Track-based Muon Alignment Status/Projections

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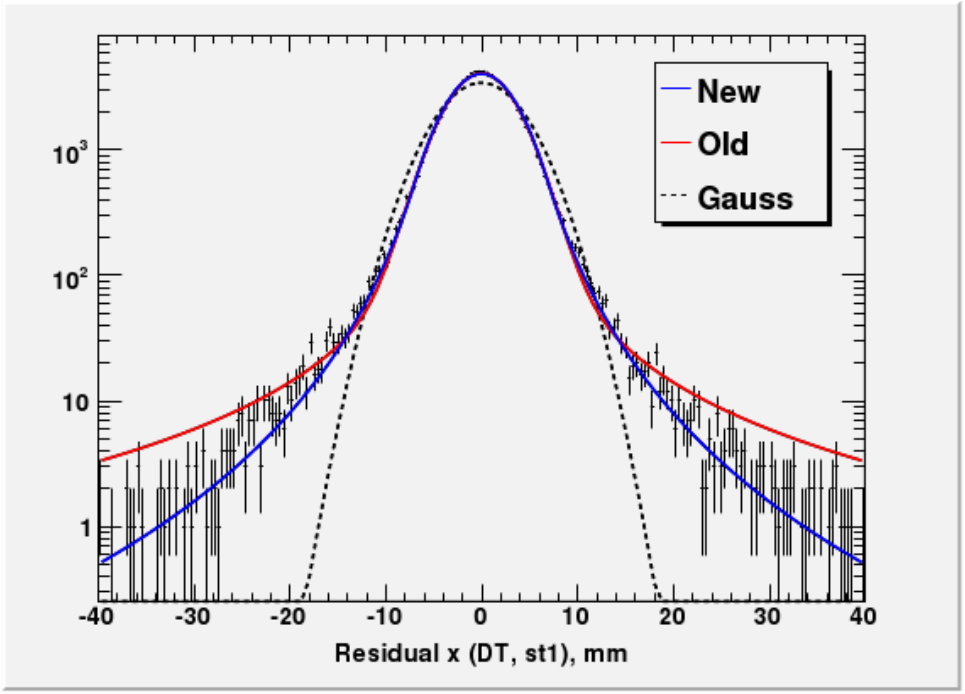
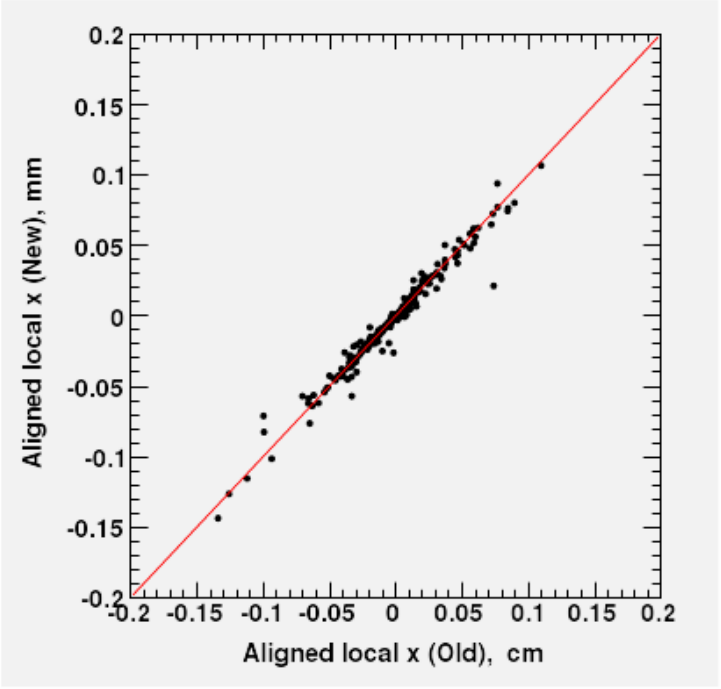
Outline

- Developments in the Reference-Target algorithm for low-luminosity
- Up-to-date projections of alignment resolution with $\mathcal{L}$
  - see also "Evolution of Muon Alignment with 2010 Data"
- Bias in the input tracks: must be resolved before low-momentum (collisions) alignment is possible
- High-momentum alignment with 2010 cosmic rays

Alignment with low luminosity

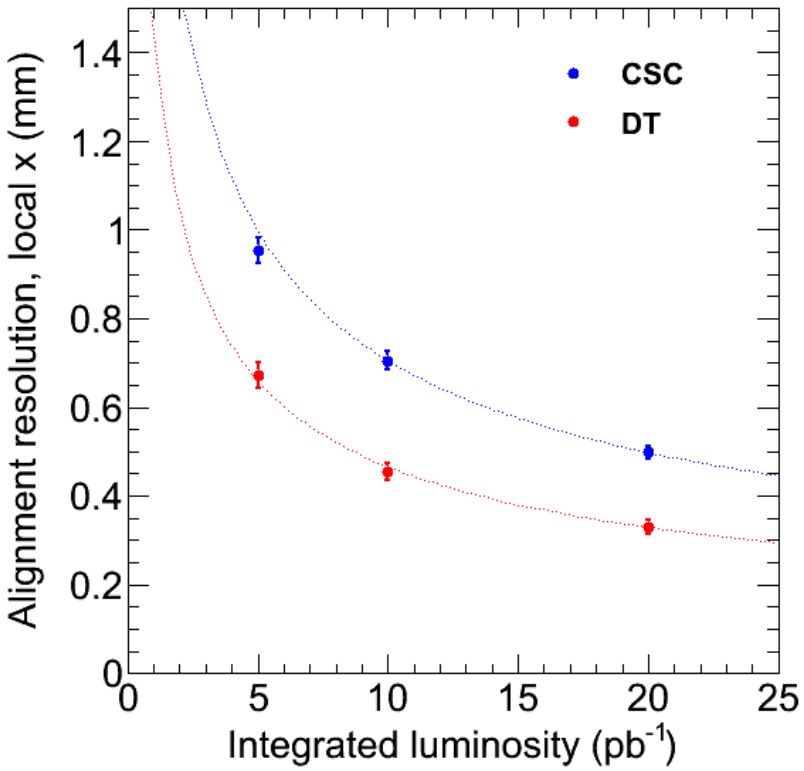
- In CRAFT-09, 61/250 DT alignment fits failed (MINUIT did not converge) for reasons related to low statistics
- For low luminosity running, we want the fits to succeed with appropriate error bars, so that we can make alignment decisions based on rigorous uncertainties
- Solution: simplified residuals fit function is more robust
  - no fit failures (with as few as 5 hits) with same accuracy
  - better description of residuals shape, too ($1/\Delta x^4$ tails)

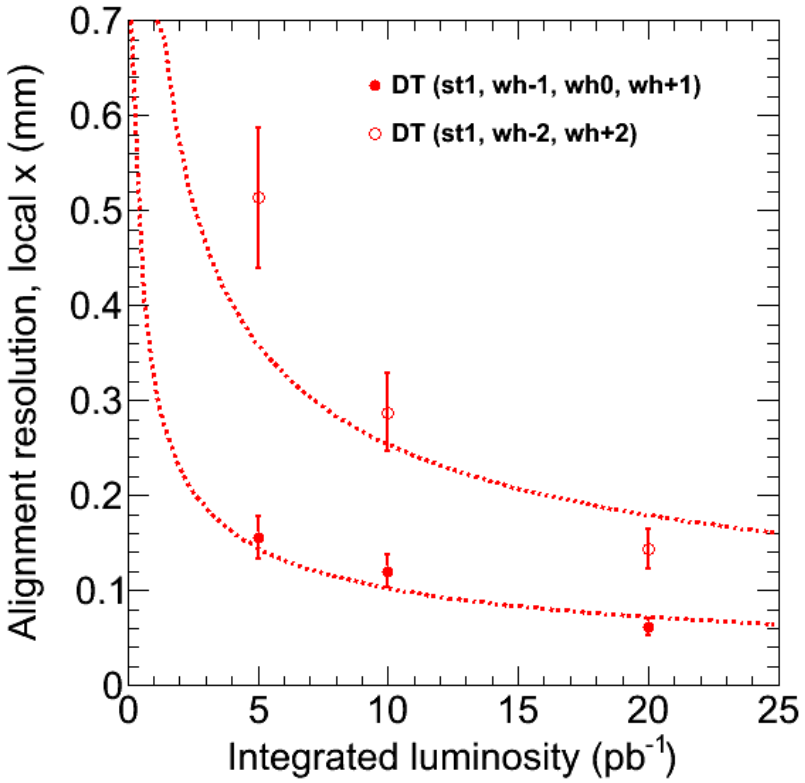




Updated resolution vs. $\mathcal{L}$

- Results of MC alignment challenge with $\mathcal{L} = 5$–20 pb^{-1}: vertical axis is RMS of aligned positions relative to true positions
- Left: all chambers, dominated by stations with the broadest distribution (station 4); curves are $1/\sqrt{\mathcal{L}}$
- Right: resolution of station 1 only (most important for track fit)

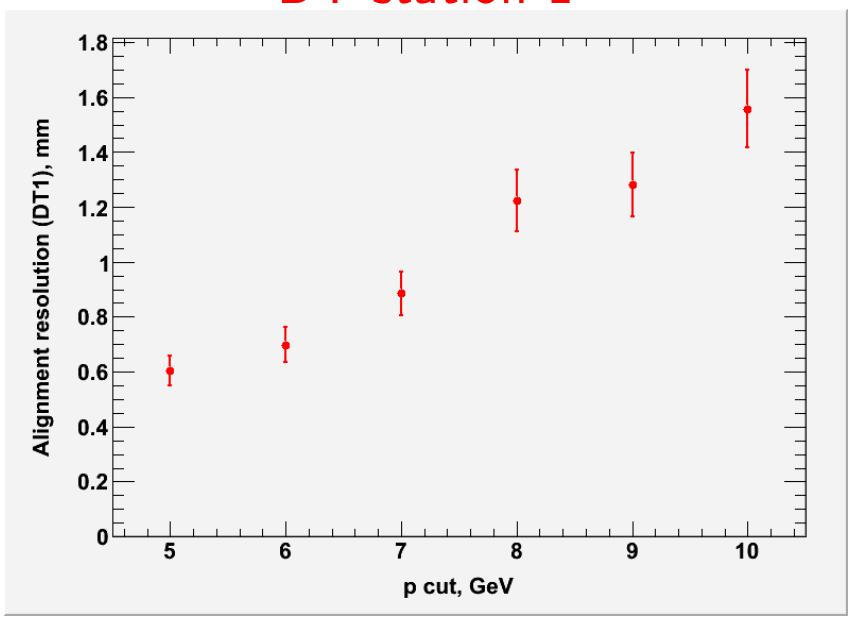




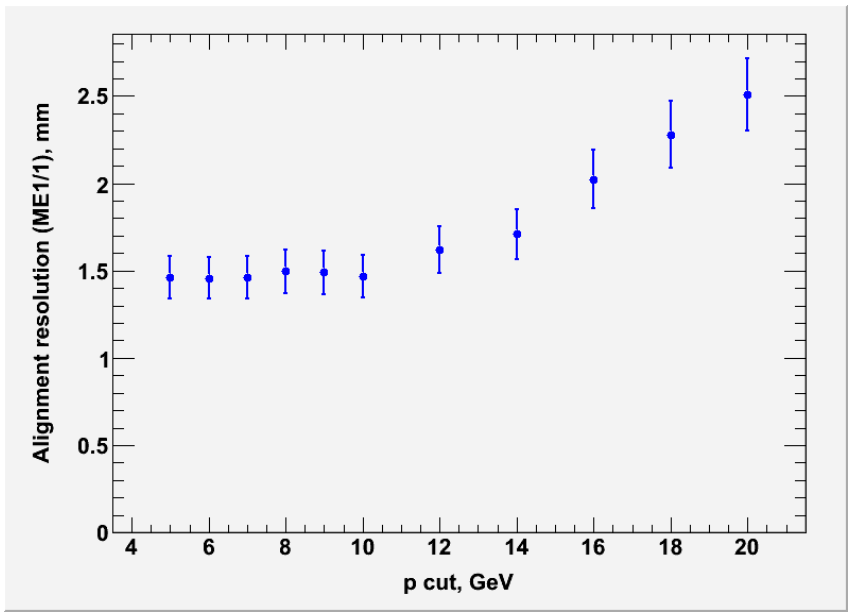
Dependence on momentum cut

- Results on previous page require $p_T > 15$ GeV (imposed in ppMuX)
- Loosening momentum cut adds more tracks for alignment but broadens residuals distribution (vs. $|p|$, not p_T); can be optimized
- ppMuXLoose sample allows us to test resolution down to $p_T > 2.5$ GeV, but $\mathcal{L} \approx 0.13$ pb^{-1} in this sample
- Advantage of more tracks outweighs broader distributions down to threshold, but it would be better to do this study with $\mathcal{L} \sim 5$ pb^{-1}

DT station 1

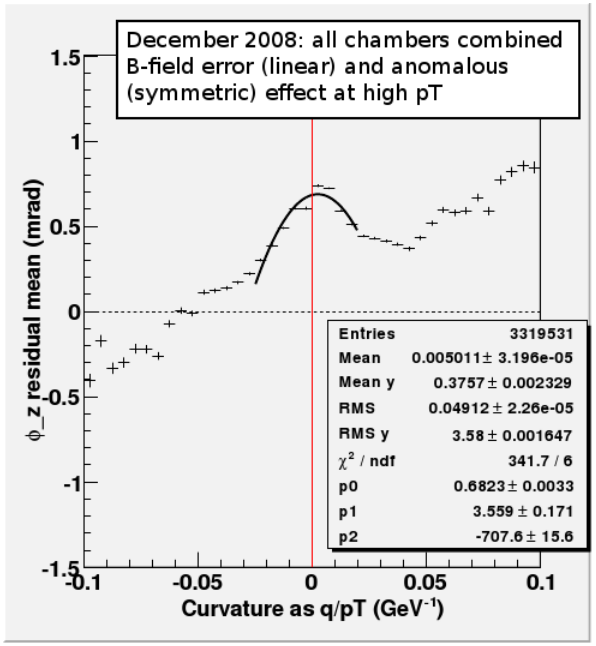


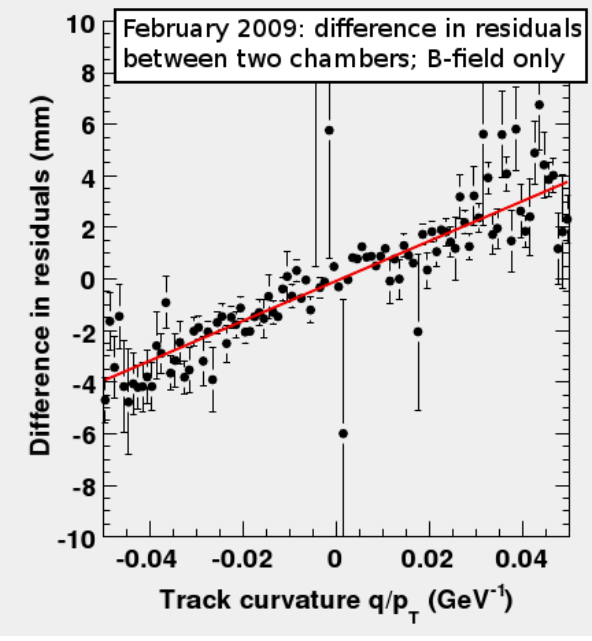
CSC ME1/1



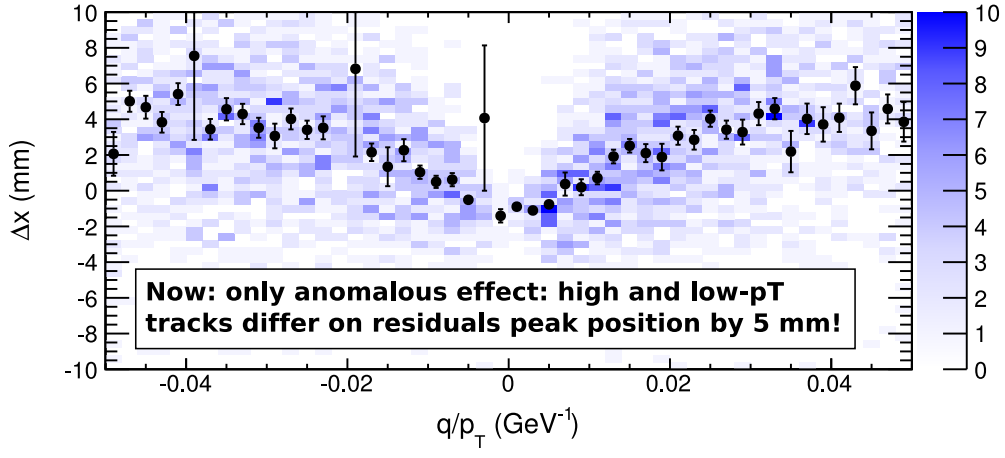
(in ME1/1, $p_T > 2.5$ GeV corresponds to $|p| > 10$ GeV)

Bias in input tracks (1/2)





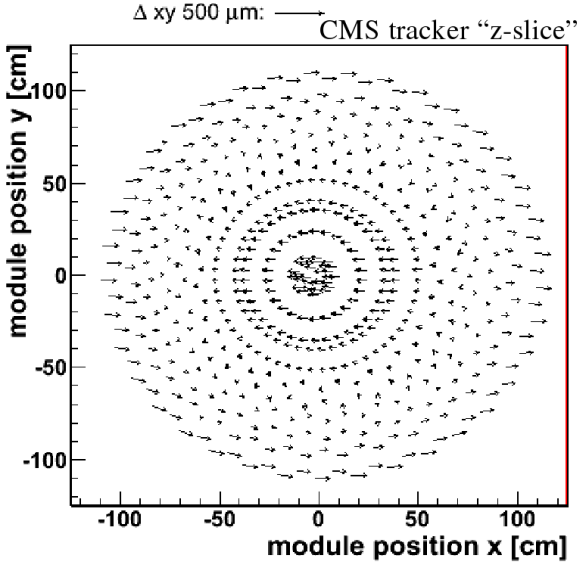
- Muon residuals depend on input track momentum (shown as curvature, q/p_T)
  - dependence is even present when plotted for a single DT layer (no influence from muon alignment)
  - linear dependence is $\vec{B}$-field error, which disappeared with the new $\vec{B}$-field maps (last spring)
  - anomalous (symmetric) effect at high-p_T only present when propagating from the tracker, not between stations

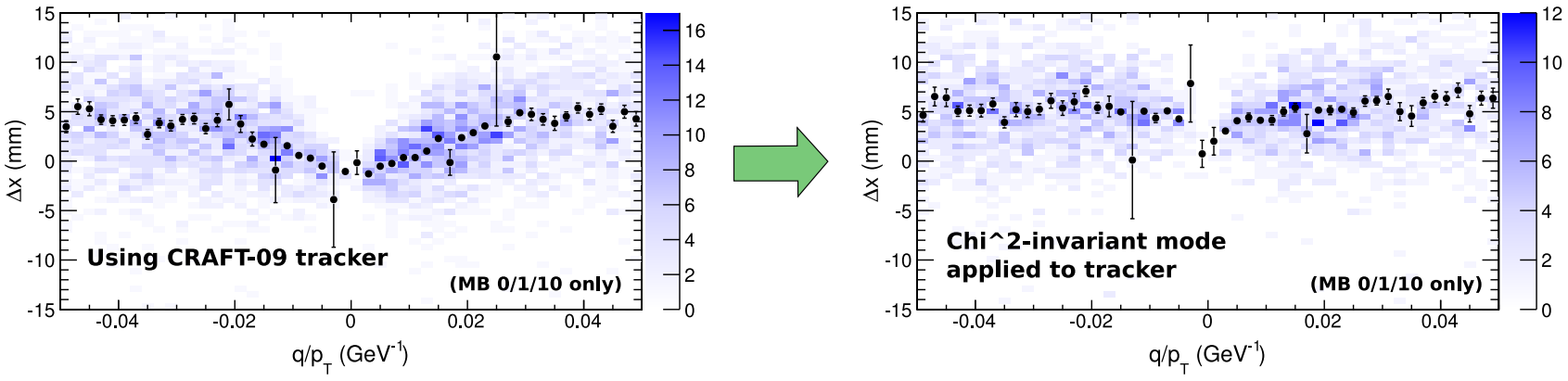


Bias in input tracks (2/2)

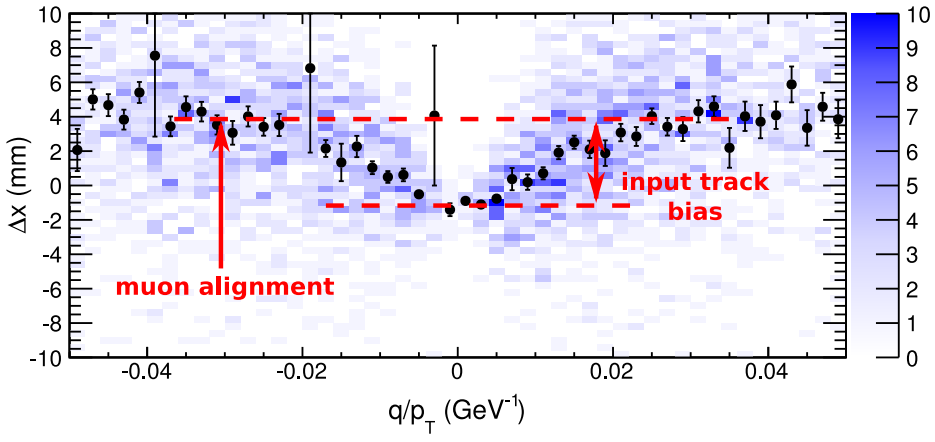
- Markus Stoye generated a realistic example of a tracker weak mode
  - coherent displacement of all tracker modules that does not affect the tracker-track χ^2 distribution
- This kind of distortion affects muon residuals with the same momentum behavior, even cancelling it at some ϕ
- Unfortunately, it does not cancel the effect for all ϕ values; a slightly different mode would be needed— under investigation by the tracker alignment group

M. Stoye





Relevance for muon alignment



- Input track bias can only be inferred from shape vs. momentum, not a constant offset in residuals, so we can only quantify *difference* between high-p_T bias and low-p_T bias

$$\text{bias}(p_T, \phi, \theta) - \text{bias}(0, \phi, \theta) = (5 \times 10^{-4}\ \text{GeV}^{-1}) \sin(\phi - 0.7) \exp\left(-\frac{(100\ \text{GeV})^2}{2\,{p_T}^2}\right)$$

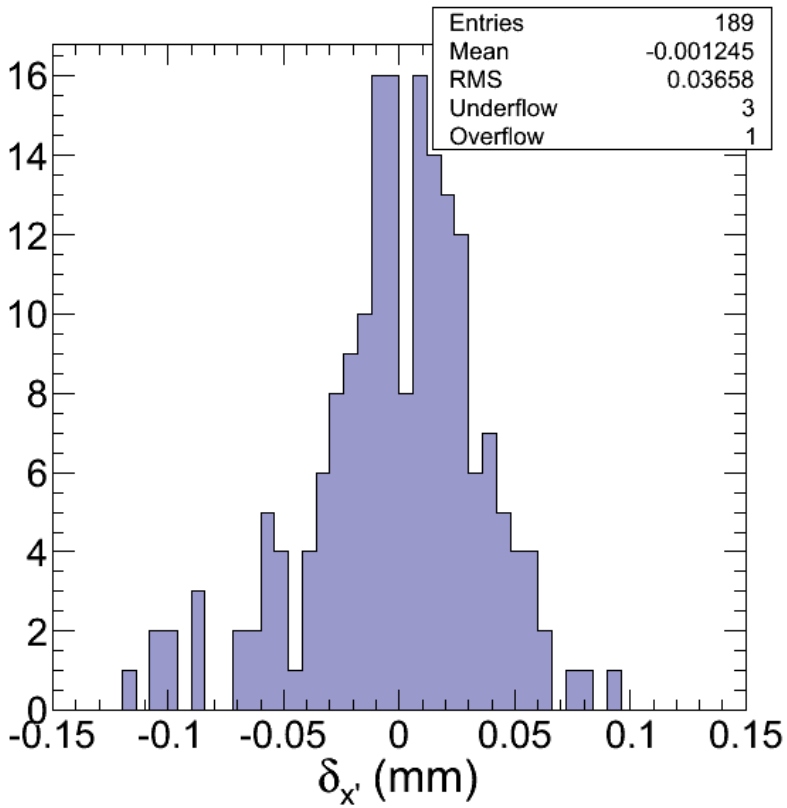
- External information from cosmic spectrum endpoint indicates that only about 10% of the bias is in the high-momentum tracks

$$\text{bias}(p_T \to \infty) \approx 5 \times 10^{-5}\ \text{GeV}^{-1}$$

- Hence, high-momentum tracks ($p_T > 100$ GeV) yield the most correct muon alignment
  - we can align using high-momentum cosmic rays now
  - *but for alignments with collisions muons, the input-track bias must first be resolved!*

New cosmic ray alignments

- General strategy:
  1. Reproduce CRAFT-09 alignment with the updated Reference-Target procedure
  2. Align system with 2010 cosmic rays the same way
- CRAFT-09 constants reproduced within 30 μm (except for the 61 chambers that could not be aligned with the old Reference-Target)



2010 cosmic ray data

- 2010 cosmics: about 80k $p_T > 100$ GeV tracks ($\frac{1}{3}$ of peak-mode CRAFT-09)
- First alignment attempt resulted in unexpectedly few hits in sectors 2–6 (top of barrel)

From the alignment quality browser

showing only $N_{\text{hits}} < 5$ warning (in yellow)

System View

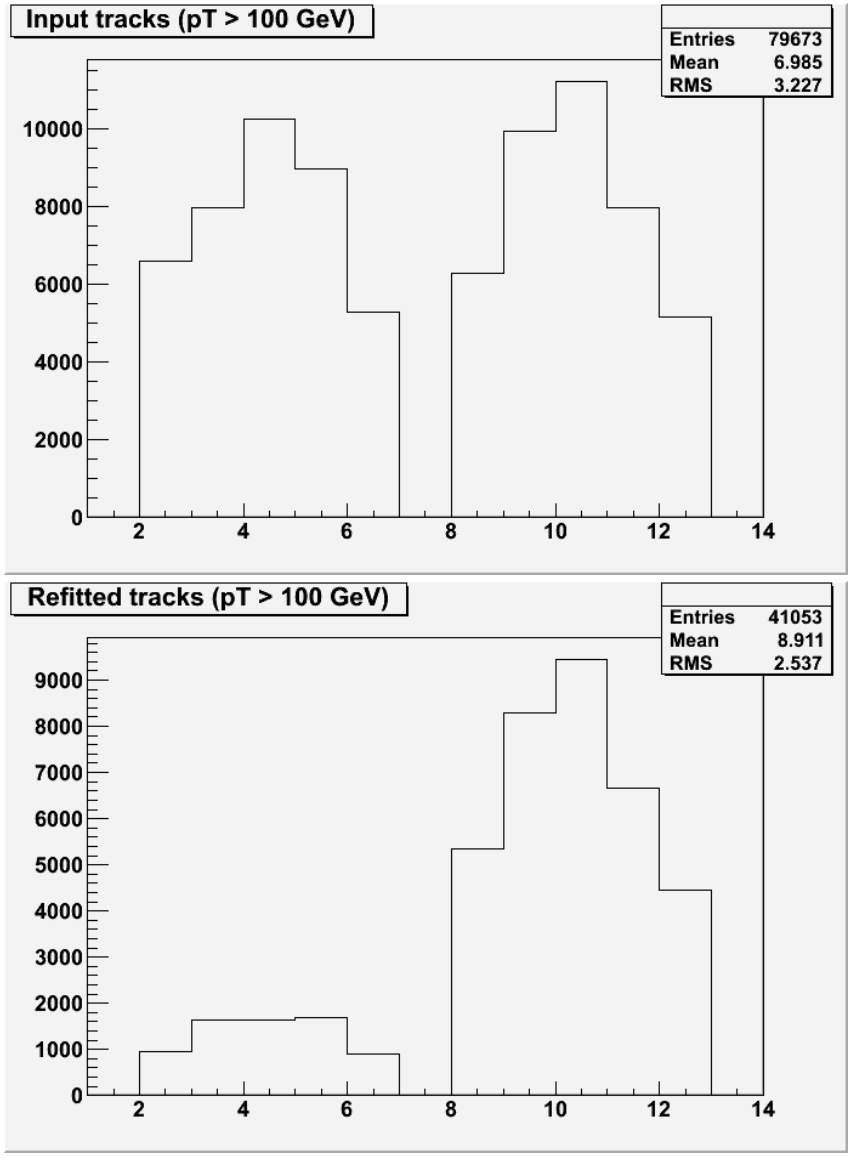
CSCs Table | DTs Table | Summary Report

Run Number: craft10-not-final_20100412231618 [ROOT file]

DT Summary

MB+2	MB+2/1	1	2	3	4		5	6	7	8	9	10		11	12
	MB+2/2	1	2	3	4		5	6	7	8	9	10		11	12
	MB+2/3	1	2	3	4		5	6	7	8	9	10		11	12
	MB+2/4	1	2	3	13	4	5	6	7	8	9	14	10	11	12
MB+1	MB+1/1	1	2	3	4		5	6	7	8	9	10		11	12
	MB+1/2	1	2	3	4		5	6	7	8	9	10		11	12
	MB+1/3	1	2	3	4		5	6	7	8	9	10		11	12
	MB+1/4	1	2	3	13	4	5	6	7	8	9	14	10	11	12
MB-0	MB-0/1	1	2	3	4		5	6	7	8	9	10		11	12
	MB-0/2	1	2	3	4		5	6	7	8	9	10		11	12
	MB-0/3	1	2	3	4		5	6	7	8	9	10		11	12
	MB-0/4	1	2	3	13	4	5	6	7	8	9	14	10	11	12
MB-1	MB-1/1	1	2	3	4		5	6	7	8	9	10		11	12
	MB-1/2	1	2	3	4		5	6	7	8	9	10		11	12
	MB-1/3	1	2	3	4		5	6	7	8	9	10		11	12
	MB-1/4	1	2	3	13	4	5	6	7	8	9	14	10	11	12
MB-2	MB-2/1	1	2	3	4		5	6	7	8	9	10		11	12
	MB-2/2	1	2	3	4		5	6	7	8	9	10		11	12
	MB-2/3	1	2	3	4		5	6	7	8	9	10		11	12
	MB-2/4	1	2	3	13	4	5	6	7	8	9	14	10	11	12
MB-ALL	MB-ALL/1	1	2	3	4		5	6	7	8	9	10		11	12
	MB-ALL/2	1	2	3	4		5	6	7	8	9	10		11	12
	MB-ALL/3	1	2	3	4		5	6	7	8	9	10		11	12
	MB-ALL/4	1	2	3	13	4	5	6	7	8	9	14	10	11	12

Top tracks lost in refitting



- Top hits were *not* lost in the trigger/data acquisition, but in the refitting stage (so this is recoverable)
- Only 51% of $p_T > 100$ GeV tracks successfully refit (compared to 99.7% in CRAFT-09)
- Preferentially drops tracks with top hits
- We're attempting to use an old version of the refitter to isolate the problem (and communicating with the experts, of course :)

Conclusions

- Reference-Target algorithm produces fit results with meaningful error bars for arbitrarily low statistics
- MC results scale statistically; 5 pb^{-1} ($p_T > 15$ GeV) yields
  - $\sim$150 μm in station 1 wheels -1, 0, $+1$
  - $\sim$500 μm in station 1 wheels ± 2
  - $\sim$700 μm throughout barrel
  - $\sim$1 mm throughout muon system

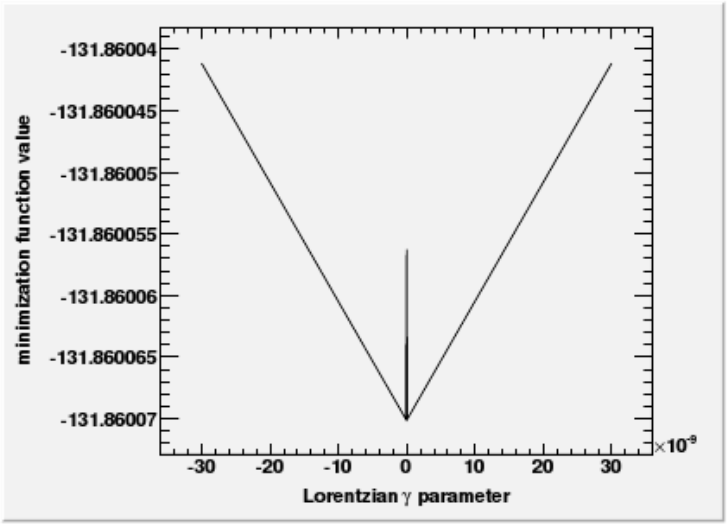
  and 20 pb^{-1} yields $\sim$400 μm throughout barrel, $\sim$500 μm throughout muon system

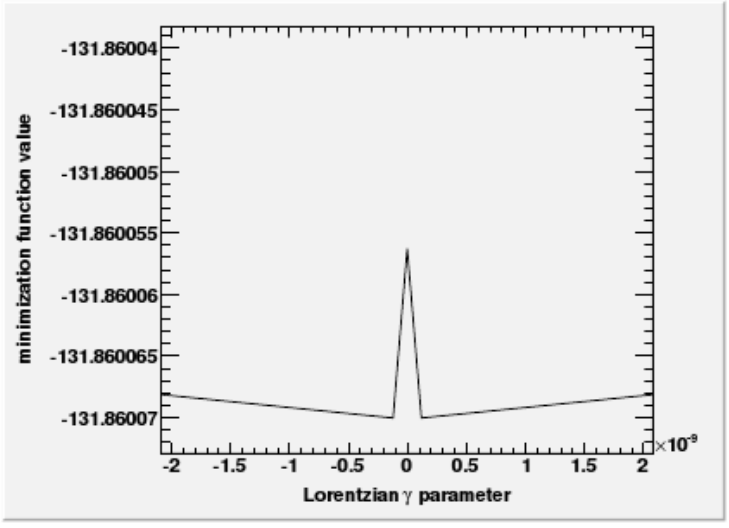
  if there were no biases in the input tracks.
- Input track bias must be resolved before we can perform a muon alignment with low-momentum ($p_T \ll 100$ GeV) tracks
- Cosmic rays remain the only source of high-momentum tracks
- CRAFT-09 alignment reproduced and used as a test to diagnose refitting problems in 2010 cosmic ray alignment

BACKUP

Stability of fitting procedure

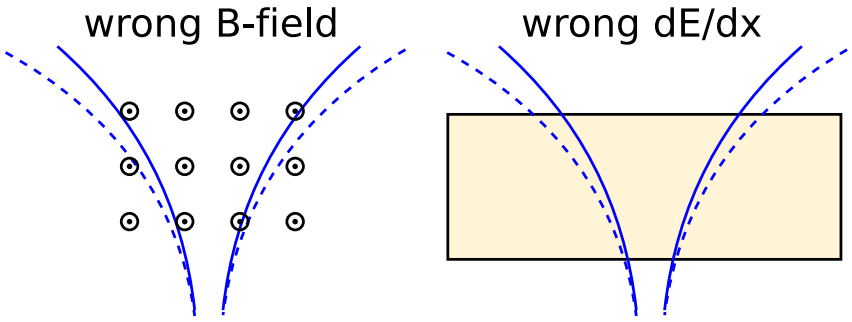
- A few cases of fit failures in low-statistics chambers (MC collisions)
- Fit failures in chambers with the fewest cosmic rays (CRAFT'09)
- Non-smoothness of the minimization function for γ parameter
  - Voigt function implementation in ROOT
  - MINUIT cannot handle this

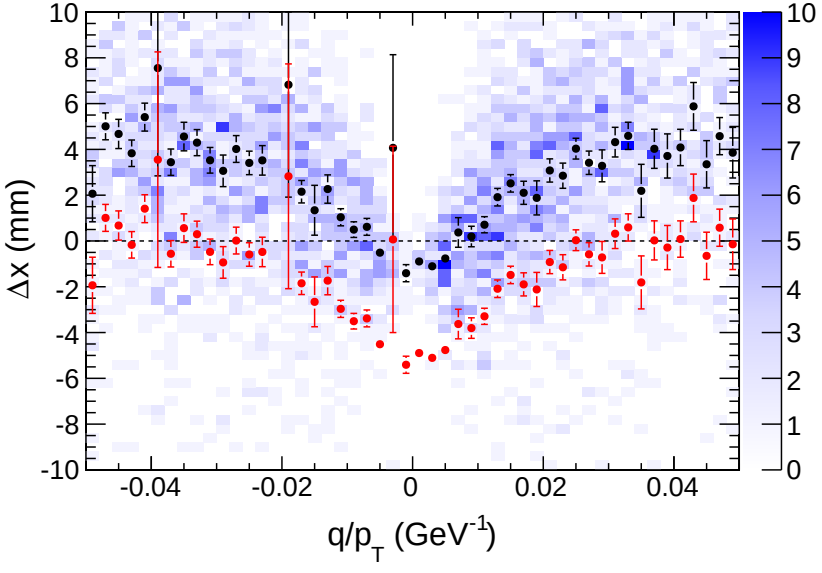




- This may be avoided by introducing new fit function

Interpretation of this plot





- Both magnetic field and material budget errors lead to antisymmetric effects on Δx
  - high-momentum feature effect is therefore neither
- When it is made with a single muon layer, layer misalignment (in $r\phi$) corresponds to vertical translation
  - ignore vertical offsets

- Transform $\Delta(q/p_T) = \dfrac{\epsilon}{x(q/p_T) - x(q/p_T + \epsilon)}\Delta x$, numerical

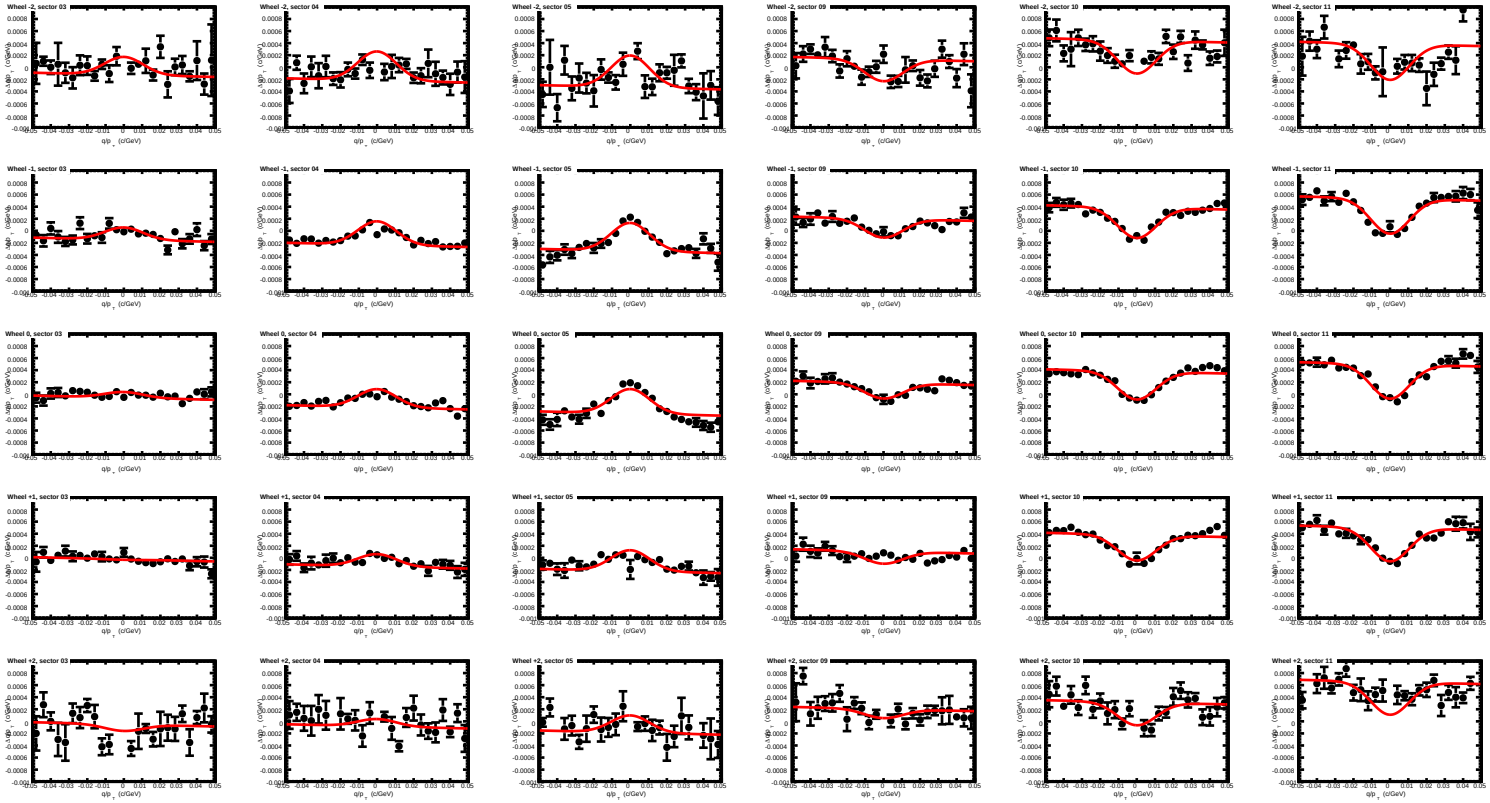
  derivative calculated by running propagator twice (purely mathematical); $\Delta(q/p_T)$ vs q/p_T quantifies tracker only

Parameterization and combined fit

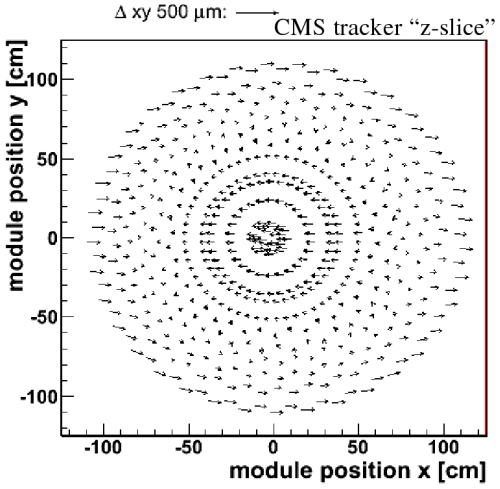
using the $\Delta(q/p_T)$ plots and expanding the expression to include wheels

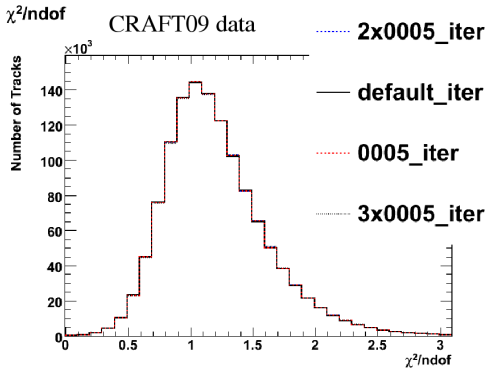
$$(A)\kappa + \Big[(F + F_\theta \cot\theta) + (S + S_\theta \cot\theta)\sin(\phi) + (C + C_\theta \cot\theta)\cos(\phi)\Big] \exp(-\kappa^2 W^2/2)$$

$$\chi^2/N_{dof} = 2194/1066 = 2.06$$



Millepede-generated mode (M. Stoye)





- Coherent distortion of tracker with no tracker χ^2 sensitivity
- We can see its effect with muon reisduals

$$(A)\kappa + \left[(F + F_\theta \cot\theta) + (S + S_\theta \cot\theta)\sin(\phi) + (C + C_\theta \cot\theta)\cos(\phi)\right] \exp(-\kappa^2 W^2/2)$$

	χ^2/N_{dof}	A	F (GeV^{-1})	F_θ (GeV^{-1})
mode×0	2194/1066	−0.000 70	−0.000 082	−0.000 039
mode×1	2171/1068	−0.000 63	0.000 098	−0.000 063
mode×3	1991/942	−0.000 68	0.000 277	−0.000 070
uncertainty		0.000 09	0.000 005	0.000 009

	S (GeV^{-1})	S_θ (GeV^{-1})	C (GeV^{-1})	C_θ (GeV^{-1})	W (GeV)
mode×0	0.000 3533	−0.000 113	−0.000 345	−0.000 057	95.0
mode×1	0.000 3892	−0.000 156	−0.000 335	−0.000 063	93.1
mode×3	0.000 4310	−0.000 170	−0.000 386	−0.000 096	84.1
uncertainty	0.000 0064	0.000 011	0.000 010	0.000 016	2.1

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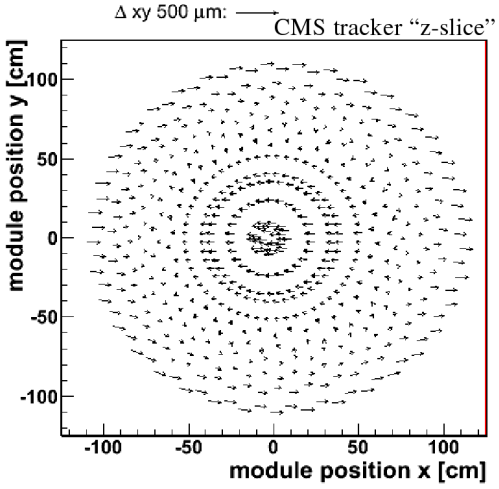

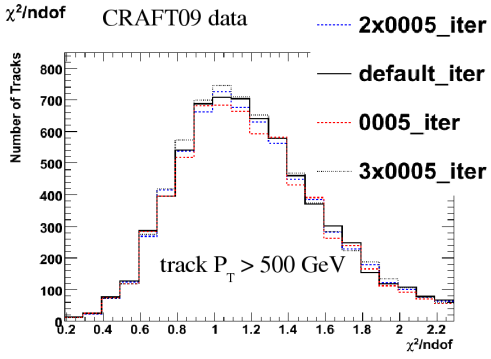

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Graphical presentation

$$(A)\kappa + \left[(F + F_\theta \cot\theta) + (S + S_\theta \cot\theta)\sin(\phi) + (C + C_\theta \cot\theta)\cos(\phi)\right] \exp(-\kappa^2 W^2/2)$$

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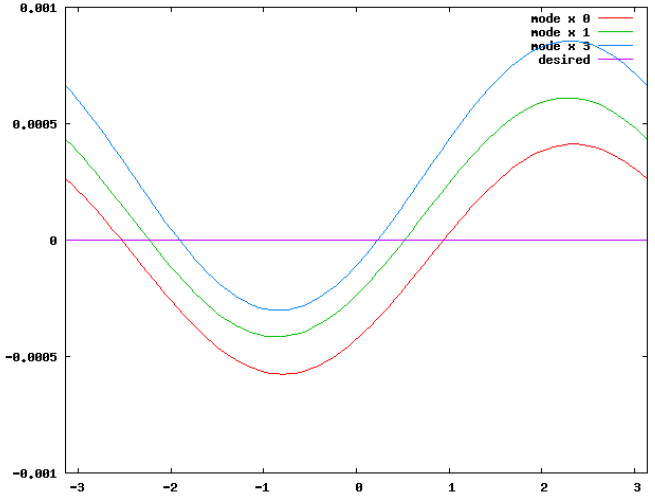
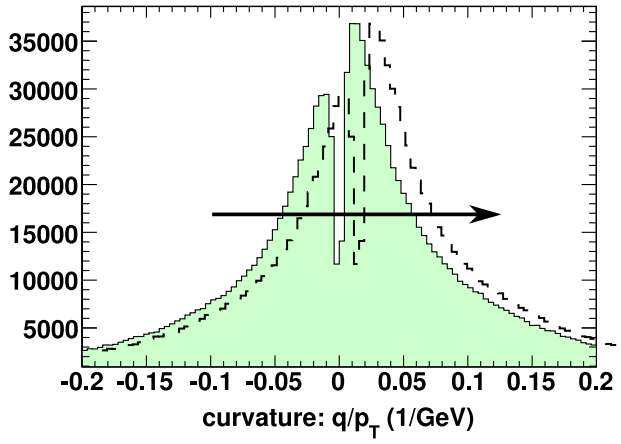


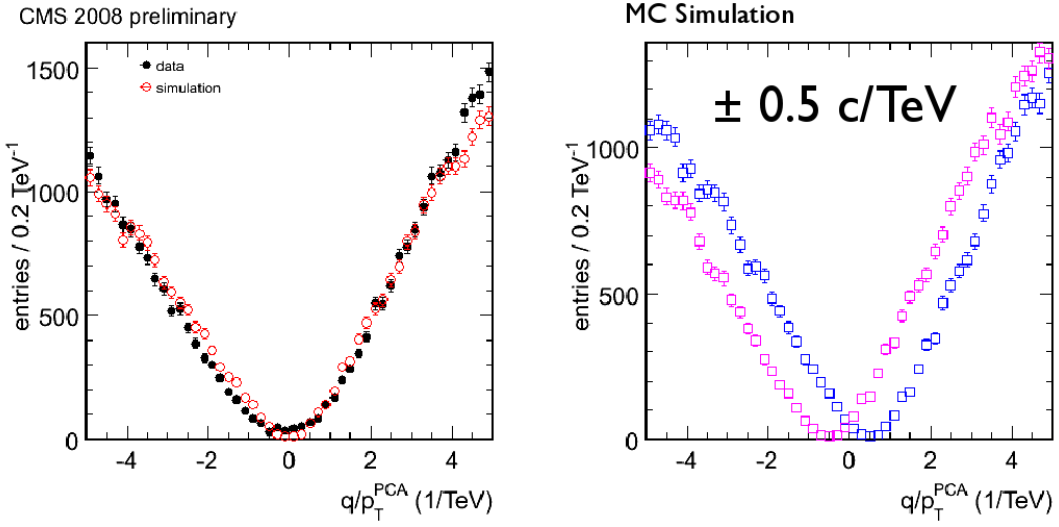
Absolute curvature bias

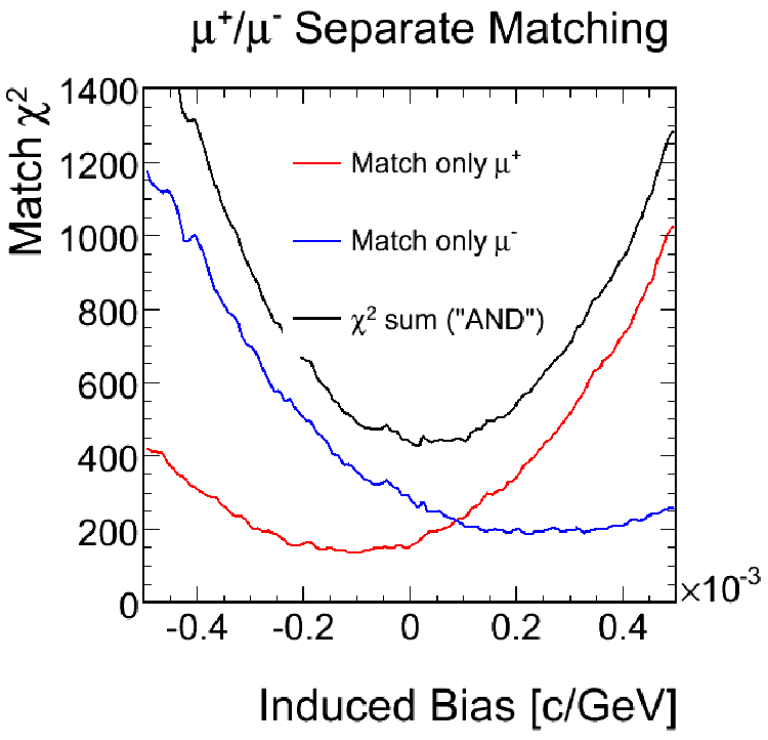
- If we could know the absolute curvature bias of either high or low momentum tracks, we could use the muon residuals to predict to the other
- Cosmics endpoint: assuming ∼flat efficiency for high-momentum muons, cosmic ray spectrum in q/p_T must point at zero (they trail off to infinite momentum)
  - identifies high-momentum constant offset in $\Delta(q/p_T)$ vs q/p_T (next slide)



- Known resonance masses: identify linear slope in low-momentum $\Delta(q/p_T)$ vs q/p_T
- Curvature of tracks in zero magnetic field: identify constant offset in low-momentum $\Delta(q/p_T)$ vs q/p_T
- $K_S \to \pi^+\pi^-$ decay direction constraint: identify constant offset in low-momentum $\Delta(q/p_T)$ vs q/p_T (following slides)

Cosmics endpoint (I. Furić)

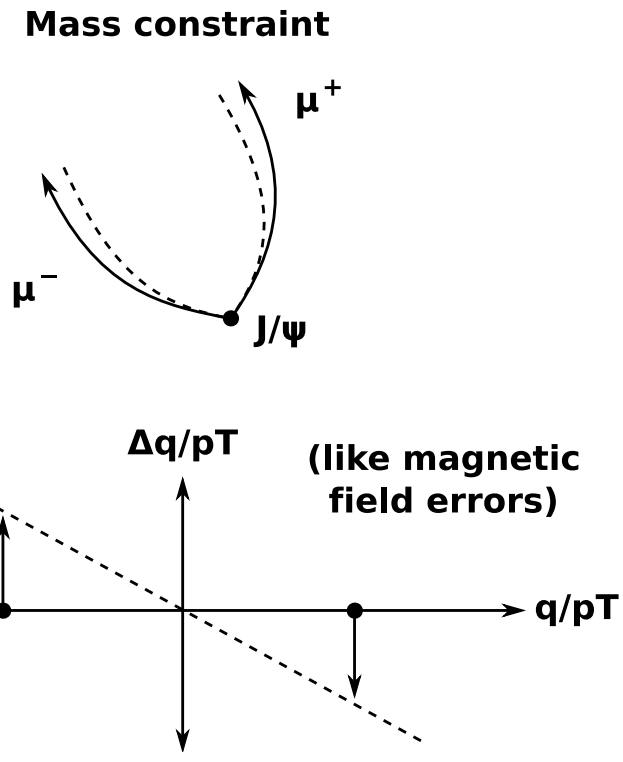


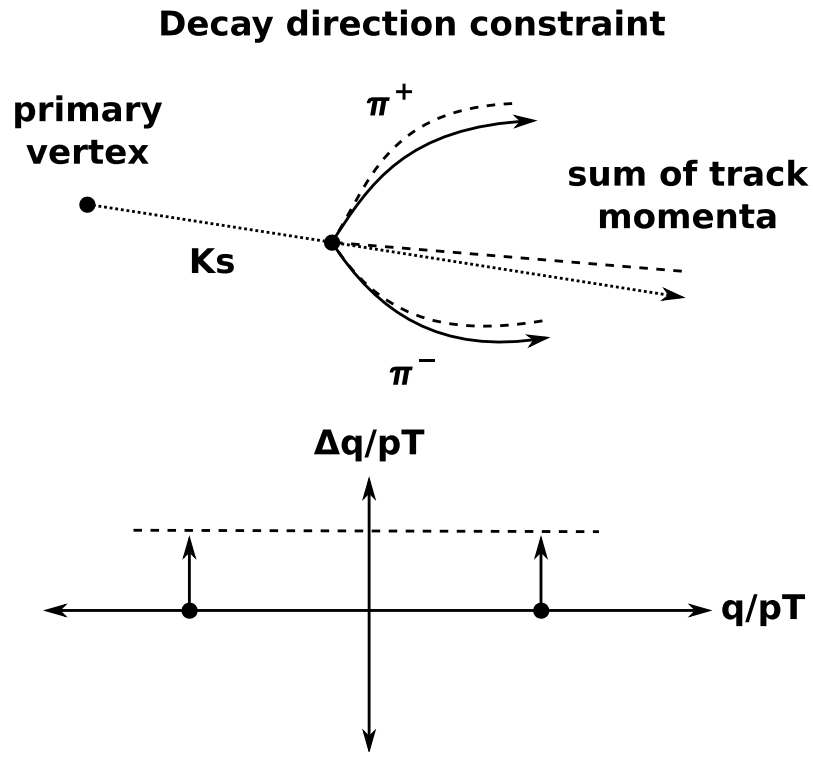


- Distribution of cosmic rays trail off at high p_T, so positive and negative distributions must both point to $q/p_T = 0$ (infinite momentum)
- Doesn't assume charge ratio, only shape of spectrum (well-known "energy$^{-2.7}$")
- Data are most consistent with $\sim 5 \times 10^{-5}$ GeV^{-1}, ten times smaller than bias(high) − bias(low) = $5 \times 10^{-4} \sin\phi$ GeV^{-1}
- Implies that the muon-residuals effect is mostly in $\Delta\kappa$(low)? Can we check that?

$K_S \to \pi^+\pi^-$ direction constraint

- Momentum sum of the $\pi^+\pi^-$ system must be collinear with the displacement of the secondary vertex
- As a constraint on momenta, this is orthogonal to resonance mass





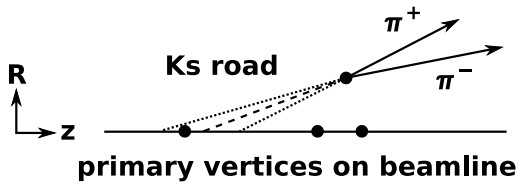
- These two are the first terms in a general $\Delta\kappa(\kappa, \phi, \theta)$ expansion in κ

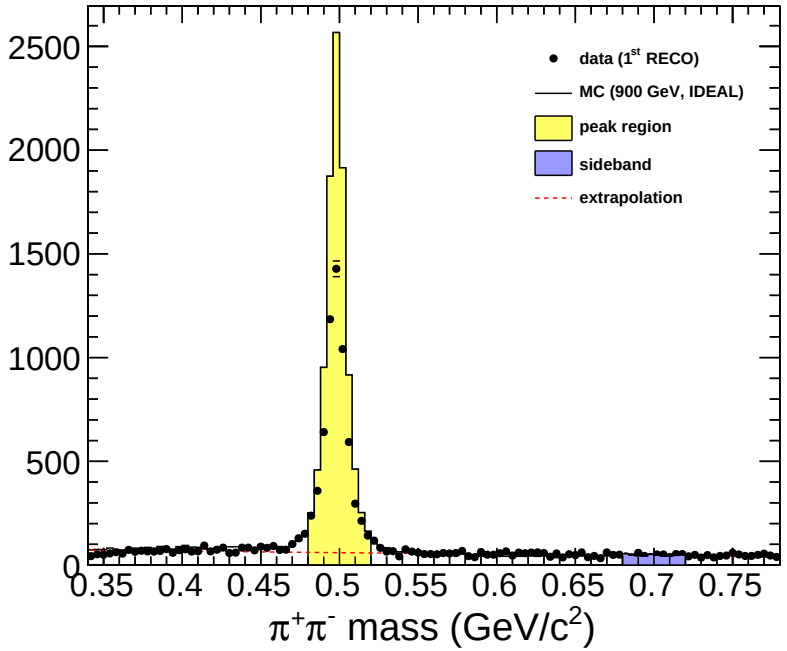
Implementing the K_S constraint

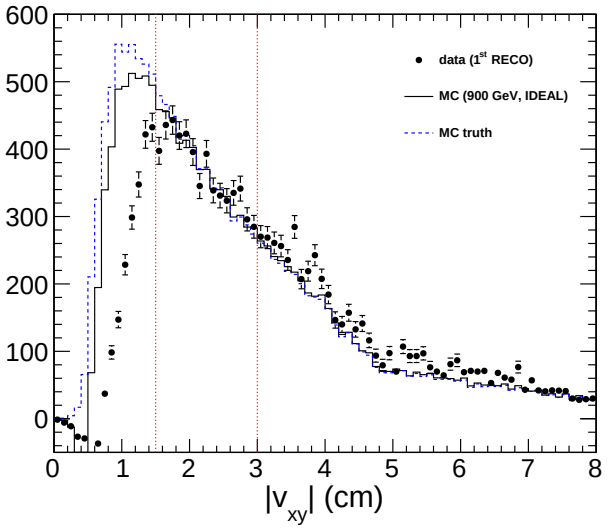
Jim Pivarski

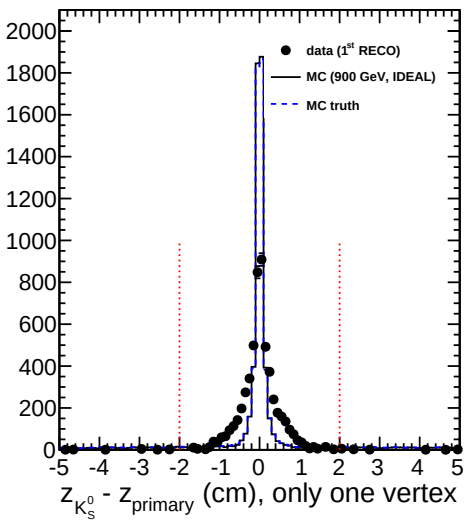
to get a sense of how tight it is from Nov-Dec 2009 data

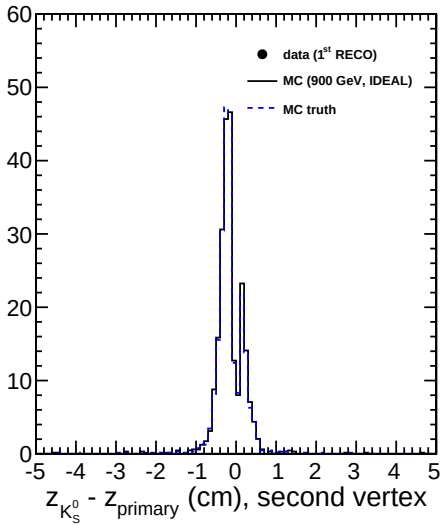
- Select events using
  - $\pi^+\pi^-$ mass with sideband subtraction
  - vertex inside the first pixel layer
- Pointing to choose the primary vertex in z projection





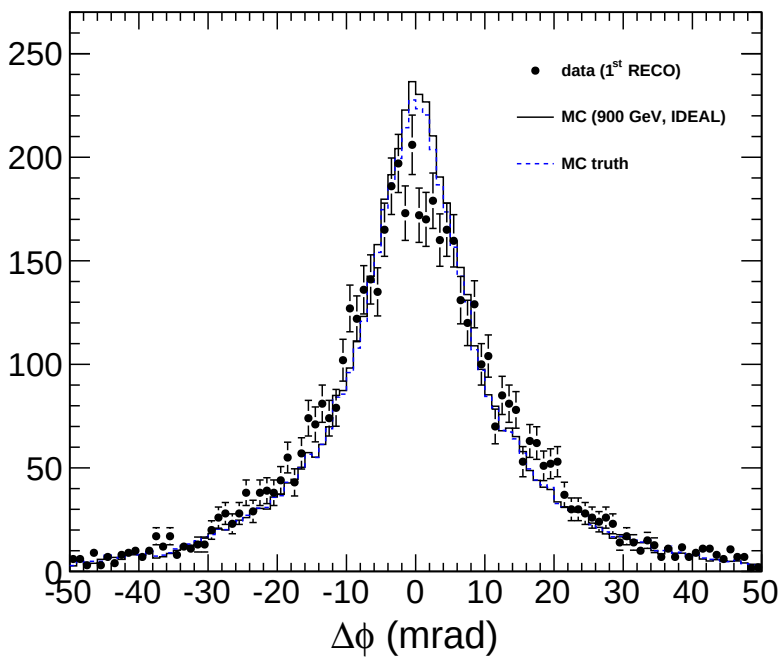


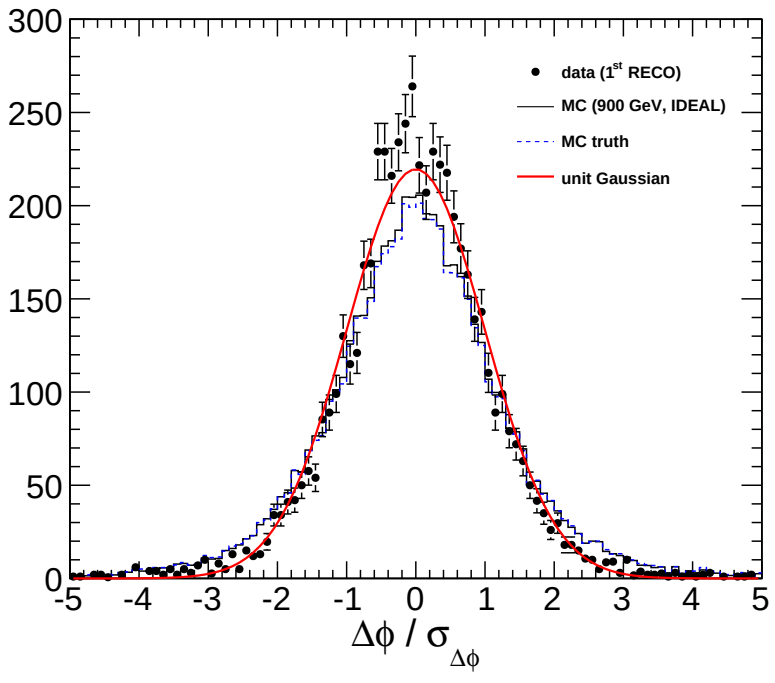




Observable: $\Delta\phi$

- Angle between primary-to-secondary displacement vector and $\pi^+\pi^-$ momentum sum in the transverse plane: $\Delta\phi$
- Not used up by any selection requirements

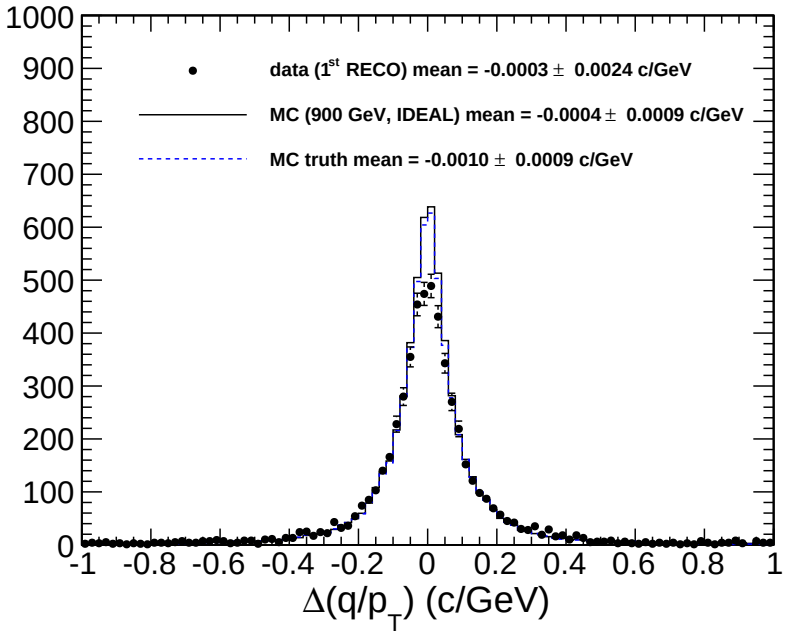


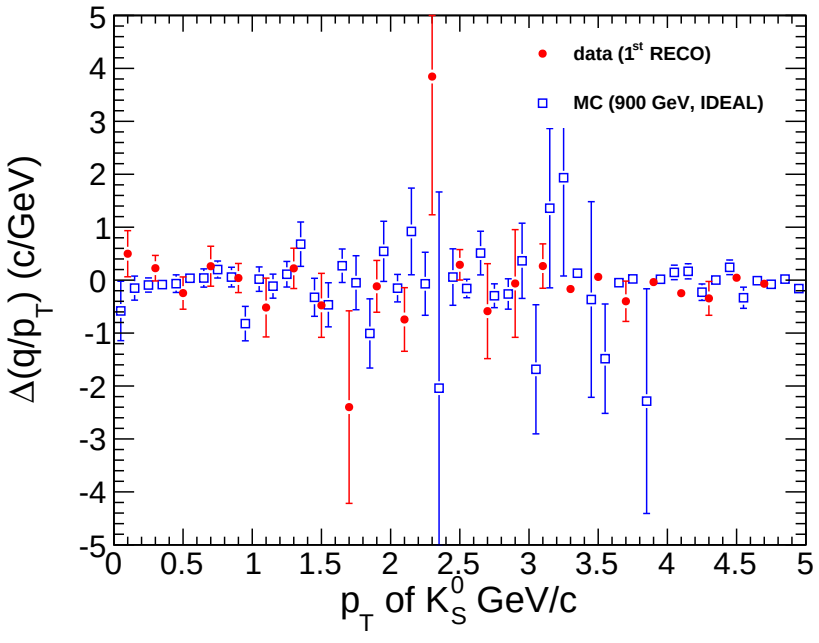


- No observed bias, with some uncertainty

Convert to absolute $\Delta(q/p_T)$

- Compute $\frac{\partial \Delta(q/p_T)}{\partial \Delta\phi}$ by taking numerical derivatives with the vertex-fitter





- $\Delta\kappa(\text{low}) = -0.000\,3 \pm 0.002\,4$ GeV^{-1}
- 0.24% uncertainty in bias of 1 GeV tracks
- Uncertainty in bias of 1 TeV tracks = 240% (plus a few percent from the $\Delta\kappa(\text{high}) - \Delta\kappa(\text{low})$ propagation)

Flat with respect to everything else