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Tracking and Alignment in the CMS Detector

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Abstract

This Report summarises the alignment strategy of the CMS detector. Track reconstruction in the silicon tracker and muon chambers is briefly described. We then present the different sources of alignment information, in particular alignment algorithms using reconstructed tracks.

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1 INTRODUCTION

The performance of track reconstruction is intimately related to the alignment of the tracking devices. A precise knowledge of the position of the various sensitive volumes is, therefore, crucial to obtain ultimate resolution on track parameters. Conversely, only track-based alignment will allow to achieve the ultimate alignment of the two tracking systems of CMS: the silicon tracker and the external muon chambers, presented below.

Alignment information, however, also comes from other sources. Combining this information, together with various samples of reconstructed tracks, defines the alignment strategy of CMS.

An overview of the track reconstruction is first given in Section 2. The alignment strategy is then presented in Section 3. (More details can be found in [1].)

1.1 The CMS tracker

The CMS Silicon tracker covers the region directly around the interaction point. It consists of more than 15 thousand silicon strip and pixel modules, covering an active area of more than 200 m^2. The full system ranges up to 110 cm in radius and $\eta = 2.4$ in pseudo-rapidity.

The barrel region is separated into an outer part (TOB), and inner part (TIB) and the pixel barrel layers (TPB) closest to the beam. The two first layers of TOB and TIB have double-sided modules. The forward region is covered by the endcap disks (TEC), the inner disks (TID) and the pixel endcap disks (TPE). Three rings of the TEC are double-sided.

The pitch size of the strip sensors is in the range $80 - 200$ μm, with resolutions of $20 - 50$ μm. The pixels have a size of $100(r\phi) \times 150(z)$ $\mu\mathrm{m}^2$, with a resolution of 10 and 15 μm, respectively. There are 11 million strips and 66 million pixels in total.

1.2 The CMS muon devices

Muon chambers are interspersed in the flux-return iron, outside the 4T magnet. Three types of gaseous detectors are used: drift tube (DT) chambers in the barrel region, cathode strip chambers (CSC) in the endcaps, and resistive plate chambers in both barrel and endcap (for triggering and redundancy). The muon system covers a total active area of 25 000 m^2.

There are 250 drift chambers in the barrel region, providing a point resolution of about 200 μm. The two endcaps comprise 486 CSCs, with a spatial resolution of $100 - 200$ μm.

2 TRACKING IN CMS

2.1 Tracking in the tracker

After reconstruction of the hits (clustering and positioning), track reconstruction proceeds through four steps [2]:

First, trajectory seeds are constructed with two hits in the pixel detector, with a vertex constraint (alternative seeding using the strip detectors or other sub-detectors of CMS also exist). Second, the trajectory are built using a combinatorial Kalman filter, proceeding layer-by-layer from the seed layer. It takes into account the effect of energy loss and multiple scattering. The best candidates are grown in parallel. Then, ambiguities due to single seeds giving multiple tracks, or single tracks using multiple seeds, are resolved on the basis of hits sharing. Finally, remaining track candidates are refitted inside-out (fitter step) and outside-in (smoother step) to obtain the optimal track parameters at each hit.

The performance of the track reconstruction in the tracker is illustrated in Fig. 1.

2.2 Tracking in muon devices

Muon reconstruction is performed in 3 stages [3]: local reconstruction, standalone reconstruction and global reconstruction. Starting from a seed (segment reconstructed in CSC and/or DT chambers), the chambers compatible with the seed are identified and local reconstruction is performed only in these chambers. Standalone muon reconstruction uses only information from the muon system, while global muon reconstruction also uses silicon tracker hits. The Kalman filter technique is used to build track candidates in a way similar to the tracker reconstruction.

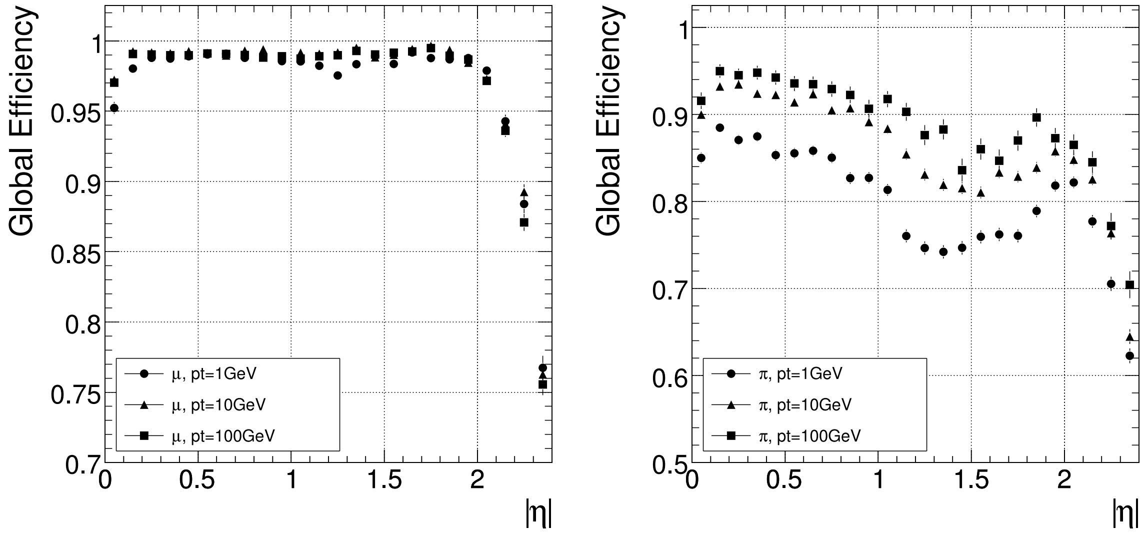

Figure 1: Global tracking efficiency for muons (left) and pions (right) of various energies.

The performance of standalone and global muon reconstruction are compared in Fig. 2, together with the tracker-only reconstruction.

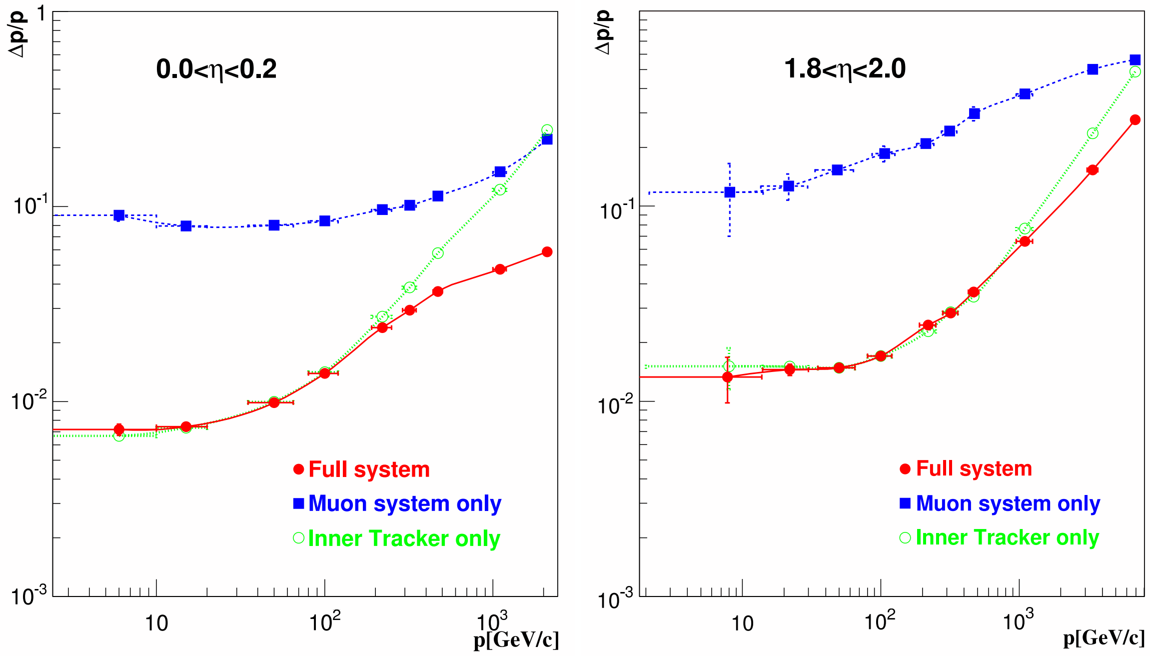

Figure 2: Resolution of $1/p$ vs. p for standalone, global and tracker-only muon reconstruction in the (left) barrel and (right) endcap regions.

3 ALIGNMENT

The residual alignment uncertainties should not significantly degrade the intrinsic resolution of the modules. For the Silicon tracker, this translates into determining more than 100 thousand parameters with a precision better than 10 μm. In the muon system, 5 thousand parameters have to be determined with a precision of $100 - 500$ μm.

Three sources of information are combined to achieve this precision: knowledge from the construction, optical alignment and track-based alignment.

3.1 Construction knowledge

During the assembly of the CMS tracker and muon chambers, information on the position and orientation of modules on supporting structures is precisely measured and stored in databases. This will provide the first corrections to the ideal geometry, as a basis for further alignment.

3.2 Optical alignment

The optical alignment systems of CMS has three components: the internal muon alignment in the barrel and endcap regions; the internal Silicon tracker alignment (alignment of TIB and TOB with respect to TEC); alignment of the muon chambers with respect to the tracker.

The muon optical alignment will provide positioning at an operational level, while track-based alignment will be used to cross-check and increase this precision further.

In the silicon tracker, optical alignment will ensure pattern recognition, and will be used to monitor movements of the larger structures. Track-based alignment is needed to achieve final alignment, and is essential for the pixel detectors, where no optical alignment is available.

3.3 Track-based alignment

Track-based alignment was already shown to be the optimal method for the alignment of large tracking devices. Three algorithms have been implemented to solve the challenging CMS problem:

The Kalman Filter algorithm [5] is an iterative method which extends the standard Kalman filter, so that the alignment parameters are updated after each track. It takes into account significant correlation between modules. This algorithm has been successfully tested on different subsets of the silicon tracker, as illustrated on Fig. 3.

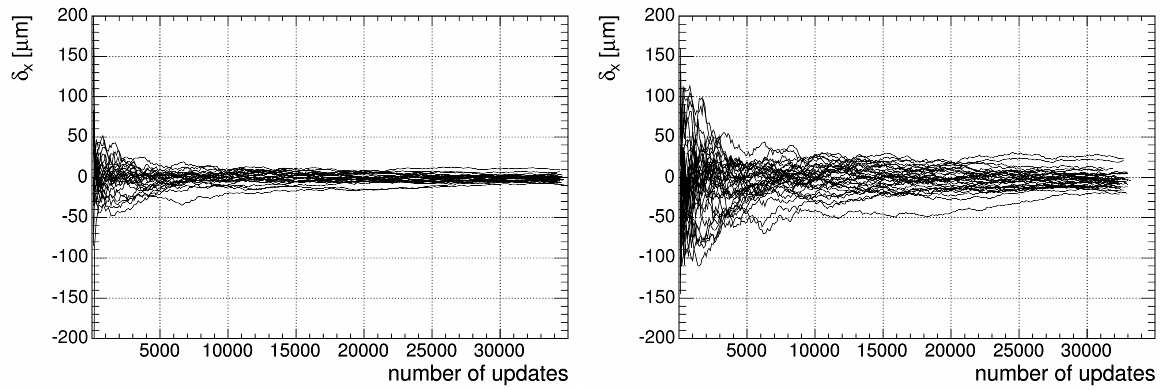

Figure 3: Kalman filter algorithm: evolution of the differences between the estimated and the true local x-shifts in (left) layer 1 and (right) layer 2 of TIB.

The MillePede algorithm [6] is a linear least-squares algorithm, which can take into account correlations among all parameters (including all modules). The solution is obtained from a matrix equation. A new version has recently been developed to solve the matrix equation using minimisation techniques. It was shown that the exact same result could be obtained, while the processing time was reduced by three orders of magnitude.

MillePede has also been successfully used to align muon chambers [7].

Finally, the Hits and Impact Points (HIP) algorithm [8] determines the alignment of individual sensors by minimising a local χ^2 function. Correlations between sensors are not explicitly taken into account, but are taken care of implicitly by iteration over the full event sample. It is a computationally light algorithm, which was also successfully applied to the silicon tracker alignment, in particular the alignment of the pixel detector with a small number of tracks.

In addition to these algorithms, several data sample are used to better constrain the parameters and their correlations: $Z \to \mu\mu$, cosmic muons, beam halo muons, etc. An optimal combination of these samples will allow to solve the full alignment problem with a minimal number of events.

4 CONCLUSION

Alignment of tracking devices is essential for good Physics performance. Because of the complexity of the silicon tracker and muon systems, it is a very challenging task in CMS. New techniques, however, have been developed and results are very encouraging. Analysis of test beam data and cosmic runs is ongoing, and CMS is proceeding well towards first data taking.

References

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