Apparent Non-Rigid Body Distortions of the DTs from Tracks

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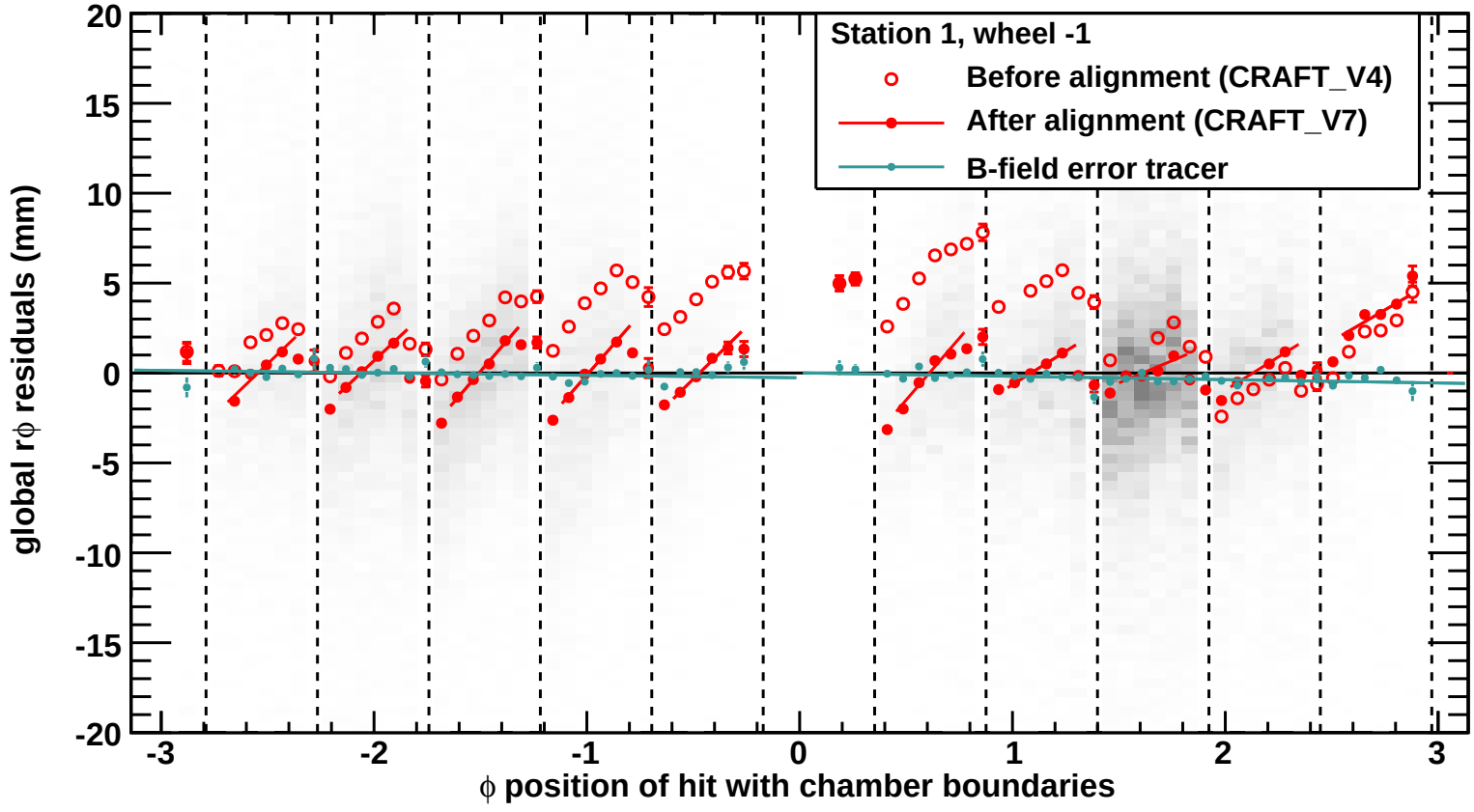
Overview

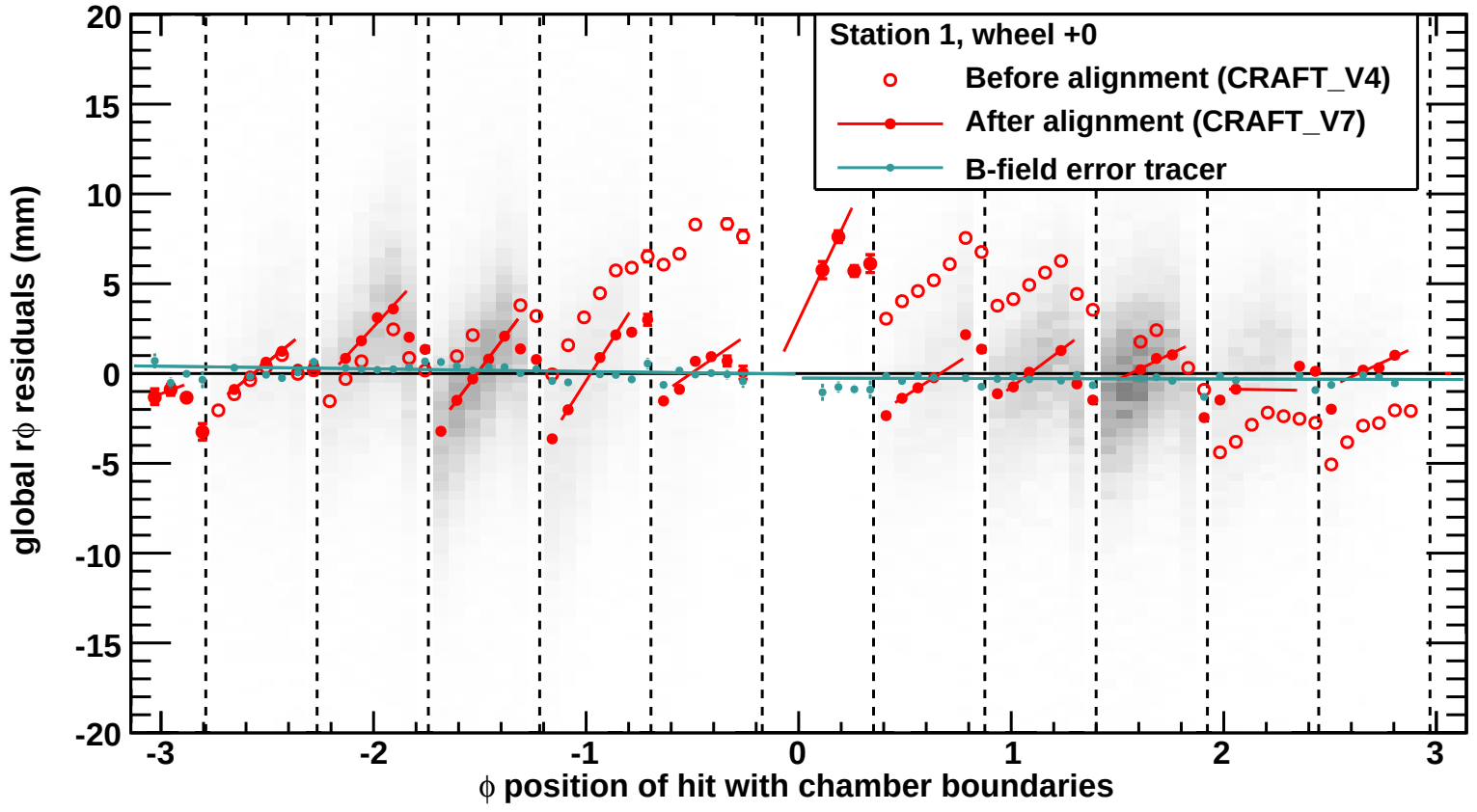
- Last week, I pointed out that DT chambers appear to be "stretched" in my presentation of alignment results, but we didn't have time for the details
- In terms of residuals, it's as important as the alignment
  - unbiased residuals on the $+x$ and $-x$ edges of the chambers differ by 5 mm
  - no translation or (reasonable) rotation of the chambers can account for that
- In this talk, I'll show where the conclusion comes from, and what kinds of distortions we're talking about when we refer to "stretching"
- For completeness, one of these is the relative ΔR of superlayers, not what anyone would call "stretching" (though non-rigid from a chamber point of view)
- This talk is largely the same as the "Epilogue" of last week's talk

The clue (1/3)



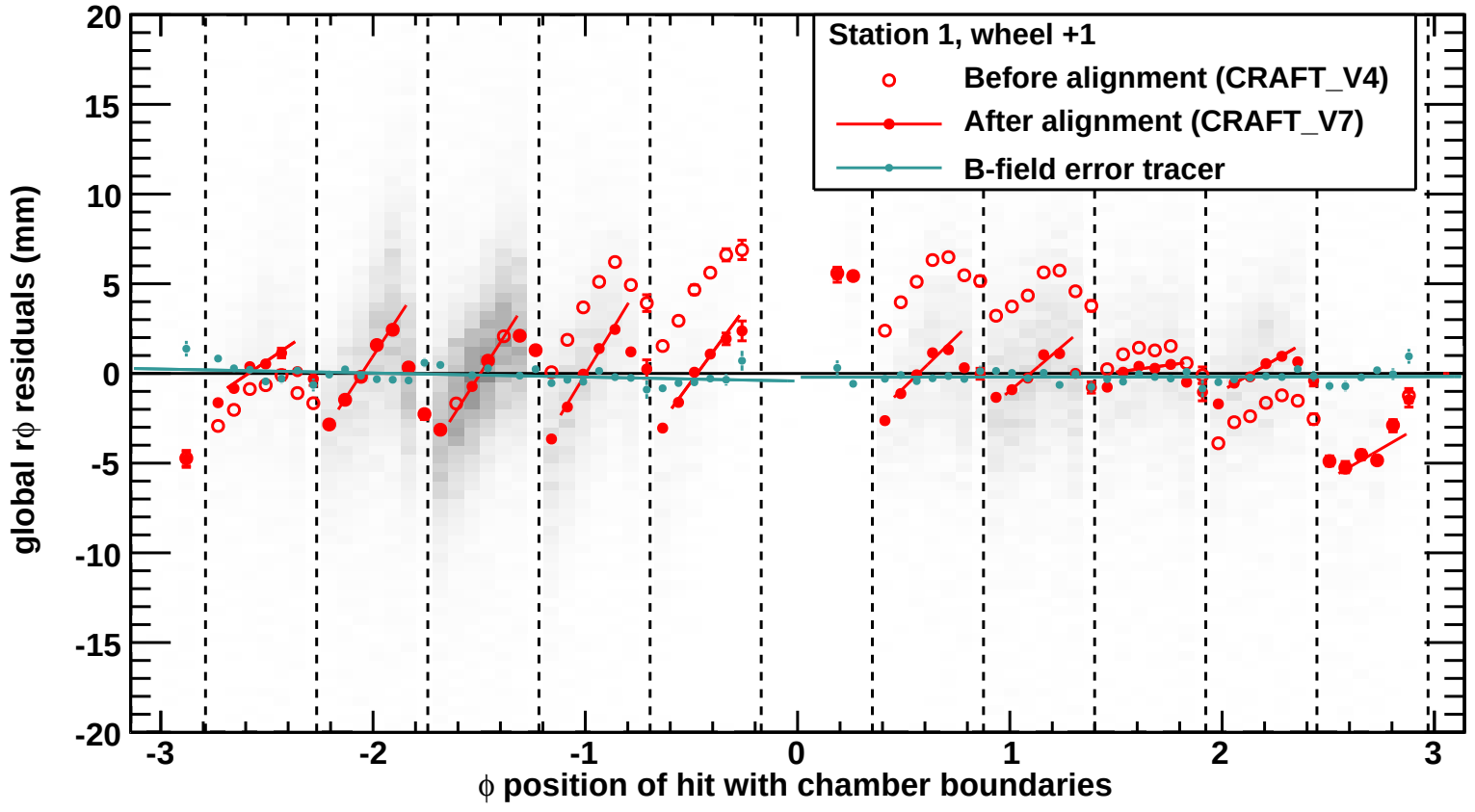
- Linear trends in unbiased $r\phi$ residual vs. ϕ inside each chamber
- Unaffected by local x alignment (as expected)
- Curious thing: they all seem to have (more or less) the same slope

The clue (2/3)



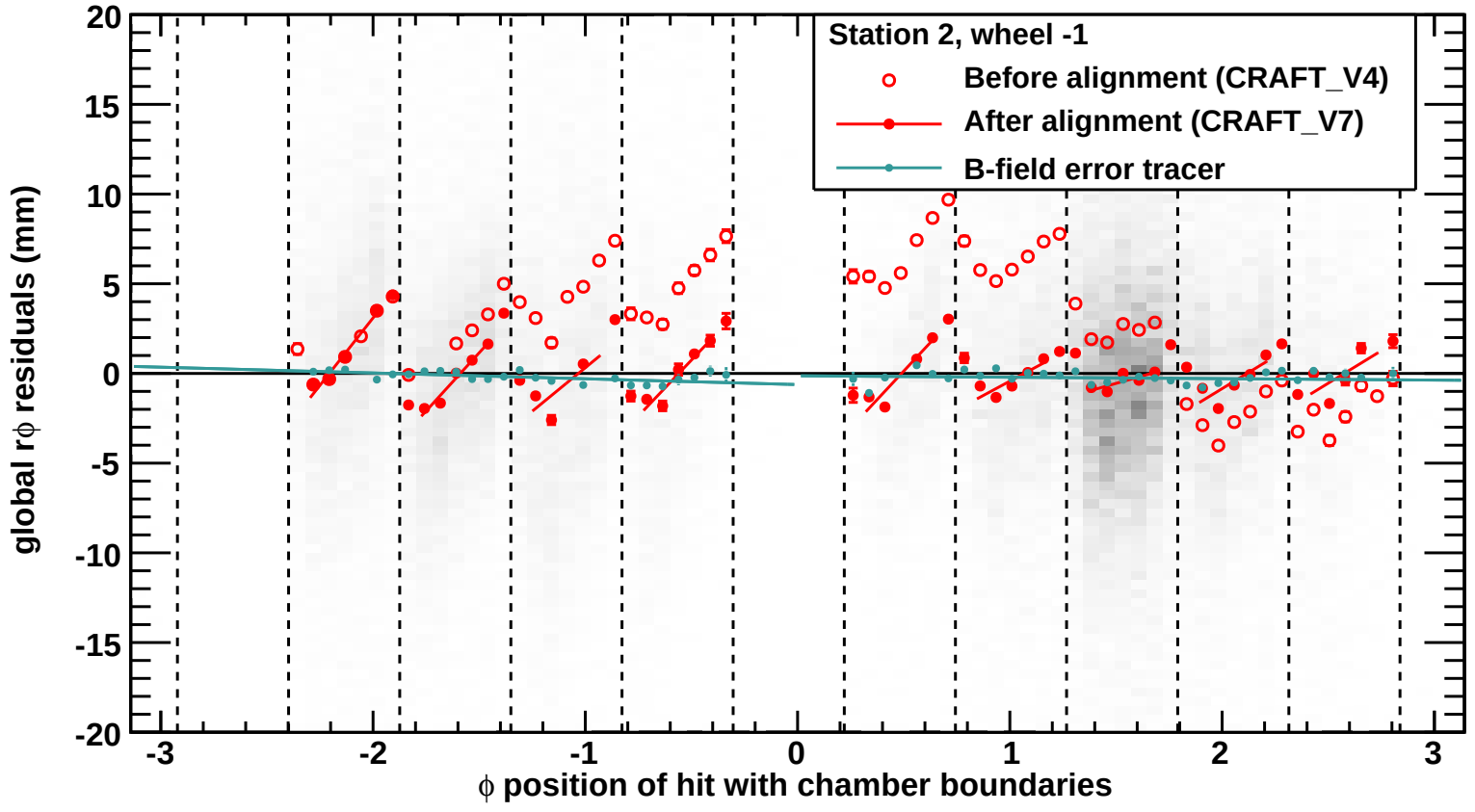
- What if it's a linear bias in the distribution from the track source, partly absorbed by the alignment?
  - impossible: ϕ must have periodic boundary conditions
  - if we realigned chambers to make a continuous line, it could not match at $\pm\pi$ (it would fail a "closure condition")

The clue (3/3)



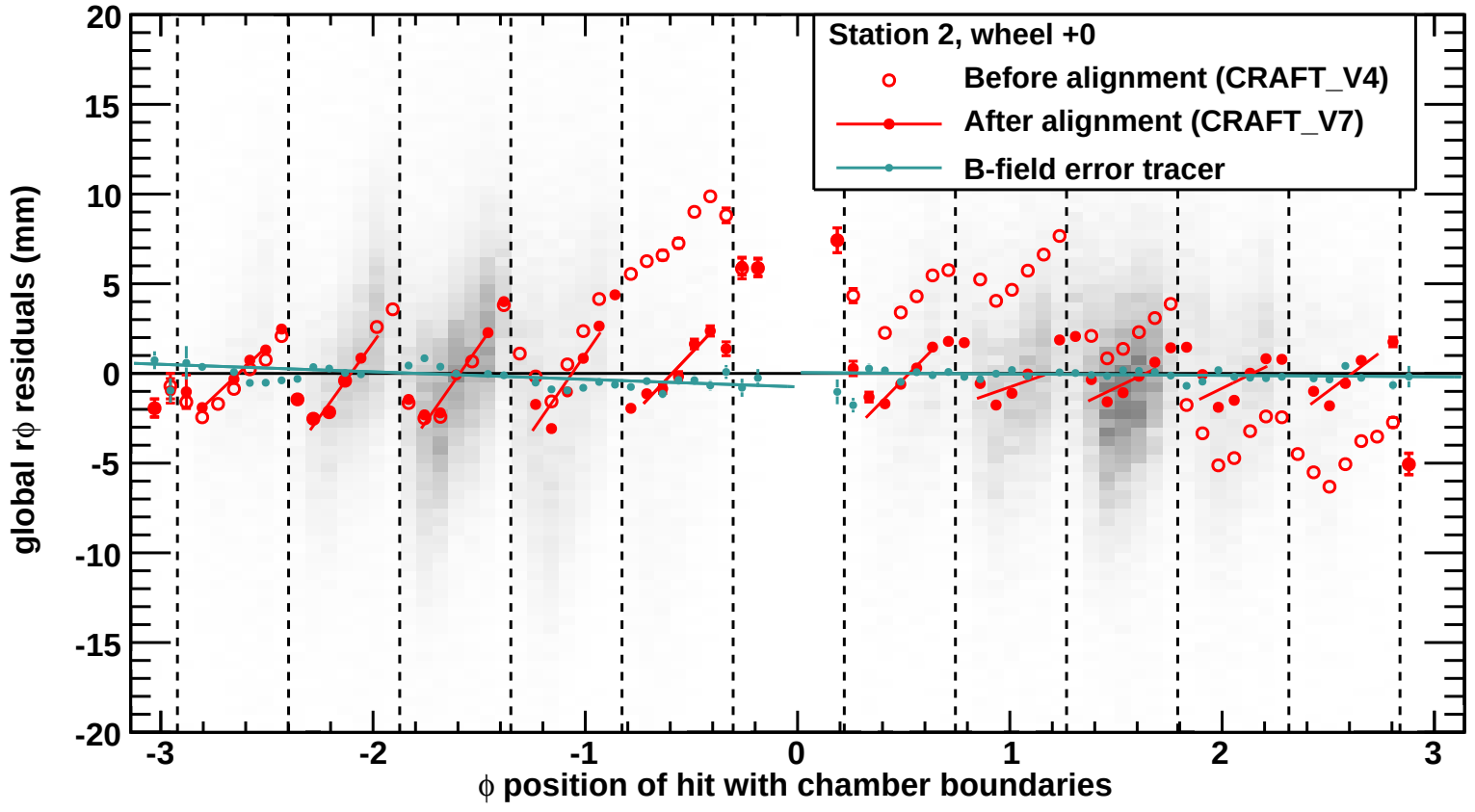
- So it's a real effect related to the chambers, not the track source
  - not fixing it would smear chamber resolution by 5 mm!
- What rigid body misalignments can cause it?
  - ϕ_y (rotation around axis parallel to the beamline)
  - ΔR (radial displacements)

Full disclosure (1/9)



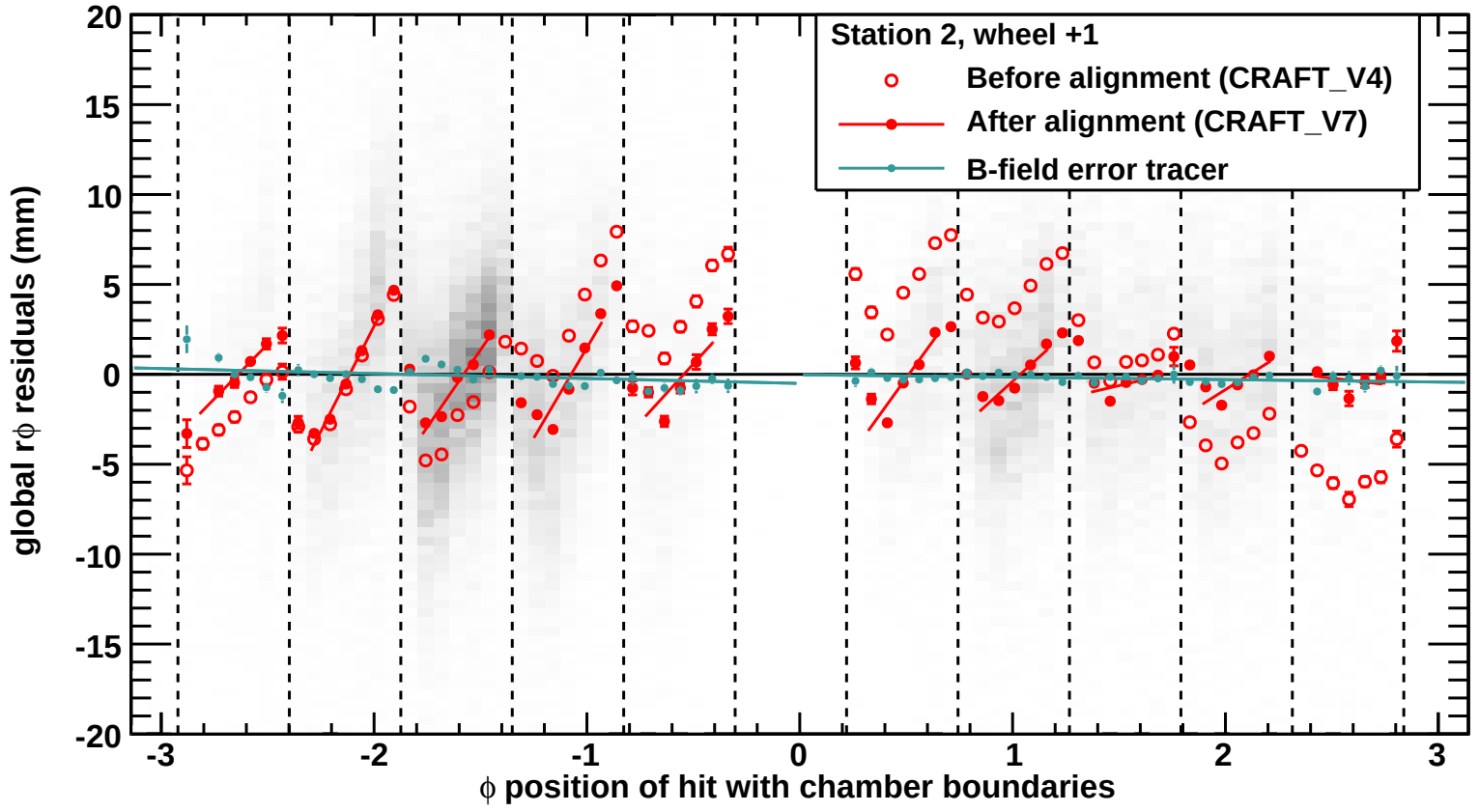
- Let's skim through all the plots: station 2, wheel -1

Full disclosure (2/9)



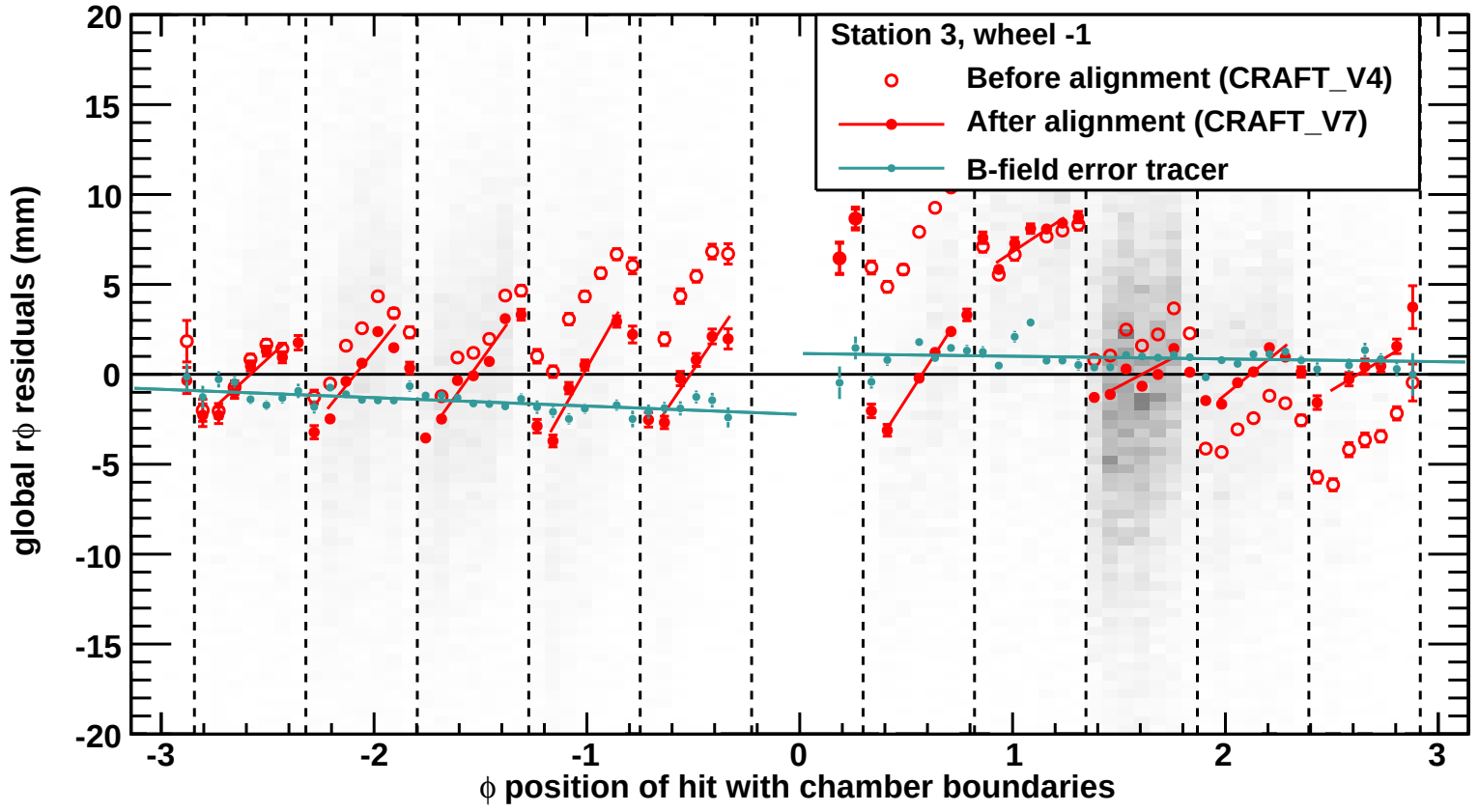
- Let's skim through all the plots: station 2, wheel 0

Full disclosure (3/9)



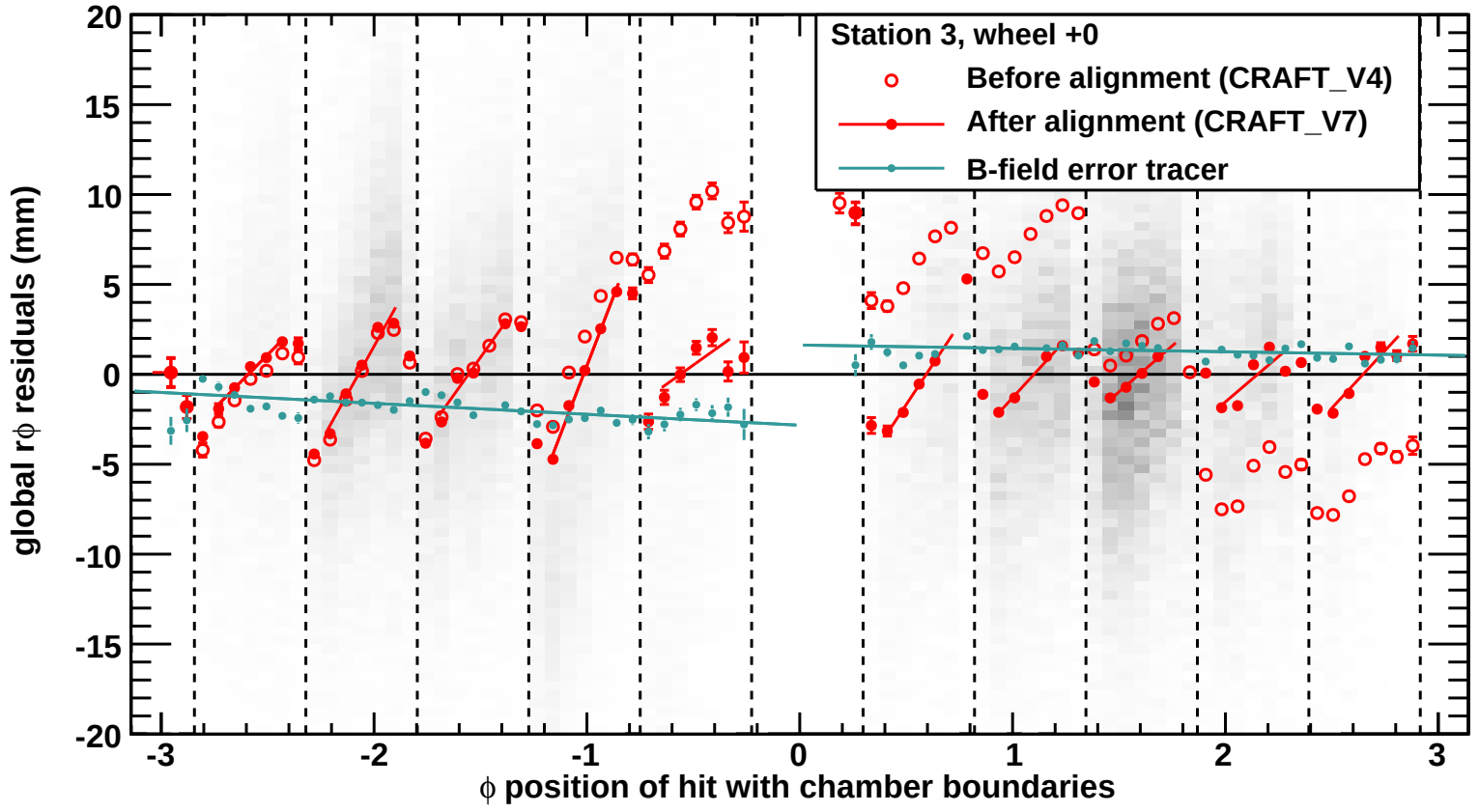
- Let's skim through all the plots: station 2, wheel +1
- See what I mean about the slopes being roughly the same everywhere?

Full disclosure (4/9)



- Let's skim through all the plots: station 3, wheel -1
- See what I mean about the slopes being roughly the same everywhere?

Full disclosure (5/9)



- Let's skim through all the plots: station 3, wheel 0
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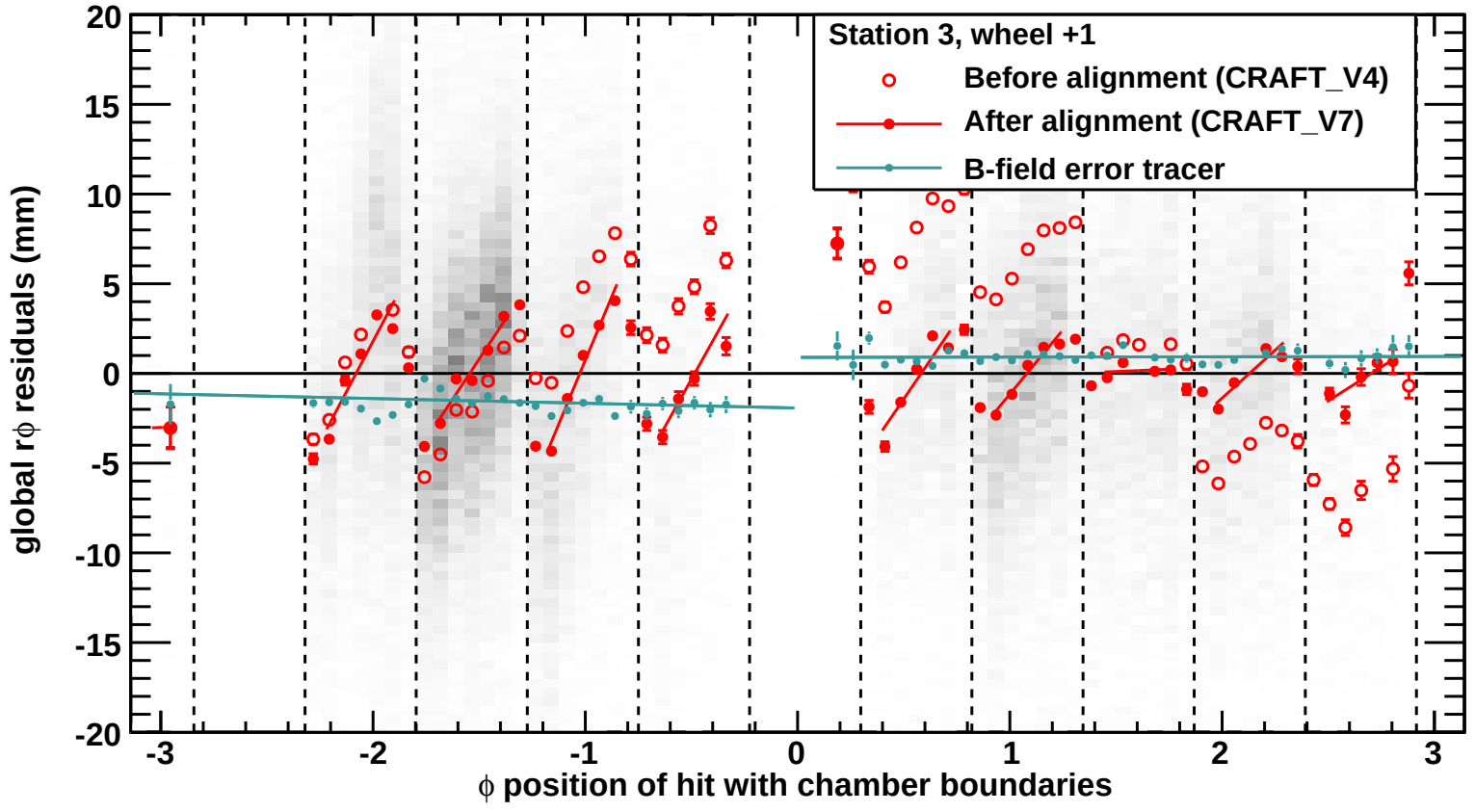
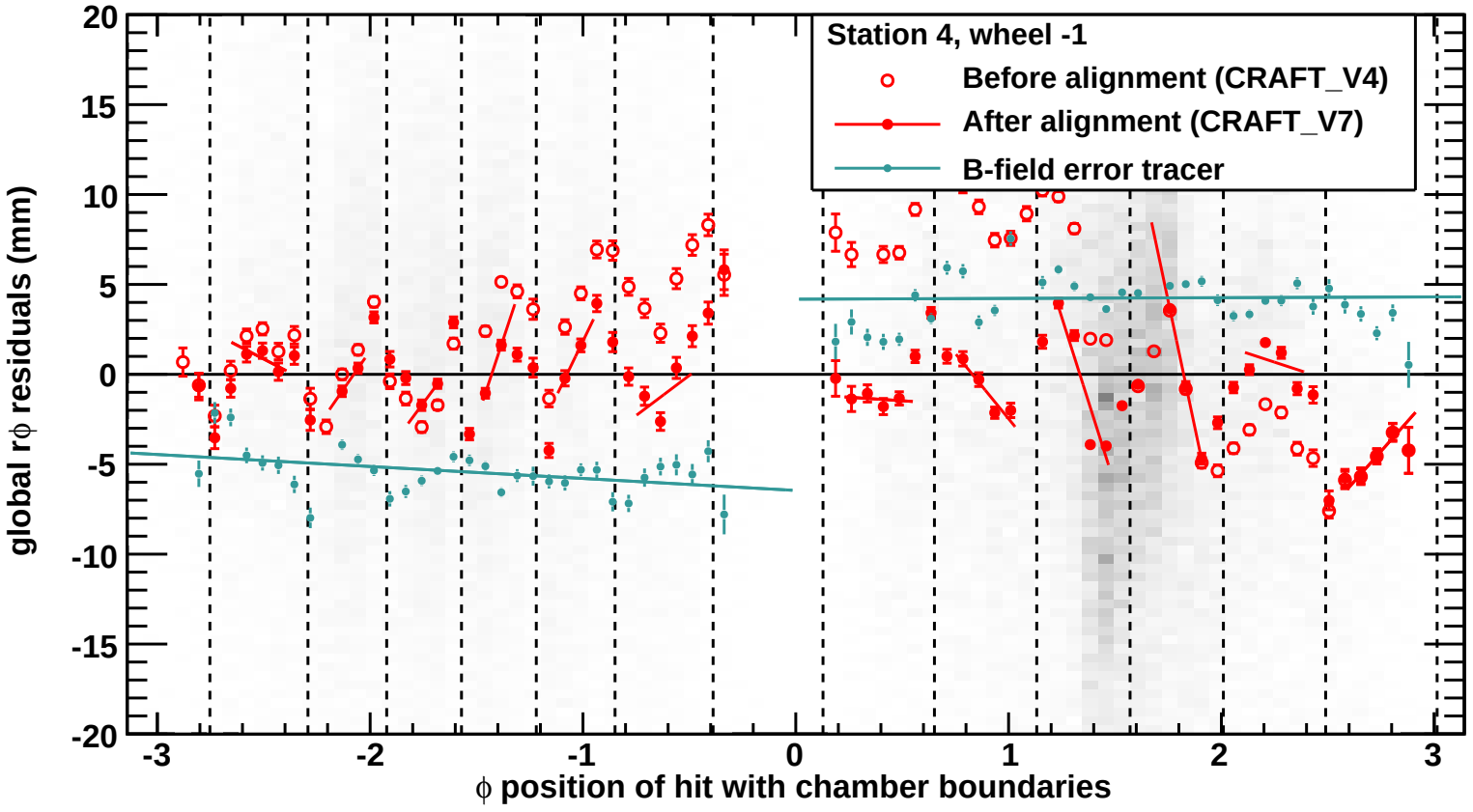
Full disclosure (6/9)



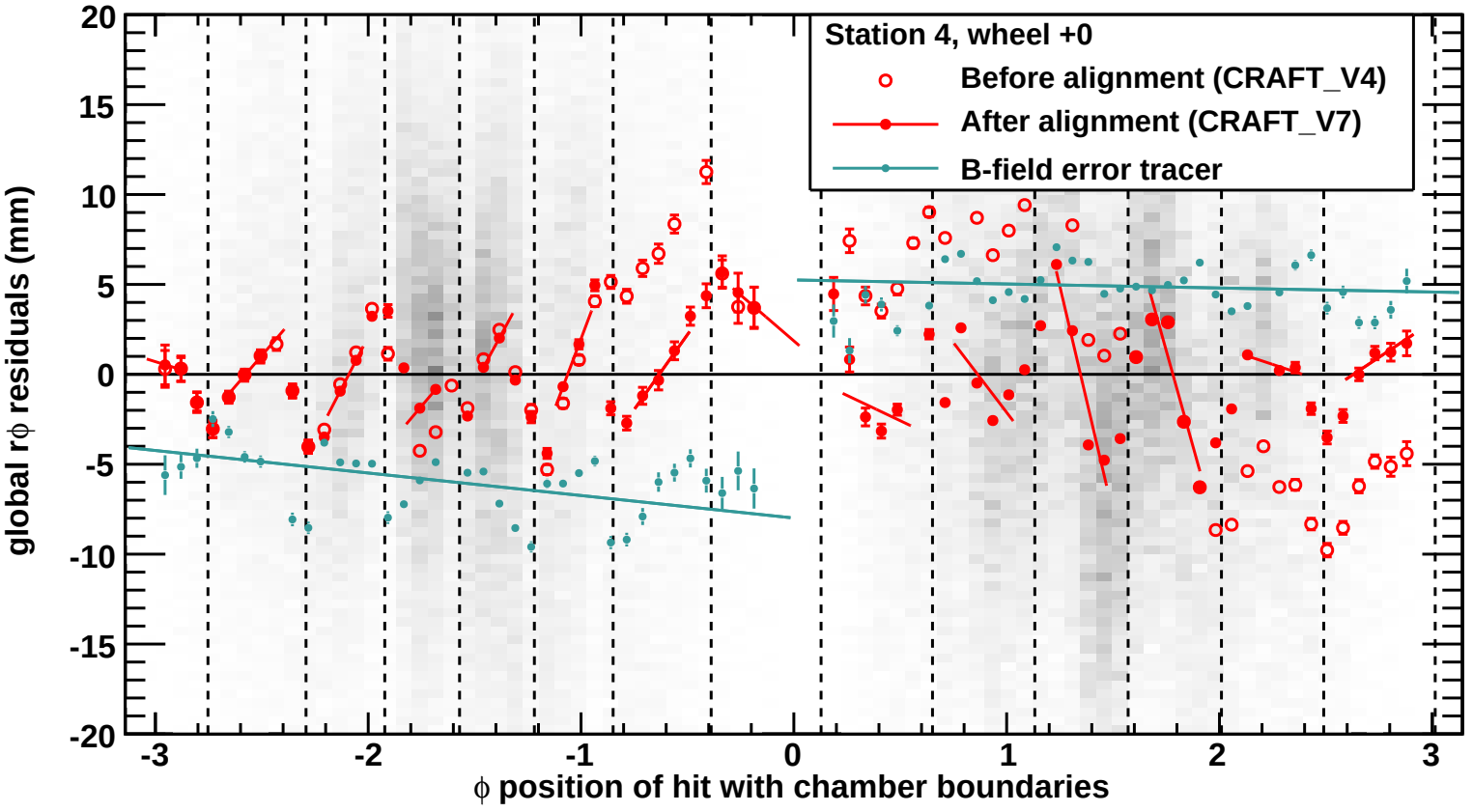
- Let's skim through all the plots: station 3, wheel +1
- See what I mean about the slopes being roughly the same everywhere?

Full disclosure (7/9)



- Let's skim through all the plots: station 4, wheel -1
- See what I mean about the slopes being roughly the same everywhere?
- In station 4, the pattern is less clear because the residuals distributions are much wider and the detector is more finely (and unevenly) divided in ϕ

Full disclosure (8/9)



- Let's skim through all the plots: station 4, wheel 0
- See what I mean about the slopes being roughly the same everywhere?
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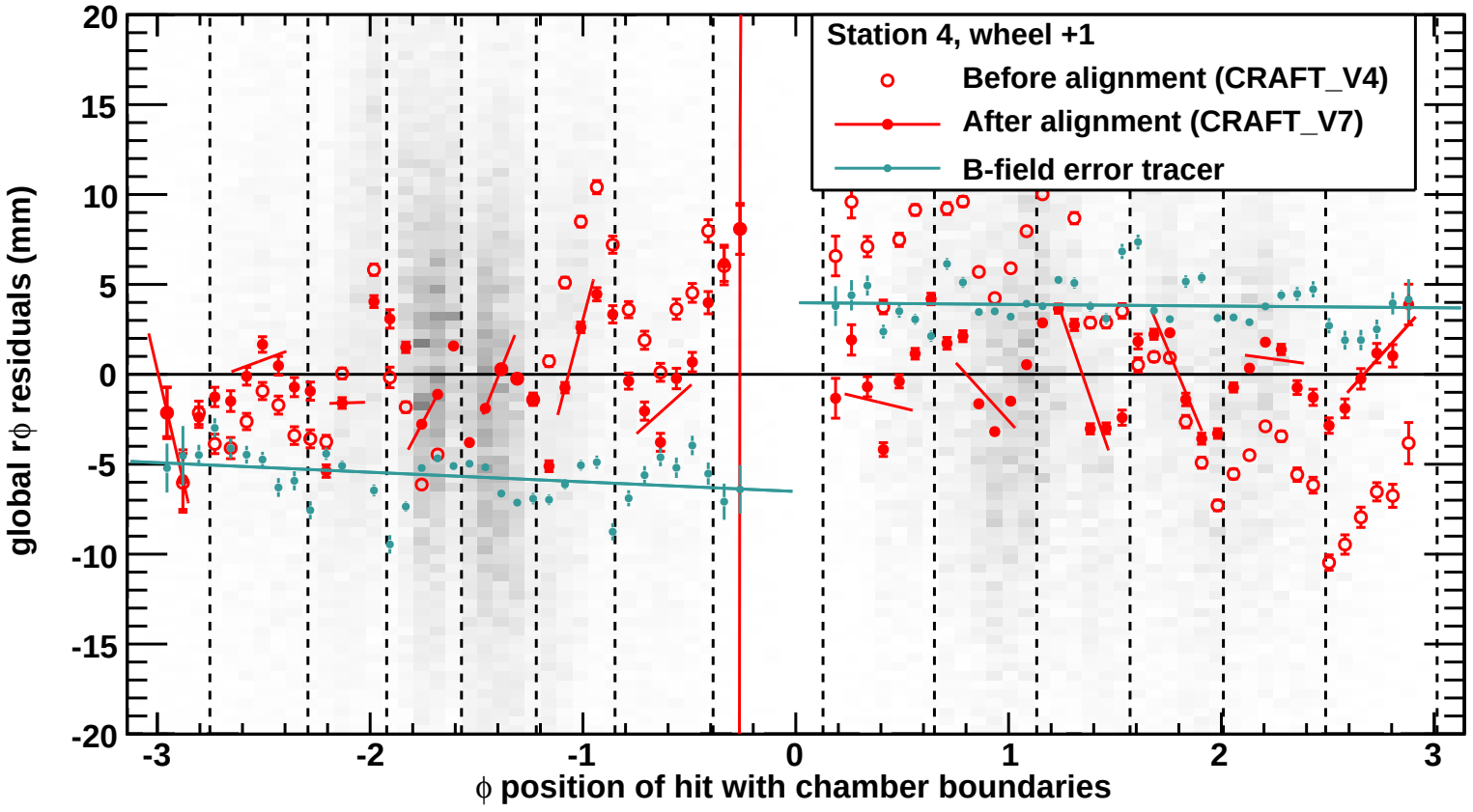
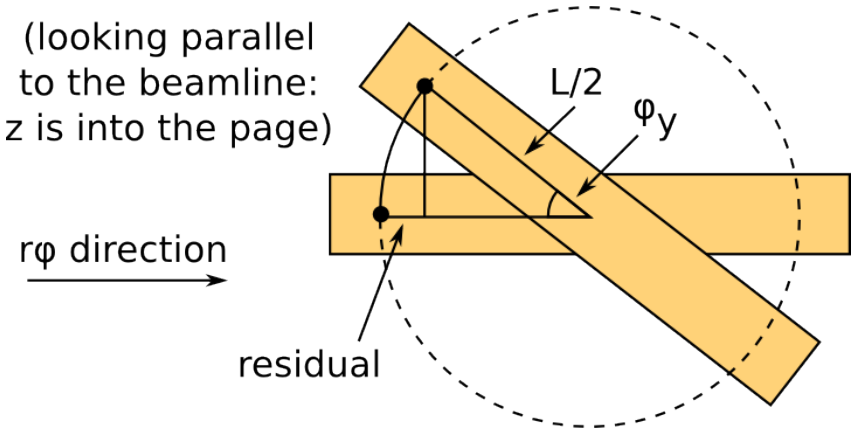
Full disclosure (9/9)



- Let's skim through all the plots: station 4, wheel +1
- See what I mean about the slopes being roughly the same everywhere?
- In station 4, the pattern is less clear because the residuals distributions are much wider and the detector is more finely (and unevenly) divided in ϕ

The ϕ_y possibility

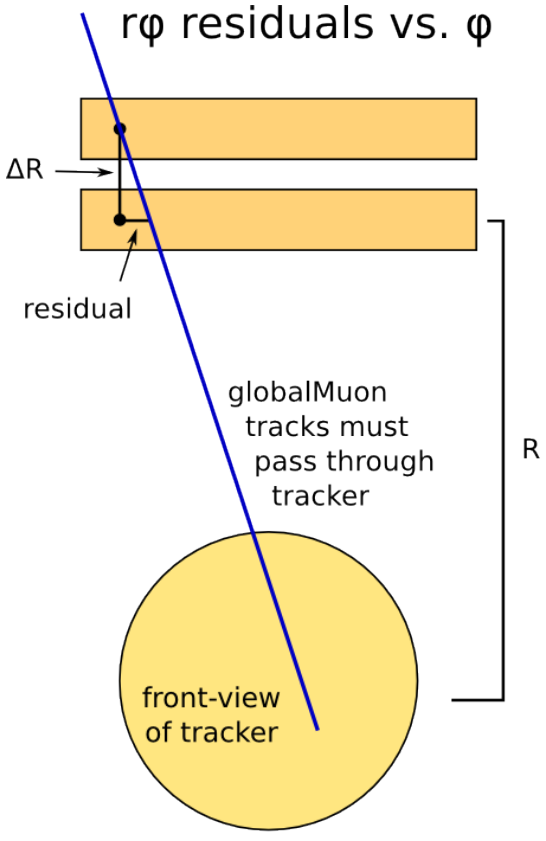


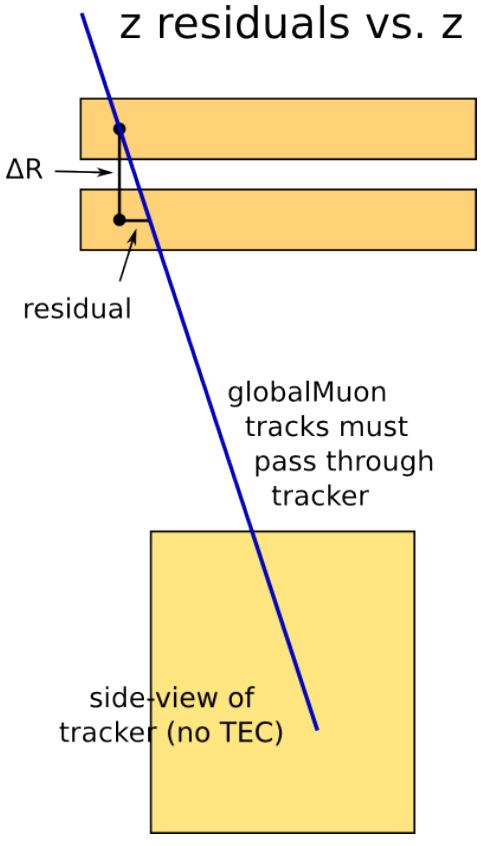
- ϕ_y rotation can make a chamber appear narrower
- but it's a second-order effect:

$$\begin{aligned} \text{residual} &= (L/2)\,(1 - \cos\phi_y) \\ 0.25\text{ cm} &\approx \frac{200\text{ cm}}{2}\left(\frac{{\phi_y}^2}{2}\right) \\ \phi_y &\approx 70\text{ mrad} \end{aligned}$$

- Could *all* the chambers be independently misaligned by about 70 mrad?
- Same effect observed in IDEAL and CRAFT_ALL_V4 constants: it would have to be a physical misalignment of real chambers
- I think we can safely say that this is not what's happening
  - the magnitude is too big, and
  - the pattern is too regular

The ΔR possibility





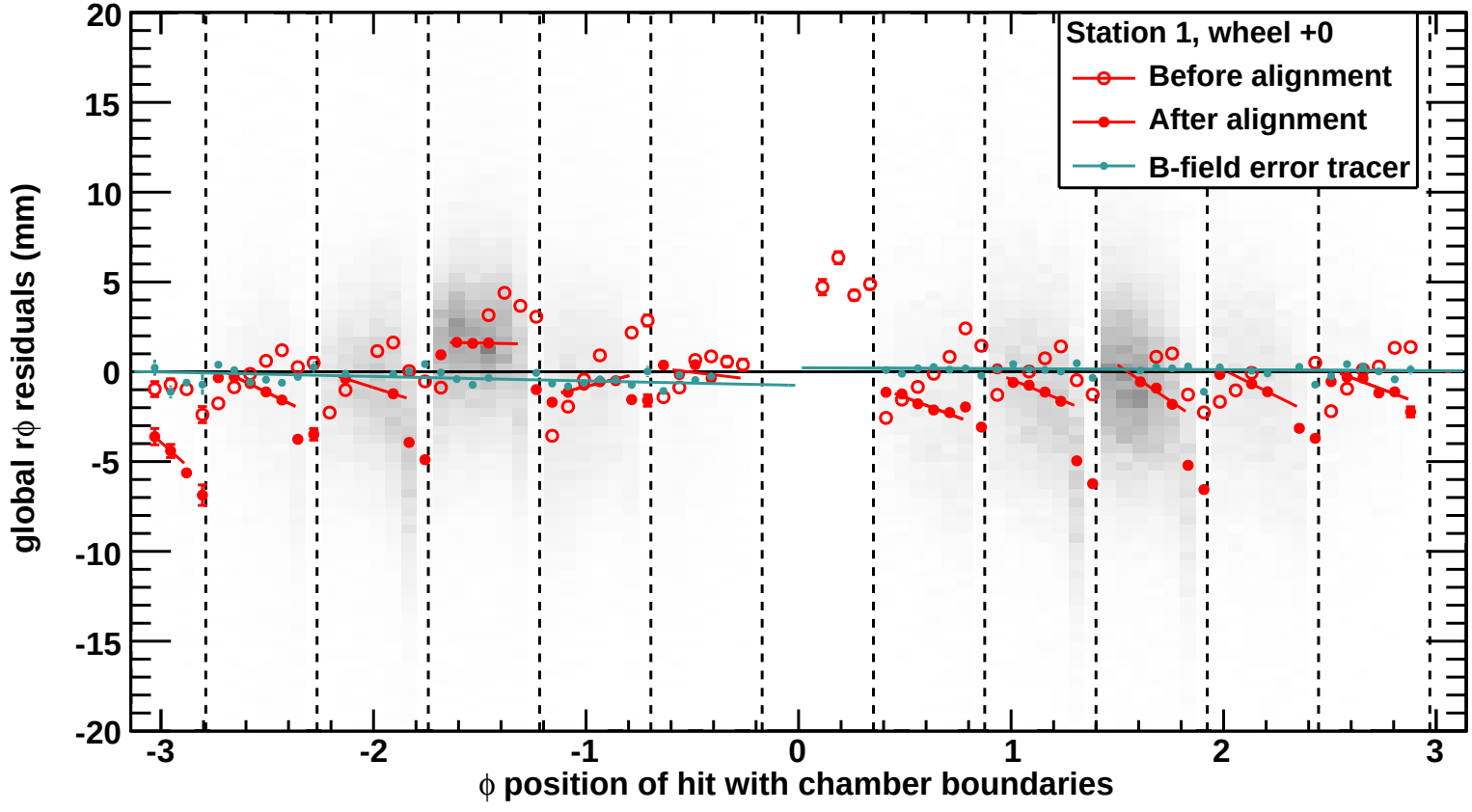
- A track sample constrained to pass through the tracker can introduce effects of this sort

$$\Delta R = \frac{R}{(L/2)}\,(\text{residual})$$

- But it has to appear in both types of residuals

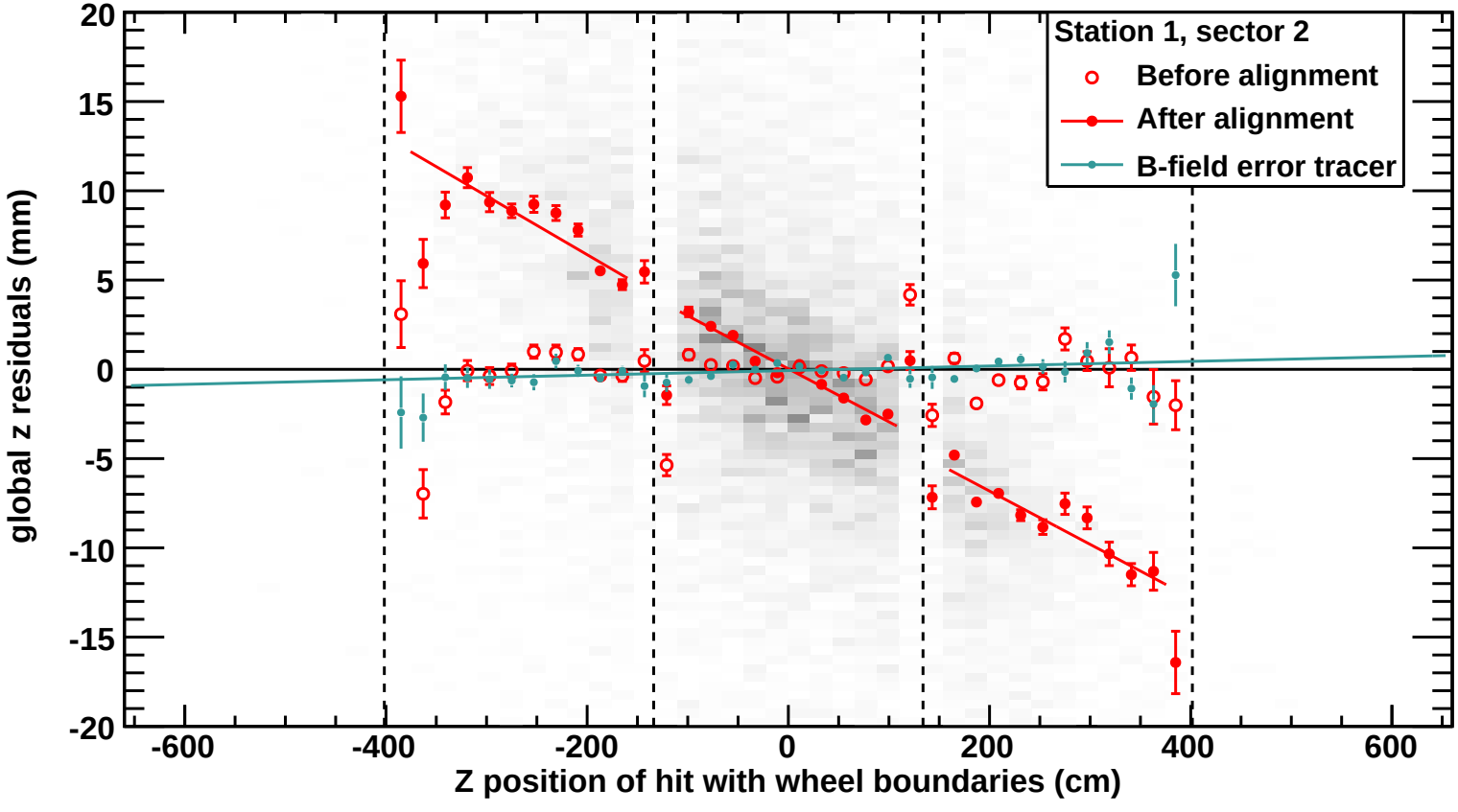
Trial ΔR alignment (1/2)

- To see if this is plausible, I expanded the radius of all DT stations by 15 mm in a private test
  - seems to cancel the $r\phi$ residual vs. ϕ trend in the $-\pi < \phi < 0$ range, but overshoot slightly in the $0 < \phi < +\pi$ range



Trial ΔR alignment (2/2)

- However, look what happens to the z residual vs. z: clearly both types of residuals can't be satisfied!
- The open circles are the case of no ΔR shift

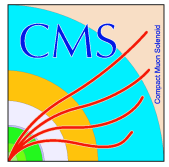


So, what could it be?

- Process of elimination for all rigid body degrees of freedom
  - ~~ϕ_y: implausible~~
  - ~~ΔR (a ΔR translation): can't reconcile both $r\phi$ and z residuals~~
  - local x, y translations: can't introduce any linear trends in residuals, only offsets
  - ϕ_z rotation: introduces a linear trend in $r\phi$ residuals vs. z and z residuals vs. ϕ, but not what we're looking for
  - ϕ_x rotation: also would have to be implausibly large, and only affects z residuals (the opposite of what we're looking for)
- Non-rigid degree of freedom

  - *some kind* of stretching would easily explain it
  - an error in the geometry description, duplicated by CMSSW, would account for its regularity (with outliers due to individual ΔR misalignments)

Analogy with CSC case



- Last year, track-based alignment found 0.8 mm error in CSC widths
- For the same reasons, chamber stretching was degenerate with increasing the distance from the beamline
- Degeneracy was resolved with photogrammetry of alignment pins
  - track-based procedure reproduced $r\phi$ positions of alignment pins with 270 μm accuracy
  - R positions of pins were therefore directly comparable, and constrained distance from the beamline
- CSC geometry experts investigated and quickly found a 10 μm strip pitch angle error, which, compounded over 80 strips, changed the width by 0.8 mm, explaining the observation with tracks
- Error was in an XML file, not the database, and originated in miscommunication (design values rather than measured)
- DTs have an advantage over CSCs in that they precisely measure z residuals in addition to $r\phi$ residuals, so we can already break degeneracy between ΔR and stretching
- In the CSC case, we got the sign wrong, but not magnitude

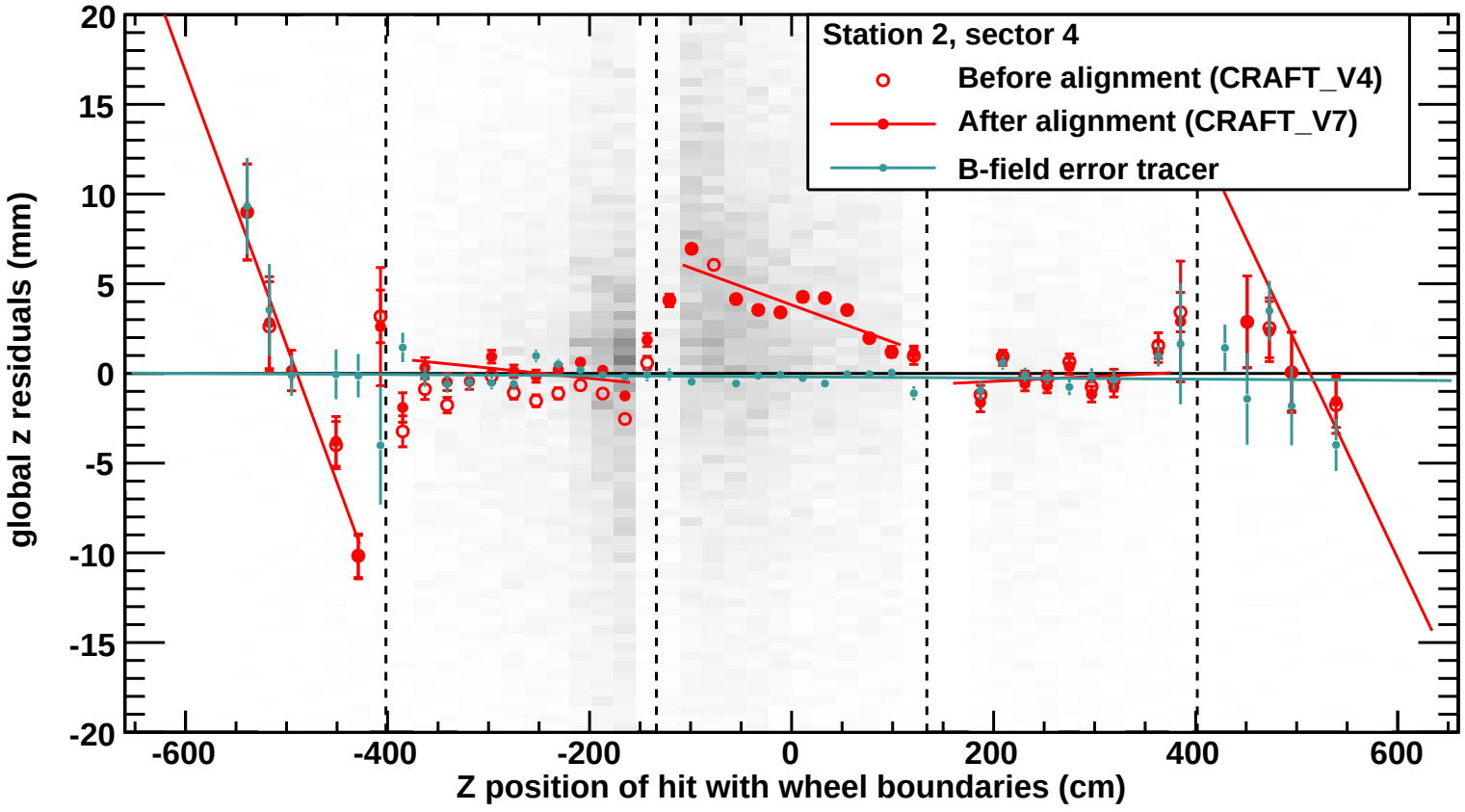
What kinds of distortions?

- A literally stretched chamber: e.g. small correction in drift tube diameter, compounded across the chamber (exact analogy with CSC)
- An effective 70 mrad rotation built into the chamber: angled layer planes
- A large ΔR error in superlayer positions, different for each superlayer
  - not what anyone would call "stretching," so I should be careful to not use that terminology for this case
  - we concluded non-rigid body distortion due to incompatibility between $r\phi$ residuals vs. ϕ and z residuals vs. z; perhaps the incompatibility is built into the chamber
  - unfortunately, the scale would have to be $\mathcal{O}(10\text{ mm})$, which I think is ruled out
- . . . more?

Non-geometric explanations?

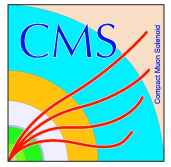
- A timing effect?
  - I don't think any drift time effect could explain it, since we don't have the spatial resolution to see the difference between the left and right sides of each wire
- $\vec{B}$-field on electron drift? No, the magnitude of the effect we're seeing is about the same in stations 1, 2, and 3
- We should continue considering possibilities that it's a tracking effect
  - constraint: it *must* be an effect in the chamber, not the track source, since it knows about chamber boundaries
  - ~~could the chamber material act like a lens? Difference in speed of muons in material causes refraction?~~ (such an effect would need to be much larger in the iron)
- I should apply this machinery to layer-by-layer residuals, see if there's a revealing pattern (multiplying number of plots by 6)

ΔRs are misaligned, too



- While the $r\phi$ residuals vs. ϕ slopes and z residuals vs. z slopes can't both be resolved by a single ΔR translation, some chambers seem to be additionally misaligned in that direction
- After the "stretch" issue is resolved, we'll know how to correct these misalignments

Summary



- $r\phi$ residuals show clear and clearly-regular trends vs. ϕ
- The simple possibility— a rigid-body translation or rotation— can't explain it on the chamber level
  - demonstrated with explicit tests
- DT stretching would be the next natural possibility
  - geometry experts investigating. . .
- Non-geometric explanations are welcome, but highly constrained
- Though the regular pattern can't conform to a universal radial correction, some radial positions will need to be corrected afterward