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Simulation of the MiniSPD Test Facility

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Abstract. The MiniSPD test facility, its main goals and objectives are discussed in this work. The model of the stand, which was implemented in the Geant4 package, is presented. The results of simulation of cosmic ray particles depending on various parameters are discussed.

INTRODUCTION

The MiniSPD test facility is designed for testing a straw detector using cosmic muons. The detector is assembled from thin-walled drift tubes. It was proposed as a tracking detector for setups of Spin Physics Detector (SPD) experiment at the Nuclotron based Ion Collider fAcility (NICA) collider [1] and for NA64 experiment [2] at the Super Proton Synchrotron (SPS) accelerator complex at CERN.

One of the main purposes of MiniSPD is to study the spatial resolution of the straw detector. This study requires tracks that can be reconstructed in assumption that they are straight. The choice of the track source was the main goal of the Monte Carlo simulation described in the present work. Initially, a source of few-MeV electrons was considered as a possible source. Another possible source is cosmic rays.

Protons dominate the composition of primary cosmic rays. There are also electrons, helium nuclei and heavier chemical elements (up to nuclei with a charge of $Z \approx 30$). Due to interactions with the Earth's atmosphere, primary cosmic rays create a large number of secondary particles. Mostly neutrinos and muons reach the Earth. These muons are suitable as a source of particles for study characteristics of the straw detector at MiniSPD, as other types of particles make little contribution. An average energy of muons which reach the Earth is 4 GeV.

EXPERIMENTAL SETUP

The MiniSPD test facility is shown in Figure 1. There are some subsystems included in the stand. Trigger system consists of three scintillation detectors (Scintillator N1, Scintillator N2, Scintillator N3). Two of them with a working area of 145 x 145 mm^2 are read out by silicon photomultipliers (SiPM), the third plane is read out by PhotoMultiplier Tube (PMT) and is located behind the lead filter.

The straw tubes contain preamplifiers. Signals of up to 128 detector channels can be processed by a time-to-digital converter with time measurement accuracy up to 100 picoseconds. A straw tube made of kapton has a diameter of 6 mm. The expected straw resolution is about 150 μm.

The MiniSPD facility includes a calorimeter, consisting of four modules. Each of these modules contains 220 plates of scintillator and lead. The modules were integrated into the general data collection system in order to increase the

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accuracy of measurements and to be able to scan triggered events by energy. The test facility uses a data acquisition system similar to that used in the BM@N experiment [3].

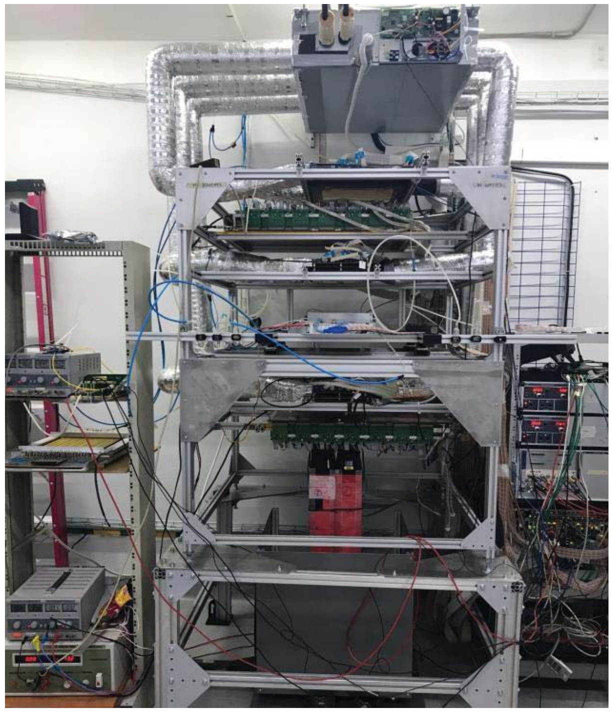

FIGURE 1. The MiniSPD test facility

Silicon detectors (SI N1, SI N2, SI N3) were used earlier in the Baryonic Matter at Nuclotron (BM@N) setup [3]. Each detector consists of Upper, Middle, and Bottom silicon planes. Upper and Bottom ones are built from two detector modules consisting of two two-sided silicon wafers (640 strips on each side). The Middle silicon plane consists of four detector modules, each of which includes a silicon sensor. Spatial resolution of SI N1, SI N2, SI N3 is 60, 100, 40 μm, respectively.

Gas Electron Multipliers (GEM) detectors (GEM N1, GEM N2) from BM@N [3]. A 375 mm thick lead absorber is used to cut off low-energy particles.

MODEL OF THE TEST FACILITY

The Geant4 software package [4] allows for full-scale simulation of modern large-scale experiments in high-energy physics and astrophysical installations using Monte Carlo methods [5]. Figure 2 shows the latest version of the MiniSPD setup built with the Geant4 package. The setup consists of three scintillators, three silicone detectors, two straw stations, two GEMs, a calorimeter and a lead filter.

The straw volumes are structured as follows. Each straw station consists of two layers of tubes with a diameter of 6 mm. The first layer is shifted in the transverse direction relative to the second one by 3 mm. Each layer includes 32 straw tubes. Each tube consists of four layers of hollow cylinders (12 μm outer layer of kapton, 7 μm layer of glue, 40 μm inner layer of kapton, gas Ar/CO_2). In the center of each tube there is a solid cylinder with a diameter of 30 μm representing a tungsten wire. The model uses two geometrically mirrored straw stations.

The silicon detectors are represented by top, middle and bottom plates made of 0.25 mm of plastic, 0.3 mm of silicon and 0.25 mm of plastic, respectively. The first and third ones consist of two parts and are geometrically mirrored with respect to each other. The second detector consists of four parts that are offset with respect to each other by 7.3 mm.

The thickness of three layers (plastic, scintillator and plastic) of the scintillation detector is 3 mm, 5 mm and 2 mm, respectively. Dimensions of GEM were taken from [3].

In the simulation, the Calorimeter is built of 4 modules standing next to each other with no empty space between them. Each module consists of 220 slices (1.5 mm scintillator and 0.3 mm lead in each one), which are placed one after another. The thickness of the lead absorber is 375 mm. The steel stand and aluminium stand are also included into the model. Positions of the detectors with respect to each other correspond to the real setup.

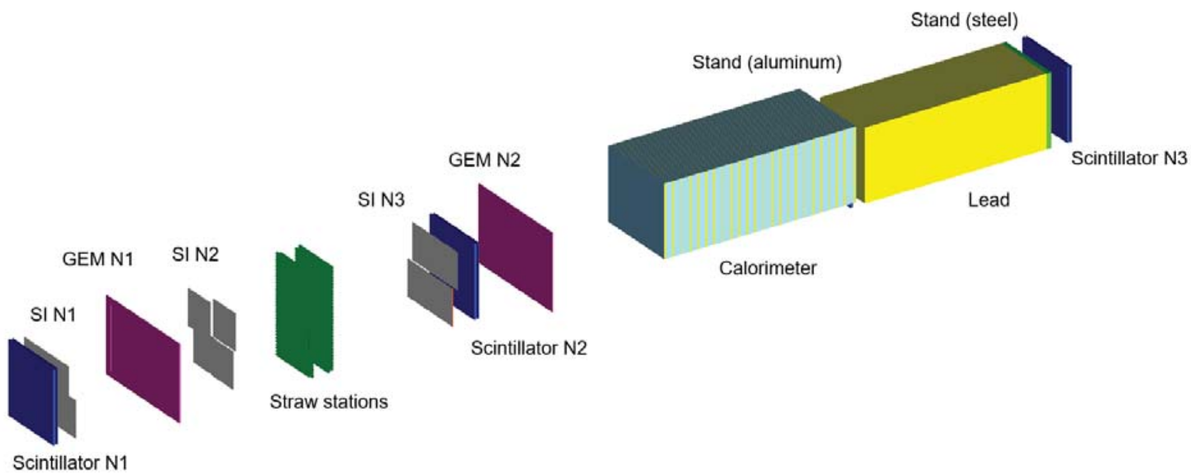

FIGURE 2. The MiniSPD test facility as described in Geant4.

Paths of incident particles start from a point-like source displaced from the Z axis by 10 mm along the both transverse coordinates X and Y. This source offset is implemented to avoid the beam hitting the empty space in the center of the silicone.

A sample of 100’000 particles has been simulated. The simulation was done for energies 0.1, 1, 10 and 100 GeV. When scanning the energy range, we were searching for the minimum energy which can still correspond to the beam width below the expected resolution of the straw chambers (~150 microns). It is done in order to prevent deterioration of the straw spatial resolution measurement.

RESULTS AND DISCUSSION

When passing through the materials of detectors, particles undergo Coulomb scattering. It causes the divergence of initial trajectories and, as a result, we observe the deviation from a straight line. The results we obtained show energy range where the scattering does not cause significant distortions [6].

Several test runs were carried out with electron and muon beams. Figure 3 shows distributions of hits produced by electrons in silicon detectors and straw stations. Since the initial electron is inseparable from the shower of secondary particles, we consider all electrons in the simulation, including those generated in the shower [7]. One can see, that the spread of hits at the straw stations and at the SI N3 silicon detector is very large for any incident electron energy.

Root Mean Square (RMS) of the electron transverse positions is near 30 mm, that is much larger than the expected straw resolution. Thus, the electron source cannot be used as a test beam in the study irrespective to the provided energy.

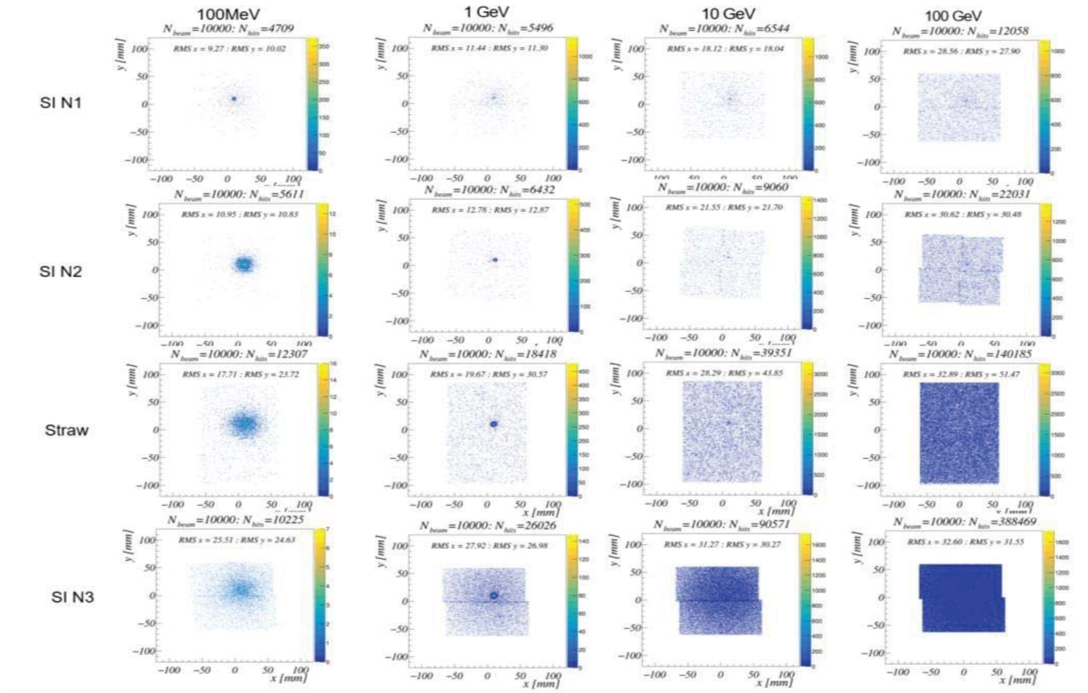

FIGURE 3. Transverse distributions of hits produced by electrons in the silicon detectors and in the straw stations (rows). The columns correspond to electrons of different energies.

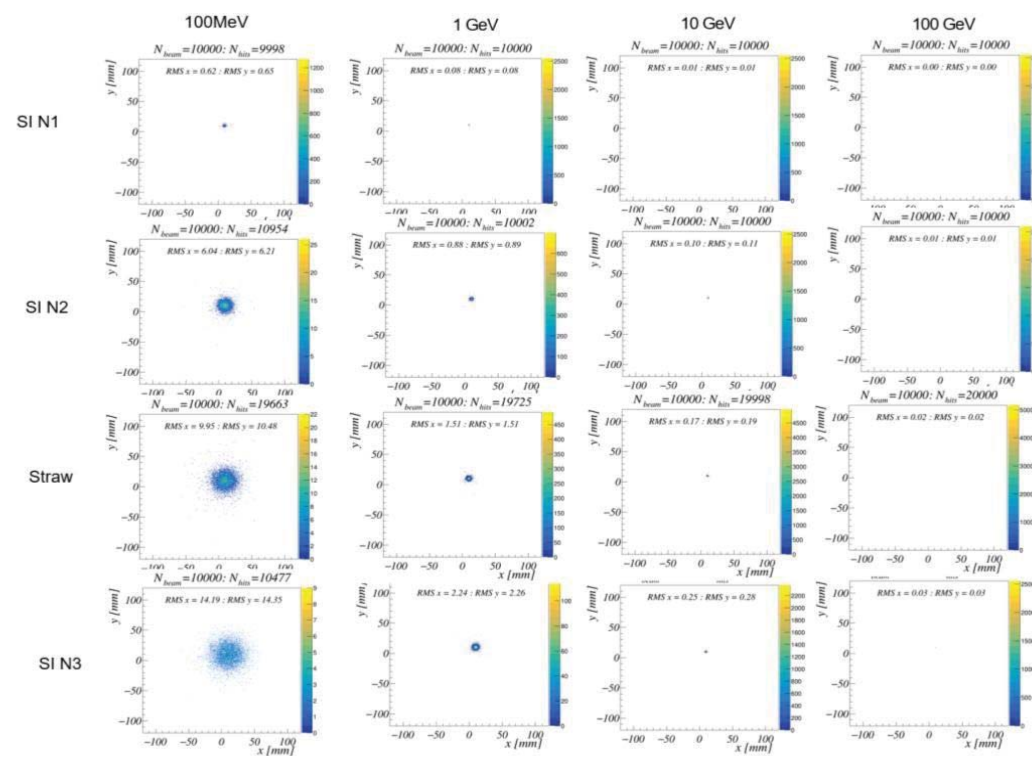

FIGURE 4. Transverse distributions of hits produced by muons in the silicon detectors and in the straw stations (rows). The columns correspond to electrons of different energies.

Results of the muon beam simulation are shown in Figure 4. One can see, that muons with energies of 1 GeV and below have RMS of transverse hit distribution equal to 1.51 mm at the straw stations and 2.26 mm at SI N3. So, at these energies the resolution is much worse than we need. However, near the muon energy of 10 GeV the scattering results in a less dramatic smearing of the beam position. At this energy, the tracks experience only a smaller deviation from the initial directions and, therefore, will not degrade the straw resolution measurement. The energy of 10 GeV corresponds to RMS = 0.19 mm at the straw stations and RMS = 0.28 mm at SI N3. These values are of the order of expected straw resolution, so with a corresponding statistical tools one can measure the straw resolution if statistics will be large enough. The simulation results clearly demonstrate that muons with the energy of the order of 10 GeV are suitable for the MiniSPD tests.

CONCLUSION

This paper describes the simulation of the MiniSPD test facility implemented in the Geant4 package. The simulation of interactions of cosmic ray particles with the MiniSPD detectors gives an understanding of the type of particles and energy range are suitable for the straw tests performed by means of the facility. The simulation results will help to improve the quality of data collected from the facility.

Several upgrades of the MiniSPD facility are planed in the future. After that, an additional muon detector will be included in the simulation. The angular and energy distribution of the cosmic ray flux, as well as the straw response caused by the charged particle hit will be simulated in future in order to provide a quantitative basis for the straw characteristic measurements.

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