A position resolution MRPC for muon tomography *

FAN Xing-Ming(樊星明)[1] WANG Yi(王义)[1,1)] WANG Xue-Wu(王学武)[1] ZENG Zhi(曾智)[1]
ZENG Ming(曾鸣)[1] ZHAO Zi-Ran(赵自然)[1] CHENG Jian-Ping(程建平)[1] D. Gonzalez-Diaz[2]

[1] Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education,
Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[2] Laboratorio de Física Nuclear y Altas Energías, University of Zaragoza, 50009, Zaragoza, Spain

Abstract: Muon tomography is a promising method in the detection and imaging of high Z material. In general, considering the quality of track reconstruction in imaging, a detector of good position resolution, high efficiency and large area is required. This paper presents the design and study of a prototype of position sensitive MRPC with 0.15 mm narrow gas gap and 2.54 mm strip readout. Through a cosmic-ray experiment, the performance of MRPC module is carefully observed and each channel is calibrated. Through an X ray experiment with a narrow slit, the position resolution is studied. The results show that the time resolution of the module can reach 61ps and the spatial resolution can reach 0.36 mm.

Key words: MRPC, muon tomography, position resolution

PACS: 29.40.Cs, 29.40.Gx **DOI:** 10.1088/1674-1137/38/4/046003

1 Introduction

In recent years, muon tomography for high Z material has become the focus of many research projects and several prototypes of a tomography system have been built all over the world. For a tomography system, in order to achieve a practical imaging or identification of high Z material, a detector with good position resolution, high efficiency and large active area is needed. The successfully built muon tomography systems have some similarities, but mainly differ in the chose of tracker. The tracking detectors include a drift chamber, sliver scintillator, scintillating fibre, GEM, RPC, and so on.

For a new muon tomography system, we have developed a prototype of Multi-Gap Resistive Plate Chamber (MRPC) module. The major goal is to achieve submillimeter spatial resolution. MRPC is a kind of gaseous detector. Because of its good time resolution, high efficiency, large sensitive area and low price, it became a common choice for time-of-flight (TOF) systems in nuclear and particle physics years ago [1–6]. An MRPC detector also has a prospectively good position resolution, depending on the structure, and the design of readout strips. MRPC is developed from a Resistive Plate Chamber (RPC). If the gas gap is wider, then the avalanche area of RPC is also enlarged, thus the spatial resolution is impaired [7]. The width of the gap should be about 2 mm to reach a high efficiency. We can conclude that the some research on the position resolution of RPC has been carried out. The results have shown that with narrow readout strips and a very narrow gap we can get a good track accuracy. For general RPC position resolution has a connection to the width of the gas gap [8]. If the gap is too narrow, then the signal would be too small for the threshold. If the gap is too wide, then the avalanche area would be too large and have a influence on the accuracy of tracking. There is a difficult balance in the accuracy and efficiency for RPC. Since MRPC has a thinner gap compared with PRC, the avalanche size inside MRPC module is also much smaller. Considering that thin gap MRPC has much better time resolution than wide gap RPC, we can conclude that MRPC also has better position resolution than RPC. There is another significant benefit if MRPC is used in a muon tomography system. The MRPC can become a combination of TOF and high accuracy tracker, and the muon energy can be measured at the same time. Since the scattering coefficient changes with the energy of incident muons, the reconstructed images can be improved by knowing the energy of cosmic ray muon.

The position resolution is highly dependent on the width of strips. M. Petrovic's experiment of an MRPC detector with 2.54 mm pitch width has got <50 μm resolution [9] and the experiment operated by H. Liang got

---

Received 4 June 2013, Revised 11 November 2013

* Supported by National Natural Science Foundation of China (11035002, 11020101059, 10775082, 11275108)

1) E-mail: yiwang@mail.tsinghua.edu.cn

<300 μm resolution with RPC [10]. Our former research on prototypes of spatial resolution RPC and MRPC has shown a sub-millimeter accuracy on both RPC/MRPC. A new prototype of position sensitive MRPC with narrow readout strips and a large sensitive area has been developed in our laboratory. This paper presents a study of the position sensitive MRPC module. Experiments from cosmic rays and X rays have been carried out. The cosmic ray experiment aims to study the time resolution, efficiency, and calibrate the electronics. The X ray experiment aims to study the spatial resolution. The results show that the time resolution is about 60 ps and its spatial resolution can reach 0.36 mm. These results show that this MRPC can be used in muon tomography and other radiation test system.

2 Structure and experimental setup

2.1 MRPC structure

The MRPC prototype is developed to study the position resolution. The structure of the prototype is shown in Fig. 1. The two stack structure is used to keep high efficiency. Several 0.7 mm float glasses are used as electrodes, the volume resistivity of the glass is of the order of 10^{12} Ωcm. The counter has 14 gas gaps and the width of gas gap is 0.15 mm. The sensitive area of the module is 25 cm×50 cm. The pitch is designed to be narrow to let more strips be fired in one event. The counter has 80 1.44 mm readout strips with 1.1 mm gap between strips (the width of the pitch is 2.54 mm). The readout strips on the middle board are for signal, and those on top and bottom boards are grounded.

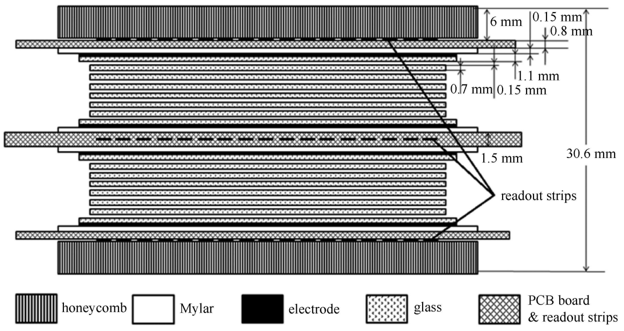

Fig. 1. The structure of position sensitive MRPC.

2.2 Setup of cosmic ray test

The cosmic ray experiment for the position sensitive MRPC is similar to the test of timing MRPC. The aim of this study is to observe the performance of the module and to obtain the parameters for charge calibration. The setup of cosmic ray experiment is shown in Fig. 2. DAQ system for the experiment is triggered by the coincidence of the 4 PMTs. PMT0 and PMT1 are connected to the upper scintillator, PMT2 and PMT3 are connected to the lower scintillator. The length of the scintillator is 220 mm and the width is 50 mm. The MRPC is connected by coaxial cables to the feed-through PCB board on the aluminum gas box. There are MCX connectors on both sides of the feed-through board. Such a design reduces the noise and keeps a good wave form of output signal. The signals are amplified and digitized by HADES Electronics. The output of Hades Electronics contains the time and charge (ToT: time over threshold) [11]. The working gas consists of 90% Freon, 5% isobutane and 5% SF_6 and the flow rate is 25sccm. The time resolution of the position resolution MRPC is measured the same way as strip timing MRPC, with a two-end readout prototype that is similar to this one-end module.

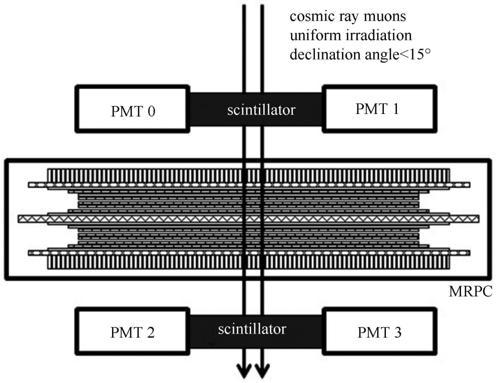

Fig. 2. The setup of cosmic ray experiment.

During the experiment, cosmic ray muons pass through the two scintillators and the MRPC module, ionizing the scintillators and working gas. By applying cuts on the data, the trigger area is about 10 cm long in the center of the PMT, and the declination angle of track is less than 15 degrees. The trigger area covers about 40 channels of MRPC, these channels are uniformly activated by the avalanches of triggered cosmic ray muons. Since all the channels in the trigger area are equivalent, the charge distribution of signal should also be identical from channel to channel.

2.3 Setup of the X ray experiment

The position resolution of an MRPC detector can be obtained by different methods. An X-ray machine and a tungsten slit are used to measure the position resolution. The layout of the experiment is shown in Fig. 3. The slit is determined by a slotted tungsten plate with lead bricks and lead plates. Two lead bricks are placed above the gas box. The gap between the lead bricks is approximately above the interval between the strip 11 and strip 12. The gap between the bricks is less than 1 mm width. The tungsten plate is placed above the bricks and the slit is right above the gap. The width of the slit is (126±1) μm. The thickness of the tungsten plate is 1 mm. The rest of the area is covered by lead plates. A Spellman XRB80 X ray generator is placed 30 cm right above the slit. The voltage was set at 35 kV.

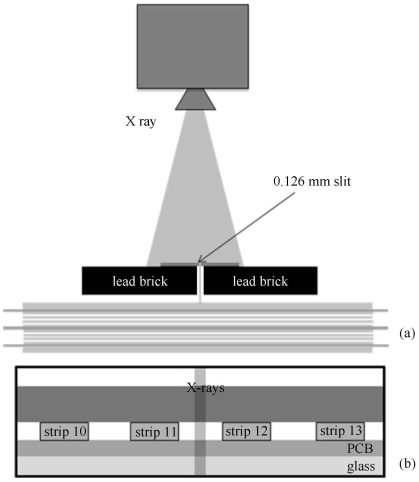

Fig. 3. Experimental setup of X ray experiment. (a) Setup of experiment; (b) X rays across the strips.

The energy spectrum of X rays is continuous and the maximum energy is 35 keV. When the X ray generator is turned on, one or more collimated X rays will generate secondary electrons in the glass. The secondary electrons will ionize the working gas and cause an avalanche inside the gas gap. The induced charges were collected by readout strips. The coincidence of two strips aside the X ray beam (strip 11 and 12) provides the trigger of the DAQ system and the dark rate of trigger is a few Hz. The setup is shown in Fig. 4.

The ToT results are linear corrected by the 'pedestal' and 'gain' obtained from the cosmic ray experiment. The hit position is reconstructed by charge distribution across strips using the centroid gravity method.

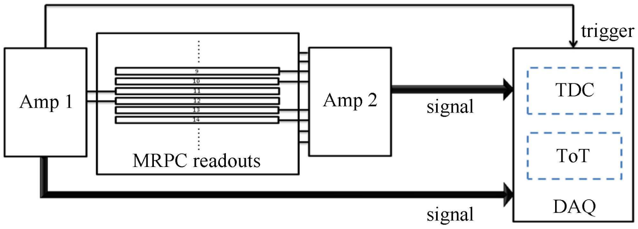

Fig. 4. DAQ-system for X ray experiment.

3 Results

3.1 Behavior of the module

Before starting the experiments, the module was trained under high voltage for 48 hours, to reach a stable condition with lower noise rate and dark current. The efficiency is scanned as a function of the voltage under cosmic rays, the results are plotted in Fig. 5. The efficiency of the counter is larger than 90% at the voltage of 6.6 kV. The working voltage was set at 6.6 kV in the experiments.

Because the strip is readout from one end, the time precision is only 150 ps if only one strip is used for time analysis. As we know, the dimension of the induced charge distribution is larger than 10 mm. More than four strips will be fired for a muon event, so four neighboring strips can be used to analysis time resolution. This can be shown in Fig. 6, the signal of channel 10–13 are used to do analysis. The reference time comes from four scintillator detectors.

$$t_{\mathrm{ref}}=\frac{t_{\mathrm{PMT1}}+t_{\mathrm{PMT2}}+t_{\mathrm{PMT3}}+t_{\mathrm{PMT4}}}{4}. \qquad (1)$$

The time resolution of t_{ref} is about 74 ps. Eq. (2) is used to eliminate the jitter

$$t_{\mathrm{MRPC}}=\frac{t_1+t_2+t_3+t_4}{4}-t_{\mathrm{ref}}. \qquad (2)$$

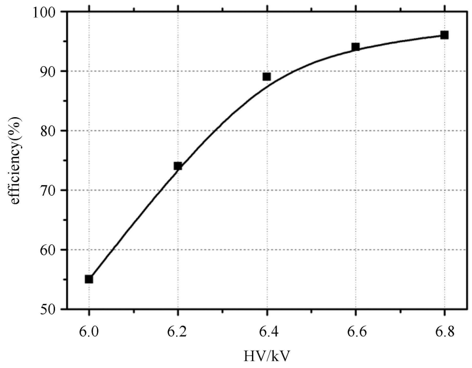

Fig. 5. Efficiency changes with HV.

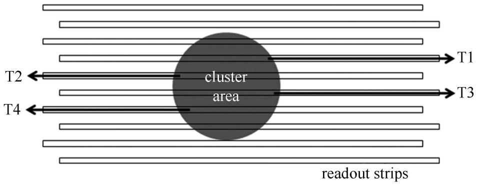

Fig. 6. The time of a signal.

The time resolution of the MRPC is described as :

$$\sigma_{\mathrm{MRPC}}=\sqrt{\sigma^2_{t_{\mathrm{MRPC}}}-\sigma^2_{t_{\mathrm{ref}}}}. \qquad (3)$$

Figure 7 shows the time spectrum of reference time and MRPC time after slewing correction. We can get that the time resolution of MRPC is about 61 ps, which is comparable with common timing MRPC.

3.2 Calibration of HADES electronics

For HADES electronics, ToT represents the induced charge of strips. It is important to make sure that the ToT changes linearly with input charge. Fig. 8 shows the ToT changes with input charge. There is a linear function relation between the charge of the channel and ToT given by the DAQ when the charge is below 3000 fC or the ToT is below 100 ns. But for different electronics channels, the response is different. The pedestal and gain are defined for the calibration of channels. In the experiment, the ToT is between 50–70 ns, a linear correction can be used in the calibration.

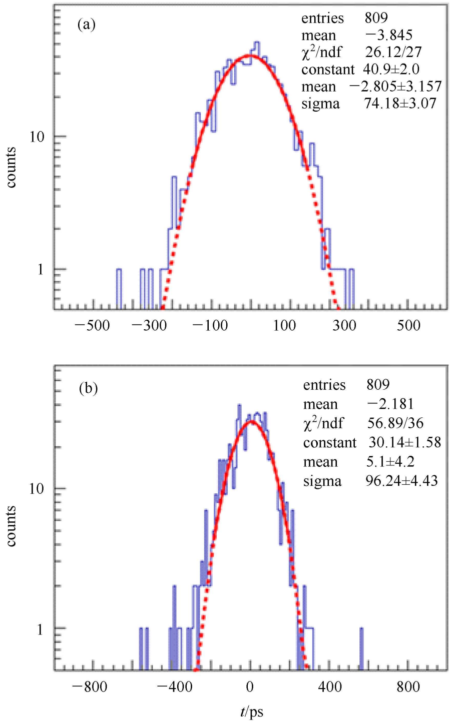

Fig. 7. (a) time resolution of four scintillator detectors; (b) time resolution of MRPC.

The charge distribution of the channels has specific use in the experiment. Since the cosmic ray 'shower' can be considered uniform, each channel has the same distribution of charge. For an MRPC module, the charge distribution of a channel is described by Polya Function [12]:

$$P(z)=\frac{(k+1)^{k+1}}{\Gamma(k+1)}z^{k}\mathrm{e}^{-(k+1)z}, \tag{4}$$

for k integer,

$$\Gamma(k+1)=k!. \tag{5}$$

In the calibration, k is set at 2, so the function becomes,

$$P(x)=C\left(\frac{x-A}{B}\right)^{2}\mathrm{e}^{-3\left(\frac{x-A}{B}\right)}, \tag{6}$$

where A and B are pedestal and gain, respectively. Fig. 9 shows the charge distribution of Channel 1 and Channel 2. It can be seen that the fitted parameters are different for different electronics channels. With these parameters, the hit position of each effective event in cosmic ray experiment is reconstructed, and the result shows a uniform distribution across the trigger area of the PMTs.

3.3 Spatial resolution

Induced charge spreading between strips can be obtained through the charge calibration. The ToT before

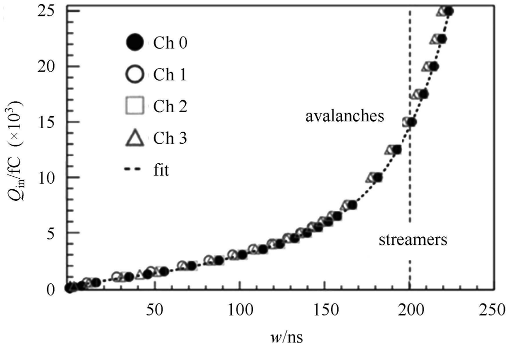

Fig. 8. ToT versus input charge.

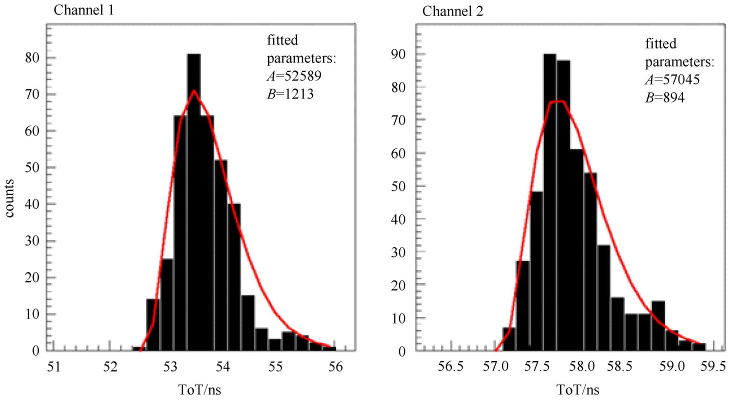

Fig. 9. Fitted parameters from the charge distribution of Channel 1 and Channel 2.

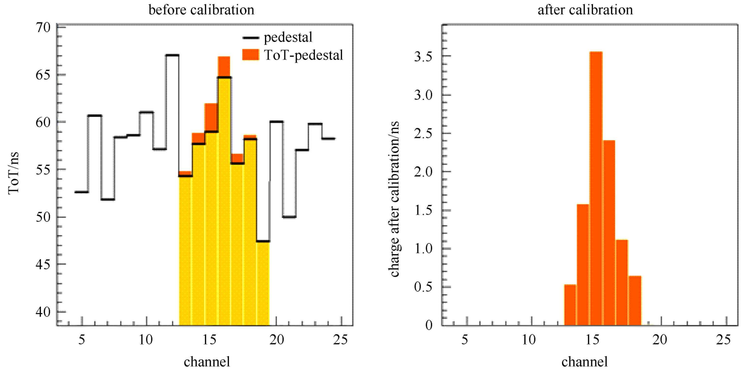

Fig. 10. The charge across the strips before and after calibration.

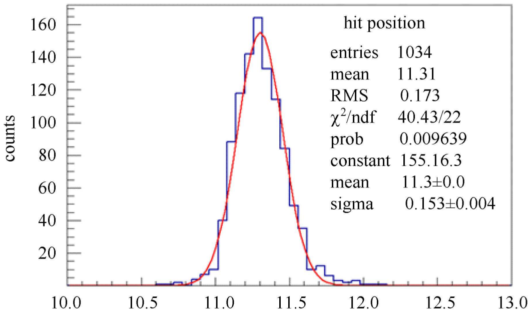

Fig. 11. The reconstructed position distribution.

calibration, and the charge calibrated from ToT are shown in Fig. 10. The events we plotted are quite Gaussian-like because the charge spread of the event is a combination of both avalanche and charge sharing effect. The charge is higher in the middle strip and decreases with the distance from the center. The cluster size of most of the events is 3–7 strips. For a certain event, the central-gravity method is applied for position reconstruction.

$$x=\frac{\Sigma_i(\text{Channel}_i\times Q_i)}{\Sigma_i(Q_i)}. \qquad (7)$$

Position resolution of the module is obtained from the distribution of constructed positions. Fig. 11 shows the distribution of X ray hit positions. The spatial resolution can be obtained from Eq. (8).

$$\sigma_{\text{MRPC}}=\sqrt{\sigma^2_{\text{all}}-\sigma^2_{\text{slit}}}. \qquad (8)$$

So the spatial resolution of the detector is $\sqrt{(0.153\times2.54)^2-\frac{0.126^2}{12}}=0.367$ mm.

4 Conclusions

The radiography of high Z material with muon from cosmic ray is a novel technology for heavy nuclear material detection. MRPC has excellent time and position resolution and has potential application in muon tomography technology. A prototype of high position resolution was developed in our laboratory. The width of readout pitch is 2.54 mm and its sensitive area is 25 cm×50 cm. Experiments from cosmic rays and X rays have been carried out. The results show that the time resolution can reach 61 ps and its spatial resolution can reach 0.36 mm. However, the signal from an X ray is not the same as the signal from muons. Cosmic ray muons travel through all the gas gaps and generate multiple avalanches, so that the signal of a cosmic ray is a comprehensive result. In the next step we will study the spatial resolution at IHEP (Beijing) with a high energy proton beam. Further study is being done to improve the spatial resolution of MRPC.

The authors would like to thank the Hades Electronics group for providing the electronics. We kindly thank Marek Palka of GSI for his great help on setting up the DAQ system.

References

1 Hatzifotiadou D. Nucl. Instrum. Methods A, 2003, **502**: 123
2 Akindinov A et al. Nucl. Instrum. Methods A, 2004, **533**: 74
3 Akindinov A et al. Nucl. Instrum. Methods A, 2009, **602**: 709
4 Bonner B et al. Nucl. Instrum. Methods A, 2002, **478**: 176
5 Bonner B et al. Nucl. Instrum. Methods A, 2003, **508**: 181
6 WANG Yi et al. Nucl. Instrum. Methods A, 2010, **613**: 200
7 Crottya I et al. Nucl. Instrum. Methods A, 2003, **505**: 203
8 Francke T et al. Nucl. Instrum. Methods A, 2003, **508**: 83
9 Petrovici M. High Counting Rate, Differential, Strip Read-Out, Multi Gap, Timing RPC, XI Workshop on Resistive Plate Chambers and Related Detectors, INFN, 2012
10 HAN Liang. Thin-Gap RPC Study for ATLAS L1Muon Upgrade, XI Workshop on Resistive Plate Chambers and Related Detectors, INFN. 2012
11 Belver D. IEEE Transactions on Nuclear Science, 2010, **57**(5): 2848
12 Sauli F. Principles of Gas Detectors. KEK March 14. 2009