



# CMS Tracker Alignment with Cosmic Data and Strategy at the Startup

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on behalf of the CMS Tracker collaboration

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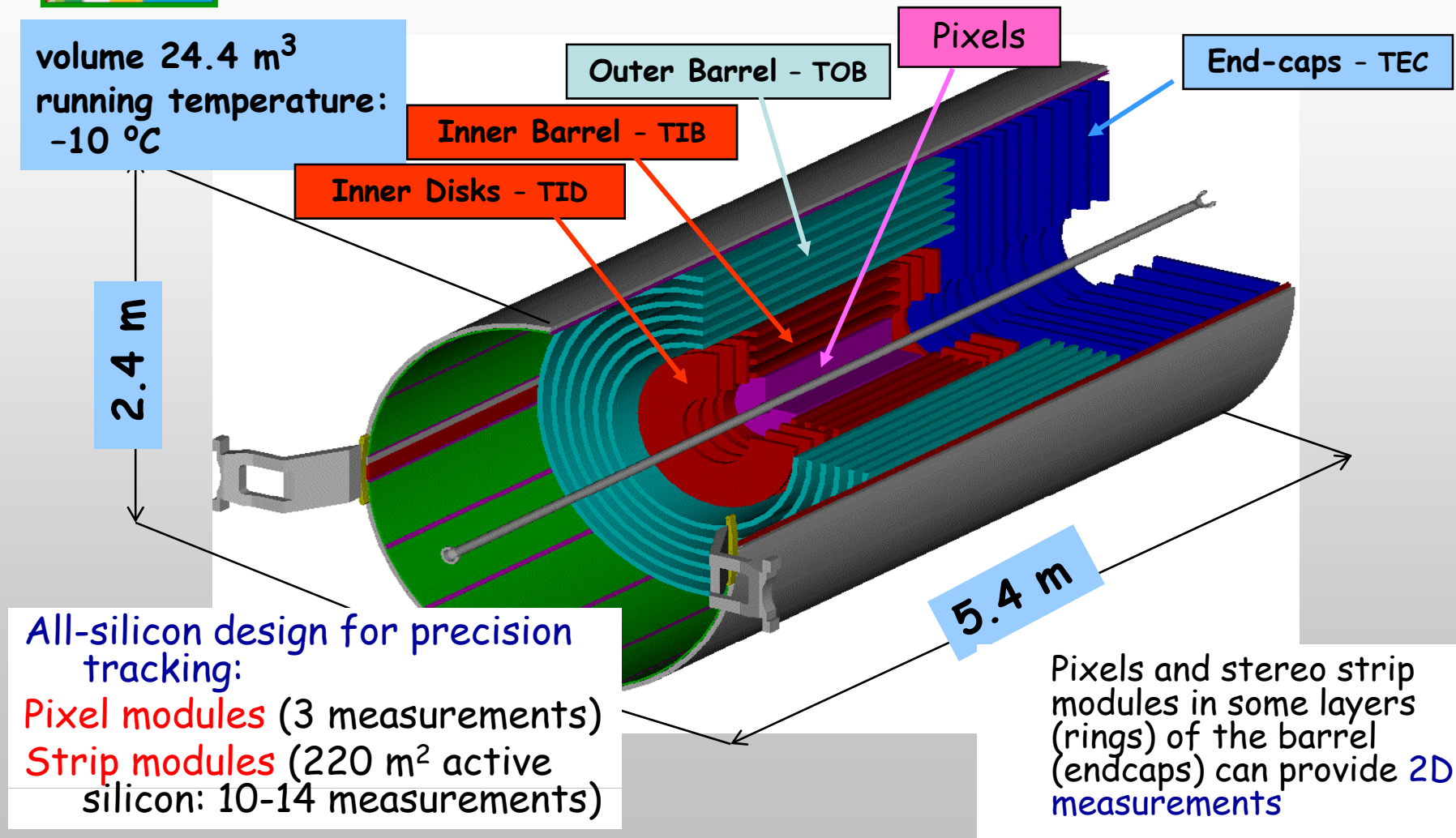
# Outline

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- Overview of the CMS silicon strip tracker
- Alignment methods: survey, laser and track-based algorithms
- The Tracker Integration Facility (TIF) cosmic data-taking:
  - Setup and cosmic muon samples
  - Event selection for alignment
  - Results and stability
  - Alignment validation: track-based and geometrical methods
  - Summary
- Introduction to other challenges towards the startup:
  - The Computing, Software and Analysis 2008 (CSA08) challenge
  - CMS “global run” analysis



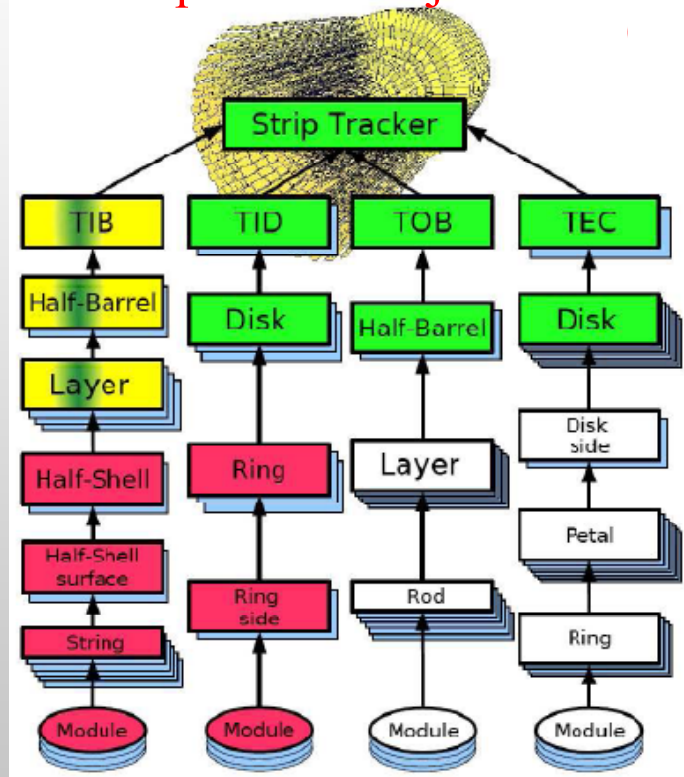
# The CMS Silicon Tracker





# Alignment Methods: Survey

## CMS strip tracker object hierarchy



■ = CMM  
■ =  
 photogrammetry  
 methods  
■ = not surveyed



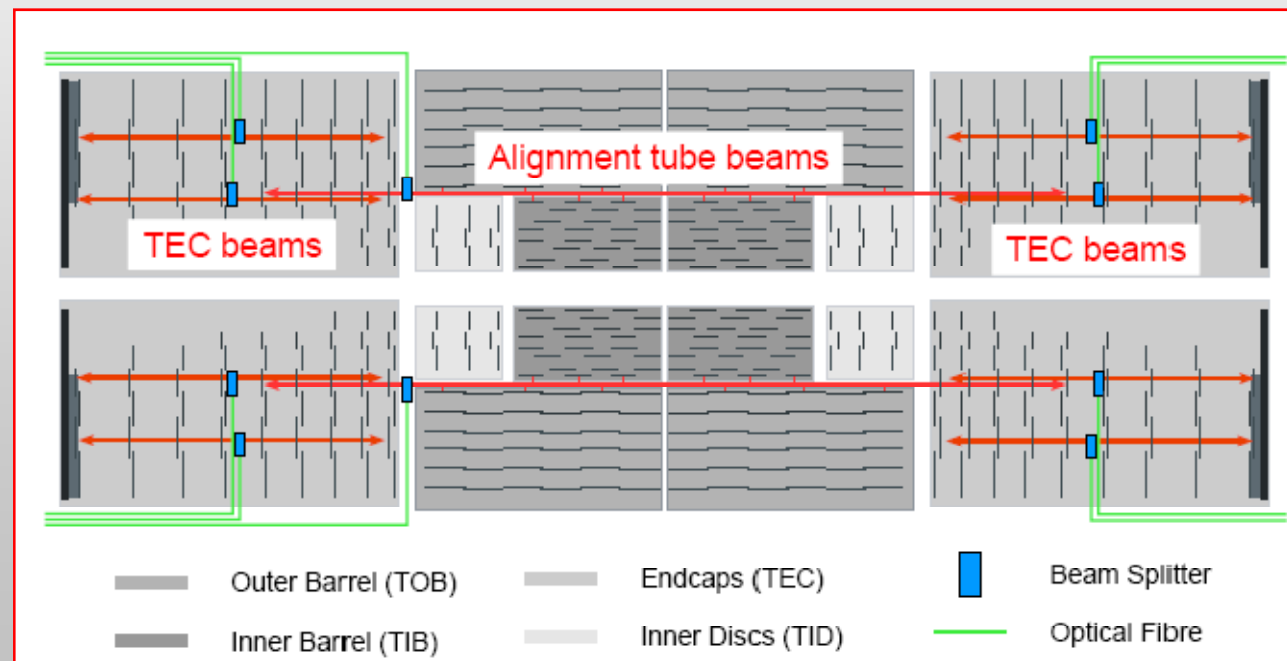
- Strip tracker survey combining on-site measurements with different methods:
  - TIB/TID:
    - Coordinate Measuring Machine (CMM) survey along layers
    - Global photogrammetry
  - TOB/TEC:
    - Wheel/disc photogrammetry

Precision dominated by resolution of photogrammetry method (~300  $\mu$ m)



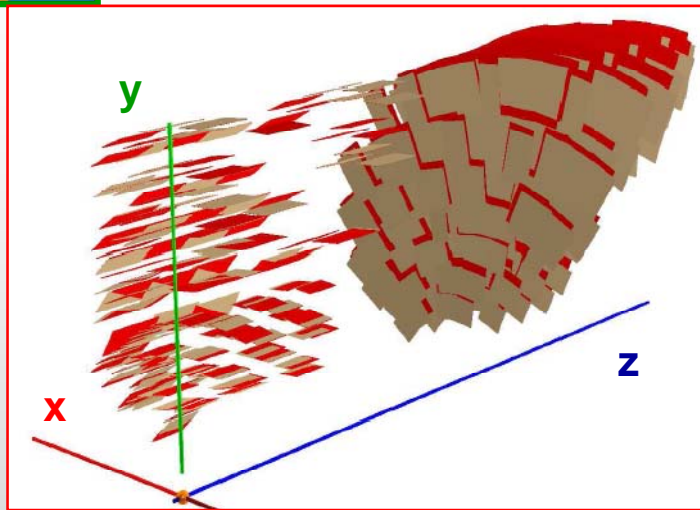
# Alignment Methods: LAS

- A **Laser Alignment System (LAS)** is designed for continuous monitoring of global alignment constants:
  - Using fixed-wavelength **infrared laser beams**
  - Pulsed working mode to trigger events and compensate for intensity quenching in silicon layers and beam splitters
  - Sensitive to:
    - ❑ TEC discs placement
    - ❑ global barrel placement



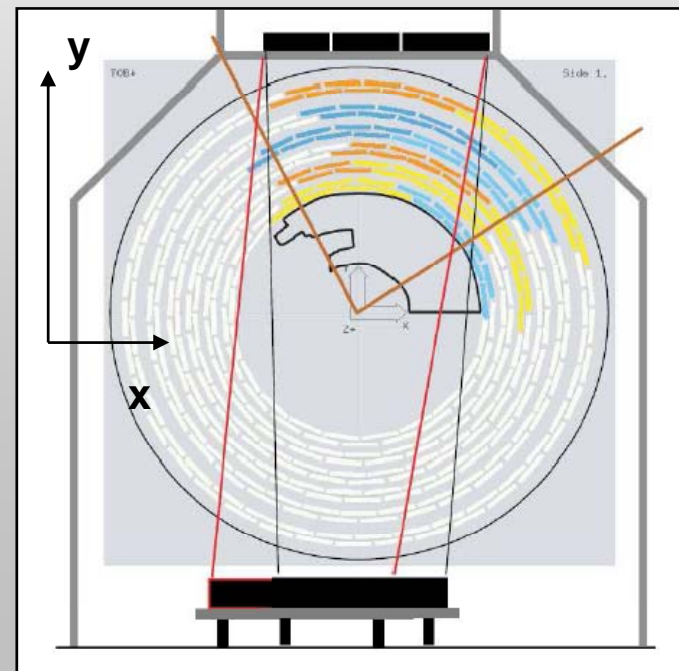


# The TIF Data-taking Setup



- Four plastic scintillators (two upper, two lower) to trigger cosmic events
- Lead shields absorb muons with  $p < 200 \text{ MeV}/c$
- 4 million events total, taken:
  - over a 4-month period
  - with different temperature conditions (room to  $-15 \text{ }^{\circ}\text{C}$ )
  - with different mechanical conditions (TEC at  $z < 0$  inserted during data-taking)

- 15% of the total strip tracker was read out:
  - No pixels
  - 444 TIB modules
  - 720 TOB modules
  - 800 TEC modules
  - 204 TID modules





# Alignment methods: Tracks

- A track-based alignment algorithm is aimed at minimizing a global  $\chi^2$  function:

$$\chi^2 = \sum_i^{\text{hits}} \mathbf{r}_i^T(\mathbf{p}, \mathbf{q}) \mathbf{V}_i^{-1} \mathbf{r}_i(\mathbf{p}, \mathbf{q})$$

$\mathbf{r}$  = hit residuals

$\mathbf{p}$  = alignment parameters

$\mathbf{q}$  = track parameters

- The parameters  $\mathbf{p}$  are different for each sub-detector at TIF:

- TIB/TOB: high statistics  $\rightarrow$  aligned at level of single modules

- $\mathbf{p} = \{u, w, \gamma\}$  ( $\{u, v, w, \gamma\}$  for double-sided modules)

- TEC: low statistics  $\rightarrow$  aligned at the level of disks

- $\mathbf{p} = \{\theta_z\}$

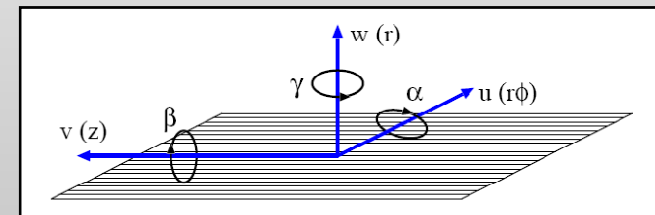
- TID: very low statistics  $\rightarrow$  not aligned

- Other challenges at TIF:

- Single-direction track pattern ( $\rightarrow \chi^2$ -invariant deformations)

- No magnetic field to measure track  $p_T$  and consequent estimates of multiple scattering effects ( $\langle p_T \rangle = 1.0 \text{ GeV}/c$  used in track reconstruction)

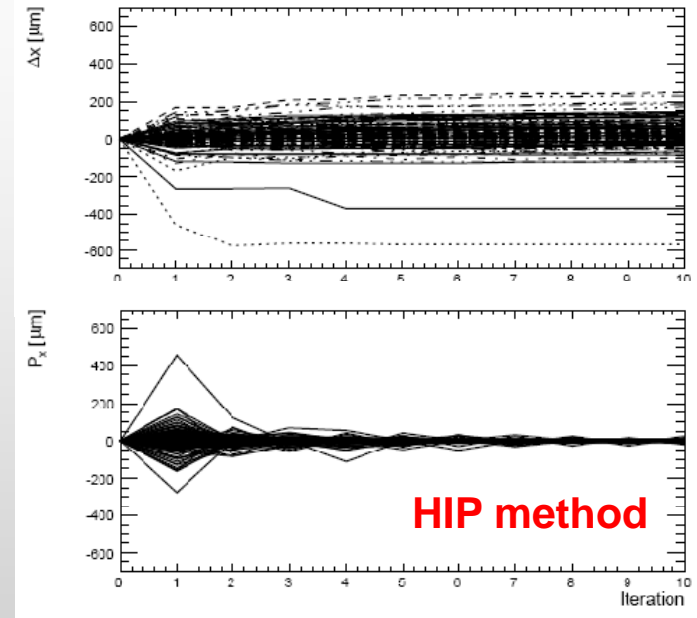
$u, v, w = \text{local } x, y, z$   
 $\alpha, \beta, \gamma = \text{local } \theta_x, \theta_y, \theta_z$





# Track-based Algorithms

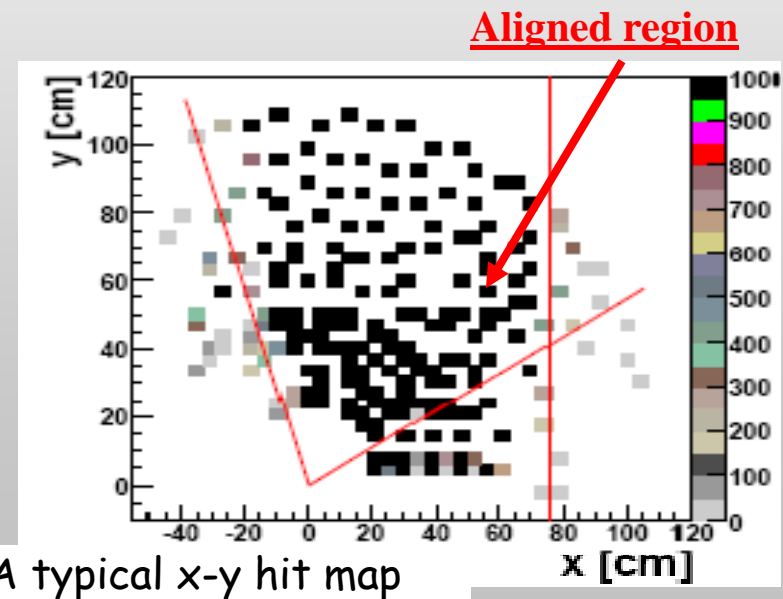
- **HIP (Hits and Impact Points):**
  - Local analytical  $\chi^2$  equation for  $\mathbf{p}$  only  
→ per object, neglecting track parameters
  - Correlations from tracks taken care of via iteration
- **Kalman:**
  - Method based on Kalman-filter trajectory updates
  - The effect of  $\mathbf{p}$  and the covariance matrix  $V_p$  enters the update equation added to the stochastic term of multiple scattering
- **MillePede-II:**
  - Global solution of the  $\chi^2$  equation for  $\mathbf{p}$  and  $\mathbf{q}$ : all correlations considered
  - Advanced numerical methods allow not to invert large matrix equation





# Clean Data Selection at TIF

- Single-track events only
- Requirements for selecting a track on:
  - fiducial scintillator geometrical region
  - minimum number of hits and 2D hits
  - $\chi^2_{\text{track}}/ndof$
- Requirements for associating a hit to a track:
  - minimum cluster charge
  - isolation (no other hit within 8 mm)
  - outlier rejection ( $\chi^2_{\text{hit}} < 5$ )
- Aligned object selection. A region in the transverse plane is chosen with:
  - sufficiently high hit statistics
  - low track incidence angle

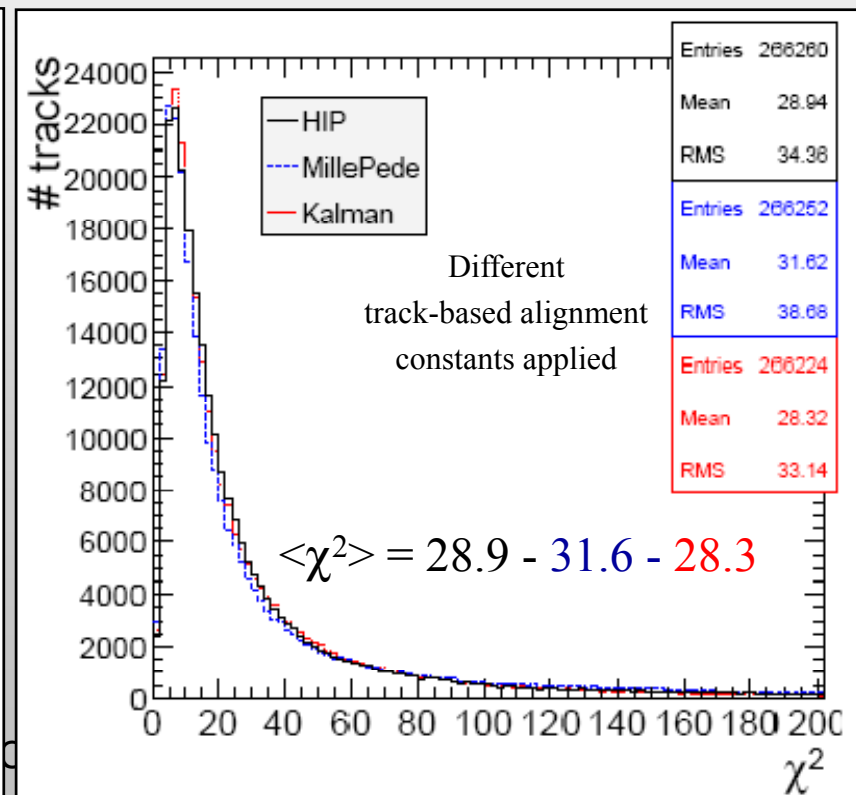
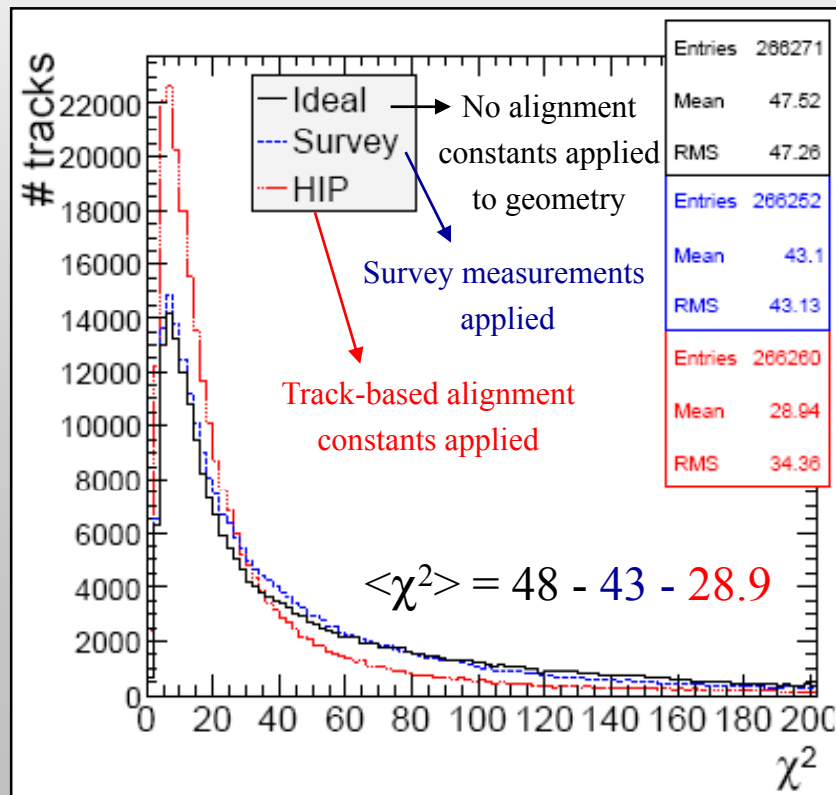


A typical x-y hit map



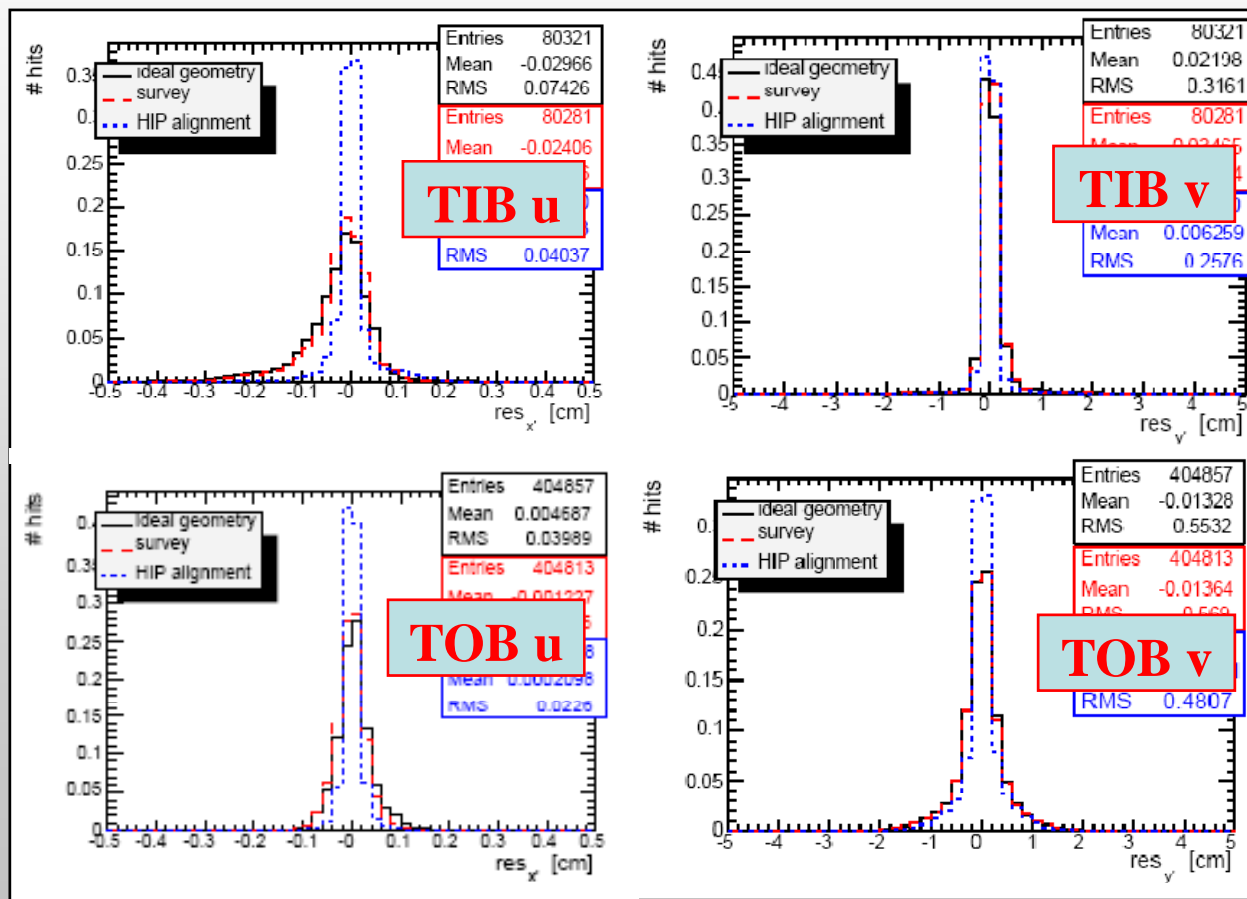
# Alignment Results: Track $\chi^2$

- Dataset: largest TIF track sample taken at nominal operating temperature (-10 °C)
  - Cut efficiency for alignment = 8.3 %  $\rightarrow$  ~90k tracks selected
  - Relaxed cuts for validation to avoid bias  $\rightarrow$  ~270k tracks selected





# Results: Hit Residuals



The same expected improvement

design geometry  $\rightarrow$

$\rightarrow$  survey  $\rightarrow$

$\rightarrow$  track-based

observed in hit residual distributions

– here shown for barrels in local  $u$  (and  $v$  when available)



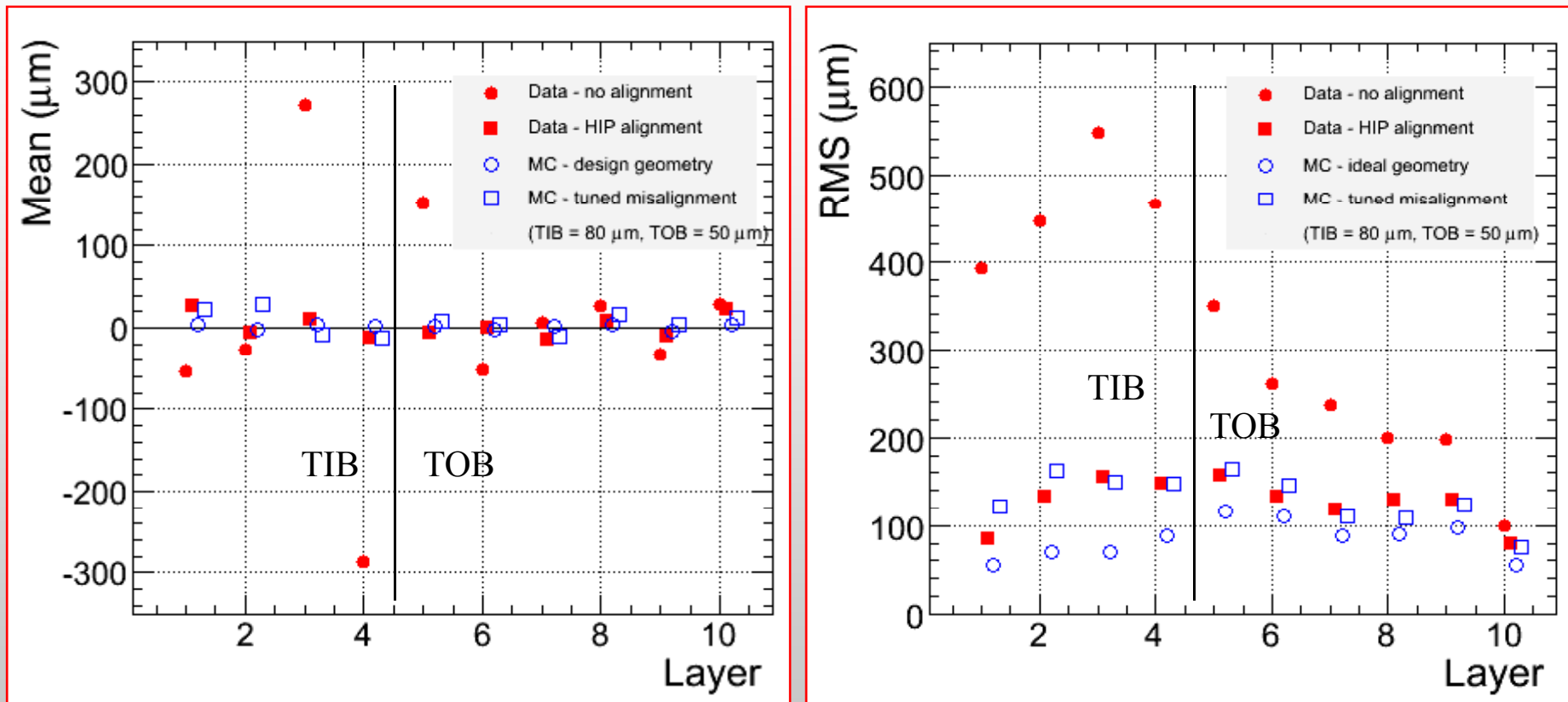
# Alignment Precision with MC

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- A cosmics MonteCarlo sample ( $\sim 500\text{k}$  single-track events) with ideal tracker geometry is generated with TIF conditions to estimate alignment precision:
  - Momentum spectrum tuned to CAPRICE data
  - Simulation of lead shields and scintillator acceptance
- Track reconstruction is performed with ideal tracker geometry then with increasing misalignment artificially applied to detectors:
  - Procedure is repeated until reconstructed quantities (residuals,  $\chi^2$ ) match those observed in data with alignment constant applied  $\leftarrow$  “tuning” method
  - The value of the misalignment at this final stage is taken as a crude estimate of remaining misalignment after TIF studies



# Alignment Precision with MC



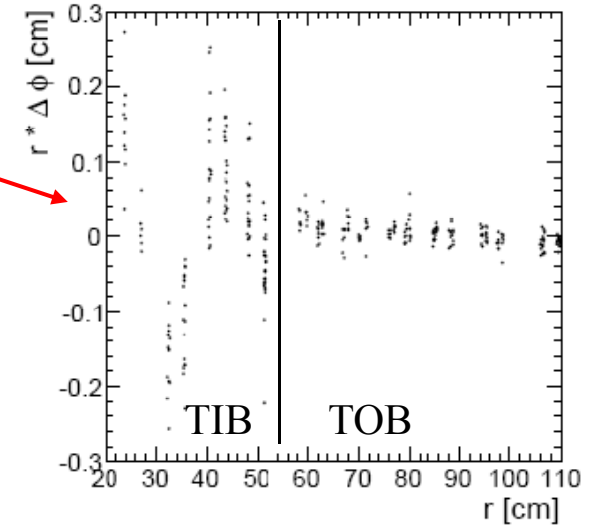
- Remaining misalignment with “tuning” method in barrel:
  - 50 μm for TOB
  - 80 μm for TIB



# Geometry Comparison: Barrel

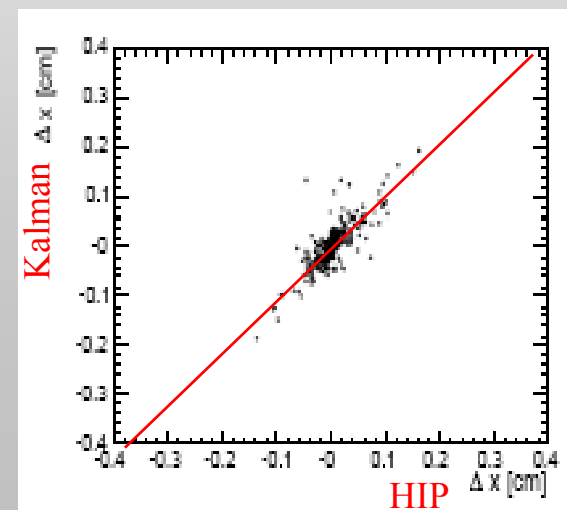
- Geometrical differences ( $\Delta$ ) between design and aligned geometries show:
  - small, **non-coherent** movements in TOB  
 $\leftarrow$  module assembly on full wheel
  - larger, **layer-wise** movements in TIB  
 $\leftarrow$  module assembly on co-axial cylinders

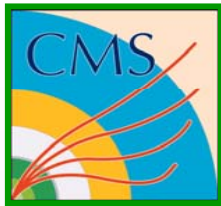
Transverse difference  
 $\Delta(r\phi)$  between  
 design geometry and  
 HIP alignment  
 vs. radial position



Geometry 1	Geometry 2	Difference ( $\Delta$ )	RMS TIB ( $\mu\text{m}$ )	RMS TOB ( $\mu\text{m}$ )
HIP	Design	$\Delta x$	525	236
Kalman	Design	$\Delta x$	542	237
HIP	Kalman	$\Delta x$	165	158

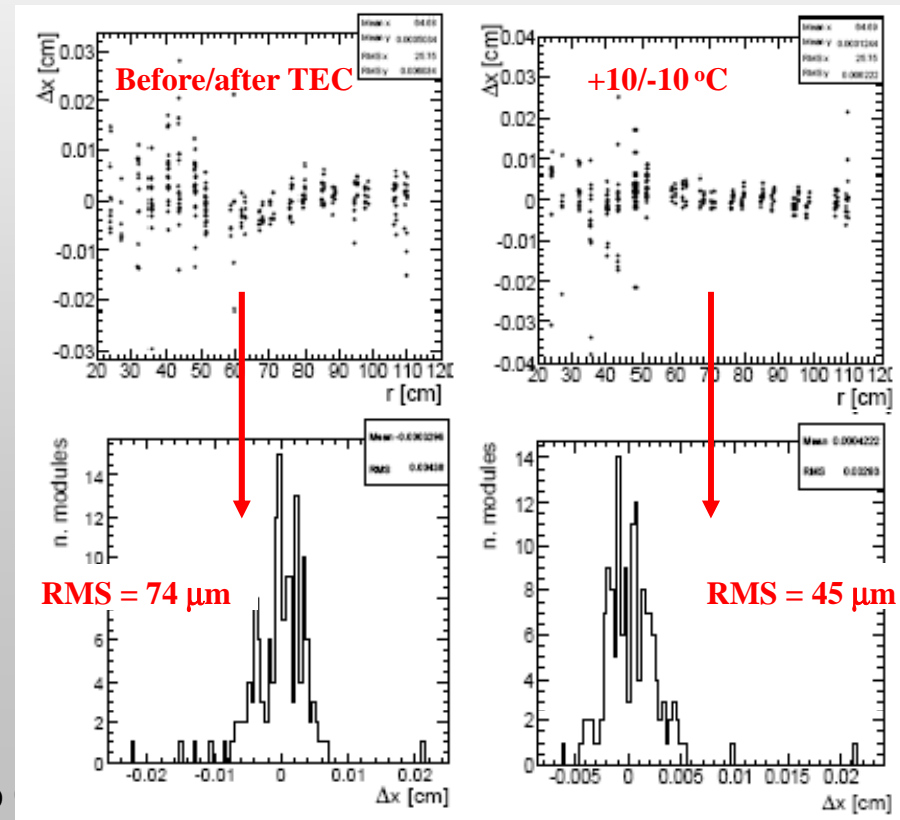
- Systematics on aligned positions estimated from the RMS of the  $\Delta$  distributions between geometries aligned with different methods





# Stability with Time: Barrel

- Alignment performed on different TIF data samples to investigate sensitivity to:
  - mechanical operations (compare room temperature data before and after TEC insertion at  $z < 0$ )
  - temperature changes (compare +10 and -10 °C)
- No sensitivity to temperature changes
- Hints of a layer-dependent twist after TEC insertion (also visible in  $\Delta$  distributions vs.  $z$ )
- Effects at the limit of TIF alignment expected sensitivity

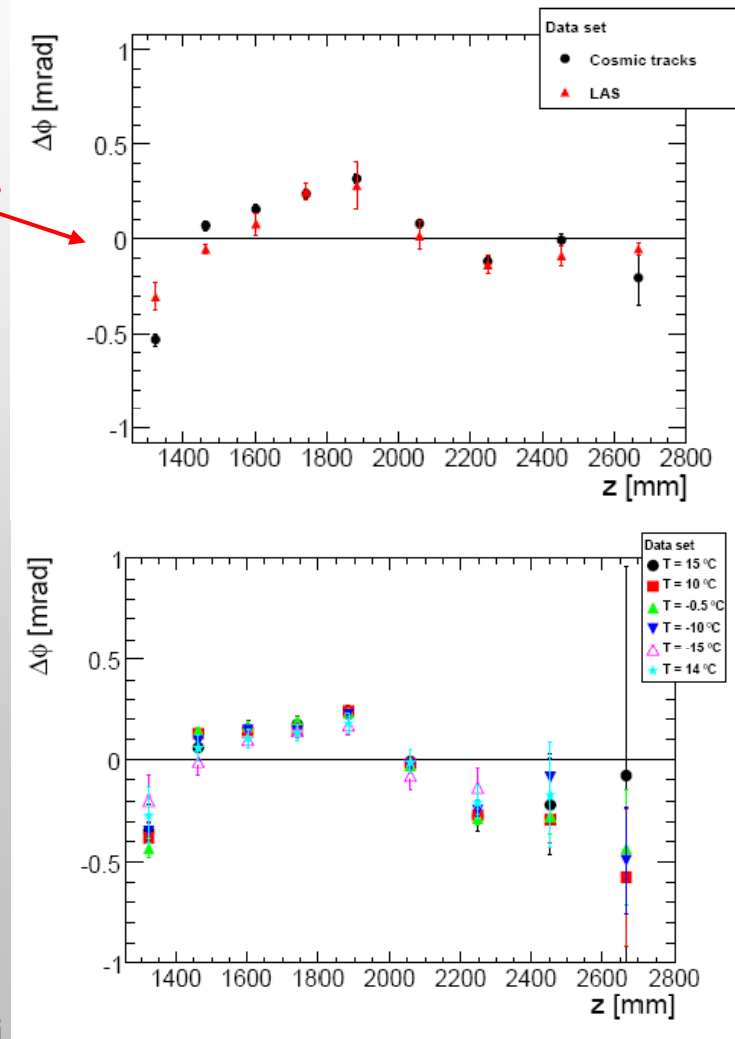




# Validation and Stability: Endcap

- LAS successfully operated at TIF
- Track-based endcap alignment done only at disc level (9 objects) due to reduced cosmics statistics at large angle
- Results compared:
  - Track-based vs. LAS (good consistency)
  - all data-taking periods with different temperatures (also good consistency, no visible effect at disc level)

Angle difference  
 $\Delta\phi$  between  
different  
alignment constants  
vs.  $z$  disc position





# Summary of TIF Alignment

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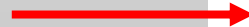
- At TIF, the first large-scale alignment of the CMS silicon strip tracker using real data has been performed:
  - Survey measurement application improves tracking performances
  - Three track-based alignment algorithm successfully tested:
    - Large improvement of residuals over design geometry and survey
    - Crude estimate of resolution from MonteCarlo studies is 50-80  $\mu\text{m}$ , dominated by approximate estimates of multiple scattering effects
    - Good consistency between algorithms has been observed
    - No significant changes with temperature or data-taking conditions observed within resolution
  - Laser Alignment System successfully operated  $\rightarrow$  consistency with track-based observed in end-caps
  - Lot of experience gained for alignment with collision data



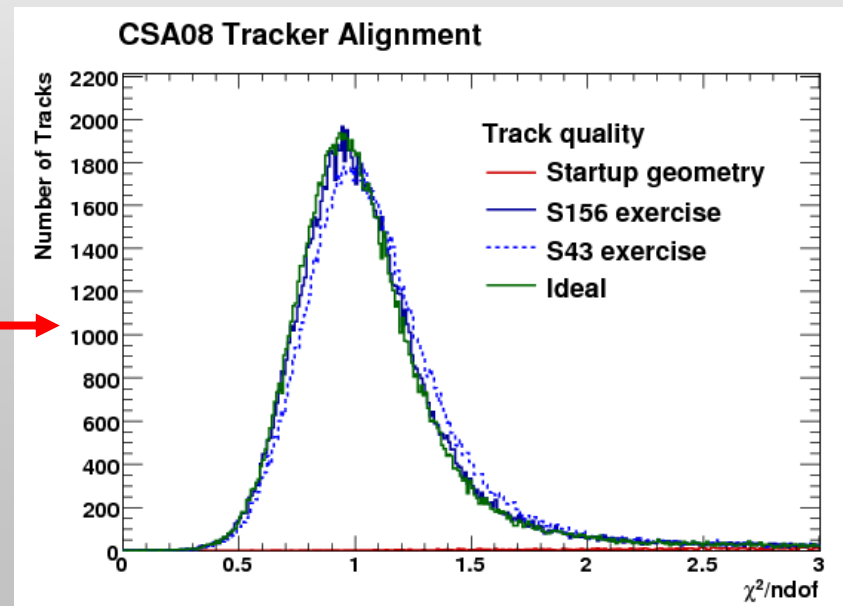
# Towards the Startup... (1)

- In parallel, many other studies towards alignment in collision data-taking are being performed:
- Computing, Software and Analysis 2008 (CSA08) challenge:
  - Large “realistic” MonteCarlo production intended to reproduce the composition of the first 10 pb<sup>-1</sup> of data (mostly minimum-bias events)
  - All three algorithms tested for:
    - precision reach
    - handling of large data samples
    - strategies for alignment at the startup

Millepede-II  
results



See also V. Chiochia's talk





## Towards the Startup... (2)

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- In parallel, many other studies towards alignment in collision data-taking are being performed:
- Global-CMS cosmic runs in the underground cavern with and without magnetic field:
  - Use of TIF experience with cosmic data on a larger-scale set of aligned objects:
    - 100% strip tracker is now on
  - First run including tracker ended mid-July (pixels expected in next) results to come out very soon

**CMS tracker alignment is doing well !**