Chapter 8

DEVELOPMENT AND CHARACTERIZATION OF MRPC DETECTORS

The RPC detectors, which have a single gap for gas flow, have been chosen as the active detector elements for the magnetized Iron CALorimeter (ICAL) detector, due to their high efficiency, position and timing characteristics besides their long-term suitability for large detector coverage [6, 7]. The typical time resolution of the RPC detectors, to be used in ICAL, is in the range 1 – 1.5 ns [120]. The muon track reconstruction uses the time information of the hits to determine the direction of the track, which is discussed in section 3.2 [9]. The time information of the hadron shower hits can also be used to determine their average direction (see Chapter 5). A detector with a better timing information would, therefore, improve the direction reconstruction of both muons and hadrons. A possible option may be the Multigap Resistive Plate Chamber (MRPC) detectors, which are the upgrades of the RPCs, with the introduction of multiple sub–gaps [30, 31]. The presence of multiple gas sub–gaps enable the detector to induce faster signals on the outer electrodes, thus

This chapter is based on [34], which has been submitted.
improving the detector’s time resolution. Due to the excellent performance and relatively low cost, the MRPC detectors have found potential application in various Time–of–Flight (TOF) systems [143, 145, 144, 146].

The work described in this chapter involves the development and performance of single cell six–gap Glass MRPC detectors with each sub–gap being about 250 µm. These detectors have been developed to find application in the future upgradation of the ICAL detector, as well as TOF detector and other experiments. This chapter starts with an introduction to the MRPC detectors and their working principle. The fabrication procedure and the optimized design of the MRPCs, the experimental set–up including the trigger and data acquisition system and the MRPC characterization follow in the subsequent sections.

8.1 MRPC DETECTORS AND THEIR WORKING PRINCIPLE

The Multigap Resistive Plate Chambers (MRPCs) are gas ionization detectors with multiple gas sub–gaps made of highly resistive electrodes (glass in this case) having bulk resistivity of $10^{10}$ – $10^{12}$ Ω cm, spaced from one another using spacers of equal thickness. These detectors were conceptualized and first developed in 1996 [30, 31]. The high voltage (HV) is applied on the outer surfaces of outermost resistive plates to create a uniform and intense electric field across them, while the interior plates are left electrically floating. The external surface of the two outermost resistive plates are coated with a thin layer of graphite, in order to apply the high voltage uniformly. All the electrodes are kept apart by some spacers having a bulk resistivity greater than $10^{13}$ Ω cm. The narrower sub–gaps enhance their time resolution capability. Results from groups involved in the study of various MRPC configurations show that a time resolution of less than 100 ps can easily be obtained. MRPCs have been chosen as optimal elements for many Time–Of–Flight (TOF) de-
tector systems (including ALICE and STAR) due to their excellent time resolution and higher efficiency for particle detection. [143, 145, 144, 146]

The working principle, including the avalanche formation of an MRPC are similar to that of a single gap RPC, apart from the fact that, the additional sub-gaps make the signal collection faster. The internal plates would also allow the detector to withstand a higher operating voltage. The illustration of an ideal MRPC is shown in Fig. 8.1, where all the gas gaps are assumed to be of uniform width. The internal plates are electrically floating, and are maintained at equal voltages due to the flow of positive ions and electrons between them. The voltage across each sub-gap is the same. So, on an average, each sub-gap will produce the same number of avalanches when a flux of charged particles passes through it. This means the flow of electrons and ions into the plates bounding a gas gap will be identical for all the gaps, and the net charge to any of the internal plates would be zero. Avalanche in any of the sub-gaps induce the signals on the electrodes and it will travel very fast to the outermost electrodes, as the inner plates are transparent to the fast signals. The fast signals in case of MRPC are produced by the flow of electrons towards the anode. The resultant signal is the summation from all the gas gaps and it enhances the amplitude of the pulse. The surface resistivity of the conductive graphite coating is high enough so that the electrodes act as dielectrics, i.e., they are transparent to the fast signal generated by the avalanches inside each gas gap. The copper pickup strips placed outside the cathode and anode electrodes collect the signal, with a reduced time jitter, through induction.

A typical gas mixture, consisting largely of an electronegative gas and small fractions of the quenchers of UV photons and electrons, similar to those used for single gap RPC operation, may be used. Though the internal plates helps in quenching the streamers to avoid a spark breakdown, at higher operating voltages they are not sufficient, which leads to the use of the electron quencher gas in slightly higher fraction.
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The intermediate plates also act as the physical barriers for the avalanche growing too big, and hence a higher electric field can be applied to the detector operated in the avalanche mode, compared to that of a single gap structure. This is advantageous in terms of the time resolution and rate capability of the device. The strong uniform electric field stimulates the avalanche process immediately after the primary ionization is created by a charged particle, leading to a very good time resolution.

The MRPCs may consist of a single stack with two external electrodes, or two stacks packed together with three external electrodes, the anode being common for both the stacks. Single cell (stack) configuration has a pair of external electrodes. As the number of floating electrodes increases, higher and higher operating voltage is needed to operate it. Double cell (stack) is basically two single cell MRPCs clamped together (usually the anodes). Bifurcating the floating electrodes in the two cells
helps in reducing the operating voltage at each of the electrodes.

8.2 DESIGN AND FABRICATION OF A 6–GAP MRPC

In this section the design and fabrication of six–gap glass MRPC detectors, with the single stack configuration, is discussed. We started with the fabrication of a six–gap MRPC with a small dimension (75 mm $\times$ 65 mm $\times$ 7.67 mm), and later optimized the design to a larger dimension. The trial configurations, various problems encountered and the final optimized design are described in the following.

8.2.1 THE TRIAL CONFIGURATIONS

The first MRPC with six sub–gaps was of a dimension 70 mm $\times$ 60 mm $\times$ 7.67 mm. all the glass plates, including the two external ones were of the same thickness, i.e., 0.410 mm, and of the same area, i.e., 70 mm $\times$ 60 mm, as shown in Fig. 8.2a. Two sided non–conducting adhesive tapes of thickness 0.267 mm, cut in circular shapes of diameter 4 mm were used as spacers. Honeycomb panel with copper strips of width 1.4 cm were used to construct the pick up panel (five strips on each side). The whole set–up was sealed in an enclosure box of dimension 200 mm $\times$ 200 mm $\times$ 60 mm and gas was flown through it. The same gas mixture as mentioned in section 2.2, which is used in RPC detectors, was used. The gas flow rate was approximately 2.81 SCCM (i.e., Standard Cubic Centimeter per Minute) which corresponds to about 2 cycles a day.

However, this configuration gave rise to certain problems. The MRPC HV was slowly ramped up to 13 kV, where the chamber current was 25 nA. During this process, the MRPC broke down a few times, and a few sparks damaged the edges of a few inner plates, as shown in Fig. 8.2b. This problem appeared mainly due to the thin external electrodes which were unable to withstand such a high voltage. Also the edges of the interior plates were on the same line of the conductive coat on the two external electrodes. In order to solve this problem, the outer pair of conductive
electrode plates were replaced by plates of thickness 2 mm and slightly larger area (75 mm $\times$ 65 mm). The graphite coating was confined to an area 58 mm $\times$ 58 mm so that it remained well within the area of the interior plates. Fig. 8.3 shows various steps of the MRPC configuration. The new structure solved the issue of sparking.

The set-up was then tested with a trigger of two scintillator paddles in 2-fold coincidence, as shown in Fig. 8.4. A high voltage of 15 kV was applied across the two external glass plates of the MRPC. This detector, however, could detect only about 25% of the triggered events.

The next MRPC constructed was of a bigger dimension, 270 mm $\times$ 270 mm $\times$ 7.58 mm. The configuration, except the detector dimension, was similar to the previous MRPC. This detector was also enclosed in a chamber through which the gas mixture was flown. This detector too, was tested with a trigger formed by scintillator paddles in 2-fold coincidence, as shown in Fig. 8.5. A raw pulse, without any amplification, as detected in the detector is shown in Fig. 8.6

The strip efficiency is defined to be the ratio of the events detected by the MRPCs to the total triggered events. The strip efficiencies of the two MRPCs, as functions of the applied high voltage, are compared in Fig. 8.7. It can be seen that the larger MRPC attained an efficiency of about 80% at 15.9 kV.
As has been mentioned earlier, these two MRPCs were put in sealed enclosures through which the gas mixture was passed. This enclosed configuration made the alignment of the trigger consisting of the scintillator paddles difficult. Also, since the narrow sub–gaps would offer high resistances to the gas flow, compared to the rest of the enclosure, a complete uniform gas flow through all the gaps is not ensured. These difficulties have been taken care of in the fabrication of the next MRPCs. The optimized design of the six–gap MRPCs have been discussed in the following subsection.
8.2.2 THE OPTIMIZED CONFIGURATION

The design of six-gap glass MRPCs with single cell structure of dimensions 305 mm × 305 mm × 7.5 mm has been optimized. A schematic of the configuration with dimensions of various components is shown in Fig 8.8. Note that the area of the internal glass plates are of dimension 256 mm × 256 mm × 0.410 mm.

Glasses of 2 mm thickness coated with a conductive layer using NEROLAC paint were used for the outer electrodes. The surface resistance of the conductive coat was in the range (0.5 – 1) MΩ/□. Two sided non-conducting adhesive tapes were stuck to both sides of a mylar sheet to make small circular spacers of diameter 4 mm and
8.2. DESIGN AND FABRICATION OF A 6–GAP MRPC

Figure 8.6: A raw pulse collected at both the anode and the cathode of the detector at an operating voltage of 15.5 kV. The trigger signal is also shown for reference.

Figure 8.7: The strip efficiencies of the two MRPCs, as functions of the applied high voltage.

thickness 250 µm. Each gas gap were maintained by 25 such spacers. The placement of the spacers are shown in Fig. 8.9 (left panel). A few trials were first made by placing this configuration in an enclosed box filled with the gas mixture. Such an enclosed structure had some drawbacks like difficulty in alignment and the problem in ensuring sufficient and uniform gas flow through the sub–gaps. The configuration was optimized with sealing the gas gaps by gluing side spacers between the outermost electrodes. As can be seen from Fig. 8.8 and Fig. 8.9, there is a gap of about 2.7 cm from the edges of the external electrodes to the edges of the internal electrodes. There is a possibility of gas following that path instead of flowing through the sub–gaps which would offer high resistances. In order to ensure a proper flow through
the sub–gaps, we introduced some blockers at appropriate places (one each near the gas inlets and two each near the gas outlets). This is illustrated in Fig. 8.10. The pickup panel consists of honeycomb panels laminated with copper strips of width 2.8 cm. The pickup strips on both the sides of an MRPC were placed parallel to each other.
Figure 8.9: The placement of the spacers. There are 25 spacers in each sub-gap in a $5 \times 5$ array, the gap between any two consecutive spacers being 6.4 cm.

Figure 8.10: The placement of the blockers and side spacer. As shown in the left panel, two blockers are placed near each gas inlet while one blocker each are placed near each gas outlet, to ensure a proper gas flow through the sub gaps. The right panel shows a side spacer, fitted with a gas nozzle. A segment of a side spacer with a blocker attached is also shown.
8.3 THE EXPERIMENTAL SET-UP

The experimental set-up to test three MRPCs with the optimized design is described here. A cosmic muon telescope consisting of three scintillator paddles has been set up. The details of the telescope, the preamplifier and the data acquisition system are as in the following subsections.

8.3.1 THE COSMIC MUON TELESCOPE

The MRPCs are operated in avalanche mode and are characterized using cosmic muons. Three scintillator paddles of width 2 cm each (two on the top of the MRPCs under test and one at the bottom) were set up in a geometry to construct a cosmic ray muon telescope as illustrated in Fig. 8.11. Time coincidence of signals from these paddles indicates passage of a cosmic ray muon particle through the detector set-up. This coincidence signal has been used to trigger the data acquisition system. The set-up including three MRPCs and three scintillator paddles is shown in Fig. 8.12.

8.3.2 NINO ASIC

For amplification and digitization, NINO ASIC, an ultra fast front end preamplifier-discriminator chip which was developed for the ALICE TOF experiment, was used \[33\]. Each chip has 8 amplifier and discriminator channels. Each channel is designed with an amplifier with < 1 ns peaking time, a discriminator with a minimum detection threshold of 10 fC, and an output stage. As shown in Fig. 8.13, each channel in the NINO ASIC chip takes differential signals from the pickup strips as input, and amplifies them in a four-stage cascade amplifier.

With a 50 Ω termination across the pickup strips of the MRPCs, no signal was obtained using the NINO ASIC. Without a termination across the strips, the signals could be recorded, and for the rest of the study the strips were kept in open condition. The threshold to the discriminator stage of the chip was optimized to 157mV after...
8.3. THE EXPERIMENTAL SET–UP

Figure 8.11: The scheme for the cosmic ray muon telescope. P1, P2 and P3 are scintillator paddles of width 2 cm each, and they are aligned on a pick-up strip of width 2.8 cm. The effective area of this telescope is 25 cm × 2 cm.

Table 8.1: Counting rates of an MRPC strip at different NINO thresholds.

<table>
<thead>
<tr>
<th>NINO thr. (mV)</th>
<th>Counting rate (kHz)</th>
<th>NINO thr. (mV)</th>
<th>Counting rate (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>310.4</td>
<td>7.2</td>
<td>157</td>
<td>60</td>
</tr>
<tr>
<td>220.1</td>
<td>8</td>
<td>151</td>
<td>100</td>
</tr>
<tr>
<td>190.2</td>
<td>12</td>
<td>149</td>
<td>200</td>
</tr>
<tr>
<td>181.8</td>
<td>14</td>
<td>115.3</td>
<td>300</td>
</tr>
</tbody>
</table>

8.3.3 THE DATA ACQUISITION SYSTEM

A CAMAC based data acquisition (DAQ) system has been assembled for the MRPC detector test set–up. MRPC pickup strips are amplified and digitized by NINO ASIC and then taken with the time coincidence of the trigger. The differential (LVDS)
The experimental set-up.

Figure 8.13: The schematic of the NINO ASIC [33].

Signals obtained from NINO output are converted to ECL and then according to the requirement of the scalar and TDC used directly or further converted to NIM signals. The counting rate of the individual strips are recorded with a ECL scalar. The trigger \( T \) is formed by putting the signals from the three scintillator paddles P1, P2 and P3 in coincidence mode. The efficiency of the MRPC strips are then obtained from the coincidence of the trigger and the strip count:

\[
\text{Strip efficiency} = \frac{\text{MRPC strip count}}{T}.
\]  

The trigger is also given as the start signal to the TDC module to get the time count, where the stop signal comes from the MRPC strips. The DAQ scheme to obtain the
counting rate, efficiency and timing has been shown in Fig. 8.14.

Figure 8.14: The DAQ scheme to obtain the strip counting rate, efficiency and time count.

8.4  THE MRPC PERFORMANCE

The characteristics of the MRPC detectors, obtained by adjusting various parameters like the gas mixture composition, HV etc., have been discussed here. The I–V characteristics, strip count rate, efficiency and the time resolution are discussed in the following.

8.4.1  MRPC CHARACTERIZATION AS A FUNCTION OF HV AND GAS MIXTURE

The gas mixture is composed of R134A, C₄H₁₀ and SF₆. Studies showed that the MRPCs would be operated with around 5% of SF₆ [32, 148], unlike the standard
composition with very less amount of SF$_6$ ($\approx 0.3\%$) [7] that is used to operate single gap RPCs. With increasing SF$_6$ fraction, two competing processes affect the MRPC characteristics. Higher electric fields would be required with increasing fractions of SF$_6$, which would also increase the drift velocity and as a result improve the time resolution. On the contrary, since SF$_6$ has large capture cross-sections for low energy electrons, increasing the SF$_6$ concentration would reduce the avalanche significantly. This would degrade the MRPC counting rate, efficiency, time resolution etc. So, it is required to optimize the gas mixture for these two contradictory effects.

A study with various concentrations of SF$_6$ at different applied high voltages has also been performed to obtain an optimized set. For this, the proportion of
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C₄H₁₀ was kept fixed at 5%, and the other two were varied. Figure 8.15 shows the efficiency, counting rate per area of the pick-up strip, the chamber current and the time resolution of an MRPC strip. The operating HV was varied between (15 – 17.9) kV. We see that at ~ 4% of SF₆, the time resolution is best and the noise rate and chamber current are reasonable without deteriorating the efficiency. So for further study, we have used the gas mixture of R134A (91%), C₄H₁₀ (5%) and SF₆ (4%). We see that even at 17.9 kV the chamber current and counting rate do not shoot up too much. In Fig. 8.15, the time resolution after correcting from the time jitter has been shown. This correction is done via a calibration of the time count with the total charge deposited in an event. This has been described in the following.

8.4.2 TIME RESOLUTION

The introduction of smaller gas sub–gaps would result in an enhanced time resolution in MRPCs. For an accurate measurement of the timing, it is important to reduce any fluctuations which may occur during the generation of the timing logic signal. A major source of such fluctuations is the walk effect. This effect is caused by the variation in the signal amplitudes and/or rise time. The signals with different amplitudes would cross the discriminator threshold at different times, resulting in a time shift (walk) in the logic signal. An additional walk effect arises due to the finite amount of charge that is required to be integrated on a capacitor to trigger the discriminator. We reduce the time walk by calibrating the time counts with the charge deposited. Fig. 8.16 shows a typical raw time distribution (before correcting for the time walk). Here the trigger is provided by the scintillator paddles in coincidence, as have been described in section 8.3.1, and this has been used as the start to the TDC. We have corrected the time distributions for the time walk according to the charge of the signal. Note that, the charge is obtained from the analog output signal from the MRPC strips. Since NINO ASIC provides LVDS output only, for this study it has been replaced with ANUSPARSH, the ASIC designed for the ICAL experiment.
A scatter plot of time vs charge is shown in Fig. 8.17. This is fitted to a function \( \exp[-a_0/x + a_1] + a_2 \). The time of each event is then corrected according to the charge information by employing a calibration through the fit parameters. Fig. 8.18 shows the comparison of raw and corrected time distributions at 17.9 kV and with the optimized gas mixture.

![TDC count (raw)](image)

Figure 8.16: The raw MRPC time distribution with respect to the trigger at 17.9 kV and with the gas mixture R134A (91%), C_4H_{10} (5%) and SF_6 (4%).

![TDC value (LSB = 25ps)](image)

<table>
<thead>
<tr>
<th>Entries</th>
<th>12783</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi^2 / \text{ndf} )</td>
<td>232 / 135</td>
</tr>
<tr>
<td>( a_0 )</td>
<td>-84.65 ± 3.44</td>
</tr>
<tr>
<td>( a_1 )</td>
<td>-2.197 ± 0.260</td>
</tr>
<tr>
<td>( a_2 )</td>
<td>397.4 ± 0.5</td>
</tr>
</tbody>
</table>

Figure 8.17: The calibration graph for correcting of the MRPC time distribution for time-walk, fitted to \( \exp[-a_0/x + a_1] + a_2 \).

As shown in Fig. 8.18, at 17.9 kV, the time resolution is \( \sim 60 \) ps, which also includes 15 – 25 ps of jitter due to electronic channels. This jitter has been estimated by replacing the MRPC strip signals with a pulser and observing the obtained time
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![Graph showing TDC values and corrected TDC values](image)

Figure 8.18: The MRPC time distribution with respect to the trigger at 17.9 kV and with the gas mixture R134A (91%), C_H10 (5%) and SF_6 (4%). The black line shows the raw distribution, while the red one shows the distribution after applying the time walk correction.

8.4.3 STUDY USING Cs-137 SOURCE

Earlier a cosmic muon telescope was employed to study the characteristics of the MRPC. Since the cosmic muon flux is scattered over θ and φ, so the paddles and the MRPC strip are hit from muons in a wide cone, and also at various points of the strip, which may deteriorate the time resolution, in particular. To verify that, a Cs–137 source of strength 3 × 10^6 dps has also been used. In Fig. 8.19 the efficiency and time resolution as functions of the high voltage are shown.

8.4.4 MRPC AS A PART OF TRIGGER

One of the potential timing applications of MRPC is then probed by adding it to the external trigger system for a single-gap RPC. In Fig. 8.20 the three different set-ups are shown. The various characteristics of the single-gap RPC from these three trigger set-ups are listed in Table 8.2. It can be seen that the introduction of the MRPC in the trigger system helps in improving the time resolution.
Figure 8.19: The efficiency and time resolution of the MRPC with a Cs-137 source, as functions of high voltage.

Figure 8.20: The three set-ups under study. Set-up I consists only the scintillator paddles P1 and P2 in coincidence to form the trigger. The other two set-ups use an MRPC in addition to the paddles.

Table 8.2: The MRPC characteristics for different trigger set-up.

<table>
<thead>
<tr>
<th>Set-up</th>
<th>Trigger</th>
<th>Eff. (%)</th>
<th>Time res. (ns)</th>
<th>Noise (Hz cm$^{-2}$)</th>
<th>I (nA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>P1, P2</td>
<td>85</td>
<td>1.42</td>
<td>1.5</td>
<td>305</td>
</tr>
<tr>
<td>II</td>
<td>P1, P2, MRPC</td>
<td>85.9</td>
<td>0.87</td>
<td>2.85</td>
<td>312</td>
</tr>
<tr>
<td>III</td>
<td>P1, P2, MRPC</td>
<td>87.8</td>
<td>0.85</td>
<td>1.87</td>
<td>311</td>
</tr>
</tbody>
</table>
8.5 REMARKS

This chapter describes the design of the MRPCs with six sub-gaps and the optimization of the single stacked configuration. The detectors are characterized with a cosmic telescope set-up and their characteristics have been studied. The parameters like the applied voltage, the gas mixture are also been optimized. The detectors are now being operated in a stable condition, with the strip efficiency being about 95% and the time resolution being 60 – 100 ps, and the stack is ready for the further study to assess its potential for various applications. It has already shown promising result when used as the part of a trigger set-up. Now, the stack is being planned to be used for a TOF measurement study which, however, is beyond the scope of this thesis.