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Monte-Carlo Simulations of the Straw Tracker Performance in SPD Setup

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The Spin Physics Detector (SPD) is a universal facility for studying the nucleon spin structure and other spin-related phenomena with polarized proton and deuteron beams proposed to be placed at one of the interaction points of the NICA collider that is under construction at the Joint Institute for Nuclear Research. The Straw Tracker (ST) is a subsystem of SPD, that, together with the inner silicon-based tracker is intended to reconstruct tracks of primary and secondary particles with high efficiency, and to measure their momenta with high precision. Additionally, it can contribute to the particle identification via dE/dx measurements. In this report the results of MC simulations of ST performance are presented. In particular, dependence of the momentum resolution on straw tube configuration and influence of power frame on the momentum resolution are discussed.

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1. Introduction

SPD (Spin Physics Detector) is a universal facility for studying the nucleon spin structure and other spin-related phenomena with polarized proton and deuteron beams that will be built in one of the two interaction points of the NICA collider at the Joint Institute for Nuclear Research (Dubna, Russia). Its main objective is a comprehensive study of the gluon content in the nucleon. Different complementary probes will be used for that end: inclusive productions of charmonia, open charm, and prompt photons [1].

SPD is planned to run in two stages. The first stage is dedicated to study various polarized and unpolarized phenomena at low energies: $\sqrt{s_{NN}}$ up to 9.4 GeV for protons and 4.5 GeV/nucleon for deuterons. The corresponding luminosities are about 10^{31} $cm^{-2}s^{-1}$ and 10^{30} $cm^{-2}s^{-1}$, respectively. Both longitudinal and transverse polarization of the beams will be available. The physics program for this stage is described in Ref. [2]. The detector setup [3] will include: straw-based tracking system and a Micromegas-based central tracker (MCT), placed within a solenoidal magnetic field, intended for charged particle momentum reconstruction; range system for muon identification and rough hadron calorimetry; a pair of beam-beam counters and a pair of zero-degree calorimeters for local polarimetry and luminosity control. Magnetic field 1.2 T will be provided by a superconducting solenoid. The straw tracker will also provide a limited particle identification via energy losses per unit length (dE/dx) measurements.

At the second stage the primary focus of the SPD physics program is planned to be studied. The collider will operate at energies up to 27 GeV for protons and 13 GeV/nucleon for deuterons in the center of mass system, and with luminosities 10^{32} $cm^{-2}s^{-1}$ and 10^{31}

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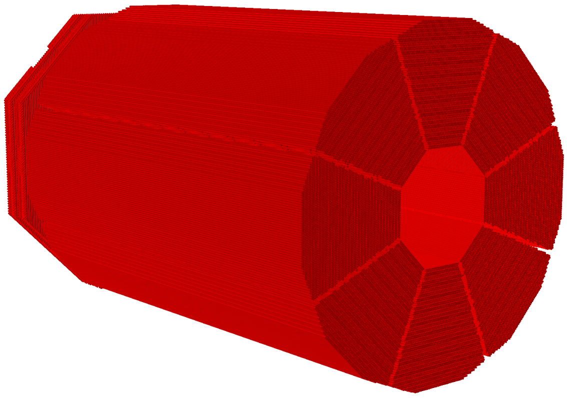

Figure 1: Schematic view of the straw tracker. Forward end-cap and power frame are not shown for clarity.

$cm^{-2}s^{-1}$, respectively. The SPD setup [3] will be supplemented by an electromagnetic calorimeter, a time-of-flight system (TOF) and an aerogel-based FARICH detector. TOF and FARICH will considerably enhance the particle identification capabilities of the setup. MCT will be replaced by a silicon vertex detector, that will allow precise measurements of vertex positions for long lived particle decays.

Thus, the straw tracker will be an essential part of the SPD setup during both the first and the second stages. Below we describe its general layout, and present some results of Monte-Carlo simulations of its performance.

2. Straw tracker description

The straw tracker consists of the barrel part and two end-caps. Schematic view is shown in Fig. 1. The barrel part is subdivided azimuthally in eight modules. Each module consists of 31 double layer of straw tubes. Diameter of each tube is 9.8 mm. Orientation of straw tubes in layers changes alternately in Z, U, and V directions. Z direction is along the beam axis. Directions U and V form angles of $3°$ and $-3°$ degrees with direction Z, respectively. Tubes are filled with a mixture of argon (70%) and carbon dioxide (30%). The achieved spatial resolution σ_R is about 200-250 μm.

To provide mechanical support, each module is enclosed in a power frame made from carbon fiber. Its bottom, top and side walls have lattice structure, with the thickness of the ribs being 4 mm. Front and back walls are solid. Front-end electronic boards and parts of gas system will be placed on them. In Monte-Carlo simulations, their widths are taken 20 mm.

Each end-cap consists of eight coordinate planes, orthogonal to the beam axis. Each plane is a double layer of straw tubes. Angle between vertical axis and straw tubes orientation in a plane takes values $0°$, $90°$, $45°$, $-45°$, $0°$, $90°$, $45°$, $-45°$ successively.

3. Momentum resolution

SpdRoot [4] is currently the main package for Monte-Carlo simulations for the SPD project. It is based on the FairRoot framework [5]. SpdRoot includes flexible geometry description (in ROOT format) of each of the subsystems of the SPD setup. As a primary event generator Pythia8 [6], FTF or artificial event generators (e.g., isotropic) can be used. Geant4 [7] is used as a toolkit for the simulation of the passage of particles through

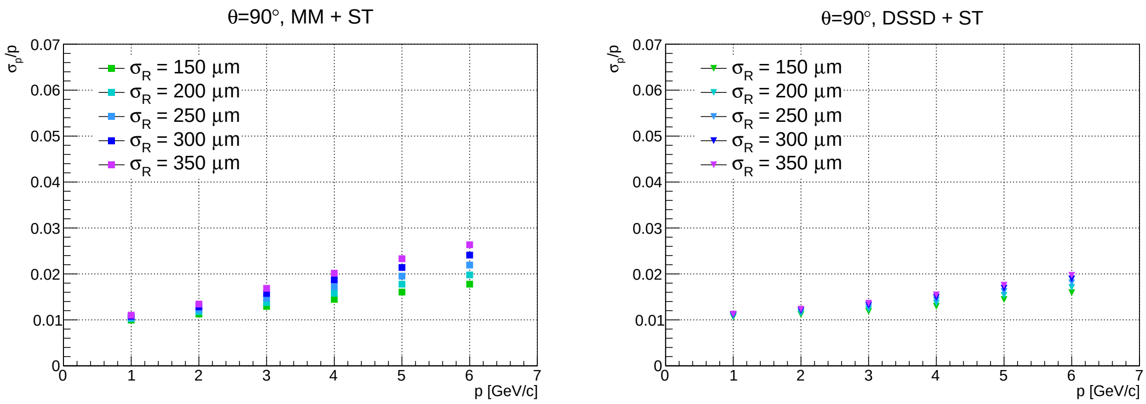

Figure 2: Relative momentum resolution of the SPD tracking system for tracks with polar angle $\theta = 90°$. Left: At the first stage (Straw Tracker + Micromegas Central Tracker). Right: At the second stage (Straw Tracker + Silicon Vertex Detector).

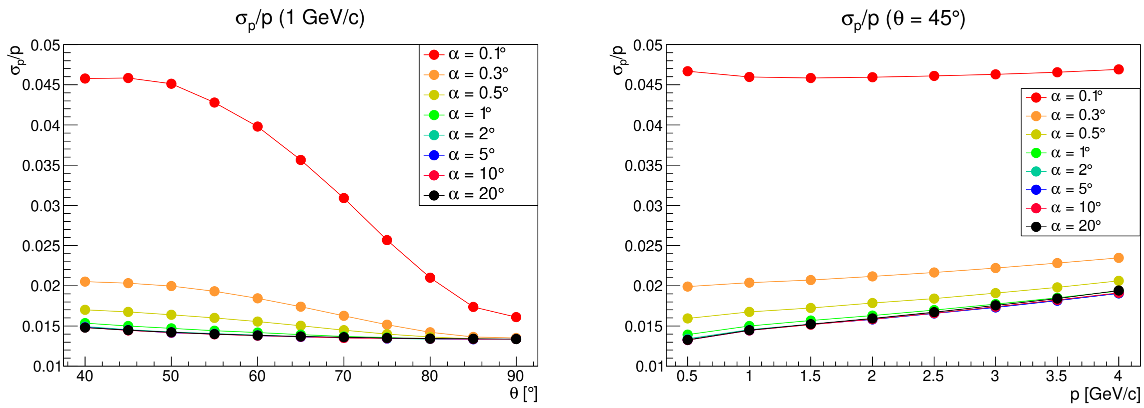

Figure 3: Momentum resolution of the straw tracker for different values of the tilt angle of straw tubes α in U and V layers. Left: Momentum $p = 1\ GeV/c$, polar angle θ of the tracks varies from 40° to 90°. Right: Polar angle $\theta = 45°$, momentum p varies from 0.5 to 4 GeV/c.

matter. Hit producing in the straw tracker is currently implemented in a simplified way: by smearing the MC hit position by Gaussian function that mimics the spatial resolution of straw tubes. For the reconstruction of track parameters Genfit2 package [8] is used.

Momentum resolution of the SPD tracking system obtained for different values of momenta and different assumed values of the spatial resolution of the straw tubes is shown in Fig. 2. Left plot corresponds to the configuration at the first stage of SPD operation: straw tracker supplemented by the Micromegas central tracker. The momentum resolution is in the range of 1 to 2.5%. Right plot corresponds to the second stage of SPD, where straw tracker is employed together with the silicon vertex detector. In this case, momentum resolution does not exceed 2% in the examined momenta range.

A separate study was dedicated to determine the optimal value of the tilt angle of straws tubes α in the U and V layers of the barrel part of the straw tracker. Technologically, smaller values of α are more desirable for construction of the straw tracker modules. The momentum resolution of the straw tracker alone was studied at various values of track momentum and polar angle for different values of α. Some of the results obtained are presented in Fig. 3. It can be seen that the momentum resolution is practically independent of α when $\alpha \geq 2°$. In the end, with a small margin, the value $\alpha = 3°$ was chosen.

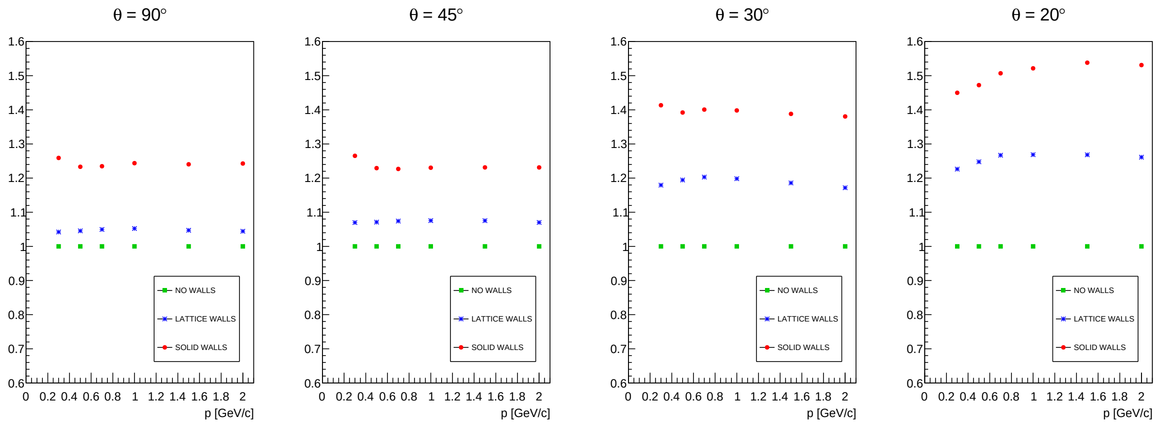

Figure 4: Relative increase in average momentum resolution σ_p/p due to the power frames of straw tracker modules. Green points: no power frame; blue points: power frame with side and bottom walls having lattice structure and front and back walls solid; red points: power frame with all walls solid.

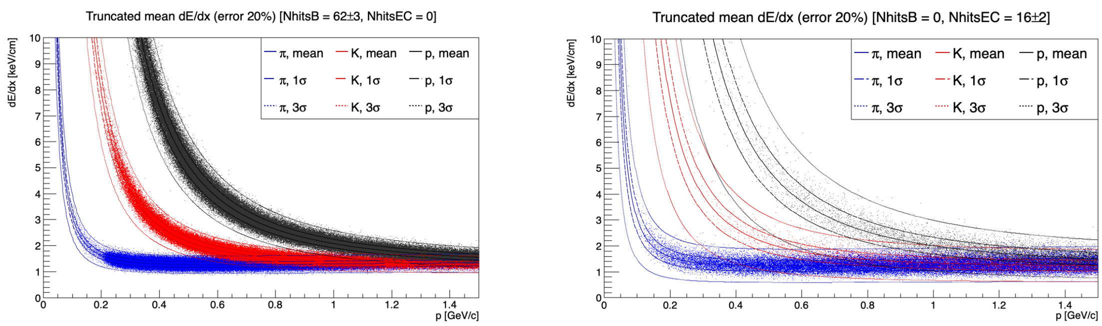

Figure 5: Truncated mean dE/dx distributions (truncation parameter 0.35). Pions are shown in blue, kaons in red, protons in black. Left plot: tracks passing through the barrel (number of hits ≈ 62). Right plot: tracks passing through the end-caps (number of hits ≈ 16).

Another study focused on the influence of module power frames on momentum resolution For this purpose, a geometric model of the power frame was implemented in SpdRoot, and simulations for the second stage setup (ST + silicon vertex detector) were performed with power frame included and without it. For comparisons, simulations were also performed with a power frame with all solid walls. Increase of average momentum resolution σ_p/p relatively to the case with no power frame for tracks with different polar angle θ and momentum is shown in Fig. 4. Larger effect is observed for tracks with $\theta < 36°$, when track crosses the front or back wall of the module: increase factor is up to 1.25. Tracks with $\theta > 36°$ are in average less affected, increase factor about 1.05 is mainly due to tracks that pass through the border between two modules.

4. Particle identification via dE/dx measurements

The straw tracker will be the only detector able to separate pions, kaons, and protons during the first stage of the SPD experiment. Particle identification is based on the measurement of ionization energy losses per unit length, dE/dx, in each tube the track crosses. Energy losses depend on the velocity of the particle, which makes it possible to distinguish between particles with the same momentum but different masses. Energy losses follow the Landau distribution and have large fluctuations due to rare acts of ionization with high energy transfer. To get around this, the truncated mean method is applied. Using this method, for each track a certain fraction of hits with the highest values of dE/dx are discarded. After that, the mean of the remaining values is calculated.

The value of the truncation parameter (fraction of hits discarded) is chosen to minimize the standard deviation of the distribution of truncated mean dE/dx. Our analysis showed that truncation parameter in the wide range of 0.3 — 0.6 give approximately the same resolution.

To account for the gas gain fluctuations, Monte-Carlo energy loss values for each hit were further smeared by 20%. This results in an increase of standard deviation of the truncated mean dE/dx distribution by 10%.

Distributions of the truncated mean dE/dx for truncation parameter equal to 0.35 are shown in Fig. 5. The achieved resolution is about 8%.

The maximum momentum up to which pions can be reliably separated (at the level of 3σ) from kaons is 0.6 GeV/c. Protons can be separated from pions/kaons up to 1.1 GeV/c.

5. Conclusion

The straw tracker will be the main tracking detector in the SPD setup. Together with Micromegas central tracker during the first stage of SPD operation, and with silicon vertex detector during the second stage, it will allow reconstruction of tracks of charged particles with high efficiency and determine their momenta with high precision. Monte-Carlo simulations were performed to estimate momentum resolution σ_p/p and to optimize the geometry of the straw tracker. Obtained momentum resolution is in the range of 1.0 to 2.5%. In addition, the straw tracker can also provide particle identification via ionization loss measurements in region of small momenta, approximately below 1 GeV/c. This capability is important for the first stage of SPD, when no other PID detector will be available.

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