

## PHENIX Transverse Spin Measurements

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Transverse single spin asymmetries are sensitive to the dynamic structure of the nucleon. The PHENIX experiment at RHIC has measured transverse single spin asymmetries,  $A_N$ , of various probes at different center-of-mass energies. 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  $\pi^0$  and  $\eta$  mesons at 200GeV, and forward/backward rapidity measurements of  $\pi^0$  at 62.4GeV,  $\eta$ -mesons, EM Clusters, the  $J/\psi$ , and  $\mu$  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.

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## 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,  $A_N$  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 transverse structure of the nucleon, which is largely unknown.

Both initial state and final state effects 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 collinear higher twist description. The Collins picture arises from a correlation between proton and quark spin or transversity, the quark transverse spin distribution, and a spin dependent fragmentation function [4]. A collinear higher twist description involves 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  $\pi^0$  and  $\eta$  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  $J/\psi$  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  $2.25 \times 2.25 \text{ cm}^2$  220cm from the collision vertex. Photon merging effects become significant for  $E > 20 \text{ GeV}$  or  $p_T > 2 \text{ GeV}/c$ . For  $\sqrt{s} = 62$  GeV, 20GeV corresponds to an  $x_F = 0.65$ , so  $\pi^0$  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.  $\pi^0$  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 ( $\pi^0$  fraction drops to 70% above 5GeV). The cluster composition is estimated through a Monte Carlo full detector simulation.

In this contribution, I report on PHENIX transverse spin data taken at 62.4 GeV (2006), and 200 GeV (2006 and 2008). Measurements include  $A_N$  for central arm  $\pi^0$  and  $\eta$  and forward  $\pi^0$ ,  $\eta$ ,  $\mu$ , and  $J/\psi$ .

### 3. Mid-rapidity $A_N$ for $\pi^0$ and $\eta$ mesons

Fig. 1 shows the transverse single spin asymmetries at mid-rapidity for  $\pi^0$  and  $\eta$  mesons as measured in the PHENIX central arms [5]. Compared to previous published results [6], the reach for  $\pi^0$  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  $\eta$  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].

### 4. Forward $A_N$ for $\pi^0$ and $\eta$ mesons

Results are presented in Fig.2 for neutral pions at  $\sqrt{s}=62.4$  GeV 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  $\sqrt{s}$  is apparent from 19.6 GeV to 200 GeV.<sup>2</sup> The backward asymmetries are consistent with zero. The  $\pi^0$  points can be put together with the BRAHMS measurement at same energy and pseudorapidity [8] to

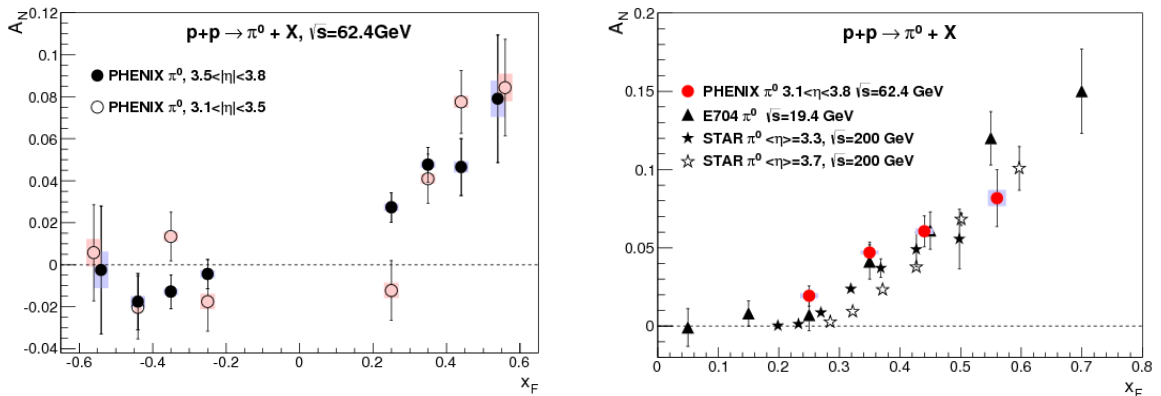


Figure 1:  $A_N$  at mid-rapidity for  $\pi^0$  and  $\eta$  mesons [5].

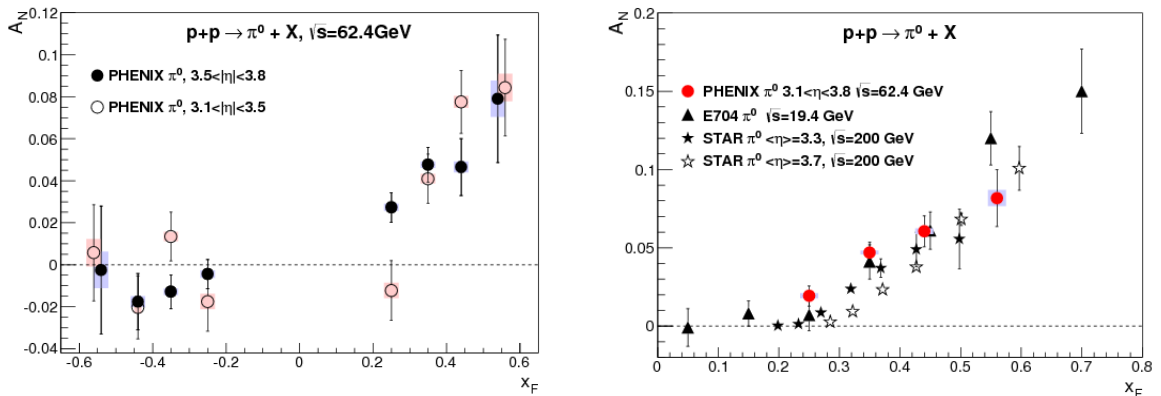


Figure 2: (left)  $A_N$  at forward rapidity for  $\pi^0$  at  $\sqrt{s}=62.4$  GeV; (right) comparison with other energies [5].

<sup>2</sup> Note: there are slight differences in pseudorapidity and/or  $p_T$  between the measurements.

complete the picture [5]. The data cannot be explained by initial state effects of quarks alone, if

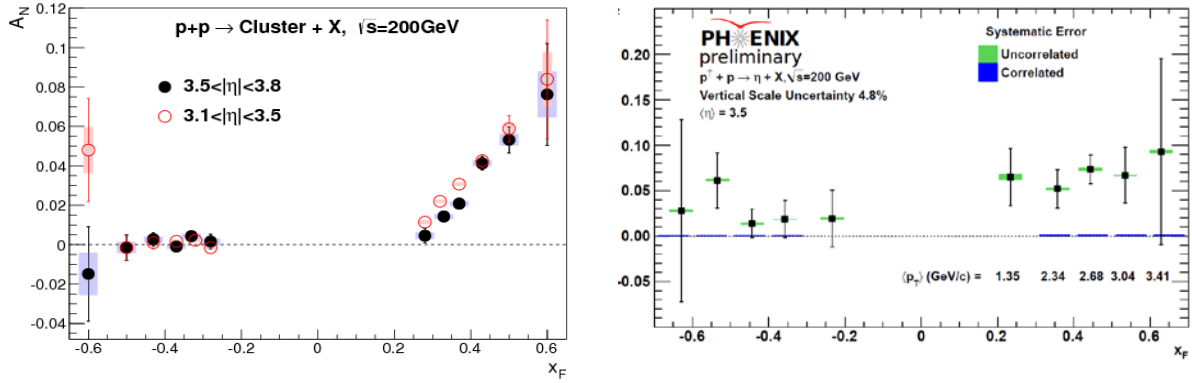


Figure 3:  $A_N$  vs  $x_F$  for EM clusters (left) and  $\eta$  mesons (right) at 200 GeV [5].

you consider just the quark origins of the pions and the Sivers functions extracted from SIDIS.

Because of merging effects, we measure EM clusters at 200 GeV. They are dominated by  $\pi^0$ 's in both the forward and backward directions. Fig. 3 shows  $A_N$  vs  $x_F$  for EM clusters at 200 GeV. The magnitude of forward asymmetries are similar to E704 (at 19.4 GeV) [9] and STAR (at 200 GeV) [10]. We can compare our EM cluster results with STAR  $\pi^0$  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  $p_T$ .

PHENIX has also measured transverse asymmetries of  $\eta$ -mesons in forward rapidities with significant non-zero values for  $x_F > 0$ , see Fig.3. They are comparable to the asymmetries of the  $\pi^0$  in the same kinematic range, where there may be variations due to the isospin dependence, the fragmentation process, and the different masses. Backward asymmetries are close to being zero, although averaged over the whole  $x_F < 0$  range the preliminary results are about  $2\sigma$  positive.<sup>3</sup>

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

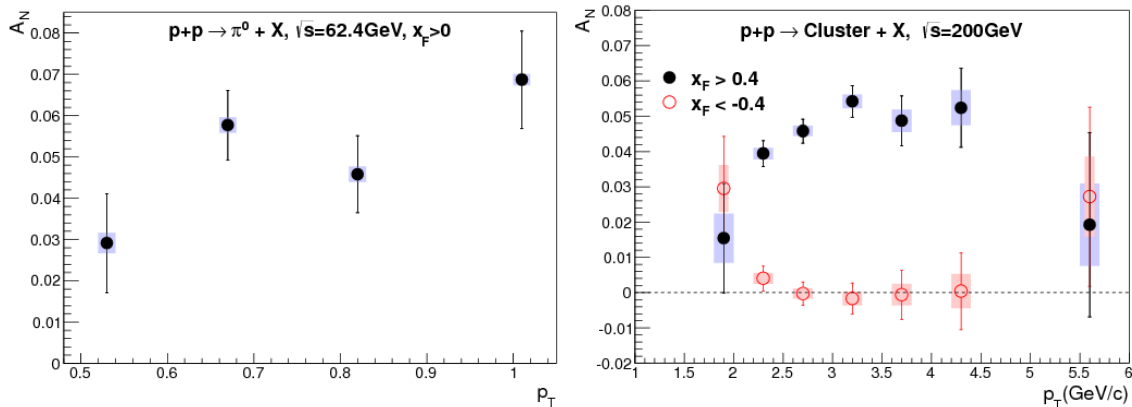


Figure 4:  $A_N$  as a function of  $p_T$  at 62.4 GeV for  $x_F > 0$  (left) and 200 GeV (right) for  $x_F > 0.4$ . [5]

<sup>3</sup> Final results have been since been submitted for publication [11].

larger than  $\Lambda_{\text{QCD}}$ . Where this turnover of the initially rising  $A_N$  happens is largely unknown, however. Cluster asymmetries have an extended  $p_T$  range compared to previous measurements of  $\pi^0$  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  $p_T > 4\text{GeV}$ .

### 5. Forward $A_N$ for heavy flavor

We have also used our forward muon detectors to measure  $A_N$  for  $J/\psi$  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. 5.

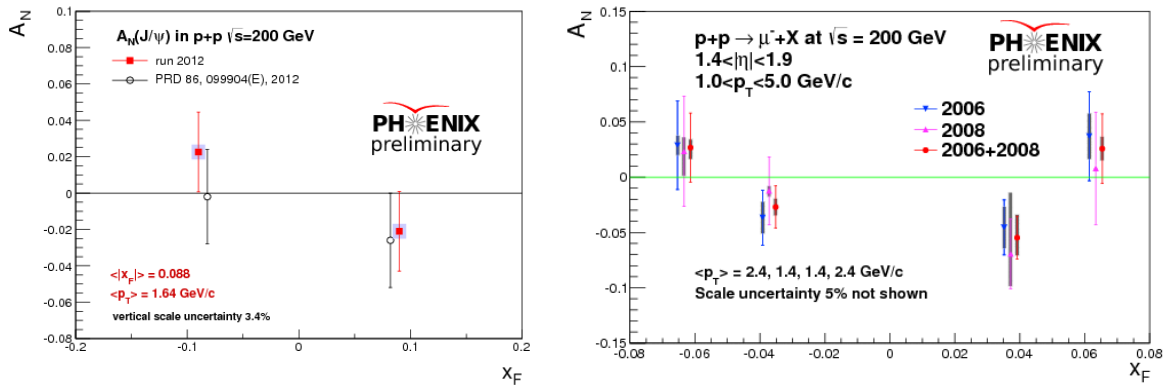


Figure 5:  $A_N$  vs  $x_F$  for the  $J/\psi$  (left) and single muon (right).

We have also measured  $A_N$  for single muons from D meson decay, see Fig. 5. 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 [12].  $A_N$  is consistent with zero. A large 2012 data sample will increase our sensitivity and a new forward vertex detector will help in rejecting hadrons decay background in Run 15.

### 6. MPC-EX Upgrade

Upgrades are needed to continue to explore  $A_N$ . The MPC-EX proposal was approved 2 years ago. 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

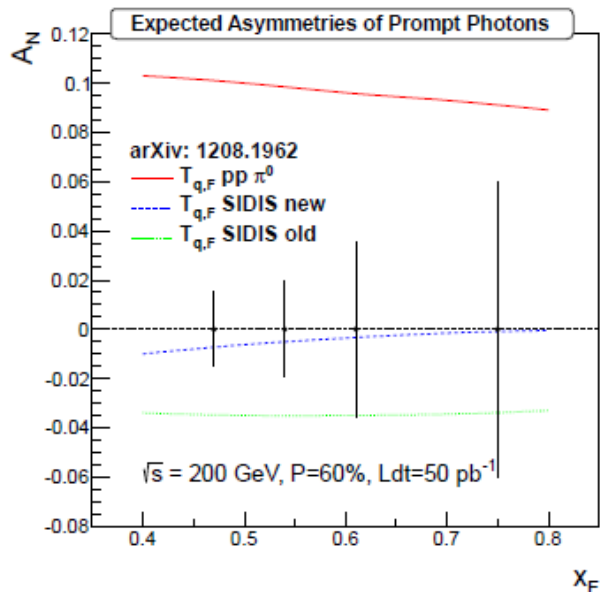


Figure 6: Expected asymmetries of prompt photons.

prompt photons can be used to verify this as they are free of the contribution from the Collins effect. This measurement is expected to occur for Run 15. Fig.6 shows our expected sensitivity compared to extractions from p+p (upper red curve) and SIDIS [13].

## 7. 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  $\pi^0$  and  $\eta$  constrain the gluon Sivers effect. Forward rapidity measurements include  $A_N$  for  $\pi^0$  and  $\eta$ , EM Clusters including  $p_T$ ,  $x_F$  dependence, single muons, and  $J/\psi$ . Comparison with data at different  $\sqrt{s}$  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 ( $\mu$ ,  $J/\psi$ ) 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 [14]. The fsPHENIX would also be well matched with ePHENIX [15].

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