**Article ID**: 1007－4627(2010)03－0291－05

# Monte Carlo Simulation of Spatial Resolution of Micromegas as a Neutron Detector*

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**Abstract**: In the present work, the spatial resolution of Micromegas as a neutron detector was simulated with GEANT4 and Garfield program. The polyethylene foil was used as neutron converter. A new method based on structural setting on the top-layer of the detector was adopted to obtain spatial resolution. According to our simulation, it turned out to be a better spatial resolution, and this method was easily realized in experiment.

**Key words**: Micromegas; neutron detector; spatial resolution; simulation

**CLC number**: O571.53　　**Document code**: A

## 1 Introduction

Micromegas is a novel two-stage parallel-plate avalanche chamber with many outstanding features. It combines high accuracy, high gain, high counting rate capability, good timing properties and robustness. A detailed description and experimental results can be found in Refs. [1—3]. Although it was originally designed for charged particles and X-rays, with a convert material it could also be used for neutron detection[4—6] and has a good spatial resolution.

A detailed Monte Carlo study for Micromegas as a neutron detector had been done. In this 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 it is not necessary to do particle identification in data analysis. On the other hand, there was no track angular correction[4, 5]. The position of an incident neutron was naively defined as the middle point of the track in the detector, which led the main part of the uncertainty of 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 for neutron detection. Based on our simulation of particles ranging from incident neutrons to electrons collected in avalanche region, a readout method by time coincidence is used and related experimental work has been proposed[7].

According to our simulation, some valuable results have been obtained, which are important to instruct and optimize the design of Micromegas as a neutron detector.

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* **Received date**: 8 Jan. 2010; **Revised date**: 31 Mar. 2010

* **Foundation item**: Creative Experimental Project of National Undergraduate Students

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## 2 Monte Carlo Simulation Methods

In our simulation, the layout of a Micromegas detector for neutron is shown in Fig. 1. This 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. In the polyethylene foil it has a possibility to transfer a part of its energy to a hydrogen by elastic scattering[8].

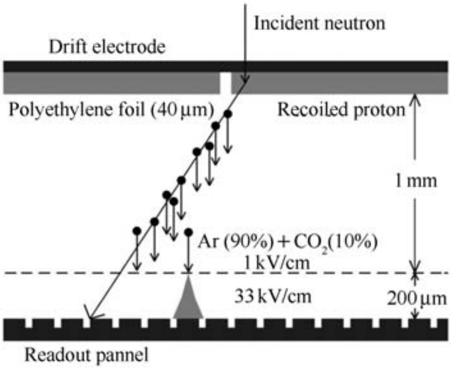

Fig. 1 Scheme of the detector.

The ratio between the number of the recoil protons and the number of the incident neutrons is defined as neutron-proton conversion efficiency of the converter. In the polyethylene foil, the incident neutrons are scattered mainly by the hydrogen nuclei, which produce recoil protons. As the thickness of the polyethylene foil increase, more recoil proton is produced. At the same time, increasing the scattering of the recoil proton may reduce the spatial resolution. On the other hand, while the thickness increases, more recoil protons vanish in the converter due to the Coulomb scattering increases, which causes more energy loss of the recoil protons. Taking into account the neutron detection efficiency being in the order of $10^{-3}$, we use the polyethylene foil with a thickness of 40 $\mu$m, and then the conversion efficiency is in the order of $10^{-3}$. The recoil proton flies out of the converter with energy dependent angular distribution when the recoil proton has enough energy to leave the foil. The correlation between the conversion efficiency and the foil thickness is shown in Fig. 2.

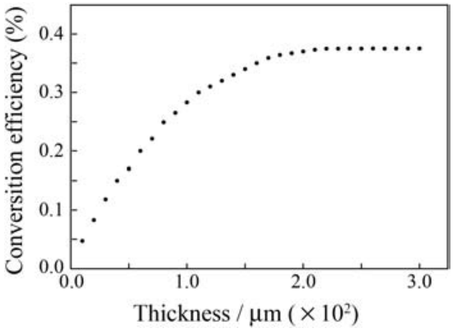

Fig. 2 Neutron-proton conversion efficiency of the converter.

In the second stage, a recoil proton loses its energy along its track in the drift gap and produces electron-ion pairs, and then the electrons drift to the mesh according to the electric field. This process will continue until the energy loss is smaller than the average ionization energy. Fig. 3 shows the distribution of ionization energy for a given track. 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.

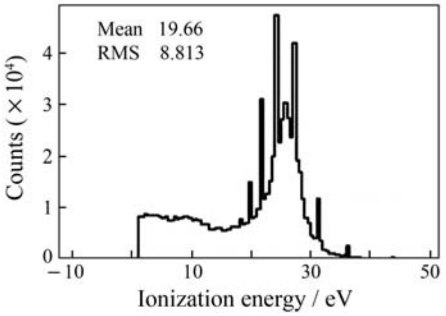

Fig. 3 Ionization energy distribution.

In the third stage, all the released electrons drifting to the mesh are assumed to pass though the mesh[1]. Every primary released electron induces an avalanche between the mesh and the readout electrodes. The size of an electron cluster made by each avalanche depends on the transverse diffusion in avalanche region. According to our simulation by Garfield program, the electrons drifted at equivalent avalanche length which is in a Gaussian distribution, shows in Fig. 4.

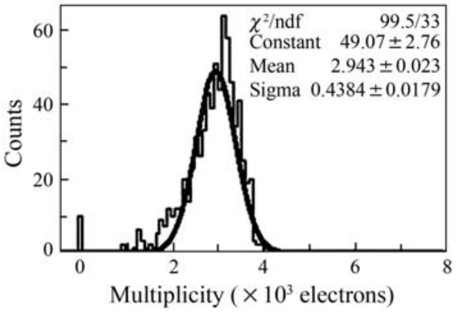

Fig. 4 Multiplicity.

The gas filled in the chamber is a mixture of argon (90%) and carbon dioxide (10%). 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 one hole of the mesh but are produced in front of another hole.

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. [9], we presume that every electron in the avalanche region is collected by the electrodes.

## 3 Mathematical Modeling

A recoil proton with kinetic energy of 1 MeV has a velocity of about 4 percent of the velocity of light in the vacuum. Such a proton spends less than 0. 5 ns on flying through the drift gap. In our detector, the electrons which are ionized 1 mm away from the mesh plane (at the top of the drift gap as Fig. 1 shows) will spend about 20 ns 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 from the place where it is ionized to 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. In our simulation, a time coincidence technology is used, to extract the initial position of a track from its signal[7].

To estimate the final spatial resolution of the detector, a set of slits with variant width were made on the polyethylene foil. Once the neutron flies into a slits, as there is nothing but mixed gas, almos no proton can be producted. So there should be a gap in the final reconstructed neutron positions caused by the slit.

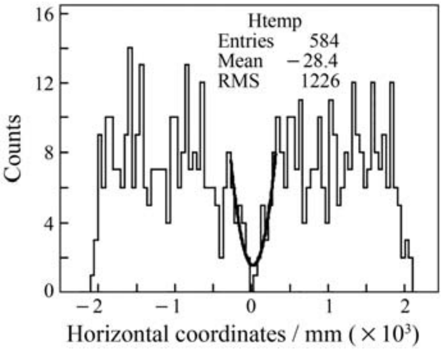

Fig. 5 Particle distribution @ 400 μm.

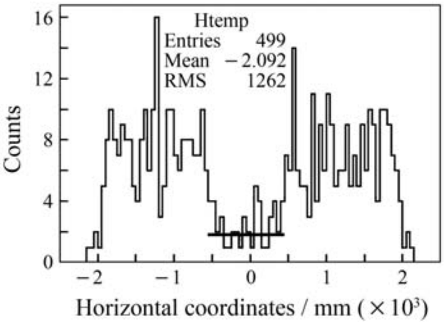

Fig. 6 Particle distribution @ 1000 μm.

In this procession, we obtain a batch of figures showing the reconstructed position of the incident neutron with different slit width in Figs. 5 and 6. Fig. 5 shows the results with a slit of 400 μm and Fig. 6 shows the results with a slit of 1000 μm. Compared with Fig. 5 and Fig. 6, it is easy to get the conclusion that when the width of the slit is too large, the intrinsic spatial resolution of the detector contributes negligibly to the reconstructed slit width.

Keeping in mind that the slit's effect on the histogram is equivalent to the effect of impulse function in the electronic signal transmission, and the electronic avalanche is equal to the effect of transfer function. We can use the convolution to deal with impulse function and the transfer function, take two step functions $\mu_1(t)$, $\mu_2(t+\tau)$ as the impulse function, and take Gaussian function $f(t)=\exp[-k/\sigma]$ as the transfer function:

$$g(t)=\mu_1(t)f(t)\mu_2(t+\tau) \ ,$$

where $g(t)$ is the convolution of impulse function and the transfer function, $t$ is the process of time.

## 4 Results and Discussion

In the simulation, to evaluate the final spatial resolution with the time coincidence method, the reconstructed positions of the incident neutrons from the incident positions are filled to a histogram shown in Figs. 5 and 6.

In Fig. 7 an mathematical approximation fitting is done and the intersection of the fitting curve with the longitudinal axis is regarded as the spatial resolution of the detector. The value is 121. 2 μm. Where histogram sigma is the spatial resolution with different slit width.

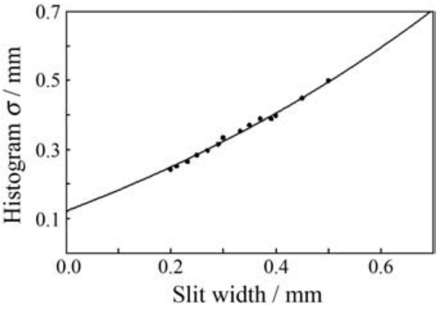

Fig. 7 Mathematical approximation fitting.

According to the relationship between the neutron conversion efficiency and the thickness of polyethylene, the counting rate can be controlled by modifying the thickness of the converter materials according to the neutron flux shown in Fig. 7. We obtain a better result of spatial resolution, based on an assumption that the count rate of incident neutrons is so low that there is only one track in the detector at most. A track lasts for few ten nanoseconds. In this interval if there is another track coming in, the readout system will get a wrong result. To estimate the conversion efficiency for different thickness of polyethylene foil, in the present simulation, the accumulation can be avoided. In our simulation, we use the polyethylene foil with a thickness is 40 μm.

In this paper, we have simulated the Micromegas detector for neutron detection by a new readout method to estimate the spatial resolution and got a better result. Furthermore, this idea could be used not only for neutron detection with polyethylene or other converter, but also for any other charged particles measurement with Micromegas, and this method is so easily realized in experiment.

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# Micromegas 中子探测器位置分辨特性的 Monte-Carlo 研究*

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**摘　要**：利用 GEANT4 和 Garfield 气体探测器模拟程序模拟了 Micromegas 中子探测器位置特性。在漂移极上加一层聚乙烯薄膜作为转换材料，通过反冲质子法测量中子的位置。提出了一套通过设定探测器上层结构的方案来得到探测器的位置分辨特性。通过对模拟结果的分析与比较，得到一种易于测定探测器位置分辨特性的方法。该工作不仅可以优化气体探测器结构设计，缩短实验周期，而且还能极大程度地节约经费。

**关 键 词**：Micromegas；中子探测器；位置分辨；计算机模拟

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*　**收稿日期**：2010 - 01 - 08；**修改日期**：2010 - 03 - 31

*　**基金项目**：国家大学生创新性试验计划基金资助

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