Performance study of new style mosaic MRPC *

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Abstract: The Compact Muon Solenoid (CMS) at LHC intends to use a high rate trapezoid MRPC for the muon system upgrade, but the size of the MRPC is limited by the dimensions of low resistivity glass. We have designed a prototype of a large MRPC in which the electrodes are developed by gluing two pieces of glass plates. Simulation of the weighting field and cosmic ray test shows that the efficiency of the glued MRPC is higher than 96% and the time resolution is better than 71 ps.

Keywords: high rate MRPC, gluing, large size

PACS: 29.40.Cs **DOI:** 10.1088/1674-1137/40/11/116006

1 Introduction

The multi-gap resistive plate chamber (MRPC) was originally developed by the ALICE TOF group at CERN to obtain a much improved time resolution detector from the Resistive Plate Chamber (RPC) [1]. With the increasing of accelerator luminosity, high rate MRPCs will have even more applications. In the Compact Muon Solenoid (CMS) experiment at CERN, the upgraded muon system requires a counting rate higher than 2 kHz/cm^2, efficiency higher than 95% and time resolution better than 100 ps, so the MRPC is a promising candidate. The excellent timing ability of the MRPC can also discriminate muons from other particles and this technology has been used in the STAR muon telescope detector (MTD) [2].

The MRPC system is supposed to lie on the endcap area of the CMS detector, which needs the shape of MRPC to be large (1 m scale) but thin (total thickness less than 2 cm). However, the size of the high rate MRPC is restricted to 30 cm ×32 cm owing to the production technique. The present large MRPC in the TOF detector is achieved by the overlap of hundreds of MRPCs, which makes the system much thicker than a single module [3] and is obviously not suitable for CMS. Thus, a thin, large-area, high-rate MRPC is needed.

We have done research and experiments on a prototype glued MRPC. A simulation of weighting field based on Maxwell shows that the lowest efficiency in the glued area can still be very high and the affected area is only 0.5% of the detector. The new glued MRPC was tested with cosmic rays, showing that it has an efficiency higher than 96% and time resolution better than 71 ps. Experiments on the glued region confirms the results of the simulation, showing 93% efficiency in the glued region.

2 Simulation of weighting field

2.1 Principle of weighting field theory

The real electric field in the gas gaps of an MRPC is always calculated by dividing the high voltage applied on graphite layers by the total gap width [4], because in a typical MRPC, the bulk resistivity of gas and glass are 10^{15} Ω· cm and 10^{12} Ω· cm respectively (10^{10} Ω· cm for low resistivity plates) which means the voltage drop on the plates is one thousandth (1/100000 for low resistivity plates) of that in the gas gap. In gluing the MRPC, the glue has a volume resistivity of 10^{12} Ω· cm, which is also one thousandth of the gas resistivity and can be ignored when calculating the real electric field. The value of the real field is around 100 kV/cm and this determines the circumstances of avalanche, i.e. the Townsend and attachment coefficients.

When original or avalanche particles move toward a resistive plate, the induced signals can be measured on the read-out electrode. According to the Ramo the-

Received 26 January 2016

∗ Supported by National Natural Science Foundation of China (11420101004, 11461141011, 11275108) and Ministry of Science and Technology (2015CB856905)

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ory [5], the induced current is

$$I(t)=\frac{E_w}{V_w}\dot{X}q, \tag{1}$$

where X represents the charge trajectory in the detector, q is the charge released in the gas gap, and E_w is called the weighting field [6], which is the value of the electric field in the gas gap when the charge is removed, the voltage of the read-out electrode set to be V_w and the others to zero. Using the coordinate defined in Fig. 1, the Z component of the weighting field in one gap for an MRPC can be given by Eq. (2) [7]:

$$\frac{E_\mathrm{w}}{V_\mathrm{w}}=\frac{\varepsilon}{ng\varepsilon+(n+1)d}, \tag{2}$$

where ε is the relative permittivity of the plates when that of gas is set to be 1, g is the gap width, d is the plate width and n is the number of gaps. The weighting field acts like a weighting factor which reflects how much the capacitors of gaps and plates affect the detector's performance. By setting a threshold Q_t in detection, the efficiency of a large uniform RPC is deduced to be [8]:

$$\mathrm{eff}=1-\mathrm{e}^{-\left(1-\frac{\eta}{\alpha}\right)\frac{d}{\lambda}}\left[1+\frac{V_\mathrm{w}}{E_\mathrm{w}}\frac{\alpha-\eta}{e_0}Q_\mathrm{t}\right]^{1/\alpha\lambda}, \tag{3}$$

where α is the Townsend coefficient, η is the attachment coefficient, λ is the average distance between clusters, and e_0 is the electron charge. Equation (3) indicates that by knowing the value of E_w, the efficiency of the detector can be estimated. For MRPCs, Eq. (3) calculates the efficiency of only one gap, and the number of gaps should be considered to obtain the total efficiency.

2.2 Simulation model and results

The analytic solutions of weighting field in the glue region are difficult to achieve mathematically, so simulation is a good method to obtain numerical values of the weighting field. ANSYS Maxwell is a common software dealing with electromagnetic problems. By solving quasi-static approximation Maxwell equations, we obtain the weighting field in a given gluing MRPC gap. Majumdar has done similar simulations of RPC weighting field previously with neBEM [9]. We have built the same model as explained in Ref. [9], and get completely the same result.

In order to study the weighting field in the MRPC, we built a 3D model of a glued MRPC with 5 gaps. The Z-Y plane is shown in Fig. 1. Read-out strips are designed to cross the glue region to better research the glue's influence.

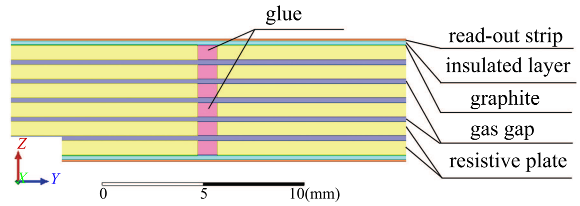

Fig. 1. Z-Y plane of MRPC model.

The geometric parameters of the MRPC components in the model are listed in Table 1. The glue is 1 mm wide and has the same thickness as the glass. 1 V voltage is applied onto the strip on top of the MRPC while the bottom one is kept at 0. 100% of boundary conditions are under consideration. The parameters of all the components are listed in Table 2.

Table 1. Geometric parameters of the MRPC.

MRPC Component	size/mm
honeycomb	$255\times472\times6$
PCB	$320\times540\times0.7$
mylar	$260\times480\times0.18$
gluing glass	$250\times270\times0.7$ & $250\times200\times0.7$
glue	$255\times1\times0.7$
gap	0.25×5

Table 2. Component parameters of the MRPC.

component	thickness /mm	relative permittivity	bulk conductivity /(s/m)
read-out strip	0.1	3.5	5.8×10^7
insulated layer	0.18	3.5	0
graphite	0.05	1	7×10^4
resistive plate (glass)	0.7	8	10^{-8}
glue	0.7	3.8	$>2\times10^{12}$ Ω·cm
gas	0.25	1.006	0

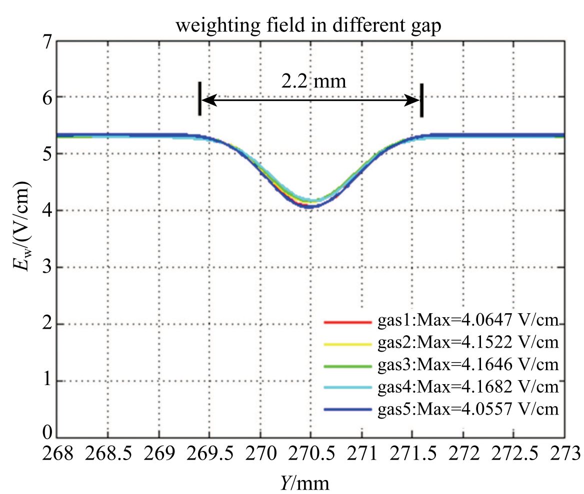

Fig. 2. (color online) Z weighting field in gas gaps.

The simulation shows that in the normal region, E_x=E_y=0, E_z=5.32 V/cm, but in the glue region, none of the 3 components of electric field is 0. We consider the Z component of the weighting field in analysis. Fig. 2 shows the weighting field in 5 different gas gaps (1-5, top-bottom) around the gluing region, which is from 270 mm to 271 mm. Since the tendency in every gap is similar, the average is taken. On average, the weighting field drops from 5.32 V/cm to 4.12 V/cm and the affected area is 2.2 mm. The real electric field in the gap is $V/5d$=11 kV/mm. From Fig. 3(a) in Ref. [10], the Townsend and attachment coefficients are around 140/mm and 2/mm respectively and λ is estimated to be 0.1 mm. In our threshold condition of around 500 electrons, the efficiency of the 5-gap MRPC is supposed to be very high according to Eq. (3), no matter whether in the standard or the glue region. This proves that the influence of this 1 mm thickness of glue is small.

3 Development and testing of glued MRPC

3.1 Structure of MRPC

Supported by the simulation results, we designed a five gap glued MRPC with 0.7 mm-thick low resistivity glass (volume resistivity around 10^{10} Ω·cm) electrodes. Figure 3 shows the structure of the glued MRPC. The parameters of each component in the glued MRPC are shown in Table 1, the same as for the simulation model. Corresponding plates were glued by an epoxy optical glue 301-2, previously used to stick light-sensitive diodes and halogen crystals in detectors. Its parameters are listed in Table 3. Signals from the glued MRPC are read out using a complete PCB board, with 12 double side reading-out strips. The whole MRPC is enlarged but is still thinner than 2 cm, suitable for the CMS upgrade.

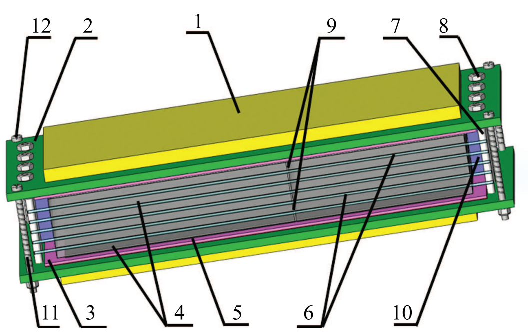

Fig. 3. (color online) Diagrammatic sketch of mosaic MRPC. 1 honeycomb board; 2 PCB board; 3 mylar; 4 low resistivity glass; 5 graphite; 6 fishing line; 7,8 stud & nut; 9 glue; 10 block; 11,12 screw & nut.

Figure 4 shows the process of adding glue and Fig. 5 is a photo of gluing the glass where the glue is as flat as the glass finally. The glass has better planarity when the liquid glue is dried naturally than when it is baked in an oven, although baking is faster. Fishing line, as shown in Fig. 5, goes across the glue to reduce the possibility of breaks in the glue due to unbalanced forces.

Table 3. Parameters of glue.

glue property	performance
lap shear strength @23 ℃	> 2000 psi
die shear strength @23 ℃	>15 kg/5000 psi
degradation temp (TGA)	360 ℃
dielectric constant (1 kHz)	3.8
volume resistivity	$>2\times10^{12}$ Ω·cm

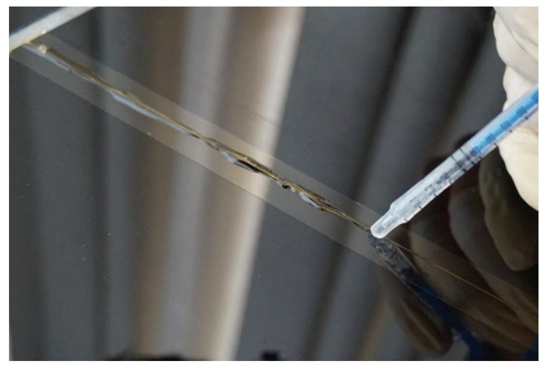

Fig. 4. Photo of gluing MRPC.

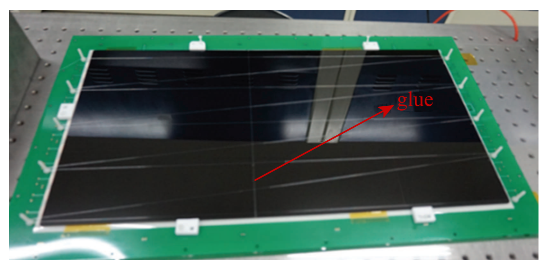

Fig. 5. Glass of glued MRPC.

3.2 Cosmic ray test and results

Cosmic ray tests have been done to test how the mosaic MRPC functions practically. The detector is put into a sealed box to supply its typical working gas–96% C_2 H_2 F_4, 3.7% iso-C_4 H_10 and 0.3% SF_6. A STAR TINO front-end card based on a NINO front-end ASIC was used and TOT signals were read out and processed. The experiment setup is shown in Fig. 3 in Ref. [11]. The glued MRPC is laid below two large scintillators (20 cm × 5 cm × 5 cm) and above one scintillator. The DAQ System of cosmic ray test is shown in Fig 6. Scintillator 1 is read out by a photomultiplier (PMT0) at a single end and scintillators 2 and 3 are read out by PMTs 1-4 at both ends. The large scintillators and MRPC are aligned vertically, so if a cosmic ray triggers both the top and bottom scintillators, then it must pass through the glued MRPC. The coincidence of PMT0 and PMT4 gives a cosmic trigger signal for the TDC and QDC and a small 2 cm × 5 cm scintillator is added into the system in the test with the long edge parallel to the glue. This small scintillator is moved around the glue to scan the efficiency change.

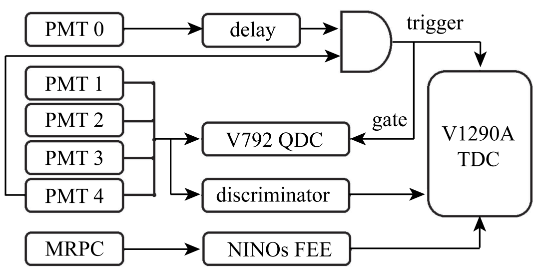

Fig. 6. DAQ for the cosmic ray test.

Figure 7 shows the efficiency plateau curve of the glued MRPC. The triangular symbols represent the efficiency data of the experiments and the square symbols represent the cluster size data. The red and blue curves in Fig. 7 are the fitting curves. Cluster size means the average number of strips triggered by one cosmic particle and is expressed in Eq. (4):

$$\text{Clustersize} = \frac{\sum_{1}^{n} \text{strips}(n)}{n}, \tag{4}$$

where strips(n) means the strips that are fired by the nth event. The maximum cluster size is 1.8 in experiments with 17 mm /19 mm strip width/pitch. When the voltage reaches ±7 kV, the efficiency can reach 96%. A plateau begins from ±6.9 kV while the efficiency is 96%, demonstrating that this gluing MRPC has a high efficiency. The dark current fluctuates from time to time when the voltage is higher than 7.5 kV, however, and this should be studied further in the future.

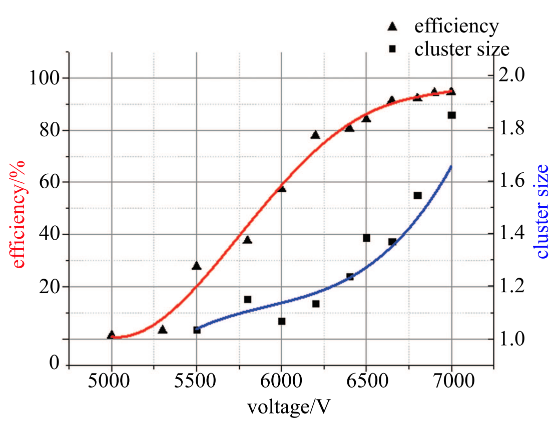

Fig. 7. Efficiency plateau and cluster size.

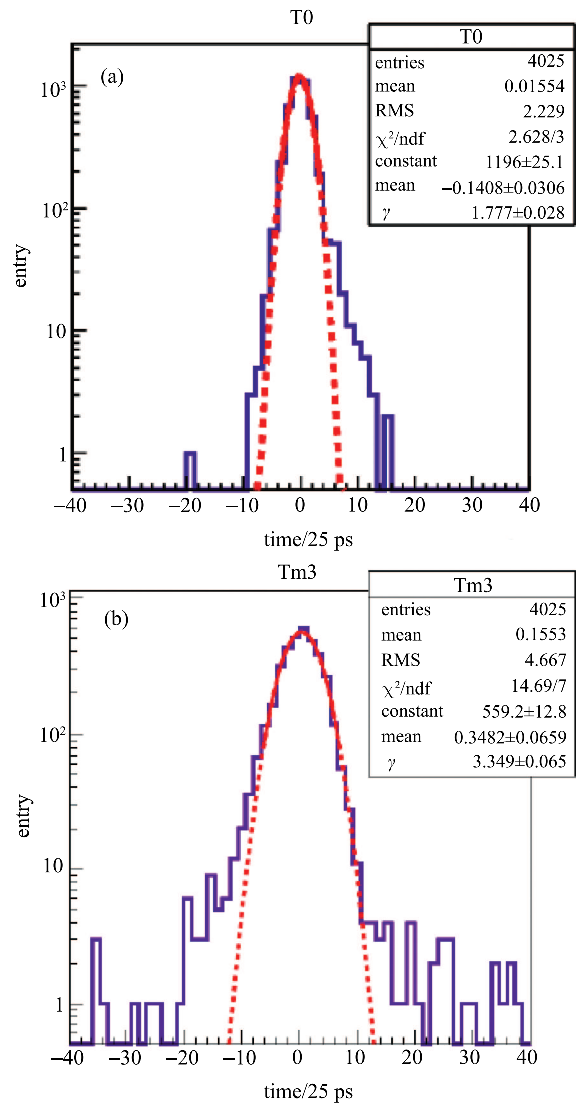

Fig. 8. Time spectrum after slewing correction (a) time of trigger, (b) time of MRPC.

Setting the working voltage to be ±6.9 kV, we collect and select around 4000 vertical incidences. Since larger signals usually have earlier leading time of the output LVDS signal, charge-time slewing corrections are made to reduce this systematic error [12]. Figure 8(a) shows the time of trigger and (b) shows that of the MRPC. Each unit in the plots is 25 ps. We get the time resolution of the chosen strip from:

$$\delta = \sqrt{3.349^2 - 1.777^2} \times 25 = 70.9 \text{ ps}. \tag{5}$$

In terms of the complete detector, the experiments show that the time resolution of the glued MRPC is around 71 ps, which is approximately equal to that of a standard MRPC. We also tested the performance of the glued region with a small scintillator, which was moved from the left to the right of the MRPC glue region in the test. Events detected by the small scintillator and the bottom large scintillator are regarded as triggers. Effective events are those detected by the MRPC and two scintillators. We have recorded 11 points around the glue over 2 weeks and the efficiency results are shown in Fig. 9.

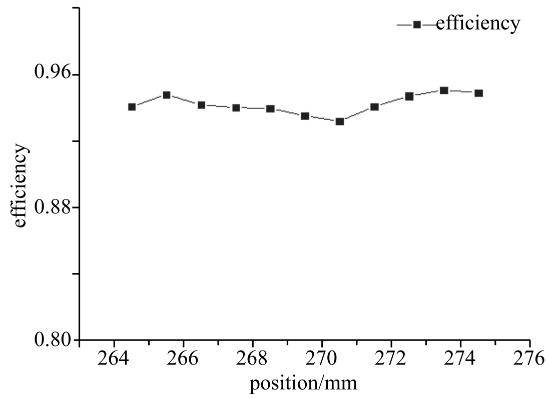

Fig. 9. Efficiency of MRPC in glued region.

The glue in Fig. 9 is from 270 mm to 271 mm and the number of events for every point is over 500. The results show that the efficiency decreases to around 93% when the small scintillator is over the glue. In general, the glued MRPC shows excellent detection ability. Since the small scintillator is still one order of magnitude wider than the glue affected region, a detailed tracking system is necessary for future study.

4 Conclusion

Detector signals induced on the read-out electrode are related to the weighting field in gas gaps, explained by Ramo's theorem. So understanding the performance of this new style MRPC cannot ignore research on the weighting field.

A large area MRPC using two or more sheets of glass glued together is shown to have good performance in detecting particles at low cost. Simulation with Maxwell indicates that 1 mm glue has little influence on the detector - the efficiency loss is very small and the affected area is less than 0.5% comparing to the total size. Cosmic ray tests have also been performed, showing that the efficiency of the mosaic MRPC reaches 96% at high voltage of ±6.9 kV and the time resolution is better than 71 ps. Experiments in the exact region of the glue shows that the efficiency drop is less than 3% of the detector. The mosaic MRPC method is demonstrated to be feasible and has bright prospects for future detectors.

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