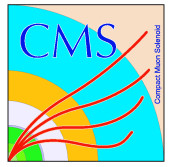

Track-based CSC Alignment and Global CMS Alignment

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9 December, 2008

Introduction

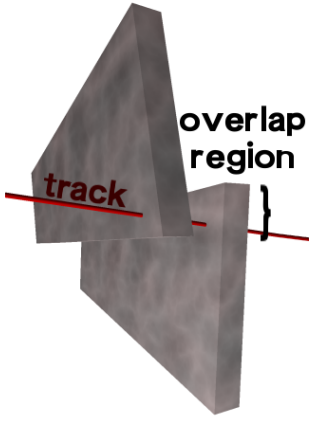
- CSC Alignment: chambers within rings
  - achieved target resolution of 300 μm
- layers within chambers
  - early plots show small misalignments
- Global CMS alignment: wheels and disks relative to tracker
  - produced muon alignment constants, but results are surprising
  - sensitivity to tracker could constrain tracker alignment

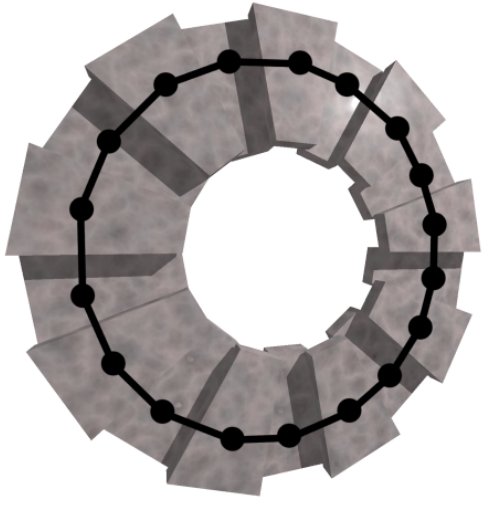
CSC Alignment

- Muon chambers can be individually aligned to the tracker with 10–100 pb^{-1} of globalMuons
- But for CSCs, it will require much less data to
  1. align chambers relative to each other in each ring — Overlaps procedure
  2. align the ring to the tracker — globalMuon procedure

Overlaps procedure:

1. select tracks that pass through overlap of two CSCs
2. require consistency in pair of segments: slope and intercept
3. solve system for all pairs





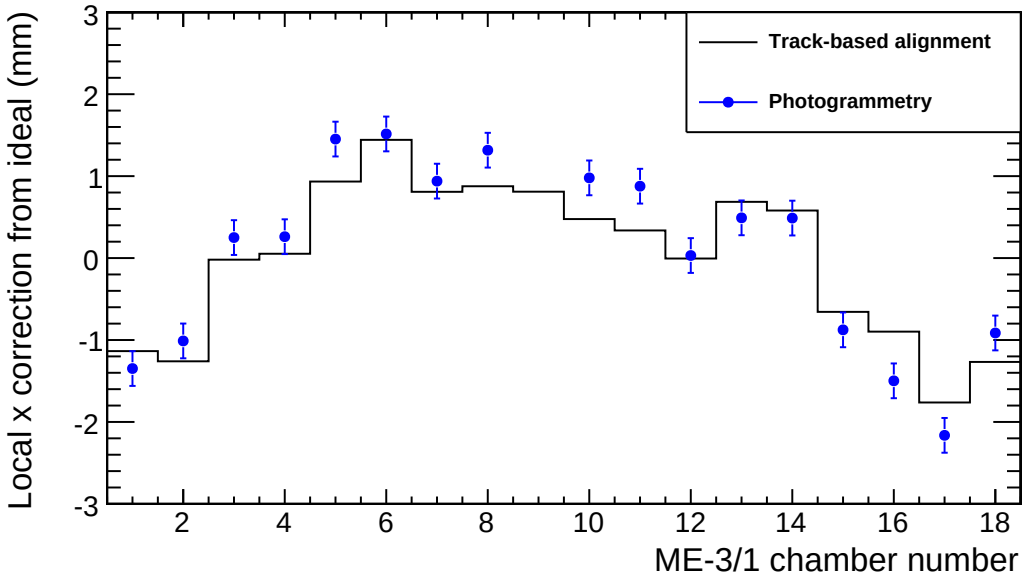
- System is over-constrained: circle can't have any gaps!

CSC Overlaps alignment results

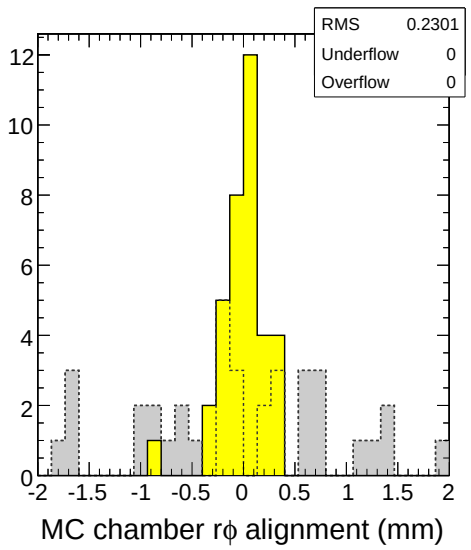
ME−2/1 and −3/1 (most complete in beam-halo dataset)

- Expect ∼230 μm resolution in $r\phi$ (MC)
- Alignment results in data follow photogrammetry (PG) measurement
- Alignment resolution from PG comparison: 270 μm
- Similarly, ϕ_z resolution is 0.35 mrad
- *Minutes* of beam-halo data!

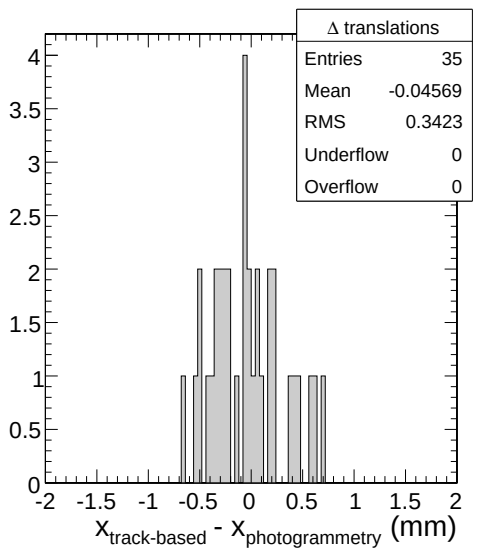
data: aligned (histogram) and PG (data)



MC: aligned - truth



data: aligned - PG



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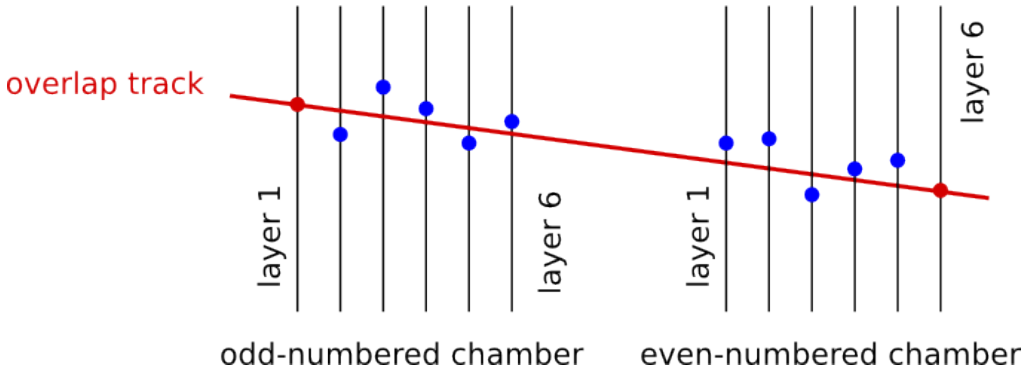
Closure constraint

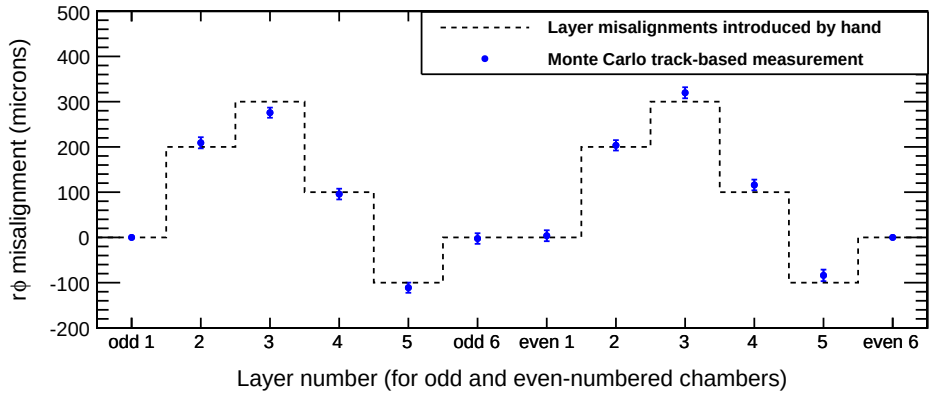
- Each residual is a difference of positions of neighbors $(x_i - x_{i+1})$
- Must sum to zero: $(x_1 - x_2) + (x_2 - x_3) + \ldots + (x_N - x_1) = 0$
- $r\phi$ residuals summed to zero in MC, but not data
- Precision agreement with photogrammetry is only possible if this is due to a uniform error in the chamber description:
  - *either* chamber active volume is 2.5 mm closer to beamline
  - *or* width of active volume is wrong by 800 μm
  - (or a little of both, or something equivalent)
- Resolution: CSC strip pitch angle in CMSSW was set to design value, rather than the measurement: a 10 μm width error $\times$ 80 strips

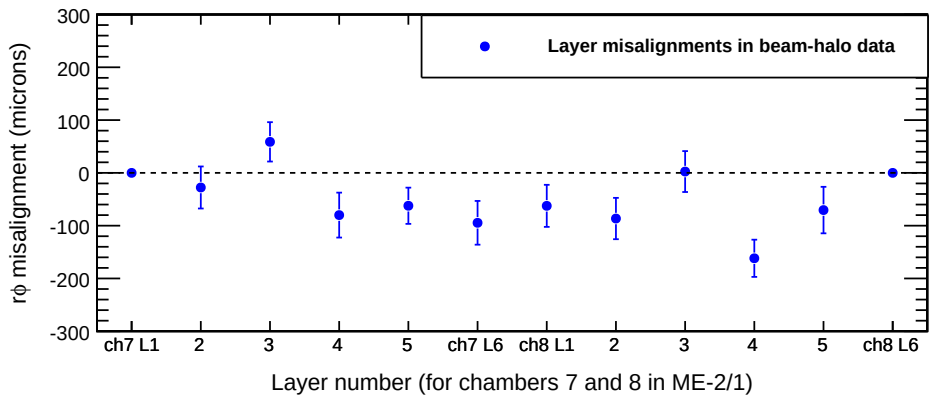
$$\sum_{\text{chambers } i} (r_i - r_{i+1}) = \left\{ \begin{array}{lll} & \text{with design pitch} & \text{with real pitch} \\ \hline \text{ME}-2/1 & +14.30 \text{ mm} & -0.72 \pm 0.42 \text{ mm} \\ \text{ME}-3/1 & +15.90 \text{ mm} & -0.36 \pm 0.51 \text{ mm} \end{array} \right.$$

Early look at CSC layer alignment

- CSC overlaps region has 12 hits − 2 to determine track = 5 unbiased hits per chamber
- 5/6 layers is a complete internal alignment
- Test in MC (middle): residuals reproduce test-pattern (high stats)
- Plot from data (bottom): typical misalignment 100–200 μm
- Need 9 minutes $\times$ 10^2 for high precision :)







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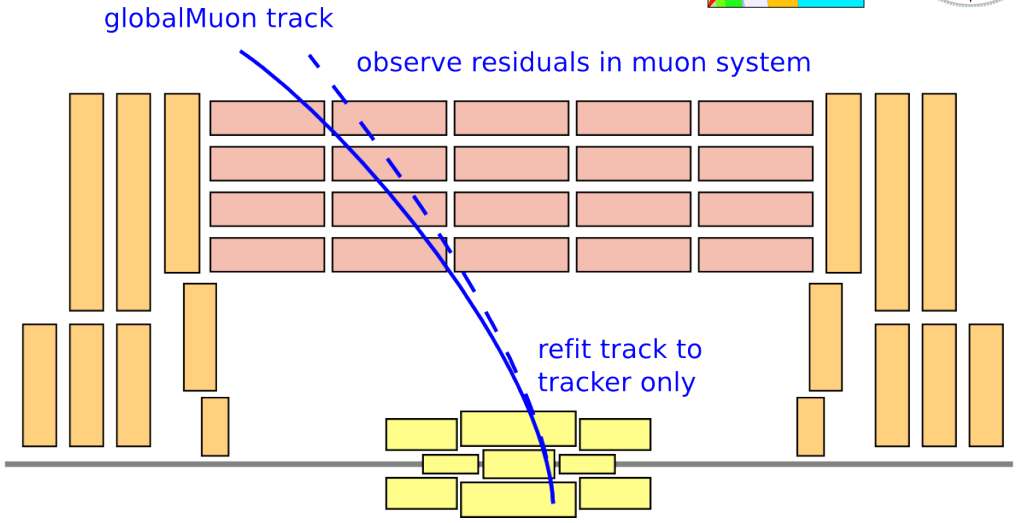
Global muon alignment

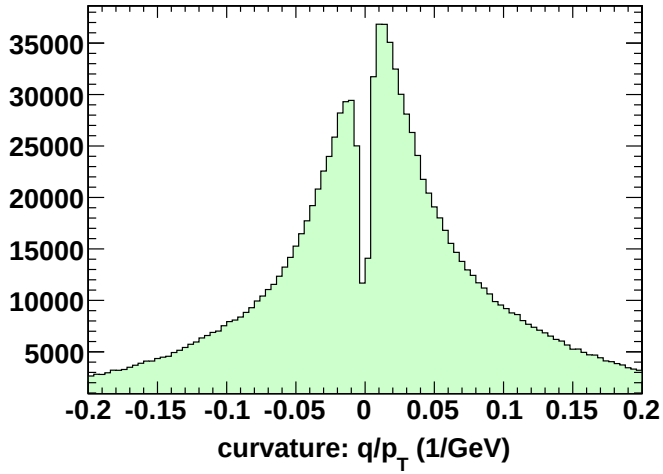
- Alignment of muon system relative to tracker:
  - select globalMuon tracks by momentum
  - refit, ignoring muon hits
  - use unbiased residuals to align wheels/disks

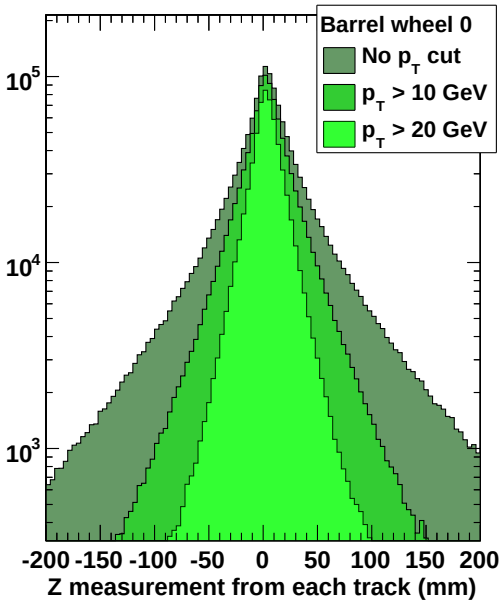


- Same procedure can later be applied to individual chambers
  - Wheel/disk alignment is both "practice" and the largest part of the alignment correction
- Both HIP and MillePede groups used procedures like this...
  - which roughly agreed with each other (6 d.o.f.)
  - in time for CRAFT re-processing
  - but they had unexpected features: twist around beamline ($d\phi_z/dz$) and z expansion
- Not used in this round of re-processing

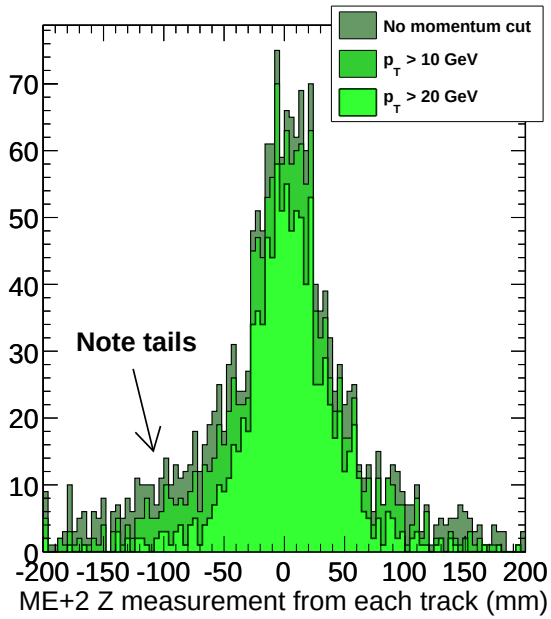
Momentum cut/extrapolation

- $\vec{B}$-field errors and multiple scattering affect low-momentum tracks
- Alignment error $\longrightarrow 0$ as $|p| \longrightarrow \infty$
- Plot vs. curvature (q/p_T), fit around 0
  - constant = misalignment
  - antisymmetric in $q = \vec{B}$ errors
  - symmetric in q = scattering

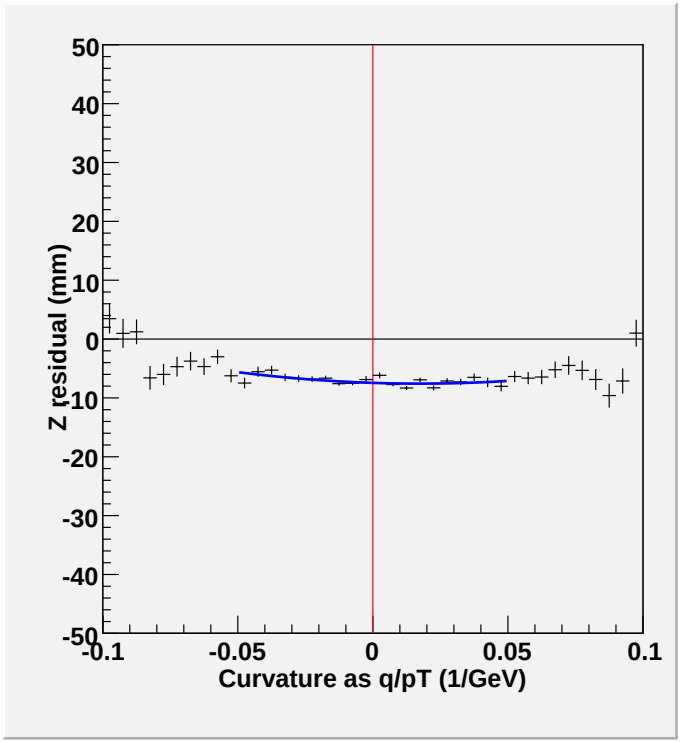




Barrel wheel 0

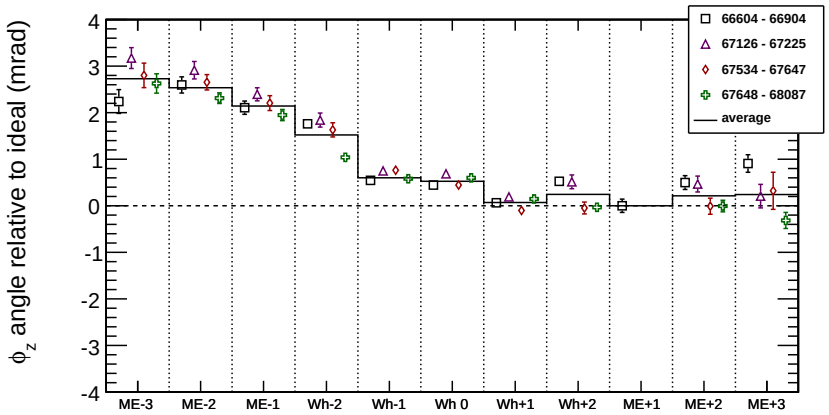


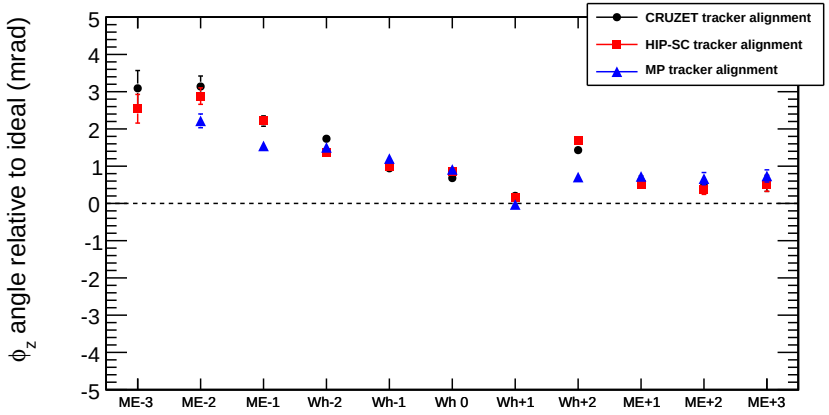
Endcap disk +2

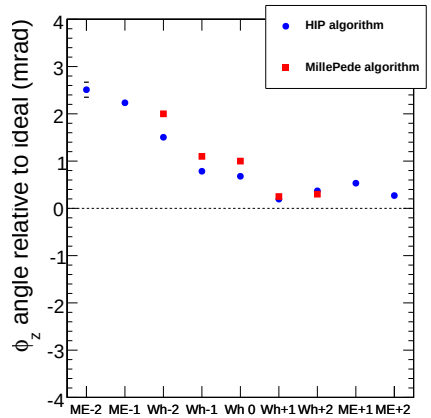


Barrel wheel −2

Twist around beamline







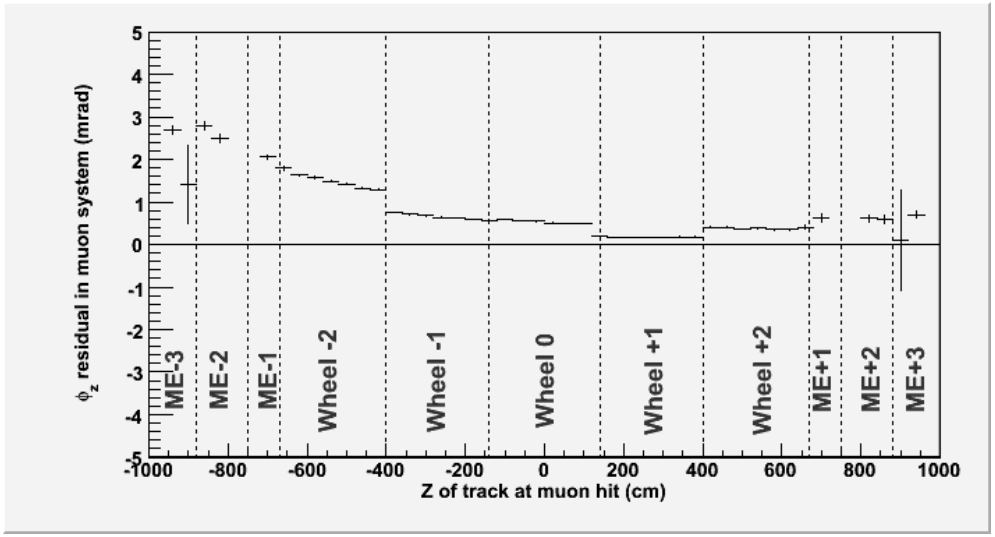
- Aligned ϕ_z for all wheels/disks with the $q/p_T \to 0$ method
  - effect of $\vec{B}$ error is minimized
- Observed a large (2.5 mrad) twist in the minus endcap
- Reproducible in
  - all stable 3.8 T runs (top plot)
  - all tracker alignments (middle)
  - both algorithms (bottom)
- $\vec{B} = 0$ photogrammetry constrains ϕ_z differences at 0.5 mrad
- Could this be
  - real twisting as $\vec{B} \to 3.8$ T?
  - an artifact of external bias?

HIP: J. Pivarski, A. Safonov
MillePede: P. Martinez, F. Matorras, J. Fernandez, A. Calderon

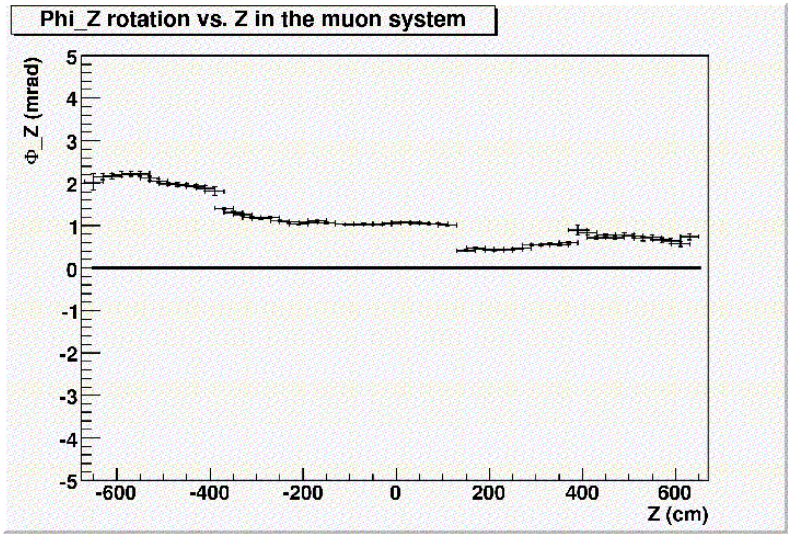
Apparently, a little of both

- Divide wheels/disks into smaller bins by plotting as a function of z
  - obvious discontinuities at wheel boundaries are real misalignments
  - slope within wheels is external bias

from the HIP group



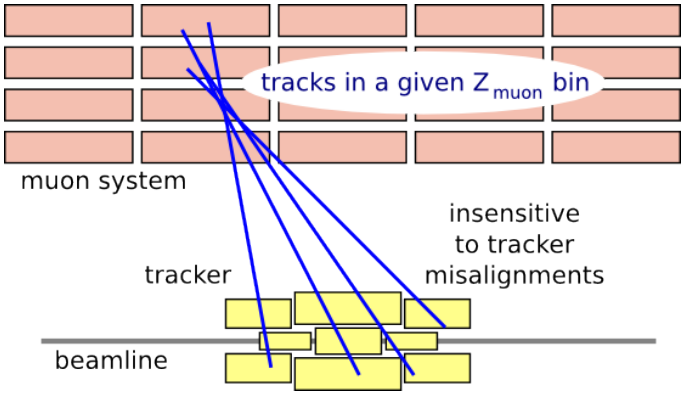
from the MillePede group



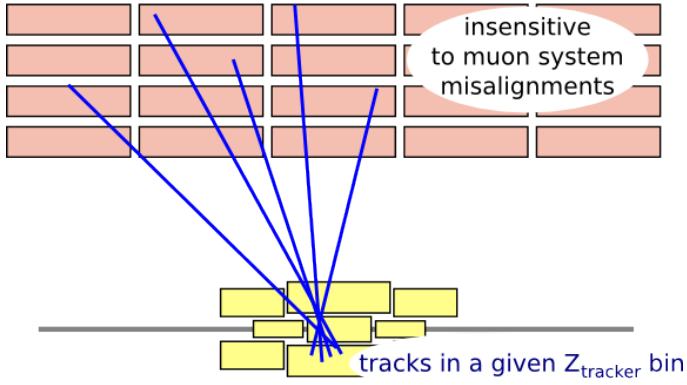
- Possible sources of external bias
  - global distortions in tracker, extrapolated to muon system
  - propagation errors?
  - ~~$\vec{B}$ errors?~~ ($|\vec{p}| > 40$ GeV in the HIP plot)

Invert problem: align tracker?

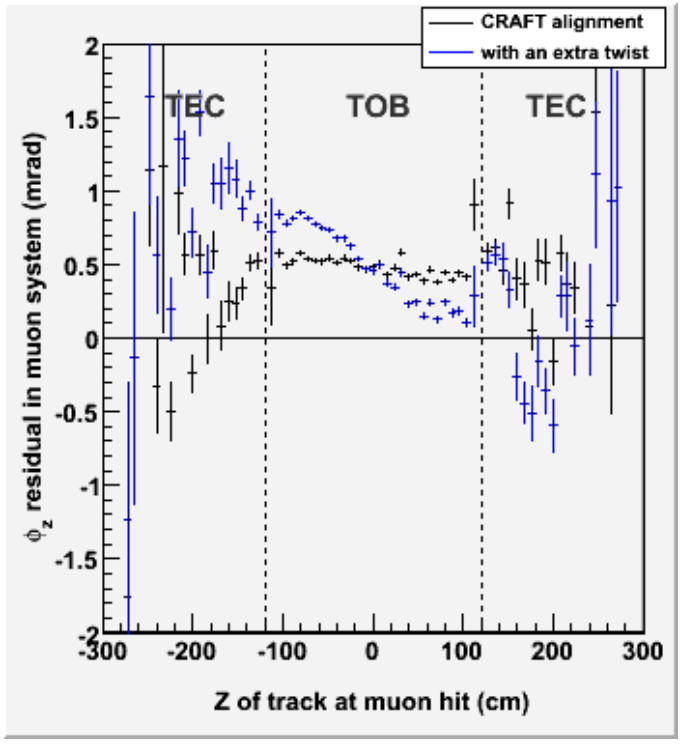
Normal muon alignment



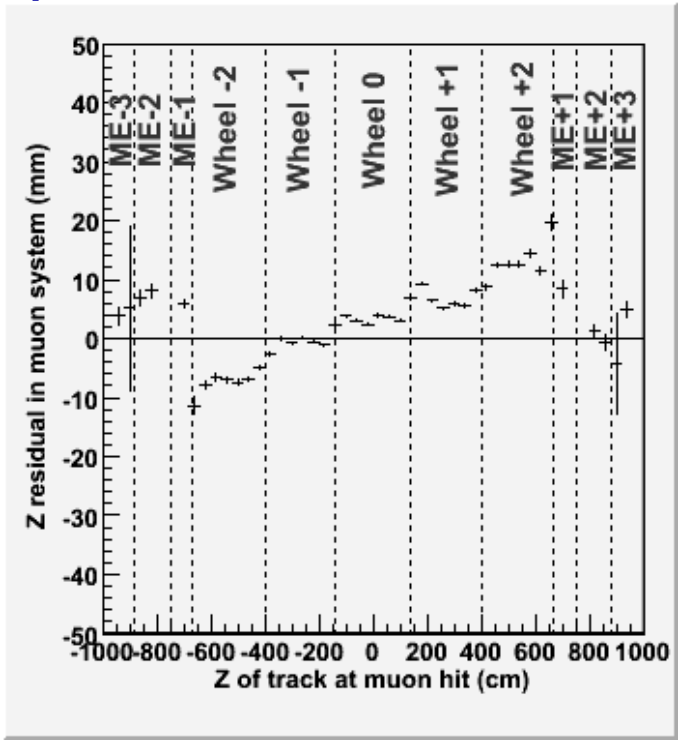
Tracker study



- Plot muon ϕ_z residuals vs. Z_{tracker} (black)
  - broad distribution of entrance angles effectively averages over the muon system
- Slope (0.2 mrad across TOB) may indicate a twist in the tracker
- Zijin Guo added a tracker twist by hand (0.6 mrad, blue): easily observed



Expansion in z

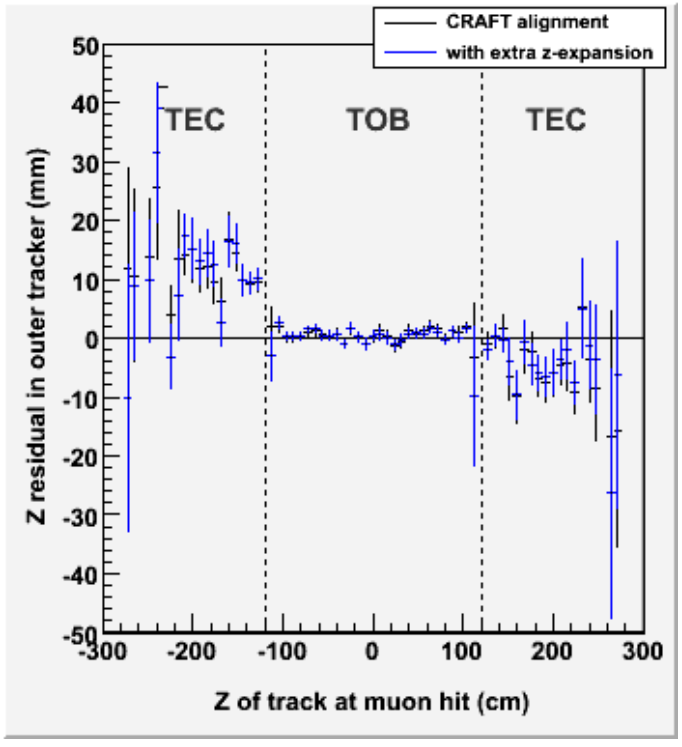


GlobalMuons think that the muon system is *wider* than ideal geometry

- +14 mm across barrel (0.2%)
- $\vec{B}$ ought to *compress* in z
- perhaps ideal isn't intended to represent $\vec{B} = 0$, and this is compression relative to true $\vec{B} = 0$?

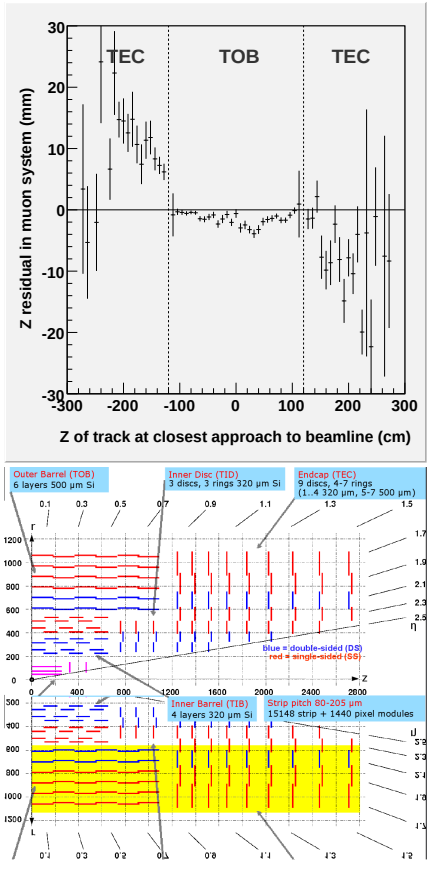
Is muon alignment affected by tracker z-expansion?

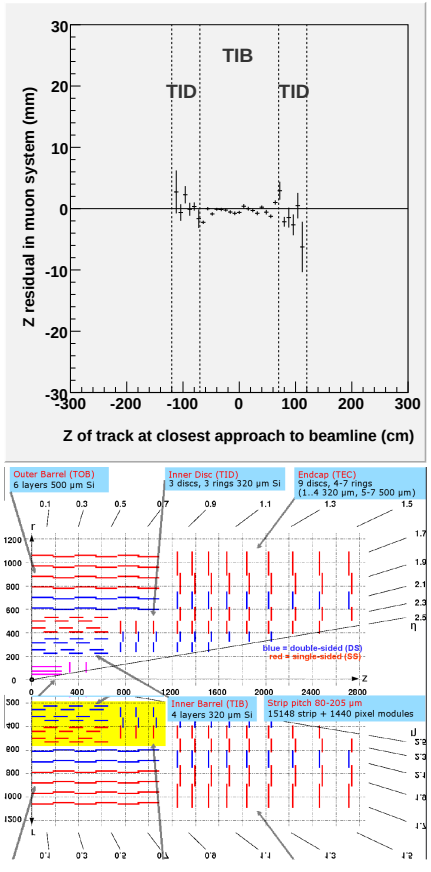
- No: muon residuals can't resolve a plausible z-expansion (black vs. blue: 0.1% tracker stretch)
- But we can see large displacements of TEC relative to TOB (discontinuity)

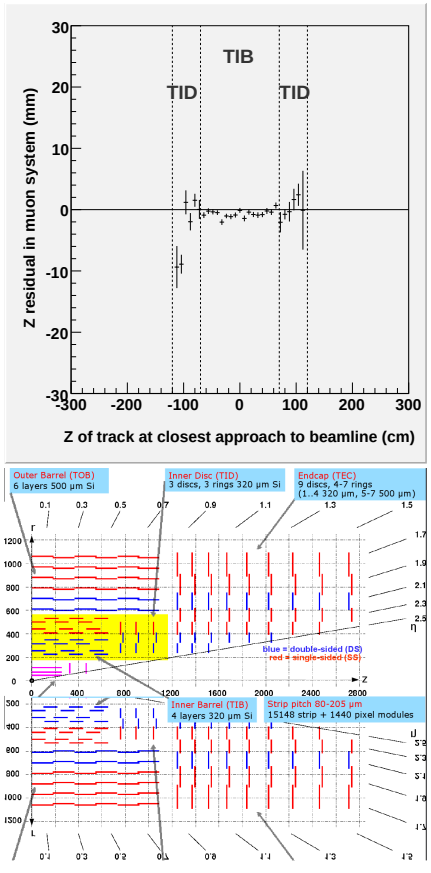


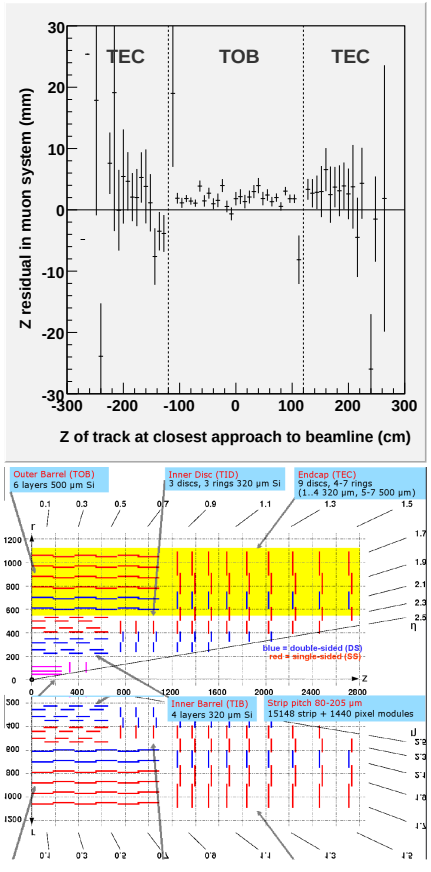
Study of tracker z alignment

- Select parts of the tracker by cutting on R_{PCA} and by removing outer tracker hits from refit (to highlight inner tracker)









Conclusions

- CSC Alignment: achieved 300 μm resolution with minutes of beam-halo data
  - verified by an independent measurement (photogrammetry)
  - predicted a 10 μm correction in chamber geometry
  - can align layers with a similar technique
- Wheel/disk alignment
  - many cross-checks are available in this huge dataset
  - a significant part of the twist we saw was real
  - is ideal-geometry barrel more compressed than real barrel at $\vec{B} = 3.8$ T?
- Global CMS alignment
  - muon system can provide feedback to tracker; we could iterate alignment