# Track Reconstruction with the CMS Tracking Detector

J.-R. Vlimant [a]

[a]University of California, Santa Barbara

With proton-proton collision energy of 14 TeV at luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$, the LHC environment poses challenges for the tracking system and for the tracking software. The system must reconstruct charged particles from the primary collision in the presence of up to 20 underlying events. CMS has built an all-silicon tracking system consisting of an inner pixel detector (1 m$^2$ active area) and an outer strip detector (200 m$^2$) with over 70 million readout channels. The CMS software has to master the dense track environment and also take into account multiple scattering due to the large amount of material (0.5 $X_0$ on average). With 13 layers crossed on average, 0.7 % to 5 % transverse momentum resolution is achievable. An overview of the tracking system and the tracking software will be given. Both general and specialized tracking algorithms covering, for example, muon reconstruction will be discussed.

## 1. CMS Tracker design and Hit Reconstruction

The CMS tracking detector has been presented by other authors at this conference[1] and is sketched in Fig. 1. Although the original design [2] includes two types of sensor technology, the CMS tracker is fully based [3] on silicon sensors.

At innermost radius less than 10.2 cm, there are three pixel barrel layers; two pixel disks are located in each end cap at longitudinal distance from the interaction region less than 50 cm. The 1 m$^2$ active area consists of about 66 million $100 \times 150$ $\mu$m pixels. Single pixel signals are clustered and hit position is calculated from the cluster edge: single hit resolution ranges from 15 to 30 $\mu$m. Pixel resolution is expected to degrade by a factor of two with time due to the high particle fluence at the LHC. The pixel high granularity yields a low occupancy, even at high luminosity.

There are ten barrel layers of strip sensors out to a radius of 1.1 m, four layers of which are double sided and mounted with a stereo angle (5.7°) to provide 3D measurement points. There are 12 strip disks in each endcap out to a longituinal distance of 2.75 m. Each disk partially consists of double-sided stereo sensors, and 40% of the 200 m$^2$ active-area of strip detector provides 3D measurement points. Strip signals are clusterized and hit position is either calculated from the edges or from the centroid depending on the cluster size. Single hit resolution ranges from 8 to 64 $\mu$m.

The tracker operates in a homogeneous solenoidal magnetic field of 4 Tesla.

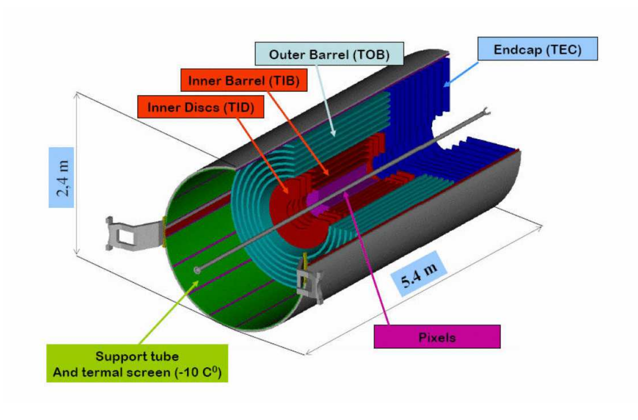


Figure 1. Sketch of the CMS Tracker Detector

## 2. Track Reconstruction Resolution

Track parameters are fitted and smoothed on a set of reconstructed hits using the Kalman fitting method. The effect of material (see Fig. 2), concentrated in the thin layer of silicon is taken into account and being combined to single point uncertainty yields a fine resolution on track $p_T$ as shown in figure 2. Transverse and longitudinal impact parameter resolution ranges from 10 $\mu$m to 100 $\mu$m and from 20 $\mu$m to 1 mm respectively, depending on track momentum and pseudorapidity.

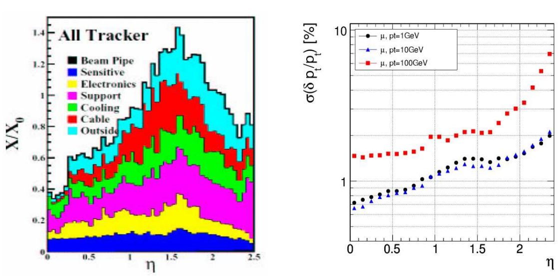


Figure 2. Amount of material in the CMS tracker volume and muon $p_T$ resolution.

## 3. Pattern Recognition

Pattern recognition consists of gathering sets of reconstructed hits consistent with the path of a charge particle and is initiated with seeding stage in which a small number of hits is selected to serve as a starting measurement.

### 3.1. Trajectory Seeding

**Hit Doublet**

A pair of hits in the tracker combined with an interaction region constraint determine initial track parameters. High efficiency is achieved by searching for hits pairs in redundant pair of tracker layers. The purity of such a set of trajectory seeds is low. Pixel pairs, strip pairs and mixed pairs are used [4] and allow for the reconstruction of tracks with vertices beyond the pixel detector volume.

**Pixel Triplet**

Pixel triplets are built [4] from pixel pairs for which a consistent hit is found on one of the outtermost pixel layers. In the baseline reconstruction, pixel triplet finding is optimized for transverse momenta greater than 1 GeV, and a specialized algorithm allows for triplet recosntruction at lower transerse momenta. Pixel doublet and triplet efficiencies are shown in Fig. 3

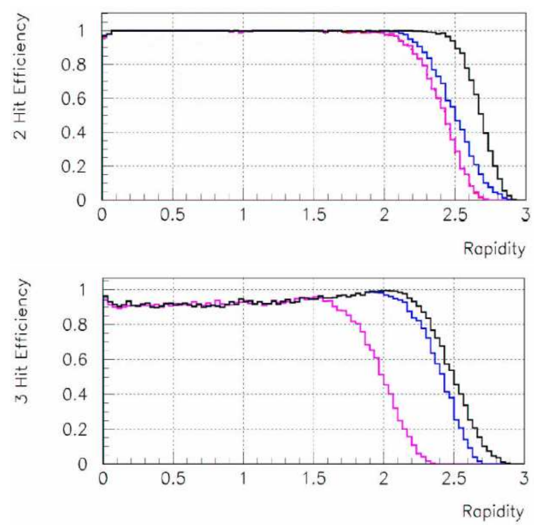


Figure 3. Reconstruction efficiency for pixel hit doublet and triplet.

### 3.2. Trajectory Building

In the baseline reconstruction, there are two pattern recognition algorithms: the combinatorial track finder (CTF) and the road search algorithm (RS).

**Combinatorial track finder**

The CTF [5] algorithm, starting from a pair or a triplet of consecutive hits, combines compatible measurements based on the Kalman trajectory filtering method.

**Road Search Algorithm**

The RS algorithm searches for compatible measurements from a predfined set of detector modules based on a trajectory seed computed from a transverse curvature assumption and pair of hits distant to provide sufficient lever arm.

### 3.3. Alternative Algorithm

Dedicated algorithms are used beyond the track reconstruction baseline due to computing power limitations. The gaussian sum filter (GSF) algorithm provides non-gaussian modeling of energy loss and is dedicated to electron. The deterministic annealing filter (DAF) and multi track finder (MTF) algorithms let tracks compete with each other for consistent hits and are dedicated to track reconstruction in jets.

## 4. Tracker Alignment

Three tracker alignement scenario are considered. The first is based on monitoring during assembly. The second is based on a laser system that can provide alignment to 100 $\mu$m precision. The last one is based on software alignement using reconstructed tracks in a few $fb^{-1}$ of data. Three algorithms are available: Millipede II [6], Kalman Filter [7] and Hits and Impact Points [8]. They are expected to provide alignment to 20 $\mu$m precision.

## 5. Tracker Issues In the high Level Trigger

Skiming collisions from the LHC (40 MHz), the CMS trigger system [9] has a hardware level 1 (L1, 50-100 kHz) and a fully sofware higher level trigger (HLT, 100 Hz). In the baseline, not enough time is available to do global track reconstruction and hence, in order to use the fine resolution of tracker track parameters, regional track reconstruction has to be initiated by external primitives: muon, jets, ... However, pixel triplet findind is fast and provides with fast track reconstruction with $p_T$ resolution from 5 to 35% and can be used for vertexing, b-jet identification, etc at trigger level.

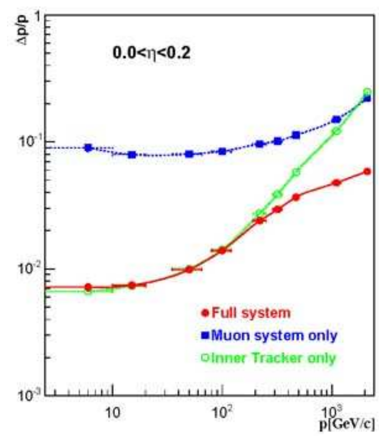


Figure 4. Momentum resolution in the central region of the CMS detector, using tracker only, muon system only and combined information.

## REFERENCES

1. G. Sguazzoni, "The Construction of the CMS Silicon Strip Tracker", poster at HCP 2007. J. Lamb, "CMS Silicon Tracker Integration and Slice Test", poster at HCP 2007.
2. The Tracker Project, Technical Design Report, CERN/LHCC 98-6.
3. CMS Physics TDR, Volume I, 2006.
4. Track reconstruction, primary vertex finding and seed generation with the Pixel Detector, CMS NOTE 2006-26.
5. Track Reconstruction in the CMS tracker, CMS NOTE 2006-41.
6. Software Alignment of the CMS Tracker using MILLEPEDE II, CMS NOTE 2006-11.
7. A Kalman Filter for Track-based Alignment, CMS NOTE 2005-22.
8. The HIP Algorithm for Track Based Alignment and its Application to the CMS Pixel Detector, CMS NOTE 2006-18.
9. CMS Collaboration, .The TriDAS Project Technical Design Report, Volume 2: Data Acquisition and High- Level Trigger,., CERN/LHCC 2002-26 (2002). CMS-TDR-006-add-2.