# CMS Tracker Alignment Strategy with Cosmic Muons

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FOR

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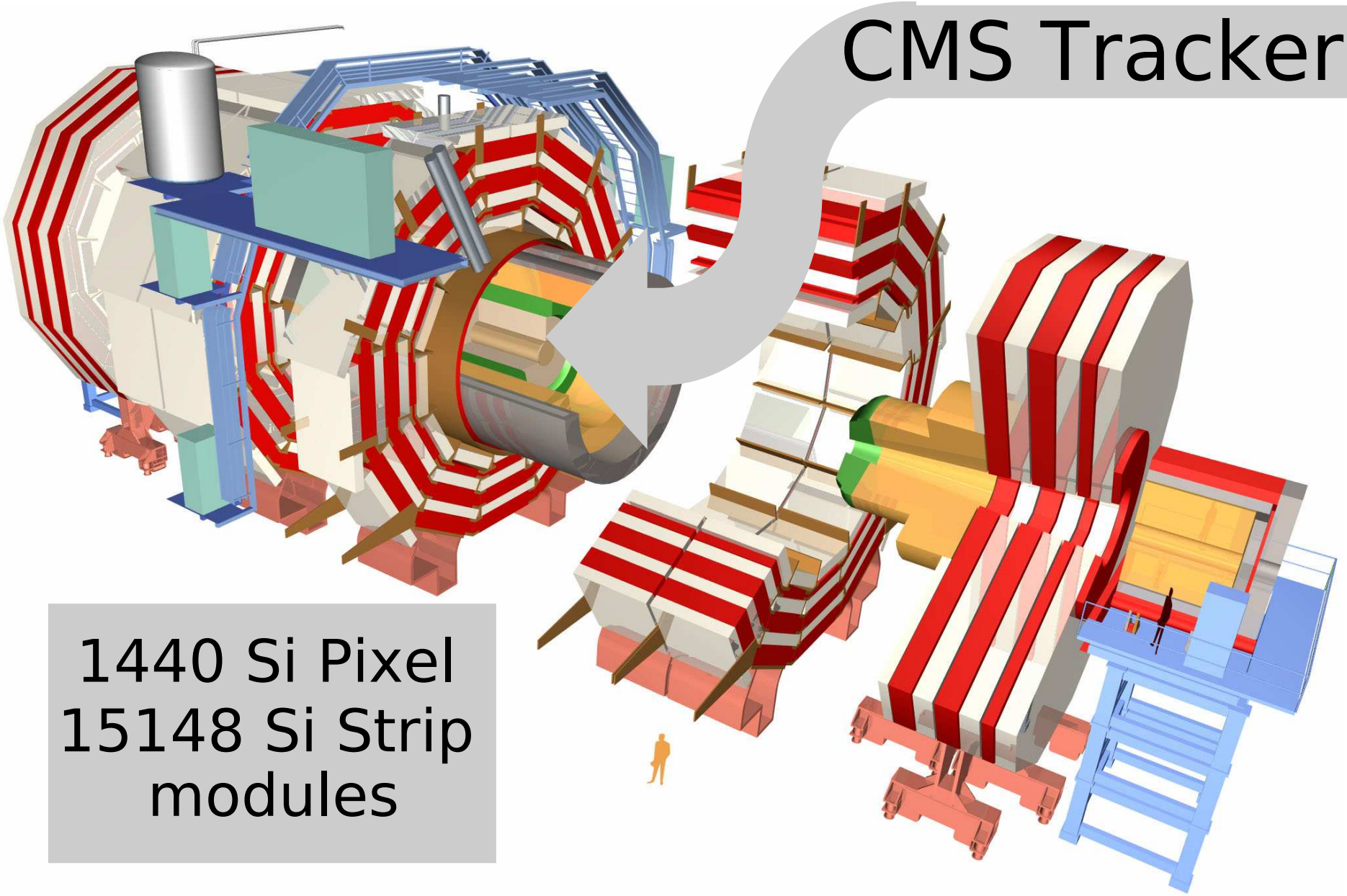
# Tracker in the CMS Detector



# Outline / Acknowledgment

- Input to CMS Tracker alignment algorithms:
  - Laser Alignment System
  - optical survey
  - tracks from cosmic muon runs $\Rightarrow$ ultimate precision

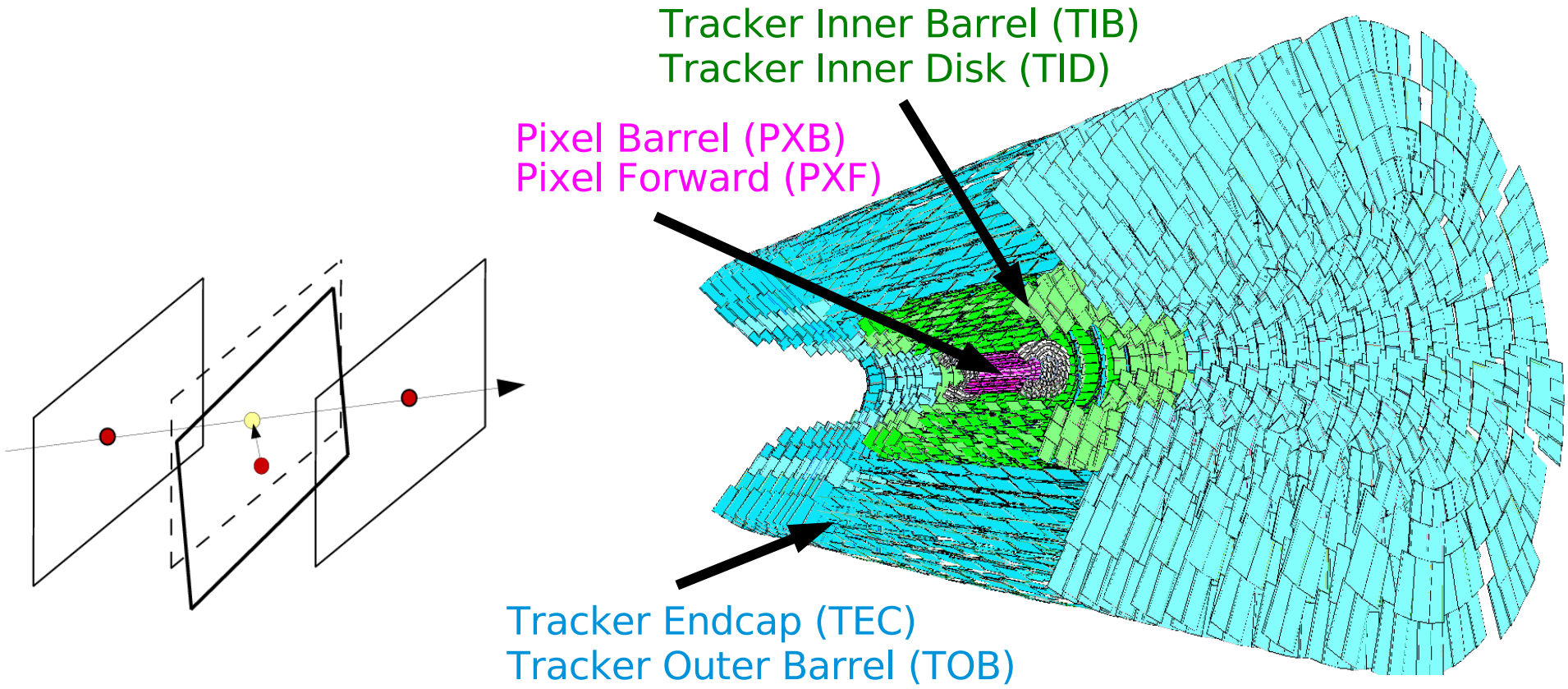
    Tracker Integration Facility (TIF) with partial Tracker in 2007

    CMS at Point-5 ("CRAFT" cosmic run) with full Tracker in 2008
- Detailed results in the next talk (by E. Migliore)
- Alignment is a big project, but only the final step in commissioning

part of the CMS tracker alignment team "on the ground"

# CMS Tracker Alignment Goal

- Alignment goal: nail down (few $\mu$m) all 16,588 modules ($\times$ 6 dof)




- Minimize residuals

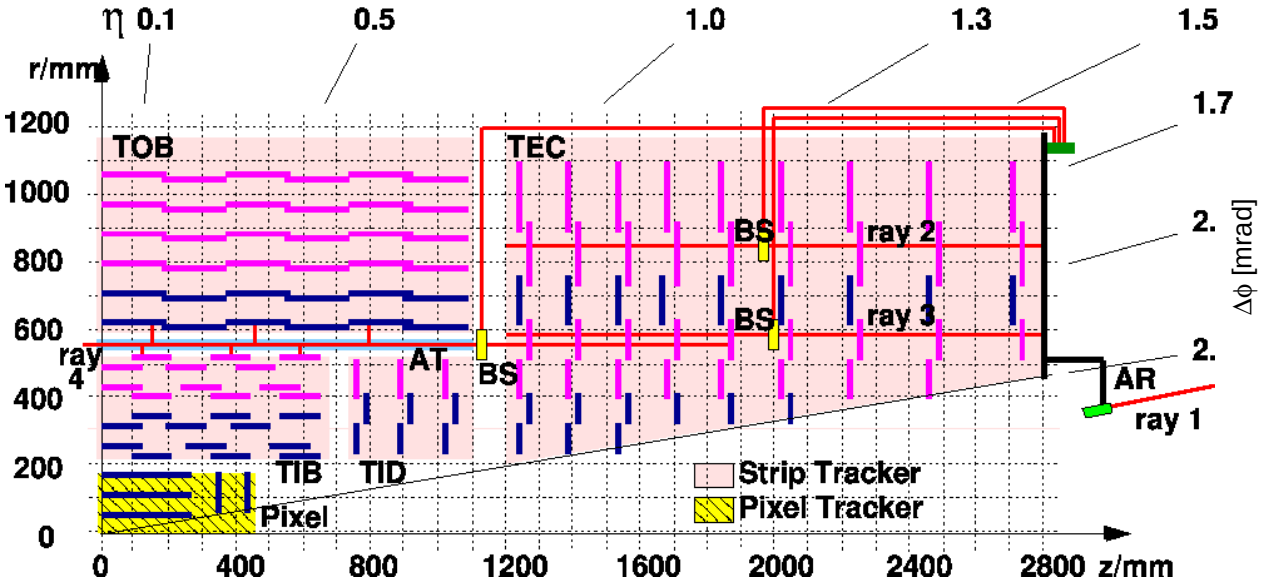
$$\chi^2(\mathbf{p}_{\text{modules}}, \mathbf{q}_{\text{tracks}}) = \sum_{i=1}^{\text{N}_{\text{residuals}}} r_i^T \mathbf{V}_i^{-1} r_i$$

# Laser Alignment System (LAS)

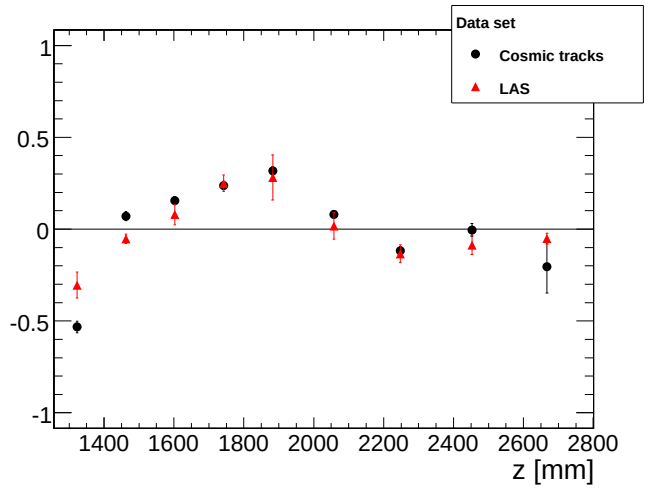
- See talk at 2nd LHC alignment workshop (June 2007):

  B. Wittmer "The Laser Alignment System of the CMS Tracker"

- Connect large structures (8 sectors in $\phi$): TIB - TOB - TEC
- Cosmic runs for commissioning: standalone $\sim 100\mu$m, relative $\sim 20\mu$m
- Tracker geometry: note 2D (100 mrad strip angle) and 1D modules




- LAS vs. Track-based $\phi$ of TEC disks



# Optical Survey of CMS Tracker

- See talk at 2nd LHC alignment workshop (June 2007):

  A.G. "First CMS Alignment Geometry: Survey Data and Their Implementation"

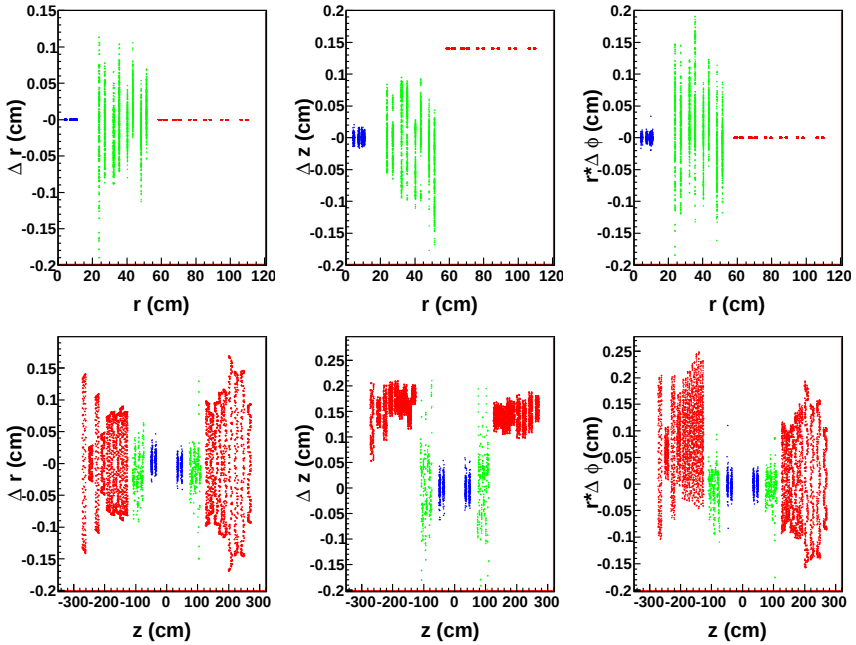
Barrels:

PXB - modules (2D only)
TIB - modules and up
TOB - barrel

Endcaps:

PXF - modules and up
TID - modules and up
TEC - disks and endcap

survey vs. design geometry



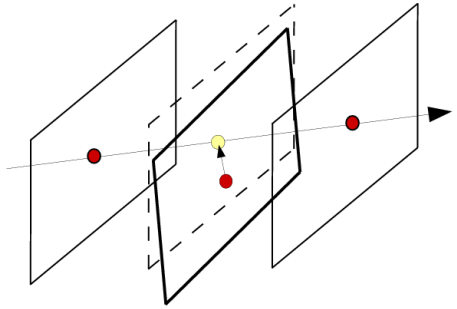

- Tracks + Survey in "local algorithm", to constrain all 6 dof:

$$\chi^2_{\text{module}} = \sum_{i}^{\text{hits}} r_i^T(\mathbf{p_m})\mathbf{V}_i^{-1}r_i(\mathbf{p_m}) + \sum_{j}^{\text{survey}} r_{*j}^T(\mathbf{p_m})\mathbf{V}_{*j}^{-1}r_{*j}(\mathbf{p_m})$$

following *BABAR* implementation: arXiv:0809.3823

# Statistical Methods in CMS Tracker Alignment

- Local iterative method ("Hits & Impact Points") CMS-NOTE-2006/018



$$\mathbf{p}_m = \left[\sum_i \mathbf{J}_i^T \mathbf{V}_i^{-1} \mathbf{J}_i\right]^{-1} \left[\sum_i \mathbf{J}_i^T \mathbf{V}_i^{-1} \mathbf{r}_i\right]$$

| | | |
|---|---|---|
| pros | full Kalman Filter track model | simple implementation, all dof |
| cons | ignore correlations in one iteration | large CPU with many iterations |

- Global method ("Millepede II") NIM A 566, 5 (2006), talk by V. Blobel

$$\chi^2(\mathbf{p},\mathbf{q}) = \sum_j^{\text{tracks}} \sum_i^{\text{hits}} \frac{(y_{ji} - f_{ji}(\mathbf{p},\mathbf{q}_j))^2}{\sigma_{ji}^2}$$

CMS implementation

| | | |
|---|---|---|
| pros | model module correlations | less CPU with one or few iterations |
| cons | simple helix trajectory model | large matrix may limit N parameters |

- Kalman filter algorithm with MC and TIF data: see talk by E. Widl

# Tracker Alignment at Integration Facility

- First integrated tracker: spring-summer 2007 arXiv:0904.1220

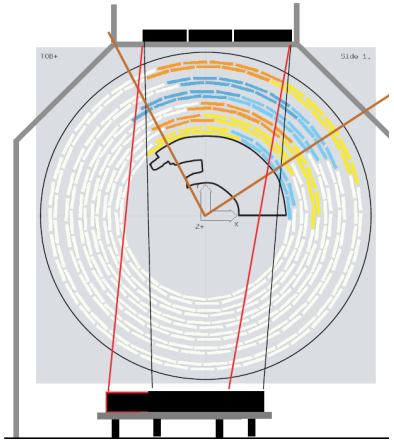
  $\sim 15\%$ of strip tracker only

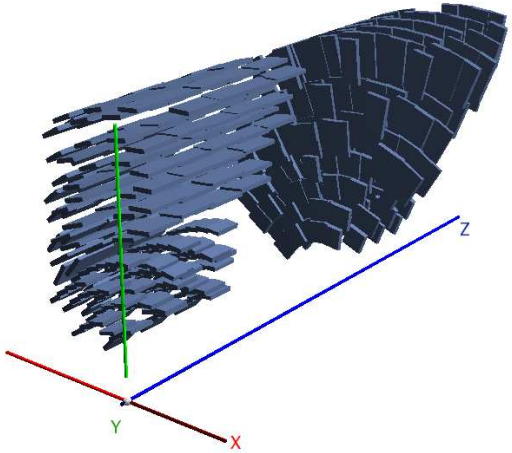
  no B-field, assume $p = 1$ GeV/$c$

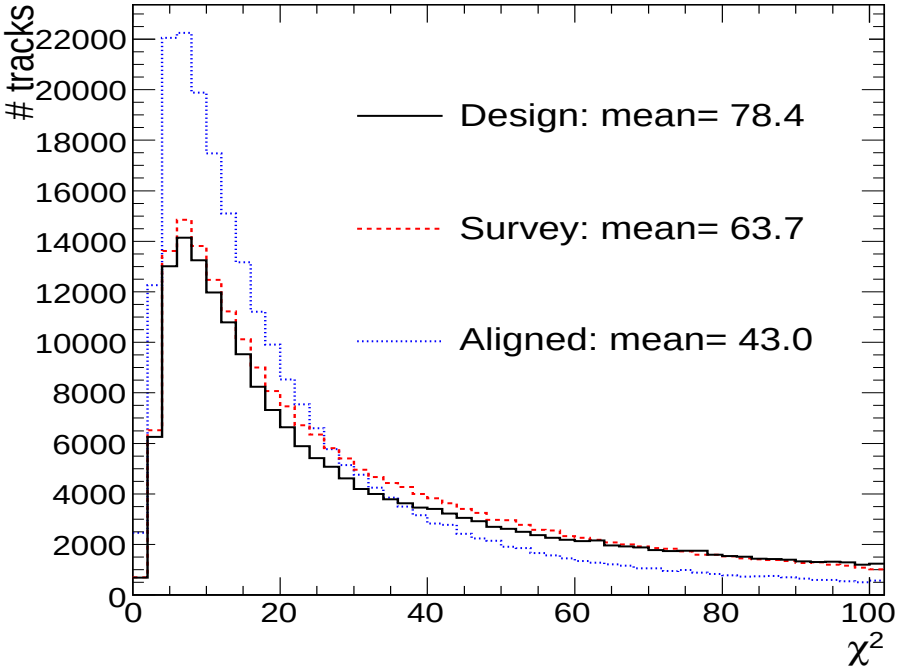
  $\Rightarrow$ multiple scattering

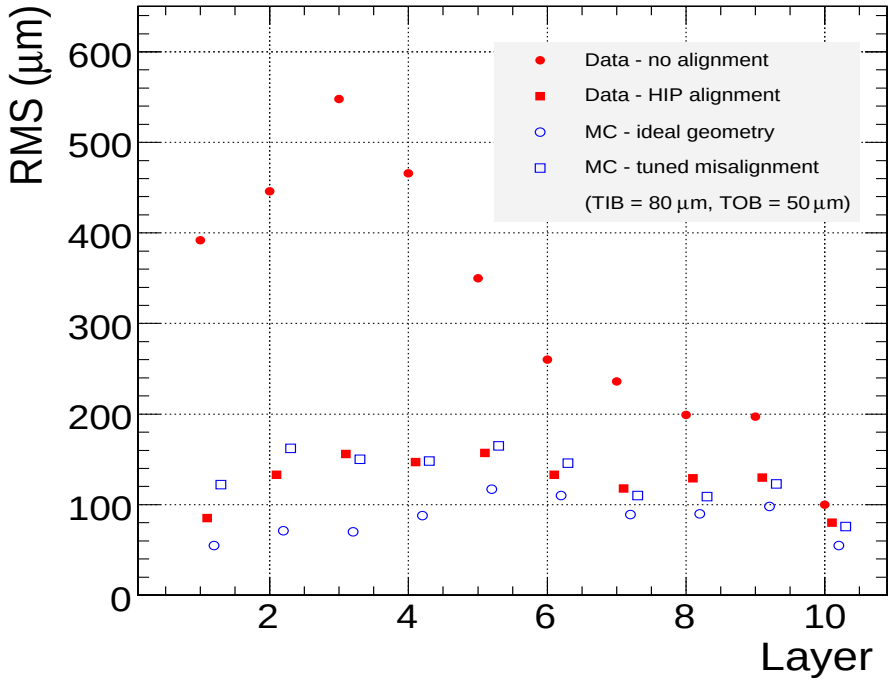
  cannot be predicted per event

- Reach $\sim 50/80 \mu$m in TOB/TIB





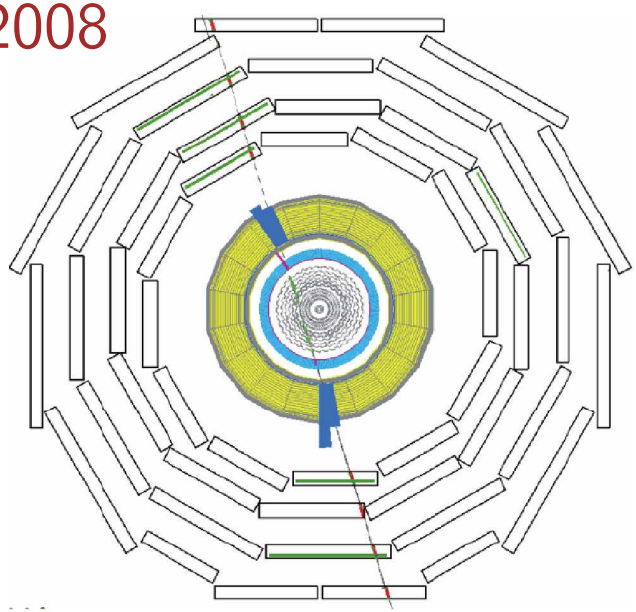



# Alignment at Point-5 without Magnetic Field

- First experience with full Tracker: summer 2008

  ∼600k cosmic tracks for Tracker alignment

  still no B-field

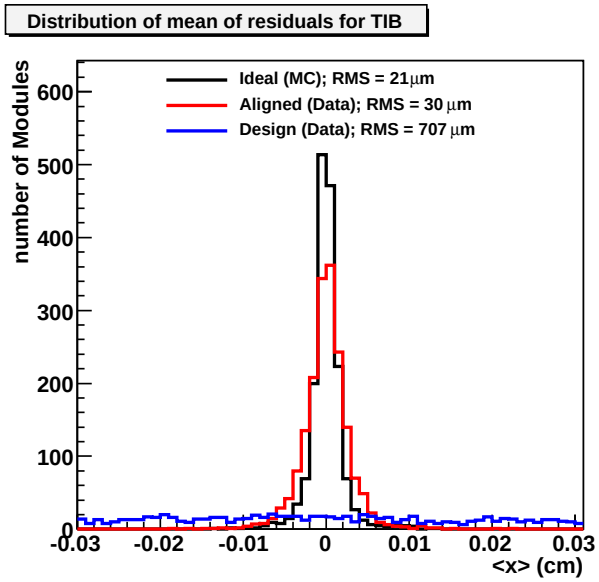


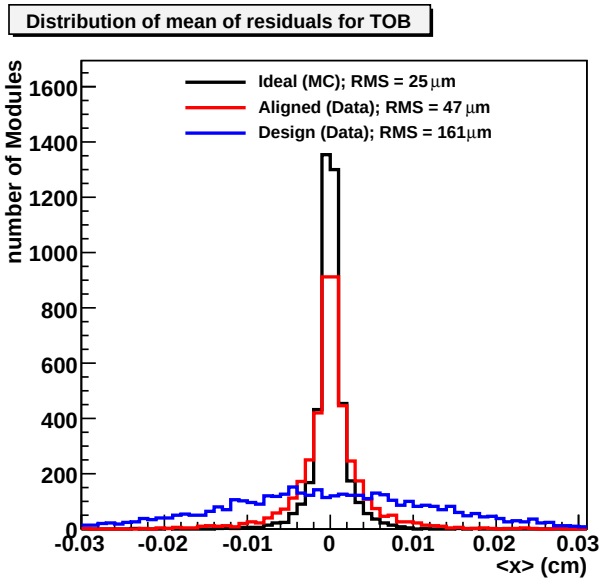
- Achieved ∼30-40$\mu$m in TIB/TOB

  low statistics in Pixels and Endcaps

- Measure of alignment precision

  Distribution of Mean of the Residuals ("DMR", more later)



# Alignment at Point-5 with Magnetic Field

- Best data for alignment of CMS Tracker: fall 2008 ("CRAFT")

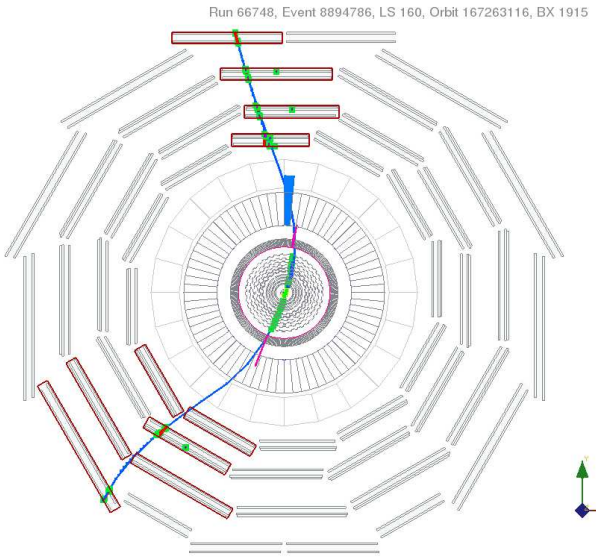
  $\sim$ 4M cosmic tracks for Tracker alignment

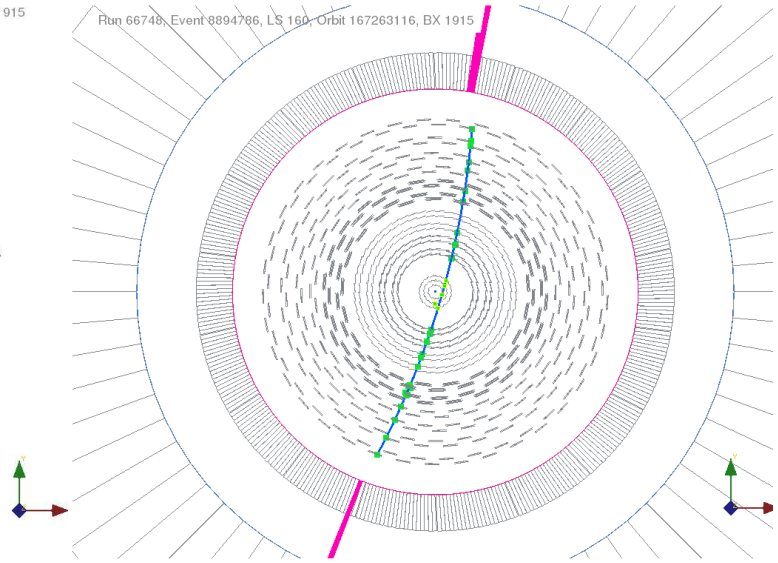
  B-field = 3.8T $\Rightarrow$ account for multiple scattering, $p > 4$ GeV/$c$

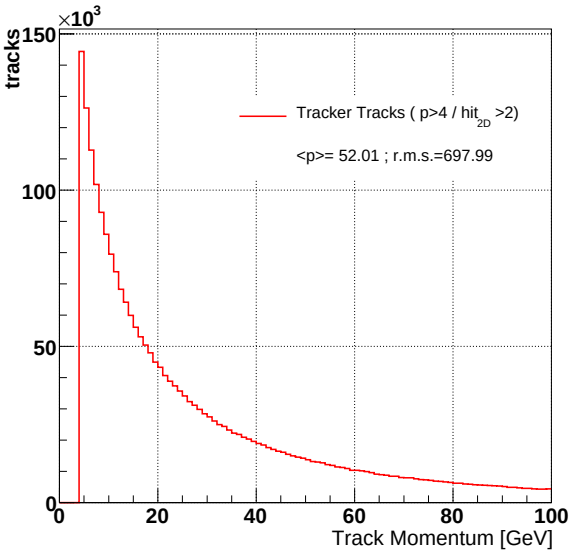
- Require good quality tracks and hits:

  clean hits, outlier hit rejection, $\chi^2$ cut, min hits, 2D hits

  accept all good tracks (statistics limited): only 3%+1.5% in Pixels

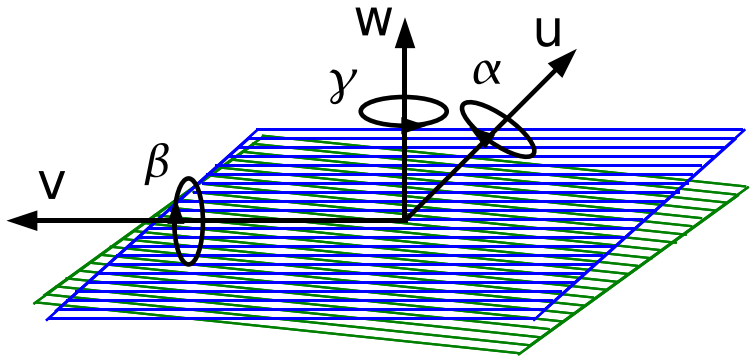


# Alignment Strategy during "CRAFT"

- Multi-step approach by both algorithms to address CMS geometry:
  - large structure movement: coherent $v$ alignment of 1D modules
  - alignment of two sides of 2D strip modules (units): $u$, $w$, $\gamma$




- Global method: 3 steps from "design"

(1) large structures (6 dof) & units (3 dof)

(2) module alignment: add $\alpha, \beta$ for TIB; 6 dof for PXB

(3) repeat (1); note above: keep <46,300 parameters, use pre-sigma

- Local method: 5 steps from survey; ∼50 iterations each

(1) large structures ($u$, $v$, $w$, $\gamma$)

(2),(3) Strip: modules (6 dof) with survey; units (3 dof)

(4),(5) Pixels: ladders (6 dof); modules (6 dof)

# Alignment Strategy: Merging Algorithms

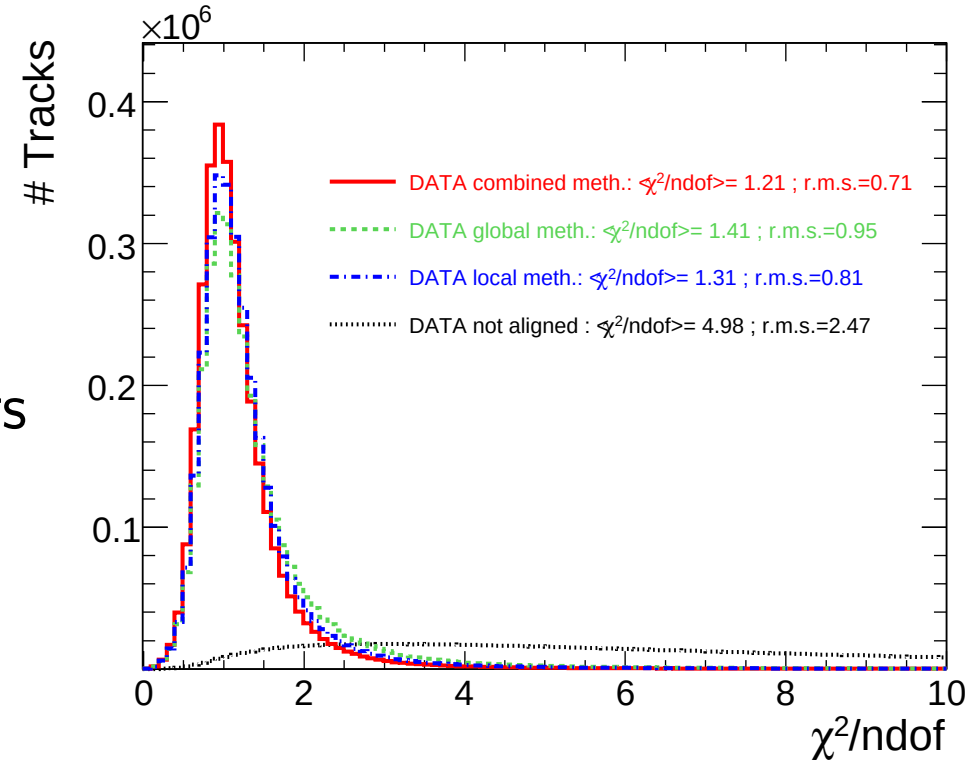
- Combined method

(1) run global method ⇒ solve global correlations efficiently

(2) run local method ⇒ solve locally to match track model in all dof

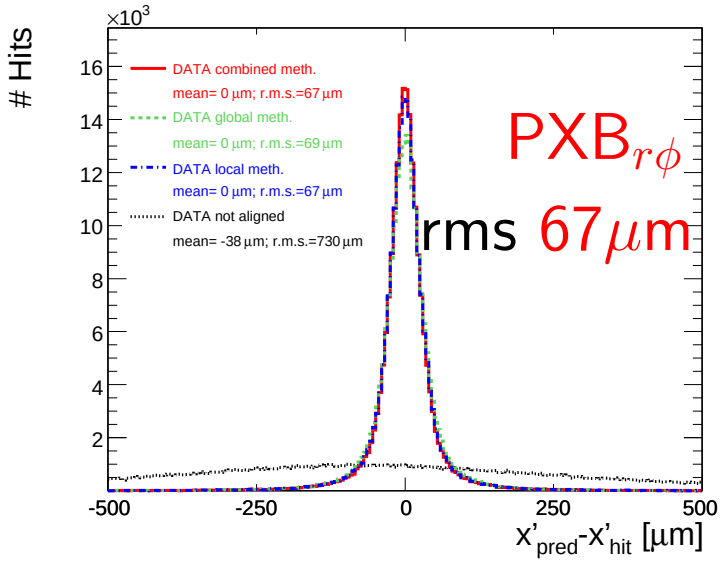
- All three results are compatible, but combined is the best
  also compare to "not aligned"

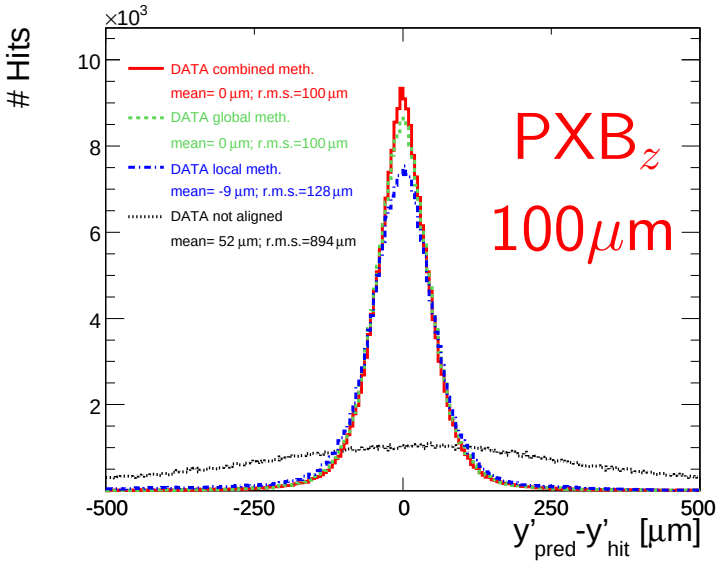
Alignment Position Errors (APE) set for combined see next talk



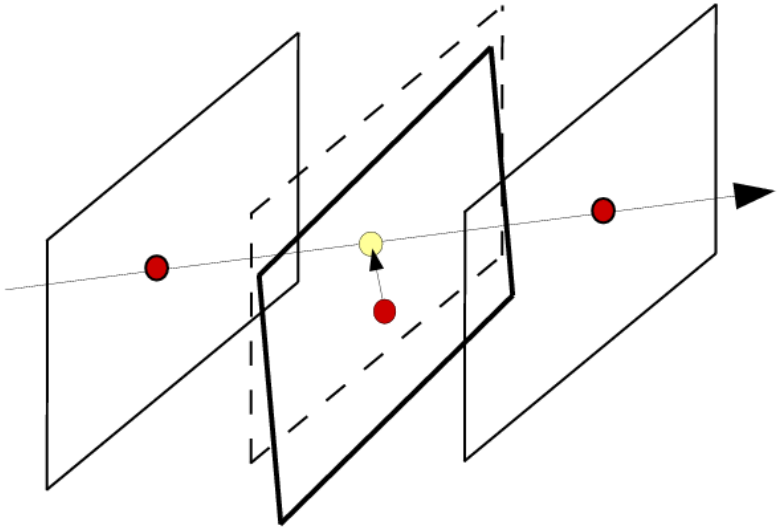

- Reference system: center-of-gravity and rotation move to design

# Example: Pixel Residuals (local, global, combined)

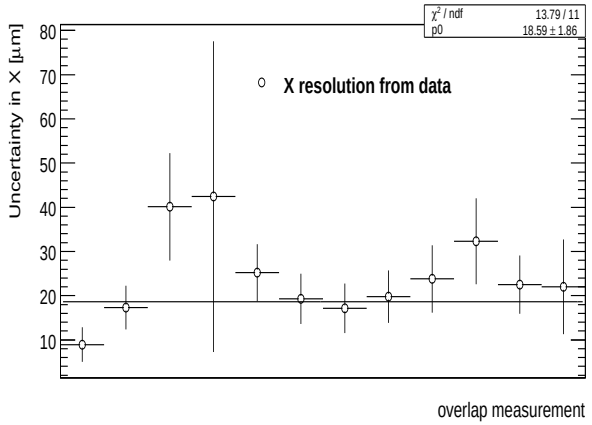



- Residuals $\Leftarrow$ multiple scattering + hit errors + alignment errors
  (random) (random) (systematic)



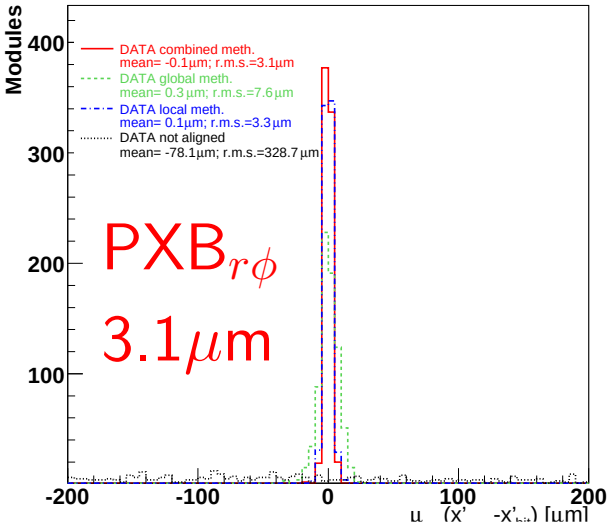
$r\phi$ pixel hit errors $\sim 19\mu$m here

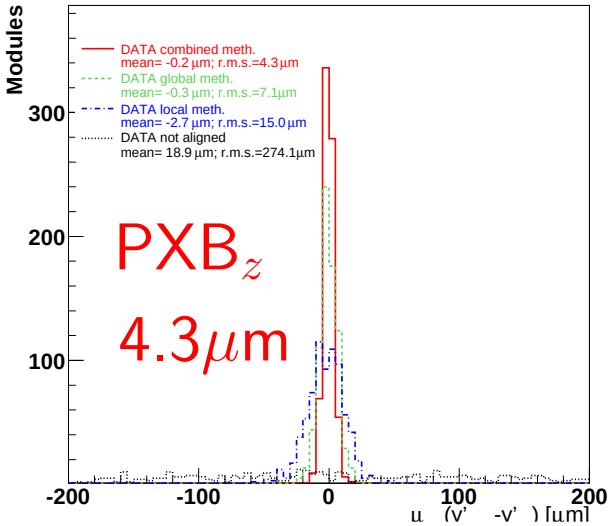


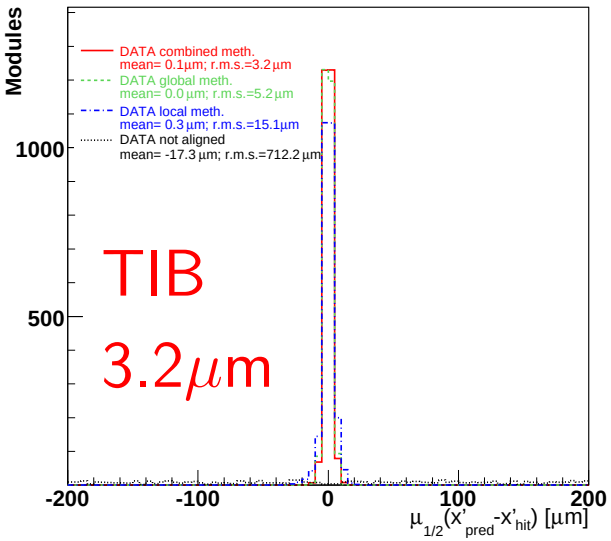
# Median of the Residuals

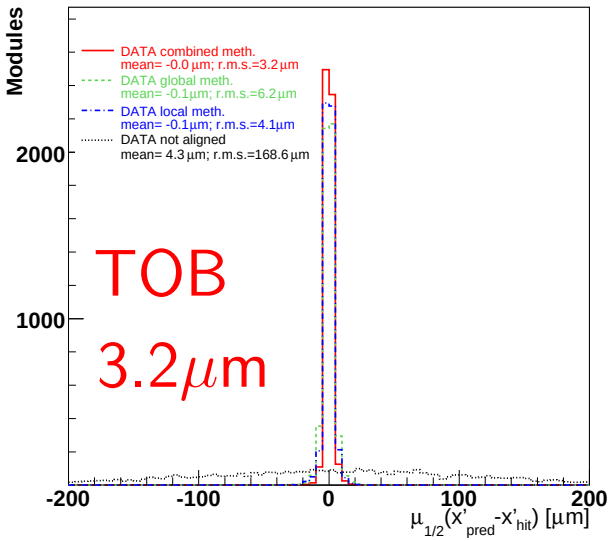
- Again global + local → best combined

  for example: PXB better local transverse, global longitudinal



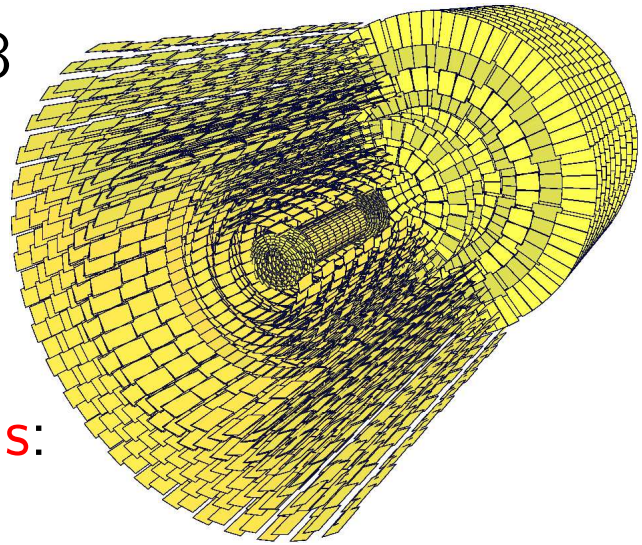



# Summary

- CMS Tracker alignment with first data:

  Tracker construction & survey in 2006-2008
  Tracker integration cosmic run in 2007
  global CMS cosmic runs in 2008



- Successful CMS Tracker alignment algorithms:

  several complementary statistical methods
  best combination of global & local
  combine track + survey (done) and LAS (in progress) data

- Result in successful CMS Tracker alignment with cosmics

  but far from being done: cosmic and beam runs in 2009-2010
  cosmics alone has limitations, see next talk...

# BACKUP

# Data Delivery: Alignment Workflow

- Track reco data: reduced skim "AlCaReco" for alignment

  see talk by G. Flucke about workflow tomorrow

- Result: 16,588 module Positions (6D) and Alignment Position Errors (APE, 3D)