MEASUREMENTS OF TRANSVERSE SPIN EFFECTS IN THE FORWARD REGION WITH THE STAR DETECTOR

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Abstract

Measurements by the STAR collaboration of the cross section and transverse single spin asymmetry (SSA) of neutral pion production at large Feynman x ($x_F$) in pp-collisions at $\sqrt{s} = 200$ GeV were reported previously. The $x_F$ dependence of the asymmetry can be described by phenomenological models that include the Sivers effect, Collins effect or higher twist contributions in the initial and final states. Discriminating between the Sivers and Collins effects requires one to go beyond inclusive $\pi^0$ measurements. For the 2008 run, forward calorimetry at STAR was significantly extended. The large acceptance of the Forward Meson Spectrometer (FMS) allows us to look at heavier meson states and $\pi^0 - \pi^0$ correlations. Recent results, the status of current analyses and near-term plans will be discussed.

Contrary to simple perturbative QCD (pQCD) predictions, measurements of inclusive pion production in polarized proton-proton collisions at center-of-mass energies ($\sqrt{s}$) up to 20 GeV found large transverse single spin asymmetries ($A_N$) [1, 2]. Measurements with the Solenoidal Tracker at RHIC (STAR) detector confirmed that the $\pi^0$ asymmetry survives at $\sqrt{s} = 200$ GeV and grows with increasing Feynman x ($x_F = 2p_L/\sqrt{s}$) [3, 4]. Similar large spin effects have recently been found in electron-positron and semi-inclusive deep inelastic scattering [7, 8]. Significant developments in theory in the past few years suggest common origins for these effects, but the large $A_N$ in inclusive pion production is not yet fully understood.

A number of phenomenological models extend pQCD by introducing parton intrinsic transverse momentum ($k_T$) and considering correlations between parton $k_T$ and proton spin in the initial state (Sivers effect [5]) or final state interactions of a transversely polarized quark fragmenting into a pion (Collins effect [6]). These models can explain the observed $x_F$ dependence of $A_N$, but their expectations of decreasing asymmetry with increasing pion transverse momentum ($p_T$) is not confirmed by the experimental data [4]. According to the current theoretical understanding both the Sivers and Collins mechanisms contribute to $\pi^0 A_N$ and discriminating between the two should be possible by measuring the asymmetry in direct photon production or forward jet fragmentation.

Hadron production in the forward region in pp collisions probes large-x quark on low-x gluon interactions and is a natural place to study spin effects. First measurements of that type at RHIC were done with the STAR Forward Pion Detector (FPD), a modular electromagnetic calorimeter placed at pseudorapidity $\eta \sim 3-4$ [3]. Prior to the 2008 run, forward calorimetry at STAR was extended with the FMS which replaced the FPD modules on one side (west) of the STAR interaction region. The FMS is a matrix of 1264 lead glass cells. It provides full azimuthal coverage in the region $2.5 < \eta < 4.0$ and...
has \( \sim 20 \) times larger acceptance than the FPD. In addition to the study of inclusive \( \pi^0 \) production, this allows us to reconstruct heavier mesons and to look at “jet-like” events and \( \pi^0 - \pi^0 \) correlations.

The 2008 run at RHIC with transversely polarized proton beams measured an integrated luminosity of \( \sim 7.8 \, pb^{-1} \) at average beam polarization \( P_{\text{beam}} \sim 45\% \). The first step in the analysis of FMS data was to look at the inclusive \( \pi^0 \) asymmetry to make a point of contact with prior FPD measurements. \( A_N(x_F) \) was found to be comparable to the previous results [9]. The \( 2\pi \) coverage in azimuthal angle \( (\phi) \) made possible a study of the \( \cos\phi \) dependence of the asymmetry, which is well described by a linear function, as expected [9]. The FMS also allowed us to extend the measured \( \pi^0 \, p_T \) region to \( \sim 6 \, GeV/c \) and added new data to investigate the \( p_T \) dependence of \( A_N \) [10].

Another use of the large FMS acceptance was a reconstruction of forward neutral pion pairs from \( pp \) collisions. This analysis followed a few steps:

- All photons in the FMS were reconstructed and a list was made of those satisfying the condition that the cluster energy was above 2 GeV and a fiducial volume requirement.

- \( \pi^0 \) reconstruction considered all possible two-photon combinations; a pion was identified if the di-photon invariant mass was between 0.05 and 0.25 GeV/c\(^2\). The “leading” pion was required to have transverse momentum \( p_{T,L} > 2.5 \, GeV/c \). The “subleading” pion was formed from the remaining photons and satisfied the requirement \( 1.5 \, GeV/c < p_{T,S} < p_{T,L} \).

- The difference in azimuthal angle between the leading and subleading pions (\( \Delta\phi \)) was calculated and the event distribution \( dN/d\Delta\phi \), normalized by the number of leading pions, was plotted.

![Figure 1](image-url)

Figure 1: (a) Invariant mass distributions for leading (left) and subleading (right) neutral pions. (b) Azimuthal correlations between two neutral pions in the FMS.
The invariant mass for both pions is presented in Fig. 1a. Coincidence probability as a function of $\Delta \phi$ is shown in Fig. 1b. The distribution has two clear peaks corresponding to “near-side” and “away-side” correlations, and is fitted by two Gaussian functions plus a constant background. The correlations are not yet normalized. Simulations to obtain efficiency corrections are under way.

The above analysis can be extended to look at the correlations sorted by the spin state of the colliding protons. Back-to-back ($\Delta \phi \approx \pi$) di-hadron measurements can provide access to the Sivers function, as suggested in [11], assuming that the neutral pions serve as jet surrogates. Near-side hadron correlations can provide sensitivity to the Collins fragmentation function and transversity.

Near-term plans for forward physics at STAR include measurements of the cross section and transverse SSA in inclusive $\pi^0$ production in polarized proton-proton collisions at $\sqrt{s} = 500$ GeV and a proposal to add a Forward Hadron Calorimeter (FHC) behind the FMS.

The 2009 run at RHIC was the first physics run at $\sqrt{s} = 500$ GeV. STAR sampled 10 $pb^{-1}$ of data with longitudinally polarized beams at this energy. A first look at the FPD data shows that with the lead-glass matrices alone, $\pi^0$ events can be reconstructed up to $x_F \sim 0.25$. Each FPD module also includes a two-plane scintillation shower maximum detector that provides essential data to separate photons from decays of pions at higher $x_F$. Measurements with transversely polarized beams at $\sqrt{s} = 500$ GeV are tentatively planned for the 2011 run.

The proposed addition of the FHC (two matrices of 9×12 lead-scintillator detectors) to the STAR detector is motivated by the following physics goals:

- to measure the transverse SSA for full jets that should allow to isolate the contribution from the Sivers mechanism to the observed $\pi^0$ asymmetry;

- measurements of polarization transfer coefficients through $\Lambda$ polarization in the $\Lambda \to n\pi^0$ channel to test pQCD predictions.

PYTHIA simulation of $pp \to n(\bar{n}) + 2\gamma + X$ events in the FMS+FHC have been done using a fast event generator method. Reconstructed mass for all $n\gamma\gamma$ events and for the $\Lambda \to n\pi^0$ process is shown in Fig. 2.

In summary, precision measurements of $\pi^0 A_N$ with the FPD allow for a quantitative comparison with theoretical models. The FMS allows us to go beyond inclusive $\pi^0$ production to heavier mesons, “jet-like” events and particle correlation studies. Measurements of $A_N$ for direct photons or jets are needed to disentangle the dynamical origins. Prospects for the more distant future include the development of a RHIC experiment to measure transverse SSA for Drell-Yan production of dilepton pairs.
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