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Transverse Single Spin Asymmetry of π^0 and η Mesons at RHIC/PHENIX*

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We presented measurements of the transverse single spin asymmetries (A_N) for neutral π and η meson at forward rapidities and central rapidity with the PHENIX detector at RHIC at 62.4 GeV and 200 GeV. At mid-rapidity, π^0 and *eta* are reconstructed from di-photon decay. At forward rapidities, π^0 and *eta* meson are measured using di-photons decays and electromagnetic clusters due to the photon merging effects are significant for energy $E > 20GeV$. The neutral-pion measurement of A_N at mid-rapidity is consistent with zero with uncertainties a factor of 20 smaller than previous publications, which will lead to improved constraints on the gluon Sivers function. At higher rapidities, both neutral π and η A_N exhibit sizable asymmetries. The origin of the forward A_N is presently not understood quantitatively. We also measured η meson cross section for $0.5 < p_T < 5.0$ GeV/c and $3.0 < \eta < 3.8$. It is well described by a NLO pQCD calculation.

Keywords: Transverse single spin asymmetry; π^0; η, A_N.

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1. Introduction

The measurement of transverse single-spin asymmetries (TSSAs) gives us the opportunity to probe the quark and gluon structure of transversely polarized nucleons. Initially, transverse-single-spin asymmetries A_N of hadrons produced in transverse polarized p + p collisions were expected to be small ,[1] but large azimuthal transverse single-spin asymmetry of up to about 40% were first observed at large Feynman-x in π meson production from transversely polarized $p + p$ collisions at $\sqrt{s} = 4.9GeV$

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in 1976.[2] and subsequently observed in hadronic collisions over a range of energies extending up to $\sqrt{s} = 200 GeV$.[3] In order to describe the large transverse SSAs observed, two theoretical frameworks have been developed over the past two decades to understand the origin of these large asymmetries; the transverse momentum dependent (TMD) framework, and the collinear twist-3 factorization framework. Within TMD framework, two effects have been proposed to explain the large asymmetries. One is so called Sivers effect, which correlates the proton spin with the partonic transverse momentum. Another effect is Collins effect, which describes the coupling of a quark transversity and a transfers spin dependent fragmentation function. Another framework requires higher-twist contributions in the collinear factorization scheme, the exchange of a gluon between one of the partons taking part in the hard scattering and the color field of either an initial- or final-state hadron. This was first proposed by Qiu and Sterman for gluon exchange in the initial state[4] and by Kanazawa and Koike for exchange in the final state.[5] Gluon exchange in either the initial or final state leads to terms including multiparton correlation functions, which can generate a non-zero TSSA. These two approaches have different but overlapping kinematic regimes of applicability and have been shown to correspond exactly in their region of overlap.[6]

We presented PHENIX A_N measurement of π^0 at $\sqrt{s} = 62.4$ GeV from the year 2006 data with integrated luminosities of 42 nb^{-1} and 4.3 pb^{-1} 200 GeV data from year 2008 run. We will also report on measurement of the cross section and A_N for η mesons at forward rapidity from the 2008 data at $\sqrt{s} = 200$ GeV with total integrated luminosity of 6.65 pb^{-1}. The comparison of π and η meson can help our understanding of the large transverse single spin asymmetries observed in forward rapidity.

2. Experimental Setup

As a unique polarized p + p collider, RHIC can deliver polarized proton beams at energies up to 255 GeV in two rings. The beams collides at several interaction points along the ring. Measurements were carried out by the PHENIX experiment at RHIC. An overview of the PHENIX apparatus can be found in earlier publication.[7] PHENIX recorded 42 nb^{-1} transverse polarized p + p collisions at 62.4 GeV in 2006 year and collected 4.3 pb^{-1} at 200 GeV in 2008. Polarizations for RHIC proton beams at 62.4 GeV are $49.0 \pm 4.4\%$ for both south and north beam. Polarization for 200GeV in 2008 are $48.0 \pm 4.0\%$ and $41.0 \pm 4.0\%$ for north and south respectively.

2.1. *PHENIX central arm*

PHENIX central arm is used to measure π^0 and η mesons via their decay into two photons. PHENIX central arm covers a pseudo rapidity range of $|\eta| < 0.35$ and two back-to-back arms each covering $\Delta\phi = \pi/2$ in azimuthal angle.

2.2. *PHENIX Muon Piston Calorimeter*

Measurement of π^0 and η are carried by Muon Piston Calorimeter (MPC). The PHENIX MPC is an electromagnetic calorimeter. The MPC consist of two separate devices placed $\pm$ 229 cm along the beam line to the north and south of the nominal collision point. South MPC and north MPC were installed in 2006 and 2008, respectively. The detector acceptance covers the full azimuthal angle and a pseudo rapidity range of $-3.8 < \eta < -3.1$ for south and $3.1 < \eta < 3.9$ for north.

3. Analysis

3.1. *Central arm π^0 and η measurement at 200 GeV*

The PHENIX measures π^0 and η through their decay into two photons. The measured A_N verses p_T for π^0 and η at mid-rapidity vs p_T are shown in Figure 1. The new $\pi^0 A_N$ measurement (left panel) exceed the former precision by a factor of 20 and extended the p_T above 10 GeV/c. Right panel is also our first η meson A_N result from mid-rapidity. All those asymmetries are consistent with zero within their uncertainties. Any difference in the two meson asymmetries would likely dominated by fragmentation effects.

3.2. *Forward π^0 meson A_N measurement at 62.4 GeV*

We also measured π^0 single spin asymmetry at forward rapidity at 62.4 GeV. The results are shown in Figure 2. Left panel is the A_N results as a function of x_F in two different pseudo rapidity ranges. Here x_F is defined as $x_F = 2p_z/\sqrt{s}$. The significant nonzero asymmetry rising with $x_F > 0$ in the forward direction, but there is no such behavior at negative $x_F < 0$ and the asymmetry is consistent with zero. The right hand panel shows the A_N as a function of p_T. There is no strong p_T dependence is observed for the range of $x_F > 0$.

Figure 3 compares our x_F dependence of π^0 A_N results with world data. We compared forward PHENIX π^0 A_N and forward BRAHMS charged π asymmetry

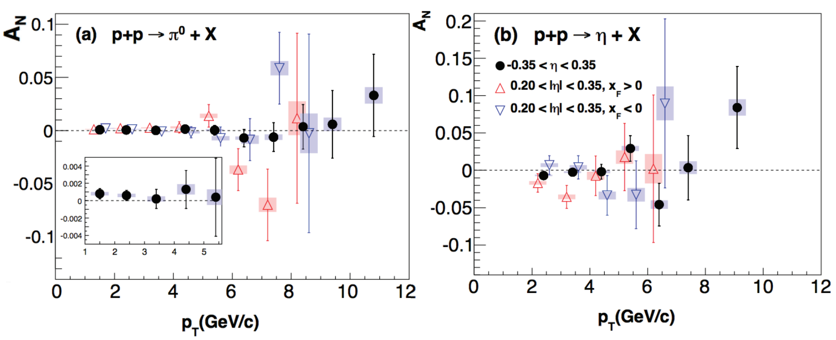

Fig. 1. The single spin asymmetry A_N at mid-rapidity as a function of p_T for π^0 (left panel) and η (right panel) at 200 GeV from 2008 year's data.

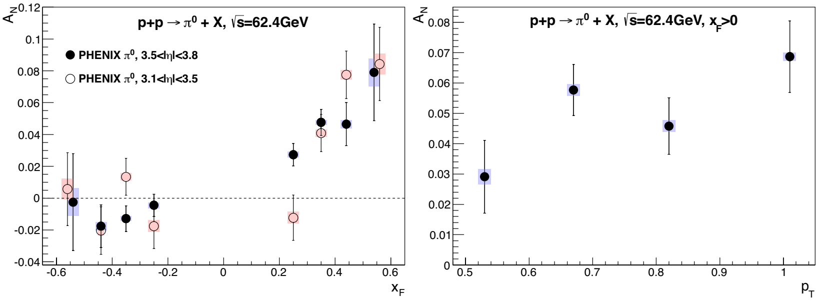

Fig. 2. π^0 A_N atat $\sqrt{s} = 62.4$ GeV as a function of x_F (left panel) in two different pseudo rapidity ranges and p_T (right panel) from 2006 year's data.

at 62.4 GeV in the left panel. Isospin dependence can be found in this comparison. π^+ and π^0 asymmetries are positive, but those of π^- are of opposite sign. The amplitudes of the charged pion asymmetries are of similar size, with the π^- perhaps slightly larger, whereas both are significantly larger than the neutral pion asymmetry. Right panel in Figure 3 shows the comparison between PHENIX current π^0 at 62.4 GeV A_N results, E704 results at 19.4 GeV and STAR results at 200 GeV. Although they were measured with slightly different pseudo-rapidity range, all the results are in a good agreement. The asymmetries show there is no collision energy dependence for a very wide center of mass energy from 19.4 GeV to 200 GeV.

3.3. *Forward cluster A_N measurement at 200 GeV*

The PHENIX MPC can distinguish two photons and reconstruct π^0 meson peak at energies below 20 GeV. However, with increasing energy, the opening angle between the two photons become so small that their electromagnetic clusters are fully merged in the detector. MPC can not measure π^0 through two photons decay when cluster energy greater than 20 GeV. We performed a full detector Monte Carlo simulation

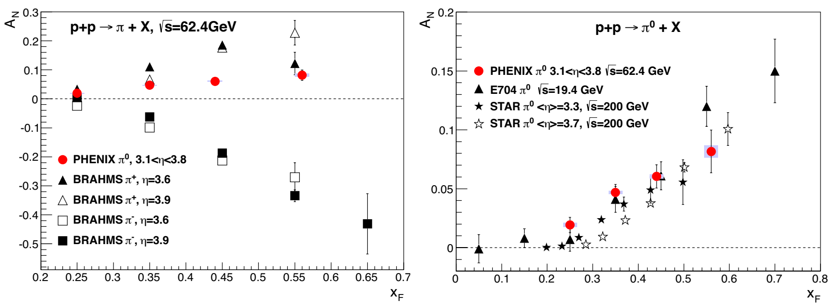

Fig. 3. π^0 A_N at $\sqrt{s} = 62.4$ GeV as a function of x_F (left panel) in two different pseudo rapidity ranges and p_T (right panel) from 2008 year's data.

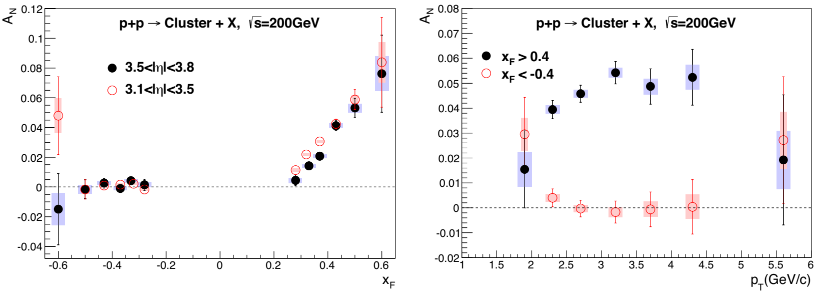

Fig. 4. Electromagnetic cluster A_N at $\sqrt{s} = 200$ GeV as a function of x_F (left panel) in two different pseudo rapidity ranges and p_T (right panel).

based on the input from PYTHIA 6.421 Tune A to understand the relative contributions to the measured clusters. There are about 80% of clusters are from decay photons of π^0. Figure 4 shows the A_N of the cluster at 200 GeV in the range of $|x_F| > 0.4$.

A_N vs x_F in the left panel shows that the asymmetries in the backward direction $x_F < 0$ are consistent with zero within statistical uncertainties, whereas in the forward direction A_N rises with x_F. The size of the asymmetries are similar compared to earlier results at different center-of-mass energies as shown in the left panel in Figure 3. The right hand panel presents the A_N as function of p_T. The asymmetry rises smoothly and then seems to saturate above $p_T > 3$ GeV/c. A significant decrease of the asymmetry as expected from higher twist calculations is not observed.[6] Again, negative x_F asymmetries are found to be consistent with zero within statistical uncertainties.

3.4. *Forward η meson cross section and A_N at 200 GeV*

The Invariant cross section of η meson was measured by MPC between transverse momentum $0.5 < p_T < 5.0$ GeV/c within the pseudo rapidity range of $3.0 < |\eta| < 3.8$. It is shown in Figure 5 upper panel and compared to a NLO pQCD calculation in the lower panel. For $p_T > 2.0$GeV/c, the NLO pQCD calculation is in very good agreement with the measured cross section. Upon approaching the pQCD limit at low momentum ($p_T < 2.0$GeV/ c) the agreement is less clear, but well within the factorization uncertainty.

Figure 6 shows the η mesons A_N vs x_F compared to other A_N results. The left panel shows a comparison between η and π in the similar kinetic rang at various collision energies. The η A_N is similar to the π A_N. It suggests that initial-state spin momentum correlations could play a role, or a common spin-momentum correlation is present in theire fragmentation.

The right panel shows a comparison to the world data. They covers slightly different pseudo rapidity range All the results are consistent with each other within uncertainties. A twist-3 calculation by Kanazawa is also overlaid with the data.

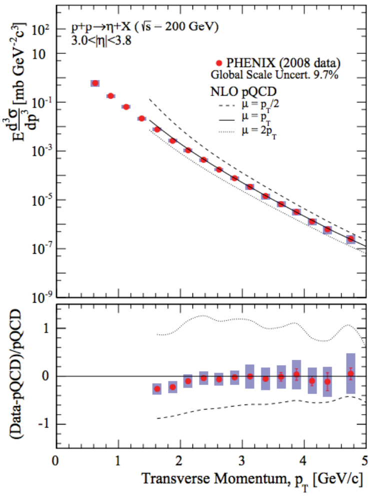

Fig. 5. The invariant cross section of η meson form $p + p$ collisions at 200 GeV at forward rapidity(upper panel). The cross section is compared with NLO pQCD calculation (lower panel).

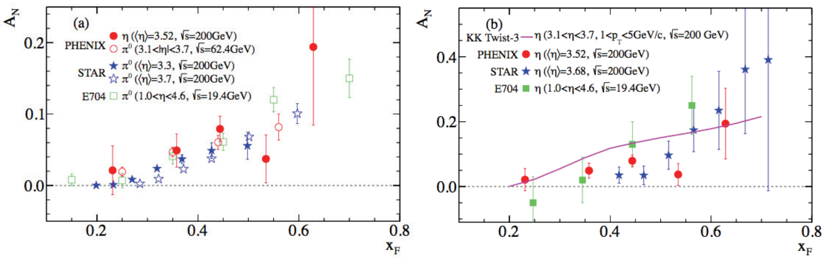

Fig. 6. η mesons A_N vs x_F compared to other A_N results and a twist-3 calculation.

Their calculation lies significantly above the three measured data points in the middle of the x_F range. We need better understanding of the theoretical uncertainties before we draw any conclusion on the agreement.

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