Forward upgrade for $W$ physics at the RHIC-PHENIX experiment

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Abstract. The RHIC-PHENIX experiment aims to reveal the flavor-sorted sea quark polarization in the proton. To achieve the goal, the PHENIX forward muon arms have been upgraded for the polarized proton-proton production run at $\sqrt{s} = 500$ GeV starting at Jan. 2011. The current status and readiness for the measurements are reported in this contribution.

1. Sea quark polarization in the proton
The contribution of the sea quarks to the total spin of the proton is one of the mysteries in the study of the proton’s spin structure. Currently, the polarization of the sea quarks is indirectly measured by semi-inclusive deep-inelastic scattering (SIDIS) experiments.[1] The PHENIX experiment at RHIC in BNL aims to directly probe the polarization of the sea quarks and their individual flavor by measuring the single helicity asymmetry ($A_L$) in $W$ boson production using collisions of longitudinally polarized protons at $\sqrt{s} = 500$ GeV. Since the $W$ boson is produced by the weak interaction, there are many advantages to this method.

The $W$ boson couples with the quark flavor selectively and only quarks (antiquarks) with negative (positive) helicity can participate in the reaction due to the $V–A$ structure of the weak interaction. Large $Q^2$ scale makes the interpretation by pQCD of the observed data simple as well. Another advantage compared to SIDIS is that $W$ measurements are free from fragmentation function uncertainties. For these reasons, measuring asymmetries in $W$ boson production is a promising method for studying the spin of the sea quarks.

2. PHENIX muon arm in the past
The $W$ bosons can be measured using their decay into high-momentum muons in the PHENIX experiment. We aim to trigger on and measure these muons using the two muon arms located at forward and backward rapidity of the collision point, expecting higher sensitivity in physics. Figure 1 displays the preexisting PHENIX muon arms [3]. The muon arm consists of a muon identifier (MuID) and a muon tracker (MuTr). The MuID consists of five layers of Iarocci tubes sandwiched between steel walls. Particles that penetrate the MuID are identified as muons. The traditional muon trigger for the PHENIX muon arm is provided by the MuID. The MuTr consists of three stations of tracking chambers (ST1, 2 and 3 in figure 1) and sits in a radial magnetic field. Each of the two stations near the collision point includes three cathode-readout strip chambers, while the last station has two chambers. Since the cathodes from both faces are read out, there

1 PHENIX can also measure the $W \rightarrow e\nu$ channel using calorimeters in central arms.[2]
are, in total, either six or four active cathode planes in each station. In each chamber two cathode planes are either non-stereo or stereo planes. The direction of the non-stereo cathode strips is radial and the stereo strips are tilted by about 10 degrees. Therefore, the MuTr is rather sensitive to the azimuthal position of a muon track while it has coarse resolution with respect to radial direction. The momentum of a muon is determined from curvature measured by MuTr.

3. PHENIX muon arm upgrade

We have upgraded the PHENIX muon arms as shown in figure 2 to accomplish the $W$ measurement. One of the greatest difficulties in measuring $W$ bosons is that the trigger rate at RHIC design luminosities will be too high to record every event with the existing PHENIX trigger system by the MuID. The MuID-based trigger fires on muons with a momentum greater than 2.5 GeV/$c$ which can penetrate the entire MuID. The proton-proton collision rate is expected to become higher than 10 MHz at the full luminosity, while the DAQ bandwidth assigned to the muon arms is limited to 2 kHz. However, the MuID-based trigger has a rejection power of only $\sim 100$, so for efficient acquisition of $W$-candidates we have developed the new trigger for the $W$ detection, which must provide better rejection of at least 5000. Figure 3 shows a schematic diagram of the new $W$ trigger system. The $W$ trigger consists of two components, additional front-end electronics for the MuTr to process fast trigger signals (MuTRG-FEE) and Resistive Plate Chamber (RPC) which provide momentum-sensitive position information with good time resolution.[4, 5]

Another major upgrade is installation of a new absorber. Dominant background in the $W$ extraction is estimated to be fake high-momentum tracks caused by hadron decays to a muon in the MuTr volume. The new absorber of 35 cm-thick stainless steel (SS310) was installed in front of MuTr as shown in figure 2. It corresponds to 2 interaction length and is expected to suppress the background by the fake tracks to $\sim 20\%$ based on simulation. In addition to the SS310 absorber, the 2.5 cm-thick borated polyethylene and 1 cm lead were partially installed to suppress slow neutrons which are suspected to cause large signal background in MuTr.

3.1. New $W$ trigger - MuTRG-FEE

The MuTRG-FEE is the additional front-end electronics (FEE) attached to the existing readout electronics for the MuTr. The MuTr cathode strip signal is divided in two parts. 95% of the

![Figure 1. A side view of the PHENIX detector.](image-url)
signal charge is sent to the existing electronics, MuTr-FEE, to measure the position offline. The remaining 5% is used for MuTRG-FEE. The MuTRG-ADTX board amplifies and discriminates the charge, and then transmits the digital signal from the interaction region to the rack room. The MuTRG-ADTX boards were installed in three (two) non-stereo cathode planes at station 1 (station 2 and 3). The signals from several MuTRG-ADTX boards are transmitted and collected in the back-end electronics, namely MuTRG-MRG located in the rack room. In the MuTRG-MRG boards, the signals from multiple cathode planes in the same station are merged by taking a logical OR/AND and then transmitted further downstream in the format sorted by MuTr strip number. Controls of MuTRG-ADTX such as reset and threshold setting are also assumed by MuTRG-MRG. The merged signals are sent to the Level 1 trigger board, where the trigger decision is made together with signals from the RPC, by looking up straight tracks which indicate high-momentum particles. Rough momentum threshold of the trigger is determined by the acceptable curvature of the track, which is represented by $\Delta s$ in figure 3. For example, $\Delta s \leq 1$ allows to fire the trigger if the displacement between station-2 hit and interpolation of straight line between station-1 and 3 hits at Station-2 is within $\pm 1$ strips.

Another capability of the Level 1 board is “clustering” which processes consecutive hits into center single hit to improve the trigger rejection.

Important indicators for the trigger performance are efficiency and trigger rejection power (RP). Figure 4 shows the efficiency of MuTRG-FEE as a function of track momentum measured by the existing MuTr readout. The efficiency becomes 90% at the plateau. The turn-on points are 8.6 GeV/c and 12.2 GeV/c with $\Delta s=0$ and $\Delta s \leq 1$, respectively. They are sufficiently high for backgrounds, but safely low for high momentum muons from $W$ decay. Figure 5 displays the correlation between RP and the efficiency with various parameter setting of the MuTRG-FEE. The RP is defined as ratio of the number of proton-proton collisions divided by the number of events accepted by the trigger. The numbers of the RP in figure 5 are calculated based on the offline trigger emulation of the MuTRG-FEE in addition to the MuID-based trigger, instead of RPC, and were obtained using data of 500 GeV proton-proton collisions during the RHIC 2009 run. It is indicated that tighter requirements provide larger RP with degradation of the efficiency. Including the RPC in the trigger is expected to improve overall RP.

The MuTr strips run at 1-cm intervals.
3.2. New W trigger – RPC

The PHENIX RPC is a standard double gap structure and is based on the RPC’s built for the Compact Muon Solenoid (CMS) experiment in CERN. Figure 6 displays a cross section of the PHENIX RPC detector. The gas chamber is constructed with two bakelite plates ($\approx 10^{10} \Omega \text{cm}$), as resistive plates, with 2 mm gap. The outside surface of the RPC is coated with graphite, which are used as electrodes. A high voltage of $-9.5 \text{ kV}$ is applied to one side of the graphite and the other side is grounded. Readout planes are made from copper strips running along the azimuthal direction to measure an azimuthal position which is sensitive to the track momentum. One of the attractive features of the RPC detector is that the readout plane is completely isolated from the gap chamber. Charge is induced on the readout strip by an avalanche in the gas gap and processed by the readout electronics.

Figure 6. Cross section of the PHENIX RPC.

Some features of the PHENIX RPC as the new W trigger are listed on table 1. Figure 7 displays cluster size, efficiency and timing resolution as a function of supplied high voltage measured on test bench. The performance satisfies the requirements of the trigger with high voltage of $-9.5 \text{ kV}$ supplied. One of the noticeable features of the RPC is the good timing resolution. Currently, the trigger timing for the muon arms is determined by beam-beam counters (BBC) which are used as the minimum bias trigger at the PHENIX experiment. However, because the BBC fires almost every beam crossing at the maximum luminosity, a

| Cluster size | <2 strips |
| Efficiency | $>95\%$ for MIP |
| Time resolution | $\approx 2 \text{ nsec}$ |
| Rate capability | $0.5 \text{ kHz/cm}^2$ |

Table 1. Characteristics of the PHENIX RPC with $-9.5 \text{ kV}$ supplied.
new timing detector to identify the crossing is essential as a trigger. The RPC thus plays the important role as a substituting timing device under the high luminosity circumstances. In addition, good timing resolution provides a strong background suppression by cosmic rays.

![Figure 7. RPC performance; (Left) cluster size, (Center) efficiency and (Right) timing resolution as a function of supplied high voltage.](image)

Before the RHIC 2009 run, an RPC prototype was partially installed in front of and behind the MuID. Commissioning was carried out in the 2009 run with beam collisions to evaluate the performance. The timing resolution of better than 2 nsec was confirmed with beam, too. We completed installation of RPC behind MuID (RPC3) for both muon arms and the preparation for the coming 2011 run is ongoing. Improvement in the rejection power with RPC3 is estimated by simulation to be at least a factor of 5 in addition to the MuTRG-FEE contribution. We schedule to install additional RPC in front of the MuTr (RPC1) during the next RHIC shutdown period in 2011. The RPC1 will improve the timing resolution by calculating timing differences from RPC3 and will provide better background suppression for W extraction in the offline analysis. Prior to the full installation, a prototype of RPC1 was partially installed to evaluate its performance and background level during the RHIC 2011 run.

4. Summary and future prospects

The new W trigger has been installed for the PHENIX forward muon arms to accomplish the measurements of $A_L$ in W production. The performance of the system has been tested with beam and with cosmic ray. Satisfactory results to meet the requirements for the trigger were obtained. In addition to the new trigger, the new hadron absorber of SS310, as well as the partial neutron absorber of borated polyethylene and lead, has been installed to suppress the background by fake high-momentum tracks. The PHENIX experiments will provide the first results of the forward $W A_L$ with the long polarized proton-proton production run at $\sqrt{s} = 500$ GeV which will start at Jan. 2011.

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