



Proposed alignments for barrel and endcap

Jim Pivarski

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- ▶ Final studies and validation of the barrel alignment
- ▶ Presentation of the endcap disk alignment

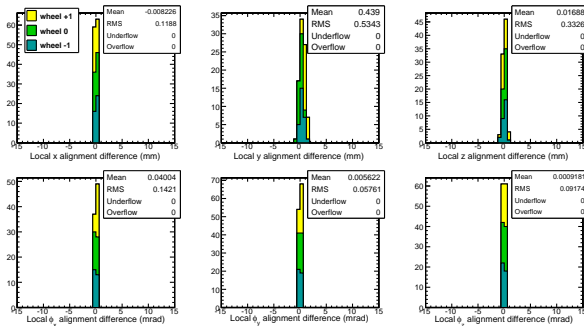


Apr 27 $\xrightarrow{\text{increase } p_T \text{ cut}}$ May 25 $\xrightarrow{\text{use final tracker}}$ May 29

twisted barrel about 0.35 mrad translated chambers with $\sigma \sim 2$ mm, no rotations

Unimportant corrections

- $\vec{B}(\vec{x})$ correction when $100 < p_T < 200$ GeV
- Using the final tracker APEs, in addition to final tracker alignment:



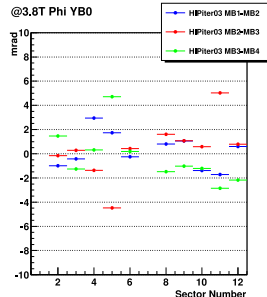
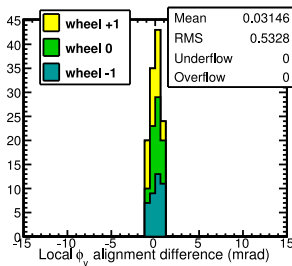
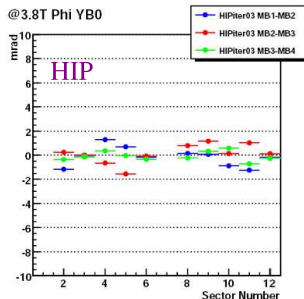


Difference in angle between station A and station B , measured by segments:

May 25

changes in DB

May 29?



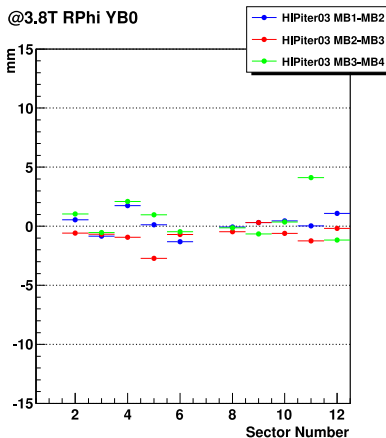
A. Calderon

- ▶ How can segment differences change by more than 2 mrad when no angle was moved in the DB by more than 1 mrad?
- ▶ Something seems to have gone wrong in this test; possibly configured incorrectly (very short timescale)

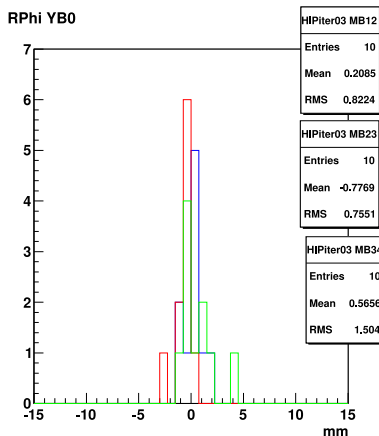


- ▶ Not admissible because of error observed in ϕ_y plots, but x plots by themselves do not indicate worse resolution
(previously: 0.8 mm in stations 1–3, 1.6 mm station 4 due to internal structure)

@3.8T RPhi YB0

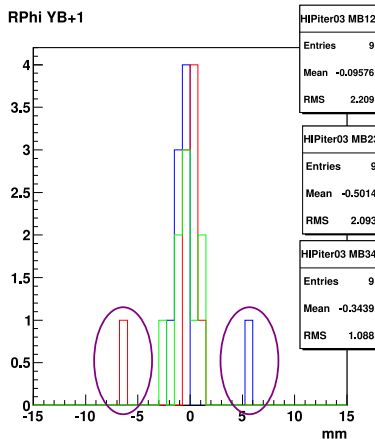
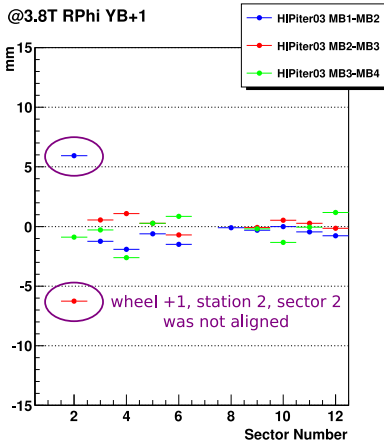


RPhi YB0





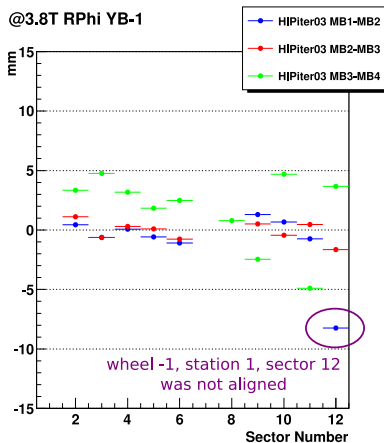
- ▶ Not admissible because of error observed in ϕ_y plots, but x plots by themselves do not indicate worse resolution
(previously: 0.8 mm in stations 1–3, 1.6 mm station 4 due to internal structure)



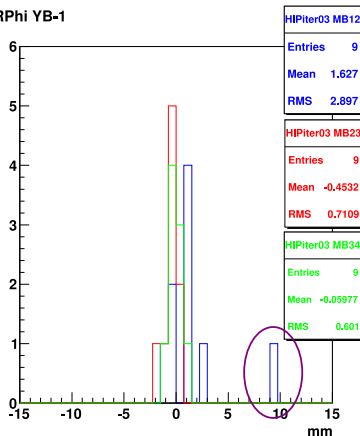


- The green points on the left (which do have a worse resolution) do not appear on the right— a mis-match within the set of plots?

@3.8T RPhi YB-1



RPhi YB-1



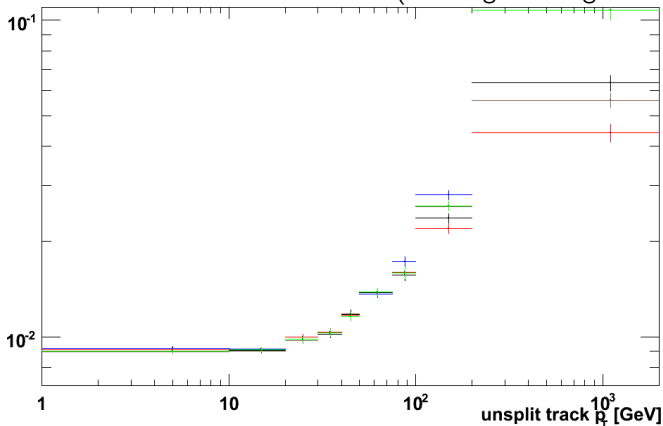
Cosmic splitting (1/4)

Jim Pivarski 8/28



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ Vertical axis is resolution from 1 to 10%
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

CRAFT_ALL_V4 (before global alignment)



Last bin is always statistically independent of tracks used for alignment

J. Tucker

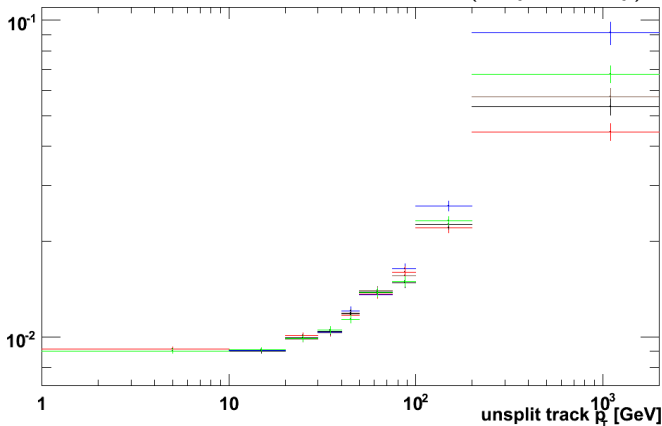
Cosmic splitting (2/4)

Jim Pivarski 9/28



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ Vertical axis is resolution from 1 to 10%
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

CRAFT_ALL_V5-12 (early February)



Last bin is always statistically independent of tracks used for alignment

J. Tucker

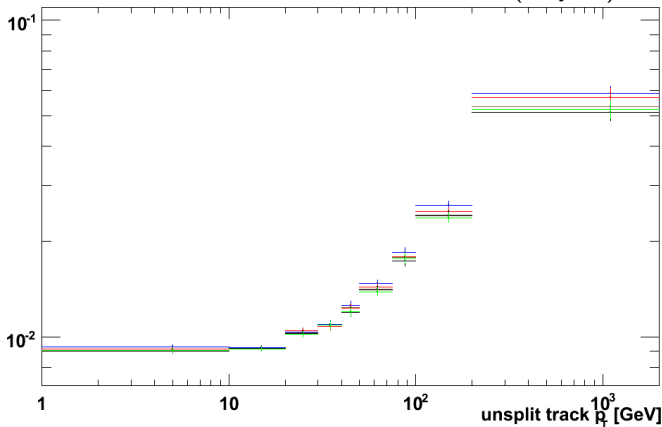
Cosmic splitting (3/4)

Jim Pivarski 10/28



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ Vertical axis is resolution from 1 to 10%
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

without latest tracker (May 25)



Last bin is always statistically independent of tracks used for alignment

J. Tucker

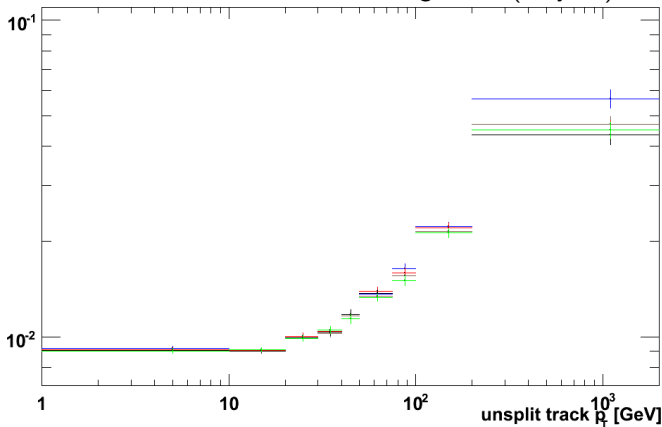
Cosmic splitting (4/4)

Jim Pivarski 11/28



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ Vertical axis is resolution from 1 to 10%
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

final muon alignment (May 29)



Last bin is always statistically independent of tracks used for alignment

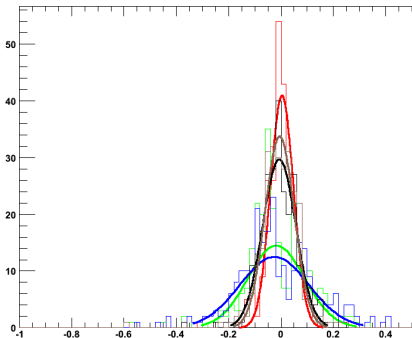
J. Tucker



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ 200–2000 GeV (these tracks were not used in alignment)
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

CRAFT_ALL_V4 (before global alignment)

Rel. res., 200 < pT [GeV] < 2000



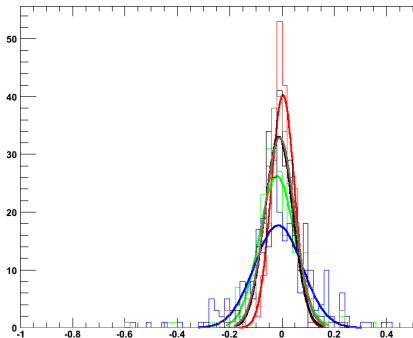
Entries	257
Mean	-0.001119
RMS	0.08089
Underflow	0
Overflow	0
χ^2 / ndf	23.21 / 12
Prob	0.02603
Constant	40.91 ± 3.76
Mean	0.003972 ± 0.003111
Sigma	0.04408 ± 0.00283
Entries	257
Mean	-0.0006
RMS	0.1492
Underflow	0
Overflow	0
χ^2 / ndf	51.11 / 25
Prob	0.001549
Constant	14.5 ± 1.4
Mean	-0.01797 ± 0.00604
Sigma	0.1076 ± 0.0076
Entries	257
Mean	-0.01063
RMS	0.1631
Underflow	0
Overflow	2
χ^2 / ndf	37.81 / 29
Prob	0.1266
Constant	12.81 ± 1.18
Mean	-0.02480 ± 0.01021
Sigma	0.1316 ± 0.0092
Entries	257
Mean	-0.006648
RMS	0.09347
Underflow	0
Overflow	0
χ^2 / ndf	14.91 / 15
Prob	0.4848
Constant	29.71 ± 2.52
Mean	-0.006551 ± 0.004442
Sigma	0.06334 ± 0.00360
Entries	257
Mean	-0.001836
RMS	0.08916
Underflow	0
Overflow	0
χ^2 / ndf	13.34 / 14
Prob	0.4998
Constant	33.74 ± 2.74
Mean	-0.00592 ± 0.00371
Sigma	0.05588 ± 0.00279



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ 200–2000 GeV (these tracks were not used in alignment)
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

CRAFT_ALL_V5-12 (early February)

Rel. res., 200 < pT [GeV] < 2000



Entries	256
Mean	-0.001523
RMS	0.08133
Underflow	0
Overflow	0
χ^2 / nff	24.17 / 13
Prob	0.02963
Constant	40.25 ± 3.67
Mean	0.003604 ± 0.001157
Sigma	0.04438 ± 0.00276
Entries	256
Mean	-0.02006
RMS	0.09793
Underflow	0
Overflow	1
χ^2 / nff	22.05 / 17
Prob	0.1827
Constant	26.26 ± 2.36
Mean	-0.0191 ± 0.0047
Sigma	0.06763 ± 0.00416
Entries	256
Mean	-0.00586
RMS	0.157
Underflow	0
Overflow	1
χ^2 / nff	43.91 / 24
Prob	0.00934
Constant	17.72 ± 1.88
Mean	-0.01445 ± 0.00692
Sigma	0.09111 ± 0.00758
Entries	256
Mean	-0.01048
RMS	0.08233
Underflow	0
Overflow	0
χ^2 / nff	25.34 / 13
Prob	0.02083
Constant	33.08 ± 2.90
Mean	-0.01221 ± 0.00382
Sigma	0.05333 ± 0.00313
Entries	256
Mean	-0.007504
RMS	0.08772
Underflow	0
Overflow	0
χ^2 / nff	9.83 / 13
Prob	0.7196
Constant	32.89 ± 2.91
Mean	-0.008821 ± 0.003905
Sigma	0.05741 ± 0.00367

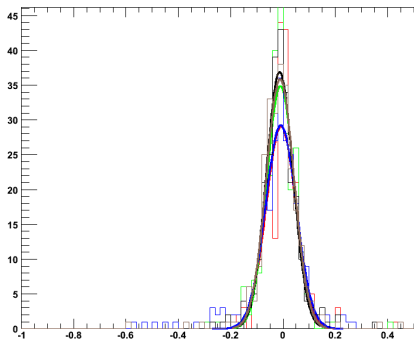
J. Tucker



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ 200–2000 GeV (these tracks were not used in alignment)
- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

without latest tracker (May 25)

Rel. res., 200 < pT [GeV] < 2000



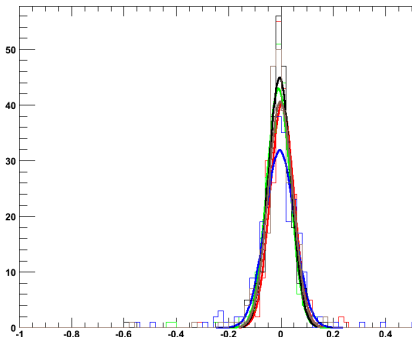
Entries	257
Mean	-0.003242
RMS	0.0994
Underflow	0
Overflow	0
χ^2 / ndf	41.3 / 16
Prob	0.000509
Constant	29.07 ± 2.75
Mean	-0.007313 ± 0.004433
Sigma	0.05701 ± 0.00302
Entries	257
Mean	-0.01684
RMS	0.08526
Underflow	0
Overflow	1
χ^2 / ndf	17.45 / 12
Prob	0.1334
Constant	34.87 ± 3.10
Mean	-0.009276 ± 0.003564
Sigma	0.05218 ± 0.00325
Entries	257
Mean	-0.0206
RMS	0.1257
Underflow	0
Overflow	6
χ^2 / ndf	24.9 / 21
Prob	0.2515
Constant	29.27 ± 2.57
Mean	-0.008179 ± 0.004025
Sigma	0.05868 ± 0.00331
Entries	257
Mean	-0.01427
RMS	0.07799
Underflow	0
Overflow	0
χ^2 / ndf	7.726 / 13
Prob	0.881
Constant	36.88 ± 3.22
Mean	-0.01271 ± 0.00327
Sigma	0.05121 ± 0.00305
Entries	257
Mean	-0.01193
RMS	0.09128
Underflow	0
Overflow	0
χ^2 / ndf	10.2 / 15
Prob	0.0609
Constant	35.84 ± 3.01
Mean	-0.01078 ± 0.00350
Sigma	0.0532 ± 0.0029



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final muon alignment (May 29)

Rel. res., 200 < pT [GeV] < 2000



Entries	264
Mean	-0.0007588
RMS	0.09097
Underflow	0
Overflow	0
χ^2 / ndf	28.08 / 13
Prob	0.00812
Constant	40.33 ± 3.77
Mean	0.004183 ± 0.003279
Sigma	0.04511 ± 0.00299

Entries	264
Mean	-0.009235
RMS	0.1038
Underflow	0
Overflow	0
χ^2 / ndf	13.62 / 16
Prob	0.4272
Constant	43 ± 3.8
Mean	-0.009653 ± 0.002896
Sigma	0.04498 ± 0.00266

Entries	264
Mean	-0.005944
RMS	0.1224
Underflow	0
Overflow	2
χ^2 / ndf	29.93 / 19
Prob	0.06057
Constant	31.89 ± 2.96
Mean	-0.004717 ± 0.003890
Sigma	0.05653 ± 0.00379

Entries	264
Mean	-0.006246
RMS	0.07162
Underflow	0
Overflow	0
χ^2 / ndf	14.3 / 11
Prob	0.217
Constant	44.89 ± 4.28
Mean	-0.005076 ± 0.002804
Sigma	0.04355 ± 0.00312

Entries	264
Mean	-0.006817
RMS	0.07834
Underflow	0
Overflow	0
χ^2 / ndf	16.84 / 12
Prob	0.1556
Constant	40.6 ± 3.6
Mean	-0.002297 ± 0.003062
Sigma	0.04687 ± 0.00289

Backup: second-highest bin

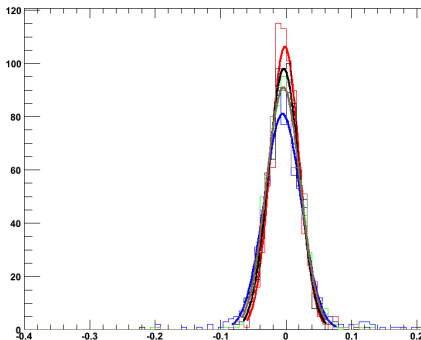
Jim Pivarski 16/28



- ▶ Sequence of $\frac{(1/p_T)_{\text{top}} - (1/p_T)_{\text{bot}}}{\sqrt{2}(1/p_T)_{\text{bot}}}$ (equal to $\frac{(p_T)_{\text{top}} - (p_T)_{\text{bot}}}{\sqrt{2}(p_T)_{\text{bot}}}$ if Gaussian)
- ▶ 100–200 GeV (these tracks were used in the May alignments)
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CRAFT_ALL_V4 (before global alignment)

Rel. res., $100 < p_T [\text{GeV}] < 200$



Entries	758
Mean	-0.006613
RMS	0.02848
Underflow	1
Overflow	1
χ^2 / nff	12.57 / 11
Prob	0.3224
Constant	106.3 ± 5.2
Mean	-0.001747 ± 0.000852
Sigma	0.02199 ± 0.00076
Entries	758
Mean	-0.001984
RMS	0.0307
Underflow	1
Overflow	1
χ^2 / nff	5.59 / 12
Prob	0.9353
Constant	90.91 ± 4.41
Mean	-0.001821 ± 0.001034
Sigma	0.02596 ± 0.00093
Entries	758
Mean	-0.002737
RMS	0.0307
Underflow	1
Overflow	2
χ^2 / nff	10.77 / 17
Prob	0.8885
Constant	81.06 ± 3.98
Mean	-0.005137 ± 0.001077
Sigma	0.02806 ± 0.00093
Entries	758
Mean	-0.001798
RMS	0.03149
Underflow	1
Overflow	1
χ^2 / nff	16.89 / 13
Prob	0.2139
Constant	98 ± 4.8
Mean	-0.003344 ± 0.000915
Sigma	0.02369 ± 0.00078
Entries	758
Mean	-0.002918
RMS	0.0322
Underflow	1
Overflow	1
χ^2 / nff	9.506 / 13
Prob	0.7337
Constant	91.13 ± 4.35
Mean	-0.0041 ± 0.0010
Sigma	0.0258 ± 0.0008

J. Tucker

Backup: second-highest bin

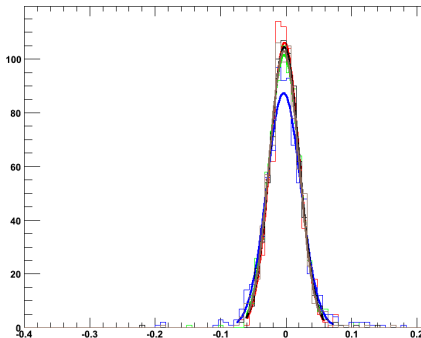
Jim Pivarski 17/28



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- ▶ Key: **tracker-only**, sometimes with station 1, **with station 1**, **all stations**

CRAFT_ALL_V5-12 (early February)

Rel. res., 100 < pT [GeV] < 200



Entries	758
Mean	-0.0007472
RMS	0.02842
Underflow	1
Overflow	1
χ^2 / nff	12.31 / 11
Prob	0.3411
Constant	106.1 ± 5.2
Mean	-0.001923 ± 0.000855
Sigma	0.02206 ± 0.00077
Entries	758
Mean	-0.001608
RMS	0.02936
Underflow	1
Overflow	1
χ^2 / nff	4.634 / 12
Prob	0.9677
Constant	101.5 ± 4.8
Mean	-0.002859 ± 0.000894
Sigma	0.02324 ± 0.00074
Entries	758
Mean	-0.001712
RMS	0.03669
Underflow	1
Overflow	2
χ^2 / nff	17.24 / 15
Prob	0.3045
Constant	87.4 ± 4.5
Mean	-0.003491 ± 0.001001
Sigma	0.02588 ± 0.00093
Entries	758
Mean	-0.001566
RMS	0.0297
Underflow	1
Overflow	1
χ^2 / nff	5.506 / 12
Prob	0.9389
Constant	104.5 ± 5.0
Mean	-0.002374 ± 0.000862
Sigma	0.02263 ± 0.00074
Entries	758
Mean	-0.002254
RMS	0.02768
Underflow	1
Overflow	1
χ^2 / nff	7.436 / 11
Prob	0.7636
Constant	103 ± 4.9
Mean	-0.002951 ± 0.000891
Sigma	0.02266 ± 0.00074

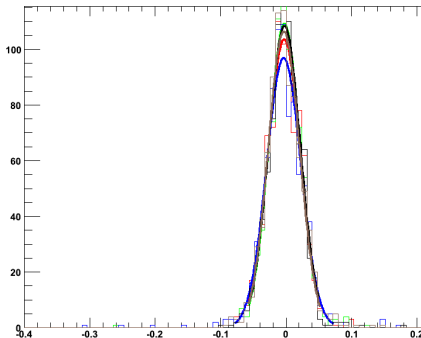
J. Tucker



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- ▶ 100–200 GeV (these tracks were used in the May alignments)
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without latest tracker (May 25)

Rel. res., 100 < pT [GeV] < 200



Entries	836
Mean	-0.002019
RMS	0.02732
Underflow	1
Overflow	1
χ^2 / ndf	13.92 / 11
Prob	0.2372
Constant	103.6 ± 4.7
Mean	-0.002683 ± 0.000966
Sigma	0.02483 ± 0.00082

Entries	836
Mean	-0.00226
RMS	0.02736
Underflow	1
Overflow	2
χ^2 / ndf	6.252 / 11
Prob	0.836
Constant	108.2 ± 5.0
Mean	-0.002364 ± 0.000898
Sigma	0.02378 ± 0.00079

Entries	836
Mean	-0.002665
RMS	0.03763
Underflow	1
Overflow	4
χ^2 / ndf	14.47 / 16
Prob	0.5639
Constant	95.94 ± 4.34
Mean	-0.003488 ± 0.000949
Sigma	0.02605 ± 0.00073

Entries	836
Mean	-0.002295
RMS	0.02614
Underflow	1
Overflow	1
χ^2 / ndf	9.38 / 10
Prob	0.4964
Constant	108.4 ± 5.1
Mean	-0.002164 ± 0.000945
Sigma	0.02422 ± 0.00091

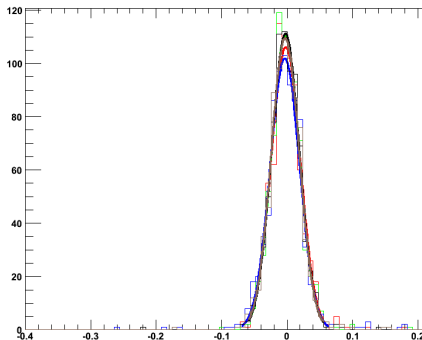
Entries	836
Mean	-0.002419
RMS	0.0274
Underflow	1
Overflow	1
χ^2 / ndf	10.94 / 11
Prob	0.4484
Constant	106.4 ± 4.8
Mean	-0.003136 ± 0.000920
Sigma	0.02467 ± 0.00078



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final muon alignment (May 29)

Rel. res., 100 < pT [GeV] < 200



Entries	760
Mean	-0.007289
RMS	0.02952
Underflow	1
Overflow	1
χ^2 / ndf	12.37 / 11
Prob	0.3366
Constant	106.1 ± 5.2
Mean	-0.001875 ± 0.000857
Sigma	0.02211 ± 0.00077

Entries	760
Mean	-0.00116
RMS	0.02713
Underflow	1
Overflow	1
χ^2 / ndf	13.29 / 11
Prob	0.2747
Constant	116.6 ± 5.4
Mean	-0.002383 ± 0.000816
Sigma	0.0213 ± 0.0007

Entries	760
Mean	-0.002216
RMS	0.03337
Underflow	1
Overflow	2
χ^2 / ndf	20.29 / 14
Prob	0.1212
Constant	101.9 ± 4.9
Mean	-0.003276 ± 0.000852
Sigma	0.02237 ± 0.00069

Entries	760
Mean	-0.001357
RMS	0.02854
Underflow	1
Overflow	1
χ^2 / ndf	6.232 / 11
Prob	0.8574
Constant	111.2 ± 5.3
Mean	-0.002235 ± 0.000813
Sigma	0.0213 ± 0.0007

Entries	760
Mean	-0.001713
RMS	0.02817
Underflow	1
Overflow	1
χ^2 / ndf	8.18 / 11
Prob	0.6971
Constant	108.6 ± 5.2
Mean	-0.002584 ± 0.000827
Sigma	0.02148 ± 0.00069



- ▶ We know that consistency with updated tracker alignment means changing muon chamber positions (not angles) by $\sigma \sim 2$ mm
- ▶ Something happened to the segment extrapolation test: it's not representing the changes we put in (angles change dramatically)
 - ▶ can't use it to test May 29 alignment
- ▶ Cosmic charge splitting indicates improvement with May 29 alignment (based on latest tracker)

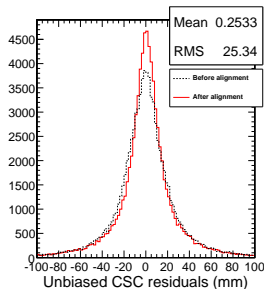
An aside, for context

- ▶ 2008 MC $\frac{(1/p_T)_{\text{meas}} - (1/p_T)_{\text{gen}}}{\sqrt{2}(1/p_T)_{\text{gen}}}$ **first-muon station (FMS)** resolution:
IDEAL: 2%, CSA08 10 pb⁻¹: 3%, STARTUP: 6% at 200 GeV
- ▶ Cosmic splitting **FMS**: May 25: 5.2% May 29: 4.5% at 200 GeV



- ▶ Photogrammetry + hardware disk-bending + disk positions from tracks
- ▶ New fits to whole-ring local residuals (next few pages)
- ▶ 3-DOF global corrections to 4 disks:

	δ_ϕ (mrad)	δ_x (mm)	δ_y (mm)
ME+1	0.06	3.3	-0.1
ME+2,3	-0.04	1.7	2.6
ME-1	1.0	3.2	-3.7
ME-2,3	1.44	4.4	-0.1



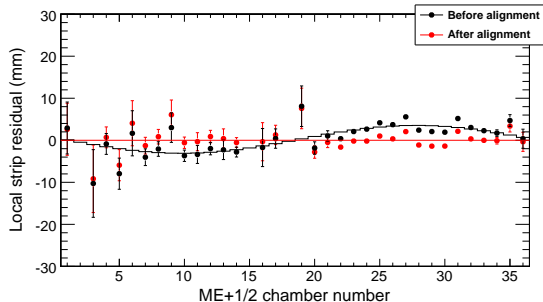
- ▶ “Non-definitive” transfer line numbers from Jim B.

	δ_ϕ (mrad)	δ_x (mm)	δ_y (mm)
ME+2,3 minus ME+1	0.98	1.03	-1.28
ME-2,3 minus ME-1	0.65	3.7	4.32

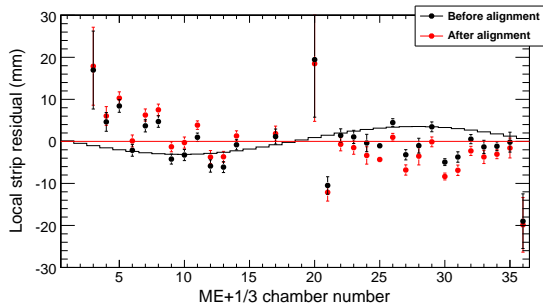
- ▶ Same rough scale; no wild disagreements

Alignment fits (1/4)

Jim Pivarski 22/28



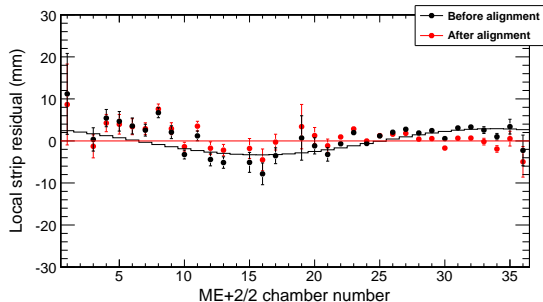
ME+1/2 (fitted)



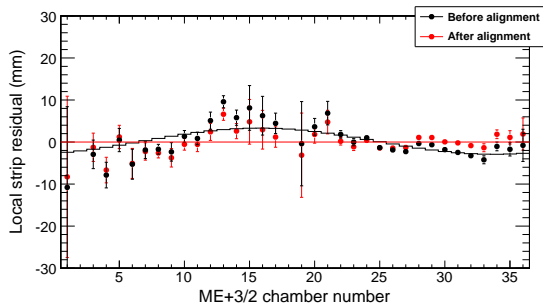
ME+1/3 (overlay
ME+1/2 fit)

Alignment fits (2/4)

Jim Pivarski 23/28



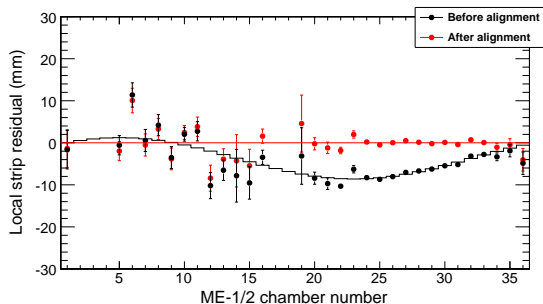
ME+2/2 (fitted)



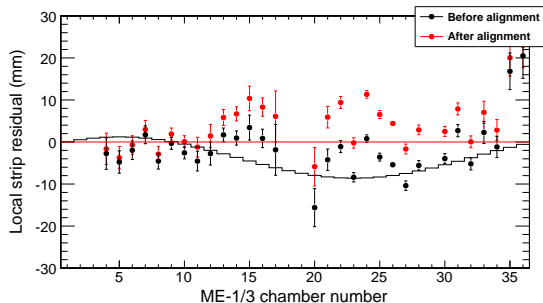
ME+3/2 (overlay
ME+2/2 fit)

Alignment fits (3/4)

Jim Pivarski 24/28



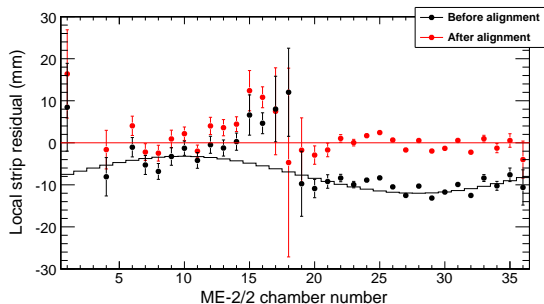
ME-1/2 (fitted)



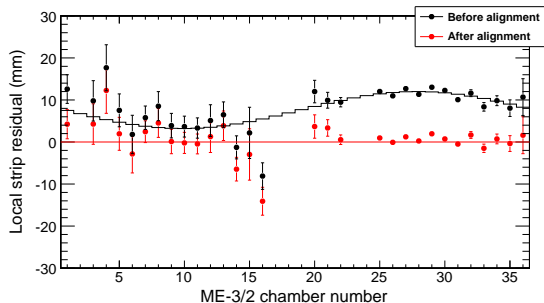
ME-1/3 (overlay
ME-1/2 fit)

Alignment fits (4/4)

Jim Pivarski 25/28



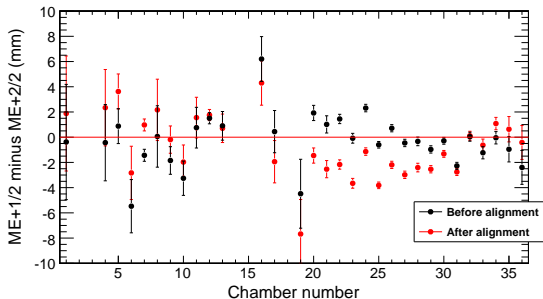
ME-2/2 (fitted)



ME-3/2 (overlay
ME-2/2 fit)

Residuals differences

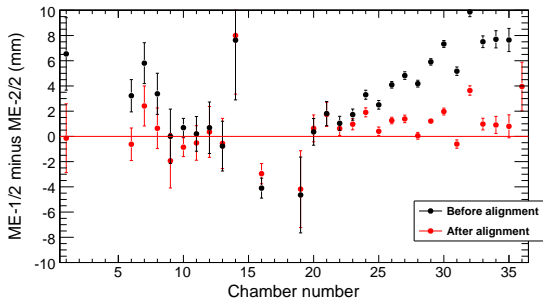
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Residuals differences are equivalent to segment extrapolation with the CMSSW propagator and a momentum assumption (from tracker)

More precise than absolute residuals and measure relative differences

New information: an independent check on alignment

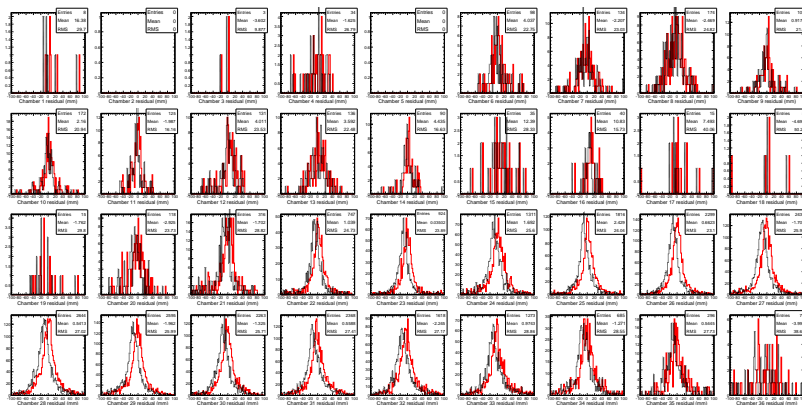


Backup: individual chambers

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- ▶ ME-2/2, before and **after** alignment (stats box applies to **after**)
- ▶ No weights, no fits, just a mean truncated at ± 100 mm





- ▶ Barrel alignment
 - ▶ DT internal alignment with tracks and checked by survey
 - ▶ global alignment relative to tracker checked by $1/p_T$ in cosmics splitting
 - ▶ aligned using $100 < p_T < 200$ GeV tracks
 - ▶ and the current tracker
 - ▶ current APEs negligibly affect results

`/castor/cern.ch/user/p/pivarski/DTCRAFTiter03_withCenteredTracker.db`

- ▶ Endcap alignment
 - ▶ CSC photogrammetry at 0 T
 - ▶ SLM disk-bending measurements at 3.8 T
 - ▶ 3-DOF \times 4 disk alignment with tracks

`/castor/cern.ch/user/p/pivarski/CSCCRAFT_HardwareAndPGAndDisk2.db`