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A thin float glass MRPC for the outer region of CBM-TOF wall

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ABSTRACT

A Multi-gap Resistive Plate Chamber (MRPC) made out of thin float glass is proposed for the outer region of the time of flight (TOF) system for the Compressed Baryonic Matter experiment at FAIR. Usually MRPCs are assembled with ordinary glass plates of 0.5 mm or more thickness, but their rate capability is less than the CBM requirement (1.5 kHz/cm^2). There are two ways to improve the rate capability. The first way is to reduce the bulk resistivity of the glass plates. The second is to reduce the thickness of the glass plates. Tsinghua University has made significant progress in the development of low resistive glass and high rate MRPCs. In this paper we report on three MRPCs produced with float glass plates of 0.7 mm, 0.5 mm and 0.35 mm thickness. Tests with cosmic rays and X-rays were performed at Tsinghua University. The results show that thin float glass MRPCs work well and have the rate capability necessary to meet the demands of the CBM-TOF outer region. Further studies were performed using a continuous 1 GeV deuterium beam at the Nuclotron accelerator at the Joint Institute for Nuclear Research (JINR). Time resolution of about 70 ps and efficiency higher than 90% were obtained for flux densities up to 3 kHz/cm^2, exceeding the requirement for the CBM-TOF outer region.

1. Introduction

Multi-gap Resistive Plate Chambers (MRPCs) are planar, gaseous detectors made with resistive electrodes and glass plates that form very thin and accurately defined gas gaps. Such detectors are known to deliver timing accuracies below 50 ps σ for minimum ionizing particles (MIP) [1]. These excellent timing characteristics together with high detection efficiency, relatively low cost, and the possible coverage of large areas make MRPCs a valuable instrument for time of flight (TOF) systems used for particle identification, particularly in high-energy heavy-ion physics. This TOF technology was first introduced in the 1990s [2] and used at the STAR [3,4] experiment at RHIC. The Compressed Baryonic Matter (CBM) experiment at the future Facility for Anti-proton and Ion Research (FAIR) accelerator in Darmstadt, Germany is planning to build a 150 m^2 TOF wall based on MRPCs. The aim is to obtain good identification for hadrons in fixed-target heavy-ion collisions at projectile energies up to 25 GeV/A. According to simulations, the expected particle flux will be approximately 20 kHz/cm^2 in the center of the CBM-TOF wall and decrease nearly exponentially to 500 Hz/cm^2 in the outermost region [5].

The CBM-TOF is divided into different rate regions [5] in the recent conceptual design, as shown in Fig.1. In the inner rate region defined as region 3 to region 1, the particle flux will range from 3.5 kHz/cm^2 to 25 kHz/cm^2. High-rate MRPCs assembled with low-resistive glass plates can work stably in a high rate flux of about 35 to 60 kHz/cm^2 [6] and they are presently the best choice for this high rate region. In the outer region (region 4) with an area of nearly 82.5 m^2, the particle flux ranges from 0.5 kHz/cm^2 to 1.5 kHz/cm^2. MRPCs made out of float glass might be used in this region. However, the counting rate capability of MRPC assembled with commercial available glass can only reach a few hundred Hz/cm^2 [2], which cannot meet the requirement of the CBM project. To improve the counting rate capability of float glass MRPCs, warming-up technology was proposed. But warming up such a large area is not easy and this method is of questionable feasibility. The warming technology may also lead to some other problems (increasing dark current, background count rate, gas pollution and so on). Thin glass MRPCs are another choice for the CBM TOF wall. This paper presents the result of three MRPC prototypes made of float silicate glass. Cosmic ray tests and X-ray tests have been performed in our laboratory at Tsinghua University and beam tests were performed at the Nuclotron accelerator at JINR in Dubna

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using a 1 GeV deuterium beam. The structure of the MRPCs and the test results are described in this paper.

2. Rate analyses

The counting rate capability of MRPCs is limited by the time interval needed for a localized discharge to dissolve from the plate electrode. A DC model, the only available analytical description of rate effects, was used to study the process. In this model, the average voltage drop on the gas gap RPC at “high rate”ϕ is given by [7]:

$$\overline{V}_{drop} = V_{ap} - \overline{V}_{gap} = \overline{I}R = \overline{q}\phi\rho d \qquad (1)$$

where $V_{ap}$is the externally power supply voltage, $\overline{V}_{gap}$the true effective voltage applied on the gas gap of RPC, $\overline{I}$ the current drawn by the detector which is proportional to the average charge per avalanche $\overline{q}$, ρ the volume resistivity of the plate, and d the thickness. It is obvious that the rate capability of the RPC depends mainly on the resistance of the plates (rate capability $\phi \propto 1/R$). To improve the rate capability we should reduce the resistance of the plates, which is proportional to $\rho d (R \propto \rho d)$. It is clear that to lower the resistance, we can lower theρ (adopt low resistivity electrodes) or reduce d (reduce the thickness of electrodes). To lower the resistivity of electrodes, we have previously developed a kind of semi-conductive glass (the counting rate capability of which can reach 35–60 kHz/cm^2). This development was enabled by the work of Ammosov [8]. In this new research, we will reduce the thickness of the glass electrodes to reduce the resistance. The counting rate of MRPCs using thicker float glass can reach a few hundred Hz/cm^2. If the rate capability is proportional to $1/d$ we estimate that the rate capability of MRPC can be increased a few times by decreasing the glass thickness.

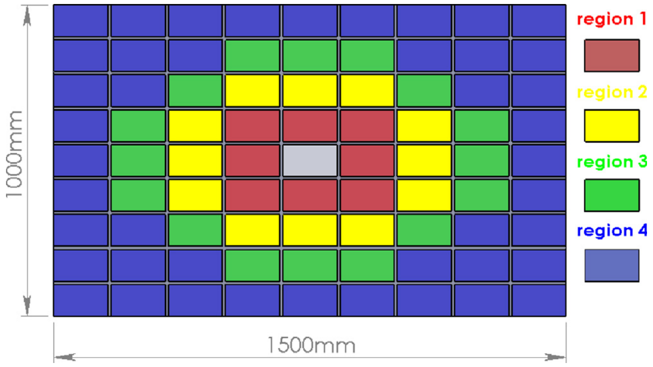

Fig. 1. Particle rate distribution in the full area of CBM-TOF.

3. Glass electrodes and structure of counters

Three kinds of glass with a thickness of 0.7 mm, 0.5 mm and 0.35 mm, respectively, were prepared in our laboratory. The 0.7 mm and 0.5 mm glass are commercially available with a bulk resistivity of $4.2 \times 10^{12}\ \Omega$ cm and $4.3 \times 10^{12}\ \Omega$ cm, respectively. The 0.35 mm glass (called thin float glass) was obtained by polishing the 0.5 mm glass plates. The measured bulk resistivity remained the same as the 0.5 mm thick glass plate. The thin float glass plate is extremely flexible and the surface smoothness is still very good. It is not too difficult to polish the plates from 0.5 mm down to 0.35 mm, and compared to the cost of semi-conductive glass, the expense is much lower. Three MRPC readout counters based on the three different kinds of glass were assembled. Except for the thickness of the glass, the other factors are kept the same for these three modules. The structure of these three counters is shown in Fig. 2. There are eight readout strips. The size of each strip is 2.2 cm × 12.5 cm. There is a 3 mm interval between each strip. The total active area is 20 cm × 12.5 cm. It is a double stack device consisting two five-gap stacks. The thickness of the gas gap is 250 μm, defined by nylon fishing line. The high voltage electrodes are covered with colloidal graphite, yielding a typical surface resistivity of about 5 MΩ/sq. This mirror-symmetrical structure is operated with the negative HV on the inner electrodes, and the positive HV applied to the outer electrodes. Compared to a single stack module with a similar number of gaps, the double-stack structure can derive a higher voltage for each gas gap with the same voltage supply. We define the three MRPCs as 0.35MRPC, 0.5MRPC and 0.7MRPC for simplicity.

4. Cosmic ray test and X-ray test

We have never assembled a large module using this thin glass plate (0.35 mm) electrode before. To measure the performance of

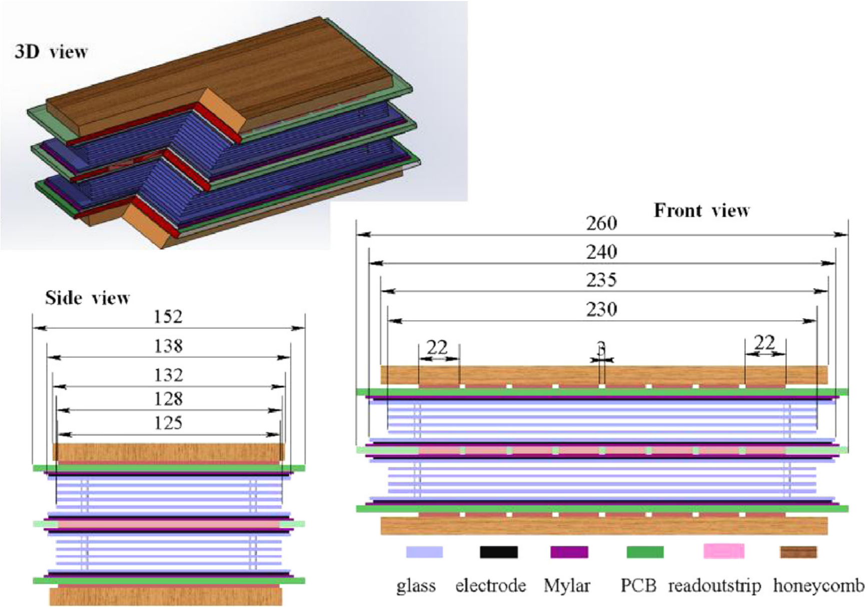

Fig. 2. Structure of the float glass MRPC with 8-strip readout.

these MRPCs and to ensure that the MRPCs have the potential to meet the requirements of the CBM-TOF outer region, cosmic ray tests and X-ray tests were performed in our laboratory after finishing the assembly.

4.1. Cosmic ray test

The same cosmic ray test system was used as for the previous cosmic ray tests of the STAR TOF MRPC detector production (for details see Ref. [4]). The working gas is a mixture of 90% Freon, 5% of iso-butane and 5% SF6, with a flow rate of 25 ml/min. The temperature of the laboratory is kept constant at 22 °C. The STAR TINO front-end card using the NINO front-end ASIC was used as the preamplifier for the three modules. The value of threshold was set at 1.6 V. The three modules were tested in turn under exactly the same conditions.

Cluster size is often used for the measurement of cross talk in chambers. In our experiment the same data used for the calculation of the detector efficiency and time resolution was used to build clusters. Efficiency plateaus together with cluster sizes versus applied high voltage (HV) of the three modules are shown in Fig.3. All three modules achieved 98% efficiency at high voltage conditions. The detection efficiency was over 95% when the applied HV is higher than 6.2 kV for the 0.35MRPC, 6.3 kV for the 0.5MRPC and 0.7MRPC. It can be seen that there is very low crosstalk, the cluster size of three modules is less than 1.35. The cluster size of the 0.35MRPC is relatively larger than the other two MRPCs. Time resolution together with the corresponding detection efficiency at the working HV point is shown in Fig. 4. Time resolution for the three counters is all better than 70 ps.

The dark counting rate of the three detectors was measured using the CAEN Mod.N1145 scaler. Fig. 5 shows test results for the three modules. The level of the noise is given as a function of the applied HV. The dark rate of the detectors increased exponentially with the increase in high voltage. The level of the dark rate is under 2.2 Hz/cm^2. The above test results indicate that the three modules were well assembled and can work properly in a low-rate environment.

4.2. X-ray test

The cosmic test results show that the 0.35MRPC can work properly in a low rate environment. To determine if this MRPC has the potential to meet the demand of CBM-TOF outer region, further studies are needed. For the limitation of time and experimental conditions, only the two most important characteristics: the current drawn by detectors and the output counting rate versus the HV supplied to the X-ray generator were measured. The output counting rate of the MRPC was measured by a scaler. The operating current drawn by the detector was recorded by the HV source N471A. The results were excellent. Fig. 6 shows the layout of the X-ray test. The X-ray machine was placed 2 m away from the aluminum gas-tight box to get a relatively uniform irradiation. A 6 cm thick lead plate

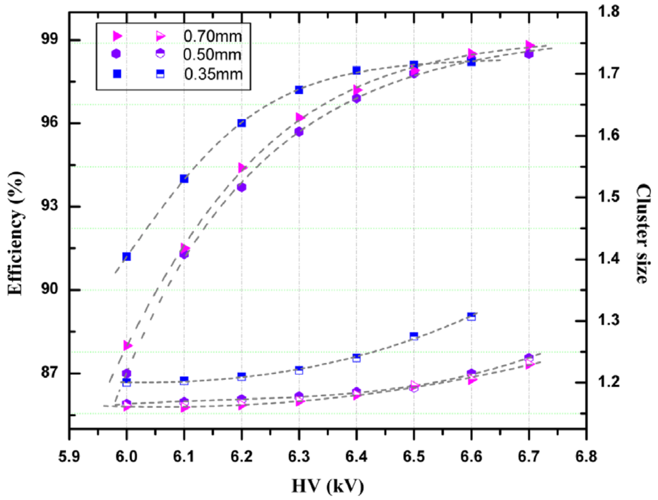

Fig. 3. Efficiency and cluster size change with applied high voltage (HV) of the modules.

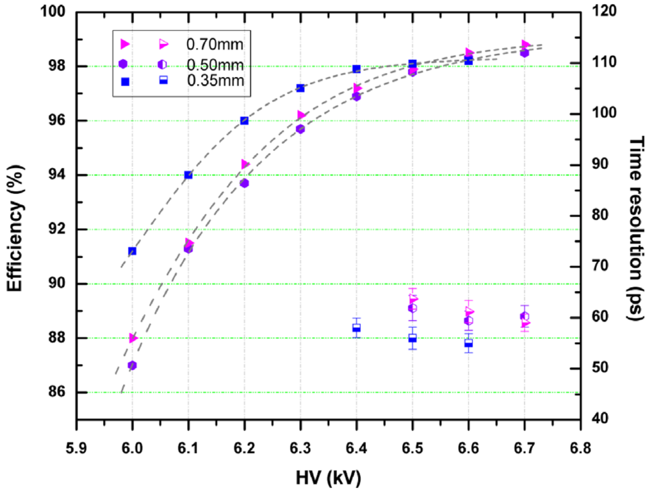

Fig. 4. Efficiency together with time resolution versus applied high voltage (HV) for the three modules.

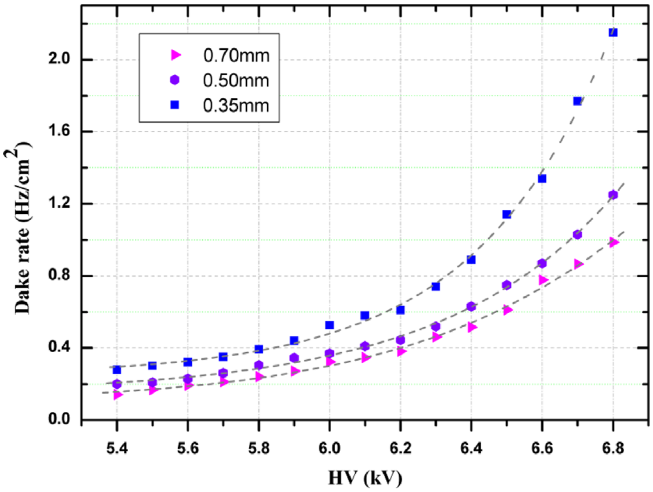

Fig. 5. Dark rate versus applied high voltage (HV) for the three modules.

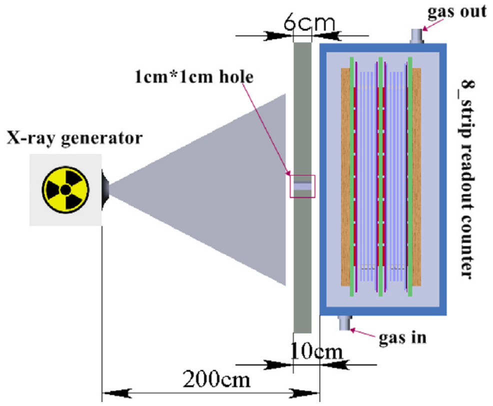

Fig. 6. Schematic view of the X-ray experiment setup.

with a 1 cm^{2}hole in the center was placed close to the box so the activated area of the counter is about 1 cm^2.

Fig. 7 shows the current and counting rate change with high voltage of the X-ray machine. Fig. 7(a) shows the current of the counters versus the voltage of the X-ray machine. It can be seen that the current is proportional to the incident particle flux. This almost linear relation dependence is due to the space charge effects in the progressing avalanche [9]. Counting rate versus applied voltage of the X-ray machine of the three modules is show in Fig. 7(b–d), respectively. From these three pictures we can see that with the increase of the voltage for X-ray machine, the output counting rate will reach a maximum value and then decline. The maximum counting rate represents the rate capability of MRPC. With the increase of glass thickness, the maximum counting rate decreases. The maximum counting rate of 0.35MRPC is about 21 kHz/cm^2, which is 4 times higher than the 0.7MRPC and 3 times over the 0.5MRPC. According to the previous study of the rate capability of conventional glass MRPCs (a few hundred Hz/cm^2), a few kHz/cm^2 rate might be achieved by 0.35MRPC. This estimate has to be validated through a detailed beam test.

5. Beam test at Nuclotron

The beam test was carried out at Nuclotron in JINR at Dubna in March 2013. The Nuclotron is a basic JINR facility which can provide

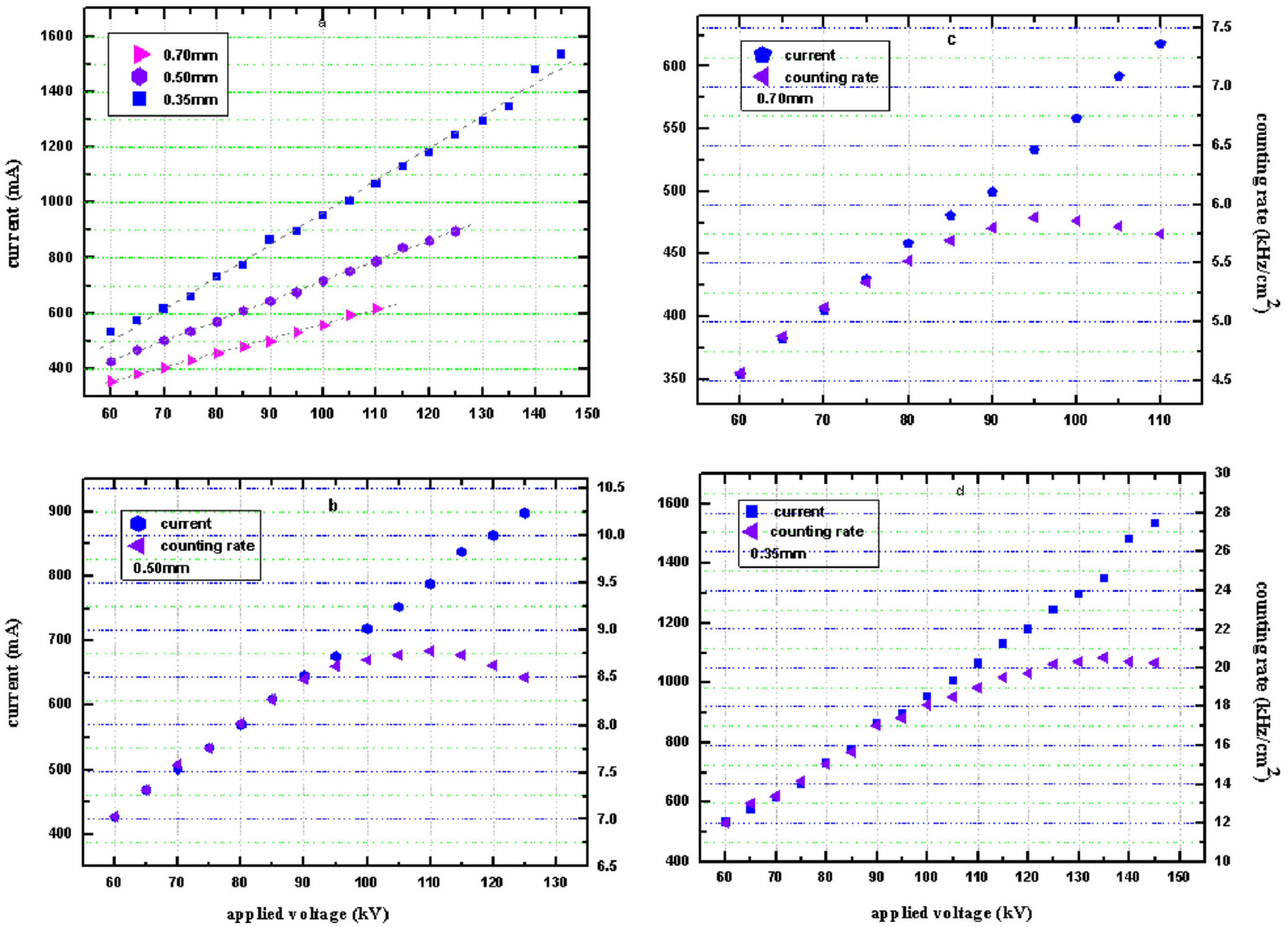

Fig. 7. (a) Current versus the applied voltage to the X-ray tube, (b–d) current and counting rate of the three MRPCs versus the voltage of the X-ray tube.

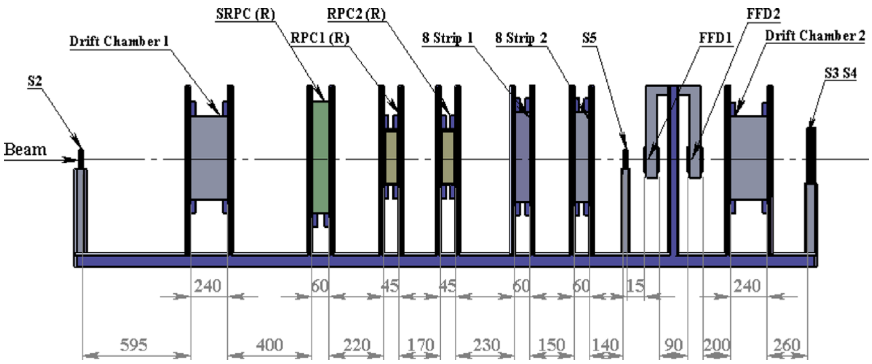

Fig. 8. Beam test setup: the beam consisted of 1 GeV deuterons. The coincidence signal of S1–S5 acted as the trigger of the system. FFD1&FFD2 provide the reference time for the MRPCs.

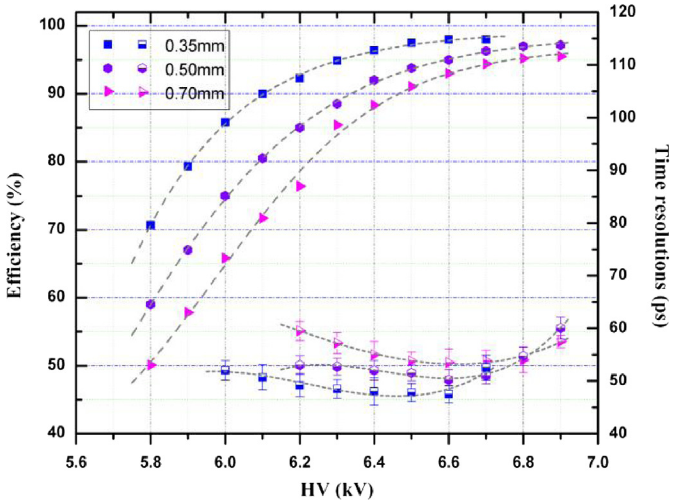

Fig. 9. Efficiency and time resolution of the three modules as a function of the working high voltage.

multi-charged ions (proton beams as well as polarized deuteron beams) with an energy of up to 6 GeV per nucleon [10]. A deuteron beams was provided for our experiment at an energy of 1 GeV/A, 2-3s/spill. The setup of the beam test and the relative position of detectors are shown in Fig. 8. Since S1 placed in front of S2 is far away from other detectors, it is not shown in this figure. All detectors were aligned with the aid of a laser. The MRPCs were embedded in a chain of scintillators, used to select straight deuteron tracks. Gas of the same composition of cosmic ray and X-ray test was piped into the sealed aluminum MRPC gas box at the flow rate of 100 ml/min. The coincidence signal of S1–S5 acted as the trigger and common start for the TDC. FFD1 and FFD2 are Cherenkov detectors which provide a reference time for the test. The measured Cherenkov time resolution was around 30 ps which is an excellent reference for MRPC time measurement. 8 Strip 1 and 8 Strip 2 are our MRPCs.

5.1. HV scan

Detectors were conditioned under high voltage for a few hours in order to attain a stable, low dark current and low noise working status.

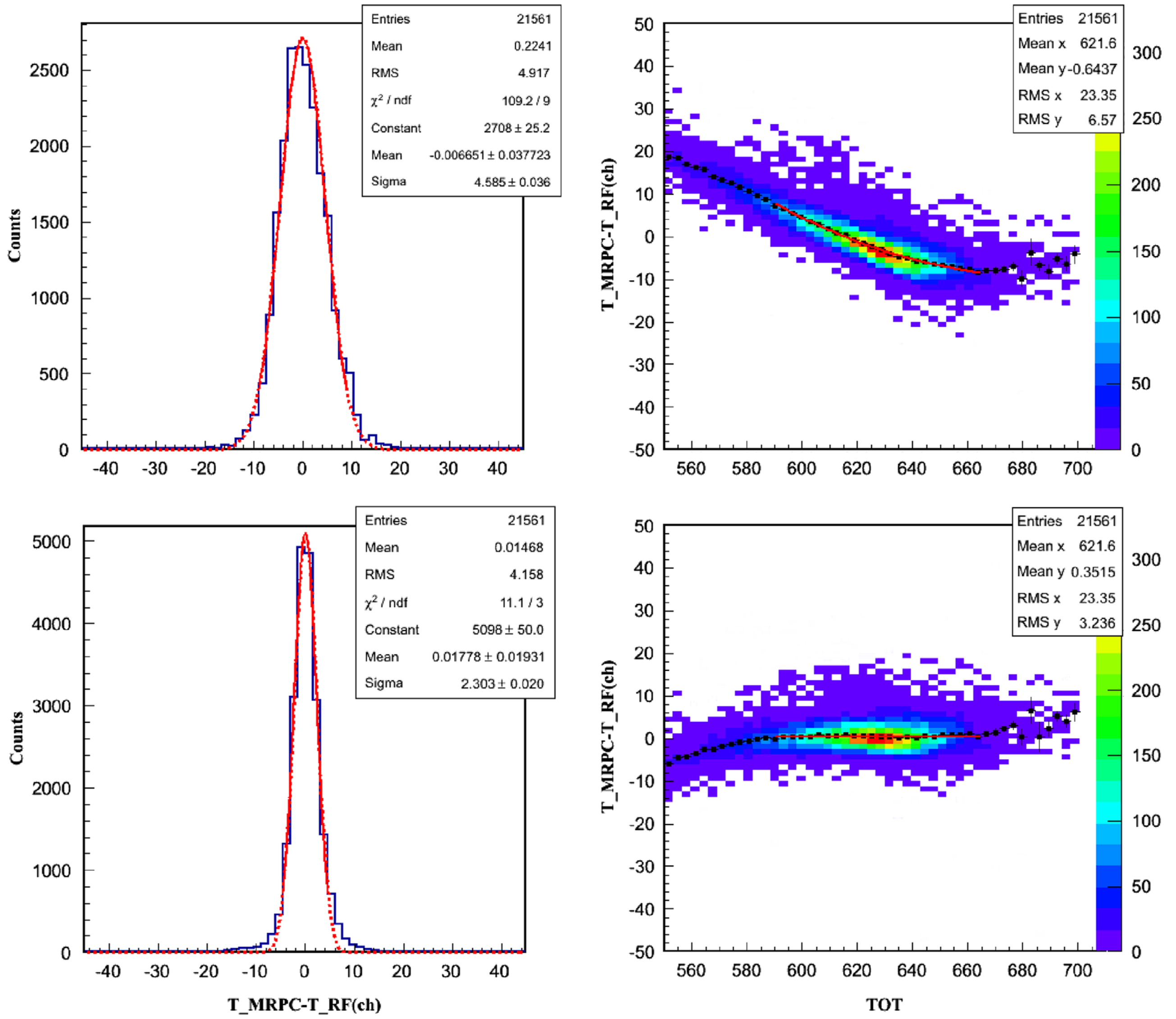

Fig. 10. Typical time distribution and T–Q correlation of 0.35MRPC. Top: raw time distribution and T–Q correlation. Bottom: time spectrum and T–Q correlation after slewing correction.

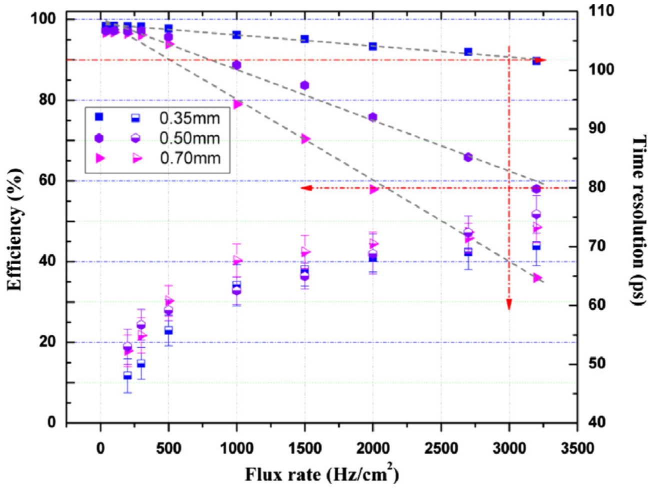

Fig. 11. Efficiency and time resolution as a function of particle flux. The efficiency of the 0.35 mm MRPC decreases from 98% to 90%, time resolution remained below 70 ps.

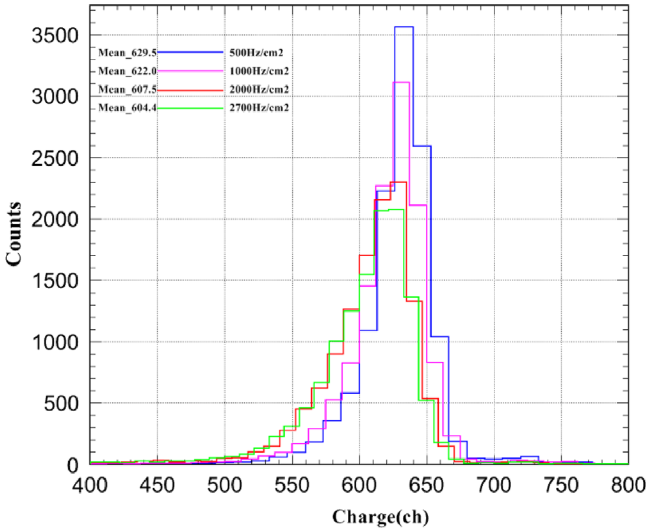

Fig. 12. Charge distribution as a function of particle flux.

The threshold of the NINO preamplifier was again set at 1.6 V. In order to find the optimum working voltage of the three MRPCs, efficiency and time resolution were scanned as a function of the applied voltage under a “low rate” flux environment of about 100 Hz/cm^2. The results are summarized in Fig. 9. All the modules achieved 95% efficiency at high voltage. The efficiency was over 90% at HV $\geq$ 6.5 kV for 0.7MRPC; at HV $\geq$ 6.4 kV 0.5MRPC; and at HV $\geq$ 6.1 kV for 0.35MRPC. The efficiency for the 0.35MRPC was always higher than the other two modules, which is a different result than the cosmic ray test. This may due to the “high rate” flux. The time resolution was around 50 ps for these modules, but the 0.35MRPC had the best result. Fig. 10 shows the measured time and the T–Q correlation of the 0.35MRPC. It can be seen that the time resolution reached 48 ps. The maximum cluster size of all modules is less than 1.35, which is the same as cosmic result.

5.2. Rate scan

XIn order to measure the rate capability, the three modules were tested as a function of deuterium flux. The working voltages of the three modules (0.7MRPC, 0.5MRPC and 0.35MRPC) are set at 6.8 kV, 6.7 kV and 6.6 kV, respectively. Results of efficiency and time resolution measured under different flux rates at the range of 50–3200 Hz/cm^2 are summarized in Fig. 11. With the increase of the flux rate, time resolution does not change very much and the resolution of the modules remains better than 75 ps. But the efficiency of the counters almost decreases linearly. For 0.7MRPC when the flux rate is higher than 500 Hz/cm^2, the detection efficiency drops below 90%. This result shows that the rate capability of this module can only reach 500 Hz/cm^2 at most, which is consistent with previous studies. We obtained the rate capability of the other two modules with the same criterion. The rate capability of 0.5MRPC and 0.35MRPC are 1 kHz/cm^2 and 3 kHz/cm^2, respectively. The charge spectrum of the 0.35MRPC under different flux rates is presented in Fig. 12. It can be seen that, with the increase of the deuterium flux, the average charge decreases and the spectrum shifts down to lower charges as expected.

6. Conclusions

The CBM-TOF wall is proposed to be assembled using MRPCs. Simulations predict that the innermost part of the TOF system will be operated under particle fluxes of about 20 kHz/cm^2 and falling nearly exponentially down to 500 Hz/cm^2 in the outermost region. In the recent conceptual design, the CBM-TOF is divided into different rate regions. For the inner region, particle flux ranges from 3.5 kHz/cm^2 to 25 kHz/cm^2. MRPCs made out of semi-conductive glass are proposed to cover this region. A new type of 0.35 mm glass has been developed to fit the requirement of the outer region with particle flux ranging from 0.5 kHz/cm^2 to 1.5 kHz/cm^2. Different thickness glass MRPCs were developed to study and compare their performance. Cosmic ray tests show that the three modules work well and X-ray tests indicates that the MRPC assembled with 0.35 mm thick glass has the potential to achieve “high rate” capability. The beam test of the thin float glass MRPC yielded satisfactory results. Time resolution below 70 ps and efficiency higher than 90% were obtained for particle flux up to 3.0 kHz/cm^2 and this counter behaved very stably during testing. Test results also indicate that this new type of very thin float glass is an excellent material for improving the rate capability of MRPCs. The MRPC assembled with this 0.35 mm thick glass can fully meet the requirement of CBM-TOF outer region.

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