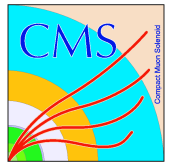


Chamber Alignment with globalMuons

Jim Pivarski

Texas A&M University

12 March, 2009

Outline

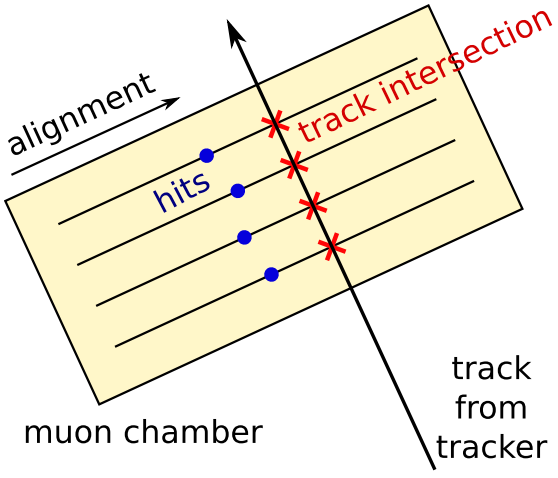
- Issues in global alignment
  - consistent tracker-muon coordinate system
  - magnetic field errors
  - single-scattering in material
  - cross-checks: is it a real alignment?

- Alignment produced for CRAFT analyses (CRAFT_ALL_V9)
  - sample map-plots, values of corrections, final residuals
  - cosmics track-splitting study

- Next steps in alignment
  - barrel improvements
  - alignment of CSCs, using barrel as reference
  - method for combining with hardware data

Consistent global coordinates

- For optimal globalMuon resolution, we need to
  - align muon chambers relative to one another, *and*
  - put muon system in the same coordinate system as the tracker
- Can accomplish both in one step by using the tracker as a reference to align the muon system:

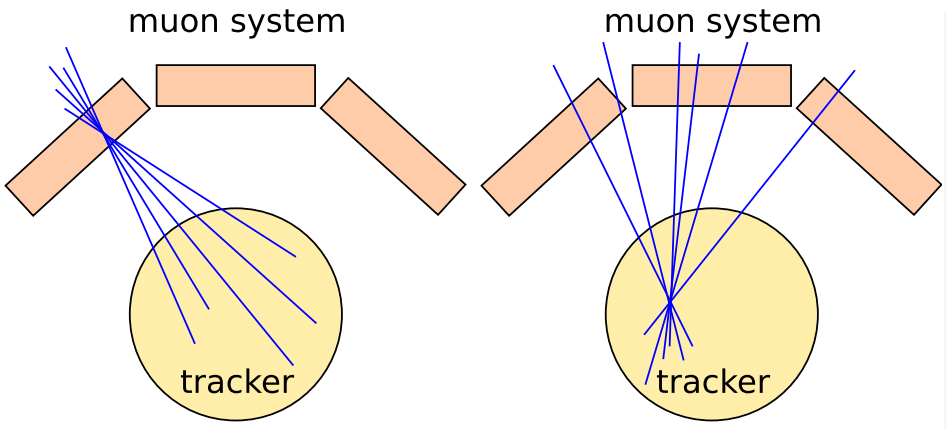


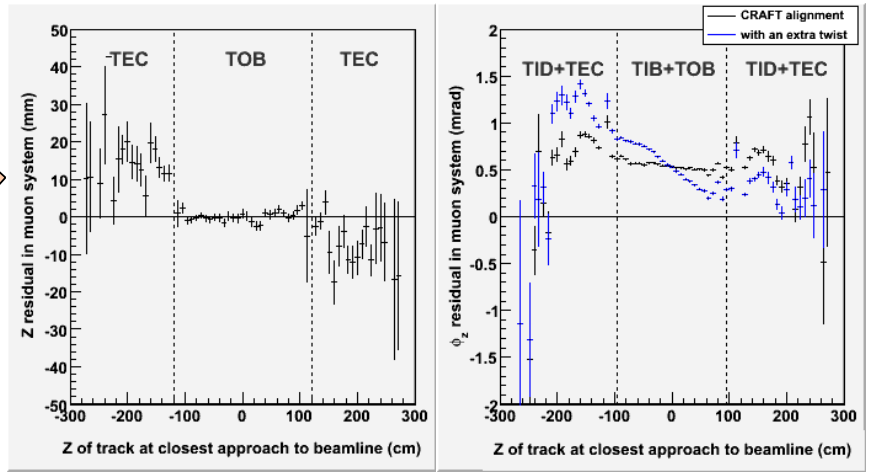
1. align the tracker (Alessio's talk, yesterday)
2. propagate tracks from tracker to muon layers
3. calculate unbiased residuals
4. adjust muon chambers to minimize residuals

- Tracker measurements dominate precision of most tracks anyway (tracks with $p_T \lesssim 200$ GeV)
- Decouples "chicken-and-egg" problem of alignment: track-fitting is independent of geometry updates (no need for global fit or iteration)

Sources of systematic error

- Tracker misalignments: resolution, weak modes
  - use non-projective cosmic rays to look for distortions in tracker



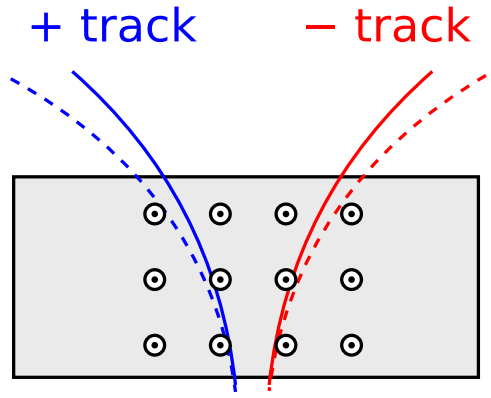


  - left: observation of TEC z misalignment (CRAFT_V4, not latest)
  - right: sensitivity study, tracker twist added by hand (blue)

- Propagation errors: wrong $\vec{B}$-field, dE/dx, and track scattering
  - $\vec{B}$-field and dE/dx errors have distinct dependences on charge and momentum (next slides)
  - scattering yields non-Gaussian outliers, accomodate with fit

$\vec{B}$-field and misalignment

- Residuals from misalignment are independent of the tracks used to measure it
- Residuals from $\vec{B}$-field errors flip sign with the charge of the muon and depend on p_T

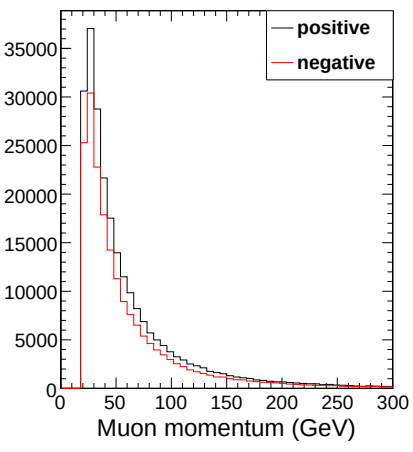


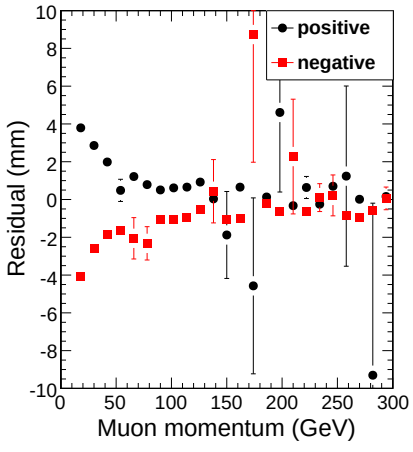
wrong B-field or dE/dx

Two-bin approach:

Fact: momentum spectra for $+$ and $-$ charges are proportional

Fact: wrong $\vec{B}$-field and dE/dx effects are antisymmetric with q

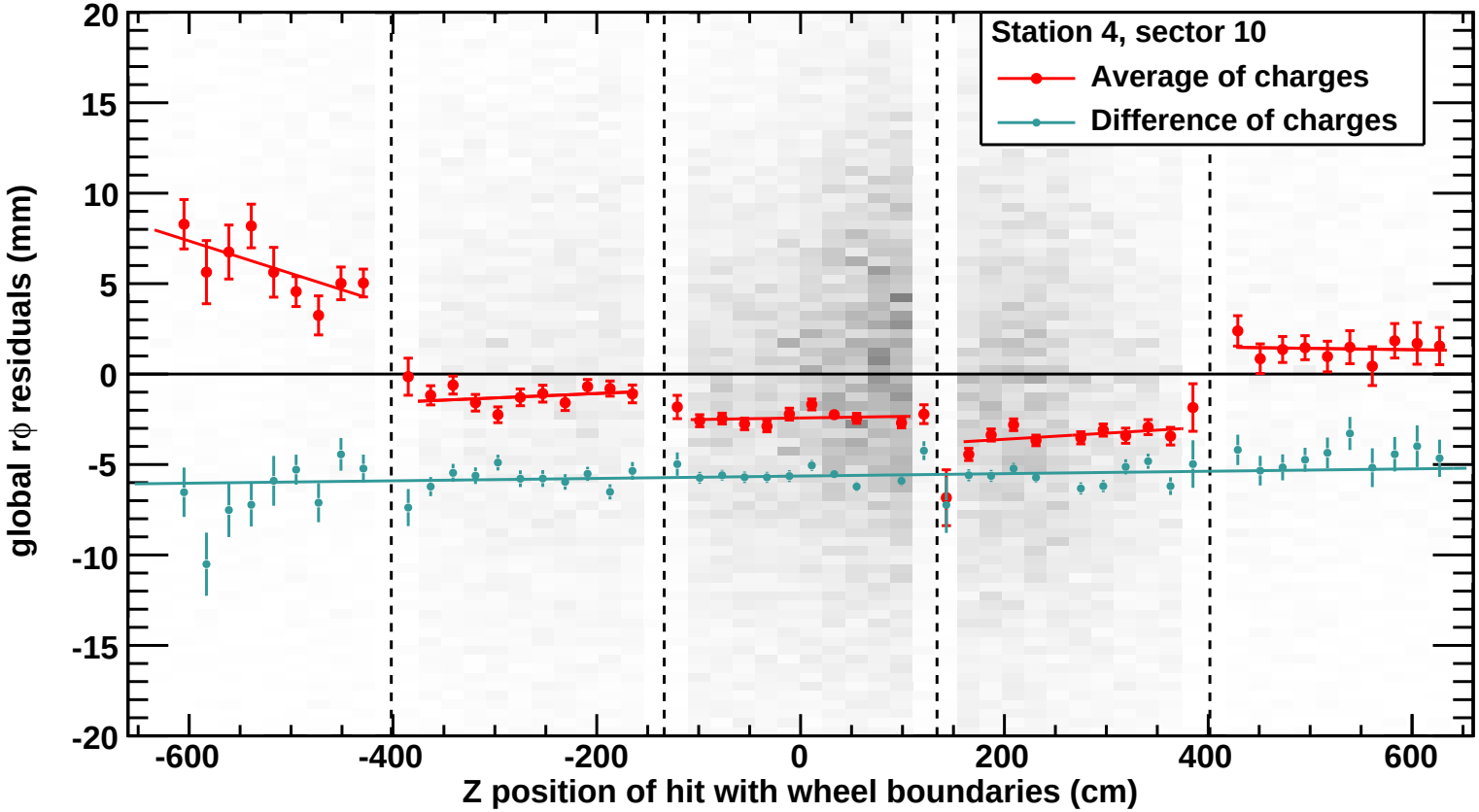




- Find peak of residuals in two charge bins: R_+ and R_-
- Average $(R_+ + R_-)/2$ is sensitive to misalignment only
- Difference is sensitive to $\vec{B}$ error and dE/dx errors only

Demonstration in station 4

- Station 4 has the largest $\vec{B}$-field errors: plot residuals across barrel
- The misalignment breaks cleanly at the chamber boundaries
- The $\vec{B}$-field error is independent of chamber



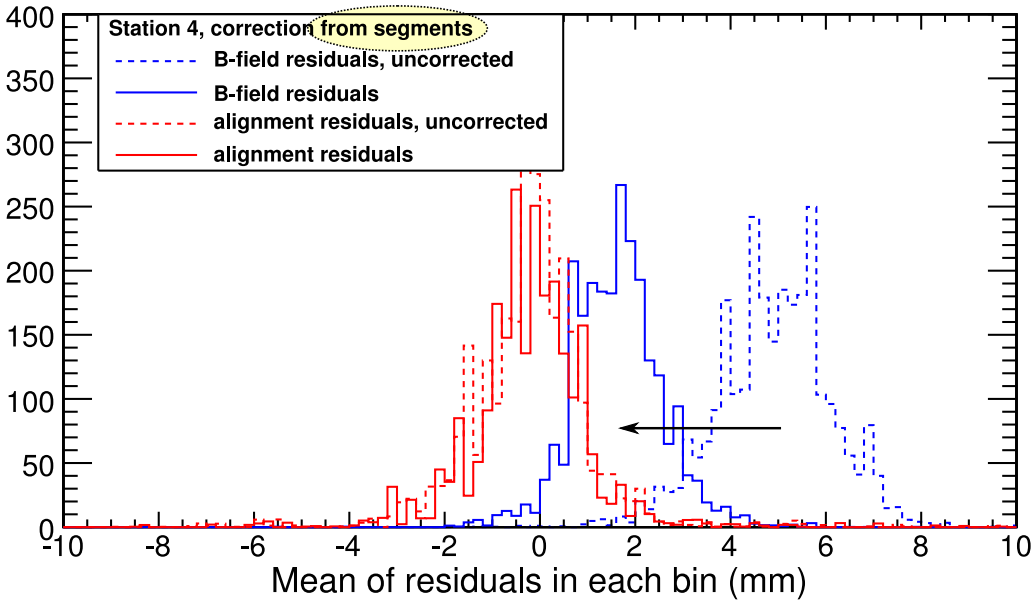
grey background is the raw 2-D residuals distribution

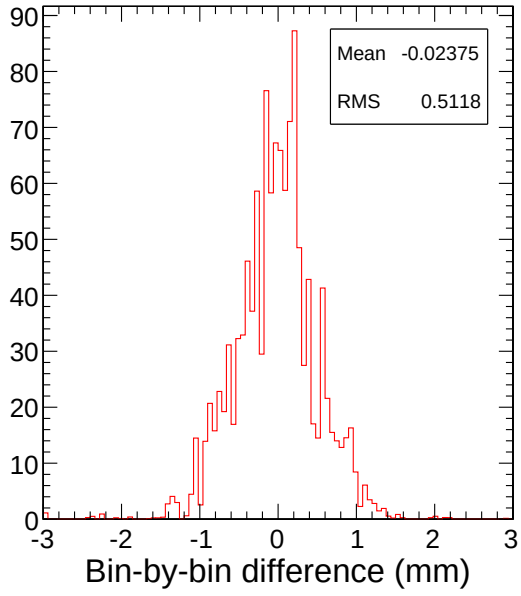
linear fits are only a guide for the eye: not used in alignment!

Residuals with new $\vec{B}(\vec{x})$ maps

- Two new field maps available:
  - scaling corrections from segments (data-based measurement)
  - new TOSCA simulation (consistent field lines)
- Opportunity to test correctness of new $\vec{B}(\vec{x})$ and insensitivity of alignment measure with tracks propagated through new field
  - left: histogram of bins from the previous plot (for all sectors)
  - right: how each bin changes when new field is applied

statistical errors in bins are $\mathcal{O}(0.5$ mm$)$





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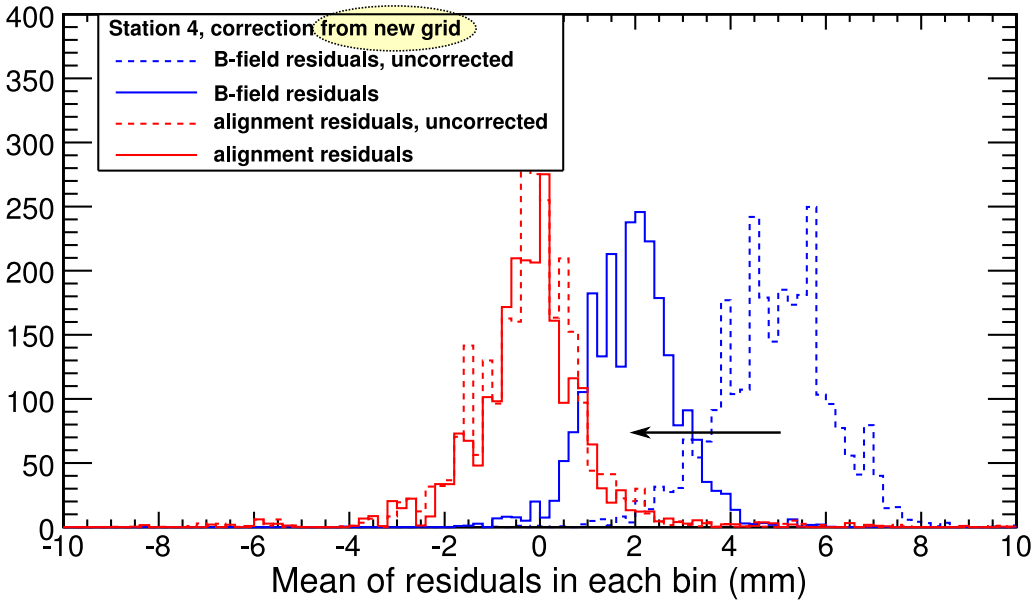
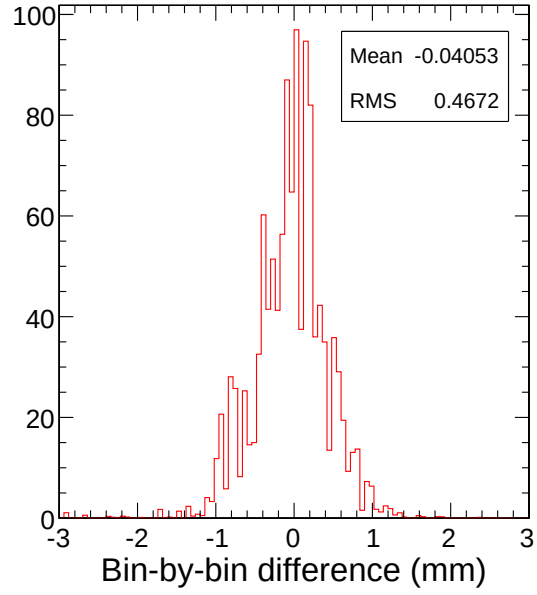
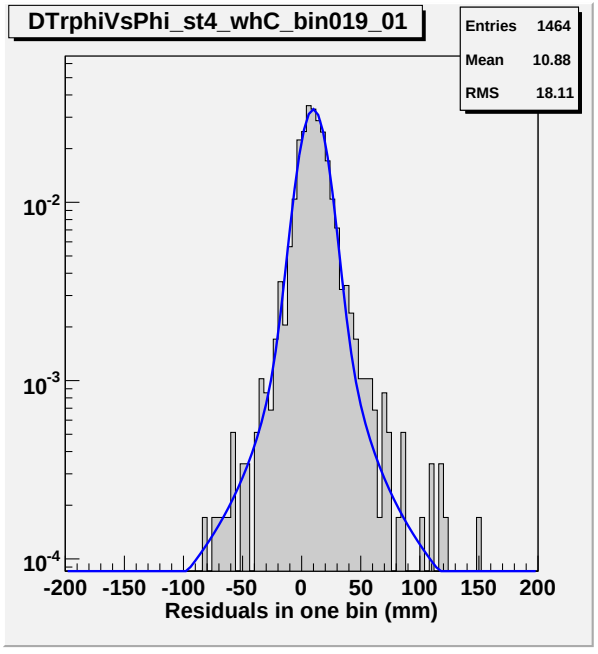




Single-scattering



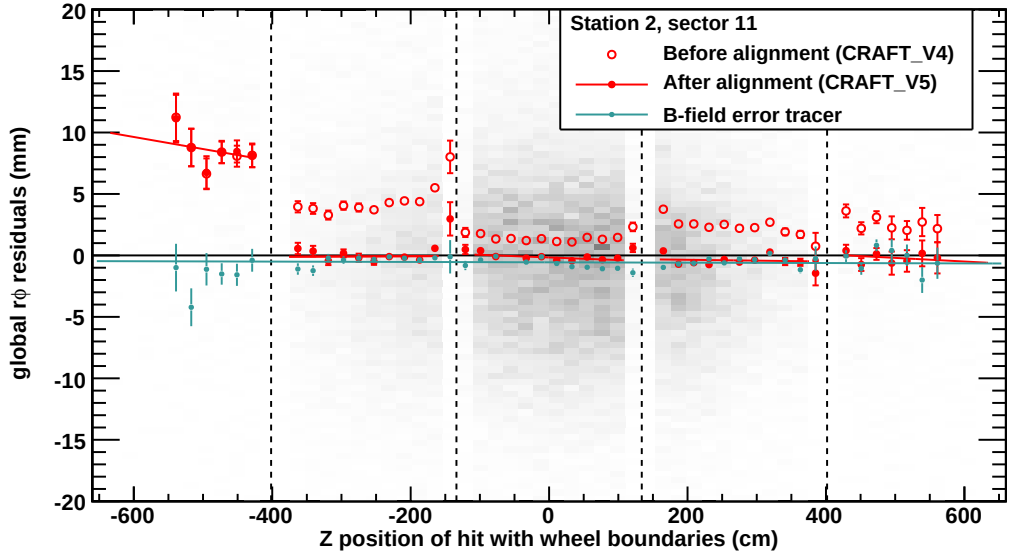
- Non-multiple scattering processes have power-law distributions, while experimental resolution is Gaussian
- Peak of residuals distribution should not be computed from the mean: it would be pulled by scattered "outliers"
- Model process as Lorentzian-Gaussian convolution:

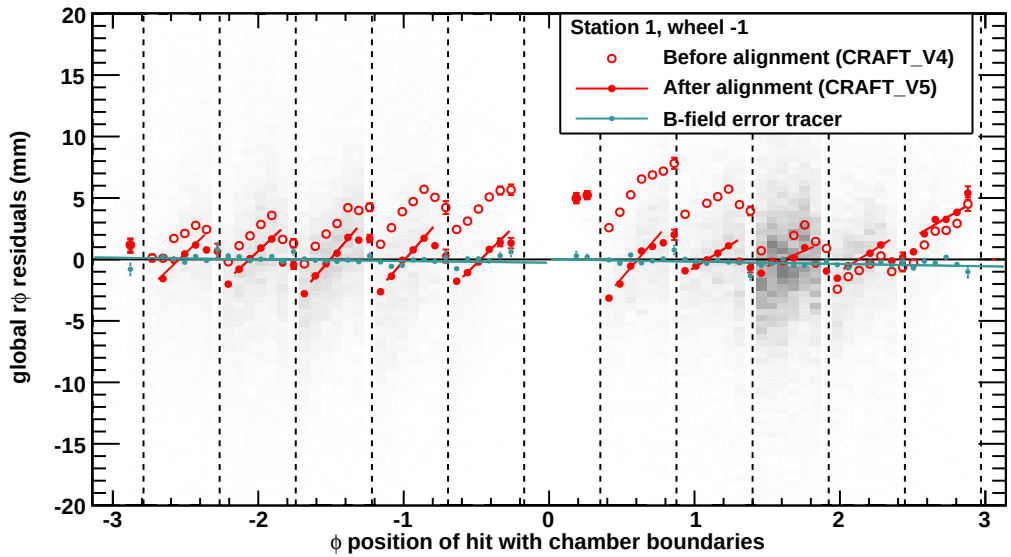
$$f(x) = \int_{-\infty}^{\infty} \frac{1}{\pi} \frac{\Gamma/2}{(x - \xi - x_0)^2 + (\Gamma/2)^2} \times \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-\xi^2}{2\sigma^2}\right) d\xi$$

- Determine peak (alignment correction) from x_0 of unbinned fit
  - regular mean $(\sum x_i/N)$ = center of an unbinned Gaussian fit
  - this is the same thing, but with tails
  - "outliers" contribute far less to $f(x)$ log-likelihood than Gaussian

Is it a real alignment?

- We want to find the real positions of chambers, not just minimize residuals
- To look for biases in the track source, plot residuals more finely than the chamber boundaries
  - bias can change residuals shape inside chambers and across boundaries
  - only misalignments can make discontinuities at chamber boundaries
- Cause of linear slopes in $r\phi$ vs. ϕ (bottom) under investigation
  (DTs stretched in x? tested ϕ_y and z-shift hypotheses. . .)



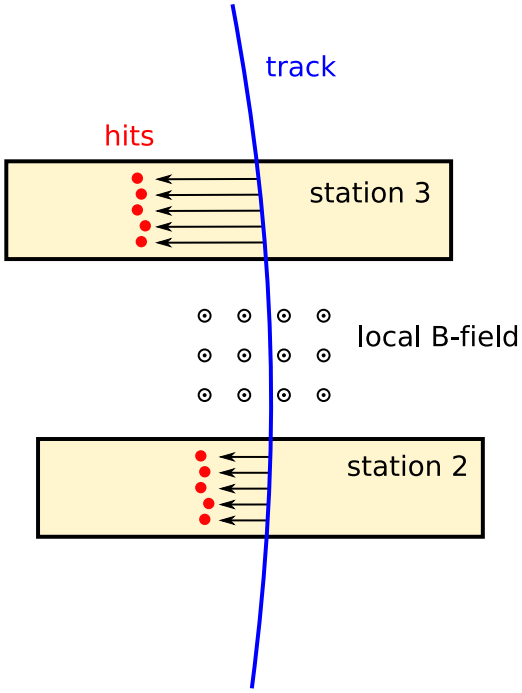


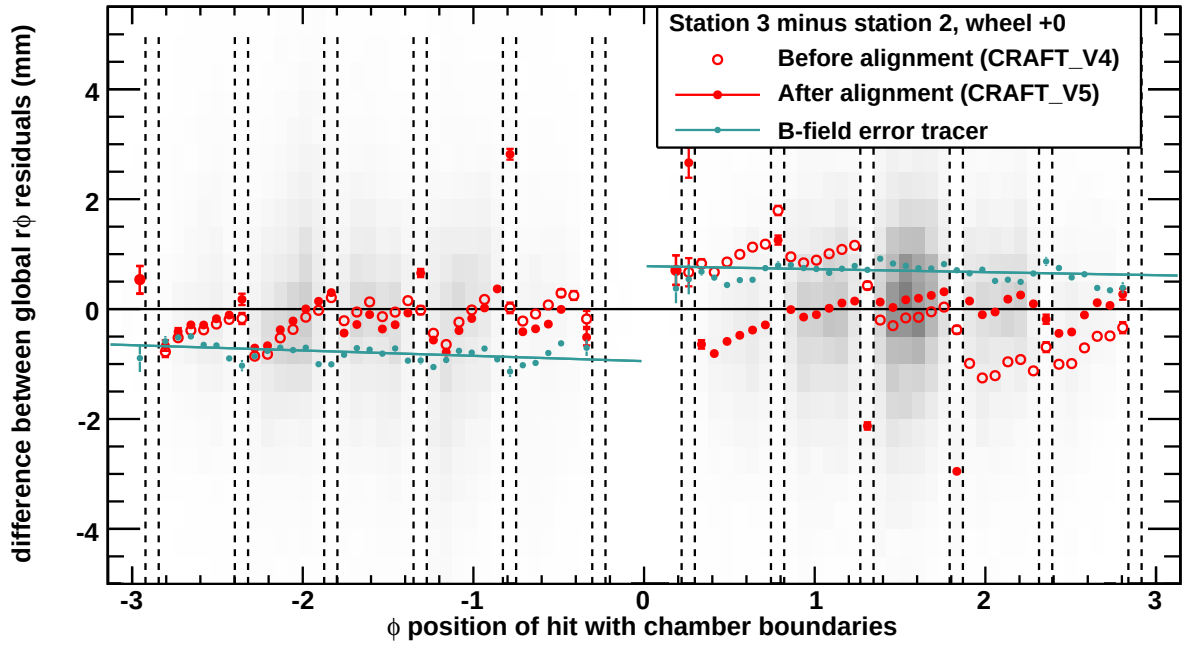
- Complete set of plots: http://indico.cern.ch/conferenceDisplay.py?confId=51267 ("more information")

Cross-check: relative positions

- Alignment procedure determines chamber positions relative to tracker
- Chamber positions relative to other chambers is a true cross-check
- Difference of residuals on the same track uses the track as a curved ruler to compare two chambers:

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

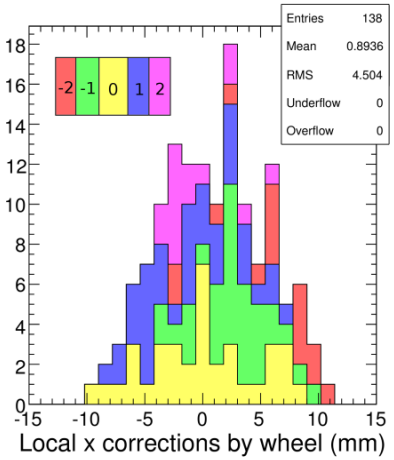


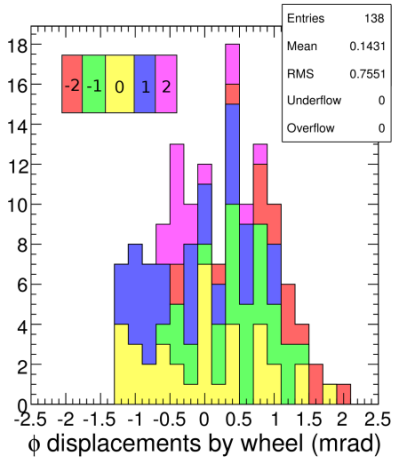


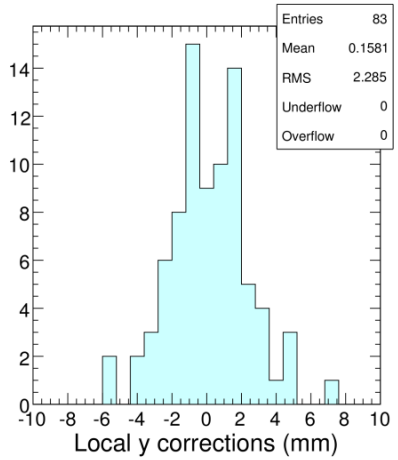
- Difference distributions are about 4 times narrower than residuals

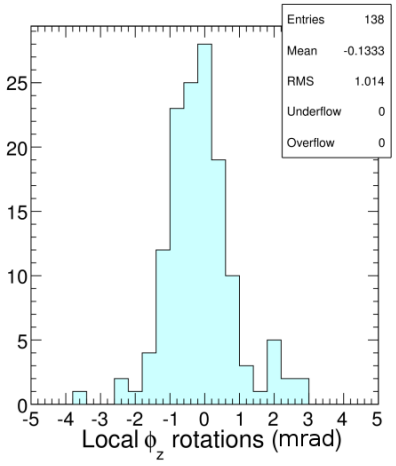
Alignment results

- The following are alignment corrections used in CRAFT re-processing
  - local x is in the $r\phi$ direction, local y is along the beamline
  - x re-expressed as ϕ to demonstrate lack of wheel rotations

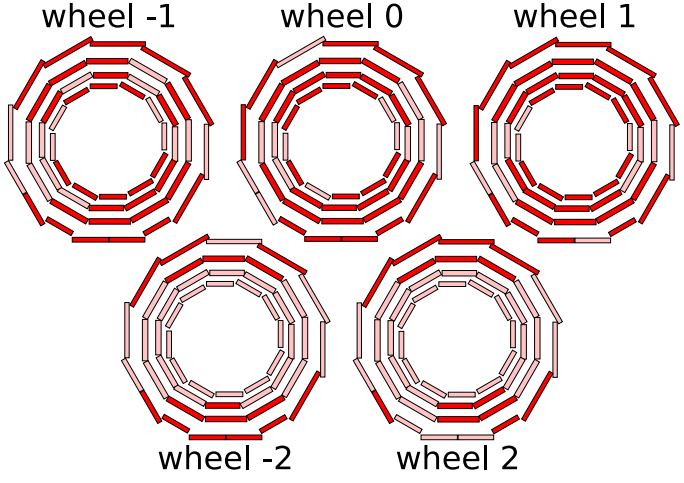




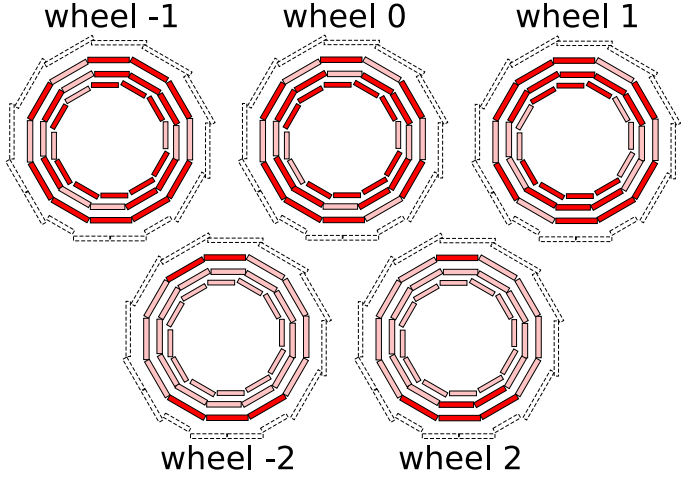




aligned in local x and ϕ_z:

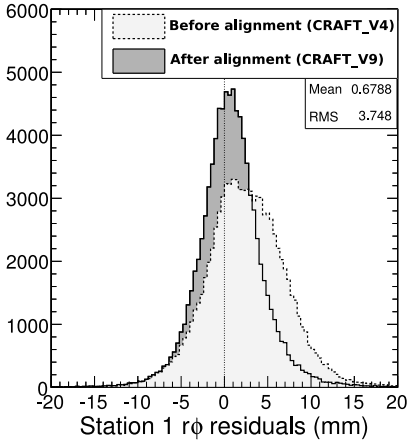


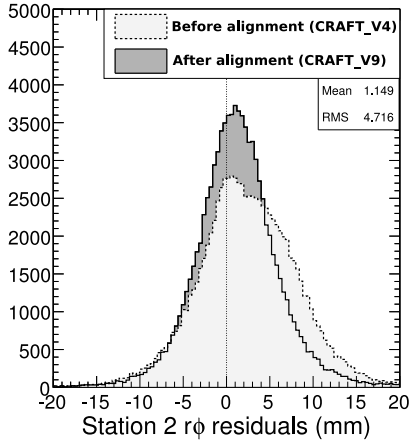
aligned in local y:

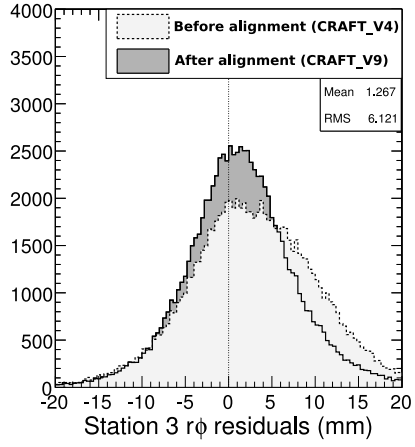


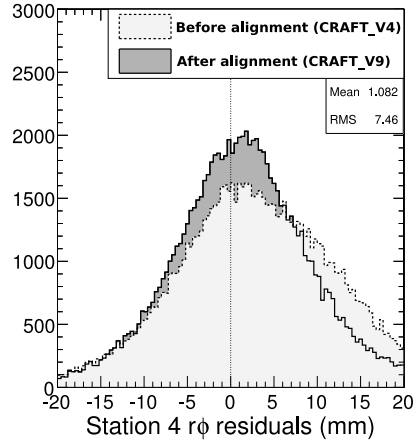
Residuals after global alignment

- Alignment narrowed and centered residuals distributions, as it must

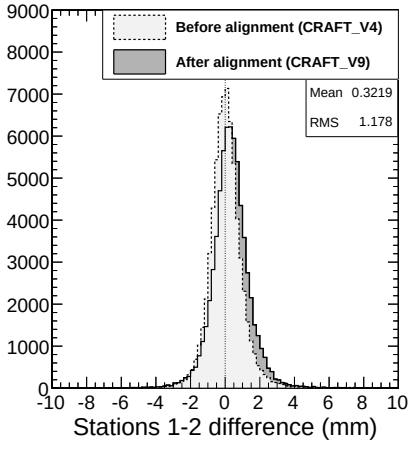


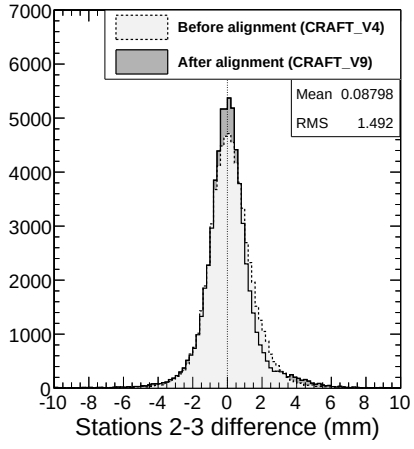


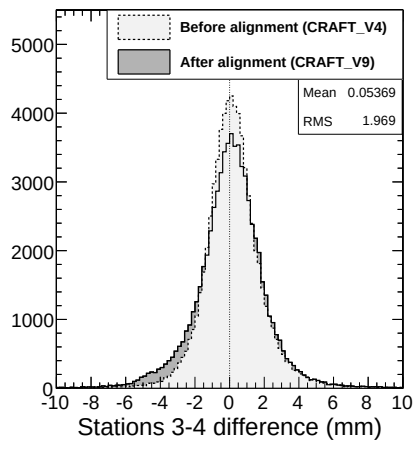




- Alignment preserved but didn't improve residuals differences
  - 1–2 mm *relative* chamber positions before and after alignment





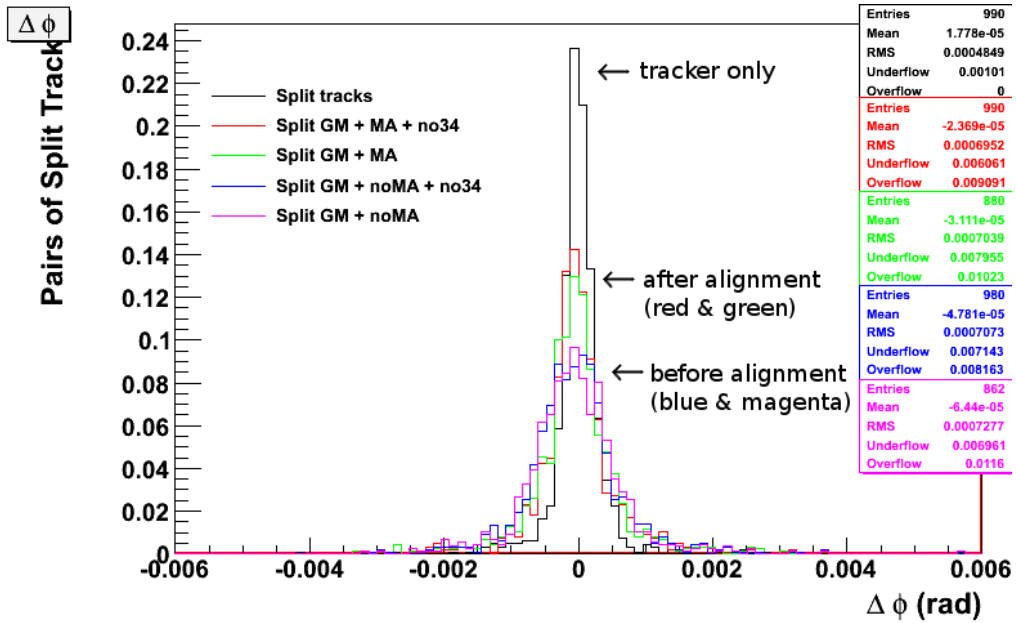


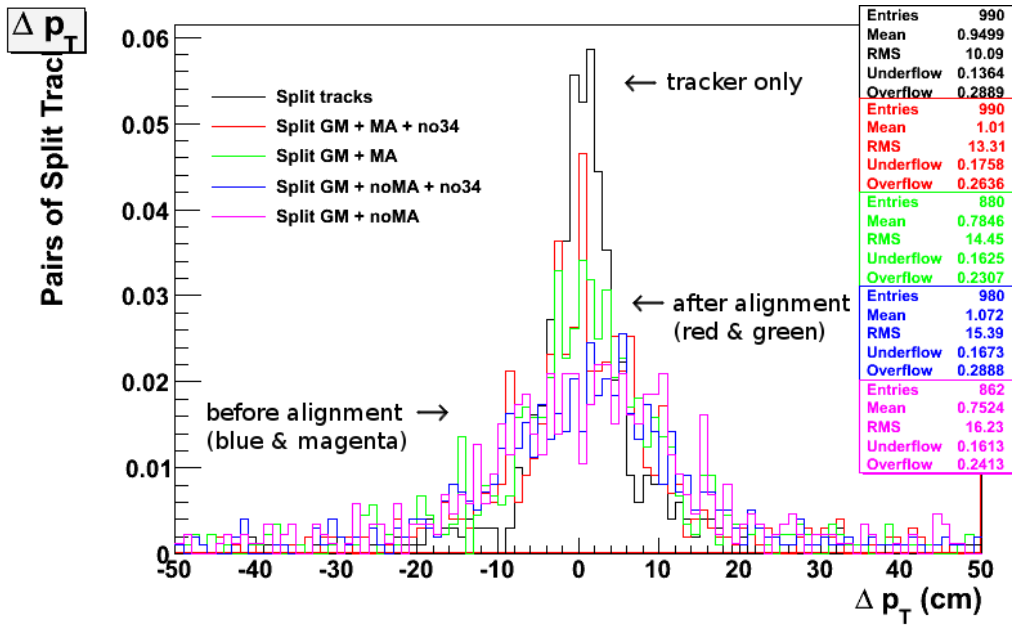
Note smaller scale

Cosmics track-splitting study

- Top and bottom half of a cosmic muon should have the same track parameters
- GlobalMuon resolution worse than tracker-only for three reasons:
  1. global misalignment
  2. magnetic field errors
  3. tracker given too little weight in global track fit
- Alignment improves matching of $p_T > 100$ GeV cosmics
  - insensitive to (2)
  - plotted before (3) corrected
- This is another cross-check because top-bottom agreement not used in alignment procedure

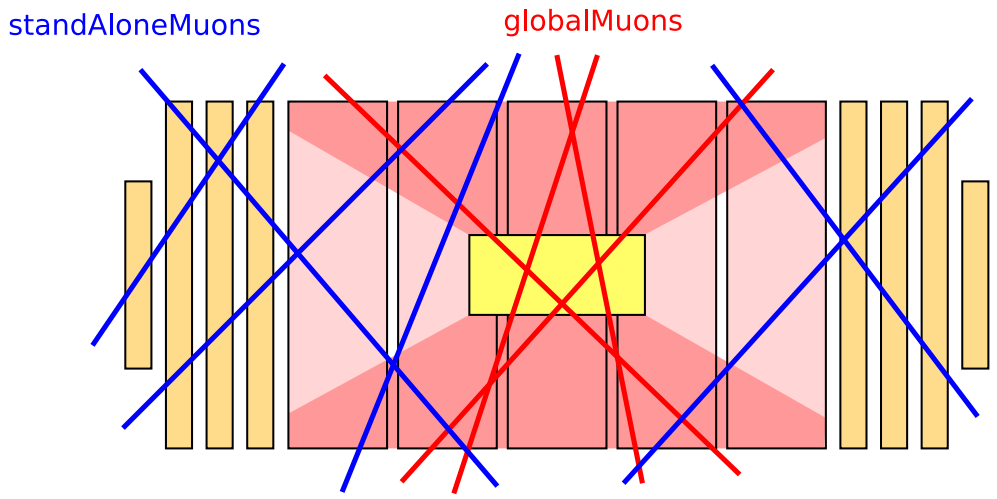
N. Tran, A. Bonato



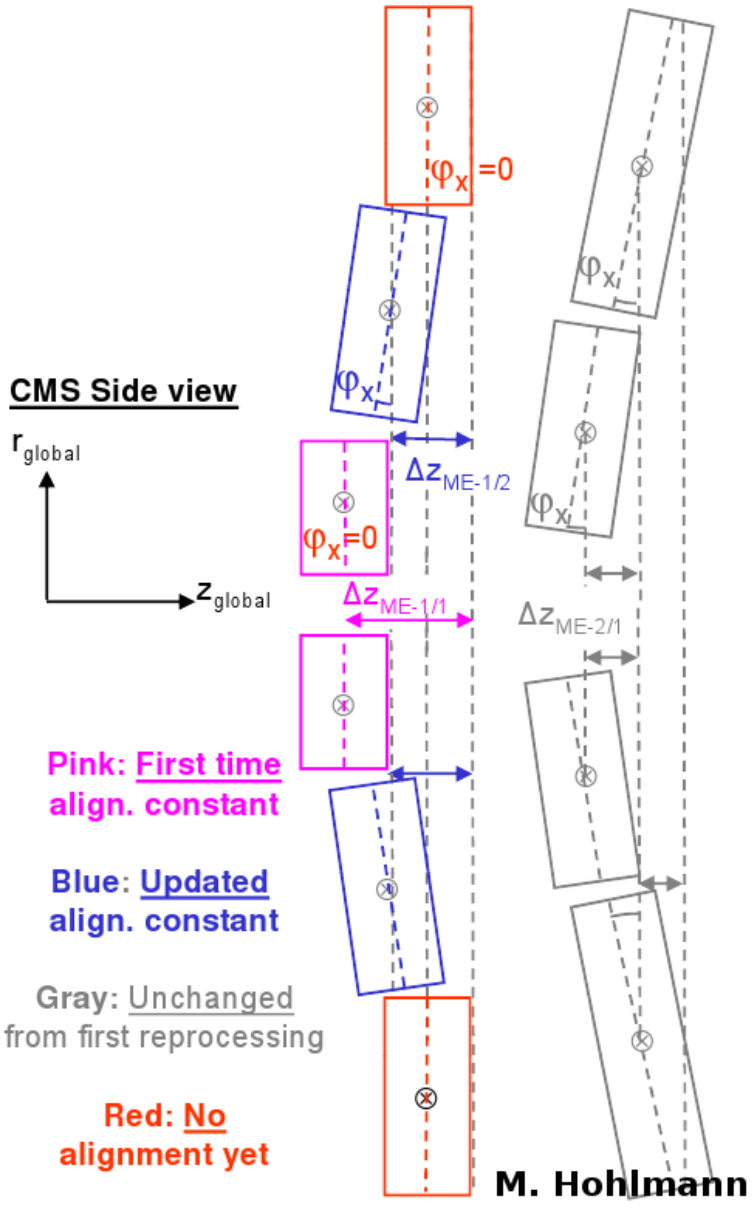


Next steps in alignment

1. Incorporate what we've learned into well-organized alignment package
   - `Alignment/MuonAlignmentAlgorithms MuonAlignmentFromReference` (CVS tag used for CRAFT alignment: V00-03-01)
   - `Alignment/CommonAlignmentMonitor AlignmentMonitorMuonSystemMap`
2. Solve "$r\phi$ residual vs. ϕ" problem (page 10), if possible
2. Re-align accessible chambers of barrel in all 6 degrees of freedom
3. Use standAloneMuons to align those DT chambers which are inaccessible to globalMuons
4. Use standAloneMuons to align CSCs, using barrel as reference
5. Do it all again in CRAFT-2009, but as a push-button procedure



Merging alignment information



- Straight-line monitors measure bending in endcap disks: z and ϕ_x parameters
  - included in CRAFT alignment
  - can measure x and ϕ_z for some chambers
- Track-based measurement of x, ϕ_y, and ϕ_z will be more complete and precise
  - can also measure z and ϕ_x
- Combine results parameter-by-parameter:
  1. hardware prepares aligned CSCAlignmentRcd, passes it on
  2. track-based doesn't update z, ϕ_x
- Final result is easier to understand than a combined or constrained fit
- Redundant measurements (x, z, ϕ_z) reserved for cross-checks

Conclusions

- First global alignment, connecting muon chambers to the tracker's coordinate system
- Careful to avoid errors due to source of tracks and propagation
- Employed multiple cross-checks:
  - redundant binning shows no distortion inside of chambers
  - aligned in absolute coordinates, checked relative differences
  - track-splitting study showed improvement
- Highly detailed misalignment scenario generated from this information, to be used in CRAFT Monte Carlo production
- Wrapping this all up into a routine procedure
  - to extend alignment into the endcap
  - and be ready for CRAFT-2009