Assembly, Testing, and Installation of the Fast RPC Muon Trigger Upgrade for PHENIX

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Abstract

Many important questions remain to be answered about the origin of the proton spin. A new fast RPC based trigger system is being developed for the PHENIX muon spectrometer arms that will allow, for the first time, the measurement of the flavor structure of the quark polarization in the proton through the observations of W-bosons in polarized proton-proton collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The new PHENIX Muon Trigger will improve the efficiency by which the data acquisition system can identify potential W events by approximately two orders of magnitude. W-bosons can be detected through the appearance of a high-energy muon in one of the two existing muon spectrometers. The trigger upgrade is based on new front-end electronics for the muon tracking chambers and RPCs that will be installed in three stations of both muon arms starting with prototype chambers in 2008. Components of the RPCs are being fabricated at many different locations around the world. After they are shipped to BNL, these components will be tested and then the RPC modules will be assembled at a newly completed facility. Once assembled, these modules will be extensively tested and jointed in half octant units for installation into the PHENIX spectrometer. Prototype chambers have been assembled and tested.

Key words: Resistive plate chamber, Muon trigger, Proton spin, PHENIX, BNL, RHIC
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1. Introduction

The PHENIX collaboration has constructed and operates a multipurpose spectrometer to study both the heavy ion collisions and the polarized proton collisions at the Relativistic Heavy Ion Collider [1]. During the first eight years of operation we have learned much about quark matter and the structure of the nucleon [2]. To continue our study of the structure of the proton we are upgrading the spectrometer. One of these upgrades will allow us to select events that produce W-bosons. The careful study of these events will allow for the spin structure of the proton to be better understood. While the production of W-bosons is rare, their decay into a single muon with high transverse momentum produces a clear signal. To select these rare events, the trigger in the muon arms will be upgraded by implementing a rapid readout of information from the cathode strip chambers and by the addition of new, dedicated trigger chambers based on resistive plate chamber (RPC) technology. The RPCs will be installed in three stations of both muon arms starting with prototype chambers in 2008. This paper will focus on this RPC component of the upgrade.

The primary physics motivation for this upgrade is to probe the quark and anti-quark spin contributions to the spin of the proton. For more details on the physics goals, please see [3].

2. Scope of this upgrade

The PHENIX spectrometer is generally divided into a pair of central arms optimized to reconstruct photons, electrons, and hadrons near central rapidity and a pair of muon arms at forward rapidities. To improve our triggering capabilities of the muon arms, 3 stations of RPCs will be installed for each muon arm. A station of RPCs will be positioned both immediately before and after the muon tracking system. The final station will be located downstream of the muon identification system. See Fig. 1 for a cross sectional view of the muon arms of PHENIX with the RPC upgrades.

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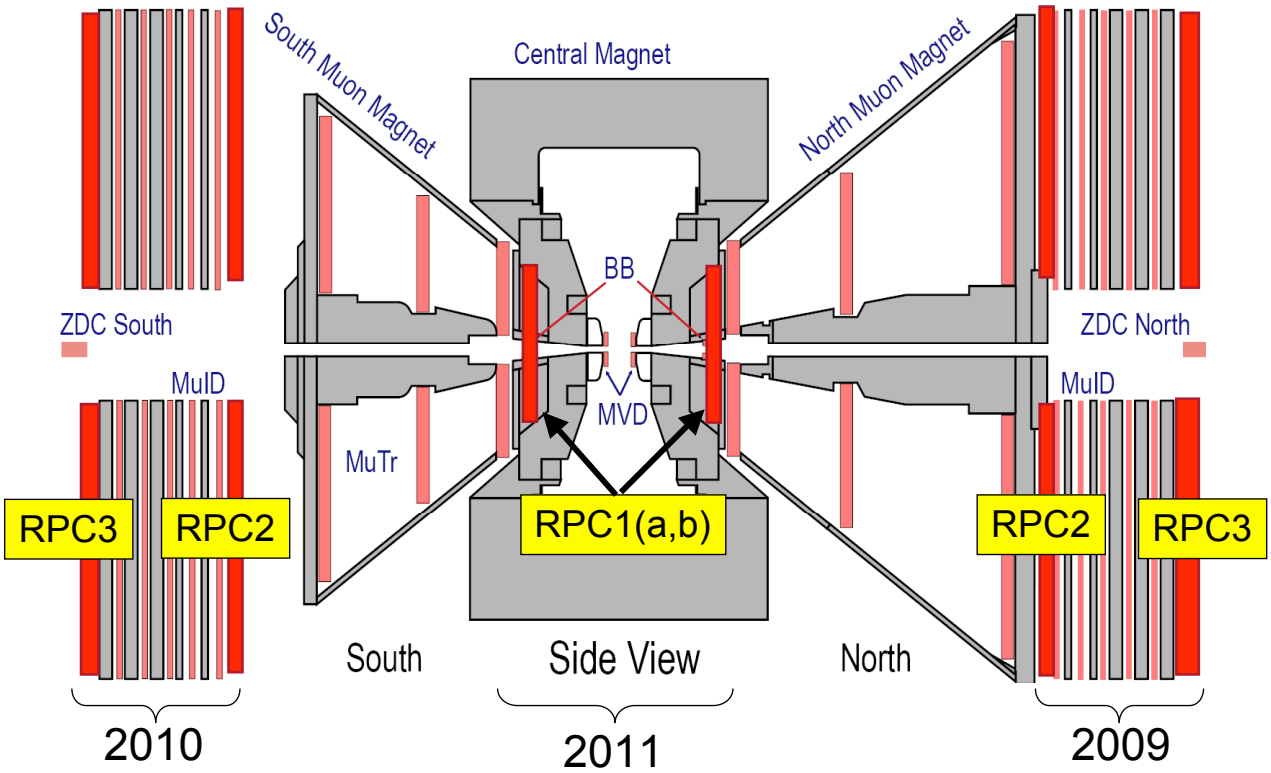

Fig. 1. Cross sectional view of PHENIX with the RPC upgrades and the estimated year of installation.

3. The Challenges of Integration

Because the PHENIX spectrometer was constructed and operated for many years before this upgrade was first considered, the difficulties of installing these RPC chambers are many and challenging. The small voids in the current muon arm where these chambers will be installed have been partly occupied by infrastructure for existing detectors that must be relocated. Additionally, installation volumes are so small (as little as 13 cm wide) that the detector and support design are highly constrained. Maintenance on the detectors in situ will be impossible and installation will be a challenge.

Other constraints on the design of the RPCs include the maximum size of detector that can be transported to the installation location. The RPC3 chambers must be moved through the RHIC beam tunnel to reach the downstream side of the MuId system. Therefore it was decided that the chambers in stations 2 and 3 will be constructed in 16 half octant units around the beam pipe. See Fig. 2 for a picture of these chambers.

4. PHENIX RPC Design Requirements

To ensure that all of the physics goals of this trigger upgrade to PHENIX are achieved, the RPCs must meet several design requirements. These requirements include timing resolution, efficiency, average cluster size, rate capability, and the maximum number of streamers. All of these requirements are in addition to the maximum physical size imposed due to the integration constraints. Table 1 summarizes these requirements.

The only proven technology that can handle the high rate capability requirements is bakelite based RPCs. To ensure the high efficiency we have decided to use a traditional double gap design. Finally, to keep the noise low we will

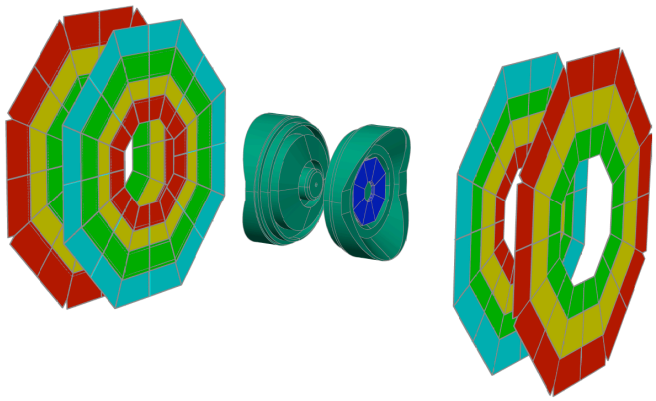

Fig. 2. Conceptual design of RPCs. Also shown is part of the PHENIX Central Magnet.

Table 1
Performance requirements of the PHENIX RPC detectors.

Efficiency	$> 95\%$
Time resolution	≤ 3 ns
Average cluster size	≤ 2 strips
Rate capability	0.5 kHz/cm^2
Number of streamers	$< 10\%$

use oil-coated bakelite for the gaps. An exploded view of the layers of the RPC are shown in Fig. 3.

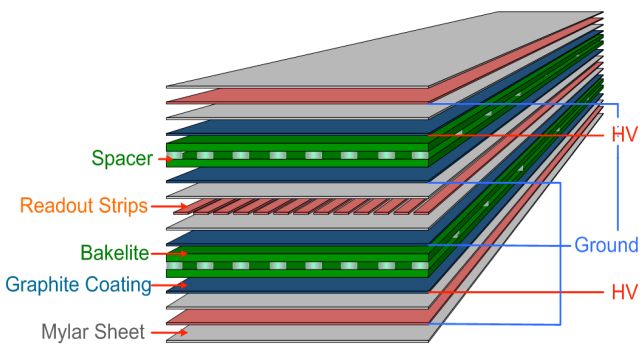

Fig. 3. An exploded view of the layers of the RPCs.

These design requirements are very similar the the Compact Muon Solenoid (CMS) endcap RPCs and therefore much of our design has been modeled after them. This not only simplifies our design effort, but allows us to take advantage of the extensive research, development, and aging studies done by the CMS collaborations. Nevertheless, we have constructed several independent RPC test stands within our group. See [4] for more information.

Each double gap RPC module has a single readout plane. The readout plane is composed of long parallel strips. The center strip is radial and adjacent strips are parallel to it. This pseudo-radial configuration allows the RPCs to match the strip configuration of the muon tracking cathode strip chambers. Radially from the beam pipe, three (in the case of RPC3) or four (in the case of RPC2) modules are aligned within a signal half octant. Figure 4 shows an expanded view of the strips within the smallest inner module (referred to as RPC3 A) and a view of how the three modules in RPC3 combine to form a half octant.

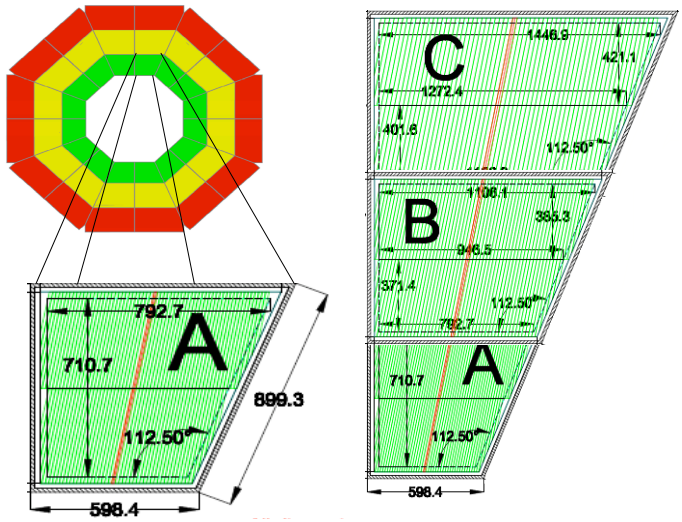

Fig. 4. On the left, an expanded view of the strips within the smallest inner module (referred to as RPC3 A) is shown, and on the right, a view of how the three modules in RPC3 combine to form a half octant is shown. The dimensions shown are not from the final design and are expressed in mm.

5. Bakelite procurement.

In December of 2007, 54 1.3 m by 2.8 m "CMS quality" bakelite sheets were produced by the Italian bakelite company for the first time in several years. In January of 2008, a group from PHENIX traveled to Italy and with the help of several CMS colleagues tested these sheets. The bakelite was required to meet the same standards required by CMS and summarized in Table 2.

Three of these bakelite sheets were cut into 24 smaller pieces and carefully studied. The bulk resistivity was measured at four points on each of these smaller pieces. The average of these 4 measurements is shown in Fig. 5. Because the resistivity of the bakelite depends on the temperature,

Table 2
Required bakelite standards for PHENIX.

average resistivity	$10^{10}\Omega cm < \rho_{20C} < 6 \cdot 10^{10}\Omega cm$
uniform resistivity	$\frac{\sigma}{\rho_{Average}} < 0.5$
thickness	thickness < 2 mm $\pm$ 0.1mm
smoothness	$R_a < 0.2\mu m$
visually	no visible blemishes

the measured resistivity was corrected to a fixed temperature of 20C using the equation

$$\frac{\rho}{\rho_{20C}} = e^{\frac{T-20C}{7.8C}}$$

where ρ is the resistivity and T is the temperature in Celsius.

The remaining 51 sheets were also inspected. The resistivity was measured at 6 points on the perimeter. Six sheets of bakelite were produced with the wrong thickness, six were produced with too low of an average resistivity, and nine sheets had an average resistivity that is too high. This means that a total of 33 out of 54 sheets were produced to the required specifications for a yield of about 60%.

These sheets of bakelite are being used to produce a final round of prototypes before we begin production of RPCs.

6. Assembly of RPCs

The gas gaps for this upgrade are being produced by the Korea Detector Laboratory (KODEL) at Korea University. The mechanical parts and the readout strips are being produced in China. All of these parts are being shipped to BNL where the final assembly will be done. To facilitate this work, an RPC assembly and testing area has been established at BNL. Figure 6 shows a layout for this factory that includes assembly tables, incoming parts quality control tables, and a cosmic ray test stand to test assembled RPCs.

As parts arrive at BNL, initial quality control measurements will be performed. For gas gaps, these tests include a leak test, a popped spacer test, and a dark current test. Results from these tests will be compared to similar tests performed at KODEL. Once the gaps have been tested, RPC modules will be assembled. Assembled modules will again be tested for leaks and excessive dark currents and then placed in the cosmic ray test stand for extended testing.

Once the individual detector modules have been completely evaluated, they will be assembled into half octants. The half octants will be transported into the PHENIX interaction region and installed.

7. Summary

PHENIX is upgrading the muon trigger by adding six stations of RPCs. When this upgrade is completed, it will allow us to learn more about the spin structure of the proton. The design of these chambers builds heavily on the CMS endcap RPC design. We are currently assembling prototypes that will be installed in the PHENIX spectrometer before the next RHIC run. Production of RPCs will begin later this year.

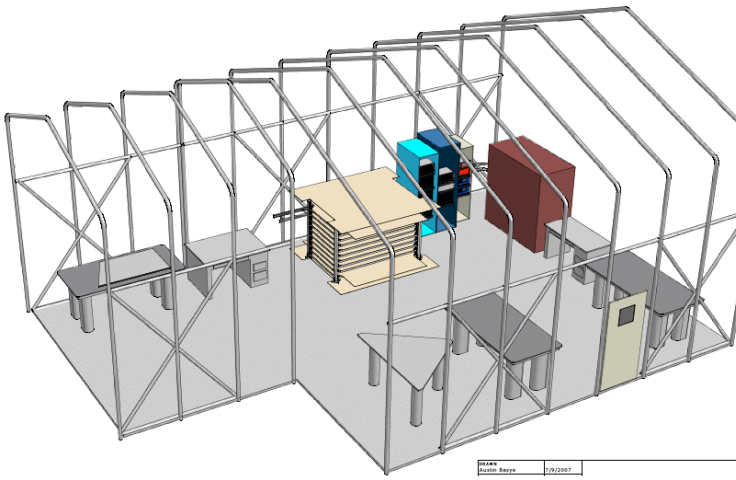

Fig. 6. The layout for the RPC testing and assembly area at BNL that includes assembly tables, incoming parts quality control tables, and a cosmic ray test stand to test assembled RPCs

References

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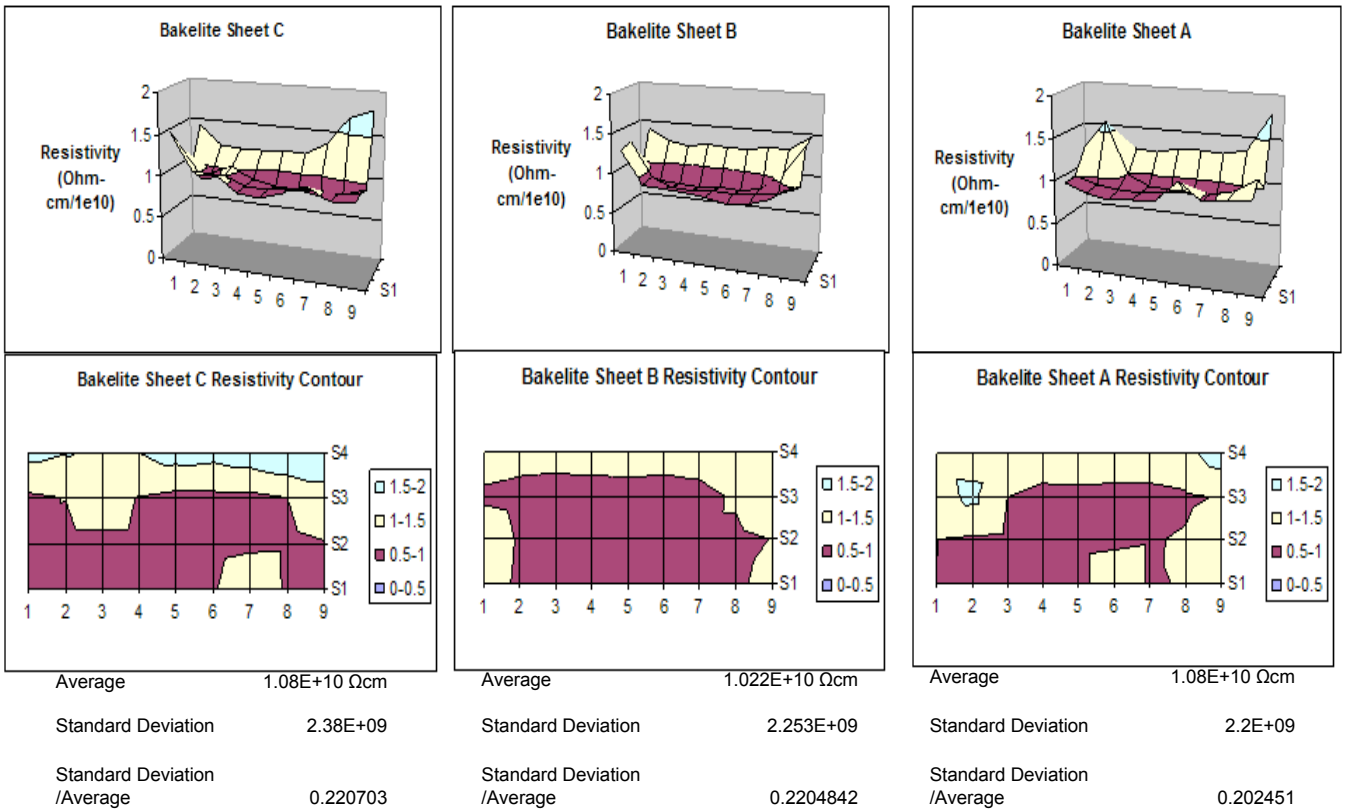
[2] K. Adcox *et al.* [PHENIX Collaboration], Nucl. Phys. A **757**, 184 (2005) [arXiv:nucl-ex/0410003].
[3] B. Hong, in these proceedings.
[4] B. Meredith, in these proceedings.



Average	1.08E+10 Ωcm	Average	1.022E+10 Ωcm	Average	1.08E+10 Ωcm
Standard Deviation	2.38E+09	Standard Deviation	2.253E+09	Standard Deviation	2.2E+09
Standard Deviation /Average	0.220703	Standard Deviation /Average	0.2204842	Standard Deviation /Average	0.202451

Fig. 5. Resistivity measurements from the careful but destructive testing of three sheets of bakelite. All three sheets would have met our requirements.