# Design and test of a Multi-gap Resistive Plate Chamber with Long readout-strip (LMRPC) *

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**Abstract** A new kind (two end readout) of Multi-gap Resistive Plate Chamber with long readout-strip (LMRPC) is developed to be used at the large-area Muon Telescope Detector (MTD) at mid-rapidity at RHIC/STAR experiment for Time-of-Flight (TOF) measurement. The LMRPC has an active area of 87 cm× 17 cm, 10 gas gaps of 250 μm arranged in 2 stacks, with readout strips of 2.5 cm wide and 90 cm long. The considerations in LMRPC design related to its performance are discussed in this paper. The cosmic ray test results of a prototype LMRPC show a detection efficiency >95% and the time resolution ∼70 ps.

**Key words** LMRPC, TOF, gaseous detector

**PACS** 29.40.-n

## 1 Introduction

Multi-gap Resistive Plate Chamber (MRPC) is a robust gaseous detector developed in the last decade[1, 2]. It works in avalanche mode. The main advantages of MRPC are the very good time resolution and relative low price compared with the scintillator + PMT based technology. It is a good choice to build a large area Time-of-Flight system in high energy physics experiments, such as in the STAR experiment at RHIC[3] and ALICE experiment at LHC[4]. In the situation where the final-state charged particle multiplicity is relatively lower, the small size of readout pad is not necessary any more. This is the motivation of our developing MRPC with long readout-strip structure. LMRPC saves the electronics channels significantly and the measured time difference of both ends of the readout strip can be used to get the hit position along the strip.

The LMRPC has been selected as a timing detector for the large-area Muon Telescope Detector (MTD)[5] at mid-rapidity at RHIC/STAR experiment, which proposed to measure muons at a few GeV/$c$ momentum to allow for the detection of di-muon pairs from a Quark Gluon Plasma (QGP) thermal radiation, quarkonia, light vector mesons, possible correlations of quarks and gluons as resonances in QGP, and Drell-Yan production as well as the measurement of heavy flavor hadrons through their semi-leptonic decays into single muons. These measurements will advance our knowledge of quark gluon plasma at the relativistic heavy ion collisions[6].The proposed MTD consists of three layers of detectors: LMRPCs, Multi-Wire Proportional Chambers (MWPC) and Scintillator trays for timing, tracking and d$E$/d$x$ measurement, respectively. The LMRPC is required to give a time resolution <100 ps and a spatial resolution <2 cm.

To fit the requirement, we designed a LMRPC prototype and tested it with cosmic ray. The experimental results show the detection efficiency >95% and the time resolution ∼70 ps.

## 2 Design of LMRPC

Since the charged particle multiplicity at MTD is very low, LMRPC is a good choice to lower the cost

Received 16 May 2008, Revised 29 May 2008

* Supported by National Natural Science Foundation of China (10775131), Knowledge Innovation Program of Chinese Academy of Sciences and China Postdoctoral Science Foundation (20070410784)

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of electronics and is easier to build large modules for coverage of the large area outside the STAR magnets. Taking into account the limitation of Printed Circuit Board (PCB) in manufacture, the size of LMRPC is set to be 95.0 cm×25.6 cm. Six long readout strips are arranged along the length of the module.

One important problem on the LMRPC design, the process of signal transmission along the strips, must be considered. If the load impedance does not match the characteristic impedance of the strip, the signal will be deformed. The characteristic impedance of the strips mainly depends on the width of strips, the thickness of strips, the space between strips and the thickness of medium material. Using the software "Maxwell 2D extractor"[7], the characteristic impedance of the strips is calculated. In the calculation, six copper strips are set to be 50 μm thick and the spaces between them are set to be 4 mm. The medium material is set to be 0.8 mm thick FR4-epoxy. The dependence of impedance on the strip width from Maxwell 2D extractor is plotted in Fig. 1. We find that the impedance can only reach around 70 Ω even for the strip of 5 cm wide under these fixed parameters. The width of 5 cm is already too wide for the MTD detector. This means it's hard to get a 50 Ω impedance which is the general input resistance of front-end electronics. Finally, 2.5 cm is selected as the strip width and the corresponding impedance is between 100—110 Ω.

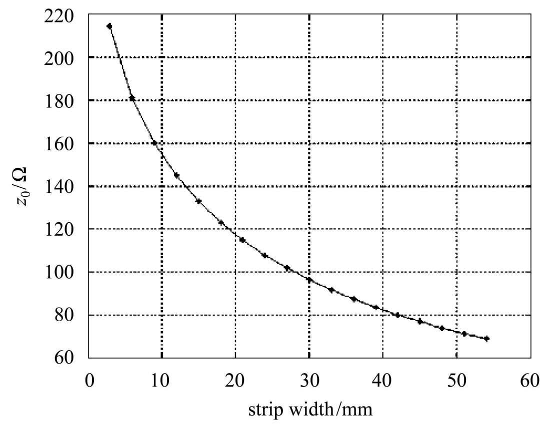


Fig. 1. The dependence of characteristic impedance on the strip width.

The pattern of the readout strips on the PCB can be found in Fig. 2(a). The signals are read out from both ends of the readout strips. The signal mean time from two ends of a strip is independent with the incident position of charged particle. This leaves out the position correction along the strip. Meanwhile, the time difference from the signal of two ends, associating with the signal propagation velocity, can be used to evaluate the hit position along the strip.

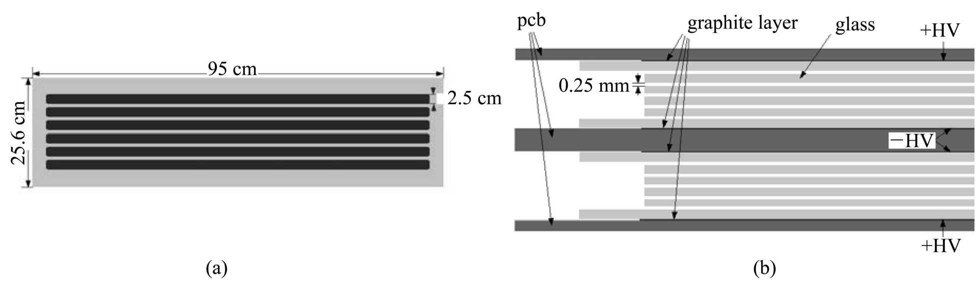


Fig. 2. The readout strips on PCB (left) and the structure of LMRPC in side-view (right).

The structure of the LMRPC is shown in Fig. 2(b). There are ten gas gaps arranged in two stacks. The thickness of each gas gap is 250 μm defined by the nylon fishing line between the glass plates of 0.7 mm thick. In each stack, two layers of graphite tape are applied on the outer surface of the outmost glass, acting as high voltage (HV) electrodes. The negative HV is applied to the center electrodes of two stacks and the positive HV to the outer electrodes. In this structure, ten gas gaps are arranged in series but the electrodes are in parallel. This definition keeps the improvement in detection efficiency and time resolution with more gas gaps[8] and relaxes the requirement of HV applied to the electrodes. Differential signals are read out from both the anode and the cathode.

The LMRPC module is sealed into a gas tight aluminum box and supplied with a gas mixture of 95% $C_2H_2F_4$ and 5% i-$C_4H_{10}$.

## 3 Cosmic test

In the cosmic ray test of a prototype LMRPC, the input impedance of the front-end electronics has been adjusted to match the impedance of LMRPC strips. The photo of the test set-up is shown in Fig. 3(a).

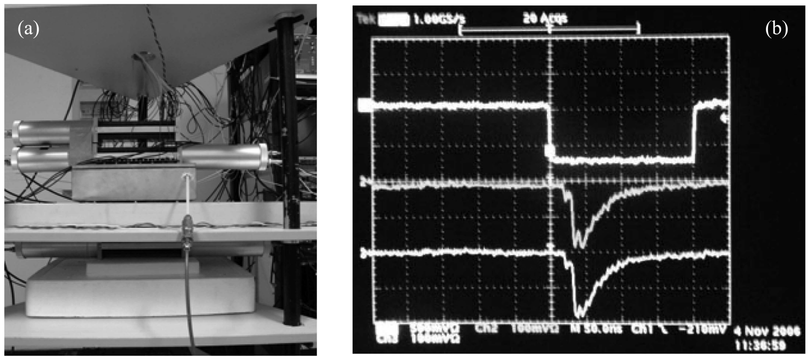


Fig. 3. (a) Cosmic ray test set-up; (b) the signal wave shapes from two ends of one readout strip.

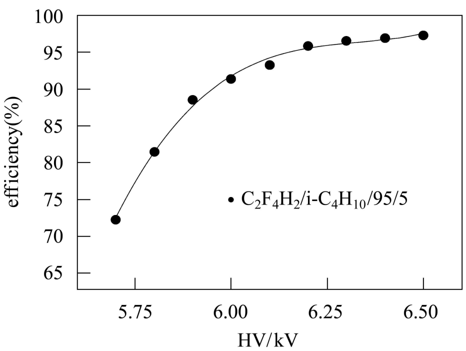


Fig. 4. Detection efficiency plateau of LMRPC operation.

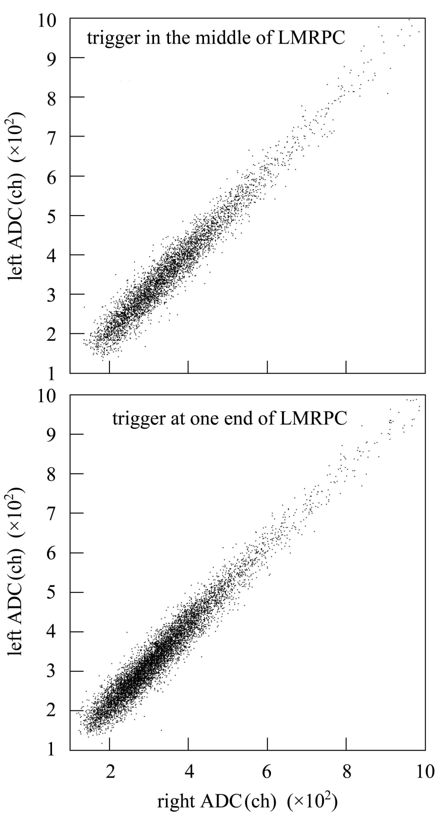


Fig. 5. Amplitudes correlation from both ends of one readout strip.

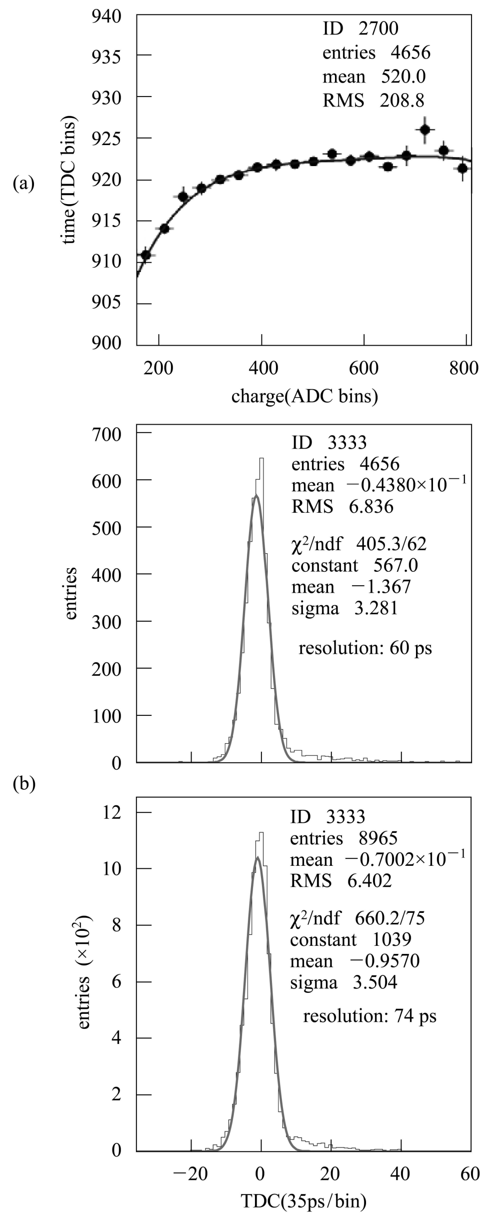


Fig. 6. (a) The mean time–mean amplitude correction; (b) the time resolution at two different positions along a strip.

The coincidence of signals from three 20 cm× 5 cm×5 cm scintillator bars acts as trigger. Two of the scintillators are read out from both ends with four fast PMTs, providing the time reference (T0, time resolution $\sigma$ ∼98 ps). The details of the cosmic ray test set-up can be found in Ref. [9]. The trigger area fully covers one LMRPC readout strip in width and half of two nearby strips. The signals read out from two ends of the central strip are shown in Fig. 3(b).

In Fig. 4, the plateau of detection efficiency of LMRPC operation is plotted. The detecting efficiency is >95% when HV greater than ±6.2 kV. The operating HV of ±6.3 kV is then selected for further test.

The relationship between the signal amplitudes from two ends (the left and right ends) of the investigated strip is plotted in Fig. 5. The linear correlation of signal amplitude, triggered either in the middle (Fig. 5, left frame) or at one end (Fig. 5, right frame) of the readout strip, indicates that the signals are transmitted properly along the strip.

Since a leading edge discriminator is used in the timing measurement, a slewing correction must be applied to evaluate the time resolution. As mentioned above, the mean time of both ends of a readout strip does not depend on the hit position. And also, the signal amplitudes from two ends are linear correlated. The slewing correction is applied to the mean time versus the mean amplitude of both ends. A 6-degree polynomial is used to get the correction parameters, as shown in Fig. 6(a). The distributions of mean time after correction are plotted in Fig. 6(b) when triggered in the middle (up) and at one end (down) of the strip. After subtracting the T0 contribution, the time resolution is 60 ps and 74 ps, respectively.

## 4 Summary

A new prototype LMRPC has been successfully built. The characteristic impedance of long readout strips has been calculated. By modifying the input resistance of frond-end electronics to match the impedance of LMRPC readout strips which is calculated between 100—110 Ω, the signals are delivered properly along the strips. The cosmic ray test of LMRPC gives a time resolution around 70 ps and a detection efficiency >95%. These results satisfy the requirements of the proposed MTD at STAR. Two LMRPC modules have been installed on STAR for more tests in physics running.

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