Transverse Single Spin Asymmetries from BRAHMS in pp Collisions at 62.4 GeV

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Measurements of x_F-dependents single spin asymmetries of identified charged hadrons $\pi^{\pm}$ and $K^{\pm}$ from transversely polarized p+p collisions at $\sqrt{s}$ =62.4 GeV at RHIC are presented. We also present results for $\pi^{\pm}$ cross sections and comparisons to pQCD at high rapidity. The results bring insight into to mechnisms of transverse spin assymmetries and QCD description of hadronic structure.

1 Introduction

The transverse spin dependence of hadron cross-setions in p+p reactions in the energy regime where perturbative QCD (pQCD) is applicable are expected to be negligibly small [2] in the lowest-order QCD approximation, whereas experimentally large left-right asymmetries have been observed [3, 4] for large Feynman-x. Understanding asymmetries in hadron reactions where a partonic QCD describes unpolarized cross-sections poses a new theoretical challenge and have attracted much attention recently. The main theoretical focus to account for the observed Single Spin Asymmetries (SSAs) in the framework of QCD has been on the role of transverse momentum dependent (TMD) partonic effects in the structure of the initial transversely polarized nucleon (Sivers mechanism)[5] and on the fragmentation process of a polarized quark into hadrons ("Collins" mechanism)[6]. Higher twist effects (twist-3) arising from quark-gluon correlation effects beyond the conventional twist-2 distribution have also been considered as a possible origin of SSA[7, 8]. SSA measurements in p+p at RHIC energies are of particular interest because the next-to-leadingorder (NLO) pQCD calculations for the unpolarized (spin-averaged) meson cross-sections at forward rapidities successfully describe the data[4, 9].

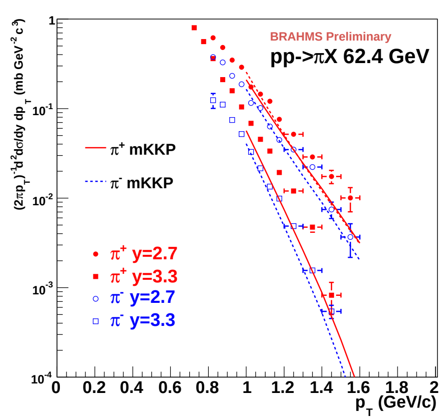

Figure 1: Invariant cross section of π^+ and π^- at rapidity 2.7 and 3.3.

We present measurement of x_F-dependent SSAs of identified charged hadrons, $\pi^{\pm}$ and $K^{\pm}$ from transversely polarized proton-proton collisions at 62.4 GeV at RHIC, comparisons to the lower and higher energies, as well as $\pi^{\pm}$ cross section at high rapidities. The 62.4 GeV SSA data from BRAHMS have just been reported in Ref.[10] with additional details.

2 Results and Discussion

The data presented here were collected with the BRAHMS detector system in pp collisions at $\sqrt{s}$ =62.4 and 200 GeV. The forward spectrometer measured identified charged hadrons in the forward region from 2.3° to 15° at momenta up to 40 GeV/c.Details of the BRAHMS experimental setup can be found in ref. [11].

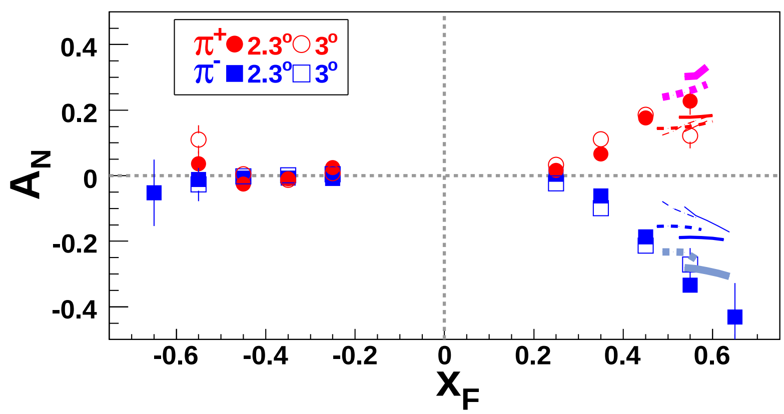

Figure 2: A_N vs. x_F for pions at 62.4 GeV. The curves are from theoretical calculations. Solid lines are to be compared with the data at 2.3° and dotted lines are for 3°. Thick lines are from the initial-state Twist-3 calculations, medium lines are from the final-state Twist-3 calculations, and the predictions from the Sivers function calculations are shown as thin lines.

At 62.4 GeV, where the beam rapidity is 4.2, the spectrometer at forward angle samples produced particle that carries a significant fraction of the available momenta (31.2). Thus particle production is influenced by the proximity to the kinematic limit. Figure 1 shows differential cross sections for π^- for rapidities 2.7 and 3.3. The cross sections changes rapidily with rapidity at high p_T where x_F values up to 0.5 are probed. The data are compared to NLO pQCD in the same figure. The calculation are done in the same manner as for the 200 GeV data using the KPP fragmentation function evalauted at $\mu = p_T$ scale. See Ref.[9] for details. The calculation describe the overall magnitude and shape quite well, though at the highest rapidity there is a tendency for the calculation to fall below the data at the highest p_T. This may be in agreement with the analysis[12] of 53 GeV π^0 data from the ISR at a fixed angle of 5° omparable to the conditions for present measurements (2.3° and 3°), but at larger x_F where NLO pQCD is considerably below the data and with increasing discrepancy with x_F. In contrast to the aforementioned paper we do though conclude that NLO pQCD gives a satisfactory description of the charged pion data at high rapidity, and thus be considered a valid basis for using pQCD base theory to understand SSA.

The SSA is defined as a *left-right* asymmetry of produced particles from the hadronic scattering of transversely polarized protons by unpolarized protons. Experimentally the asymmetry can be obtained by flipping the spins of polarized protons, and is customarily defined as the analyzing power A_N:

$$A_N = \frac{1}{P}\frac{(N^- - LN^-)}{(N^+ + LN^-)}$$

where P is polarization of the beam, L is the spin dependent relative luminosity ($L = L^+/L^-$) and $N^{+(-)}$ is the number of detected particles with beam spin vector oriented up (down). Since both colliding beams are polarized at RHIC, the polarization of "target" protons is averaged over in Eq. 1. The systematic error on the $A_N$measurements is estimated to be 10% including uncertainties from the beam polarization, $\delta P/P \sim 7.2\%$ for the *Blue* beam ($x_F > 0$) and 9.3% for the *Yellow* beam ($x_F < 0$).

The analyzing powers for charged pions, $A_N(\pi^+)$ and $A_N(\pi^-)$ at $\sqrt{s}$ =62.4 GeV as a function of x_F are shown in Fig.2 for the 2.3°and 3° angle settings. At a fixed x_F value, the 3° setting samples higher p_T. The $\langle p_T \rangle$ values at x_F=0.55 are 1.08 and 1.28 GeV/c at 2.3° and at 3°, respectively. The measured $A_N$values show strong dependence in $x_F$reaching large asymmetries up to 40% at x_F 0.6 and no significant asymmetries at negative x_F. The decrease of A_N at high-p_T(p_T>1 GeV/c) and high-x_F, especially for π^+, as shown in Fig. 2 by comparing the two sets of measurements at 2.3° and and at 3° might indicate that A_N is in accordance with the expected powersuppressed nature of A_N[13] The asymmetries and their x_F-dependence are qualitatively in agreement with the measurements from FNAL/E704 at $\sqrt{s}$ =19.3 GeV and also most recent $A_N(\pi^0)$ measurements at RHIC $\sqrt{s}$ =200 GeV [3, 15]. Figure 2 also compares A_N with a pQCD calculation in the range of p_T> 1 GeV/c using *twist-3* parton distributions[7] including the *non-derivative* contributions [13]. In this framework, results of two calculations from the model are compared with the data: One is with only two quark valence densities (u_v,d_v) in the ansatz, which is shown in Fig.2. As the calculations show, the dominant contribution to SSA is from valence quarks with contributions from sea- and anti- quarks small. The calculations, which were done in the same kinematic range as the data, describe the data, within the uncertainties. A_N calculated from the *final-state twist-3* which uses twist-3 fragmentation function for the pion underpredicts the data[14]. The data are also compared with calculations including Sivers mechanism which successfully describe the FNAL/E704 A_N data. The calculations use valence-like Sivers functions[15] for u and d quarks with opposite sign. The calculations underestimate A_N, which indicates that TMD parton distributions are not sufficient to describe the SSA data at this energy. All A_N calculations compared with the data shows $|A_N(+)| \approx |A_N(-)|$ while the data exhibit $|A_N(+)| < |A_N(-)|$ where p_T< 1 GeV/c.

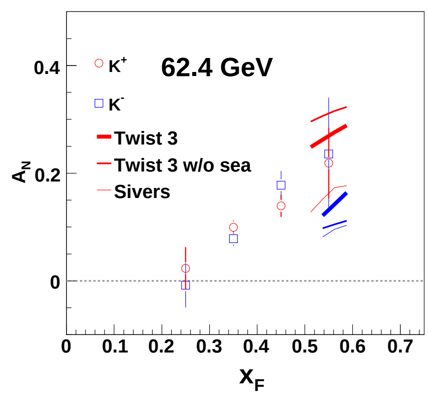

Figure 3: SSA of K^+ and K^- vs. x_F at 62 GeV. Circle symbols are for K^+ and box symbols are for K^-. The solid (K^+) and dotted (K^- lines are from the initial-state twist-3 calculations with (thick lines) and without (medium lines) sea- and anti-quark contribution. Calculations for the Sivers function are shown as thin lines.

The SSAs for charged kaons as a function of x$_F$ are shown in Fig.3 together with twist-3 and Sivers calculations (see the figure caption for details). The asymmetry for $K^+(u\bar{s})$ is positive as is the A$_N$ of $\pi^+(u\bar{d})$, which is expected if the asymmetry is mainly carried by valence quarks, but the measured positive SSAs of $K^-(\bar{u}s)$ seem to contradict the naive expectations of valence quark dominance. The current calculations for kaon asymmetries at 62.4 GeV need an extra or a different mechanism to account for positively non-zero A$_N(K^-)$ at similar level of A$_N(K^+)$ as shown in Fig.3.

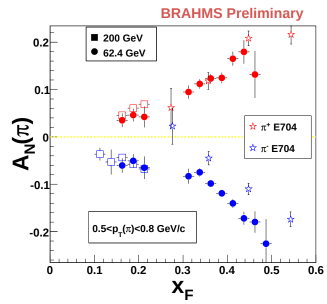

Figure 4: Comparison of pion A$_N$of 200, 62 and 19 GeV for a selected p_T-range.

The two sets of data at $\sqrt{s}$ =20 GeV and 200 GeV cover a similar kinematic range in x$_F$ and p_T. The measurements show that SSAs for pions are energy independent to first approximation.This is demonstrated in Fig. 4 where we compare the data from 62 and 200 GeV in a selected p_T-range of $0.8 - 1.0$GeV$/c$ and with the E704 data for p_T> 0.7GeV$/c$. For the π^+a remarkable overlap of SSA is observed, while the $\pi^-$are absolutely lower at the lower energy. Since pQCD description of cross-sections at the high-energy region is quite successful, while it fails at the low energy domains, it might imply that the dominant mechanism responsible for the large SSAs at the two different energies are a manifestation of two different phenomena. It is though intriguing and should be kept in mind when describing the x$_F$-dependence of SSA at both low and high energy.

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