Garfield++/LTSpice studies of the straw tube time and charge resolution for various readout parameters

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The report is dedicated to detailed simulation studies of different readout electronics options for straw drift tubes aiming the best performance of the SPD Straw Tracker. The Straw Tracker of the SPD detector should provide track coordinate measurements and also should serve the Particle Identification of low momentum charged particles. This requires simultaneous precise measurement of the signal time and charge, so optimization of the readout electronics parameters is necessary.

Garfield++ package is used to generate a realistic straw response. The readout electronics response is modeled using LTSpice. Different parameters, such as the preamplifier gain, shaper peaking time, discriminator threshold and electronics noise level are studies.

Time and charge distributions are obtained. The drift time distributions for various discriminator threshold levels and shaper peaking times are analyzed in order to reach the best tracking performance. Influence of the peaking time on the precision of charge measurements is studied as well. Comparison between the experimental data and modeling results is presented.

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Introduction

Future experiments, such as DUNE [1] and SPD [2], require not only precise measurements of charged tracks, but also particle identification for low momenta particles. To minimize error on coordinate measurements, the straw signal should cross a reasonable discriminator threshold as soon as electrons created by ionization at the closest distance from the anode wire will reach it. This requires small peaking time of the straw readout electronics. Charge measurements require large peaking time to minimize energy loss fluctuations. The aim of simulation studies and test beam measurements is

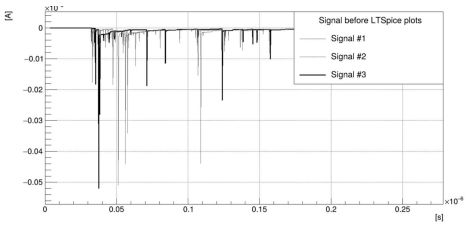
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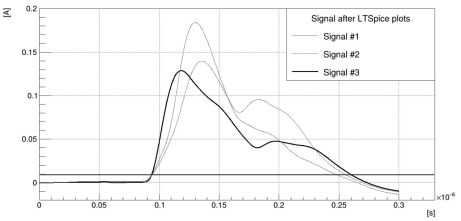
to find optimal electronics parameters for both coordinate and charge measurements to satisfy controversial requirements. Another simulation goal is to prove that the straw charge resolution is sufficient for particle identification (PID) taking into account a finite electronics dynamic range on tracker PID. Final results of the simulation studies are used as an input for realistic SPDroot / SAMPO simulation of the SPD tracker response [3].

Straw signal simulation

Garfield++ is developed for detailed simulation of signal induced on electrodes of gaseous detectors and is used to model straw signals for different particles [**?**]. Straw signals obtained with Garfield++ are interfaced to LTSpice package to simulate response of the readout electronics [4]. A model of VMM3a ASIC is used in the studies. Examples of the straw signal generated with Garfield++ are shown in Fig. 1(a). The corresponding signals at the output of the front-end electronics obtained with LTSpice are shown in Fig. 1(b) together with the discriminator threshold level considered for the straw readout.



(a) Garfield++ signal examples before front-end electronics simulation



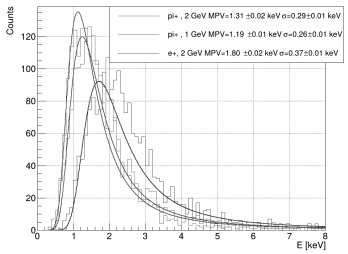
(b) Garfield++ and LTSpice output signals after front-end electronics simulation

Fig. 1: Examples of signals at different stages of simulation.

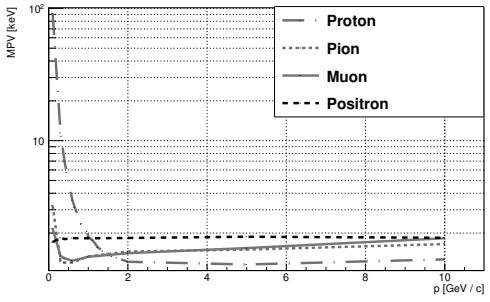
The simulation studies are performed for straws with diameter of 10 mm and the anode wire diameter of 30 μm. The gas mixture is 70% Ar + 30% CO_2, the gas temperature is 20^o C and the absolute pressure is 1 atm. Straw response to ionizing particles, such as muon, proton, pion, kaon and electron with momentum of 0.1, 1 and 10 GeV are simulated. The angles between the wire and the track are chosen to be 90^o and 13^o. The mean gas gain value is fixed to $4.5 \cdot 10^4$. Influence of the magnetic field of the SPD detector is studied comparing the straw tube responses without the field and when the field of 1.3 T is collinear to the straw axis.

Charge resolution studies

Garfield++ allows to analyze the particle ionization energy loss in straw tube. The ionization energy loss distribution is described with Landau distribution with the most probable value (MPV) and width (Sigma) defined by the gas parameters, particle type and its track length. Examples of the ionization energy loss distribution for different types of particles crossing a straw tube at the distance of 0.1 mm from the anode wire are demonstrated in Fig. 2(a). The Fig. 2(b) shows the most probable values of the ionization energy loss as functions of the particle momentum for different types of charged particles.



(a) Example of ionization loss distribution fitted with Landau function



(b) MPV of Landau fits of the ionization energy loss for different particle types as functions of the particle momentum

Fig. 2: Performance for particle identification with dE in the straw tube. Distance between particle track and the anode wire is 0.1 mm

Straw signals measured with readout electronics correspond to the charge induced on the straw electrodes during the peaking time, which is significantly smaller than the complete straw signal charge. So the ionization energy loss measured with readout electronics will have the Landau distribution MPV and Sigma depending on the signal integration time: the longer signal gets collected, the better resolution is. To study the dependence, the straw signals generated with Garfield++ are integrated for different time values, and the ratio of the charge distribution width Sigma to MPV are shown in Fig. 3.

Straw charge resolution measurements were performed with test beams at PS (CERN) and SC-1000 (PNPI, Gatchina) proton accelerators. The test beam data obtained at PNPI also serve for testing the required dynamic range for PID of low momenta protons. Fig. 4 shows comparison of the PS test beam measurements and Garfield++ simulation results. The distance between the simulated particle track and anode wire is 0.1 mm. In the experimental data sample the tracks with the distance to the wire less 0.2 mm are selected. Such selection corresponds to variation of the particle path by at most 0.1%

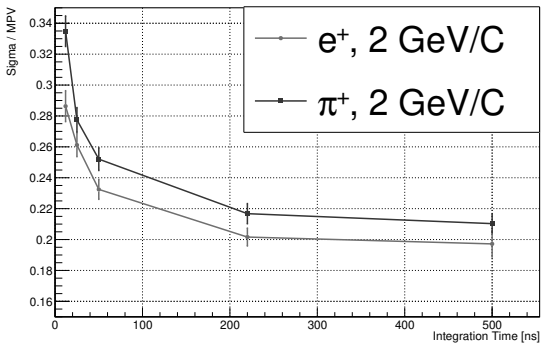


Fig. 3: Landau Sigma/MPV as a function of the charge integration time.

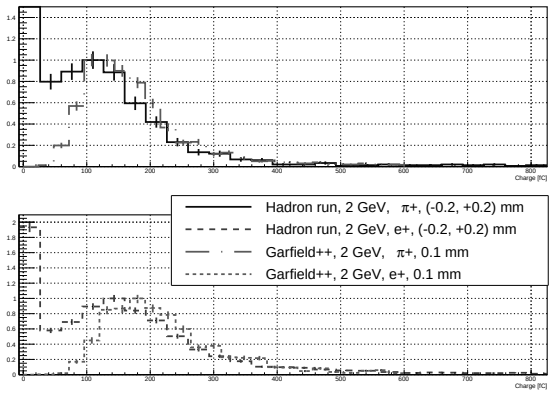
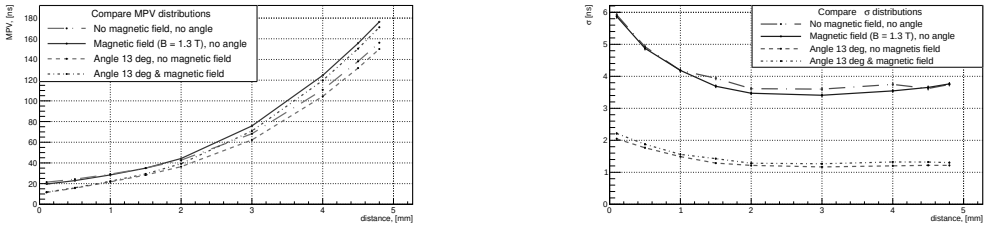


Fig. 4: Collected charge distribution from e+ and π+ particles crossing a single straw tube at distance 0.1 mm for Garfiled++ model and in range [-0.2; +0.2] mm for PS Test Beam data.

Spatial resolution studies

Time distribution of the Garfield++/LTSpice simulated straw signals crossing the threshold of 10 mV has Gaussian shape. The most probable value and width (sigma) of Gaussian fits are shown Fig. 5(a) and (b) as functions of the distance between the particle track and the anode wire. The results are obtained for the magnetic field of 0 and 1.3 T collinear to the anode wire. A corresponding straw response parametrization was proposed for the SPDroot simulation package [5].

The spatial resolution is studied for 1 GeV/c muons and for protons with various momenta. The time resolution as a function of the discriminator threshold is obtained for different values of the peaking time (10, 25, 100, and 150 ns), and for preamplifier gains of 3, 9, and 12 mV/fC. The equivalent noise charge of the readout electronics is fixed to 0, 1500, 3000 or 5000 electrons as described in [6]. The spatial resolution is shown to be better for smaller peaking time. The spatial resolution slightly affected by electronic equivalent noise charge. For low momenta protons the signal amplitude is larger due to the larger ionization losses, so the time resolution is significantly better then



(a) Most Probable value (MPV) (b) Width (sigma)

Fig. 5: Characteristics of the fitted Gaussian function describing the time distribution of the Garfield++/LTSpice simulated signals crossing the threshold of 10 mV as functions of the track position and the wire obtained with and without magnetic field.

for high momentum muons.

Conclusion

The paper presents a comprehensive simulation-based analysis aimed at optimizing the readout electronics for the straw drift tubes. The tracker's electronics requires a careful balance of properties. By modeling the system with Garfield++ and LTSpice, the effects of gain, peaking time, threshold, and noise were investigated. The agreement between the model and experimental data confirms the validity of the simulation and provides a reliable foundation for selecting the final electronics design.

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