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R&D and mass production of LMRPC module for the STAR-MTD system

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Abstract: A new Long-strip Multi-gap Resistive Plate Chamber (LMRPC) prototype with 5 gas gaps has been developed for the Muon Telescope Detector (MTD) of the STAR experiment at RHIC in order to reduce the working High Voltage of previous design. Technical specifications related to the final infrastructure present in the experiment have motivated this effort. Its performances have been measured with cosmic rays. The efficiency of this prototype can reach 98% and the time resolution is around 95 ps. It shows a good uniformity among strips. The noise level is less than 0.2 Hz/cm^2. The signal transmission and crosstalk of the modules was measured with a vector network analyzer, showing a good match with simulations within the amplifier bandwidth.

A new cosmic-ray test system with long scintillators has been developed to accelerate the Quality Control process during the mass production of STAR-MTD. A selection of perpendicular cosmic-ray events for more accurate evaluation of the time resolution is achieved. The time resolution with this method is better, albeit with larger error, than the result obtained without any selection. A new spacer is used, resulting in a much reduced streamer ratio at comparable fields. Fourteen modules have been built with the new spacer by the middle of February of 2012. They have been tested and they all have passed the QC.

Key words: Resistive Plate Chamber, Muon Telescope Detetor, signal transmission, mass production

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1. Introduction

Data taken over the last several years have demonstrated that the Relativistic Heavy Ion Collider (RHIC) has created a dense and rapidly-thermalized state of strongly-interacting partonic matter [1]. The next objective of RHIC is to study the properties of this partonic matter in terms of the color degrees of freedom and the equation of state. The precise measurement of the transverse momentum distributions of quarkonia, such as the J/Ψ and ϒ mesons, at different centralities in different collision systems and energies, serves as a thermometer of this partonic matter. A large-area and cost-effective Muon Telescope Detector (MTD) at mid-rapidity for the Solenoidal Tracker at RHIC (STAR) has thus been proposed to improve its capabilities at directly identifying the decay muons from quarkonia. Due to the low occupancy, the MTD will be constructed with the Long-strip Multi-gap Resistive Plate Chamber (LMRPC) technology instead of the smaller pad Multi-gap Resistive Plate Chambers (MRPCs) used in the STAR Time of Flight (TOF) system. With this design the number of electronic channels can be reduced and the hit position along a strip can be obtained by the time differences of the two ends of the strip. Prototypes of such LMRPCs have been running for the last four years in STAR [2, 3] and many important results were obtained [4, 5]. A close-to-final prototype of 6-gap LMRPC module had also been developed with excellent performances [6] in 2010. In order to operate the detector with lower working high voltage due to technical reasons, a new LMRPC prototype with 5 gas gaps has been developed and the performance has been measured with cosmic rays. It is the final version of the LMRPC module for the STAR-MTD system. The mass production for STAR-MTD has been started and the first batch of the LMRPC modules has been sent to STAR from Tsinghua. In this paper we will introduce the performance of the 5-gap LMRPC modules for the STAR-MTD system. R&D for mass production and the status of the mass production in Tsinghua will also be presented.

2. 5-gap LMRPC prototype for STAR-MTD

2.1 The structure of the 5-gap LMRPC prototype for STAR-MTD

The working high voltage of the 6-gap LMRPC module for STAR-MTD is ±7.3 kV, which is close to the limit of the high voltage supplies already available in STAR. In order to reduce the working high voltage of the module, we reduce 1 gas gap from the module. Fig. 1 shows the structure of the 5-gap LMRPC module. It's the same structure as that of 6-gap LMRPC module [6] but with 1 gap less. The cosmic-ray test system used for the tests of the STAR-MTD LMRPC prototypes is similar to the one used for the tests of the STAR-TOF MRPC prototypes [7], which is shown in Fig. 2.

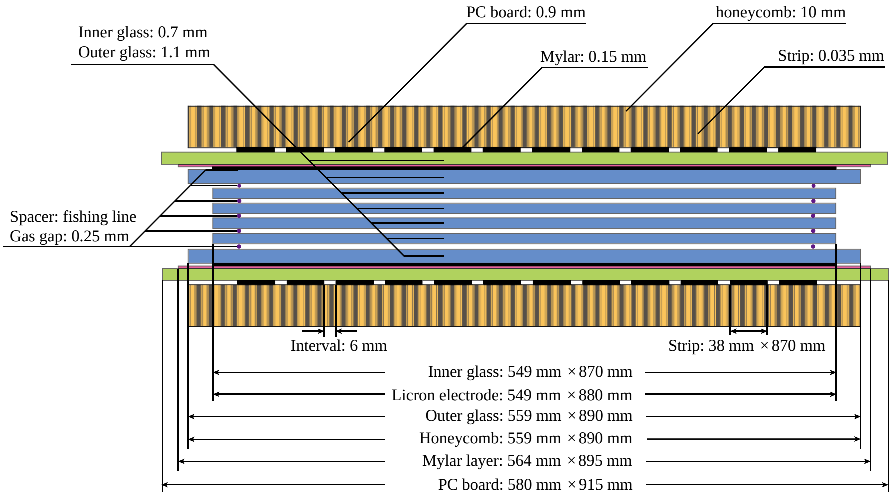

Fig. 1 The structure of the 5-gap LMRPC module built for the STAR-MTD system.

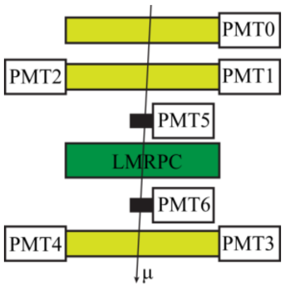

Fig. 2 The configuration of the cosmic-ray test system.

2.2 Cosmic-ray test results

The 5-gap STAR-MTD LMRPC prototype was tested in the cosmic-ray test system with a working gas mixture consisting of 95% Freon and 5% iso-Butane. The efficiency and time resolution versus the electric field in the gas gap, E, is shown in the left of Fig. 3. The electric field, E, is equal to the applied high voltage (total voltage drop between HV anode and cathode) divided by the total thickness of the gas gaps (5×0.025cm). The efficiency of the module reached 98% and the time resolution was around 95 ps. We also measured the efficiency and time resolution of all the strips at the standard working point (HV = ±6.3 kV, E = 100.8 kV/cm), which is shown in the right of Fig. 3. The efficiency of each strip was higher than 90% and the time resolution was in the range of 90 – 110 ps.

The left figure of Fig. 4 shows the noise level of the STAR-MTD LMRPC module as a function of the electric field in the gas gap. The noise is less than 0.13 Hz/cm^2 when the electric field was around 100.8 kV/cm (HV = ±6.3 kV). The noise rate on every strip was also measured at the standard working point (HV= ±6.3 kV, E= 100.8 kV/cm), and is shown in the right of Fig.

4. The noise level of every strip was less than 0.3 Hz/cm^2. And the noise level on most of the strip was below 0.2 Hz/cm^2.

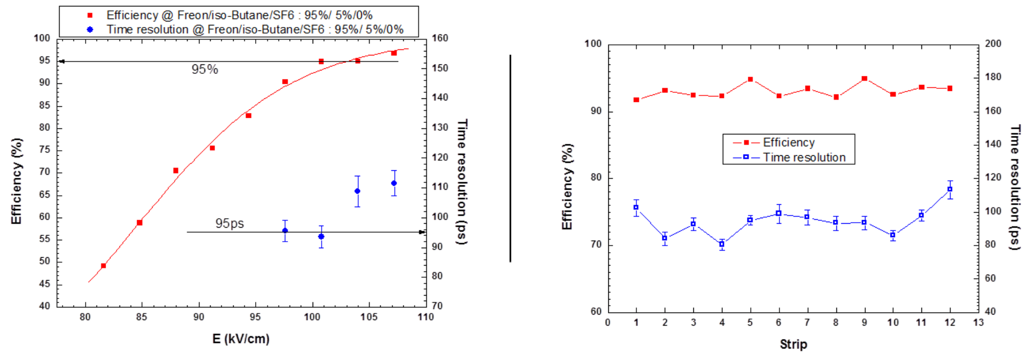

Fig. 3 Left: Efficiency and time resolution of the 5-gap STAR-MTD LMRPC prototype in cosmic-ray tests as a function of the electric field in the gas gaps. Right: Efficiency and time resolution of every strip of the 5-gap STAR-MTD LMRPC prototype in cosmic-ray tests, for an electric field of 100.8kV/cm.

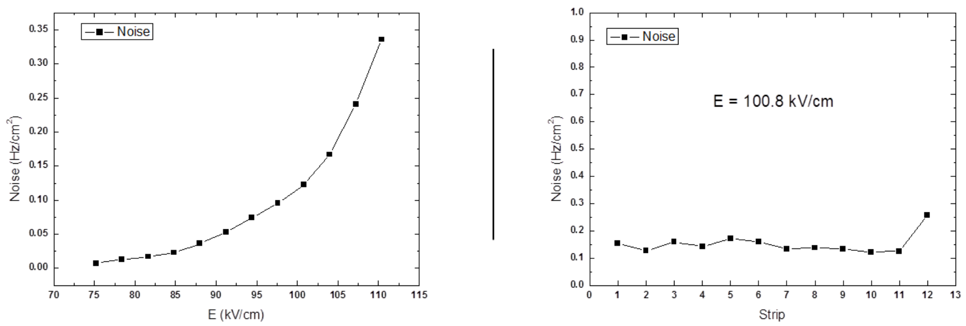

Fig. 4 Left: Noise level of the 5-gap STAR-MTD LMRPC module as a function of the electric field in the gas gaps. Right: Noise level of each strip of the STAR-MTD LMRPC module at the standard working point (E = 100.8 kV/cm, HV = ±6.3 kV).

2.3 Simulation and measurement of signal transmission properties with a network analyzer

We measured the signal transmission of a STAR-MTD LMRPC prototype with a network analyzer. With the scattering-matrix parameters provided by the network analyzer, we are able to verify whether the module is matched and whether the module is electrostatically compensated. An electrostatically compensated system has many nice properties, such as maximal transmission and minimal crosstalk. [8]

The STAR-MTD prototype we measured had six 250-μm gas gaps. The thickness of the floating glass was 0.7 mm for the inner glass and 1.1 mm for the outer ones respectively. This module had 6 pairs of 25 mm-wide readout strips with intervals of 4 mm. The lowest strips were connected together to the ground, which was provided by the network analyzer. The ports that were not connected to the network analyzer were terminated with 50 Ω resistors. The honeycomb was taken off in order to put additional FR4 plane with different thickness on top of the strips. The FR4 plane was used to electrostatically compensate the module.

The measurement results are shown in Fig. 5 for the cases without any additional material on top, with 1 mm-thick additional FR4 plane and with 2.3 mm-thick additional FR4 plane on top of the readout strips. S_{21}, S_{41} and S_{61} represent the signal transmission, the crosstalk level on the far-end of the first neighbor strip and the crosstalk level on the far-end of the second neighbor strip respectively. For the case with 1mm-thick FR4 plane on top, the module had the maximal transmission (S_{21}) and minimal crosstalk for the first neighbor (S_{41}). Thus the system was almost compensated with 1 mm-thick additional FR4 plane. The module with honeycomb behaved similarly to the module without honeycomb but with 1mm-thick FR4 plane on top, in which situation the system was close to electrostatic compensation. This can be explained since the honeycomb structure is effectively attached to an approximate 1 mm-thick glass-fiber plate that seems to behave electrically as a signal FR4 plane.

Fig. 5 also gives the simulation results using the methods described in reference [8]. The simulation results were close to the measurement results within the amplifier bandwidth. But in the high frequency part, the S_{21} simulated in the case without FR4 showed a slightly higher bandwidth than the measured one. It might be attributed to the impedance break at the connection between the strips and the cable. In the cases with 2 mm-thick FR4 planes on top, the measured S_{21} showed a higher bandwidth reduction as compared to data. This was possibly due to the mutual conductance (G_m) which is not included in the simulation.

3.Mass production for STAR-MTD

3.1 New cosmic-ray test system with long scintillators

In order to speed up the process of quality control during the mass production of the LMRPC modules for the STAR-MTD, a new cosmic-ray test system with long scintillators has been developed. It consists of two 27 cm × 5 cm × 2.5 cm scintillators with PMTs and one 25 cm × 5 cm × 5 cm scintillator with a PMT at one end. The whole telescope is able to cover 6 strips of the STAR-MTD LMRPC module at the same time. The time resolution of T0 of the new cosmic-ray test system is around 70 ps.

Using this new cosmic-ray test system, we were able to select roughly perpendicular cosmic-ray events from the time difference of the two PMT signals on each scintillator to evaluate the time resolution of the LMRPC modules. We process it in the following procedure:

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1) Get the relationship between the hit position and the time difference of the two PMT signals of each of the two scintillators. With this relationship, we are able to get the hit positions of the cosmic-ray particles on each of the two scintillators.

2) Set a window on the hit positions of the cosmic-ray particles to select the perpendicular events hitting on certain strip.

3) Calculate the time resolution with the selected events. Slewing correction is also applied.

The comparison of the time resolution calculated without and with selection of perpendicular cosmic-ray events is shown in the right of Fig. 6. The results with two different selection windows are presented. It shows that the time resolution was better if we selected perpendicular cosmic-ray events but the error was larger since fewer events were used for the time resolution evaluation.

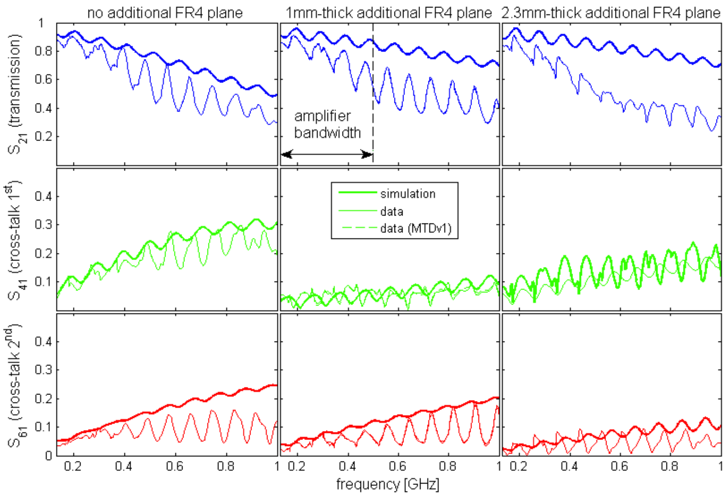

Fig. 5 Simulation (using the method of reference [8]) and measurements (with a vector network analyzer) of the signal transmission and crosstalk of the STAR-MTD prototype, shown in the frequency domain.

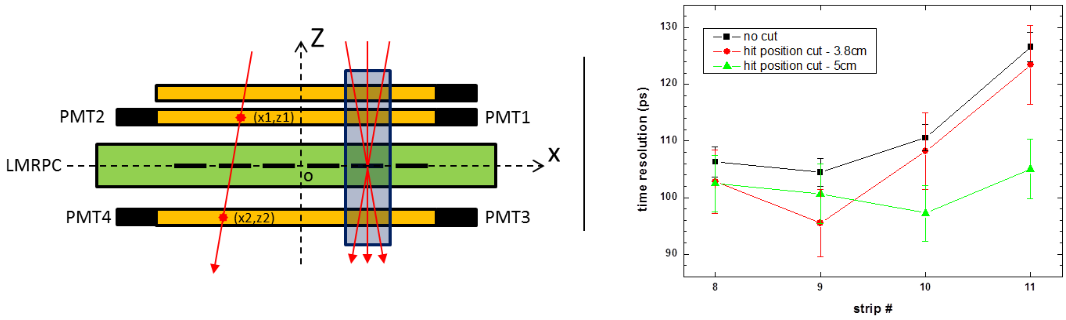

Fig. 6 Left: Illustration of the method for selecting perpendicular cosmic-ray particles using the time differences of the two PMT signals of each of the long scintillators. Right: Time resolution obtained from

all events (squares) for perpendicular events within 3.8 cm window (circles) and 5 cm window (triangles) for strips # 8, 9, 10 and 11.

3.2 Influence of the fishing line

Two different kinds of fishing line were used for the production of the LMRPC modules. At first, we were using a kind of fishing line with a mean diameter of 0.246 mm. But the streamer ratio of the modules mounted with this kind of fishing line is quite high. The streamer ratio is 21.9% for an electric field of 95.93 kV/cm (HV = ±5.9 kV) and 50.7% for an electric field of 102.43 kV/cm (HV = ±6.3 kV). Then we changed to another kind of fishing line with a mean diameter of 0.258 mm. The streamer ratios of the modules using this kind of fishing line were much lower. It is only 6.4% for an electric field of 97.67 kV/cm. The reason for this phenomenon is still under investigation.

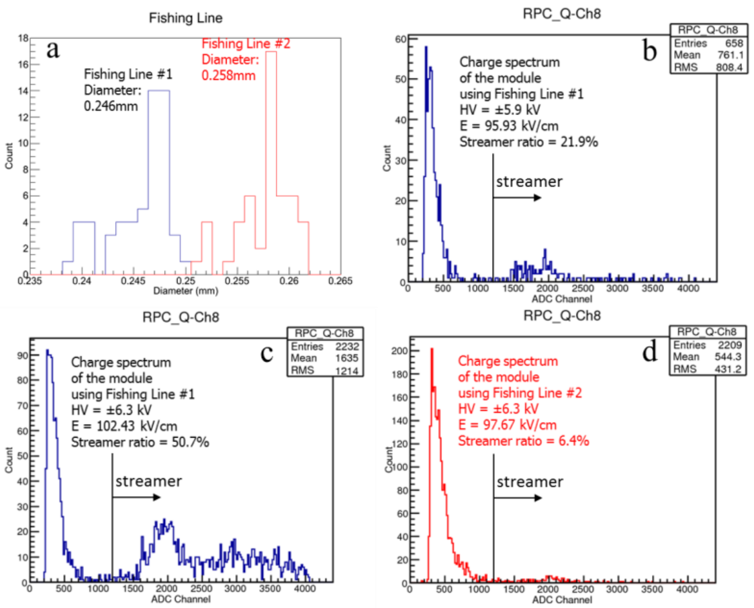

Fig. 7 (a) Distribution of diameters of the two different fishing lines as measured at various positions along it. (b) Charge spectrum of the module using the first kind of fishing line for an electric field of 95.93 kV/cm (HV = ±5.9 kV). The streamer ratio is 21.9%. (c) Charge spectrum of the module using the first kind of fishing line for an electric field of 102.43 kV/cm (HV = ±6.3 kV). The streamer ratio is 50.7%. (d) The charge spectrum of the module using the second kind of fishing line for an electric field of 97.67kV/cm (HV = ±6.3 kV). The streamer ratio is 6.4%.

3.3 Status of mass production for STAR-MTD

The QC criterions of acceptance for the STAR-MTD LMRPC modules are shown as follows:

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1) The efficiency of the module should be better than 90%.

2) The module should not have more than 1 strip which has a time resolution worse than 120ps.

3) The noise of each channel should be less than 1 Hz/cm^2.

Up to mid-February of 2012, Tsinghua had mounted 14 STAR-MTD LMRPC modules with the second kind of fishing line. All the strips have been tested and all the modules have passed QC. The efficiency, time resolution and noise level are shown in Fig. 8. In total, 120 LMRPC modules will be produced in China in the next few months.

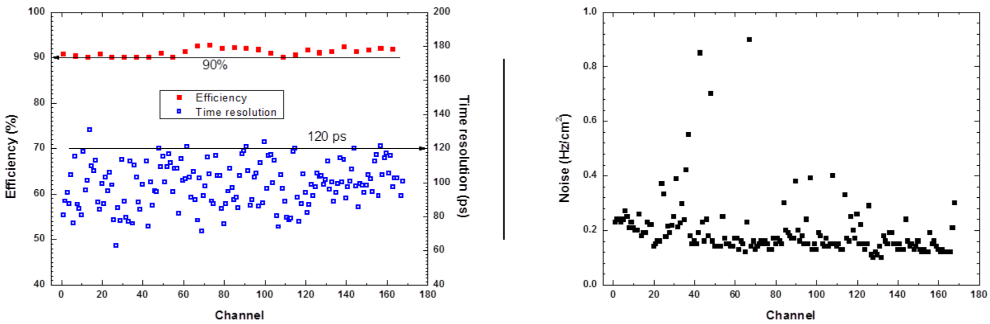

Fig. 8 Left: efficiency and time resolution of all channels of the 14 MTD modules built with the second kind of fishing line. The efficiency was measured for every six strips and the time resolution was measured for every strip. Right: noise level for all channels of the 14 MTD modules mounted with the second kind of fishing line.

4. Conclusions

The 5-gap STAR-MTD LMRPC module has efficiency up to 98% and the time resolution is in the range of 95-110 ps. At the standard working point, the modules have efficiency larger than 90% and each of them has less than 1 strip with time resolution worse than 120 ps. The noise level of such modules is quite low. The signal transmission and crosstalk properties can be measured by a network analyzer. The simulation in reference [8] is able to reasonably describe the measurements of the signal transmission and crosstalk properties within the bandwidth of the Front End Electronics used (0.5GHz). There is some discrepancy in the high frequency part, which is more obvious in the case of a thicker additional FR4 plane. Discrepancies are likely due to non-perfect connections and the losses in the mutual coupling.

A new cosmic-ray test system with long scintillators has been developed to speed up the Quality Control process during mass production of the STAR-MTD LMRPC modules. Using the time difference of the two PMT signals of each of the two long scintillators, a selection of perpendicular cosmic-ray particles is done to get a better time resolution evaluation.

A new fishing line is used in order to reduce the streamer ratio of the STAR-MTD LMRPC modules at fixed field. Fourteen LMRPC modules have been built with new fishing line and they all have passed QC. In the next few months, 120 LMRPC modules will be produced.

5. Acknowledgements

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