Measurement of Sea Quark Polarization with $W$ Boson Production at PHENIX

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Abstract. $W$ boson production is observed in $\sqrt{s} = 500$ [GeV] proton proton collision at RHIC-PHENIX experiment. The single longitudinal spin asymmetry $A_L(p\bar{p} \rightarrow W^+X)$ is measured via decay positrons in the mid rapidity region. The measured asymmetry $-0.83 \pm 0.31 \pm (11\%$ scale uncertainty) is consistent within uncertainty to calculations from various polarized parton distribution functions.

1. Introduction
Although the polarizations of valence quarks have been determined well by DIS (Deep Inelastic Scattering) and Semi-Inclusive DIS [1, 2, 3, 4, 5], large uncertainty about the polarization of sea quarks still exists. One of the main objectives at RHIC involving polarized $p+p$ collisions is to measure the polarization of sea quarks by producing $W$ bosons [6]. The single longitudinal spin asymmetry ($A_L$) in $W$ boson production is a clear indication of the polarization of sea quarks since the chirality of the interacting quarks is conserved in the V-A coupling. It is also possible to identify the flavor of the sea quarks by the charge-separated measurement of $W^+/W^-$. This measurement is a complementary approach to Semi-Inclusive DIS experiments, where the quark flavor is identified only via the fragmentation process.

In 2009, RHIC provided the first polarized proton proton collision at $\sqrt{s} = 500$ [GeV]. The proton polarization is achieved to be 39 % for both beams. In this article, the observation of $W$ boson production and the measurement of single longitudinal spin asymmetry of $W^+$ production at RHIC-PHENIX are reported.

2. RHIC-PHENIX Experiment
The data were collected by the PHENIX detector [7]. The central arm detector covers a range of $|\eta| < 0.35$ in pseudo-rapidity and 2 times 90° in azimuth angle ($\phi$). The primary detector for this measurement is electromagnetic calorimeters (EMCal). Each calorimeter tower covers $\Delta \eta \times \Delta \phi \sim 0.01 \times 0.01$. A tracking system consists of drift chamber (DC) and pad chamber (PC) is used to identify the charge sign. Events were collected with the EMCal trigger, which is fully efficient at 12 GeV of the transverse energy. The calibration of EMCal energy scale was done with two photons’ invariant mass for $\pi^0$ and $\eta$ mesons. For the tracking system, the beam position and the angle offset were calibrated with zero magnetic field data. Compared with the bending angle from the magnetic field, there is 2.1 $\sigma$ charge separation capability for 40 [GeV/c] particles.

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A coincidence of beam-beam counters (BBC) located at pseudo-rapidity $3.1 < |\eta| < 3.9$ provides an event trigger. The number of events counted by the BBC was converted to the integrated luminosity. The conversion factor was obtained via the van der Meer scan technique [8], which measures the transverse profile of the beam overlap. A correction was necessary for the event overlap in a single beam crossing. An integrated luminosity of $8.6 \text{[pb}^{-1}]$ after a vertex cut of $\pm 30 \text{[cm]}$ is used in this analysis.

3. W Boson Signal

$W$ boson is tagged by its decay electron. Electron candidates were selected from charged tracks reconstructed in the tracking system (DC + PC) which match the EMCal cluster with $|\Delta \phi| < 0.01 \text{[rad.]}$. Loose cuts on the time of flight measured by the EMCal (ToF cut) and the energy-momentum matching ($E/p$ cut) are applied in order to suppress accidental matches and cosmic backgrounds. Figure 1 and 2 shows the transverse momentum spectra. The transverse momentum ($p_T$) is calculated from the energy deposit in the EMCal. These histograms are overlaid with curves of background (QCD events) and signal ($W$ boson decays). The main contribution from the QCD background are charged hadron clusters and photons from hadrons’ decay converted to electrons before the tracking system. Some backgrounds are from track mis-association in the same jet event. These backgrounds are estimated from all EMCal cluster distribution scaled by the probability of track association and the remnant is filled by the shape of charged pion distribution calculated by the NLO pQCD folded by the EMCal response, so that the range from 10 to 20 [GeV/c] is explained. Because decay electrons from $Z$ bosons have similar spectra to the ones from $W$ bosons, they cannot be separated in the current PHENIX detector acceptance. The signal shape is take from PYTHIA MC smeared by the EMCal resolution including the decay electrons from both $W$ and $Z$ bosons. A significant excess corresponding to the Jacobian peak of $W$ bosons is observed in the spectra.

4. Single Longitudinal Spin Asymmetry

The single longitudinal spin asymmetry is defined as $A_L^W = \frac{1}{P} \frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$, where $P$ is the beam polarization. and $N^\pm$ is the number of signals normalized by the integrated luminosity.
in positive and negative helicity beam. For the luminosity measurement, number of BBC coincidence was used. Since there are two beams polarized at RHIC, the same sample can be used twice, therefore the statistical uncertainty follows \( \delta A_L = \frac{1}{P} \cdot \frac{1}{\sqrt{2(N^+ + N^-)}} \).

Any cut can be applied for the spin asymmetry measurement as long as it is spin independent, because the efficiency of the cut appeared both in the numerator and the denominator are canceled out. In this analysis, an isolation cut, which requires no jet activity in the vicinity of the electron, was applied to increase the signal to noise ratio. The cut is to require less than 2 \([\text{GeV}]\) of energy deposit around the electron candidate. Figure 3 and 4 show the spectra of inclusive and the one with the isolation cut for positive and negative particles. It is seen the background component from the QCD events \((p_T < 25 \text{ [GeV/c]})\) is suppressed by a factor of about 4, and the signal from \(W\) boson \((p_T > 30 \text{ [GeV/c]})\) is mostly remained. This is another evidence for the \(W\) boson signal is in sample.

In the \(A_L\) calculation, the sample was divided into 4 spin states \((2 \text{ beams } \times 2 \text{ spin states})\), then a simultaneous fit was applied to get raw asymmetries \((\equiv P \cdot A_L)\). Table 1 shows the raw asymmetry of positive particles. (The asymmetry of negative particles is not shown here because of its small amount of statistics and rather large uncertainty.) The asymmetry of the background region is also shown for a sanity check expecting the asymmetry to be 0.

**Table 1.** Single longitudinal spin asymmetry for positive particles.

| \(p_T\) range \([\text{GeV/c}]\) | Raw asymmetry   |
|-------------------------------|-----------------|
| 12-20 (Background)            | 0.035 ± 0.047   |
| 30-50 (Signal)                | −0.29 ± 0.11    |

For the physics asymmetry of \(W\) bosons, the contribution of \(Z\) boson and QCD background in the sample work as a dilution factor and have to be taken into account. The contribution of QCD background is estimated to be 1 ± 1 event from the extrapolation of the lower \(p_T\) part of the spectra. The ratio of \(Z\) boson to \(W\) boson is taken from PYTHIA MC \(((W+Z)/W = 1.08)\).
Figure 5 shows the physics asymmetry of $W^+$ production after the correction. The systematic uncertainty is from the absolute polarization measurement ($\delta P/P = 9.2\%$) and the estimation of dilution effect ($\sim 4\%$). The asymmetry is consistent with predictions of various polarized PDF (parton distribution function) parameterization within the uncertainty and it is $2.7\sigma$ away from 0.

5. Summary

The $W$ boson production is observed through its decay electrons at RHIC-PHENIX in the data collected in 2009 ($\int L = 8.6$ [pb$^{-1}$], $P = 39\%$). The single longitudinal spin asymmetry of $W^+$ boson is measured for the first time and it is consistent with various predictions within the uncertainty. This is the first trial of direct measurement of sea quark polarization.

6. Outlook

The RHIC spin program is planning to accumulate $\sqrt{s} = 500$ [GeV] collision data for the next few years. There is also a plan to measure $W$ boson to muon channel in the forward muon detectors. It has better sensitivity to the polarized $\bar{u}$ distribution than the central arm because of its decay kinematics. In the forward muon detectors, an upgrade to improve the trigger capability is the major challenge for the next data taking.

The measurement of beam polarization will be an important systematics for non-zero helicity asymmetries. The systematic uncertainty has been already achieved at the level of $\sim 5\%$ in the absolute polarization measurement in the past 200 [GeV] data periods. It is expected to be at the same level in the next 500 [GeV] data period.

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