Muon Trigger Upgrade at PHENIX

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Abstract. The Relativistic Heavy Ion Collider (RHIC) at BNL provides a unique opportunity to collide polarized protons. One of the highlights of the spin program at $\sqrt{s} = 500$ GeV is the direct measurement of sea quark contribution to the proton spin via W-boson production by measuring parity violating single spin asymmetry. A new trigger on forward muons in PHENIX identifies and triggers on high momentum Ws suppressing a large number of low momentum muons coming from hadronic decays. Since the current muon trigger will fire on any muon above 2 GeV/c, it will not provide the required rejection factor for 500 GeV running, which is about 7500. Two major upgrade projects are parts of this Muon Trigger: 1) Resistive Plate Chambers, 2) the muon tracker front end electronics upgrades. The status of these upgrade projects is discussed in this document as well as physics goal of W program at RHIC.

1. INTRODUCTION
Parity-violating production of the W boson with longitudinally polarized protons at RHIC provides a direct measure of the individual polarizations of the quarks and anti-quarks in the colliding protons. The high energy scale set by the W-mass makes it possible to extract quark and anti-quark polarizations from inclusive lepton spin asymmetries in W-production with minimal theoretical uncertainties. Sub-leading twist and higher-order terms in the perturbative QCD expansion are strongly suppressed, and a direct extraction without additional assumptions becomes possible[1]. This program thus will break new ground in our detailed understanding of the proton's structure. Especially, our present knowledge for the anti-quark contribution to the proton spin is limited by SIDIS measurements. In addition to aforementioned naturally set high energy scale, the sea quark measurement via W has certain advantage with respect to SIDIS in following sense: 1) The W boson couples with the quark flavor selectively and quarks (antiquarks) with negative (positive) helicity can participate in the reaction due to the V-A structure of the weak interaction, 2) free from fragmentation function which is the unavoidable dominant source of model uncertainties for SIDIS on their way to extract the sea quark polarization from observed asymmetries. Due to unbalanced $x_1$ and $x_2$, the measurement of W asymmetry in forward/backward angle further enhances the sensitivity to the sea-quark polarization.

The W program is initiated by the first operation of RHIC polarized proton beams at its highest operational energy $\sqrt{s} = 500$ GeV in 2009 (Run9). This W program is the highlight of RHIC spin project for the next 5 years and thus following upgrade projects to PHENIX muon arms have been pursued to prepare for the rare probe measurement under high-background rate circumstances.
2. MUON TRIGGER AT PHENIX
A new trigger on forward muons in PHENIX identifies and triggers on high momentum muons from W decay suppressing a large number of background low momentum muons coming from hadronic decays. Since the current muon trigger will fire on any muon above 2 GeV/c, it will not provide the required rejection factor for 500 GeV running, which is about 7500. Two major upgrade projects are parts of this Muon Trigger; 1) Resistive Plate Chambers[2], 2) the muon tracker front-end-electronics (MuTr-FEE) upgrades[3]. Each projects are discussed in detail hereafter.

2.1. MuTr-FEE Upgrade
The MuTr-FEE upgrade features additional fast readouts to the existing MuTr-FEE, which provides momentum sensitivity to the existing muon trigger beyond 2 GeV/c. There are three tracking stations of cathode strip (5mm pitch) chambers in the muon tracker for measuring the trajectory of particles in a magnetic field (with an integrated \(B - dl\) of approximately 0.75 Tesla-meters). A new amplifier discriminator (MuTRG-ADTX) board[4] divides the signal into two paths; existing read out path and the digitization path for the fast trigger.

Figure 1 visualizes the principle of the momentum sensitive trigger. The hit signals from three tracking chambers (named station-1, 2, and 3, respectively from the collision point) are immediately digitized and processed by MuTRG-ADTX and are sent to new merger boards (MuTRG-MRG)[5]. The MuTRG-MRG board collects hit signals from multiple MuTRG-ADTXs and formats the data to meet the input format of the Local Level-1 (LL1) trigger module. The LL1 module receives data from MuTRG-MRG and then select the events which have ±1 strip sagitta at station-2 from the linear interpolation between station-1 and station-3 hits, providing the trigger of only high transverse momentum track.

The R&D, production of these new boards were completed by the end of 2008. The
installation to North muon arm was completed in 2008 and they were commissioned in Run9, whereas South muon arm was completed in 2009 and were commissioned in Run10 Au-Au collision data as well.

Shown in Fig. 2 is the turn on curve of the trigger efficiency plotted as a function of track momentum evaluated using reconstructed tracks in South and North MuTr. The trigger threshold is certainly pushed higher to around 5.1 and 7.6 GeV (parameter p1 in Fig. 2 fit) for South and North, respectively compared to the maximum threshold limit of about 2 GeV given by MuID. The plateau saturates around the efficiency of 0.93. This is the consequence of the product of the individual efficiencies in each station (about 0.98) and the vertex cut efficiency. Better efficiency can be achieved by relieving the operating conditions of the trigger electronics such as threshold, acceptance range of track sagitta, with or without strip clustering, AND or OR logic selection of MuTr redundant planes in each stations (MuTr chambers of Station-1, 2, and 3 consisted of 3, 3, and 2 gaps, respectively. New trigger electronics were implemented to 3, 2, and 2 non-stereo planes of these stations, respectively for redundancy.)

![Figure 2](image)

**Figure 2.** Turn on curve of the muon trigger as a function of track momentum evaluated from Run10 data.

On the other hand, the higher efficiency would be the trade off between the rejection power. Shown in Fig. 3 is the correlation between the trigger efficiency versus the total rejection power (BBC×MuID×MuTrig) evaluated at the BBC rate of 1.5MHz. Plotted data points are the performance of different operating conditions of new trigger electronics as described previously. The achieved efficiency of > 0.9 is satisfactory at this BBC rate, which requires only the total rejection power of 750. Projected efficiency is about 0.8 at the rejection factor of 3000, which is the required factor at the projected luminosity of $1 \times 10^{32}$ (expected BBC rate of about 6MHz) for Run11.

Note this performance may be degraded as a function of the luminosity, particularly for rejection performance due to increasing accidental hits. Nevertheless, these results are still preliminary stage and there are still plenty of rooms to improve the trigger performance. Following items are some ideas to be addressed in future study to retrieve the performance:

- More efficient MuID trigger algorithm
- Track Matching with MuID
- Timing cut by RPC
- Track matching with RPC
- Tighter background shields
- Quenching cross talks in MuTr chamber
- Etc.
Figure 3. Correlation between the trigger efficiency vs. rejection power observed at BBC rate of 1.5MHz. 40mV and 100mV are threshold condition applied to the cathode signal at new trigger boards. ∆s=1 and 0 represent the acceptance of sagitta range of strip ±1 and ±0 from the central strip of the trajectory.

2.2. RPC

In addition to lack of rejection power, another critical aspect of the muon trigger at high luminosity in PHENIX forward/backward arm is the timing resolution. The timing information from BBC would not work at the maximum luminosity at 500 GeV, because BBC is anticipated to be fired every single beam crossing. Given the fact Muon ID has the timing resolution of 2 beam clocks, we would not be able to determine which beam crossing the observed track comes from. This is the fatal situation for polarized proton experiments at its full intensity operation because polarization vector, e.g. + or - is altered every bunch in RHIC on purpose. Thus new timing device in muon arm was introduced called RPC.

Shown in Fig. 4 is the cross section structure of the RPC detector (left panel). The design of PHENIX RPC is based on precedent RPC detector developed for Compact Muon Solenoid (CMS) experiment in CERN. The RPCs are built with two parallel plates of high resistive material, i.e. bakelite as electrodes. The plates have a resistivity of the order of $1 \sim 10^{10} \Omega \text{cm}$. The sensitive gas volume gap is typically 2 mm thick between the two plates. 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 signal readout is made of copper strips and is located outside of the sensitive gas volume. This is one of the very 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. Strips are running along the radial direction to measure an azimuthal position of a trajectory which is the orientation of momentum kick in the magnetic field of MuTr. Taking advantage of the long level arm of RPC3 (behind MuID), additional requirement of track matching between MuTRG-FEE and RPC hits is expected to boost the rejection power against low momentum tracks.
Figure 4. Structure of RPC (Left) and ToF peak observed by RPC2 prototype in Run9.

Table 1. Required performance of RPC

| Requirement                  | Specification          |
|------------------------------|------------------------|
| Efficiency                   | > 95%                  |
| Time Resolution              | ≤ 3 ns                 |
| Average Cluster Size         | ≤ 2 strips             |
| Rate Capability              | 0.5 kHz/cm$^2$         |
| Operation Plateau            | > 300 V                |

Considering overall forementioned demands, required performance for the PHENIX RPC is summarized in Table 1. Shown in Fig. 4 (right panel) is the observed timing resolution of RPC2 prototype using the actual beam during Run9. As can be seen in the figure, satisfactory timing resolution of $\sim 4.4$ ns was observed. Also presented in Fig. 5 are the efficiency (left) and the size of the cluster (right) as a function of operating HV observed with cosmic rays in test bench. These test bench results demonstrated high efficiency $> 95\%$, plateau region $> 300$ V, and small enough cluster size $< 2$ strips at reasonable operating voltage.

Figure 5. The efficiency of RPC (Left) and the size of the cluster (right) as a function of operating HV observed with cosmic rays in test bench.
3. TOWARDS COMPLETION OF UPGRADE

Figure 6. Installation schedule of PHENIX muon arm upgrade projects. Year in solid square is the scheduled year of installation.

The PHENIX muon arm upgrade project continues to improve the performance of the muon detection system as shown in Fig.6. An additional hadron background absorbers are in preparation in front of the MuTr. The absorber supposed to be installed in post Run10 shutdown period getting ready for the first production run of polarized proton-proton collision at 500 GeV in Run11. While implementing new devices as an upgrading performance of muon arms, efforts to improve performance of existing detectors are also underway in parallel. The momentum resolution of MuTr is one of the major concern, since it has been demonstrated only factor of 2 to 3 worse resolution in the past than its intrinsic one (100\(\mu\)m). One of the claim is the day-by-day motion of MuTr chambers which deteriorates the alignment precision. The relative alignment between MuTr chambers is carried out using straight particle trajectories in the zero magnetic field volume. Indeed we observed the chamber movement in the order of 100 \(\mu\)m over the course of months during Run9 using optical alignment system (OASys) implemented to MuTr chamber frames. The OASys consisted of light sources, lenses, and CCD cameras attached to Station-1, Station-2 and Station-3 chambers, respectively and tracks chambers’ relative motion by continuously monitoring the light spot in the CCD camera[8]. The chamber displacement predicted by the OASys can be cross checked by the zero field data which are taken months a part. This consistency analysis is now underway.

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