First Alignment of the Complete CMS Silicon Tracker

RD09

On behalf of the CMS Tracker Alignment Group

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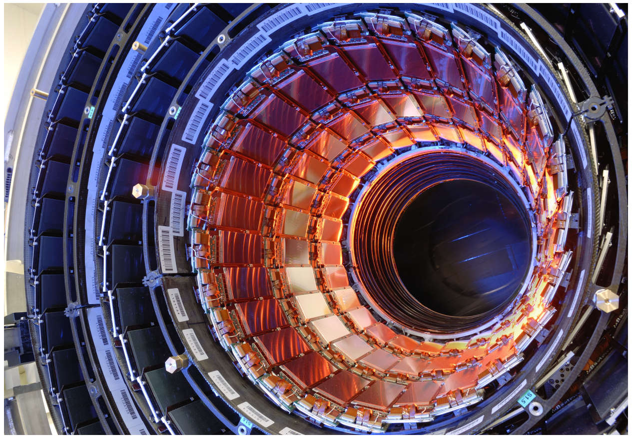
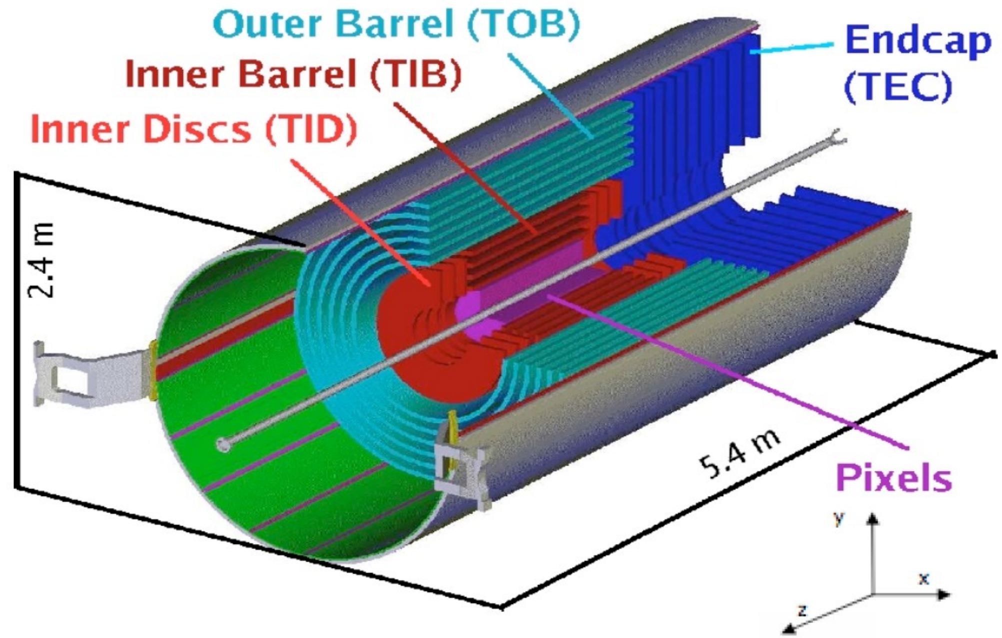
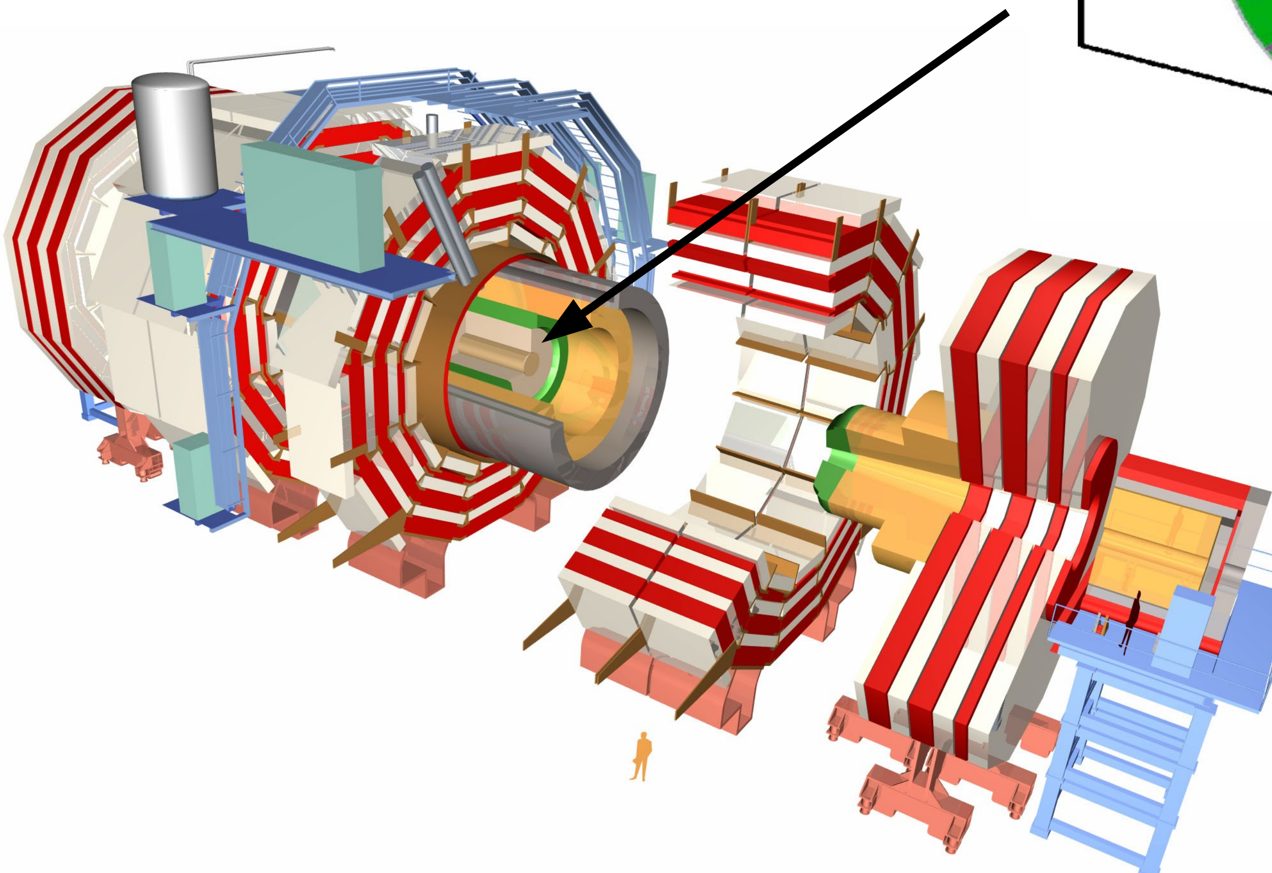
Outline

- Introduction
    - CMS tracker
    - Tracker Alignment: methods and strategies
- Results from complete tracker alignment exercise with cosmic ray data from 2008
- Analysis of remaining misalignment
- Latest alignment results from the cosmic ray data taking in 2009
- Summary & Outlook

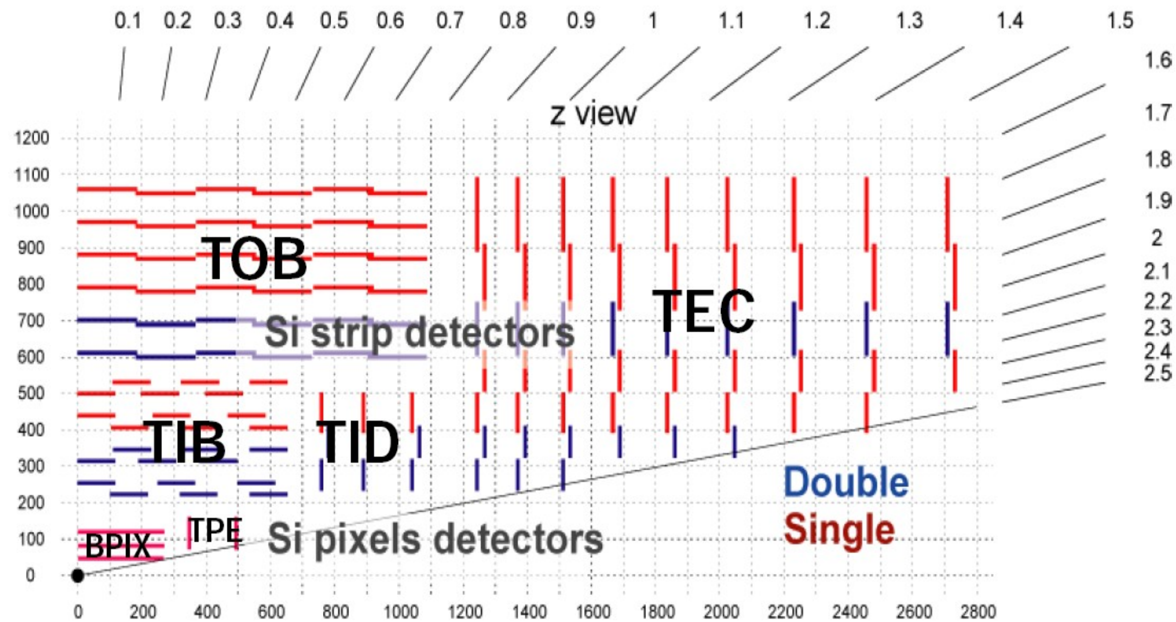


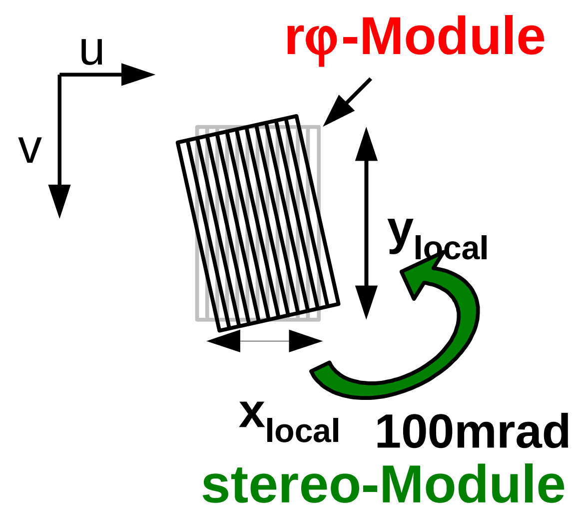




- 1440 silicon pixel modules
  - 3 layers in the barrel
  - 2 disks in each forward direction
- 15148 silicon strip modules
  - TIB 4 layers
  - TOB 6 layers
  - TID 3 disks
  - TEC 9 disks

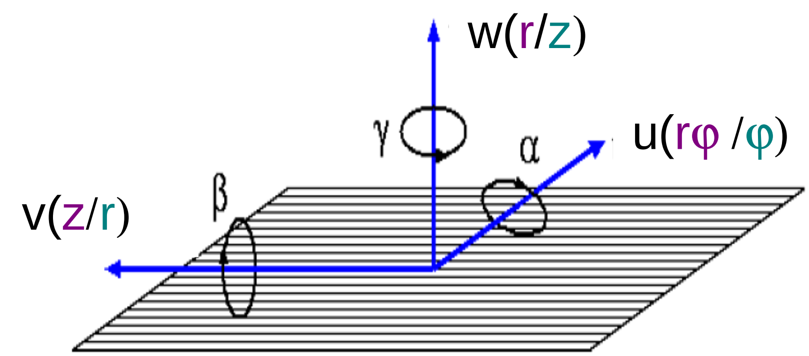
CMS Silicon Tracker(2)

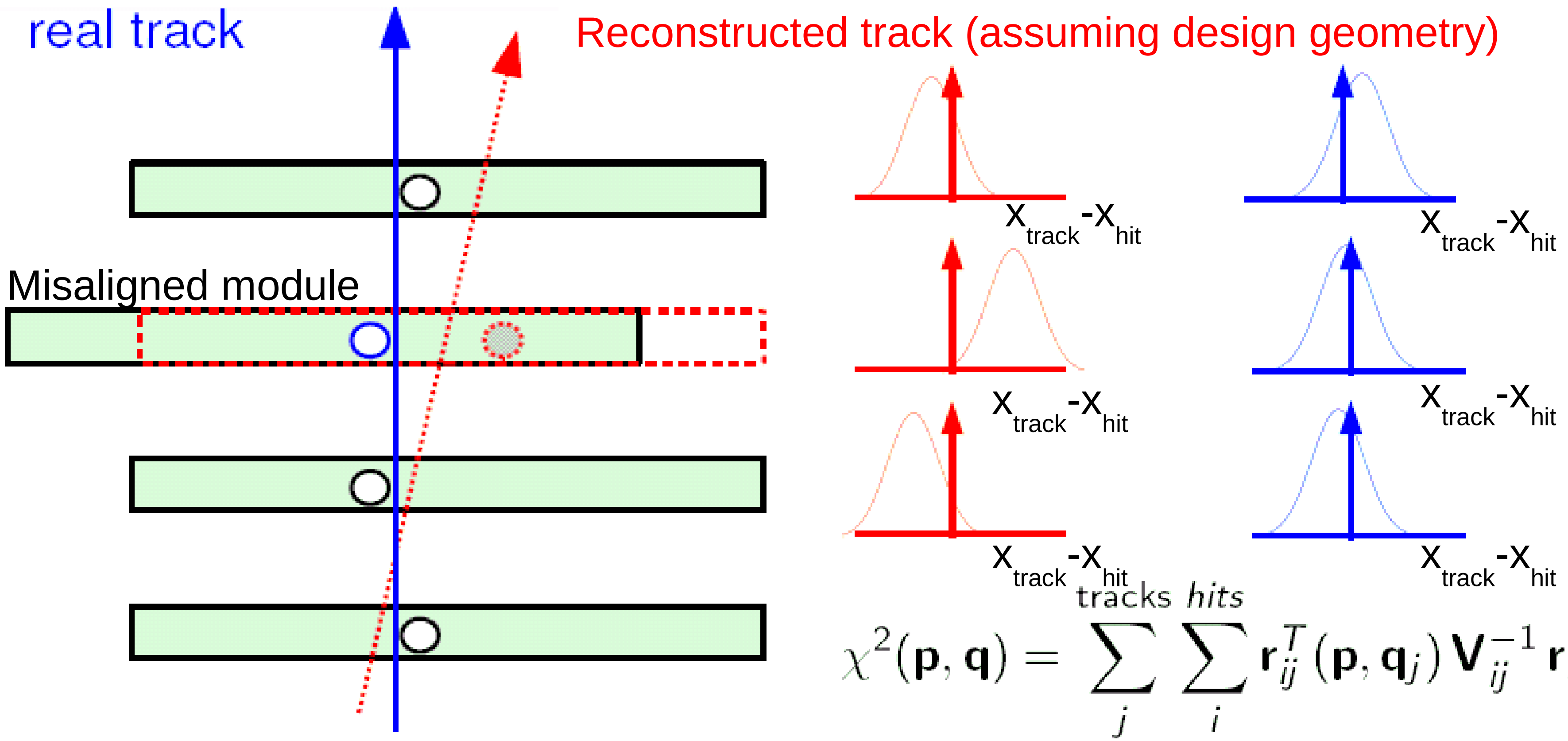




- 1d-modules(single): sensitive coordinate in u (rφ barrel, φ endcaps)
- 2d-modules(double): rφ- + stereo-module-unit rotated by 100mrad around local y
- 16588 modules x 6dof = $O(10^5)$ parameters → alignment challenge

Alignment parameters per module (barrel/endcaps)





$$\chi^2(\mathbf{p},\mathbf{q}) = \sum_j^{\text{tracks}} \sum_i^{hits} \mathbf{r}_{ij}^T(\mathbf{p},\mathbf{q}_j)\,\mathbf{V}_{ij}^{-1}\,\mathbf{r}_{ij}(\mathbf{p},\mathbf{q}_j)$$

- Use tracks to determine 'real' module position via minimisation of track residuals ($r = x_{track} - x_{hit}$)
- Global χ^2 depends on local track parameters q and global alignment parameters (module positions) p = parameters of interest

Alignment Algorithms

- Global method Millepede II (V.Blobel):

    + includes module correlations

    + only a few iterations necessary (internal outlier rejection)

    - CMS used simplified track model, but more realistic models available

- Local method HIP:

    + information from survey measurements included

    + same track model (Kalman) as for CMS track reconstruction

    - module correlations ignored

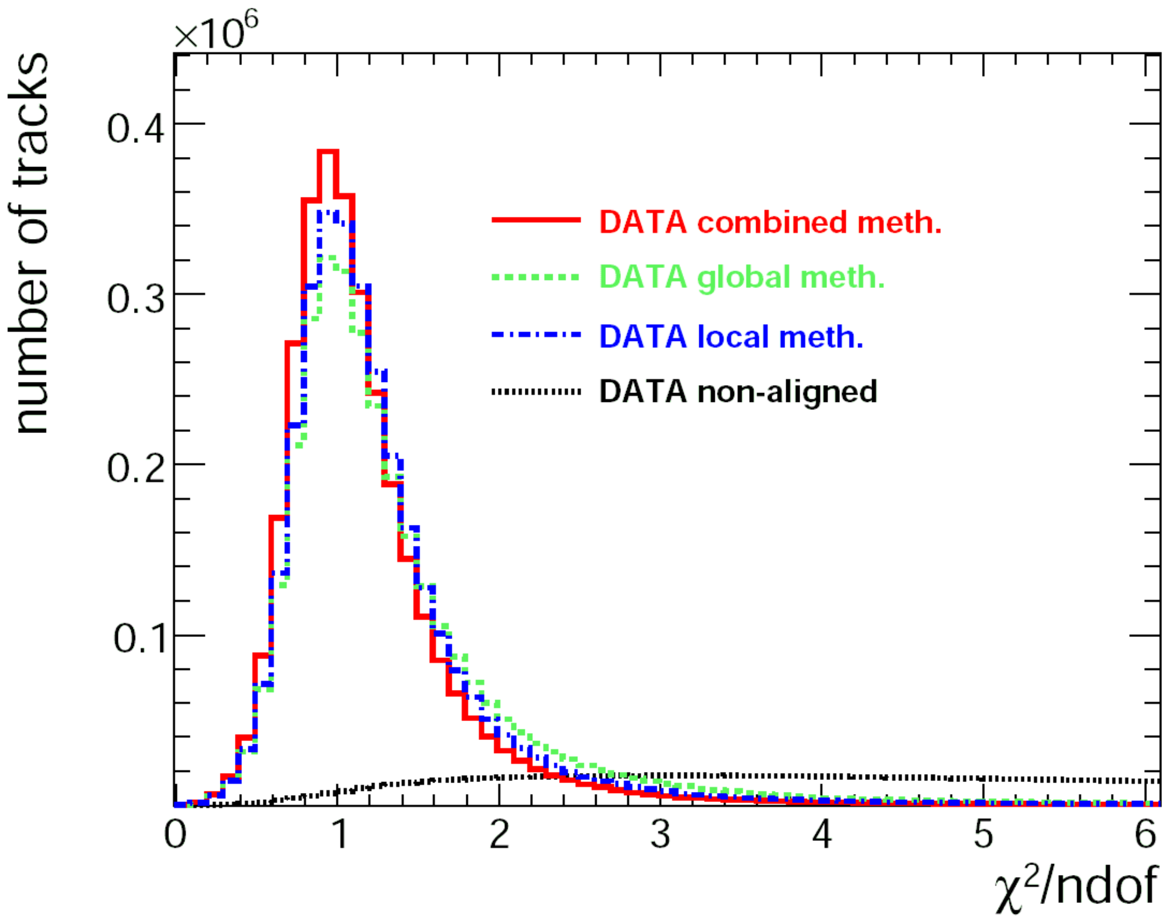
    - large number of iterations necessary to account for loosely connected parts of the tracker

- Both algorithms were used in a hierarchical multi-step approach (large detector structures → module level(**separate alignment of 2d-module units = large impact on alignment precision**))

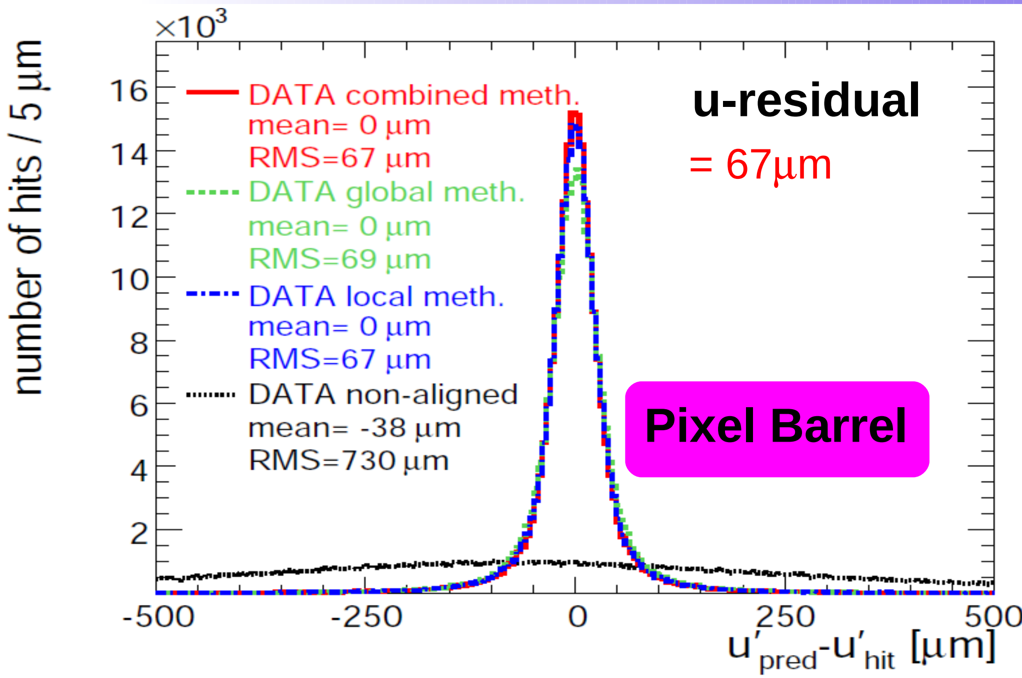
- Combined method: HIP on top of Millepede II

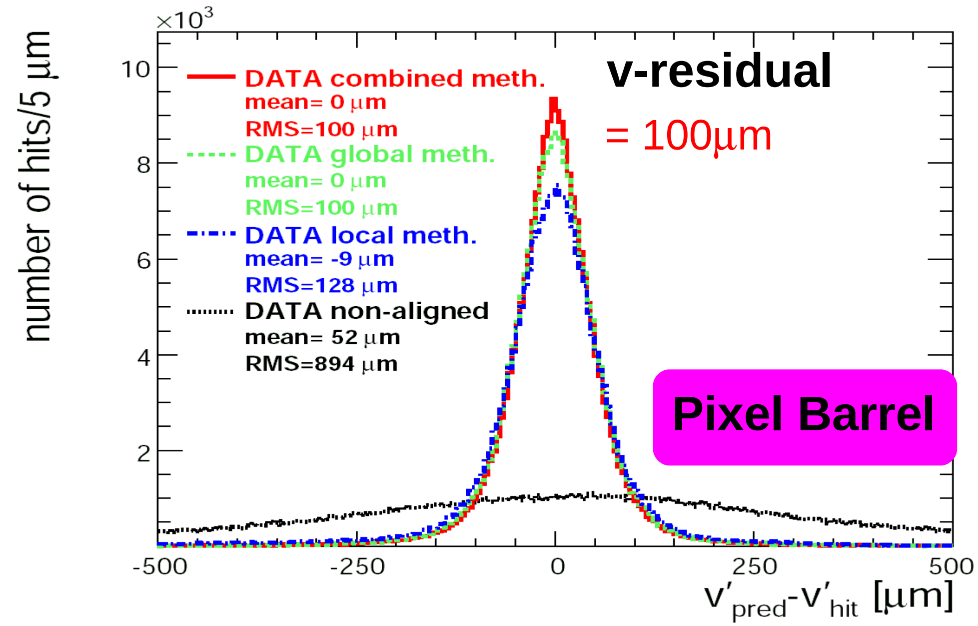
Alignment Results with Cosmic Ray Data in 2008

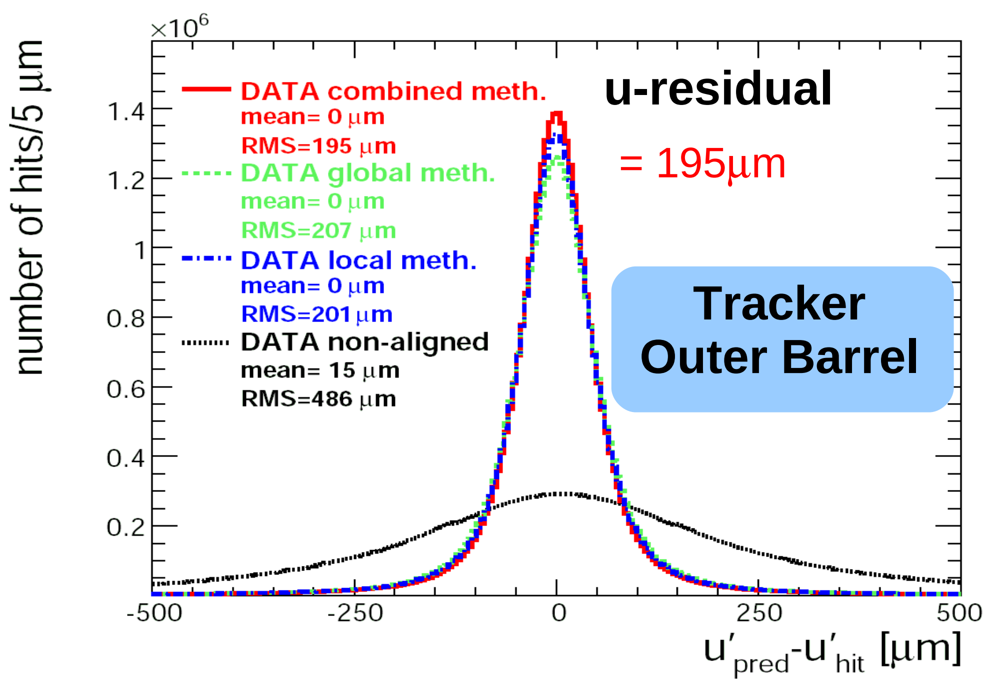
- Cosmic ray data in 2008 used for alignment:
  - about 3.2Mio. tracks from cosmic muons with magnetic field on
  - Different illumination of the various detector parts, sufficient statistics in most of the barrel and good track quality for modules hit vertically
  - Hit fraction in pixel barrel 3%, in the pixel endcaps 1,5%
- Normalized χ^2 before and after the alignment for the global and local method + their combination (local method applied on top of the global method (best performance))



Alignment Validation: Residual Distributions



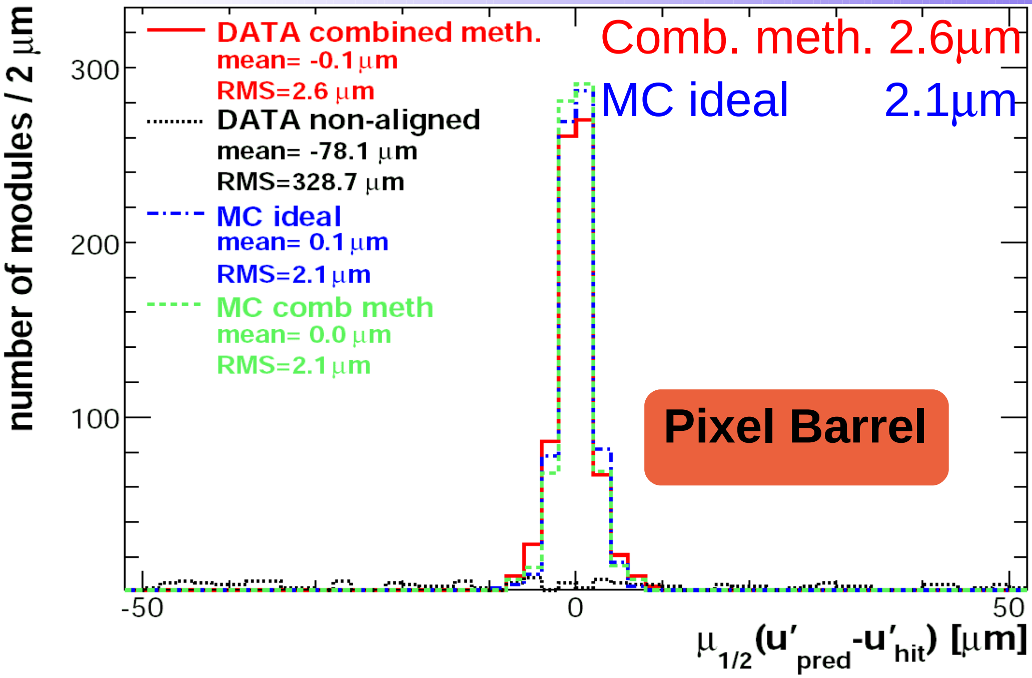


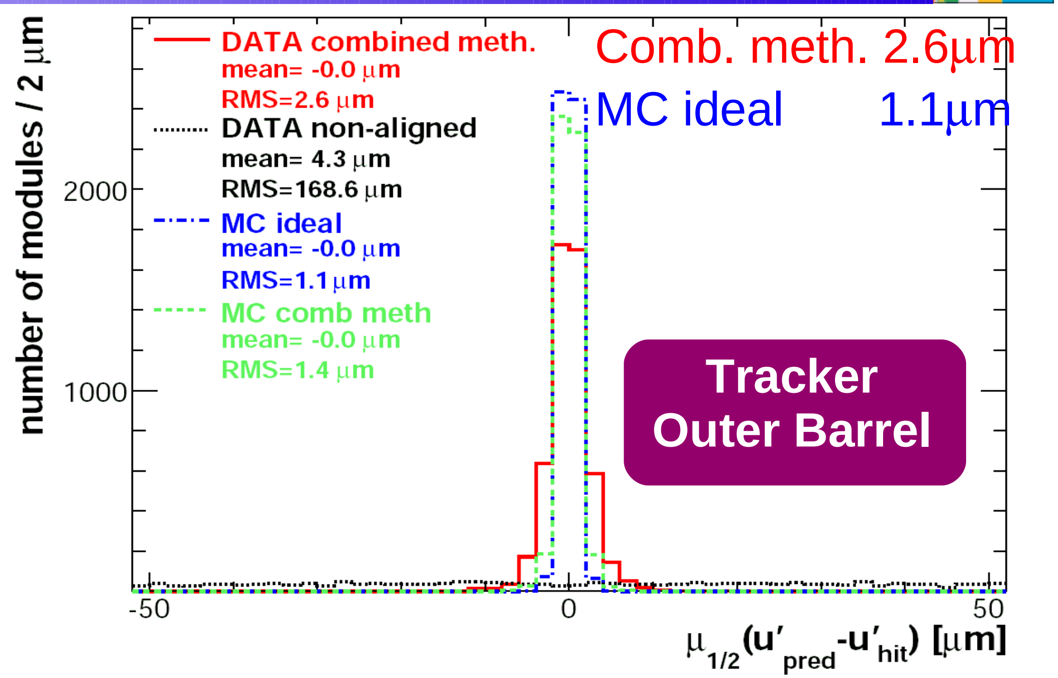


- Residuals dominated by random effects (multiple scattering & hit error)

→ Distribution of the median of the residuals on module level as additional quality check of the alignment performance

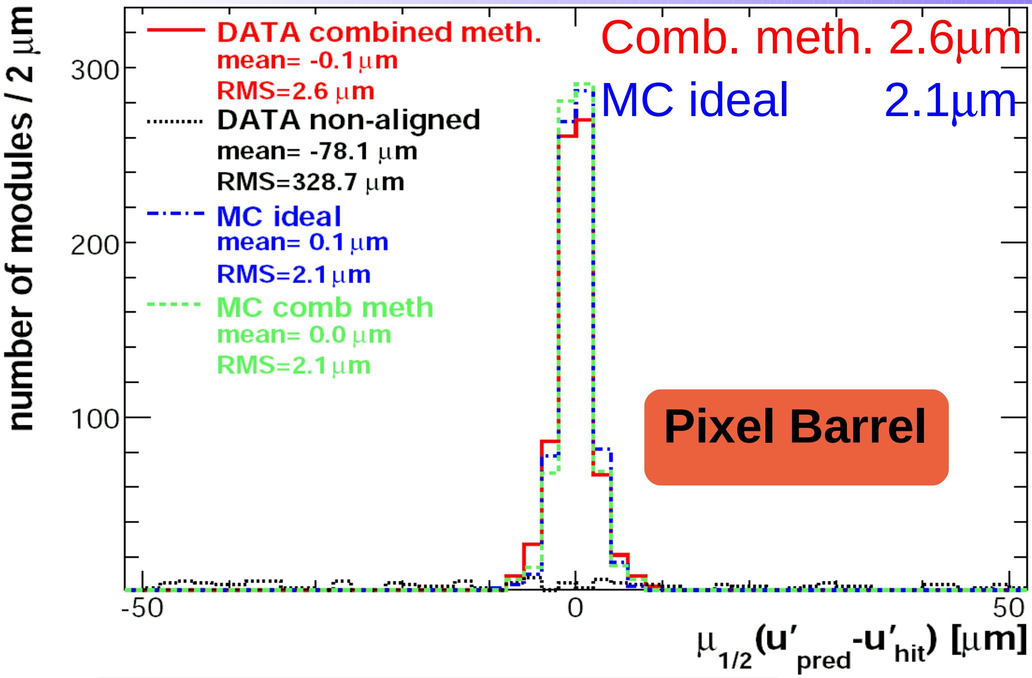
Alignment Validation: DMRs

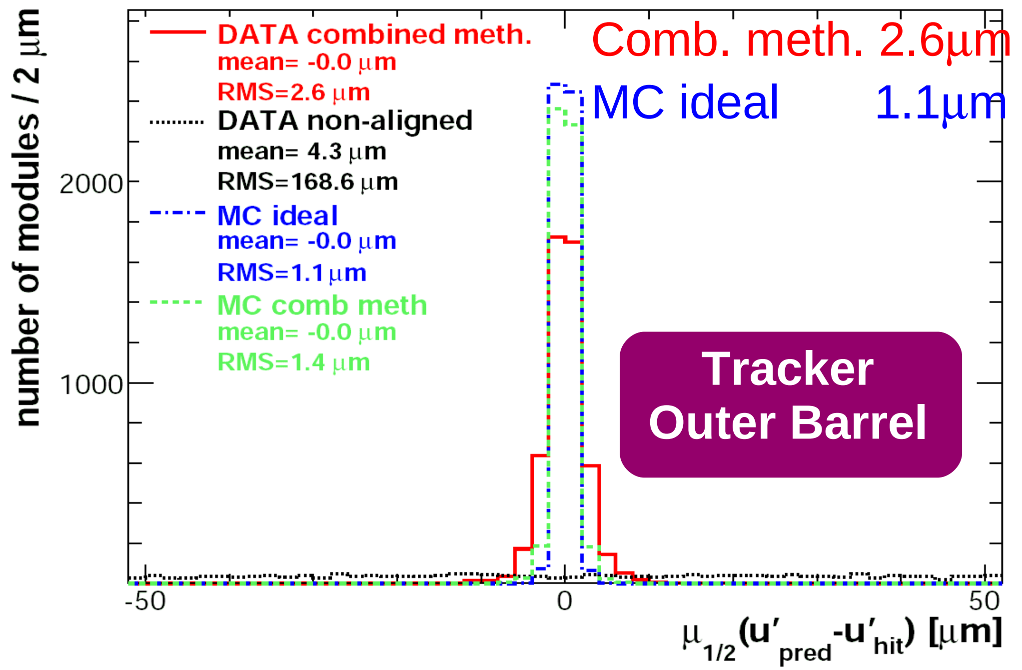




subdetector (coordinate)	non-aligned [μm]	global [μm]	local [μm]	combined [μm]	modules >30 hits
PXB (u')	328.7	7.5	3.0	**2.6**	757/768
PXB (v')	274.1	6.9	13.4	**4.0**	
PXE (u')	389.0	23.5	26.5	**13.1**	391/672
PXE (v')	385.8	20.0	23.9	**13.9**	
TIB (u')	712.2	4.9	7.1	**2.5**	2623/2724
TOB (u')	168.6	5.7	3.5	**2.6**	5129/5208
TID (u')	295.0	7.0	6.9	**3.3**	807/816
TEC (u')	216.9	25.0	10.4	**7.4**	6318/6400

Alignment Validation: DMRs



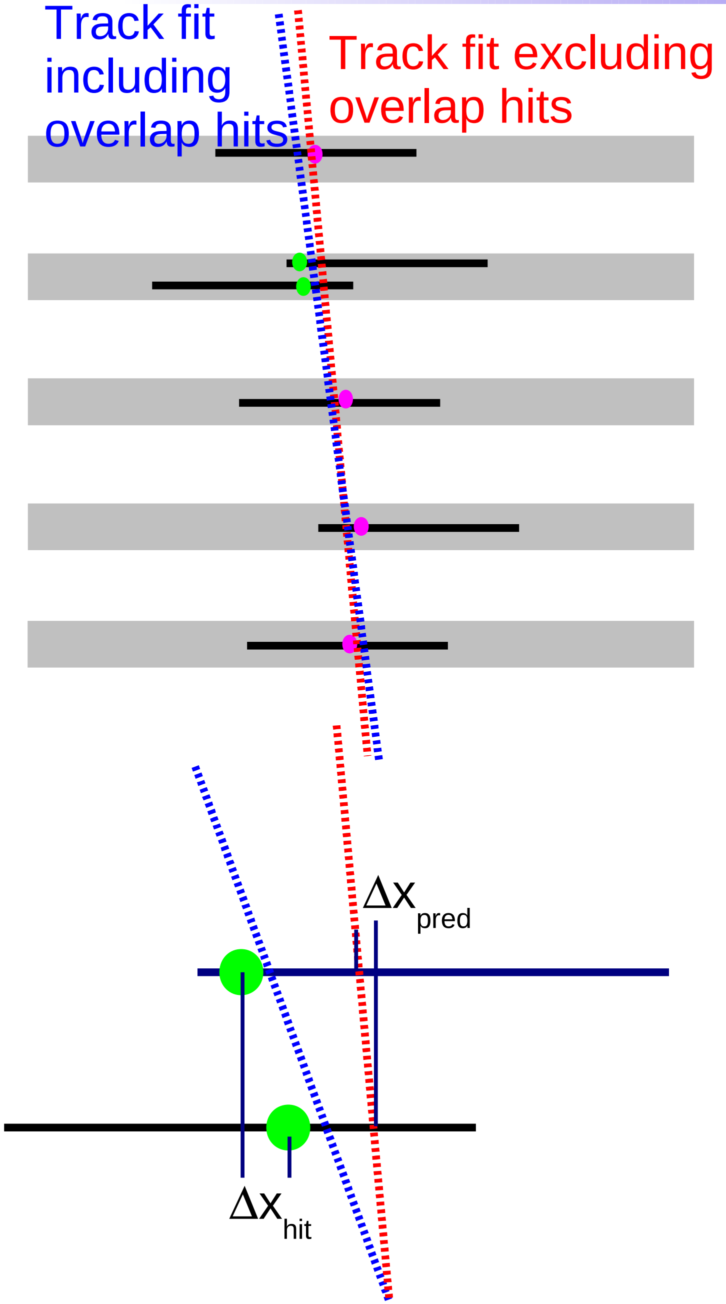


MC combined method:

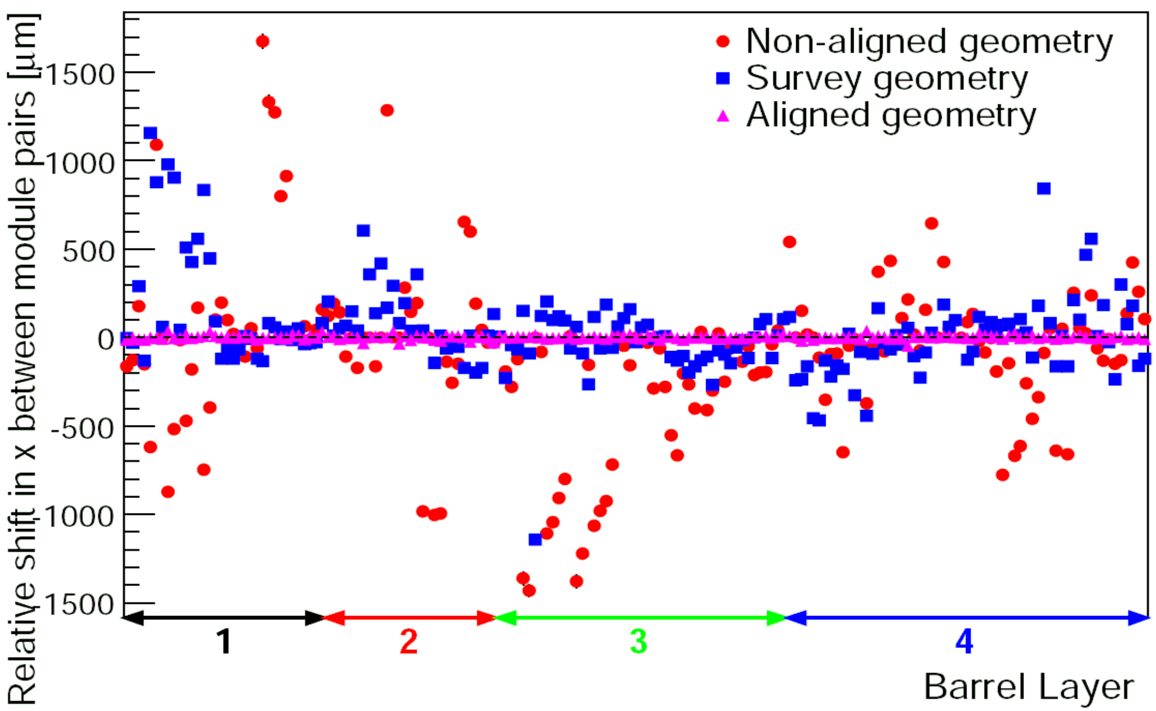
- Use the **alignment** geometry (comb.meth) as **start geometry on MC** and align back
- Estimate/approximation of remaining misalignment achieved with a standalone cosmic alignment

subdetector (coordinate)	combined [μm]	combined MC [μm]	ideal MC [μm]
PXB (u')	**2.6**	2.1	2.1
PXB (v')	**4.0**	2.5	2.4
PXE (u')	**13.1**	12.0	9.4
PXE (v')	**13.9**	11.6	9.3
TIB (u')	**2.5**	1.2	1.1
TOB (u')	**2.6**	1.4	1.1
TID (u')	**3.3**	2.4	1.6
TEC (u')	**7.4**	4.6	2.5

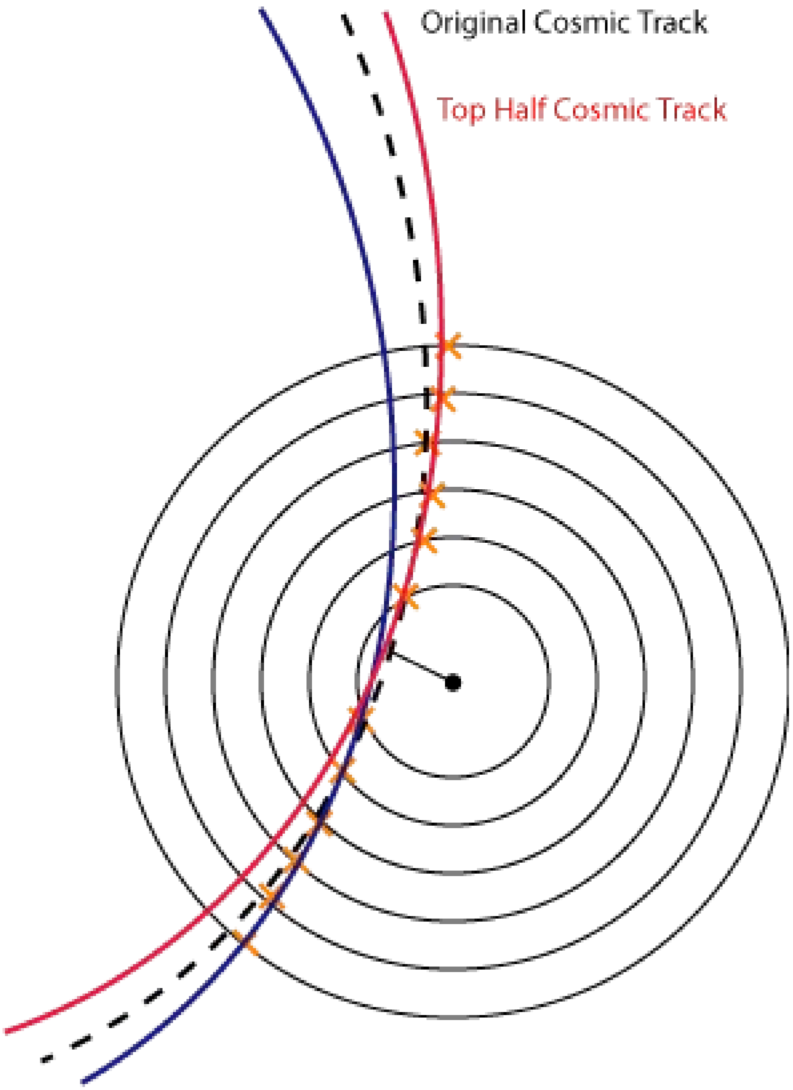
High level validation: Overlap studies



- Overlapping modules in one layer → 2 hits with only small amount of material in between + small uncertainties from track extrapolation
- Measure the accuracy of the track prediction excluding the overlap hits via the double-difference between the hit postions $\Delta x_{hit} = \Delta x_{hit1} - \Delta x_{hit2}$ and the track predictions $\Delta x_{pred} = \Delta x_{pred1} - \Delta x_{pred2}$

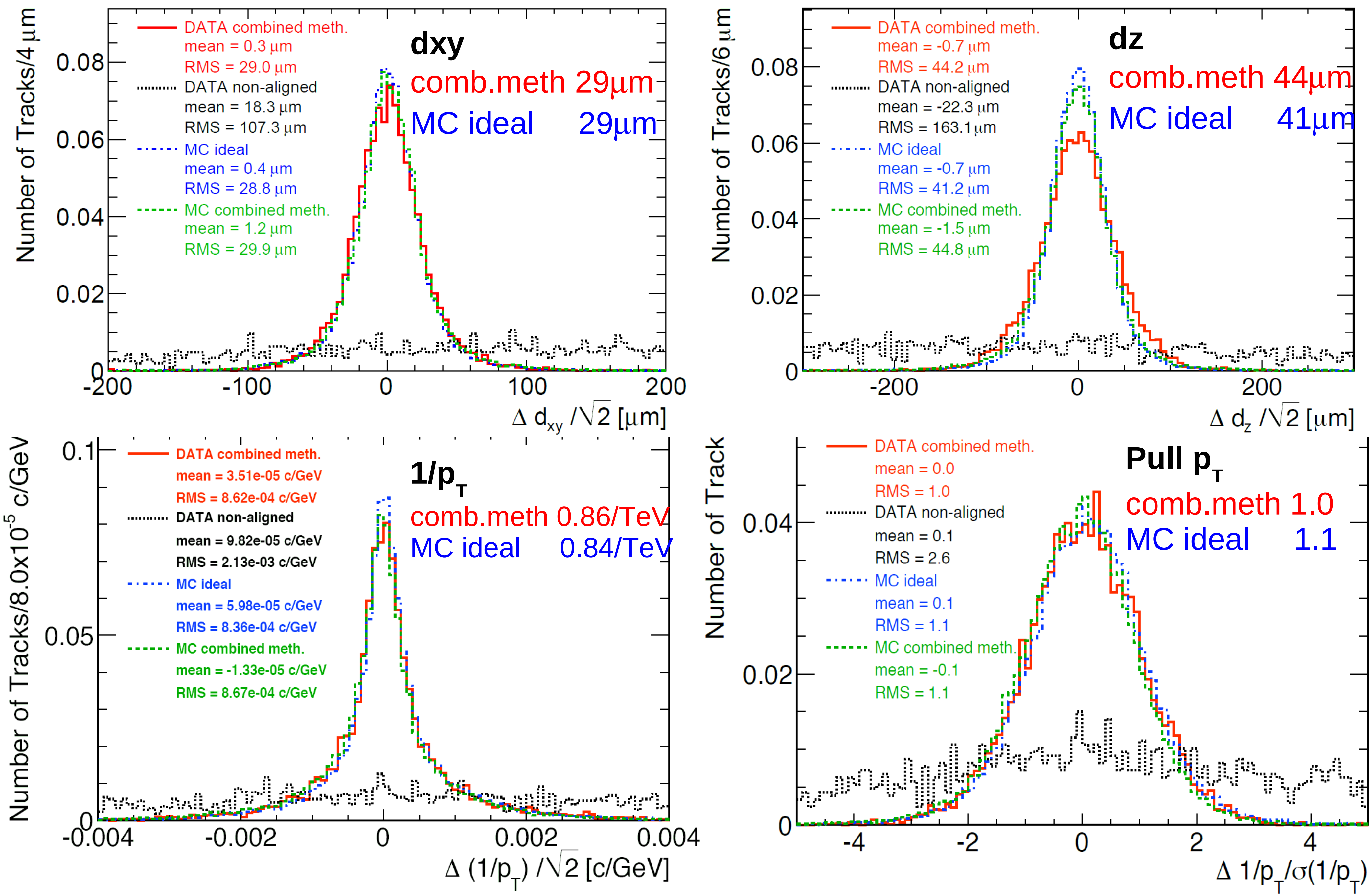


Double difference : dd = $\Delta x_{hit} - \Delta x_{pred}$



- Split cosmic track along the distance of closest approach to the nominal beamline
- Select only tracks with 3 pixel hits per leg
- Refit bottom and top part separately and compare resulting track parameters

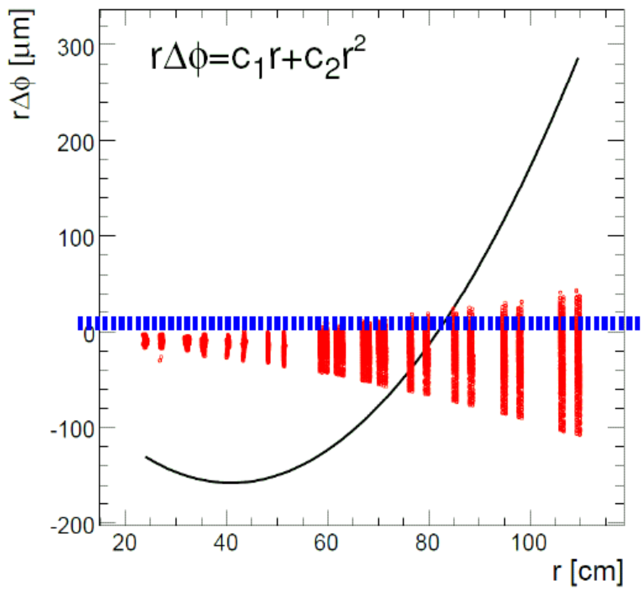
High level validation: Cosmic Track Splitting

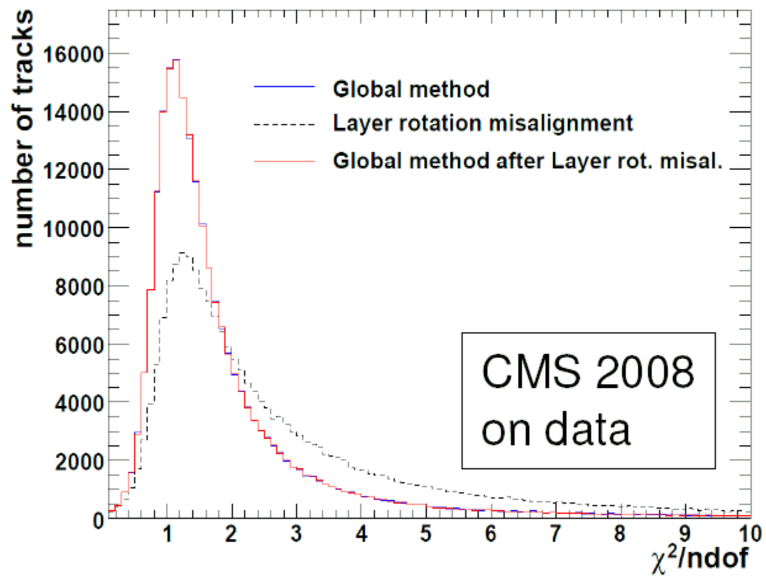


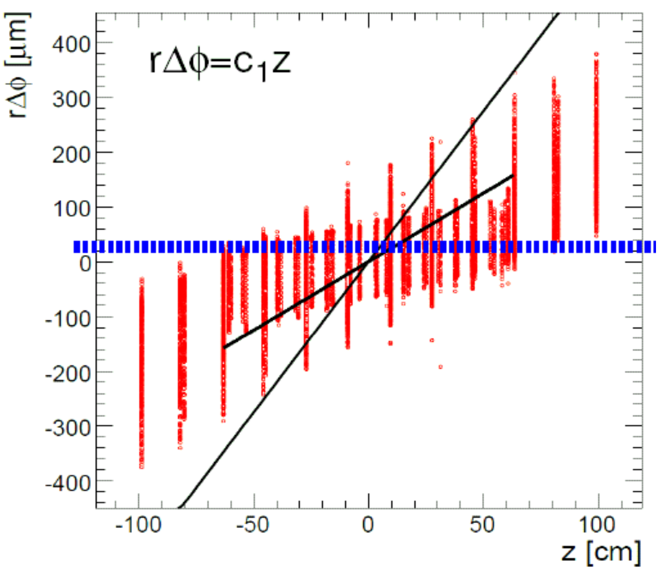
Systematic misalignment effects: Weak modes

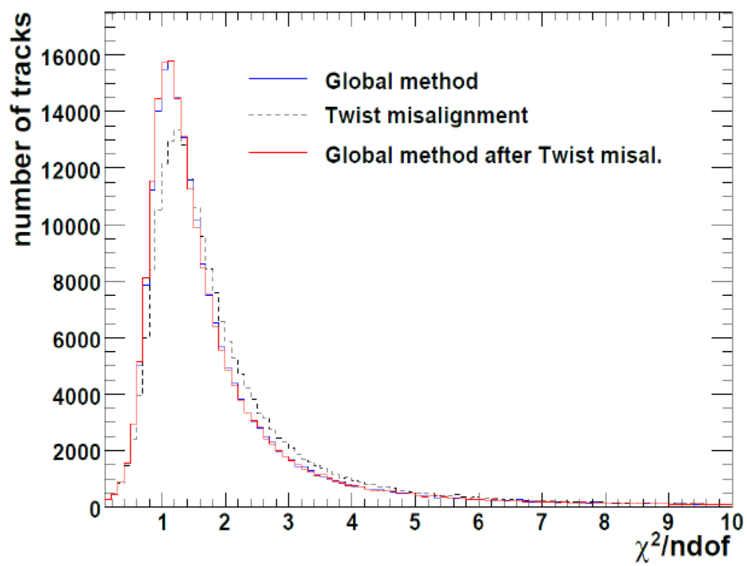
shift of modules (in $r\Delta\phi$)

χ^2/ndof change







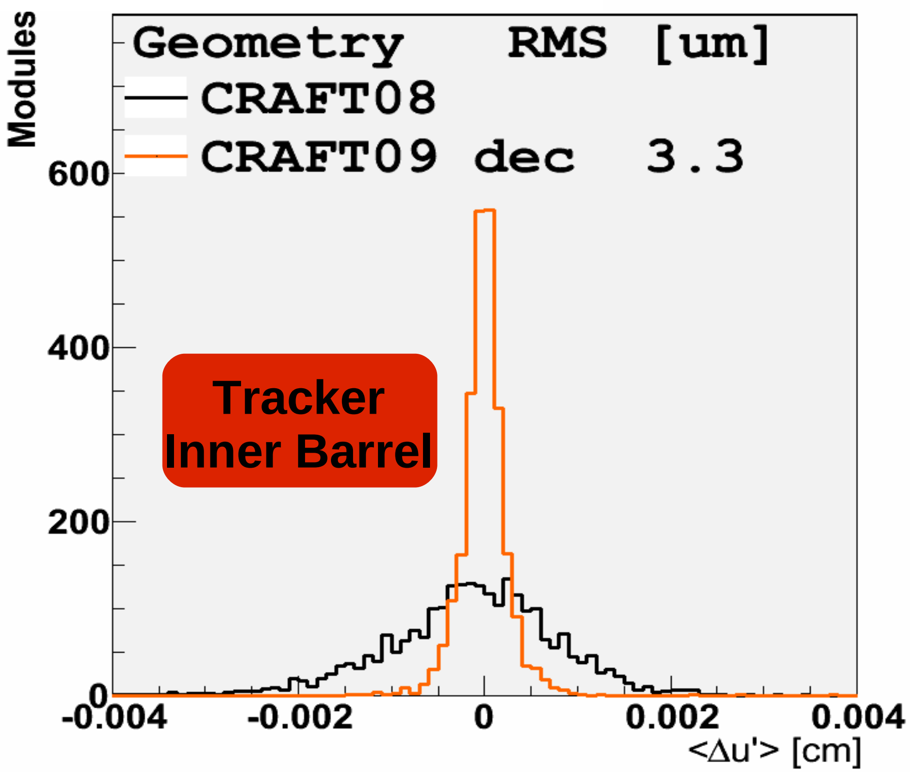


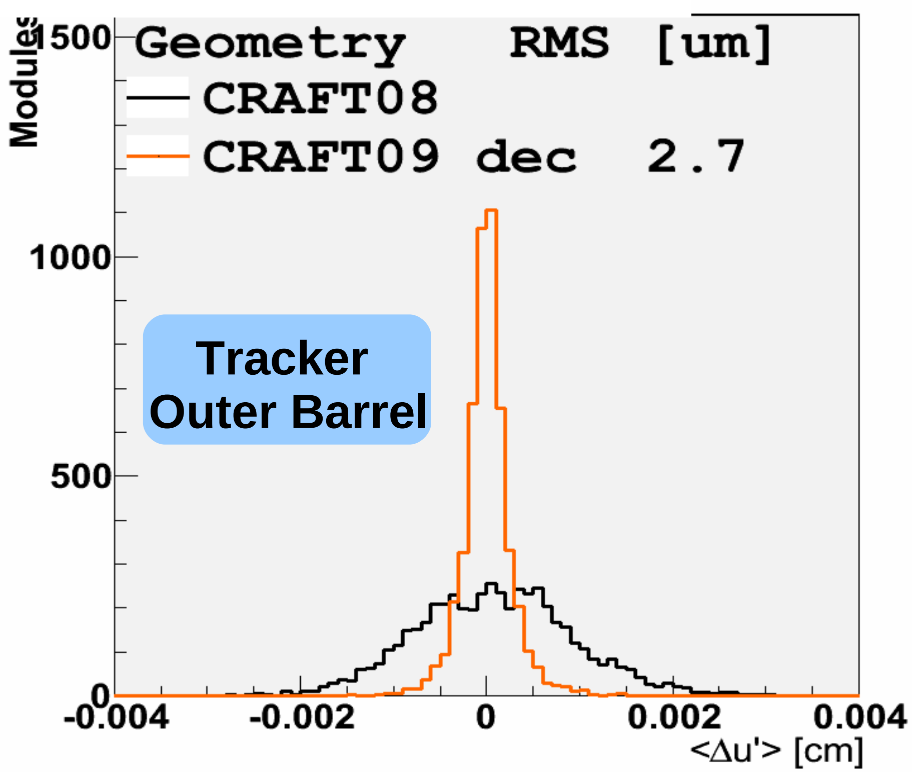
- Starting from aligned geometry (global method data)
- Add some systematic misalignment on top of the aligned geometry
- Rerun alignment procedure with the same tracks as before

Artificial misalignment can not be recovered completely using only tracks from cosmic rays → need for complementary datasets (tracks coming from the beamspot, beam halo)

First Results from Cosmic Ray Data in 2009

- Distributions of the median of the residuals for TIB and TOB using cosmic ray data from 2009
  - Geometry gained from 2008 alignment exercise still valid for strip barrel
  - Alignment results improve with cosmic ray data taking in 2009
  - Caveat: CRAFT09 not statistically independent

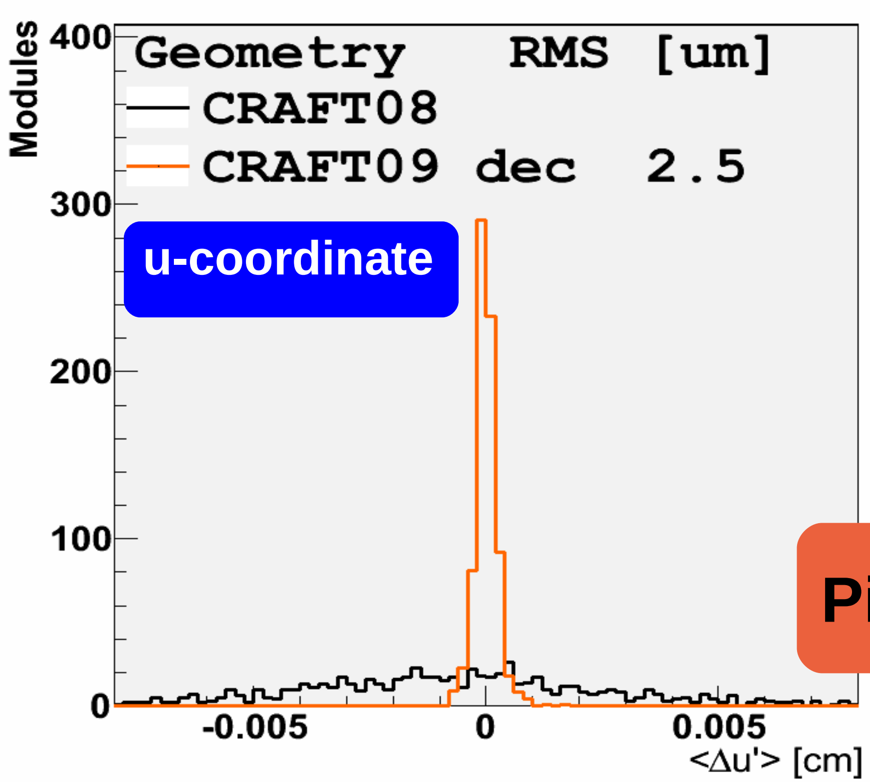




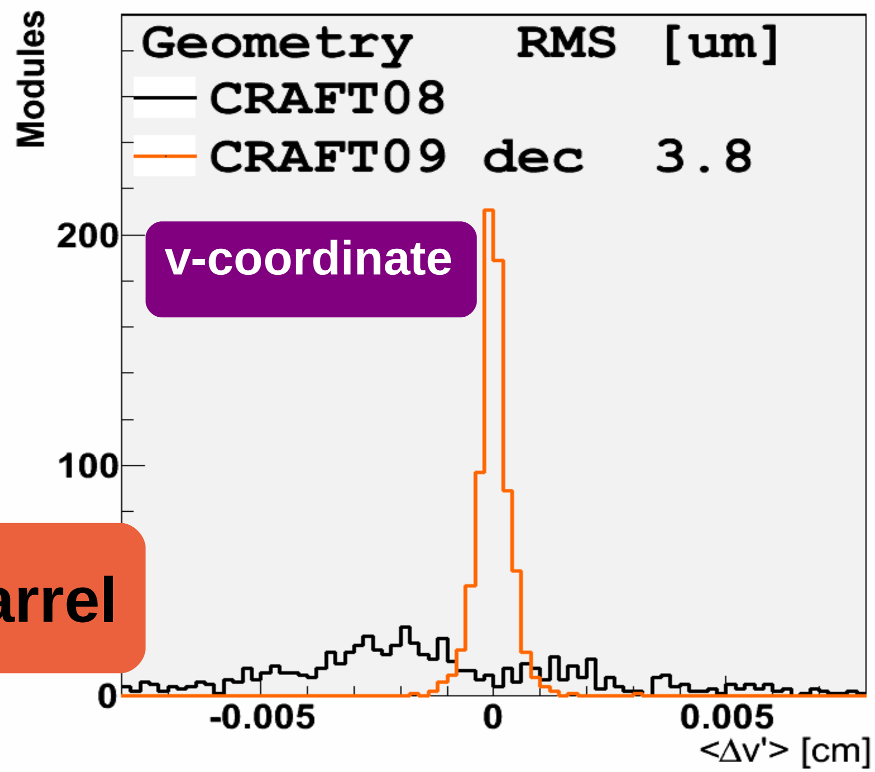
First Results from Cosmic Ray Data in 2009

- Pixel detector was removed and reinstalled between data taking in 2008 and 2009
  - 2008 geometry shows different shape (mean shifted especially in v coordinate)
  - Recovered after alignment with cosmic ray data from 2009

Distribution of the median of the residuals



Distribution of the median of the residuals



Pixel Barrel

Summary

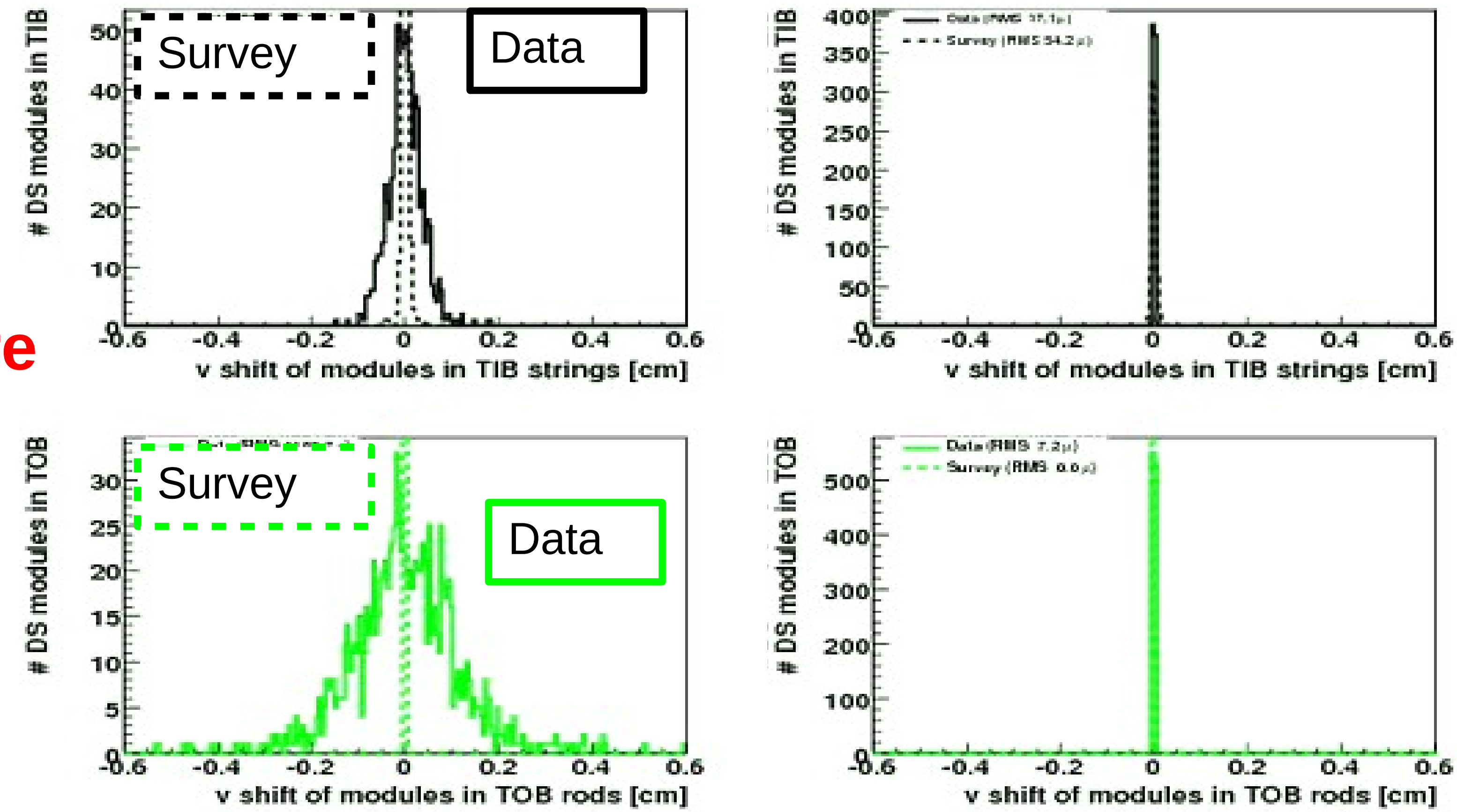
- CMS full tracker alignment with cosmics
  - Challenging task (16588 modules)
  - Separate 2d-module alignment improved the alignment results significantly
  - Complementary alignment methods (local and global) show best results in combination
  - Powerful/flexible validation tools in place
- alignment exercise with data taken in 2009 ongoing
  - First results indicate confirmation/improvement of the results using data from 2008
- Remaining misalignment/weak modes need complementary data from the beamspot or beamhalo

➔ We are looking forward to **November 2009**!

THANKS!

Backup: Motivation for separate 2d-module alignment

before



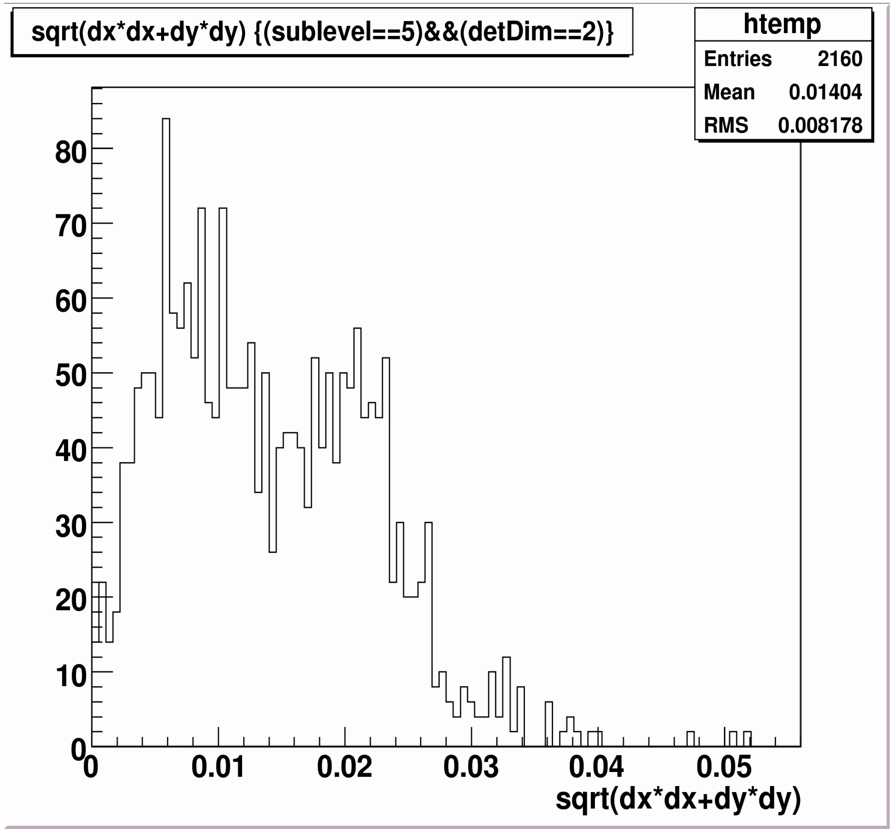
after

- 2d-modules aligned as one led to large movements of the modules within a string/rod compared to survey measurements

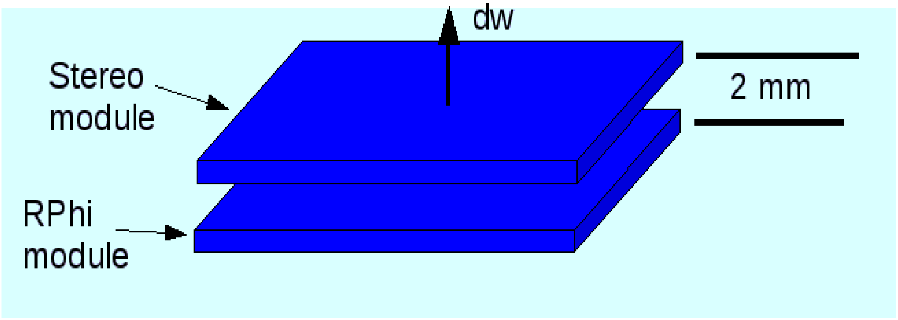
➔ Necessity of separate module-unit alignment for 2d modules

Backup: separate 2d-module alignment

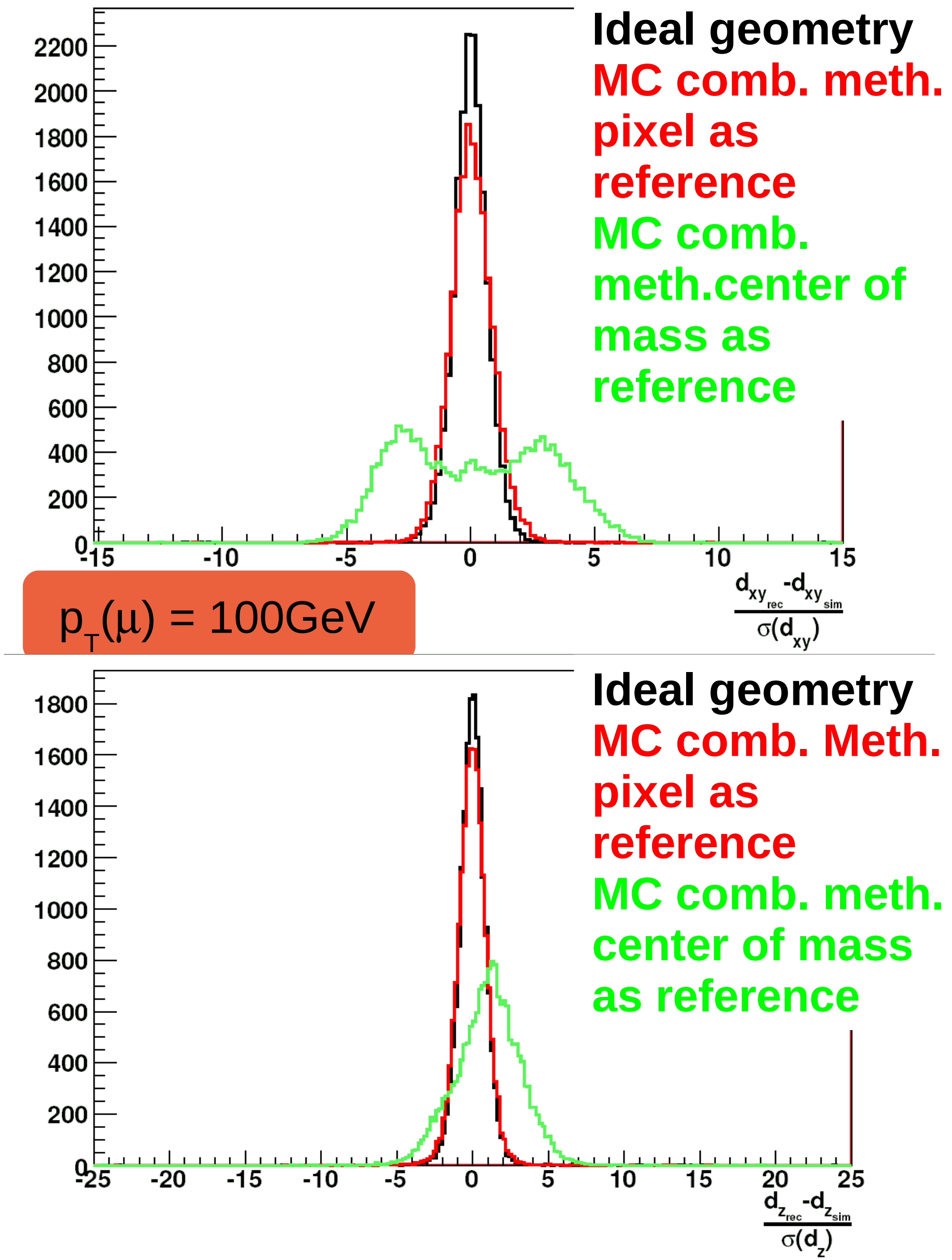
- Check that correction in dw of module-units in 2d-modules do not swap place (2mm in TOB, less in TIB)
- Not seen in CRAFT data



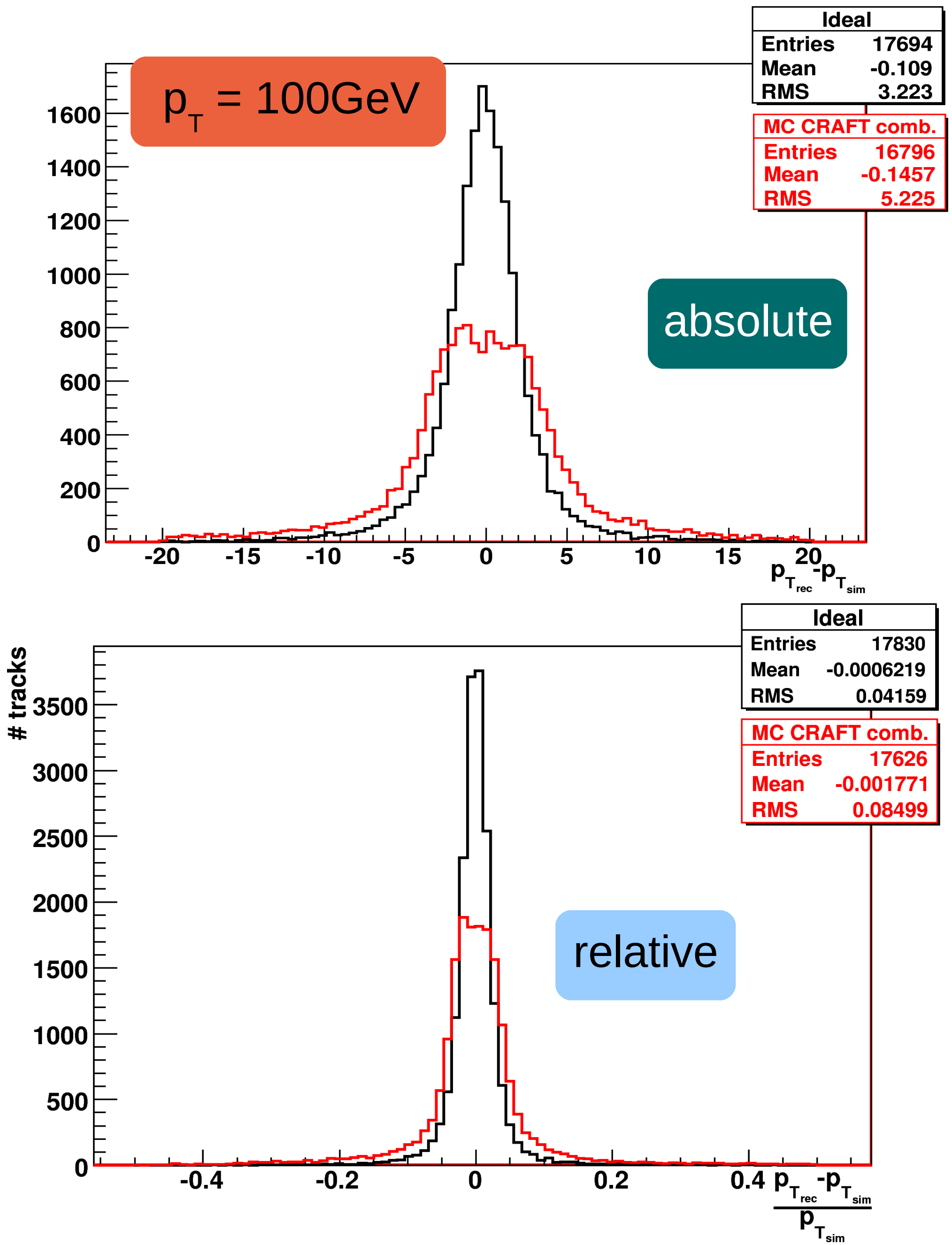
DS Module



- **MC comb. method geometry** as an equivalent/approximation of the **remaining misalignment**
- High p_T muons from beamspot to investigate influence of remaining misalignment on track parameters
- Alignment procedure run without fixed reference point → alignment object is centred afterwards
- Choice of reference:
  - Strong dependence of track parameter from pixel
  - Pixel as reference system shows less impact on track parameters



- **MC combined geometry** as an equivalent/approximation of the **remaining misalignment**
- p_T is independent of centering reference
- Diminution of performance in comparison to ideal due to remaining misalignment
  - Nonuniform illumination → detector parts with low statistics
  - χ^2 invariant detector distortions not sensitive to cosmic rays → weak modes



Comparison of Geometries: impact parameters and angles