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Tracking inside the ALICE Inner Tracking System

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Abstract

One of the main purposes of the ALICE Inner Tracking System (ITS) is to improve the resolution of the track parameters found in the main ALICE tracker detector, the Time Projection Chamber (TPC). Some results about tracking efficiency and resolution of track parameters obtained with a tracking code, based on the Kalman filter algorithm are presented.

1 Introduction

ALICE (A Large Ion Collider Experiment) [1] is an experiment at the Large Hadron Collider (LHC) planned to study nucleus-nucleus collisions at a centre of mass energy of about 5.5 TeV/nucleon. The central part of the ALICE detector, which covers $\pm 45°$ ($|\eta| < 0.9$) over the full azimuth, is embedded in the large L3 magnet which can run with a field between 0.2 T and 0.5 T. In this central part the tracker detectors: the Time Projection Chamber (TPC) [2], the Transition Radiation Detector (TRD) [3] and the Inner Tracking System (ITS) [4] are installed. The goals of the ITS detector are the determination of primary and secondary vertices of hyperons and open charm decays, the identification and tracking of low momentum particles and the improvement of the parameters (azimuthal and dip angle, momentum, impact parameter) of the tracks found in the TPC.

Track finding inside the ALICE detector is one of the most challenging tasks due to the high particle multiplicity expected which may reach values of 8000 charged particles per unit of rapidity at η=0. Thus, about 84000 primary particles will be generated in the all solid angle. The track-finding method

Table 1
Parameters of the ITS detectors. The value in parenthesis refer to the outer layer.

Parameter	SPD	SDD	SSD
Radius (cm)	4.1(7.2)	14.8(23.5)	38.5(43.6)
±z (cm)	14.3(14.3)	22.2(29.7)	45.1(50.8)
Cell size (μm^2)	50×425	150×294	95×40000
Spatial precision rϕ (μm)	12	38	20
Spatial precision z (μm)	100	28	830

adopted up to now for the system TPC+ITS is based on the Kalman filter algorithm [5]. The overall tracking procedure is still under development and the results, reported here, refer to its current status. In the past a first tracking code was written and some results were obtained with a simplified prototype of the detector [6]. Due to the progresses made in the implementation of a detailed geometry of the ITS, as well as of the other ALICE detectors, inside the ALICE simulation and reconstruction framework (AliRoot [7]), the need for a new version of the tracking code has arisen. Some results and a detailed description of the new tracking code for the TPC detector can be found in ref. [2]. We have developed a new version of the ITS tracking code for the TPC-ITS matching and for tracking inside the ITS. We show here some results on TPC-ITS tracking performance obtained with this new tracking code. A more exhaustive description of the ITS tracking code can be found in ref. [8].

The paper is organized as follows: in Sect.2 we briefly describe the ITS, Sect.3 is devoted to summarize the main points of the tracking algorithm, while some results about tracking efficiency and resolution of track parameters are reported in Sect.4.

2 The ALICE Inner Tracking System

The ALICE Inner Tracking System is made of six cylindrical layers of coordinate-sensitive silicon detectors based on three different technologies depending on the granularity and resolution requirements. The large (up to 90 cm^{-2}) particle densities expected in the four innermost layers imposed the choice of detectors with a truly two-dimensional readout: Silicon Pixel Detectors (SPD) and Silicon Drift Detectors(SDD). The two outer layers, where the track densities expected are below 1 cm^{-2} will instead be equipped with double-sided Silicon Strip Detectors (SSD). The four outer layers will have analog readout for particle identification by a dE/dx measurement in the non-relativistic region. Some characteristics of the ITS detectors are summarized in Table 1.

The ITS inner radius has to be as close as possible to the beam pipe (r_{beam} = 3 cm) in order to optimize vertex and impact parameter resolution. The outer radius has to be large enough to ensure efficient track matching with the TPC, whose inner radius is fixed at 80 cm by the maximum acceptable occupancy.

The momentum and impact parameter resolution of tracks with small transverse momenta (P_t) are dominated by multiple scattering effects; therefore the amount of material in the active volume has to be reduced as much as possible. However, from signal-to-noise ratio considerations, the detectors providing dE/dx information must be about 300 μm thick and, in addition, the detectors must slightly overlap in order to avoid holes in the acceptance window. In the reality, they will have a global thickness of 1.7% of X_0. Thus, great care was devoted to the choice of non sensitive materials and globally the material budget of the ITS in the active volume is about 6% of X_0.

The ITS detectors have in the rϕ coordinate a spatial resolution in the order of a few tens of μm, and the detectors closest to the primary vertex have the best precision (12 μm), since the resolution of the track impact parameter mainly at high momenta is determined by the spatial resolution of the ITS detectors. This resolution is especially important for charmed particles detection for which the radial impact parameter resolution has to be better than 100 μm.

3 TPC-ITS tracking procedure

The track finding method developed for the system TPC and ITS is based on the Kalman filter algorithm [5], widely used in high-energy physics experiments. This algorithm has the drawback to require a good track-seed to start a stable filtering procedure. However, it has the following important advantages: 1) it is a method for simultaneous track recognition and reconstruction; 2) multiple scattering and energy loss can be handled more easy than in the global methods; 3) it is a natural method to find extrapolation from one detector to another (from TPC to the ITS, for example).

As it is well known in the Kalman filter procedure, a track is identified by a state vector x of 5 parameters which define the track, and by its covariance matrix. Here, we briefly describe the TPC tracking. For a complete description of this detector and of its performance see ref. [2]. Tracking starts from the track-seed finding performed considering all the pairs of points in the outermost pad row and in a pad row located n rows closer to the interaction point. A second seed finding is performed using another couple of pad rows (for examples the 10th and the (n+10)th). Then it proceeds with the Kalman filter through the whole TPC, starting with the stiffest tracks and continuing with the softer ones. The procedure starts from a track-seed that is prolonged to the next pad row. During this extrapolation, multiple scattering (by adding the corresponding matrix to the track covariance matrix [9]) and energy loss (by means of the Bethe-Bloch formula) were taken into account, assuming that the particle to be tracked is a pion.

Therefore, for all the clusters, whose coordinates are inside suitable "windows", the $\chi^2 - increment$ is calculated. The "windows" are estimated taking into account the cluster position precision and the uncertainty of the track position extracted from the covariance matrix associated to the track state vector. The cluster with the minimum $\chi^2 - increment$, if this value is lower than a given $\chi^2_{minimum}$, is assigned to the track and the state vector and its covariance matrix are updated according to the standard filtering procedure. A current track that reaches the inner limit of the TPC is defined as "found" if at least 40% of all possible clusters are attached to it. Then, the clusters belonging to a "found" track are removed from the event.

The TPC-ITS matching is the most difficult part of the tracking procedure, due to the rather large distance (about 40 cm) between the TPC and the ITS sensitive parts and to the high track density inside the ITS. In order to overcome these drawbacks, the "normal" Kalman filter procedure (which is used in the TPC) was modified to transform a "local" tracking method in a more "global" approach [6]. Also in this case the program starts from the stiffest tracks found in the TPC and continue with the softer ones. To find the prolongation of a TPC track inside the ITS, for each track found in the TPC a tree of candidate tracks through all the ITS is built. This is performed in the following way. A track is extrapolated to an ITS layer and energy loss and multiple scattering are taken into account in the way described above. All the clusters, whose spatial coordinates are within suitable windows, are considered for the Kalman filter procedure. For each cluster giving a $\chi^2 - increment$ lower than a given χ^2_{min}, a new candidate track is defined, adding this cluster to the original track and updating its state vector and its covariance matrix according to the standard filter procedure. Then, when the track-tree is built up to the first ITS layer, the path which has the minimum χ^2 for the maximum number of assigned clusters is taken. If the number of assigned clusters is at least 5, this track is defined as "found" and the clusters belonging to it are removed from the event.

The second improvement is the use of a "vertex constraint". This is done adding two new elements to the measurement vector in the Kalman procedure, which normally has, as components, the coordinates of the cluster position. These new elements are calculated supposing that the vertex position is known with a precision of 50 μm in the transverse direction and 100 μm along the beam axis. The ITS detector will be able to determine the vertex position with a better resolution [10]; however, in the tracking procedure we tried to use looser values (i.e. less constraint) which still give a reasonable improvement in the tracking quality. This gives us the potential to find also tracks originating from decays close to the interaction point in a single tracking pass.

In order to calculate the tracking efficiency we have to define when a track is findable or found in the TPC and in the ITS. A track is findable in the TPC if it crosses at least 40% of all pad rows and produces hits on the pad rows chosen for the seed-finding procedure. A track is found in the TPC if it is formed of a number of clusters larger than 40% of the total number of pad rows. A found track is "good" if no more than 10% of the clusters are incorrectly assigned and if at least half of the innermost 10% of clusters are assigned correctly, otherwise it is fake. For the ITS a track is findable if it has a cluster in, at least, five ITS layers. Therefore a track is found in the ITS if it is formed of, at least, 5 clusters. To be "good", at least 5 clusters have to be correctly assigned.

Then the tracking efficiency is defined as:

$$tracking\ efficiency = \frac{good\ tracks}{findable\ tracks} \tag{1}$$

In a similar way, the probability of fake tracks is defined as:

$$fake\ track\ probability = \frac{fake\ tracks}{findable\ tracks} \tag{2}$$

4 Tracking performance

All the simulations were done using the ALICE simulation and reconstruction package AliRoot (vers. 3.05). All the ALICE detectors were included in the geometrical description. All the physical processes in GEANT were switched on, and full responses of TPC and ITS detectors were used in the reconstruction process. The magnetic field was set to 0.2 T.

4.1 Track parameter resolution

Particles coming from any secondary vertex, can have an impact parameter larger than the imposed one by the vertex constraint. In order to track inside the ITS these particles a second iteration of the tracking will be performed, releasing the "vertex constraint". The resolution of track parameters for pions as a function of transverse momentum (P_t) was, then, evaluated both with and

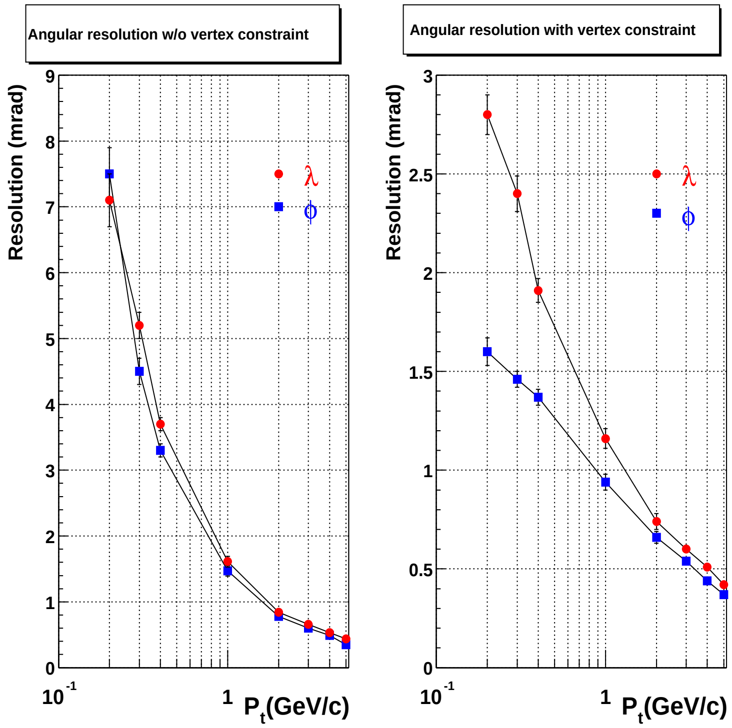

Fig. 1. Azimuthal and dip angle resolution (squares and circles, respectively) as a function of P_t for pions. Tracking was performed without vertex constraint (left panel) and with vertex constraint (right panel).

without vertex constraint. The angular resolution of the reconstructed tracks is very sensitive to the vertex constraint which was used for the estimate of the track parameters. For low momentum tracks the angle information is deteriorated by multiple scattering and then it is determined mainly by the position of the vertex and of the first measured point in the innermost SPD layer. Azimuthal and dip angle resolution, obtained with and without vertex constraint, are shown in Fig. 1. For a transverse momentum P_t= 5 GeV/c we found a resolution of about 0.4 mrad. At lower P_t, this value rapidly increases and for P_t=0.2 GeV/c it is about 1.6 and 2.8 mrad for the azimuthal and dip angle, respectively, if tracking is performed with the vertex constraint. A value of about 7.2 mrad is obtained instead for both angles if the tracking is performed without vertex constraint. For the TPC alone the azimuthal angle resolution varies between about 9 and 1.7 mrad when P_t ranges between 0.2 and 5 GeV/c.

Also the momentum resolution is strongly affected by multiple scattering. The role of the ITS is fundamental to improve the momentum resolution of high momentum tracks ($P_t > 1$ GeV/c). In fact, for these tracks, TPC space points precision is insufficient. Moreover the TPC momentum resolution deteriorate when the track density increases. This is mainly due to the cluster overlapping which is more probable for higher particle multiplicity. For the TPC alone we

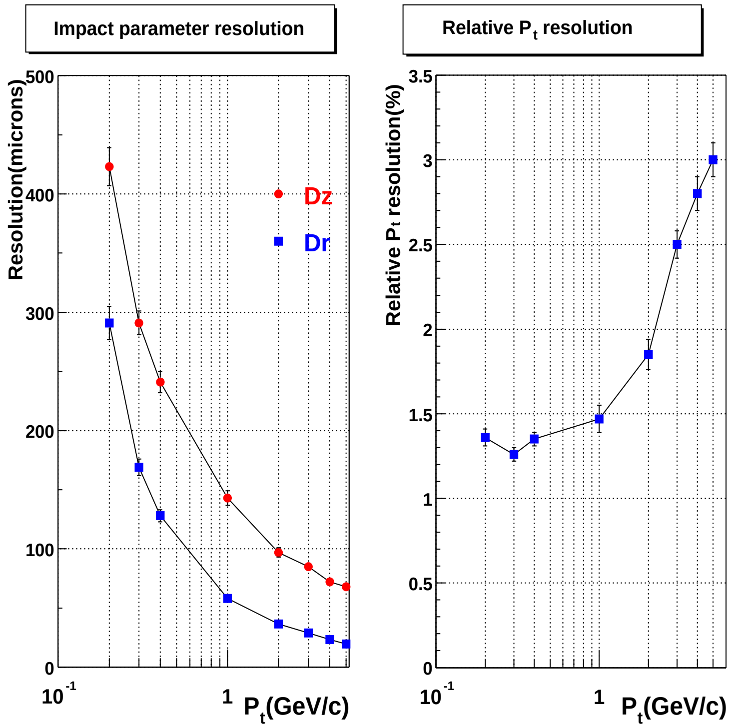

Fig. 2. Left panel: radial (Dr) and longitudinal (Dz) impact parameter resolution for pions. Tracking was performed without vertex constraint. Right panel: relative transverse momentum resolution as a function P_t for pions. Tracking was performed with vertex constraint.

have for pions of $P_t = 5$ GeV/c a relative momentum resolution of about 7%. For tracking with vertex constraint we found for the TPC+ITS system a relative momentum resolution which varies between 1.4% to about 3% for pions when P_t ranges from 0.2 to 5 GeV/c (see Fig. 2, right panel).

In order to detect unstable particles via their decays it is important to have a good resolution in the distance of closest approach between the track prolongation and the primary vertex (impact parameter). The transverse momentum dependence of the radial (rϕ projection) and longitudinal (z projection) impact parameter for pions is shown in Fig. 2 (left panel). This is obtained in case of tracking without vertex constraint. For pions having a momentum larger than 0.6 GeV/c, the radial impact parameter is less than 100 μm, which is the upper limit for the open charm detection. Due to the large distance from the primary vertex, the TPC detector is not able to give a good impact parameter resolution. In fact, performing a simulation without the ITS, we get for pions a radial impact parameter in the order of some millimeters.

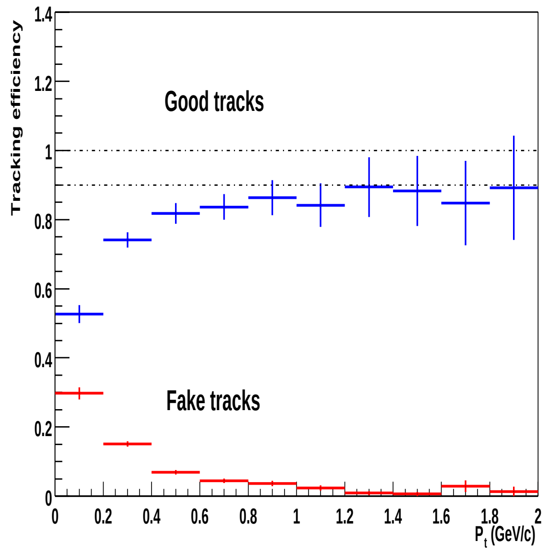

Fig. 3. Tracking efficiency and fake track probability as a function of P_t for an event of high multiplicity. The event was generated in the range -0.9$\leq \eta \leq$ 0.9 and $0 \leq \phi \leq 2\ \pi$.

4.2 Tracking efficiency

The tracking efficiency reported in this section only refers to primary tracks. Using the definitions (1) and (2) we obtained for a central event of medium ($dN_{charged}/dy = 4000$) and high multiplicity ($dN_{charged}/dy = 8000$) the tracking efficiency and the fake track probability listed in Table 2. The events were generated in the sensitive part of the central detectors (-0.9$\leq \eta \leq$ 0.9 and $0 \leq \phi \leq 2\ \pi$) using the HIJING event generator with the total multiplicity scaled by an appropriate factor in order to get the correct charged particle density in the central region (Hijing parameterized generator)[11]. The increase in the event multiplicity involves a decrease in the efficiency (from 86% to 76%) and an increase in the fake track probability (from about 4% to about 11%). This effect is more relevant for low momentum tracks. In Fig. 3 the tracking efficiency and the fake track probability as a function of P_t for the high multiplicity event are shown. Track-finding efficiency is about 90% for high momentum particles while, starting from 0.6 GeV/c, it goes down to about 55% for particles with P_t lower than 200 MeV/c. At the same time, the fake track probability grows with the decrease of the transverse momentum. The lower track-finding efficiency and the higher fake track probability for low momenta are due to larger multiple scattering and energy loss fluctuations for slow particles. In the future, these results will be improved by a more accurate handling of the energy losses, taking into account the measured energy loss.

For this event the differences between generated and reconstructed track pa-

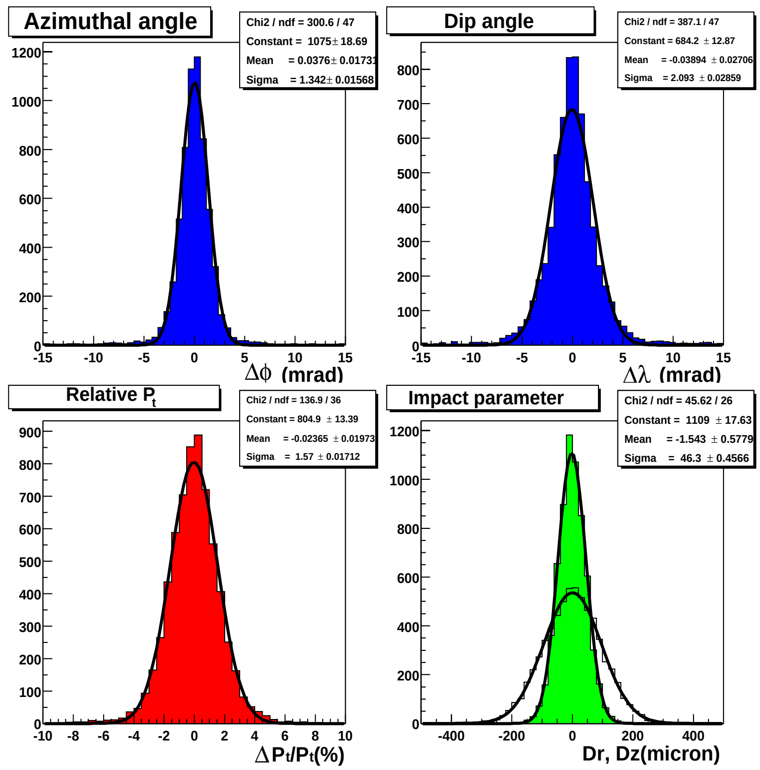

Fig. 4. Differences between generated and reconstructed track for an event of high multiplicity, generated in the range -0.9$\leq \eta \leq$ 0.9 and 0 $\leq \phi \leq$ 2 π. The upper part is for the azimuthal (left) and dip angle (right). The lower-left part is for the relative transverse momentum, the lower-right part is for the impact parameter (the narrower distribution is in the transverse plane, the wider along the beam axis)

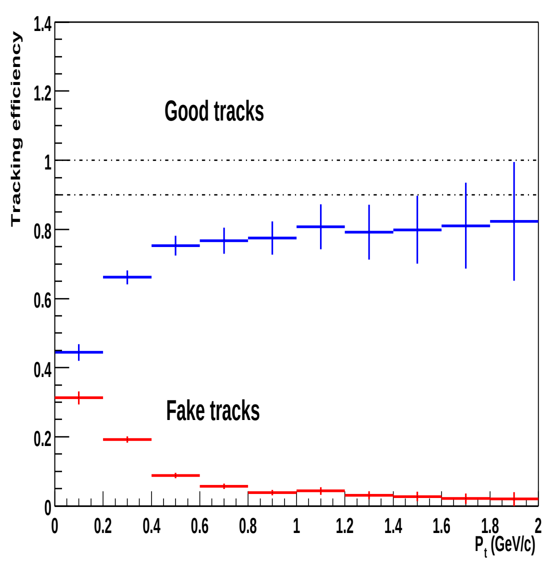

Fig. 5. Tracking efficiency and fake track probability as a function of P_t for an event of high multiplicity generated in the range -6$\leq \eta \leq$ 6 and 0 $\leq \phi \leq$ 2 π.

Table 2
Tracking efficiency and fake track probability for an event of medium and high multiplicity (see text for multiplicity definition). Events were generated in the range -0.9≤ $\eta \leq 0.9$ and $0 \leq \phi \leq 2\,\pi$.

Multiplicity	Efficiency (%)	Fake tracks (%)
Medium	86 ± 2	4.5 ± 0.3
High	76 ± 1	11.6 ± 0.4

rameters are shown in fig. 4. The global angular resolution is about 1.3 and 2 mrad for azimuthal and dip angle, respectively. The global relative momentum resolution ($\Delta P_t/P_t$) is about 1.6%. The resolutions for the transverse and longitudinal components of the impact parameter are about 45 and 95 μm, respectively. These values reflect the momentum distribution of the generator. In fact we have shown that these resolutions are strongly momentum dependent.

In the case of an Hijing parameterized event with high multiplicity generated in the all solid angle (-6≤ η ≤6 and $0 \leq \phi \leq 2\,\pi$) we get the tracking efficiency and the fake track probability shown in Fig. 5. We have a global tracking efficiency of (69 ± 1)% and a fake track probability of (14 ± 0.4)%. The observed deterioration of tracking efficiency is mainly caused by the increase in the occupancy due to secondary particles outside the acceptance. The TPC tracking efficiency decreases from about 95% to about 90%.

5 Conclusions

For the ALICE detectors, Time Projection Chamber and Inner Tracking System, a track finding method based on the Kalman filter algorithm has been developed inside AliRoot, the ALICE simulation and reconstruction framework. We have written a version of the ITS tracking code for the TPC-ITS matching and track-finding in the ITS and typical results have been reported here with the latest version of this code.

The resolution of the track parameters for pions as a function of the transverse momentum was estimated performing tracking with and without vertex constraint. The found values are reasonable for the detection of secondary vertices as hyperons and open charm and for the particle correlation studies.

We evaluated tracking efficiency and fake track probability for Hijing parameterized events generated only in the central detector zone ($|\eta| < 0.9$). Tracking efficiency is deteriorated when the multiplicity of the event increases. The effect is much more relevant for low momentum particles due to the larger multiple scattering and energy loss fluctuations. This result will be improved by a more accurate handling of the energy losses.

A further worsening in the tracking efficiency was obtained when the parameterized Hijing event with high multiplicity was generated in the all solid angle. This is especially due to a deterioration of the TPC tracking performance due to the background originated outside the detector acceptance for primary particles. Then, possibles sources of background are, at present, under investigation.

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