HIP/MP Comparisons and HIP Results

Jim Pivarski

Alexei Safonov

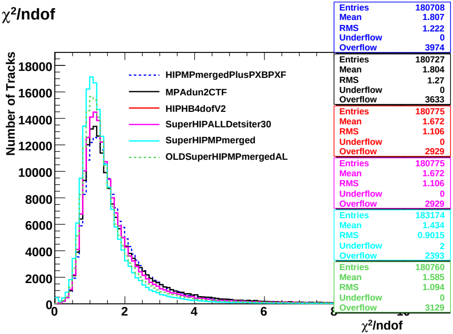
Texas A&M University

25 May, 2009

- Pablo and I discussed implementation details early in the week
- We synchronized all of the inputs and many of the parameters/cuts, and set up parallel CRAFT alignments and tests in cosmic ray MC
- We didn't finish our comparison— I have not seen all of the MP results— and we never got a chance to discuss how we might converge (schedule conflicts? a bad week?)
- What I know is the following:
  - even with the same inputs and similar cuts, HIP and MP differ in data by 2–4 mm, 0.5–2 mrad, systematic trend in y, z
  - HIP yields high-accuracy results in Monte Carlo
- What I'll present here:
  - comparative study of HIP and MP implementations and results
  - possible explanations for the discrepancy
  - my HIP recommendation, and arguments to support it as a good sub-millimeter alignment

Comparison of HIP and MP (1/3)

- Inputs to the procedures (differences between HIP and MP in blue)
  - V11_StreamMuAlGlobalCosmics_227_Tosca090216_FromTrackerPointing_v5 (RunReg 3.8 T only)
  - newest tracker alignment (c. May 19)
  - last month's tracker APEs (c. Apr 24): update not available
  - tracker hits ≥ 15, $\chi^2/N_{\mathrm{dof}} < 10$, TIB and TOB only
  - high momentum: $100 < p_T < 200$ GeV
  - latest magnetic field: "grid_1103l_090322_3_8t"
  - latest internal DT alignment (agreement between tracks and survey)
  - HIP: CMSSW_2_2_11, MP: CMSSW_2_2_10 *(very likely no difference for our purposes)*



- Newest tracker alignment is the light blue one
- New χ^2/N_{dof} peaks at 1.4 without APEs, old peaks at 1.6
- Tracker alignment still needs to be centered and APEs need to be produced

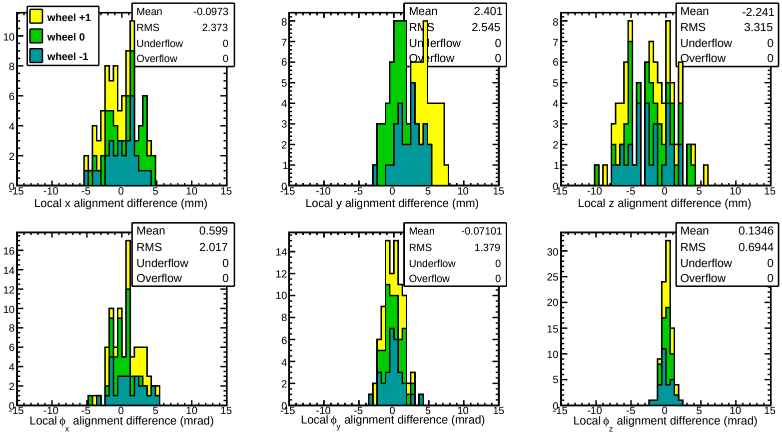
  Final muon alignment will need to be consistent with final tracker alignment

- Alignables/parameters (differences between HIP and MP in blue)
  - only wheels -1, 0, $+1$, all sectors except 1 and 7
  - stations 1–3: 6 degrees of freedom
  - station 4: HIP: x, ϕ_y, ϕ_z, MP: x, ϕ_y *(we'll compare only stations 1–3)*
- Algorithmic implementation
  - no treatment of $\vec{B}$-field, dE/dx effects (HIP and MP implementations differ, so we turned them both off; note that $p_T > 100$ GeV)
  - residuals calculated from standard CMSSW track-refits with muon chamber APEs $\to \infty$ (1000 cm)
  - segment residuals: HIP: linear fit to (extrapolated track $-$ hits), MP: (extrapolated track) $-$ (linear fit to hits) *(negligible: $\vec{B} \approx 0$ inside DTs)*
  - cut on muon residuals: HIP: keep residuals tails (cut only unphysical values), MP: cut $1\,\sigma$ symmetrically around the peak
  - treatment of residuals tails: HIP: fit tail shape and misalignment together, MP: calculate misalignment from matrix inversion of hits
  - residuals weights: HIP: segment residual $(\chi^2/N_{\mathrm{dof}})^{-1}$, MP: the same?
  - iteration: HIP: 2 required, 3 applied, MP: 1 applied

We'll discuss the algorithmic differences soon

- Absolute differences (MP − HIP) on the order of 2–4 mm, 0.5–2 mrad
- In this comparison, station 4 is excluded, as are 3 failed fits (too few hits):

  wh−1, st2, sec08 wh+1, st2, sec02 wh+1, st3, sec08
- Orientation of local x, y, z directions are ideal (for symmetric comparison):

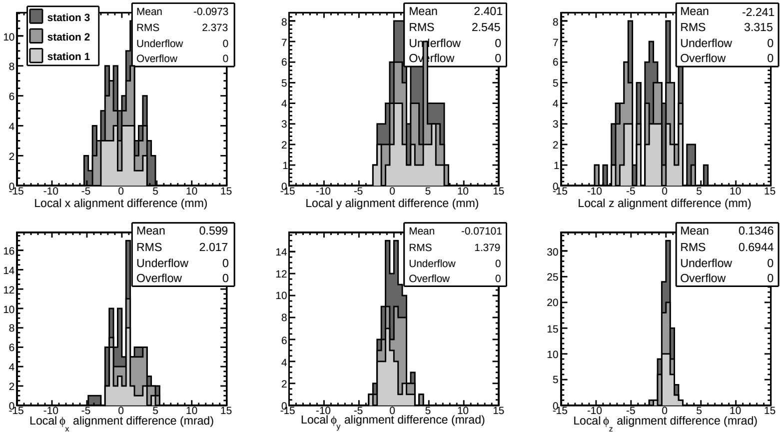


Comparison of HIP and MP (3/3)

- Absolute differences (MP − HIP) on the order of 2–4 mm, 0.5–2 mrad
- In this comparison, station 4 is excluded, as are 3 failed fits (too few hits):

  wh−1, st2, sec08   wh+1, st2, sec02   wh+1, st3, sec08

- Orientation of local x, y, z directions are ideal (for symmetric comparison):

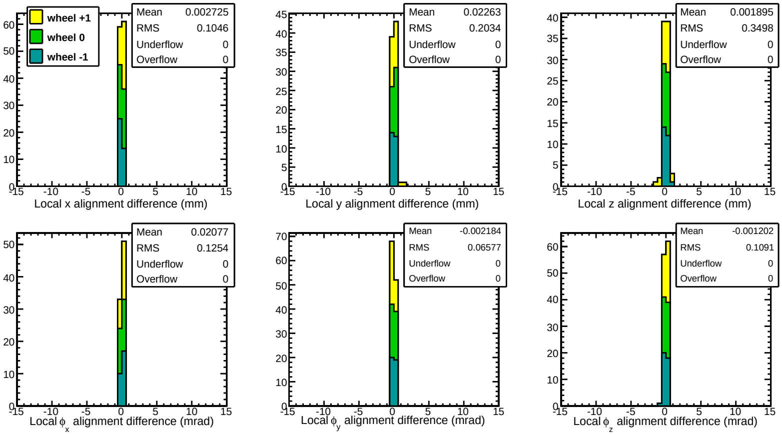


- Most of the implementation differences that couldn't be easily synchronized are deep in the algorithms
- These probably aren't responsible for the discrepancy in results:
  - $\vec{B}$-field, dE/dx controls (we turned them off!)
  - calculation of segment residuals
  - weighting of residuals
- These might have something to do with it:
  - treatment of tails in residuals
  - residuals $\leftrightarrow$ alignment corrections matrix
- I'll present each implementation difference in order

Turning off $\vec{B}$ correction

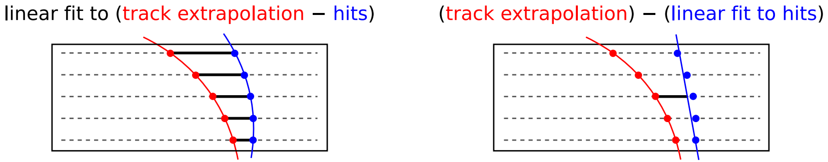
- To avoid differences in our $\vec{B}$ and dE/dx controls, we simply turned them off for this alignment
- Correction is irrelevant at $100 < p_T < 200$ GeV, anyway

(Difference between corrected and uncorrected HIP shown below)



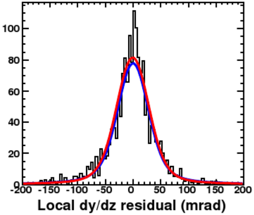
Segment residuals

- Both algorithms combine all hits in one chamber on one track to take advantage of 4 independent residuals: Δx, Δy, $\Delta\frac{dx}{dz}$, $\Delta\frac{dy}{dz}$
- The implementations differ:
  - HIP: linear fit to (track extrapolation − hits) error $\propto$ Δcurvature
  - MP: (track extrapolation) − (linear fit to hits) error $\propto$ curvature



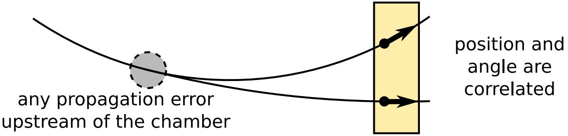
- Only matters when the muon is expected to curve significantly inside the chamber, e.g. ME1/1 and ME1/2
  - probably negligible the DTs

- "Bad" segments distort residuals distribution, so weight segment residuals by their $(\chi^2/N_{\text{dof}})^{-1}$ (good fits get the most weight)
- Normalized with $\langle(\chi^2/N_{\text{dof}})^{-1}\rangle = 1.0$, so that errors are meaningful
- The usual dangers with weights are:
  - parameterized hit uncertainties *might* be unrepresentative
  - unphysically low-weight events can bias a distribution (they appear as spikes in a histogram)
- Not an issue with these weights because:
  - consistency with a line is a geometric attribute, not very sensitive to the precise hit uncertainties
  - we exclude the lowest 1% of weights



- *Necessary* for good fits in wheel ± 2, station 1 $\Delta\frac{dy}{dz}$ (above)

- Residuals are influenced by misalignment geometry and propagation/instrumental effects:
    - misalignments distort residuals according to an exact 6×4 matrix
    - some propagation errors are Gaussian (statistical error, multiple scattering, etc.) and some power-law (single-scattering)
    - propagation correlates Δx with $\Delta \frac{dx}{dz}$ and Δy with $\Delta \frac{dy}{dz}$



    - sources of systematic error to be quantified or controlled: tracker misalignment, imperfect $\vec{B}(\vec{x})$ and material maps, internal DT misalignment
- All of the above are convoluted together in an 9 dimensional space: (Δx, $\Delta \frac{dx}{dz}$, Δy, $\Delta \frac{dy}{dz}$, x position, $\frac{dx}{dz}$ angle, y position, $\frac{dy}{dz}$ angle, q/p_T)

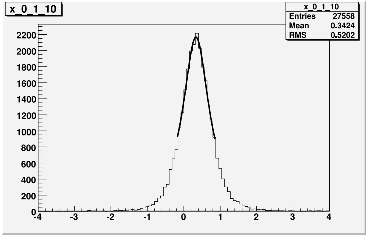
- Incorporate misalignment, Gaussian and Lorentzian propagation effects, with Δx-$\Delta \frac{dx}{dz}$ correlations, into a single ansatz
  - 6 alignment parameters, σ and Γ for each of the 4 residuals, 2 correlation parameters = 16 parameters for each $\text{DT}_{\text{station 1–3}}$
  - 3-way convolution:

$$\text{residuals} = [\text{Gaussian} \otimes \text{Lorentzian}](\text{misalignment})$$

- Fit all chamber variables simultaneously (unbinned log-likelihood)
  - include all the physical tails (cut unphysical $|\Delta x_i|, |\Delta y_i| < 1000$ cm)
  - seed fit with truncated means and standard deviations for stability
  - project the fit results on all axes to make sure it's working
- Usually separate two q/p_T bins to account for the $\vec{B}(\vec{x})$ and $dE/dx(\vec{x})$ instrumental effects (but turned off for this alignment)
- Tracker and DT internal alignment are external inputs, assumed to be correct and worth investigating as systematics studies
  - quantified misalignment scenarios test sensitivity in MC (e.g. CSA08)
  - non-pointing cosmic rays reveal global distortions (e.g. TEC)
  - p_T dependence provides some information (e.g. tracker curl study)

What MillePede does (3/4)

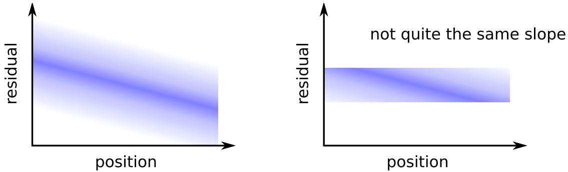
1. Fit peaks of residuals distributions to Lorentzian (or Gaussian) to identify a [peak $-\sigma$, peak $+\sigma$] window
2. Compute the residuals $\rightarrow$ alignment corrections inversion for all hits in the window



- All alignment parameters are fitted simultaneously, but residuals tails from propagation effects are explicitly cut out
  - this is a matrix-mean: in a 1-DOF case (e.g. aligning δ_x only), it is equivalent to a computation of the mean within the selected window
  - trade-off: loose cut lets in non-Gaussian tails, tight cut introduces a dependence on its value
- Control $\vec{B}(\vec{x})$ and $dE/dx(\vec{x})$ instrumental effects with a linear q/p_T fit (but turned off for this alignment)
- Same systematics issues as HIP

My commentary (4/4)

- The mean of a distribution with such a tight cut (deep in the bulk of the distribution) would depend on the placement of the cut boundary
- *However,* the perfect symmetry of [peak $-\ \sigma$, peak $+\ \sigma$] should balance the residuals on each side of the peak, as long as the pre-fit is a good fit $\surd$
- *However,* the matrix inversion depends on trends in the residuals distributions, which may not be as well balanced
  - for example, a term contributing to δ_{ϕ_z} alignment is the slope of Δx residuals versus y position (there are many other terms like this)
  - the slope can be distorted by a tight cut:



- The example I drew has misalignment $\sim$ residuals σ, which would be about 4 mrad for ϕ_z
- Monte Carlo can verify whether the MillePede alignment is sensitive to these sorts of effects

- HIP alignment matrix, presented last month with a suite of MC tests (including turning off measurement error to observe pure geometric effects)

$$\begin{pmatrix} \Delta x \\ \Delta y \\ \Delta \frac{dx}{dz} \\ \Delta \frac{dy}{dz} \end{pmatrix} = \begin{pmatrix} -1 & 0 & \frac{dx}{dz} & y\,\frac{dx}{dz} & -x\,\frac{dx}{dz} & y \\ 0 & -1 & \frac{dy}{dz} & y\,\frac{dy}{dz} & -x\,\frac{dy}{dz} & -x \\ 0 & 0 & 0 & \frac{dx}{dz}\,\frac{dy}{dz} & -1 - \left(\frac{dx}{dz}\right)^2 & \frac{dy}{dz} \\ 0 & 0 & 0 & 1 + \left(\frac{dy}{dz}\right)^2 & -\frac{dx}{dz}\,\frac{dy}{dz} & -\frac{dx}{dz} \end{pmatrix} \begin{pmatrix} \delta_x \\ \delta_y \\ \delta_z \\ \delta_{\phi_x} \\ \delta_{\phi_y} \\ \delta_{\phi_z} \end{pmatrix}$$

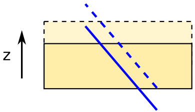
- MP alignment matrix in SegmentAlignmentDerivatives4D.cc

$$\begin{pmatrix} \Delta x \\ \Delta y \\ \Delta \frac{dx}{dz} \\ \Delta \frac{dy}{dz} \end{pmatrix} = \begin{pmatrix} -1 & 0 & \frac{dx}{dz} & y\,\frac{dx}{dz} & -x\,\frac{dx}{dz} & y \\ 0 & -1 & \frac{dy}{dz} & y\,\frac{dy}{dz} & -x\,\frac{dy}{dz} & -x \\ 0 & 0 & \frac{dx}{dz} & 0 & -1 & \frac{dy}{dz} \\ 0 & 0 & \frac{dy}{dz} & 1 & 0 & -\frac{dx}{dz} \end{pmatrix} \begin{pmatrix} \delta_x \\ \delta_y \\ \delta_z \\ \delta_{\phi_x} \\ \delta_{\phi_y} \\ \delta_{\phi_z} \end{pmatrix}$$

- First column of differences (blue) say that δ_z misalignment causes angle residuals (e.g. $\Delta \frac{dx}{dz} = \delta_z \frac{dx}{dz}$)
- Second two columns are an approximation that $\frac{dx}{dz}$ and $\frac{dy}{dz}$ are small ($\left|\frac{dx}{dz}\right|$ reaches 0.25 in every chamber, $\left|\frac{dy}{dz}\right|$ reaches 0.7 in wheel ± 1 and 0.9 in ± 2)

Error in the MP matrix? (2/2)

- Biggest discrepancy between HIP and MP is in local δ_z, and the biggest difference between the matrices contributes to δ_z
- δ_z translations do not change segment angles:



- A Monte Carlo test would catch this immediately

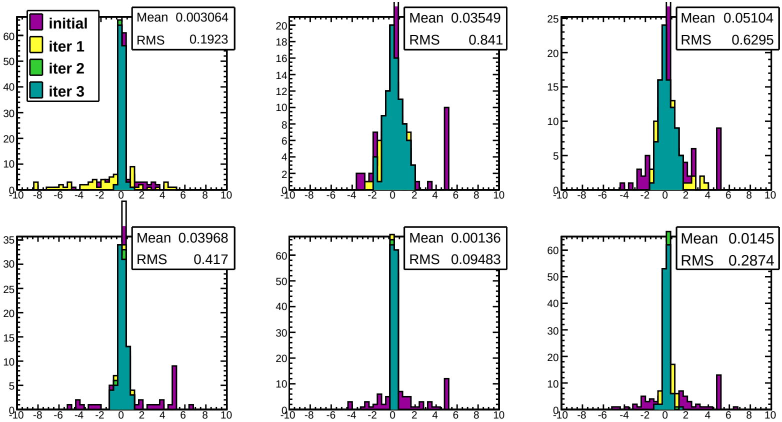
Cosmic ray Monte Carlo

- Summer08 tracker-pointing AlCaReco skims available
- Everything is the same as in CRAFT data except:
  - ideal tracker alignment, magnetic field, and DT internal alignment
  - about 4 times the sample size
- All HIP/MP implementation differences should be modeled by MC
  - if not, we can add realistic tracker, field, and DTs to diagnose

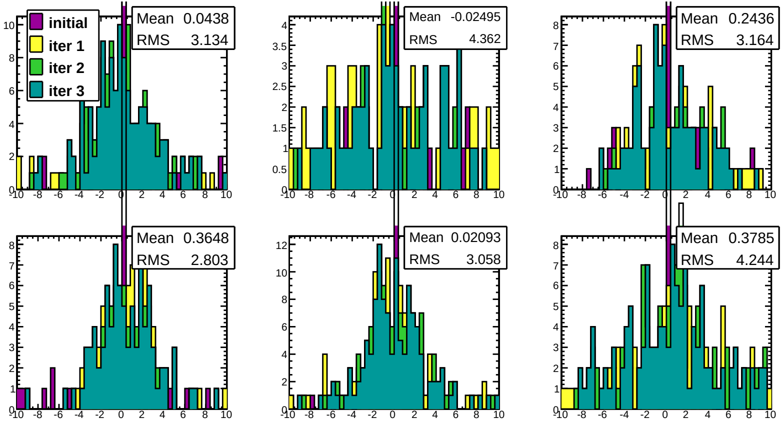
HIP accuracy in MC

- Same convergence as in data (2 iterations necessary, 3 taken)
- 200 μm in $r\phi$ (with about 4 times as many tracks)
- More accurate in y and z than collisions MC test because of high p_T

  (Local z is degenerate with q-antisymmetric effects like $\vec{B}$ and dE/dx)

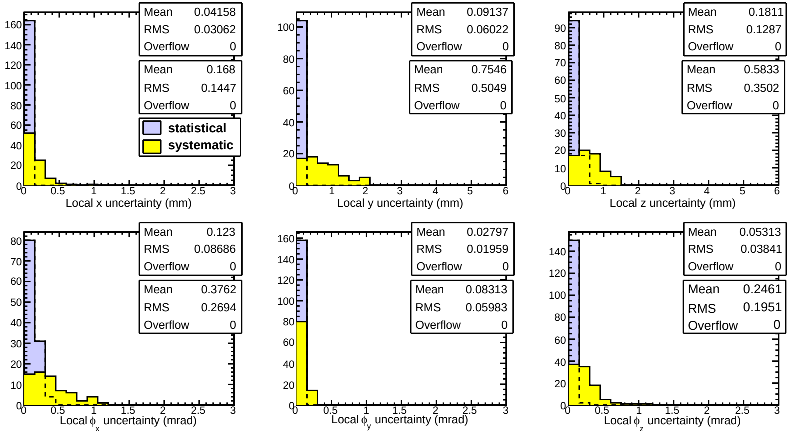


- Statistical uncertainties are 3–4$\times$ smaller than accuracy



HIP uncertainties

- Define systematic error $= \sqrt{(\text{absolute error})^2 - (\text{statistical})^2}$
  - this "systematic" doesn't include tracker misalignments, imperfect $\vec{B}$ map, DT internal misalignments
  - we expect statistical to scale with $\sqrt{N}$, but not systematic



Proposed constants

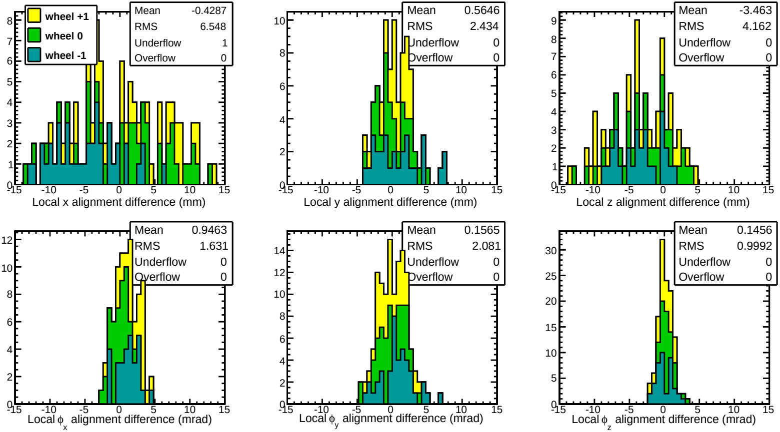
- Pablo and I did not get to talk about proposing constants, and I have not seen the MillePede Monte Carlo results
- What I know is:
  - the constants from the two implementations differ
  - the $\pm 1\ \sigma$ cut in residuals can distort results derived from slopes
  - the error matrix in SegmentAlignmentDerivatives4D.cc will cause errors in z (and propagate to y for wheels ± 1)
  - the HIP procedure is well-behaved in cosmic ray Monte Carlo
  - if there are global distortions in the tracker, it would not affect HIP and MP differently
- Therefore, I will propose the HIP results, show the validation, and list all of the known mysteries

  (All cuts and parameters for this alignment were listed on pages 3–4)

DB comparisons (1/5)

CRAFT_ALL_V4 – proposed constants

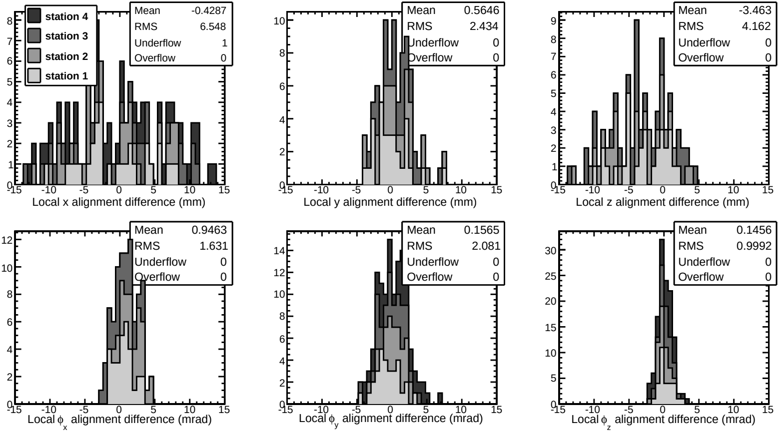
- CRAFT_ALL_V4 is before global alignment
- We have seen these large absolute δ_x corrections before: they preserve local alignment within sectors (like moving fingers)



DB comparisons (2/5)

CRAFT_ALL_V4 – proposed constants

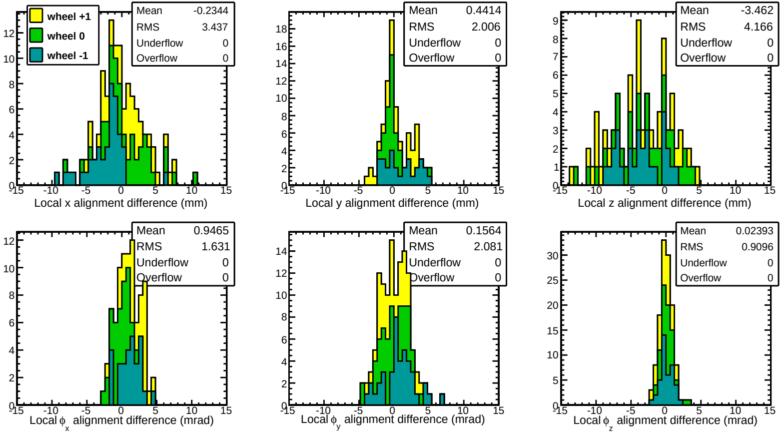
- CRAFT_ALL_V4 is before global alignment
- We have seen these large absolute δ_x corrections before: they preserve local alignment within sectors (like moving fingers)



DB comparisons (3/5)

CRAFT_ALL_V11 – proposed constants

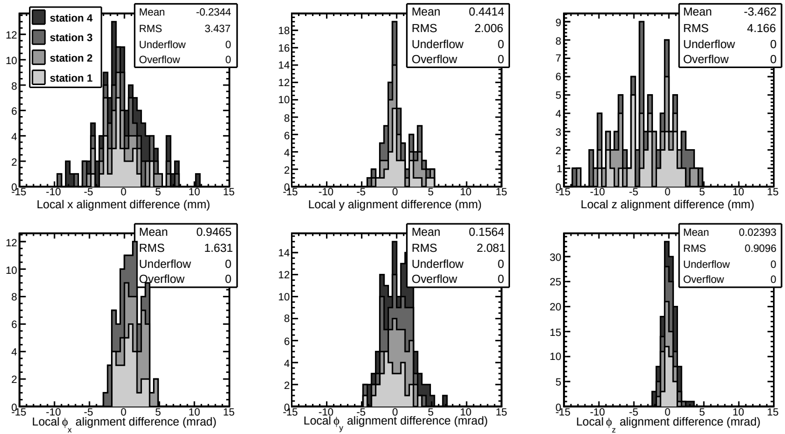
- CRAFT_ALL_V11 is the first global alignment
- The wheel rotation is a known effect, related solely to difference in momentum cuts (and also preserves local alignments):
  - old: $20 < p_T < 100$ GeV, new: $100 < p_T < 200$ GeV



DB comparisons (4/5)

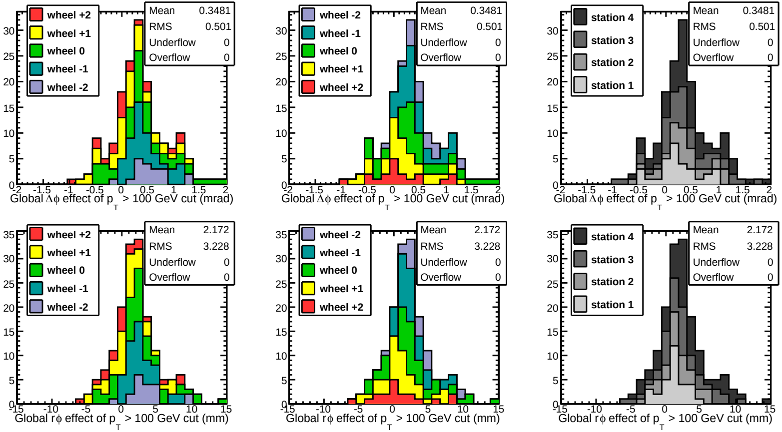
CRAFT_ALL_V11 – proposed constants

- CRAFT_ALL_V11 is the first global alignment
- The wheel rotation is a known effect, related solely to difference in momentum cuts (and also preserves local alignments):
  - old: $20 < p_T < 100$ GeV, new: $100 < p_T < 200$ GeV



Rotation with high p_T (5/5)

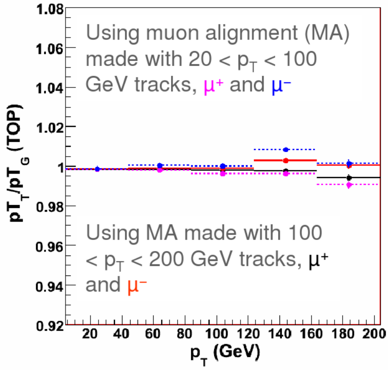
- These plots show the difference between low p_T and high p_T (everything else is the same; this is a systematics study)
  - global coordinates: $\Delta\phi$ (top) is rotation around beamline, $r\phi$ (bottom) is the same orientation for all chambers
- 0.35 mrad rotation, 0.04 mrad/m twist, and 3.2 mm spread

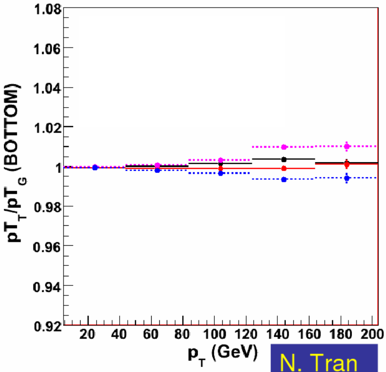


Studies of p_T effect (1/2)

Alignments from low and high p_T differ: how do we know which is right?

- Ratio of tracker p_T and globalMuon p_T vs. momentum in CRAFT
- Study repeated with low and high p_T alignments (from prev page)
- Alignment made with high p_T (solid red and black) yields more correct ratios (1.0) at all momenta



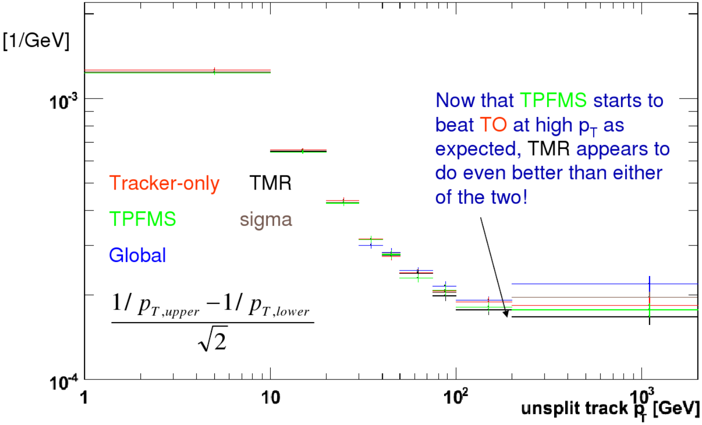


N. Tran

Studies of p_T effect (2/2)

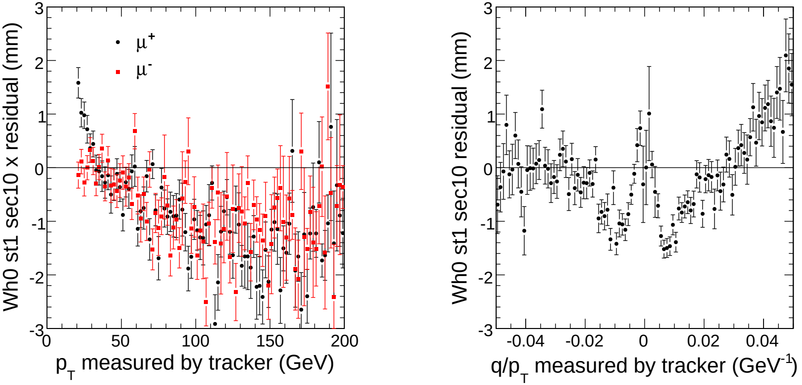
Alignments from low and high p_T differ: how do we know which is right?

- Cosmic track splitting: difference between top and bottom half of cosmic ray
- Tracks with station 1 muon hits (TPFMS and TMR) yield better resolution than tracker only (TO) for the first time!
  - this was not the case for the low-p_T alignment, or any previous alignments
- Highest-p_T bin in this study is statistically independent of 100–200 GeV alignment

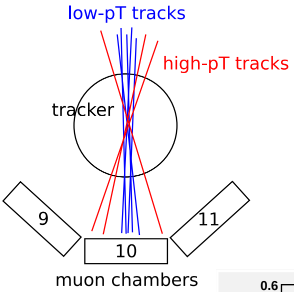


J. Tucker

p_T effect in raw residuals

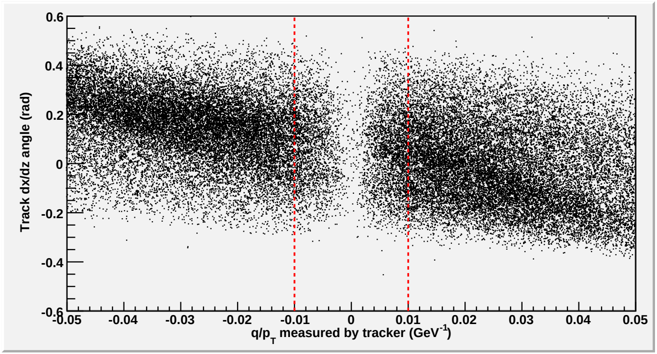


- Single chamber (wheel 0, station 1, sector 10, bottom of barrel)
- μ^+/μ^- splitting at low p_T is due to $\vec{B}(\vec{x})$ and dE/dx errors
- Charge-independent variation with p_T is not
- Not the same shape in all chambers

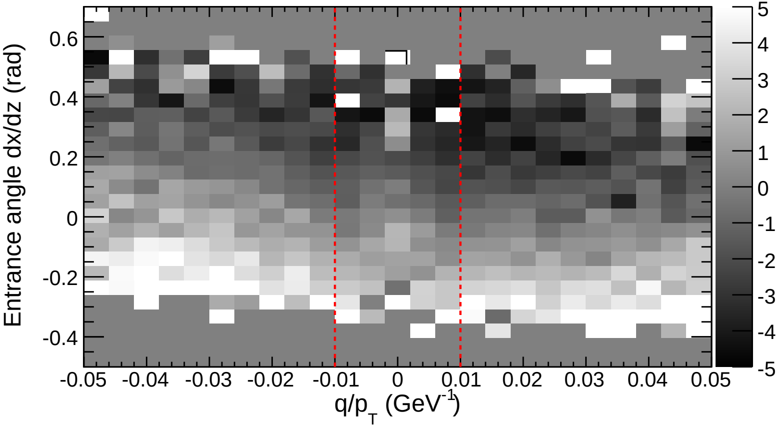


- Still looking at only one chamber, note that $\frac{dx}{dz}$ and p_T are related
- Expected because low-p_T muons are more vertically collimated by the Earth
- Unique to cosmic rays: in ϕ-symmetric collisions, p_T and $\frac{dx}{dz}$ will be independent

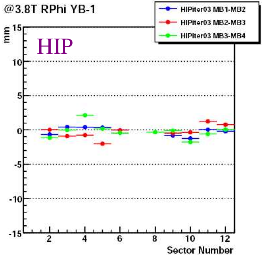
- Low-p_T band is sloped because of $\vec{B}$

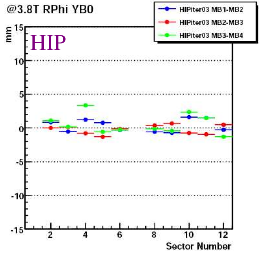


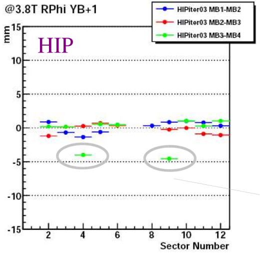
- Residuals (greyscale, mm) are a function of both p_T and $\frac{dx}{dz}$
  - sawtooth effect is vertical trend from dark to light
  - p_T effect is horizontal darkening in center
- Sawtooth and p_T effect may be related

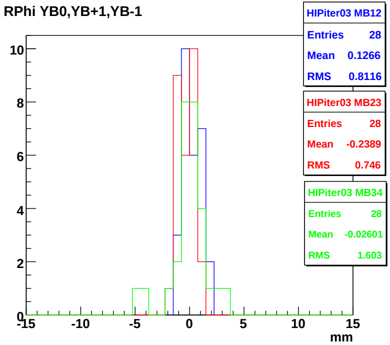


Verification with segments (1/2)





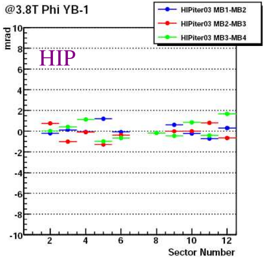


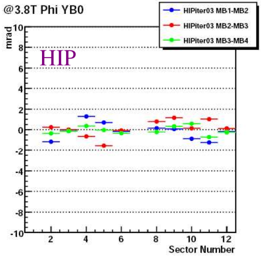


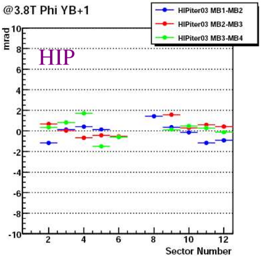
- Segment-matching among stations 1–3 yields $\sim$800 μm
- Station 4 RMS is dominated by a few outliers, mostly in sector 4

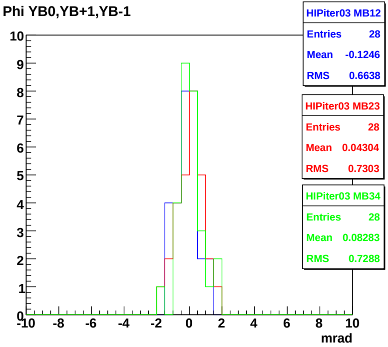
A. Calderon

Verification with segments (2/2)







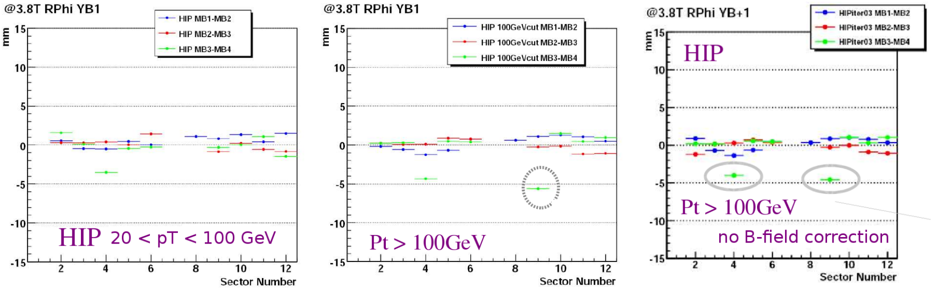


- Segment angle-matching is $\sim$0.7 mrad

A. Calderon

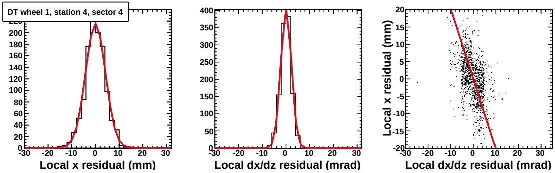
Station 4 outliers

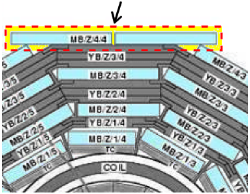
Segment-extrapolation plots:

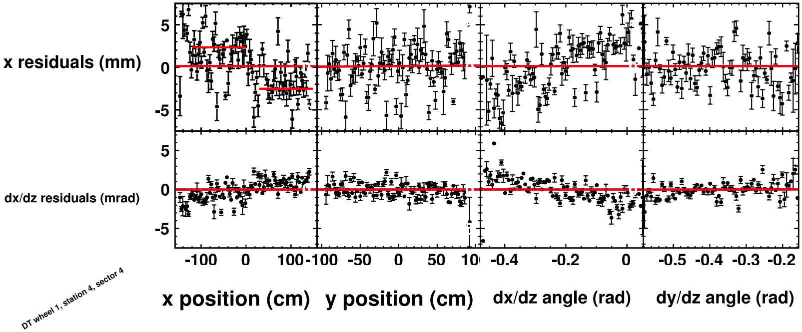


- Station 4, sector 4 is always an outlier
  - it has an apparent internal misalignment (next slide)
  - detailed fit results on next slide
- Wheel +1, station 4, sector 9 became an outlier at high p_T
  - low statistics + non-uniform coverage?
  - detailed fit results on in two slides

Wheel +1, station 4, sector 4

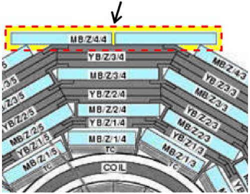


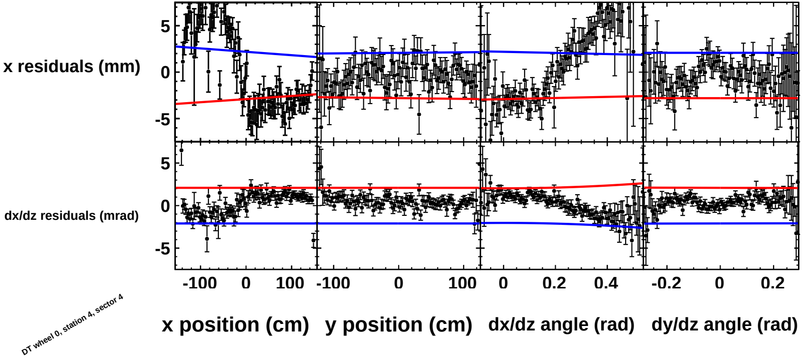


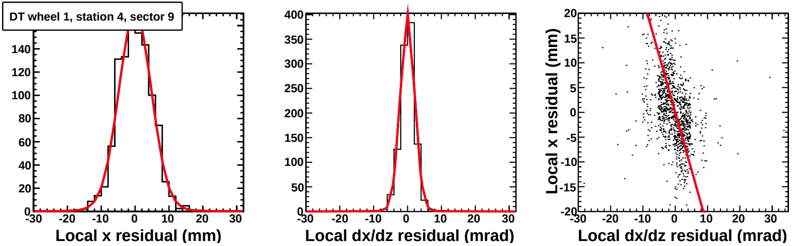


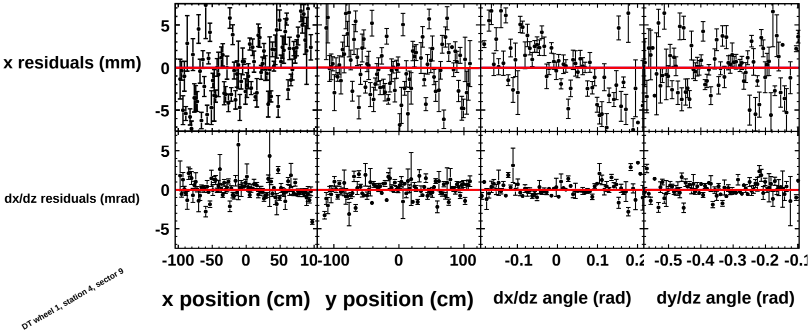
Reminder from Apr 27

- This is what wheel 0, station 4, sector 4 looked like with high statistics (low-p_T alignment)
- It *really* looks like a misalignment between the two halves of the chambers in this sector

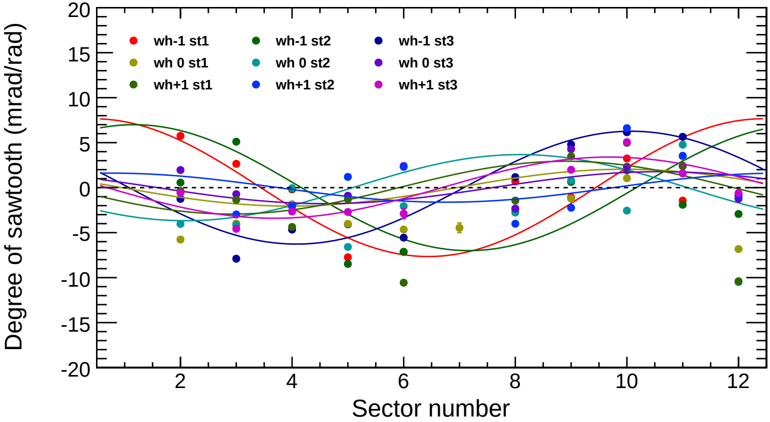





DT wheel 1, station 4, sector 9
Local x residual (mm)
Local dx/dz residual (mrad)
Local x residual (mm)
Local dx/dz residual (mrad)

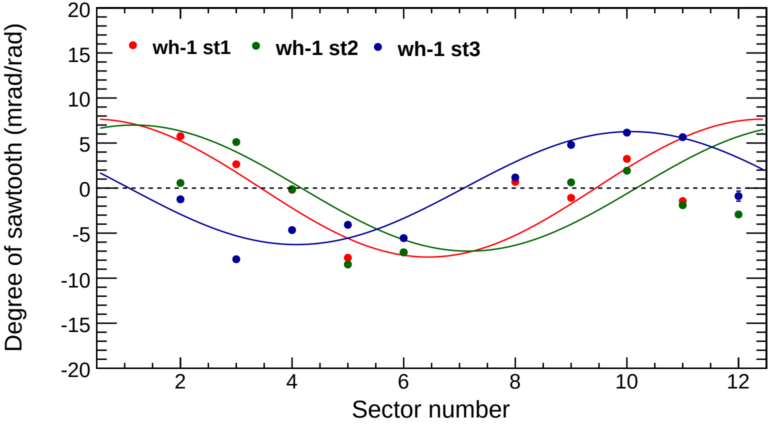

x residuals (mm)
dx/dz residuals (mrad)
DT wheel 1, station 4, sector 9
x position (cm)
y position (cm)
dx/dz angle (rad)
dy/dz angle (rad)

- Slope in $\Delta \frac{dx}{dz}$ versus $\frac{dx}{dz}$ which feeds into other diagnostic plots due to the correlation between Δx and $\Delta \frac{dx}{dz}$ and the correlation between x and $\frac{dx}{dz}$
- Not a rigid body misalignment of the whole chamber, but can be related to internal layer δ_x corrections

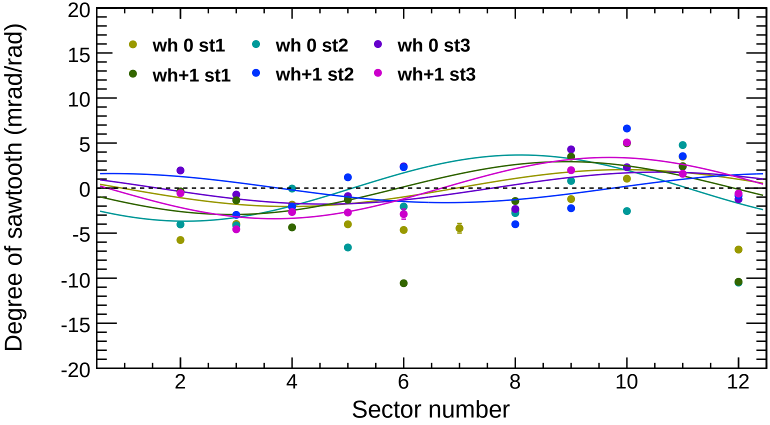


Sawtooth effect (2/3)

- Slope in $\Delta \frac{dx}{dz}$ versus $\frac{dx}{dz}$ which feeds into other diagnostic plots due to the correlation between Δx and $\Delta \frac{dx}{dz}$ and the correlation between x and $\frac{dx}{dz}$
- Not a rigid body misalignment of the whole chamber, but can be related to internal layer δ_x corrections
- Largest in wheel -1, with a sinusoidal structure



- Slope in $\Delta \frac{dx}{dz}$ versus $\frac{dx}{dz}$ which feeds into other diagnostic plots due to the correlation between Δx and $\Delta \frac{dx}{dz}$ and the correlation between x and $\frac{dx}{dz}$
- Not a rigid body misalignment of the whole chamber, but can be related to internal layer δ_x corrections
- Largest in wheel -1, with a sinusoidal structure



- Simultaneous solution of alignment and propagation effects
  (which are not easily separable due to convolution)
- Method verified in cosmics Monte Carlo with high accuracy (200 μm), including geometry-only test of residuals $\leftrightarrow$ alignment corrections matrix
- Alignment in data verified by:
  1. ratio of tracker p_T to globalmuon p_T: discovered source of rotation
  2. cosmic ray track splitting: first alignment which improves upon tracker
  3. segment extrapolation: 800 μm in stations 1–3

  (1) Nhan Tran, (2) Jordan Tucker and Nhan Tran, (3) Alicia Calderon
- What we don't understand:
  - origin of charge-independent variation of residuals with p_T (though we know that high p_T is more correct)
  - sawtooth effect (non rigid-body variation of residuals with $\frac{dx}{dz}$)
- These conditions are external to the alignment algorithm and should affect MillePede equally
- Note that alignment will need to be repeated, with exactly the same parameters and the new tracker alignment and APEs when they become available

Timeline of updates

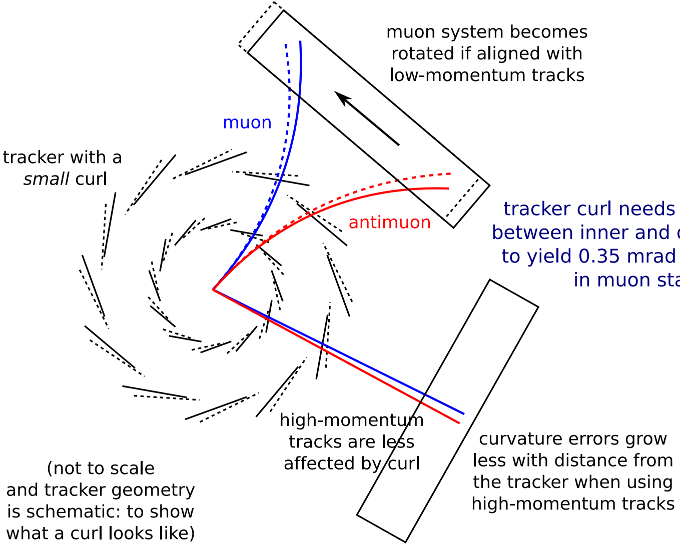
All dates correspond to talks where I presented the updates

Nov 11, 2008	First CRAFT globalMuon alignment attempt: combining residuals from all chambers in each wheel, observed rotation + twist
	Control $\vec{B}$ with q/p_T extrapolation
Nov 24	Used muon residuals to x-ray tracker, observed TEC misalignment
Jan 21, 2009	Split residuals by chamber, rotation + twist disappeared (low p_T)
	Gaussian $\otimes$ Lorentzian convolution to model residuals tails
	Detailed residuals maps show discontinuities at chamber boundaries: only evidence of global structure in tracks from TEC
	Excluded tracks from TID/TEC, control $\vec{B}$ with two-bin method
Jan 29	Signed-off x, y, ϕ_z chamber-by-chamber constants from 1-D fits with tails, only about half the chambers (now known as CRAFT_ALL_V11)
Jan 28 and Feb 5	First study of sawtooth: not a rigid-body misalignment (z or ϕ_y)
Feb 20	Detailed MC scenario based on CRAFT_ALL_V11 alignment
Mar 31, Apr 2, Apr 14	Updates in expanding 1-D fits into a combined 6-DOF fit
	Wrote 40-page track-based alignment note
Apr 27	Presented complete 6-DOF alignment with systematics studies and MC study (but low p_T), not accepted for sign-off
May 11	Discovered q-symmetric p_T dependence and origin of old rotation + twist, followed-up with resolution studies in POG
May 18	Discovered global structure in sawtooth distribution
May 25	Proposing a high-p_T HIP alignment for sign-off

CRAFT_ALL_V11 global alignment	This HIP alignment
Tight criteria for accepting an aligned chamber; only half of DTs passed	Loose criteria (5 hits and a successful fit), only 3 fail within selected region: wheels -1, 0, $+1$, all sectors except 1 and 7
x, y, ϕ_z only from independent 1-D fits	All 6 DOF from a combined fit, though station 4 is only x, ϕ_y, ϕ_z
Combining hits into segment-residuals only for their statistical properties	Also using angular information for tighter control of DOF
$20 < p_T < 100$ GeV	$100 < p_T < 200$ GeV
Control $\vec{B}$ with two-bin method	Temporarily turn off $\vec{B}$ control (not needed at this high momentum)
No residuals weights	Weight residuals by $(\chi^2/N_{\mathrm{dof}})^{-1}$
2 iterations	3 iterations (third not needed)
Require 10 tracker hits, no TID/TEC	Require 15 tracker hits (for synchronization with MillePede), no TID/TEC
CMSSW_2_2_7, tracker alignment, APEs, and $\vec{B}$ map of that time	CMSSW_2_2_11, new tracker alignment, APEs, $\vec{B}$ map
Internal DT alignment from CRAFT_ALL_V4	New internal DT alignment (with tracks-survey agreement)
Data source: first CRAFT reprocessing	Latest CRAFT tracker-pointing reprocessing

Tracker curl hypothesis

p_T-dependent rotation could be curl in tracker, if large enough

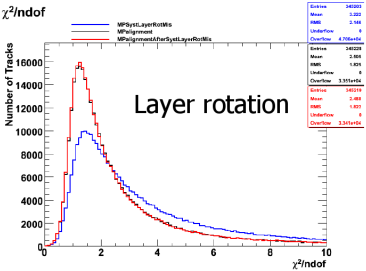


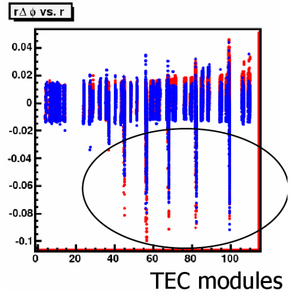
tracker curl needs to be 86 μrad between inner and outermost radii to yield 0.35 mrad misalignment in muon station 1

Tracker curl constraints

Black= MP starting object

Blue= misaligned Red= aligned on top of misalignment





- Studies performed in CRAFT data Zijin Guo, Roberto Castello
- Left: tracker tracks are sensitive to 300 μrad curl (blue: adding curl worsens χ^2 and red: re-aligning restores it)
- Right: also restores wafer positions within 150 μrad except TEC
  - TEC not used in muon alignment; not relevant here
  - restored chamber positions randomly distributed around zero: no *systematic* trend on the scale of 86 μrad

All the numbers

Relative to ideal in mm and mrad

wheel station sector	CRAFT_ALL_V4 (before global alignment) x, y, z, ϕ_x, ϕ_y, ϕ_z	CRAFT_ALL_V11 x, y, ϕ_z *(unaligned in italics)*	This HIP alignment x, y, z, ϕ_x, ϕ_y, ϕ_z *(unaligned in italics)*
-1, 1, 2	-5.28, -1.02, -3.54, 1.10, -1.65, -0.50,	*(0.19)*, -1.27, *(0.44)*,	1.88, -2.22, -3.85, 2.53, 0.41, 0.91,
-1, 1, 3	-3.14, -0.74, 2.09, 0.77, -1.17, -0.00,	1.33, -0.01, 0.48,	2.45, 0.32, 1.97, 0.53, -3.24, 0.63,
-1, 1, 4	-0.32, 0.28, 4.89, 1.98, 0.93, -0.29,	1.54, 1.94, -0.32,	2.17, 3.16, 3.56, 1.86, -0.20, -0.10,
-1, 1, 5	4.51, -0.38, 1.78, 0.29, 1.63, -0.35,	3.82, *(1.78)*, -0.88,	4.57, 2.09, 4.47, -0.63, 3.33, -1.46,
-1, 1, 6	0.64, -1.24, -2.95, 0.50, 1.83, -0.80,	*(-0.26)*, -1.24, *(-0.80)*,	2.43, 0.07, -2.55, -0.63, 5.16, -0.35,
-1, 1, 8	-1.90, -0.04, -3.37, -0.95, -2.13, 0.18,	0.38, 1.39, -1.38,	1.49, 3.78, -3.34, 0.49, -0.46, -2.36,
-1, 1, 9	-2.24, -1.16, 1.84, -0.58, -1.78, 0.44,	0.27, 0.18, -1.05,	1.26, 0.47, 5.11, -0.51, -1.57, -1.94,
-1, 1, 10	-0.08, 0.36, 5.31, 1.91, 0.69, -0.02,	2.29, 0.24, 0.13,	3.99, -1.82, 10.23, 1.25, 0.26, 0.32,
-1, 1, 11	3.60, -0.46, 0.96, 1.48, 2.49, -0.11,	7.45, -2.79, 0.20,	9.74, -7.72, 7.61, -1.44, 2.10, 0.22,
-1, 1, 12	2.63, 0.45, -3.90, 1.44, 2.54, 0.02,	6.57, 0.56, 0.92,	9.92, -4.07, 4.77, -0.48, 2.50, 0.84,
-1, 2, 2	-5.29, 2.12, -4.56, 0.22, -1.78, 0.27,	1.11, 0.91, 1.19,	3.32, -2.27, -2.67, -1.73, -4.77, 1.32,
-1, 2, 3	-4.37, -0.74, 0.77, -0.49, -1.67, -0.67,	*(1.97)*, -0.81, *(0.19)*,	3.48, -0.66, 0.83, -3.37, -3.21, 0.45,
-1, 2, 4	-1.63, -0.26, 3.75, -0.08, -1.36, -0.15,	1.15, 1.03, -0.16,	2.77, 1.86, 2.97, -1.43, -2.28, -0.06,
-1, 2, 5	4.03, -2.28, 1.60, 0.06, 0.61, -0.31,	*(1.81)*, *(-0.55)*, *(0.37)*,	3.00, -2.31, 8.93, -3.19, 2.45, 0.16,
-1, 2, 6	3.06, -0.73, -3.87, -0.53, 1.10, 0.29,	1.40, -4.08, -1.17,	1.98, -3.04, -0.90, -3.14, 4.18, -0.87,
-1, 2, 8	-0.83, -1.06, -4.94, -0.98, -2.36, -0.65,	*(0.97)*, -1.06, *(-0.65)*,	*(-0.83, -1.06, -4.94, -0.98, -2.36, -0.65)*,
-1, 2, 9	-1.99, -1.28, 0.81, -1.20, -1.92, 0.25,	*(-1.99)*, *(-1.28)*, *(0.25)*,	0.88, 1.00, 4.92, -2.64, -2.41, -0.76,
-1, 2, 10	-0.15, -0.83, 4.97, -0.10, 0.10, 0.26,	1.51, *(-0.83)*, 0.26,	4.90, -3.58, 11.11, -0.58, -0.34, 0.42,
-1, 2, 11	2.40, -0.35, 1.30, -0.67, 1.67, -0.13,	6.55, -4.02, 0.68,	11.24, -8.12, 8.29, -3.30, 1.19, -0.59,
-1, 2, 12	0.90, -0.44, -4.58, 1.13, 1.79, -0.77,	5.17, -1.26, 0.51,	10.55, -5.11, 3.62, -3.10, 0.50, 1.38,
-1, 3, 2	-4.15, -2.75, -4.37, -0.17, -1.19, -0.26,	3.60, 0.68, 1.23,	5.87, -3.13, -0.95, -1.57, -3.87, 1.12,
-1, 3, 3	-3.17, -1.33, 1.20, 0.36, -1.20, 0.03,	*(-3.60)*, -1.33, *(0.03)*,	5.80, -3.29, 5.28, -1.23, -3.04, 0.27,
-1, 3, 4	-0.19, -0.11, 2.82, 0.06, -0.82, 0.18,	1.99, 2.38, 0.29,	3.60, 0.79, 6.54, 1.36, -1.45, 0.29,
-1, 3, 5	3.53, -0.76, 1.61, -0.05, 1.71, -0.03,	1.05, *(0.43)*, -0.64,	0.79, 2.08, 3.17, -1.47, 1.92, 0.99,
-1, 3, 6	7.54, -1.53, -3.92, -0.03, 1.49, 0.62,	3.79, -2.86, -0.38,	4.06, -2.96, -1.01, -2.95, 3.13, -0.32,

All the numbers

Relative to ideal in mm and mrad

wheel station sector	CRAFT_ALL_V4 (before global alignment) x, y, z, ϕ_x, ϕ_y, ϕ_z	CRAFT_ALL_V11 x, y, ϕ_z *(unaligned in italics)*	This HIP alignment x, y, z, ϕ_x, ϕ_y, ϕ_z *(unaligned in italics)*
-1, 3, 8	1.10, -1.21, -3.72, -0.59, -1.95, -0.54,	*(1.77)*, -0.01, *(-1.96)*,	1.83, 1.81, -3.71, 0.67, -2.50, -1.31,
-1, 3, 9	-1.81, -2.27, 2.31, -0.16, -1.79, 0.48,	0.47, -1.34, -0.70,	1.60, -1.51, 6.65, 0.20, -3.24, -1.49,
-1, 3, 10	0.10, 0.85, 5.31, -0.22, 0.71, 0.42,	1.43, 2.83, 0.19,	4.72, -0.62, 12.89, 0.35, -0.48, 0.63,
-1, 3, 11	1.42, 0.14, 1.81, -0.16, 2.00, 0.16,	5.17, -2.79, 0.89,	10.75, -7.02, 8.72, -2.12, 0.30, -0.94,
-1, 3, 12	0.24, -0.06, -4.60, 0.26, 2.44, -0.75,	4.52, -1.48, 1.42,	11.20, -3.30, 0.30, -0.49, 2.17, 0.67,
-1, 4, 2	-2.42, -0.81, -5.07, -0.34, -0.50, -0.54,	5.74, *(-0.81)*, -0.54,	9.74, -0.82, -5.03, -0.34, -5.53, -0.55,
-1, 4, 3	-1.15, -0.26, -1.27, -0.40, -0.86, 0.30,	8.48, *(-0.26)*, 0.30,	9.92, -0.26, -1.17, -0.39, -7.59, -0.43,
-1, 4, 4	1.24, 0.04, 1.88, 0.19, -0.28, 0.51,	7.19, *(0.05)*, 0.51,	8.71, 0.05, 1.93, 0.19, -4.79, 1.19,
-1, 4, 5	4.05, -0.66, 1.04, 1.04, 0.89, -0.56,	0.70, *(-0.67)*, -0.56,	0.53, -0.66, 1.05, 1.04, -1.27, -2.08,
-1, 4, 6	3.84, -1.47, -4.56, -0.08, 0.77, -0.76,	*(3.84)*, *(-1.47)*, *(-0.76)*,	-2.33, -1.47, -4.55, -0.08, -0.93, -1.39,
-1, 4, 8	-0.39, -2.54, -3.70, -1.04, -0.97, -0.58,	0.77, *(-2.54)*, -0.58,	0.20, -2.54, -3.70, -1.03, -0.62, -2.08,
-1, 4, 9	-1.20, 0.22, 1.68, -1.05, -1.19, 0.02,	-0.21, *(0.22)*, 0.02,	0.20, 0.23, 1.69, -1.05, 1.62, -1.68,
-1, 4, 10	-0.95, 1.05, 4.22, -0.93, 0.10, 0.03,	-2.11, *(1.06)*, 0.03,	2.28, 1.05, 4.24, -0.93, -2.59, -0.66,
-1, 4, 11	1.92, -0.74, 2.13, 0.27, 2.02, -0.36,	4.90, *(-0.73)*, -0.36,	12.16, -0.75, 2.15, 0.27, 6.09, 0.49,
-1, 4, 12	-2.51, -2.00, -2.32, -0.03, 1.19, 0.01,	2.58, *(-1.97)*, 0.01,	10.39, -1.99, -2.31, -0.04, -3.46, 2.06,
-1, 4, 13	2.01, -1.05, 2.90, -0.22, 0.22, -0.31,	1.90, *(-1.07)*, -0.31,	3.69, -1.05, 2.92, -0.22, -2.92, 0.47,
-1, 4, 14	-1.84, 1.59, 5.28, 0.19, 0.28, 0.05,	1.66, *(1.59)*, 0.05,	5.75, 1.60, 5.29, 0.19, -2.11, 1.63,
0, 1, 2	6.69, 0.83, -2.23, -0.81, 2.41, 0.44,	*(1.27)*, 1.23, *(-0.25)*,	-0.08, 2.15, -0.71, 0.66, 6.79, 0.36,
0, 1, 3	5.68, 1.11, 5.83, -0.28, 1.80, 0.67,	0.74, 1.53, -0.69,	-0.21, 2.16, 6.69, -0.23, 4.71, -0.83,
0, 1, 4	-0.96, -2.22, 8.49, 0.39, -0.21, -0.32,	0.65, -3.82, -0.12,	2.00, -4.80, 7.51, 1.19, 2.36, -0.10,
0, 1, 5	5.69, 1.21, 5.02, 0.26, 3.00, -0.31,	2.79, 2.02, 0.02,	3.36, 1.61, 3.91, 0.89, 3.28, -0.50,
0, 1, 6	-5.34, 1.27, -4.36, -0.00, -2.92, -0.48,	-2.24, 0.26, -1.24,	-2.02, 0.83, -1.67, -0.76, -5.04, -1.41,
0, 1, 8	-3.84, 0.30, -6.65, 0.28, -3.81, -0.35,	-4.11, *(-1.36)*, -1.05,	-5.39, -1.90, -4.06, -0.51, -2.45, -2.02,
0, 1, 9	-3.22, -0.14, 3.21, 0.08, -2.97, -0.14,	*(-4.37)*, -0.13, *(-0.14)*,	-3.34, -0.12, 8.76, -0.12, -2.82, -0.89,
0, 1, 10	-0.70, 0.73, 5.46, -0.18, 1.04, -0.54,	-3.18, 2.76, -0.68,	-4.55, 3.30, 14.19, 1.21, 1.97, -1.10,

All the numbers

Relative to ideal in mm and mrad

wheel station sector	CRAFT_ALL_V4 (before global alignment) x, y, z, ϕ_x, ϕ_y, ϕ_z	CRAFT_ALL_V11 x, y, ϕ_z *(unaligned in italics)*	This HIP alignment x, y, z, ϕ_x, ϕ_y, ϕ_z *(unaligned in italics)*
0, 1, 11	-2.79, -0.49, 3.52, -0.96, -3.73, 0.06,	-6.42, 1.35, 0.24,	-10.26, 2.26, 8.83, -0.36, -2.86, 0.08,
0, 1, 12	4.18, -0.13, -7.80, 0.83, 3.91, 0.16,	11.81, -1.33, -0.56,	14.49, -1.25, -2.88, 0.43, 3.22, -0.36,
0, 2, 2	5.63, 0.31, -4.74, -0.26, 2.21, 0.16,	1.62, 0.11, -0.09,	-1.69, 1.13, -0.76, -0.86, 2.32, -0.14,
0, 2, 3	5.27, -1.41, 4.60, -0.45, 2.57, 0.41,	-0.52, -1.35, 0.13,	-2.43, -0.75, 5.60, -1.92, 3.43, 1.22,
0, 2, 4	-0.21, -2.01, 8.59, 0.19, -0.97, -0.39,	2.25, *(-2.00),* -0.39,	4.09, -6.83, 4.44, 1.06, -3.90, -0.09,
0, 2, 5	5.57, 1.21, 5.73, 0.48, 2.51, -0.14,	2.35, 1.80, -0.24,	3.54, 2.06, 5.92, -0.23, 0.50, 0.80,
0, 2, 6	-5.24, 1.27, -1.75, -0.57, -3.03, 0.54,	-0.72, -1.25, -0.22,	-0.68, -0.33, -2.15, -2.58, -4.90, 0.38,
0, 2, 8	-2.73, 0.93, -5.64, 0.12, -3.72, 0.13,	*(-3.28),* -1.61, *(-0.61),*	-4.33, -1.90, -3.43, 0.47, -3.08, -1.25,
0, 2, 9	-2.67, 1.34, 2.36, 0.00, -3.37, -0.23,	-2.71, 0.89, -0.44,	-3.03, 1.34, 9.51, 0.06, -3.02, 0.24,
0, 2, 10	0.55, 1.32, 6.66, -0.68, 0.93, -0.12,	0.72, *(2.97),* -0.29,	-2.42, 3.13, 19.34, -1.39, -0.14, -0.20,
0, 2, 11	-1.98, 0.06, 3.29, -0.31, -3.19, -0.01,	-3.56, 2.39, 0.13,	-9.93, 3.71, 10.15, -0.47, -4.86, 1.19,
0, 2, 12	4.28, 0.74, -6.53, 0.09, 3.66, -0.08,	11.77, -1.38, -1.00,	16.39, -1.04, 0.92, -0.14, 1.77, 0.70,
0, 3, 2	5.43, 0.59, -4.23, -0.73, 1.88, 1.13,	*(-1.53),* -0.30, *(0.15),*	-5.34, 0.80, -6.72, 1.43, 4.17, 1.07,
0, 3, 3	4.16, 0.69, 5.01, 0.10, 2.10, 0.26,	-3.66, *(0.67),* 0.26,	-6.07, 0.32, 5.05, 2.63, 4.23, -0.23,
0, 3, 4	0.43, 0.96, 10.25, -0.05, -0.49, -0.35,	2.37, -2.63, 0.12,	4.85, -2.06, 7.47, -1.22, -0.23, -0.70,
0, 3, 5	6.16, 1.81, 6.29, 0.45, 2.54, -0.42,	0.59, *(4.62),* -0.32,	2.30, 3.96, 3.25, -0.71, 4.52, -0.39,
0, 3, 6	-4.73, 1.27, -3.45, -0.25, -2.39, -0.30,	0.98, -4.13, -0.88,	1.68, -2.70, -5.59, -0.45, -3.99, -0.62,
0, 3, 8	-3.13, 1.31, -4.89, -0.27, -2.61, 0.11,	-3.88, 0.66, -0.66,	-6.63, -0.42, 1.62, 0.59, -3.73, -1.24,
0, 3, 9	-1.69, 0.42, 3.22, 0.32, -2.59, 0.30,	-2.02, -0.09, 0.00,	-3.24, 1.33, 7.57, 0.42, -1.94, -0.02,
0, 3, 10	-1.09, 1.03, 7.39, -0.19, 0.74, -0.22,	-1.34, 2.55, -0.10,	-4.96, 2.89, 18.28, 1.77, 0.81, -0.45,
0, 3, 11	-3.81, 1.16, 4.06, -0.41, -2.28, -0.16,	-5.75, *(1.54),* -0.38,	-13.04, 3.38, 13.69, 0.20, 2.00, -0.14,
0, 3, 12	4.24, -0.99, -5.93, 0.28, 3.19, 0.16,	12.47, -3.75, -0.98,	17.98, -3.72, -2.11, 1.56, -0.56, 0.35,
0, 4, 2	3.17, -0.48, -6.37, -0.54, 1.46, -0.20,	-3.58, *(-0.48),* -0.20,	-8.14, -0.48, -6.33, -0.54, 4.38, -0.17,
0, 4, 3	2.79, 1.37, 1.50, -0.17, 1.55, 0.40,	-6.40, *(1.36),* 0.40,	-9.83, 1.37, 1.52, -0.18, 2.68, -0.69,
0, 4, 4	2.06, 0.16, 6.59, 0.08, -0.64, -0.35,	7.95, *(0.15),* -0.35,	10.88, 0.15, 6.60, 0.08, -2.26, -0.77,

Relative to ideal in mm and mrad

wheel station sector	CRAFT_ALL_V4 (before global alignment) x, y, z, ϕ_x, ϕ_y, ϕ_z	CRAFT_ALL_V11 x, y, ϕ_z *(unaligned in italics)*	This HIP alignment x, y, z, ϕ_x, ϕ_y, ϕ_z *(unaligned in italics)*
0, 4, 5	5.43, 0.61, 4.83, -0.09, 1.47, -0.36,	-1.01, *(0.61)*, -0.36,	-0.53, 0.61, 4.85, -0.09, -0.62, -0.46,
0, 4, 6	-4.91, 1.27, -4.91, -0.70, -1.35, -0.73,	1.28, *(1.25)*, -0.73,	2.52, 1.26, -4.90, -0.70, -2.10, -0.91,
0, 4, 8	-2.13, 1.19, -9.72, -0.14, 0.94, 0.10,	*(-2.13), (1.19), (0.10),*	-5.64, 1.20, -9.71, -0.14, 3.02, -2.93,
0, 4, 9	-2.27, -2.96, 4.94, 0.05, -2.96, -0.04,	-1.86, *(-2.97)*, -0.04,	-4.17, -2.96, 4.94, 0.05, -1.25, -1.42,
0, 4, 10	-2.10, 1.21, 7.99, -0.74, 0.51, -0.23,	0.25, *(1.22)*, -0.23,	-2.43, 1.22, 7.99, -0.74, -1.05, 0.26,
0, 4, 11	-3.99, 1.26, 4.84, 0.62, -2.24, -0.38,	-3.22, *(1.26)*, -0.38,	-13.85, 1.26, 4.82, 0.62, -0.74, -0.27,
0, 4, 12	3.65, -0.13, -5.10, 1.31, 1.26, -0.43,	10.82, *(-0.14)*, -0.43,	19.14, -0.14, -5.11, 1.31, 0.38, -1.49,
0, 4, 13	2.69, 1.15, 6.88, -0.15, 0.22, 0.08,	*(2.69), (1.15), (0.08),*	4.66, 1.16, 6.88, -0.15, 1.54, -0.59,
0, 4, 14	-1.28, -0.60, 3.34, -0.27, -4.58, -0.16,	-1.75, *(-0.61)*, -0.16,	-7.94, -0.61, 3.32, -0.25, -7.10, -2.79,
1, 1, 2	5.27, -0.75, -3.42, 1.67, 1.55, -1.00,	0.55, *(-0.22)*, -1.93,	0.52, 0.45, -3.38, 1.60, 3.52, -2.42,
1, 1, 3	5.27, -2.40, 2.94, -0.22, 1.35, 0.04,	0.89, -1.66, -0.41,	1.52, -1.18, 4.03, -2.78, 2.85, -1.34,
1, 1, 4	0.01, -1.72, 5.88, 1.44, -0.57, -0.18,	-1.10, -0.66, 0.11,	-1.64, 1.82, 4.06, -1.71, -1.32, -0.13,
1, 1, 5	-3.54, -2.43, 2.43, 1.11, -2.14, 0.64,	-1.35, -4.40, 0.62,	-0.95, -3.90, 1.39, -0.20, -3.17, 0.66,
1, 1, 6	-2.93, -2.37, -3.06, 1.38, -2.00, -0.25,	*(-2.93), (-2.37), (-0.25),*	1.79, -4.53, -0.03, -1.76, -5.26, -0.15,
1, 1, 8	4.27, -1.79, -3.36, 0.31, 2.01, 0.38,	5.32, -0.97, 0.93,	7.97, -1.47, 1.75, 0.34, 0.52, 1.18,
1, 1, 9	2.82, -1.67, 2.76, 0.40, 1.65, 0.01,	2.88, 0.24, -0.09,	5.78, -2.17, 10.68, -1.19, 3.12, 0.27,
1, 1, 10	0.10, -1.10, 4.61, -0.07, 0.41, 0.11,	0.00, 1.83, 0.24,	-0.88, -1.56, 14.39, -1.12, 1.14, 0.87,
1, 1, 11	-2.51, -0.45, 2.29, -0.31, -2.23, 0.02,	-6.07, 1.42, -0.48,	-8.26, 0.30, 7.41, -1.93, -0.17, -0.59,
1, 1, 12	-3.94, -1.75, -4.34, 0.32, -1.96, 0.60,	-8.19, *(-1.76)*, -0.33,	-12.01, -4.02, -0.68, -1.25, -1.04, 0.60,
1, 2, 2	5.93, -2.42, -3.38, 0.16, 1.92, -0.04,	1.17, -3.03, -0.75,	*(5.93, -2.42, -3.38, 0.16, 1.92, -0.04),*
1, 2, 3	4.80, -1.09, 2.01, -0.10, 1.62, -0.35,	0.46, -1.52, -0.63,	-0.98, -1.61, 5.99, -3.10, 2.11, 0.07,
1, 2, 4	0.24, -1.16, 3.55, 0.78, -0.45, -0.76,	-0.88, -0.70, -0.89,	-1.51, 2.44, 3.66, -2.70, 1.49, -0.58,
1, 2, 5	-2.76, -0.59, 2.97, 0.17, -1.92, 0.03,	0.46, -4.36, 0.03,	0.72, -2.50, -0.62, -3.70, -3.12, -0.14,
1, 2, 6	-2.73, -0.33, -3.25, 0.30, -1.88, 0.07,	2.77, -1.11, -0.01,	4.15, -0.11, -4.49, -4.23, -4.11, -0.57,
1, 2, 8	4.19, 0.10, -3.94, -0.37, 2.08, 0.25,	5.98, *(-0.55)*, 1.09,	8.43, -2.36, 5.43, -3.79, 2.43, 0.24,

All the numbers

Relative to ideal in mm and mrad

wheel station sector	CRAFT_ALL_V4 (before global alignment) x, y, z, ϕ_x, ϕ_y, ϕ_z	CRAFT_ALL_V11 x, y, ϕ_z *(unaligned in italics)*	This HIP alignment x, y, z, ϕ_x, ϕ_y, ϕ_z *(unaligned in italics)*
1, 2, 9	4.09, -1.50, 1.52, 0.26, 1.90, 0.13,	4.28, -1.17, 0.47,	6.88, -4.47, 11.85, -2.79, 1.97, -0.06,
1, 2, 10	0.38, 0.63, 3.81, -0.44, 0.21, 0.34,	2.46, 3.04, 0.36,	0.09, 0.11, 13.51, -2.14, -1.12, 0.97,
1, 2, 11	1.96, -0.12, 1.39, -0.40, -2.13, 0.48,	-0.86, 1.19, -0.11,	-5.13, -2.11, 10.24, -2.46, -2.46, 1.11,
1, 2, 12	0.22, -1.23, -3.77, 0.35, -2.15, -0.05,	*(-3.05), (-1.88), (-0.79),*	-8.11, -1.96, -1.64, -2.38, -1.00, 0.05,
1, 3, 2	5.76, -2.34, -2.53, -0.35, 1.34, 0.57,	-1.83, -3.80, -0.66,	-2.67, -3.09, -1.34, 0.13, 3.58, -0.33,
1, 3, 3	3.41, -1.59, 1.37, -0.41, 1.57, -0.03,	-3.10, *(-2.31),* 0.07,	-3.79, -2.01, 5.31, -2.07, 3.37, -1.33,
1, 3, 4	-0.03, 0.16, 3.85, -0.51, -0.37, 0.06,	-1.25, -2.59, -1.21,	-2.29, 1.25, 2.91, -2.38, 0.94, 0.41,
1, 3, 5	-3.07, -0.88, 2.43, 0.59, -1.01, -0.23,	1.04, -6.71, -0.26,	1.34, -3.30, -2.06, -2.49, -3.03, -0.74,
1, 3, 6	-4.47, -0.49, -3.18, -0.16, -1.44, 0.01,	1.79, -2.24, -0.12,	3.72, -0.70, -5.39, -3.74, -2.68, -0.66,
1, 3, 8	3.06, -0.64, -4.56, -0.42, 1.95, 0.21,	*(2.29),* -0.64, *(0.21),*	*(3.06, -0.64, -4.56, -0.42, 1.95, 0.21),*
1, 3, 9	2.66, -1.81, 2.12, 0.57, 1.59, -1.05,	1.37, *(-0.28),* 0.23,	5.68, -3.20, 11.96, 0.16, 2.07, -1.00,
1, 3, 10	-1.64, -0.20, 4.15, -0.42, 0.58, 0.25,	0.21, 1.49, -0.29,	-1.70, -1.70, 17.57, -3.80, -1.56, -0.59,
1, 3, 11	0.17, -0.62, 1.71, -0.62, -2.08, 0.23,	-3.56, 1.00, -0.28,	-8.35, -2.59, 12.99, -0.27, -1.18, -0.06,
1, 3, 12	-1.43, -2.02, -4.96, -0.62, -2.04, 0.29,	-6.06, -3.10, -1.87,	-12.38, -2.96, -1.32, 1.24, 0.74, -0.98,
1, 4, 2	2.87, -2.72, -4.73, 0.00, 0.55, -0.80,	-5.09, *(-2.72),* -0.80,	-7.88, -2.71, -4.73, 0.00, 1.05, -1.13,
1, 4, 3	1.74, -1.78, 0.54, 0.07, 0.89, -0.52,	-5.71, *(-1.78),* -0.52,	-7.20, -1.77, 0.56, 0.06, 4.13, -1.92,
1, 4, 4	-0.29, 0.38, 3.63, -0.19, 0.96, 0.23,	-6.17, *(0.37),* 0.23,	-8.08, 0.38, 3.64, -0.20, 3.10, -0.95,
1, 4, 5	-2.73, -0.13, 2.02, 0.41, -0.48, -0.26,	2.08, *(-0.13),* -0.26,	3.36, -0.13, 2.04, 0.41, -4.45, 1.01,
1, 4, 6	-3.33, -1.17, -3.87, 0.48, -0.98, -0.54,	4.37, *(-1.17),* -0.54,	6.60, -1.18, -3.86, 0.48, -1.78, 0.26,
1, 4, 8	0.22, -0.18, -3.92, 0.09, 0.61, -0.21,	2.92, *(-0.16),* -0.21,	6.50, -0.18, -3.92, 0.09, -0.78, 2.00,
1, 4, 9	2.60, -1.45, 1.74, -0.30, 1.10, 0.23,	0.94, *(-1.43),* 0.23,	6.11, -1.45, 1.73, -0.30, 1.54, 0.71,
1, 4, 10	-0.53, -1.67, 3.56, 0.64, -1.33, -0.43,	2.79, *(-1.67),* -0.43,	1.82, -1.67, 3.57, 0.63, -2.71, 1.92,
1, 4, 11	0.17, -0.62, 1.71, -0.62, -2.08, 0.23,	-5.77, *(-0.62),* 0.23,	-13.28, -0.62, 1.69, -0.62, -0.54, -0.51,
1, 4, 12	-2.47, -1.36, -3.98, 0.31, -2.05, -0.78,	-6.48, *(-1.37),* -0.78,	-13.63, -1.35, -3.98, 0.31, 1.90, -1.57,
1, 4, 13	-1.18, -0.33, 3.31, -0.00, -0.59, -0.31,	0.06, *(-0.32),* -0.31,	-1.54, -0.33, 3.31, -0.00, -0.78, 1.25,
1, 4, 14	-0.57, -1.05, 2.15, -1.92, 1.85, -0.39,	*(-0.57), (-1.05), (-0.39),*	-3.55, -1.04, 2.18, -1.92, -1.65, 0.06,