Updated Internal Alignment of CSC Rings

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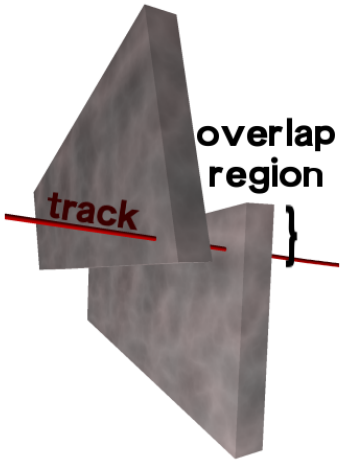
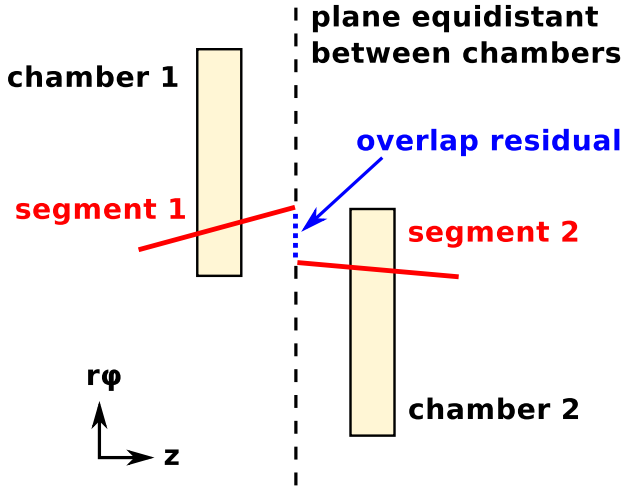
8 November, 2010

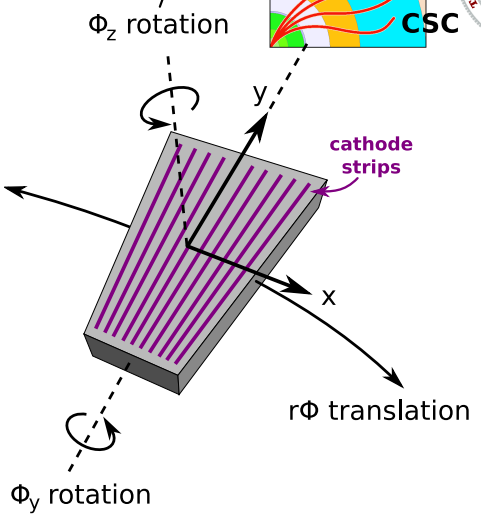
New alignment motivation

- Previous internal ring alignments with beam-halo data:
  - Sep. 2008 "first beam" (9 minutes) with $\vec{B} = 0$, only two rings (ME$-2/1$, $-3/1$), not uploaded to the database
  - Dec. 2009 "first collisions" (21 days) with $\vec{B} = 3.8$ T, too few halo events
  - Mar. 2010 "Tertiary Collimator Triplet (TCT) test" (40 minutes) with $\vec{B} = 3.8$ T, new technique to use photogrammetry to supplement missing overlaps, aligned all chambers: current CSC geometry
- Jun.–Sep. 2010 beam-halo during collisions (83 days):
  - 10$\times$ more events than the TCT dataset
  - collisions muons allow us to pre-align ϕ_y (potentially reduces a systematic error)
  - proposed new internal alignment (to be combined with whole-ring alignments)

Reminder of the method





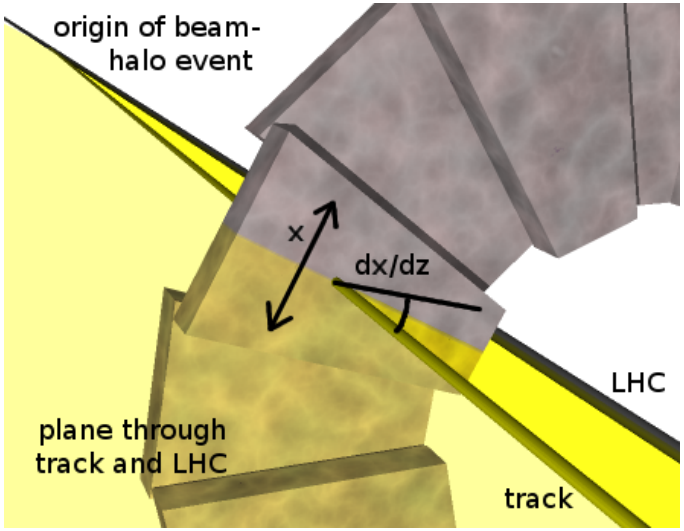


1. Align ϕ_y angles from collisions (next slide)
2. Select beam-halo tracks that cross overlap of neighboring CSCs
3. Quantify relative misalignment of the two chambers with overlap residual (above)
4. Solve for best fit of all relative measurements:

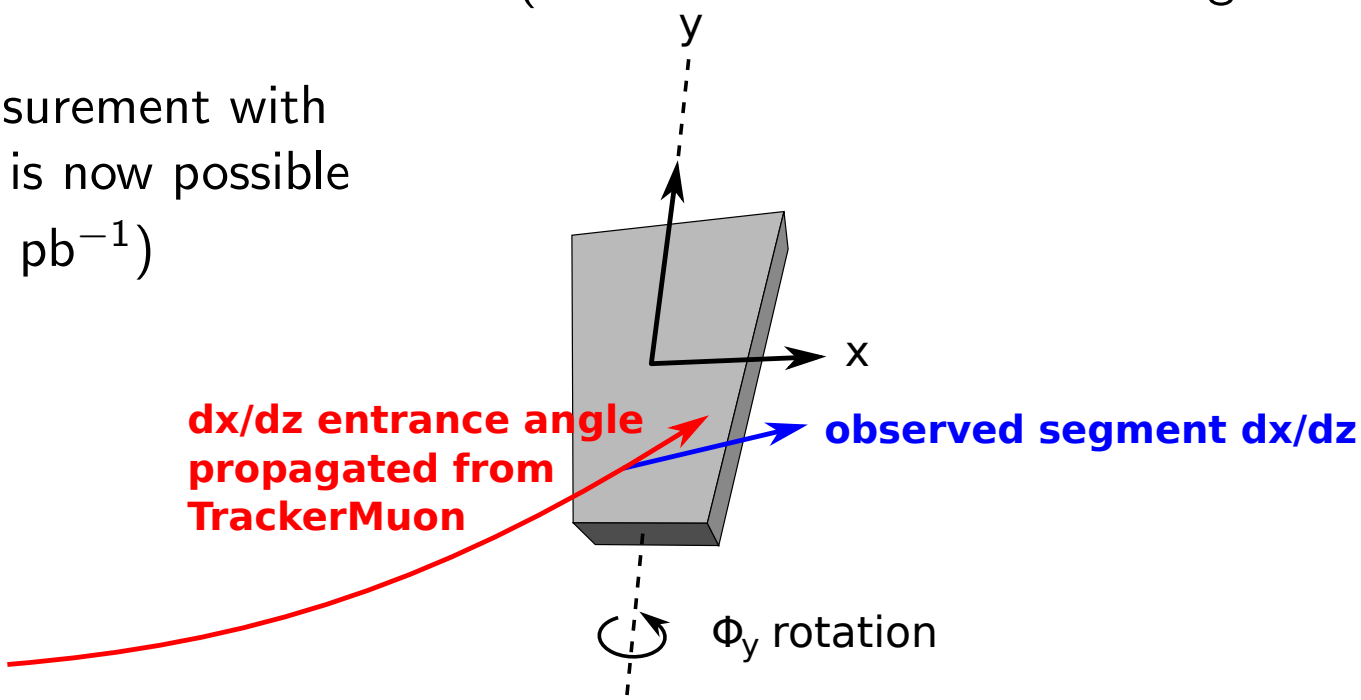
$$\chi^2 = \sum_{m_{ij}}^{\text{constraints}} \frac{(m_{ij} - A_i + A_j)^2}{{\sigma_{ij}}^2} + \text{ Lagrange multiplier}$$

where $m_{ij} \pm \sigma_{ij}$ is a measurement between i and j and A_i, A_j are alignment corrections (variables to minimize χ^2) in $r\phi$ and ϕ_z

ϕ_y pre-alignment

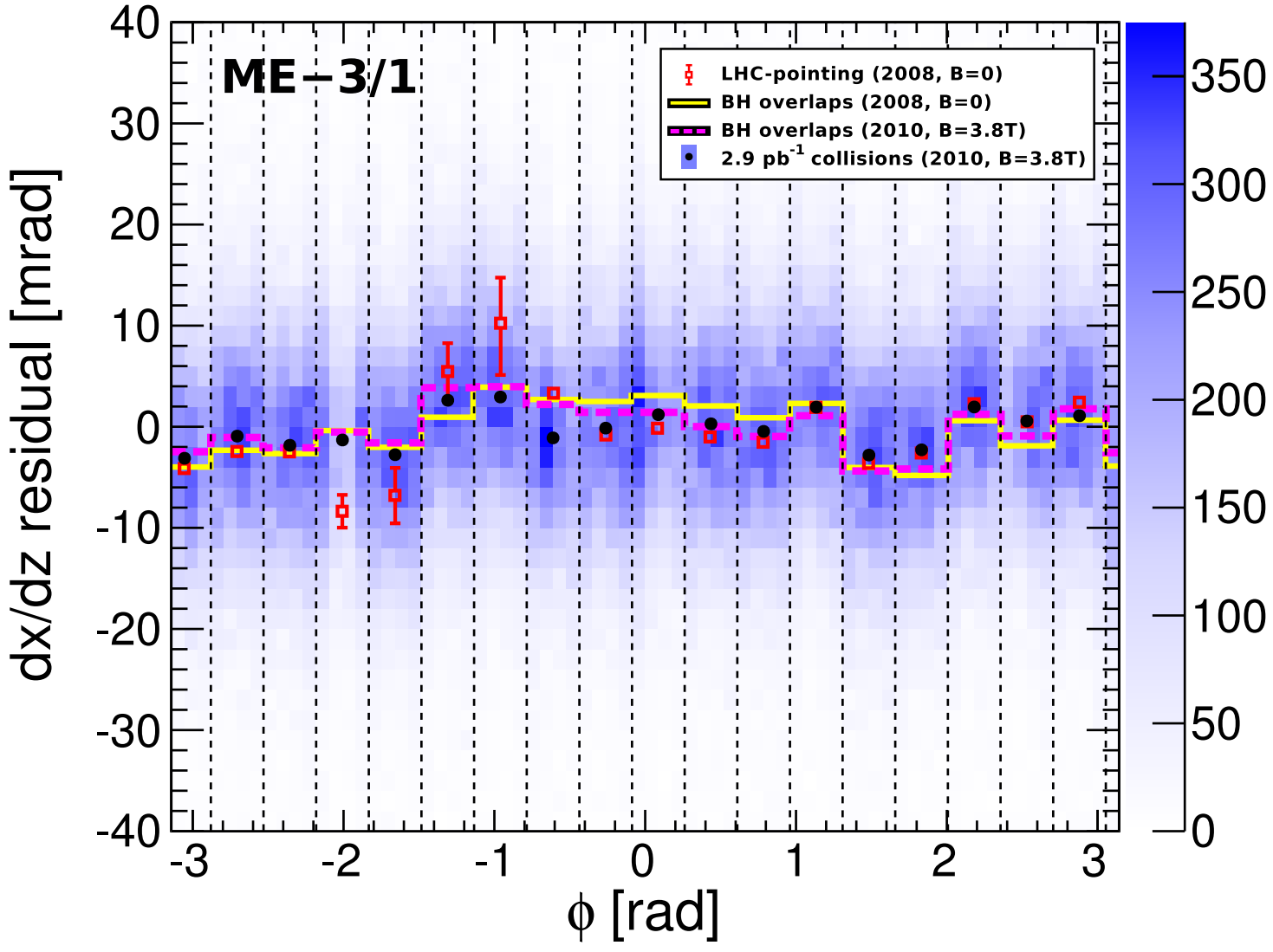


- ϕ_y not measured by photogrammetry
- First ϕ_y alignment attempt with 2008 $\vec{B} = 0$ data by assuming that beam-halo points back to a long, straight LHC beamline (not used)
- Attempted to align ϕ_y with beam-halo overlaps method, but resolution is poor (fixed to zero in Mar. 2010 alignment)
- New measurement with collisions is now possible (used 2.9 pb^{-1})



ϕ_y pre-alignment

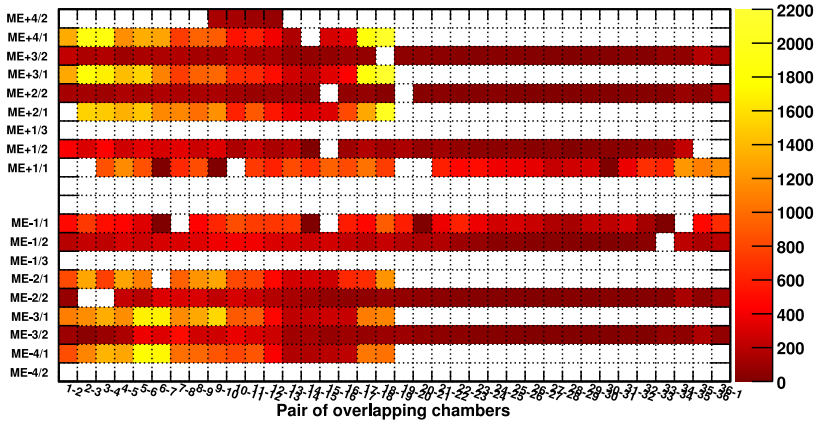
Comparison of 3 (4?) methods over the years: (now using collisions)



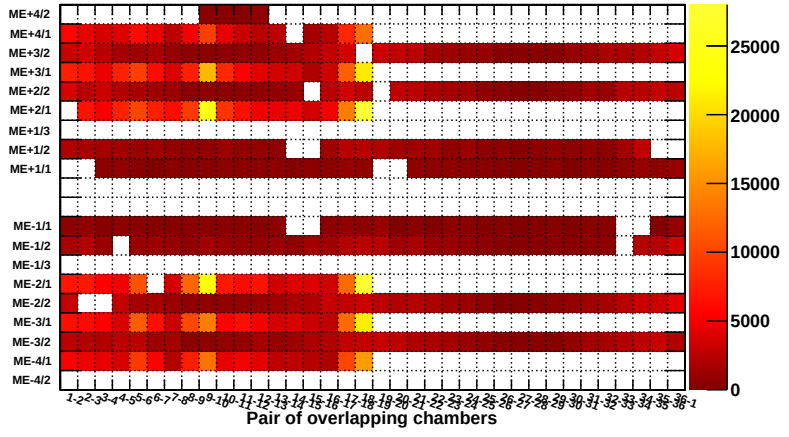
Beam-halo data quality

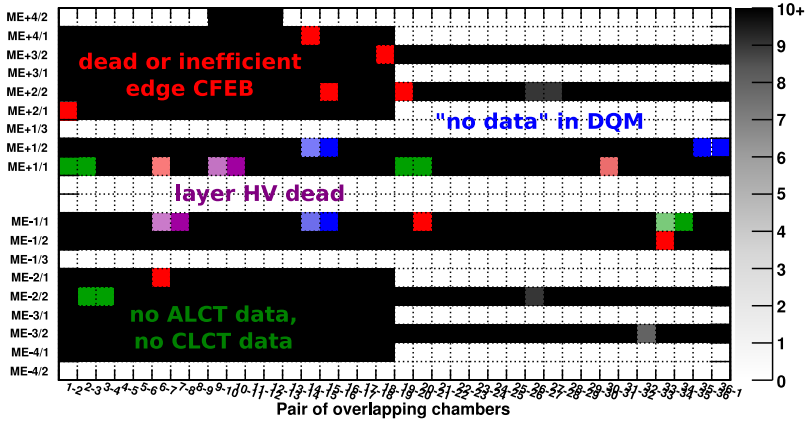
- Occupancy maps of the overlap regions (bottom: suppressed scale)
- 7 problems were fixed (all in ME1/1); 1 new problem (ME−1/2/4-5)

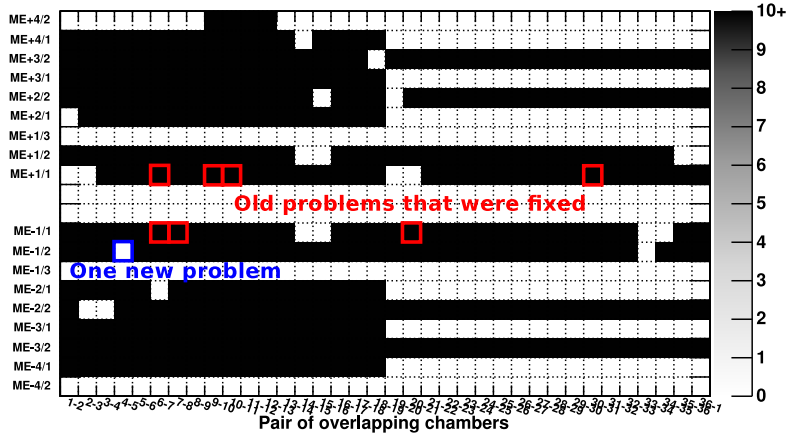
Mar. 2010 (TCT)



Summer 2010 (collisions)

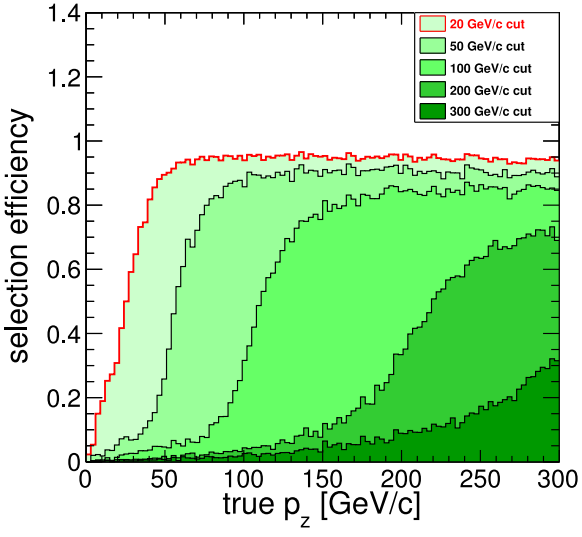


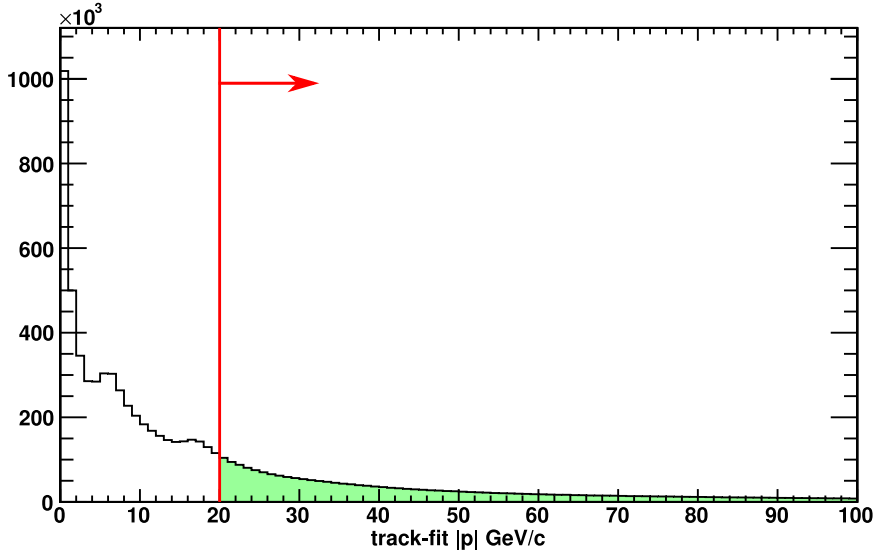




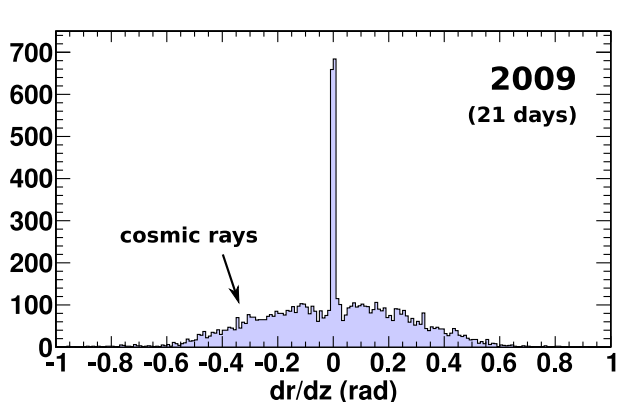
Beam-halo data quality

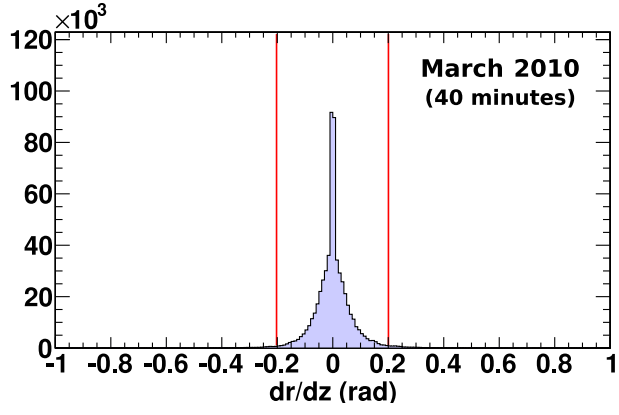
- Momentum cut ($|\vec{p}|$ measured primarily by *radial* magnetic field)

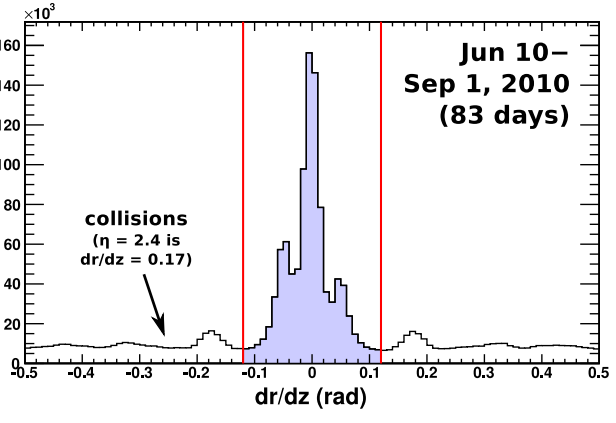




- Radial entrance angle dr/dz (horizontalness)

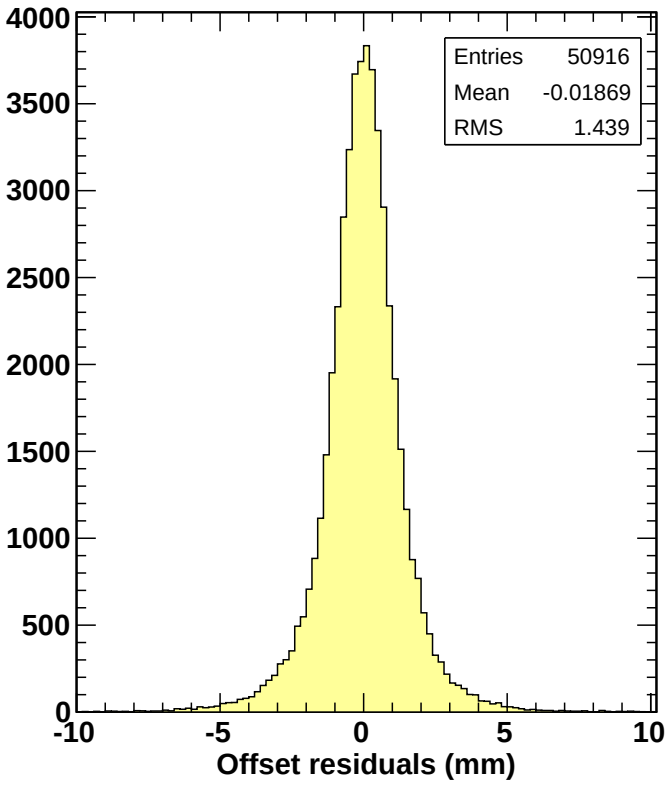


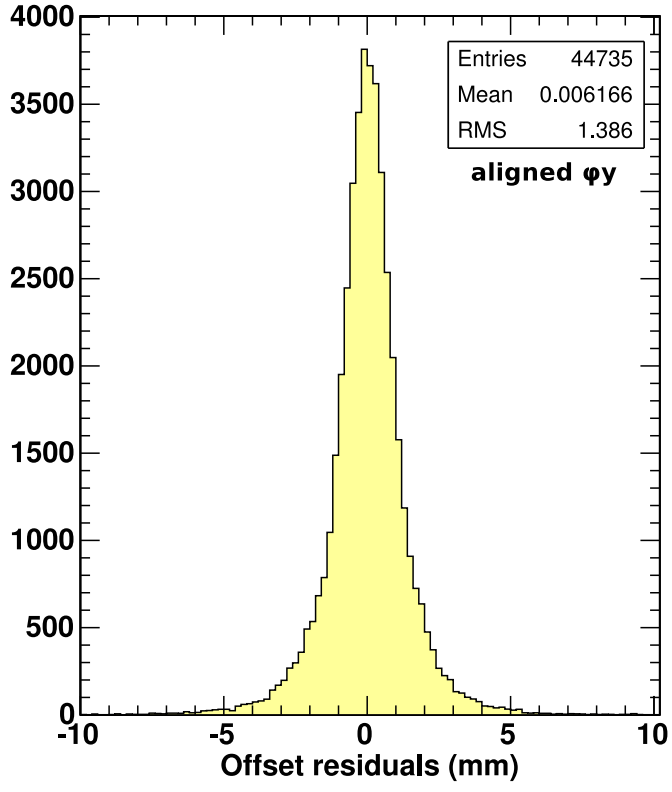




Residuals

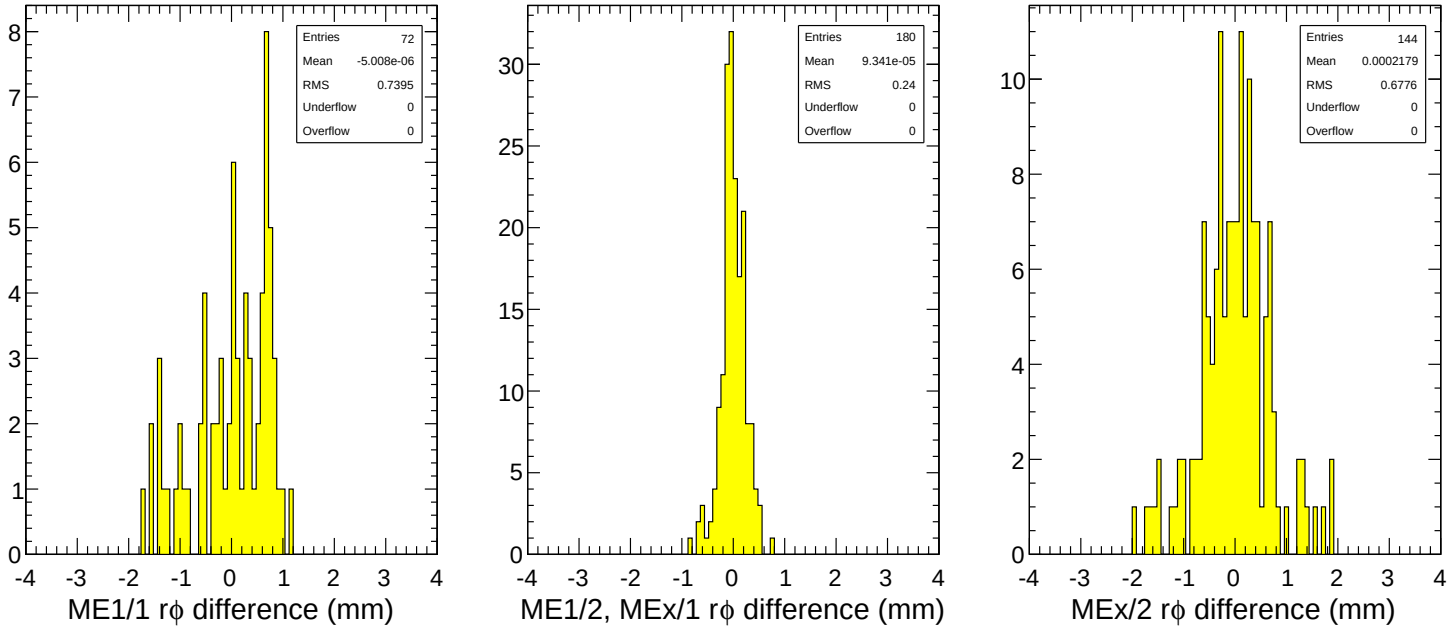
- The short track-segments used in overlaps alignment are not very sensitive to the size of the ϕ_y corrections (nor are the final results)





Results: March → summer

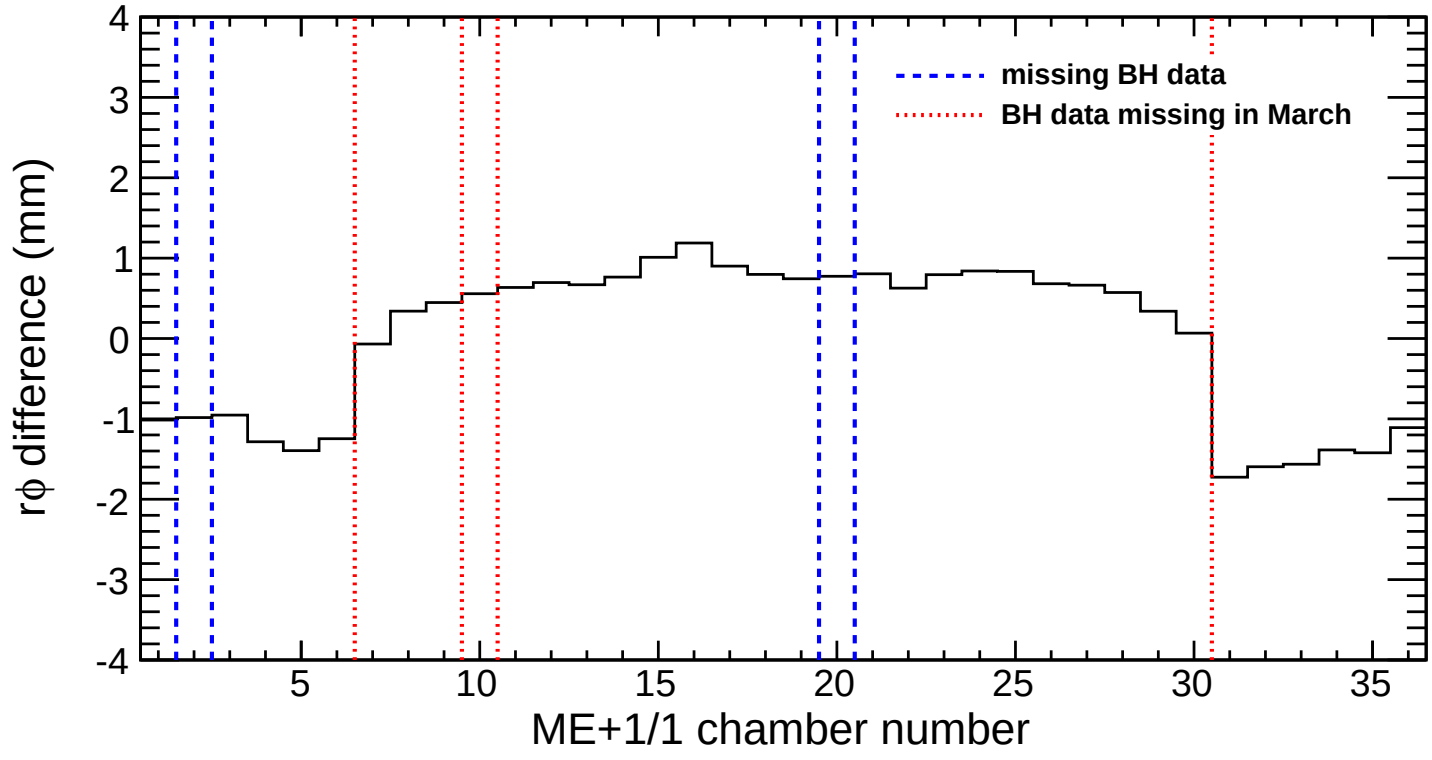
- Differences in $r\phi$ chamber positions between March and summer:



- ME1/1 benefited from the corrected chambers (next page)
- ME1/2, $x/1$ (where $x \geq 2$) are closest to the beam: always get high beam-halo statistics
- MEx/2 benefited the most from the 10× increase in statistics

Results: March → summer

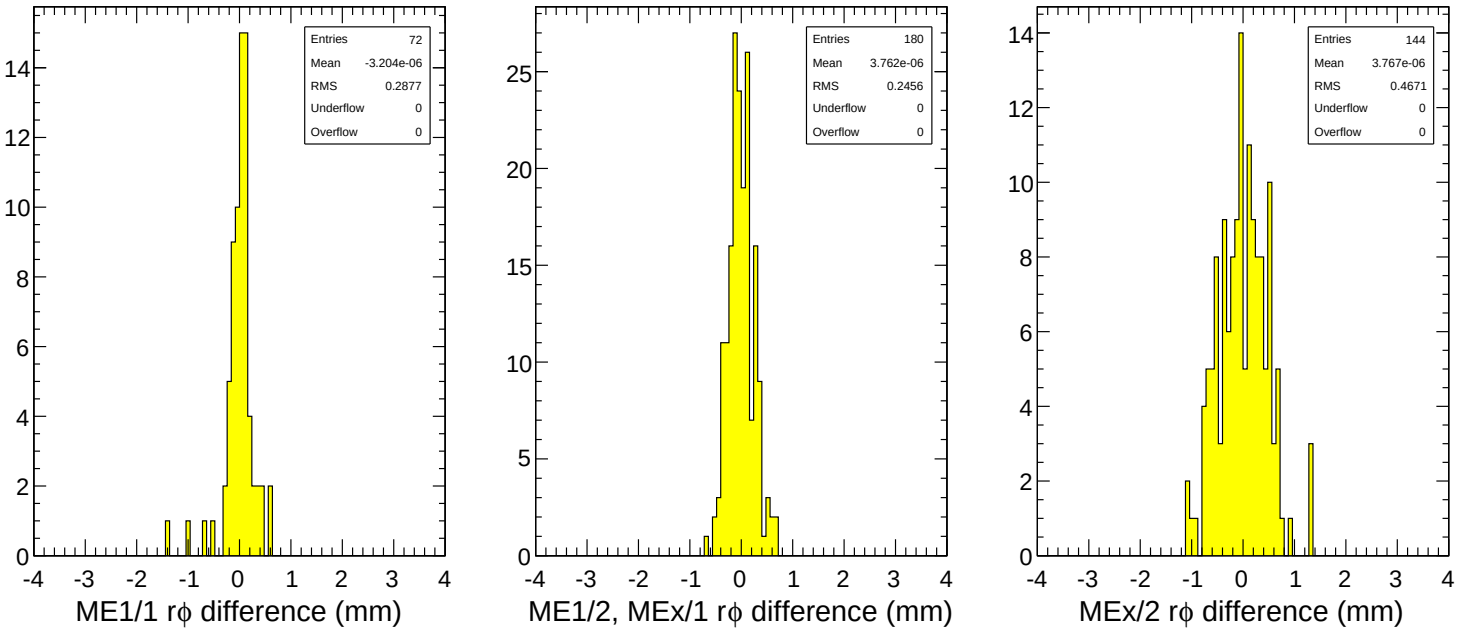
- Biggest ME1/1 March → summer differences in the interfaces between ME+1/1/6-7 and 30-31
- These are two of the missing-data overlaps in March that have since been repaired:



- Technique of constraining missing information with photogrammetry doesn't work in ME1/1 (no photogrammetry)

Results: no $\phi_y \rightarrow$ with ϕ_y

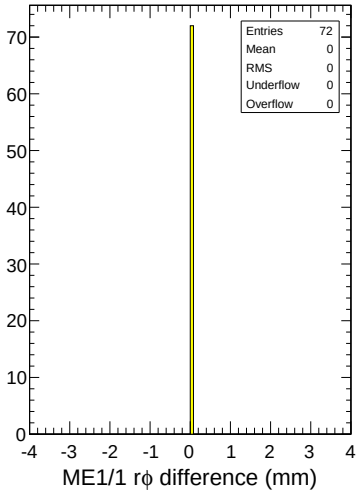
- Differences in $r\phi$ chamber positions with and without the ϕ_y pre-alignment:

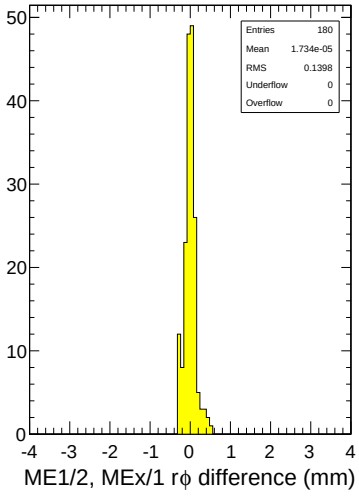


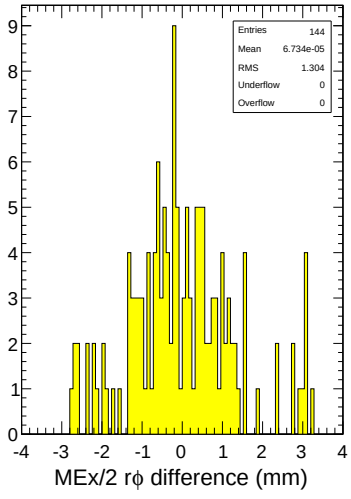
- 0.25–0.50 mm sensitivity

Results: no PG → with PG

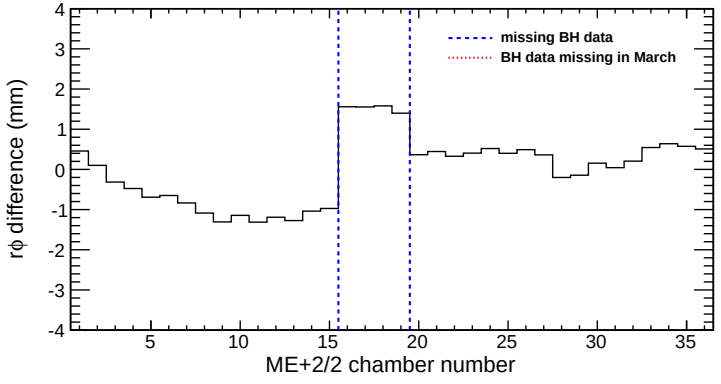
- Photogrammetry constraint makes a big difference in outer rings:

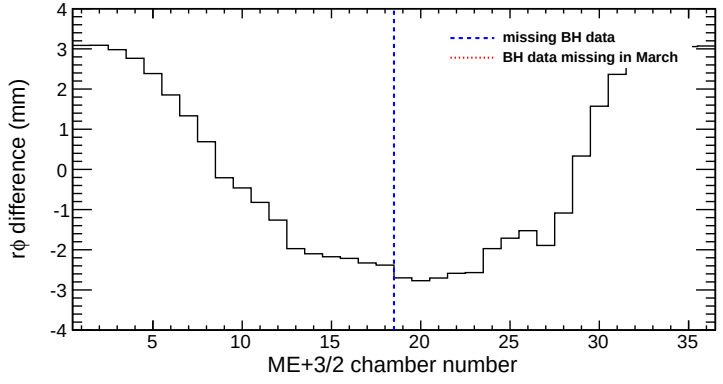




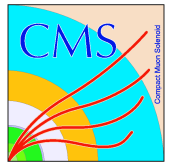


- ME+2/2: correction mainly at missing overlaps (good)
- ME+3/2: systematic trend for all chambers (bad)





Minimal use of PG



- In the March alignment, the complete set of photogrammetry data was used with the beam-halo data in a combined fit (properly weighted)
- This forces the aligned result to be centered on the photogrammetry's x-y origin (differences appear as sinusoidal deviations in $r\phi$ vs. ϕ curves, most dramatically in ME+3/2)
- This is especially undesirable after the rings have been aligned with respect to the tracker
- Solution: minimize use of constraints
  - only "patch holes" in beam-halo data with photogrammetry
  - only one photogrammetry constraint allowed per ring (this is possible with the current pattern of holes)
  - allow PGFrame to float as a free parameter in the alignment fit

Minimal use of PG

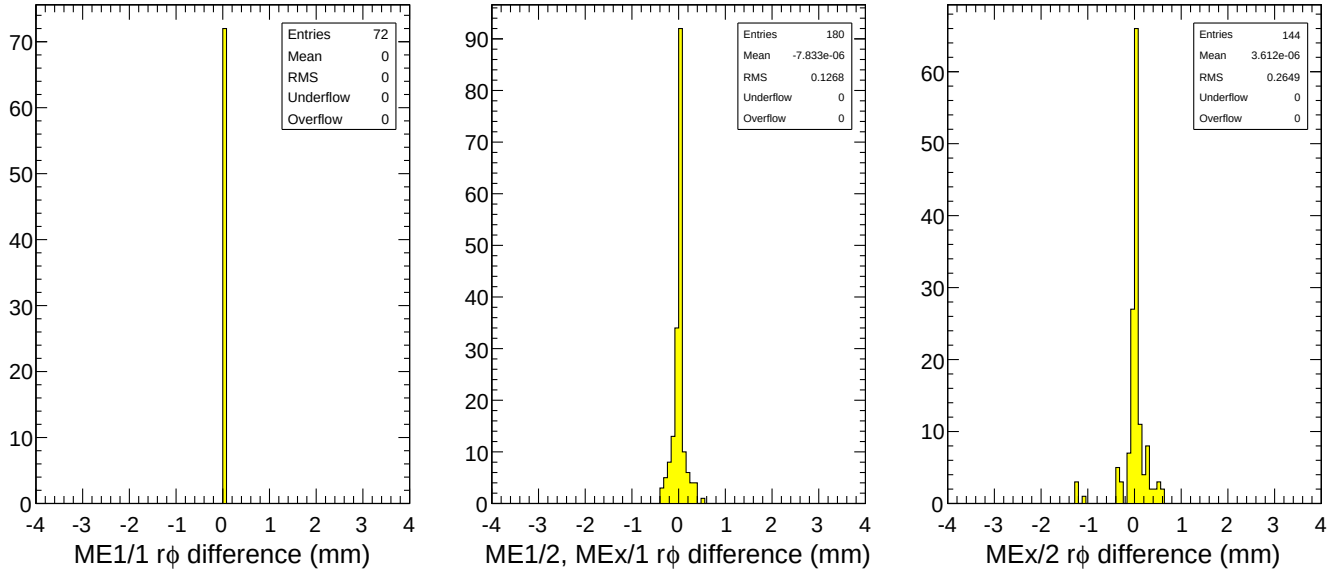
- Complete set of constraints on finalized beam-halo alignment

Photogrammetry constraints	ME+4/1/14 and ME+4/1/15
	ME+3/2/18 and ME+3/2/19
	ME+2/2/19 and ME+2/2/20
	ME+2/1/01 and ME+2/1/02
	ME+1/2/14, ME+1/2/15, and ME+1/2/16
	ME−1/2/33 and ME−1/2/34
	ME−2/1/06 and ME−2/1/07
	ME−2/2/02, ME−2/2/03, and ME−2/2/04

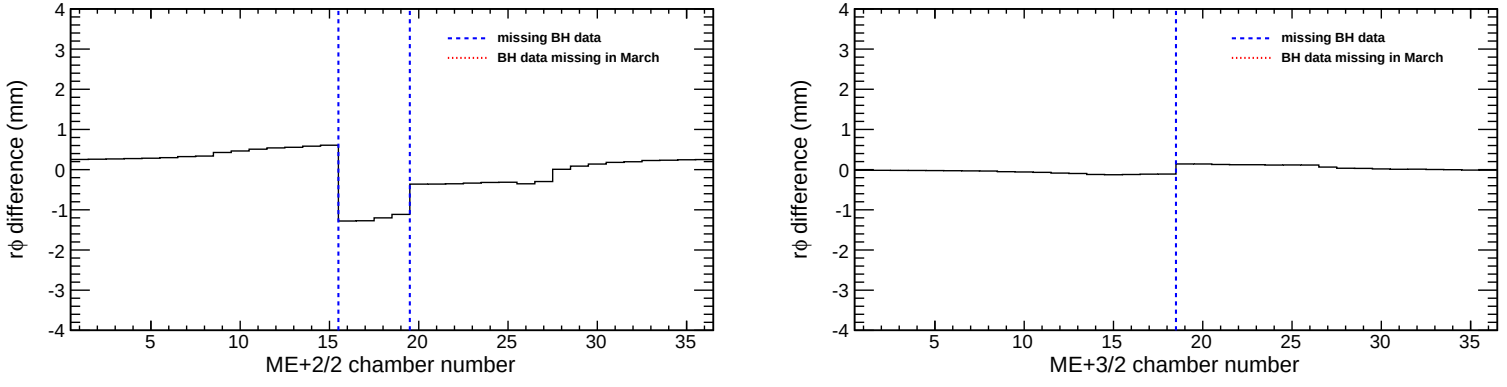
- Also adding measurements from TrackerMuons used to "patch holes" in ME1/1 data (in lieu of photogrammetry)

Constraints from TrackerMuon residuals	ME+1/1/01 and ME+1/1/03
	ME+1/1/19 and ME+1/1/21
	ME+1/1/30 and ME+1/1/31
	ME−1/1/14 and ME−1/1/16
	ME−1/1/33 and ME−1/1/35
	ME−1/1/30 and ME−1/1/31

Results: no PG → minimal PG



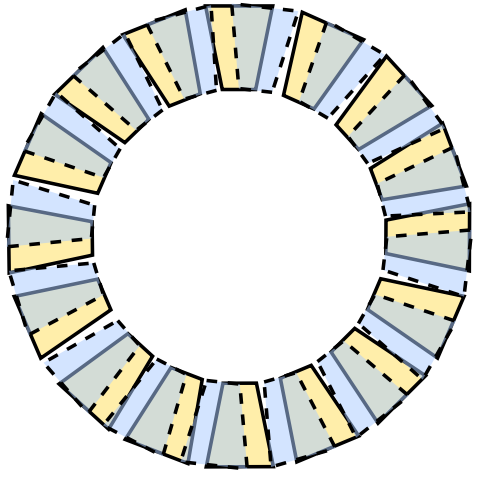
- ME+2/2: still corrects the parts of the ring with missing data
- ME+3/2: no longer pulls the whole ring to a new center



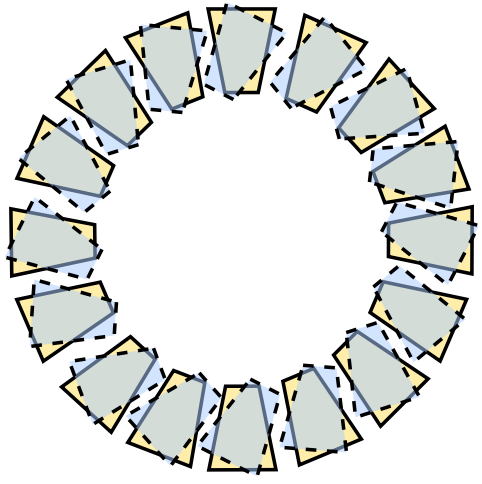
Unconstrained modes of the fit

- By definition, the fit is insensitive to global shifts:

Global shift in rφ

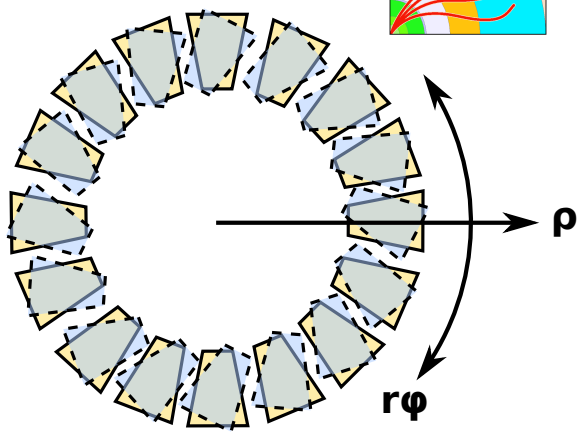


Global shift in φ_z

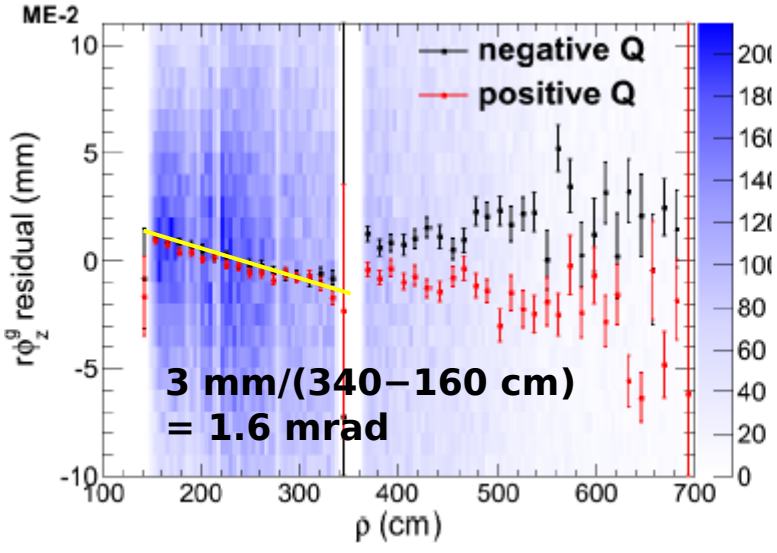


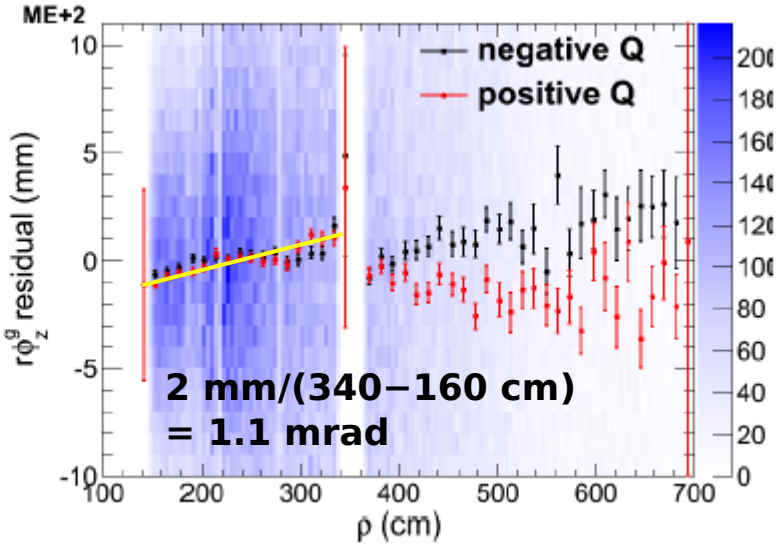
- Global shifts are not introduced by the algorithm: the value of these unmeasured degrees of freedom are set to zero
- The $r\phi$ global shifts are later corrected by the whole-ring position measurement relative to the tracker, so they are resolved in the final geometry
- Any global shifts in ϕ_z are not

Unconstrained modes of the fit



- My observation at the end of the new constants preparation:
- I think we may be seeing evidence for coherent ϕ_z torsion in the TrackerMuon residuals (Vadim's plots)





- Treated as a systematic error in the ring-alignment procedure
- This is the next level of detail, to be corrected in the next round; if the Reference-Target algorithm is applied to collisions, it would be resolved directly

Conclusions

- Internal ring alignment has been updated with beam-halo muons
  - using the 10× larger beam-halo dataset we collected during collisions (before the halo-trigger was retired Sep. 1)
  - improved ϕ_y measurement with collisions before applying beam-halo alignment procedure: good agreement with historical results but negligible impact on beam-halo alignment
  - minimized global-position bias from photogrammetry by only using it to "fill holes" in the overlaps data
  - new geometry is presented for approval
- The next step (beyond this sign-off) is to apply the Reference-Target procedure with collisions muons
  - Reference-Target is much more direct but relies on long propagations of tracker-tracks
  - obtaining the same result would be a non-trivial validation
  - but we should keep in mind which degrees of freedom the beam-halo does not constrain when we do that comparision