New Muon System Alignment Procedure and the Effect of Residual Misalignments on TeV-scale muons

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Overview

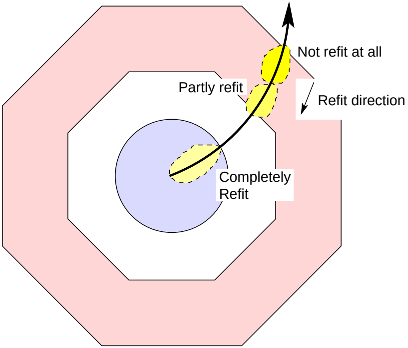
- Lessons learned from CSA07
- New alignment procedure developed as a response
- New alignment results
- Effect of misalignments on TeV muons

Lessons from CSA07

Story since our last meeting

- CSA07 exercise was just like our private tests, *except* that misalignment was applied during original track fits
- Should be irrelevant, because misalignment is reapplied (replaced) during track refits, every iteration
- But this difference unveiled a mistake in our procedure which made our old results too optimistic (next slide)
- We corrected the mistake
- Retuned the procedure
- Repeated the 10 pb^{-1} exercise
- Results from this exercise and effect on TeV muons in this talk

What was wrong in the old procedure?



- Tracks were refit from the outermost radius, inward
- The refit algorithm was told to de-weight muon hits (because their exact locations are not well known before alignment)
- Resulting track is mostly unmodified in the muon system, especially at large radius
- This yields too-optimistic alignment results because the unmodified part of the track "remembers" the alignment used in the original track fit (usually ideal, but not in CSA07)
- Solution: fit outward to extrapolate from tracker, as intended

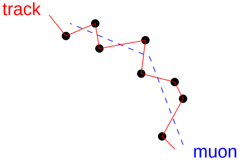
What does this affect?

- Our alignment results presented before November need to be replaced, including systematics studies
- We should re-address questions such as whether to prefer a high momentum cut or large statistics
- CPU requirements will be larger (people in charge of the CAF have been notified)
- With proper track extrapolations, we find that scattering in material is more significant than we previously thought: we'll need special techniques to minimize extrapolation

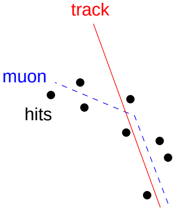
The new procedure and first results

Track propagation through material

- Real muons can change direction in the iron/solenoid/calorimeter, leading to changes in trajectory of $\mathcal{O}$(cm)
- The track-fitter knows this and compensates
- With small Alignment Parameter Errors (APEs), misalignments are absorbed into scattering; resulting track is useless for alignment
- With large APEs, residuals are huge; alignment is imprecise
- Minimizing track extrapolation helps a lot



Small APEs



Large APEs

Aligning in passes

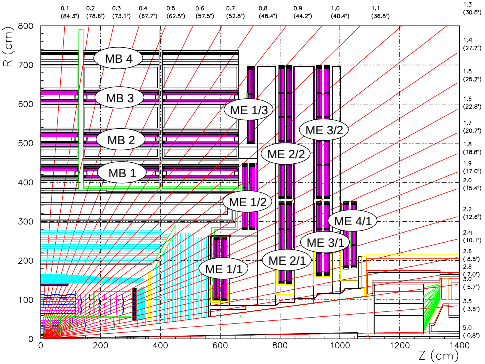
- One way to minimize extrapolation is to align stations sequentially, propagating tracks only from previous station
- For example, to align station 2
  1. Guarantee that station 1 is fully aligned
  2. Fit tracks with APE = 0 in station 1, APE = medium in station 2, and APE = large in stations 3 onward
  3. Align station 2 to residuals
- Pro: smaller extrapolation length without new code
- Con: CPU intensive (same tracks are refit many times)

Alternative

- Change track-fitter, e.g. alignment from overlaps

9-pass procedure

1. Align wheels and disks
2. Pass 1: align MB1 and ME1/1
3. Pass 2: align MB2 and ME1/2
4. Pass 3: align MB3 and ME2/1
5. Pass 4: align MB4 and ME1/3
6. Pass 5: align ME2/2 and ME3/1
7. Pass 6: align ME3/2 and ME4/1
8. "Stage 3": re-align everything with 500 μm APEs
9. "Stage 4": re-align everything but MB1, ME1/1, and ME1/2



- Stations aligned simultaneously don't share any tracks
- APEs independently optimized for each stage
- Stage 3 makes sure we don't end with relative alignments only
- Stage 4 makes sure we still have relative alignments

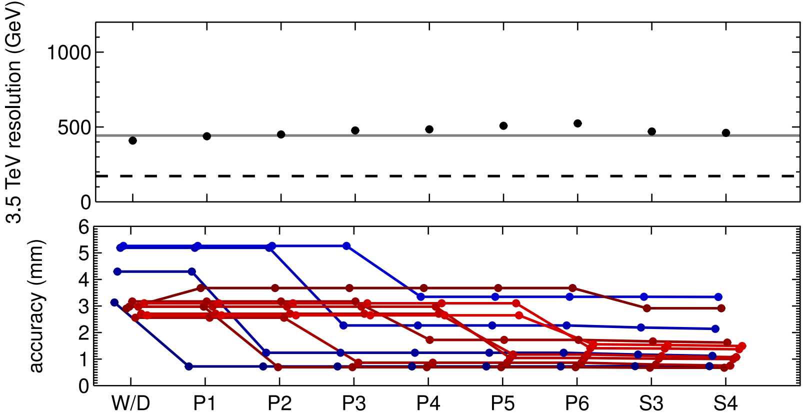
First results: test for alignment quality

- Using 66,000 muons from 10 pb^{-1} of W decays (adding the 5,400 muons from Z can only help)
- Starting with complete misalignment: ± 5 mm, ± 5 mrad at all levels (chamber and wheel/disk)
- Includes known layer misalignments in CSCs (which we won't improve with this procedure)
- Two cases:
  - Ideal tracker
  - 10 pb^{-1} misaligned tracker
- Two methods to judge quality:
  - Dimuon resolution for 3.5 TeV Z' (where muon alignment matters most)
  - Stdev of local x (global $r\phi$) residual misalignment, for each station

Ideal tracker case

Dashed line: perfect muon system alignment (best-case goal)

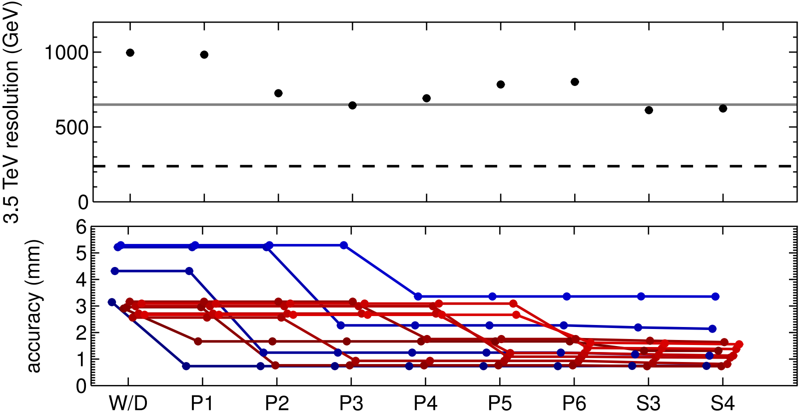
Grey line: official 10 pb^{-1} scenario (not a mean)



Reds: endcap stations, Blues: barrel stations

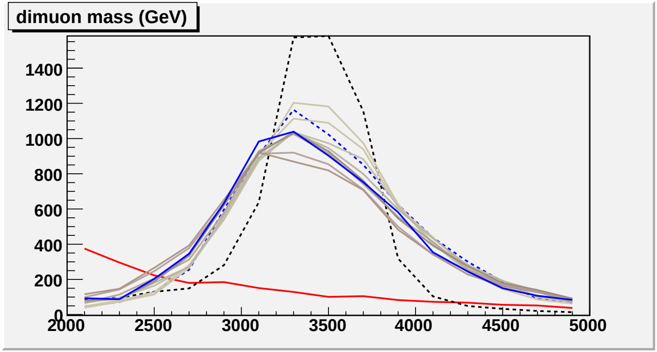
Misaligned tracker case

Dashed line: perfect muon system alignment (best-case goal)
Grey line: official 10 pb^{-1} scenario (not a mean)



Reds: endcap stations, Blues: barrel stations

Shown as a raw dimuon spectrum (ideal tracker case)



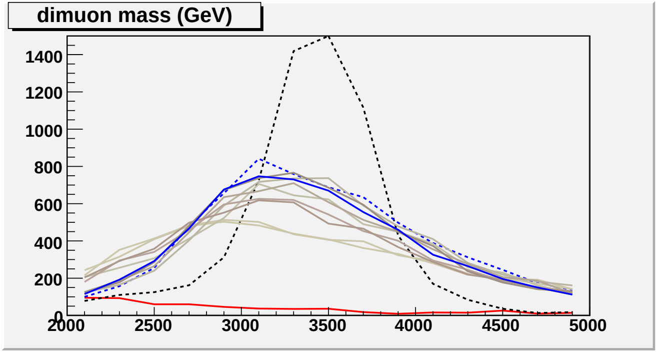
Red: before alignment (peaks at 1 TeV)

Darkening shades of gray: alignment passes, ending in blue

Dashed blue: official 10 pb^{-1} scenario

Dashed black: perfect muon system alignment

Shown as a raw dimuon spectrum (misaligned tracker case)



Red: before alignment (peaks at 1 TeV)

Darkening shades of gray: alignment passes, ending in blue

Dashed blue: official 10 pb^{-1} scenario

Dashed black: perfect muon system alignment

General studies of TeV muon resolution

State of the "official" muon misalignment scenarios

- 10 and 100 pb^{-1} muon misalignment scenarios in the database were generated under different assumptions

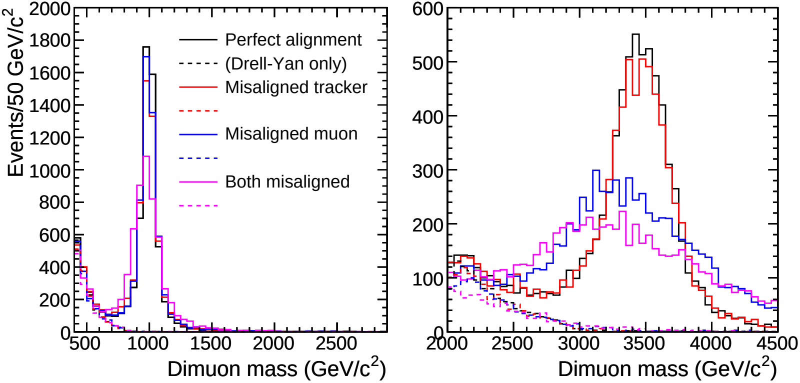
10 pb^{-1} (short-term)	100 pb^{-1} (long-term)
0.5 mm chamber misalignments	0.2 mm chamber misalignments
2 mm wheel/disk misalignments	1 mm sector misalignments
	1 mm whole muon system misalignment

- Misalignment of largest structures dominate TeV muon resolution
- 100 pb^{-1} scenario depends strongly on random number seed
- 10 and 100 pb^{-1} scenarios in the database have nearly equal TeV muon resolutions (100 pb^{-1} is slightly worse; it fluctuated up)

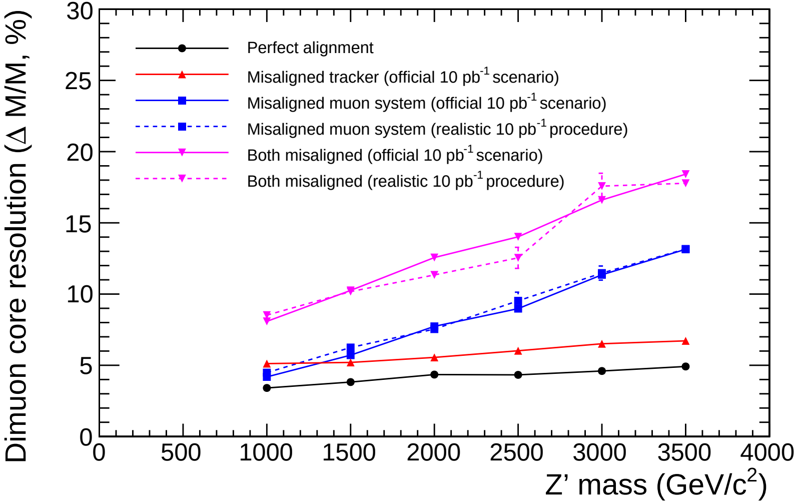
Misalignment scenario from new alignment procedure

- More realistic because
  - errors derived directly from measurements (including $\sigma_x \neq \sigma_y$)
  - correlations along line of sight of tracks are implicitly included
  - as well as all other detector effects modeled by the Monte Carlo
- Still conservative because
  - procedure has not been fully optimized yet, nor does it include input from hardware alignment system
  - adding muons from Z will help, low-p_T muons may help
  - assumes CSC layer misalignment is not improved
- Currently, only the 10 pb^{-1} results are available: included as a place-holder in the following plots
- Will be replaced by 100 pb^{-1} results in 2 weeks

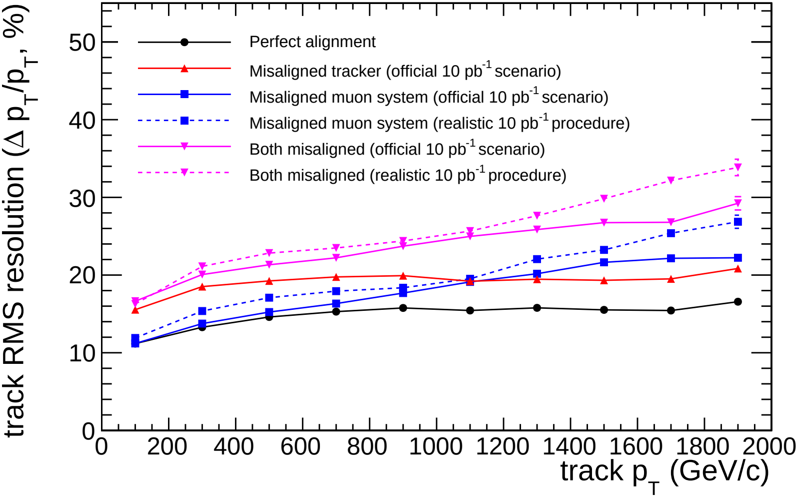
Effect on resonance peak (Z'_{SSM} from 1 to 3.5 TeV)



- "Misaligned muon" is from the realistic alignment procedure, but results are similar to official scenarios
- Drell-Yan background doesn't spread up, but peak shifts down



- "Core resolution" from a fit to each $\frac{\Delta M}{M}$ peak (ignores tails)



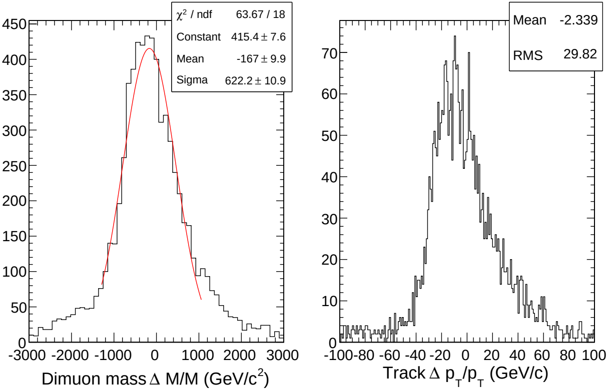
- RMS of $\dfrac{\Delta p_T}{p_T}$ = RMS of $\dfrac{\Delta(1/p_T)}{(1/p_T)}$ (affected by tails)

Summary

- CSA07 unveiled a mistake that allowed "MC-truth" to leak into our pre-November alignment results
- Correcting that mistake, we observe that muon scattering is an even more serious issue
- We developed a procedure that addresses it, and are propagating the new results
- Results from new procedure match the official scenario; we are working to improve them further
- Quantified effects of tracker and new muon system misalignment on TeV muons

Backup: sample points in the resolution plots

- Worst-case: 3.5 TeV, both tracker and muon misaligned (the rest are much more Gaussian)



- Dimuon mass "core resolution" is a fit to $\pm 1.5\sigma$
- Track p_T resolution is the RMS truncated at $\pm$100 GeV