CSC Overlaps Alignment: Review and Conclusions

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Disclaimer

- We'll be talking about a discrepancy that we've previously described as an indication of an error in our track-based alignment
- Since then, we've significantly cleaned up the analysis, understanding and correcting track-based errors, and the discrepancy has reduced by a factor of 3
- By comparing final alignment results with photogrammetry, we have very strong circumstantial evidence that the remaining discrepancy is not due to misalignment or track-based issues
- We have two remaining hypotheses that we propose here to get expert input. If what we're suggesting is not possible, given what is known about the chamber geometry, then we (collectively) will have to scratch these out and find another explanation

Outline for this talk

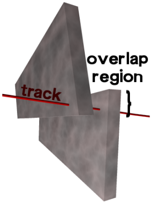
- Motivation and overview of the CSC Overlaps procedure
- Developments since CMS Week, including
  - narrow and uniform residuals distributions
  - agreement with photogrammetry at the level of 300 μm
- However, the ring still doesn't close (the "discrepancy" from page 1)
- Conclusions: what might be causing the lack of closure, and what has been ruled out

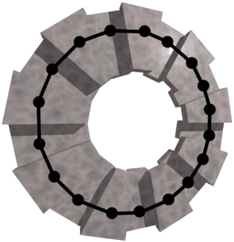
Motivation for CSC Overlaps

- Baseline alignment procedure shown to require 10–100 pb^{-1} for a few hundred micron precision
- Quicker alternative:
  - relative alignment of chambers in each ring (CSC Overlaps)
  - align whole ring relative to tracker with ∼1000s of quality tracks
- Can be done with CRAFT data

Overlaps procedure:

1. select tracks that pass through overlap of chambers in a ring
2. require consistency in pair of segments: slope and intercept
3. solve system

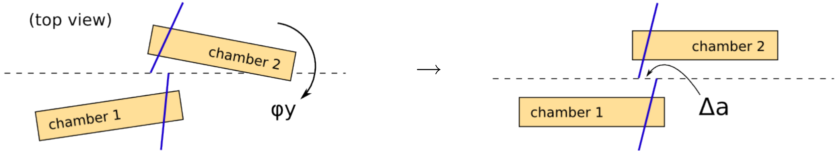




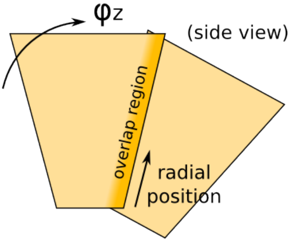
System is over-constrained: must be consistent with a circle ("closure")

Details of implementation

- Select good tracks, refit segments to 1-D straight lines: $\phi(z) = a + bz$
- Align φ_y angles by requiring segments to have equal slopes ($\Delta b = 0$)



- Now intercept residual (Δa) tells us about misalignment in the $r\phi$ direction: align ϕ positions with fixed r (arcs centered on beamline)
- Linear trend in intercept residual versus radial position is due to φ_z misalignment



Parameters decouple when corrected in this order: first φ_y, then $r\phi$, then φ_z

(repeated alignment yields zero corrections)

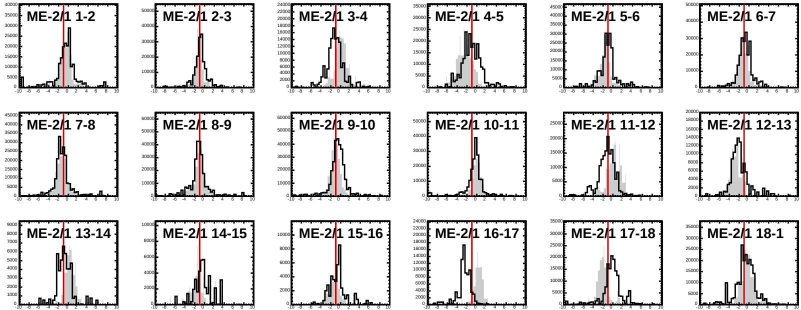
- Four types of residuals, each measures a different parameter:

	segment slopes	intercepts
evaluated at center of chambers	φ_y angles	$r\phi$ positions
linear trend versus radial position	chamber twist	φ_z angles

- No significant "twist" observed (shear of alignment pins)
- Residuals measure chamber-by-chamber differences: in a ring, they must add to zero
- All types of residuals add to zero ("close") except $r\phi$
- $r\phi$ residuals fail to close if chambers are the wrong width in some sense:
  - if the chambers are literally too wide or narrow
  - if the average distance to the beamline (radius) is wrong (potentially measurable by closure, if we can rule out other effects)
  - ~~if chambers are rotated in φ_y~~ (discussed in last DPG presentation)
- Last effect is second-order in φ_y, but we have a direct first-order measurement of φ_y angles

- Only aligned φ_y and $r\phi$ (and some φ_y corrections were questionable)
- Wide residuals, presumed due to misaligned φ_z

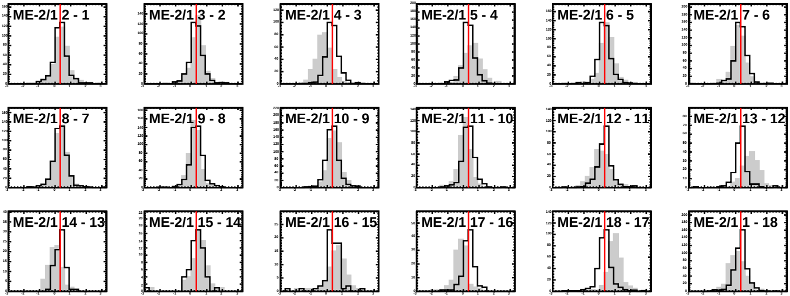
Hollow: aligned (ME−2/1 & −3/1 combined), grey: unaligned, red line: ME−2/1-only fit



- ME−2/1, ME−3/1 whole-ring underclosure: 18 mm, 20 mm
- Cross-checked overlaps alignment results against other track-based measurements (which are less precise than overlaps)

- Full φ_y, $r\phi$, φ_z alignment; intercept residuals are all 1.2 mm wide

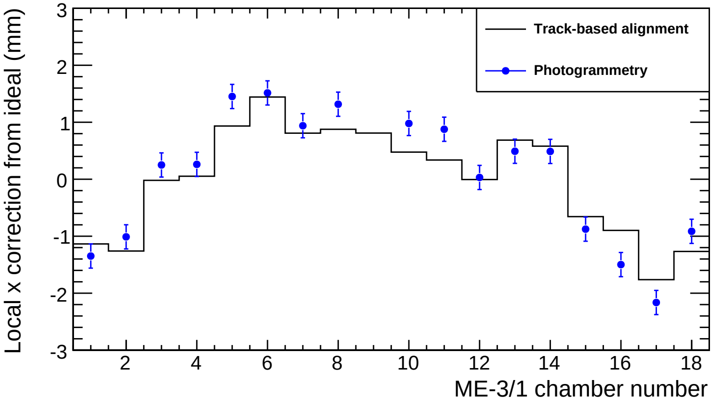
Hollow: aligned (ME−2/1-only fit), grey: unaligned, red line: common mean



- Used photogrammetry to set chamber-by-chamber distances from beamline: reduced underclosure by 20%, but still significant
- ME−2/1, ME−3/1 whole-ring underclosure: 16 mm, 14 $\pm$ 0.4 mm
- Interpreted as radial corrections: 2.5 mm, 2.3 mm inward
- Cross-checked track-based alignment results against photogrammetry

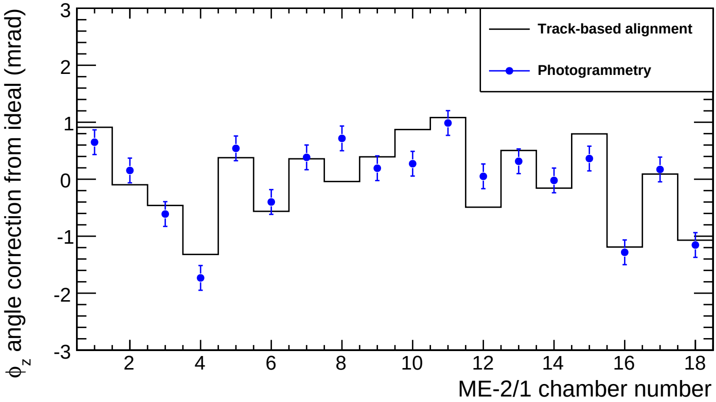
- The method is sound: Monte Carlo closure is consistent with zero
- In data, all residual types have zero closure except $r\phi$
- $r\phi$ and φ_z constants compare favorably with photogrammetry

Overlay of $r\phi$ translations, track-based and photogrammetry relative to ideal



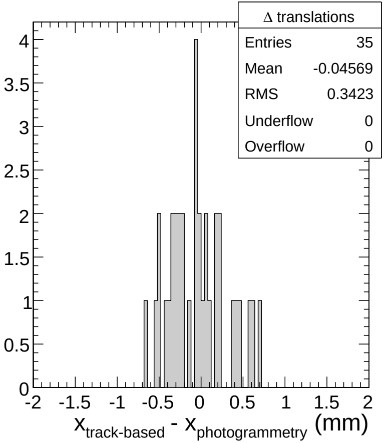
- The method is sound: Monte Carlo closure is consistent with zero
- In data, all residual types have zero closure except $r\phi$
- $r\phi$ and φ_z constants compare favorably with photogrammetry

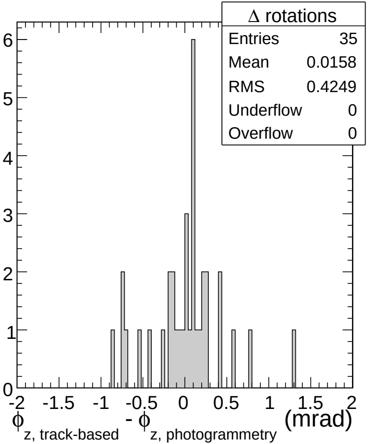
Overlay of φ_z rotations, track-based and photogrammetry relative to ideal



Confidence in alignment results

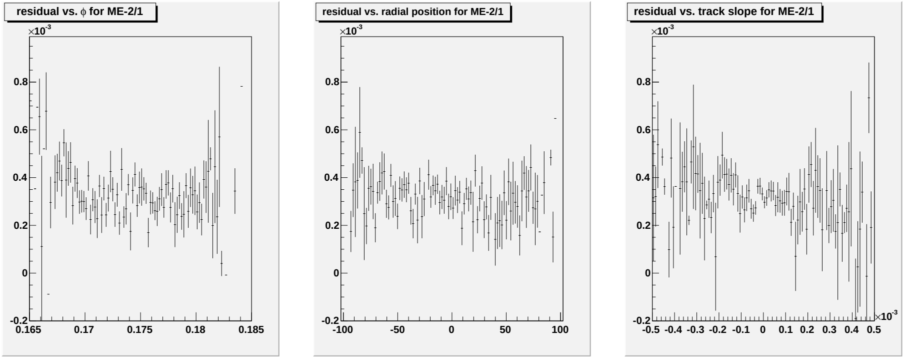
- RMS difference between track-based and PG: 340 μm, 0.42 mrad
- Photogrammetry $r\phi$ uncertainty is $(300/\sqrt{2})\ \mu\text{m} = 210\ \mu\text{m}$
- $\sqrt{340^2 - 210^2} = $ 270 μm errors in track-based method alone
- Statistics from one large beam-halo run (62232, 9 minutes)





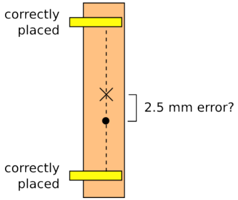
What about closure?

- High-precision agreement with photogrammetry gives us confidence in alignment results (with closure error distributed uniformly)
- Therefore, closure error is due to a systematic effect which is the same for each chamber
- Are there trends versus ϕ, radial position, or track slope? No.



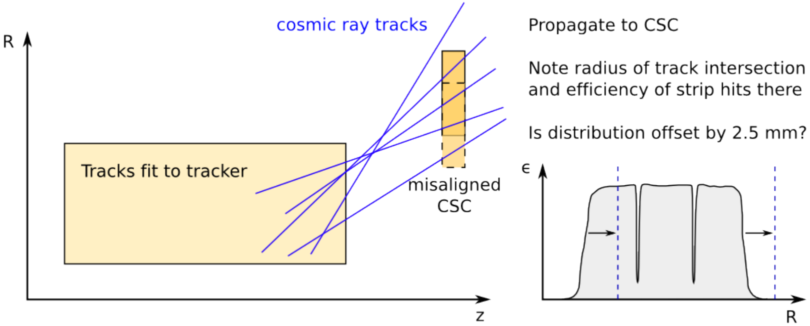
Remaining possibilities

- Hypothesis 1: layers are *narrower* in real life than in software by 0.8 mm at the center (0.087% error in total width, or 10 μm per strip)
  - Maybe "narrowing" is due to bowing, e.g. if layer surface pinched to fit frame? No: sagitta = 9.6 mm, bow angle = 4.8°
- Hypothesis 2: chamber centers are *closer* to the beamline by 2.5 mm in ME−2/1 and 2.3 mm in ME−3/1 ($\pm$ 0.06 mm each)
  - We've verified the alignment pin positions in ϕ, and can therefore be certain that they are correct in r (photogrammetry errors must be isotropic in x and y!)
  - Therefore, we're not disputing the global pin positions, but the chamber centers relative to those pin positions (from mf.xml)
  - Also, this is not the chamber center as measured by the wires (the normal way of measuring radial position), but measured through angle of strips



Ideas to search for the effect

- It was a *different* 2.5 mm offset that we found a few months ago by looking at the drawings (ME2/2 and 3/2, and in opposite direction)
- We didn't see an analogous effect in other rings, but there might be a different drawing/DDD discrepancy, e.g. distance from pins to center, rather than bottom of chamber frame to center
- Track-based method to cross-check hypothesis #2 (radial shift): wire residuals or strip efficiency turn-on curve (more direct)



Conclusions

- Our alignment results are correct, to desired precision (300 μm)
- However, $r\phi$ residuals very clearly do not close when summed around rings ME−2/1 and ME−3/1
- The problem is uniform across all these chambers: if it were not, we would not be able to reproduce photogrammetry
- Real chambers are ______ than in simulation
  - 0.8 mm narrower across the center
  - 2.4 mm closer to the beamline
  - ~~pinching layers such that they bow by 4.8° more~~
  - ~~50-70° C colder~~
  - or. . . ?