The PHENIX Muon Trigger Upgrade

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Abstract. The PHENIX muon trigger upgrade adds Level-1 trigger detectors to existing forward muon spectrometers and will enhance the ability of the experiment to pursue a rich program of spin physics in polarized proton collisions at $\sqrt{s} = 500$ GeV. The additional muon trigger detectors and Level-1 trigger electronics will allow the experiment to select high momentum muons from the decay of $W$-bosons and reject both beam-associated and low-momentum collision background, enabling the study of quark and antiquark polarization in the proton. The muon trigger upgrade will add momentum and timing information to the present muon Level-1 trigger, which only makes use of tracking in the PHENIX muon identifier (MuID) panels. Signals from three new resistive plate chambers (RPC’s) and re-instrumented planes in the existing muon tracking (MuTr) chambers will provide momentum and timing information for the new Level-1 trigger. An RPC timing resolution of 2 ns will permit rejection of beam related backgrounds.

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PHYSICS WITH POLARIZED W BOSONS

A central goal of high-energy physics is to understand the quark and gluon structure of QCD bound states. The most fundamental of these bound states is the nucleon, and current measurements indicate that only about 25% of the spin of this object is carried by its quark content [1]. Contributions from gluons, orbital angular momentum, and the sea quarks are poorly understood. Measurements of the single longitudinal spin asymmetry $A_L$ in $W$-boson production in polarized proton collisions will make it possible to better understand the contributions of the of the sea and valence quarks to the spin of the proton.

THE PHENIX EXPERIMENT

The PHENIX experiment is one of two large experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. The experiment consists of two central arms designed for measuring leptons, photons, and charged hadrons produced at midrapidity as well as two muon arms at forward and backward rapidities. The muon arms themselves consist of a set of tracking chambers (the Muon Tracker, or MuTr) in an approximately radial magnetic field followed by a Muon Identifier (MuID) which consists of layers of absorber interspersed with Iarocci tubes.

RHIC is an extremely versatile accelerator complex, capable of accelerating Au and lighter nuclei as well as polarized protons with 60% polarization [2]. The PHENIX experiment has an active spin physics program, including measurements of the spin structure of the nucleon through $\Delta G$, $\Delta q=q$, $\Delta T=T$ and transversity measurements $\delta q$.
While measurements of $\Delta G$ have already been reported [1] based on running at $\sqrt{s} = 200$ GeV, measurements of the quark and antiquark distribution functions will be made in future running at $\sqrt{s} = 500$ GeV using polarized $W$-bosons, identified through their decay into high momentum muons. The PHENIX experiment has excellent data acquisition (DAQ) and trigger capabilities, and is capable of a sustained Level-1 accept rate of 5kHz with very low deadtime. This combination of a selective trigger and high bandwidth allows the PHENIX experiment to take data for multiple physics signals in parallel.

THE MUON TRIGGER UPGRADE

In future running at $\sqrt{s} = 500$ GeV it is expected that luminosities near $2 \times 10^{32} cm^{-2}s^{-1}$ will be achieved, corresponding to an interaction rate of 12MHz. This high event rate, coupled with the requirement that muon triggers consume no more than 2kHz of the available DAQ bandwidth, will require an event rejection $> 10000$ at Level-1. While PHENIX currently has an existing Level-1 muon trigger based only on the MuID, the achieved rejection at $\sqrt{s} = 200$ GeV of 250-500 is inadequate. In addition, the rejection for the MuID based trigger is highly sensitive to beam-related background processes in the collider.

While there are many sources of low-momentum muons in proton-proton collisions (mainly charm and beauty decays), above a transverse momentum of 20 GeV/c the muon spectrum at $\sqrt{s} = 500$ GeV is dominated by decays of $W$ bosons. In order to achieve the desired event rejection momentum selectivity at Level-1 is required. The PHENIX collaboration plans to add this momentum selectivity through a combination of additional instrumentation in the existing PHENIX muon arms. First, three resistive plate chamber (RPC) tracking chambers will be installed in the PHENIX muon arms, as shown in Figure 1. All three RPC chambers will use strip readout, with the strips organized as 360 segments in azimuthal angle around the beam axis, and between four and six segments in polar angle theta. (Only two theta segments will be used in the
FIGURE 2. Schematic view of the signal split from the existing MuTr station 2 cathode plane.

trigger.) This portion of the upgrade is funded by a grant from the U.S. National Science Foundation.

While RPC development and testing have been ongoing at test stands at the University of Illinois, the University of Colorado, and Georgia State University, we plan to make use of existing RPC designs from the CMS experiment at the Large Hadron Collider. By doing this we leverage the considerable man-years of research and development experience obtained by the CMS collaboration and accelerate the schedule for deploying the detectors in PHENIX.

In addition to the additional information from the RPC chambers, the PHENIX muon trigger upgrade will also include the ability to make use of high-resolution tracking from the existing MuTr stations by splitting the signal from the chambers and adding an additional electronics chain to provide information to the Level-1 trigger (see Figure 2). Ongoing tests with a MuTr chamber at Kyoto University have demonstrated that this split can be achieved with passive electronics in such a way that it does not significantly degrade the resolution of the MuTr cathode planes. This portion of the upgrade is funded by the JSPS.

Momentum selectivity in the PHENIX muon trigger upgrade is achieved by matching hits in the first and second RPC stations and making a straight line projection into MuTr station 2. Because of the radial magnetic field in the PHENIX muon arms, tracks will be bent along the measurement direction in azimuthal angle, so that the deviation of a hit found in MuTr station 2 and the straight line projection is an indication of the momentum of the track. A cut on all candidates such that the MuTr station 2 hit deviates from the projection by less than three cathode strips is efficient for momenta above 20 GeV/c and has been demonstrated to achieve event rejection factors $> 10000$ in simulations using the pythia [5] event generator. It should be noted that in addition to a candidate track in the muon trigger upgrade, the existing MuID-based muon trigger is also required.

As was mentioned previously, at RHIC substantial beam-related collider backgrounds degrade the performance of the existing MuID based trigger. Because the magnitude of the background is unknown at $\sqrt{s} = 500$ GeV running at RHIC, it is essential that the trigger be designed to be insensitive to such backgrounds. In order to achieve this, we will take advantage of the good timing resolution of the RPC chambers, in particular RPC 3, to make a timing cut on the RPC hits such that only hits consistent with tracks originating from the vertex are considered in the trigger. This will eliminate hits (and backgrounds) from particles that arrive coincident with the beam bunches in the collider.
FIGURE 3. The PHENIX muon trigger upgrade algorithm. Hits in RPC 1 and RPC 2 are used to project into MuTr station 2 and matched to hit.

FIGURE 4. Expected sensitivity of the RHIC measurements using polarized $W$-bosons, assuming the full goals of the RHIC $p_T^s = 500$ GeV program. The theory curve and uncertainty band are from an AAC analysis of existing data.

OUTLOOK

It is expected that the current RHIC polarized proton program at $p_T^s = 200$ GeV will be completed in 2009, with the $p_T^s = 500$ GeV program beginning at this point and continuing through 2012. Luminosity is expected to improve throughout the $p_T^s = 500$ GeV program, with a total expected integrated luminosity 950 pb$^{-1}$ and beam polarization at 70%. The PHENIX muon trigger upgrade will be in place for the start of high energy polarized proton running in 2009. Expected sensitivity for the polarized $W$-boson program at RHIC for $\Delta q = q$ are shown in Figure 4.

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