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FULL 3D EVENT-BY-EVENT VERTEX RECONSTRUCTION IN ALICE BY PIXEL LAYERS

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Abstract

An algorithm for full 3D event-by-event vertex finding in ALICE by the use of the two pixel layers has been designed as a part of the reconstruction procedure needed for the Physics Performance Report. The effect of the LHC beam displacement off the z-axis has been explicitly considered in the reconstruction of the primary vertex. Vertex resolution has been studied as a function of the nominal vertex location in the transverse plane. The performance of the method has been also checked for high magnetic field settings in ALICE (B=0.2-0.5 T).

1 Introduction

The problem of primary vertex finding in ALICE has been recently discussed [1, 2] and results have been reported [1] concerning the estimation of the vertex location along the z(beam)-axis under different conditions (nominal vertex location, particle multiplicity, collision centrality,...). In this Note we want to describe the general algorithm which has been designed as a part of the reconstruction procedure for the needs of the simulations to be carried out in view of the preparation of the Physics Performance Report (PPR). In particular, we will show additional considerations about the effect of the beam shift in the transverse (xy) plane on the vertex finding, and will present the general results following full 3D vertex reconstruction.

It is known that the vertex diamond in LHC can be parametrized by a Gaussian along the z-axis (with σ_z=5.3 cm) and in the x,y directions. The width parameter in the transverse plane, $\sigma_{x,y}$, which has been reported as 15 μm in all previous ALICE documents [3], will however depend on the choice of the beam parameter β^*, which also affects the beam luminosity and life-time. In particular, since $\sigma_{x,y} = \sqrt{(\epsilon\beta^*)}$, where $\epsilon = 0.57$ nm rad is the beam emittance, a large value of β^* (of the order of 10 meters), will give a width parameter $\sigma_{x,y}$ of about 75 μm [4]. Different fillings of the LHC ring will give moreover average beam positions in the transverse plane which may differ by several millimeters.

It is then important to evaluate the effect that such beam displacement may have on the overall vertex reconstruction and to design a full 3D algorithm for vertex finding. The beam displacement off the z-axis has two mainly effects on the vertex finding: first of all it alters the information on the z coordinate of the vertex, thus requiring to introduce some correction on an event-by-event basis to correctly evaluate the z location of the vertex; secondly, it introduces the requirement of a full 3D vertex reconstruction in itself. The information on the vertex location in the transverse plane can in principle be achieved on real data by summing several events altogether, since the xy position of the interaction point will only change within a range governed by $\sigma_{x,y}$ from event to event. However, due to the above mentioned effect of the choice of β^* on the width parameter in the transverse plane, it could be preferable to devise a suitable method to reach a good precision even within the individual event. Sect.II is devoted to a discussion on how to correct the information on z in case of beam displacement. Sect.III will introduce a full 3D algorithm for vertex finding, together with the tests done under different conditions. Sect. IV reports some comparison between the results obtained at B=0.2 T and the expected results at higher field settings. Some conclusion is drawn in Sect. V.

2 Beam displacement and vertex reconstruction along the beam axis

The simulation framework used for this additional study on the vertex finding problem was similar to the previous one [1]. However, the latest available version of Aliroot (3.05) [5] was used. Here we want briefly to recall the simulation conditions. Events were generated mostly with the HIJING parametrization option, at full central PbPb multiplicity (N_{part}=84210) and at lower particle densities. Particles were simulated over 0° to 180° in polar angle ϑ, from 0° to 360° in ϕ, and in the full momentum range. Different vertex locations, even off the z-axis (with radial distances R from 0 to 10 mm) were used throughout these simulations. Where necessary, full HIJING events were generated as well, to check the consistency.

In the geometrical description we included all the ITS detector layers, the beam pipe, the space frame and the magnet. We verified that the inclusion of the muon front absorber, as well as other detectors in the central part of ALICE, do not alter at all the results. The short length of the pixel ladders has been adopted in the simulation (overall z length equal to $\pm$14.35 cm), with a pixel size of 50 μm (rϕ) x 425 μm (z). All the physical processes in GEANT were switched on, with an energy cut-off equal to 1 MeV. For all of the sensitive materials and SPD sensitive volumes, however, the cut-off was 70 KeV. Full response of the pixel detectors was considered in the reconstruction process (slow simulation).

Recalling the results of Ref. [1], the precision to which the vertex location along z may be found is of the order of 5 μm for a central ($(dN_{ch}/d\eta)_{\eta=0}$=8000) Pb-Pb collision, and about a factor two worse for peripheral Pb-Pb collisions or for lighter systems (Ca-Ca). To get such good results however it is essential to have access to at least a rough knowledge of the vertex location in the xy plane. Fig. 1 shows as an example the degradation in the reconstruction of the vertex in case of beam displacement along the x-axis (up to 2 mm) if no knowledge of the vertex location in the xy plane is introduced in the algorithm. As it can be seen, the difference between the nominal z-position of the vertex (z_{true}) and the found position (z_{found}), which is of the order of a few μm at x=0 may reach values as high as a few hundreds of μm as soon as the beam is shifted by 2 mm. The resolution parameter σ_z, given by the uncertainty in the found vertex position, also reflects such degradation in the performance, increasing to about 200 μm for beam displacement around 2 mm.

This is of course due to the actual geometrical distances between the vertex and the reconstructed points in the two pixel layers, which depend on whether the vertex is along the z-axis or off this axis. For such reason it is essential to include in the algorithm some correction which takes into account the beam displacement. This

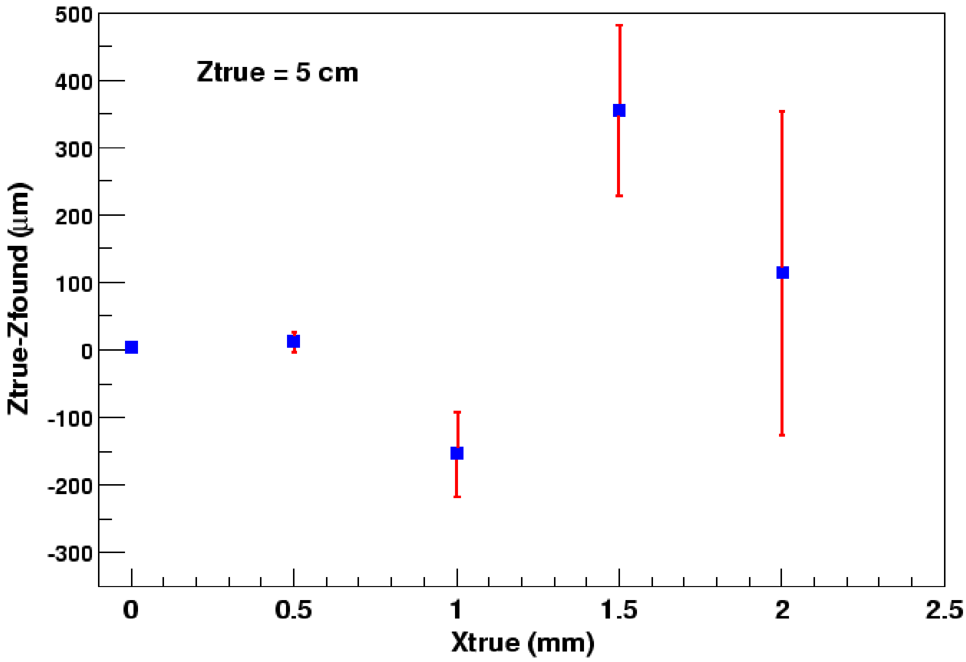

Figure 1: Difference between z_{true} and z_{found} and vertex resolution (reported as error bar on each point) for vertex locations away from the z-axis. In this case no correction has been introduced for the x and y-position of the vertex. PbPb central collisions, with a particle density $(dN_{ch}/d\eta)_{\eta=0}$=8000.

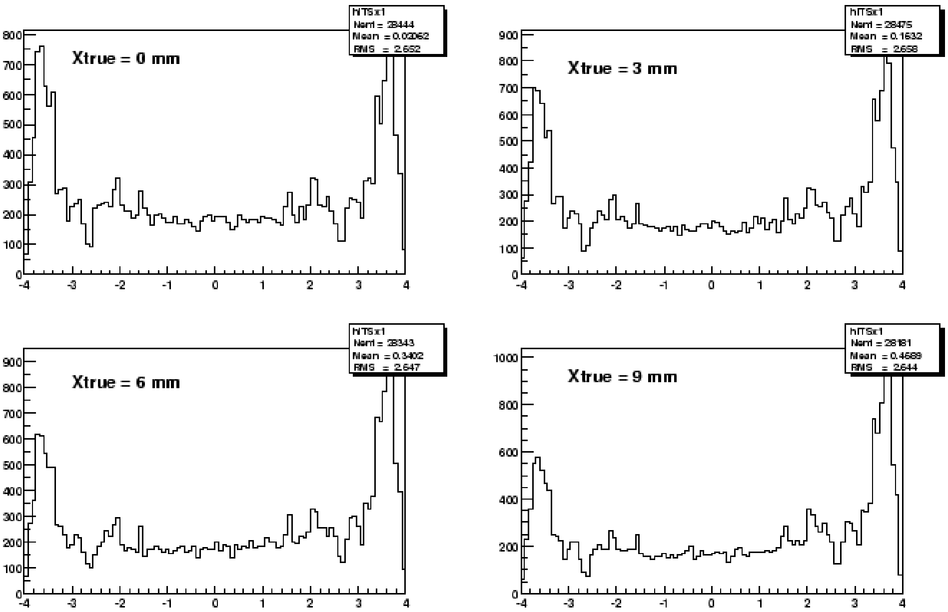

Figure 2: Multiplicity of reconstructed points in the first pixel layer, projected along x, for several values of the nominal vertex position x_{true}. Central PbPb collisions, with a particle density $(dN_{ch}/d\eta)_{\eta=0}$=8000.

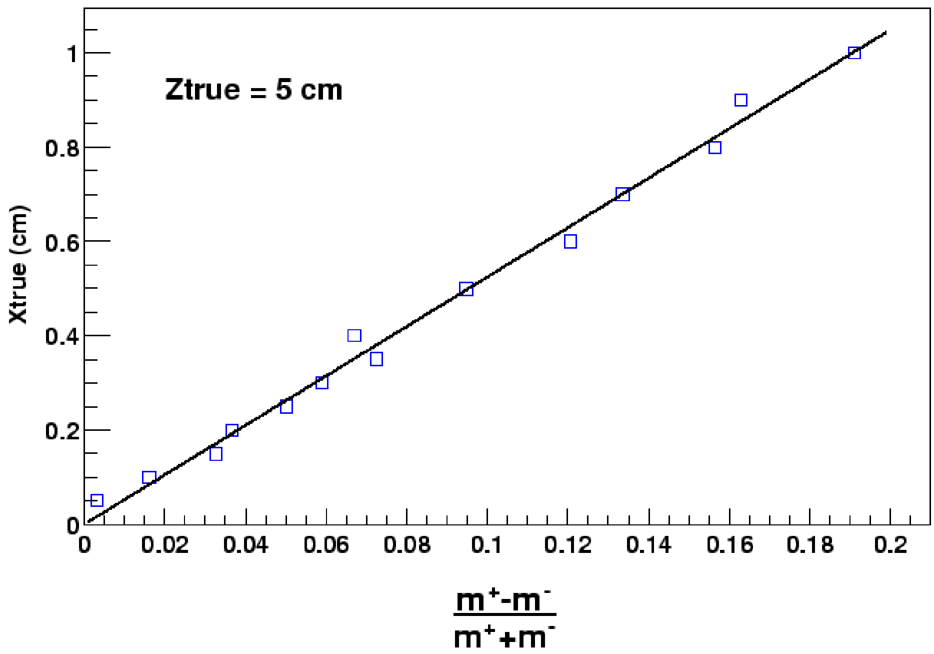

Figure 3: Correlation between the true x-position of the vertex and the asymmetry parameter originating from the left and right multiplicities of the reconstructed points in the first pixel layer.

has been already done in Ref. [1, 2]. In our case [1] such information was derived from the *left* (90° $\leq \varphi \leq$ 270°), *right* (-90° $\leq \varphi \leq$ 90°), *upper* (0° $\leq \varphi \leq$ 180°), and *lower* (270° $\leq \varphi \leq$ 360°) multiplicities in the first pixel layer. Fig.2 shows the multiplicity distributions of the reconstructed points (projected along x), for several values of the nominal vertex position (x_{true} = 0, 3, 6 and 9 mm). As it can be seen, the distribution, which is roughly symmetric for x_{true}=0, becomes more and more asymmetric when the vertex is moved along the x axis, and a larger number of points are collected between 0 and the average radius of the first pixel layer (4 cm), due to the larger solid angle subtended by the region with -90° $\leq \varphi \leq$ 90°.

The asymmetry between the two halves of the distribution, $(m^+ - m^-)/(m^+ +$

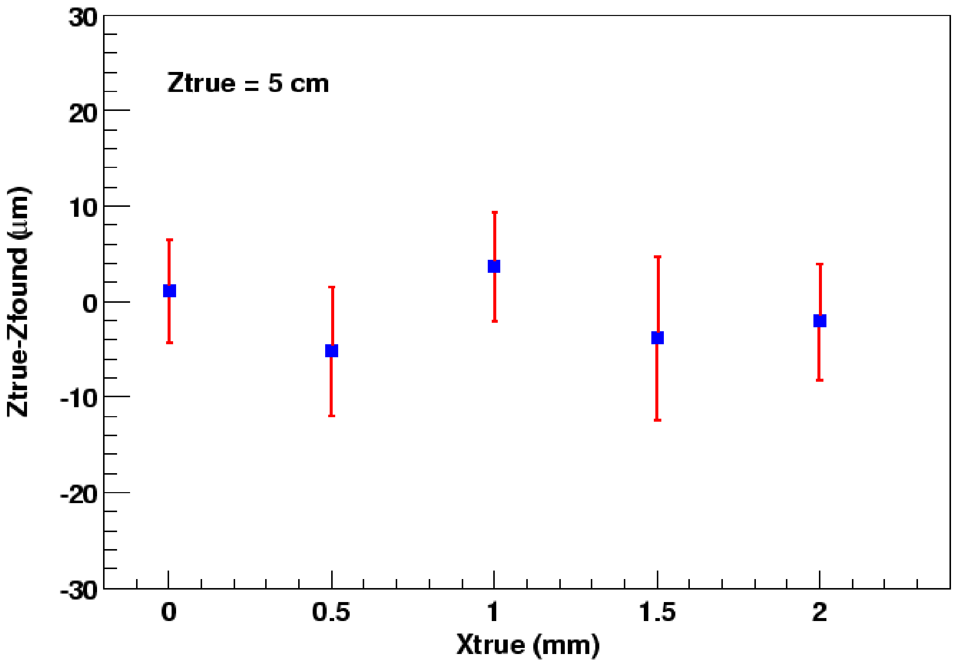

Figure 4: As in Fig.1, but with corrections which take into account a first estimate of the vertex location along x and y.

m^{-}) is almost linearly correlated to the true vertex position, as it is shown in Fig.3, and such correlation may be used for a first estimate of the vertex location in the transverse plane. The same is done along the y-axis, in order to get a two-dimensional information on the vertex location in the xy plane. Fluctuations around such linear trend are of the order of 500 μm, which proved to be adequate in the first estimation process.

Such information is used to evaluate the correct radial distances and to get a final definition of the z-coordinate of the vertex. With such correction, the difference between z_{true} and z_{found} as well as the uncertainty in z_{found} are recovered back to values of the order of a few μm, even in case of beam displacement up to several mm (Fig.4).

3 Full 3D vertex finding

In the transverse plane the correlation of the points reconstructed from the hits generated by a track in the two pixel layers cannot be strictly done through a straight line - as for the z axis - due to the magnetic field. However, because of the very small average radii of the pixel layers (4 and 7 cm), the deviation from a straight line is small, and a reasonable result may be obtained even within such approximation, especially for particles of high momentum. On the other hand, the combinatorial background may be reduced nearly to zero, once a good knowledge of the vertex location along the beam axis has been achieved. In the correlation between the points in the two layers, we have chosen a fiducial region of 4 σ_z around the estimated vertex location z_v and a $\Delta\phi$ cut dependent on the magnetic field. It must be noted that even to introduce such cut in $\Delta\phi$ we need to have a starting estimate of the vertex in the xy plane (see Fig.5). The distribution of the intersection of all the straight lines connecting the points (x_1,y_1), (x_2,y_2) with the axes X', Y' (Fig.5) will have its minimum width (best resolution) only if X',Y' are close to the true vertex coordinates. For such reason, we used an iterative procedure, starting from a first approximation position of the vertex, evaluating the corrected position and using once again the same procedure. We verified that one does not need more than 2-3 iterations, since after that the limiting factor will be given by the straight line approximation in itself.

With such procedure, typical x_v and y_v distributions are obtained, such as in Fig.6, which show how the combinatorial background is virtually absent. The width of the distribution originates from the straight line approximation.

By taking the centroids of the x_v, y_v and z_v distributions (see Ref. [1] for typical plots of the z_v distribution), it is possible to reconstruct the location of the primary vertex in three dimensions. Figs.7-9 show the results along the x, y and z axes, as differences between the true vertex position along that axis and the found one. For such calculations, the event vertex was randomly generated in the xy plane at radial distances between 0 and 10 mm.

As it is seen from Figs. 7-9, the resolution is still of the order of a few μm along the z-axis, while it is a little bit higher - as expected - along the x- and y-axes,

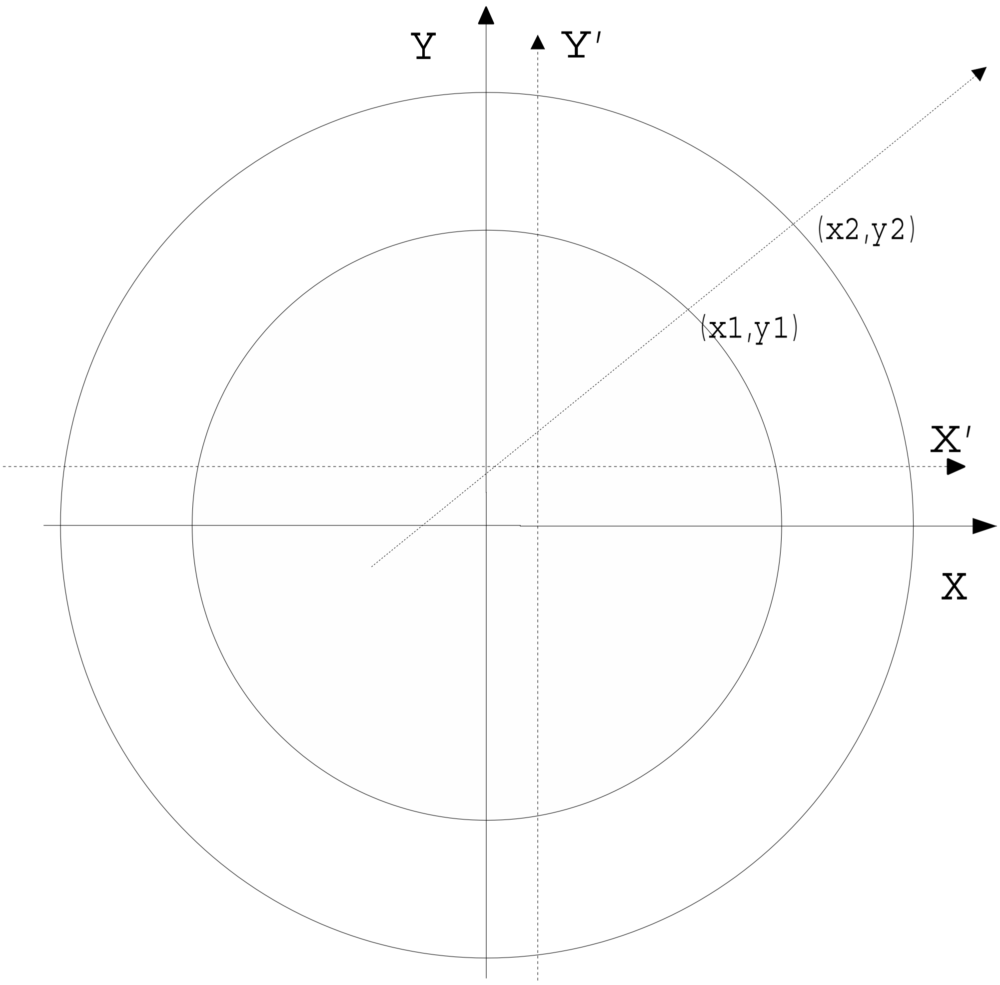

Figure 5: Geometrical sketch of the two pixel layers with the reconstructed points in the transverse plane. Correlation between the points (x_1, y_1) and (x_2, y_2) may be used to determine the distribution of the intercepts with axes X', Y' (estimated from a first-order evaluation of the vertex coordinate).

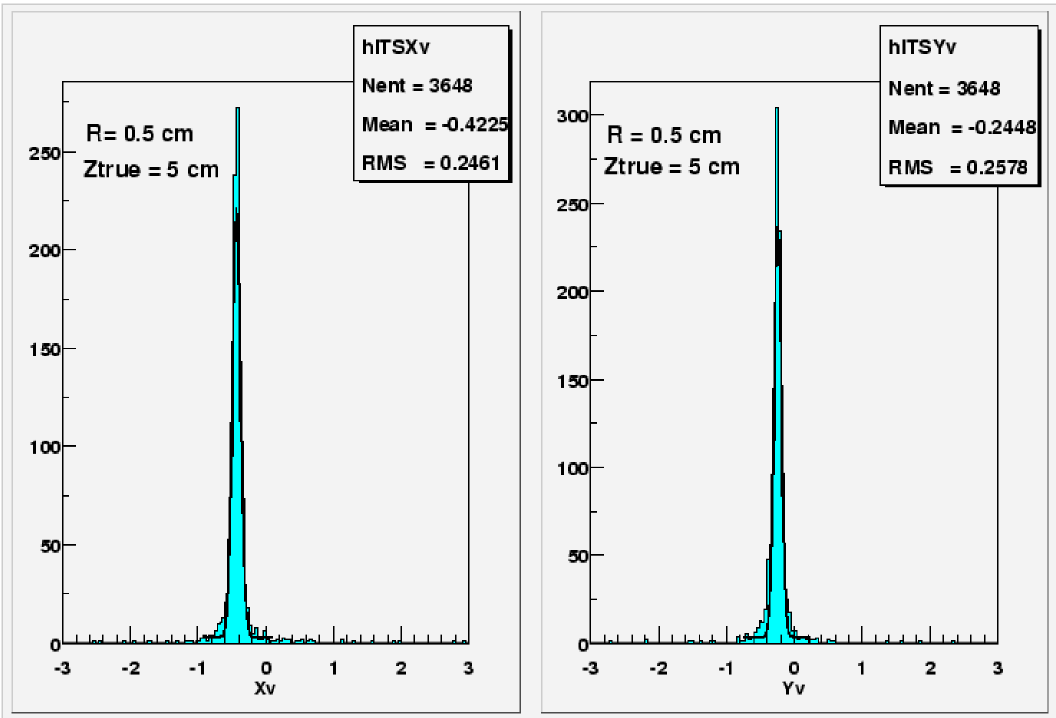

Figure 6: Vertex distributions along the x and y-axes.

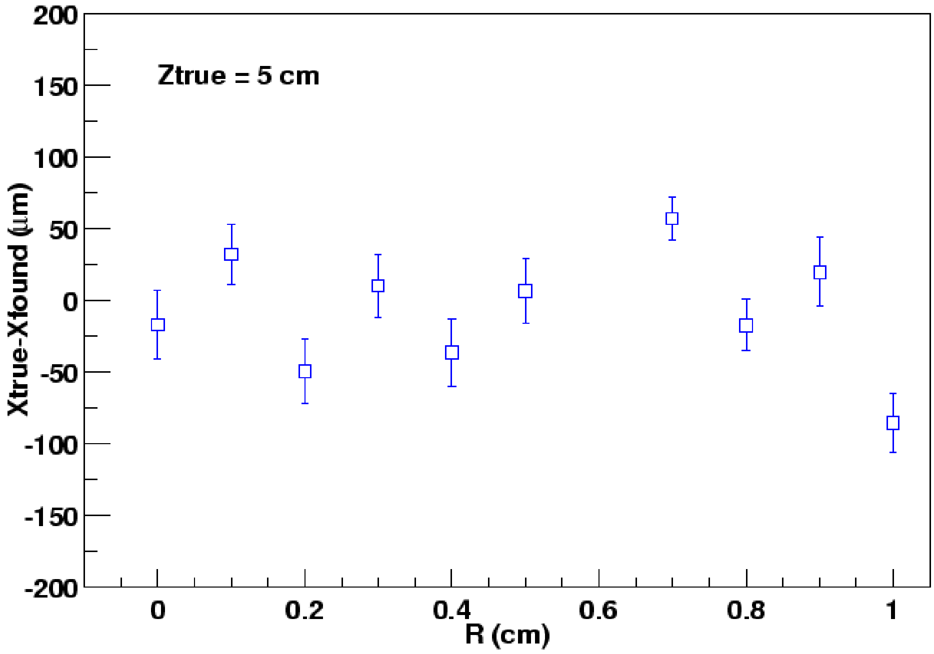

Figure 7: Difference between x_{true} and x_{found} as a function of the radial distance of the vertex location from the z-axis.

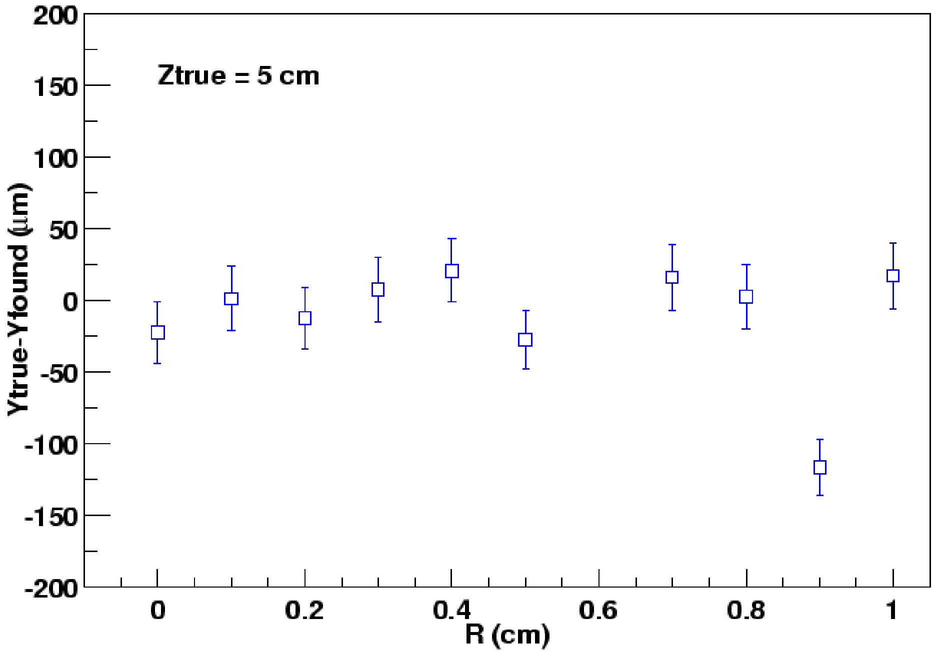

Figure 8: Difference between y_{true} and y_{found} as a function of the radial distance of the vertex location from the z-axis.

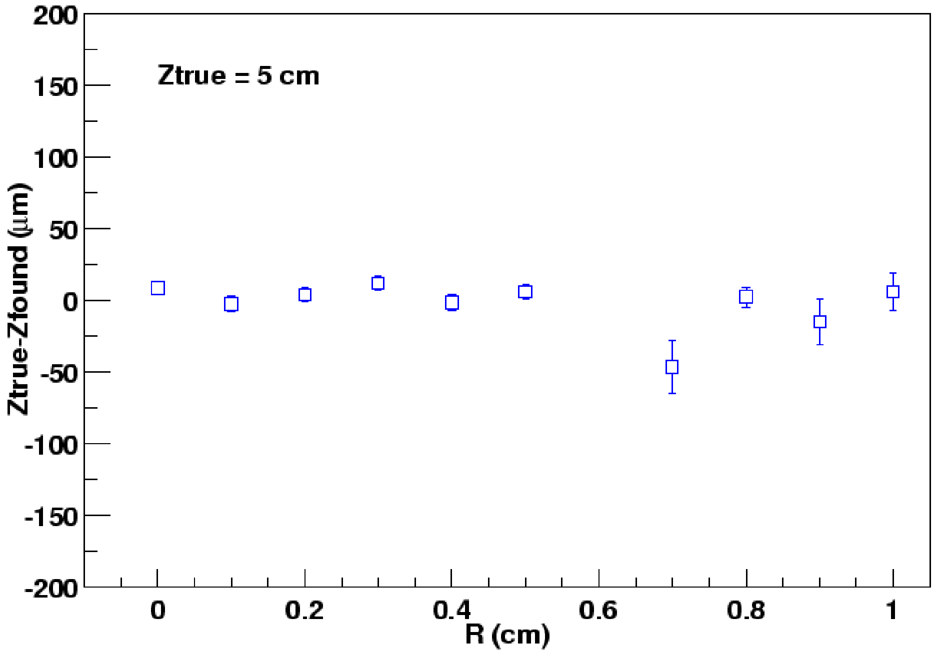

Figure 9: Difference between z_{true} and z_{found} as a function of the radial distance of the vertex location from the z-axis.

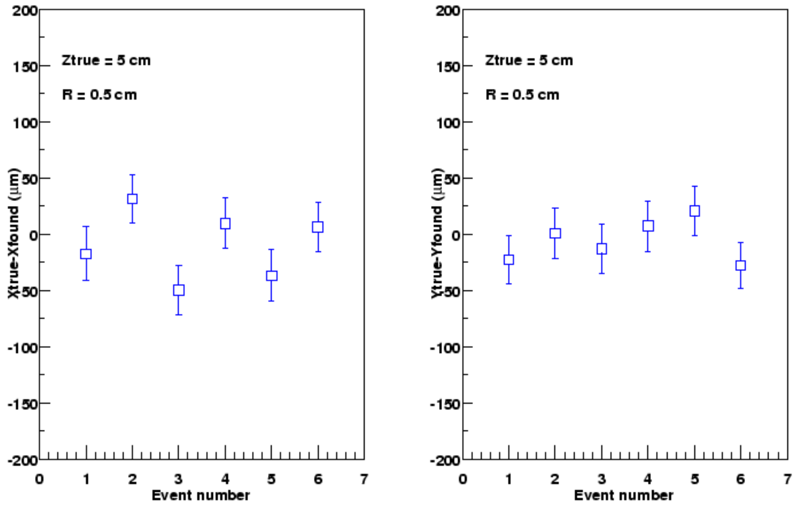

Figure 10: Fluctuations from event to event in the estimated difference between the found vertex location and the nominal one.

around 25 μm. Such values are still very good for most of the physics to be done with ALICE. In particular, strangeness (K_s^0, Λ, Ξ, Ω) production which relies on the determination of secondary vertices, does not need a precision much better than this, due to the $c\tau$ for the hyperons of interest. On the other hand, open charm detection will probably require some alternative method to get an even better precision. This however must be compatible with the beam characteristics if several events have to be summed together.

As a statistical check, we also verified that the fluctuations which are observed from event to event (see Fig.10) are comparable to the estimated resolution.

4 Vertex finding as a function of the L3 magnetic field

In view of the possible high magnetic field setting for the ALICE detector (up to 0.5 T) we verified the performance of the overall method for vertex finding as a function of the magnetic field, from B=0.2 T to B=0.5 T. For higher magnetic field settings, a possible increase of the occupancy may be expected on the first two layers, due

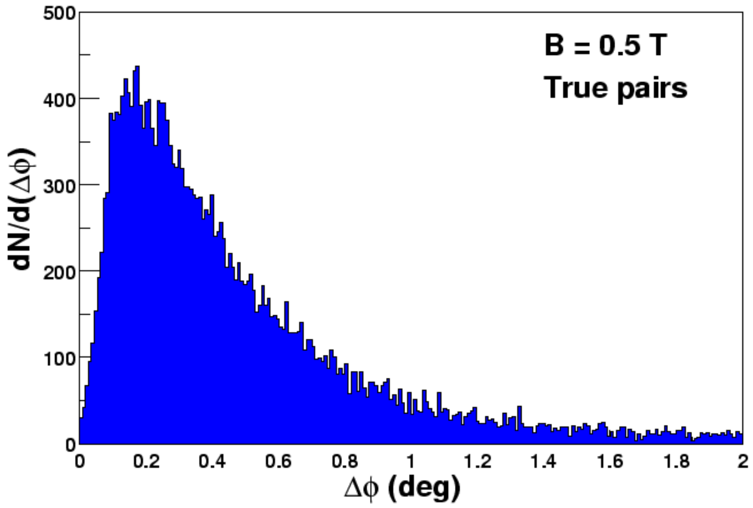

Figure 11: $\Delta\varphi$ distribution of the true pairs at B=0.5 T, for a central PbPb collision.

to low momenta particles. This could increase the combinatorial background, and hence worsen the resolution. We verified however that the occupancy (evaluated after reconstruction of the digits in the two pixel layers) increases only slightly from B=0.2 T to B=0.4 T (from about 1.71 % to 1.73 % for the first layer and from 0.93 % to 0.96 % for the second layer).

Another effect is related to the straight line approximation in the transverse plane, which is less and less good as B increases. The distribution of the $\Delta\varphi$ difference for the true pairs is shown in Fig.11. This has a maximum around 0.2°, whereasa value around 0.05° is found at B=0.2 T. However, the main reason for choosing a larger $\Delta\varphi$ cut is related to the uncertainty by which the individual φ_1, φ_2 angles may be estimated.

Fig.12 shows the difference between z_{true}-z_{found} as a function of B. As it is shown, the differences, as well as the resolution (reported as error bars on the points), show only a very slight increase with the magnetic field, from about 5 μm to 7-8 μm.

Figs.13-14 show the same result along the x- and y-axes, for a radial distance R=0 (Fig.13) and R=5 mm (Fig.14). In both cases the resolution goes from about 25 μm at low field (B=0.2 T) to 30-35 μm for high fields (B=0.5 T).

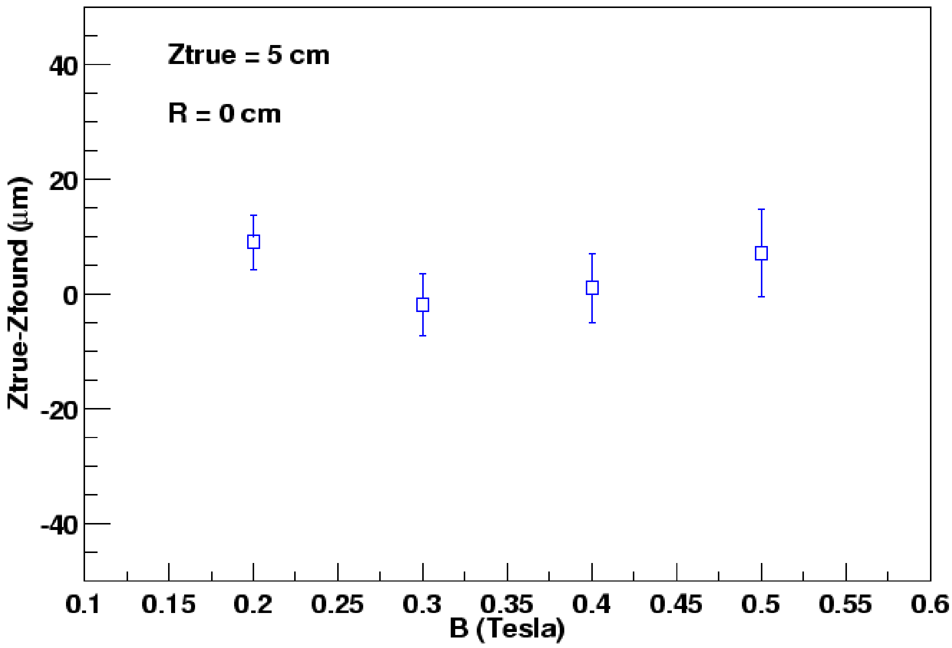

Figure 12: Difference between z_{true} and z_{found} as a function of the magnetic field setting.

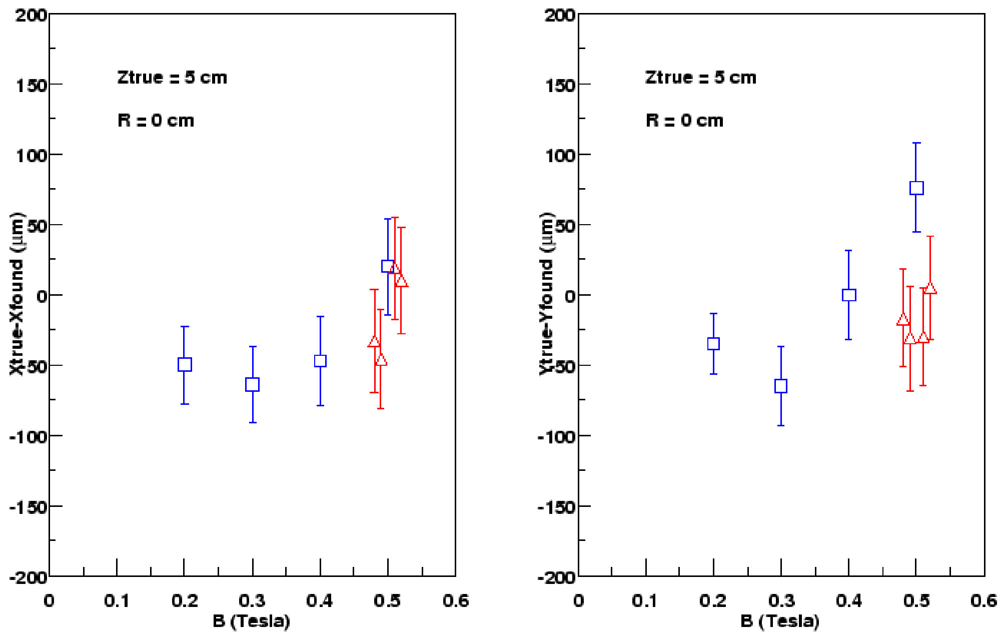

Figure 13: Differences x_{true}-x_{found} and y_{true}-y_{found} as a function of B, for a radial distance R=0. The last 5 points on the right refer to events at the same magnetic field (B= 0.5 T), which are only plotted slightly shifted to show statistical fluctuations.

5 Conclusions

We have carried out a complete study of the vertex finding problem in the general case of a vertex located outside the z-axis. A full 3D algorithm has been designed and tested as a part of the reconstruction procedure, using the information from the two innermost (pixel) layers. The full response of the pixel detectors was included in the simulations. The x, y and z coordinates of the vertex were found by the correlation of the reconstructed points in the two pixel layers, with proper cuts on the $\Delta\phi$ difference and on the fiducial region around the first estimate of the vertex position. The results show that it is possible to achieve a very good resolution, of the order of 5 μm along the z-axis, even in case of beam displacement off the z-axis, up to radial distances of 10 mm. The (x,y) coordinates of the vertex are found within 25 μm, due to the intrinsic limitation of the straight line approximation in

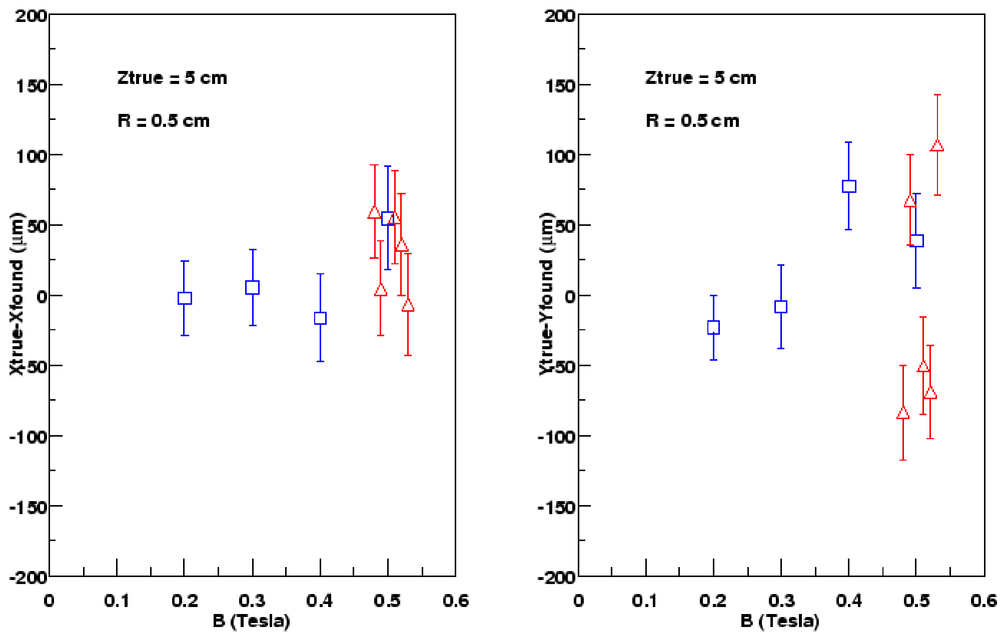

Figure 14: Differences x_{true}-x_{found}, y_{true}-y_{found} as a function of B, for a radial distance R=5 mm. The last 6 points on the right refer to events at the same magnetic field (B= 0.5 T), which are only plotted slightly shifted to show statistical fluctuations.

the transverse plane. The choice of a high magnetic field setting, such as B=0.5 T, was seen not to alter dramatically the performance of the method, only increasing the resolution from 25 to 30-35 μm in the transverse plane. All these results may be obtained on an event-by-event basis, which could be important especially in case a large value of the β^* parameter is chosen, which give a large width of the Gaussian profile along x, y.

Following the procedure outlined above, a general AliITSVertexFinding class has been designed for 3D vertex finding within Aliroot 3.05 and may be used from now on for different purposes concerned with the preparation of the PPR. The CPU time needed for the full 3D vertex finding is of the order of a few minutes on a medium class processor, for a central PbPb collision.

References

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