JOINT INSTITUTE FOR NUCLEAR RESEARCH
Dzhelepov Laboratory of Nuclear Problems

The time slice simulation in the SPD straw tracker

Final report of the START Programme

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Abstract

The Spin Physics Detector (SPD) will operate at JINR NICA complex, which is currently under construction [1]. The purpose of the work was to develop methods and software for modelling the response of SPD tracker in the trigger-free regime, study the temporal structure of signals, investigate reconstruction efficiency and purity on Monte-Carlo simulation data and develop prototype software for event reconstruction at the stage of online data filtering.

1 Introduction

The Spin Physics Detector a universal facility for studying spin related phenomena with deuteron and proton beams. One of the key detector subsystems is a straw tracker, that should provide charged track momentum measurements. For the data taking it is necessary to develop fast data processing algorithms, event selection and primary vertices reconstruction.

2 Detector Model

The straw tracker is the main tracking system of the SPD detector. Using the GEANT4 software package [2] we model a geometry of the SPD straw tracker (ST), its sensitive volumes and their response. We adopt a number of simplifications against the real ST geometry which would be insignificant for this stage of our study. We model the ST by a system of nested cylinders constructed by one layer of parallel cylidrical tight-fitted straw tubes, as illustrated in the Fig.1, (right plot). The ST tubes have the outer polyethylene shell of thickness $R = 0.036$ mm and the inner CO_2-filled cylindrical volume of radius $R = 4.934$ mm, which includes tungsten filament (anode) of radius $R = 0.03$ mm, see Fig.1, (left plot). We assign a sensitive detector object of GEANT4 to the inner volume of each tube and adopt the tube numbering scheme where the unique number corresponds to the each tube.

The length of the time window (time slice) of the experiment is 10μs, while the proton beams crossings occur every 76 ns. The probability of proton-proton hard interaction during intersection of pp beams is simulated by Poisson distribution $f(k) = \frac{\lambda^k}{k!} e^{-\lambda}$ with $\lambda = 0.3$. The interaction point is placed into $(0, 0, z)$, where z is defined by Gaussian distribution with $\sigma = 30$ cm and central value of $z_0 = 0$ $f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$. The charged reaction products are modelled by muons carrying the energy of $E = 1$ GeV with the momentum direction randomized according to uniform destribution. The number of muons produced in the pp collision is defined by a Poisson distribution with expected value of $\lambda = 7$.

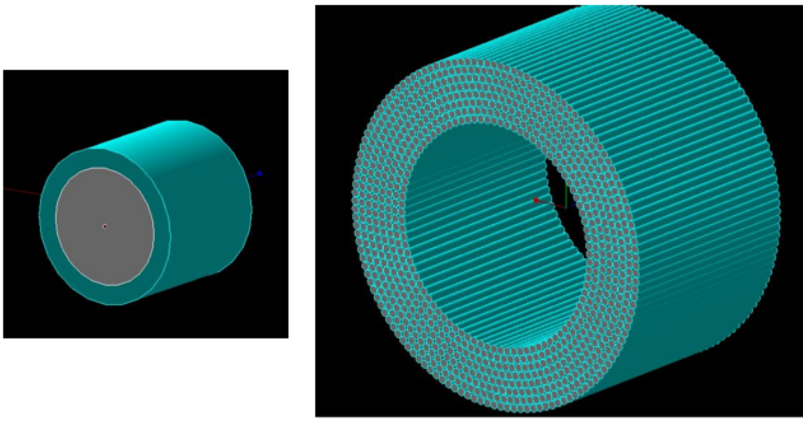
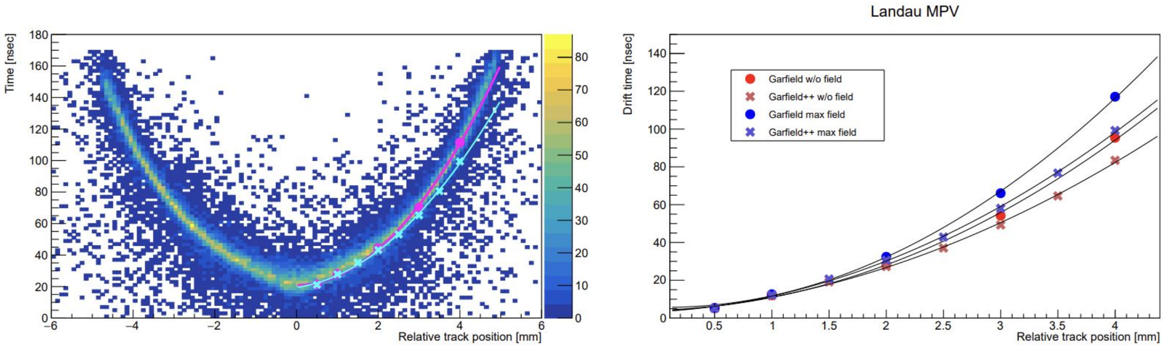


Figure 1: Single straw tube (left) and 6 layers of straw detector model (right). Turquoise layer – polyethylene, grey – gas, red – tungsten filament.

3 Straw tubes response time simulation

The propagation of the charged particle through the gas leads to its energy loss through ionization of gas. We declare the hits collection object to store the characteristics of particle energy loss points. In this work only primary tracks are taken into account. To simulate the ST response time we should determine the shortest distance from the particle track to the anode, since the drift time is defined by the ionization point closest to the anode (e.g. tube axis). In case there are several energy loss points in the same logical volume we adopt the approximation where the only first and last points are considered, then the shortest distance is calculated by crossing lines formula. The dependence of the electron avalanche drift time on the distance was simulated using Garfield simulation software [3], [4] TDR [5]. We approximated this dependence by the analytic formula and used it to obtain the time distributions of ST response, that presented in the Fig.2.



(a) (b)

Figure 2: The most probable drift time of the first arriving cluster simulated with GARFIELD and GARFIELD++. (a) Values obtained with GARFIELD (magenta points) and GARFIELD++ (cyan points) delayed with a constant value compared to the experimental results, obtained for an NA62 tracker straw (2D histogram). (b) Most probable values of the first cluster arrival time for 0 T and 1.5 T magnetic field. The simulation results are fitted to a quadratic function.

The results of our simulation are presented in the Fig.3, where all the histograms were created using CERN ROOT tools [6]. We found a significant overlap of the ST response times for particles produced in different bunch crossings from the same time slice. This fact points out to the problem of signal decoding for event reconstruction when collecting data in a real experiment.

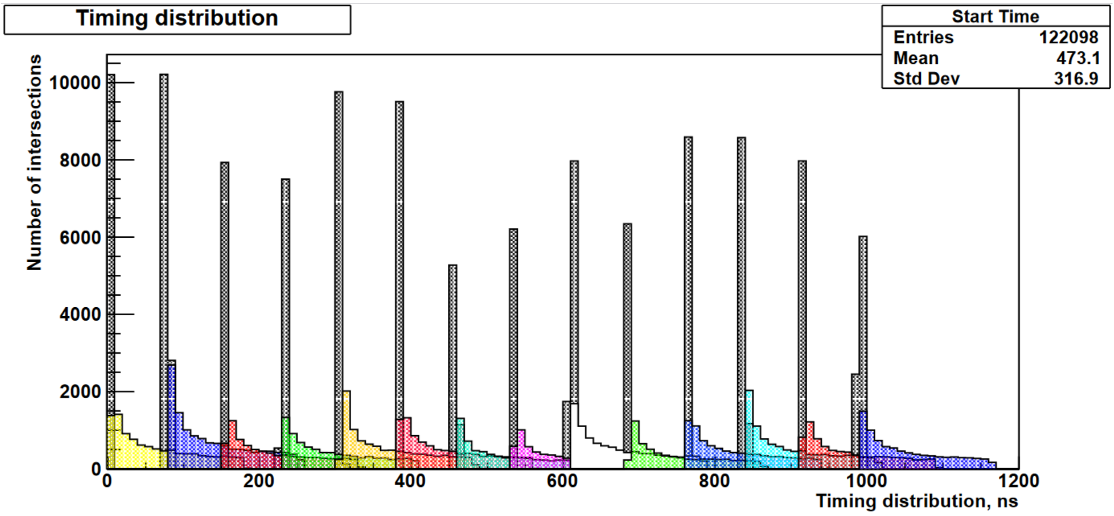


Figure 3: Timing distribution averaged by 100 time slices. Grey area – time of the intersection of the sensitive volume by the sample particle. without taking into account the electronic avalanche. Coloured area – ST response time distribution.

4 Primary vertex reconstruction

Using the hits collection data one can perform a reconstruction of particle tracks. We skipped the hits recovery step assuming the 3D coordinates of the particles hits are already known. For approximation we need to determine the point of the closest approach to the wire. Consequently, in each tube we calculate the distance from the hit to the axis and search for the smallest one, the coordinates of the corresponding hit are recorded in the array.

Global coordinates of hits relative to the centre of the detector and local coordinates relative to the centre of a particular tube were obtained from the GEANT4 simulation. The distance from the hit to the anode is searched using the local coordinates, the tracks are approximated in global coordinates.

We suppose a uniform magnetic field along z axis of $B = 1$ T without endcup effects. Thus, we approximate the sample charged particle trajectories in the XOY plane transverse to the field by parabolic function $y = a_1x^2 + a_2x + a_3$, where the coefficients a_i, $i = 1, 2, 3$ are determined from the hits data using the least-squares method. The simulated tracks and hits in the XOY plane from the primary particles of one time slice are illustrated in the Fig.4, left, while the corresponding example of track-approximating curve is shown in the right.

The coefficients a_i determine the $z(l)$ dependence for each primary particle, where l is the arc length of the parabolic segment. It can be calculated by the simple formula $l = \int_0^{x_0} \sqrt{1 + (2a_1x + a_2)^2}dx = \frac{1}{4a_1} \ln\left(\left|\sqrt{(2a_1x + a_2)^2 + 1} + 2a_1x + a_2\right|\right) + (2a_1x + a_2)\sqrt{(2a_1x + a_2)^2 + 1}$. Then, $z(l)$ can be approximated by the linear function, which should be extrapolated to the intersection with Z-axis to determine the primary vertex position. The simulated tracks and hits in the ZOY plane from the primary particles of one time slice are illustrated in the Fig.5.

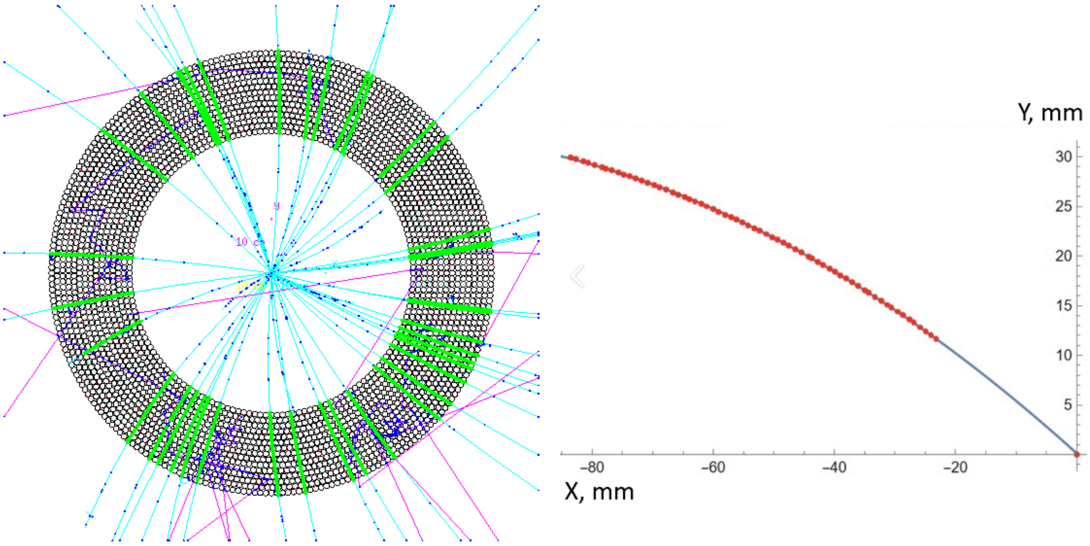


Figure 4: Launch 1 time slice (XOY). Green points – Hits (left), example of approximation of points of one track in XOY(right).

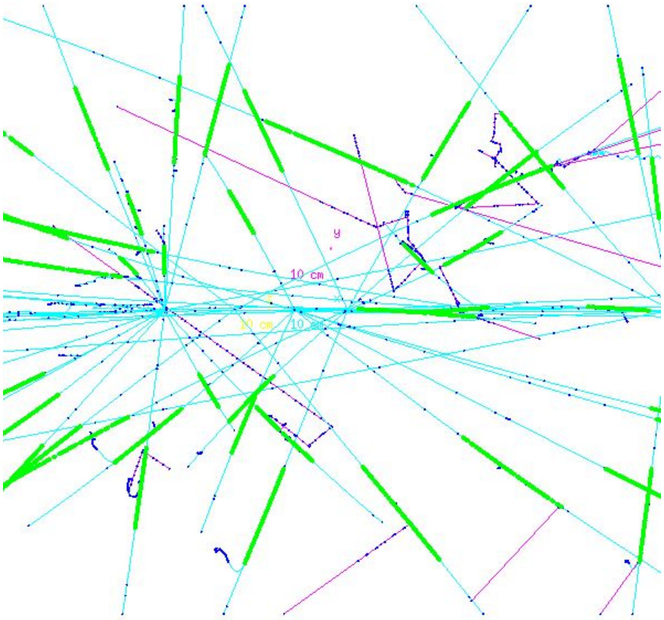


Figure 5: Launch 1 time slice (ZOY). Green points – Hits.

5 Cluster formation

After recovering the starting Z-position of each track, name Z_0, it is necessary to separate the tracks into clusters with common vertices and evaluate the vertex recovery efficiency. Partitioning into clusters is performed according to the following algorithm:

1. Partitioning the obtained set of vertices Z_0 into clusters with some step H. This is done as follows: we have an array of Z_0 sorted in ascending order, we take Z_0 minimal (Z_{min}O), then the interval within which we will proceed further is $[Z_{min} - 1cm; Z_{min} + H - 1cm]$. The 1 cm shift is introduced to account for situations where the Z value of a vertex lies close to the reconstructed position but is smaller than any of the reconstructed Z_0 values. Without the shift, such a vertex will not fall into the interval and will be considered to be reconstructed incorrectly;

2. Averaging Z_0 within the interval. $\bar{Z} = \frac{\sum Z_0}{N}$, where N is the number of points in the interval, $\bar{Z}$ is the reconstructed position.

3. Compiling a complete list of tracks by Z_0 within the interval. Each track has a unique TrackID number.

4. Search for a vertex, Z coordinate of which belongs to the interval.

5. Compilation of the complete list of tracks that have left this vertex.

6. Comparison of TrackID lists.

A vertex is considered to be recovered correctly if there are no other vertices within the interval, i.e. there is no overlap of several vertices, and TrackID lists of tracks completely coincide. In the case of attributing extra tracks or vice versa, the vertex is considered to be recovered incorrectly. The recovery efficiency is calculated as the ratio of correctly recovered vertices to the total number of true track vertices obtained from the simulation at the clustering stage. In this way, we can separate tracks primary vertices, and then combine tracks with common vertices into clusters, which will correspond to the intersection of separate proton beams. The maximum recovery efficiency achieved by this method at $H = 3cm$ is 93% However, it is important to consider the factor of information loss in the online filtering stage. The tracks are overlaid with the following cuts for the purity of their fitting:

- The trajectory should not be overly rounded, i.e. $|x|, |y|$ increase as the particle moves. At this stage the track loss is 7%.

- Checking for the quality of approximation, the coefficient c of the obtained parabola should be $c < 1$, since the origin of the trajectory of any particle lies on the OZ axis. At this stage the track loss is 2%.

The hit coordinates are approximated with the assumption that the particle flew out from the point with coordinates $\{0, 0, Z_0\}$. This assumption strongly improves the fit results, but in some cases the resulting parabola runs as presented in Fig.6.:

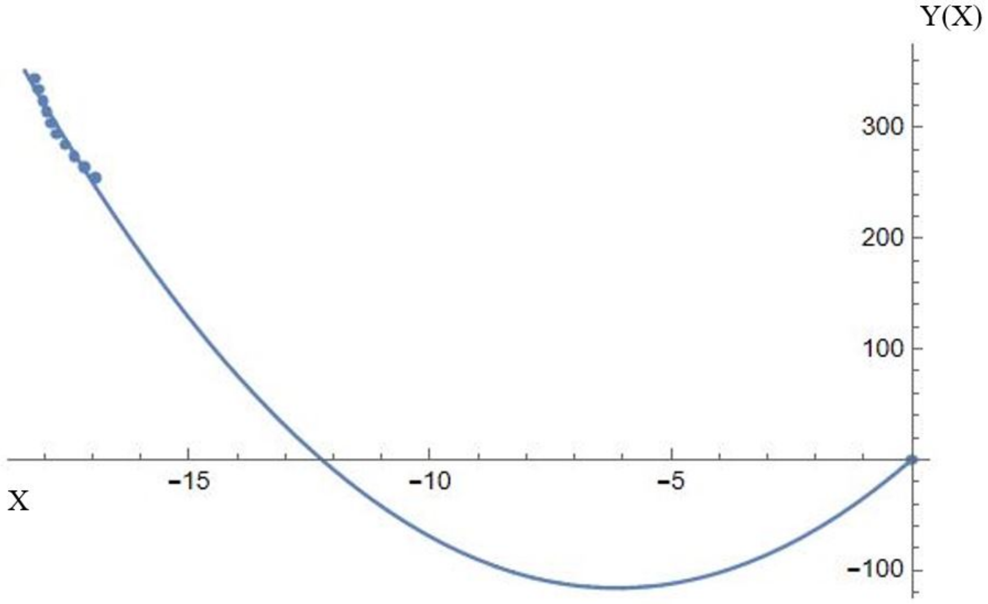


Figure 6: Graph of hits data and approximating function.

For this reason the length is calculated incorrectly, because the particle did not move along the given trajectory. By checking the location of the vertex of the obtained parabola with respect to the x coordinates, we can ignore the tracks that introduce a large error in the vertex reconstruction. The distributions of the deviation of the reconstructed vertex from the true vertex in the general case and in the vertex selection case are shown in Fig.7 and in Fig.8.

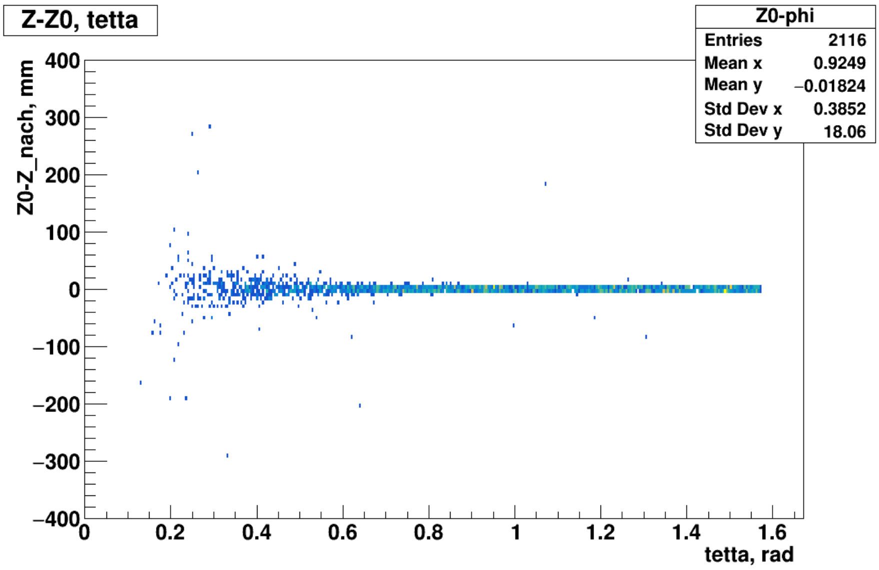


Figure 7: Distribution of the deviation of the reconstructed vertex position from the true vertex position in polar angle θ.

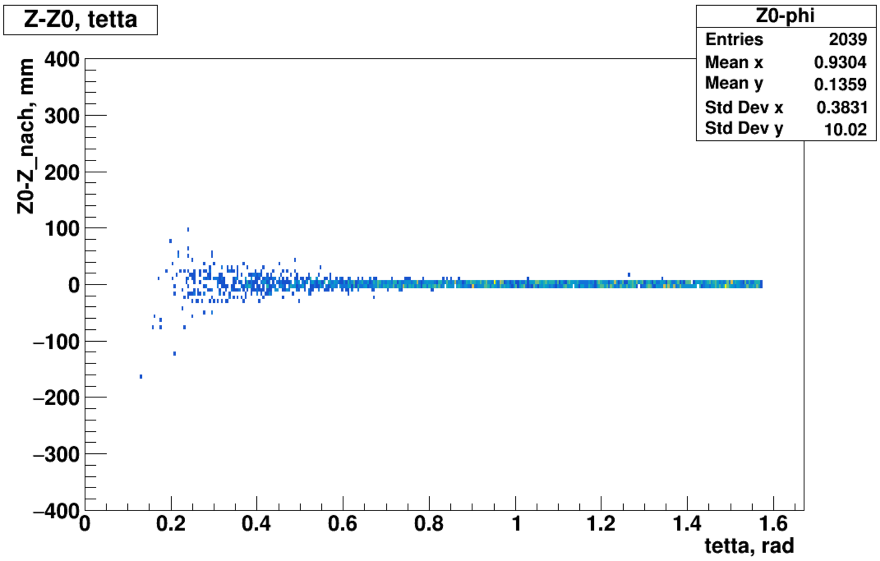


Figure 8: Distribution of the deviation of the reconstructed vertex position from the true vertex position in polar angle θ after cutting tracks whose vertex of the parabola lies between 0 and the first hit.

At this stage, the track loss is 3%.

- Analysing the distribution of the vertex reconstruction error from the polar angle we can conclude that at small angles, when the particle flies close enough to the Z-axis and can capture not all layers of the detector, the reconstruction accuracy drops, because even a small error in the fit gives a large extrapolation error. Therefore, it was decided to cut off all tracks whose polar angle $\theta < 0.5$. At this stage, the track loss is 16%.

After all exceptions, the information loss at the online track filtering stage is 28%. Taking into account the information loss, the efficiency of vertex recovery is 79%. This work was performed with time slice of 1 µs, in case of increasing the time window within one time slice there are more vertices unsolvable within the interval, i.e. true vertices located less than H apart. This phenomenon leads to an increase in the number of incorrectly recovered vertices. At the same time, the accuracy of fitting does not allow to put H smaller. At $H < 3cm$ the efficiency drops and ranges from $89 - 92\%$.

6 Conclusions

In this study we created a simplified model of the straw tracker of SPD NICA detector using GEANT4 software tools. Introducing the hit collections, we studied the temporal structure of the events, and found a significant overlap of straw tubes response times from different bunch crossings. Using the hits collection data we developed an algorithm for primary vertex recovery with current efficiency of 93%, obtained with the most strict conditions on the purity of the vertex reconstruction. These results are to be a part of prototype for the online data processing software.

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