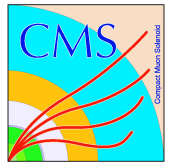

Follow-up Studies in Track-Based Muon Alignment

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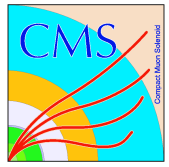
Background and motivation

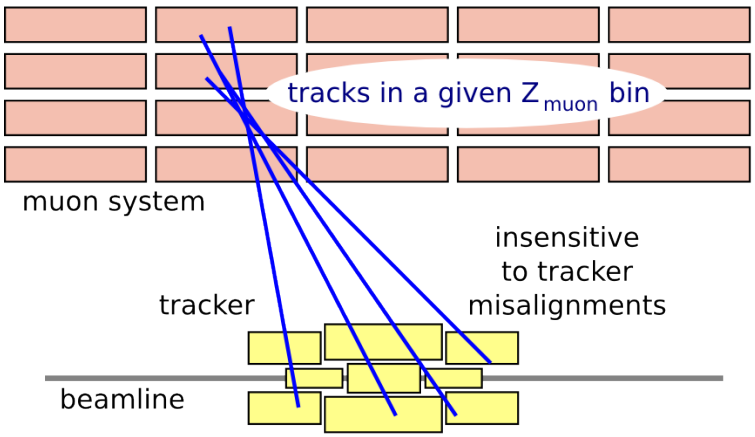


- First attempt at track-based muon alignments were presented by both algorithms (HIP and MillePede), showing rough agreement with each other, but not with expectations
- Questions raised:
  - are there really 2–3 mrad rotations in the minus muon endcap?
  - why is the z compression so much larger in track-based alignment than expected?
  - are there biases coming from the tracker's weak modes (χ^2-invariant global distortions)?
- Track-based muon alignment not used for first CRAFT re-processing
- The dataset is huge; we should be able to answer some of these questions by slicing it up appropriately
- These slides partially answer the above questions
  - by studying the tracks in more detail
  - by applying trial distortions to the tracker, to quantify sensitivity of muon alignment to these weak modes

Slicing up the dataset

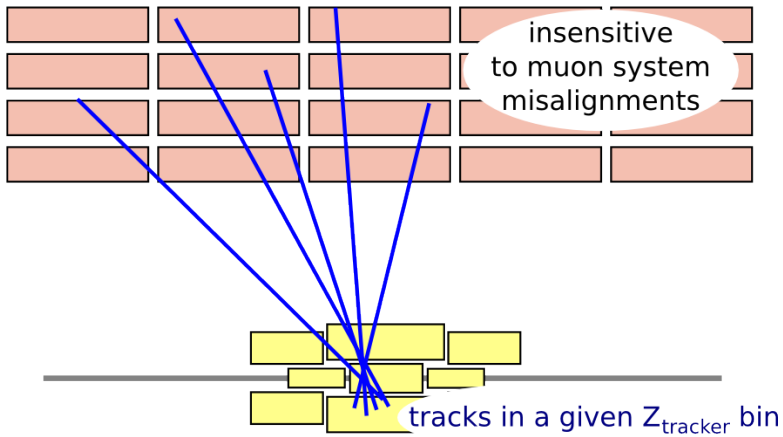
- Track-based procedure treats each wheel/disk as one bin for averages
- With 10^{4-5} globalMuons in the barrel, we can afford smaller bins
- Plot the same muon residuals as a function of (1) muon hit position and (2) Point of Closest Approach (PCA) to beamline, in the tracker
  - muon misalignments will show up as steps in Z_{muon}; tracker misalignments will make strong trends in the Z_{tracker} plot
  - steps at the interfaces is a smoking gun of real misalignment

(1) Plot muon residuals at Z of muon hit



should see muon structures in the plot

(2) Plot same muon residuals at Z of PCA to beamline in tracker

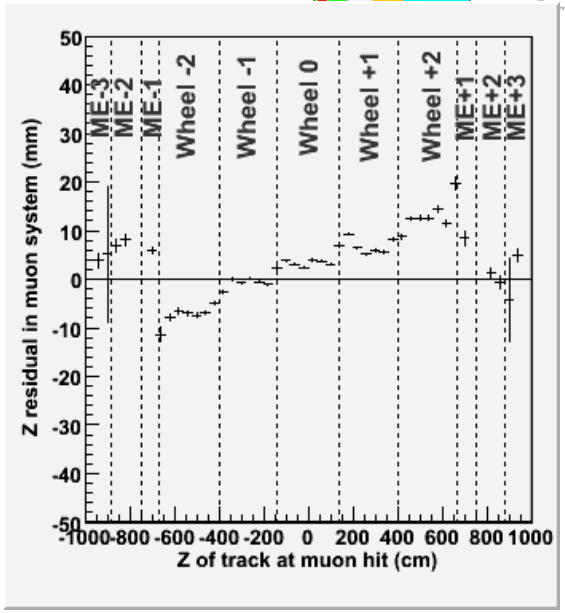


should see tracker structures

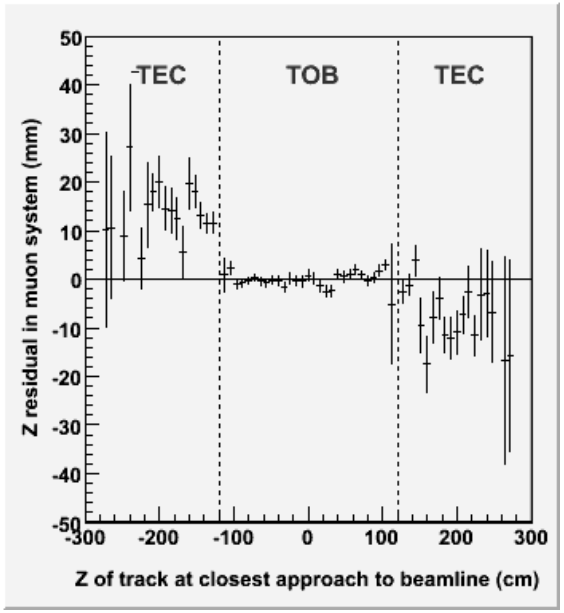
- To eliminate multiple scattering and $\vec{B}$ errors, select $|\vec{p}| > 40$ GeV
- All plots made with the latest CRAFT constants

Expansion/compression in z

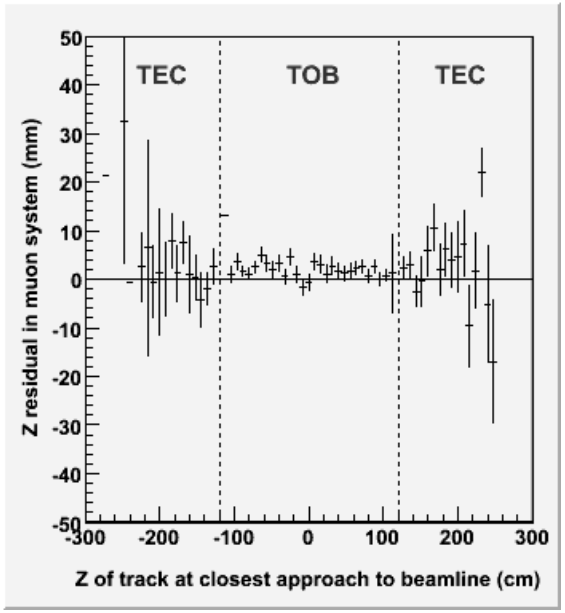
- Plot on the right: z residuals vs. Z_{muon} at $550 < R < 660$ cm from beamline (station 3)
- Bottom 3 plots: same muon resids vs. Z_{tracker}
- We see a shift of TEC relative to TOB on bottom ($y < 0$) but not top ($y > 0$), indicates z translation and ϕ_x rotation
- 10 mm seen in station 3 $\Longrightarrow$ 1 mm in TEC
- Effect is more distinct in *outer* tracker ($R_{\text{PCA}} > 60$ cm), implicating TEC, not TID



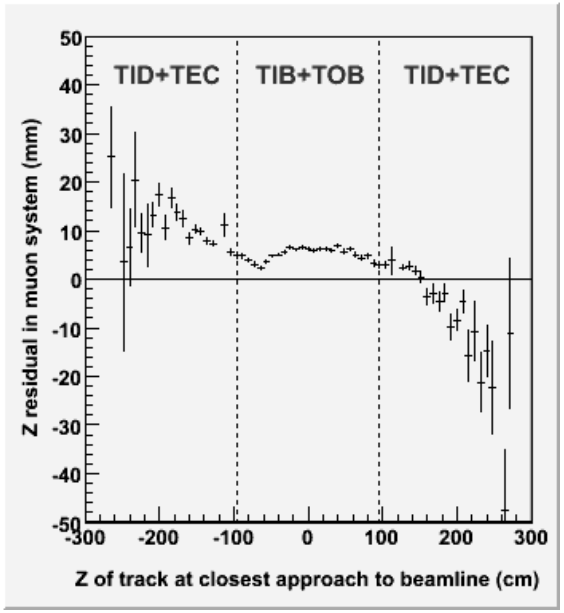
vs. z in outer tracker bottom



vs. z in outer tracker top



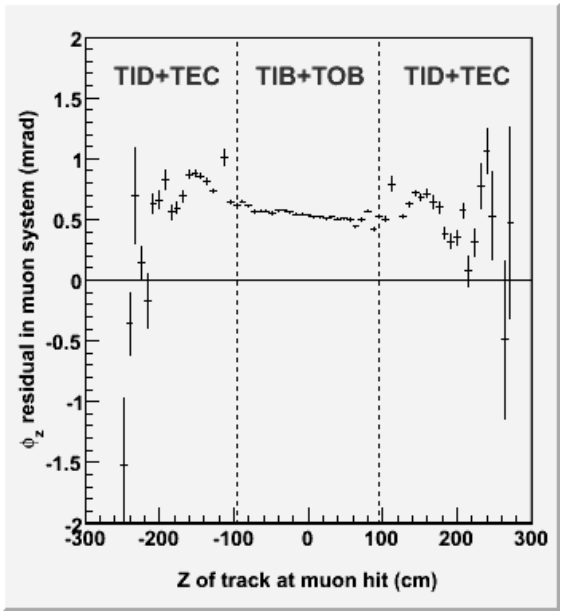
vs. z in inner tracker bottom



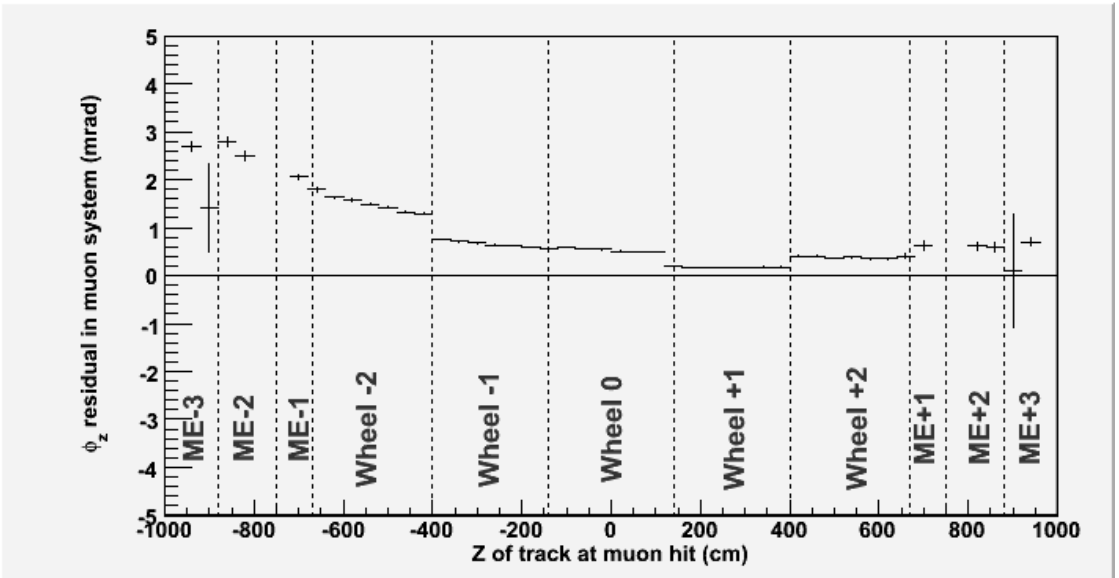
Rotation around the beamline

- Below: ϕ_z (rotation around beamline) residual vs. z in muon system; right: same in tracker
- Part of the rotation seen in the muon system is a real misalignment, indicated by the discontinuities at the wheel boundaries; slope within wheels caused by external bias
- TIB/TOB has a large rotation, 0.5 mrad, and a small twist, 0.1-0.2 mrad end-to-end; vertical tracks may be between TID/TEC layers

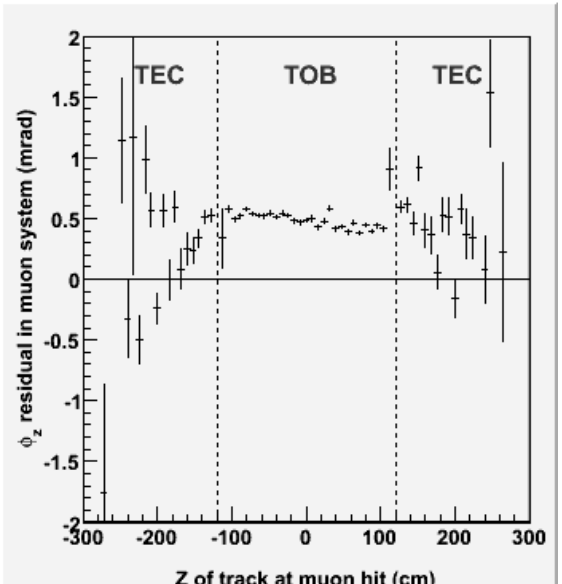
ϕ_z resid vs. inner tracker z



ϕ_z resid vs. muon z (twist)



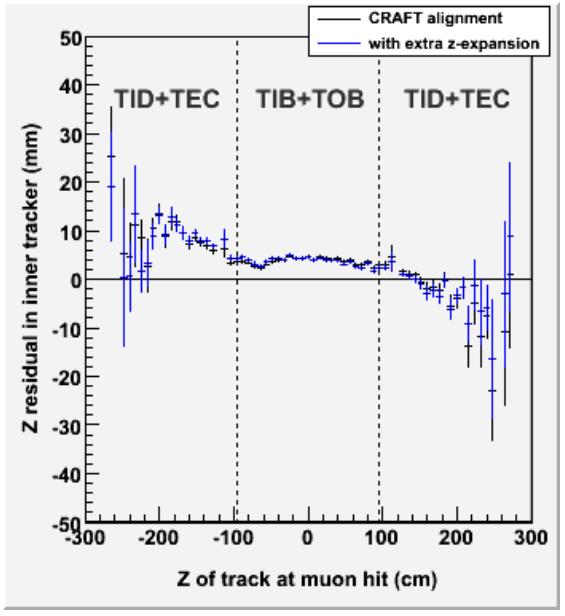
ϕ_z resid vs. outer tracker z



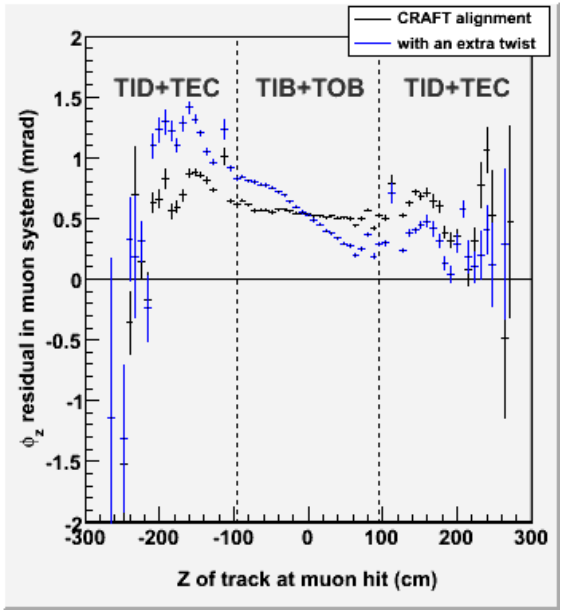
Sensitivity to tracker weak modes

- Zijin prepared distortions of the tracker CRAFT alignment with an extra z-expansion (stretch z as a linear function of z) and twist (ϕ_z rotation as a function of z)
- We reproduced the muon residuals versus Z_{tracker} plots with these tracker geometries
- Extra twist is observable (two plots below), the 0.1% z-expansion isn't (two on right)

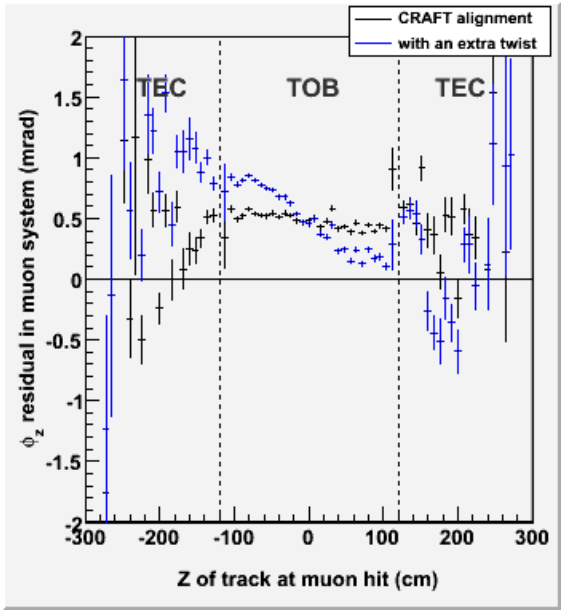
z resid vs. inner tracker z



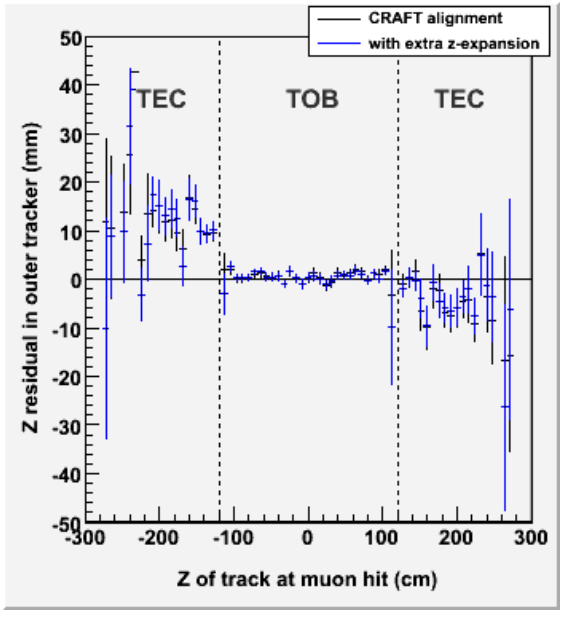
ϕ_z resid vs. inner tracker z



ϕ_z resid vs. outer tracker z



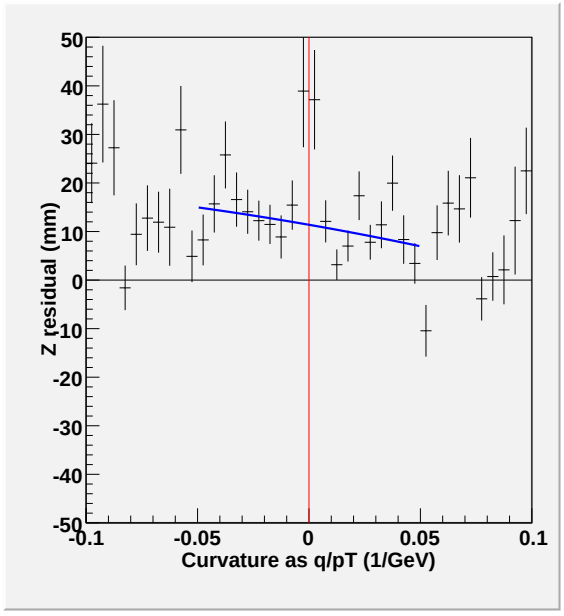
z resid vs. outer tracker z



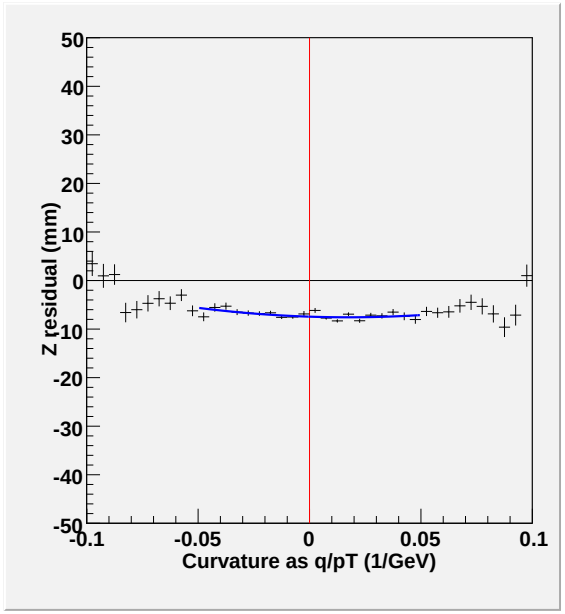
Uncovered tracking problem

- The z compression results differ from what we quoted in the past few weeks because means of z residuals had been skewed by rare large values
  - effect is independent of momentum, so "extrapolation to infinite momentum" method didn't eliminate it
  - adds positive residuals on minus side and negative residuals on plus side: exaggerates CMS contraction
  - affected both HIP and MillePede algorithms equally, which is a clue because we do the refitting using slightly different tools
- We will follow up on this

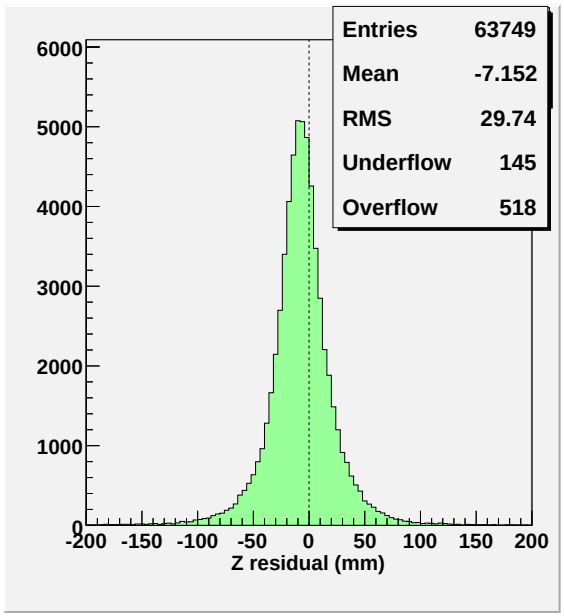
Old wheel -2 "Alignment Plot"



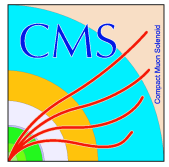
Same with $|z_{\text{resid}}| < 200$ mm



$|q/p_T| < 0.05$ GeV^{-1} bins

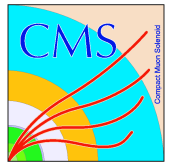


Conclusions



- Surprises in muon track-based alignment has inspired deeper diagnostic studies
- Summary of preliminary conclusions presented in these slides
  - Muon wheels ± 2 want to *expand* 19 mm relative to CRAFT constants? (not expected: maybe "ideal" doesn't represent $\vec{B} = 0$?)
  - TEC appears to be misaligned about 1 mm in z
  - Tracker is rotated 0.5 mrad relative to muon system with a 0.1-0.2 mrad end-to-end twist in the barrel; unsure about endcap
  - Minus side of muon system has at least 1.0 mrad of real rotation; the rest may be due to external biases (TEC rotation? an unidentified tracking error?)
  - We can easily see a 0.6 mrad end-to-end twist in the tracker barrel with this method, but not a 0.1% z-expansion
  - Something gives rare refitted tracks large z residuals, independent of p_T but antisymmetric with η
- Reminder: track-based alignment was not used to determine muon geometry for CRAFT re-processing; this is about improving it for next time

Unraveling misalignments



A proposal for correcting coupled tracker-muon misalignments by hand:

1. Fix the straight-forward misalignments, visible as discontinuities
   - rotate wheels to get a smooth curve in ϕ_z residual vs. Z_{muon}
   - TEC z shift/ϕ_x angle: rotate such that the top is a fixed point and the bottom swings inward or outward
     - generate tracker geometries with $+1$ and -1 mm shift
     - find the sign that improves residuals vs. Z_{tracker} and scale magnitude of final correction from response
2. See if there are still smooth trends in ϕ_z residual vs. Z_{muon} and Z_{tracker}
   - if so, interpret ϕ_z residual vs. Z_{tracker} as real and untwist it
   - see if ϕ_z residual vs. Z_{muon} is still present
3. See if wheel-by-wheel z contraction is still large and negative (expansion)
   - try putting in the largest z-expansion the tracker can tolerate, given the measured bounds (is this 0.1% close to the limit?)
4. ...