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The Compact Muon Solenoid Experiment

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The CMS Tracker alignment in p-p collisions

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Abstract

The CMS all-silicon tracker consists of 16588 modules. Aligning these with the desired precision of a few micrometers is only feasible using track based alignment procedures. Ultimate local precision is now achieved by the determination of sensor curvatures. This leads to about 200 000 parameters to be calculated simultaneously. The Millepede II program interfaced with CMS software is optimized to provide solution in one step. The main remaining challenges are systematic distortions in the achieved geometry that are systematically biasing the track parameters like the track momenta. These distortions are controlled by adding further information into the alignment workflow, e.g. the mass of decaying resonances. In addition, the orientation of the tracker with respect to the magnetic field of CMS is determined with a stand-alone chi-square minimization procedure. The geometries are finally carefully validated. The monitored quantities include the basic track quantities for tracks from both collisions and cosmic muons and physics observables like resonance masses.

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The CMS Tracker Alignment in pp Collisions

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on Behalf of The CMS Collaboration

Abstract

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Key words: CMS, tracker detector, silicon sensor, high energy physics
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1. Introduction

The tracker of the CMS detector at LHC consists of 25 684 silicon sensors. They are distributed on 1440 Si pixel modules arranged in pixel barrel (PBIX) and pixel endcap (FPIX) subdetectors, surrounded by 15148 Si strip modules arranged in tracker inner barrel (TIB), tracker outer barrel (TOB), the tracker inner disks (TID) and the tracker endcaps (TEC). All sub-detectors are concentrically arranged around the z-axis. Modules at $r > 60$ cm contain two daisy-chained sensors, leading to 24 244 strip sensors in total. The resolution for the strip modules is typically between 23 to 60 μm and for the pixel it is around 9 μm. The analysis of physics processes requires precise knowledge of the sensor positions of the order of a few micrometers. Therefore, sophisticated track based alignment algorithms are employed at CMS [1]. They exploit as input the 2011 collision dataset, consisting of 23M tracks including 375k muon track pairs from *Z* boson decay, 15M tracks of loosely selected muons, 3M low momentum tracks, and 3.6M cosmic ray tracks taken before and during collisions and also between LHC fills.

In this work we first discuss the track based alignment using the Millipede II algorithm [2], and then present the results during 2011 *pp* collisions, followed by a summary.

2. Track Based Alignment Technique

Track based alignment can be treated as a least square minimization problem where the data from hits generated by tracks are used. The objective function, χ^2, is the square of the normalized track-to-hit residuals r_{ij} for hit i along track j and is given as

$$\chi^2 = \sum_{j}^{tracks} \sum_{i}^{measurements} \left(\frac{m_{ij} - f_{ij}(p, q_j)}{\sigma_{ij}} \right)^2$$

where measurements m_{ij} with uncertainties σ_{ij} are independent, f_{ij} is the track model from broken lines [3] prediction at the position of the measurement depending on the alignment (p) and track (q_j) parameters. In the global fit approach as implemented in the Millipede II program, the objective function is minimized after linearization of f_{ij}. It takes all correlations between modules and higher hierarchies into account and works in a single step. However, due to rejection of tracks with very large χ^2 (outlier rejection), a small number of iterations are still required.

3. Results

Sensor surfaces are not flat, in contrast to what was originally assumed in the track reconstruction.

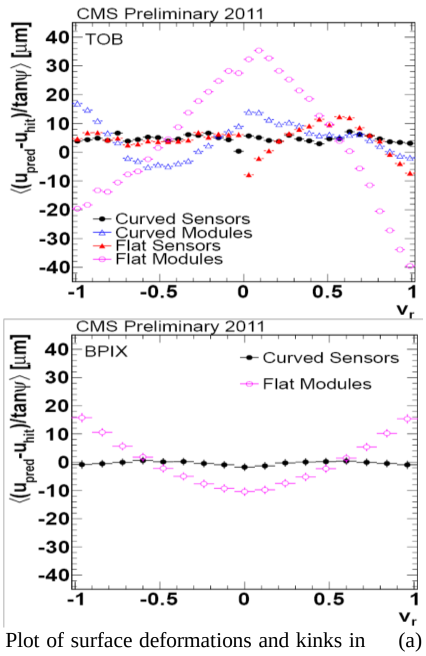

Figure 1: Plot of surface deformations and kinks in (a) TOB and (b) BPIX; Curved Sensors: determination of kinks (for TOB and TEC only) and curvatures; Curved Modules: determination of curvatures on module level only; Flat Sensors: determination of only kinks (for TOB and TEC only); Flat Modules: ignoring kinks and curvatures.

In sensor alignment parameterization, Cartesian coordinate system *(u,v,w)* is used, where *u* and *v* are translational parameters lying in the sensor plane and *w* is normal to the plane of the sensor. Figures 1(a) and 1(b) show the offset $dw = du/tan\Psi$, calculated from the residuals in *u* and the track angle Ψ from the sensor normal in the *uw* plane. For the flat modules geometry a strong track angle and position dependence of hit residuals is observed, which gets eliminated after determination of kinks/bows in the alignment. Figure 2 shows the improved track fit probability for cosmic ray tracks when kinks and bows are taken into account.

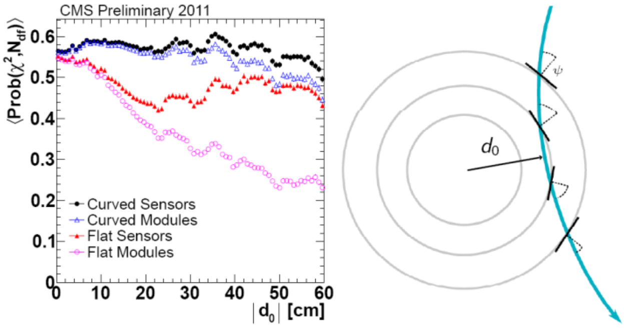

Figure 2: Plot of track fit probability vs d_0.

Minimising residuals is not the final step in the alignment procedure. Systematic movements of silicon sensors and changes of track parameters can balance each other without changing the overall χ^2, potentially biasing the track parameters. However, these so-called weak modes might affect track parameters significantly. Making use of cosmic ray tracks and other physics constraints in the alignment eliminates several weak modes. The tracker twist deformation changes the curvature of positively and negatively charged particles oppositely. Figure 3 shows the dependence of the position of the Z-mass peak as a function of the pseudo-rapidity of the positively charged muons. It can be seen that adding Z-mass information in alignment contributes to removing the twist dependence.

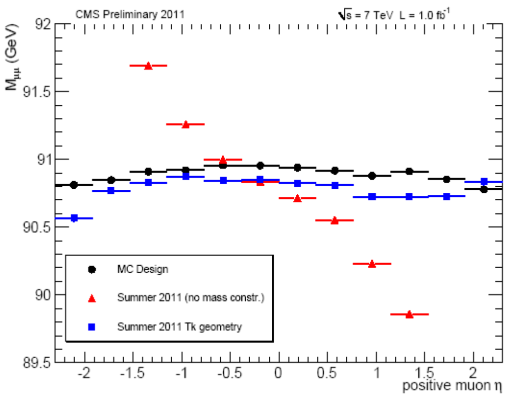

Figure 3: Reconstructed mass peak positions for $Z \rightarrow \mu^+\mu^-$ decays as a function of η of the μ^+.

Also, the sensitivity to weak modes was checked by using as input data a sample into which a systematic twist-misalignment was built in. This sample was realigned and the track χ^2 as well as the resulting geometry on a module-by-module basis was compared with the Summer 2011 geometry. It is found that χ^2 for collision tracks is almost unaffected by twist-misalignment as shown in Figure 4. Figure 5 shows that the applied twist misalignment is eliminated after re-alignment due to the usage of virtual *Z* boson mass as a constraint.

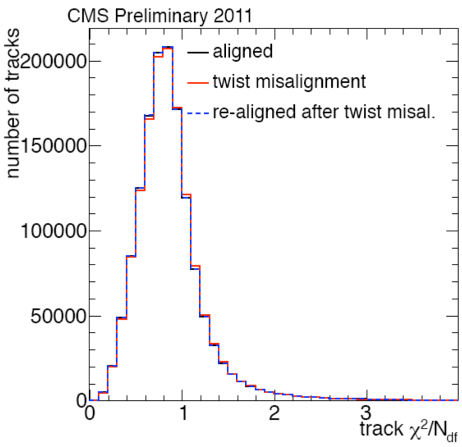

Figure 4: Loosely selected isolated muon track- χ^2/N_{df} of requiring track pT>5GeV (statistically independent sample from the alignment one).

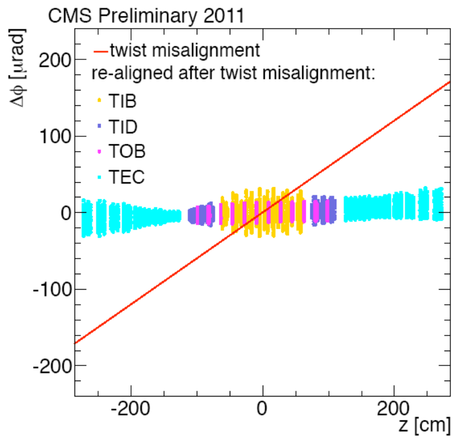

Figure 5: Geometry comparison w.r.t. Summer 2011 geometry: module-by-module difference after subtraction of global movements and rotations.

4. Summary

The large apparatus and finer segmentation of the CMS Si Tracker is a challenge for the alignment. In Summer 2011 with track based alignment 200 000 parameters were determined. Certain weak modes in the alignment procedure (like Twist deformation) were suppressed by using cosmic tracks and by using the *Z* mass measurement. During 2011, the CMS Tracker Alignment has provided the desired precision for physics analysis discoveries.

5. Acknowledgement

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6. References

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