PROCEEDINGS OF SCIENCE

PHENIX Forward Transverse Spin Measurements

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The PHENIX experiment at RHIC has measured transverse single spin asymmetries, A_N, of various probes at different center-of-mass energies. Transverse single spin asymmetries are sensitive to the dynamic structure of the nucleon. These measurements provide information to constrain Collins, Sivers, and twist-3 effects. In this paper, I report on recent A_N measurements of central rapidity π^0 and η mesons at 200GeV, and forward/backward rapidity measurements of π^0 at 62.4GeV, η-mesons, EM Clusters, the J/ψ, and μ at 200GeV. I will summarize the recent results from PHENIX, and discuss the near-term prospects of new physics measurements enabled by the newly installed silicon vertex tracker (FVTX) and the MPC-EX detector currently under construction.

XXIII International Workshop on Deep-Inelastic Scattering
27 April - May 1 2015
Dallas, Texas

[1] Speaker

1. Introduction

Transverse single spin asymmetries (TSSAs) emerge as left-right asymmetries in scattering processes with one of the colliding particles momentum perpendicular to the polarization vector: $A_N=(d\sigma\uparrow - d\sigma\downarrow)/(d\sigma\uparrow + d\sigma\downarrow)$. They were originally expected to be very small at RHIC energies as in collinear QCD, which describes the cross-sections well, where A_N should scale like $A_N \sim m_q \alpha_s / p_T$. However TSSAs were observed in pion production in various experiments ranging in center-of-mass energies from $\sqrt{s}$=4.9 GeV and 19.6 GeV and have persisted all the way to $\sqrt{s}$=500 GeV in forward meson production [1]. Large transverse asymmetries carry potential information about QCD dynamics beyond a 1-dimensional picture providing a glimpse into the trasnverse structure of the nucleon, which is largely unknown.

Both initial state and final state efects can give rise to transverse spin asymmetries. Initial state descriptions include the Sivers Transverse Momentum Dependent (TMD) PDF picture and collinear higher twist effects. The Sivers TMD picture arises from the correlation between proton-spin and intrinsic transverse quark momentum [2]. A collinear higher twist description involving quark-gluon and gluon-gluon correlators in polarized hadrons is more appropriate for single scale quantities such as inclusive A_N, which are reported on in this paper. However, they can be related to moments of the Sivers distribution [3]. Final state descriptions include the Collins TMD picture and colinear higher twist description. The Collins picture arrises from a correlation between proton and quark spin or transversity, the quark transverse spin distribution, and a spin dependent fragmentation function [4]. A colinear higher twist description inolves a twist-3 quark-gluon fragmentation function that can be related to the Collins function.

2. The PHENIX Detector at RHIC

The PHENIX detector has a high rate capability utilizing a fast DAQ and specialized triggers, high granularity detectors, and good mass resolution and particle identification at the sacrifice of acceptance. Detection of π^0 and η mesons utilize the finely grained central arm electromagnetic calorimeter $|\eta|<0.35$ and forward muon piston calorimeter (MPC) $3.1<|\eta|<3.8$ (3.9) South (North) and J/ψ are detected with electrons in the central spectrometer $|\eta|<0.35$ and muons in our forward spectrometer consisting of Muon ID and Muon Tracker $-2.2<\eta<-1.2$ and $1.2<\eta<2.4$.

The MPC detector is a lead-tungstate electromagnetic calorimeter with a tower size of 2.25x2.25cm^2 220cm from the collision vertex. Photon merging effects become significant for E>20GeV or p_T>2GeV/c. For $\sqrt{s}$=62 GeV, 20GeV corresponds to an x_F=0.65, so π^0 mesons can be measured via a two photon analysis. For $\sqrt{s}$=200 GeV, 20GeV corresponds to x_F=0.20, so the analysis proceeds through “single clusters”, which are clusters consistent with EM radiation after shower shape cuts, etc. π^0 mesons are the dominant source (80% at p_T=3), but with increasing p_T there is a sizable increase in contributions from direct and other photon (π^0 fraction drops to 70% above 5GeV). The cluster composition is estimated through a Monte Carlo full detector simulation.

In this paper, I report on PHENIX transverse spin data taken at 62.4GeV (2006), and 200GeV (2006 and 2008). Measurements include A_N for central arm π^0 and η and forward π^0, η, μ, and J/ψ.

3. Mid-rapidity A_N for π^0 and η mesons

Fig.1 shows the transverse single spin asymmetries at mid-rapidity for π^0 and η mesons as measured in the PHENIX central arms [5]. Compared to previous published results [6], the reach for π^0 has been extended to over 10 GeV/c, the statistical uncertainties have been reduced by a factor of over 20 at low p_T, and results for η mesons are new. The asymmetries are consistent with zero, leading to constraints on the gluon-Sivers effect as the gluon-gluon and quark-gluon processes are dominant and the transversity effect is suppressed [7].

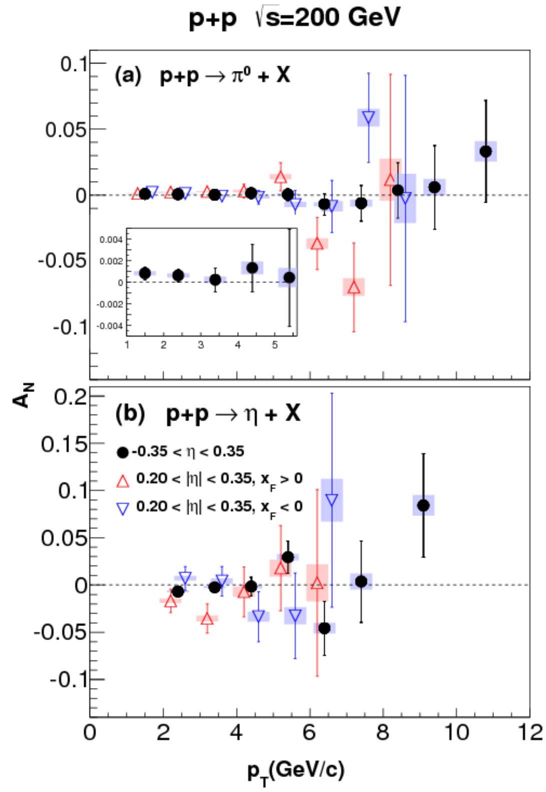

Figure 1: A_N at mid-rapidity for π^0 and η mesons [5].

4. Forward A_N for π^0 mesons and electromagnetic clusters

Results are presented in Fig.2 for neutral pions at √s=62.4GeV as function of x_F in the forward and backward directions using the MPCs. Significant asymmetries are seen for $x_F>0$ and A_N scales approximately linearly for $x_F >0.2$, which is consistent with earlier observations from other experiments at lower center-of-mass energies. No dependence on √s is apparent from 19.6GeV to 200GeV.[2] The backward asymmetries are consistent with zero. The π^0 points can be put together with the BRAHMS measurement at same energy and pseudorapidity [8] to complete the picture [5]. The data cannot be explained by initial state effects of quarks alone, if you consider just the quark origins of the pions and the Sivers functions extracted from SIDIS.

Because of merging effects, we measure electromagnetic (EM) clusters at 200GeV. They are dominated by π^0's in both the forward and backward directions. Fig.3 shows A_N vs x_F for EM clusters at 200GeV. The magnitude of forward asymmetries are similar to E704 (at 19.4 GeV) [9] and STAR (at 200GeV) [10]. We can compare our EM cluster results with STAR's π^0 measurement as a function of p_T. We find good agreement for $x_F<0$. For $x_F>0.4$ it is statistically limited, but there is a possible difference, leaving room for a direct photon contribution as the photon contribution to EM clusters increases with p_T.

Collinear higher twist calculations predict that A_N decreases with increasing transverse momentum once p_T is of the same order as the partonic momentum scale Q and both are much larger than Λ_{QCD}. Where this turnover of the initially rising A_N happens is largely unknown,

[2] Note: there are slight differences in pseudorapidity and/or p_T between the measuerments.

however. Cluster asymmetries have an extended p_T range compared to previous measurements of π^0 mesons, see Fig.4, but the data still do not allow for a conclusive answer for the onset of this drop of the asymmetry up to p_T>4GeV.

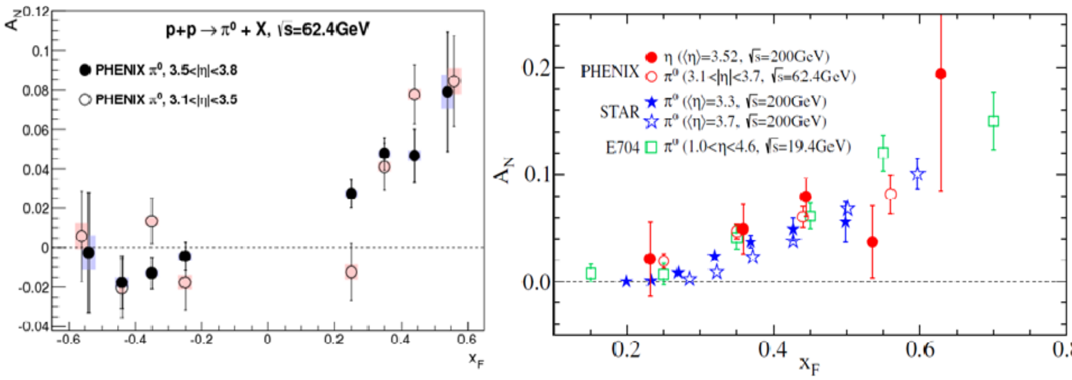

Figure 2: (left) A_N at forward rapidity for π^0 at $\sqrt{s}$=62.4GeV[5]; (right) comparison with other energies and the η [11].

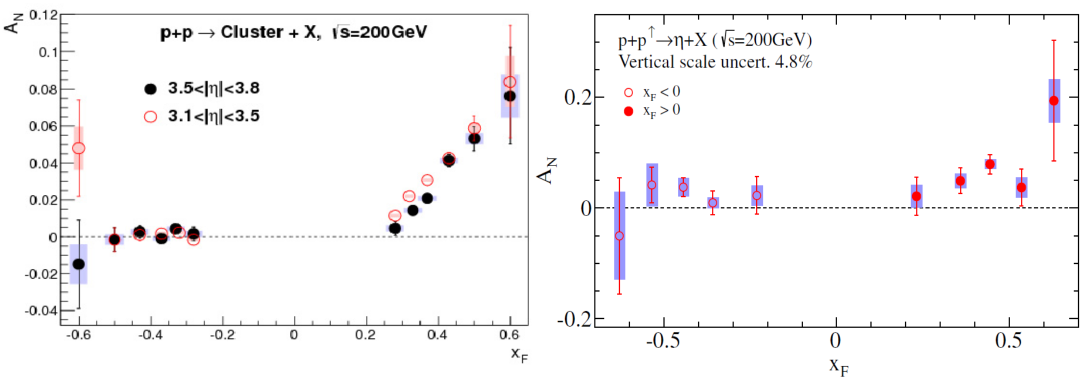

Figure 3: A_N vs x_F for EM clusters [5] (left)and η mestons (right) at 200GeV [11].

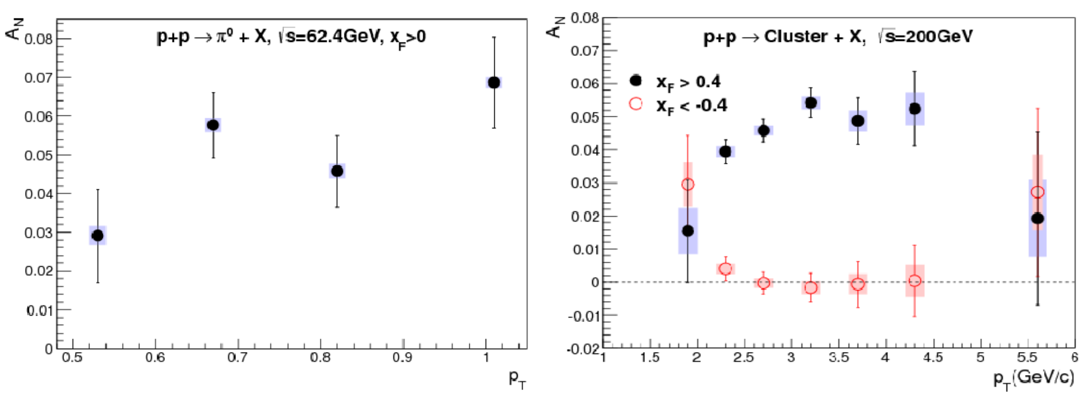

Figure 4: A_N as a function of p_T at 62.4 GeV for x_F>0 (left) and 200 GeV (right) for x_F>0.4. [5]

5.Forward η mesons cross-section and A_N

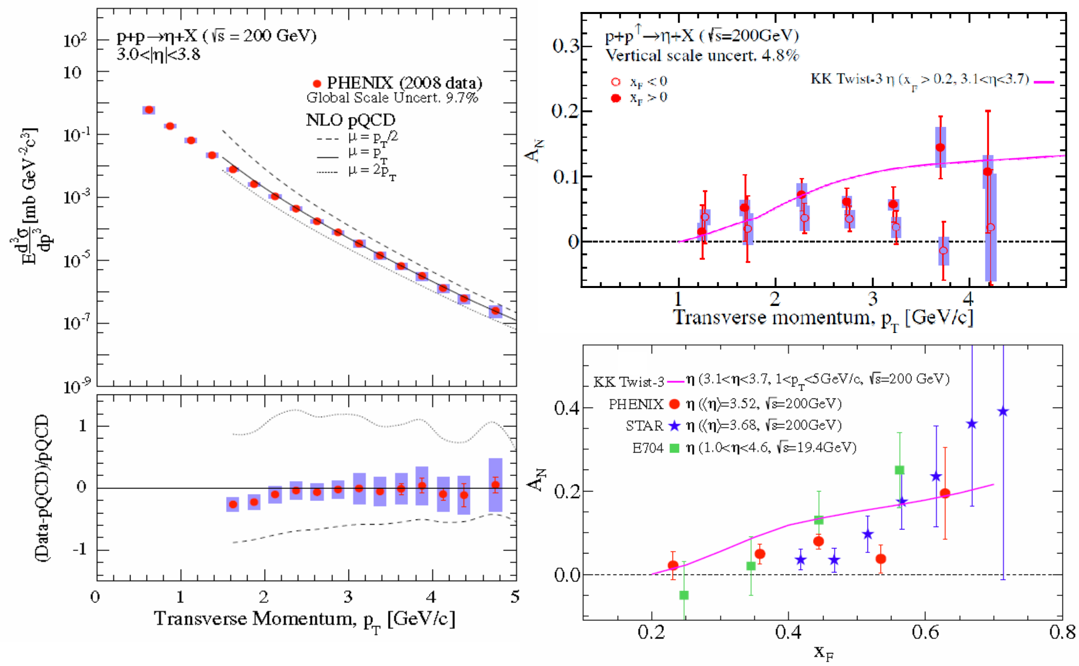

Figure 5(left) Forward η cross-section at 200GeV at forward; (right) Comparison between the η meson A_N and other results and theoretical calculations. [11]

Comparisons of π, η, and K may provide information about initial vs final spin-momentum correlations as well as possible isospin, strangeness, and mass effects. PHENIX has measured the forward η cross-section [11] at 200GeV, as shown in Fig.5. A pQCD calculation [12] at a scale of $\mu=p_T$ are found to be consisten with the data. These measurements can be used to improve constraints on the hadronization process in future global analysis of the η fragementation functions. Transverse asymmetries measurements of η-mesons in forward rapidities at 200GeV show significant non-zero values for $x_F>0$, see Fig.3. A clear rising asymmetry is seen for forward x_F ($x_F>0$) ranging from 2% to 20% over the measured range. The p_T dependence of the asymmetries are shown in Fig.5. For $x_F>0.2$, a non-zero asymmetry is seen with $\langle A_N\rangle=0.061 \pm 0.012$. For $x_F<-0.2$, the asymmetry is consistent with zero within 1.7s. Backward asymmetries are consisten with 0 and flat when averaged over x_F within 1.7σ when taking statistical and systematic uncertanties into account. The measured asymmetries are similar to previous $A_N(\pi^0)$ measurements despite differences in isospin, mass, and strangness and potentially different polarized fragmentation functions. See Fig.2. This indicates that initial state spin momentum correlations could play a role or a common spin-momentum correlation is present in the fragmentation of the π^0 and η mesons. Fig.5 includes a comparison with η meson results from E704 (19.4GeV) and STAR (200GeV). For $x_F>0.55$ the STAR A_N measurement may be larger, but are consistent within type-A uncertainites. Fig.5 includes a comparison with twist-3 calculations from [13], The data is consistent with this particular calculation at low and high p_t and x_F, but consistency with mid x_F and p_T is not clear. Theoretical uncertainties are uncertain, and the development of a theoretical framework is underway [14]. With higher statistics data, a double differential measurement of A_N in x_F and p_T could privde a more stringent test of models.

6. Forward A_N for heavy flavor

We have also used our forward muon detectors to measure A_N for J/Ψ at 200GeV. Only color singlet generates SSA, so it is sensitive to production mechanism. A_N is consistent with zero, precision limited by statics, see Fig.6.

We have also measured A_N for single muons from D meson decay, see Fig.6. The production is dominated by gluon-gluon fusion, and the measurement is sensitive to initial state gluon related correlations functions, which are related to the gluon Sivers distribution [15]. A_N

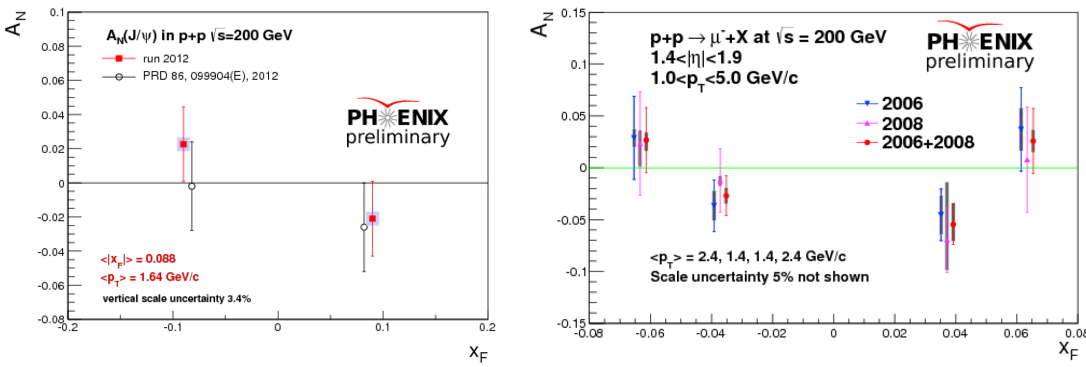

Figure 6: A_N vs x_F for the J/ψ (left) and single muon (right).

is consistent with zero. A large 2012 data sample will increse our sensitivity and a new forward silicon vertex detector will help in rejecting hadrons decay background in Run 15.

7. MPC-EX Upgrade

Upgrades are needed to continue to explore A_N. The MPC-EX proposal was installed for run 15. It is for a 8 layer silicon minipad tungsten sandwich pre-shower detector in front of the lend-tungstate MPC EM in the forward and backward regions. A main motivation is investigate the "sign mismatch" between twist-3 quark gluon distribution function extracted from RHIC and moments of the Sivers function from SIDIS measurements. The Collis fragmentation function may be the explanation. A_N of prompt photons can be used to verify this as they are free of the contribution from the Collins effect [16]. The data from Run 15 is being analyzed.

8. Summary and Outlook

PHENIX has measured transverse single spin asymmetries A_N of various probes at different center-of-mass energies. Central rapidity measurements A_N for π^0 and η constrain the gluon Sivers effect. Forward rapidity measurements include A_N for π^0 and η, EM Clusters including p_T, x_F dependence, single muons, and J/ψ. Comparison with data at different √s and charged pions provides information to constrain Collins, Sivers, and twist-3 effects.

Upgrades will significantly extend physics capabilities. The FVTX will enhance forward heavy-flavor program (μ, J/ψ) and the MPC-EX will enable forward $A_N(\gamma)$ measurements. A proposed new Forward Spectrometer (fsPHENIX) is being proposed for jet correlations/structure and Drell-Yan measurements. The fsPHENIX would also be well matched with ePHENIX [17].

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