Measurements of Transverse Spin Effects with the Forward Pion Detector of STAR

L. Nogach for the STAR collaboration

Institute of High Energy Physics
1 Pobeda street, Protvino, Moscow region 142281, Russia

Abstract. Measurements by the STAR collaboration of neutral pion production at large Feynman x (xF) in the first polarized proton collisions at √s = 200 GeV were reported previously. Cross sections measured at η = 3.3, 3.8 and 4.0 are found to be consistent with next-to-leading order perturbative QCD calculations. The analyzing power is consistent with zero at negative xF and at positive xF up to 0.3, then grows more positive with increasing xF. This behavior can be described by phenomenological models including the Sivers effect, the Collins effect or higher twist contributions in the initial and final states. Forward calorimetry at STAR has been extended, and there are plans for further expansion. An integrated luminosity of 6.8 pb⁻¹ with average beam polarization of 60% from online polarimetry measurements was sampled with the upgraded FPD in the 2006 RHIC run. This data sample will allow for a detailed map of the π⁰ analyzing power over kinematic variables bounded by 0.3 < xF < 0.6 and 1.2 < pT < 5.0 GeV/c at √s = 200 GeV. The expanded FPD has observed multi-photon final states expected to have "jet-like" characteristics. The transverse spin dependence of jet-like events can discriminate between the Collins and Sivers effects and lead to further progress in understanding the origin of single spin asymmetries in forward particle production. Data were also obtained at √s = 62.4 GeV for xF → 1 to test predictions based on phenomenological fits to earlier STAR results. Recent results, the status of the analysis of 2006 run data and near-term plans will be discussed.

In about twenty years after the first measurements of significant spin effects in hadronic reactions [1, 2], the study of single spin asymmetry AN for π⁰ inclusive production is still of current interest. As is known, large single spin effects cannot be explained within collinear perturbative QCD at leading twist due to helicity conservation. A number of theoretical models based on generalizations of the factorization theorem were proposed to account for significant values of AN. These models assume the presence of (i) higher twist correlation functions in the initial or final state (for example, twist-3 in the Qui-Sterman [3] and Efremov-Teryaev [4] models), (ii) parton intrinsic transverse momentum kT and spin dependence of the distribution functions (Sivers effect [5]), (iii) kT and spin dependence of the fragmentation functions (Collins effect [6]). There is some indication from recent theoretical studies [7] that with all partonic motion properly taken into account the Collins mechanism is suppressed and cannot alone explain large measured AN. Consequently, both the Sivers and the Collins effects can contribute to the pion asymmetry, as they are observed to do so in semi-inclusive deep inelastic scattering from a transversely polarized target [8].

First measurements by STAR [9] showed that the π⁰ AN revealed at lower energies persists for pp collisions at √s = 200 GeV and that the measured AN can be described by several models. Thus, more precise measurements were needed to distinguish be-
between different mechanisms of the emergence of $A_N$. Owing to improvements in both luminosity and beam polarization at RHIC, an integrated luminosity of 6.8 pb$^{-1}$ with average beam polarization of 60% was sampled with the STAR Forward Pion Detector (FPD) in the 2006 run.

The FPD are calorimeters consisting of lead glass cells located on both sides of the STAR interaction region (IR) at a distance of about 8 m (East FPD) and 7 m (West FPD++) and close to the beam pipe. They provide for triggering and reconstruction of $\pi^0$-mesons at forward rapidities. The FPD++ was installed for the 2006 run as a prototype of the Forward Meson Spectrometer [10]. The calorimeter modules on the two sides of the IR were placed at different distances with respect to the beam line, corresponding to the average values of pseudorapidity 3.7 and 3.3. This allowed to expand the covered range of transverse momentum at fixed $x_F$. A strong correlation between $x_F$ and $p_T$ is observed in individual calorimeters because of their narrow acceptance. The reconstruction algorithm, which uses a fit to the experimentally measured shower shape, was carefully studied previously with Monte-Carlo simulations. The energy scale of the detector was determined from the $\pi^0$ peak position in the di-photon invariant mass distribution. The accuracy of calibration was at the level of 2%. The cross-ratio method is used to obtain $A_N$, thereby eliminating many possible sources of systematic errors in the measurements.

The new measurements of $A_N$ as a function of $x_F$ are shown in Fig.1. Confirming the earlier measurements [11], the analyzing power at positive $x_F$, relative to the polarized beam, grows from 0 at $x_F \sim 0.2 - 0.3$ up to 0.1 at $x_F \sim 0.6$, and the $A_N$ at negative $x_F$, equivalent to the unpolarized beam direction, is consistent with zero. Calculations from two theoretical models based on twist-3 contribution [12] and the Sivers effect [13] are
FIGURE 2. Dependence of \(\pi^0 A_N\) on \(p_T\) for \(x_F > 0.4\) from the 2006 run (circles) in comparison with the previous measurements by STAR (squares).

The high precision of these measurements allows for a quantitative comparison with theory predictions and should enable a discrimination between different dynamics.

Fig.2 shows the analyzing power as a function of \(p_T\) averaged on \(x_F > 0.4\) where the \(A_N\) is significantly non-zero. There was a hint from the previous measurements that \(A_N\) decreases with increasing \(p_T\) in the range \(1 \leq p_T \leq 2\) GeV/c. In the 2006 run, the region of higher \(p_T\) has been explored. The data in the overlapping region are consistent, but the \(p_T\)-dependence of the asymmetry looks more complicated now, although a sign in Fig.2 of the asymmetry growing at \(p_T \sim 2 - 3\) GeV/c may be a consequence of residual \(x_F\)-dependence.

To get rid of the correlation between the average values of \(x_F\) and \(p_T\) in the \(p_T\) bins, the \(p_T\) dependence of \(A_N\) has been measured in five narrow \(x_F\) intervals. The results based on the combined data from the three runs are presented in Fig.3. An increase of \(A_N\) with increasing \(p_T\) is observed in all but the highest \(x_F\) bin, where the statistics are limited. It should be pointed out that the unpolarized cross section for \(\pi^0\) production in \(pp\) collisions at \(\sqrt{s} = 200\) GeV is found to be generally consistent with next-to-leading order pQCD calculations [14, 15] in this range of \(x_F\) and \(p_T\), unlike at lower energies.

All available models that aim to explain the \(A_N\) for pion production predict a monotonic decrease of \(A_N\) with increasing \(p_T\), approximately falling as \(1/p_T\). As an example, the results of calculations based on the Sivers effect [13] are shown in comparison to the data in Fig.3. The dependence of the data on \(p_T\) is not explained by the calculation, with the possible exception of the highest \(x_F\) bin where the statistical errors of the measurement are large. The data do not show a monotonic decrease of \(A_N\) with increasing \(p_T\).

Also in the last run data were obtained with the FPD in \(pp\) collisions at \(\sqrt{s} = 62.4\) GeV. Data analysis is in progress with a view to test theoretical predictions based on phenomenological fits to earlier STAR results [12]. Future studies with the FMS which is now under construction at STAR and expected to be operational in the 2007 RHIC run, will include, among other things, further measurements of spin effects in \(pp\) collisions. The FMS will provide full azimuthal coverage at \(2.5 < \eta < 4.0\) and broader acceptance in \((x_F, p_T)\) plane. Thus, it is a well suited tool to isolate the Sivers mechanism from the
Collins effect by measuring analyzing power in $\pi^0 - \pi^0$ and jet production. The most interesting results to be expected from these measurements is an estimate of the quark orbital momentum contribution to the spin of nucleon.

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