Cross sections and analyzing powers in forward π^0 production from polarized proton collisions at $\sqrt{s}$ =200 GeV

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Measurements of the production of high energy π^0 mesons at large pseudorapidity ($3.3 < \eta < 4.2$) and $15 < E_\pi < 80$ GeV from the collisions of transversely polarized protons at $\sqrt{s} = 200$ GeV are reported. The invariant differential cross section is in fair agreement with next-to-leading order perturbative QCD calculations. The analyzing power is large and positive, increasing from zero with Feynman-x (x_F) for $x_F \gtrsim 0.3$, in qualitative agreement with perturbative QCD model expectations.

An early qualitative expectation from perturbative Quantum Chromodynamics (pQCD) was that the chiral symmetry of the theory would make transverse single-spin asymmetries for inclusive particle production be small. Contrary to this expectation, measurements of the analyzing power (A_N) for the production of charged and neutral pions at moderate transverse momenta (p_T) and large Feynman-x ($x_F = 2p_L/\sqrt{s}$) in $p_\uparrow + p$ collisions at center-of-mass energies $\sqrt{s} = 20$ GeV were observed to be of order $20 - 40\%$ [1]. Recently, fixed-target semi-inclusive DIS experiments have reported measurements of azimuthal single-spin asymmetries which are significantly different from zero [2]. These results have sparked significant theoretical activity to gain an understanding of transverse spin effects within the framework of pQCD.

Perturbative QCD calculations involve the convolution of distribution and fragmentation functions with a hard partonic interaction. As $\sqrt{s}$ increases, the expectation is that the origin of forward pions will shift towards collisions involving the partonic constituents of the proton. Measurements of the cross

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section for forward pion production are important to establish that pQCD is a suitable framework for understanding polarization observables.

Data were collected by the STAR experiment during the polarized proton run at the Relativistic Heavy Ion Collider (RHIC) in January 2002. The average beam polarization for each fill was measured by the Coulomb-Nuclear Interference (CNI) polarimeter located in RHIC. At 24.3 GeV, the injection energy into RHIC, the analyzing power of the CNI reaction is $A_N^{CNI} = 0.0133 \pm 0.0041$[3], and can be used to deduce the absolute polarization of the proton beam. However, at 100 GeV, the beam energy used for RHIC collisions, A_N^{CNI} has not yet been measured. Therefore, the beam polarization is calculated by using the average value of the CNI asymmetry at 100 GeV, divided by A_N^{CNI} at 24.3 GeV. The CNI asymmetries measured at 24.3 GeV and 100 GeV were comparable for many fills. The P_{beam} quoted here represents an upper limit at 100 GeV, as the beam acceleration process is unlikely to increase P_{beam}. The average beam polarization for the data presented here is $P_{beam} = 0.16$.

A prototype forward π^0 detector (pFPD) was installed at STAR 750 cm from the interaction region (IR). The pFPD consisted of an electromagnetic Pb-scintillator sampling calorimeter [4] with a shower-maximum detector placed with its edge $\approx$ 30 cm left of the oncoming polarized beam. To address systematics, 4×4 arrays of Pb-glass detectors were placed to the right of, above, and below the oncoming beam. All calorimeters were read out for events that deposited $\gtrsim$ 15 GeV electron-equivalent energy in any one calorimeter.

The luminosity was measured at STAR using beam-beam counters (BBC) [5] spanning $3.3 < |\eta| < 5.0$. Proton collisions were identified by the coincidence of at least one BBC scintillator segment fore and aft of the IR. Absolute luminosity was determined by measuring the transverse size of the colliding beams and the total charge in each beam. The value of the spin-dependent relative luminosity depended on the beam conditions, and averaged 1.15.

Neutral π mesons are reconstructed with an algorithm described in Ref. [6]. The π^0 detection efficiency is determined in a matrix of E_π and η from a simulation using PYTHIA and GEANT. The simulation matches the data well for several kinematic variables, including $M_{\gamma\gamma}$, p_T, E_{tot}, and η [6]. The efficiency is dominated by the geometrical acceptance of the calorimeter.

The inclusive π^0 sample is distorted by the detection of coincident particles from the jet of which the π^0 is part. Both the data and the simulation used for the efficiency correction include π^0 events with E_π mismeasured due to the jet contribution. The E_π dependent systematic uncertainty in the cross section is about 20%, dominated by the uncertainties in the jet contribution correction.

The invariant differential cross section for inclusive π^0 production is presented in Fig. 1, plotted versus $\langle E_\pi \rangle$. The dominant source of the normalization uncertainty is the knowledge of the transverse position of the pFPD.

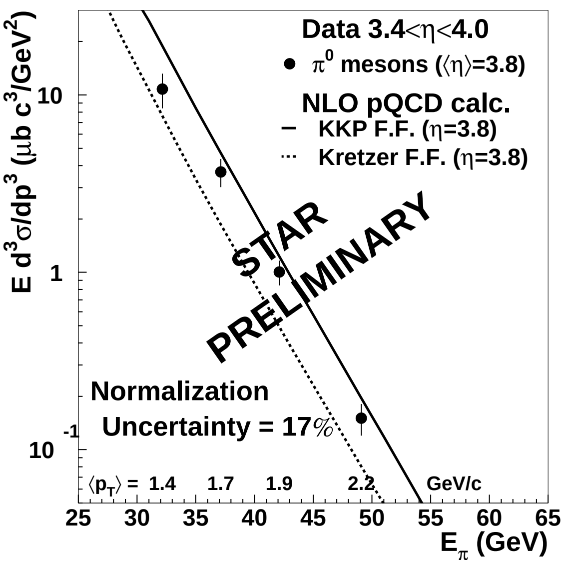

Figure 1: Differential cross section for π^0 production versus leading π^0 energy. The vertical bars are the point-to-point systematic uncertainties. Statistical uncertainties are smaller than the symbols. The curves are NLO pQCD calculations evaluated at $\eta = 3.8$ using different fragmentation functions [7, 8].

The curves on the plot are next-to-leading order (NLO) pQCD calculations [7] evaluated at $\eta = 3.8$, using the CTEQ6M parton distribution functions and equal renormalization and factorization scales of p_T. The NLO pQCD calculations are in fair agreement with the data, suggesting that π^0 production at these kinematics is dominated by hard scattering at $\sqrt{s} = 200$ GeV. The solid line uses the "Kniehl-Kramer-Pötter" (KKP) set of fragmentation functions (F. F.), while the dashed line uses the "Kretzer" set [8]. The difference between the two reflects uncertainties in the F. F. at these kinematics. The KKP F. F. tend to agree with the data better than Kretzer, consistent with what has been observed for π^0 production at midrapidity [9].

The analyzing power is presented in Fig. 2, plotted versus $2\,\langle E_{tot}\rangle/\sqrt{s} \approx x_F$. The points are the total energy in the calorimeter with neither fiducial volume

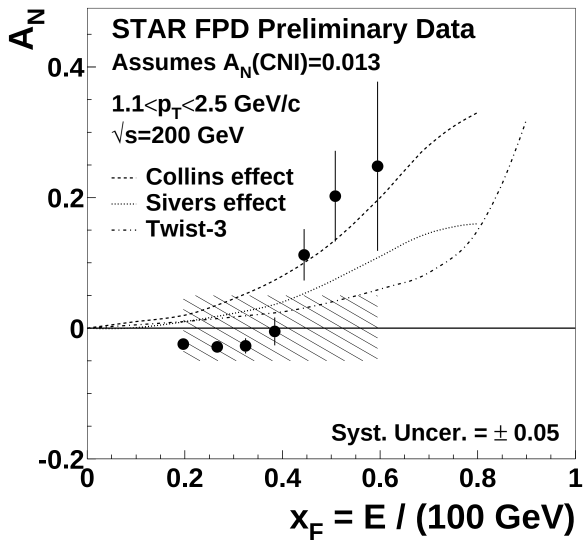

Figure 2: Analyzing power of the total electromagnetic energy versus x_F. The sample is dominated by π^0 mesons. The error bars are the statistical uncertainty, and the hatched box represents the systematic uncertainty. The curves are predictions from pQCD models evaluated at $p_T = 1.5$ GeV/c [10, 11, 12].

constraints nor any attempt to identify the π^0. The A_N for identified π^0 mesons is consistent with these data, indicating that A_N is not sensitive to the analysis constraints used to identify π^0 mesons. The A_N seen at beam right with the Pb-glass array is similar to that seen at beam left with the pFPD, while A_N seen with the Pb-glass arrays above and below the beam are consistent with zero, as expected [6]. The systematic uncertainty for A_N is $\delta A_N = 0.05$, with three primary components: the average difference between the left and right detectors, between the energy spectra and identified π^0 mesons, and the fill dependence. The systematic uncertainty does not include the asymmetric normalization uncertainty from the beam polarization.

The curves on the plot come from pQCD model predictions, fitted to data at $\sqrt{s} = 20$ GeV, extrapolated to $\sqrt{s} = 200$ GeV and evaluated at

$p_T = 1.5$ GeV/c. One model attributes A_N to the convolution of the transversity distribution function with a spin-dependent Collins fragmentation function [10]. The Sivers model examines the effects from the orbital angular momentum of quarks [11]. A third model ascribes A_N to twist-3 parton correlations before the hard scattering [12]. The data are qualitatively consistent with these predictions. This is the first significant spin effect seen at a polarized proton collider in the hard scattering regime.

References

[1] D. L. Adams *et al.*, Phys. Lett. B **261**, 201 (1991); **264**, 462 (1991).

[2] A. Airapetian *et al.*, Phys. Rev. Lett. **84**, 4047 (2000); Phys. Lett. B **535**, 85 (2002); **562**, 182 (2003).

[3] I. G. Alekseev *et al.*, AIP Conf. Proc. **675**, 812 (2003); O. Jinnouchi, *et al.*, *ibid.*, **675**, 817 (2003).

[4] C. E. Allgower *et al.*, Nucl. Instr. Meth. **A499**, 740 (2003).

[5] J. Kiryluk, AIP Conf. Proc. **675**, 424 (2003); A. Drees *et al.*, Proc. of the PAC2003 Conf. (2003).

[6] G. Rakness, AIP Conf. Proc. **675**, 400 (2003); or see hep-ex/0211068.

[7] B. Jager *et al.*, Phys. Rev. D **67**, 054005 (2003); D. de Florian, *ibid.* **67**, 054004 (2003).

[8] B. A. Kniehl *et al.*, Nucl. Phys. **B597**, 337 (2001); S. Kretzer, Phys. Rev. D **62**, 054001 (2000).

[9] S. S. Adler *et al.*, hep-ex/0304038.

[10] J. Collins, Nucl. Phys. **B396**, 161 (1993); M. Anselmino, M. Boglione, and F. Murgia, Phys. Rev. D **60**, 054027 (1999).

[11] D. Sivers, Phys. Rev. D **41**, 83 (1990); **43** 261 (1991); M. Anselmino, M. Boglione, and F. Murgia, Phys. Lett. B **362**, 164 (1995); M. Anselmino and F. Murgia, *ibid.* **442**, 470 (1998).

[12] J. Qiu and G. Sterman, Phys. Rev. D **59**, 014004 (1998).