Monte Carlo studies of micromegas as a neutron detector and its track reconstruction*

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Abstract In this paper a two dimensional readout micromegas detector with a polyethylene foil as converter was simulated on GEANT4 toolkit and GARFIELD for fast neutron detection. A new track reconstruction method based on time coincidence technology was developed in the simulation to obtain the incident neutron position. The results showed that with this reconstruction method higher spatial resolution was achieved.

Key words simulation, neutron detector, track reconstruction

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1 Introduction

Micromegas as a kind of micro-pattern gaseous detector has many outstanding features. Its gain can be large enough so that it doesn't need an additional preamplification[1]. Especially for its good radiation hardness and excellent timing properties it has been used for many highly radioactive cases. Although it was originally designed for charged particles and X-rays[2], with a convert material it could also be used for neutron detection[3—5] and have a good spatial resolution.

A detailed Monte-Carlo study for micromegas as a neutron detector had been done in Ref. [4], but converters used in that work were only ^{6}Li and ^{10}B. In their work the recoil protons were cut off as a kind of background particles. However, for fast neutron detection, polyethylene could be also used as an important convert material for its cheap price. Furthermore, the only charged ion in elastic (n,n′) reaction in polyethylene is proton. So there is no need to do particle identification in data analysis as Refs. [3, 4] have done. On the other hand, there was no track angular correction in Refs. [3, 4], while the production of the nuclear reactions induced by incident neutrons did not fly into the detector perpendicularly. The position of an incident neutron was simply defined as the middle point of the track in the detector, which causes the main errors in determining the actual location of incident neutron.

Simulation is of considerable value in testing different methods when determining the incident neutron position. In this paper, many processes have been simulated to study the performance of micromegas with a polyethylene foil using recoil proton for neutron detection. Based on our simulation of particles ranging from incident neutrons to electrons collected in avalanche region, a new readout method by time coincidence is developed. Related experimental work has been proposed at the Institute of Modern Physics, CAS.

2 Monte-Carlo simulation methods

In our simulation, the neutron micromegas detector layout is shown in Fig. 1.

The neutron detection is mainly composed of three stages. In the first stage, a neutron with an initial kinetic energy of 14 MeV perpendicularly flies into the detector, and in the polyethylene foil it has a possibility to transfer a part of its energy to a hydrogen atom by elastic scattering. The recoil proton

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flies out of the converter with energy dependent angular distribution when the recoil proton has enough energy to leave the converter for the drift gap.

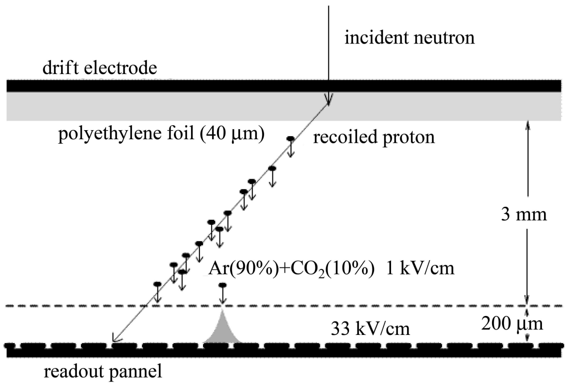

Fig. 1. Scheme of the detector.

In the second stage, a recoil proton looses its energy along its track in the drift gap and produces ion-electron pairs. And then the electrons drift to the mesh due to the electric field. This process will continue until the energy loss is smaller than the average ionization energy. The fluctuation of ionization energy is taken into account and its mathematic description is based on another simulation with GARFIELD[6]. Fig. 2 shows the distribution of ionization energy for a given track. Furthermore, in each step of the track, the initial direction of released electrons distribute randomly in the step. The transportation of the released electrons in different position is simulated by a parameterized transportation function which is position dependent and derived from a computation based on GARFIELD. The batch file used here was download from Ref. [6] but modified for our cases. As the field in drift gap is roughly uniform, the longitudinal and transverse diffusion of electrons which drift from their product vertex to the mesh plane can all be simply described as two Gaussian functions.

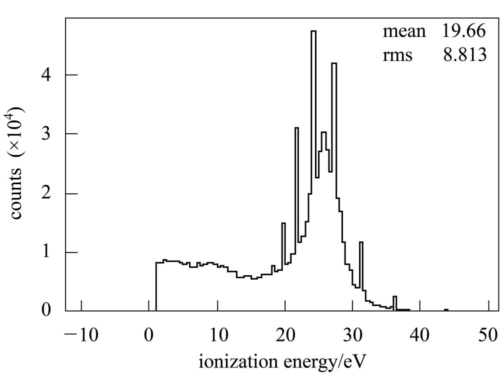

Fig. 2. Ionization energy distribution.

In the third stage, all the ionized electrons drifting to the mesh are assumed to pass though the mesh according to Ref. [2]. Every primary ionized electron induces an avalanche between the mesh and the readout electrodes. The size of an electron cluster made by one avalanche depends on the transverse diffusion in avalanche region. The multiplicity of this process may vary in a large range, while its logarithm roughly obeys Gaussian distribution (shows in Fig. 3), according to our simulation by GARFIELD. It means that in simulation, the electrons drift at equivalent avalanche length which is in a Gaussian distribution. All electrons are collected by a 2 dimensional readout plane, whose width for each channel is set to 317.5 μm, to compare the results with the experiment data in Ref. [3].

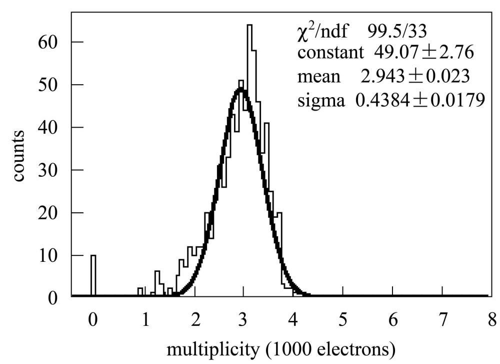

Fig. 3. Multiplicity of electron.

The gas filled in the chamber is a mixture of argon (90%) and carbon dioxide (10%). It is not the best but a safe configuration. The metallic mesh and the avalanche region are not simulated directly in our present work but their main effects in electron transportation are taken into account in the transportation functions. Most of the recoil protons produced by the 14 MeV incident neutron don't have enough energy to pass through the mesh and induce a detectable effect on the final signal. Because the mesh and avalanche regions are not directly present in the simulation, in the final spatial resolution, it is impossible to take into account the contribution induced by the primary ionized electrons which pass though a hole of the mesh but are produced in front of another hole. Systematic error induced by this effect is less than 10 μm according to Ref. [7], which can be neglected compared with the total error of few hundreds microns.

In our simulation, the other following effects are neglected: the signal induced by ions, the space charge effect, the electric noises and crosstalk between adjacent readout strips. Based on the discussion in Ref. [7], we presume that every electron in the avalanche region is collected by electrodes.

3 Signal readout

For an electron knocked out by a recoil proton in the drift gap, the σ_t, which is the position variance induced by transverse diffusion, is proportional to the square root of drift distance. Therefore the profile of an event induced by a proton on the y-z plane (on the mesh) should be a cone as Fig. 4 shows. Every point in that figure stands for the position of a primary ionized electron that has drifted to the mesh plane. It is an ideal case that there is no error in readout. Fig. 4 clearly shows the ionization process of the recoil proton in drift gap. The track of the proton starts at the position on z axis larger than -2000 μm and ends at the position on z axis about -5700 μm. Furthermore, one can find that the track's projection is roughly anti-parallel to z axis. In experiment it is difficult to obtain all of the information.

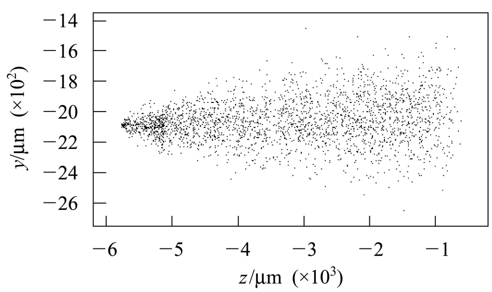

Fig. 4. A typical event projected on the mesh plane.

Figure 5 shows the response function induced by a proton. One can compare them with the corresponding figures from experiment in Ref. [3]. Because the protons don't always fly into the chamber perpendicularly, it is necessary to have an angular correction to obtain higher spatial resolution. In Refs. [3, 5] it was obtained by event cut that FCS (Fitted Cluster Size) should be smaller than 4.5. However, this method leads to a rejection of 53% of the total events.

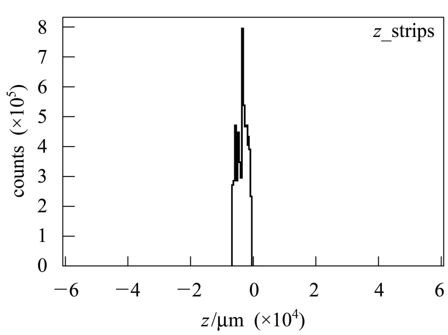

Fig. 5. A typical response of the detector.

In fact, there is an important character in these signals which makes measuring a track's start point possible.

Figure 6 shows the time information of the track in Fig. 4. The longitudinal axis is the time interval from the event start to a free electron arrival on the mesh plane. The transverse axis is the positions of primary ionization electrons on z axis. The time spent by the recoil protons flying in drift gap can actually be ignored in Fig. 6. For instance, a recoil proton with kinetic energy of 1 MeV has a velocity of about 4 percent of the velocity of light in vacuum. Such a proton spends less than 0.5 ns on flying through the drift gap. Thus Fig. 6 actually shows that the electrons ionized in different places spend different time on drifting to the mesh plane. In our detector, for the electrons which are ionized 3 mm away from the mesh plane (at the top of the drift gap as Fig. 1 shows), according to Fig. 6, it will cost about 60 ns for them to drift to the mesh. Since the electric field in the drift chamber is roughly uniform, the electron drifting velocity is a constant. Consequently, the electron drifting time is proportional to the distance between the ionization place and the mesh plane. No matter how large the kinetic energy of a recoil proton is, the signal induced by it should have the same time character which only depends on the configuration of the detector.

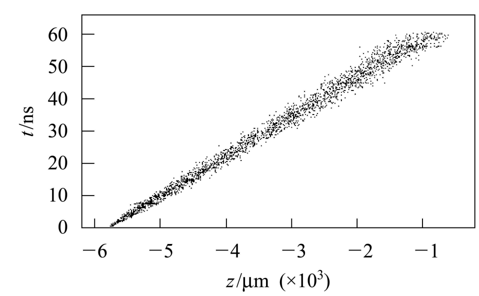

Fig. 6. Time information of the track as a function of z.

Based on these arguments, a time coincidence technology is developed to extract the initial position of a track from its signal. In this technology, the main thing to do is to measure an event in few fixed time intervals. As all of the signals have the same time character, the relationship between different intervals is invariant to all of the recoil protons with different kinetic energies. The simplest one readout system using this technology is shown in Fig. 7. According to Fig. 7, once an event triggers the electronics by its electrons ionized near the mesh, the readout system will record signals after 55 ns later. According to Fig. 6, it is obvious that by this way only the beginning part of the track could be recorded. The centroid of the recorded signals gives the position of the incident neutron. The 55 ns time delay (the delay time of the or and trigger unit is meglected) depends on the detector configuration and is not even an optimal value for our case. In this one-readout-system method, too large delay time makes large statistic error for the case with few primary electrons to be recorded whereas the too small one makes the signal centroid far away from the incident neutron position. The best one should minimize the total experimental error.

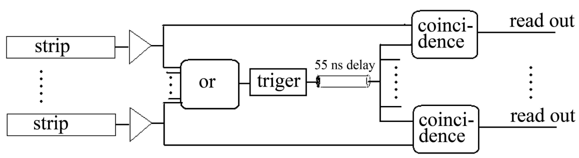

Fig. 7. Schematic diagram of the readout electronics.

Another readout way using the time coincidence technology has a more complicated configuration but with slightly higher spatial resolution. As an example, suppose we have two readout systems. The first one records the first 20 ns parts of a track produced by a proton and the second one leaves 40 ns parts of the track. Further, if the centroid of the first 20 ns parts of the track is denoted by p_1 and the centroid of the second part by p_2, the position of the incident neutron (denoted by p) can be easily calculated from the relationship of $3\times p=5\times p_2 - 2\times p_1$. As the first part records electrons ionized near the mesh, the drift distances of these electrons are very short and the transverse diffusion is small in this part. Thus the two-readout-system method can provide us with more accurate position information of the incident neutron but needs an obvious more complicated readout system. In the present work, only the one-readout-system method is studied.

4 Results and discussion

In the simulation, to evaluate the final spatial resolution with the one-readout-system method, the deviations of measured positions of the incident neutrons from the incident positions are filled to a histogram shown in Fig. 8.

The deviations decay in an exponential way. In Fig. 8 an exponential fitting is done and the reciprocal of the slope of the fitted function is regarded as the spatial resolution of the detector. The value is 326.3 μm. To compare the effect of the readout method, the deviation from a readout system without delay is shown in Fig. 9. The spatial resolution got by this method is 3463.8 μm, which is about ten times larger.

To obtain higher spatial resolution, one simple way is to reduce the width of the drift gap. In the simulation the width was reduced to 1 mm while the delay time was also shortened to 19 ns.

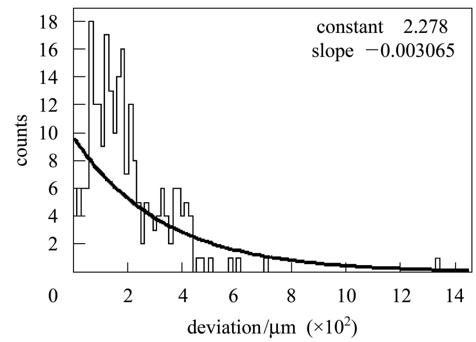

Fig. 8. Deviation of the measured position.

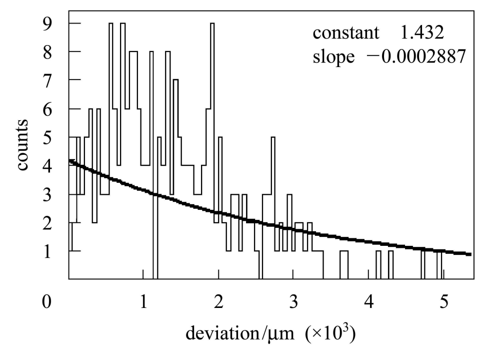

Fig. 9. Deviation of the measured position.

An exponential fitting shows that the spatial resolution for this detector configuration is only 91.9 μm. In our future experimental work this configuration will be taken into account.

The time coincidence technology used here is based on an assumption that the count rate of incident neutrons is low enough so that there is only one track in the detector per time. A track lasts for few ten nanoseconds. In this time interval if there is another track in the detector, the readout system will provide a wrong result. However, in future experiment, the count rate of tracks can be controlled by modifying the thickness of the converter materials according to the neutron flux. To estimate the convert efficiency for different thickness of polyethylene foil, another independent simulation has been done.

Furthermore, as this technology can only detect the event which has a complete track in the drift chamber, it has an apparent suppression of gamma and X radiation.

In principle, using time coincidence technology doesn't have any significant effects on the detector's time response, as a good event always needs the same time to be collected, and the delay time for coincidence is aimed at collecting only one part of the total signal which is induced by one event. Technically, it does bring some additional dead time by a little bit more complicated electronics. However, as the depth of drift chamber has been reduced by two thirds, definitely there is a significant enhancement on the detector time response. Thus the additional dead time from electronics should not be a big issue.

To summarize, in this paper we developed a new method reconstructing the recoil proton track to measure fast neutron and get a better spatial resolution for neutron than ever before. Furthermore, this method could be used not only for neutron detection with polyethylene or other converter, but also for any other charged particles measurement with micromegas.

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