CMS Silicon Tracker: Track Reconstruction and Alignment

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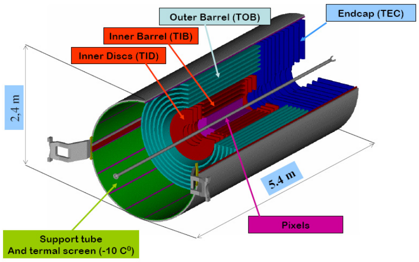
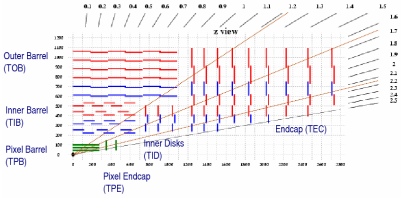
The CMS Silicon Tracker

… is one of the main components of the CMS experiment at the LHC. It consists of ~16000 silicon strip and pixel sensors covering an active area of ~200m² within the tracker volume of 24.4m³.



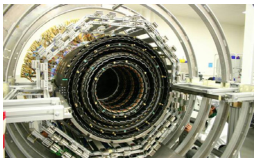
Components of the Tracker

The **Barrel strip detector** consists of 4 inner (TIB) and 6 outer (TOB) layers. The first two layers in TIB and TOB use double-sided sensors. The **Endcap strip detector** is made of 3 inner (TID) and 9 outer (TEC) discs (rings 1,2 and 5 are double sided). The **Pixel detector** consists of 3 barrel layers at r= 4.4, 7.3 and 10.2 cm, and of two endcap discs.



The **Strip Sensors** consist of 512 or 768 strips with a pitch of 80…200μm. Their resolution in the precise coordinate is in the range 20…50μm. The **Pixel sensors** are made of pixels of size 100(rϕ) x 150(z) μm², with a resolution of 10…15μm.

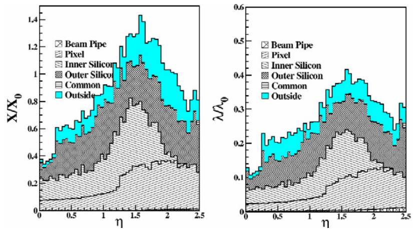
TEC integration



One half of TIB/TID completed

Tracker Material Budget

A large fraction of the tracker material consists of electrical cables, cooling pipes, support structures, electronics etc. As a result, the tracker material budget can exceed the equivalent of one radiation length for certain regions of η, which affects hadron and electron reconstruction.



Tracker material budget in units of radiation length (left) and interaction length (right) as a function of η

Track Reconstruction

The baseline algorithm for track reconstruction in CMS is the Combinatorial Kalman Filter. Track reconstruction proceeds through the following four stages:

(continued in next column)

•Trajectory Seeding

Trajectory seeds, the starting points for track finding, are reconstructed from pairs of hits in the pixel detector and a vertex constraint.

•Pattern Recognition

Trajectory building using the Kalman filter proceeds inside-out, propagating from layer to layer and taking the effects of energy loss and multiple scattering into account. Trajectory candidates are added for each compatible hit, and the best candidates are grown in parallel up to the outermost layers.

•Trajectory Cleaning

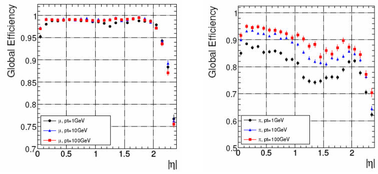
Ambiguities which would lead to track double counting are resolved, using the fraction of shared hits for any pair of trajectories.

•Track fitting and smoothing

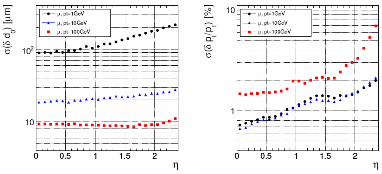
The final track parameters are obtained by running two Kalman filters in opposite directions. The smoothed track states correspond to the weighted mean.

Tracking Performance

The track finding efficiency for muons is excellent, exceeding 98% over most of the tracker acceptance. For pions it is between 75 and 95%, depending on the momentum, due to the hadrons interacting with the tracker material.



Track finding efficiency for muons (left) and pions (right) with p_t=1,10 and 100 GeV as a function of η



Resolution in transverse impact parameter d_0 (left) and in p_t (right) for muons with p_t=1,10 and 100 GeV

Impact of Misalignment

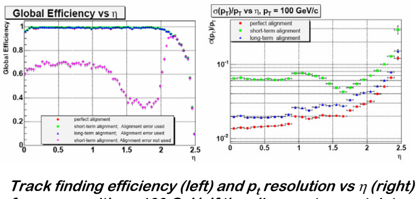
To assess the impact of misalignment on the tracking performance, two "misalignment scenarios" have been implemented in the simulation:

- "First Data" Scenario
  Situation at LHC start-up (first few 100 pb^{-1}):
  Construction position information; Laser alignment available; Pixel detector aligned with tracks
- "Long Term" Scenario
  After first few fb^{-1} have been taken:
  Alignment at the sensor level to ~20μm

	Pixel		Silicon Strip			
	Barrel	Endcap	Inner Barrel	Outer Barrel	Inner Disk	Endcap
First Data Taking Scenario						
Modules	13	2.5	200	100	100	50
Ladders/Rods/Rings/Petals	5	5	200	100	300	100
Long Term Scenario						
Modules	13	2.5	20	10	10	5
Ladders/Rods/Rings/Petals	5	5	20	10	30	10

Assumed alignment uncertainties in the misalignment simulation

The following distributions illustrate the impact of misalignment on the tracking performance:



Track finding efficiency (left) and p_t resolution vs η (right) for muons with p_t=100 GeV. If the alignment uncertainty is not accounted for, the efficiency is significantly degraded. The p_t resolution detoriates significantly with misalignment, in particular for the short-term scenario.

Alignment of the CMS Tracker

The alignment of the CMS tracker requires O(100k) alignment parameters to be determined with a precision of ~10μm, in order not to degrade the very good intrinsic resolution of the silicon modules.

In addition to the knowledge of the positions of the modules from measurements at construction time, alignment will proceed by two means:

Laser Alignment System

The Laser Alignment system will be used to monitor movements of the larger tracker structures (half-barrels and endcap discs) on a continuous basis at the level of 10μm.

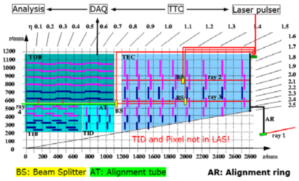


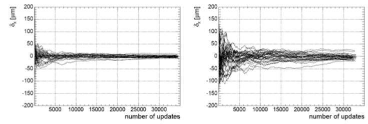
Illustration of the CMS Laser Alignment system

Track Based Alignment

CMS has implemented three alignment algorithms in the reconstruction software:

•Kalman Filter

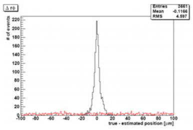
Extension of the Kalman Filter track fitter for alignment. Update of alignment parameters and covariances after each track. Full account of correlations between different modules.



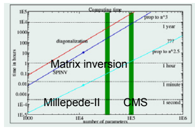
Kalman Filter alignment: Residuals in local x for TIB layers 1 (left) and 2 (right) as a function of the number of processed tracks

•Millepede-II

Improved version of the well-known method for global alignment, which is significantly faster than the old one, and expected to be scaleable to 100k alignment parameters.



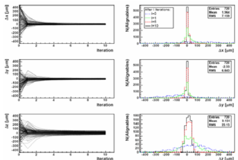
Residuals in rϕ in the strip tracker barrel before (red) and after (black) alignment using Millepede-II



CPU time as a function of alignment parameters for matrix inversion (blue) and Millepede-II

•HIP Algorithm

Local χ^2 solution on each sensor. Correlations between modules are taken care of by iterating the process.



Alignment of the Pixel barrel modules with the HIP algorithm

References:

See CMS Collaboration, Physics TDR Vol. 1 "Detector Performance and Software", **CERN/LHCC 2006-001** (2006) and references therein

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