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Performance of high rate MRPC with different gas mixtures

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ABSTRACT: A Time Of Flight system (TOF) based on MRPC technology is widely used and plays an important role in modern high energy and nuclear physics experiments. With the increase of the energy and luminosity of the accelerators, many experiments have higher demand for a better resolution TOF detectors working in an high data rate environment, which undoubtedly represents a big challenge for this technology. FAIR-CBM is a typical high rate experiment and the particle rate of its TOF can reach 30 kHz/cm^2. A new type of MRPC, built with low resistive glass with bulk resistivity of about 10^{10} Ohm cm, has been developed. The rate capability of this high rate MRPC can reach 70 kHz/cm^2. The standard gas mixture for the high rate MRPC used for the FAIR-CBM-TOF is 90% $C_2H_2F_4$, 5% i-C_4H_{10} and 5% SF_6. For the high rate MRPC used for the STAR-eTOF the gas mixture contains only two components, namely 95% $C_2H_2F_4$ and 5% i-C_4H_{10}. In order to ensure the long time stability of the high rate MRPC and its use with different gas mixtures, we have studied the performance with different gas mixtures. The first measurements were performed with the standard gas mixture and different gas mixtures were tested by reducing the content of SF_6. Three high rate MRPCs were tested at the same time for a cross-check, using a cosmic ray test-stand. The result of the test shows that the working point of the high rate MRPC moves toward a lower value of the high voltage by reducing the SF_6 content in the gas mixture. The working point for a chamber efficiency of 95% without SF_6 is about 800 V lower than the one with the standard gas mixture. Other properties such as time resolution, noise rate, dark current and cluster size have also been measured with different gas mixtures.

KEYWORDS: Instrumentation and methods for time-of-flight (TOF) spectroscopy; Timing detectors

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Contents

1 Introduction

A Multi-gap Resistive Plate Chamber (MRPC) was developed at CERN as Time Of Flight (TOF) detector [1]. It is widely used in high energy particle physics experiments due to its excellent time resolution, high efficiency and lower cost. Moreover a system of several MRPCs allows to cover a large detection area, has a time resolution of about 60 ps [2] allowing particle identification in high energy physics experiments by measuring time of flight of particles. However, further study of physics needs particle accelerators with higher luminosity.

All over the world new large colliders are planned and several existing experiments will be upgraded to cope with the higher energies and higher luminosities foreseen. Compressed Baryonic Matter (CBM) [3] is a high rate experiment aiming to investigate the phase diagram of strong interaction matter in the region of the highest baryon densities. The CBM-TOF detector made of MRPCs is critical for charged hadron identification and its particle rate capability may reach 30 kHz/cm^2. In the STAR experiment [4], a fixed-target program is planned at energy below 7.7 GeV during the beam energy scan-II, to study the phase diagram of quantum chromodynamics matter. The endcap TOF (e-TOF) detector upgrade will provide particle identification in an extended pseudorapidity range [5]. High rate MRPCs have been proposed for the CBM-TOF and the STAR-eTOF upgrades. They are made of low resistive glass sheets, whose bulk resistivity is about 10^{10} Ohm cm [6]. The rate capability of these new high rate MRPCs can reach 70 kHz/cm^2 [7].

The MRPC works in avalanche mode and the gas mixture plays an important role in this working regime. However, different experiments use different gas mixtures for MRPCs. The standard gas mixture for the high rate MRPCs in the CBM-TOF detector is 90% $C_2H_2F_4$, 5% i-C_4H_{10} and 5% SF_6, while for the high rate MRPCs used in the STAR-eTOF detector, a gas mixture consisting of only 95% $C_2H_2F_4$ and 5% i-C_4H_{10} with no SF_6 is employed. Therefore the test of a long term stability of the high rate MRPCs with different gas mixtures is crucial. Besides that, the global warming potential of SF_6 is more than 23000 and contributes to the greenhouse effect. Therefore, the use of SF_6 should be limited.

In this paper the properties of high rate MRPCs with different gas mixtures are presented.

2 Structure of the high rate MRPC

The high rate MRPC detector has 8 gaps totally and each gas gap is 0.25 mm wide. The gaps are made by inserting 0.25 mm fishing lines between low resistive glass sheets. The dimension of a low resistive glass sheet is $330 \times 276 \times 0.7\,\text{mm}^3$, which is limited by the maximal dimension of this type of glass sheet. The high rate chamber is built with two similar stacks to decrease the required high voltage. The outer surfaces of the outermost glass sheets of each stack are coated with a conductive layer. They are used as electrodes. Between the electrodes and PCBs there are mylar layers insulating the electrodes. PCBs with 32 readout strips are used for collecting the information of the induced signals. The strips are 270 mm long and 7 mm wide with a 3 mm distance between two strips. To increase the mechanical strength of the chamber and keep its uniformity, honeycomb boards are put on the two sides of each chamber.

The High Voltage (HV) connection for the high rate MRPC uses a specific design which reduces noise and crosstalk [8]. It is shown in figure 1. The top PCB and the bottom PCB have 32 readout strips in the inner side which is close to the mylar. The distance between the HV connection and the first strip is small to get the maximal active area. There is no HV copper foil, replaced by a hole with a 4 mm diameter, to avoid sparks between the first strip and the HV copper foil. For the middle PCB, the readout strips are inside the PCB and the HV copper foils are on both sides of it. This is feasible because the readout strips and the HV coppers foils are not in the same plane. Therefore, they are well insulated without the possibility of sparks. As shown in figure 2, the HV cables are soldered, during the assembly process, to copper foils after going through the top PCB or the bottom PCB and the close-by mylar foils. The hole and the surroundings are coated with silicone. The anodes of the high rate MRPCs are formed by connecting the electrode glass sheets with HV copper foils using a carbon tape. For the cathode, the HV cable is soldered directly to the

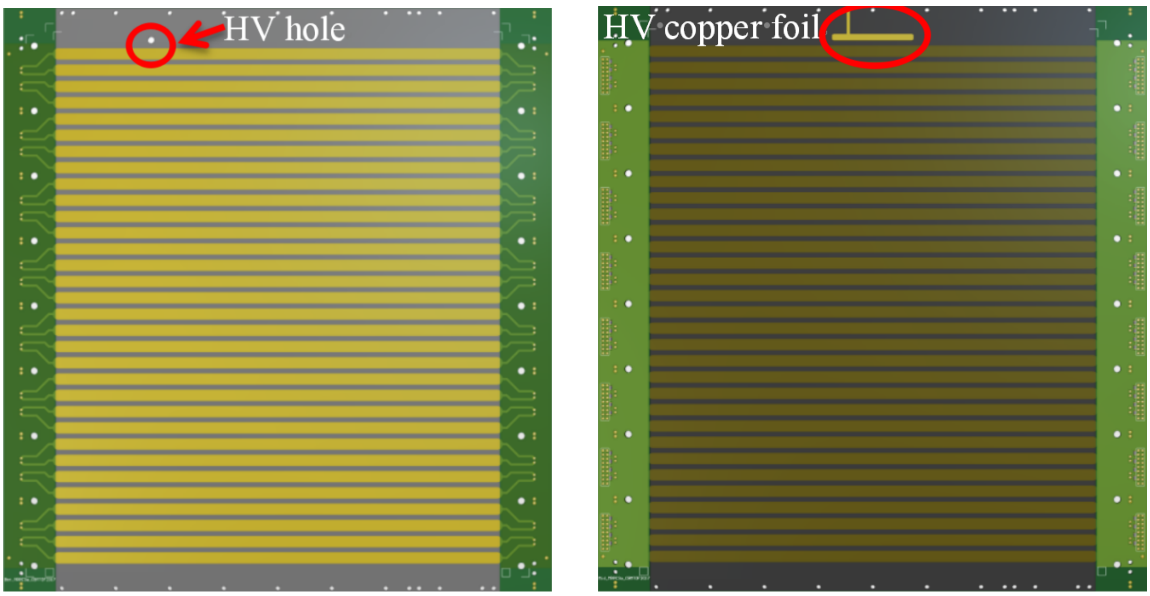

Figure 1. Design of the HV connection. Left: the HV connection design on the top and bottom PCB; right: the HV connection design on the middle PCB.

HV copper foil on the middle PCB. The electrode glass sheets are connected to the copper foil with a carbon tape through the hole in the mylar foil.

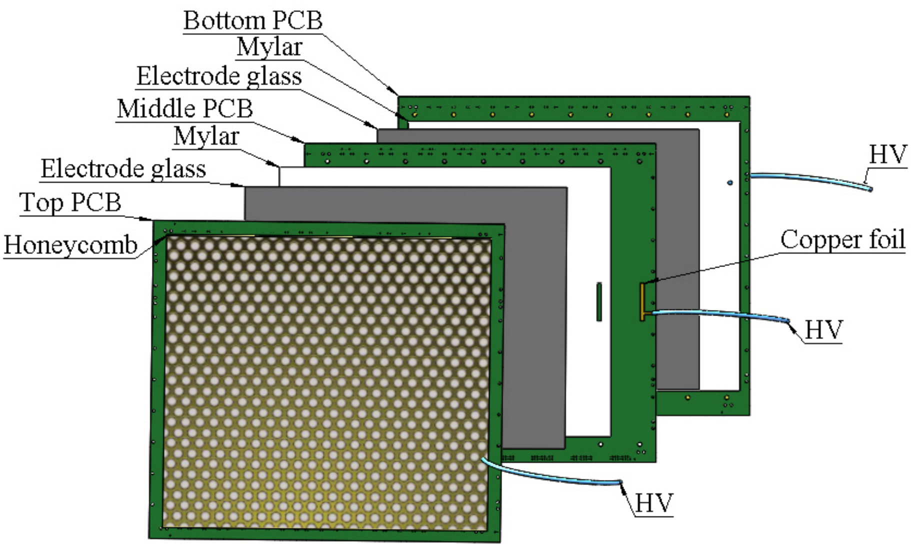

Figure 2. The HV connection and the construction procedure of the electrodes.

3 Experimental set-up

The experimental set-up consisted of 5 detectors, including three MRPCs and two scintillators as shown in figure 3. The coincidence of the upper and lower scintillator signals were used for the trigger. For each MRPC, the cathode was connected with negative HV and the anode with positive HV. The signals induced with both polarities were sent in differential mode to the front

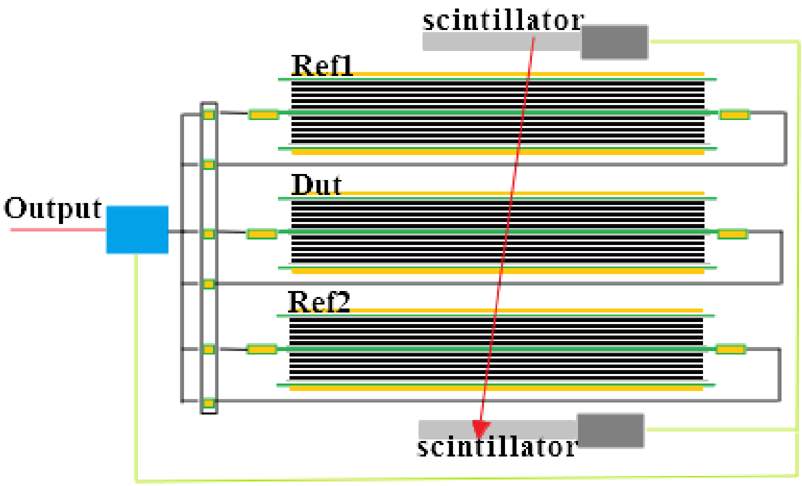

Figure 3. A drawing of the experimental set-up. Ref1 and Ref2 represent the two detectors used as reference. Dut represents the one under test. Scintillators were used for triggering.

end electronics. The analog output signals were sent to a time to digital converter (TDC) module and the data collected for the analysis. The three MRPCs were tested together. The upper and lower MRPCs were used as reference detectors working with efficiency higher than 95% to test the performance of the middle MRPC. An efficiency plateau of the middle MRPC with different gas mixtures was obtained by an high voltage scan. Different gas mixtures were tested by changing the proportion of the gas components. The experiment started with the standard gas mixture. The gas flow during the test was 60 ml/min.

4 Cosmic ray test results

Cosmic ray test data were analyzed with CbmRoot based on the CREN ROOT framework [9]. The chamber efficiency η, is defined as the ratio of the events measured by the coincidence of the three detectors (Ref1, Ref2, Dut) over the events measured by the coincidence of Ref1+Ref2:

$$\eta = \frac{n(\mathrm{Ref}_1 + \mathrm{Ref}_2 + \mathrm{Dut})}{n(\mathrm{Ref}_1 + \mathrm{Ref}_2)} \tag{4.1}$$

Where, n is the number of the events recorded. The performance of the high rate MRPC was tested with three different gas mixtures. In figure 4 it is shown the efficiency of the low resistivity MRPC under test with different gas mixtures. The working point with 95% efficiency for a double-stack MRPC without SF_6 is about 800 V (4 kV/cm) lower than the one measured with a standard gas mixture while, working with only pure $C_2H_2F_4$, the high rate MRPC reaches an efficiency of 95% at a voltage about 200 V lower.

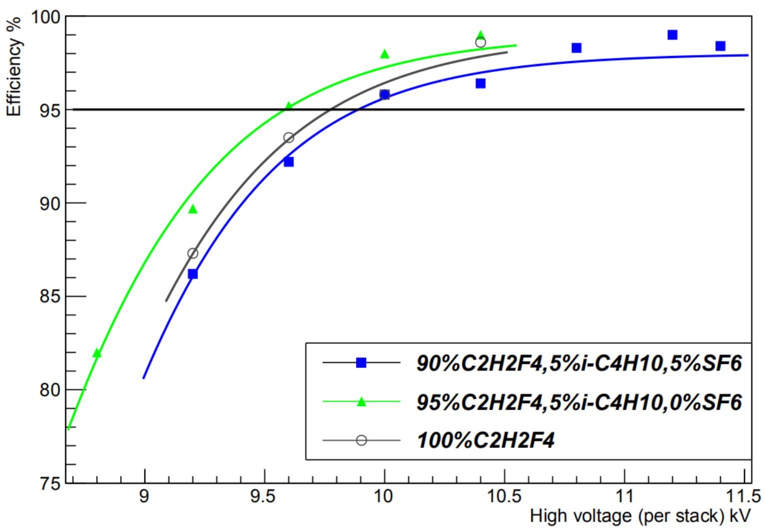

Figure 4. Efficiency of the high rate MRPC versus the applied HV (per stack) with different gas mixtures.

A flow chart of the data analysis, using the CbmRoot, is shown in figure 5. Firstly, the center of the readout strips are aligned in the initial calibration. Corrections for time walk, gain, Y-position and velocity are done with an iterative procedure. The time during which the signal voltage is above the discriminator threshold is measured for the time walk correction. After sufficient corrections, the cluster size is performed. The mean detection time of all hits in one cluster is assumed to be the best measurement of a particle crossing the detector.

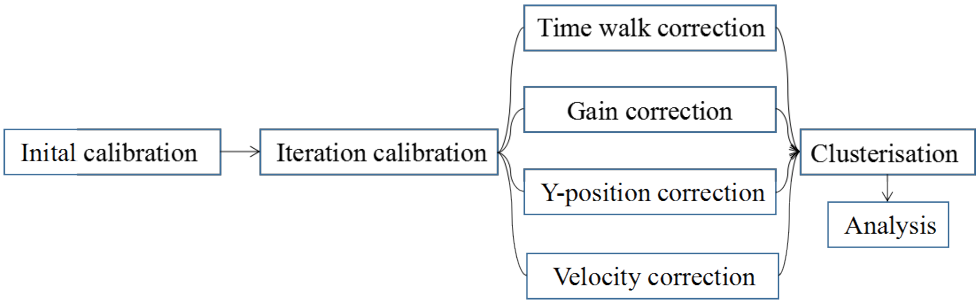

Figure 5. Flow chart of the data analysis.

Figure 6 shows the time difference between the Dut and Ref1 detectors, both at a working point with efficiency higher than 95% using two different gas mixtures. The width of the time difference divided by $\sqrt{2}$ is the time resolution, which is affected by the SF_6 content. The electron attachment is weak in the first stage of avalanche, causing the shift of the operating voltage. It becomes very strong when the avalanche starts to saturate [10]. The time resolution measured with the standard gas mixture is about 66 ps and it is better than the one measured with no SF_6 whose value is about 74 ps. This is the result of two competing processes [11]. The reduction of SF_6 will promote growth of the avalanche and results in a better time resolution and a lower working point. On the contrary, the lower HV will weaken the avalanche and reduce the drift velocity of the electrons, resulting in a worst time resolution. Figure 6 shows that using a gas mixtures with and without SF_6, the MRPCs time resolution is always smaller than 125 ps and meets the requirements of the cosmic ray test in table 1.

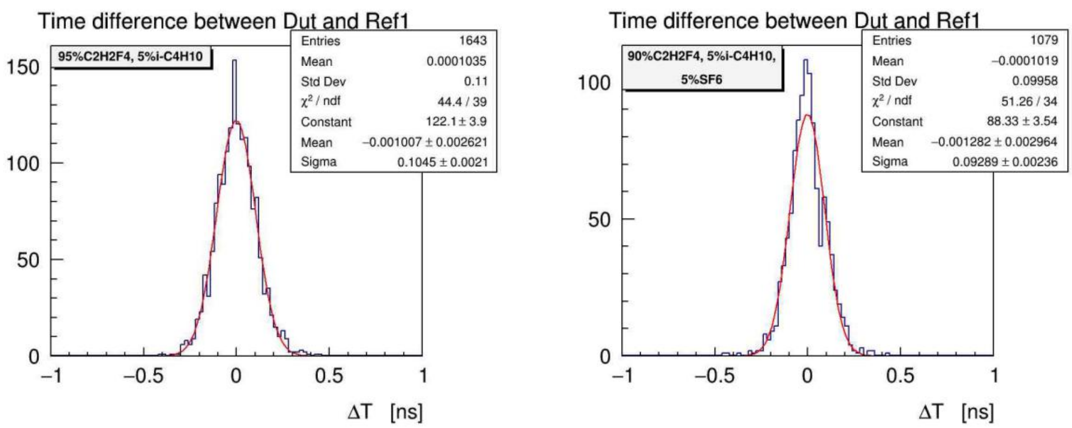

Figure 6. Time difference between the Dut and Ref1 detectors. The width of this distribution corresponds to the combined system time resolution of DuT and Ref1. Left: time difference at ±5200 V with 95% $C_2H_2F_4$, 5% i-C_4H_{10}; right: time difference at ±5600 V with 90% $C_2H_2F_4$, 5% i-C_4H_{10} and 5% SF_6.

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Table 1. Required performance of the high rate MRPC in a cosmic ray test.

Performance	Requirement
Efficiency	$> 95\%$
System time resolution of two MRPCs	< 125 ps
Noise	$< 2\,\mathrm{Hz/cm^2}$
Dark current	< 50 nA
Cluster size	< 2

The measured properties such as noise rate, dark current and cluster size are shown in figure 7, figure 8 and figure 9 for three different gas mixtures. The noise rate is lower than $2\,\mathrm{Hz/cm^2}$ when the voltage reaches the efficiency plateau. Setting an higher HV value does not improve the efficiency instead increases the noise rate. The measured cluster size is about 2 and it is slightly smaller with no SF_6 in the gas mixture. The dark current of each stack is less than 50 nA. The cluster size with the standard gas is smaller due to an higher fraction of SF_6.

The results of these measurements show that high rate MRPCs meet the requirements of table 1 using all three different gas mixtures but the chamber requires different working points.

A cross-check method was used to verify the results. The performance of the other two MRPCs with different gas mixtures was similar to the MRPC in the middle of the set-up, which confirms that the performance of the high rate MRPC is very stable.

The measurements show that the working point of high rate MRPCs with less or zero SF_6 in the mixture can be set at a lower voltage. Other parameters, such as dark current, noise rate and dark current are similar. The working point shift happens because SF_6 absorbs electrons strongly and keeps the avalanche away from streamers. Thus the reduction of the SF_6 leads to the increase of electrons during the avalanche grow. In order to keep the MRPC working in pure avalanche mode,

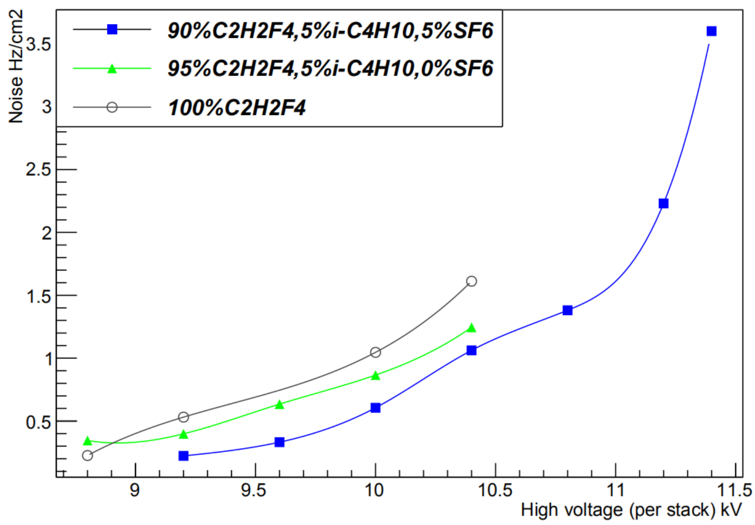

Figure 7. Noise versus the applied HV (per stack) of the high rate MRPC with different gas mixtures.

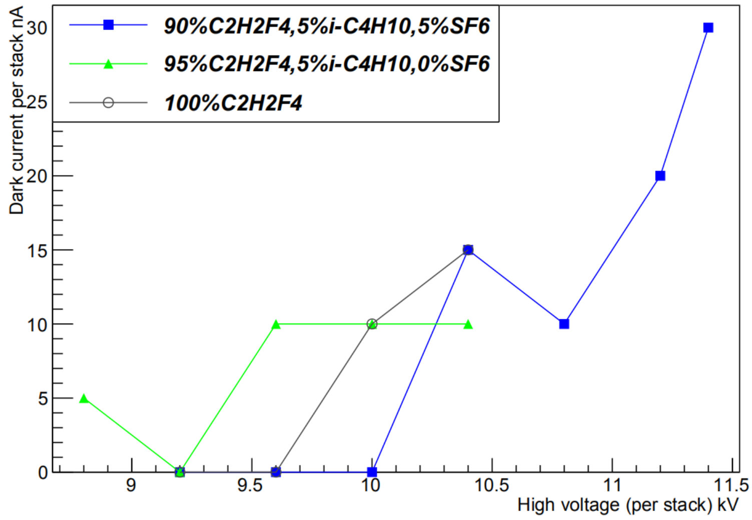

Figure 8. Dark current versus the applied HV (per stack) of the high rate MRPC with different gas mixtures.

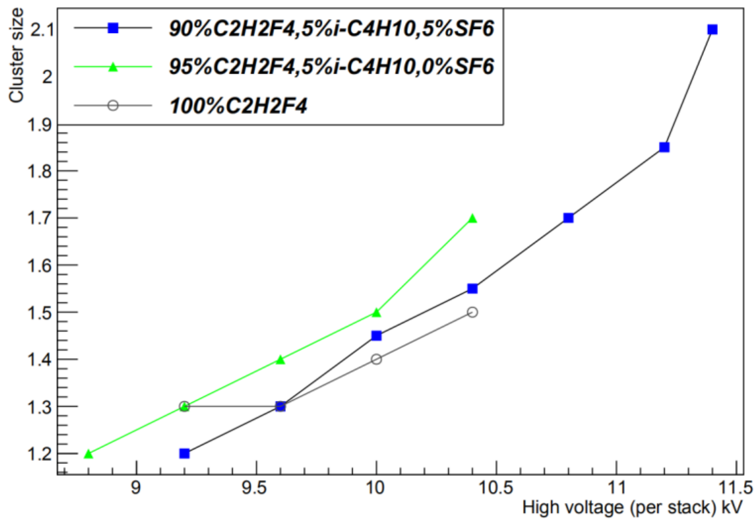

Figure 9. Cluster size versus the applied HV (per stack) of the high rate MRPC with different gas mixtures.

the high voltage should be decreased. The 95% efficiency working point of eight 0.25 mm gas-gap high rate MRPC shifts of about 800 V in total with different gas mixtures, using the standard gas mixture up to no SF_6. A MRPC constructed by low resistive glass sheets is different from that made by float glass sheets. Although the behavior of the working point shift with different gas mixtures is quite similar, the working point shift of a MRPC constructed with low resistive glass is more pronounced. For the MRPCs constructed with float glass layers used for the STAR TOF, the 95% efficiency working point shift is about 3.3 kV/cm changing the content of SF_6 from 5% to 0 [12]. The shift is less pronounced compared to the one measured for the high rate MRPCs that is about 4 kV/cm. Another MRPC was constructed with float glass sheets with six 0.25 mm wide gas gaps. It had different gas flow structure to ensure a uniform and proper gas flow, using an enclosed structure to replace the gas box. Moreover, the spacers were small circular disks instead of fishing wires. Test results for this detector did not show a working point shift [11].

5 Conclusion

A high rate MRPC, made of low resistive glass sheets, was tested with cosmic rays. It shows good performance with the three different gas mixtures used in the test. We observe that the working point decreases with a reduction of SF_6 content in the gas mixture. The high voltage of the working point with 95% efficiency without SF_6 is about 800 V lower than the one measured using the standard gas mixture. Compared with the MRPC constructed with float glass sheets, the working point shift of the high rate MRPC is more pronounced. We believe that more studies on high rate MRPCs are necessary to verify these results. If our preliminary results are confirmed, it is critical to set the correct high voltage when using different gas mixtures.

Other properties of the high rate MRPCs, such as noise, time resolution and dark current, show little changes when the gaps are filled with one of the three different gas mixtures.

In conclusion, we observe that reducing the amount of SF_6 in the gas mixture decreases the operating high voltage of the MRPCs and it is also beneficial for the environment. The results obtained show that high rate MRPCs can work well also without SF_6. For future work, we are considering to use new eco-friendly gases and to study the MRPC performance using these new gases.

Acknowledgments

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References

[1] E. Cerron Zeballos, I. Crotty, D. Hatzifotiadou, J. Lamas Valverde, S. Neupane, M.C.S. Williams et al., *A New type of resistive plate chamber: The Multigap RPC*, Nucl. Instrum. Meth. **A 374** (1996) 132.

[2] B. Bonner, H. Chen, G. Eppley, F. Geurts, J. Lamas Valverde, C. Li et al., *A single Time-of-Flight tray based on multigap resistive plate chambers for the STAR experiment at RHIC*, Nucl. Instrum. Meth. **A 508** (2003) 181.

[3] I. Deppner et al., *The CBM Time-of-Flight wall - a conceptual design*, 2014 *JINST* **9** C10014.

[4] STAR collaboration, *The fixed-target experiment at STAR*, J. Phys. Conf. Ser. **742** (2016) 012022.

[5] STAR, CBM eTOF Group collaborations, *Physics Program for the STAR/CBM eTOF Upgrade*, `arXiv:1609.05102`.

[6] J.-B. Wang et al., *Development of multi-gap resistive plate chambers with low-resistive silicate glass electrodes for operation at high particle fluxes and large transported charges*, Nucl. Instrum. Meth. **A 621** (2010) 151.

[7] Y. Wang et al., *Development and test of a real-size MRPC for CBM-TOF*, 2016 *JINST* **11** C08007 [arXiv:1605.02395].

[8] Z. Weiping, W. Yi, L. Yuanjing and C. Jianping, *A new design of MRPC to reduce noise and crosstalk*, 2014 *JINST* **9** C07007.

[9] CbmRoot, http://cbmroot.gsi.de/.

[10] P. Camarri, R. Cardarelli, A. Di Ciaccio and R. Santonico, *Streamer suppression with SF-6 in RPCs operated in avalanche mode*, *Nucl. Instrum. Meth.* **A 414** (1998) 317.

[11] M.M. Devi, N.K. Mondal, B. Satyanarayana and R.R. Shinde, *Design, development and performance study of six-gap glass MRPC detectors*, *Eur. Phys. J.* **C 76** (2016) 711 [arXiv:1509.08586].

[12] A.N. Akindinov et al., *Study of gas mixtures and ageing of the multigap resistive plate chamber used for the Alice TOF*, *Nucl. Instrum. Meth.* **A 533** (2004) 93.