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Full Length Research Paper

Simulation of spatial and energy resolution in signal for gas proportional detector

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Computer simulations of charge transport and signal generation mechanism have been performed for the Aleph Inner Tracking Detector geometry. A number of factors influence the signal arising from the charge carriers generated within detector volume. In the present simulation, signal fluctuations due to changing of incident charged particle energy and position of the primary generated electron-ion pairs in the gas volume have been examined. The simulation calculations are in good agreement with experimental results.

Key words: Signal generation mechanism, signal fluctuation, Monte Carlo device simulation, PACS: 21.60.Ka, 24.60.Ky, 29.40.Cs, 29.40.Gx.

INTRODUCTION

The ideal detector would give a clear and precise signal for each particle which passes through. A charged particle loses relatively little energy in the gas filled ionization detector since there is little gas material in the path of the particle. The small amount of electron-ion pairs released by charged particle should then be multiplied in the gas volume to give the clear signal required.

The signal mechanisms of gas proportional detectors have been investigated by several authors. Miyamoto and Knoll (1997) have investigated the fundamental limits to the energy resolution of proportional counter. Kundu and Morton (1999) have developed a new Monte Carlo simulation code in order to examine the nature of single electron-induced avalanching in cylindrical single wire proportional counters. Bronić and Grosswendt (2000) have measured the gas amplification factor in mixtures of argon with propan and DME at various pressures. Date et al. (2000) have investigated the electron kinetics in proportional counter using a Monte Carlo simulation. Deptuch and Kowalski (2007) have measured gas multiplication factor at various gas mixtures.

In a previous investigation (Tapan and Demir, 2004), we studied the simulation of gain fluctuation and the behaviour of the relative variance depends on the gain and anode voltage for various gas mixture ratios. In this work we purposed to investigate spatial and energy resolution in the signal for gas proportional detector, developing previous our Monte Carlo simulation code. In order to compare simulation and experimental results, the simulation code has been performed for the well known ALEPH Inner Tracking Detector geometry which is an argon based gas detector that is operated in a proportional mode.

The Inner Tracking Chamber (ITC) is a cylindrical multiwire drift chamber which forms part of the tracking system of the ALEPH experiment at LEP. It has eight concentric layers of axial sense wires, with these layers being paired, to give 4 double layers of cells. The four inner layers have 96 cells per layer and the four outer layers have 144 cells per layer. The drift cells of the ITC are hexagonal, with a central sense wire surrounded by 6 field wires. The sense wires are operated at a positive potential in the range 1.8 - 2.5 kV depending on ethane mixture ratio. The field wires are held at earth potential. The sense wires are made from 30 μm diameter gold plated tungsten, field wires are made from 147 μm diameter gold plated aluminum. Hexagonal shape of the drift cell and its dimensions can be seen in Figure 1 (Tapan and Demir, 2004; ALEPH handbook, 1995).

The gas gain obtained for the ITC drift cell above using argon-ethane gas mixture at the different operating voltage (Tapan and Demir, 2004). It can be seen from Figure 2 that our simulation results are in agreement with experimental results.

Signal generation mechanism in drift cell

A charged particle passing through the ITC drift cell loses its energy by ionizing gas atoms and produces primary electron-ion pairs

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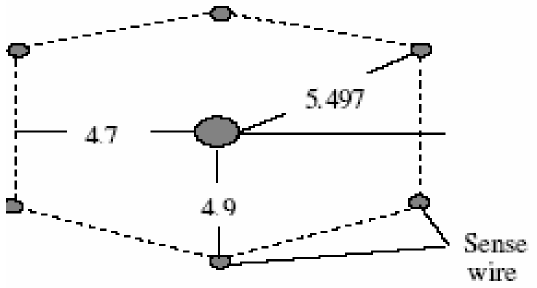

Figure 1. The geometry of the ITC drift cell (All dimensions are milimeters).

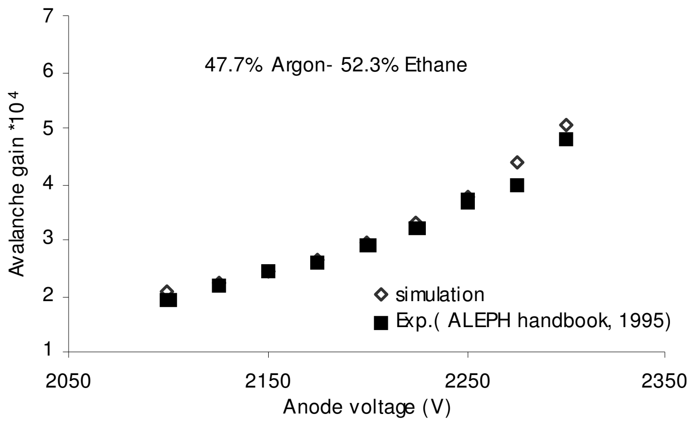

Figure 2. The calculated gas gain as a function of anode voltage in an Argon-Ethane mixture.

along its path. Energy loss distribution of charged particle is strongly asymmetric. This distribution can be parametrized by a Landau Distribution (Landau 1944) and it is given as a function of the reduced energy variable, λ:

$$L(\lambda)=\frac{1}{\sqrt{2\pi}}\exp\left[-\frac{1}{2}(\lambda+e^{-\lambda})\right] \tag{1}$$

The produced primary electrons drift in the electric field towards the anode wire while the positively charged ions drift slowly toward the cathode. By increasing the electric field in the gas volume (above a few kV/cm) electron has gained enough energy between successive collisions to ionize the gas atoms on collision. After such an ionization collision, an electron-ion pair is produced and the primary electron continues its trajectory. Electrons from ionized atoms are also accelerated and can knock out more electrons which in turn ionize other atoms, giving amplification by a factor of M in the number of electrons finally collected at the anode wire. In non-uniform electric field, the number of electrons will grow exponentially as they are drawn in a direction opposite to that of the applied field. The gas multiplication factor or gas avalanche gain is given by;

$$M = \exp\left[\int_{x_1}^{x_2}\alpha(x)\,dx\right] \tag{2}$$

The lower integration limit x_1 is the coordinate at which the charge multiplication starts due to high electric field strength, x_2 is the coordinate where multiplication process stops, and α is the first Townsend coefficient that depends on electric field strength and gas mixture ratio (Sharma and Sauli, 1993).

The electrons already generated at any stage in the avalanche gain mechanism may also be absorbed upon collision. The electron may attach itself to a neutral atom, so the intensity of free electrons, I_{oe}, traversing the gas falls exponentially.

$$I_e = I_{oe}\exp(-\eta x) \tag{3}$$

Where, η is called the attachment coefficient. This coefficient depends on the incident particle energy and is strongly affected by the presence of an electric field (Fernow, 1986).

Signal fluctuation

The statistical fluctuation of the signal created at the anode wire in the drift cell contain two separate terms, given by following relation (Miyamato and Knoll, 1997);

$$\left(\frac{\sigma_S}{S}\right)^2 = \left(\frac{\sigma_{N_i}}{N_i}\right)^2 + \left(\frac{1}{N_i}\right)\left(\frac{\sigma_M}{M}\right)^2 \tag{4}$$

Where, S is the average number of the charge carriers collected or means value of the signal, σ_s the standard deviation of S, N_i the average number of primary electrons, σ_{Ni} the standard deviation of N_i, M the mean avalanche gain and σ_M the standard deviation of M. The resolution in the signal is a function of the energy loss of incident charged particle or number of produced primary electrons and its fluctuation in the detector volume. The main contributions to the signal fluctuation come from the second term which involves the fluctuation of the gas amplification. Equation (4) is valid as long as all individual avalanches develop independently and there is no interaction between the ionization produced by incident electrons and that resulting from the avalanches (Miyamato and Knoll, 1997). This is the principal idea of Single Particle Monte Carlo technique.

RESULTS AND DISCUSSION

The signal was simulated by tracking a large number of individual primary electrons produced by incident charged particle traversing the cell and then following the generated electrons through the drift cell according to the signal generation mechanism described in Section 2, using Single Particle Monte Carlo (SPMC) technique. This is an approximate method that simulates the ensemble of carriers by monitoring the history of a single carrier transport processes. It is straightforward and can be carried out without needing to assume any particular shape for the distribution functions. From the calculation performed here, different values of signal have been produced for the charged particles traversing the ITC drift cell seen in Figure 3.

In order to see fluctuations in the signal, signal distributions have been produced. Figure 4 shows the simulated signal distributions for different passage of the charged particles with energy of 250 MeV. The fluctuation

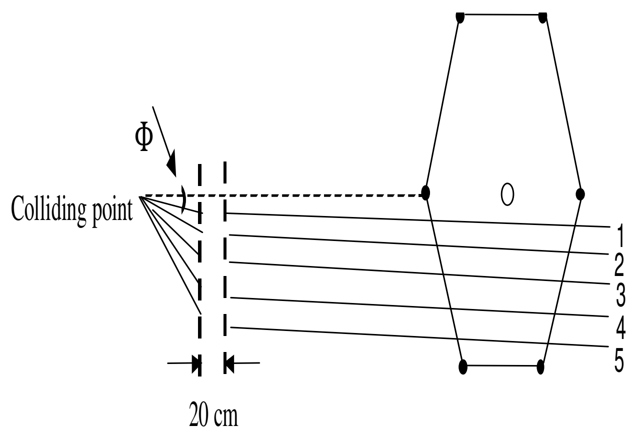

Figure 3. Schematic representation of the charged particles passing through the ITC drift cell.

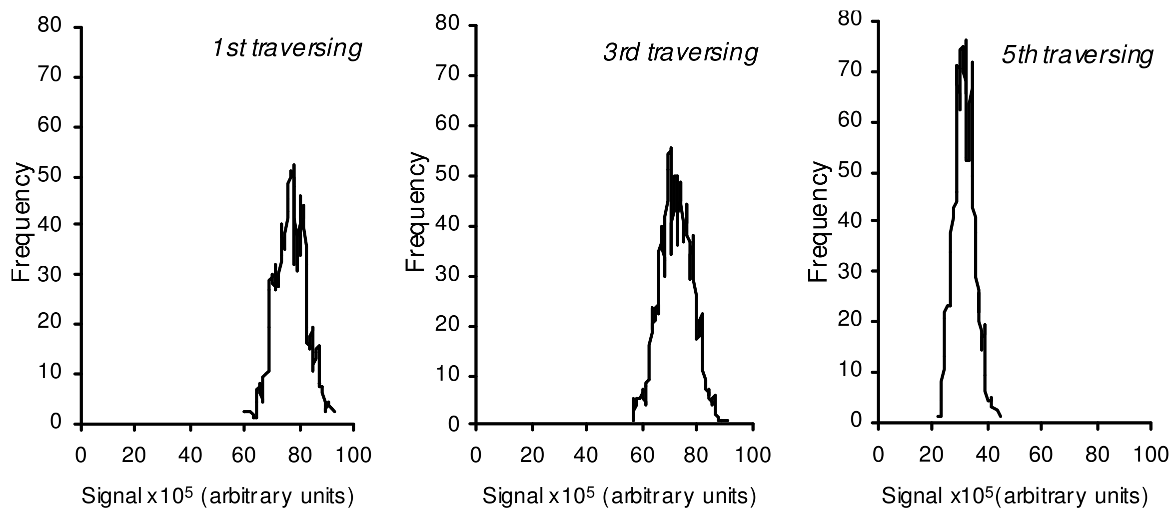

Figure 4. Signal distributions for different traversing.

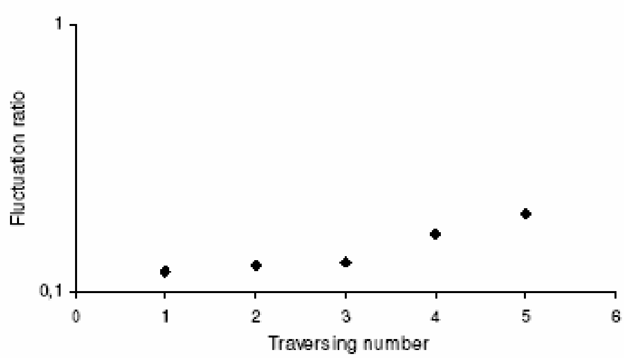

Figure 5. Relative fluctuation versus traversing position.

in the signal arises because of fluctuation in the number of the primary electron-ion pairs generated by incident particle and fluctuation in the avalanche gain mechanism.

The fluctuation in the signal was measured from the standard deviation of the distribution. The signal fluctuation ratio or the relative fluctuation in the signal, σ_s /S, was calculated and plotted in Figure 5 as a function of charged particle traversing position. By comparing how the fluctuations in the signal develop for the particles passing through the cell which has same mean avalanche gain and fluctuation, it is found from the simulation that the traverses close to the anode wire have the better resolution. This is because, in this case, incident charged particles lose more energy by creating more primary electron-ion pairs in the cell. The increasing of the number of primary charged carriers increase the mean signal as $S = N_i.M$ and this reduce the fluctuation in the signal.

The other reason is the spatial resolution depends on the amount of diffusion suffered by the primary electrons as they drift to the anode (Leo, 1987). In order to obtain higher

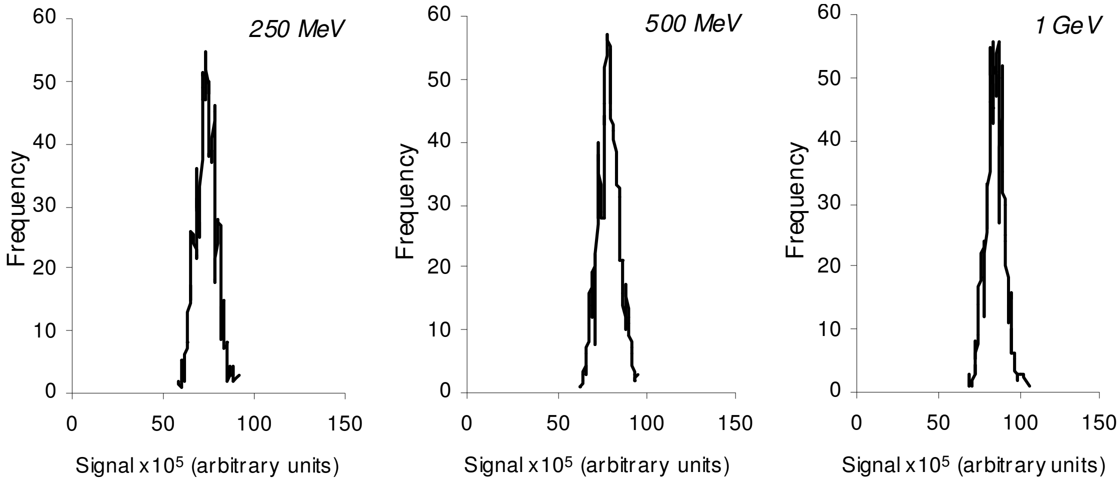

Figure 6. Signal distributions at three different particle energies.

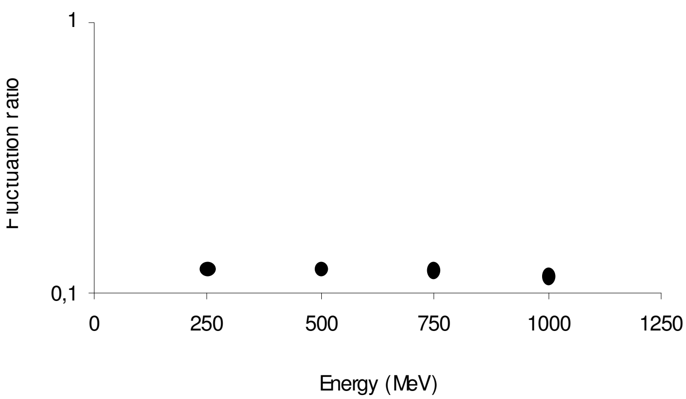

Figure 7. Relative fluctuation versus particle energy.

higher spatial resolution in the signal, therefore, a smaller drift length is necessary.

Signal distributions have also been produced, at the second traversing position, for the charged particles at different energies. Increase of the mean signal value with increasing incident particle energy for the same mean avalanche gain (the number of electrons collected at the anode from a single electron induced avalanche) can be seen in signal distributions in Figure 6. This is because, increasing of the incident particle energy, increase the number of primary electron-ion pairs generated in the cell volume.

The relative fluctuations in the signal are plotted in Figure 7 as a function of incident charged particle energy. In general, the resolution is a function of the energy deposited in the detector volume. The ratio σ_{N_i}/N_i improve with higher energy. Since the incident particle energy increases, the number of the ionization events which means the number of the primary electron-ion pairs increases resulting in the smaller relative fluctations in the signal. The simulations also suggest that better energy resolution in the signal is obtained for drift cells of lower radii for the same mean avalanche gain.

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