CMS Tracker Performance and Alignment with Cosmic Muons

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Frontier Detectors for Frontier Physics,
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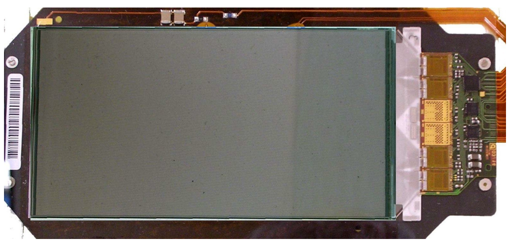
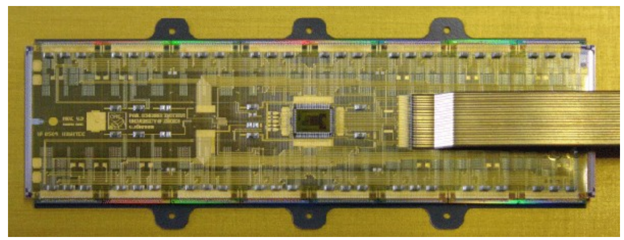
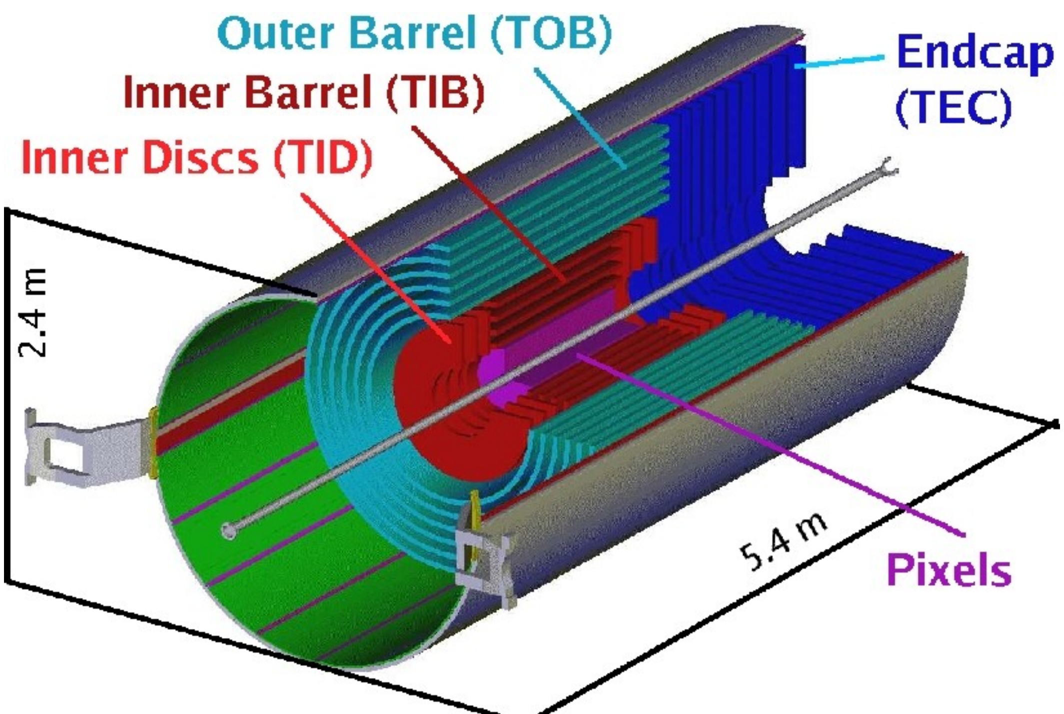
Outline

- Introduction: the CMS Tracker and the Cosmic global run data taking (CRAFT).
- Data Quality Monitoring of the CMS Tracker.
- Calibration and performances of the Si micro-strip modules at CRAFT.
- Alignment of the CMS Tracker modules with cosmic rays.

The CMS Tracker







ALL-Si Tracker

- Total Si surface: ~200 m^2
- MicroStrip (**15 k**) & Pixel (**1.5k**)
- **CMS TK divided in six parts**:
  - PXB – 3 layers
  - PXE – 2 disks
  - TIB – 4 layers (2 stereo)
  - TID – 3 disks (2 stereo rings each)
  - TOB – 6 layers (2 stereo)
  - TEC – 9 disks (3 stereo rings each)
- Different sensor geometries:
  - Strip pitch: 80-205 μm
  - Strip lenght: 6-12 cm
  - Pixel size: 100x150 μm^2
- Sensor precisions:
  - **Strip (Rϕ) ~ 10-30 μm**
  - **Strip (Z) ~ 100-300 μm**
  - **Pixel ~ 10 μm**

Key device for all physics analyses at CMS !

CRAFT

Cosmic**R**un**A**t**F**ull**T**esla

A 'global run': **ALL** CMS detectors participated.
Data taking 24/7 for 3 weeks (Oct 2008).
Major milestone demonstrating CMS capability of running over long periods.
300M cosmic muon triggers collected @ **3.8 T**.
6M tracks in SiStripTracker (SST), ~4% through Pixel.
Not only an academic proof of principle but the chance for performing the first tests, debugging, calibrations, alignments.
Input for collision data taking !

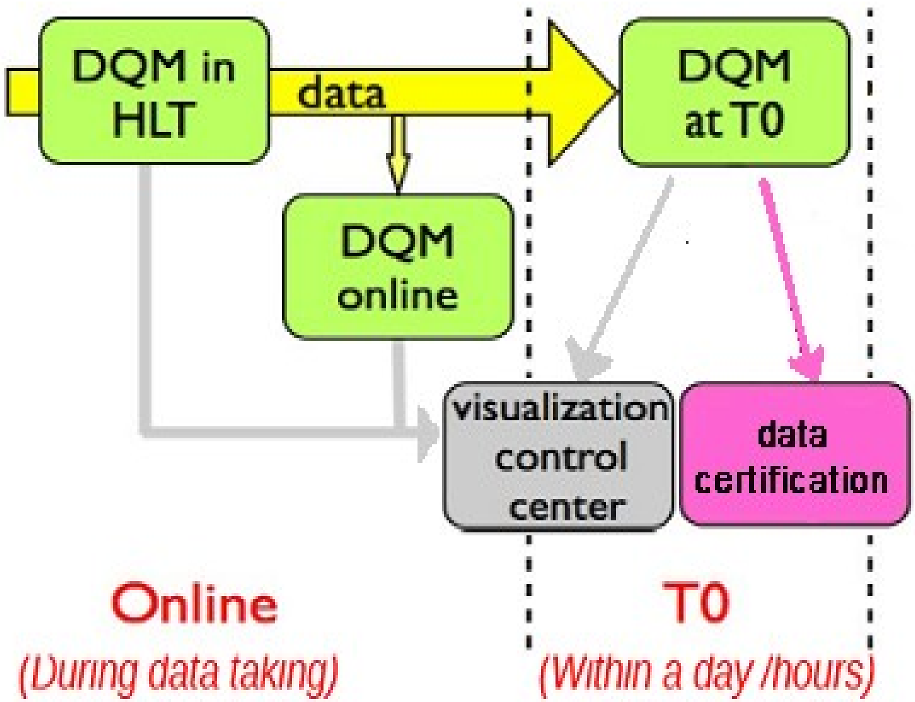
Modules in the read-out	
SubDetector	Fraction (%)
PXB	**99.1**
PXE	**94.0**
TIB/TID	**96.7**
TOB	**98.1**
TEC	**98.8**

Tracker (almost) completely in the DAQ

SiStripTracker Data Quality Monitor

Check the SST performances via tools that produce set of plots (both online and offline).

- Quantities monitored:
  - Raw data (readout and unpacking errors)
  - Digi and cluster properties (stand-alone and relative to tracks)
  - Global track parameters
  - Residuals of hits
- **Data certification**.
- **Full suite of tools** that produce O(300k) histograms, run automatic quality test and publish them on the web.
- **DQM results monitored by online and offline shifters**.

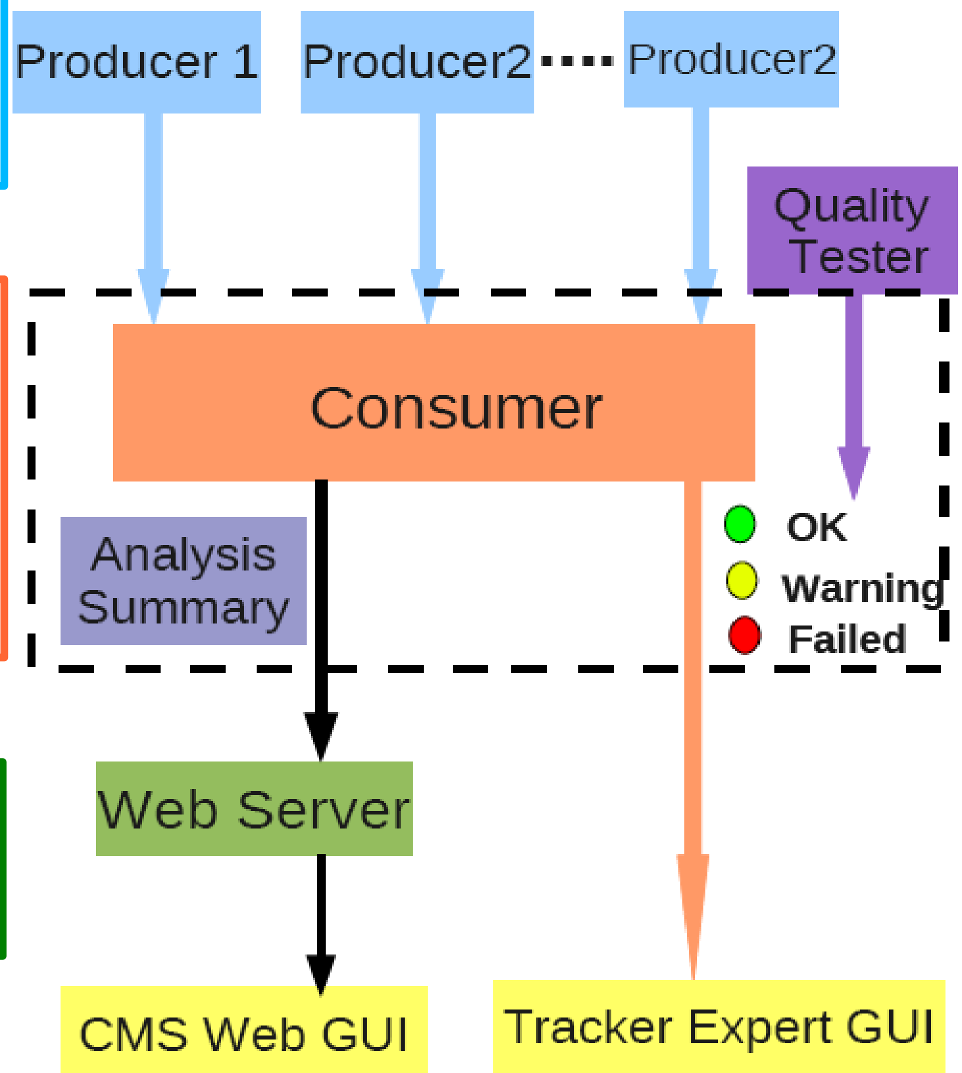


DQM workflow

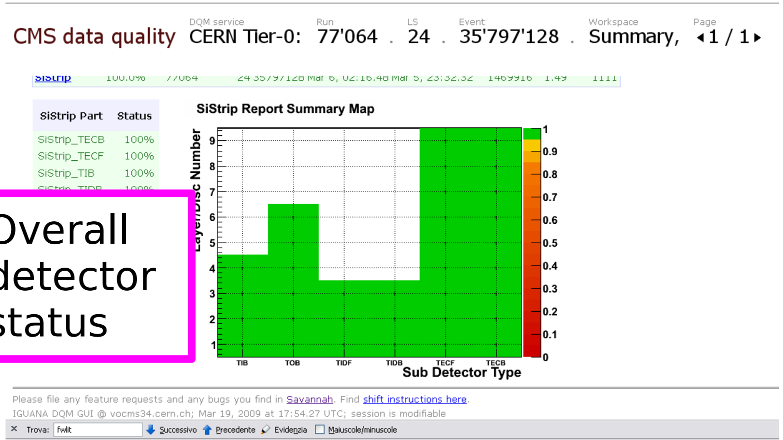
DQM producer:
- Books/fills histos,
- Makes them available to the DQM consumer

DQM Consumer
- perform further analysis;
- produce summary plots;
- run automatic quality test;
- writes out ROOT tree files;

Web GUI visualization. No need to install any client program.

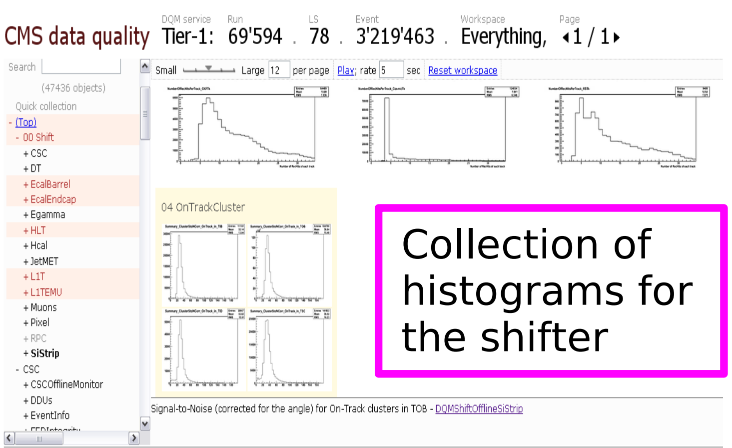


Automatic tool that allows the application of statistical tests on histograms to check the quality.



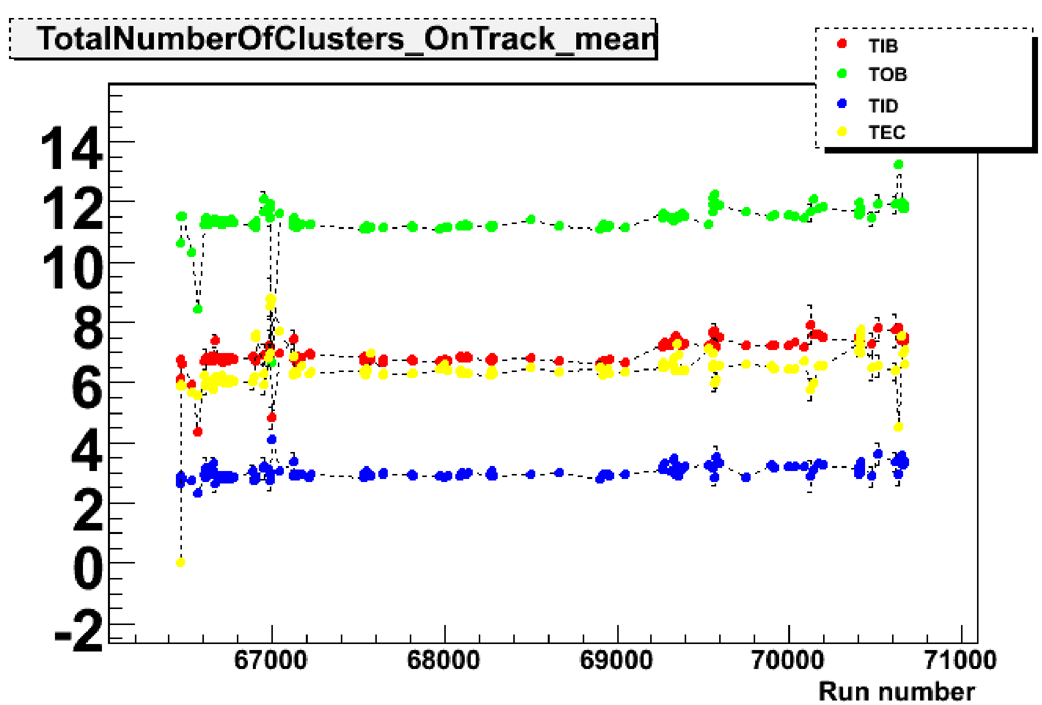
Overall detector status

Hierarchic structure of the plots allows the shifters an easy and intuitive browsing.



Collection of histograms for the shifter

Summary plots for each run are saved into a db. Used for **medium and long term monitoring** of the TK performances.

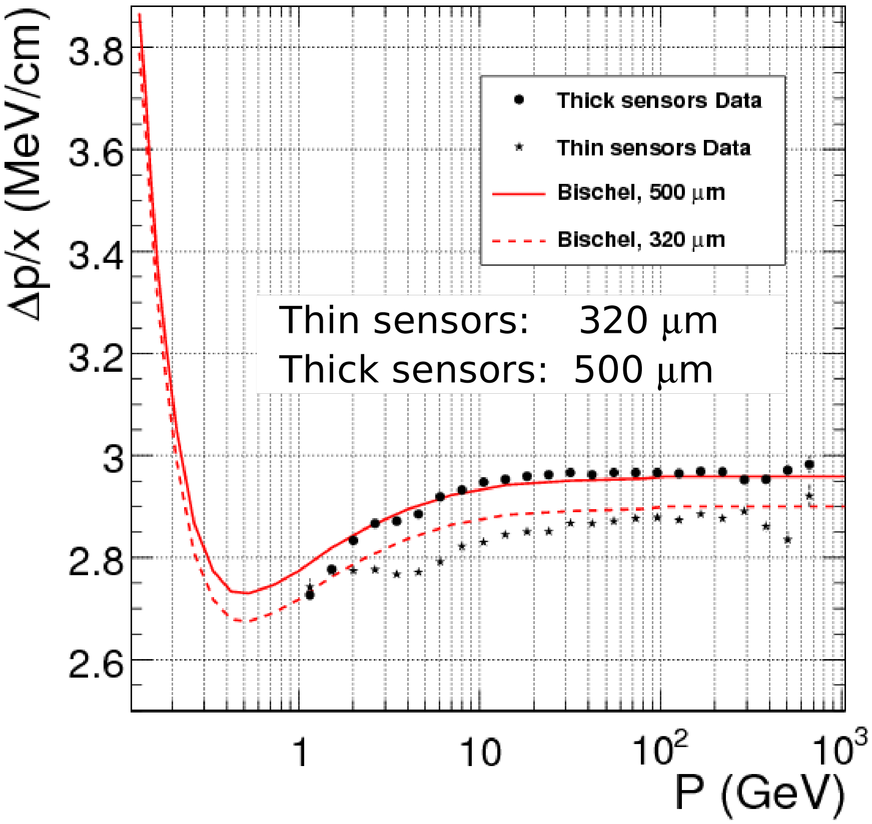


SST Calibration and Local Reconstruction

CRAFT was the first opportunity for a full and in-depth commissioning of the Tracker in view of collisions.

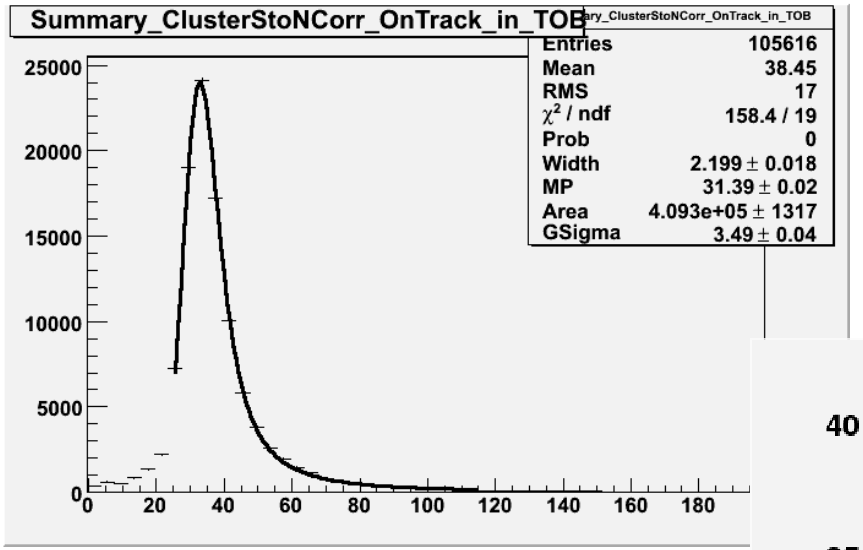
Thorough program of commissioning and calibration:

- Strip detector quality
- Cluster properties
- Gain calibration
- dE/dx measurement
- Lorentz Angle measurement
- Hit reconstruction efficiency
- Hit resolution

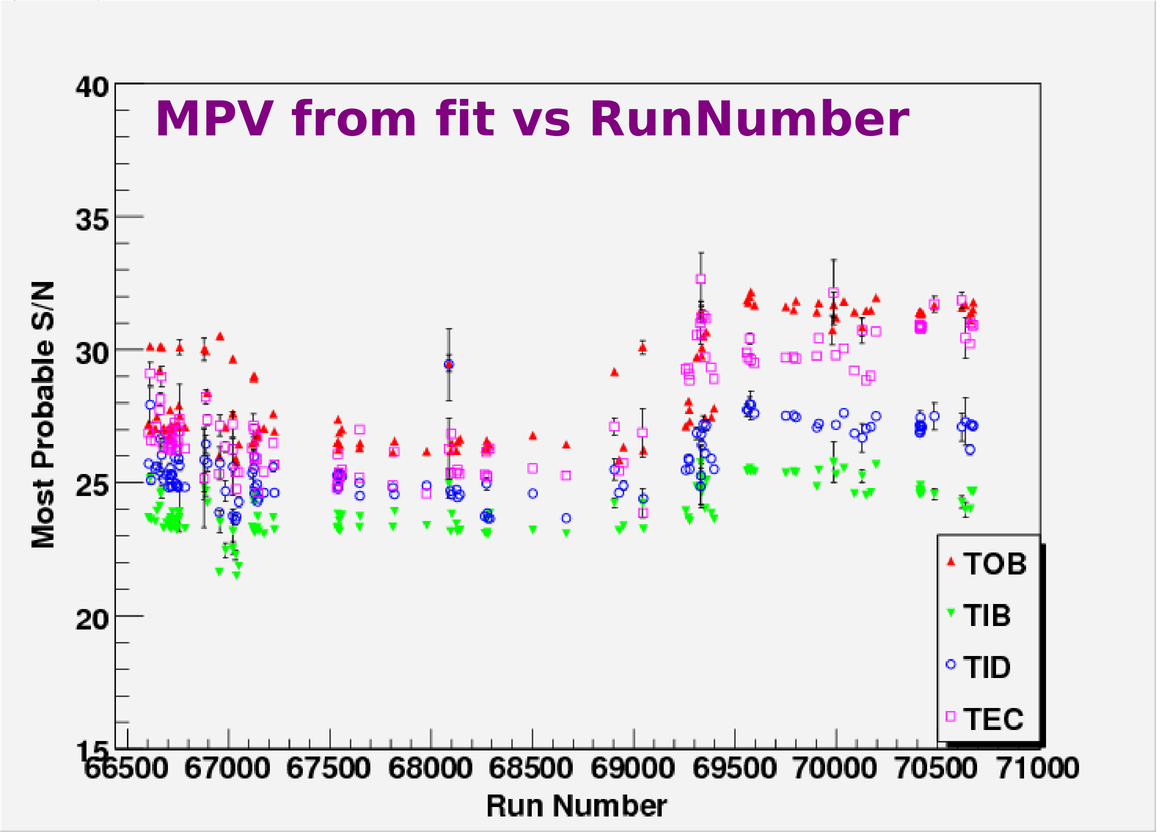


- **dE/dX correction** estimated from MC and applied to data.
- Data points (TIB/TOB/TEC only) compared to Bischel function.

Signal/Noise in the SST



Signal/Noise distribution of the clusters in TOB.
Monitored looking directly at the output of the DQM tools.
Fit with a Gauss+Landau.



Stable performances during the data taking in all the SST subdetectors.

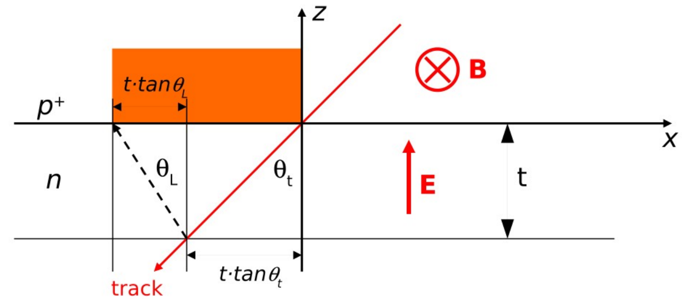
(variations due to latency tuning)

Lorentz Angle

The magnetic filed in the CMS TK (3.8 T) changes the drift direction of the holes respect to the depletion field by θ_L.

$$\Delta x = t \cdot \tan\theta_L$$

$$\tan\theta_L = \mu_H \cdot B$$

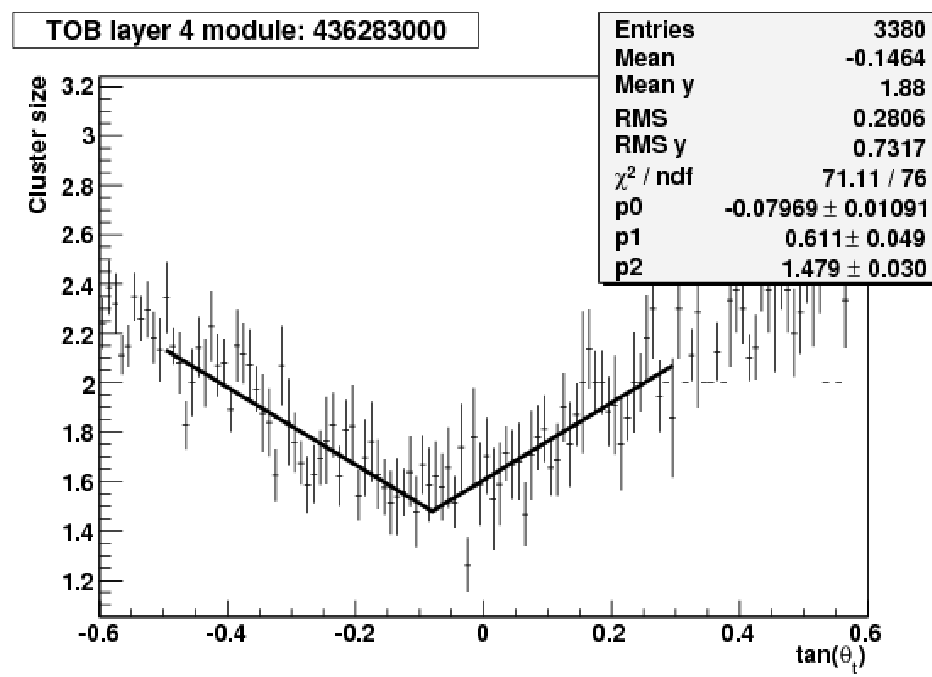


Plot cluster size vs incident angle of the track on the module.

Minimum of the distribution ⟶ θ_L

$<\mu_H>$ (TIB, 320 μm sensors) = 0.018 T^{-1}

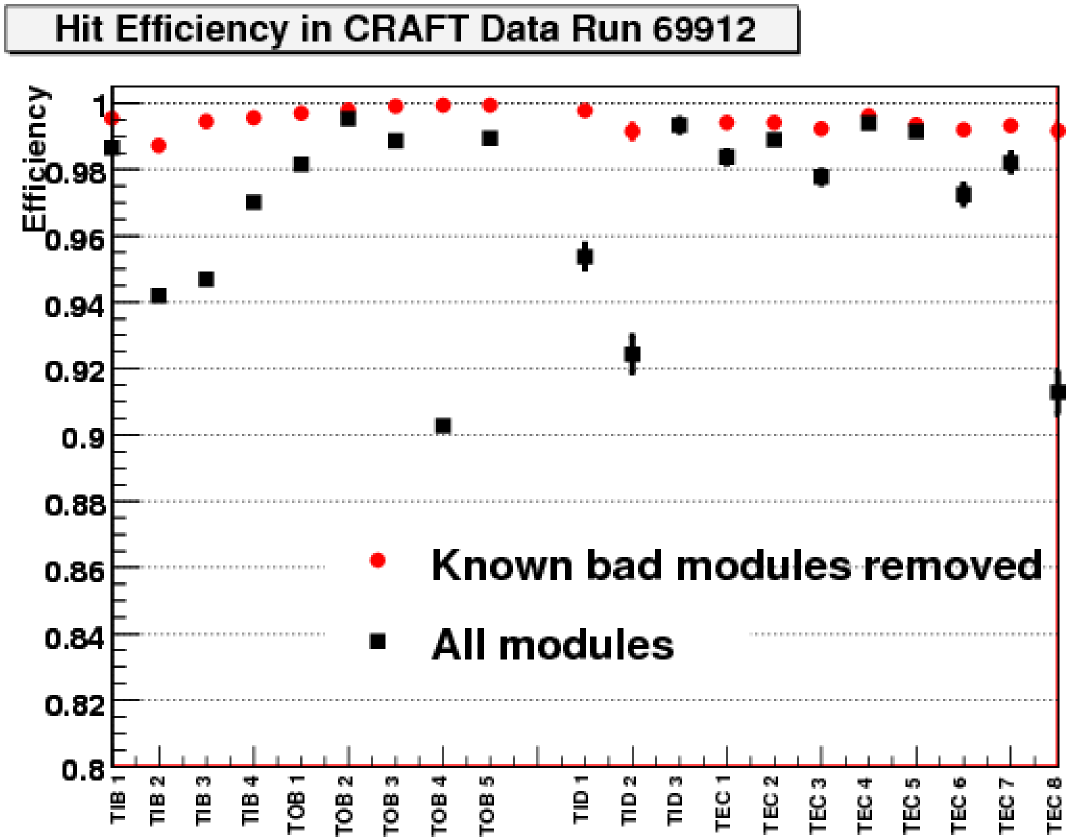
$<\mu_H>$ (TOB, 500 μm sensors) = 0.023 T^{-1}



Different analyses techniques give compatible experimental results. Independent test from alignment confirms them.

Hit efficiency

For each layer of the SST:
- exclude hits from this layer
- perform a full track reconstruction chain
- check if there is a hit in the layer close to the position predicted by the new reconstruction



Modules known to be out of DAQ or flagged as 'bad' by the DQM excluded from this study (red circles).

Most of the tracker >99% efficient.

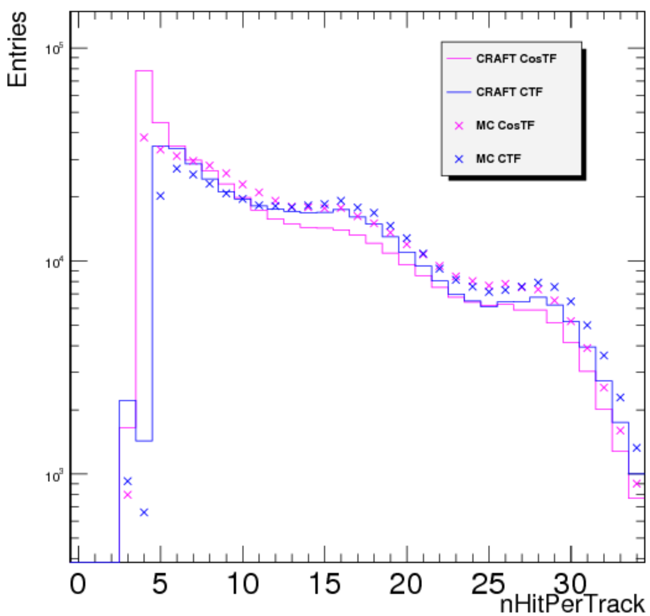
Some evident inefficiencies in some regions. Very well localized (e.g., one TIB string with 0% efficiency). **Information integrative to DQM**.

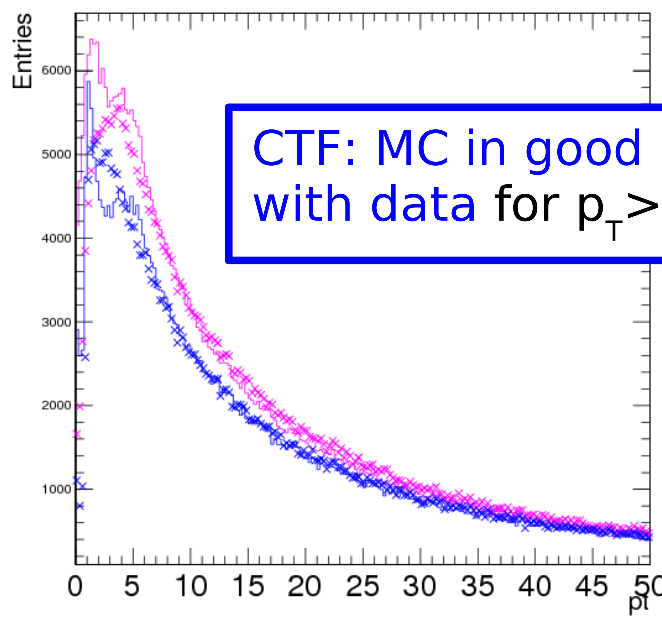
Tracking

Two different tracking algorithms (differing mainly for pattern recognition):
CTF (std algorithm, will be used also for collisions) & CosmicTF
Both with high reconstruction efficiency.

	Eff. In DATA (%)	Eff. In MC (%)
CTF	99.5±<0.1	99.9±<0.1
CosmicTF	99.3±<0.1	99.7±<0.1

Efficiency: look for a track in the TK matching a track in the CMS muon detector. Only tracks pointing to the inner volume of the CMS TK.





CTF: MC in good agreement with data for p_T> 4 GeV

Tracker Alignment

- **Task**: find the positions of ~17k modules (SST+Pixels) within a precision negligible if compared to hit resolution.
- Use all available sources of information: tracks & optical surveys, (oncoming: Laser Alignment System).
- Hit residual, **ε**: difference between measured position of the hit and prediction from the track fit.
- **Basic principle**: find the tracker geometry that minimizes the χ^2 of the hit residuals.

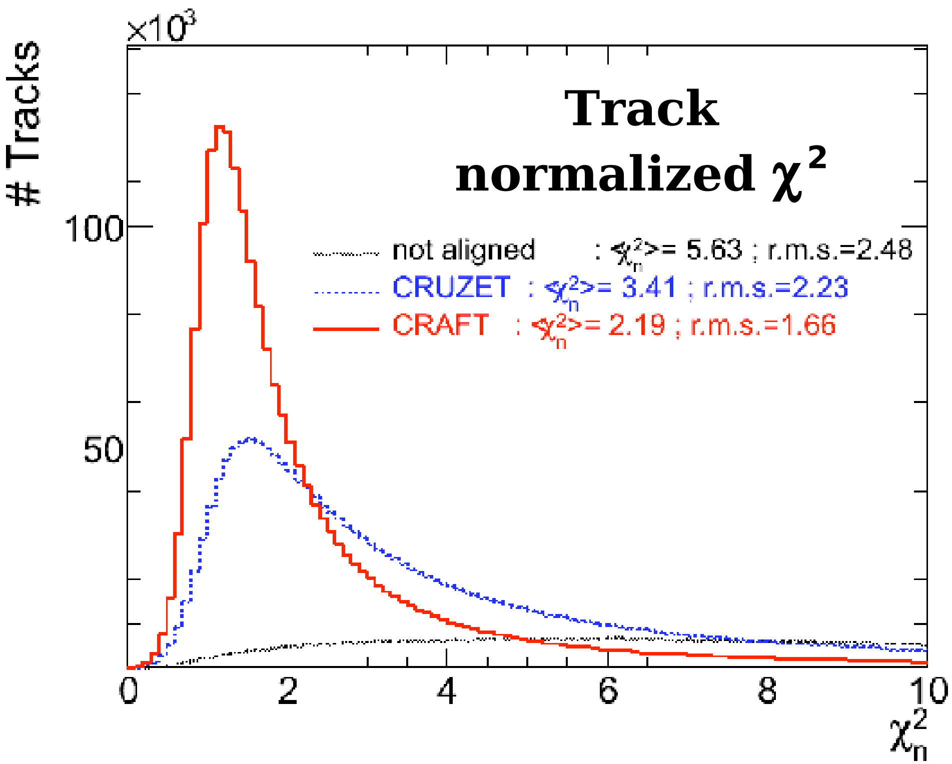
$$\vec{\varepsilon} = (\vec{x} - \vec{p}) \qquad \chi^2 = \vec{\varepsilon}_T V \vec{\varepsilon}$$

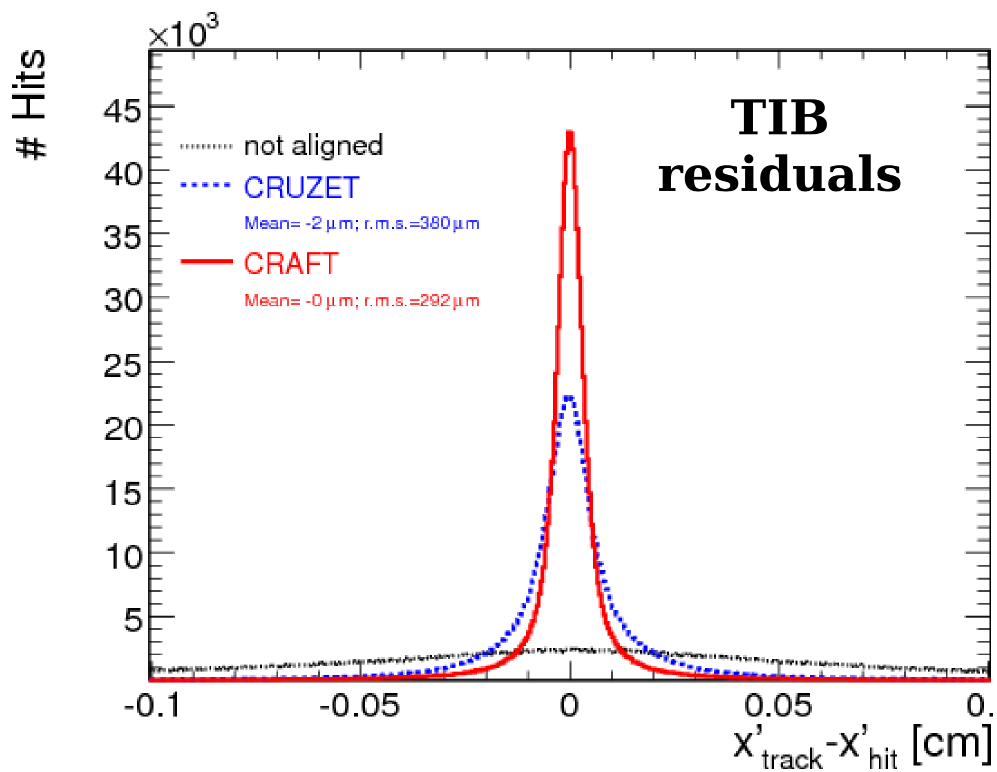
V = covariance matrix, contains tracking and meas uncertainties

Two independent statistical methods:
Hit and Impact Point (HIP): local method, solves by large # of iterations
MillePede (MP): global method, solves by inversion of large matrices

Alignment results

Best performances obtained using a combination of the two alignment algorithms: align with the local iterative algorithm on top of the result from the global algorithm.





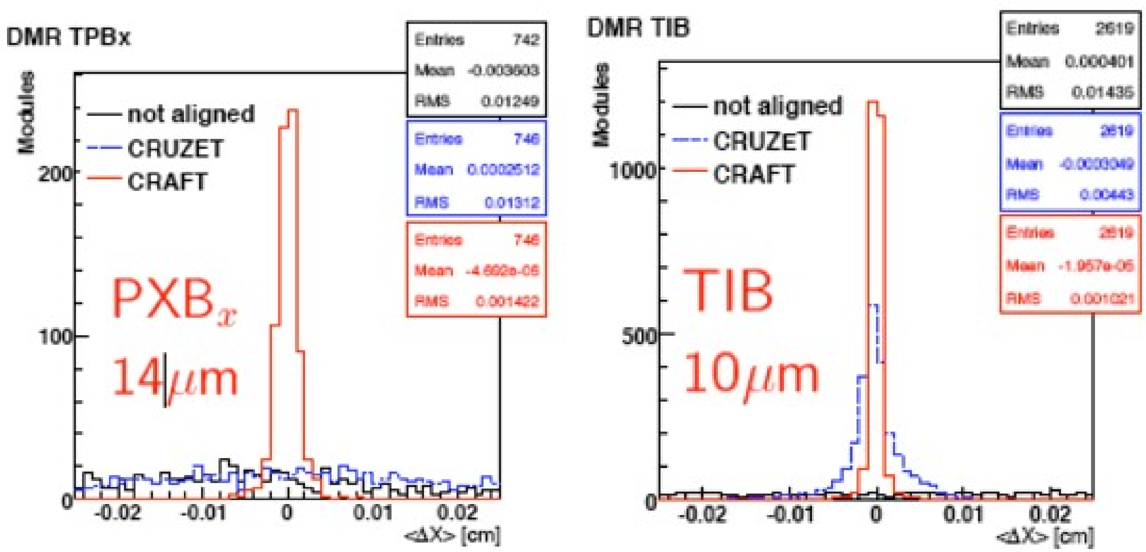
Validation plots run on the full statistics from CRAFT.
Alignment Parameter Errors (APE) == 0 .
CRAFT geometry compared to "**not aligned**" geometry and result from previous alignment with cosmic rays taken @ 0T ("**CRUZET**").

Distribution of the Median of the Residuals

For every module in the TK:

- Make the distribution of the residuals
- Take the median of this distribution
- Fill with it a distribution (as many entries as modules) → **DMR**

Multiple scattering effects average out.
Ideally aligned detector: the DMR is a delta function.

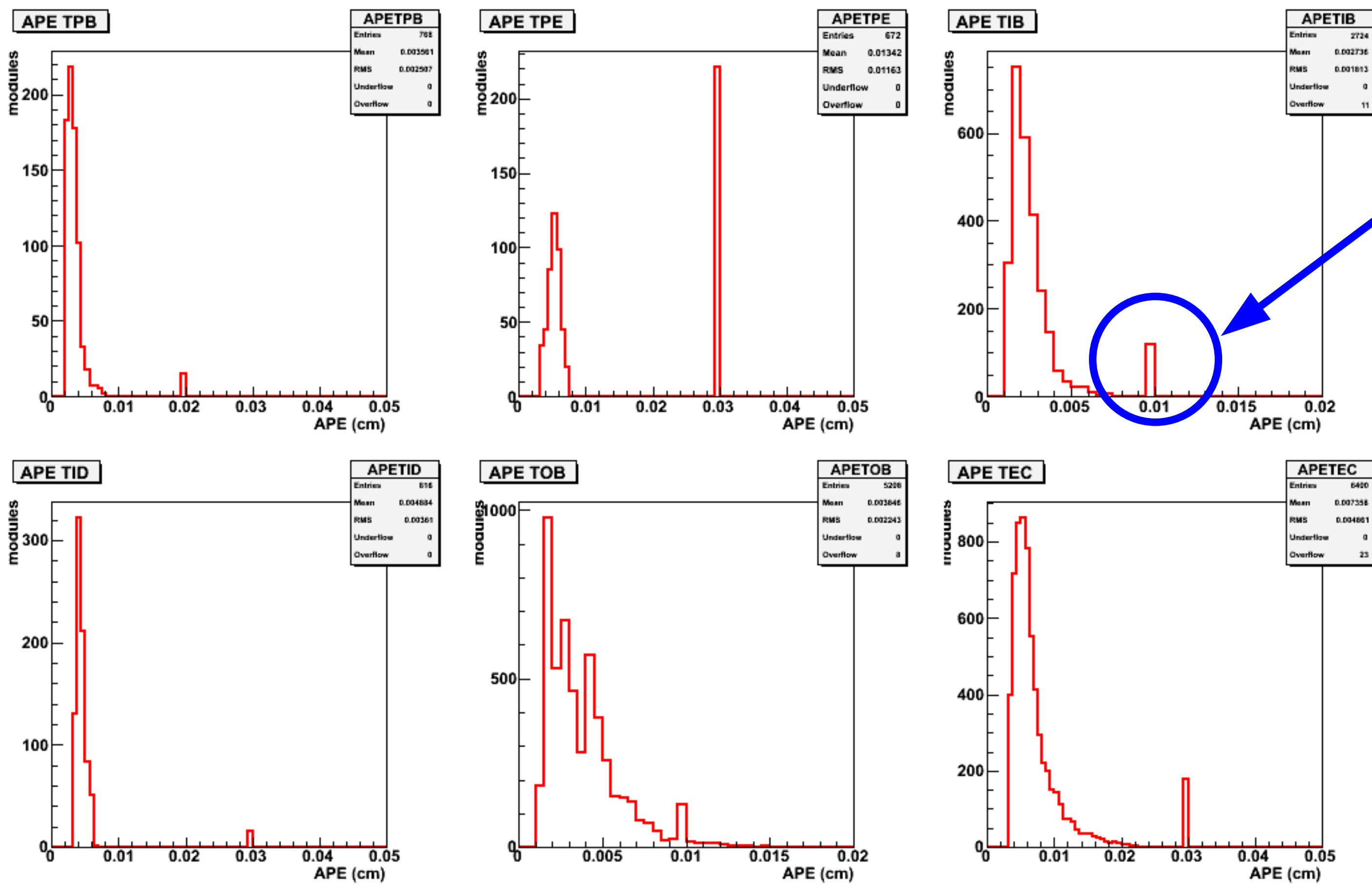


	r.m.s. of DMR (μm)
PXB (x)	14
PXB (y)	14
PXF (x)	41
PXF (y)	39
TIB	10
TID	23
TOB	9
TEC	28

CAVEAT: DMR sensitive only to local remaining misalignment.
Global (χ^2 invariant) misalignments are not spotted by these distributions.

Alignment Parameter Errors

- Estimated precision of the alignment: crucial for tracking !
- Framework able of using module-dependent APE
- Starting from the DMR, define some starting values and apply a scaling law based on the statistic collected by the module

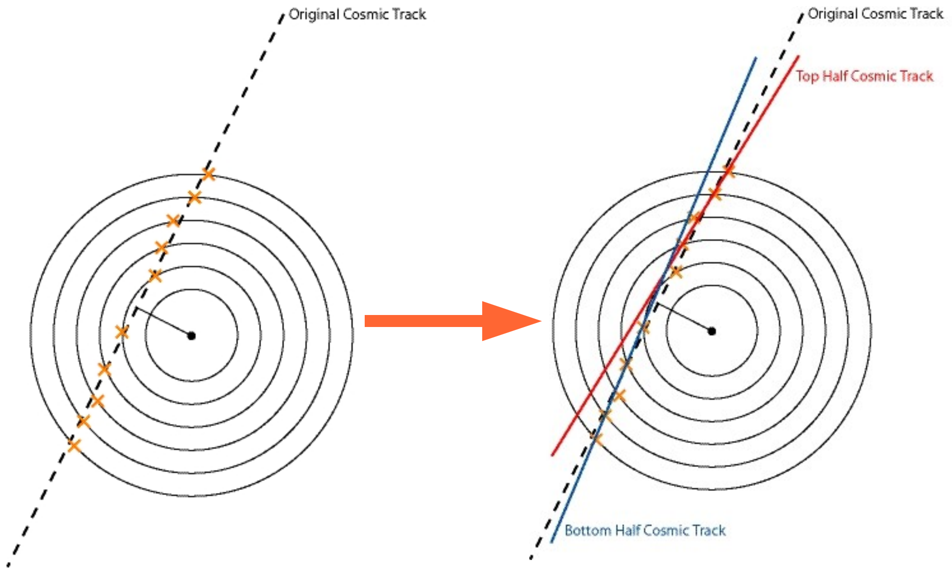


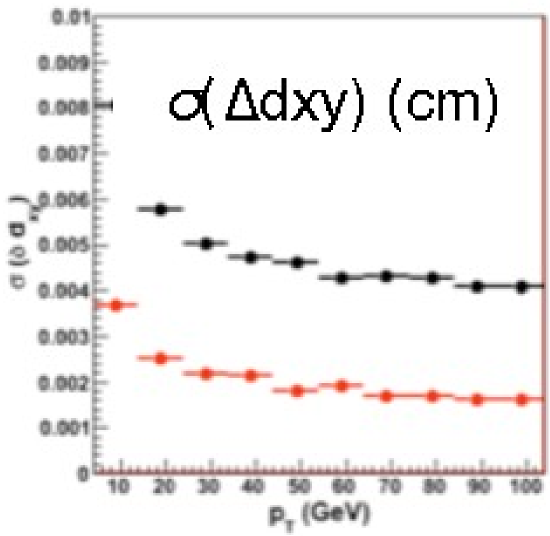
Low statistic modules: APE set to a default

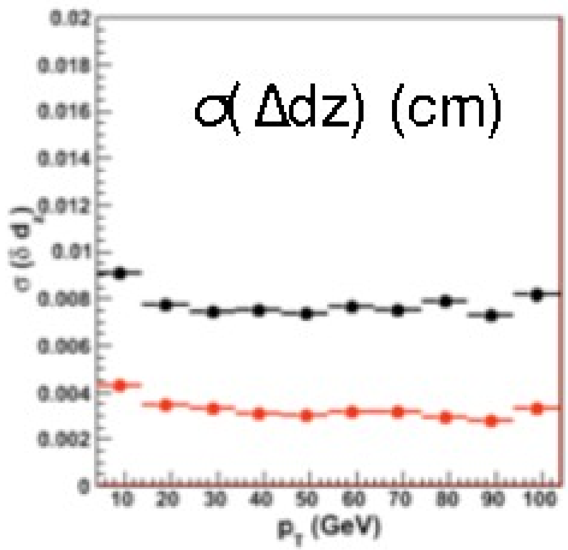
Most of the TK modules have APE < 50 μm !!!

Cosmic Track Splitting

- Powerful data-driven method for validating both tracking and alignment.
- Split the cosmic track at the PCA and compare the two halves.
- Distributions of Δp_T, $\Delta\theta$, $\Delta\phi$, Δd_{xy}, Δd_z show significant improvements brought by the alignment.
- Impact parameter resolution vs track PT shows expected dependencies.







CRAFT
IDEAL MC

Summary

- The data taking of cosmic rays in fall 2008 was an invaluable chance for a thorough commissioning of the CMS Tracker.
- CMS Tracker taking data continuously and robustly. DQM system automatised and flexible. Fundamental tool for guaranteeing high quality data.
- A lot of data for commissioning: full set of calibrations carried out. Great improvement of the knowledge of the detector.
- Tracking proved to be highly efficient and accurate.
- Alignment took advantage of the efficiency of the reconstruction chain, reaching very good precisions (<50 μm in most of the tracker).