Transverse Spin Physics at STAR

Len K. Eun for the STAR Collaboration

Pennsylvania State University, University Park, PA 16802

Abstract. The large values of the Transverse Single Spin Asymmetry, $A_N$, seen in forward $\pi^0$ production from polarized proton collisions have stimulated important questions and have been studied in many QCD based transverse spin models. Previously, STAR has reported large $A_N$ for forward $\pi^0$ production in the kinematic region where the cross-section is well described by pQCD. More recently, STAR reported the first RHIC measurement of $A_N$ for forward $\eta$-meson production. The current analysis suggests that in this kinematic region, the $\eta$-meson asymmetry is larger than the already large $\pi^0$ asymmetry. Continued upgrades to the STAR forward calorimetry, leading to the commissioning of Forward Meson Spectrometer in 2008, provides STAR with greatly improved electromagnetic coverage, and opens up exciting future possibilities for the transverse spin program.

Transverse Single Spin Asymmetry

Large transverse single spin asymmetry ($A_N$) for forward meson production has been observed in previous experiments, most notably FNAL E704 [1,2] with its center of mass energy of 19.4 GeV. Over the years, several theoretical models were developed to explain the phenomenon in the framework of perturbative QCD, the best known of which are the Collins effect [3,4] and the Sivers effect [5]. Both models introduce small spin dependent transverse momentum ($k_T$) that generates the observed spin asymmetry. For the Sivers effect, the extra $k_T$ comes from the spin dependent initial state parton distribution function, while for the Collins effect, it comes from the transversity dependence of the jet fragmentation. Consequently for the Collins effect, the asymmetry is in the hadronization relative to the jet axis, and full jet reconstruction should suppress this type of asymmetry. For the Sivers effect, the final state particle carries the asymmetry, and di-jets and $\gamma$-jets would not be exactly back to back. Unlike the Collins effect, the Sivers effect can generate spin asymmetry for prompt photons.

STAR Transverse Spin Physics

STAR Forward Pion Detector (FPD) is a modular lead glass calorimeter positioned at very forward regions of the STAR wide angle hall. Until RHIC run 6, the FPD was placed at both east and west ends of the interaction point. The main modules for each side were two 7x7 lead glass arrays positioned on both sides of the beam pipe. The distance from the modules to the beam was varied to sample a range of pseudo-rapidity points from 3.3 to 4.1.

STAR has reported both cross-section [6] and transverse single spin asymmetry ($A_N$) for forward neutral pion production [7]. Cross-section was measured at pseudo-rapidity of 3.3, 3.8, and 4.0. $A_N$ was measured at pseudo-rapidity of 3.3 and 3.7. The data were collected during RHIC run 3, 5 and 6 polarized proton runs with $\sqrt{s}=200$ GeV.
As shown in the left-hand panel of figure 1, the $\pi^0$ cross-section at $\eta=3.3$ and 3.8 were found to be in good agreement with the NLO pQCD predictions. In the same kinematic region, $A_N$ was found to be large and positive as illustrated in the right-hand panel of figure 1. The result confirmed that the previously observed large transverse spin effect persists to the RHIC energy where pQCD describes the cross-section well. Furthermore, the existing QCD based theoretical models can also explain the $x_F$ dependence of $A_N$ reasonably well. However, the $p_T$ dependence of $A_N$, shown in figure 2, was found to be at odds with all current theoretical predictions. While theory in general expects $A_N$ to fall with $p_T$, we found that $A_N$ rises with the increasing $p_T$. This trend was confirmed by the more recent STAR preliminary result from RHIC run 8, which is also included in figure 2.
In addition to the $\pi^0$, we observed $\eta$-mesons in the east FPD during RHIC run 6. Due to the relatively small physical size of the main FPD modules, (~27 cm square) we had very limited acceptance for the $\eta$-mesons at the range of $x_F$ where previous $\pi^0$ measurements were performed. ($x_F<$0.5) However, at higher $x_F$, ($x_F>$0.5) we found sizeable $\eta$-meson signal in the FPD around the pseudo-rapidity of 3.7 through $\eta \to \gamma \gamma$ channel. This allowed us to measure the single spin asymmetry for the forward $\eta$-meson production for the first time at $\sqrt{s}$=200 GeV, up to $x_F$ of 0.7.

During RHIC run 6, the east FPD was positioned so that the average pseudo-rapidity of the $\pi^0$ was around 3.8. Events were triggered if the energy summed over any one of the two 7x7 arrays was nominally greater than 30 GeV. Due to the relatively small size of the FPD, the photon pairs from $\eta$-meson decay had a much greater chance of being contained in the FPD if the $\eta$-meson was heading towards the center of the detector. Consequently, we were able to enhance the $\eta$-meson signal by looking at photon pairs whose center of mass fell within a circle of radius 0.15 on the pseudo-rapidity and $\tan(\phi)$ plane centered at (3.65,0). The contamination from the decays of heavier particles was minimal, as the opening angle for such decays would be too large for the FPD. Figure 3 shows the di-photon invariant mass distribution in three energy bins from 40 GeV to 70 GeV, with the aforementioned event cuts. We see the emergence of the $\eta$-mass peak as the energy increases. The data were collected from most of the RHIC run 6 transversely polarized proton collisions, which amounted to the integrated luminosity of about 6.8pb$^{-1}$. The average polarization for the projectile proton beam was 56%.
FIGURE 4. LEFT: $A_N$ vs. Di-photon Invariant Mass. Shaded regions indicate the mass cuts for $\pi^0$ and $\eta$-meson. RIGHT: $A_N$ vs. $x_F$ for the $\pi^0$ and $\eta$ mass regions, with 56% beam polarization. The dotted lines indicate weighted mean $A_N$ for $x_F>0.55$, with the corresponding shaded area indicating the error of the mean.

The left-hand panel of figure 4 shows the preliminary result for transverse single spin asymmetry ($A_N$) as a function of the di-photon invariant mass. There is a clear structure in $A_N$ that resembles the mass spectrum, with an “asymmetry valley” separating the two mass resonances. We then looked at the $A_N$ as a function of $x_F$ with mass cuts around the $\pi^0$ and $\eta$ mass regions, as shown in the right-hand panel of figure 4. Despite the large statistical errors for high $x_F$ bins, the surprisingly large $A_N$ within the $\eta$ mass region makes the measurement significant. We found that the average asymmetry for the $\eta$-mass region above $x_F=0.55$ is 4 standard deviation greater than that of the $\pi^0$. Similar measurement had been made by FNAL E704, which found the $A_N$ for $\eta$-meson to be greater than $\pi^0$ for $x_F>0.4$, albeit with little statistical significance [8]. The result does not include background corrections, and therefore should be interpreted as average $A_N$ in the given mass cut region. Systematic errors have not been calculated, but it is expected to be smaller than the statistical errors.

Since RHIC run6, the west FPD has received significant upgrades, leading eventually to the commission of the Forward Meson Spectrometer (FMS) during RHIC run 8. The FMS is a lead glass calorimeter similar to the FPD in components, but it consists of 1264 cells rather than 98 for the west FPD. Unlike the FPD, which only covered small regions on both sides of the beam pipe, the FMS covers full azimuth between $\eta$ of 2.5 and 4.0. Along with the existing Barrel and Endcap calorimeters, STAR now has almost complete electromagnetic coverage from $\eta$ of -1.0 to 4.0. The $\eta-\phi$ coverage map for STAR is shown in the left-hand panel of figure 5. The right-hand panel of figure 5 shows preliminary result for $\pi^0 A_N$, based on the data taken by the FMS during run 8. The result is consistent with the previously published measurements [7].
FIGURE 5. LEFT: Momentum Measuring Subsystems of STAR in $\eta$--$\phi$ space. From $\eta$ of -1.0 to 4.0, the only gap in electro-magnetic coverage is between $\eta$ of 2.0 and 2.5. RIGHT: Preliminary $A_N$ for Forward $\pi^0$ Production measured with the FMS during RHIC run 8. The result is consistent with the previous measurements [7].

The dramatically improved coverage of the FMS opens up new opportunities for forward spin physics. With much larger area to serve as veto, FMS has the potential to measure forward prompt photons. In conjunction with the central detectors, this can also lead to the measurement of the Sivers type asymmetry for $\gamma$-jets. Another possibility is to disentangle the relative contributions from Collins and Sivers mechanism for the observed $A_N$ for the $\pi^0$ and $\eta$. Furthermore, the FMS has the acceptance for neutral mesons heavier than the $\eta$, which provides the possibility of measuring spin asymmetry and cross-section for wider range of final states. With the potential future upgrades of charged particle tracking and/or hadron calorimetry in the forward region, full forward jet reconstruction and Drell-Yan are also future possibilities.

Summary

STAR has produced exciting results for the forward transverse spin physics. We have shown that $A_N$ for forward $\pi^0$ production continues to be large at RHIC energy, where we can rely on pQCD to describe the cross-section. Our results suggest that while QCD based models can describe the $x_F$ dependence of $A_N$, they fail to predict the observed $p_T$ dependence. We have also reported the first measurement of $A_N$ for forward $\eta$-meson production at RHIC energy, and found evidence that it is significantly larger than that of the $\pi^0$ around pseudo-rapidity of 3.7. With the vastly improved acceptance provided by the new Forward Meson Spectrometer, there are many new physics possibilities for the STAR transverse physics.
REFERENCES

1. D. L. Adams et al., Phys. Lett. B 261, 201 (1991).
2. D. L. Adams et al., Phys. Lett. B 264, 462 (1991).
3. J. Collins et al., Nucl. Phys. B 420, 565 (1994).
4. J. Collins, Nucl. Phys. B 396, 161 (1993).
5. D. Sivers, Phys. Rev. D 41, 83 (1990).
6. J. Adams et al., Phys. Rev. Lett. 97, 152302 (2006).
7. I. Abelev et al., Phys. Rev. Lett. 101, 222001 (2008).
8. D. L. Adams et al., Nucl. Phys. B 510, 3 (1998).
9. AIP Conf. Proc. 1149 517 (2009).