Track-based CSC Alignment

Jim Pivarski

Alexei Safonov

Károly Banicz

Texas A&M University
and US-CMS

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- Completed and global-tagged, in database for whole CRUZET period with IOVs to follow opening and closing
- Assumes nominal geometry inside of disks

Muon System Real Data Constants

Muon System Real Data Constants CMSSW_2_1_X

APE or Constants	Tag	IOV	Description/Link	Comments
CSCAlignmentRcd	CRUZET1234-CSCStation-2mmRadialGood_v1	1-46529	CRUZET-1	from CRUZET1-CSCStation-xyz-2mmRadialFix_v1_v1: no minus-side data, so minus-side disks were left in their nominal positions, plus side is at about 10 meters
		46530-50599	CRUZET-2	from CRUZET2-CSCStation-xyzphiz-2mmRadialFix_v2_v1: no minus-side data, so minus-side disks were left in their nominal positions, plus side is at about 3.7 meters
		50600-56499	CRUZET-3	alignment of both endcaps, both were about 10 meters away
		56500-57999	first run of CRUZET-4	from CRUZET4-CSCStation-xyzphiz-2mmRadialGood_v1: alignment of both endcaps, ME+1 was nearly closed (3 cm), other plus-side stations at 3 meters, minus-side at 10 meters
		58000-4294967295	rest of CRUZET-4	also from CRUZET4-CSCStation-xyzphiz-2mmRadialGood_v1: no minus-side data, so minus-side disks were left in their nominal positions, plus side is closed, but apparently over-closed (1.8 cm closer than nominal). Ongoing investigation into this, which shouldn't be physically possible. Possibly related to reference tracks from the barrel, so if wheel Z positions are added to barrel alignment, we'll need to update this endcap position!

Notes:

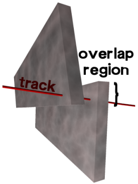
- CSCAlignmentRcd contains disk positions, measured with tracks from the muon barrel and tracks from one endcap disk to the next. Chambers relative to each disk are left in their nominal positions (later measured to have been physically aligned with an accuracy of at least 750 microns, so this isn't a bad approximation).
- There are so many IOVs because the endcaps were being moved around a lot while the detector closed. The end of CRUZET-4, and hence the last valid region in this constants set, represents a fully closed detector. As noted in the comment, there is an outstanding feature in this alignment which can be resolved by further studies, and must be updated if the muon barrel alignment changes. With the exception of two plausible few-centimeter shifts in X, all values were consistent with zero except for the dramatic changes in Z positions.
- In all of these constants (equally applicable to CMSSW_2_0_X), ME2/2 and ME3/2 radial positions are correctly set, following an update that was only put into the DDD description (ideal detector) in an early CMSSW_2_1_X release. Because constants are stored as absolute positions, rather than offsets relative to ideal, there is not need to coordinate data constants with software release.
- When the endcap was far from the barrel, the barrel-to-endcap measurement was uncertain by as much as tens of centimeters. Relative displacements between disks was always better: +/-2 cm (in Z) when the endcaps were far from the barrel, +/-4 mm (in Z) when closed (because we have an additional cross-check from the barrel, we can constrain that better). X-Y positions were determined with +/-8 mm when far from the barrel, +/-2 mm when close. PhiZ ? rotations, when they were included in the alignment, were +/-0.25 mrad. See Jim Pivarski's talks at EMU, CSC-DPG, and AlCa.

Closed endcap geometry

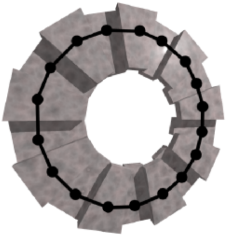
- Only significantly non-zero parameter throughout CRUZET period was Z measurement (and two small, plausible X displacements with open detector)
- End of CRUZET-4: endcap is 1.8 cm closer to barrel than nominal
- Consistency from barrel to ME+1, +2, +3, individually, multiple cross-checks on the sign
- Not physically possible
- Current hypothesis: artifact of $\mathcal{O}$(mm) wheel Z positions distorting tracks
- Should be reanalyzed after barrel wheel alignment

CSC overlaps alignment

- Locally reconstruct tracks through overlapping CSC edges
- Essentially no multiple scattering, but sensitive to small effects (no averaging over a large volume)
- Need to reconstruct whole ring of alignment corrections A_i from pairwise residuals $\alpha_{i,i+1}$



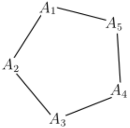
  - Methods:
    - Propagate one at a time: simple diagnostic, but error is cumulative
    - Iterate many times: generates 1-D waves (can be dampened)
    - Solve for global best-fit: only an 18×18 or 36×36 matrix



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

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

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



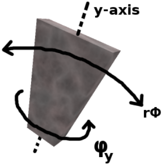
Alignment with beam-halo

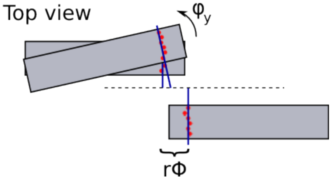
- On September 12, dataops delivered an AlCaReco sample of 110,000 overlaps events and 825,000 generic beam-halo, reduced to tracks and hits for optimized reading
- Armed with a working procedure in Monte Carlo, we went to work on the data immediately
- The rest of this talk will show a snapshot of alignment status and current best results

Parameters

- φ_y angles first,

  then $r\phi$ positions
- ME$-$2/1 & ME$-$3/1 (highest statistics)
- Run 62232: 2/3 of full statistics in short time

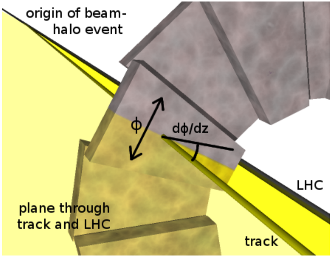




Determining φ_y angles

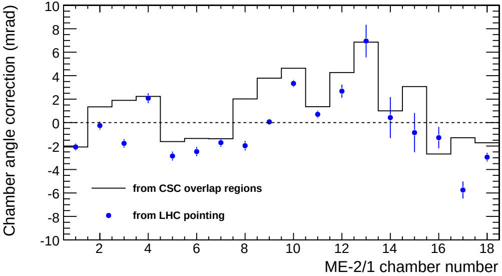
Three independent methods (for cross-checks):

1. Pure overlaps: $d\phi/dz$ 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



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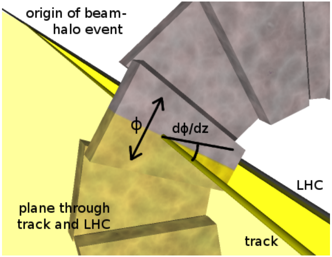

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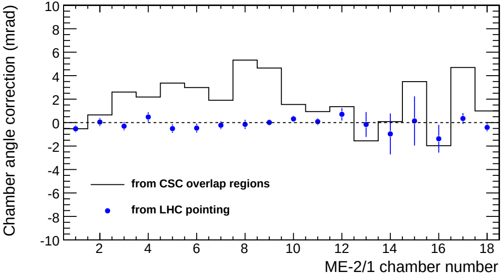
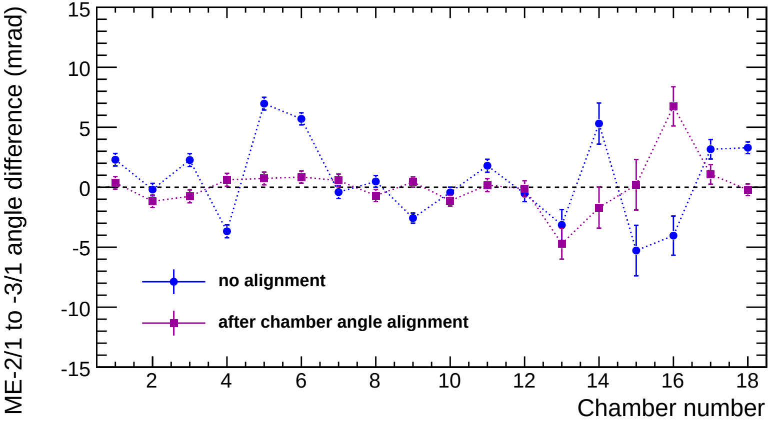


- Apply (3) (LHC pointing), plot (2) (ME−2/1 to ME−3/1 comparison)



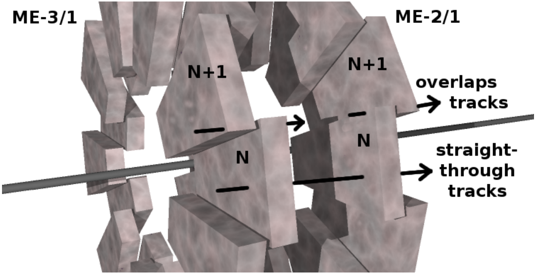
Determining $r\phi$ positions

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

(one needs a 10 mrad φ_y misalignment to make a 1.25 mm mistake in $r\phi$, and we saw at most 4 mrad disagreements)

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 $N_{ME-3/1}$

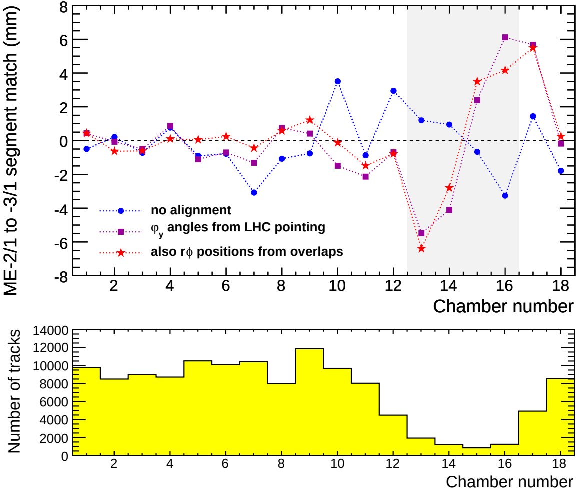


Align with (1) and look at a plot of (2) for each N (data-driven estimate of alignment quality)

- straight-through tracks pass through more material
- but there are more of them

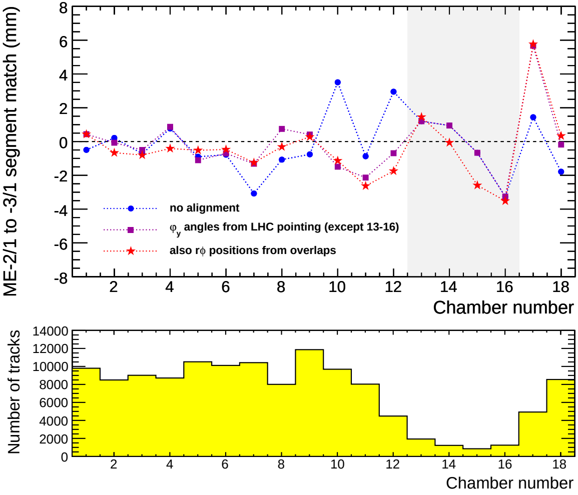
Cross-checking $r\phi$ positions

- 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



Cross-checking $r\phi$ positions

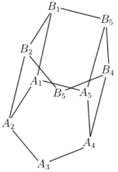
- Don't attempt to align φ_y on chambers 13–16 (leave at default value) and repeat



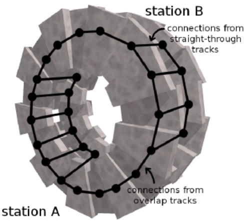
- Overlaps and straight-through tracks form a rigid frame: if errors are not correlated between the rings, a combined fit would isolate errors to one chamber (single-ring fit tries to distribute error uniformly)
- Two benefits:
  - diagnostic tool for identifying which chambers don't fit
  - yields the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

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

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

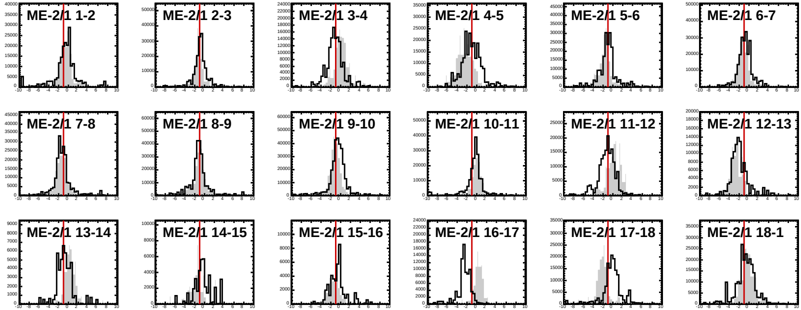


$$\begin{pmatrix} 0 \\ \alpha_{23} - \alpha_{12} + T_2 \\ \alpha_{34} - \alpha_{23} + T_3 \\ \alpha_{45} - \alpha_{34} + T_4 \\ \alpha_{51} - \alpha_{45} + T_5 \\ \beta_{12} - \beta_{51} - T_1 \\ \beta_{23} - \beta_{12} - T_2 \\ \beta_{34} - \beta_{23} - T_3 \\ \beta_{45} - \beta_{34} - T_4 \\ \beta_{51}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



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 14), also in ME$-3/1$, likely also a bad φ_y angle
- Also relevant to look at wide residuals vs. y (for φ_z rotation effects)

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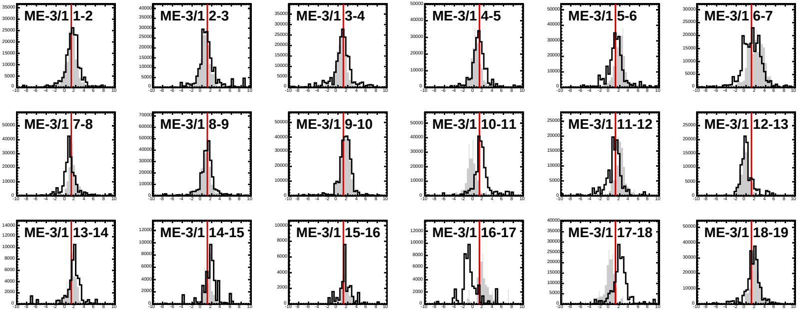

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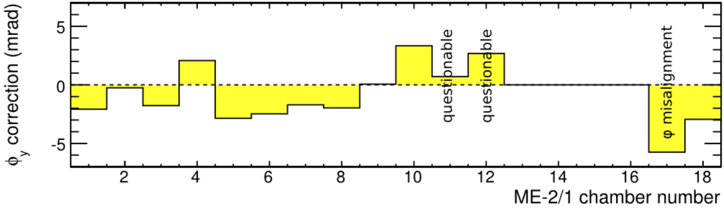
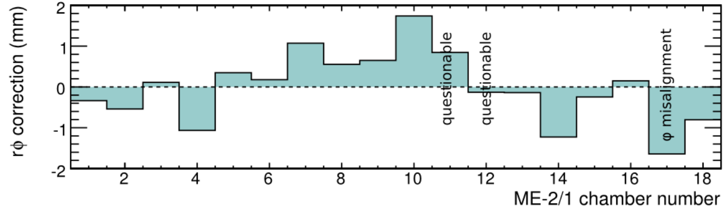
Current best results

- 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, 370 μm in $r\phi$





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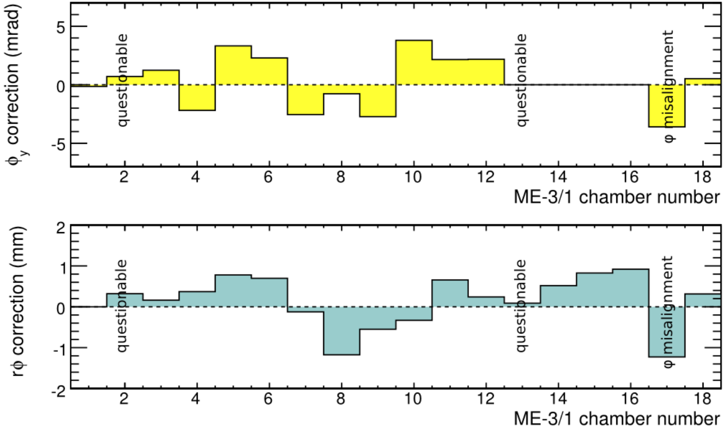

Conclusions

- RMS of $r\phi$ constants is 750 μm, suggesting that the random error in both physical CSC placement and track-based alignment are small (RMS of φ_y is 2.5 mrad)
- Beam-halo events provide several different cross-checks on alignment (all with different systematics), in addition to comparison with hardware alignment
- Part of a two-step process in which internally-aligned rings can be set relative to a reference (barrel or tracker)
- Rings must be complete (only ME+2/1, ME+3/2, ME−2/1, ME−2/2, ME−3/1) or augmented with hardware measurement
- Still trying to get a deeper understanding of these residuals (the overconstrained systems are not perfectly satisfied)