Recent Transverse Spin Results at STAR

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Large transverse single spin asymmetries have been measured in high energy proton-proton collisions for mesons produced in the very forward region relative to the polarized proton. A summary of these asymmetries, as recently observed by the STAR collaboration at the Brookhaven Relativistic Heavy Ion Collider, will be presented. Using the STAR forward electromagnetic calorimeters, asymmetries for photon pair production in the π^0 and η meson mass regions will be shown and discussed. A surprising result for π^0 mesons includes a non-decreasing transverse momentum dependence for asymmetry at fixed Feynman X. Another surprise is a very large difference in asymmetry for photon pairs from neutral pions as compared to the asymmetry in the η mass region.

1 Introduction

The STAR collaboration has measured the transverse single spin asymetries for forward mesons produced in polarized proton-proton collisions at $\sqrt{s} = 200GeV$. These data were obtained at the Relativistic Heavy Ion Collider (RHIC) during transverse pp running periods from 2003 to 2008. STAR has measured neutral forward mesons with a variety of configurations of lead glass calorimeters, placed at a forward location relative to the collision point. STAR has increased the size of the forward calorimetry coverage in stages. The current FMS detector provides full azimuthal forward coverage in the pseudorapidity range from $+2.5 < Y < +4.0$, with positive pseudorapidity associated with particle production toward the west direction. This nicely complements the barrel and endcap electromagnetic calorimetric coverage in STAR, which span the range from $-1.0 < Y < +2.0$. Measurement reported here, with data collected before 2007, involved the smaller calorimeter modules called the FPD modules. The FPD modules consist of 7x7 arrays of lead glass blocks. Each block presents a cross sectional area of 3.8 x 3.8 cm. FPD modules had been placed both east and west of the STAR interaction region, symmetrically left and right of the vertically polarized beam line. The distance from the STAR interaction point was about 7 meters and the distance from the beam line was adjustable, allowing coverage over various pseuderapidity intervals in $3 < Y < 4.2$ range.

Single spin asymmetries can be defined as the ratio of the difference to the sum of cross sections for the two initial proton spin states. An equivalent definition for transverse single spin asymmetry involves the ratio of difference to sum of cross sections for production at symmetric angles left and right of the beam line when beam spin is aligned with the vertical direction. Where possible, STAR quotes the cross ratio transverse single spin asymmetry, defined as combination of the above two approaches. The cross ratio is defined as

$$A_N \equiv \frac{1}{P_{bm}} \frac{\sqrt{N_{L+}}\sqrt{N_{R-}} - \sqrt{N_{R+}}\sqrt{N_{L-}}}{\sqrt{N_{L+}}\sqrt{N_{R-}} + \sqrt{N_{R+}}\sqrt{N_{L-}}}.$$

with N_{L+}(or N_{L-}) the event rate for mesons observed to the left of the polarized beam where the proton spin vertical projection is +1/2 (or -1/2). The quantities N_{R+} and N_{R-} are similarly defined for mesons scattering at a symetrical angle to the right. Large transverse single spin asymmetries for charged and neutral pion production have been reported in various experiments at lower energy, in particular by the Fermi Lab E704 experiment [4] and more recently by BRAHMS[5] at RHIC. E704 also reported a large transverse single spin asymmetry for η meson production [6] with fairly large uncertainty. The forward transverse asymmetry pattern from charged and neutral pions can be summarized by the observation that large positive transverse single spin asymmetries are observed for forward π^+ and π^0 production and similarly large negative asymmetries are observed for π^- production. For these kinematics, the large X_F forward mesons cross sections has been measured [7, 8] and is consistent with next to Leading Order Perturbative QCD (NLO PQCD) calculations of the spin averaged cross section [9, 10, 11]. These cross sections are therefore apparently dominated by amplitudes where a very large x (parton momentum fraction) quark from a polarized proton scatters from soft components in the other proton. The resulting quark jet fragments into the observed meson. However, measurements of A_N are characterized by a high degree of correlation between the isospin projection (I_3) of the produced pion and the sign of the asymmetry. We see this in the opposite sign of A_N for π^+ and π^- forward production. From this point of view, the difference between the π^0 and π^+ asymmetry is natural, reflecting the expected excess of u quarks over d quarks in the proton. But any observed differences in A_N for π^0 and η mesons raises new questions. In the comparison between η and π^0 production, the isospin difference is reflected in a relative sign change between $u\ \bar{u}$ and $d\ \bar{d}$ amplitudes in the meson wave function. The η and π^0 mesons differ not only in isospin but also in the strangeness content of the wave function,

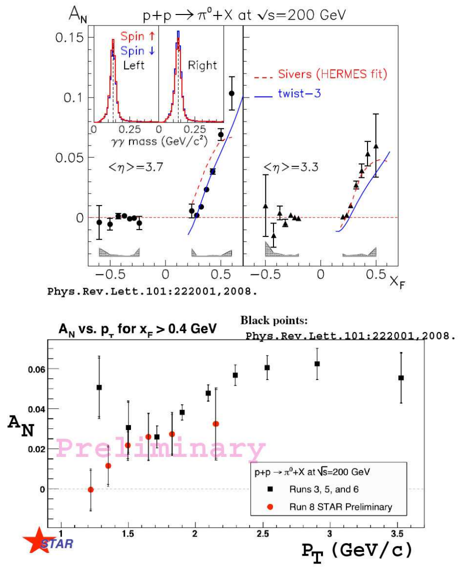

Figure 1: Top: Asymmetry A_N as measured in this experiment is shown as a function of Feynman X_F[1]. The dashed line is a fit to the Sivers model [2] and the solid curve is a fit two a twist 3 calculation[3]. Bottom: Asymmetry A_N as a function of p_T for $X_F > 0.4$. The data points shown as black squares was collected prior to 2008 (Run 8). The red circle data points are from new 2008 FPD data.

$$\pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}) \quad \eta \simeq \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} - s\bar{s})$$

where to obtain the simple expression for η, the η, η' mixing angle has been approximated as $\theta_P \simeq -19.4°$ [12]. The η meson is similar in quark content to the π^0 and a differences in A_N would imply dependence on total isospin, with isospin=1 for π and isospin=0 for η.

Differences between η asymmetry and π^0 asymmetry could be related to the role of strangeness or isospin. But any interpretation should be constrained by the relative success of NLN PQCD predictions for the π^0 cross section in this region. In these calculations the general trend of p_T dependence of the cross section would result from a hard interaction between a fast quark in the polarized proton and a soft parton in the unpolarized proton. Small transverse spin dependent modifications of the relatively large transverse momentum can produce significant values of A_N. One mechanism for spin dependent changes in p_T, involving spin dependent contributions to initial state transverse momentum in the struck proton, is called the Sivers Effect[13]. Another possible mechanism for producing a spin dependent change in p_T is called the Collins Effect[14], where the p_T shift is the result of spin dependent fragmentation of a transversely polarized quark. Either of these mechanisms is expected to lead to a prediction for A_N that falls with p_T. The nominal leading twist PQCD calculations with colinear factorization that adequetly predict the π^0 cross section in this kinematic region do not predict a non-zero single spin asymmetry. A third approach involves the inclusion of higher twist terms[15]. The expectation from higher twist processes is again that A_N should fall with increasing transverse momentum.

2 Transverse Momentum Dependence of A_N for π^0 mesons.

From general symmetry arguments, the transverse single spin asymmetry must vanish as p_T approaches zero. However, based upon general arguments and detailed calculations with models based upon Collins or Sivers effect, the expectation is that above some nominal p_T, perhaps about 1 GeV/c, A_N is expected to fall with p_T.

STAR has published data on the X_F and p_T dependence of the π^0 asymmetry[1]. The general trend, shown in Figure 1, is similar to the lower energy E704 results, with A_N sharply rising as a function of X_F for $X_F > 0.4$. No significant asymmetry is seen in the backward scattering region, $X_F < 0$. In fixed X_F bins, the dependence of A_N on p_T is not consistent with the prediction that A_N should fall with p_T.

In Figure 1 the published data from STAR runs before 2008 (Run 8) are shown as black squares. The hint that A_N as a function of p_T might have a local minimum near $p_T \simeq 1.7 GeV/c$ is not confirmed in new preliminary Run 8 data, shown with red circles. The new data supports a monatomicly increasing A_N with p_T in this lower p_T region.

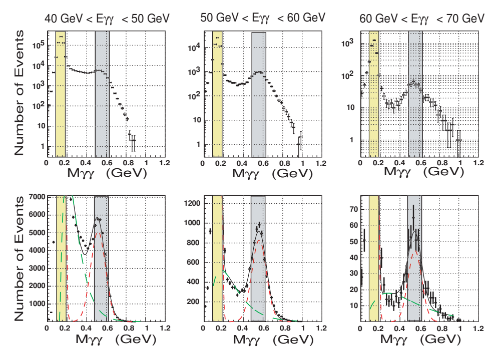

Figure 2: The two photon mass distributions are shown in three pair energy ranges, left: 40-50 GeV, middle: 50-60 GeV and right: 60-70 GeV. In the top row, the vertical scale is logarithmic and in the bottom row, the vertical scale in linear but the pion peak is off scale.

3 Observation of A_N for forward η meson.

Using Run 6 STAR data from the east FPD during transverse pp running, the η peak in the two photon mass spectrum was observed. The FPD detectors are appropriately sized for observation of photon pairs from π^0 decays in the energy range from 10 to 70 GeV. To contain photons from η decays, a larger detector would be ideal. However, for photon pair energy above about 40 GeV, the acceptance of the FPD for η mesons becomes significant for the most asymmetric decays. To improve the ratio of acceptance for η mesons to π^0 mesons in the FPD modules, the combined momentum vector of the photon pair is restricted to point toward the central part of the FPD detectors. For these data, a cut was used to selected only cases where the two photon momentum pointed toward the center of the FPD. The "center cut" used was defined in terms of the psuedorapidity (Y) and the azimuthal angle (ϕ) associated with the two photon momentum vector,

$$((Y - 3.65)^2 + tan(\phi)^2) < (0.15)^2.$$

The two photon mass distributions of events that reconstruct to a two photon pair is shown in Figure 2. In this preliminary analysis, no attempt has been made to estimate the background contribution below the η and π^0 peaks. Background could involve non-photon contributions from hadronic energy deposited by charged pions and protons in the lower energy region and perhaps even a direct photon contribution in the high energy region. It is clear that the η signal appears to be dominant in the η mass region for photon pair energies greater than 50 GeV.

In Figure 3, the cross ratio transverse single spin asymmetry A_N is shown for events in the π^0 and η mass bands indicated in Figure 2. A comparison of A_N for the π^0 and η regions suggests that the A_N for the η meson region is significantly larger than for the π_0 region. For the range of two photon energy from 55 GeV to 75 GeV ($0.55 < X_F < 0.75$), the average asymmetry for photon pairs in the η mass band is $< A_N >_\eta = 0.361 \pm 0.064$. This is more than 4 times the value of A_N observed in the π^0 mass region and the significance of this is characterized by a difference of more than 4 standard deviations. Furthermore, there may be a trend in the η asymmetry shown for even larger values in the largest X_F region.

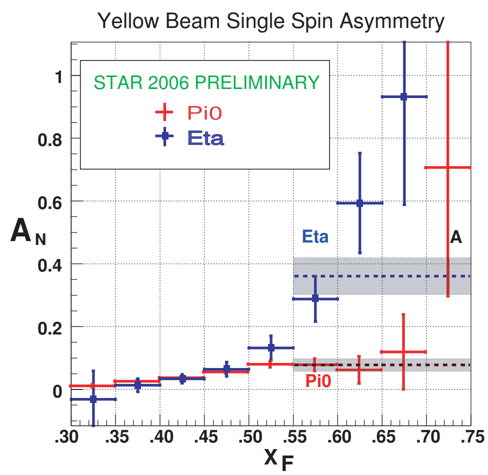

Figure 3: The asymmetry A_N is plotted as a function of X_F for photon pairs in the π^2 and η mass regions indicated in Figure 2. The errors shown are statistical.

This is generally consistent with what was seen in the E704 experiment. All of the errors shown here are statistical and it is statistical errors that dominate the uncertainty in our measured A_N for this high X_F region.

4 Conclusion.

While the success of NLO PQCD calculations of π^0 forward cross sections give credibility to the view that events in this region are primarily related to hard scattering between a large x quark and a soft parton, the striking p_T dependence of A_N for π^0 production at fixed X_F may require physics input beyond this basic framework. The apparent large difference between π^0 asymmetry and η asymmetry may also pose an interesting new class of questions.

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