Forward π^o Production from Transversely Polarized Protons at STAR

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Abstract. Forward clectromagnetic calorimeters have been installed in the STAR detector at the Relativistic Heavy Ion Collider to enable the identification and reconstruction of photons from π^0's in the large rapidity region, $\eta>3$. First measurements of pp collisions with a transversely polarized proton beam at $\sqrt{s} = 200GeV$ indicate that the π^0 production in the region of $X_F>0.3$ (Feynman X) exhibits a large single spin asymmetry A_N. These results are similar to those observed at lower energy, in Fermilab E704. Furthermore, for backward production, relative to the polarized beam, no significant asymmetry is observed.

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Over the past 30 years, very large transverse asymmetries were observed in the production of pions in the interaction $p^{\uparrow} + p \rightarrow \pi + X$ within the forward kinematic region where the pion carries a large fraction X_F of the momentum of the incident proton. These results have long been a source of excitement and controversy. An early prediction of pQCD was that, at leading twist and with collinear factorization, the chiral properties of the theory would make the analyzing power A_N small for particles produced with transversely polarized proton beams [1] at high energy and with transverse momentum large compared to the hadronic scale. However from AGS energies [2] to Fermi Lab energies [3] and most recently at STAR [4] a large transverse spin analyzing power has been observed. The consistent trend is that the asymmetry in $p_{\uparrow} + p \rightarrow \pi^0 + X$ increases rapidly for X_F above about 0.3. Transverse single spin asymmetries have also been observed in semi-inclusive DIS from polarized targets [5] and experimental studies of these spin effects is an active area of research.

While there are many possible phenomenological effects that can be identified as contributing sources for these large transverse asymmetries, they naturally divide into two types of contributions. One is the Sivers effect [6, 7], which depends upon an initial state correlation between the parton intrinsic transverse momentum k_T and the transverse spin of the incident nucleon. Within the Sivers framework, A_N is sensitive to the contribution of quark orbital angular momentum to the nucleon spin. Large transverse asymmetries are the result of a spin dependent p_T trigger bias favoring events where k_T is in the same direction as p_T.

As the Sivers effect connects A_N to the orbital angular momentum of quarks, a second effect, called the Collins effect [8,9], is directly sensitive to the transversity distribution function of the nucleon. Transversity is the transverse polarization of quarks (and antiquarks) in a transversly polarized proton. In the Collins picture, the quark scatters preserving its transverse spin. It then fragments into pions and other hadrons with an azimuthal angular distribution reflecting the spin of the quark. The fragmentation function reveals the polarization of the fragmenting quark and thus the initial quark state. In this example, the asymmetry does not appear in the jet production directly, but only in the fragmentation. The jet axis would not show the transverse asymmetry, but a pion fragment would. It should be noted that even if the Collins effect makes a small contribution to the observed transverse spin asymmetry, the effect may still provide uniquely important information about the proton transversity structure.

If the Sivers effect is present, we can further characterize the effect with a measurement of the away side jet. Measurement of the difference in transverse momentum of these two back-to-back jets, or their surrogates, will depend upon k_T of the struck quark [10]. The asymmetry in this k_T measurement is exactly what the Sivers model predicts. If events are selected with a pair of π^0's separated by approximately 180° in azimuthal angle and produced within the very forward kinematic region, the momentum of an observed π^0 represents a very large fraction of the jet energy. The typical fragmentation fraction for these events is about 90%.

The STAR collaboration has established that these dramatic transverse spin asymmetries persist at the higher energies of the RHIC collider $\left(\sqrt{s} = 200 GeV\right)$. With improving forward calorimetry, used in conjunction with the existing more central STAR detector systems, STAR will be able to distinguish the signatures of the Collins and Sivers effects.

The original plan for electromagnetic calorimetry in STAR emphasized coverage in the central rapidity region $\left(-1 < \eta < 2\right)$. Beginning in 2000, attempts were made to add electromagnetic coverage in the more forward region $(\eta > 2)$. Adding forward calorimetry to STAR proceeds in phases.

1. For the 2002 RHIC running period, a prototype calorimeter (**prototype FPD**) module was installed in the forward region. Asymmetry data from that run have been published [4].
2. Starting in the 2003 RHIC running period, arrays of lead glass photon detectors consisting of lead glass blocks of size 3.8 cm. x 3.8 cm. were installed left, right, above and below the beam. The left/right detectors consisted of 7x7 arrays of blocks and the top/bottom detectors consisted of 5x5 arrays. These detectors are referred to as the Forward Pion Detectors (**FPD**). Preliminary data from the FPD are shown as the $\eta = 3.8$ data in Figure 1.
3. STAR is in the process of increasing the scale of the forward electromagnetic coverage, extending to full forward coverage in azimuthal angle over the rapidity interval $2.5 < \eta < 4$. This new calorimeter, called the Forward Meson Spectrometer **FMS**, will consist of a single wall of lead glass. The inner blocks (nearest to the beam) will be of the same type as the FPD. The outer cells will be made from larger glass blocks. When the FMS is combined with the central STAR detector, it will provide nearly continuous coverage for the identification

and reconstruction of π^0's over the rapidity range $-1 < \eta < 4$. This coverage will allow us to distinguish between the signatures of Collins effect or Sivers effect.

From inclusive forward π^0 production with transversely polarized proton collisions $p^{\uparrow} + p \rightarrow \pi + X$, measurements have been obtained for the invariant cross sections and for the transverse asymmetry within the kinematic region defined by

$$1\frac{GeV}{c} < p_T < 2.5\frac{GeV}{c} \quad \textbf{and} \quad 3.3 < \eta < 4.1.$$

The transverse asymmetry is defined with the usual definition,

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}},$$

where $d\sigma^{\uparrow}$ represents a differential cross section for incident proton spin aligned along a transverse measurement direction and $d\sigma^{\downarrow}$ represents the corresponding differential cross section for the spin anti-aligned with that direction. The observed events are chosen to scatter in the plane transverse to the vertical axis (axis of spin quantization). Transverse asymmetry measurements with the prototype FPD (2002) and preliminary measurements with the FPD (2003), are shown in Figure 1.

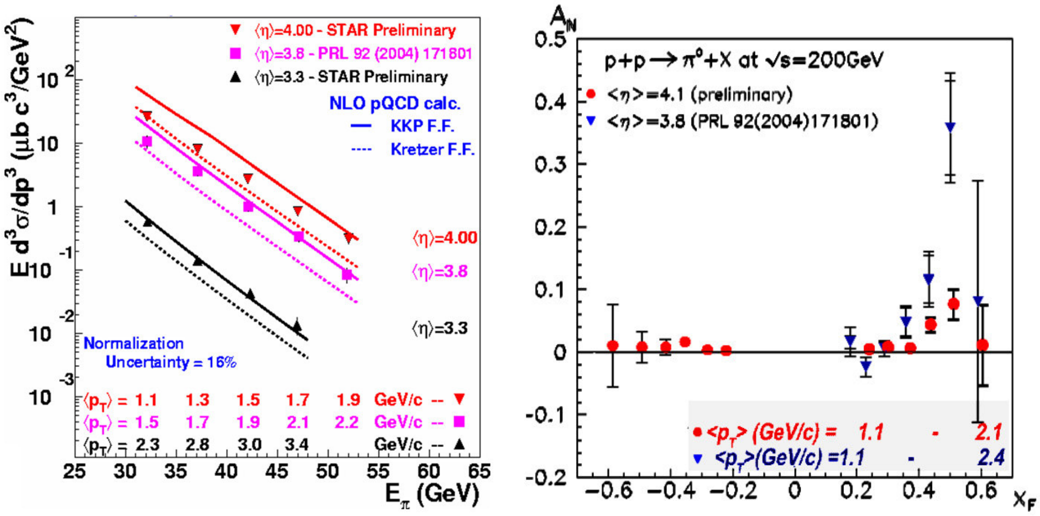

FIGURE 1. (Left) Invariant cross sections for inclusive π^0 production at large rapidity in p+p collisions at $\sqrt{s}$=200 GeV [4] compared to NLO pQCD calculations [11-13]. (Right) The corresponding STAR measurements of single spin asymmetry (A_N) for production of π^0's at the same energy. The η=4.1 data, shown with round markers, are preliminary. The published [4] η=3.8 data are shown with triangles. The equivalent p_T scale for these data is also indicated.

It is seen that the asymmetry measured has a form similar to that seen at much lower energy. The measurement of these cross sections is in good agreement with next to leading order perturbative calculations. It is noted that while the asymmetries observed are similar to those seen at lower energy, the cross sections at lower energy did not agree with perturbative calculations. We believe that this new RHIC result represents an interesting convergence of perturbative interpretations and asymmetry mechanisms which sets it apart from lower energy measurements, severely constraining the theoretical interpretation of the asymmetries.

With the FMS in place, STAR will be able to measure not only single inclusive π^0's but also correlated pairs of π^0's. These pairs can be generally associated with either a single jet (same side π^0's with small azimuthal separation angle) or with pairs of jets (π^0 pairs with nearly back to back azimuthal angles). These two topologies also correspond to regimes where Collins effect or Sivers effect can be identified and quantitatively studied.

By looking at pairs of same-side neutral pions, we can measure the asymmetry as a function of the two pion kinematics. With the FMS we will separately measure the contributions to this asymmetry that comes from the jet axis vs. that which comes from the jet structure. Many theory papers have studied this problem: however, the need for data is great. The FMS STAR experiments on transverse polarization will provide to theorists the necessary input to determine the relative contributions from the Sivers effect and the Collins effect.

The performance of the polarized RHIC collider has been steadily improving. Transverse polarization data sets from 2003 and 2004 were both obtained with less than ½ Picobarn^{-1} of beam. The average proton beam polarization in 2003 was less than 20%. In current running (2005), online polarization values in excess of 50% have been seen. Integrated luminosity for longitudinal running in 2005 will be about an order of magnitude greater than that corresponding to data presented in Figure 1. A much higher statistics measurement of these transverse asymmetries can be expected in the near future.

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REFERENCES

1. G.L. Kane, J. Pumplin and W. Repko, Phys. Rev. Lett. **41** (1978) 1689.
2. R.D. Klem *et al.*, Phys. Rev. Lett. **36** (1976) 929; W.H. Dragoset *et al.*, Phys. Rev. **D18** (1978) 3939; S. Saroff *et al.*, Phys. Rev. Lett. **64** (1990) 995; B.E. Bonner *et al.*, Phys. Rev. **D41** (1990) 13; K. Krueger *et al*, Phys. Lett. **B459** (1999); C.E. Allgower *et al.*, Phys. Rev. **D65** (2002) 092008.
3. B.E. Bonner *et al.* Phys. Rev. Lett. **61** (1988) 1918; D.L. Adams *et al.*, Phys. Lett. **B261** (1991) 201; Phys. Lett. **B264** (1991) 462; Z. Phys. **C56** (1992) 181; A. Bravar *et al.* Phys. Rev. Lett. **77** (1996) 2626.
4. J. Adams *et al.* (STAR collaboration), Phys. Rev. Lett. **92** (2004) 171801 [hep-ex/0310058].
5. A. Airapetian *et al.* (HERMES collaboration), Phys. Rev. Lett. **94** (2005) 012002.
6. D.Sivers, Phys. Rev. **D41** (1990) 83; **43** (1991) 261.
7. M. Anselmino, M. Boglione and F. Murgia, Phys. Lett. B362 (1995) 164; M. Anselmino and F. Murgia, Phys. Lett. B442 (1998) 470.
8. J. Collins, Nucl. Phys. **B396** (1993) 161; J. Collins, S.F. Heppelmann and G.A. Ladinsky, Nucl. Phys. **B420** (1994) 565.
9. M. Anselmino, M. Boglione and F. Murgia, Phys. Rev. **D60** (1999) 054027.
10. Daniel Boer and Werner Vogelsang, Phys. Rev. **D69** (2004) 094025 [hep-ph/0312320].
11 F. Aversa *et al.*, Nucl Phys. **B327** (1989) 105; B. Jager *et al.*, Phys. Rev. **D67** (2003) 054005; and D. de Florian, Phys. Rev. **D67** (2003) 054004.
12. B.A. Kniehl, G. Kramer and B. Poetter, Nucl Phys. **B597** (2001) 337.
13. S. Kretzer, Phys. Rev. **D62** (2000) 054001.