ALICE silicon tracker alignment and performance

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The Inner Tracking System (ITS) is the detector of the ALICE central barrel located closest to the beam axis and it is therefore a key detector for tracking and vertexing performance. It consists of six cylindrical layers of silicon detectors with three different technologies: two layers each of pixel, drift and strip detectors. We present here the results obtained for the ITS alignment using charged tracks from cosmic rays and the first *pp* collision data, including the validation of survey measurements, the analysis of the track-to-track and point-to-track residuals as a tool for determining the residual misalignment and monitoring the global alignment of the system. A first look at the track impact parameter resolution extracted from the data is also presented.

1 Alignment of the Inner Tracking System

The ALICE experiment [1] at the Large Hadron Collider at CERN is dedicated to the study of the properties of hot and dense strongly-interacting matter produced in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV. The large Time Projection Chamber (TPC) and the Inner Tracking System (ITS) [2] are the main track reconstruction devices in the ALICE central barrel.

The ITS consists of six cylindrical layers of silicon detectors with almost 2200 active modules and a total surface of 6.3 m^2. Three different technologies are used: 240 modules of pixels in two layers at a distance of 3.9 and 7.6 cm from the beam axis (the Silicon Pixel Detector, SPD), 260 modules of silicon drifts at 15 and 24 cm (Silicon Drift Detector, SDD), and 1698 modules of double-sided strips at 38 and 43 cm (Silicon Strip Detector, SSD).

The ITS was designed with the aim to improve the position, angle, and momentum resolution for tracks reconstructed in the TPC, to identify the secondary vertices from the decay of hyperons and heavy flavoured hadrons, and to reconstruct the interaction vertex with a resolution better than 100 microns. ITS is also used for low momentum tracking (below 200 MeV/c) and for recovering the high momentum tracks that are lost in the dead zones between the TPC sectors.

In order to achieve the required high precision on the track parameters, the relative position (location and orientation) of every module needs to be determined precisely. The number of parameters to be determined in the spatial alignment of the 2198 sensor modules of the ITS is about 13000, with a target alignment precision well below 10 microns in some cases (pixels).

The alignment procedure uses the optical and mechanical survey measurements as a starting point for the realignment. Survey information about the sensor positions on ladders (linear assemblies of sensors at the same azimuthal angle) are currently available for both SSD and SDD. Also positions of the SSD ladders with respect to the supporting cones have been measured.

The final alignment precision can be reached using reconstructed tracks. Two different algorithms for the minimization of the point-to-track residuals are used to determine the most probable position of the modules in the ALICE reference frame: Millepede [3] and an iterative module-by-module approach. The current strategy includes the use of both cosmic ray and proton-proton collision tracks, with and without magnetic field. In the case of drift detectors (SDD), Millepede is also used to help the calibration procedure, because of the strong interplay between alignment and calibration parameters (drift velocity).

The level of the alignment is checked by looking at several benchmark variables: for both *pp* collision tracks and cosmic ray tracks we evaluate the mean values and widths of the distributions of "unbiased" local residuals (i.e. the distribution of distances in the module reference frame between a given point and the track fitted without using that point) and the point-to-track distance for clusters in the overlapping regions between modules of the same layer (thereafter referred to as "extra clusters"). For cosmic ray tracks we also look at the track-to-track distance between two half-tracks reconstructed in the top and bottom halves of the detector. The track-to-track distance is measured both as angular distance and as linear distance for tracks passing close to the beam line. In the latter case, the width of the distribution provides a direct measurement of the resolution on the track impact parameter in the transverse direction (often indicated as d_0), one of the key detector performance figures in the scope of the ALICE heavy-flavour physics program.

The first alignment of the ITS using a sample of about 10^5 cosmic ray tracks collected in 2008 is extensively described in Ref. [4]. The recorded tracks allowed the alignment of most of the SPD, the validation of the SSD survey measurements and a first global alignment of the SPD+SSD system, while they did not allow a satisfactory alignment of the SDD modules, mainly because of the interplay of the alignment parameters and the calibration parameters.

A new alignment using about 2×10^7 *pp* collision tracks at 7 TeV and a few 10^4 cosmic ray tracks collected in 2009−2010 was performed this year and used in the extraction of the first physics results of ALICE [5].

As in the first case, the alignment procedure starts by applying the survey corrections available for SSD and SDD modules. Thanks to the large *pp* collision statistics available, a complete validation of the alignment of SSD using extra clusters over the full azimuthal angle and as a function of the transverse momentum has been performed. The widths of the point-to-track distributions of extra clusters confirm that the residual misalignment is compatible with the nominal precision of the survey measurements (i.e. less than 5 μm RMS for modules on the same ladders and less than 20 μm RMS for modules on different ladders), as already verified in [4] for the top and bottom regions of the detector.

The SPD modules were then aligned with Millepede, keeping the SSD modules fixed and using cosmic ray tracks and *pp* collision tracks with magnetic fields B=0, B=+0.5 T and B=-0.5 T at the same time. With respect to Ref. [4] a better alignment especially on the horizontal sides of the detectors was achieved. As shown in the left panel of Figure 1, the mean values of "unbiased" local residual distributions for SPD modules on both layer 1 and layer 2 are of the order of a few microns over the full azimuthal angle (except for a few modules with poor or null statistics because of functioning problems). We verified also that the point-to-track distributions of extra clusters for *pp* data at 7 TeV (not used for the alignment) are compatible with the MC simulation with a residual misalignment of about 8 μm RMS.

A preliminary alignment of a subset of SDD modules with good calibration and uniform drift velocity was also performed. For these modules a special implementation in Millepede of the drift time initial value and the drift speed as extra alignment parameters has been used.

The width of the "unbiased" local residual distributions for SDD modules in layer 4 is shown in the right panel of Figure 1 as a function of the transverse momentum. A final systematic uncertainty (calibration + alignment) of about 60 μm in the $r\phi$ plane can be extracted. The current value, even if still large, starts to be comparable with the intrinsic resolution of the detector (about 35 μm), showing the possibility to get close to the nominal performance of the detector in the near future.

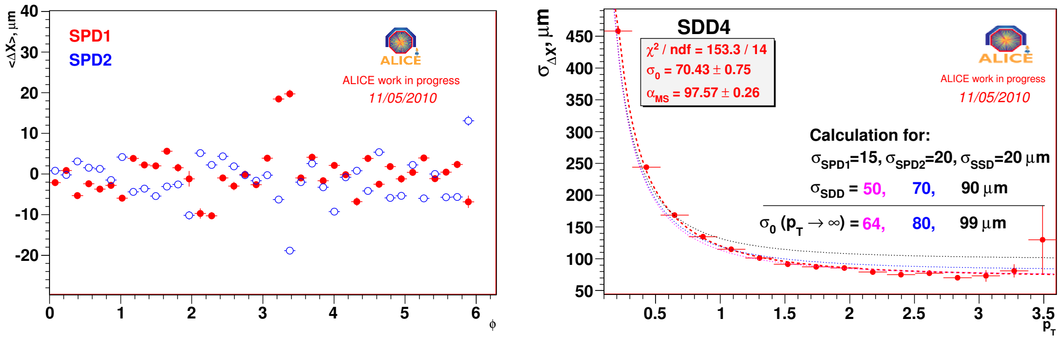

Figure 1: Mean values of the "unbiased" local residual distributions for SPD modules (left panel) and widths of the "unbiased" local residual distributions for SDD modules in layer 4 (right panel) – see text for details.

2 Tracking prolongation efficiency and track impact parameter resolution

As already mentioned at the beginning of this paper, a good ITS performance is required in order to accomplish the rich heavy flavour physics program of ALICE. We report here the TPC-to-ITS tracking prolongation efficiency and a first evaluation of the transverse track impact parameter resolution as a function of the transverse momentum, two of the main performance figures for the Inner Tracking System. The latter, in particular, is strongly correlated with the level of alignment reached in the first 2 layers of pixel detectors.

In the left panel of Figure 2 we show the probability for a track reconstructed in the TPC to be prolonged inside the ITS. The considered TPC tracks are requested to meet minimum quality requirements (number of TPC clusters > 70, χ^2/cluster < 4, $|\eta| < 0.8$, ellipsoidal cut on the distance of closest approach (DCA) using the TPC-only track parameters, with main axes $|DCAxy| < 2.4$ cm and $|DCAz| < 3.2$ cm). Two cases of ITS points selection are shown here: at least two points in ITS (dark squares) and at least one point in SPD (light circles). In the first case an efficiency greater than 96% on the full p_T range was reached, while in the second case the efficiency is reduced because a significant fraction of SPD modules were inactive during the considered data taking. In both cases a good agreement between data (filled markers) and MC simulation (open markers) was found.

The right panel of Figure 2 shows a first estimate of the transverse impact parameter resolution as a function of the transverse momentum. The above mentioned quality cuts in

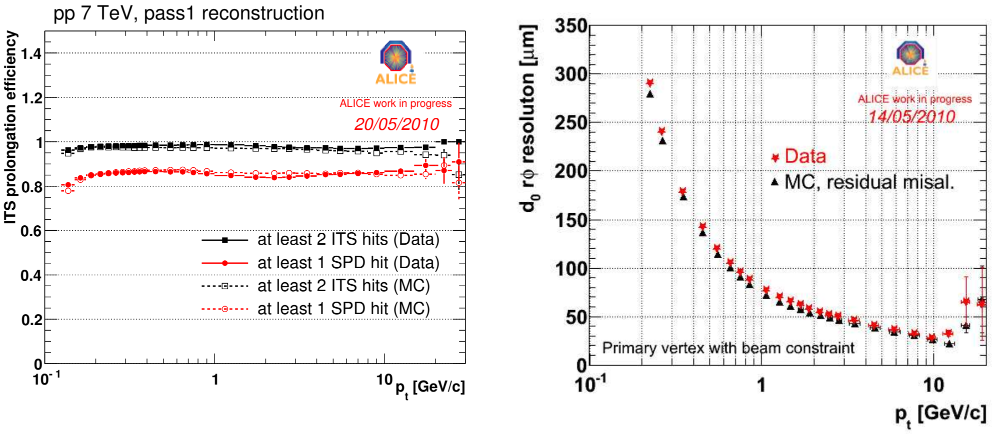

Figure 2: TPC-to-ITS prolongation probability (left panel) and transverse impact parameter resolution (right panel). See text for details.

TPC and a requirement of two points in SPD have been applied for track selection. The impact parameter of each track was estimated with respect to the primary vertex reconstructed using the other tracks in the same event and the beam constraint. An agreement within a few percent between data and MC was found.

3 Conclusions

The status of the alignment and first performance figures for the ALICE Inner Tracking System have been presented. Using the large *pp* collision data sample collected in 2009−2010 we could validate the SSD survey measurements and complete the SPD alignment on the full azimuthal angle. A first preliminary alignment of SDD has been performed as well. The overall ITS performance is now within 10% of the MC target. Further studies are ongoing to address possible correlated alignment effects and to understand the current data-to-MC differences, e.g. possible material budget effects.

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