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The PHENIX Resistive Plate Chamber Forward Upgrades

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Abstract. The PHENIX experiment at Brookhaven National Laboratory will use W-boson production to study the valence and sea quark contributions to proton spin by measuring the parity violating single spin asymmetry of the W-boson in $\sqrt{s} = 500$ GeV/c polarized p+p collisions. Since W-bosons decay far too quickly to be directly observed, decay muons will be collected in the PHENIX forward spectrometers, which cover $1.2 < |\eta| < 2.2$ with full azimuthal acceptance. The large W-boson mass results in decay muons with large p_T that dominate other prompt muon sources for $p_T > 20$ GeV/c. The high luminosity required for the W measurement will demand a nearly two order of magnitude increase in the PHENIX muon Level-1 triggering capabilities. Two trigger upgrades have been funded to address this challenge. One upgrade will add timing and position information to Level-1 via multiple planes of Resistive Plate Chambers. The other will make information from the existing muon trackers (MuTR) available at Level-1 by upgrading the front end electronics. The combined pointing, momentum and timing selectivity of the upgrades will allow PHENIX to collect a large sample of muons with transverse momentum greater than 20 GeV/c from the decays of W-bosons, while rejecting significant background from non-collision related particles.

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1. Introduction

The partonic structure of nucleons is fairly well understood, but the details of how the spin and angular momentum of the constituent partons contribute to the total spin of a nucleon are far less well understood. Measurements show that about one third of a nucleon's spin is due to quarks [1] in a mixture of valence and sea quark contributions. The single longitudinal spin asymmetry of the W-boson, as defined in Equation 1, can be used to help disentangle the valence and sea quark contributions to proton spin.

In Equation 1, P is the polarization and N is the number of W-bosons or their decay muons. The subscript of N refers to the helicity of the polarized beam.

$$A_L^{W^+} = \frac{1}{P} \times \frac{N_-(W^+ \to \mu^+) - N_+(W^+ \to \mu^+)}{N_-(W^+ \to \mu^+) + N_+(W^+ \to \mu^+)} \tag{1}$$

At leading order, $A_L^{W^+}$ can be written as Equation 2,

$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) - \bar{d}(x_1)u(x_2)}, \tag{2}$$

where $\Delta f(x)$ are the polarized parton distribution functions. The equations for $A_L^{W^-}$ are given by the substitution of W^- for W^+ and interchange of d and u. At large x_1 or x_2 the first order asymmetry equations reduce to either $\frac{\Delta u}{u}$, $\frac{\Delta\bar{d}}{\bar{d}}$, $\frac{\Delta d}{d}$, or $\frac{\Delta\bar{d}}{\bar{d}}$ since the parton distribution functions for antiquarks become small at large x. Because x_1 and x_2 determine the rapidity of the W-boson, $x_1 = \frac{M_W}{\sqrt{s}}e^{y_W}$ and $x_2 = \frac{M_W}{\sqrt{s}}e^{-y_W}$, experimental measurements at very forward and backward rapidities give access to these simplifying kinematic regions.

2. The PHENIX Experiment

The forward and backward muon spectrometers of the PHENIX experiment [2] and the capabilities of the Relativistic Heavy Ion Collider (RHIC) are designed to facilitate this type of W-boson measurement. As show in Figure 1, each muon spectrometer includes a tracker (MuTR), three multi-layer stations of cathode strip chambers in a magnetic field, to provide precision momentum information and a muon identifier (MuID), five layers of horizontal and vertical Iarocci tubes sandwiched between steel absorbers, to help separate muons from hadrons. Currently, the MuID is the only detector in the muon system used in a Level-1 trigger.

RHIC is designed to accelerate and collide heavy ions over a wide energy range of up to $\sqrt{s_{NN}} = 200$ GeV and polarized protons up to $\sqrt{s} = 500$ GeV. Only short development runs have been attempted for $\sqrt{s} = 500$ GeV p+p collisions thus far, but the machine is expected to sustain luminosities corresponding to a 12 MHz interaction rate when the W-boson program is fully underway.

The sensitivity of $\Delta f/f$ measurements for 800 pb^{-1} of $\sqrt{s} = 500$ GeV p+p collisions as measured with muons in the PHENIX acceptance has been previously estimated [3]. One of the simplifying assumptions used in the estimates is that the p_T of the W-boson is exactly zero. This assumption allows the kinematics of the decay μ to exactly map to the true W-boson kinematics. Since the W-boson p_T is generally non-zero and the kinematics of the ν_μ cannot be measured, some uncertainty is introduced into the true measurement. A recent estimate [4], based on PYTHIA [5], for the amount of smearing due to the $p_T^W = 0$ assumption is shown in Figure 2. The effect of experimental p_T resolution will also be an important effect and is currently being investigated.

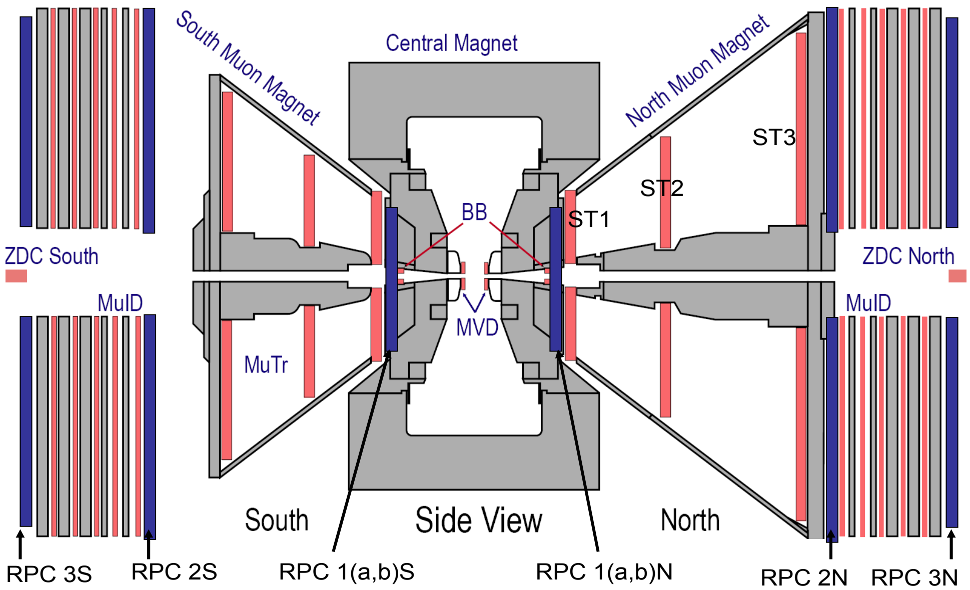

Fig. 1. Section view of the PHENIX experiment including locations of the future RPC detectors.

3. Forward Trigger Upgrades

To allow sufficient bandwidth for other physics triggers, a 2kHz cap has been placed on the $W \rightarrow \mu$ Level-1 trigger rate. The current Level-1 muon trigger, based solely on hit information from the MuID, only provides a maximum event rejection of around 500 for $\sqrt{s} = 200$ GeV p+p collisions. Given the expected interaction rate of 12 MHz, this falls far short of the needed rejection. The current MuID trigger is also susceptible to beam related backgrounds entering from the tunnel which are likely to increase significantly for high luminosity $\sqrt{s} = 500$ GeV runs. A minimal event rejection target of 10,000 and good rejection of particles entering the detector from the tunnel have been set as goals for a new trigger. Since inclusive muon production, from prompt sources, is dominated by $W \rightarrow \mu$ for $p_T > 20$ GeV/c, momentum selectivity is a key feature to achieving the rejection.

Two proposed and funded upgrades will work together to meet this challenge. One upgrade, funded by the NSF with additional manpower support from DoE, will add Resistive Plate Chambers (RPCs) made of bakelite material at up to three

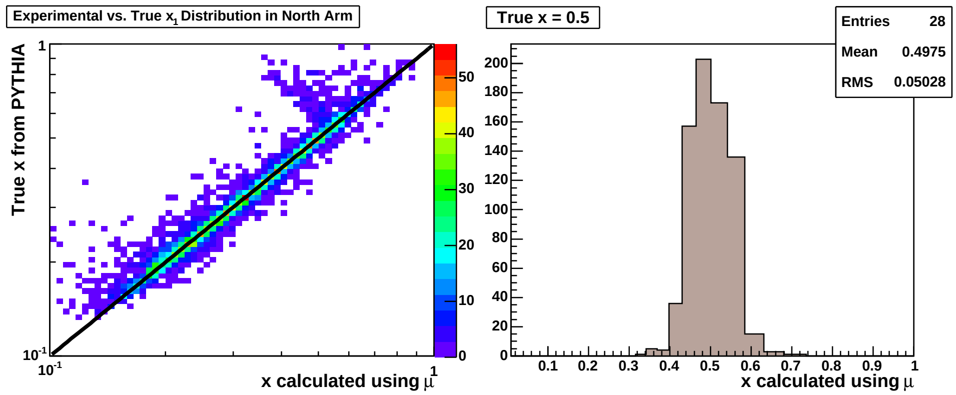

Fig. 2. Left: two dimensional view of the smearing caused by assuming the p_T of the W-boson is zero when calculating x from the decay muon. Right: A one dimensional slice of the smearing for $x = 0.5$.

planes along the beam-axis for each muon spectrometer as shown in Figure 1. With fine segmentation of about 1° in azimuth, the RPCs will be able to reject tracks with a significant bend in the magnetic field. The RPCs closest to the tunnel will also serve the critical role of rejecting non-collision particles entering from the tunnel side via a timing cut which requires that the hits are consistent with a particle produced at the vertex during a bunch crossing. This ability requires the timing resolution of ≈ 3 ns for the RPCs, combined with their FEE.

The aggressive time schedule of the RPC upgrade is only possible because it will be based on the RPC designs of the CMS experiment [6], which has spent a decade on research and development. The gas gaps for the PHENIX RPCs will be manufactured at the same Korea University based facility which produced them for CMS. Important local expertise in the technology is also being developed though several test stands and prototype chambers which have been developed at PHENIX institutions.

The second upgrade, funded by the JPSP, will utilize the existing MuTR detector by splitting off a small fraction of charge from the cathode strips to new front end electronics (FEE), as diagrammed in Figure 3. The upgrade will instrument the "straight" (i.e. non-stereo) planes in stations 1 and 2 for each MuTR. The upgraded FEE will provide a list of hit strips to Level-1 trigger electronics which will also have RPC hit information.

Although the RPC readout geometry is not finalized, it is designed to contain the same essential symmetries as the MuTR. The RPCs will be divided into octants to maximize the overlap of any dead areas. Strips will have the same orientation as the non-stereo MuTR planes. The RPCs will be segmented in rings which cover

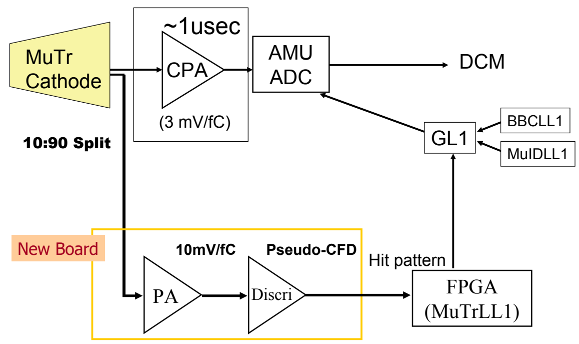

Fig. 3. Simplified diagram of the signal spit to the MuTR trigger FEE upgrade.

the same η range in each RPC. RPCs 1 and 2 will have eight rings while RPC 3 will only have the inner six rings due to space constrains as shown in Figure 4. The total channel count in the RPCs will be about 10,000 per arm. Each RPC will have a similar channel count with RPC 2 having the most. Pad sizes will range from about 1 cm$\times$14 cm for inner RPC 1 to roughly 55 cm$\times$6.5 cm in outer RPC 3.

Momentum selectivity is achieved by matching hits in RPC 1, or MuTR station 1, and RPC 2. A straight line projection is then made to MuTR station 2 as shown in Figure 5. A cut on all candidates such that the MuTr station 2 hit must be within three cathode strips produces an event rejection factor of around 14K for $\sqrt{s}$ = 500 GeV PYTHIA events ran through the full PHENIX, GEANT based, simulation framework. The track forming and matching is performed within each η ring of each octant, and the existing MuID-based muon trigger is also required to fire for an event to be accepted. Also note that physical η rings are ORed to form only four η rings in the trigger. The three cathode strip cut meets the requirement of being efficient for accepting muons with momenta above 20 GeV/c.

4. Considerations for Reconstruction

While the upgrades outlined in the previous sections will give PHENIX the ability to sufficiently trigger on $W \to \mu$ events. There will likely be challenges to reconstructing the W-boson decays with a satisfactory signal to background due to the rare nature of the signal. One of the more obvious backgrounds to consider is the small fraction of high p_T hadrons which penetrate through, or nearly through, the detector. Our studies have shown that only about 1 in 10,000 GeV p_T muons cleanly penetrates the entire detector making them impossible to distinguish from muons. With standard quality cuts about 7 in 1,000 produce an accepted track. This number falls to a more acceptable 1 in 1,000 when tighter quality cuts are

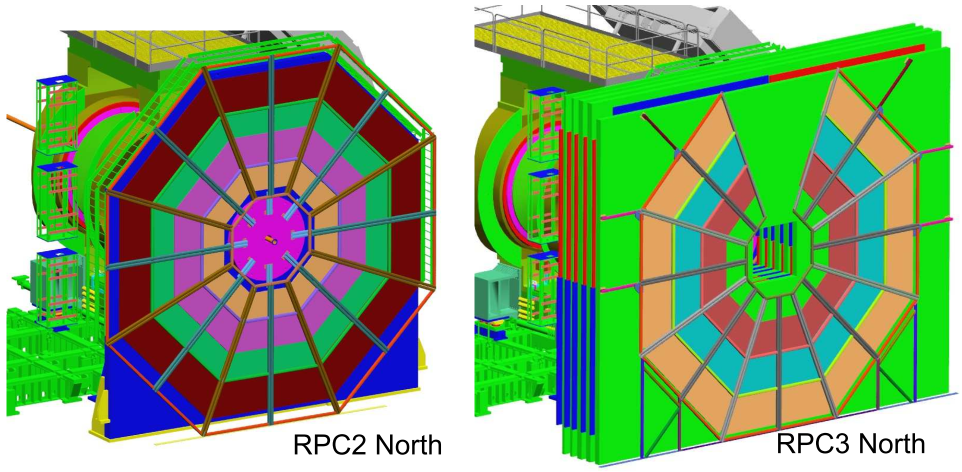

Fig. 4. Engineering drawings of North RPC 1 and 2. Note the shading (coloring) denoting the different rings of η coverage.

applied. This translates to the penetrating hadron yield dropping well below the expected $W \rightarrow \mu$ signal at around $p_T = 20$ GeV/c. Any additional interaction lengths, such as would be added by the proposed Nose Cone Calorimeter, would only serve to further reduce penetrating hadrons.

Another, less intuitive, background occurs from hadrons which penetrate the initial nose cone absorber and decay inside the MuTR. These decays can occasionally appear to cancel the bend from the magnetic field to produce a very straight, and therefor high momentum, reconstructed tracks. The precise magnitude of this effect in not yet sufficiently determined, but it is large enough to be of concern. Several approaches from tighter matching cuts between the MuID and MuTR, tighter vertex projection matching, isolation cuts in the proposed Nose Cone Calorimeter, additional absorber to reduce the number of hadrons which reach the tracker volume, and many others can substantially reduce this background. These continue to be active areas of investigation.

5. Summary and Outlook

The PHENIX muon trigger upgrade is designed to meet the challenges of the impressive RHIC design luminosity for $\sqrt{s} = 500$ GeV/c polarized p+p collisions and the associated W-boson physics program. The staged installation of the RPC upgrade and the MuTR trigger FEE upgrade should give sufficient triggering capabilities for one muon spectrometer by Fall 2008 and improved triggering for both spectrom-

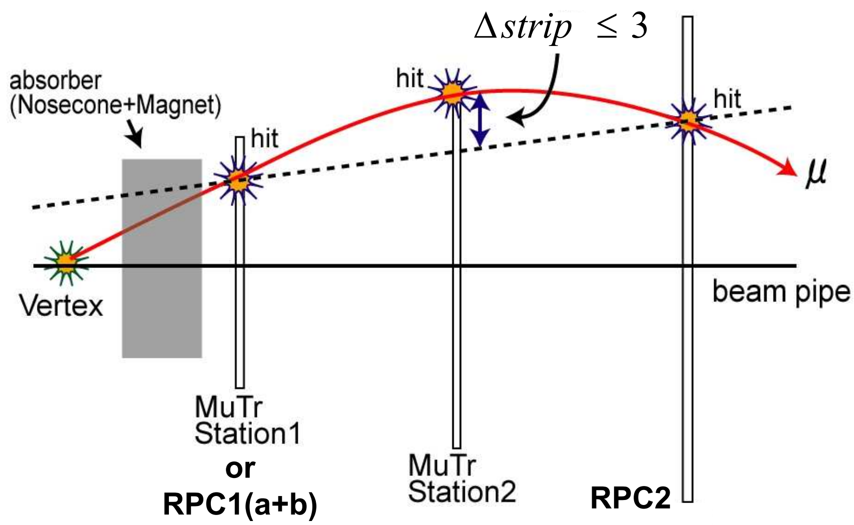

Fig. 5. Diagram of the forward upgrade trigger algorithm. Hits are required to be within three cathode strips of straight line projection to station 2.

eters by Fall 2009. These upgrades along with continued investigation of possible backgrounds and solutions will position PHENIX to make significant contributions to understanding the spin structure of the proton.

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