PROCEEDINGS OF SCIENCE

The alignment of the CMS Silicon Tracker

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The complex system of the CMS all-silicon Tracker, with 15148 silicon strip and 1440 silicon pixel modules, requires sophisticated alignment procedures. In order to achieve an optimal track-parameter resolution, the position and orientation of its modules need to be determined with a precision of few micrometers. We present results of the alignment of the full Tracker, in its final position, used for the reconstruction of the first collisions recorded by the CMS experiment. The aligned geometry is based on the analysis of several million reconstructed tracks recorded during the commissioning of the CMS experiment, both with cosmic rays and with the first proton-proton collisions. The geometry has been systematically monitored in the different periods of operation of the CMS detector. The results have been validated by several data-driven studies. The influence of remaining χ^2-invariant detector movements is estimated by investigating the sensitivity of the alignment procedure to some correlated detector distortions and testing their influence on physics analysis like the B-fraction measurement in J/Ψ events.

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1. Strategy and Results of the CMS Tracker Alignment using first 7 TeV Data

The exact knowledge of the position of all 16588 silicon modules of the CMS tracking detector [1] is essential for most physics analyses performed within the CMS collaboration. Although the tracker was assembled with the upmost care and precision, the alignment cannot be absolutely perfect. Improved knowledge of the alignment of the tracker can be gained using the tracks observed in the tracker. The module positions are determined by minimizing the overall χ^2 of the track fit, allowing the modules to be shifted/rotated in all 6 degrees of freedom.Within the CMS collaboration, there are currently two methods in use to solve the minimization problem: A global algorithm, called Millepede II [2], reduces the size of the matrix in the minimization equation to the number of alignment parameters preserving the module correlations. A local method, called Hit and Impact Point (HIP) [3], provides a solution for each module and thus needs a large number of iterations, especially for large misalignments. The alignment procedure starts from a pre-aligned detector using data from cosmic rays only [4].

Two similar-size samples of tracks are used for the alignment procedure: one from cosmic ray data and one from collisions at a centre-of-mass energy of 7 TeV. These two samples provide optimal coverage of the tracker for alignment purposes: long tracks from cosmic rays connect the top and bottom halves of the detector, while minimum bias collisions provide tracks that illuminate the endcap regions of the detector. For a detailed detector description see [1]. The alignment results for data are compared to the results from simulation in table 1. The simulation results are given for the detector with no misalignment, as well as for a detector aligned using cosmic rays only (MC startup). As the residuals are dominated by random effects (e.g multiple scattering) the distribution of the median of the residuals (DMR) is used to judge the quality of the alignment. The combination of data from collisions and muons from cosmic rays clearly improves the align - ment, especially in the endcap regions and in the pixel detector.

Distribution of the median of the residual	Data 7 TeV RMS [μm]	MC startup RMS [μm]	MC no misalign. RMS [μm]
pixel tracker			
barrel (x)	1.6	3.1	0.9
barrel (y)	5.5	8.9	1.8
endcap (x)	5.7	10.7	2.5
endcap (y)	7.3	14.4	6.1
strip tracker			
inner barrel (x)	5.1	10.1	3.2
outer barrel (x)	7.5	11.1	7.5
inner disk (x)	4.0	10.4	2.4
endcaps (x)	10.1	22.1	2.9

Table 1: RMS of the distribution of the median of the residuals on module level

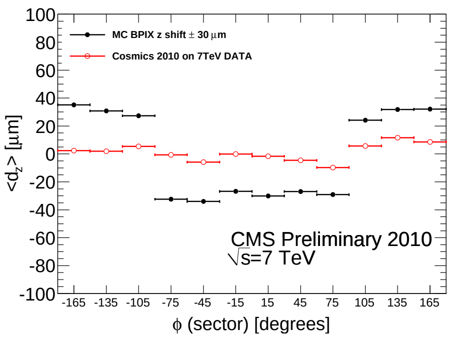

Figure 1: PV validation for a simulated Δz separation of pixel half barrels

To monitor the alignment quality in the pixel detector over time, a validation procedure based on the primary vertex (PV) location is used. For all tracks originating from a PV, the PV is refitted using all tracks except one probe track. Residuals with respect to the unbiased refitted PV are evaluated and plotted versus the probe track parameters in different bins of η, ϕ and the transverse momentum to spot degradations of the alignment. Figure 1 shows the distribution for data (red open circles) and for an artificially distorted pixel geometry with the half barrels moved apart by 60 micron (black solid dots) as an example.

2. Systematic Alignment Studies and their Implication on Physics Analyses

The future challenge concerning the alignment will be the detection and restriction of distortions which do not or only weakly influence the χ^2 of the track fit ('weak modes') but still effect the track parameters.

To detect and investigate the influence of possible weak modes, the correlated detector deformations depicted in figure 2 were applied on top of the latest tracker geometry. The alignment procedure is repeated following the same strategy as for the initial alignment and the resulting geometry is compared to the aligned geometry without distortions. Any remaining differences are attributed to the weak modes of correlated detector distortions.

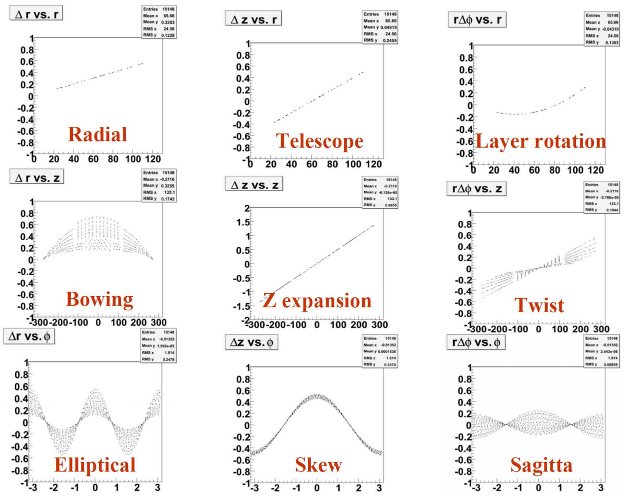

Figure 2: Correlated detector movements applied to investigate influence of weak modes

The measurement of the B-fraction in events with a J/Ψ in the final state [5] has been used as an example analysis to estimate the influence of these remaining distortions. The analysis was repeated for each of the nine possible deformations shown in figure 2 on top of the existing aligned geometry plus a combination of the sagitta deformation in x and y (referred to as dk_add05 in figure 3) and for all corresponding realigned geometries (referred to as combined_weakmode). The resulting B-fraction measurements are compared in figure 3. Therefore the J/Ψ mass was fitted with a Gaussian and a crystal-ball function to describe the background. For this example the systematic uncertainty on the B-fraction arising from possible correlated misalignment is overall estimated to be 1% for J/Ψ with a transverse momentum between 5 and 20 GeV.

References

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[3] V. Karimäki, T. Lampén, and F.-P. Schilling, "The HIP Algorithm for Track Based Alignment and its Application to the CMS Pixel Detector," CMS NOTE-2006/018, 2006.

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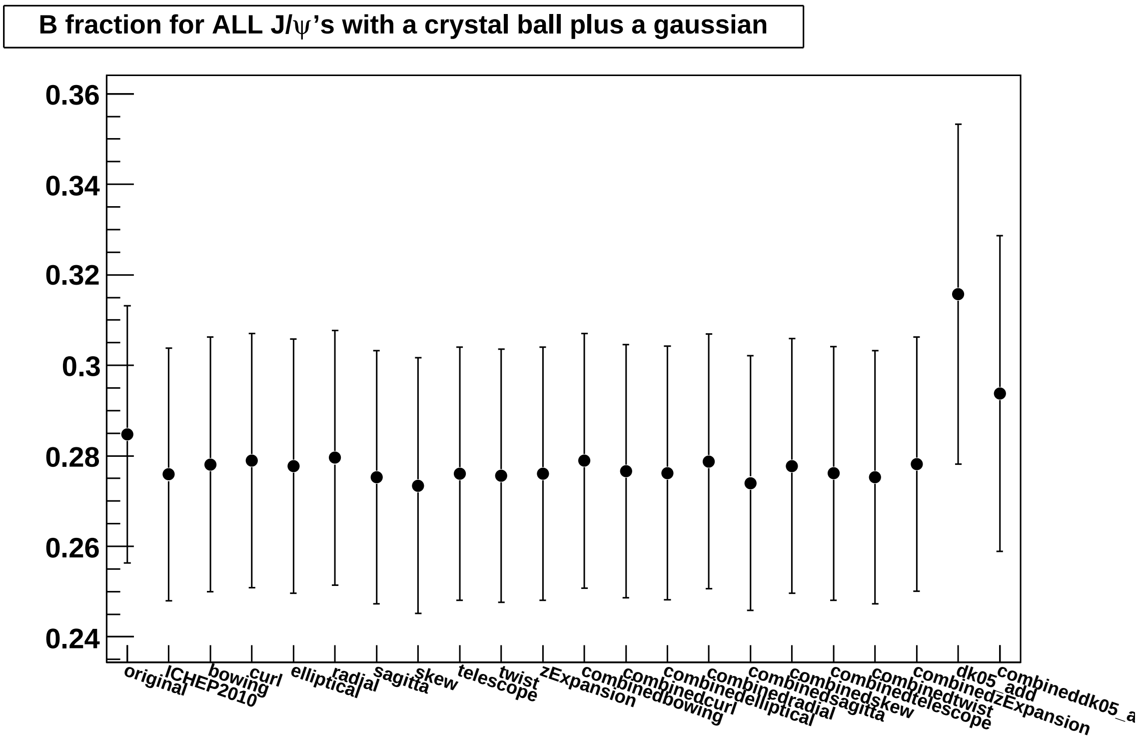

Figure 3: B-fraction of all J/Ψ tested for 2 different geometries in data, the 10 different artificial detector distortions from figure 2 (sagitta twice in x and y) and the realigned geometries. The deformation referred to as dk_add05 is an overlay of a sagitta deformation in x and y with an increased amplitude, compared to the other deformations tested, but even here the realigned geometry shows only a small effect on the resulting B-fraction.