Development and test of a real-size MRPC for CBM-TOF

Y. Wang, a P. Lyu, a X. Huang, a D. Han, a B. Xie, a Y. Li, a N. Herrmann, b I. Deppner, b C. Simon, b P.-A. Loizeau, b P. Weidenkaff, b J. Frühauf c and M. Laden Kiss c

a Key Laboratory of Particle and Radiation Imaging, Department of Engineering Physics, Tsinghua University, Beijing 100084, China
b Physikalisches Institute, University Heidelberg, Heidelberg, Germany
c GSI Helmholtzzentrum für Schwerionenforschung, GSI, Darmstadt, Germany

ABSTRACT: In the CBM (Compressed Baryonic Matter) experiment constructed at the Facility for Anti-proton and Ion Research (Fair) at GSI, Darmstadt, Germany, MRPC (Multi-gap Resistive Plate Chamber) is adopted to construct the large TOF (Time-of-Flight) system to achieve an unprecedented precision of hadron identification, benefiting from its good time resolution, relatively high efficiency and low construction price. Aiming at CBM TOF, we’ve developed a kind of double-ended readout strip MRPC which applies low resistive glass to keep good performance of time resolution under high-rate condition. There are 24 strips on one counter, and each is carefully designed to match the 100 Ω impedance of PADI electronics. The prototype of this strip MRPC has been tested with cosmic ray, a 98% efficiency and 60ps time resolution is gotten. In order to further examine the performance of the detector working under higher particle flux rate, the prototype has been tested in the 2014 October GSI beam time and 2015 February CERN beam time. In both beam times a relatively high rate of 1 kHz/cm² was obtained. The calibration is done with CBM ROOT, and an efficiency of 97% and time resolution of 48ps are obtained. All these results show that the real-size prototype is fully capable of the requirement of the CBM-TOF, and new designs such as self-sealed are modified into the strip counter prototype to obtain even better performance.

KEYWORDS: Gaseous detectors; Instrumentation and methods for time-of-flight (TOF) spectroscopy
1 Introduction

Since its birth in 1996 [1], large amount of efforts has been devoted into R&D of Multi-gap Resistive Plate Chambers (MRPCs) for improved performance including time resolution and detection efficiency. These inexpensive MRPCs has become widespread in modern nuclear and particle physics experiments in these years [2–5]. In the CBM (Compressed Baryonic Matter) experiment constructed at the Facility for Anti-proton and Ion Research (Fair) at GSI, Darmstadt, Germany, MRPCs are also the best solution to construct the large Time-of-Fight (TOF) system for an unprecedented precision of hadron identification [6]. The challenge for CBM is an extremely high requirement of MRPCs’ rate capability, because the CBM-TOF will work at very high rate (∼25 kHz/cm²) environment [7]. At the same time, CBM-TOF is designed to work at free-running mode, thus the detectors’ noise level must be as low as possible. According to the particle flux rate distribution, the whole CBM-TOF wall is divided into four rate regions named Region D, C, B and A (from inner to outer) [8, 9]. Aiming at the Region C and B where the rate ranges from 3.5 to 8.0 kHz/cm², we’ve developed a kind of double-ended readout Strip-MRPC [10, 11]. The prototype has been produced and tested in two beam tests in GSI and SPS CERN.

This article is organized as follows: section 2 presents a general introduction of Strip-MRPC’s structure; section 3 is devoted to the performance of Strip-MRPC in GSI 2014 and CERN SPS 2015 beam time, including the analysis process and results; section 4 describes the results obtained by a new slewing method of time-walk correction; section 5 summarizes the conclusions and outlook.

2 Strip-MRPC module

This Strip-MRPC module is of differential double stack structure with 2 × 4 gas gaps. Compared with single stack MRPC with 8 gas gaps, this double stack structure can help to reduce the required high voltage to half. There are 24 strips on one counter. Each of them is 270 mm long, 7 mm
wide and the interval is 3 mm. Low resistive glass instead of float glass is applied to keep good performance of time resolution under high-rate condition [12–14]. Ground is placed onto the MRPC’s electrode. Feed through is carefully designed to match the 100 $\Omega$ impedance of PADI electronics. This method aims to minimize the noise caused by reflection. The ground of high voltage and electronics are connected to the aluminum gas box that holds the MRPC.

![Figure 1](image)

**Figure 1.** Strip-MRPC’s readout PCB: strip and transmission line is designed to fit 50 $\Omega$ impedance, and a differential combination of two readout PCB match the 100 $\Omega$ impedance of PADI electronics.

This prototype has been tested with cosmic ray system [5] in our lab. In the high voltage scan, the Strip-MRPC has achieved an efficiency above 98% at 5400V and a time resolution of 60ps. Additionally, the noise rate of MRPC has been measured in two different setup: one with PADI FEE plugged to MRPC inside the gas box, another with PADI connected outside the box though interface board. The average noise rate is around 0.1 Hz/cm$^2$ and the noise value of PADI inside box is relatively lower than outside box.

3 Analysis results of beam test

Before the experimental setup of MRPC in two beam time is presented, how the CBM-Root does analysis on raw data should be explained first. The analysis code, developed by CBM-TOF group, deals with a series of influences factors. Time-walk correction corrects the dependence of measured time on amplitude of the analogue signal; gain correction eliminates the amplification variance of different PADI channel; strip alignment removes the shifting center of different strip caused by different cable length; velocity correction calibrates the time difference brought by different particle speed. Before we do these calibrations, there is a cluster building process which selects the average time information of all fired strips as the cluster’s time. Then all these 4 corrections are operated in an appropriate order. After walk correction, strip alignment and velocity correction are looped over with different parameters by multiple times. Then we get the fully calibrated data of the analyzed detector.

3.1 GSI Oct 2014 beam time

The experimental setup of this beam time is shown in figure 2, which is generated by CBM Root geometry file. All of these tested MRPC modules are divided into two parts. The Strip-MRPC (THU-Strip in figure 2) module is among the lower setup. In this beam test, we have 1.1 A GeV $^{152}$Sm beam on 0.3 mm/4 mm/5 mm Pb target respectively. A flux rate of several hundred Hz/cm$^2$ is available.
In order to get the Strip-MRPC’s performance, we define it the detector under test (Dut) in the analysis. HD-P2 counter is Mref, and only with a reference counter all the information (time difference, time resolution, efficiency, etc.) of Dut can be obtained. Diamond counter (so called Bref) is used to give the starting time of one event. This is required in velocity correction. After setting calibration parameters to kick out noise and do hits selection, all the calibration modes are carried out in an iterative way until all unrelated influence on time of flight is calibrated out. Then we get the calibrated time resolution of detector under test. For run Sun1205 with Strip-MRPC’s HV 5500 V and threshold 200 mV, we get a system time resolution of 68.86 ps shown in figure 3. Assuming the THU-Strip and HD-P2’s time resolution are the same, an independent timing ability of $68.86/\sqrt{2} = 48.7$ ps is calculated.

Figure 2. Beam time setup of GSI Oct 2014. THU-Pad and BUC-Ref are in upper setup, while HD-P2 and THU-Strip are among lower setup. PMTs are applied for counting rate calibration. The diamond detector is placed before Pb target to record starting time of each event.

Figure 3. System time resolution of THU-Strip and HD-P2 in run Sun1205 achieves 68.9 ps in GSI Oct 2014 beam time.
All four available runs with different PADI threshold from 170 mV to 200 mV have been analyzed. As is shown in figure 4 and figure 5, the time resolution is around 50 ps. Efficiency is 97% and cluster size is 1.6. All of these results are very stable for change in threshold is not significant.

![Figure 4](image1.png)  
**Figure 4.** Time resolution (around 50 ps) of Strip-MRPC under different PADI electronics threshold.

![Figure 5](image2.png)  
**Figure 5.** Efficiency (97%) and cluster size (1.6 to 1.7) of Strip-MRPC under different PADI electronics threshold.

### 3.2 SPS Feb 2015 beam time

For SPS beam time in Feb 2015, the setup is also divided by two parts. More counters are added in, which means more combinations of these counters to be Dut, Mref and Bref. This time 13A GeV Ar beam is applied. The rate has thus increased to 1 kHz/cm².

Diamond counter is not available in this test, so we need to get counters for MRef and Bref among the 3 detectors except THU-Strip in the upper setup. Among all the combinations, we’ve got the best result of Dut THU-Strip by setting HD-P2 Mref and USTC Bref. The analysis sequence is
Figure 6. Beam time setup of SPS Feb 2015. HD-P2, THU-Strip, USTC and HD-P5 are in upper setup, while BUC-2013, THU-Pad, BUC-Ref are among lower setup. PMTs are applied for purpose of counting rate calibration.

same to that of Oct’s analysis. To get better calibration result, some parameter selection is done, especially on the Y position selection along the strip and chi2 selection limit on the time difference distribution between THU-Strip and Mref. When $10 \text{ of chi2 limit and 0.3 of Y Position selection}$ is required to satisfy, we can get a relatively best result. For run01Mar1126, the system time resolution is 96 ps.

Figure 7. System time resolution of THU-Strip and HD-P2 in run 01Mar1126 achieves 96.0 ps in Sps Nov 2015 beam time.
Apparently, the time resolution in this beam time is not as good as in GSI Oct 2014. One possible reason is diamond detector is not applied as Bref anymore. The distance between MRef and BRef is closer, thus the velocity correction is not calibrated in an ideal way. Lately the tracking method is introduced by TOF group. Tracks are built in the four counters to calibrate efficiency and correct time and space for hits in Dut. After tracking, time resolution is greatly improved by 10 to 20 ps. Since the rate information is recorded throughout this beam time, we choose several runs at different flux rates. The results are shown in figure 8. The efficiency is stable with growth of rate, because low-resistive glass Strip-MRPC apply can maintain its performance under high rate. From the time resolution, we can easily find out the tracking method has done a lot benefit.

![Figure 8](image)

**Figure 8.** Efficiency (98%) and system time resolution of Strip-MRPC under different flux rate. The efficiency under rate 300 Hz/cm$^2$ and 600 Hz/cm$^2$ is relatively low because these two runs have less events. From the time resolution, tracking has provided an improvement up to 20 ps.

4 Slewing correction

We also introduce a new correction method called slewing correction to the time-walk correction process in CBM Root. As mentioned before, the time difference is calibrated to be independent from the time over threshold (TOT), thus the mean value of each bin in the 2D plot should be a horizontal line. The original method takes the subtraction of mean time of each bin and average time of all bins as the correction. For points between centres of each bin, the correction value is got by linear interpolation. While in RHIC-STAR, an equation is introduced to fit the mean value of each bin. The subtraction of this fitting value of each point and the total mean value will be the correction.

$$y = \text{par}[0] + \text{par}[1]/\sqrt{x} + \text{par}[2]/x + \text{par}[3] \times x$$

The equation has 4 parameters. We modify the code of this slewing method in relevant CBM Root macros. Figure 9 shows the independence level of time difference and TOT right after the step of walk correction. It can be noticed that in the red circle, the mean value line is obviously flatter in slewing method.
We also scan the time resolution under different condition in both two beam time. The time resolution is always 1 ps better, and this is outside the error bar. This modification is beneficial for the walk correction.

Figure 9. Walk correction results of original method and slewing correction method. In the slewing correction the mean value line of time difference is a little better.

Figure 10. Time resolution difference between original walk correction and slewing method in GSI Oct 2014 (a) and SPS Feb 2015 (b), and slewing method always owns a better calibrated result.

5 Conclusion

The Strip-MRPC developed by Tsinghua University is proved to have an efficiency above 97%, time resolution below 60 ps and cluster size around 1.6 through the two beam time of GSI Oct 2014 and SPS Feb 2015. The rate capability is mainly determined by the bulk resistivity of glass. Equipped with low-resistive glass, Strip-MRPC can maintain these good performances under high flux rate up to 25 kHz/cm². This has been already proved on a smaller Strip-MRPC prototype with similar structure in ELBE beam test [12]. This Strip-MRPC is fully capable of meeting the demands of TOF wall. Some attempts on walk correction of CBM Root macros have been carried out and some progress is made. Another 3 strip prototypes with similar structure and real dimension have been developed and tested at SPS in Nov 2015, and the data analysis is undergoing.
Acknowledgments

The work is supported by National Natural Science Foundation of China under Grant No. 11420101004, 11461141011, 11275108. This work is also supported by the Ministry of Science and Technology under Grant No. 2015CB856905.

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