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Software for Tracks and Primary Vertex Reconstruction for the SPD Experiment

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Abstract—The article describes the software development for charged tracks and primary vertex reconstruction for the SPD [1] experiment at the future NICA collider (JINR, Dubna). The use of these programs makes it possible to quickly simulate various configurations of both the magnetic field and the track system of the SPD experiment and, thus, determine the optimal experimental setup for better track reconstruction. The article also presents preliminary results of the program for the reconstruction of charged particle tracks.

Keywords: SPD experiment, Kalman filter, track fit, track reconstruction, vertex reconstruction, Monte Carlo simulation

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1. INTRODUCTION

Reconstruction of charged particle tracks and primary vertex are an important part of experiments in high energy physics. In general, the track reconstruction programs can be divided into two parts: track finding and track fitting tasks. The task of finding track candidates begins with the selection from the entire set of measurements only those that we believe belong to a particular track. Then, for the determination of the track parameters a fitting program is used using the already selected measurements. In existing experiments, various algorithms are used to determine the track parameters, but the most common of them is the Kalman filter method [2] and its various modifications [3]. This method is an efficient recursive algorithm that estimates the state vector of a dynamical system using a series of sequential measurements and their error matrices. The Kalman filter method is proposed to be used in the SPD experiment to determine the track parameters.

The development of software for such large experiments as SPD requires a lot of time and effort and, therefore, at the initial stage of defining the potential of the experiment, special standalone programs are developed that allow to quickly determine the track and primary vertex parameters. Additionally, software tools are created to visualize the magnetic field map, materials and trajectories of charged particles inside the SPD experiment.

2. TRACK FITTING PROCEDURE

To develop a fitting program, it is reasonable to use existing track fitting software packages. One such program, created on the basis of open-source software, is the Genfit program (Generic Track-Fitting Toolkit) [4], the elements of which were adapted and used in our work. The developed program uses as input data the results of Monte Carlo simulation of the tracking system of the SPD experiment with the SPDroot software package [5]. A special interface was written to read the simulation results of the SPDroot program and convert them into the format of the track fitting program. Figure 1 shows a block diagram of the data flow between the SPDroot package used to simulate the response of the SPD detectors and the standalone track fitting program.

It is assumed that the track system of the SPD experiment will consist of vertex and track detectors. The vertex silicon detector will contain 5 cylindrical layers in the central part (barrel) and 5 discs in each of the endcap parts of the setup. The thickness of each layer of the silicon detector is assumed to be 300 μm. The main tracking system in the central part of the setup will consist of several layers of straw-tube detectors located around the central part of the vertex detector. The thickness of each straw detector will be 10 mm. The required number of layers in the central part of the track system will be optimized based on Monte Carlo simulation and the requirement of the best reconstruction of charged tracks. The end-cups of

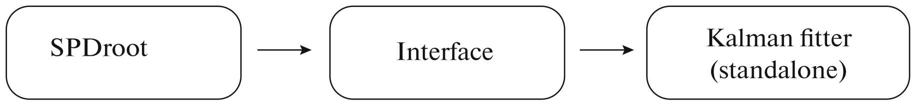

Fig. 1. Scheme of data exchange between the SPDroot package for simulation of the response of the SPD detectors and a standalone track fitting program.

the track system will consist of 3 stations, each of which is supposed to contain 8 layers of straw detectors in the front and rear parts of the SPD setup. In addition to the parameters of MC hits obtained in the SPDroot simulation program, a spatial resolution of 150 μm for the tracking and 50 μm for the vertex detectors are added. Thus, this procedure makes it possible to take into account the influence of both the material of which the various detectors are composed and the influence of the spatial resolution of tracking detectors itself on the determination of the track parameters.

Figure 2 shows the dependence of the momentum resolution for 1 GeV/*c* charged muons as a function of the polar angle θ (the results are averaged over the azimuthal angle φ) for various configurations of the SPD tracking system and a hybrid configuration of the magnetic field, when the field in the central part of the setup is toroidal, and the field in its end-cups is solenoidal. As can be seen from the presented results, an increase in the magnetic field can significantly improve the momentum resolution, but the maximum value of the magnetic field will be determined by the final design and type of the magnetic system.

At the stage of optimization of the geometry of tracking detectors, the following configurations of the magnetic field were considered and the influence of each configuration on the precision of the track parameters determination was studied:

- constant magnetic field along the *z*-axis of 12.5 kG (used for comparison);
- hybrid configuration of the magnetic field;
- pseudo-solenoidal field created by 6 coils;
- a special version of the magnetic field, when 3 coils create a field in one direction, and the other 3 coils create a field in the opposite direction.

Figure 3 shows the momentum resolution for 1 GeV/*c* charged particles as a function of the polar angle θ for the considered configurations of the SPD magnetic system. The obtained results make it possible to understand the effect of various configurations of the magnetic system on the precision of charged particles parameters determination and to take into account the results of these studies when the final configuration of both the magnetic system and the geometry of the tracking system of the SPD experiment will be chosen.

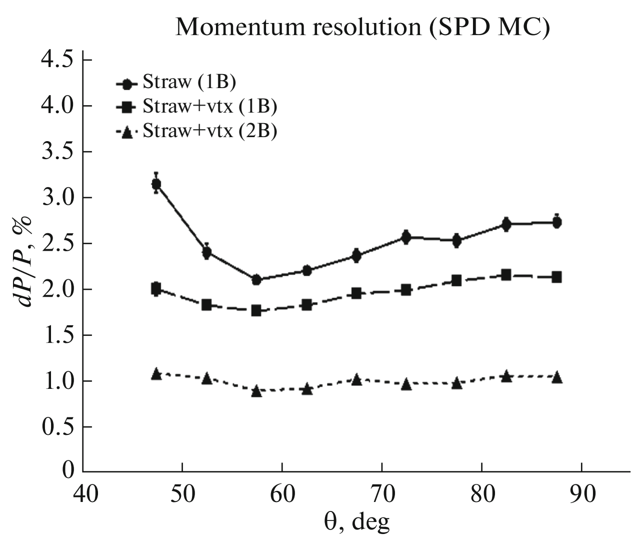

Fig. 2. Momentum resolution for 1 GeV/*c* charged muons as a function of the polar angle θ for different configurations of the tracking system: (●) only straw detector; (■) straw and vertex detectors; (▲) straw and vertex detectors, as well as double value of the magnetic field.

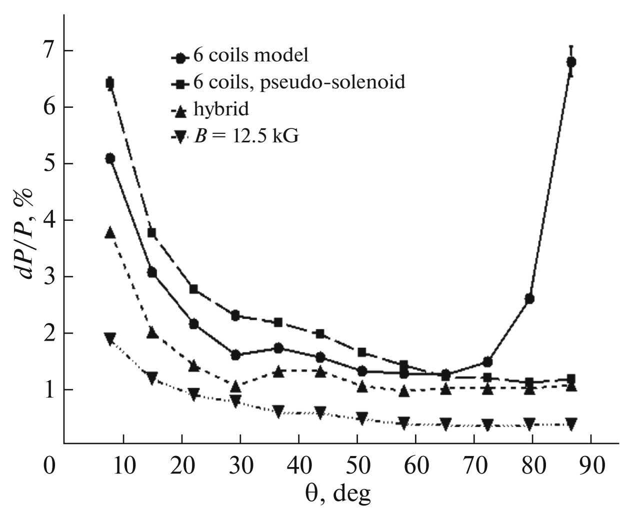

Fig. 3. Momentum resolution for charged particles with a momentum of 1 GeV/*c* as a function of the polar angle and various configurations of the magnetic field: (●) a special version of the magnetic field with 6 coils; (■) pseudo-solenoidal field with 6 coils; (▲) hybrid configuration of the magnetic field; (▼) constant magnetic field along the *z*-axis of 12.5 kGs.

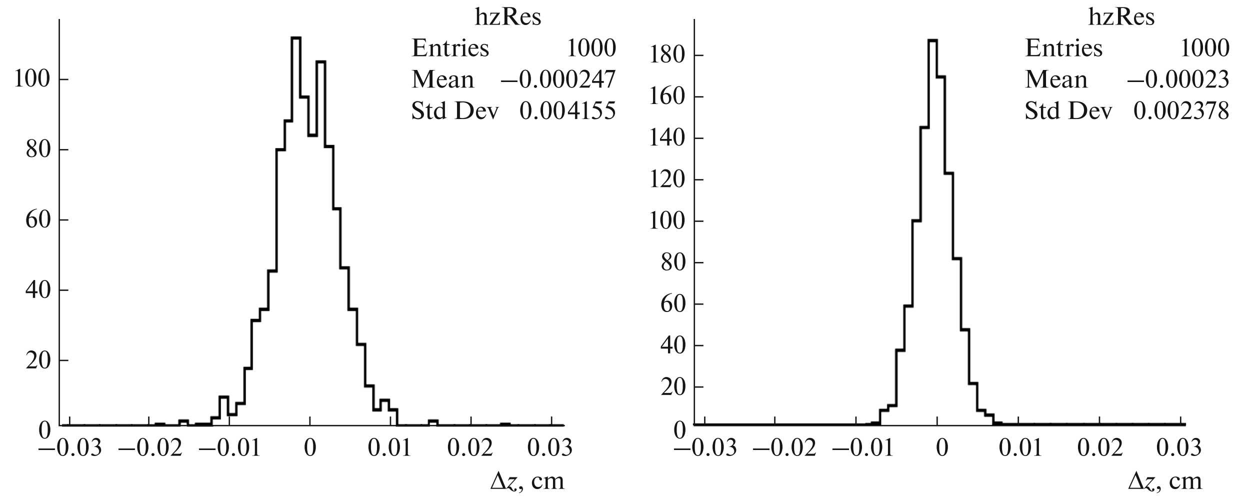

Fig. 4. Reconstruction precision of the z-coordinate of the primary vertex for two values of the primary particle momentum: for 1 GeV/*c*—left panel; and for 3 GeV/*c*—right panel.

3. PRIMARY VERTEX RECONSTRUCTION

The next important element in the event reconstruction is the reconstruction of the primary interaction vertex. To solve this problem, a special standalone program was developed based on the Kalman filter algorithm, in which elements of the program for the primary vertex reconstruction of the CBM experiment were used [6]. The vertex reconstruction program uses the parameters of the tracks obtained after the fitting procedure with the Kalman filter algorithm as input. The accuracy of the reconstruction of the coordinates of the primary interaction vertex was determined by the following procedure:

• at the primary vertex with coordinates $x = 0.0$, $y = 0.0$, $z = 0.0$, 6 charged particles with a momentum of 1 or 3 GeV/*c* were generated, uniformly distributed in the angular range $45° < \theta < 135°$ for the polar angle and $0° < \varphi < 360°$ for azimuthal angles;

• then, using the SPDroot program, the response in the vertex and tracking straw detectors was simulated;

• then, using a standalone Kalman fitting program, the parameters of charged particle tracks were determined;

• and, at the final stage, the obtained track parameters were used in the developed program for reconstruction of the primary interaction.

The result of this reconstruction program is presented in Fig. 4, which shows the reconstruction precision of the *z*-coordinate of the primary vertex for two values of the momenta of the generated particles—1 and 3 GeV/*c*. The data obtained indicate a significant improvement in the accuracy of *z*-coordinate reconstruction with increasing momentum of the primary particles (from ~42 μm for 1 GeV/*c* to ~24 μm for 3 GeV/*c*). The influence of the resolution in the vertex detector itself on the accuracy of the reconstruction of the primary vertex was also checked. The results of simulation and reconstruction showed that the accuracy of the *z*-coordinate reconstruction also improves from ~42 to ~20 μm when the resolution in the vertex detector changes from 50 to 25 μm.

4. TRACK RECONSTRUCTION PROGRAM

Reconstruction of tracks begins by finding track candidates or a set of measurements that we assume should belong to the selected track. The general scheme of the track reconstruction program contains the following elements:

• at the first step, using the SPDroot program, the response of the tracking detectors (vertex and straw) is simulated and MC hits are produced when charged particles pass;

• at the second step (digitization), the type and spatial resolution of the detectors themselves are taken into account;

• the next step (pattern recognition) begins with finding the track seeds in the vertex detector, and then successively adding MC hits in the straw detector layer by layer;

• at the last step, the Kalman fit procedure is applied to each track candidate, which can contain MC hits of both the vertex detector and straw detectors.

Finding track candidates begins with considering all possible 2-point combinations between MC hits located on different layers of the vertex detector. Since at present the main configuration of the magnetic field for the SPD experiment is considered to be a pseudosolenoidal configuration with the direction of the magnetic field along the *z*-axis, the projection of the charged particle trajectory on the *xy*-plane will be a

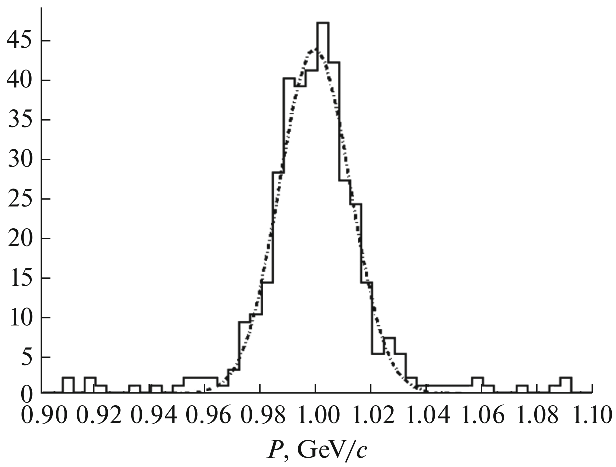

Fig. 5. Distribution of the reconstructed momentum for 1 GeV/c charged particle.

circle. To describe the trajectory of a particle in the vertex detector, we propose to use the parabolic function $y = a + bx + cx^2$, the parameters of which can be determined using the coordinates of the MC hits. To simplify the procedure for finding the points of the track candidate, we assume an exact knowledge of the x-coordinate, and in this case only the measurement error of the y-coordinate was taken into account. The procedure starts with 2-point track candidates and a new point is added based on the χ^2 criterion defined as follows:

$$\chi^2 = \sum_{n=1}^{N} \frac{\left(y_n - a - bx_n - cx_n^2\right)^2}{\sigma_{yn}^2},$$

where x_n and y_n are the MC coordinates of hits on the xy-plane and σ is the coordinate measurement error. As a result of this procedure, we get a set of track candidates containing 3, 4, or 5 vertex detector hits.

At the next step, using the parameters of the track candidates obtained in the vertex detector, the track is extrapolated to the layer of straw detectors closest to the primary vertex. Further, all MC hits in this layer are checked for possible belonging to this track using the χ^2 criterion. MC hits that meet certain conditions are added to the points of the track candidate, and then the track parameters are updated taking into account the new measurement and the track is extrapolated to the next layer of straw detectors. If two or more measurements (MC hits) satisfy the criterion of belonging to a given track candidate, then one or more additional track candidates are created and, further, the procedure for extrapolating and updating track parameters is applied to all newly created candidates. As a result of this procedure, a large number of track candidates will be formed, to which at the final stage the track fitting procedure is applied by the Kalman algorithm.

To test the track reconstruction procedure, events with different multiplicity of primary particles in the event were simulated, with the momentum of each particle equal to 1 GeV/c. Then, the efficiency of the track finding algorithm and accuracy of the track parameters determination are estimated. Figure 5 shows as example the distribution of the reconstructed momentum for 1 GeV/c particles after applying all reconstruction steps.

On the basis of the special standalone software created, a preliminary study of the accuracy of determining the track parameters of charged particles, depending on the configuration of the magnetic field and the characteristics of the SPD track system, was carried out. Later, the developed programs were included in the program system for simulation and reconstruction of the SPD experiment. Currently, the development of programs for the reconstruction of tracks is underway, and first preliminary results were obtained.

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