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Transverse Single Spin Asymmetries of charged hadron production from $p+p$ and $p+\mathrm{Au}$ collisions in PHENIX

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Transverse single-spin asymmetries (TSSA) of light hadron production from $p^{\uparrow}+p$ collisions provide valuable information on the spin structure of the nucleon. The TSSA in the process $p^{\uparrow}+p \rightarrow h+X$ has been described in terms of twist-3 spin-dependent three-parton correlation functions, or twist-3 fragmentation functions in the QCD collinear factorization approach. In addition, studying the TSSA for inclusive hadron production in $p^{\uparrow}+A$ collisions can give new insight on the underlying mechanism because different contributions to the TSSA are affected differently by the saturation effect in large nuclei. We will report a recent study on the TSSA of charged hadron production at forward and backward ($1.4<|\eta|<2.4$) rapiditiy over the the transverse momentum range of $1.25<p_T<7.0$ GeV$/c$ and Feynman-x range of $-0.2<x_F<0.2$ from $p^{\uparrow}+p$ and $p^{\uparrow}+\mathrm{Au}$ collisions at $\sqrt{s_{NN}}=200$ GeV in the PHENIX experiment at RHIC. Nonzero A_N is observed in $p^{\uparrow}+p$ while surprisingly smaller A_N is measured in $p^{\uparrow}+\mathrm{Au}$.

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1. Introduction

The origin of the Transverse Single Spin Asymmetry (TSSA) in inclusive single hadron production from transversely-polarized proton-proton collisions ($p^{\uparrow}+p \rightarrow h+X$) is a long standing puzzle for over 40 years. Surprisingly large asymmetries at large $x_F (= \frac{2p_L}{\sqrt{s}})$ persist up to Relativistic Heavy Ion Collider (RHIC) energies. For the case of high p_T inclusive hadron production at RHIC energy, twist-3 collinear factorization within perturbative QCD is appropriate for explaining the TSSA, denoted A_N [1, 2]. In recent years, TSSA in light hadron production in $p^{\uparrow}+A$ collisions ($p^{\uparrow}+A \rightarrow h+X$) has gained attention as it could be an interesting interplay between small-x physics and spin physics [3, 4, 5, 6, 7]. A_N in $p^{\uparrow}+A \rightarrow h+X$ will give a new insight in the effort to pin down the true source of A_N because different contributions to A_N can be affected differently by gluon saturation in the nucleus.

The Relativistic Heavy Ion Collider (RHIC), located at Brookhaven National Laboratory, is the only polarized proton-proton collider. It also has provided data from heavy ion collisions (d, He, Al, Cu, Au, U, etc.). During the 2015 RHIC run, transversely-polarized $p^{\uparrow}+A$(Au, Al) data were collected for the first time. The PHENIX muon spectrometers, shown in Figure 1, are composed of the Muon Tracker (MuTr) and the Muon Identifier (MuID) and cover the full azimuthal angle in the pseudorapidity range $1.2 < |\eta| < 2.4$. The MuTr measures momentum of charged particles and the MuID provides good discrimination between muons and hadrons. Charged hadrons ($\pi^{\pm}, K^{\pm}$) stop partway of MuID while high momentum muons penetrate all MuID layers due to the low probability of interaction with the material of the detector. The calculation of A_N and track quality cuts are based on a recent publication, A_N for $\mu^{\pm}$ from open heavy flavor [8], where the same detector was used.

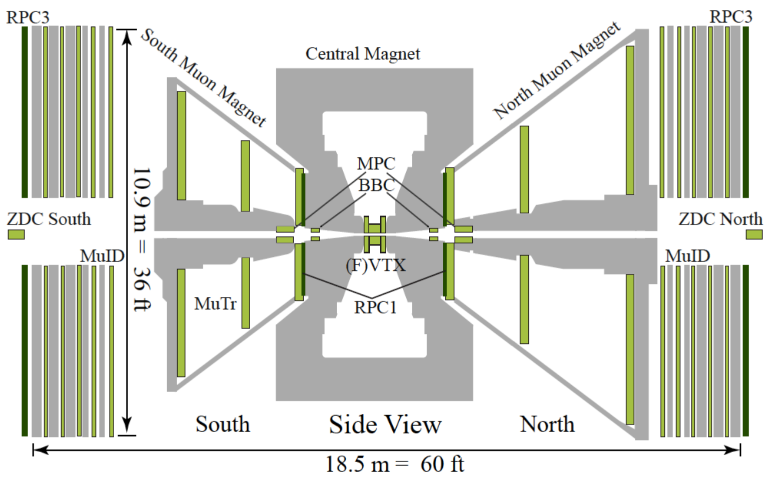

Figure 1: Side view of the PHENIX muon spectometers

2. Results and discussion

Figure 2 (left panel) shows A_N of positively-charged hadrons (π^+, K^+) and negatively-charged hadrons (π^-, K^-) from transversely-polarized $p^{\uparrow}+p$ collisions. At $x_F > 0$, $p^{\uparrow}+p \rightarrow h^+ + X$ shows

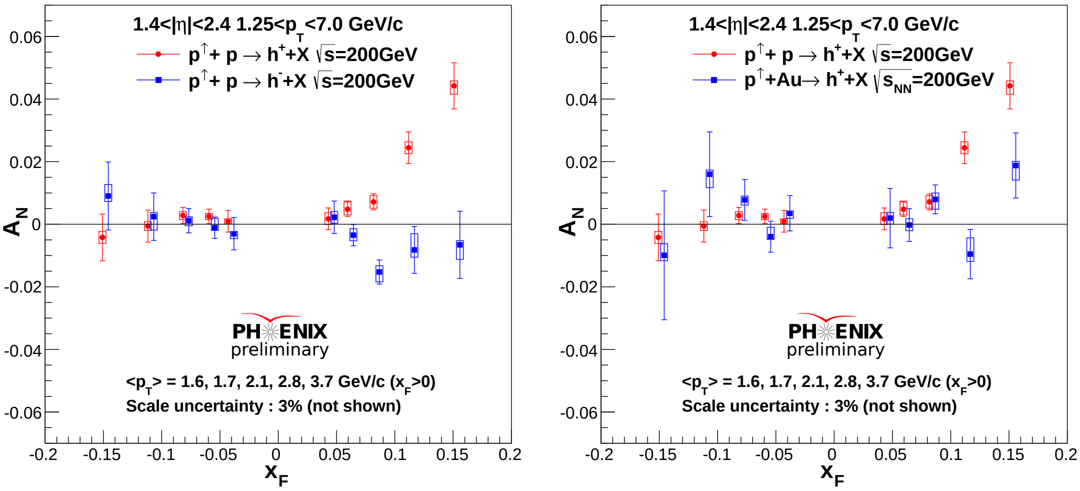

Figure 2: A_N for positively-charged hadrons and negatively-charged hadrons from transversely-polarized $p^{\uparrow}+p$ collisions (left side), and A_N for positively-charged hadrons from $p^{\uparrow}+p$, $p^{\uparrow}+\mathrm{Au}$ collisions (right side) as a function of x_F for $1.4<|\eta|<2.4$, $1.25<p_T<7.0$ GeV$/c$, $0.035<|x_F|<0.2$

a positive A_N. The increasing trend of A_N for increasing x_F is consistent with the global trend of A_N in $p^{\uparrow}+p\to h+X$ at forward rapidity. At $x_F>0.1$, the size and sign of A_N for π^+, K^+ mixture are comparable with the lowest x_F region of previous BRAHMS results, which showed A_N for π^+ and K^+ are positive and comparable in size [9, 10]. Also, A_N for π^- has negative sign and A_N for K^- has positive sign; a cancellation of the A_Ns for π^-, K^- can explain the small size of A_N in $p^{\uparrow}+p\to h^-+X$. A_N at $x_F<0$ is consistent with zero for both charges. Fig. 2 (right panel) shows A_N for positively-charged hadrons from $p^{\uparrow}+p$, $p^{\uparrow}+\mathrm{Au}$ collisions. $p^{\uparrow}+\mathrm{Au}\to h^++X$ at $x_F>0.1$ indicates suppression of A_N for heavy nuclei.

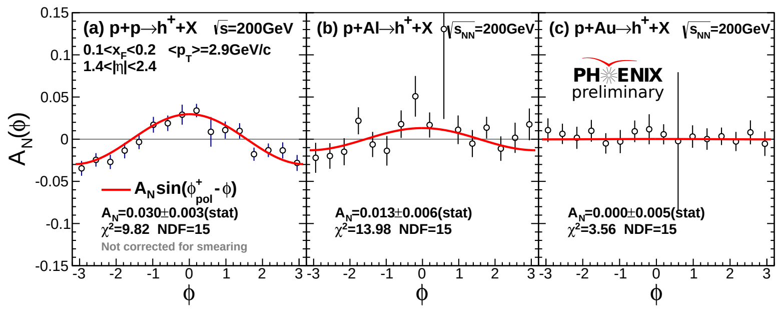

Figure 3: Sine-modulation for positively-charged hadrons at $0.1<x_F<0.2$ from $p^{\uparrow}+p$, $p^{\uparrow}+\mathrm{Al}$, and $p^{\uparrow}+\mathrm{Au}$ collisions. $p^{\uparrow}+\mathrm{Au}$ result shows strong suppression of modulation compared to $p^{\uparrow}+p$ result.

Suppression of A_N in $p^{\uparrow}+A$ is obvious at x_F greater than 0.1. Fig. 3 shows sine-modulations for positively charged hadrons from $p^{\uparrow}+p$, $p^{\uparrow}+\mathrm{Al}$, and $p^{\uparrow}+\mathrm{Au}$ collisions at $0.1<x_F<0.2$. ϕ is the azimuthal angle of each track in the PHENIX lab frame, ϕ_{pol} is the beam polarization direction ($\pm\frac{\pi}{2}$). The modulation is clear in $p^{\uparrow}+p$, weaker in $p^{\uparrow}+\mathrm{Al}$, and disappears in $p^{\uparrow}+\mathrm{Au}$. The systematic uncertainty is not included; only the size of statistical uncertainty is shown. A clear suppression is seen for A_N in p+A.

The direct comparison between $p^{\uparrow}+p$, $p^{\uparrow}+$Al, and $p^{\uparrow}+$Au results is done after including systematic uncertainties. The A-dependence of A_N for positively-charged hadrons at $0.1 < x_F < 0.2$ is calculated from fitting with a function proportional to $A^{-1/3}$. The left panel of Fig. 4 shows the result of the fit where the x-axis is $A^{1/3}$. The fit returns a value close to 1 for the power parameter α, corresponding to an $A^{-1/3}$-dependence. When the total uncertainty is considered, the results favor an A-dependence over the No-A-dependence (α=0). The $\Delta\chi^2$ distribution for the wide range of values for α is shown on the right panel of Fig. 4. The $\Delta\chi^2$ for the case of $\alpha = 0$ is about 21. This rejects the idea of the No-A-dependence of A_N.

Also, $p^{\uparrow}+$Al and $p^{\uparrow}+$Au data are categorized by centrality, 0-40%, 40-72% for $p^{\uparrow}+$Al, and 0-20%, 20-50%, 50-84% for $p^{\uparrow}+$Au. The left panel of Fig. 5 shows the result of the fit where the x-axis is averaged-N_{coll} (N_{coll}^{Avg}). The N_{coll}^{Avg} is the average number of binary nucleon-nucleon collisions and is related to the medium length in the target nucleus. The right panel is $\Delta\chi^2$ distribution for the wide range of values for the power parameter β. The $\Delta\chi^2$ for the case of $\beta = 0$ is about 22. This supports the idea that A_N is affected by the medium length in the target nucleus.

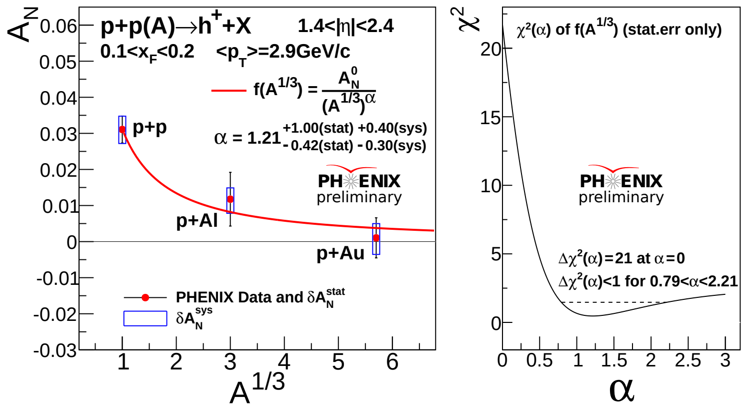

Figure 4: Nuclear dependence of A_N for positively charged hadrons at $0.1 < x_F < 0.2$. The right panel is the $\Delta\chi^2$ distribution of the power parameter α. $\alpha = 0$ corresponds to the No-A-dependence.

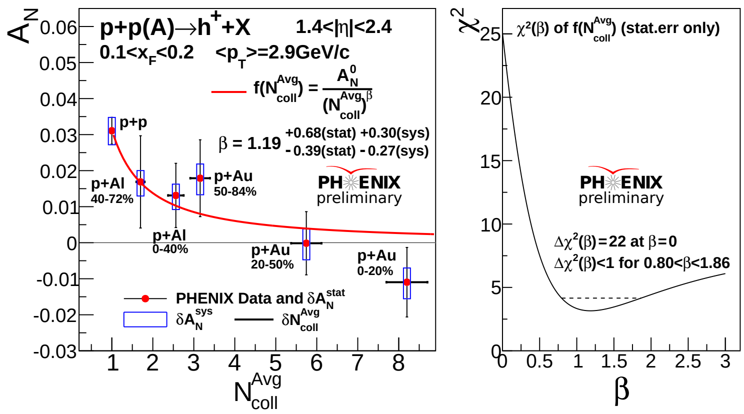

Figure 5: Averaged N_{coll} dependence of A_N for positively charged hadrons at $0.1 < x_F < 0.2$. The right panel is the $\Delta\chi^2$ distribution of the power parameter β. $\beta = 0$ corresponds to the No-N_{coll}^{Avg}-dependence.

3. Summary

The Transverse Single Spin Asymmetry of charged hadron production at $1.4 < |\eta| < 2.4$, $|x_F| < 0.2$ from transversely-polarized $p^{\uparrow}+p$, $p^{\uparrow}+$Al, and $p^{\uparrow}+$Au collisions at $\sqrt{s_{NN}} = 200$ GeV has been measured by the PHENIX experiment. Nonzero A_N is measured in $p^{\uparrow}+p \rightarrow h^{(+)}+X$ at positive x_F. Strong suppression of A_N is observed in $p^{\uparrow}+\mathrm{Au} \rightarrow h^{(+)}+X$ at $0.1 < x_F < 0.2$. A_N for positively-charged hadrons at $0.1 < x_F < 0.2$ indicates an A-dependence and medium length dependence in the target nucleus.

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