High Precision Measurement of Transversity Using Di-hadron Correlations in $p^\uparrow + p$ Collisions at $\sqrt{s_{NN}} = 500$ GeV

Michael J. Skoby
 for the STAR Collaboration

*Center for Exploration of Energy and Matter, Indiana University,
 2401 N. Milo B. Sampson Lane, Bloomington, IN 47408, USA
 mskoby@indiana.edu*

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The transversity distribution, which describes transversely polarized quarks in a transversely polarized nucleon, is a fundamental component of the current picture of the spin structure of the nucleon, and is only loosely constrained by existing semi-inclusive deep inelastic scattering data. The di-hadron interference fragmentation function (IFF), which describes the fragmentation of transversely polarized quarks, is expected to give rise to spin-dependent di-hadron correlations in $p^\uparrow + p$ collisions. Significant di-hadron correlations have recently been measured at RHIC in $p^\uparrow + p$ collisions at $\sqrt{s} = 200$ GeV at mid-rapidity. In 2011, STAR collected $p^\uparrow + p$ data at $\sqrt{s} = 500$ GeV, allowing STAR to extend these di-hadron asymmetries into a previously unexplored kinematic region. The status of the charge-ordered pion pair asymmetry measurement from $\sqrt{s} = 500$ GeV $p^\uparrow + p$ collisions will be presented.

Keywords: Transversity; di-hadron correlations; interference fragmentation function.

1. Introduction

Transversity, $h_1^q(x)$, describes transversely polarized quarks, q , with fractional momentum, x , in a transversely polarized nucleon.¹ Transversity has previously been studied in polarized $p + p$ collisions at $\sqrt{s_{NN}} = 200$ GeV² and semi-inclusive deep inelastic scattering (SIDIS) measurements³⁻⁷. Azimuthal di-hadron correlation asymmetries are proportional to the product of transversity and the interference fragmentation function (IFF), and allow for point-to-point extraction of transversity in SIDIS. The IFF is independent of the intrinsic transverse momentum from the hadronization process,^{8,9} allowing for the universality of the IFF between $p + p$ and SIDIS to be tested. However, high precision data is lacking at relatively high x , which can be seen in Ref. 10. The high-precision $\pi^+\pi^-$ correlation asymmetry in

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polarized $p + p$ collisions at $\sqrt{s_{NN}} = 500$ GeV, presented in this analysis, probes a new range of x compared to recent measurements in polarized $p + p$ collisions at $\sqrt{s_{NN}} = 200$ GeV. This measurement will also help constrain the transversity due to the d -quark, which is charge-suppressed in SIDIS.

2. Experiment

The data used in this analysis were recorded at the Solenoidal Tracker at RHIC (STAR) in 2011 with 25 pb^{-1} integrated luminosity and an average beam polarization of 53%. Kinematic observables of charged particles are measured using the Time Projection Chamber (TPC) with 2π azimuthal coverage and pseudorapidity range $-1 \leq \eta \leq 1$.¹¹ The endcap and barrel electromagnetic calorimeters (E)BEMC and the vertex position detector are used to select events. A 95% pion purity is achieved by measuring the average energy loss, dE/dx , of particles as they traverse the TPC and comparing it to the theoretical expectation for pions. The transverse momentum, p_T , of each particle is ≥ 1.5 GeV/c and the sum of p_T for each pair, $p_T^{\pi^+\pi^-}$, is ≥ 3.75 GeV/c.

3. Analysis

The azimuthal angles in the scattering system used to calculate the $\pi^+\pi^-$ correlation asymmetry are shown in Fig. 1, where the scattering plane is defined by the polarized beam direction, $\vec{P}_B$, and the direction of the total momentum of the pion pair, $\vec{P}_C$. The two-hadron plane is defined by the momentum vectors from each pion in the pair, where the pions are chosen to be in close proximity to each other in $\eta - \phi$ space with $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \leq 0.7$. The angle between the scattering plane and the polarization of the incident beam, $\vec{S}_B$, is ϕ_S . The angle between the scattering plane and the two-hadron plane is ϕ_R , which is used to define $\phi_{RS} = \phi_R - \phi_S$.

Fig. 1. Azimuthal angle diagram.

The $\pi^+\pi^-$ correlation asymmetry observable is defined in ref.,¹² but an alternative form, independent of the relative luminosity, is used in this analysis:¹³

$$A_{UT}(\phi_{RS}) = \frac{1}{P} \cdot \frac{\sqrt{N \uparrow(\phi_{RS})N \downarrow(\phi_{RS} + \pi)} - \sqrt{N \downarrow(\phi_{RS})N \uparrow(\phi_{RS} + \pi)}}{\sqrt{N \uparrow(\phi_{RS})N \downarrow(\phi_{RS} + \pi)} + \sqrt{N \downarrow(\phi_{RS})N \uparrow(\phi_{RS} + \pi)}}. \quad (1)$$

In eq. (1), P is the beam polarization and $N \uparrow(\downarrow)$ is the number of pion pairs when the polarized beam is polarized up(down). A_{UT} is calculated for 8 ϕ_{RS} bins of equal width, which is then fitted with a single-parameter function, $A_{UT} \sin(\phi_{RS})$, to extract the asymmetry. This procedure is carried out as a function of the η of the pion pair, $\eta^{\pi^+\pi^-}$, where $\eta^{\pi^+\pi^-} > (<) 0$ is forward(backward) with respect to the polarized beam direction. A_{UT} is also measured for several invariant mass bins, $M_{\pi^+\pi^-}$, and $p_T^{\pi^+\pi^-}$.

4. Results

A_{UT} as a function of $\eta^{\pi^+\pi^-}$ is shown in Fig. 2 for the highest(magenta) and lowest(black) $p_T^{\pi^+\pi^-}$. The intermediate $p_T^{\pi^+\pi^-}$ bins were also measured but are not shown here. Since valence quarks of the incident proton, described by transversity, have large x , transversity will be manifested in forward pion pairs, resulting in the significant rise of the asymmetry for increasing $\eta^{\pi^+\pi^-}$ in the highest $p_T^{\pi^+\pi^-}$ bin as shown in Fig. 2.

Fig. 2. The asymmetry A_{UT} as a function of $\eta^{\pi^+\pi^-}$ for the highest and lowest $p_T^{\pi^+\pi^-}$ bin shown in magenta and black, respectively. Statistical error bars are shown.

Fig. 3. The asymmetry A_{UT} as a function of $M_{\pi^+\pi^-}$ for the highest and lowest $p_T^{\pi^+\pi^-}$ bin shown in magenta and black, respectively. Statistical error bars are shown.

A_{UT} as a function of $M_{\pi^+\pi^-}$ for $\eta^{\pi^+\pi^-} > 0$ is shown in Fig. 3 for the highest(magenta) and lowest(black) $p_T^{\pi^+\pi^-}$. The intermediate $p_T^{\pi^+\pi^-}$ bins were also measured but are not shown here. A significant signal is seen in the highest $p_T^{\pi^+\pi^-}$ bin, with an enhancement near the ρ mass at mid- $M_{\pi^+\pi^-}$. This enhancement is expected from the transverse spin dependent IFF due to the interference of vector meson decays in a relative p-wave interfering with the non-resonant background in a relative s-wave.

A_{UT} as a function of $p_T^{\pi^+\pi^-}$ for $\eta^{\pi^+\pi^-} > 0$ is shown in Fig. 4 for the highest(magenta) and lowest(black) $M_{\pi^+\pi^-}$. The intermediate $M_{\pi^+\pi^-}$ bins were also measured but are not shown here. A significant asymmetry is observed at high $p_T^{\pi^+\pi^-}$ in the highest $M_{\pi^+\pi^-}$ bin. A_{UT} is small for $\eta^{\pi^+\pi^-} < 0$ in all $M_{\pi^+\pi^-}$ and $p_T^{\pi^+\pi^-}$ bins.

The largest systematic uncertainty in this analysis comes from the 4.5% scale uncertainty due to the beam polarization. Additionally, the events chosen to be recorded are biased towards pions that fragment from quarks. However, pions that come from gluons should make no contribution to transversity due to the chiral odd nature of gluons.¹ To investigate this bias, a Pythia¹⁴ simulation was used along with GEANT,¹⁵ which models the STAR detector, to estimate the quark/parton ratio of a biased sample over the quark/gluon ratio in a unbiased sample as shown in Fig. 5. This correction factor has not been applied to the results shown here.

Fig. 4. The asymmetry A_{UT} as a function of $p_T^{\pi^+ \pi^-}$ for the highest and lowest $M_{\pi^+ \pi^-}$ bin shown in magenta and black, respectively. Statistical error bars are shown.

Fig. 5. The quark/parton ratio in a biased sampled over the quark/parton ratio in a unbiased sample as a function of $p_T^{\pi^+ \pi^-}$. Statistical error bars are shown.

Fig. 6. (left) The average x of quarks in the forward (blue) and backward (red) direction as a function of $p_T^{\pi^+\pi^-}$. Error bars represent the RMS of the x distribution. (right) The single spin asymmetry fit to HERMES and COMPASS data. The STAR x coverage is shaded blue.

Figure 6 shows the x range probed by measurements presented here (left panel) and where this range appears (shaded blue) with respect to previous measurements¹⁰ (right panel). x was determined from the aforementioned simulation. Compared to previous measurements STAR has measured asymmetries with high precision at relatively high x and a much higher effective Q^2 .

5. Conclusions

STAR has measured the first $\pi^+\pi^-$ correlation asymmetries in $p^\uparrow + p$ collisions at $\sqrt{s_{NN}} = 500$ GeV. Preliminary STAR data show high precision asymmetries at high $p_T^{\pi^+\pi^-}$ and $M_{\pi^+\pi^-}$ for $\eta^+_{\pi^+\pi^-} > 0$. These measurements are at much higher Q^2 and sample a different mixture of quark flavors than SIDIS. The results may be used to test universality of transverse polarization dependent quantities (SIDIS vs $p + p$).

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