Results from Tracker Alignment Studies for CSA07

Rainer Mankel (DESY)

CMS Hamburg Meeting

7-Nov-2007

based on the following presentations:

11:00	**Millepede CSA07 results** (20') (Slides)	Rainer Mankel (DESY)
11:20	**HIP CSA07 results** (20') (Slides)	Chung Khim Lae (John Hopkins U.)
11:40	**LAS CSA07 results** (20') (Slides)	Maarten Thomas (RWTH Aachen)

Outline

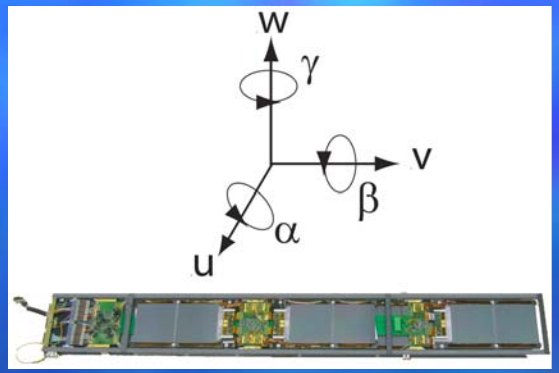
- Aims for tracker alignment within CSA07
- CSA07 studies
  - Laser alignment
  - Track-based alignment
    - with MillePede-II
    - with HIP algorithm
- Conclusions

Aims

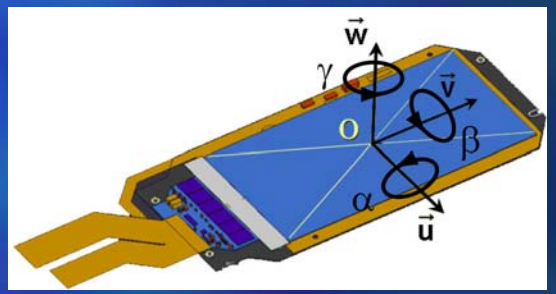
- Exercise full alignment workflow on CMS CAF
  - starting from AlCaReco format (centrally produced)
  - read misaligned geometry from database
  - write aligned geometry to database
  - validation of results
- Use 2 different algorithms for track-based alignment
  - HIP (already used in CSA06)
  - MillePede-II (new)
- Extend statistics to 1.7 million $Z \rightarrow \mu\mu$ events
- Perform laser alignment study

Definition of Alignment Parameters (Reminder)

ROD level:



Det level:

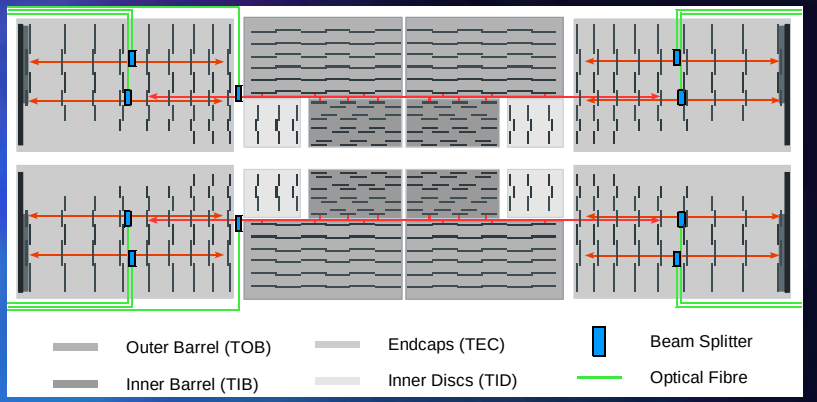


- u = preferred measurement direction
- v = second direction in detector plane
- w = normal to detector plane
- α, β, γ specify rotations around u, v, w axes

Misalignment Scenarios

- MillePede-II & HIP: similar to CSA06 scenario
  - TIB misaligned at detector ("det") level
    - DS: Δu, Δv, Δw: ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
    - SS: Δu : ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
  - TOB misaligned at rod level
    - DS: Δu, Δv, Δw: ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
    - SS: Δu : ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad; but layer 6 fixed
  - Pixel & end caps fixed
  - in total 11880 free parameters
- Laser alignment study: use 10 pb^{-1} scenario
  - features TEC misalignments of moderate size, since at 10 pb^{-1} we assume already existing improvements from laser alignment
  - 50 free parameters

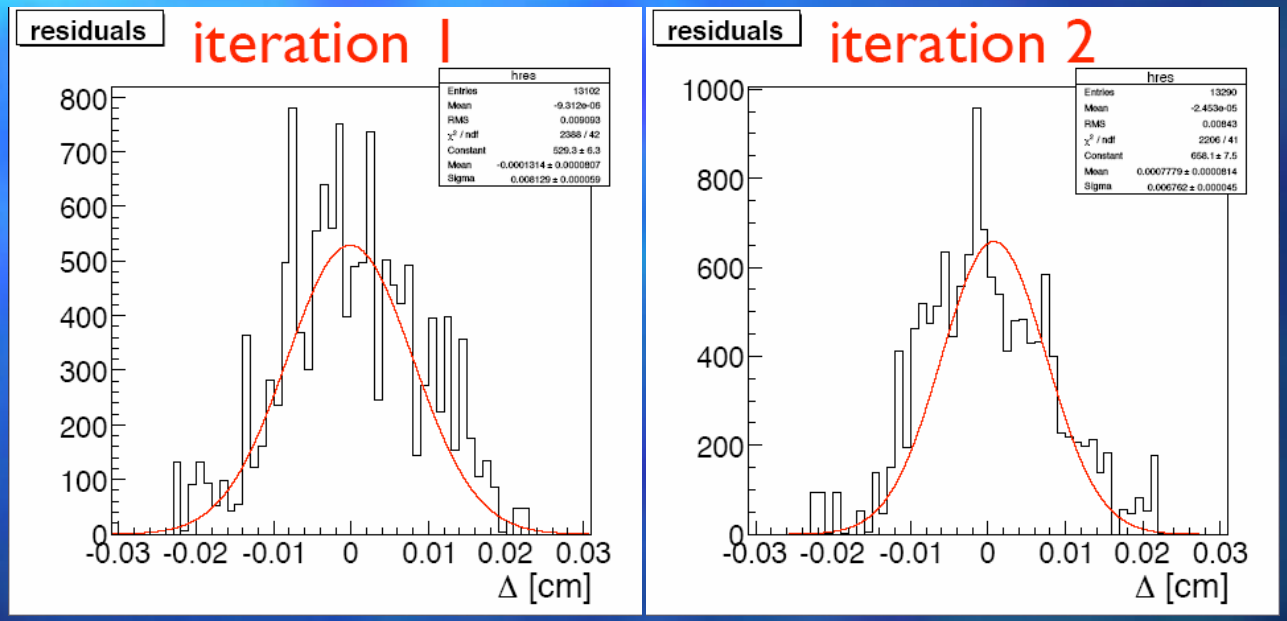
Laser Alignment



- Simulated laser events were digitized on the grid & copied to the CAF disk pool at CERN
- First step:
  - misalign
  - reconstruct laser beam positions
  - calculate & store alignment parameters (per disk: x, y, φ)
  - this took 1:19 hours
- Second step:
  - validate by redoing the same steps using the aligned geometry from previous step

Laser Alignment: Results

- Residuals of laser hits in the TEC



➔ Fitted Gaussian width improves from 81 μm → 68 μm
- consistent with expected resolution

Reminder: Methodology of Track-Based Alignment Methods Used in CSA07

HIP algorithm:

- "Hit Impact Point"
- fit alignment parameters locally for each object → few degrees of freedom per fit
- well manageable from mathematical point of view
- needs many cycles of iteration
- needs dedicated farm infrastructure

MillePede algorithm:

- global fit of all track & alignment parameters
- sophisticated mathematical procedure to handle large number of fit parameters
- MillePede-II suitable to fit O(100000) alignment parameters
  - choice of several internal fit methods

V. Blobel

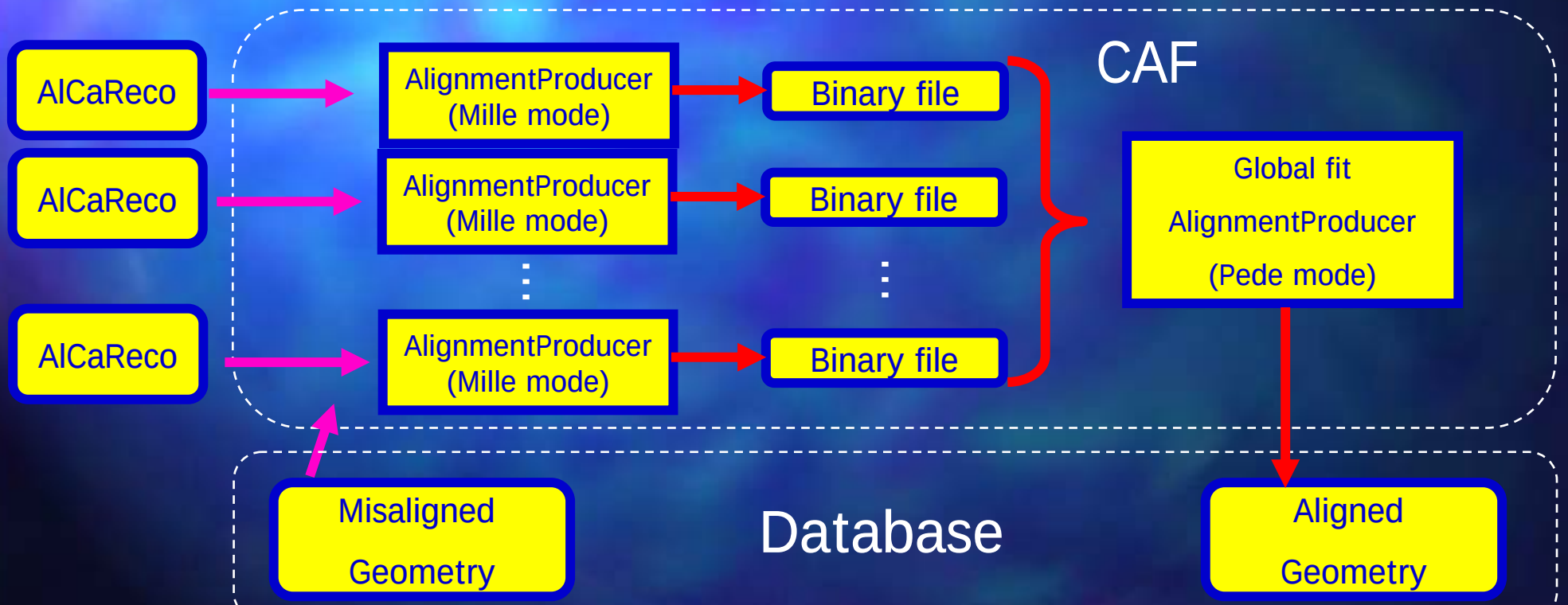
Workflow for MillePede-Based Alignment in CSA07

Step 1: track-level analysis & track-by-track matrix elements:

- can/should be parallelized

Step 2: global fit of alignment parameters

- cannot be parallelized



CPU Resources & Turnaround

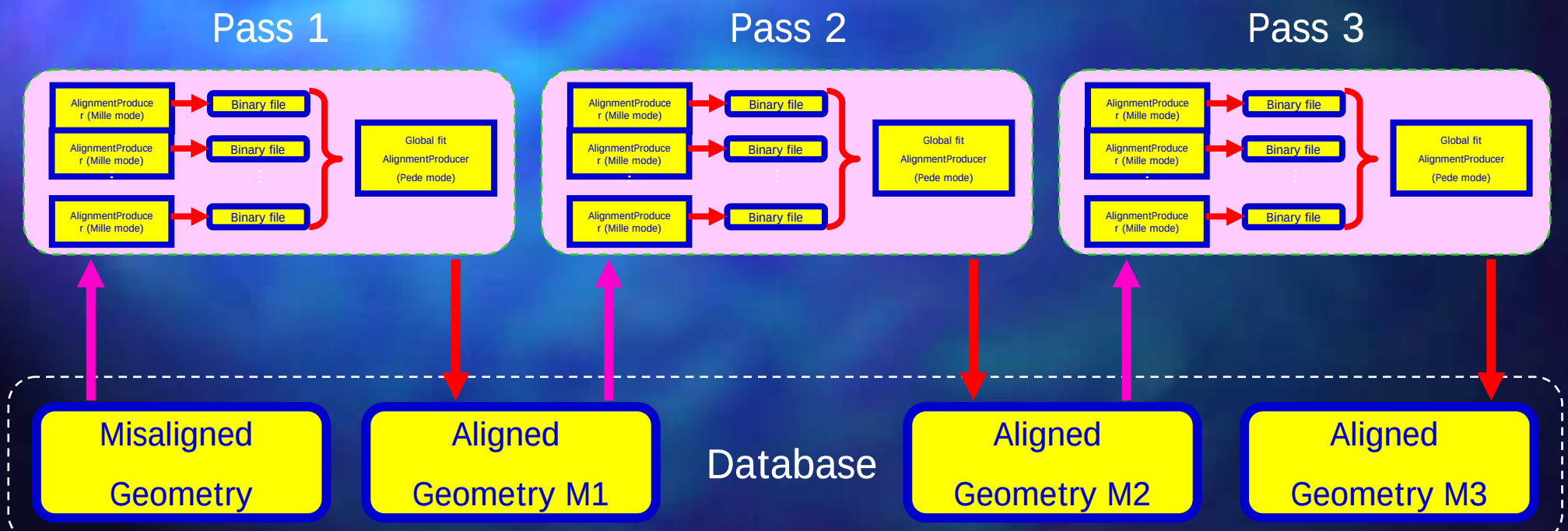
- Due to Castor problems, in total 3 of 49 AlCaReco files were excluded from production → affected jobs resubmitted
  - remaining statistics: 1.65 M events

	CPU time [min]	Wall time [min] incl. resubmissions
Mille (16 jobs)	25 (per job)	78
Pede	32	109
Total	432	187

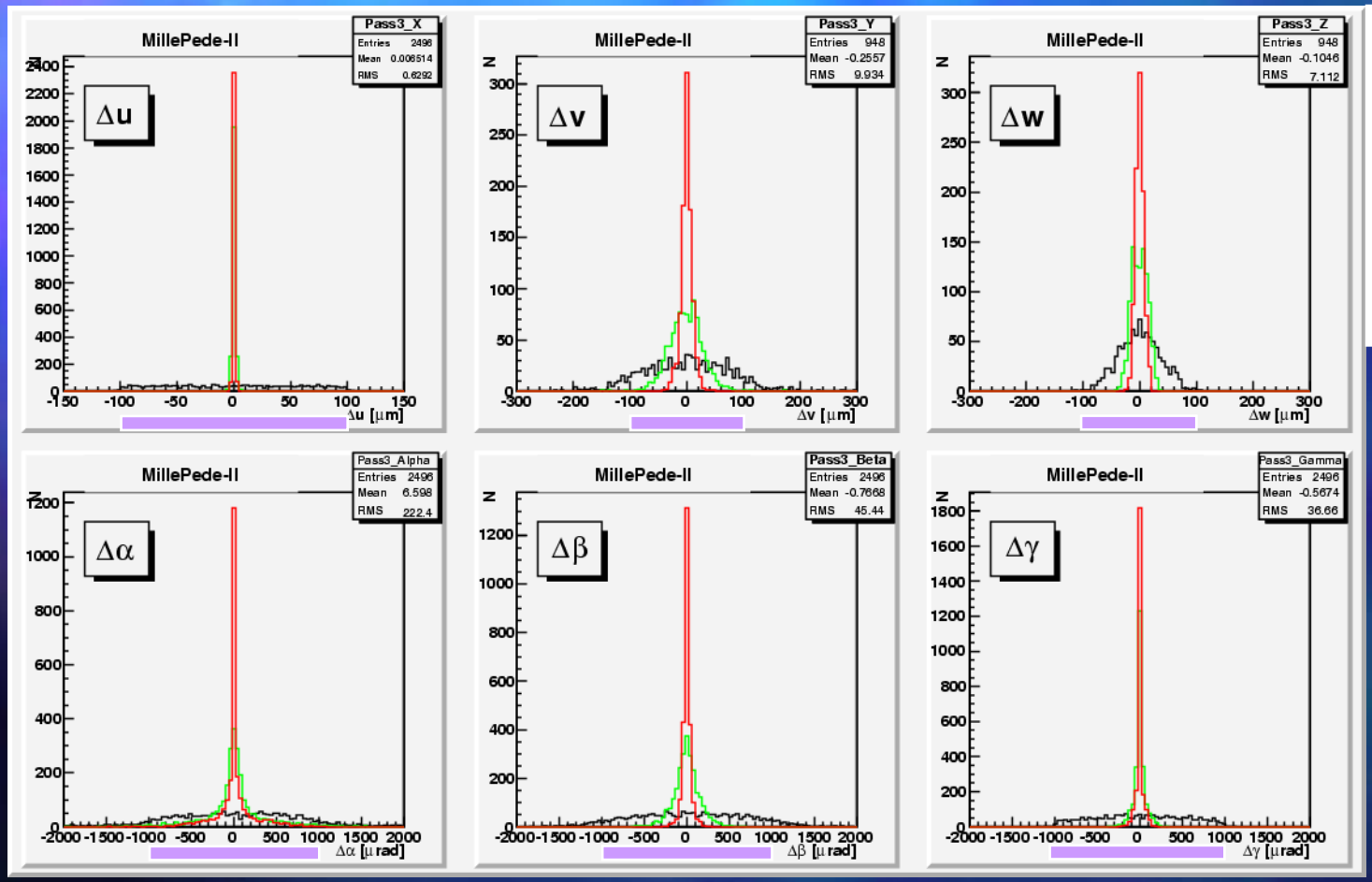
- Three hours of latency until upload of first constants is already fair
  - could be further reduced by running more Mille jobs in parallel, and a dedicated server for Pede with local storage (since I/O dominated)

New: Multi-Pass Operation of MillePede

- Tested for the first time in CMS. Motivation:
  - validation of previously applied alignment
  - possibly further improvement of alignment constants



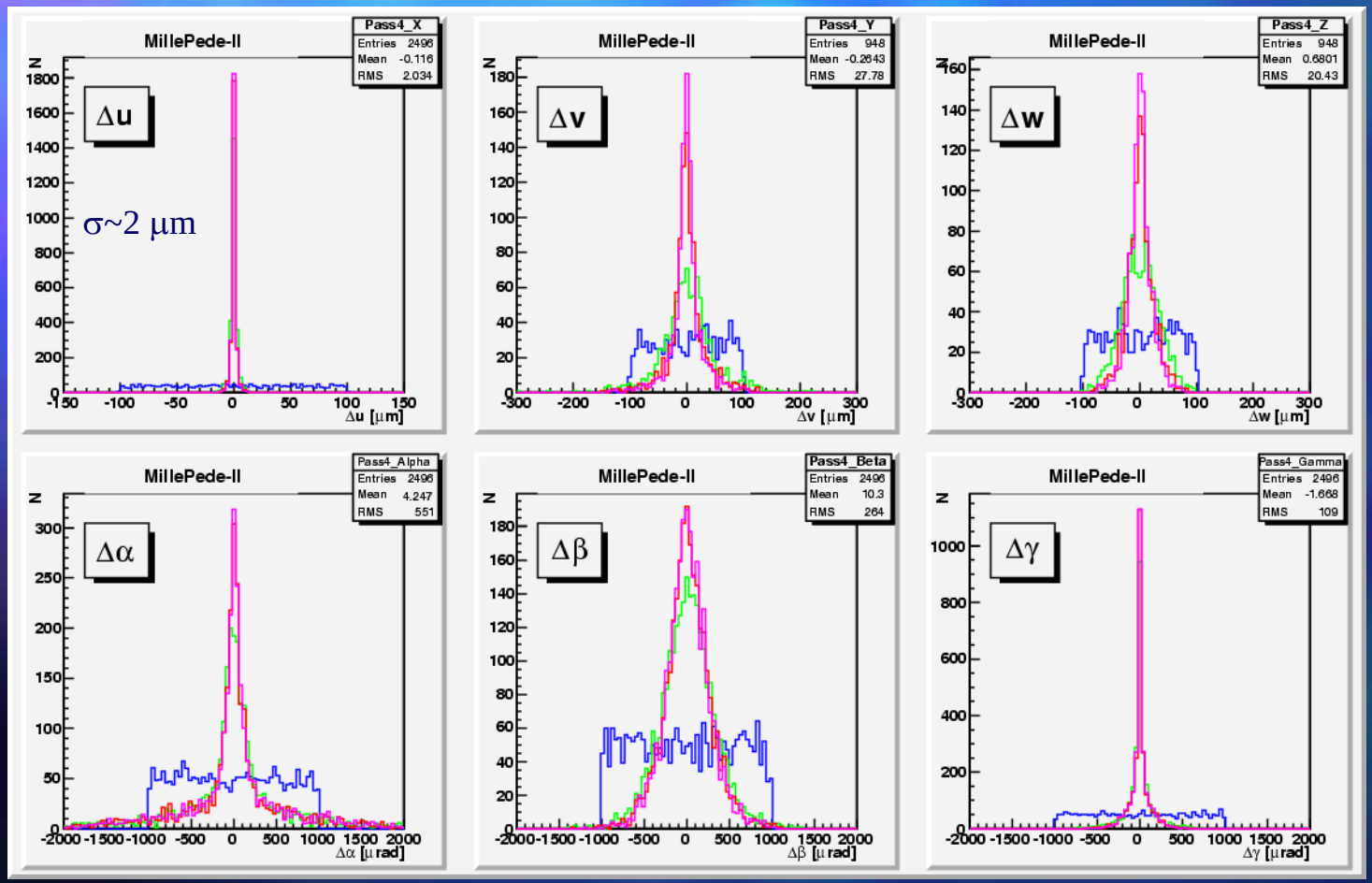
(Validation of) Alignment Parameters



Pass 1
Pass 2
Pass 3

- Fast convergence, already pass 2 corrections are small
- Important validation method, which is independent of MC & can be also applied with real data

Alignment Parameter Residuals (Aligned Geometry vs MC Truth)



misaligned

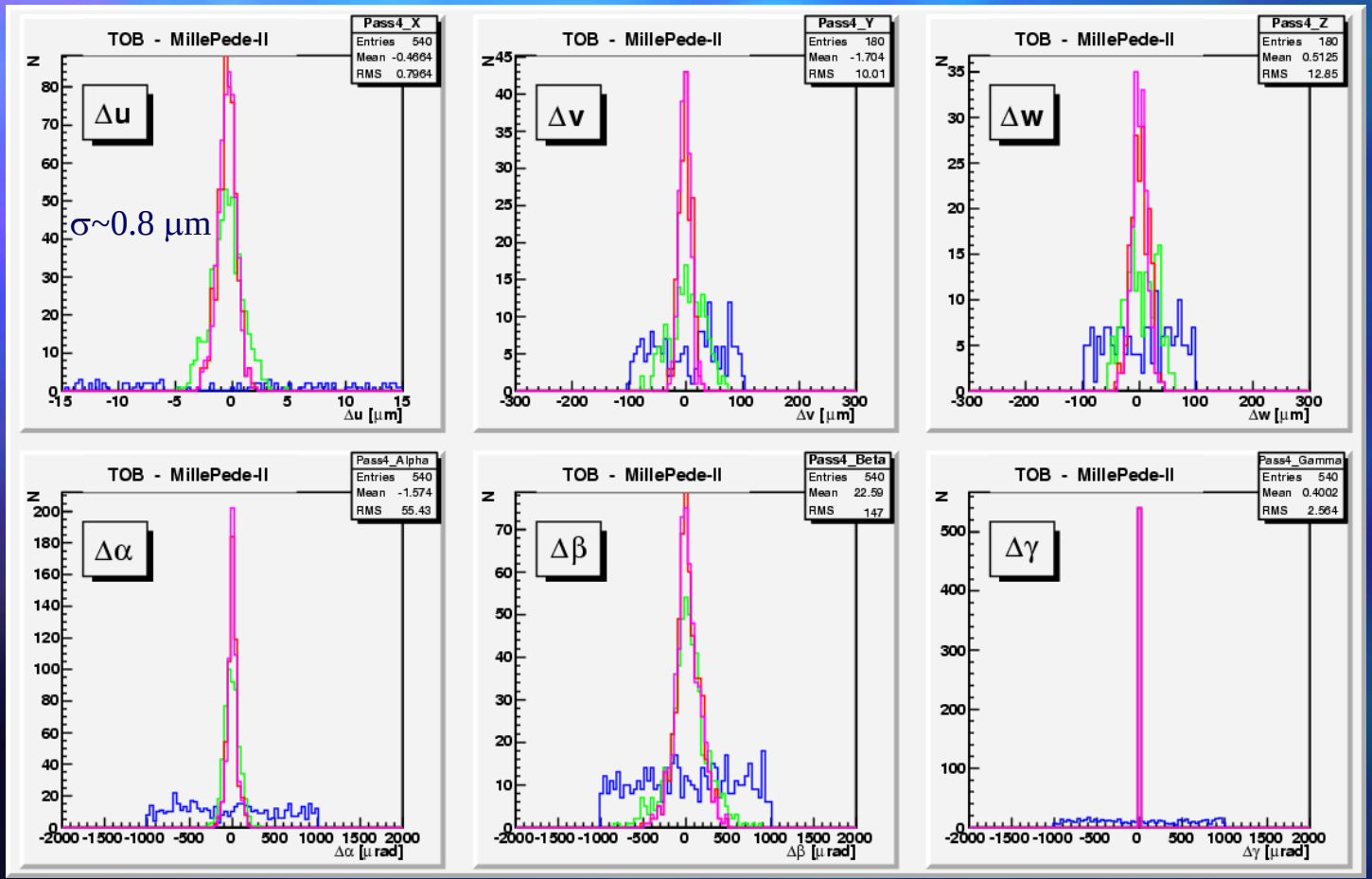
Pass 1

Pass 2

Pass 3

- Pass 1 results are already quite good
  - though essentially no optimization of MillePede parameters for CSA07 scenario has been done
- Second pass still gives visible improvement
  - depends in general on size of misalignment (reevaluation of expansion coefficients)
  - if no big misalignments, one pass is probably sufficient

Alignment Parameter Residuals: TOB Layer 1-5 only



misaligned

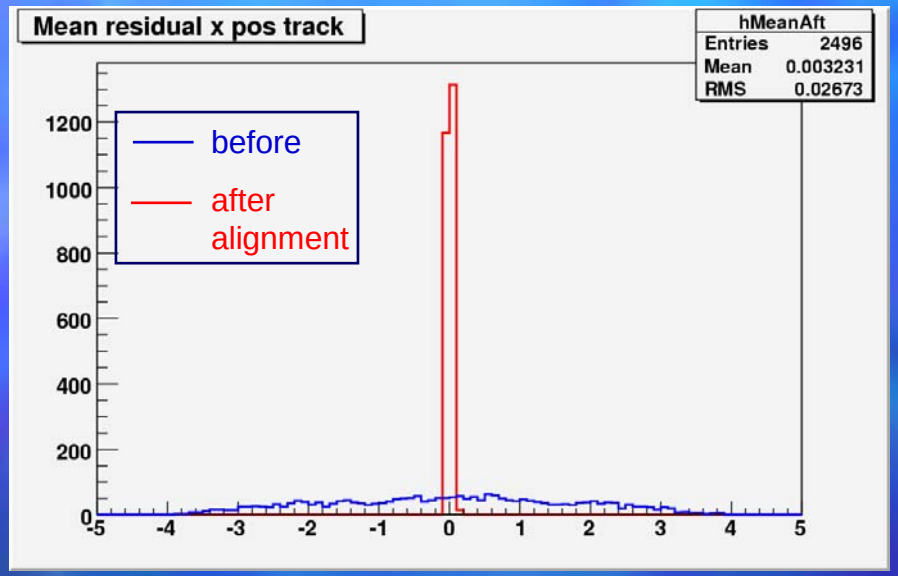
Pass 1

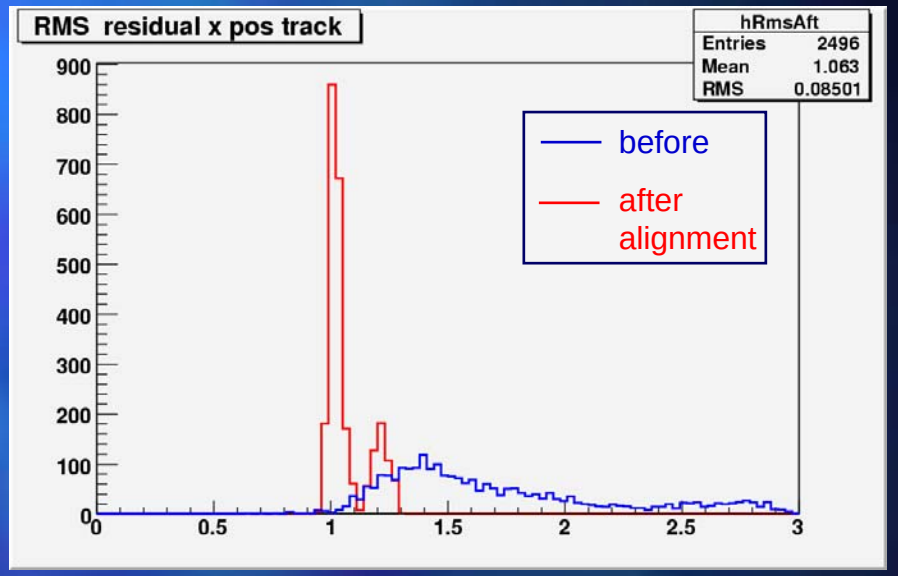
Pass 2

Pass 3

- TOB rods have generally better resolution than individual sensors, in particular for angles α and γ
  - much higher leverage, except for β
- Detailed resolution table can be found in appendix

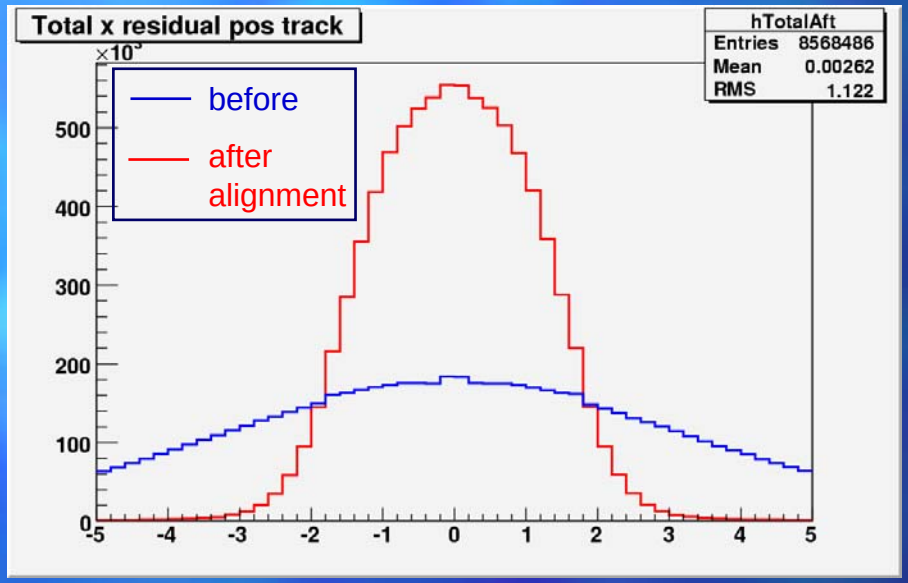
Analysis of Hit Residuals





- This validation method is based on histograms of the "Alignment Monitor" (by Jim Pivarski & Chung Khim Lae). Residuals are normalized to estimated error.
- ➔ After alignment, the individual residual distributions are well centered, and their RMS width is significantly reduced

Analysis of Hit Residuals (cont'd)

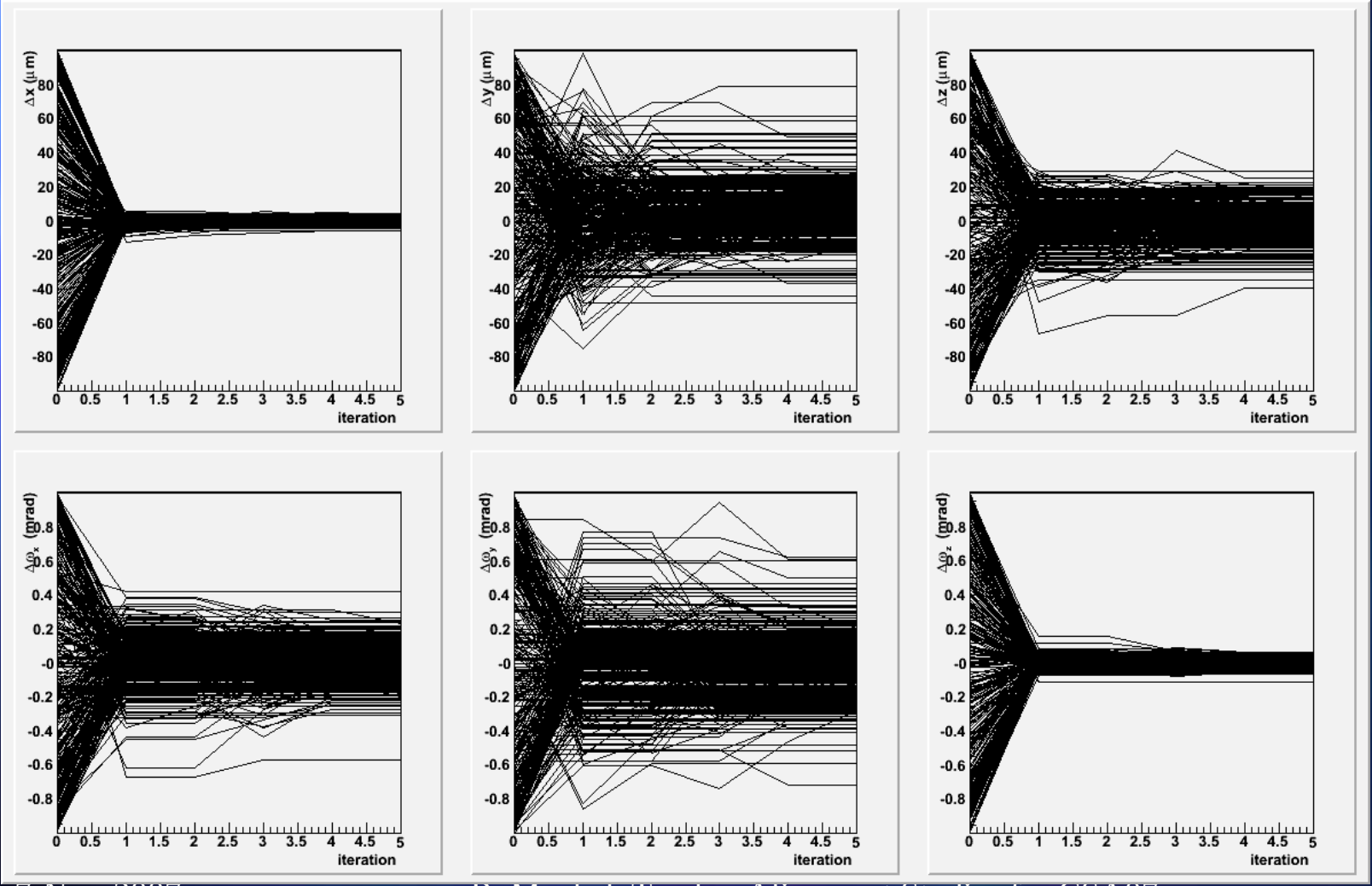


- "Total residual" = sum of the individual residual histograms. (Residuals are normalized to estimated error.)
- After the alignment, the total residual distribution is much narrower & its RMS width close to ideal

HIP Algorithm

- Intrinsically iterative approach
  - each iteration organized in 10 parallel jobs
    - 15-20 minutes CPU per job
  - performed with five iterations
- Jobs were run overnight
  - after initial problems with database access & insufficient local storage

HIP Convergence Behavior (TIB Dets Layer 1)



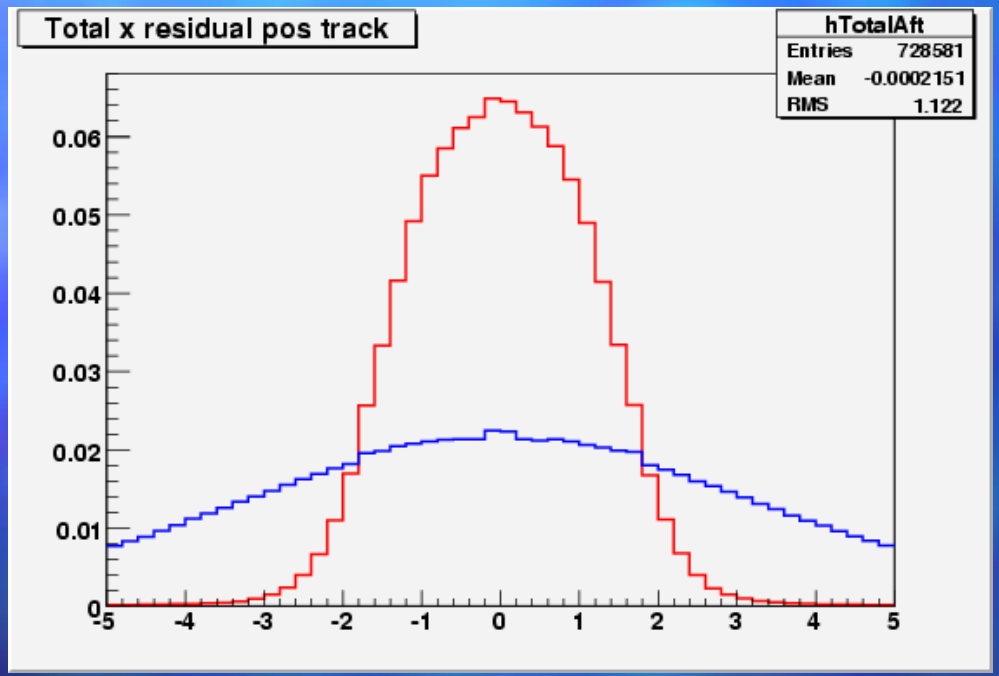
HIP: Alignment Parameter Resolutions

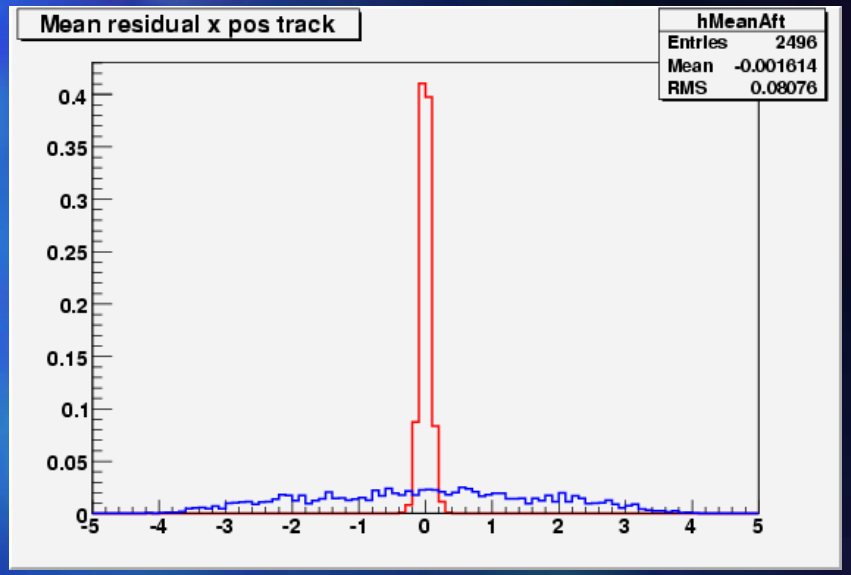
TIB	σ_x (μm)	σ_y (μm)	σ_z (μm)	σ_α (mrad)	σ_β (mrad)	σ_γ (mrad)
Stereo	2.5	19	16	0.15	0.27	0.029
Mono	1.2	Fixed	Fixed	0.90	0.32	0.15

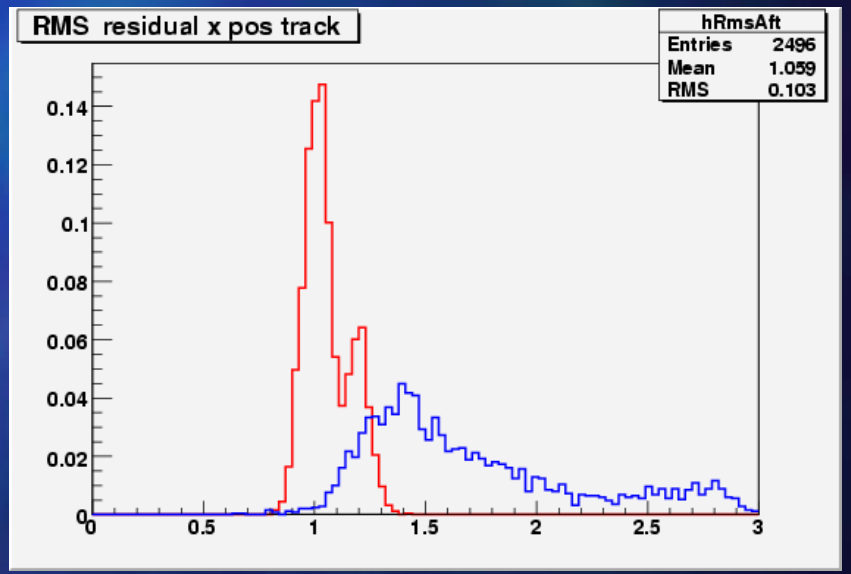
TOB	σ_x (μm)	σ_y (μm)	σ_z (μm)	σ_α (mrad)	σ_β (mrad)	σ_γ (mrad)
Stereo	0.77	8.3	10	0.60	0.54	0.57
Mono	0.54	Fixed	Fixed	0.57	0.60	0.61

- Largely similar resolutions as with MillePede-II
- In general better than in CSA06 (higher statistics)
- Angular resolutions for TOB rods still under study

HIP Validation (I)

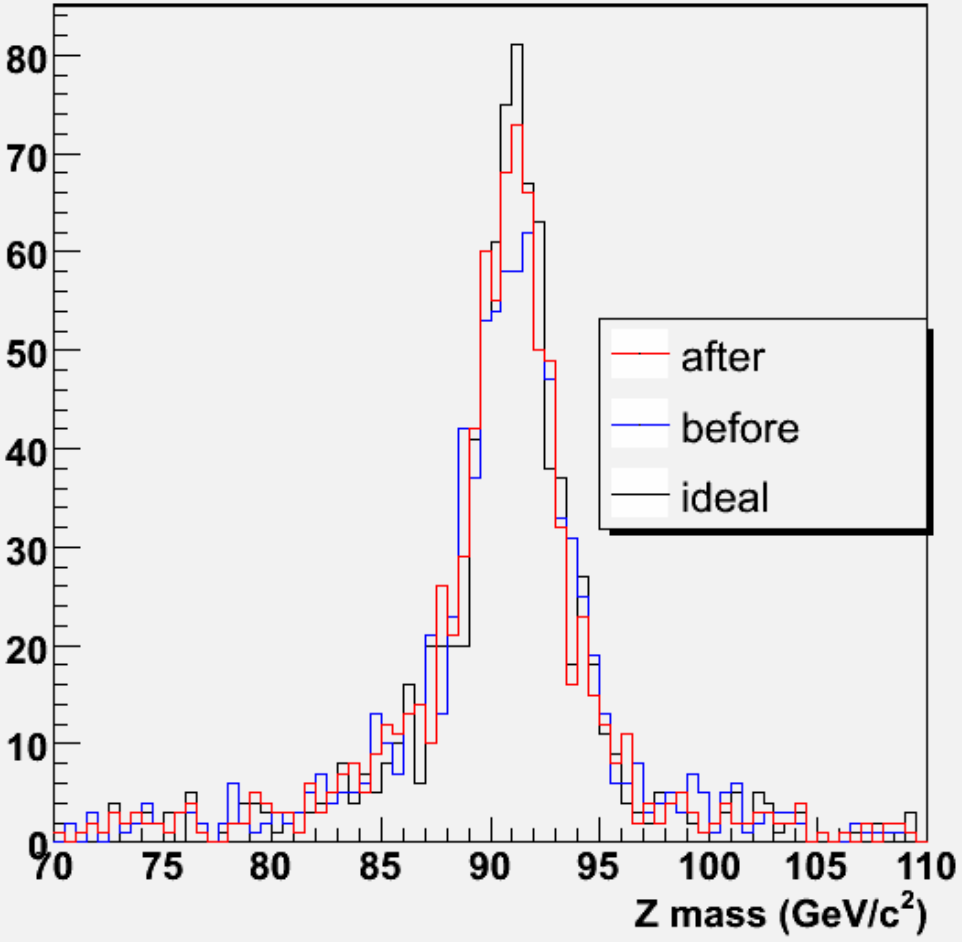






- Plots based on hit residuals resemble those from MillePede

HIP Validation (II)



- $Z^0 \rightarrow \mu^+\mu^-$ mass resolution
  - improvement after alignment is visible
  - close to ideal geometry

Summary

- Successfully exercised production-style alignment
  - with two track-based algorithms & laser alignment
- Some important developments made & lessons learned
  - work flow on grid & CAF (Laser)
  - new production system & multi-pass approach (MillePede)
  - storage issues (MillePede & HIP)
  - resolution still improves with number of events (HIP)
- Turnaround in real-time is very encouraging
  - e.g. 3 hours until upload of first constants in MillePede
  - also validation of constants has been exercised

[Note: more detailed results regarding alignment performance are available under https://twiki.cern.ch/twiki/bin/view/CMS/TkAlignmentCSA07]

Lessons

- Reliability of access to mass storage (CASTOR) is still a topic
  - maybe there is a “training effect” – data samples under frequent use seem to operate more smoothly
- We should foresee a dedicated batch server for the Pede step
  - with ample memory & local disk space
  - improves turnaround for Pede
- We should foresee non-user level storage for job steering directories etc (AFS, a few GB).
  - mass storage output could already now be moved to TkAlign CASTOR disk pool

Credits

- I would like to thank Gero Flucke & Chung Khim Lae for their help during the preparations. Thanks also to Volker Blobel for his advice on using his MillePede-II program.

The End

The CSA07 Misalignment Scenario

- TIB misaligned at detector ("det") level
  - DS: Δu, Δv, Δw: ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
  - SS: Δu : ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
- TOB misaligned at rod level
  - DS: Δu, Δv, Δw: ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
  - SS: Δu : ± 100 μm; $\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$: $\pm$ 1 mrad
    - except for layer 6 (fixed)
- Pixel & end caps fixed

The CSA07 Misalignment Scenario (cont'd)

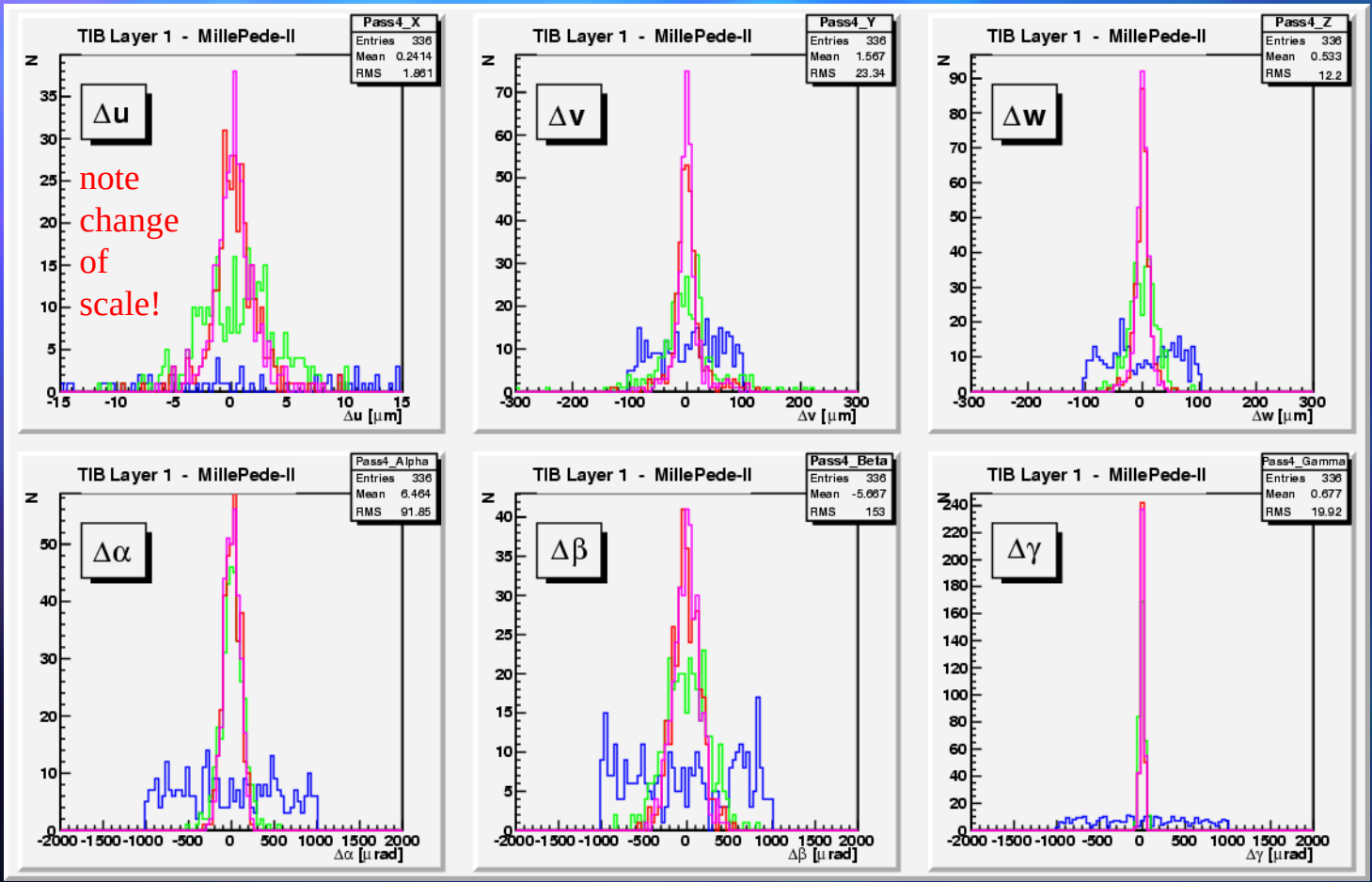
- #free parameters:
  - TIB Dets DS: 768 x 6 = 4608
  - TIB Dets SS: 1188 x 4 = 4752
  - TOB rods DS: 180 x 6 = 1080
  - TOB rods SS: 360 x 4 = 1440
  - total: 11880
- already a respectable problem (~1/5 of full tracker parameter set)
- use "GMRES" method of MillePede-II instead of traditional "inversion" method

Misalignment Scenarios

Table 6: Values used in the misalignment scenarios. Installation uncertainties and applied misalignments are given as well as misalignments used in previous scenarios. For the misalignment scenarios, RMS values are given together with scaling factors (comparison to initial uncertainties). Uniform distribution is denoted as Uxx, where xx signifies the range $\pm$xx μm. Gaussian distribution is denoted as Gxx, where σ = xx. If not mentioned, the distribution is Gaussian. Angular misalignment $\phi = \alpha, \beta, \gamma$ is expressed in μrad.

	Updated initial uncertainties	Scenarios *10* pb^{-1}			*100* pb^{-1}			*1000* pb^{-1}			Previous scenarios *First Data*		*Long Term*	
		x, y, z	Scale	ϕ	x, y, z	Scale	ϕ	x, y, z	Scale	ϕ	x, y, z	ϕ	x, y, z	ϕ
TPB														
Dets	G60	60	1.00	270	10	0.17	45	5	0.08	22	G13	—	G13	—
Rods	U50	10	0.35	7	10	0.35	7	5	0.17	3	G5	—	G5	—
PixelHalfBarrelLayers	U100	10	0.17	7	5	0.08	3	5	0.08	3	G10	G10	G10	G10
TPE														
DetUnits	G5, ϕ:G100	5	1.00	100	5	1.00	11	5	1.00	11	Dets G5	—	G5	—
Panels	G10, ϕ:G200	10	1.00	200	10	1.00	22	5	0.50	11	—	—	—	—
Blades	G10, ϕ:G200	10	1.00	15	10	1.00	15	5	0.50	7	Petals G2.5	—	G2.5	—
HalfDisks	G50, ϕ:G1000	10	0.20	15	10	0.20	15	5	0.10	7	EndcapLayers G5	G5	G5	G5
TIB												—		—
Dets	G180	180	1.00	412	30	0.17	70	10	0.06	20	U200	—	G20	—
Rods	G450	100	0.22	65	30	0.07	20	10	0.02	5	U200	—	G20	—
BarrelLayers	G750	100	0.13	65	15	0.02	10	10	0.01	5	G105/G500	G90	G10.5/G50	G9
TOB														
Dets	G32	32	1.00	75	32	1.00	70	18	0.56	40	U100	—	G10	—
Rods	G100	100	1.00	40	40	0.40	15	18	0.18	7	U100	—	G10	—
BarrelLayers											G67/G500	G59	G6.7/G50	G5.9
HalfBarrels	$r\phi$: G60, z: G500	60/100	1/0.2	10	20	.33/.04	5	10	.17/.1	2				
TEC														
Dets	G22	22	1.00	50	22	1.00	50	22	1.00	50	U50		G5	
Petals	G70	70	1.00	30	55	0.79	20	40	0.57	15	U100		G10	
EndcapLayers	$r\phi$: G60 z: G150	60/150		15	30		5	20		5	G57/G500	G46	G5.7/G50	G4.6
TID														
Dets	G54	54	1.00	250	50	0.93	230	25	0.46	110	U105		G10.5	
TIDRings	G185	185	1.00	850	50	0.27	230	25	0.14	110	U300		G30	
TIDLayers	G350	250	0.71	380	25	0.07	40	12	0.03	20	U400	U100	G40	G10

Alignment Parameter Residuals: TIB Layer 1 only



misaligned

Pass 1

Pass 2

Pass 3

- For double-sided TIB sensors, parameters α and γ have generally better resolution than for single-sided ones
  - not surprising, since v coordinate is important for their determination

Parameter Residual RMS – Layer by Layer

TIB	σ(u) [μm]	σ(v) [μm]	σ(w) [μm]	σ(α) [mrad]	σ(β) [mrad]	σ(γ) [mrad]
Layer 1	1.9	23.3	12.2	0.092	0.153	0.020
Layer 2	4.1	35.0	27.1	0.167	0.335	0.032
Layer 3	1.0			0.699	0.288	0.126
Layer 4	1.1			0.879	0.308	0.178
TOB	σ(u) [μm]	σ(v) [μm]	σ(w) [μm]	σ(α) [mrad]	σ(β) [mrad]	σ(γ) [mrad]
Layer 1	0.7	8.7	11.4	0.022	0.079	0.003
Layer 2	0.7	10.2	13.9	0.026	0.099	0.002
Layer 3	0.8			0.053	0.146	0.003
Layer 4	0.8			0.058	0.178	0.003
Layer 5	0.7			0.080	0.173	0.002