Alignment of the CMS tracker and track reconstruction with collision data in CMS

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The CMS all-silicon tracker was aligned using more than three million cosmic rays particles. The positions of the modules were determined with respect to cosmic ray trajectories to a precision of $3-4$ μm in the barrel and $3-14$ μm in the endcap in the most sensitive coordinate. The trajectories of charged particles produced in the LHC collisions were reconstructed and their momenta were measured in the 3.8 T solenoidal magnetic field. Reconstructed tracks are used to determine the position of the primary interaction vertex in the event and to monitor the position of the colliding beams. The tracks have been used further to reconstruct the hadronic decays of several mesons, including K_S^0, $D*$, Λ, and ϕ. The performance of track reconstruction has been measured in the data and is compared to the expectation from simulation.

1 Introduction

The Compact Muon Solenoid (CMS) [1] detector is one of the multi-purpose experiments developed for data taking at the Large Hadron Collider (LHC). The main goals of the experiment range from the measurement of Standard Model parameters to the potential discovery of physics beyond the Standard Model. For all these tasks, it is required a precise measurement of the momentum of the charged particles generated in the collisions. The main component of CMS dedicated to the tracking is the silicon Tracker (TK) [2] positioned in a solenoidal magnetic field of 3.8 T. This is the largest tracker ever built with Si-based detectors. Two detector technologies are used: 1440 Si-pixel modules, organized in one barrel (BPIX) and two forward (FPIX) sub-assemblies, and 15148 Si microstrip modules composing the Silicon Strip Tracker (SST). The operation and calibration of the pixels and the SST were carried out successfully during the early LHC data taking [3]. In order to achieve the desired performances, a careful alignment of the modules must be carried out. The uncertainty related to the module position has to be negligible when compared to the intrinsic hit resolution (typically $10-20$ μm for pixel detectors and $20-60$ μm in SST). The performance of the tracking must be monitored in order to assess the quality of the reconstruction algorithms and to spot any potential problem in the alignment and calibration. A review of the status of the alignment of the TK, the tracking performances - controlling both the kinematic properties of the tracks and those of known resonances - and the b-tagging is presented after the very early stage of the LHC run at $\sqrt{s} = 7$ TeV.

2 Alignment of the Si Tracker

Two different statistical methods were used: the *Hit and Impact Point* (HIP) algorithm [4] and *MillePede II* (MP) algorithm [5]. The inputs to the algorithms were cosmic rays recorded shortly before the start of the LHC operations and tracks from minimum bias events with $\sqrt{s} = 7$ TeV. The statistics were chosen to be approximately the same: 2M cosmic rays and 1.7M minimum bias events (corresponding to $\approx 1\ nb^{-1}$). The selected tracks had to pass requirements on the momentum, $p > 2$ GeV (4 GeV for cosmic rays), length and normalised χ^2. The hits given as input to the algorithms had to pass several selections in order to be used, including signal-over-noise ratio in the SST and cluster shape in the pixels. The compatibility of the two data sets used was checked by means of the Primary Vertex (PV) residuals validation tool. This validation looks at the distributions of the Impact Parameter (IP) of the tracks respect to the PV refitted without that track. The mean of these distributions must be zero for an unbiased geometry. Figure 1 shows the result of this test on minimum bias tracks using a TK geometry aligned using only the cosmic rays sample. No large deviations from zero are observed. A MC simulation with an artificially introduced displacement of the two halves of BPIX is also presented. Such a displacement is mechanically allowed in the pixel detector, the plot shows the sensitivity to it of this validation tool.

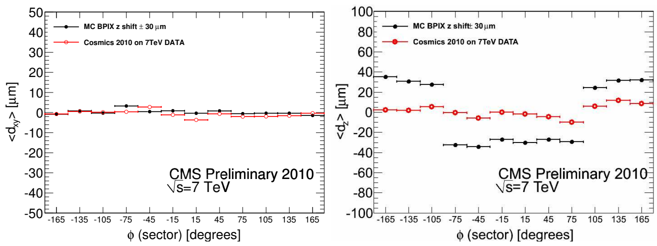

Figure 1: Result of the validation on minimum bias tracks using the residuals of the track impact parameter with respect to the Primary Vertex. The means of the distribution of the PV residuals in the transverse (left) and longitudinal planes (right) are presented for both data (open circles) and MC (full dots).

The alignment using only cosmic tracks achieved excellent results [6]. The inclusion of the minimum bias events in the alignment of the TK brought significant improvements in the precision of the alignment of the modules in the endcap region. This holds in particular for the FPIX modules that were poorly aligned using only cosmics due to the lack of statistics related to its small geometrical acceptance for vertical tracks. The comparison with the MC simulation exhibits a remarkable agreement when using a geometry in simulation that realistically reproduces the expected level of alignment precision after a cosmics-only alignment (STARTUP scenario). In Figure 2 the MC simulation using both a perfectly aligned geometry and the STARTUP scenario geometry is compared to data. The distribution of the normalized χ^2 and the distribution of the median of the residuals for every module in FPIX (that collected more than 30 hits) are presented as they are obtained from the validation of 1M minimum bias events. The performance in data surpasses that of the STARTUP in FPIX and gets close to the performance predicted with a perfectly aligned TK.

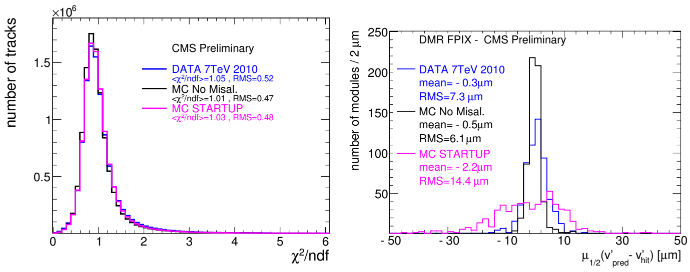

Figure 2: Distribution of the normalized χ^2 of the tracks (left) and of the median of the residuals of hits collected in FPIX (right). The distribution from real data is compared to two different MC distributions obtained fitting the same tracks with a perfectly aligned geometry and a realistic misalignment scenario of the Tracker before the alignment with collision tracks.

3 Tracking performance

The performance of the TK has been analyzed starting from the study of the resolution and efficiency in reconstructing the PV and the track parameters. Studies have been carried out at both $\sqrt{s} =$ 900 GeV [7] and $\sqrt{s} = 7$ TeV [8]. The efficiency in reconstructing the PV is $> 99.9\%$ if at least four tracks are used in the fit. The PV resolution depends strongly on the number of tracks used in the fit and their p_T. It is measured as a function of the number of tracks in the events and their average p_T. The tracks used in the former fit are divided randomly in two smaller collections, each of them used for recalculating the PV. The distribution of the difference in position between the two new PV are fitted with a single Gaussian distribution. The standard deviation of the fitted Gaussian gives the resolution. For the minimum bias events at 7 TeV with more than 30 tracks, the resolution on the PV is found to be 20 μm (25 μm) in both the x and y (z) direction. The distribution of the basic track parameters like p_T, pseudorapidity, and IP are well described by the MC (Pythia 8 Tune 1).
A higher level of validation of the TK performance is to look at the reconstruction of the resonances decaying in charged particles. Figure 3 presents a study of reconstruction of $D*$ mesons decaying in the chain $D* \to D^+(\to K\pi)\ \pi_s$. The excess over the combinatorial background due to the $D*$ is evident in the distribution of the difference between the invariant masses of the $K\pi\pi$ and $K\pi$ systems. The invariant mass of the $K\pi$ combinations exhibits a clear peak corresponding to the D^+ mass. These plots give an example of the capability of the TK in reconstructing in a precise and unbiased way the invariant mass peak of low-mass resonances. It also shows the readiness of the commissioning of the TK and of the tracking tools. Similar performances are observed for many other resonances like K^0_s, Λ, ϕ, Ω. Overall the value of the mass of the resonances agrees with the PDG value at level of few per mille. The lifetimes of the K^0_s and Λ are measured to be well compatible with the world averages.

The TK is the main device for carrying out the rich b-physics program at CMS. In order to have a b-tagging with high efficiency and purity, a very high quality of the alignment is mandatory, as well as a precise estimation of the errors sourcing from the alignment. The commissioning of the b-tagging performance is described more in detail in [9]. The first b-tagging algorithms being commissioned rely essentially on the measurement of the significance of the IP of the tracks and of displaced vertixes. The precision achieved by the CMS TK is a few tens of microns. The agreement with the STARTUP MC is very good.

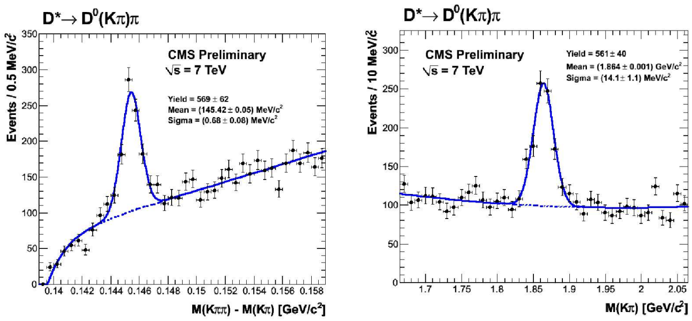

Figure 3: Distribution of the difference between the invariant masses of the $K\pi\pi$ and $K\pi$ systems (left) and of the reconstructed invariant mass of the $K\pi$ system (right). The error bars are presenting only the statistical uncertainty.

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