Muon Alignment without RPC-hit Bias

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Pablo's Grand Unified Theory

of Muon Track Residuals Mysteries

Cause of nearly all of our problems: RPC hits were being included in alignment track refits, biasing the residuals (should be tracker hits only)

- Sawtooth effect: why are there discontinuities at DT borders?

  Because RPC borders are at the same place as DT borders

- Why does it depend on momentum, like an input-track bias?

  Because the input tracks are biased— by the RPCs, not tracker

- Why do we see it most strongly in ME1/2 with collisions muons (new)?

  Because that's where the RPCs are in the endcap

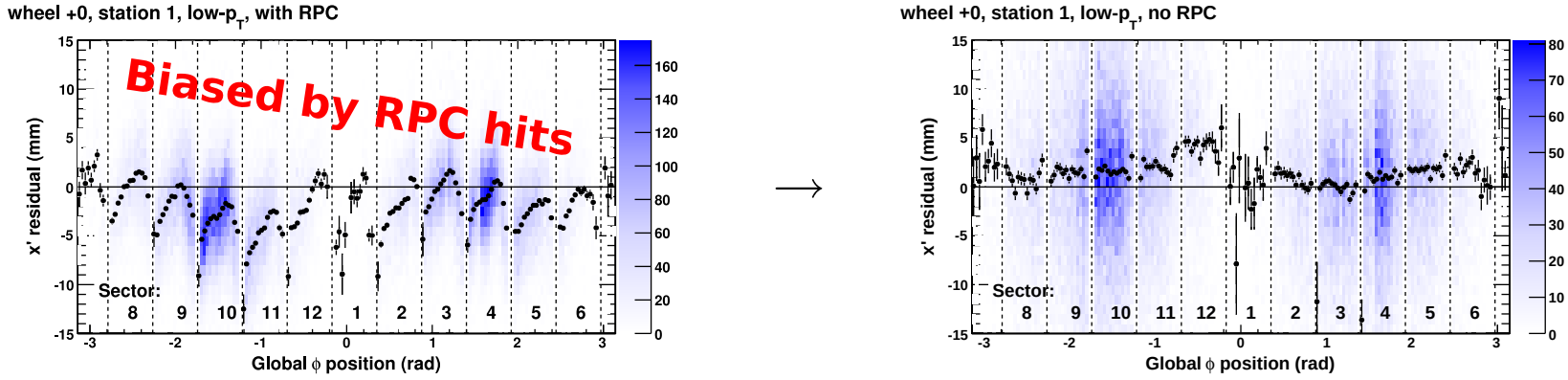
- Why does tracker weak-mode effect have a characteristic scale of 100 GeV/c, even with a scale-invariant tracker weak mode?

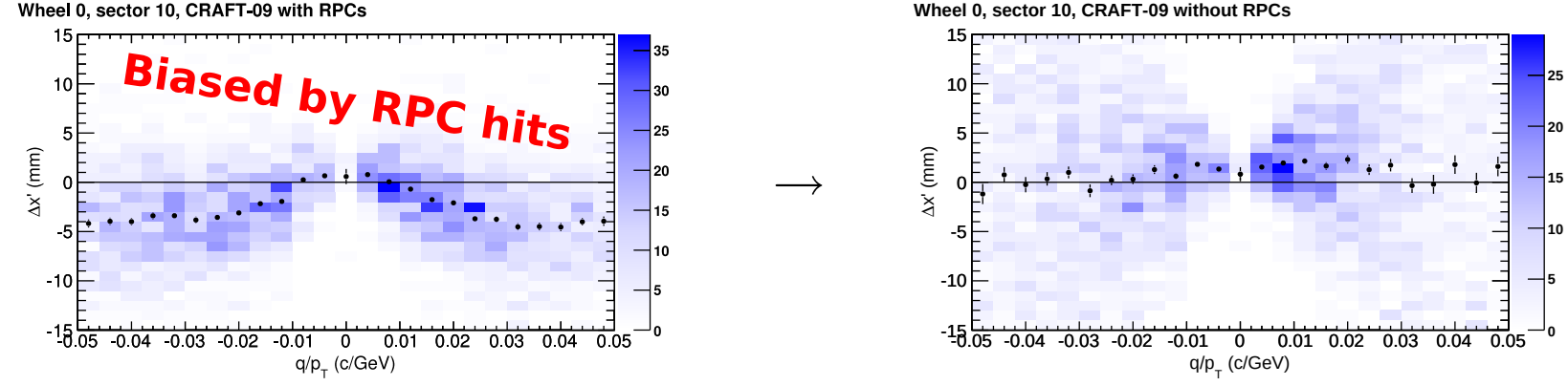
  Because the distance of the RPCs to the beamline, their resolution, and the CMS magnetic field set a characteristic scale of about 100 GeV/c, not the tracker weak mode

- Why does Reference-Target disagree with Sasha Spiridonov's global cross-alignment (also track-based)?

  The cross-alignment algorithm performed a fit at the level of standAloneMuons, not residuals, so it was much less affected by RPC hits ($\sigma_{RPC} \gg \sigma_{DT}$).

Avoid overlap with Pablo's talk





Outline

- Recomputed muon alignment without this bias
- Redo tracker weak mode study
- We confirm the momentum scale error that Pablo sees in CRAFT-10 (and we do *not* see it in CRAFT-09)

How did this happen?

Feb 2007: Discovered that RPC hits were biasing the alignment track refits (should have muon APE $\rightarrow \infty$, can't set RPC APEs)

Aug 2007: "RefitRPCHits" switch integrated into CMSSW; track refits are unbiased by RPC hits when set to "False"

sometime before CRAFT-08: Made the following mistake in Python configuration file:

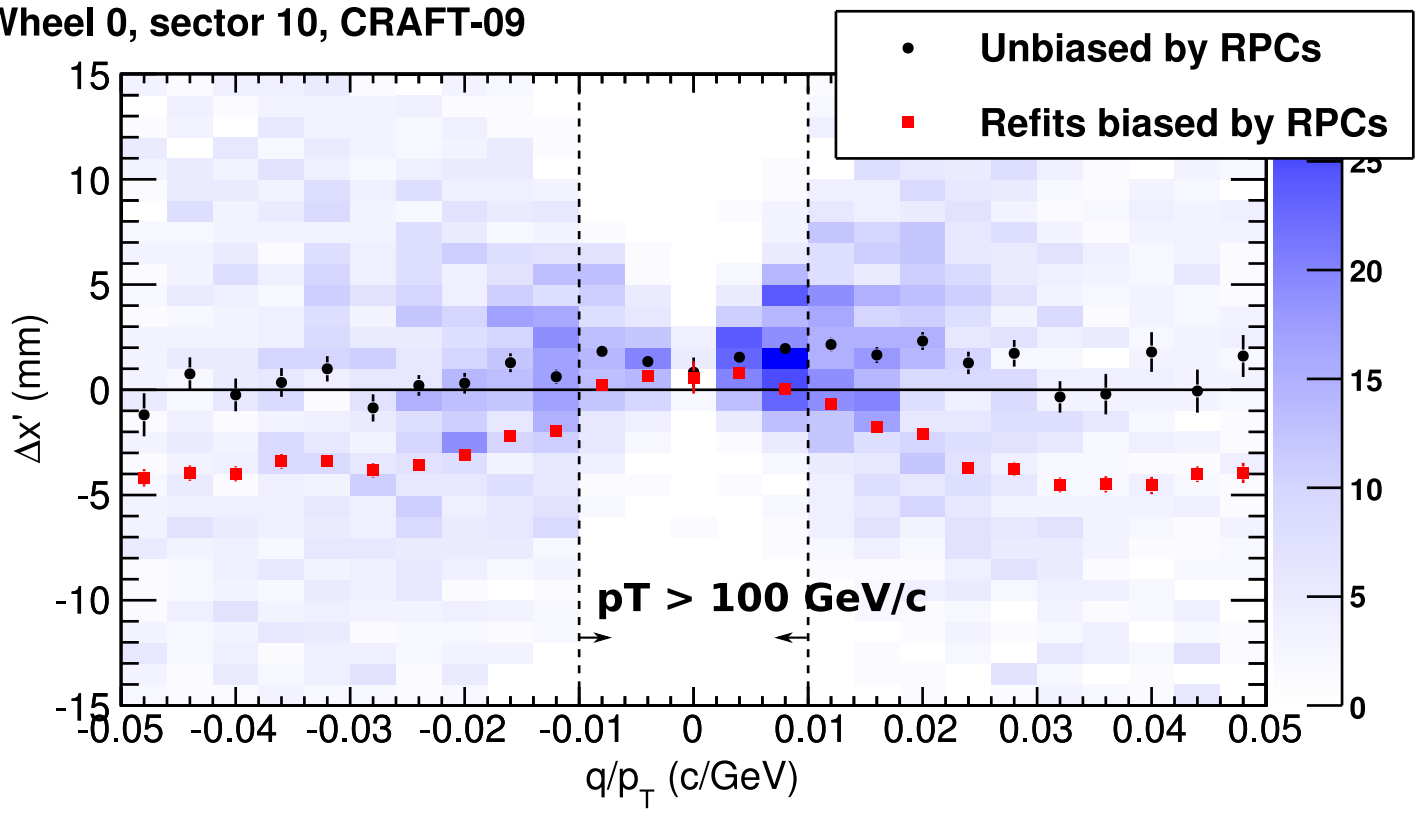
```
TrackRefitter.RefitRPCHits = False
                    # CMSSW doesn't complain; uses default (True)
```

instead of

```
TrackRefitter.TrackTransformer.RefitRPCHits = False
                                    # what we want
```

RPC hits were being included in track refits because of a typo

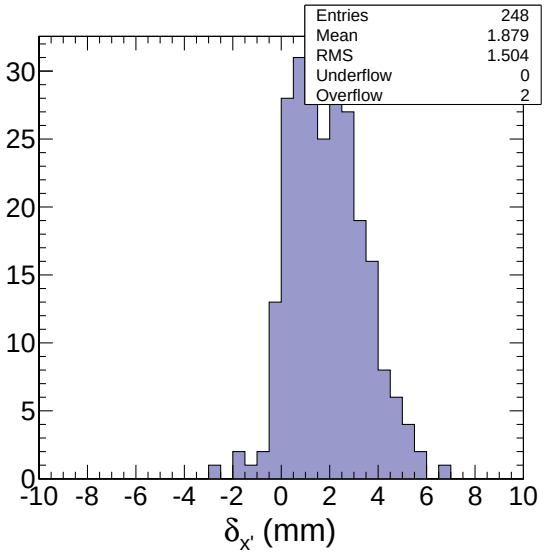
Controlling the problem

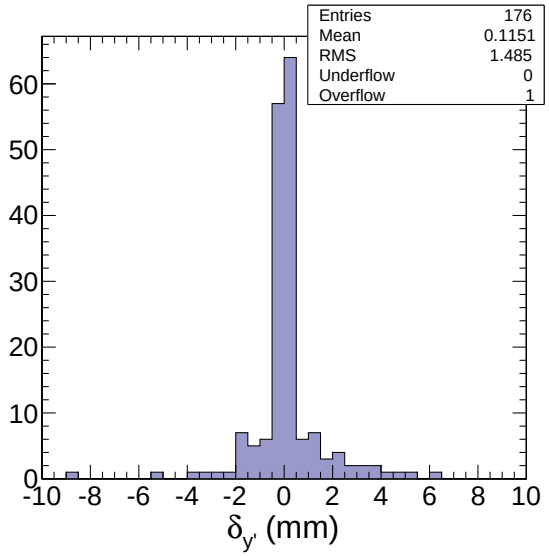


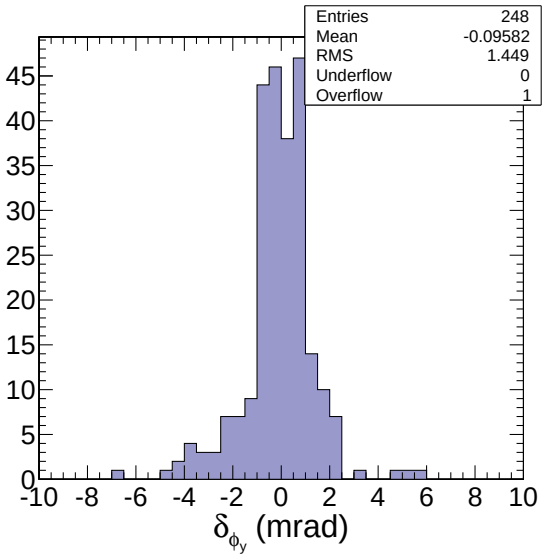
- We saw that we had a problem, but couldn't identify the source
- We knew from other studies that the high-momentum tracks were the most trustworthy
- Applied a $p_T > 100$ GeV/c cut to limit the bias
  - now that it is understood, we can loosen this cut

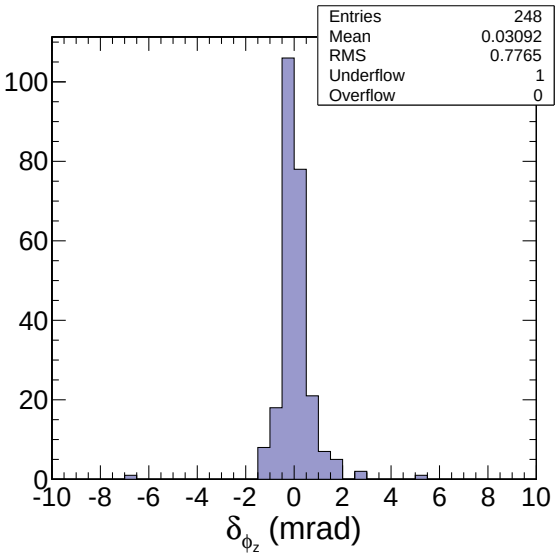
Re-alignment without RPC bias

- Below: differences between aligned parameters without RPC-hit bias and aligned parameters with the bias







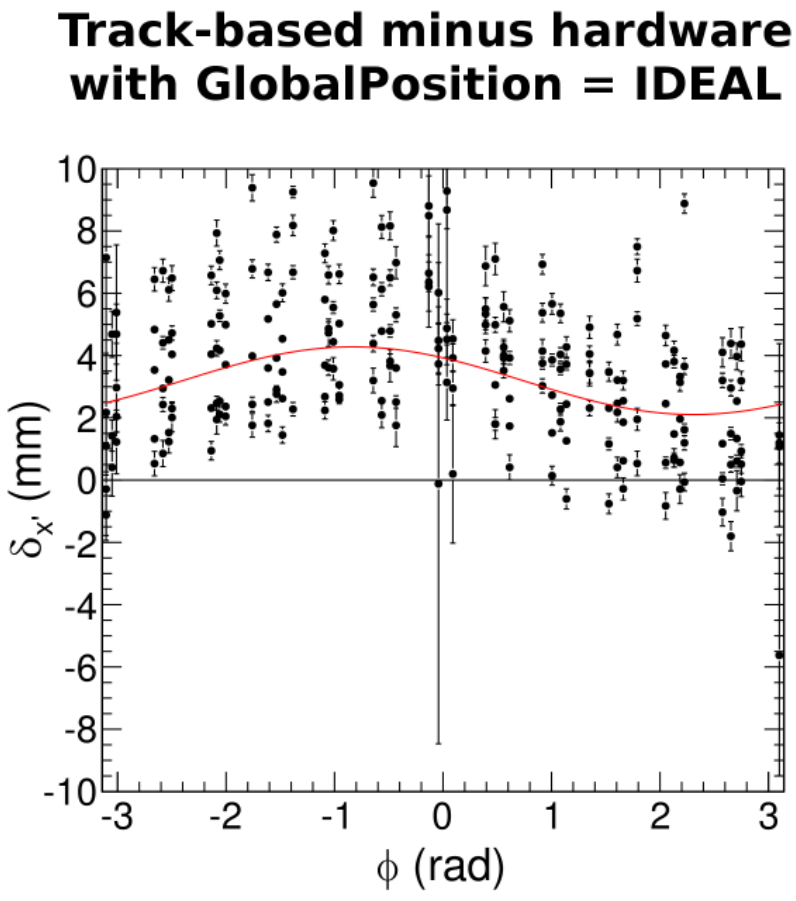


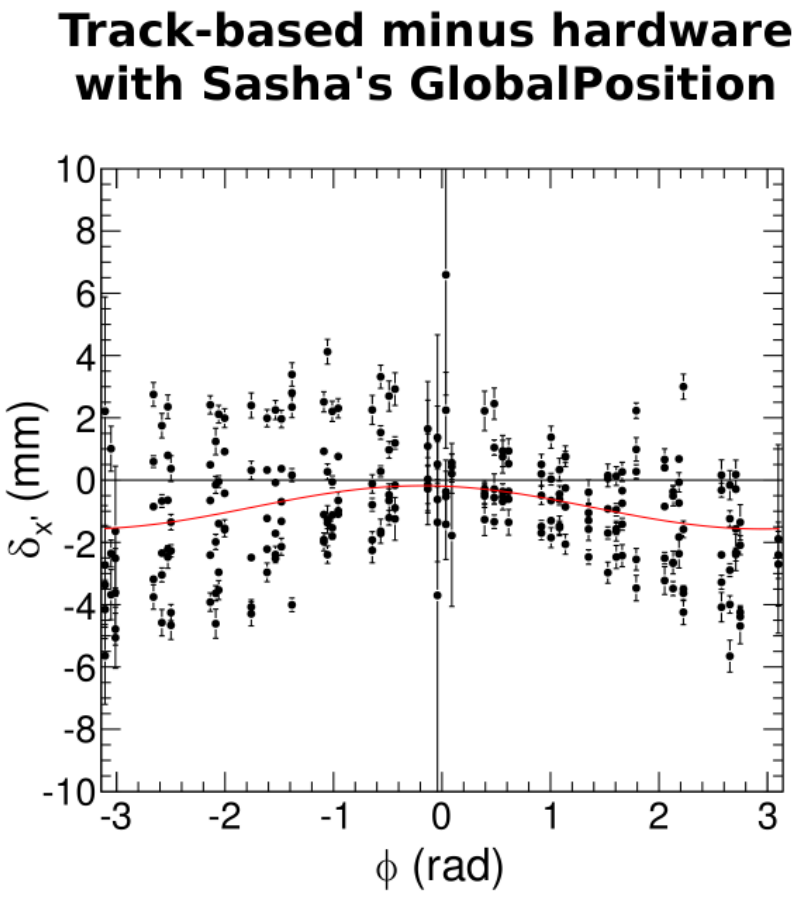
This will be a significant correction!

- Effective rotation of about 0.3 mrad around the beamline ($\delta_{x'}$)
- RMS spread of 1.5 mm
- Would have been 5 mm if not for the 100 GeV/c cut

Agreement with cross-alignment

- Sasha Spiridonov developed a method to align the muon system relative to tracker by comparing tracker tracks with standAloneMuons
  - standAloneMuons are insensitive to RPC hits
- Without RPC bias, Reference-Target now agrees with this method





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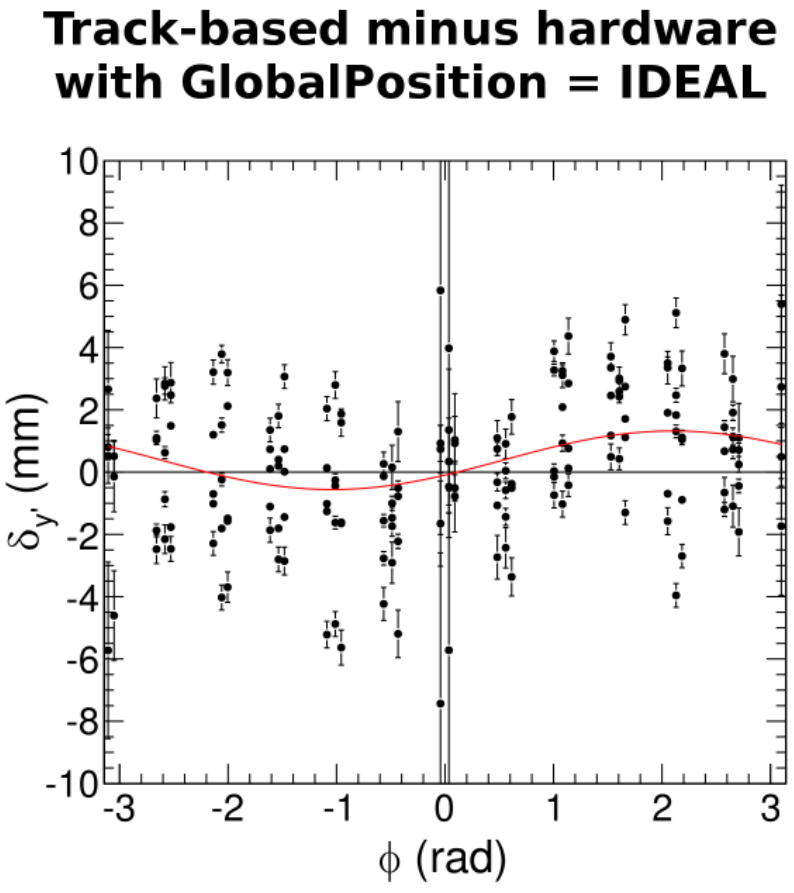
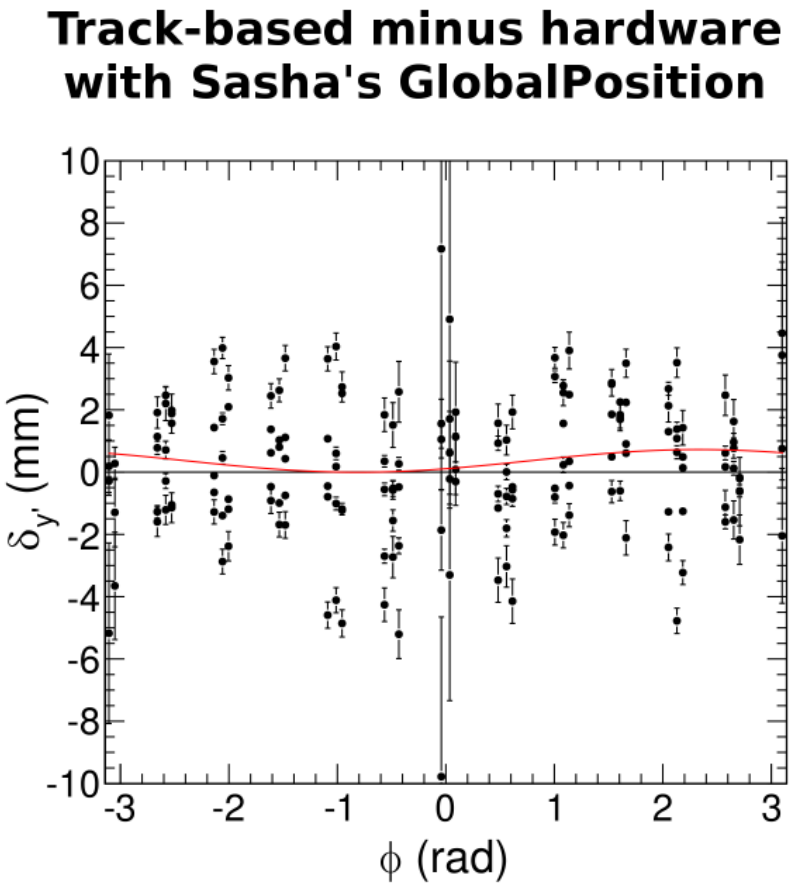
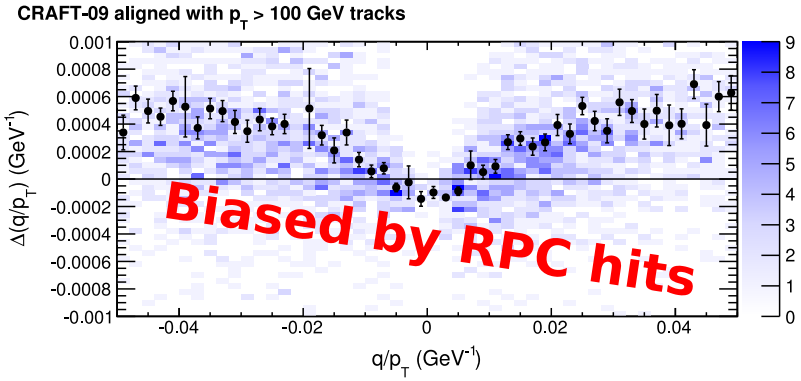
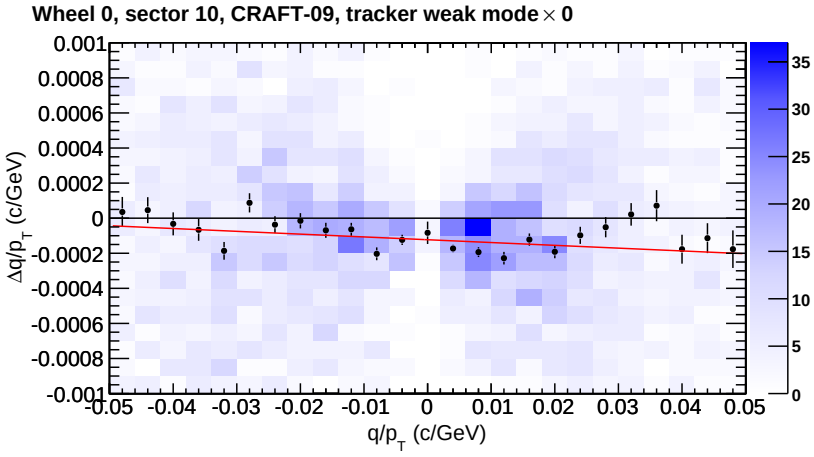
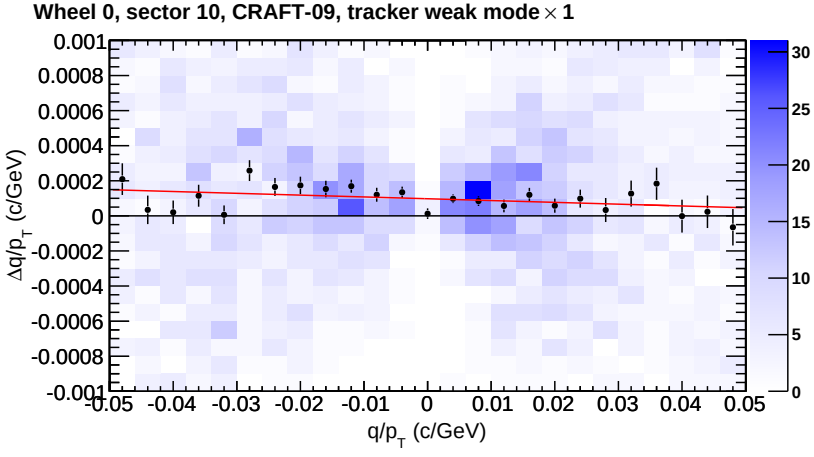




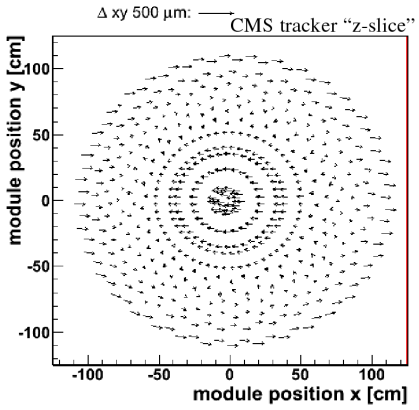
Tracker weak mode study

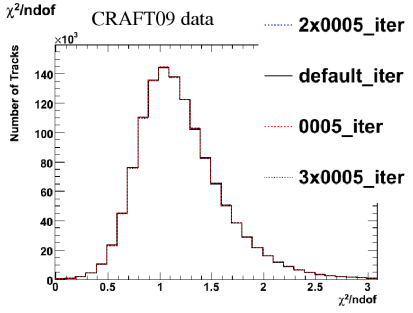






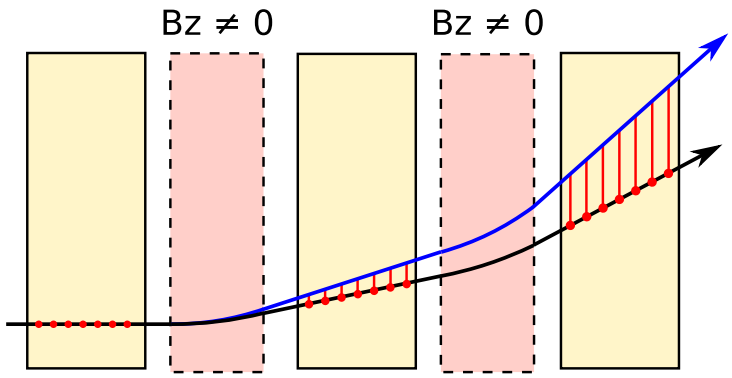
CRAFT-09



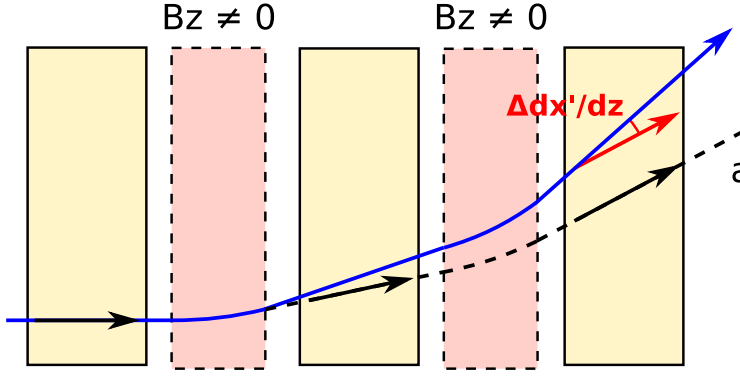


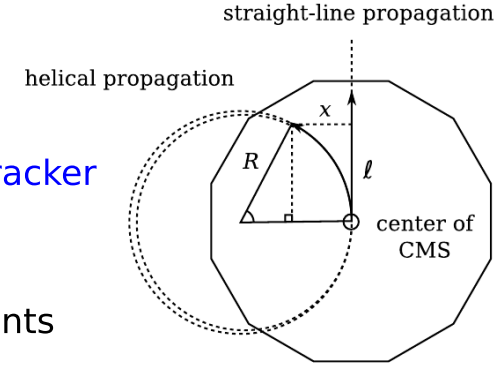
- Apply Millepede-generated mode to correctly-calculated muon residuals
- No distortion with "100 GeV/c characteristic scale": that was the RPCs
- Only a constant shift in $\Delta(q/p_T)$
- Can't distinguish tracker weak mode from muon alignment (but limits on tracker weak modes imply $\sigma_x \lesssim 0.25$ mm)

Reminder of $\vec{B}$-sensitive residuals



Position residuals: more sensitive to a momentum scale problem, but harder to interpret





Angle resids: $\dfrac{\Delta dx'/dz}{q/p_T} = \displaystyle\int \frac{\Delta B_z(\ell)}{330\text{ cm}} d\ell$

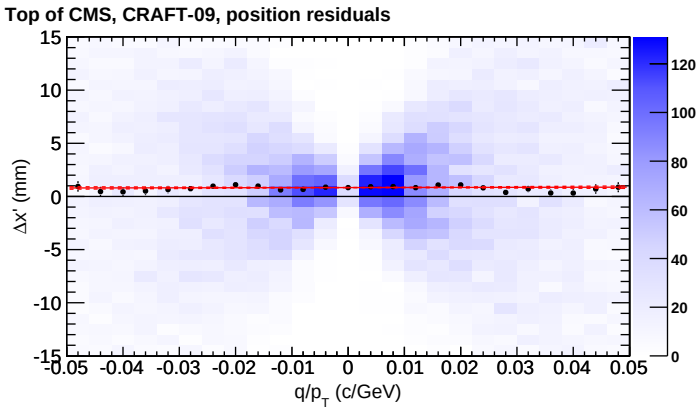
$\Delta dx'/dz$ in rad, q/p_T in c/GeV, ΔB_z in Tesla

Note: sign of inferred ΔB_z is reversed in the top of CMS (sectors 1–6), where the muons' momentum vector points toward the beamline.

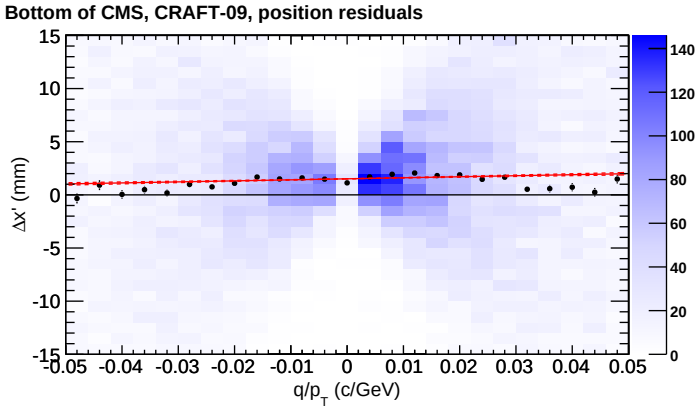
Position residuals

Momentum scale error introduced this year (same sign in top and bottom)

CRAFT-09

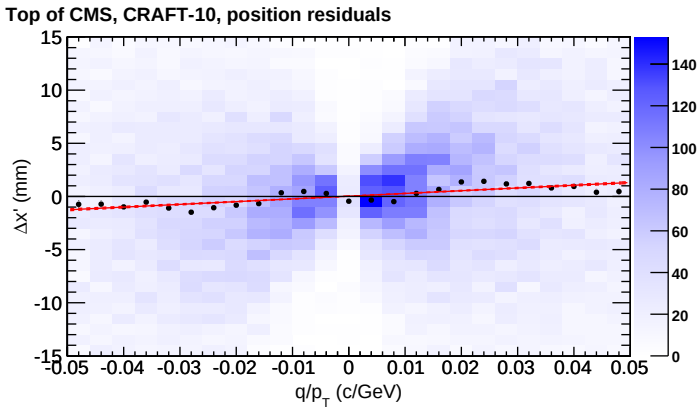


Top: 0.07 ± 0.23 cm·GeV/c

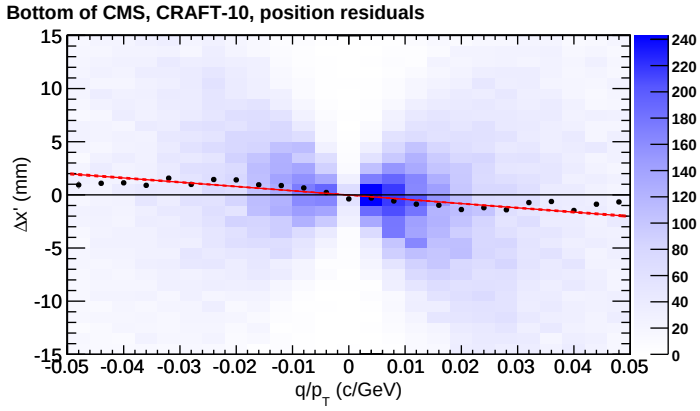


Bottom: 0.97 ± 0.22 cm·GeV/c

CRAFT-10

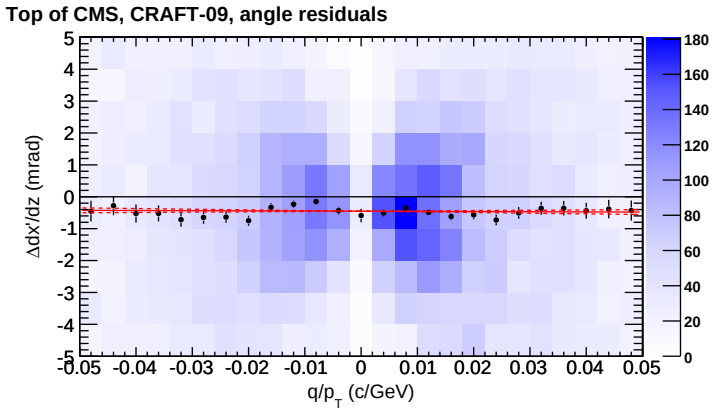


2.57 ± 0.18 cm·GeV/c

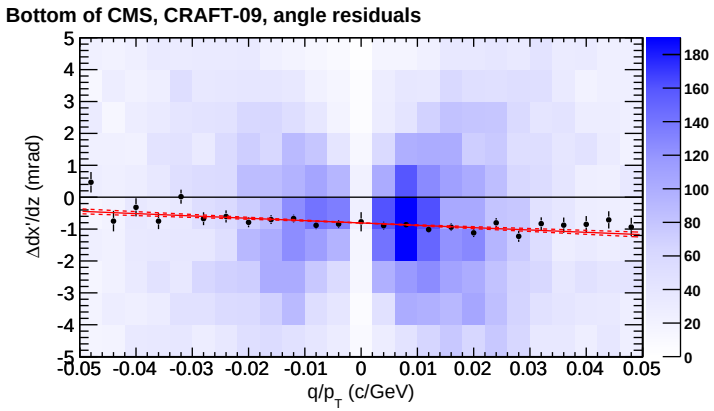


-4.02 ± 0.16 cm·GeV/c

CRAFT-09

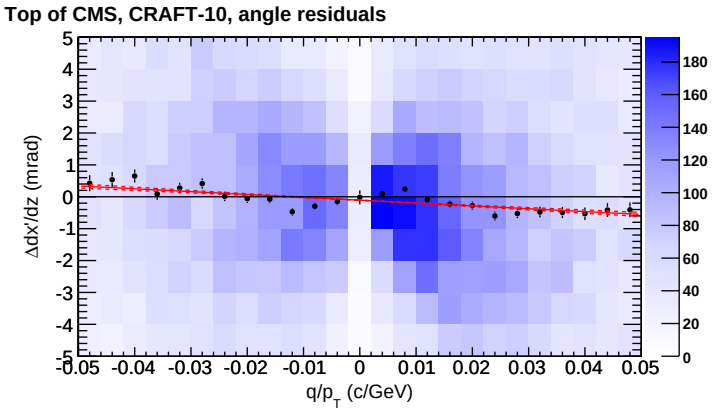


Top: -0.0005 ± 0.0015 rad·GeV/c

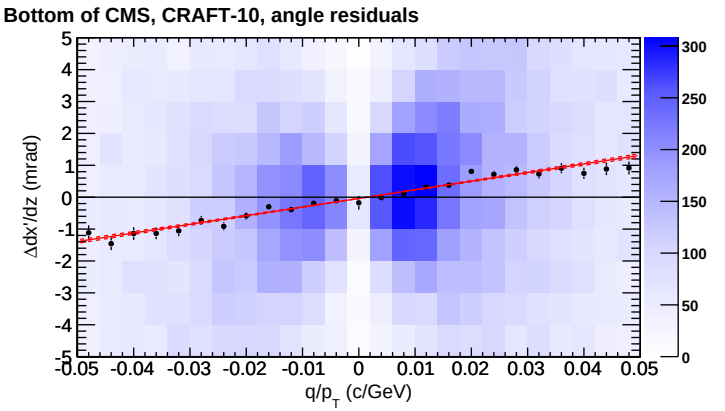


Bottom: -0.0073 ± 0.0015 rad·GeV/c

CRAFT-10



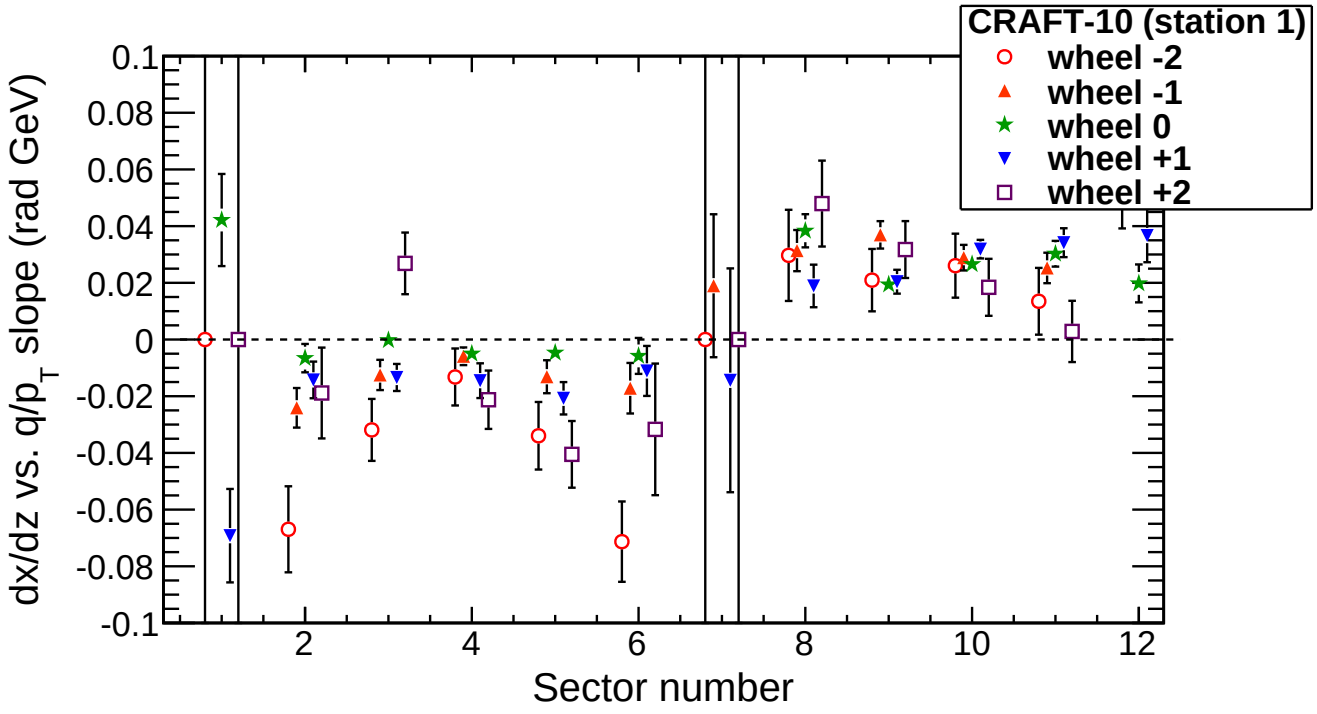
-0.0089 ± 0.0013 rad·GeV/c



0.0271 ± 0.0011 rad·GeV/c

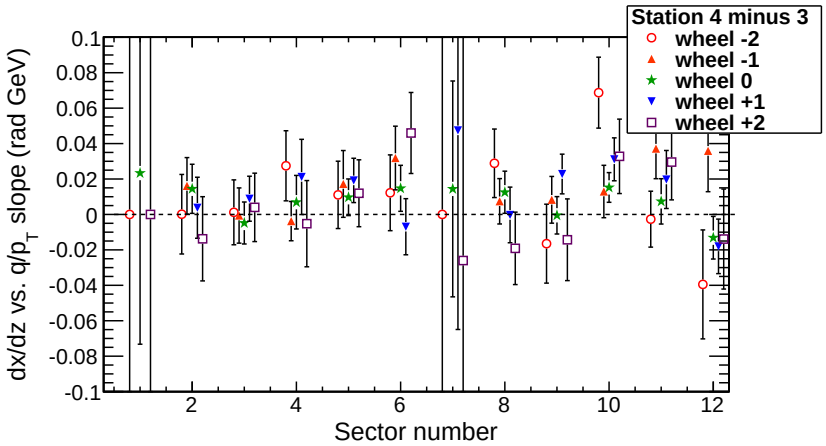
Individual chambers (angle resids)

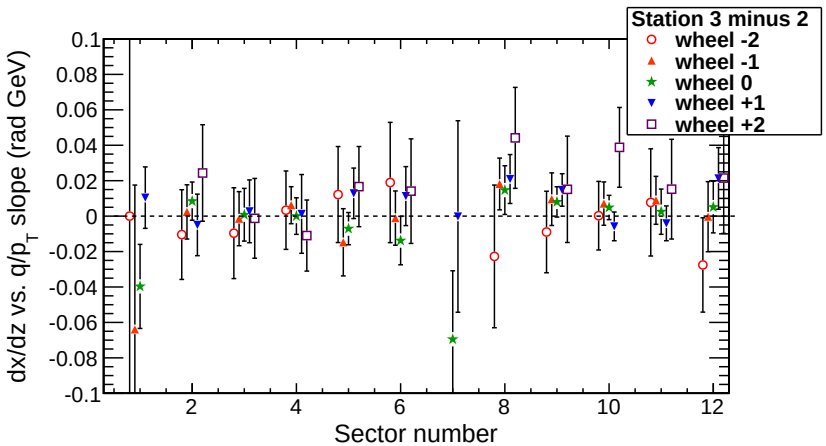
- If each chamber is fitted individually, the top slopes (1–6) are self-consistent and the bottom slopes (7–12) are self-consistent

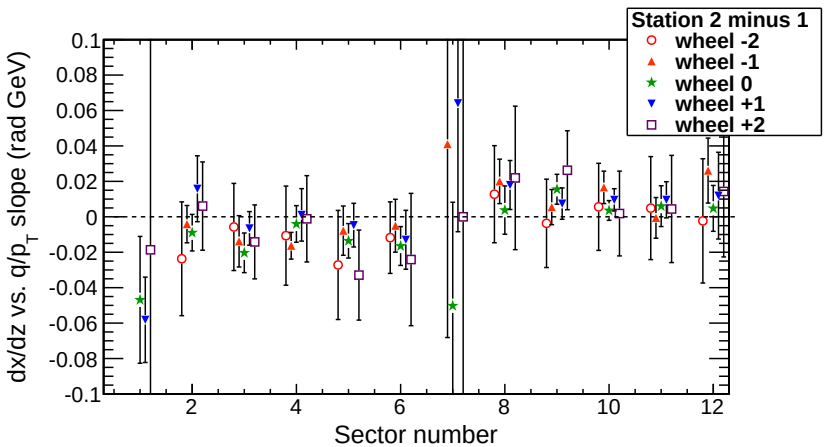


- Assuming $\int \Delta B_z(\ell) d\ell = \Delta B_z \times 210$ cm,
  - $|\Delta B_z| = 0.014$ T on top — 0.3% of 3.8 T
  - $|\Delta B_z| = 0.043$ T on bottom (same sign) — 1.1% of 3.8 T

Station-to-station differences







- For each track, subtract $\Delta \frac{dx'}{dz}$ in station N from $\Delta \frac{dx'}{dz}$ in station $N+1$
- Quantifies magnetic field error *between* stations
- Only MB1 $\rightarrow$ MB2 is non-zero (~ 0.01 rad·GeV/c)
- Assuming $\int \Delta B_{z,1\rightarrow 2}(\ell) d\ell = \Delta B_{z,1\rightarrow 2} \times 20$ cm
  - $|\Delta B_{z,1\rightarrow 2}| \sim 0.16$ T

Conclusions

- RPC hits were included in alignment track refits by mistake, biasing the residuals
  - removing these hits eliminates nearly all unexplained features
  - one correction resolves many mysteries, some of them years old
- Effect on muon chamber alignment is $\mathcal{O}$(1–2 mm) with a systematic trend (rotation around beamline)
- Muon residuals do not constrain tracker weak modes
- We confirm the momentum scale bias seen by Pablo in CRAFT-10
  - *not* observed in CRAFT-09
  - interpreted as a $\vec{B}$-field error, it would have to be something that *changed* recently
  - $\sim$0.5% offset in Z mass for barrel standAloneMuons only ($\sim$0.1% offset in barrel standAlone J/ψ)
- Tangential observation: RPC hits cause a linear trend in Δx vs. x, which could imply that the size of RPC chambers is incorrectly modeled by about 5 mm (instead of DTs, as we originally thought)