$Z' \to \mu\mu$ and Alignment/Misalignment

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- Tracker Alignment
  - basic procedures have been mature since CRAFT
  - studying weak modes through vertex constraints, invariant mass constraints, and comparison of collisions to cosmics
  - discovered 10's of μm bows/kinks in sensors; adding non-rigid alignment parameters to fit them
- Muon Alignment
  - relative tracker/muon position established with track-based method, in good agreement with survey measurements
  - track-based and hardware DT alignments are producing similar results: largest discrepancy is a 4 mm twist from one end of the barrel with respect to the other (13 m apart)

    hardware barrel geometry used in offline reprocessing
  - CSC alignment pieced together from beam-halo tracks, hardware disk-bending measurements, and tracks from the tracker to find the disks: mostly orthogonal measurements

- 50 pb^{-1} scenario:
  - tracker: randomly misaligned by throwing Gaussian deviates
  - muon: simulated cosmic-ray followed by collisions alignment using real algorithms on Monte Carlo samples
- STARTUP used in current MC productions:
  - tracker: simulated cosmic-ray alignment using real algorithms
  - muon: simulated cosmic-ray alignment using real algorithms
  - weakly constrained modes in the real alignment are weakly constrained in this Monte Carlo scenario, *but won't necessarily drift in the same direction with the same magnitude*
- Tracker weak mode scenarios:
  - nine systematic distortions of an ideal tracker for studying the effects of potential weak modes on analyses

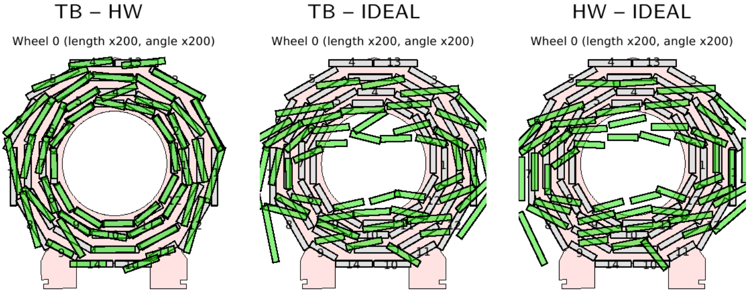
https://twiki.cern.ch/twiki/bin/view/CMS/SWGuideAlignmentConstants

- IDEAL geometry is too optimistic, but a well-defined state of the system: resolution can't get any better than this
- STARTUP is a rough guide for how bad the geometry could be
  - uncertainties in geometry are primarily systematic
  - if we could identify the shape and magnitude of the errors, we would correct them in the real-data geometry
  - okay for planning analyses: "statistical reach with misalignment is X," but not for doing analyses "we compared IDEAL and STARTUP, so our uncertainty from alignment is X" (unless X is sub-dominant)
- An analysis driven by misalignment uncertainties may need to do tests with special geometries, produced using the latest information from alignment studies (example in this talk)

- Smearing ("high multipole moments"): some misalignment uncertainties are tightly localized; in any reasonable binning of physics quantities, their effect merely broadens the distribution
  - can be modeled in a misalignment scenario because patches of η, ϕ space form a statistical ensemble
  - examples: statistical errors, bows and kinks of tracker sensors, CSC chamber position uncertainties derived from comparison with photogrammetry
- Skewing ("low multipole moments"): others are uncertainties about large-scale twists or stretching of the system (tracker and muon); this biases distributions or smears them in a way that depends on kinematics
  - similar to "cosmic variance" in cosmology: only one sky
  - examples: Z-expansion and other weak modes of the tracker, twist uncertainty of muon barrel from the single comparison between track-based and hardware alignments

- Tracker alignment procedure is purely track-based, but in the muon system we have track-based (TB) and hardware (HW)
- The two methods independently "found" the muon chambers

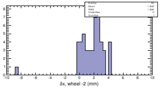
  Diagram shows differences between geometries as exaggerated displacements in a wheel end-view:



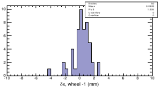
- But the remaining differences are significant: see next page

Example: muon barrel twist

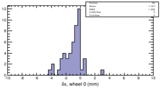
Histograms of $r\phi$ (local x) TB-minus-HW differences, separated by wheel



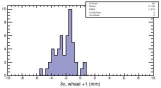
DT wheel -2
$\delta x = (1.7 \pm 2.0)$ mm



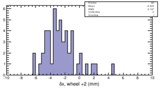
DT wheel -1
$\delta x = (0.3 \pm 1.2)$ mm



DT wheel 0
$\delta x = (-1.0 \pm 1.3)$ mm

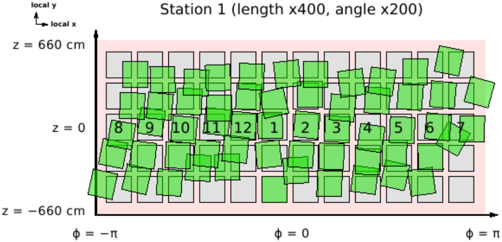


DT wheel +1
$\delta x = (-2.2 \pm 1.3)$ mm



DT wheel +2
$\delta x = (-2.5 \pm 2.1)$ mm

- 5-chamber groups from wheel -2 to wheel $+2$ seem to be coherently rotated: about 4 mm end-to-end
- barrel also compressed in z by about 4 mm end-to-end (less relevant for physics)
- $\mathcal{O}(1.3\text{ mm})$ individual-chamber variations



Example: muon barrel twist

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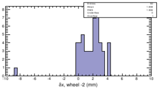

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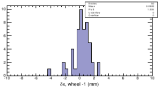

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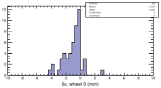

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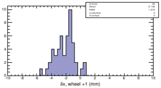

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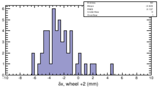

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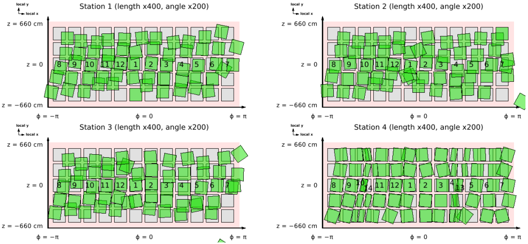
- 5-chamber groups from wheel -2 to wheel $+2$ seem to be coherently rotated: about 4 mm end-to-end
- barrel also compressed in z by about 4 mm end-to-end (less relevant for physics)
- $\mathcal{O}(1.3\text{ mm})$ individual-chamber variations
- Same trends in all four stations (if from the tracker, it would grow with radius)

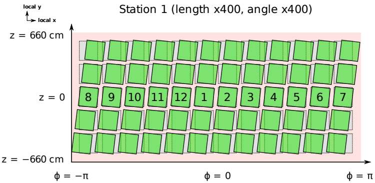


- On the next few pages, I'll show the effect of this possible systematic misalignment on Z'
- Express its effect on curvature $\kappa = q/p_T$, which is both meaningful for physics and easy to relate to alignment errors:

$$\Delta\kappa \propto \Delta(r\phi) \text{ at a specified radius}$$

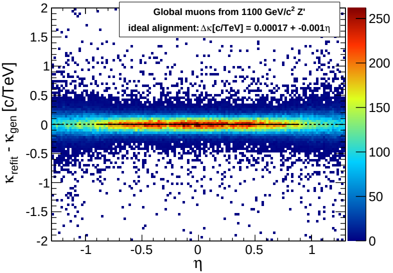
In barrel station 1 (4.2 m from beamline), $\Delta\kappa \approx 0.1 \frac{c/\text{TeV}}{\text{mm}} \Delta(r\phi)$

- Studied the effect by twisting the IDEAL barrel geometry (no misalignment in endcap)

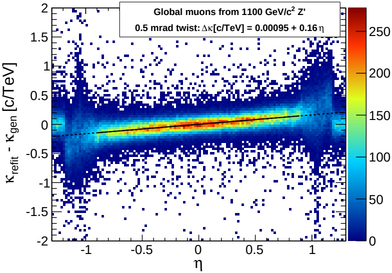


Example: muon barrel twist

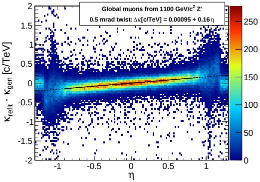
Ideal



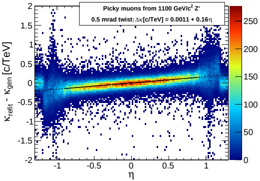
0.5 mrad twist



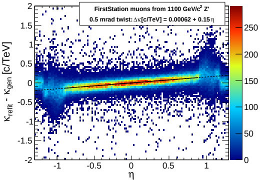
GlobalMuons



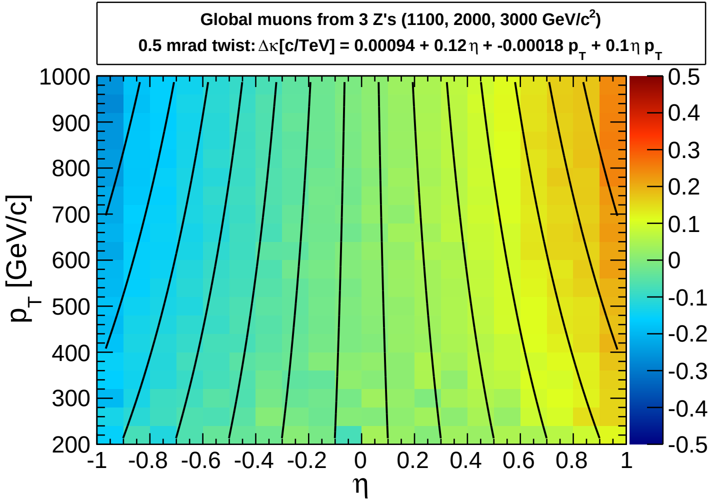
Picky



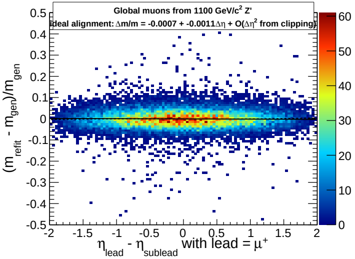
FirstStation

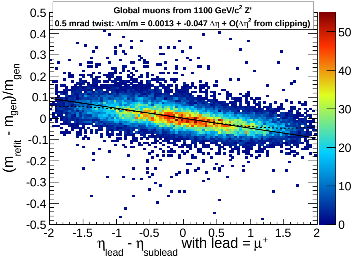


- In this plot, color scale is average $\Delta\kappa$ in c/TeV (we get to see the bias, but not the width of the distribution)
- Lines are contours of the 2-D fit result (bilinear ansatz)

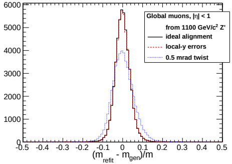


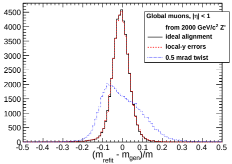
- Effect on Z' mass (quantity of interest is $(m_{\text{refit}} - m_{\text{gen}})/m_{\text{gen}}$)
- Key variables: $(\eta_{\text{lead}} - \eta_{\text{sublead}})$ and q_{lead}

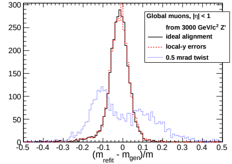




- 1-D distributions for Z' with $|\eta| < 1$, $m_{Z'} = 1.1$, 2, 3 TeV/c^2







How to proceed

- Naturally, the tracker and muon alignment groups will continue their studies to improve resolutions and reduce uncertainties about biases

Physics-level tests

- Split cosmics: compare κ of top and bottom halves of a reconstructed cosmic ray
  - CRAFT-08 with $p_T > 200$ GeV$/c$ was sensitive to 0.6 c/TeV
  - relaxing impact parameter cuts and larger cosmics samples could increase reach to 0.1 c/TeV or better...
  - twist would show up as $\Delta\kappa = (0.13\ c/\text{TeV}) \cot\theta$
- Cosmics endpoint: distribution of cosmic rays $\to 0$ as $\kappa \to 0$, so offset of the minimum of the distribution in κ indicates a bias
  - CRAFT-08 sensitive to 0.05 c/TeV
  - can it be binned in $\cot\theta$?
- Z mass constraint: most collisions tracks with $p_T > 200$ GeV$/c$ come from boosted Z; starts to be sensitive at about 1 fb^{-1} (backups)

Z' analysis specifically

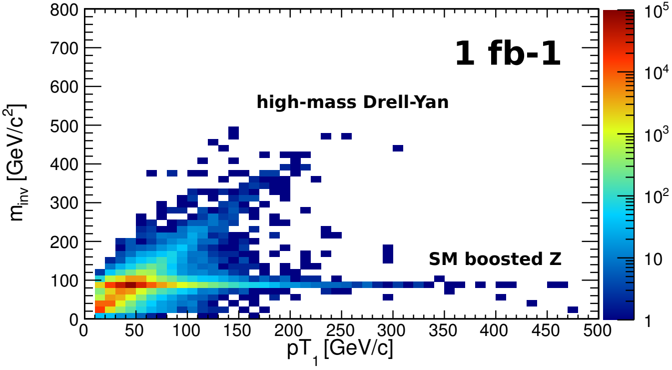
- First, a question: will a detector resolution (or bounds on detector resolutions) be assumed in the peak-search fit?
  - if yes, then we need to minimize *uncertainty* in resolution
  - in either case, resolution must be made as narrow as possible
- Suppose that we still have a several-fold ambiguity, such as TB versus HW in the barrel (two distinct possibilities)
  - we could model the difference in MC with specialized scenarios, like I showed here, to understand the consequences of choosing the wrong one

    this could be a systematic uncertainty
  - we could search for peaks with both real-data geometries, though that would reduce the statistical significance of the result in a complicated way
- Opinions?

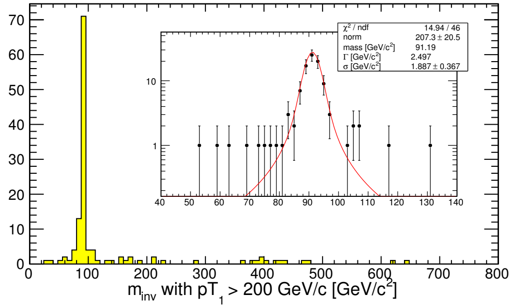
Conclusions

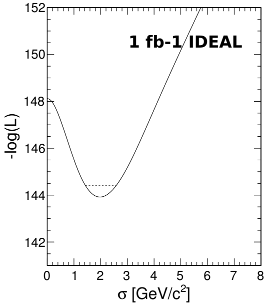
- Most important issues in alignment to be aware of:
  - while local misalignments (smearing) are under control, the possibility of global distortions (skewing) is still significant
  - MC scenarios cannot encapsulate the latter
  - independent alignments in muon barrel differ by a systematic distortion, a twist and a Z-compression
  - we can quantify the error introduced by choosing the wrong one, but that's a systematic uncertainty, not a resolution
  - to know the resolution, we need to resolve the discrepancies between TB and HW alignment methods or measure it with physics-level tests
- How this relates to the Z' analysis workflow depends on whether the peak-search fit assumes knowledge of detector resolution or not

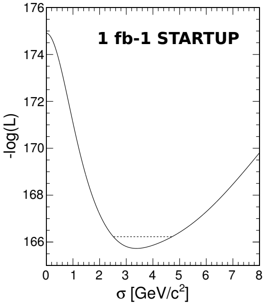
- Track momentum scale and resolutions can be determined from $Z \to \mu\mu$ (AN-2010/059), but how sensitive is this technique to the muons relevant for Z'?
- The good news: most $p_T > 200$ GeV/c muons come from Z (below: 1 fb^{-1} Zmumu_M20_CTEQ66-powheg GlobalMuons, both in plateau region of HLT_Mu9; gen-level MC@NLO looks the same)



Backup: resolutions from Z







- negligible background from Drell-Yan
- ansatz simplifies to Voigt with known mass and Lorentzian width
- only parameter: detector resolution
- IDEAL: 2.0 ± 0.6 GeV/c^2
- STARTUP: 3.4 ± 1.0 GeV/c^2

Backup: resolutions from Z

- Mass resolution (σ_m) depends primarily on resolution of muon momentum magnitudes (σ_{p_1} and σ_{p_2} for leading (1) and sub-leading (2))

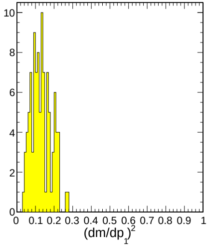
$$ {\sigma_m}^2 = {\sigma_{p_1}}^2 \left(\frac{\partial m}{\partial p_1} \right)^2 + {\sigma_{p_2}}^2 \left(\frac{\partial m}{\partial p_2} \right)^2 + \text{other parameters} $$

- Best to do deconvolution, but resolution of p_1 dominates because $\sigma_{p_1} \left| \frac{\partial m}{\partial p_1} \right| \gg \sigma_{p_2} \left| \frac{\partial m}{\partial p_2} \right|$ (because $\sigma_{p_1} \gg \sigma_{p_2}$)

- $\dfrac{\partial m}{\partial p_1}$ is 0.05–0.20 (plot on right), so

uncertainty in σ_m	uncertainty in σ_{p_1}
0.6 GeV$/c^2$	$\sim$4.6 GeV$/c$
1.0 GeV$/c^2$	$\sim$7.6 GeV$/c$

Uncertainty in σ_{p_1} is about the same as σ_{p_1}



- 1 fb^{-1} is just barely sensitive to σ_{p_1} (can be used as a sanity check)