Track-based Alignment of the Muon System

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Introduction and Overview

- Development of infrastructure: ready for CSA07
- Survey measurements (used as constraints for track-based alignment)
- MC: developing the procedure
- Alignment results in MC
- MTCC: early attempts on real data

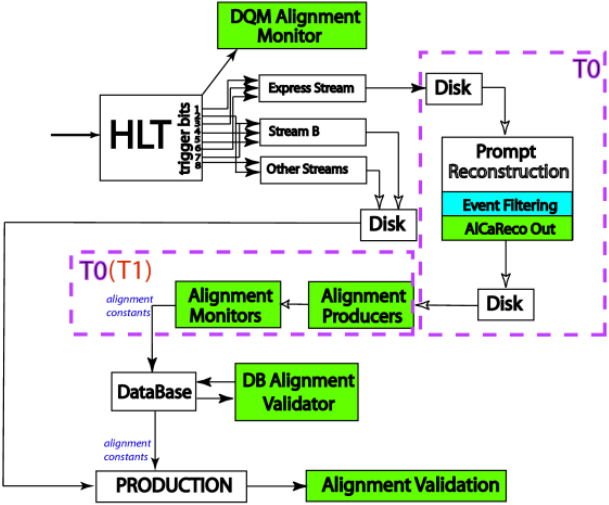
Notes for the previous page (page 2)

- You have downloaded the *annotated* version of this talk. I didn't show these notes (grey pages) visually when I presented the talk, though I should have made the following points orally.

  If you are following the presentation as I am making it, please download the other version (should say "download-this-one") which is the same, minus the grey pages.

- This will be a general overview, but with a focus on A&M work
- The majority of this talk will be about developing and testing the procedure with MC

Infrastructure



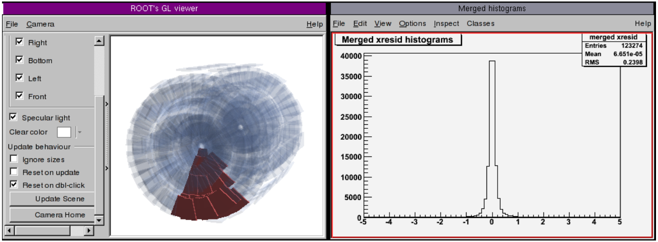
- Defined data path and triggers
- Defined data format for muon alignment stream
- Developed monitoring tools
- Ready for CSA07

Notes for the previous page (page 3)

- We plan to get muons from all available triggers (single-, di-muon. . .)
- Express stream is 25% of all data (in early running), very inclusive
- We have completed the pipeline from express stream, through prompt reconstruction, AlCaReco, Alignment Producers, Alignment Monitors, to database (SQLite file, at least).
- DQM Monitor, DB Validator and the last stage of Alignment Validation (external legs on this graph) still need work

Alignment Monitor Tool

1. CommonAlignmentMonitor: general plotting package integrated into AlignmentProducer
   - Manages iteration, collection after parallel processing
2. AlignmentMonitorMuonHIP outputs histograms for every chamber (or every layer): residuals versus everything
3. pyROOT script merges histograms on the fly



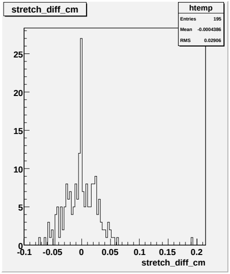
- Offline Alignment Validation, the last step in monitoring, sees changes in p_T, Z' resolution (Javier Fernandez)

Notes for the previous page (page 4)

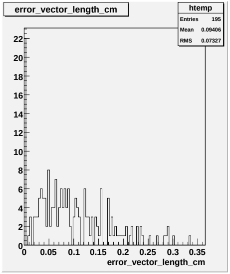
- Command for the featured plot: "r.select(lambda c, h: not c.barrel and h.GetEntries() $>$ 0)"
- Can pass arbitrary Python functions to select by chamber information (c) or histogram features (h)
- Almost as much versatility as an ntuple, this tool will allow us to "zoom in" on alignment problems, to understand specific outliers and allow human decision-making in early data
- ROOT file sizes are $\sim$10 MB per iteration
- A link to information about Javier's analyzer: http://indico.cern.ch/conferenceDisplay.py?confId=13742
- Due to the way we do track refitting, the integrated monitor is sensitive to updated residuals but not updated track parameters. Thus, we can use AlignmentMonitorMuonHIP to see narrowing residuals/χ^2, and then re-reconstruct from scratch with Javier's analyzer to see the change in p_T distributions, the Z' peak, Drell-Yan seepage, etc.

Survey measurements

- This is the initial geometry used in track-based alignment
- Can also be used as a constraint on track-based alignment
- Positions of optical targets are measured by photogrammetry and later transformed into chamber positions/orientations
- CSC measurement is good; transformation contains an error



Measurement resolution: $\sim$300 μm



Consistency check: $\sim$1 mm

Notes for the previous page (page 5)

- Survey constraint implemented for tracker alignment, not yet tested for muon alignment, but we use the same infrastructure
- Pablo Martinez Ruiz del Arbol has transformed DT survey measurements into chamber orientations, but has not yet uploaded to the database
- Dmitry Yakorev has transformed CSC survey measurements into chamber orientations and performed the consistency check that revealed the error. He's dividing-and-conquering the problem now...

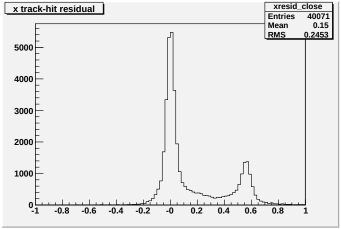
Testing the alignment system in MC

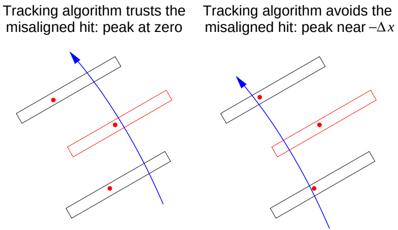
MC: developing the procedure

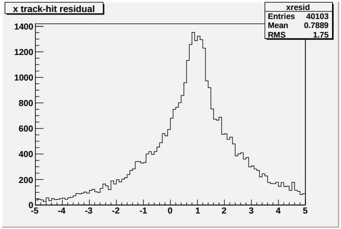
- More realistic than this spring's test-run (presented at UCLA)
  - Large datasets: 10 pb^{-1} and 100 pb^{-1} of muons from W and Z (simulated by Z only)
  - More ambitious precision goals (200 μm, rather than 1 cm)
  - Random misalignments with SurveyOnlyScenario (rather than moving all chambers in the same direction)
  - First attempt at muon system self-measurement
- Two major approaches, developed simultaneously
  - Align the muon system to the tracker (globalMuons)
    - converges more quickly
  - Align the muon system to itself (standAloneMuons)
    - independent of the tracker

Aligning to the tracker

- Residuals from globalMuons have two peaks per chamber, due to track-fitting bias







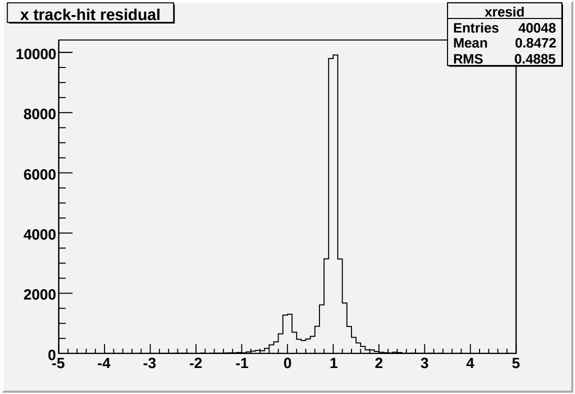
- Simply extrapolating a tracker track into the muon system removes the bias, but at a severe resolution cost (note wider scale)
- Neither is optimal

Notes for the previous page (page 8)

- The tracker-to-muon extrapolation is what I presented in my last EMU talk at UCLA
- Alignment resolution was $\sim$4 mm

The "lowbias" method

- Re-fit globalMuon tracks with inflated hit uncertainties in the muon system
- Resulting tracks are determined mostly by the silicon tracker, but they "know" about scattering in the muon system

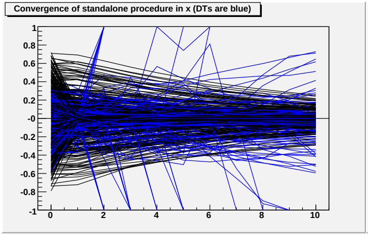


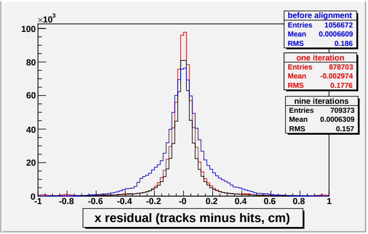
Notes for the previous page (page 9)

- The tall peak at 1 cm is the misalignment, small peak at 0 is due to bias
- Usually converges in one iteration

The "standalone" method

- standAloneMuons have the two-peak structure in residuals, and therefore need to iterate to decouple track-fitting from chamber alignment
- With a $|\text{residuals}| < 5$ cm cut, this method shows clear convergence for most chambers:



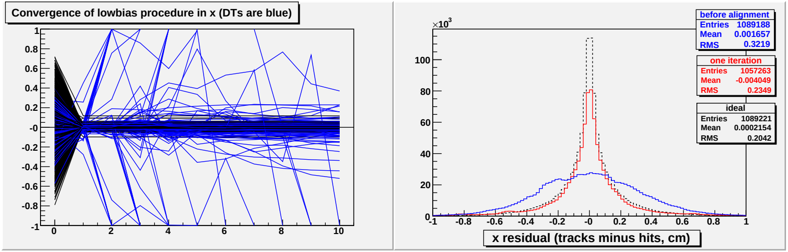


- We are keenly interested in saving the tails. . .

Notes for the previous page (page 10)

- We need to study the outliers! Figure out what's happening to the tails! Find a way to diagnose it in data, also (shape of residual distribution?)
- Muon alignment is especially important for keeping Drell-Yan backgrounds from smearing into high dimuon-mass channels for New Physics. We therefore care very much about the higher moments of the p_T distribution, which is to say, alignment outliers.

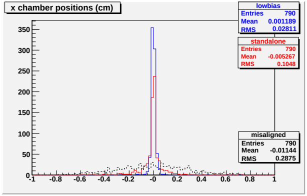
The same plots for "lowbias"



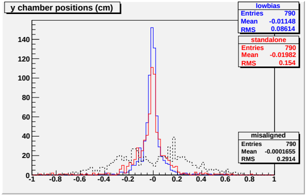
- Converges in one iteration
- Beyond that most chambers are stable, but a few DTs wander
- There's also a cumulative problem with hit efficiency

Alignment Results (10 pb^{-1})

- Starting from MuonSurveyOnlyScenario: positions misaligned 2.5 mm, ϕ_z misaligned 0.25 mrad
- Five degrees of freedom in alignment: x, y, ϕ_x, ϕ_y, ϕ_z
- Accuracy: one iteration lowbias, ten iterations standalone



$x_{\text{aligned}} - x_{\text{true}}$ (cm)



$y_{\text{aligned}} - y_{\text{true}}$ (cm)

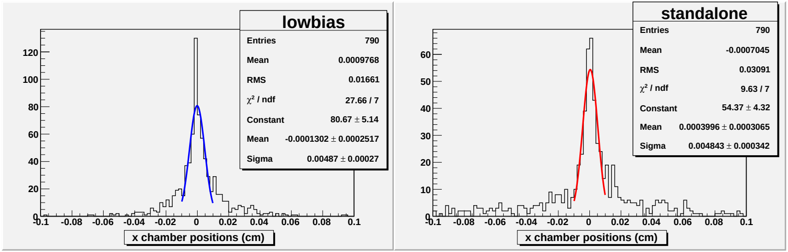
- Precision: alignment uncertainties are still underestimated by a factor of 3–4

Figures of merit

1. σ of core Gaussian (best-measured chambers)
2. RMS, cut at 1 cm
3. $|\max|$ (worst outlier)

790 chambers	core σ	RMS	$\lvert\max\rvert$
lowbias x	50	280	4500
lowbias y	270	860	6000
standalone x	50	1040	∞
standalone y	290	1540	34000

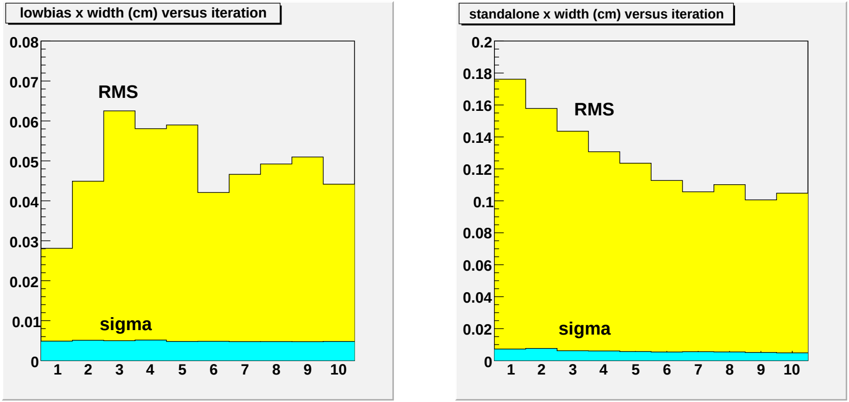
microns



Notes for the previous page (page 13)

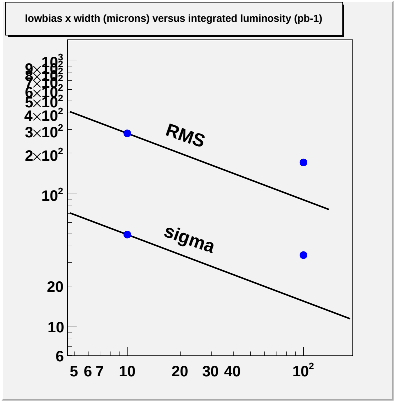
- Fits are purely Gaussian on a restricted range: ± 100 μm for x and ± 500 μm for y.
- The RMS that I quote is cut at 1 cm (as stated on the previous page). The RMS that ROOT reports in its statistics boxes is cut to the current window width, and I zoom into some of the plots for detail. Therefore, ROOT sometimes a different RMS in its statistics box than I quote in the table and in plots on the next few pages. I was careful to always use a 1 cm cut in all the numbers I report!
- $|$max$|$ is extremely twitchy, as you may imagine. These $|$max$|$ numbers are dominated by the few chambers that diverge, so the numerical value doesn't have a precise meaning, it's only a guide to say that I still have divergent chambers. It will become more useful when I fix that DT problem.
- For the sake of the table, I selected the largest "reasonable" value. A few values were 5098450298475e+4598; I skipped those. In the case labelled with an ∞, there wasn't a clear break between reasonable and unreasonable.

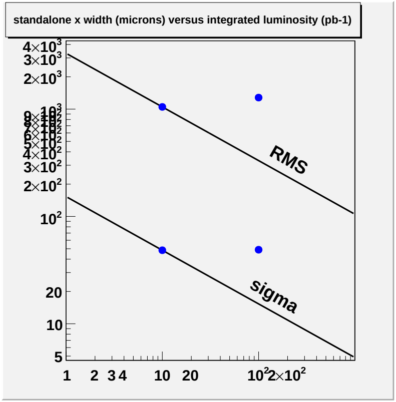
Figures of merit versus iteration



- Core σ largely unchanged after first iteration
- standalone method requires 7 iterations

Figures of merit versus integrated luminosity

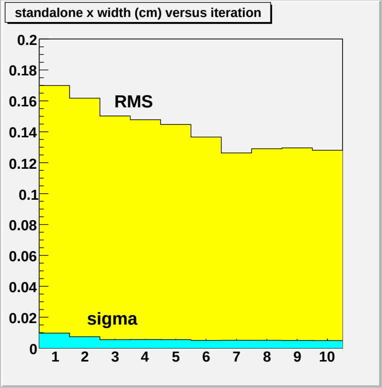




- lowbias reaches sensitivity limit between 10 and 100 pb^{-1}
- standalone technique reaches limit below 10 pb^{-1}

Notes for the previous page (page 15)

- That second plot looks very strange because the high-luminosity point actually has less resolution than the low luminosity point. If you look at the corresponding resolution vs. iteration, you'll see that this difference is in the noise. If I assigned errorbars, the points would be consistent.



Planned systematics studies

- Dependence of lowbias on tracker alignment — in progress
- Dependence on fitting constraints — in progress
- Dependence on survey constraints
  - obtain survey geometries and apply constraints
- Dependence on tracking algorithm
  - Uncertainty in distribution of material
  - Uncertainty in $\vec{B}(\vec{x})$
- Background studies in CSA07
  - Multiple scattering in low-p_T muons
    - Alignment with $J/\psi \to \mu\mu$
  - Effect of fake muons in the alignment stream
    - Obtain realistic background samples from CSA07
    - Finalize track quality cuts

Notes for the previous page (page 16)

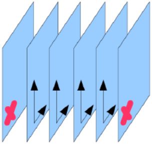
- We already have a small J/ψ sample that we can work with. Due to inefficiencies of low-p_T muons, it probably won't be possible to do an alignment with these J/ψs, but we can at least compare the widths of the residual distributions, and scale from that.

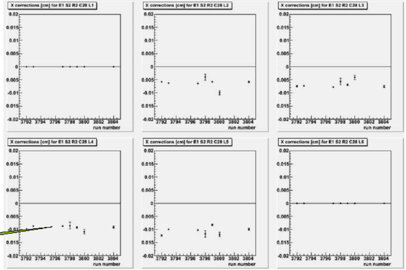
Testing the alignment system in MTCC

Karoly Banicz's (re-)discovery of layer offsets

- Agrees with FAST site measurements
- We want to reproduce this study in AlignmentProducer

- Pick good segments, fix end-points and look at residuals in intermediate layers:





- Example:
  - ME2/28:

~ 100 microns

120 aligned layer positions	mean	stdev	|max|
x	-55 μm	190 μm	670 μm
y	110 μm	330 μm	1.2 mm
ϕ_z	0.01 mrad	0.04 mrad	0.15 mrad

Preliminary MTCC alignment with AlignmentProducer

- Alignment attempts were beset by random crashes
- A single standalone iteration survived; not enough for a reliable alignment, but enough for order-of-magnitude

102 semi-aligned layer positions	mean	stdev	$\lvert$max$\rvert$
x	8 μm	192 μm	440 μm

- in rough agreement with Karoly's results

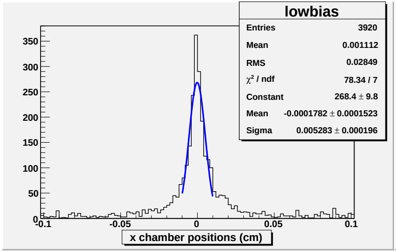
- We'll need more data and more robust computation
- Likely to get both with MTCC 1_5_0 re-reconstruction

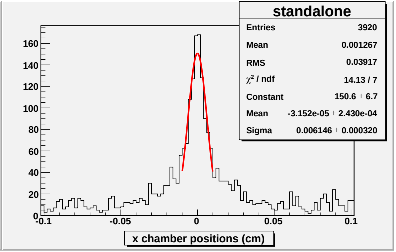
How well can we do layer-by-layer alignments anyway?

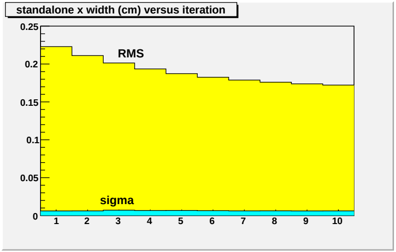
Back to MC...

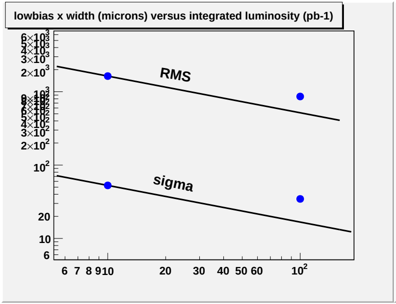
3920 layers	core σ	RMS	$\|max\|$
lowbias x	50	1630	6600
lowbias y	360	1830	13000
standalone x	60	1720	6600
standalone y	380	1970	6400

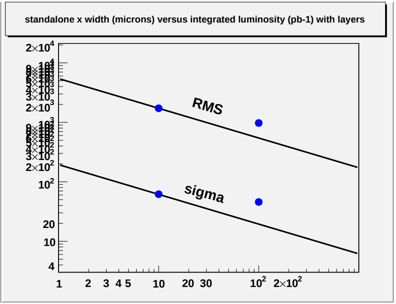
microns






standalone x width (cm) versus iteration
RMS
sigma


lowbias x width (microns) versus integrated luminosity (pb-1)
RMS
sigma


standalone x width (microns) versus integrated luminosity (pb-1) with layers
RMS
sigma

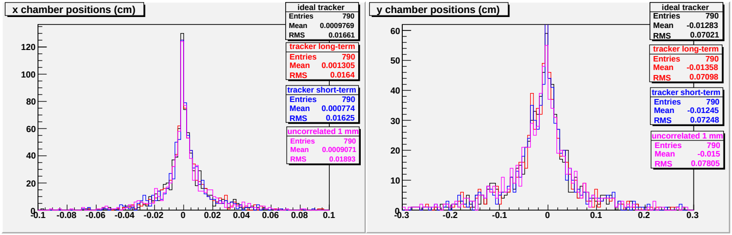
Summary

- Overall scheme and infrastructure components are now mature
- Entering the era of precision alignment studies
- Procedure is ready for CSA07, some updates need to be checked into CVS
- We have taken a first glance at MTCC data and are ready to apply our software to 1_5_0 re-reconstructed data
- Concrete list of systematics studies planned for CSA07
- The software is available for cosmic ray/beam halo studies...
- We're starting to write a CMS Note

Backup Slides

Dependence of lowbias on tracker alignment

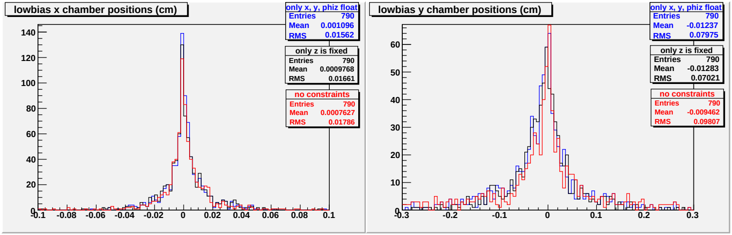
- The lowbias technique aligns the muon system using tracks which were fitted to the silicon tracker
- How does muon alignment depend on the tracker's alignment?



- Differences between alignment scenarios appears to be weak

Dependence on fitting constraints

- Reducing the number of degrees of freedom should improve convergence



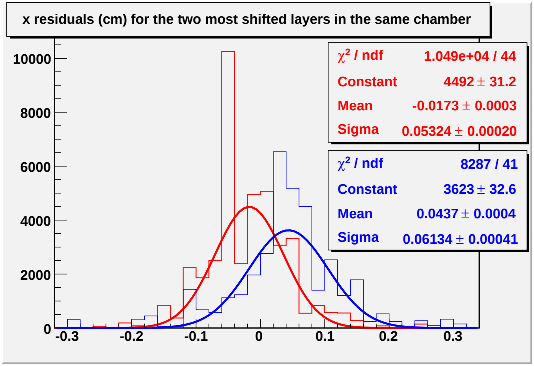
- Again, dependence is weak

Notes for the previous page (page 25)

- Both of the last two studies, the dependence on tracker alignment and on fitting constraints, seem pretty conclusive, but I'm not sure how to interpret the statistics.
- At face value, it looks like there are no statistically significant differences between anything, though the histograms are not exactly the same (which would be evidence of a mistake).
- But they all began with the same misalignment (at least they were supposed to!) and aligned on the same data, so they're not statistically independent.
- There are several follow-up studies I can do: (a) make sure that the initial misalignments are the same, (b) follow each chamber individually in the various cases.

Are the MTCC layer offsets real?

- Or are we under-reporting our uncertainties?
- Can we find a pair of divergent layers in the same chamber?



- red is layer 3, blue is layer 6 in chamber 27 in ME+3/2

Notes for the previous page (page 26)

- This is not completely convincing because I haven't controlled for the possibility that the whole chamber hasn't rotated, in, say, ϕ_y. This can lead to the x projection showing a discrepancy between layers. There could be rock-solid evidence of $\sim$200 μm misalignment here (other than, of course, Karoly's alignment calculation and its agreement with FAST measurements), but it will take more work to rule out other hypotheses.