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First Alignment of the Complete CMS Silicon Tracking Detector

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Abstract

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First Alignment of the Complete CMS Silicon Tracking Detector

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1. Introduction

CMS (Compact Muon Solenoid) is one of the two general purpose experiments at the Large Hadron Collider (LHC) at CERN. The 12500 ton CMS detector consists of a 4T superconducting solenoid, a muon detector, a hadron calorimeter, an electromagnetic calorimeter and the all-silicon tracker.¹ The tracker comprises a silicon pixel and a silicon strip detector within a diameter larger than 2m and a length of more than 5m. The pixel detector is built out of 1440 pixel modules. It consists of a barrel (PXB) and a forward part. A single hit resolution varies from 9 μm to 20 μm in the sensitive coordinate. The strip detector is subdivided in mechanically separate parts: Inner Barrel(TIB), OuterBarrel(TOB), InnerDisk(TID) and Endcap(TEC). All parts together comprise 15148 single-sided silicon strip modules with strip pitches ranging from 80 μm to 205 μm . The single-strip resolution varies from 20 μm to 60 μm along the sensitive coordinate. The task of alignment consists in determining module positions in order to better reconstruct charged particle trajectories.

In this paper we describe the alignment strategy and results employed to determine the position and orientation of all the 16588 silicon modules, with the track-based approach using cosmic data. This strategy includes

precise assembly, survey measurements,¹ and the laser alignment system.¹ Finally, we consider the implications of tracker alignment on the tracking performance.

2. CMS Tracker Alignment Strategy

The strategy of CMS tracker alignment incorporates all the available information: optical survey information, laser alignment system and tracks.

The first detailed information about the relative position of a module within detector components and of large-level structures within the Tracker is available from the optical survey.

Additionally, the CMS tracker is equipped with a Laser Analysis System (LAS), using infrared laser beams with fixed wavelength to monitor the position of selected modules. It operates globally on tracker substructures (TIB, TOB barrels and TEC disks) and cannot determine the position of every module. The goal of the system is to generate alignment information in a continuous way.

The final tool to achieve the desired precision is the track based alignment. The common principle is the minimization of a χ^2 -like function built up from the normalized unbiased track hit residuals. The residual is the difference in local module coordinates between the track extrapolation and the hit. CMS has employed two different algorithms: the Hits and Impact Point algorithm² (HIP local method) and MillepedeII³ (global method). The first algorithm minimizes the sum of the residuals of each aligned object, independently from the others. Since the track fit predicting the track impact point is biased by misalignment, this is repeated iteratively until convergence is achieved.

The latter is an upgraded version of the Millepede program. The basic principle is the minimization of the linearised χ^2 -like, simultaneously taking into account track and alignment parameters.

3. Full Tracker Alignment

In the second half of 2008, CMS collected about four millions of muons (originating from air showers) suitable for the alignment of the CMS tracker at 3.8 T magnetic field. For alignment purposes, a selection is applied to the tracker samples based on: the number of reconstructed tracks in an event, the track fit normalizes, the number of associated hits in the tracker

modules, the total charge collected in the corresponding clusters, the hit isolation and the rejection of outliers. The two alignment algorithms were run. In particular, HIP ran a track-based alignment using the survey constraints, while Millepede ran a solely track-based alignment. The best performances were obtained using a combination of the two algorithms: the two methods are combined in a sequential approach to solve most effectively both global (Millepede) and local (HIP) correlations of module positions with respect to charged particle tracks.⁴

The estimator of the alignment used is the track χ^2/ndof , where ndof is the number of degrees of freedom, shown in Fig. 1(left). The hit residuals (differences in the coordinate of the module between position of hit and the position of the extrapolated trajectory) are shown in Fig.1(right). In practice, the residuals are dominated by two effects, other than alignment track extrapolation uncertainties: the multiple scattering and hit reconstruction uncertainties. Both of these effects are random, while misalignment leads to systematic shifts of the residuals. Figure 2 shows the distribution of the

Fig. 1. Track χ^2/ndof (left), and track residual (right) in the PXB: before alignment (dotted line), alignment with the local method (dashed-dotted line), alignment with the global method (dashed line), and alignment with the combined method (solid line).

median of the residuals (DMR) which is taken as the most appropriate evaluation of the alignment, since it reduces the contribution to the residuals from multiple scattering. Comparison between data before and after alignment shows the large improvement reached.

Another method to monitor and validate the results of the alignment is to use the hits of tracks passing through region where two modules overlap, shown in Fig. 3. The difference in the residuals for the two measurements are compared. The hits in the layer under consideration are removed from the track fit to minimize the bias on the trajectory measurement. The

Fig. 2. Distribution of the median of the residuals for PXB modules with more than 30 hits. Shown are distribution before alignment (black dotted), after alignment with the combined method (red solid) based on reconstructed mode, to cross check are also shown the same strategy but using Monte Carlo (MC) samples combined method (green dashed), and ideal MC (blue dash-dotted).

Fig. 3. Relative shift between module pairs in the most sensitive coordinate in the TIB.

amount of material between the two hits is minimum in the overlap region so that the uncertainties from multiple scattering effect are reduced. The deviation between the reconstructed hits and the predicted position allows the relative alignment between two adjacent modules.

4. Track splitting method

The track parameter resolution has been validated with an independent reconstruction of the upper and lower segment of the cosmic tracks and then comparing of the track parameters at the point of closest approach. In Fig. 4 we see an improvement from the designed to aligned geometry, as measured resolutions are close to those that would be observed in a detector with perfectly placed modules.

Fig. 4. Distributions of differences between upper and lower track parameters measured at the point closed to the beamline and scaled by $1/\sqrt{2}$. Four geometry are shown: data not aligned (black dotted line), data with combined method alignment (red solid), combined method MC (green dashed), and ideal MC (blue dash-dotted).

5. Summary

The first results of full CMS tracker alignment have been presented. The track based alignment is performed with two different statistical approaches significant improvements in track χ^2 and hit residuals are achieved. Detailed studies have been performed to estimate alignment performance using overlap modules and track splitting method.

References

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