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Study of high time resolution MRPC with the waveform digitizer system

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Abstract: A high time resolution Multi-gap Resistive Plate Chamber (MRPC) is proposed for the TOF system of SoLID experiment at Jefferson Lab. Efforts have being devoted to the research of a new MRPC structure, aiming at a time resolution of 20 ps. Two 32-gap MRPCs with 104 µm gap thickness have been developed for the initial test. By using the fast amplifier and waveform digitizer system, the performace of these MRPC detectors is studied using the cosmic rays. Time resolution of the order of 20 ps and efficiency around 95% are obtained. Detector simulations are simultaneously carried out for MRPCs with different structures. Meaningful results and future plans are discussed in detail.

Keywords: Detector modelling and simulations II (electric fields, charge transport, multiplication and induction, pulse formation, electron emission, etc); Instrumentation and methods for time-of-flight (TOF) spectroscopy; Resistive-plate chambers; Timing detectors

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Contents

1 Introduction

Multi-gap Resistive Plate Chamber (MRPC) [1–3] is an advanced gas detector with good efficiency, high time resolution and relatively low cost. Nowadays MRPCs are used to build the TOF (Time of Flight) system for particle identification at ALICE [4, 5], CMS [6], CBM [7, 8], STAR [9–11], PHENIX [12], and other experiments.

With the development of nuclear and particle physics experiments, higher performance MRPCs [13] have been demanded. For instance, JLab (Jefferson Lab) [14] is upgrading its facility by doubling the energy of its accelerator's electron beam from 6 GeV to 12 GeV, which will expand the opportunity for studying the basic building blocks of the universe. For full exploitation of the 12 GeV upgrade, SoLID (Solenoidal Large Intensity Device) [15] was proposed and designed to be a large acceptance high luminosity device. With multi-dimensional measurements and high statistics, SoLID could be ideal to measure the SIDIS (semi-inclusive deep inelastic scattering) [16] production of charged kaons. A high resolution TOF is a practical way to do kaon identification over a momentum range of 1 GeV/c to 7 GeV/c. For the 8 meters flight distance from the target, a TOF time resolution of 20 ps is required to obtain a 3-sigma separation between pions and kaons.

A new type of MRPC [17] assembled with a low resistivity glass was proposed and developed by our group in Tsinghua University. A beam test with scattered high energy electrons at JLab showed a time resolution of 80 ps and 95% efficiency over a flux rate of 15 kHz/cm^2, which corresponds to the expected flux rate of SoLID. Thus more efforts need to be devoted to the search for a new MRPC structure, aiming at a much higher resolution. The typical time resolution of the currently running MRPC detectors is in the range of 60–100 ps [4–12]. The main solutions for the readout

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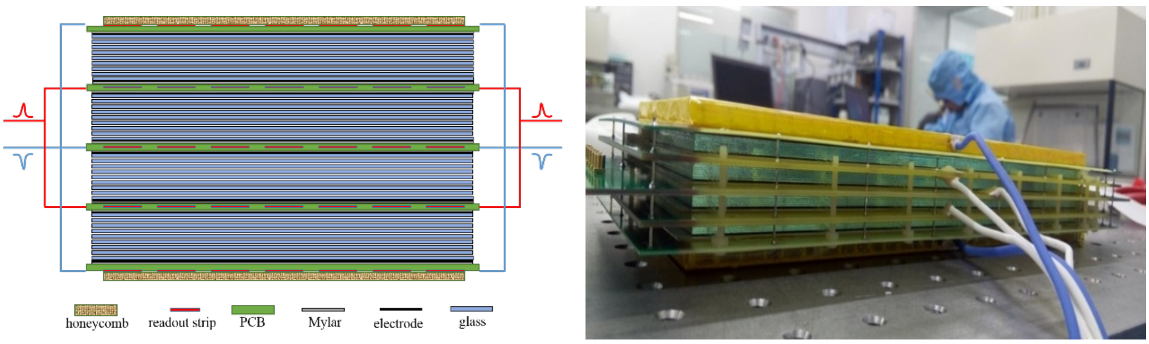
electronics are based on the fast and low-power amplifier/ discriminator [18, 19] and the Time-to-Digital Converter (TDC) [20–22]. The overall time jitters of NINOs/HPTDC (PADI/GET4) are usually beyond 20 ps, which obviously can't meet our requirement. Thus, we propose the waveform sampling solution based on a very thin-gap MRPC detector and readout electronics of a fast low-noise preamplifier module and a waveform digitization module. This paper will present a 32-gap MRPC prototype and describe the cosmic test setup and the data analysis results. Simulations based on the Geant4 package [23] and the ANSYS Maxwell [24] are carried out in detail. Meaningful results and future plans will be discussed.

2 Description of the 32-gap MRPC prototype

Based on the previous research [25, 26] and the timing jitter analysis [27], the idea is that when we decrease the gap thickness, much higher working voltage can be applied in order to ensure the avalanche mode and the detector efficiency. Thus, fast charge will be dominant in the induced signals and signals with short leading edge and little variance can be obtained. In addition, more gas gaps are considered to maintain the signal amplitude and the efficiency. As a result, we developed the 32-gap MRPC detector, shown in figure 1. It's divided into 4 stacks, each stack with 8 gaps. The gas gaps with a thickness of 104 µm are defined by nylon fishing lines to confirm a homogeneous thickness. Float glass sheets of 500 µm thickness are used as the resistive electrodes. The surfaces of the outer glass sheets are coated with graphite tapes, so that a high voltage can be applied. On each of the readout PCBs, there are 6 pickup strips on a 10 mm pitch with 3 mm separating each strip from its neighbour. The signals induced with both polarities read out at both ends. The top and bottom honeycomb boards are attached to the outer surfaces using glue, which can support the whole detector.



(a) (b)

Figure 1. Schematic drawing of the cross-section **(a)** and picture **(b)** of the 32-gap MRPC.

3 Cosmic test

3.1 Experimental setup

The sketch map of the cosmic test system is shown in figure 2. Two identical MRPC detectors are put in the gas box and flushed with a gas mixture of 90% Freon, 5% iso-butane and 5% SF_6. By

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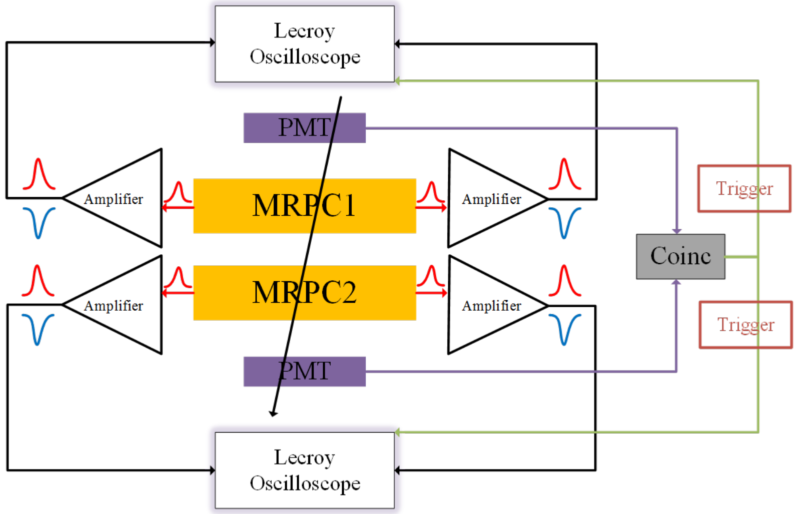

Figure 2. The sketch map of the cosmic test system.

analyzing the time difference between these two detectors, we can simply get the time resolution. The coincidence of the two PMTs placed on the top and bottom of the gas box gives a trigger signal for the DAQ. The chambers should be flushed for two days at a 60 ml/min flow rate. After that, positive and negative high voltage can be applied on the MRPCs using the CAEN A1526 modules.

The high-performance electronics [28] are developed by the University of Science and Technology of China (USTC). They have designed an 8-channel Analog Frontend Electronics (AFE) prototype based on the cascaded amplifiers. It consists of two stages, each with 20 dB high-bandwidth amplifier. The lab test results show that the time resolution is better than 4 ps, which is really good. The waveform digitization module is based on the 1024 sampling capacitors of SCA chips. This module is under lab test and verification, and will be ready soon for the future test. Therefore, we first used a CAEN Desktop 5742 module for efficiency study and two Lecroy HDO6104A oscilloscopes for time resolution during this preliminary test. Two detectors were tested for timing, so test of 1 channel needs 4 AFE channels. The AFE output signals are differential, and they can be recorded and digitized by the two Oscilloscopes with 1 GHz bandwidth and 10 GS/s sampling rate. The coincidence signal was connected to the EXT input for the trigger configuration. All displayed waveforms on each trigger can be saved to binary file or excel file. Time and voltage values recorded can be easily analyzed within the ROOT framework [29].

3.2 Timing methods

Different from the traditional solution based on the discriminator and TDC, we can get the whole signal waveform benefiting from the waveform sampling technology. The machine learning method [30] and time over threshold (ToT) method are both useful to get the arrival time of the signals. Two simple ToT methods with a fixed threshold are used in this paper, as shown in figure 3. The reference time can be easily obtained by a linear interpolation between the two data points. Another timing method is by polynomial fitting of the leading edge of the signal, which fits well as seen below. Due to the low noise and short rising time of the signals, both these two methods show good timing results.

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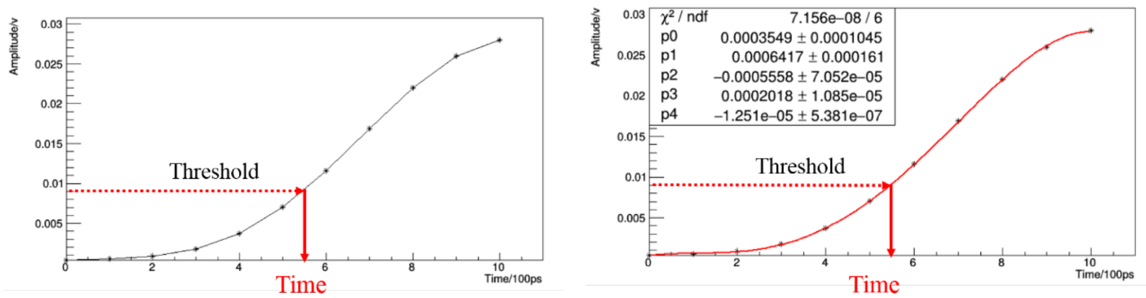

(a) **(b)**

Figure 3. (**a**) Linear interpolation method. (**b**) Polynomial fitting of the leading edge.

3.3 Efficiency and time resolution

After two days' gas flow, the MRPCs were conditioned under high voltage for a few hours to reach a stable working regime. Then by applying high voltage from 5800 V to 13300 V, an efficiency curve as a fuction of the applied voltage can be obtained as shown in figure 4. The efficiency is defined as the ratio of the number of events where a hit is found within 4 cm of the expected position of muon to the expected number of muons triggered by the coincidence of the two PMTs. The MRPC has reached the efficiency plateau (∼ 95%) above 11 kV in the cosmic rays setup.

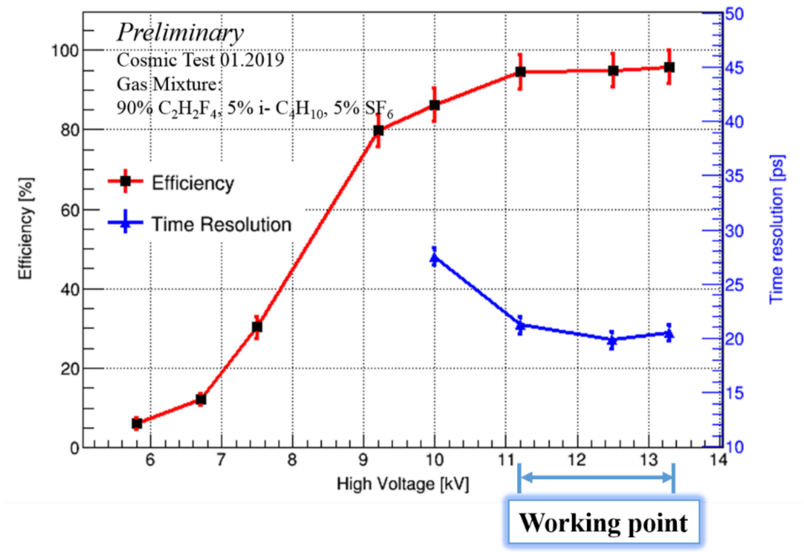

Figure 4. Efficiency and time resolution as a function of high voltage.

The average value of the times measured at both ends of the strips defines the arrival time of the particle, which is independent of the hit position along the strip. Therefore, the time resolution can be derived from the distribution of the differences of the arrival times measured by the two MRPCs. The raw time distribution at the high voltage of 12.5 kV is shown in figure 5(a). The variance of this distribution is accumulated from the variances of the time resolution of each MRPC. Assuming that the two MRPCs have the same performance, the sigma divided by $\sqrt{2}$ is identified as the time resolution

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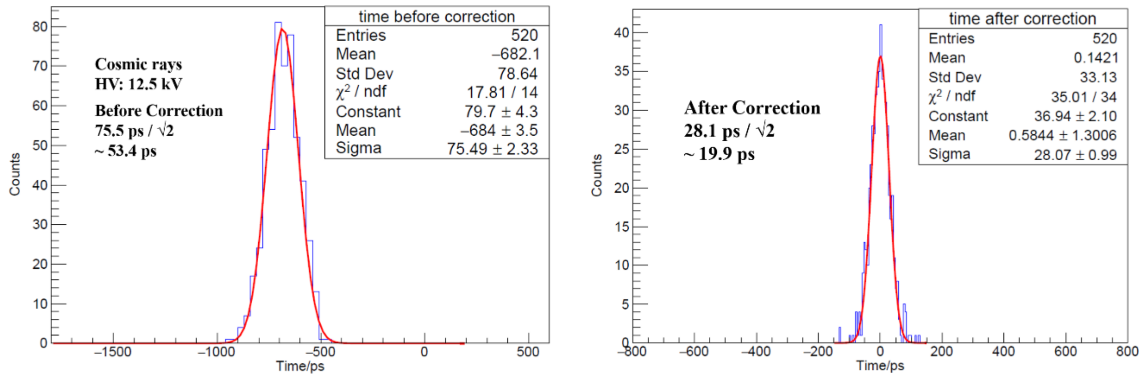
of each MRPC. Due to the ToT method with a fixed threshold, the time difference should be corrected by the slewing correction using both the amplitudes of the two MRPCs. As shown in figure 5(b), after the slewing correction, the final resolution reaches (19.9 ± 0.7) ps. Moreover, time resolution of around 20 ps at the working voltages is shown in figure 4, which verifies our technical solution.



(a) **(b)**

Figure 5. Time resolution results before **(a)** and after **(b)** the slewing correction.

4 Simulation based on Geant4

4.1 Simulation process

In the meantime, a Monte Carlo simulation of the detector based on the simulation framework developed in our group [31, 32] is carried out. The typical simulation process of the detector is summarized in figure 6. For comparison with the cosmic ray test conducted in our laboratory, the

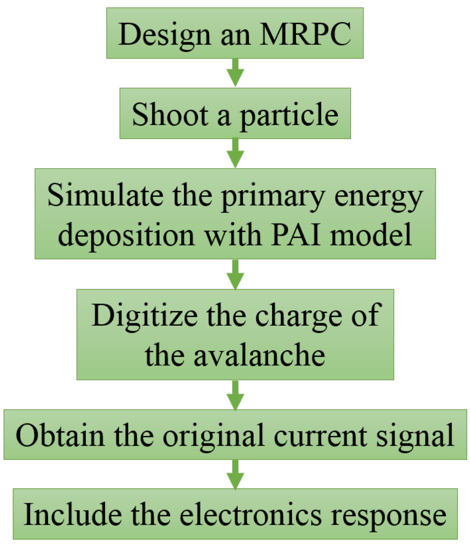
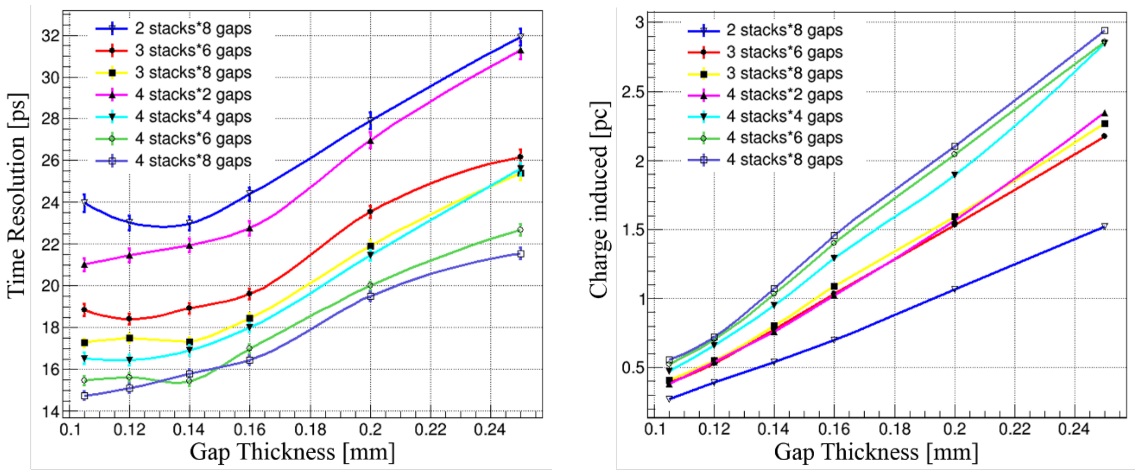


Figure 6. The simulation process of the MRPC detector.

incident particle source is specified as muons with an energy of 4 GeV. As mentioned in [32], we can achieve more real simulation of the whole sensitive area in an MRPC by introducing the 3D weighting field results into our standalone simulation framework. Here only particles perpendicularly impinging on a random position of one strip pitch area of the MRPC detector are considered, which can save simulation time and basically represent the experimental situation. A gaussian electronics noise, comparable to our test results, is added to the readout signals. Therefore, simulation results for MRPC detectors with different structures can be obtained and analyzed by the same method mentioned before.

4.2 Simulation results and discussions

Figure 7(a) shows the time resolution results from the simulation of MRPC detectors with different structures. The time resolution dependence on the number of stacks, the number of gaps in each stack and the gap thickness is studied. In general, we can improve the time resolution of the MRPC detector by increasing the number of gas gaps and decreasing the thickness of each gap, which is as expected. It should be also noticed that much thinner gap thickness and many more gas gaps can't improve the time resolution significantly when the thickness of the gap is below 140 μm and the number of gaps in each stack is more than 6. Moreover, we can find that gap thickness below 160 μm, at least 3 stacks and 4 gaps in each stack are required to achieve 20 ps resolution.



(a) **(b)**

Figure 7. **(a)** Time resolution and **(b)** The average charge induced from the simulation for MRPC detectors with different structures.

In an actual experiment, electronics noise and signal transmission should be considered carefully. Thus, the charge induced and charge distribution are studied in detail. Figure 7(b) shows the average charge induced for MRPC detectors with different structures. It can be seen that the charge increases significantly with the increasing gap thickness and the number of stacks. Figure 8(a) and (b) show the charge distribution of different MRPCs. We can see them more clearly and get the same conclusion that the thickness of the gap and the number of stacks mainly affect the induced charge of an MRPC detector. Considering the Signal to Noise Rate (SNR), it is the small signals that worsen

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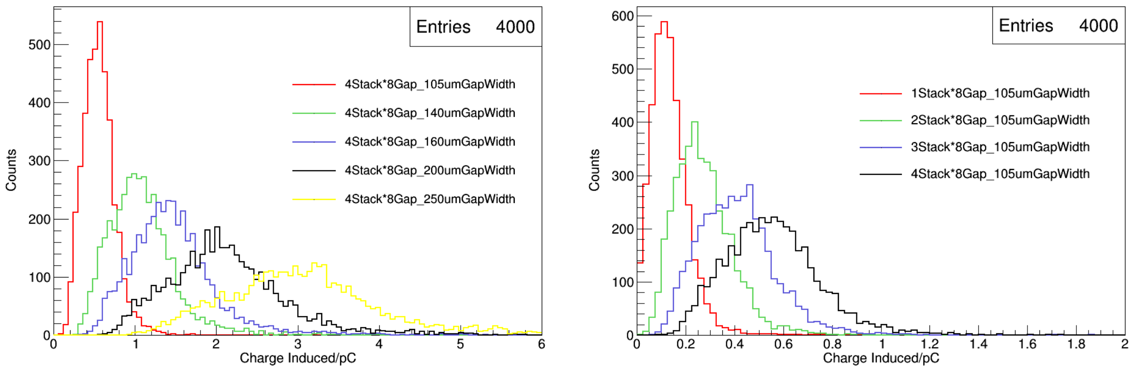

(a) **(b)**

Figure 8. **(a-b)** The charge distribution for different MRPCs.

the time resolution. Therefore, we decide to increase the gap thickness of our MRPC detector from 104 µm to 128 µm. In the near future, new MRPCs with low resistive glass will be built and tested.

5 Conclusion

To study the time resolution of the MRPC detector, experimental tests and detector simulations have been carried out by our group. We have successfully developed two 32-gap MRPC detectors. Their gap thickness is only 104 µm. The cosmic test based on the fast amplifier and waveform digitizer system shows the efficiency around 95% and time resolution of 19.9 ps, which confirms our technical solution. Detailed simulations based on Geant4 for MRPC detectors with different structures have been discussed. They provide useful references to the optimization of the detectors and the future tests. Due to this work, a slightly larger gap thickness will be considered for the future studies.

Acknowledgments

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