Deeper Investigations into Alignment Residuals and Proposal for Second CRAFT Reprocessing (fast download version)

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- We have the means of producing alignment constants (and can do it before next Wednesday)
- But what we need to do is
  - strengthen the case that the results are true, physical positions
  - make the calculation more robust, where necessary
- Due to the distribution of cosmic rays, we must align the barrel before the endcap
  - globalMuons connect barrel to tracker
  - standAloneMuons connect endcap to barrel

What we saw last time

- Shapes in the wheel-by-wheel residuals that indicated some real misalignments and some apparent tracking biases

Since last time

- Improved fitting procedures with better control of $\vec{B}$-field and scattering
- Zoomed in to chamber-by-chamber level of detail (rather than wheels)
- Discovered evidence for
  - real several-millimeter DT misalignments in local x, ϕ_z
  - possible misalignments in R (radial) or ϕ_y (rotation around local y)
  - interesting distribution of $\vec{B}$-field mismodelling
  - local y misalignments on top of a tracking bias in this direction

What we can do about it

- Definitely align DT local x, ϕ_z (my recommendation)
- Possibly align DT ΔR (or ϕ_y) and local y, pending other studies

Outline for this talk

- Justified assumptions that underlie this analysis
- Plots illustrating key effects
- ~~Appendix: complete set of 152 plots~~ (see full version of this talk)

Justified assumptions

1. A discontinuity or sharp edge in the residuals distribution at a chamber boundary is due to an effect in the chamber itself, not a tracking bias
   - timing miscalibration? no, wrong timing affects two sides of wire in opposite ways, cancelling in the residuals mean
   - chamber description? (this happened for CSCs) *only* if all chambers of the same type show the same effect
   - misalignment by process of elimination
2. Residuals from $\vec{B}$-field mismodelling strictly flip sign with charge
   - key point: cosmic charge ratio is not 1:1, but momentum spectra for the two charges are proportional (this fact is used in the charge ratio analysis)
3. Broad distortion across all of CMS is probably (but not certainly) due to a bias in the tracks source, rather than misalignment

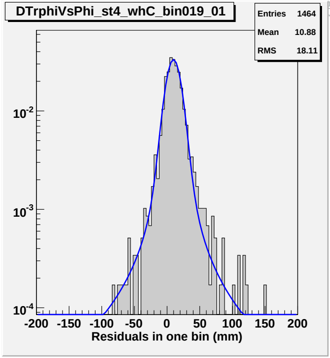
Improved fitting procedure

- Last time:
  - distinguished misalignment from $\vec{B}$-field and scattering effects by a calculus-style $p \to \infty$ limit
  - but detailed plots were simple TProfiles (bin-by-bin truncated mean of residuals)
- Shortcomings:
  - TProfiles don't incorporate the same limit (just a high p_T cut)
  - $p \to \infty$ limit fit is sensitive to choice of binning
  - doesn't take advantage of the useful fact that $\vec{B}$-field displaces the peak of the distribution, while scattering adds tails
- Improvements:
  - determine every bin from a fit
  - incorporate scattering tails in the fit ansatz
  - handle $\vec{B}$-field with exactly two bins: positively-charged tracks in one, negative in the other
    - (positive bin $+$ negative bin)/2 is insensitive to antisymmetric errors from $\vec{B}$-field
    - (positive bin $-$ negative bin)/2 is maximally sensitive

Residuals ansatz

Residuals in each bin are fit to a convolution of a Gaussian and a Cauchy-Lorentzian

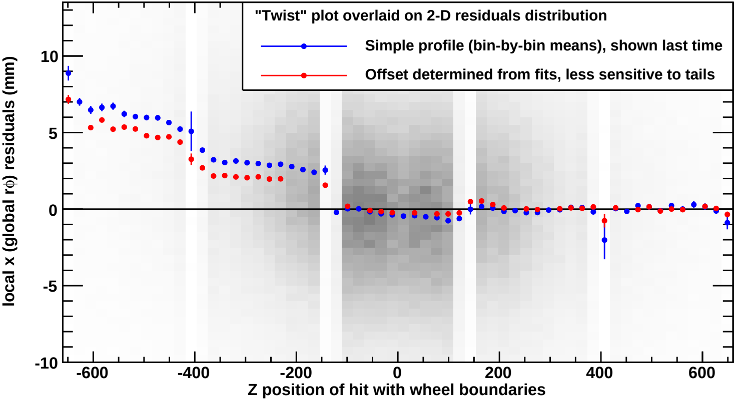
$$f(x) = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-\xi^2}{2\sigma^2}\right) \times \frac{1}{\pi} \frac{\Gamma/2}{(x-\xi)^2 + (\Gamma/2)^2} \, d\xi$$



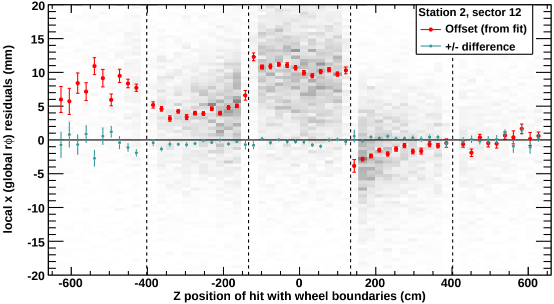
- Naturally has a Gaussian core, power-law tails, and is self-normalized
- Models the physical process: scattering effects yield power-law distributions, experimental resolution adds Gaussian convolution
- Unbinned fit acts like a mean that de-emphasizes outliers
  - power-law contributes far less to log liklihood than exponential
  - regular mean ($\sum x_i/N$) would be equal to center of an unbinned Gaussian fit; this is a small extension, adding the tails

What difference does it make?

- Similar to old profile plots (this is the “twist” plot from last time)
- Small corrections compared to the effects we showed before
- Added confidence that what we’re doing is rigorous

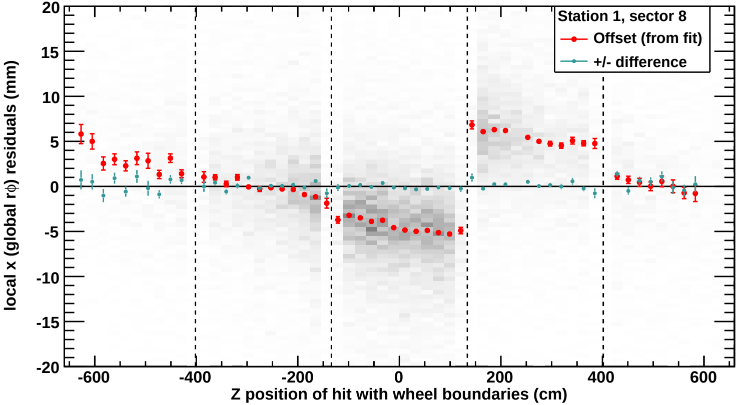


- I've split up the data so that we can see individual chambers
  - plots vs. z are split by sector, plots vs. ϕ are split by wheel: you only see one chamber at a time
- All have the same features:
  - grey background is raw 2-D residuals distribution
  - red points are bin-by-bin fit results, insensitive to $\vec{B}$-field mismodelling because of $+/-$ averaging procedure
  - small blue points are $+/-$ difference: the error we would incur if we were crazy enough to use only positive tracks (maximal)

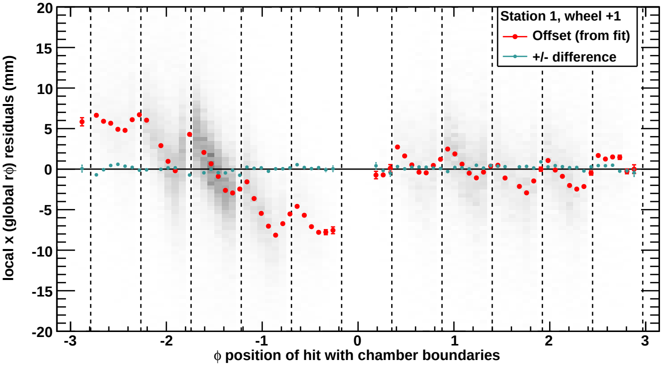


Geography: local x cliffs

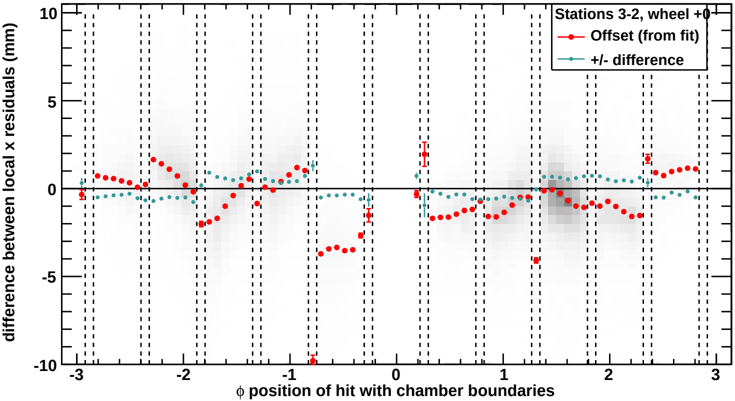
- Offsets in local x residuals from one chamber to the next are (rather large) $r\phi$ displacements
  - discontinuities in the curve are a smoking gun!
- Linear slopes with respect to z can be easily explained by local ϕ_z rotations



- Linear slopes in local x residuals vs. ϕ can be explained by
  - rather large radial displacements:
    $$\Delta R \approx (\text{maximum residual}) \times (R/\text{chamber half-length})$$
  - or huge local ϕ_y rotations:
    $$(\Delta\phi_y)^2 \approx 1 - (\text{maximum residual})/(\text{chamber half-length})$$
- If one of these is responsible, it will become more clear in the track-by-track calculation of ΔR and $\Delta\phi_y$ (I can also plot that vs. ϕ)

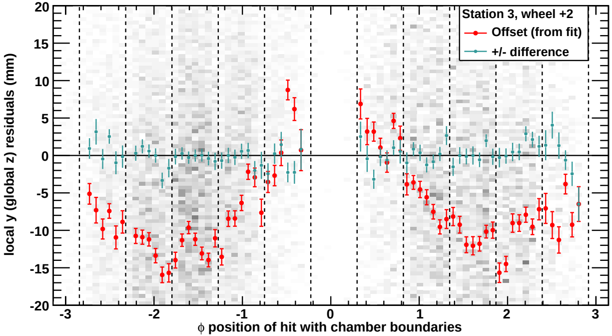


- $\vec{B}$-field mismodelling (blue points) is visible in station 3 and especially 4
- They can be better localized by considering track-by-track differences in station 3 residuals minus station 2 residuals (for example)
- In wheel 0 only, they show a chamber-by-chamber dependence: a clue to the problem in $\vec{B}$-field modelling? (material between chambers?)



Geography: smooth valleys

- Local y residuals have a global trend with a maximum amplitude at $\phi = \pm\pi/2$ and large $|z|$
  - appears in all stations, consistently in "vs. ϕ" and "vs. z" plots
- Though in principle this could be a systematic distortion of the whole barrel, we first consider the possibility that it is a tracking bias
  - could be due to tracker TEC misalignment (also misaligned parallel to beamline, affecting large $|z|$ the most)
  - easy to check: drop tracks with TEC hits and replot



Conclusion: CRAFT proposals

- Minimal:
  - incorporate improved fitting in alignment procedure
  - align local x ($r\phi$) and local ϕ_z
  - the plots present a clear picture of their current misalignment
- More ambitious 1:
  - make these kinds of plots for track-by-track ΔR and $\Delta\phi_y$
  - if one of these parameters is confirmed as being responsible for the "sawtooth," apply corrections
- More ambitious 2:
  - exclude tracks with TEC hits
  - if "smooth valleys" disappear, leaving only local y cliffs, align local y (an important parameter)
- Combine with anything better measured by hardware, of course (through the DTAlignmentRcd format as input to track-based)
- Too ambitious: aligning CSCs as well. I don't think I have enough time...