Study on spatial resolution of micromegas as a neutron detector under condition of high neutron flux and γ ray background*

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Abstract In this paper Micromegas has been designed to detect neutrons. The simulation of the spatial resolution of Micromegas as neutron detector is carried out by GEANT4 toolkit. The neutron track reconstruction method based on the time coincidence technology is employed in the present work. The influence of the flux of incident 14 MeV neutron and high gamma background on the spatial resolution is carefully studied. Our results show that the spatial resolution of the detector is sensitive to the neutron flux, but insensitive to the intensity of γ background if the neutron track reconstruction method proposed by our group is used. The γ insensitivity makes it possible for us to use the Micromegas detector under condition which has high γ-rays background.

Key words micromegas, neutron detection, GEANT4, spatial resolution, γ sensitivity

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1 Introduction

During the last several years, Micromegas, which is initially used for tracking particles in high-rate, high-energy physics experiments[1], as a novel micro-pattern gaseous detector has been widely developed for many different applications. It has many outstanding characteristics, such as high gain, high rate capability, good spatial resolution, excellent timing properties and robustness[2]. Therefore, it has been used for many highly radioactive cases. Due to these properties, the Micromegas detector is also exploited as a new neutron detector and operated with some high neutron flux and in high temperature environment[3—5]. However, in the neutron flux measurement, the neutron flux always accompanies high γ-rays background. Then, it is necessary that the neutron detector is sufficiently sensitive to neutrons and insensitive to γ-rays.

In the case of neutron, first, the neutron reacts with special converter material to produce the charged particle through nuclear reaction or elastic scattering, and then by testing induced charged particles, the information of the incident neutron can be indirectly obtained. Monte Carlo simulation had been done for Micromegas neutron detector in Ref. [6] in which the converter materials were ^{6}Li and ^{10}B for low energy neutrons. In our work, we use a polyethylene foil as the neutron/charged particle solid converter to detect the 14 MeV neutron and extract the position information of the impact neutron. The position information of neutron is very important in the neutron tomography or CT.

In this paper, the neutron track reconstruction method based on the time coincidence technology is employed. By simulating the whole physical processes from the moment that neutron beam enters the boundary of the detector to the moment that electrons are collected by anode strips, we have studied the variation of the spatial resolution of Micromegas with different primary neutron flux and the intensity of gamma background. The results indicate that the spatial resolution of the detector is insensitive to γ-rays using the time coincidence technology. So the

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new concept of neutron detection can be used in some fusion experiments or experiments with nuclear reactor, which require the detector not to be blinded by the high γ-rays flux.

2 Detector description

The structure of the Micromegas detector is shown in Fig. 1. It is separated into a double stage parallel gaseous chamber (1 mm drift gap and 200 μm amplification gap) by three planar electrodes. The drift electrode is made of a 50 μm aluminized mylar, under which is a 40 μm polyethylene foil as converter. The middle electroformed mesh is made of pure nickel, and the third (anode) electrode is composed of 2-D gold-plated copper strips with a pitch of 317.5 μm. The gas mixture filled in the chamber is Ar(90%)+CO_2(10%) at atmospheric pressure. By applying negative voltage of a few hundred volts on the micromesh and a slightly higher voltage on the drift electrode, the electric field in the drift gap is about several keV/cm and in the amplification gap is around tens keV/cm. Because of the action of electron field, the ionized electrons produced by the avalanche process are collected by the PCB electrode. Meanwhile, the positive ions drifting at a relatively slow velocity in the opposite direction are collected by the micromesh.

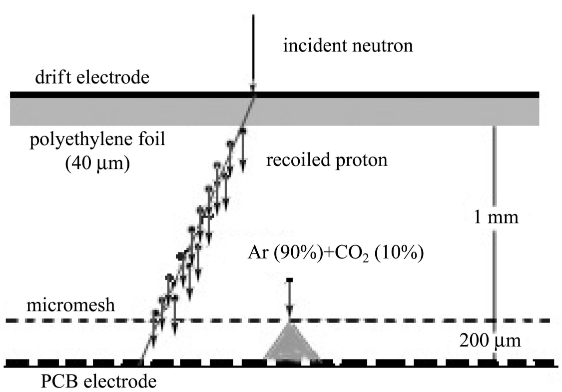

Fig. 1. The structure of the micromegas detector.

3 Physical processes

The neutron can be indirectly tested by the interaction of neutron with solid converter material deposited on the drift electrode or gaseous in the detector. In this paper, the solid converter is used. The main advantage of the solid converter is the excellent spatial resolution by using small drift gap. Such performance is not easy to obtain using gaseous converters. By GEANT4 toolkit, the main physical processes within the detector are simulated as follows:

First, the neutron beam enters normally the detector and has H(n, n')p elastic scattering with hydrogen in the CH_2 converter. The recoil protons are continually slowed down in polyethylene. When the proton's energy is high enough, it flies out from converter layer and enters the drift gap. The proton which enters the drift gap impacts the working gas and loses part of its energy. When the energy loss is larger than the average ionization energy, the gas is ionized to produce initial electron-ion pair. The fluctuation of ionization energy in each step is taken into account. The ionization positions of the electron-ion pairs are randomly distributed in each step. Based on the simulation of GARFIELD[7], the longitudinal and transverse diffusion of ionized electron in transportation process can be roughly regarded as two Gaussian distribution[8].

Then, electrons pass through the micromesh under the action of electron field and induce electron showers in the narrow amplification gap. The multiplicative electrons induce electronic signal in PCB electrode in the transportation process. In our simulation, the transportation processes in avalanche region are not directly simulated. But the main effects of multiplication and transverse diffusion of electron are considered. According to the simulation of GARFIELD, the logarithm of the electron multiplication and the size of an electron cluster obey Gaussian distribution too[8].

In our simulation, the influences of the signal induced by ions, micromesh grid, space charge effect and electronic noises on the spatial resolution are not considered.

4 Results and discussion

In this simulation, we have studied the deviation between the reconstruction position, which is calculated with the signals from PCB electrode plate, and the position of the incident neutron. This deviation conforms to the exponential distribution, so the exponential fit is adopted. The reciprocal of the fit function's slope is treated as the spatial resolution of the detector[8]. The time information of the track in drift gap had been simulated in Ref. [8]. Because the velocity of proton is much faster than the drifting velocity of ionization electron, it was thought that all primary ionization electrons were produced at the same time. When electrons were ionized 1 mm away from the micromesh, it took about 20 ns to arrive at the micromesh. By contrast, the electron which was ionized in the surface of the micromesh only spent several ns to the micromesh. It is known that the primary ionization electrons near the converter are close to the position of the incident neutron. So, the delay method based on time coincidence technology is employed. According to the method, the mean position of recorded signals after the delay 19 ns in every 22 ns gives the position of the incident neutron. To show the advantage of this method, the common position reconstruction method of getting the mean position of all recorded signals in every 22 ns is also adopted at the same time.

4.1 Spatial resolution

We have simulated the spatial resolution of the detector when a 14 MeV neutron perpendicularly flies into the detector before[8]. In this paper, we study the variation of the spatial resolution versus the different flux of 14 MeV neutron beam in Fig. 2. Square dots represent the spatial resolution using the common position reconstruction method and empty circular dots represent the spatial resolution got from the delay method. According to the simulation the conversion efficiency of 14 MeV neutrons in 40 μm of polypropylene is about 2×10^{-4}. When the flux of neutron beam is 1×10^{10} n/s, there is only one proton flying into the drift gap in the region of time resolution of the detector. In this situation, the spatial resolutions got with these two position reconstruction methods are 834 μm and 87 μm respectively. When the flux of neutron beam reaches 2.5×10^{11} n/s, within the time resolution of the detector there is more than one proton flying into the drift gap and only the first one is assumed to generate the signal in our simulation. The spatial resolutions are 3409 μm and 7980 μm respectively. From our simulation, it is clear that the delay method can provide better spatial resolution. However, when the flux of neutron beam is higher than 2.5×10^{11} n/s and it is possible to have more than one track in the detector every time, the detector can not provide high spatial resolution and detection efficiency. Fig. 3 is the simulated detection efficiency as a function of the flux of the neutron beam.

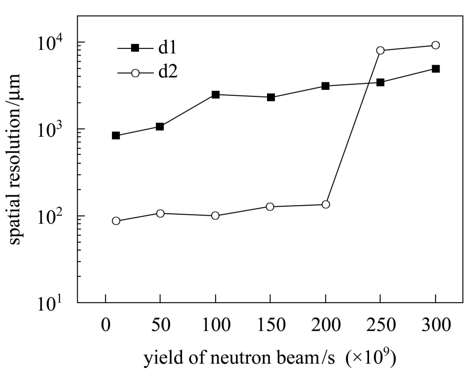

Fig. 2. The spatial resolution as a function of the flux of neutron beam. (d1) common position reconstruction method; (d2) delay method.

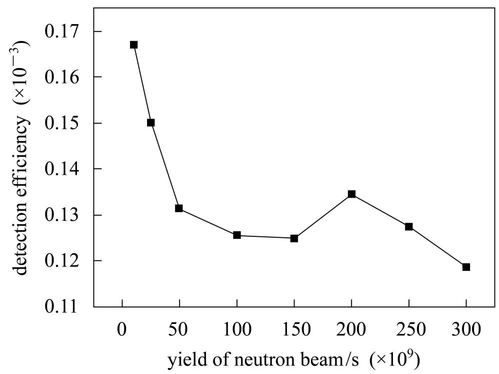

Fig. 3. Relationship between the detection efficiency and the neutron flux.

4.2 γ-rays insensitivity

Before the neutron beam flies into the detector, part of these primary neutrons interacts with the material surrounding the target, such as reaction chamber, supports, grounds, walls, leading to γ-rays emissions[9]. When the neutron beam enters the detector, it accompanies high γ-rays background. The influence of high gamma background on the spatial resolution is also simulated. The insensitivity of detector to γ-rays under certain conditions has been studied in some experiments[9, 10]. In their work, because the depositing energy of gamma is much less than neutron, they set a threshold on electronic to reject gamma. The track reconstruction of the incident neutron wasn't done in their work.

In our simulation, the γ-rays background spectrum induced by 14 MeV neutrons is shown in Fig. 4[1)]. Fig. 5 is the spatial resolution variation in high gamma background when the flux of incident neutron beam is 1×10^{10} n/s. The results indicate that with increasing the gamma background, the spatial resolution becomes worse for the common position reconstruction method. By contrast, the spatial resolution from the delay method is insensitive to high gamma background. This is because, if the delay

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method is used, the signals are recorded only when electrons are ionized to produce the signals along the whole track in the draft gap. The interaction between γ-rays and converter or gas in the chamber leads to electron emission by photoelectric, Compton effect or pair creation. The proton induces more electron-ion pairs than electrons or γ-rays do[9]. In most situations, the ionization induced by gamma happens only within a small area, unlike the recoil proton which ionizes electron-ion in the whole drift gap. So gamma is hardly recorded. With the increasing of gamma background, the recorded electrons may be only induced by gamma or X-ray in 22 ns and these events are regarded as noise and neglected in our simulation. As shown in Fig. 6, the efficiency of the detector decreases with increasing the gamma background.

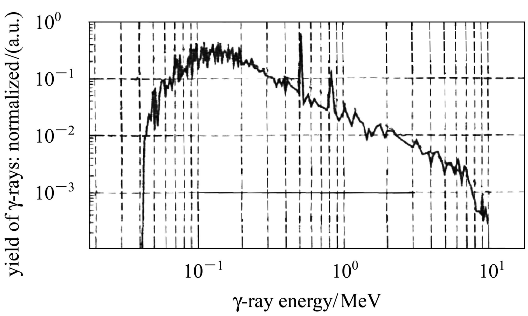

Fig. 4. γ-rays spectrum induced by 14 MeV neutrons.

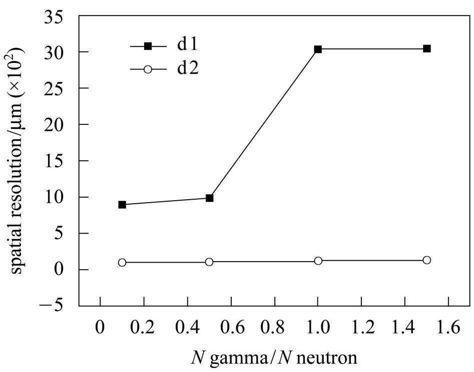

Fig. 5. The dependence of spatial resolution on the gamma background. (d1) common position reconstruction method; (d2) delay method.

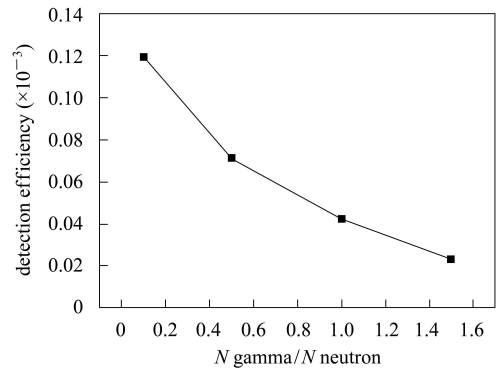

Fig. 6. Relationship between the detection efficiency and the gamma background intensity.

5 Conclusions

In actual measurement, the specific position of the incident neutron can not be precisely known, but can only be estimated by the recorded signals in anode electrode, whereas the precise neutron location is known in simulation. So the simulation of a Micromegas neutron detector is of considerable value for one to study the spatial resolution. The present simulation results indicate that the spatial resolution from the delay method can be as good as 100 μm, much better than that from the common position reconstruction method if the flux of incident neutron is less than 10^{11} n/s. Meanwhile, the spatial resolution from the delay method is insensitive to gamma background. These novel properties make it very appealing to apply the Micromegas as neutron detector under huge gamma environment induced by the intensive neutron beam.

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