Study of Performance of MRPC with Different Gas Mixtures *

SHAO Ming [1;1)] CHEN Hong-Fang[1] LI Cheng[1] WANG Xiao-Lian[1] HUANG Sheng-Li[1]
LI Jie[1] RUAN Li-Juan[1] WU Jian[1] XU Zi-Zong[1] WANG Zhao-Min[1]
G. Eppley[2] W.J. Llope[2] F. Geurts[2] J. Schambach[3]
1 (Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China)
2 (Rice University, Houston, TX 77005-1892, USA)
3 (University of Texas, Austin, TX 78712, USA)

Abstract A prototype with 28 modules of 168-channel multi-gap resistive plate chamber (MRPC) time-of-flight system for the STAR experiment at RHIC was built, and its 12 modules (72 readout channels) equipped with read out electronics were tested for 10 weeks at the AGS, BNL from February 2002. The working gas mixtures have significant influence on the performance of MRPC. Several gas mixtures such as 90% $C_2H_2F_4$ + 5% iso-C_4H_{10} + 5% SF_6, 95.3% $C_2H_2F_4$ + 4.7% iso-C_4H_{10} and 100% $C_2H_2F_4$ were tested. The results on detection efficiency, time resolution and streamer probability are presented.

Key words MPRC, gas mixtures, detection efficiency, time resolution, streamer probability

1 Introduction

The main goal of the relativistic heavy ion program at RHIC is to produce a new phase of matter, the quark-gluon plasma (QGP) and to study quantum chromo-dynamics (QCD) matter at high temperature. The experiments have been under way since 1999, by 4 collaboration groups (namely STAR, PHENIX, BRAHMS and PHOBOS) at Brookhaven National Laboratory (BNL). Recent RHIC results have offered a new view into nucleus-nucleus collisions. Some exciting results have been reported [1—3]. STAR Collaboration proposes to upgrade its detector in order to enhance the physics capacity.

As one of the most important upgrade projects, STAR proposes to build a barrel Time-Of-Flight (TOF) system based on newly developed multi-gap resistive plate chamber (MRPC) technology. This detector will significantly extend the reach of the STAR scientific program. The proposed TOF will have large acceptance, covering 2π in azimuth, 2 pseudo-rapidity units, $|\eta|\leqslant 1$, and with total area of about $64m^2$.

The Chinese group (STAR) has devoted to this project since late 2000, and great progresses have been achieved [4—9]. Many studies are carried on with the gas mixture of 90% $C_2H_2F_4$ + 5% iso-butane + 5% SF_6. In STAR, there are other gas detectors such as the large volume time projection chamber (TPC), people worry about that SF_6 may hurt its operation characters very much. So in order to optimize MRPC's practical performance and better understand its working mechanism, several different gas mixtures are investigated.

In this paper, the experimental results of MRPC operating with three kinds of gas mixtures are presented.

Received 27 October 2003, Revised 10 March 2004
* Supported by National Science Foundation of China (10375062)
1) E-mail: swing@ustc.edu.cn

The three gas mixtures we studied are (A) 90% $C_2H_2F_4$ + 5% iso-C_4H_{10} + 5% SF_6, (B) 95.3% $C_2H_2F_4$ + 4.7% iso-C_4H_{10} and (C) 100% $C_2H_2F_4$, respectively. The experiment setup is introduced in Section 2, and then in Section 3 the test results as well as some discussions will be presented. Finally in section 4 we will give the conclusion.

2 Experiment Setup

The test is performed at AGS, BNL. The beam is not actually a test beam but rather a high radiation area on the floor of the AGS caused by the beam spill. All 28 MRPC modules are installed in an aluminum box, but only 12 modules (72 readout channels) are equipped with electronics. The setup scheme is shown in Fig. 1 (a). Six parallel trigger paddles, which consist of fast scintillator and PMT, are placed perpendicular to the test beam. Four of them (No. 3, 4, 5 and 6) have one PMT coupled to the scintillator at one side and the other 2 (No. I and 2) have 2 PMTs coupled to both sides. Each PMT produces a timing signal and the coincidence of them brings a trigger signal. The MRPC module is placed between paddle 4 and paddle 5.

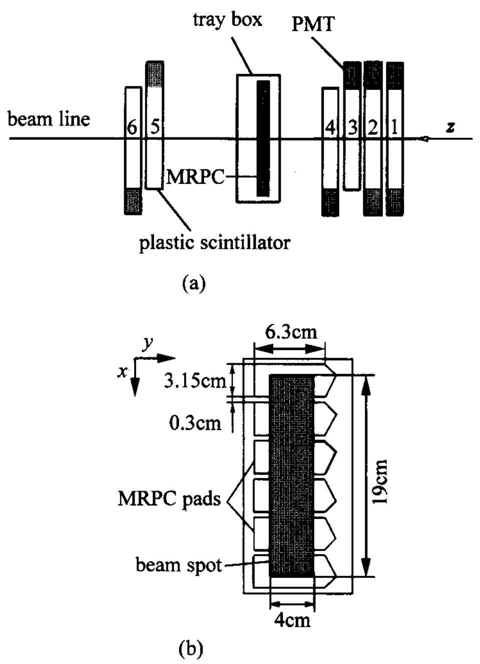

Fig. 1. (a) The beam test setup scheme at AGS (along z direction); (b) the beam spot area on MRPC (in x-y plane).

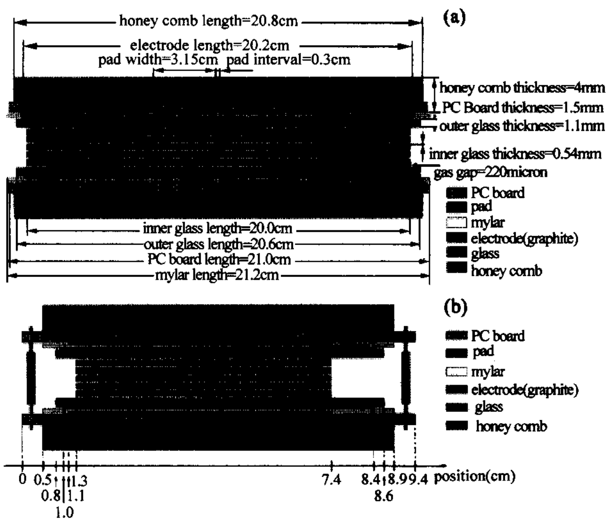

Fig. 2. Structure of the MRPCs (side view). (a) longitudinal view; (b) transverse view.

The MRPCs for testing are similar to the one reported in Ref [5], but each only has 6 readout strips (3.15cm×6.3cm per strip, see Fig. 1 (b)) instead of the previous 12 channels (3cm×3.1cm each). The structure and size of MRPC is shown as Fig. 2. The active region of a 6-pad MRPC module is defined by the transverse dimensions of the five inner glass sheets, which is 6.1cm×20cm. Signal from each strip is fed to front-end electronics (FEE), then to TDC and ADC. CAMAC TDC and ADC modules are included to record the timing and amplitude information of each PMT and each strip of the MRPC modules for later offline analysis.

The trigger defines a rectangular beam spot of 4cm×19cm, so most of the active area is covered and hits could occur in any of the 6 strips, as shown in Fig. 1 (b).

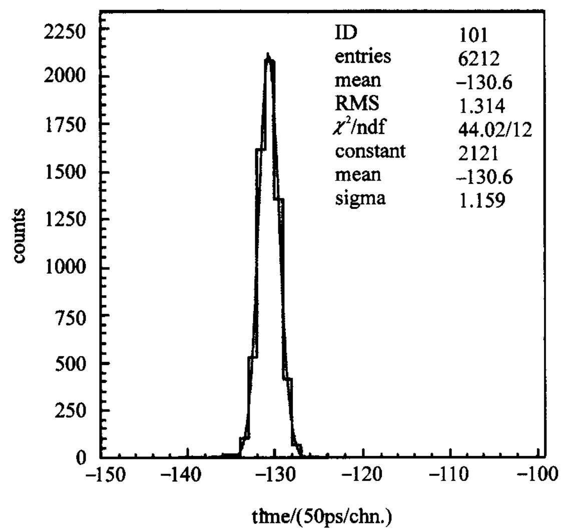

Fig. 3. Reference time resolution after T-A slewing correction.

To test the time resolution of the MRPC module, which is generally below 100 ps, the reference start time resolution of this setup must be good enough. Since the leading edge discrimination is used, the time we measured (i.e., time over threshold) will be affected by the signal amplitude, which is called the time-amplitude slewing correlation. This correlation can be corrected to achieve a fine (better) time resolution. We take the average of the eight PMT timing as the system reference timing signal and make a time-amplitude slewing correction to each PMT (similar to the T-A correction introduced in Ref. [5]). Fig. 3 shows the time distribution of the reference after the correction. So for such a large beam spot (4cm × 19cm), we can get a reference time resolution (σ_{ref}) of around 60ps.

As mentioned above, this is not actually a test beam, there contains a significant non-relativistic momentum spread. This may broaden the MRPC's time distribution. In order to minimize this effect, the relative position of the MRPC modules and the trigger paddles are carefully chosen, so that the "effective" flight length of a particle (which means the velocity of the particle times the measured time by MRPC minus the reference time, here one should note the reference time is the average of eight PMT timing) can be minimized (this is why the MRPC module is placed between paddles 4 and 5), thus the beam momentum spread will not have a significant contribution to the time resolution measurement.

3 Results and Discussions

The main characters of 12 MRPC modules are tested both with gas A and B, while only 4 of them are tested with gas C due to the beam time restriction. Among all MRPC modules one (2#) is chosen for high-voltage (HV) plateau test, and the others are tested with a fixed HV, which is 14500 V for gas A, 14000 V for gas B and 14250 V for gas C.

The detection efficiency is defined as the ratio of the number of triggered events with a valid TDC stop in any of the six channels to the total number of triggered events. The beam test results of the efficiency of MRPC module 2# with 3 different gas mixtures are shown in Fig. 4. The discrimination threshold is chosen to be 1.2 V, which will give a good efficiency and is also well above the noise level. As can be seen, with different gas mixture, MRPC reaches its efficiency plateau at different HV. To get an efficiency of 96%, the high voltages applied should be around 14500, 14000 and 14250 V for gas A, B and C, respectively. This can be explained as follows. Since gas A contains SF_6, which has quite strong "quenching" effect on the drift electron [10], it will suppress the development of the electron avalanche in it. Thus with gas A, higher HV is needed for MRPC to reach its efficiency plateau compared to that with gas B and C. Then as for gas B and C, although their avalanche intensities, i.e. the effectively Townsend coefficients, would be similar, gas B has a larger primary ionization density than gas C because of the iso-butane used. So MRPC needs lower HV to operate with gas B then with gas C.

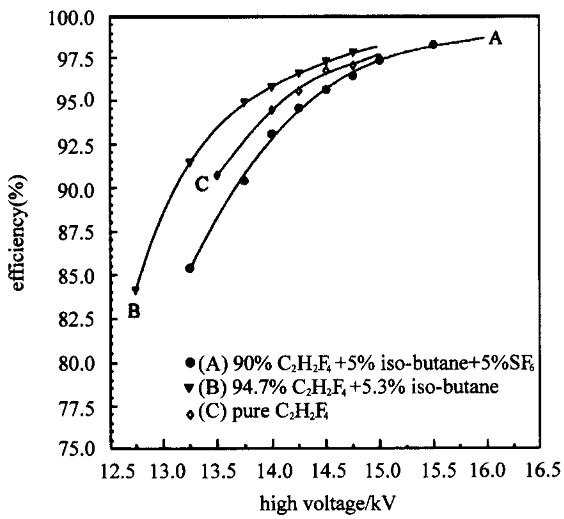

Fig. 4. MRPC detection efficiency with different gas mixture.

For all MRPC modules tested, the average detection efficiencies are summarized in Table 1. Note the different high voltage applied for different gas mixtures. MRPC in all cases can get high enough efficiency for STAR operation.

Table 1. Results of MRPC test with different gas mixtures. The high voltages applied are fixed at 14500 V for gas A, 14000 V for gas B and 14250 V for gas C.

gas	efficiency(%)	time resolution/ps
A	96.4	72.4
B	97.2	76.8
C	96.1	87.0

Shown in Fig. 5 is the time resolution of MRPC module 2# vs. the high voltage applied. In order to get the coherent MRPC time resolution (σ_{mrpc}), the reference time jitter as introduced in section 2 has been quadra-subtracted already ($\sigma_{mrpc}^2 = \sigma_{meas}^2 - \sigma_{ref}^2$). One can conclude from this figure that with gas A and B, the MRPC's time resolutions do not have significant difference. Both of the time resolutions can reach ~ 65ps, which is compatible with the results reported before [5,7]. But for gas C, the time resolution is around 80ps, which is definitely larger than that with gas A and B, and is also marginal for the requirement of STAR, The average time resolutions of all MRPC modules tested with different gas mixtures are summarized in Table 1.

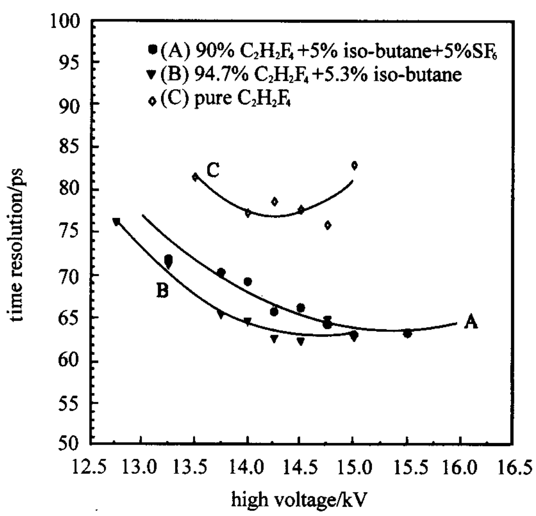

Fig. 5. MRPC time resolution with different gas mixture.

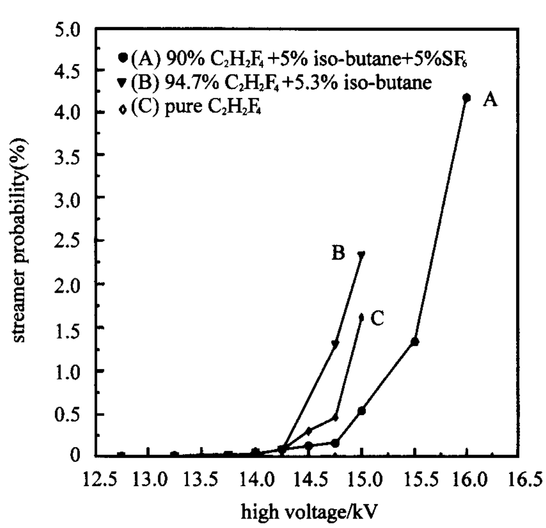

Fig. 6. The streamer probability vs. HV with different gas mixtures.

One of the main characteristics of MRPC is that it works at the avalanche mode [11,12]. This feature ensures that MRPC has good time resolution and rate capacity. The streamer probability of MRPC is measured to confirm that it indeed works at the avalanche mode. The result of module 2# is shown in Fig. 6. Here the streamer probability is taken as the ratio of the number of events whose amplitudes are 3σ over the average to the number of valid triggered events. So when worked at the starting region of their efficiency plateau, MRPC with all three gas mixtures has neglectable streamer probability. However, it seems to have clue that the streamer probability with gas C increases faster at higher HV than those with gas A or B. This will require a further experiment to confirm.

Let us make a rough estimate on the HV range for MRPCs to work "safely", i.e., in avalanche mode. Choose a detection efficiency of 95% to be the lower limit, and a maximum streamer probability of 1%, we can draw from Figs. 4 and 6 that for gas A, B and C, MRPC has a "safe" operating range of 1000 V, 850 V and 750 V, respectively.

4 Conclusions

With all the test results mentioned before, the main conclusions are as follows:

1. With different gas mixture, the efficiency vs. HV curve will shift a few hundred volts, but still can reach their plateau with efficiency over 96%.

2. Time resolution is significantly larger with pure Freon than with gas A or B, and is marginal for STAR operation.

3. Streamer probability measurement confirms that MRPC indeed works in the avalanche mode. MRPC has longest HV range (1000 V) for "safe" operating in gas A. While in gas C, this range is shortest.

4. With gas B MRPCs could have good time resolution, but the working voltage range would be shorter than with gas A, so its operating may be not as easy as working with gas A.

We would like to thank the help and support from BNL CAD, especially Dr. Y. Makdisi and Dr. P. Pile for their many helps and advices.

References

1 STAR Collaboration. Strange Anti-Particle to Particle Ratios at Mid-rapidity in $\sqrt{S_{NN}}$ = 130 GeV Au + Au Collisions. Submitted to Phys. Lett., B

2 Adler C et al. Phys. Rev. Lett., 2003, **90**:032301

3 Adler C et al. Phys. Rev. Lett., 2002. **89**:202301

4 LI C, WU J, CHEN H F et al. HEP & NP, 2001, **25**:933 (in Chinese)
(李澄,伍健,陈宏芳等. 高能物理与核物理,2001,**25**:933)

5 CHEN H F, LI C, WANG X L et al. HEP & NP, 2002, **26**:201 (in Chinese)
(陈宏芳,李澄,汪晓莲等. 高能物理与核物理,2002,**26**:201)

6 LI C, CHEN H F, SHAO M et al. HEP & NP, 2002, **26**:455 (in Chinese)
(李澄,陈宏芳,邵明等. 高能物理与核物理,2002,**26**:455)

7 SHAO M, RUAN L J, CHEN H F et al. Nucl Instrum. Methods, 2002, **A 492**:344

8 SHAO M, RUAN L J, CHEN H F et al. HEP & NP, 2003 **27**:67 (in Chinese)
(邵明,阮丽娟,陈宏芳等. 高能物理与核物理,2003,**27**:67)

9 RUAN L J, SHAO M, CHEN H F et al. HEP & NP, 2003, **27**:712 (in Chinese)
(阮丽娟,邵明,陈宏芳等. 高能物理与核物理,2003,**27**:712)

10 Camarri P, Cardarelli R, Ciaccio A D et al. Nucl. Instrum Methods, 1998, **A 414**:317

11 Zeballos E C, Cotty I, Hatzifotiadou D et al. Nucl. Instrum. Methods, 1996, **A 374**:132

12 Zeballos E C, Cotty I, Hatzifotiadou D et al. Nucl. Instrum. & Methods, 1997, **A 392**:145

工作气体对 MRPC 性能影响的研究*

邵明[1;1)]　陈宏芳[1]　李澄[1]　汪晓莲[1]　黄胜利[1]
李洁[1]　阮丽娟[1]　伍健[1]　许咨宗[1]　汪兆民[1]
G. Eppley[2]　W. J. Llope[2]　F. Geurts[2]　J. Schambach[3]

1 (中国科学技术大学近代物理系　合肥　230026)
2 (Rice University, Houston, TX 77005-1892, USA)
3 (University of Texas, Austin, TX 78712, USA)

摘要　多气隙电阻板室(MRPC)飞行时间探测器模型从2003年2月开始在美国布鲁克海文国家实验室(BNL)的AGS束流上顺利完成了为期10周的测试(共28个MRPC模块168路读出,其中12个模块即72个读出道配置了读出电子学). 实验表明工作气体的选择对MRPC的工作性能有很大影响. 测量了几种不同成分的混合气体(A)90% $C_2H_2F_4$ + 5% iso-C_4H_{10} + 5% SF_6、(B)95.3% $C_2H_2F_4$ + 4.7% iso-C_4H_{10}及(C)100% $C_2H_2F_4$下MRPC探测效率和时间分辨等特性的变化,并给出了相应条件下的流光信号几率.

关键词　多气隙电阻板室　混合气体　探测效率　时间分辨　流光几率

2003-10-27收稿,2004-03-10收修改稿

* 国家自然科学基金(10375062)资助

1) E-mail:swing@ustc.edu.cn