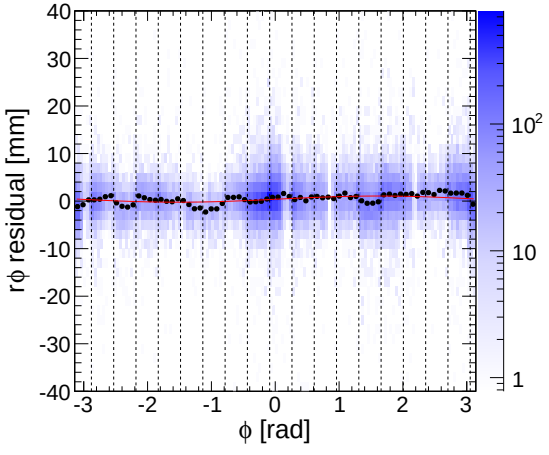
TCT (unaligned)



vs. ϕ (aligned)



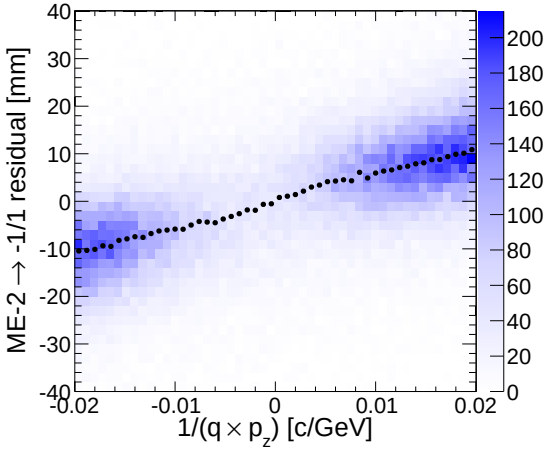
without ϕ_y alignment



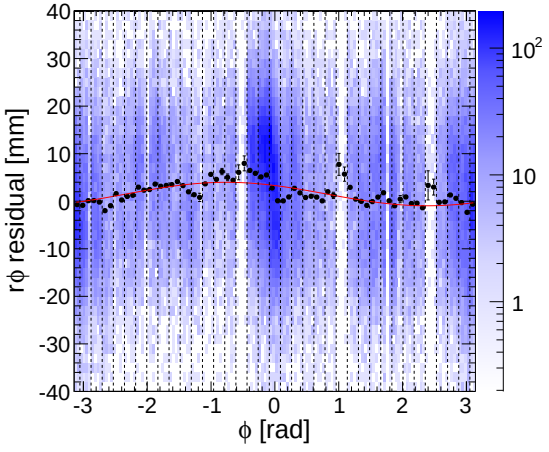
All of the beam-halo results

ME−2 → ME−1/1 (a and b)

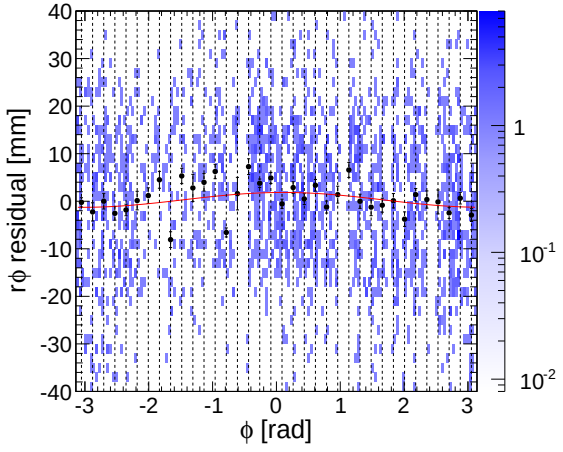
vs. momentum (aligned)



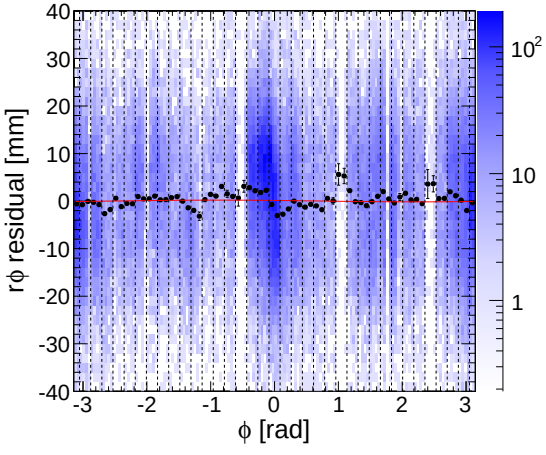
vs. ϕ (unaligned)



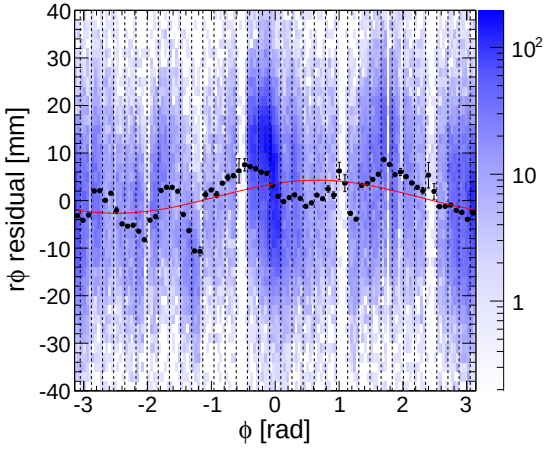
TCT (unaligned)



vs. ϕ (aligned)



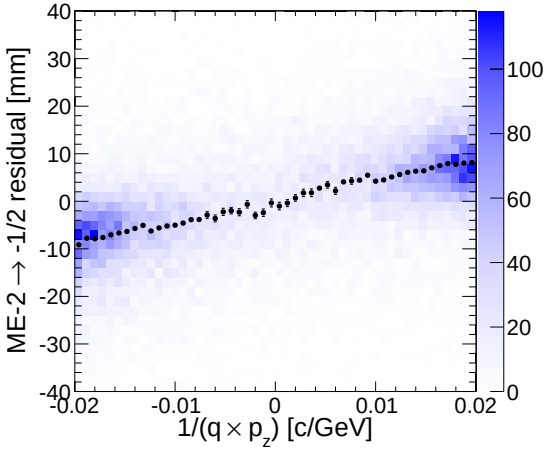
without ϕ_y alignment



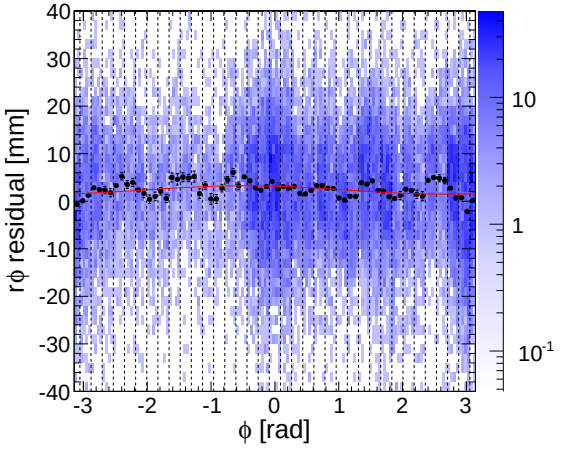
All of the beam-halo results

ME−2 → ME−1/2 and 1/3

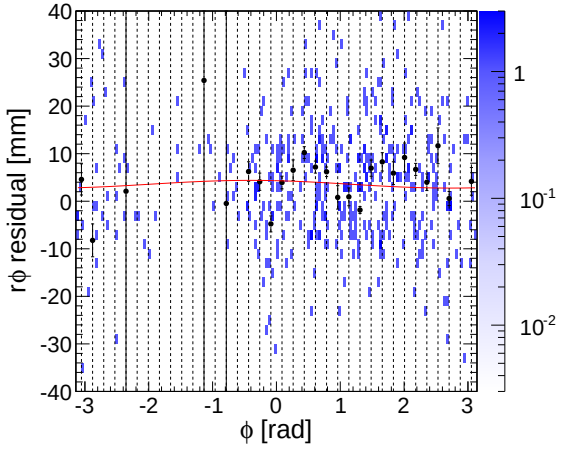
vs. momentum (aligned)



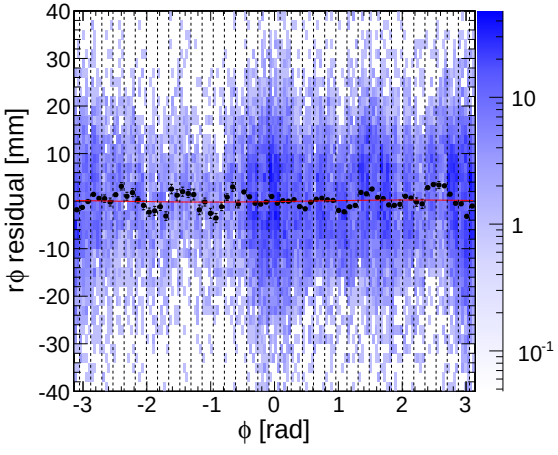
vs. ϕ (unaligned)



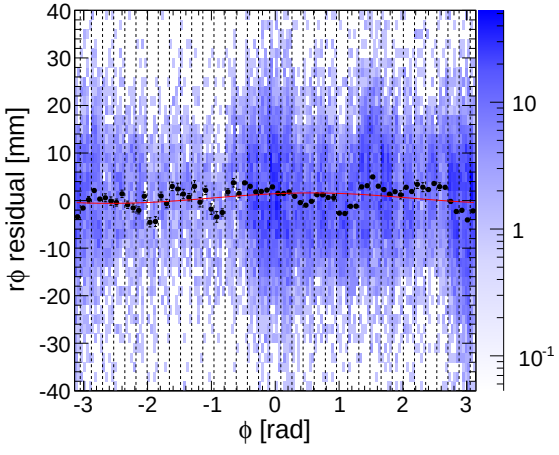
TCT (unaligned)



vs. ϕ (aligned)



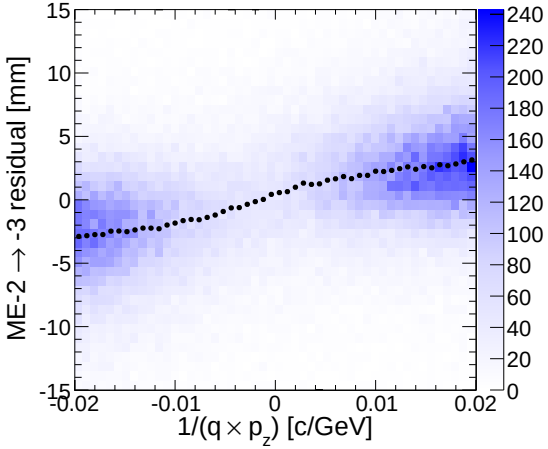
without ϕ_y alignment



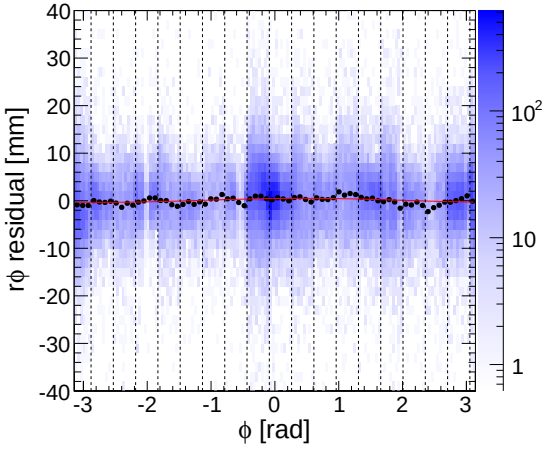
All of the beam-halo results

ME−2 → ME−3

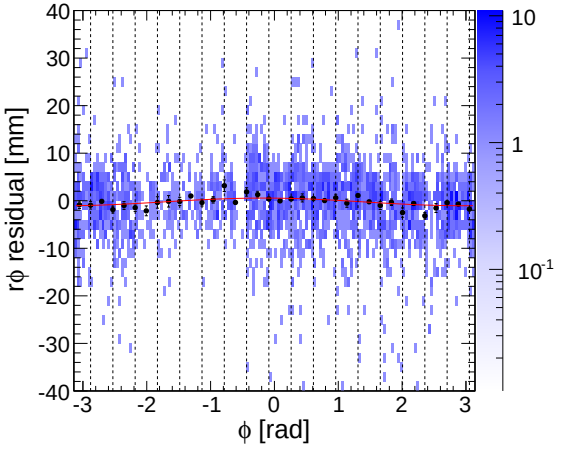
vs. momentum (aligned)



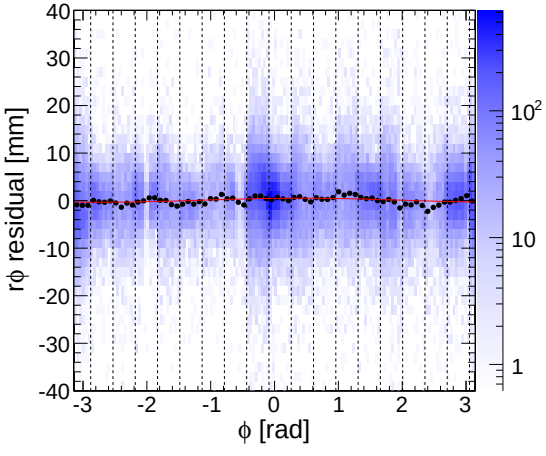
vs. ϕ (unaligned)



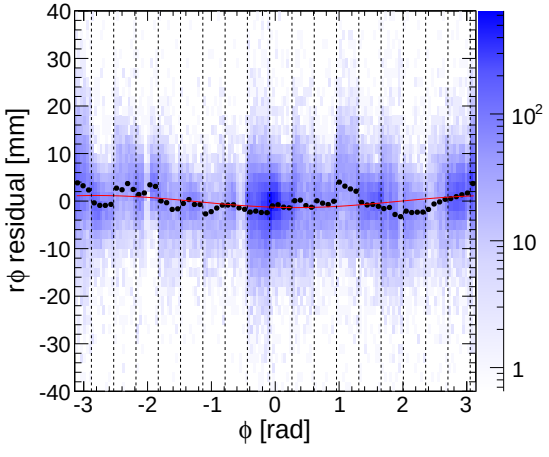
TCT (unaligned)



vs. ϕ (aligned)



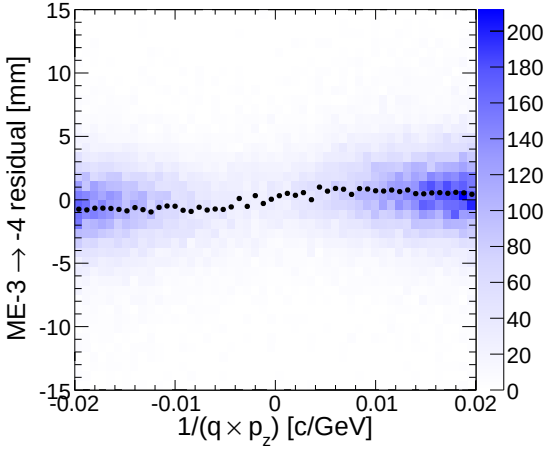
without ϕ_y alignment



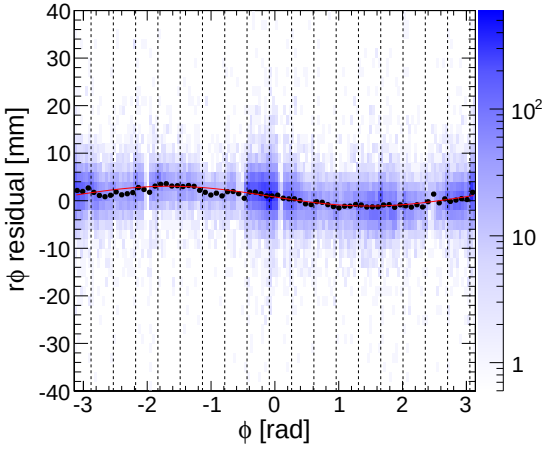
All of the beam-halo results

ME−3 → ME−4

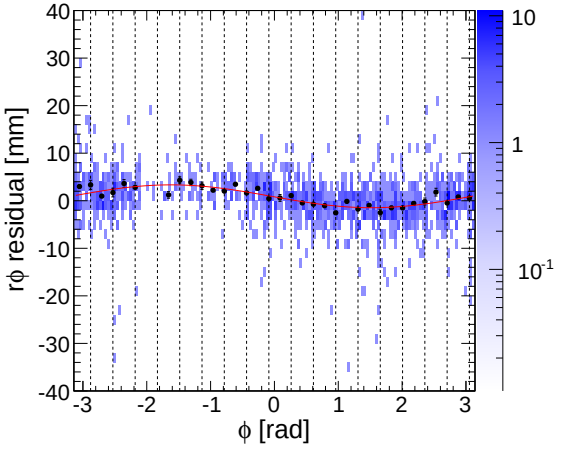
vs. momentum (aligned)



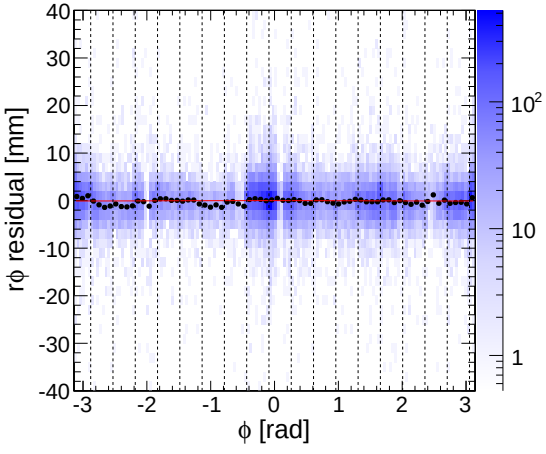
vs. ϕ (unaligned)



TCT (unaligned)



vs. ϕ (aligned)



without ϕ_y alignment