An MRPC for fast neutron detection*

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Abstract The possibility to detect fast neutrons with a multi-gap resistive plate chamber (MRPC) has been investigated. To detect fast neutrons, a thin polyethylene layer is coated on the surface of electrode glass as a fast neutron converter. The MRPC detects the charged particles generated by neutrons via the (n,p) reaction on hydrogen. A prototype detector has been developed and tested on fast neutron sources in order to evaluate its performance: good agreement between experimental results and simulation has been achieved. A detailed description of the detector and the experimental test results are presented.

Key words MRPC, fast neutron, flight time

PACS 25.40.Cm, 28.75.Gz, 21.60.-n

1 Introduction

A multi-gap resistive plate ctamber (MRPC) is a kind of gas detector. It has a narrower gas gap (about 200 micrometers) and better time resolution (less than 100 ps) relative to the resistive plate chamber (RPC). The MRPC is widely used to construct the time of flight system in a couple of large scale experiments, for example RHIC-STAR, LHC-ALICE, FAIR-CBM et al [1–4]. This detector consists of a stack of resistive plates, spaced one from the other with spacers of equal thickness creating a series of gas gaps (six gas gaps of about 220 micrometers). A non-flammable gas mixture which contains 97% tetra-fluoro-ethane and 3% iso-butane is used. In general, this detector is a gaseous detector and is sensitive to high energy charged particles. In this paper we try to use MRPC technology to detect fast neutrons. As we know, fast neutrons can generate secondary electrons in glass, electrons which escape from the glass can cause an avalanche in the working gas, which can also induce signals on readout strips. In the mean time, we studied the method to improve the neutron sensitivity of MRPC [5]. A thin polyethylene layer is placed on the surface of electrode glass; when neutrons interact with polyethylene, protons are produced which can ionize the working gas. Electrons and ions will produce avalanche by strong electric field and charges are induced on collecting electrodes. This kind of neutron detector can be used to measure the flight time spectrum of fast neutrons. It can aslo be used to detect pulsed neutrons.

2 Monte Carlo simulation

The MCNPX program is used to simulate the detector's neutron sensitivity. The structure of the detector is shown in Fig. 1. In order to enhance the neutron sensitivity, 0.13 mm thick polyethylene adhesive tapes are stuck on one surface of glass plates. The electrode glass is 0.54 mm thick; neutrons go into the glass from one side and secondary protons can be detected on the other side. Table 1 shows the neutron sensitivity of different electrode plates. The energy of the incident neutron is 14 MeV. It can be seen that there are more protons generated in polyethylene than in glass. This is because there are more hydrogen atoms in polyethylene, which can interact with incident neutrons and generate more recoiled protons. Fig. 2 shows the simulated energy spectrum

Received 18 February 2009, Revised 17 March 2009
* Supported by NSFC (10675072, 10775082, 10620210287)
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of a proton generated by 14 MeV neutrons. The solid line shows the glass electrodes coated with polyethylene, and the dashed line shows only the glass electrodes. This demon strakes that polyethylene can enhance the neutron sensitivity of MRPC. Fig. 3 shows the simulated sensitivity of different neutron energies. The sensitivity of this detector is about 10^{-3}, and it can be seen that when the incident energy is about 8 MeV, the sensitivity is the highest.

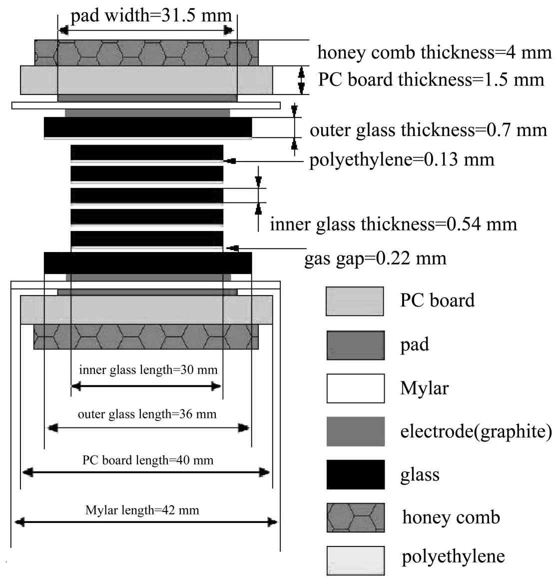

Fig. 1. The structure of the neutron detector.

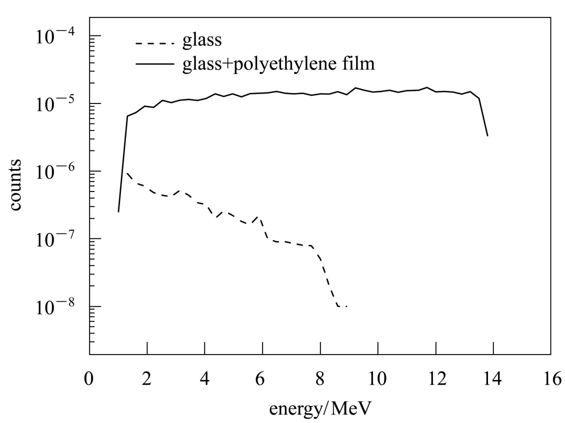

Fig. 2. MC simulated energy spectra of a proton generated by a 14 MeV neutron.

Table 1. Neutron sensitivity of different electrode plates.

	proton	
	sensitivity (protons/one neutron)	⟨energy⟩
glass	3.2×10^{-5}	4.62 MeV
glass+polyethylene tape	1.2×10^{-3}	8.17 MeV

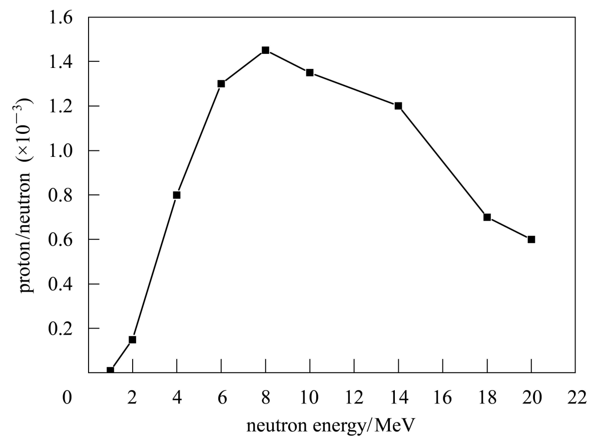

Fig. 3. MC simulated sensitivity of neutrons with different energies.

3 Experiment results

A dense plasma focus (DPF) neutron source is used to measure the detector response to fast pulsed neutrons. The detector is about three meters away from the source. The flux of 14 MeV neutrons generated by DPF can reach 1.5×10^{9} n/s, the pulse width is about 15–20 ns. As we know, there are a lot of gamma rays emitted simultaneously with neutrons. A Tektronix digital oscilloscope is used to record the signals of the detector and neutron source. In Fig. 4, channel 1 (lower panel) represents the detector output signal and channel 4 (upper panel) represents the discharge signals of the DPF source. It can be seen that the discharge signal comes earlies than the detector's signal. The horizontal scale is 100 ns. The vertical scale of channels 1 and 4 is 400 mV and 2 V respectively. Two peaks can be seen in channel 1. The left peak is from the gamma rays and the right peak is from neutrons. Its time interval is about 50 ns, which is fitted with three meters distance. So we can obtain the neutron flux at the detector which is about 2.4×10^{4} n/pad. In order to avoid gamma ray disturbance, 60 mm thick lead is put in front of the detector to absorb the gamma rays. It can be seen in Fig. 5 that the gamma ray peak is absorbed. So we can determine for sure that the second peak in Fig. 4 is the neutron signal. Fig. 6 shows that the detector's signal strength changes with the distance between the DPF and the detector. It can be seen that with increasing of distance the output voltages decrease. These experiments show that the detector can be used to detect pulsed fast neutrons.

This kind of neutron detector has a good time resolution and can be used to measure the energy spectrum of fast neutrons. We try to use the detector to measure the flight time of pulsed fast neutrons. The

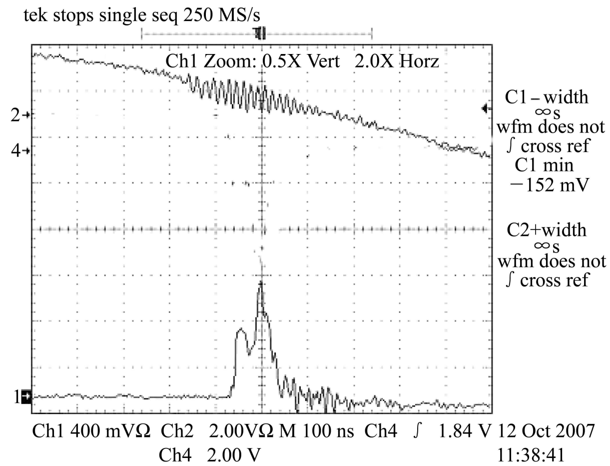

Fig. 4. Detector response to pulsed neurons and rays.

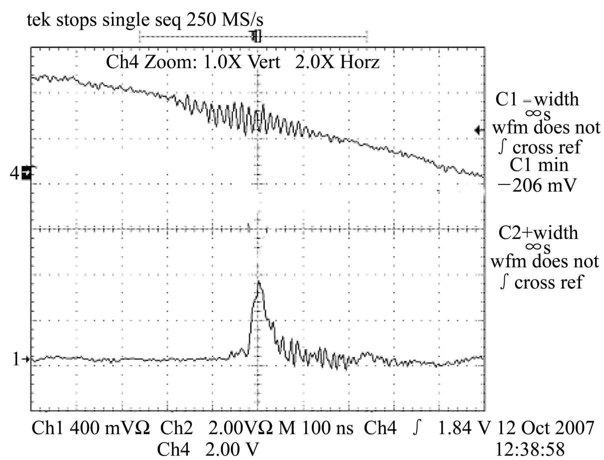

Fig. 5. Detector (with 60 mm thick lead in the front) response to pulsed neutrons.

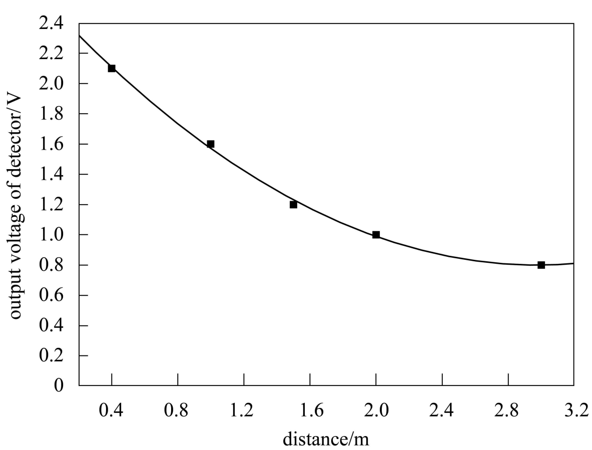

Fig. 6. Detector's signal strength changes with distance.

pulsed neutron source emits 14 MeV neutrons. The pulse frequency is about 1.5 MHz. Fig. 7 shows the experiment setup. Synchronous signals from the neutron generator are discriminated by a constant fraction discriminator and used as the STOP signal of the TAC. The detector signal is discriminated by a low threshold discriminator (LTD) and used as the START signal of the TAC. A PCI ADC card is used to digitize the TAC signals. Figs. 8 and 9 show the flight time spectrum of fast neutrons. It can be seen that with increasing distance, the flight time difference between neutrons and gamma rays also increases. Formula (1) shows the time difference,

$$\Delta t=\left(\frac{72.3}{\sqrt{E}}-3.33\right)L, \tag{1}$$

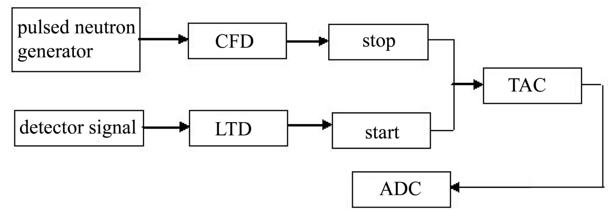

Fig. 7. Experiment layout.

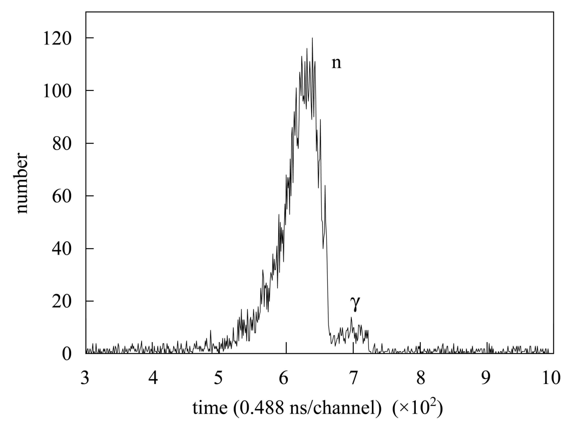

Fig. 8. Flight time spectrum of fast neutrons. The distance from the source to the detector is 1.7 m.

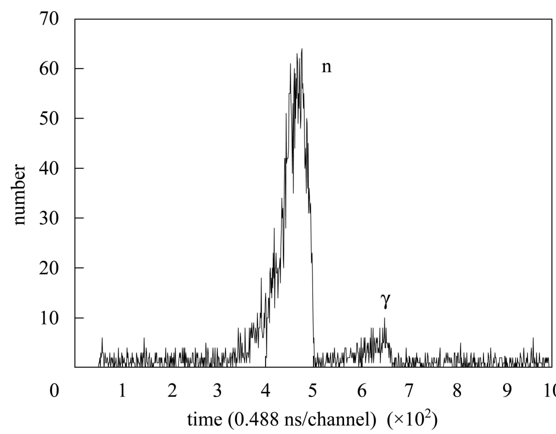

Fig. 9. Flight time spectrum of fast neutrons. The distance from the source to the detector is 4.7 m.

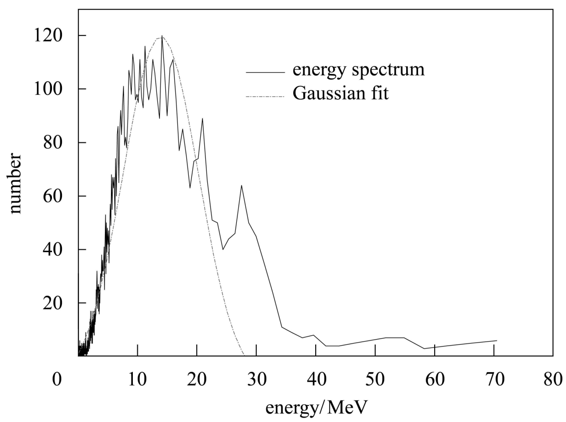

Fig. 10. Energy spectra measured at 1.7 m distance.

where Δt is the time difference in ns, E is the neutron energy in MeV, and L is the distance in meters. In Fig. 8, the distance is 1.7 m, so the time difference calculated by the formula is about 27.1 ns. The fitted neutron peak is at 636 channels, the fitted peak is at 695 channels, so the measured time difference is 28.8 ns. The time difference measured at 4.7 m also accords with the calculated result. Fig. 10 shows the energy spectrum deduced from Fig. 8. The average energy is 14 MeV and the standard deviation is 8.9 MeV.

4 Conclusions

In this paper we try to use MRPC technology to detect fast neutrons. By detailed Monte Carlo simulation, we get the fast neutron sensitivity of the MRPC theoretically. In order to improve the neutron sensitivity of the MRPC, a thin polyethylene layer is placed on the surface of electrode glass. A DPF neutron source is used to test the detector's performance. We also use this detector to obtain the flight time spectrum of fast pulsed neutrons. 10^{-3} sensitivity is obtained. This kind of detector can be used to measure the intensity and energy spectrum of fast pulsed neutrons.

The authors would like to thank Prof. Hou Long and their colleagues of CIAE for their efforts at beam testing and helpful discussions.

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