Confirmation of the Effect of RPC Hits and Updated Alignment without RPC Bias

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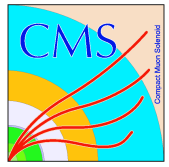
Thank you, Pablo!

The inclusion of RPC hits in the track refits was the cause of most muon alignment mysteries

Pablo's Grand Unified Theory

of Muon Track Residuals Mysteries



Yesterday morning, none of the following were understood; now they all are

- 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?

  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

How did this happen?

Feb 2007: Discovered that RPC hits were biasing the track refits

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

sometime thereafter: 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

Conclusions

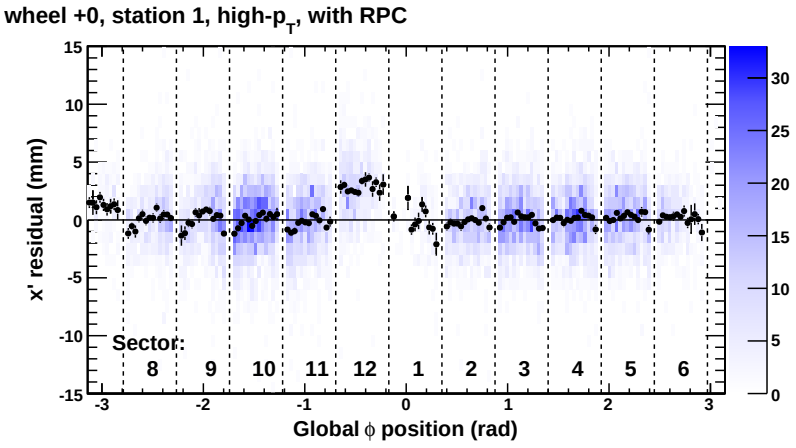
(will be repeated at the end of this talk)

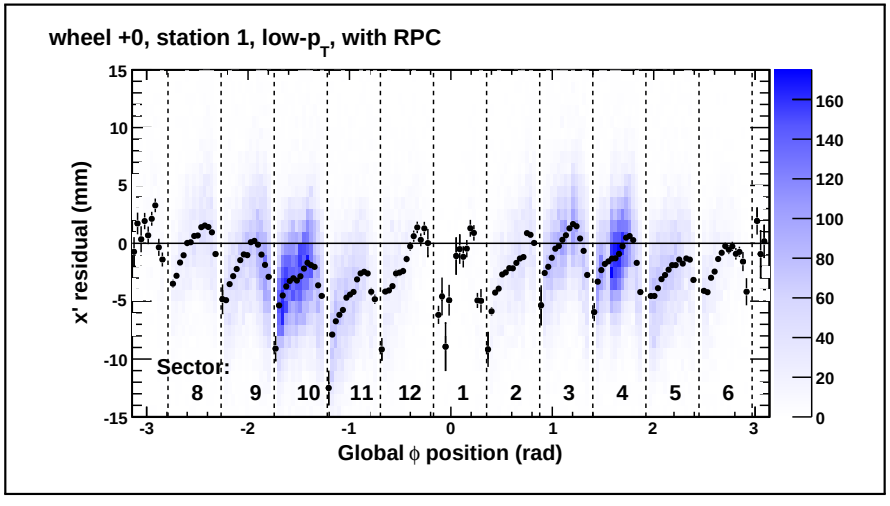
- Confirmation: sawtooth and dependence on q/p_T disappear when tracks unbiased by RPC hits
  - $p_T > 100$ GeV/c cut limits effect on alignment results
- We do not see large $\vec{B}$ field bias: less than 1% before station 1
- Modified interpretation of tracker weak modes
  - no more "high-momentum vs. low-momentum" discrepancy
  - muon residuals cannot probe tracker weak modes
  - cosmic endpoint constraint on tracker weak modes $\Rightarrow$ $\sim$0.25 mm bias in chamber x positions
- New 2010 muon alignment without RPC bias
  - RPC bias effectively a 0.3 mrad rotation and 1.5 mm chamber position error
  - unrelated to "twist" with respect to hardware geometry
- We no longer need the $p_T > 100$ GeV/c cut, which will make alignments with collisions possible
  - resolution vs. integrated luminosity estimates must be revised

Sawtooth (confirmation)

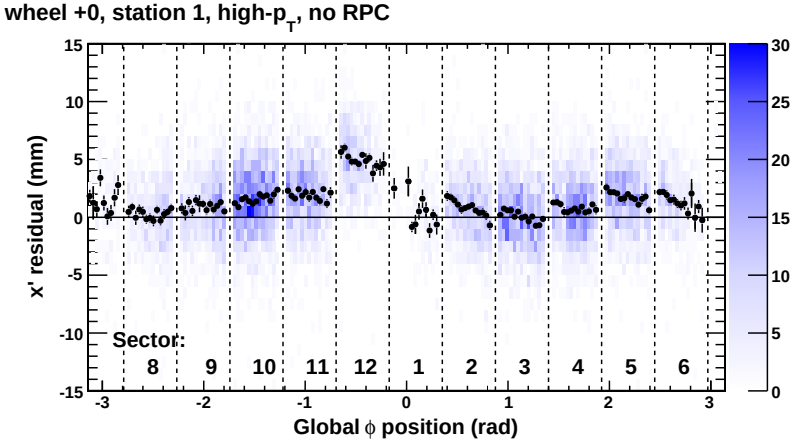
"high-p_T" means $p_T > 100$ GeV/c, "low-p_T" means $20 < p_T < 100$ GeV/c

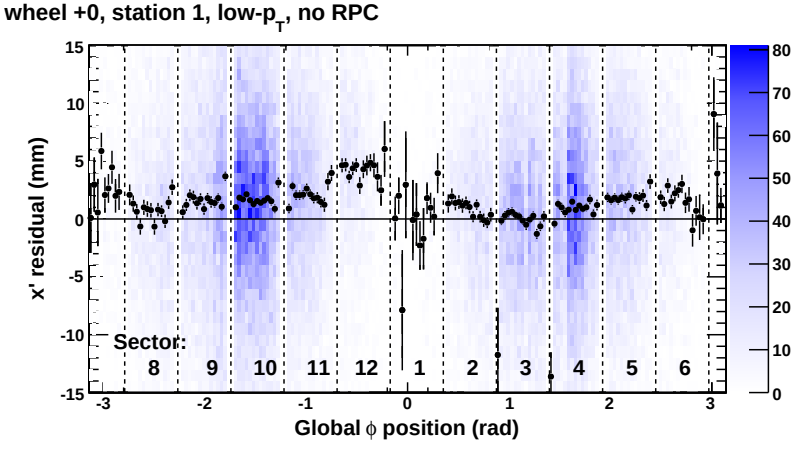
track refits biased by RPC hits





unbiased track refits





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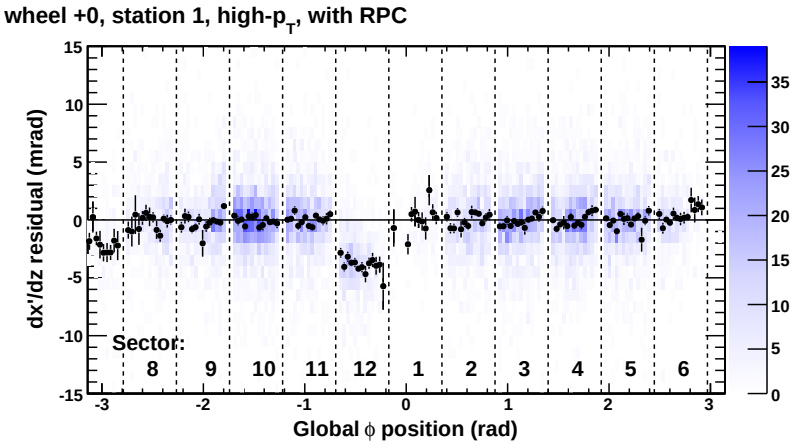

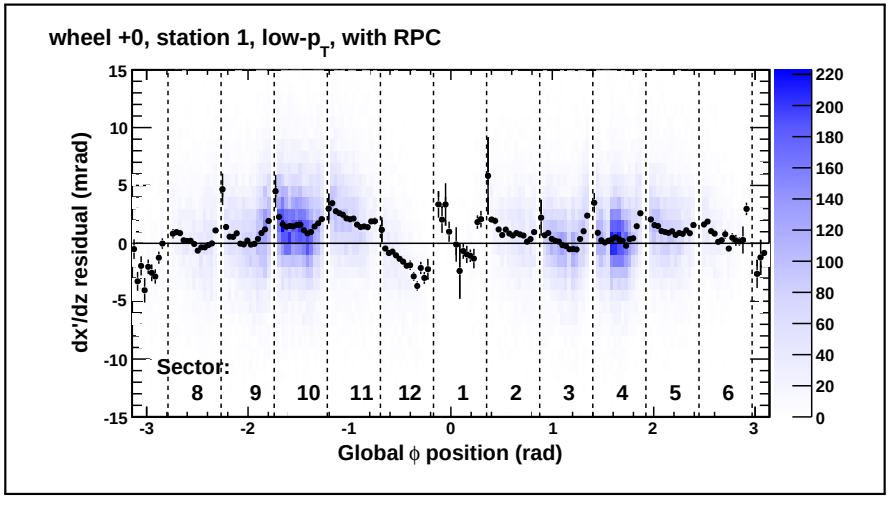

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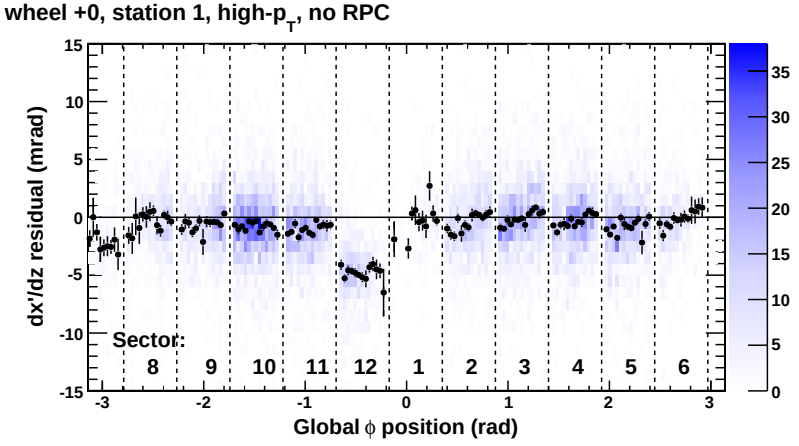

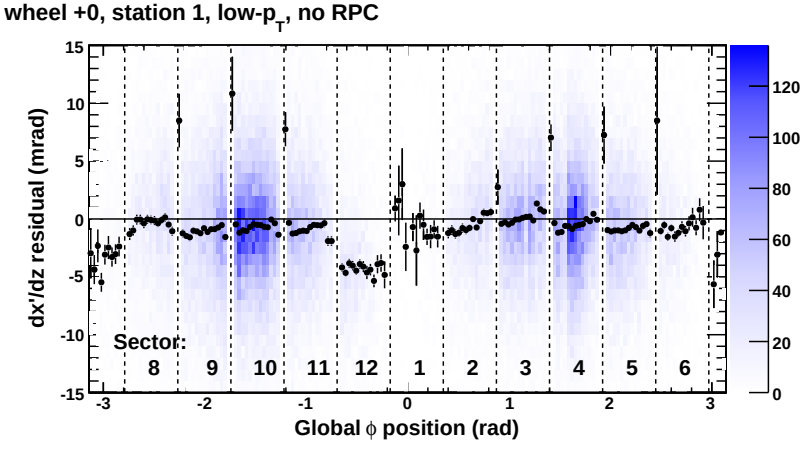

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RPC hits shouldn't affect local y or dy/dz residuals

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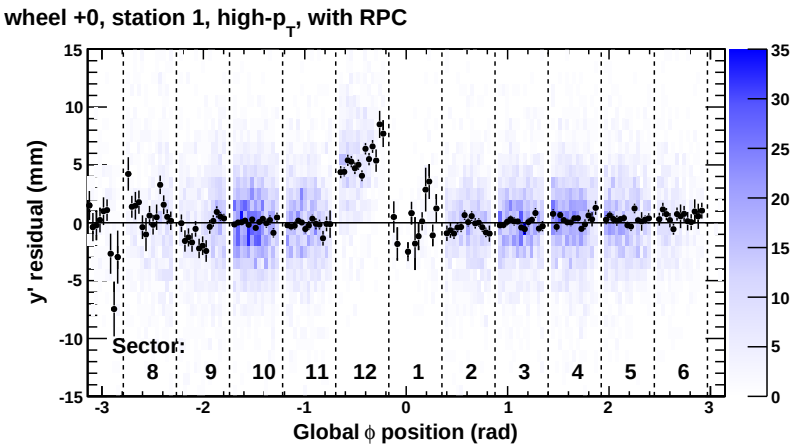

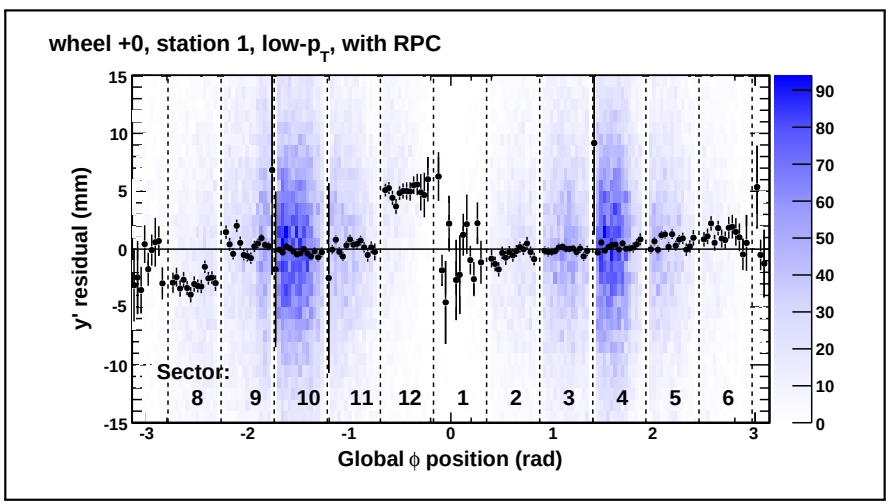

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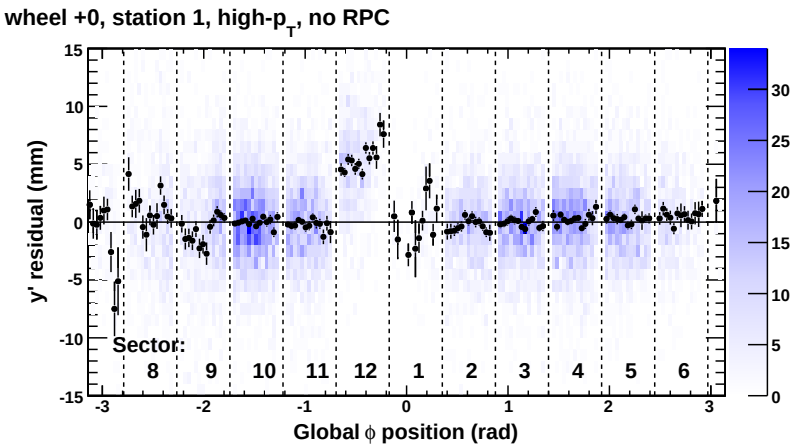

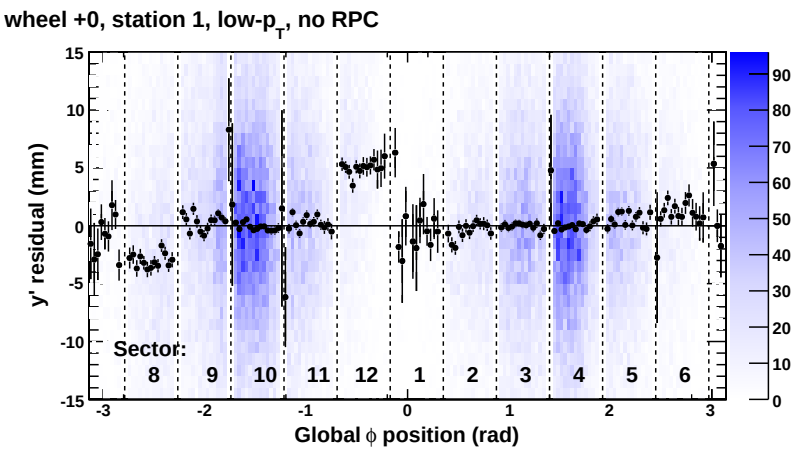

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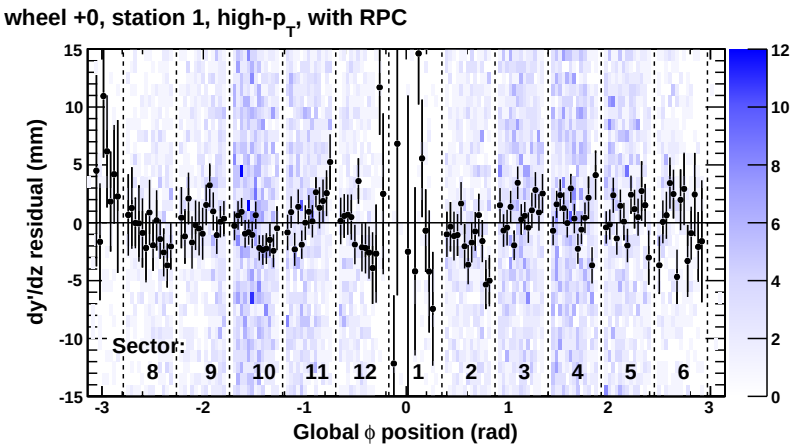

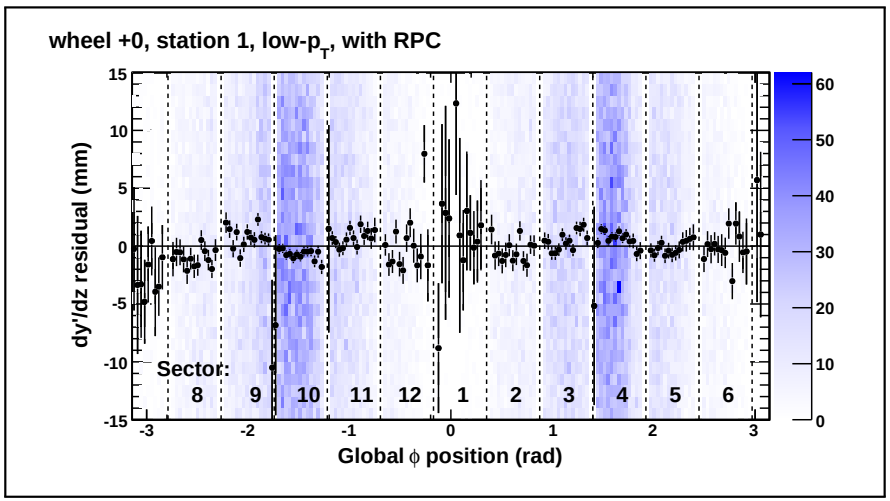

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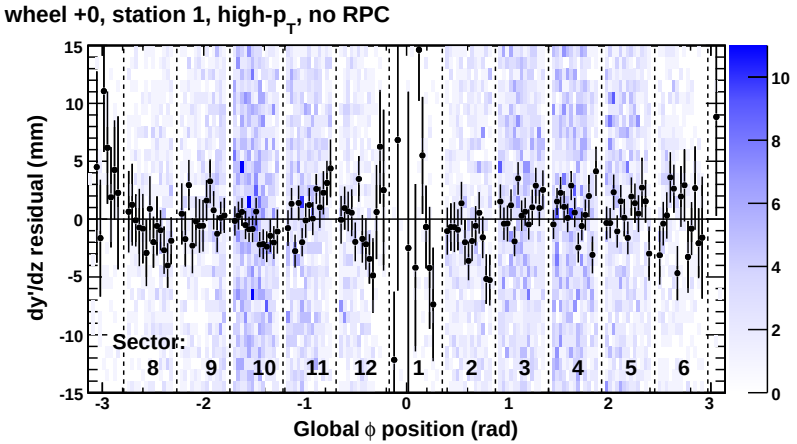

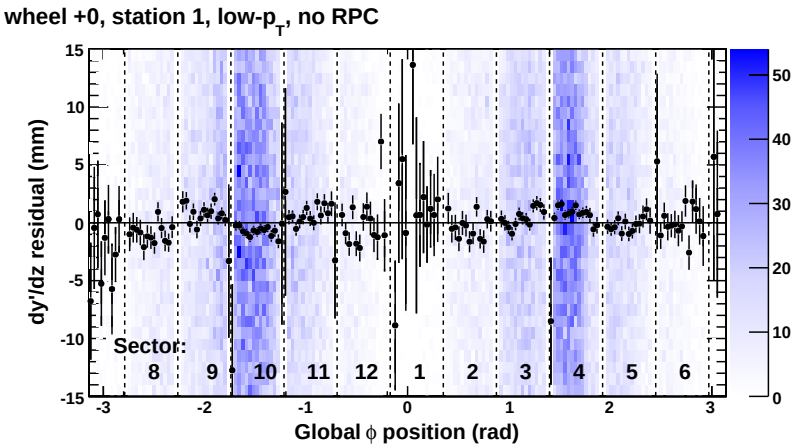

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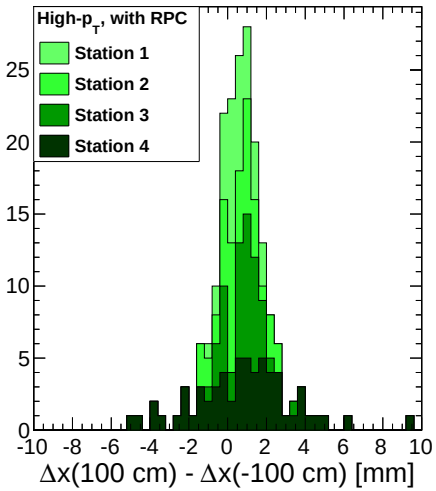

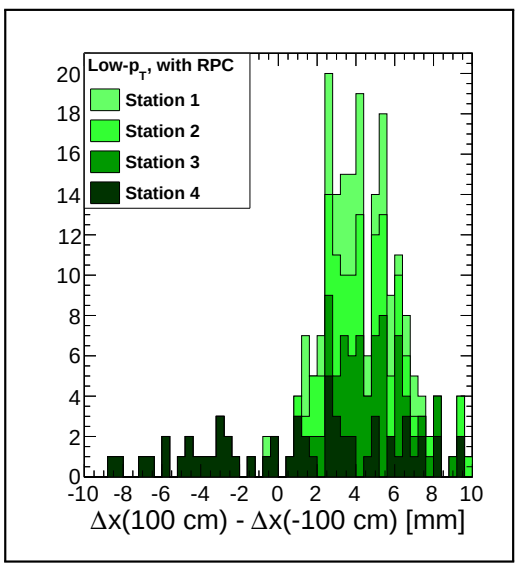

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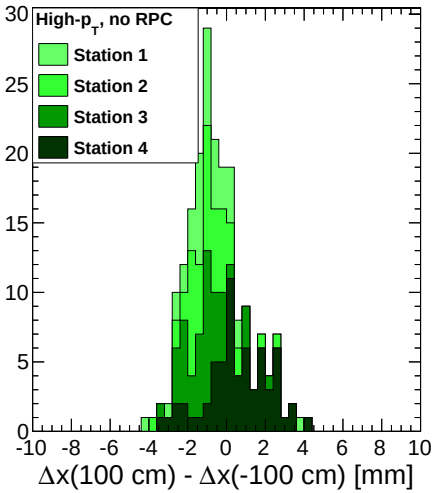

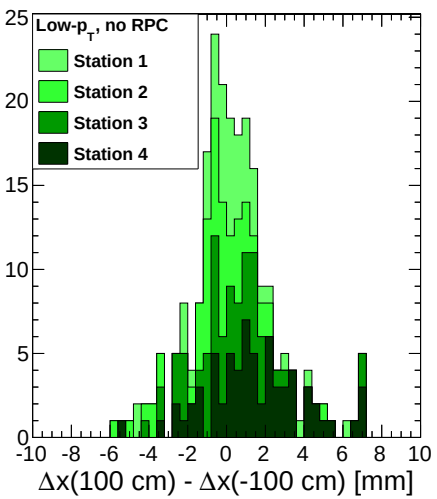

To make a summary plot:

1. Linear-fit to each chamber residual Δx as a function of position x (rough)
2. Express slopes of fits as Δx at $x = +100$ cm minus Δx at $x = -100$ cm (size of "tooth" in sawtooth plot for a 200 cm chamber)
3. Make histograms of slopes

(are there any RPCs in station 4?)

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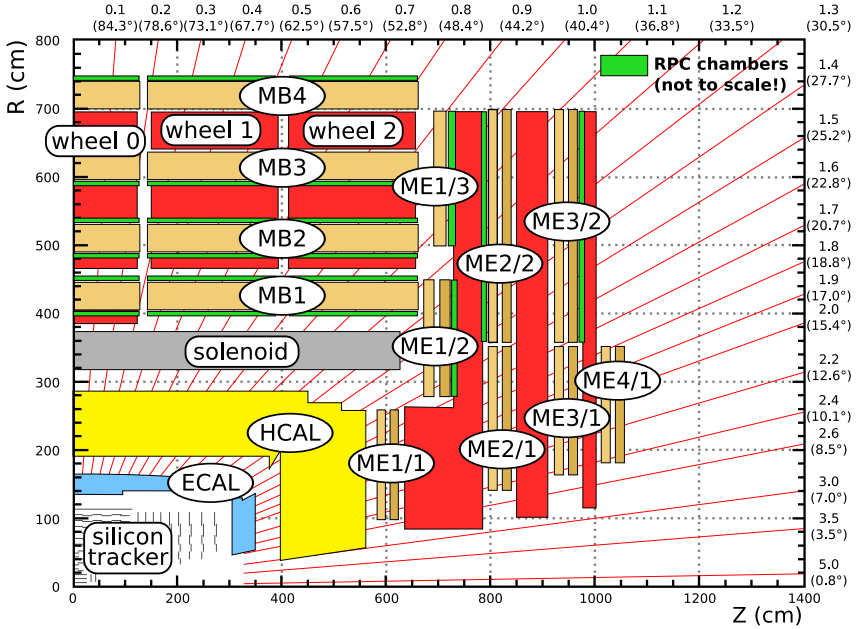
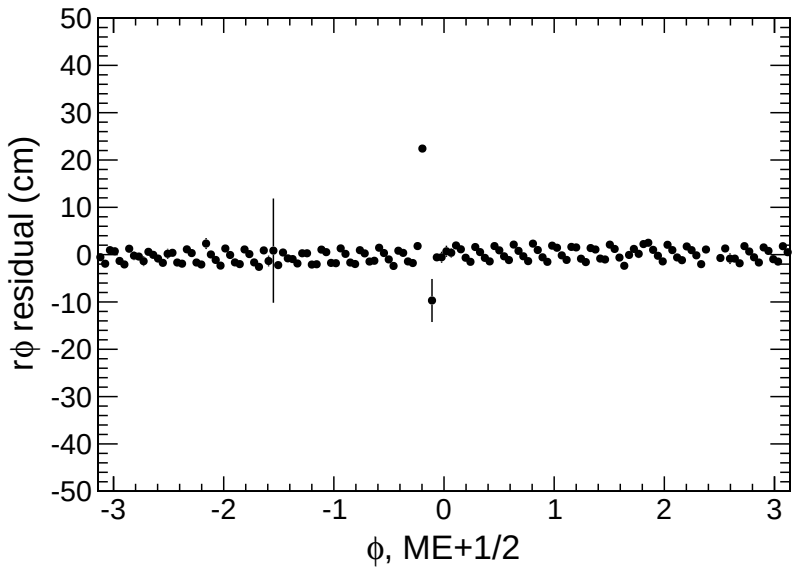
Sawtooth in endcap (new)

- Aysen began studying CSC residuals from collisions globalMuons just two days ago
- Saw strong sawtooth in ME1/2, but not elsewhere; also eliminated with RefitRPCHits = False



track refits biased by RPC hits



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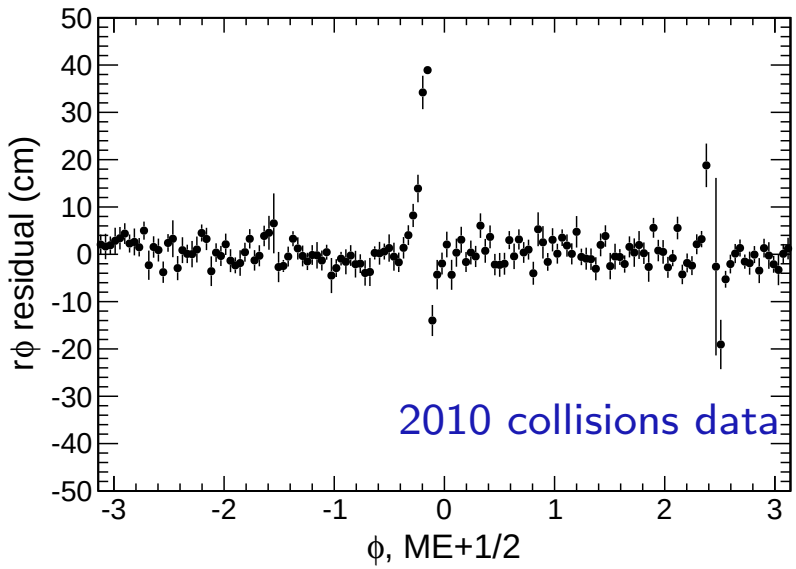
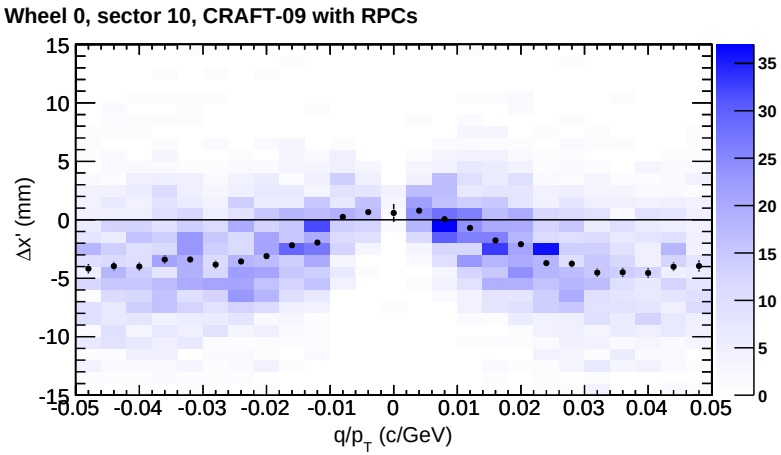
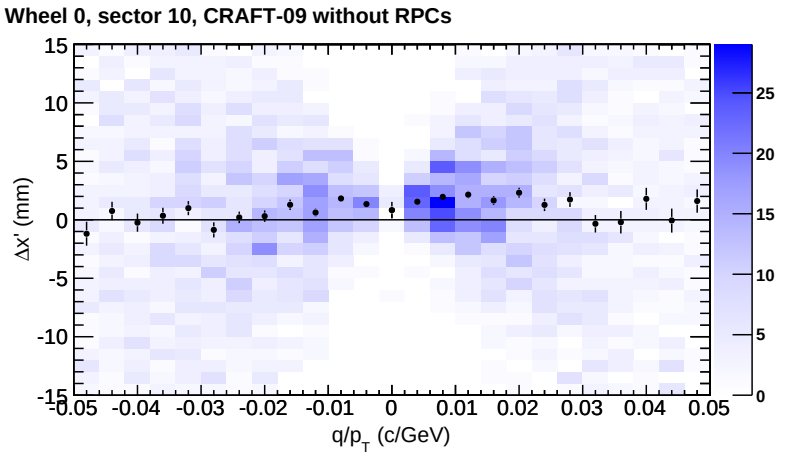
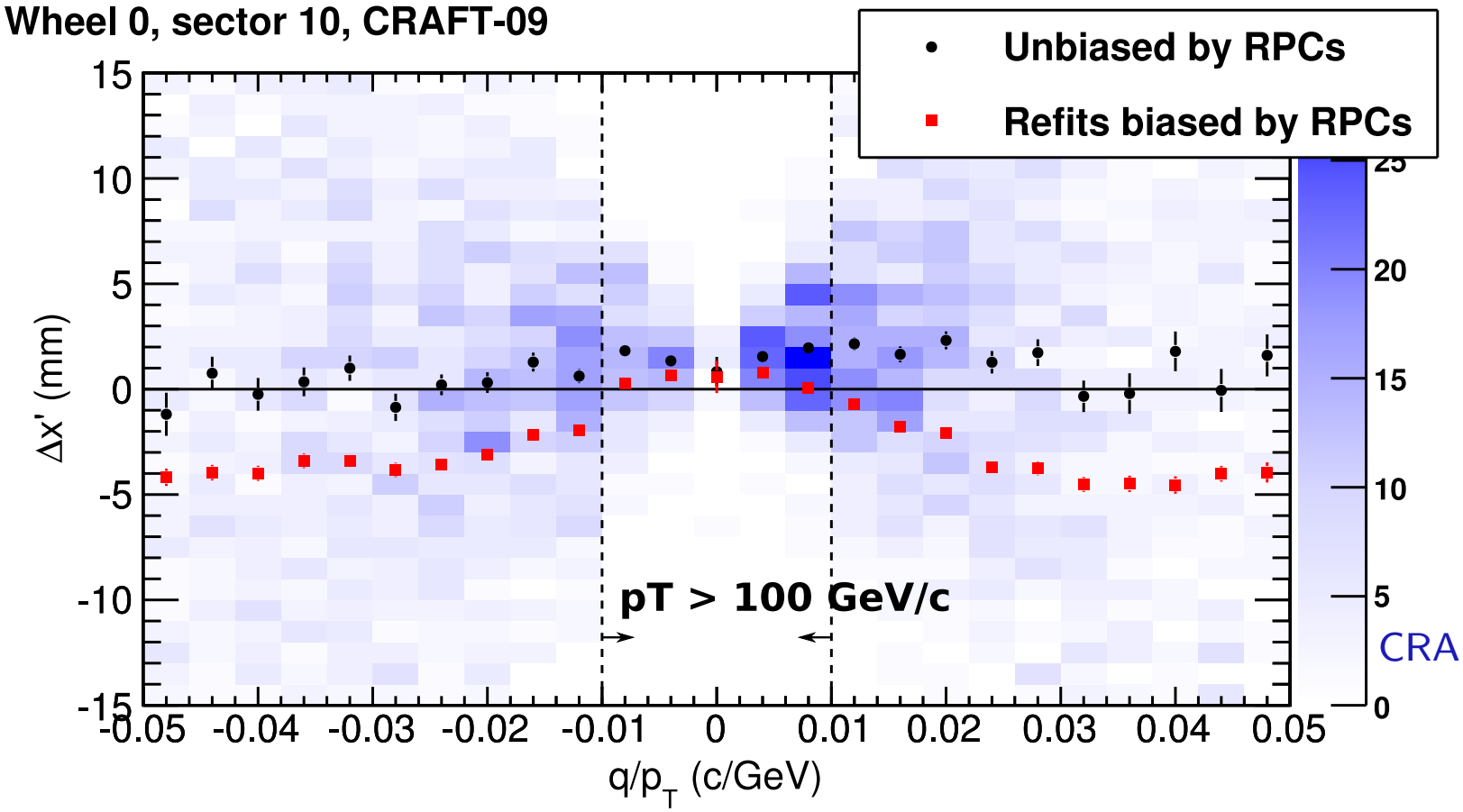


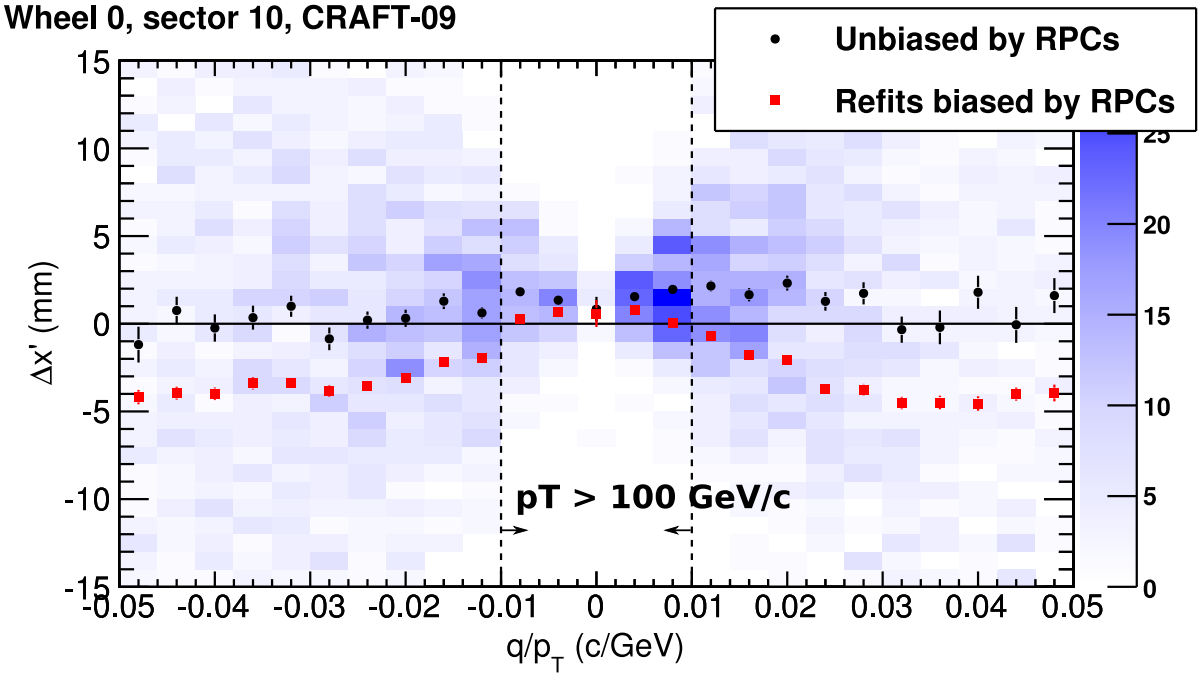
q/p_T dependence (confirmation)







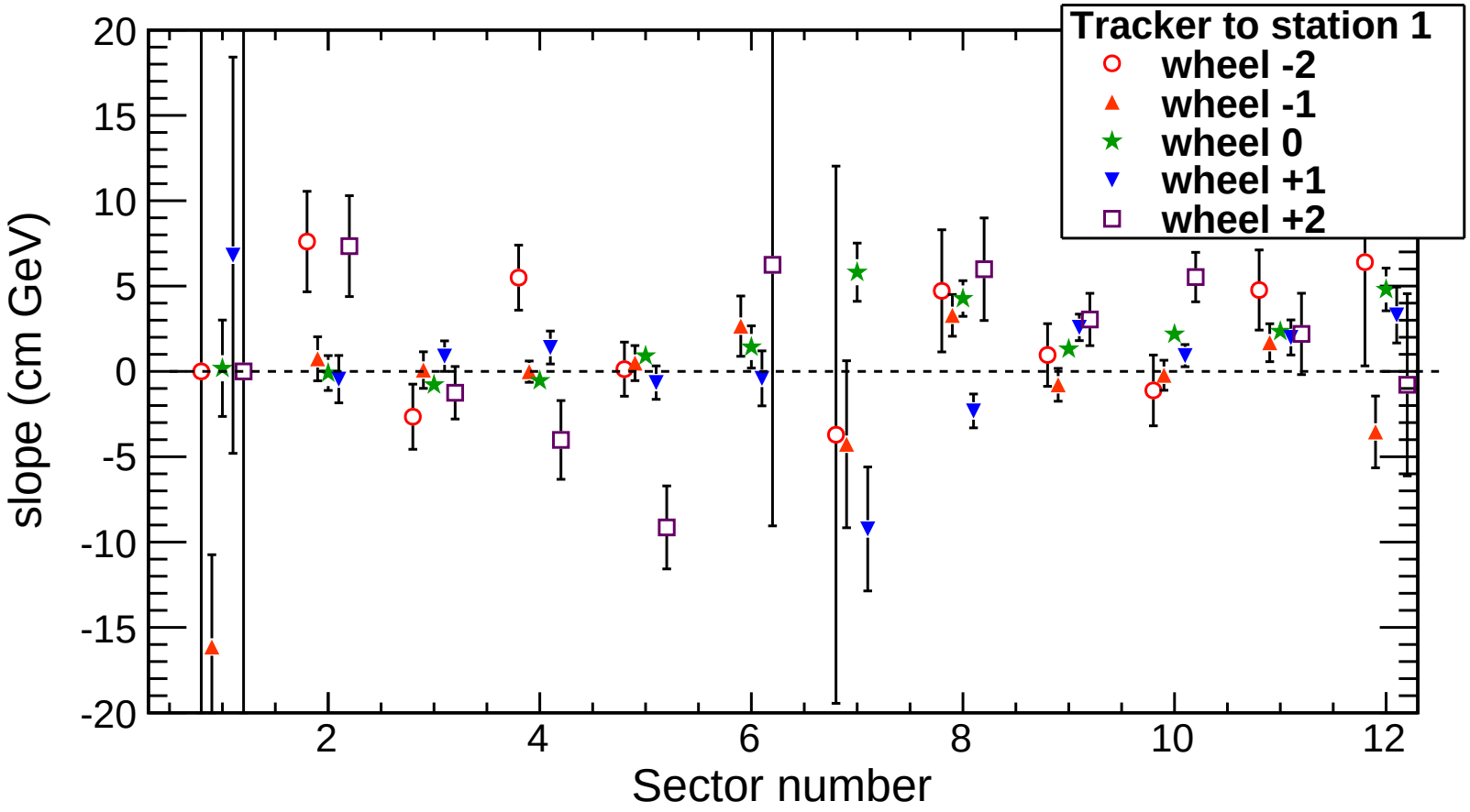
Re-interpretation of this plot



- The "100 GeV/c" scale is set by RPC bias, not by tracker
- Without RPC bias, there is no "high-momentum vs. low-momentum" discrepancy to explain: it's flat
- The $p_T > 100$ GeV/c cut limited impact of known but previously-unidentified bias
- No significant linear slope: $\vec{B}$ appears to be okay

$\vec{B}$-field study

1. Fit all Δx vs. q/p_T plots in station 1 to straight lines
2. Plot all of the slopes (in cm $\cdot$ GeV/c)



$$\Delta x \cdot p_T = \frac{\ell^2}{2(333\text{ cm})} 3.8\text{ T} \left(\frac{\Delta B}{B}\right) = \begin{cases} 10\text{ cm} & \text{for } \ell = 400\text{ cm} \\ 5\text{ cm} & \text{for } \ell = 300\text{ cm} \end{cases} \quad \text{and} \quad \frac{\Delta B}{B} = 1\%$$

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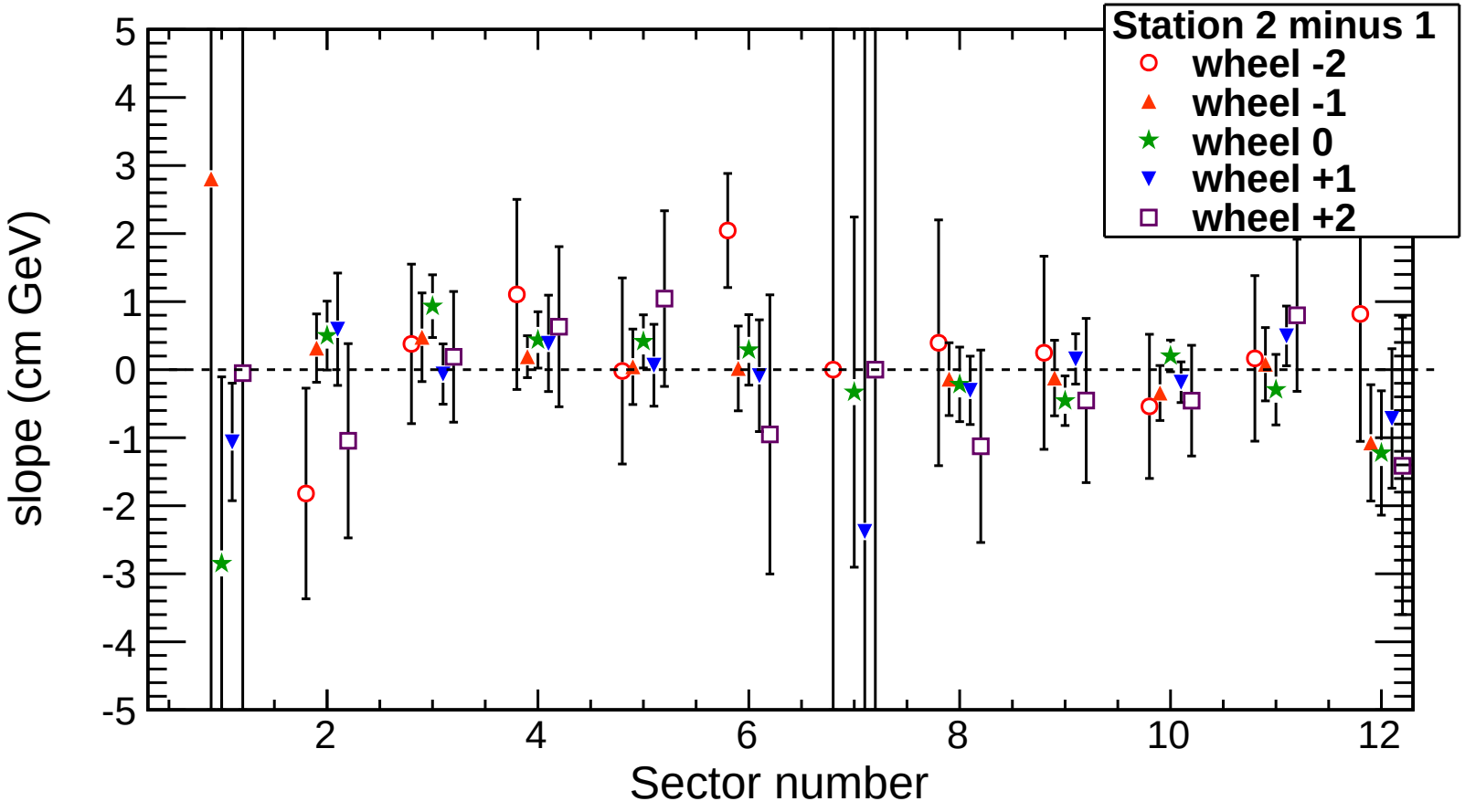
$\vec{B}$-field study

- Same for differences in residuals between stations 1 and 2
- Quantifies $\vec{B}$-field between stations 1 and 2: ∼10% level



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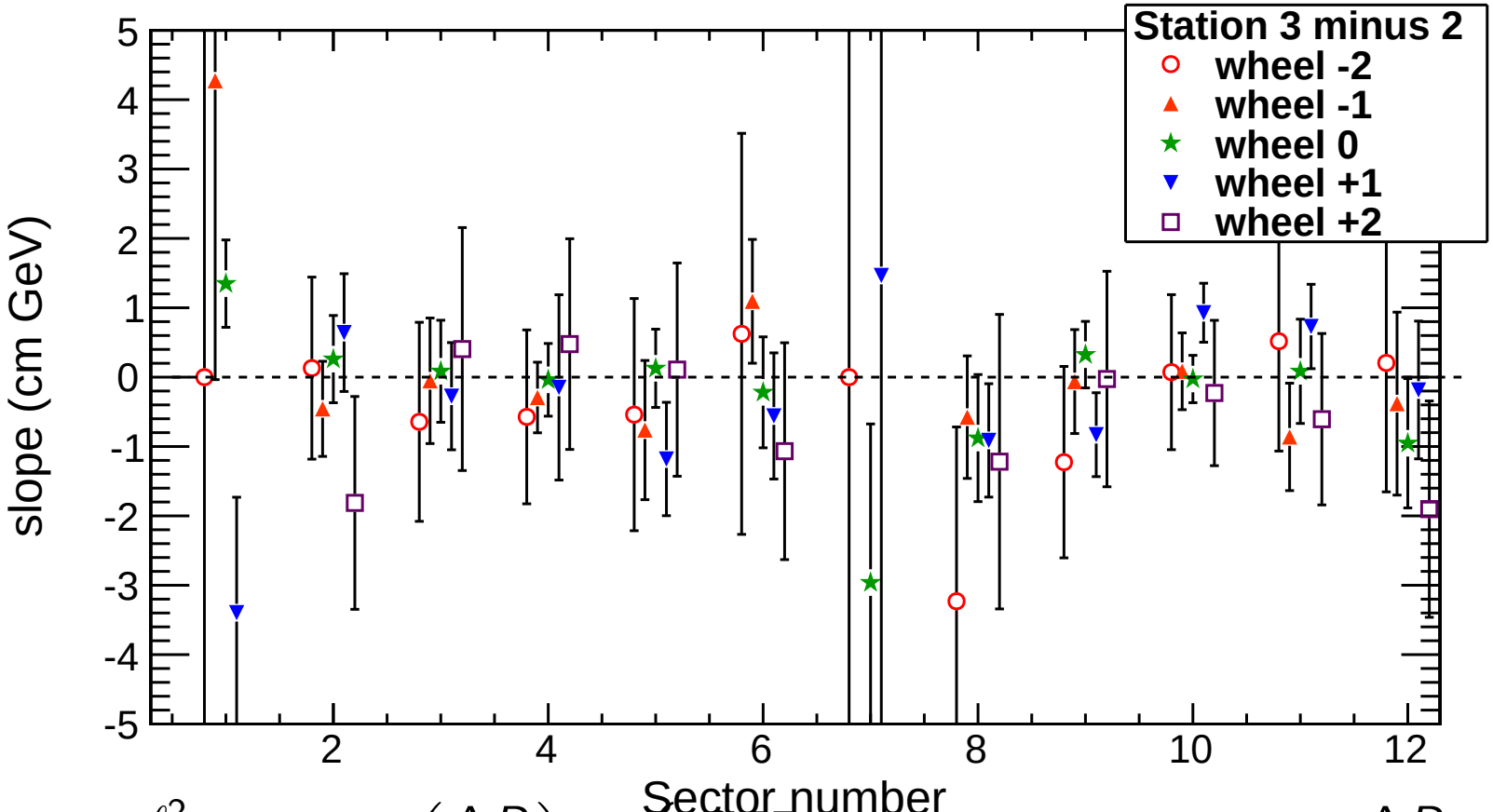
$\vec{B}$-field study

- Same for differences in residuals between stations 2 and 3
- Quantifies $\vec{B}$-field between stations 2 and 3: ∼10% level



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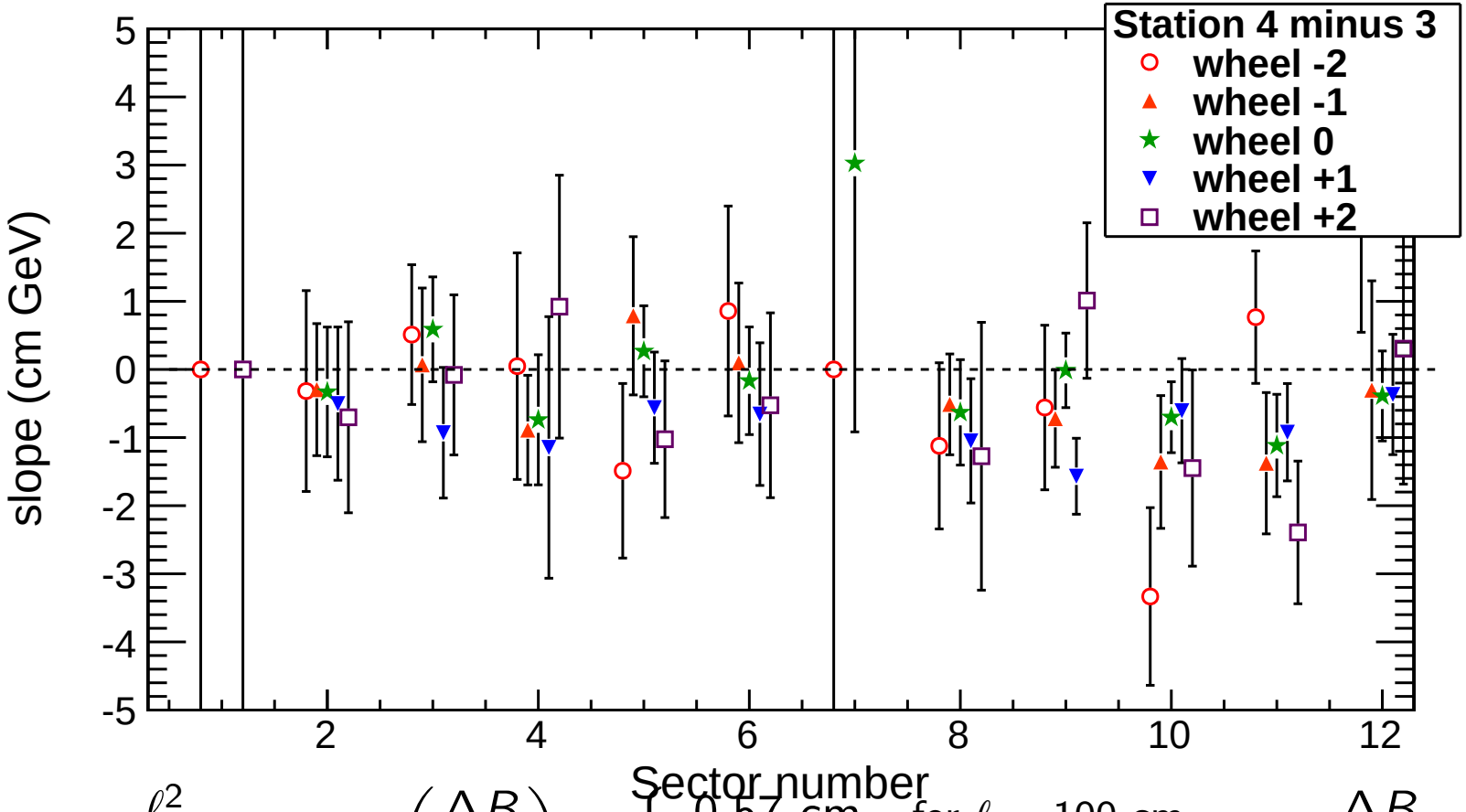
CRAFT-10

$\vec{B}$-field study

- Same for differences in residuals between stations 3 and 4
- Quantifies $\vec{B}$-field between stations 3 and 4: $\sim$10% level



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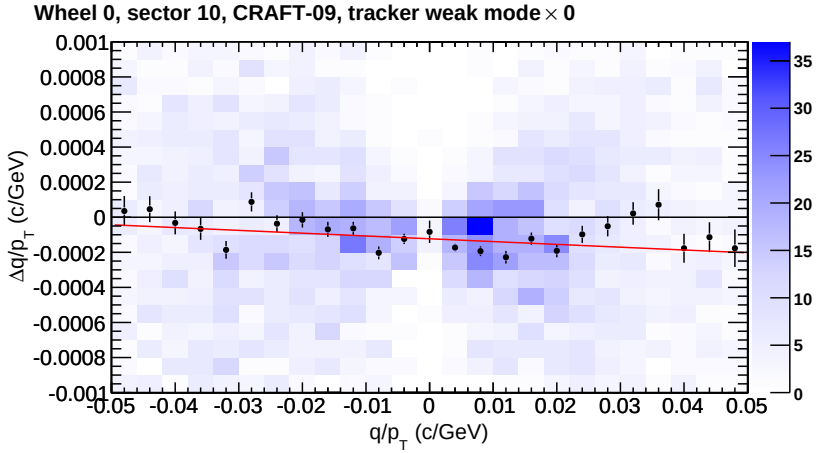
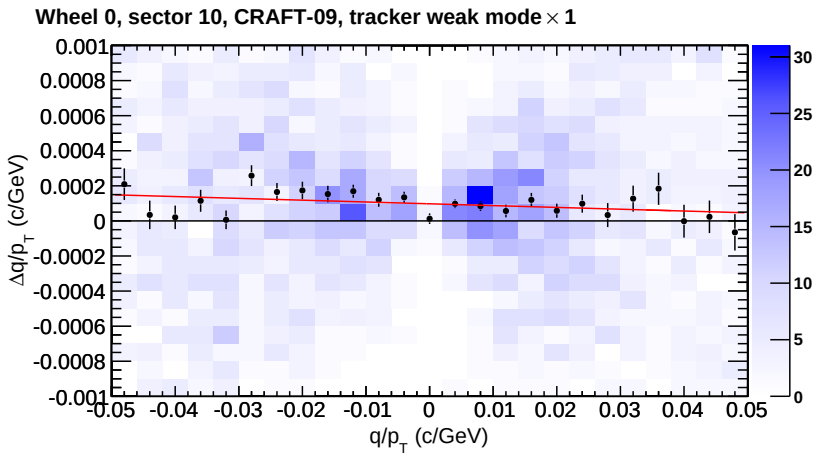
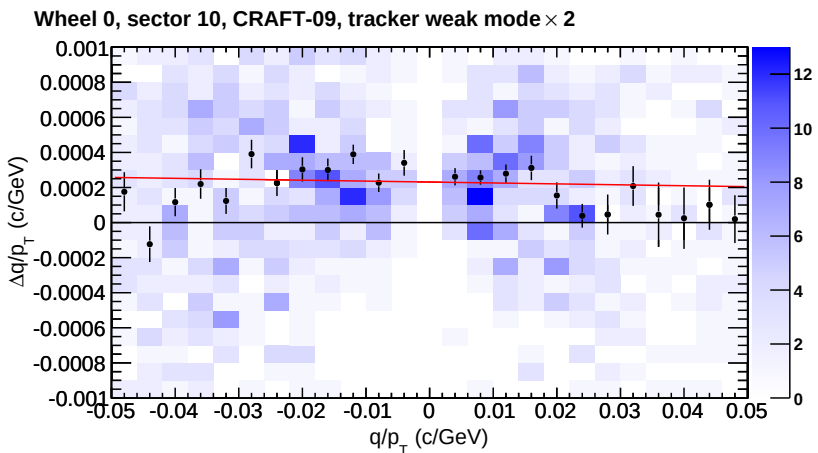
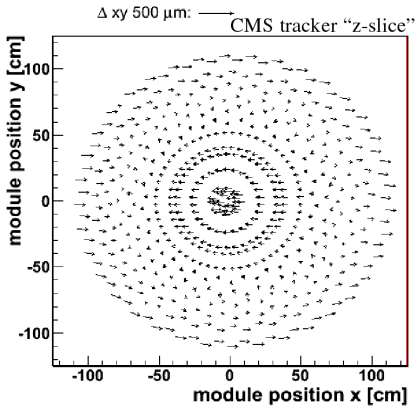
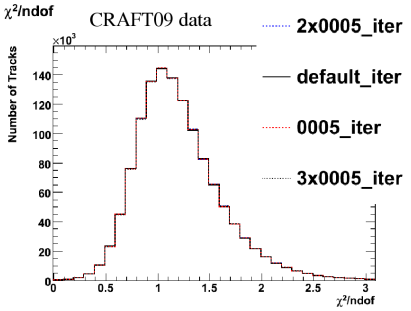
Tracker weak mode study











- 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 $\Delta(q/p_T)$

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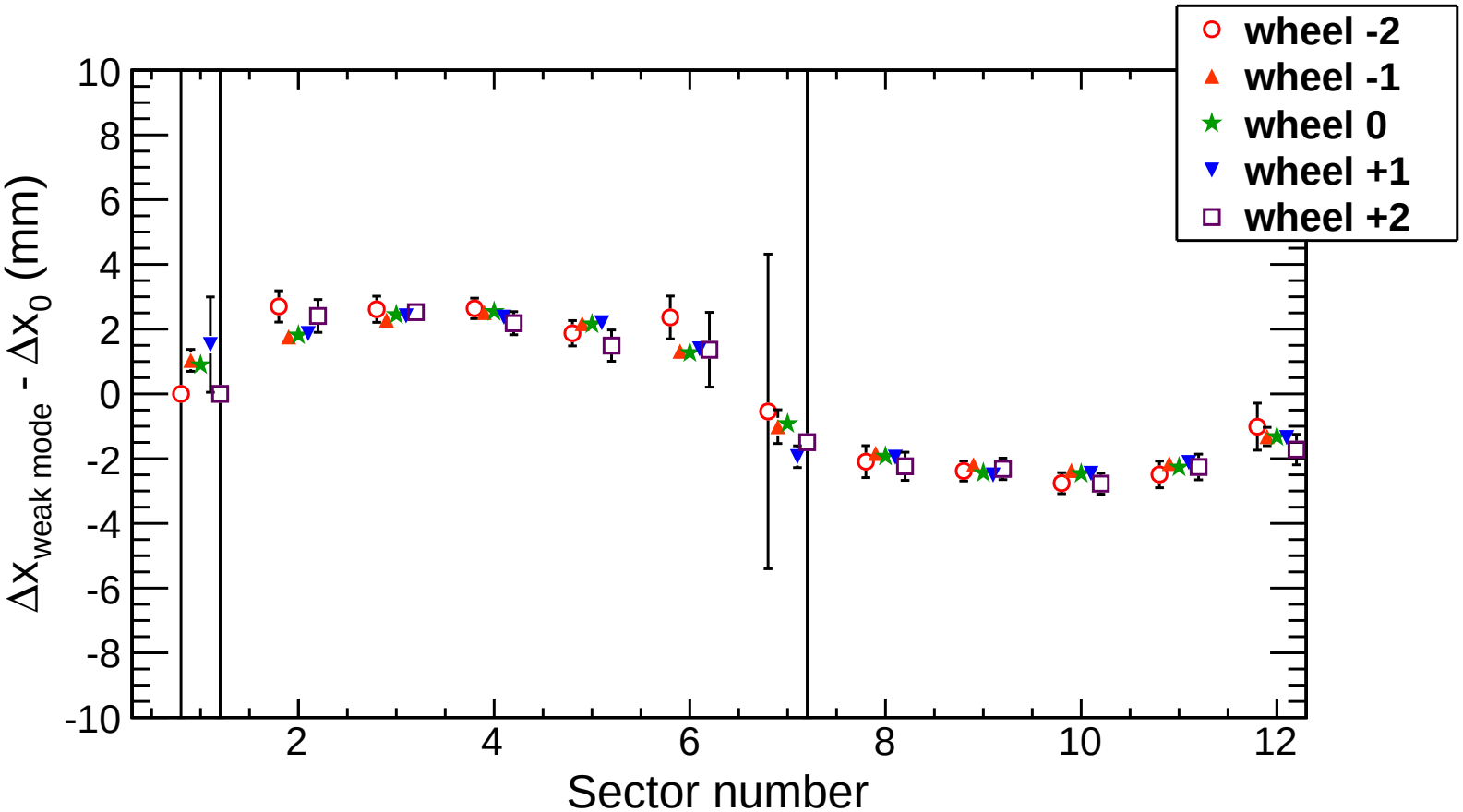
Tracker weak mode study

- How are the "constant shifts in $\Delta(q/p_T)$" distributed? (i.e. Δx?)



- Sinusoidally, which implies nothing more than a global x translation between the "weak mode" tracker geometry and the normal tracker

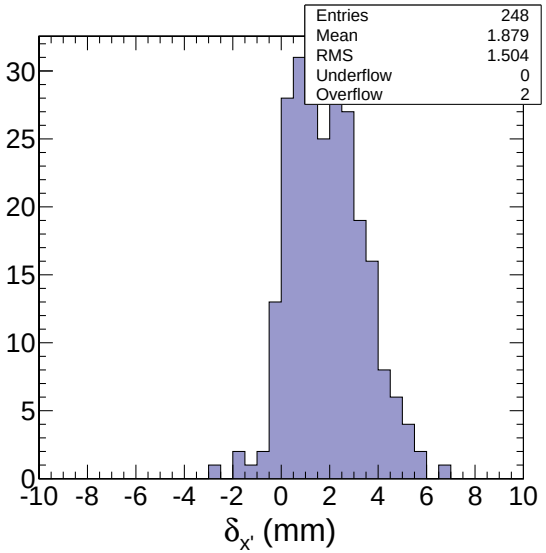
Tracker weak mode study

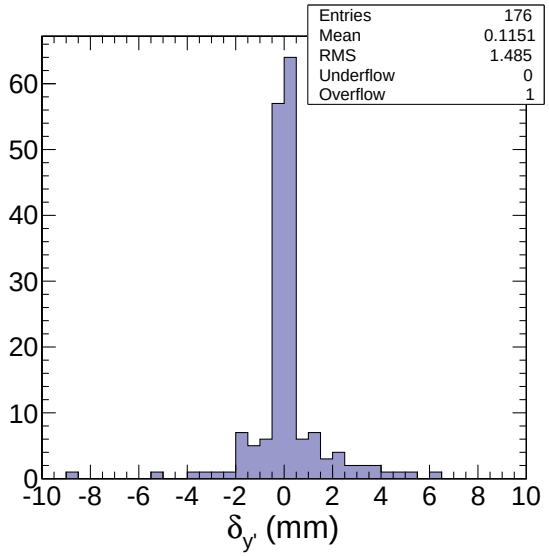
- Conclusion: muon residuals are *insensitive* to the Millepede-generated weak mode
- Implication: we cannot use muon residuals to bound this kind of distortion in the tracker (constant $\Delta(q/p_T)$)
- Bound from Cosmics Endpoint is still valid: $\sim$0.05 c/TeV
- In muon station 1, $\Delta x = 1$ mm is $\Delta(q/p_T) = 0.2$ c/TeV

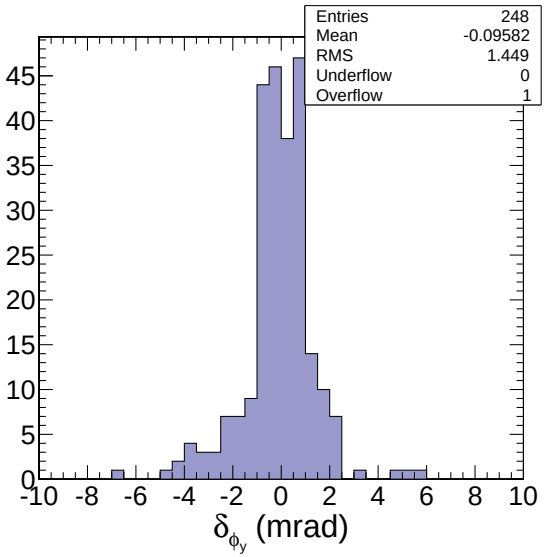
  so error in muon alignment from tracker $\Delta(q/p_T)$ bias is $\sim$0.25 mm in station 1
- Independent of p_T; we can now loosen the cut for higher statistics (and alignments using collisions muons)
  - keep in mind that resolution vs. integrated luminosity will need to be revised (residuals distributions are wider)

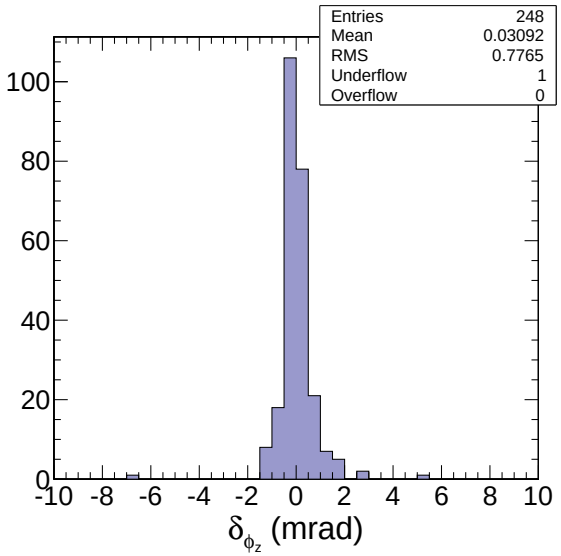
New 2010 muon alignment

1. Re-ran 2010 muon alignment without RPC bias
2. Compare alignment parameters with and without RPC bias









- Effective rotation of about 0.3 mrad
- RMS spread of 1.5 mm
- Most chamber y are unaffected
- Double-peak in ϕ_y is related to rotation and local sign conventions

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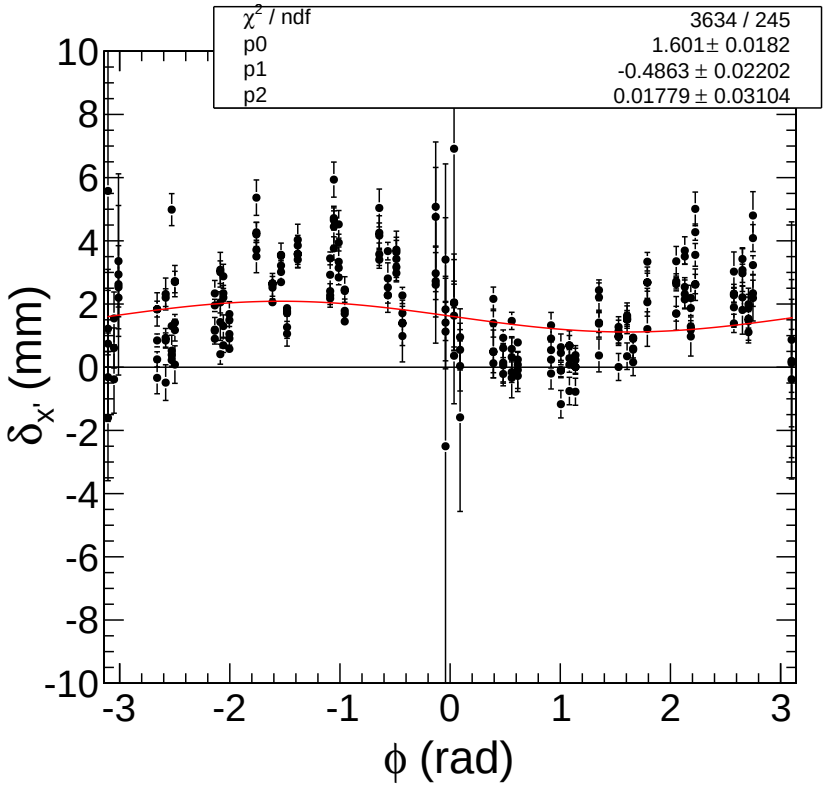
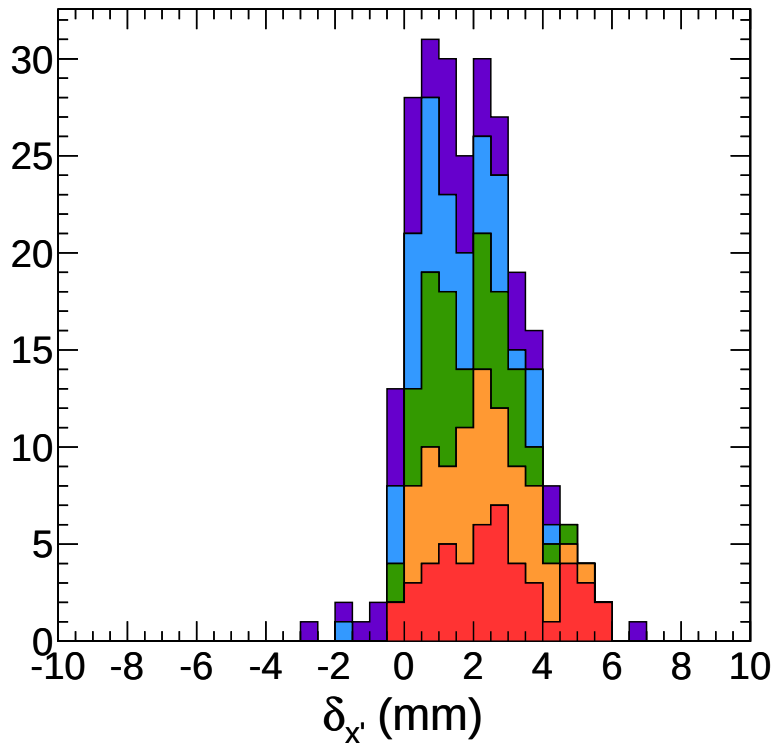
New 2010 muon alignment

(Comparing alignment with RPC bias against unbiased alignment)

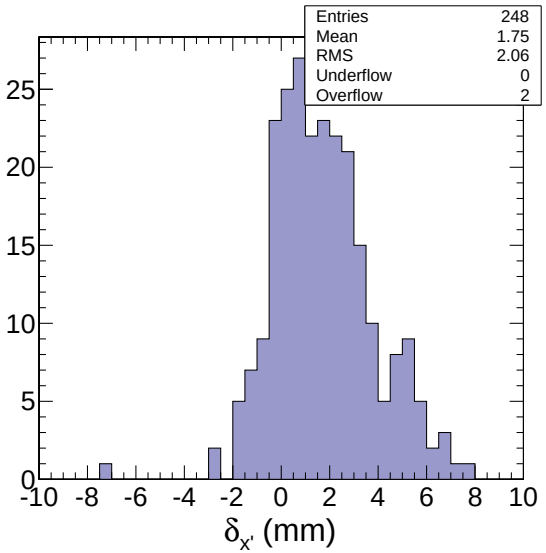
- Structure vs. ϕ not exactly sinusoidal; must be related to placement of RPCs somehow
- No structure vs. wheel (RPC bias not responsible for "barrel twist")

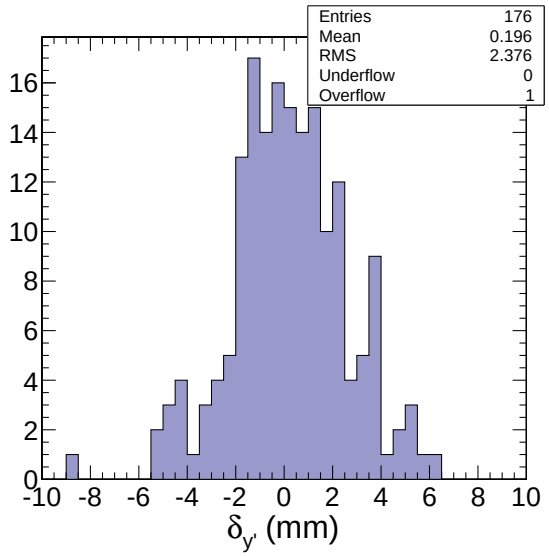


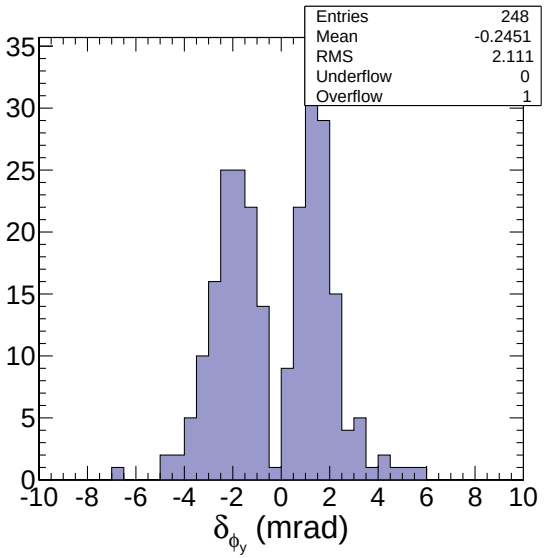


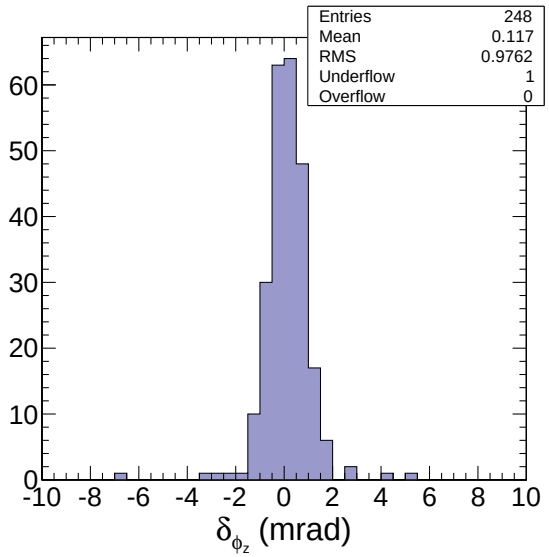
New 2010 muon alignment

- Now comparing alignment parameters without RPC bias to hardware









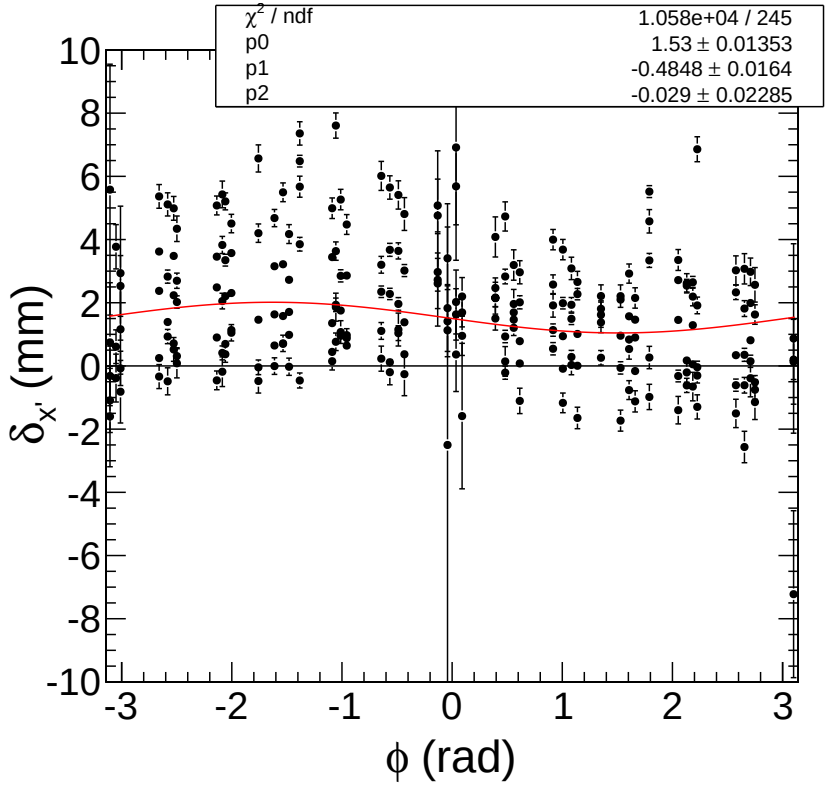
- Mostly what we saw last time, except for unaccounted-for global rotation

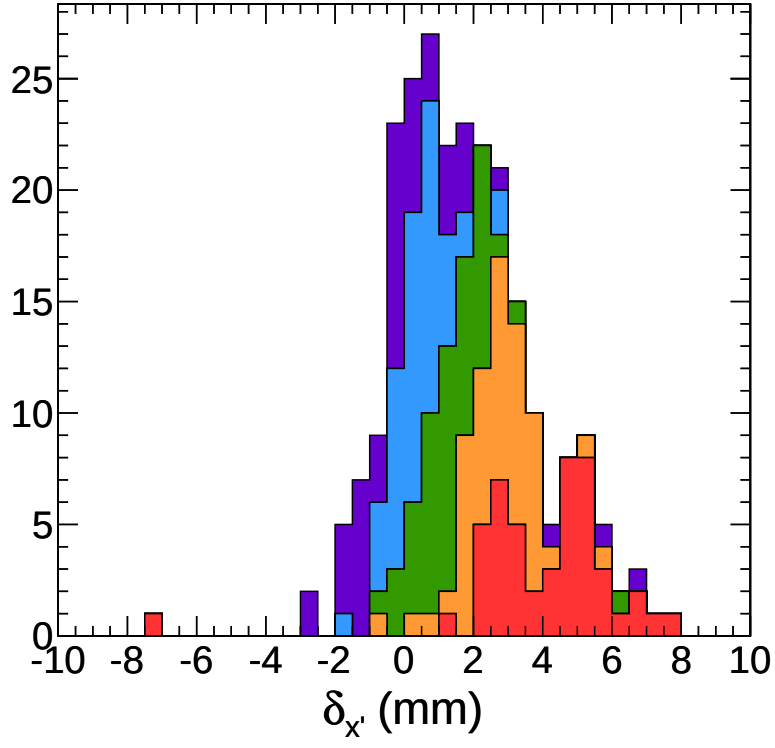
CRAFT-10

New 2010 muon alignment

(Comparing alignment without RPC bias to hardware)

- "Barrel twist" is still present with the same magnitude plus unaccounted-for global rotation





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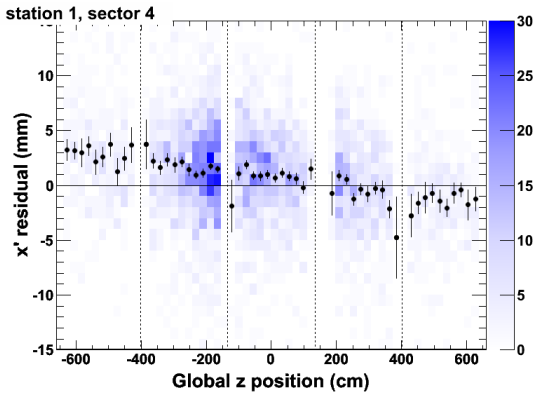
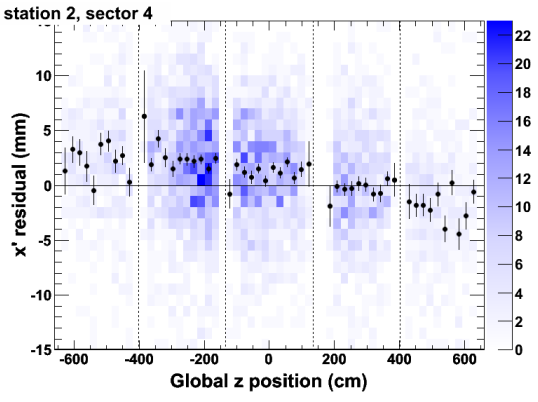
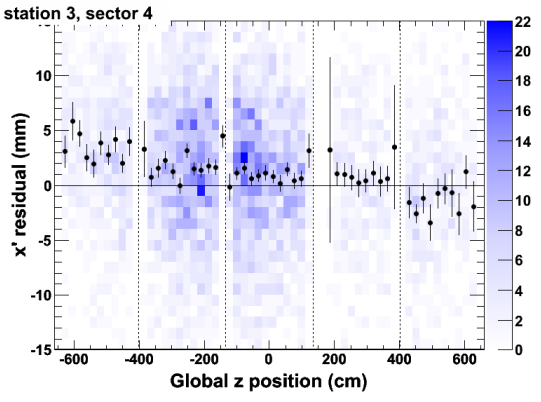
"Barrel twist" in residuals

Unbiased by RPC hits

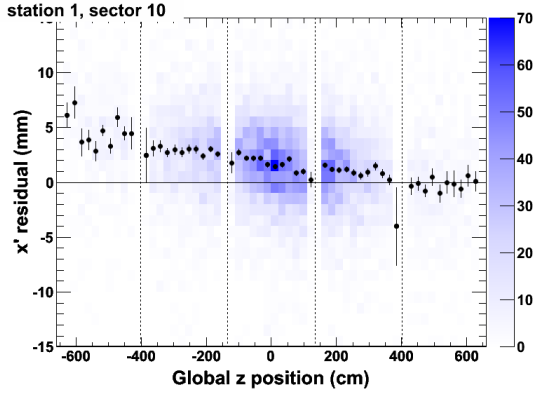
Top of CMS

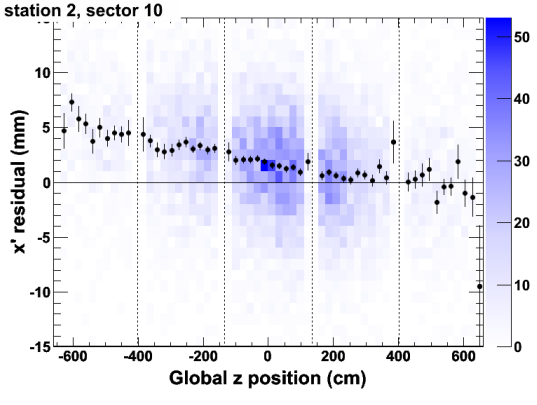


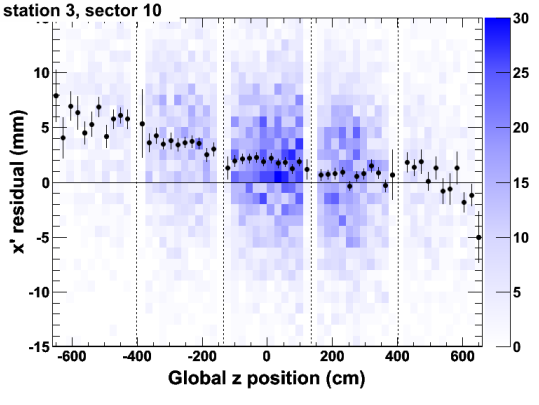




Bottom of CMS







CRAFT-10

Conclusions

- Confirmation: sawtooth and dependence on q/p_T disappear when tracks unbiased by RPC hits
  - $p_T > 100$ GeV/c cut limits effect on alignment results
- We do not see large $\vec{B}$ field bias: less than 1% before station 1
- Modified interpretation of tracker weak modes
  - no more "high-momentum vs. low-momentum" discrepancy
  - muon residuals cannot probe tracker weak modes
  - cosmic endpoint constraint on tracker weak modes $\Rightarrow$ $\sim$0.25 mm bias in chamber x positions
- New 2010 muon alignment without RPC bias
  - RPC bias effectively a 0.3 mrad rotation and 1.5 mm chamber position error
  - unrelated to "twist" with respect to hardware geometry
- We no longer need the $p_T > 100$ GeV/c cut, which will make alignments with collisions possible
  - resolution vs. integrated luminosity estimates must be revised