CSC Alignment with Beam-Halo Data

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HIP-based program

Long-term (collisions)

- Align each chamber with tracker-fitted tracks (baseline MuonHIP)
  - no coupling between track-fitting and alignment
  - no hierarchial uncertainties
  - yields tracker-muon interalignment
- Prefer cosmic rays so that tracks through a given chamber don't all come from the same part of the tracker (or use Z mass constraint)
- Need to be cautious of magnetic field uncertainties, esp. in endcap

Medium-term (CRAFT)

- Align 200 out of 250 DTs with baseline MuonHIP
- Align chambers within endcap rings using Overlaps Procedure
- Align endcap rings to tracker as rigid bodies
  - Plot alignment correction as a function of q/p_T to distinguish effects of misalignment (constant), multiple scattering (symmetric, through origin), and magnetic field (antisymmetric)

Short-term (now)

- Align endcap disks to muon barrel in CRUZET (done)
- Align chambers in ME$-2/1$ and ME$-3/1$ using Overlaps Procedure (mostly done, debugging)
- Align disks and wheels to tracker in a large globalMuon sample (if there is a large globalMuon sample)

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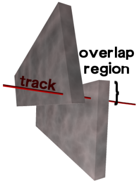
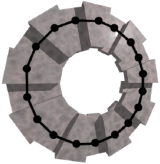
Overlaps Procedure

- Segments in overlap region of neighboring CSCs must agree on slope and intercept
- Average difference $\alpha_{i,i+1}$ is a relative correction between A_i and A_{i+1}, solve for global solution (at most 36×36 matrix inversion)

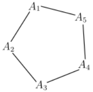




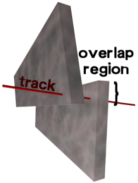
$$\chi^2 = (\alpha_{12} - A_1 + A_2)^2 + (\alpha_{23} - A_2 + A_3)^2 + \ldots$$

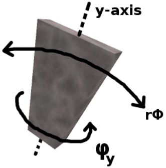
$$\frac{1}{2}\frac{\partial \chi^2}{\partial A_2} = (\alpha_{12} - A_1 + A_2) - (\alpha_{23} - A_2 + A_3) = 0$$

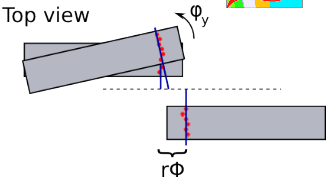
$$\begin{pmatrix} 0 \\ \alpha_{23} - \alpha_{12} \\ \alpha_{34} - \alpha_{23} \\ \alpha_{45} - \alpha_{34} \\ \alpha_{51} - \alpha_{45} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ -1 & 2 & -1 & & \\ & -1 & 2 & -1 & \\ & & -1 & 2 & -1 \\ -1 & & & -1 & 2 \end{pmatrix} \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{pmatrix}$$ for



Important parameters







φ_y angles: rotation around axis of symmetry

- determined from difference in segment slopes (1-D linear fit $d\phi/dz$)
- must be aligned first!

$r\phi$ translations: displacement along a circular arc, centered on beamline

- determined from difference in segment intercepts on a common plane between them
- local parameters $\Delta x = r\sin(\phi)$, $\Delta y = r(\cos(\phi) - 1)$, $\Delta\varphi_z = \phi$

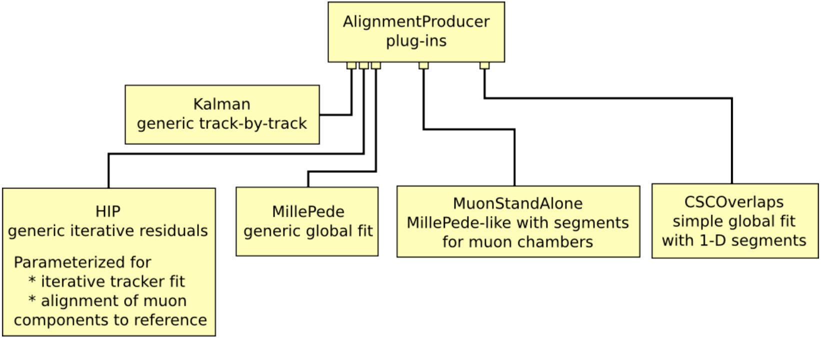
φ_z angles: rotation in plane

- determined from intercept residual as a function of y

Apply procedure three times, with appropriate definitions of $\alpha_{i,i+1}$ and A_i (pedestrian approach is wiser than a combined fit at this time)

State of software

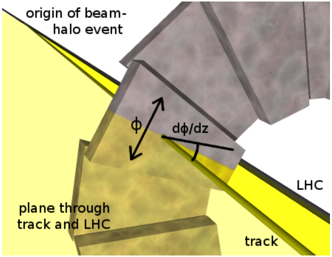
- First draft of procedure was a reparameterization of HIP
- Final version is very different, very specific to CSC geometry
- All changes were necessary! (see "Evolution of Procedure" backup)
- This is a correct algorithm: works perfectly in Monte Carlo
- Encapsulated as a new AlignmentProducer plug-in, to be uploaded to CVS after clean-up



Measuring φ_y angles in data

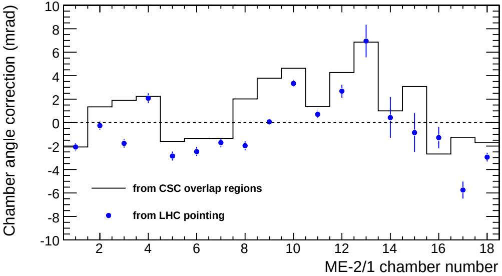
Three independent methods (for cross-checks):

1. Overlaps Procedure: $d\phi/dz$ slope must agree in pairs
2. Generic beam-halo: $d\phi/dz$ must agree on a track from ME$-2/1$ to ME$-3/1$
3. $d\phi/dz$ must be on average zero, because beam-halo tracks come from the LHC (absolute, not pairwise)



Corrections from (1) and (3):

Completely different methods, disjoint sets of tracks, reproduces some trends

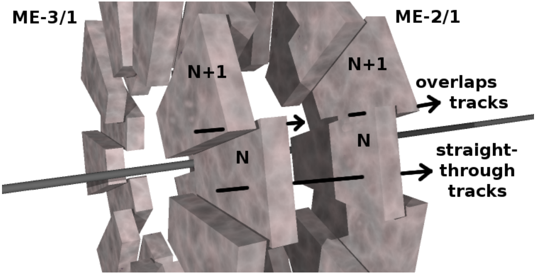


Measuring $r\phi$ positions

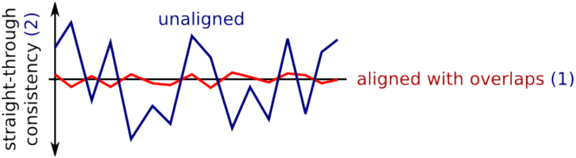
Taking φ_y from LHC pointing for now, attempt $r\phi$ alignment

Two independent methods:

1. Overlaps: track intercepts must match between N and $N+1$
2. Straight-through: track must match between $N_{ME-2/1}$ and $N_{ME-3/1}$

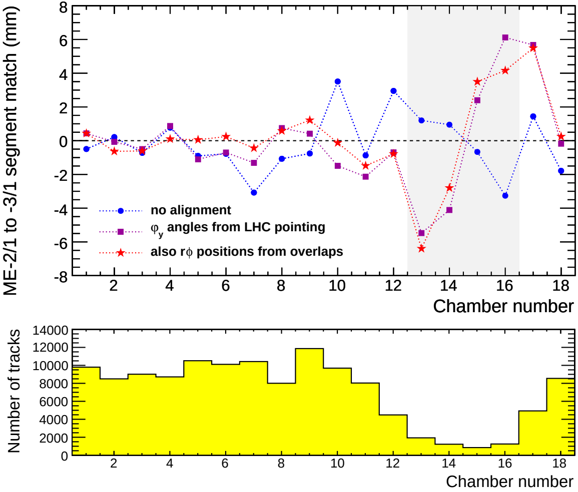


Align with (1) and look at a plot of (2) for each N (data-driven estimate of alignment quality)

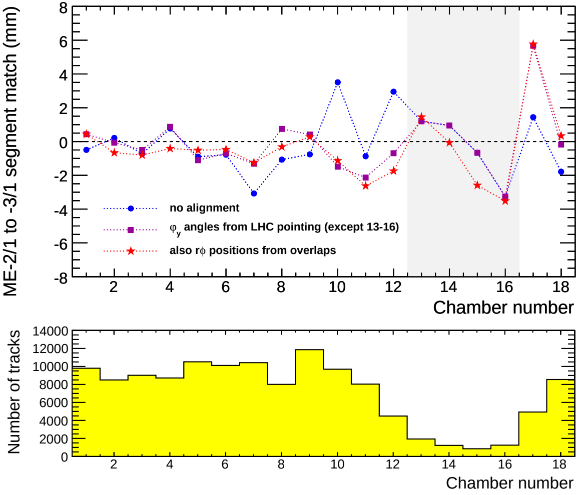


Cross-checking $r\phi$ positions

- As we apply corrections, we improve alignment (as seen by straight-through tracks) in chambers 1–12 & 18
- Chambers 13–16 are unreliable due to poor statistics on φ_y



- Don't attempt to align φ_y on chambers 13–16 (leave at default value) and repeat

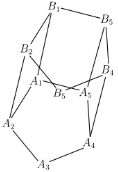


Diagnostic tool: 2-station fit

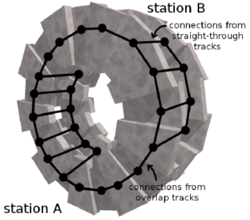
- Overlaps and straight-through tracks form a rigid frame: if errors are not correlated between the rings, a combined fit would isolate errors to one chamber (single-ring fit tries to distribute error uniformly)
- Two benefits:
  - diagnostic tool for identifying which chambers don't fit
  - yields the best set of constants with our present knowledge (excluding outliers)
- But lose an independent cross-check

$$\chi^2 = (\alpha_{12} - A_1 + A_2)^2 + (\alpha_{23} - A_2 + A_3)^2 + \ldots$$
$$(\beta_{12} - B_1 + B_2)^2 + (\beta_{23} - B_2 + B_3)^2 + \ldots$$
$$(T_1 - A_1 + B_1)^2 + (T_2 - A_2 + B_2)^2 + \ldots$$

$$\frac{1}{2}\frac{\partial \chi^2}{\partial A_2} = (\alpha_{12} - A_1 + A_2) - (\alpha_{23} - A_2 + A_3) - (T_2 - A_2 + B_2) = 0$$

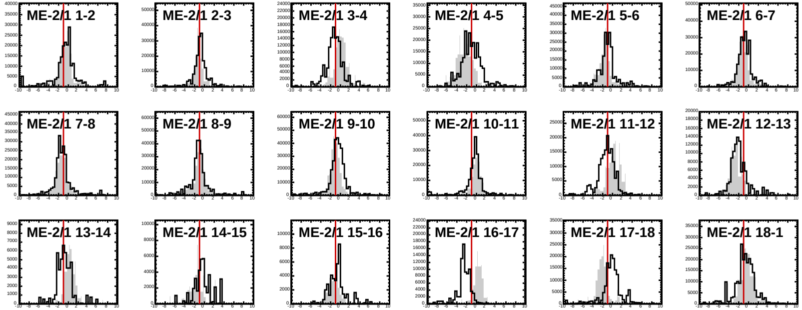


$$\begin{pmatrix} 0 \\ \alpha_{23} - \alpha_{12} + T_2 \\ \alpha_{34} - \alpha_{23} + T_3 \\ \alpha_{45} - \alpha_{34} + T_4 \\ \alpha_{51} - \alpha_{45} + T_5 \\ \beta_{12} - \beta_{51} - T_1 \\ \beta_{23} - \beta_{12} - T_2 \\ \beta_{34} - \beta_{23} - T_3 \\ \beta_{45} - \beta_{34} - T_4 \\ \beta_{51} - \beta_{45} - T_5 \end{pmatrix} = \left(\begin{array}{ccccc:ccccc} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 3 & -1 & & & & -1 & & & \\ & -1 & 3 & -1 & & & & -1 & & \\ & & -1 & 3 & -1 & & & & -1 & \\ -1 & & & -1 & 3 & & & & & -1 \\ \hdashline -1 & & & & & 3 & -1 & & & -1 \\ & -1 & & & & -1 & 3 & -1 & & \\ & & -1 & & & & -1 & 3 & -1 & \\ & & & -1 & & & & -1 & 3 & -1 \\ & & & & -1 & -1 & & & -1 & 3 \end{array}\right) \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{pmatrix}$$



Example diagnostic

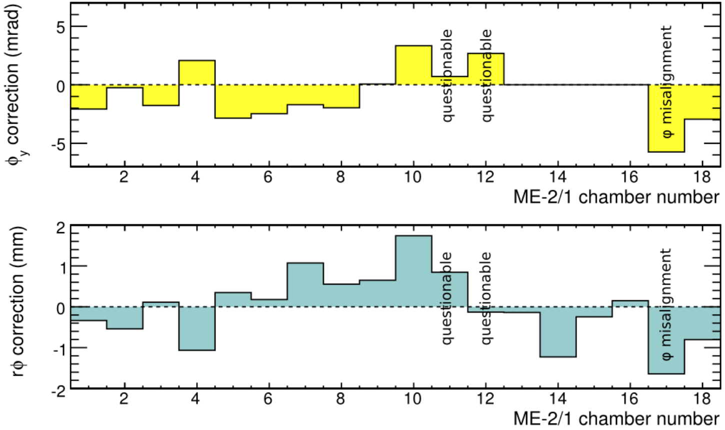
Overlap residuals from combined fit (red line is single-ring fit, grey is unaligned)



- Chamber 17 is clearly wrong (as we could have guessed from slide 10), also in ME$-3/1$, likely also a bad φ_y angle
- Single-ring fit would have made all final residuals equal
- Wide residuals from unaligned φ_z

Current best results

- Constants from combined fit with chambers 13–16 unrotated
- Chamber 17 has the wrong angle in either ME−2/1 or ME−3/1
- Chambers marked "questionable" also don't fit well
- ∞-stats Monte Carlo resolution is 2.2 mrad in φ_y, 0.37 mm in $r\phi$



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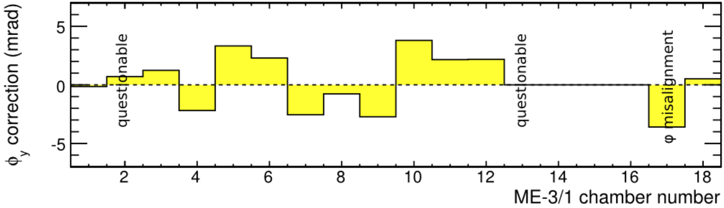

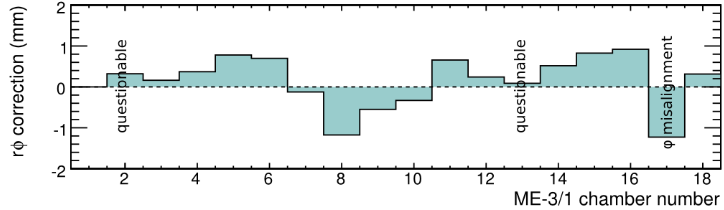

Conclusions

- CSC Overlaps project has evolved into a special-purpose tool, but integrated into framework
- Algorithm is correct: Monte Carlo alignment is perfect
- Not all constraints satisfied in data: indication of unsimulated effects to discover in detector. Diagnosing with cross-checks
- However, current best constants have an RMS of 750 μm ($r\phi$) and 2.5 mrad (φ_y), indicating that random error in physical CSC placement and track-based alignment are both small
- Comparison with hardware alignment in progress
- Will be important for CRAFT because cosmic rays through both tracker and muon endcaps are scarce, magnetic field should be cross-checked

- Plan in February: HIP iterations, alternating even and odd chambers
- Given few observables, reduced to 1D (local x) for better control
- Switched from full tracker to linear fits, again for better control
- Discovered a weak mode due to cancellation between left and right side of chamber; dropped hits from one side (used other side as cross-check)
- Removed discretization effects from wire granularity by parameterizing alignment in global $r\phi$, rather than local x
- Solve whole-ring alignment in one step to speed up convergence
- Algorithm works very well in Monte Carlo! (accurate, ring closes)
- But in data, there were still some effects
  - Misalignment angles are significant, switched from a track fit on one side to track fits on both sides to be sensitive to relative angles
  - Observe system with as many different data-driven methods as possible for confidence