Magnetic Field from a Muon Alignment Perspective

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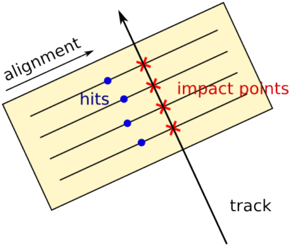
Entangled problems?

- The alignment of the muon chambers and the distribution of magnetic field are both imperfectly known
- Both cause deviations in muon trajectories with respect to tracks propagated from the tracker
- How can they be distinguished?
  - residuals from misalignment are independent of track momentum and charge
  - residuals from $\vec{B}$-field mismodelling depends on momentum and is antisymmetric with charge
- This talk will be about exploiting the above to
  - align the DT chambers
  - verify $\vec{B}$-field error calculations using techniques developed for alignment

Basic alignment technique



HIP algorithm: "Hits and Impact Points"

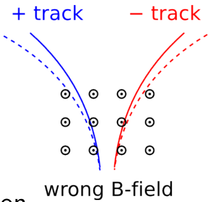
- Using a track as reference, alignment correction is the peak of the residuals distribution
- Our residual $\equiv$ (impact point) $-$ (hit)

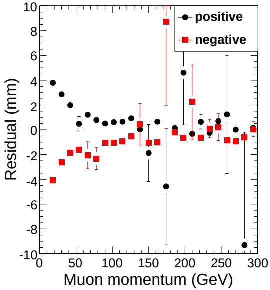
Implementation is not exactly the same as that in the tracker

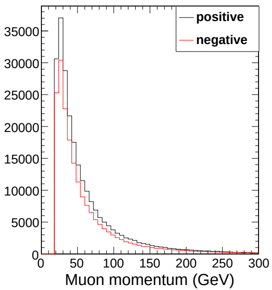
- Muon hits excluded from refitted tracks: tracker is external reference
  - breaks the circularity between fitting tracks and aligning chambers
  - no need to iterate: convergence in one step
- Muon chambers are much bigger than silicon wafers: study residuals as a function of position throughout each chamber

Effect of $\vec{B}$-field on residuals

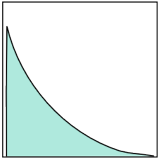
- Track propagation is sensitive to the integral of $\vec{B}$-field error along its path
- Effect on residuals flips sign with charge
- The number of positively-charged tracks is not equal to the number of negatively-charged tracks
- But both charges have the same momentum distribution (a fact used in the cosmics charge ratio analysis)



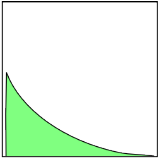




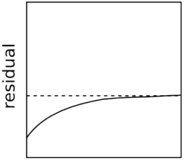
Controlling $\vec{B}$-error in alignment



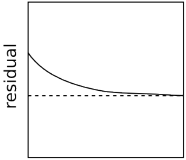
momentum spectrum of positively-charged tracks



momentum spectrum of negatively-charged tracks



momentum of positively-charged tracks



momentum of positively-charged tracks

- Measure residuals peak in two bins, one for each charge
- Non-weighted average is insensitive to $\vec{B}$-field errors

  $$\text{alignment} = \frac{R_+ + R_-}{2}$$

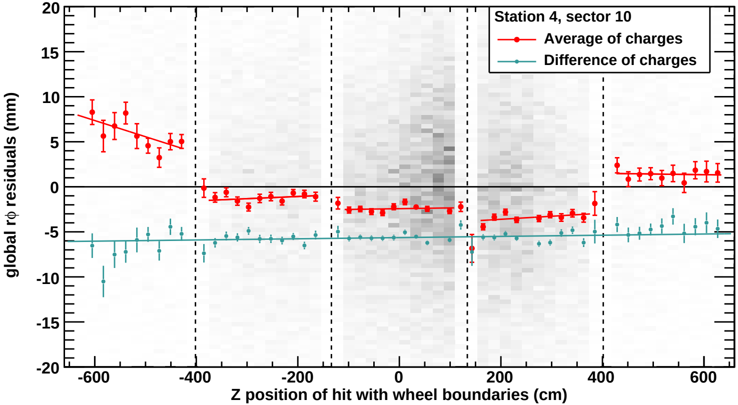
- Difference is maximally sensitive

  $$\text{error tracer} = \frac{R_+ - R_-}{2}$$

- Alignment calculation effectively scales up negatively-charged muon contribution so that the $\vec{B}$-field errors cancel
- Systematic error $=$ (error tracer) $\times$ (charge mismeasurement) $\times \dfrac{0.3}{2.3}$

  $\sim$ (error tracer) $\times$ (a few percent or less)

- Station 4 has the largest $\vec{B}$-field mismodelling
- The misalignment measure breaks cleanly at the chamber boundaries
- The tracer of $\vec{B}$-field errors is constant



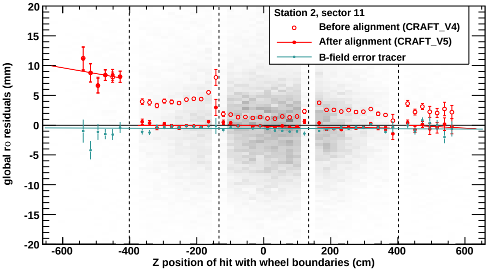
grey background is the raw 2-D residuals distribution

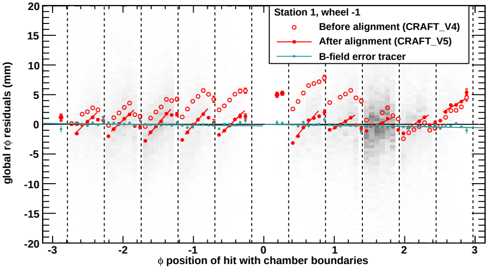
linear fits are only a guide for the eye: not used in alignment!

Alignment results

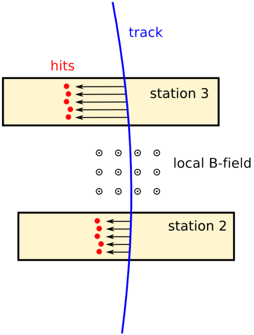
- Sample before-and-after residuals plots from alignment shown at right
- Complete set of 152 pages at last DT-DPG ("more information")

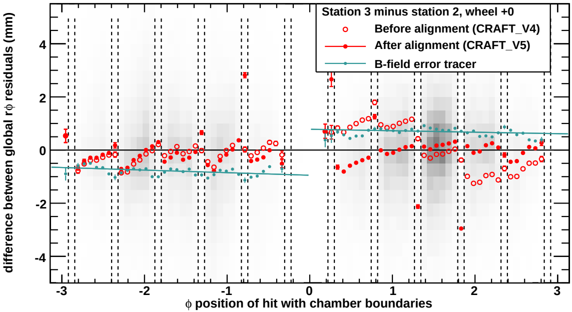
  http://indico.cern.ch/conferenceDisplay.py?confId=51267
- Aligned local x, y, ϕ_z for DT chambers with sufficient statistics
- Trend in $r\phi$ residual vs. ϕ suggests DT chamber description error (under investigation)
- 5–10 mm misalignments reduced to $\mathcal{O}(1\text{–}2\text{ mm})$





Residuals differences plots





- Consider difference of residuals between stations on the same track:

$$\text{difference} = \left(\text{st. 3 track} - \text{st. 3 hit}\right) - \left(\text{st. 2 track} - \text{st. 2 hit}\right)$$

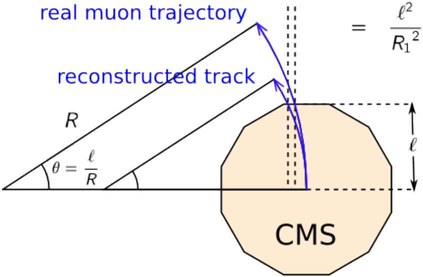
- Linearly-independent cross-check on alignment because it displays relative alignment of chambers, rather than absolute position
- Also sensitive to local $\vec{B}$-field error, rather than integral over path
  - wrong sign in $\phi > 0$ part because cosmic muon's velocity is down

Calculating B_z error in Tesla

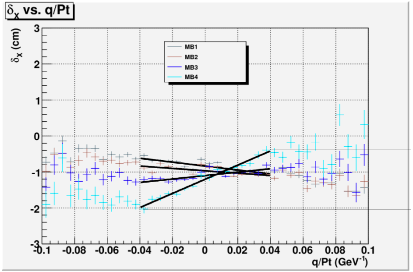
$$\text{residual} = R_1\left(1-\cos\theta_1\right) - R_2\left(1-\cos\theta_2\right) = R_1{\theta_1}^2 - R_2{\theta_2}^2$$

$$= \frac{\ell^2}{{R_1}^2} - \frac{\ell^2}{{R_2}^2} = \left(\frac{\ell^2}{300\text{ cm}}\right)\frac{\Delta B}{p_T}$$

$$\Delta B = \text{residual}\left(\frac{300\text{ cm}}{\ell^2}\right) p_T$$



P. Martinez: $r\phi$ residual vs. q/p_T by station



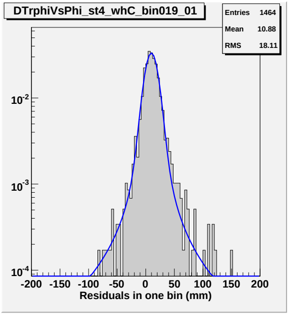
- $r\phi$ residual as a function of track curvature (q/p_T) is linear if B_z is mismodelled
- quadratic in extrapolation length (ℓ)
- charge confusion with charge ratio $\neq 1$ distorts linear dependence at small $|q/p_T|$ if extrapolation length is large
  - use residuals differences
- scattering distorts linear dependence at large $|q/p_T|$

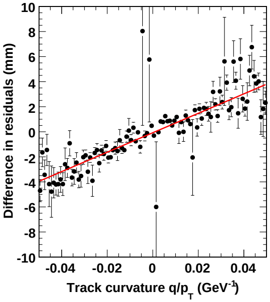
Fit function for residuals

- Scattering processes have power-law distributions, while experimental resolution is Gaussian
- "Peak" of residuals distribution used in alignment comes from an unbinned fit to Lorentzian-Gaussian convolution

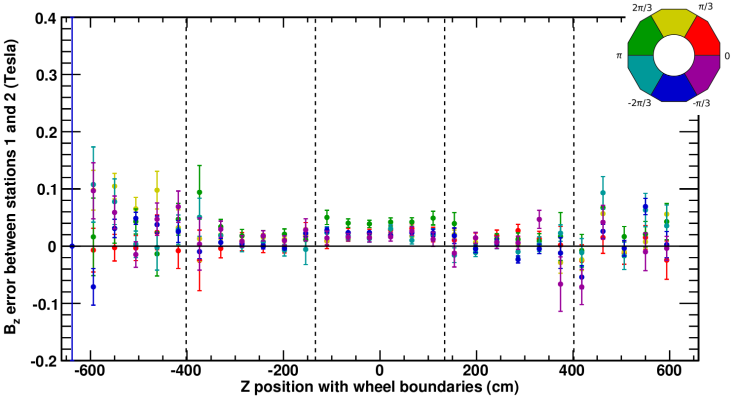
$$f(x) = \int_{-\infty}^{\infty} \frac{1}{\pi} \frac{\Gamma/2}{(x-\xi)^2 + (\Gamma/2)^2} \times \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-\xi^2}{2\sigma^2}\right) d\xi$$

- Regular mean $(\sum x_i/N)$ = center of an unbinned Gaussian fit; this just adds tails
  - outliers matter less in peak-finding
- For B_z measurement, make peak a linear function of q/p_T (red is crest of 2-D fit)





- Points calculated from unbinned 2-D fits to $r\phi$ residuals and q/pT
- Assumptions: $B_x = B_y = 0$, uniform B_z between stations, no dE/dx error
- Shown as a function of ϕ, z (same magnitude as combined fit)
  - largest B_z errors seem to be 8% between stations 3&4
    (dataset is all 3.8 T: 66604-66904, 67126-67225, 67534-67647, 67680-68087)
  - slight wheel-by-wheel dependence? or dE/dx error?



B_z error between stations 2&3

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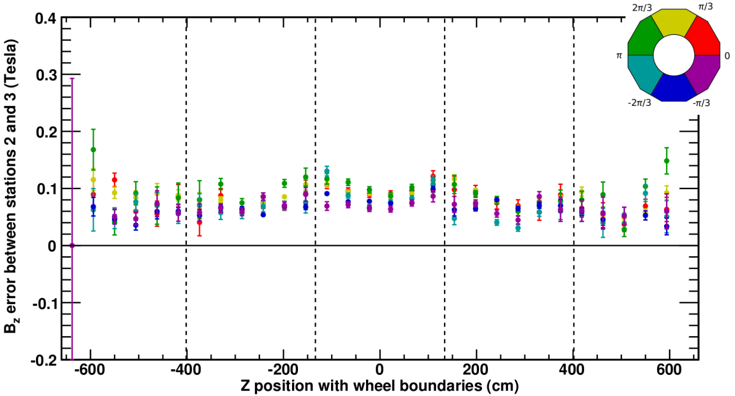

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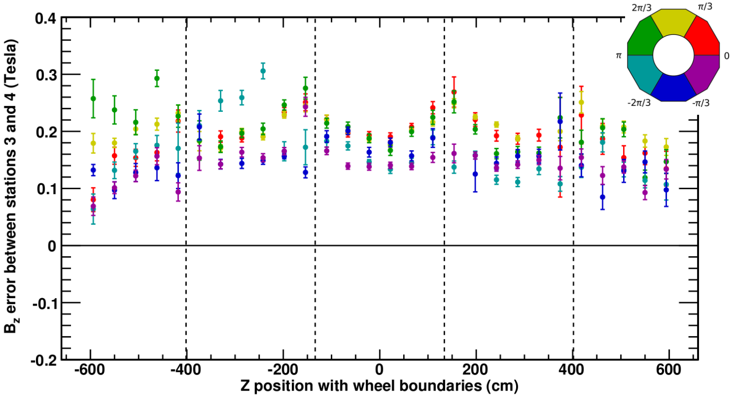

Conclusions

- Misalignments and $\vec{B}$-field errors can be disentangled
- Alignment validation plots quantify systematic error from $\vec{B}$-field (times a large factor) in millimeters
- Residuals differences localize $\vec{B}$ error between stations, rather than integrated along the whole track
- B_z error in Tesla can be calculated from linear dependence in $r\phi$ residuals vs. q/p_T
- Largest B_z errors seem to be only 8% of 3.8 T