DEVELOPMENT AND EVALUATION OF THE MUON TRIGGER DETECTOR USING A RESISTIVE PLATE CHAMBER

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Received February 16, 2011 / 1st Revised March 21, 2011 / Accepted for Publication March 22, 2011

The PHENIX Experiment is the largest of the four experiments that have taken data at the Relativistic Heavy Ion Collider. PHENIX, the Pioneering High Energy Nuclear Interaction eXperiment, is designed specifically to measure direct probes of the collisions such as electrons, muons, and photons. The primary goal of PHENIX is to discover and study a new state of matter called the Quark-Gluon Plasma. Among many particles, muons coming from W-boson decay gives us key information to analyze the spin of proton. Resistive plate chambers are proposed as a suitable solution as a muon trigger because of their fast response and good time resolution, flexibility in signal readout, robustness and the relatively low cost of production. The RPC detectors for upgrade were assembled and their performances were evaluated. The procedure to make the detectors better was optimized and described in detail in this thesis. The code based on ROOT was written and by using this the performance of the detectors made was evaluated, and all of the modules for north muon arm met the criteria and installation at PHENIX completed in November 2009. As RPC detectors that we made showed fast response, capacity of covering wide area with a resonable price and good spatial resolution, this will give the opportunity for applications, such as diagnosis and customs inspection system.

Keyword : Resistive Plate Chamber, PHENIX, Muon Detector, Cosmic Ray, Fast Response, RPC Detector

1. INTRODUCTION

Resistive Plate Chamber (RPC) developed early of 1980's by a group of university of Rome [1] has been widely used in many high-energy experiments. Main features of RPC are good time resolution, fast time response to incoming charged particles, and high efficiency. Such characteristics make fast and accurate charged particle triggering and tracking possible. Simple detector structure and large pulse signal of RPC bring low material costs to build and no need to use expensive and complex readout electronics. Thus, RPC has low production cost of the larger area to cover as required for modern detector system in most nuclear and high-energy experiments [2][16–21].

The original RPC was single-gap counters operated in streamer mode. This operation mode allows to get good efficiency and resolution when the particle rate is low.

At particle background rates higher than 200 Hz cm⁻², however, the rate capability of RPC was decreased. The way to overcome this kind of problem is operating RPC in avalanche mode [3–8]. When a RPC signal pulse is developed, a certain time is required to recover the electric field across the RPC gap. The recovery time for the avalanche mode is roughly 100 times smaller than the one for the streamer mode. In this mode the rate capability can be improved. Furthermore, the double-gap structure was introduced to improve the detection efficiency along with the avalanche mode of operation [4][9–14], which extends its counting rate capabilities because operating high voltage is less than the one for single gas RPC.

2. PRINCIPLE OF THE RPC

In PHENIX (Pioneering High Energy Nuclear Interaction experiment) experiment, double gap RPC is chosen due to not only its faster response time but also higher effi-
ciency than single gap RPC. The RPCs are built with two parallel plates of high resistive material, like phenolic polymer (bakelite) or glass, as electrodes. The plates have a resistivity of the order of $\sim 10^9 \Omega \cdot \text{cm}$. The sensitive gas volume gap is typically 2 mm thick between the two plates. In order to keep the plates at a fixed distance over the entire plate area, spacer disks of polycarbonate are glued between the plates. The edges of the gas gap are sealed with polycarbonate strips (with the same thickness as the spacers) to ensure gas tightness. Four small gas tubes are inserted into the gas gap at each corners of the chamber for gas inlet and outlet. The outside surfaces of the RPC plates are coated with graphite for distributing high voltage on one side and the ground on the other in order to establish a strong electric field in the gas gap. The graphite coat has a surface resistivity of about order of tens $\Omega \cdot \text{cm}$. The graphite surface is then covered with high resistive thin film, for example PET or Mylar, in order to prevent potential damage to the graphite coat. The signal readout, typically made of copper strips or pads, is located outside of the sensitive gas volume (Fig. 1). This is one of the most attractive features of using RPCs. Ionizing particles create electron-ion clusters in the gas, where an intense constant electric field is present between the two parallel electrode plates. The working principle of the RPC detector is shown in Fig. 2.

![Fig. 1. Structure of double gap RPC.](image1)

![Fig. 2. Working principle of RPC detector.](image2)

3. PROCEDURE FOR THE RPC MODULE ASSEMBLY

3 different types of RPC modules will be made and assembled as a half-octant as shown in Fig. 3. Each module has a different size but the procedure to make them is same. Before making the modules, performance of the RPC gaps including gas leakage and electrical stability should be checked. The RPC bottom frame is placed on the table and wiped with alcohol and covered with the slot for the high voltage (HV) connector with kapton tape. The mylar sheet is put on the plate and fitted in its position inside the casing. This mylar insulate the plate from the copper foil. Over the mylar, the precut copper sheet is placed on.

The octant side of the casing is lined up with the copper foil (there should be about 3 inches of excess copper that overhangs the casing). There should be enough copper so that it can be folded back on the gas gap completely sandwiching it to protect the gaps from electromagnetic field outside. The position of the HV slot is marked on the copper, and the foil needs to be cut to protect the HV. The cut copper foil is pushed into the HV slot. The kapton tape is put on each side where the gas tubes are passing to prevent discharge from around gas cap and tube (Fig. 4). The protective film of the lower gas gap is removed. The surface should be wiped with alcohol and the appropriate mylar sheet is fitted on HV side of the gas gap and tape with kapton on each gas in-outlet. Slits should be cut on the two
long sides of the HV connector. Since the gas piece is fragile, one end of polyethylene gas tubes should be heated up by using a heat gun so that it will slide on easily. It needs to slightly bend the gas tube to match with the hole of the frame bar. The tube should be bended to the appropriate direction and the kapton tapes are put at the border of the gas gap and areas where the gas tubes are connecting because these areas are easy to discharge. The gas gap is flipped into place so that the mylar sits between the gas gap and the copper foil and the sidebar is placed into its position (Fig. 5).

After placing the lower gap on the copper foil, HV cable with a bulk head should be connected to the HV cable from the gas gap. 3 different shrink wraps are slipped on and the inner cables should be soldered through the copper pin. The HV cable is placed through the appropriate hole (smaller hole from bottom) and needs to be screwed in sidebars. The inner side of the bar should be covered with kapton tape so that the signal cable can not touch them which cause a short. Every wire on the transition card needs to be soldered on the card. The other side of wire will be prepared and soldered on the signal strip and put the kapton tape on the spot where we solder them to prevent the ground cables from contacting the signal strips, which can also cause a short as shown in Fig. 6. When it is done with signal strip, it is placed on the lower gas gap and the flag is attached, which tells us the exact position of the strip. Once the upper gap is prepared, repeat the same process as lower gap.

Fig. 3. Construction of RPC modules and half-octants.

Fig. 4. Cut Copper foil and put kapton tape.

Fig. 5. Connecting the gas tube and protecting with kapton tape.
When the upper gap is placed on the strip, it should not sit on the soldered point. A foam needs to be squeezed between the upper gas gap and the sidebars to ensure a tight fit. Next step is to check the leakage from the gap. The tubes are connected from each gaps and the gas leakage test is performed as shown in Fig. 7. Four ground cables coming from gaps and HV cables should be cut and the terminal rings are added, then connect them on the octant side bar. The position of the side bar should be fixed and bolt it. The copper is folded back and an excess should be trimmed so that copper fits inside casing. All folds should be secured with copper tape. To prevent the gaps from moving squeeze foam between the space as shown in Fig. 8. In the past, the ground cables were connected to the separate wire and the operation stability such as a noise rate was unstable. This time, however, the ground cables were attached directly to the copper foil which is being used as a Faraday cage so that the chambers can operate stably. That copper will be connected to the module frame. Then every grounds will gather to the module frame and it will help the module operating better. The check to see if there is any short should be conducted by multimeter before covering the module. Once everything is done, the cover plate is put over the frame. Fig. 9 shows the completed module and 3 different types (A, B, C) of RPC detectors will be assembled again as a half-octant.
4. QUALITY ASSURANCE (QA) OF RPC MODULES

The assembled modules should meet the criteria required by PHENIX (Table 1).

Table 1. PHENIX RPC Detectors Requirements.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Efficiency</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>Time resolution</td>
<td>≤ 3 ns</td>
</tr>
<tr>
<td>Average cluster size</td>
<td>≤ 2 strips</td>
</tr>
<tr>
<td>Rate capability</td>
<td>0.5 kHz/cm²</td>
</tr>
<tr>
<td>Fraction of streamer</td>
<td>&lt; 10 %</td>
</tr>
<tr>
<td>Intrinsic noise rate</td>
<td>&lt; 10 Hz/cm²</td>
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QA tests here are divided into 2 main tests: one is noise rates test and the other is cosmic ray test which includes measuring the efficiency and cluster size and correlation of both timing and position. Noise rate was performed at 9.5 kV and FEE threshold level was 160 mV. For cosmic ray test, they are scanned as a function of the HV and threshold level. By using DAQ system shown in Fig.10, QA test were performed. the noise rate for each modules is taken and the data flow diagram is shown in Fig. 11. To simplify the procedure DAQ program based on ROOT was written. This code helps with not only debugging when module had a problem with a high noise rate but saving time and effort. The results with the codes for all 48 modules for RPC-3 north station are displayed in Fig. 12. The red color of strip means that the noise rate of that channel is high and violet color of strip means that it could be disconnected or short. With the optimized procedure, 99.7% of the whole channel met the criteria which should be less than 10 Hz/cm². To measure the efficiencies by using muon data from cosmic ray, the trigger was provided by the coincidence of between top and bottom scintillators mounted at Photo Multiplier Tubes (PMTs). To make sure, the scintillators which are used as a trigger should cover all area of RPC modules. The setup and logic diagram are shown in Fig. 13.
Fig. 10. A typical PDAQ system.

Fig. 11. Noise rate test diagram.

Fig. 12. Noise rate result of whole modules for north station.

Fig. 13. Cosmic ray test setup and logic diagram.
Fig. 14. Timing (Upper) and Position (Lower) resolution and correlation between two neighbor modules.

Fig. 15. One of the result from each type of module (Efficiency and cluster size).
At this test, the ROOT code to see the time correlation and channel correlation which provide the reliability of the efficiency was written. By using this code as well, the final results of the efficiencies were calculated and summarized as a function of HV and threshold level. The efficiencies of the RPCs were evaluated by the TDC data, coincident with the trigger within a 100 ns of time window. For north installation, total 48 modules (number of A module : 16, B module : 16, C module : 16) were scanned at a different level of HVs and thresholds. As we applied high voltage from 9.1 kV to 9.9 kV, the efficiency started to saturate from 9.5 kV, while the cluster size increased to the value 3, which means the position resolution got worse. When we increase threshold level, the efficiency decreased while the cluster size became smaller. The efficiencies and cluster sizes were compatible with the HV and threshold level. The operating HV and threshold level was determined so that both criteria could be met at once which is 9.5 kV and 160 mV. The correlation of timing and channel between two neighboring modules should be checked while taking the data. Fig. 14 show good correlation results at 9.5 kV and 160 mV. Fig. 15 shows the efficiency and cluster size results of each type of the modules. All of them satisfied the criteria. And Fig. 16 is the modules installed at North Muon Arm.

The RPC detectors for upgrade were assembled and their performances were evaluated. The procedure to make the detectors better was optimized and described in detail in this thesis. The performance of the detectors made was perfect, and all of the modules for north muon arm met the criteria and installation at PHENIX completed in November 2009.

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REFERENCES


