# SINGLE SPIN ASYMMETRIES OF IDENTIFIED CHARGED HADRONS IN POLARIZED P+P AT $\sqrt{S} = 200$ GEV*

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Measurements of the single spin asymmetries of identified charged hadrons, $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$, from transversely polarized proton collisions at $\sqrt{s} = 200$ GeV are presented. The flavor dependent asymmetries combined with the cross-sections bring new insight into the perturbative Quantum Chromodynamical description of partonic dynamics at RHIC.

At leading twist in massless pQCD, single spin asymmetries (SSA) in semi-inclusive reactions at high energy are expected to be negligible, whereas large SSAs have been observed at high $x_F$[1]. Main theoretical focuses to account for the observed SSA have been on the role of partonic transverse momentum effects in the structure of the initial transversely polarized nucleon[2] and the fragmentation process of a polarized quark into hadrons[3]. Higher twist effects arising from quark-gluon correlations have been also considered as a possible origin of SSA[4]. Recently, SSA measurements in $p_{\uparrow}+p$ at $\sqrt{s} = 200$ GeV have been reported[5]. The measurements at this energy are particularly interesting because the next-to-leading-order (NLO) pQCD calculations for the unpolarized cross-section are successfully describing the data, whereas the numerical calculations get almost an order of magnitude smaller than the measurements at $\sqrt{s} \sim 20$ GeV where FNAL/E704 observed large SSAs. The two sets of data cover approximately the same $x_F$ range and the measurements show that SSA is energy independent to a first approximation. This might imply that the $A_N$ at two different energies are manifestation of two different phenomena.

We present here measurements of SSA and cross-sections for $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$ at $\sqrt{s} = 200$ GeV. A simultaneous description of $A_N$ and the

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unpolarized cross-section for different quark flavor in wide kinematic range will be a crucial test for partonic pQCD description. In particular flavor dependent SSA measurements allow more complete and stringent tests of theoretical models due to flavor dependence in fragmentation processes. The asymmetry or analyzing power $A_N$ is defined as

$$A_N = \frac{1}{\mathcal{P}} \frac{(N^+ - \mathcal{L}N^-)}{(N^+ + \mathcal{L}N^-)}, \tag{1}$$

where $\mathcal{P}$ is polarization of the beam, $\mathcal{L}$ is the spin dependent relative luminosity ($\mathcal{L} = \mathcal{L}_+/\mathcal{L}_-$) and $N^{+(-)}$ is the number of detected particles with beam spin vector oriented up (down).

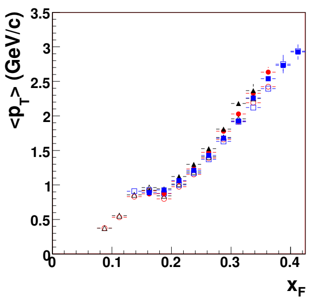


Figure 1. Average $p_T$ vs. $x_F$ for pions (circles), kaons (triangles), and protons (squares) for the data used in the analysis. Solid symbols are for positive particles and open symbols are for negative particles.

The data presented here were collected with the BRAHMS detector system[6] from RHIC-Run5 with recorded integrated luminosity corresponding to 2.4 pb$^{-1}$ of polarized p+p at $\sqrt{s}$ = 200 GeV. The Forward Spectrometer (FS) in BRAHMS has unique capability of measuring tracks in forward kinematic region ($\theta$ = $2.3° - 15°$) with good momentum resolution and particle identification (PID). The momentum ($p$) resolution is estimated to be $\delta p/p \approx 1\%$ at $p = 22$ GeV/$c$. The PID separation of pions and kaons is up to $p \sim 35$ GeV/$c$ and protons can be identified up to 45 GeV/$c$. The acceptance for the data taken with FS at 2.3° and 4° as a function of $\langle p_T \rangle$ and $x_F$ in Fig. 1. The luminosity was measured using the "CC" counter which is a set of Cherenkov radiators placed symmetrically with respect to the nominal interaction point. The counters cover pseudo-rapidity ($\eta$) range in $3.26 < \eta < 5.25$, and are estimated to be sensitive to 70% of the total inelastic cross-section of 41 mb.

The inclusive cross-sections are presented in Fig. 2. The curves on the plots are NLO pQCD calculations evaluated at the same rapidity ranges using different sets of fragmentation functions (FF). The modified "Kniehl-Kramer-Pötter" (mKKP)[7,8], tends to agree with the data better than "Kretzer"[9] FF for pions and kaons. To describe protons, "Albino-Kniehl-

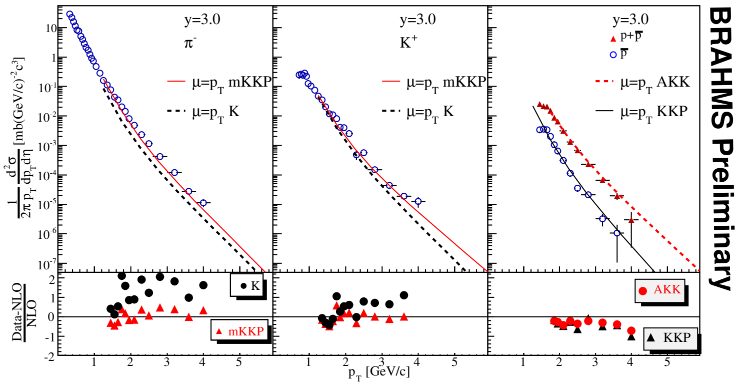


Figure 2. Comparisons between cross-sections for $\pi^-$, $K^+$, and $p+\bar{p}$ production at $y = 2.95$ and the NLO calculations. The ratios (Data-NLO)/NLO are shown in the bottom panels.

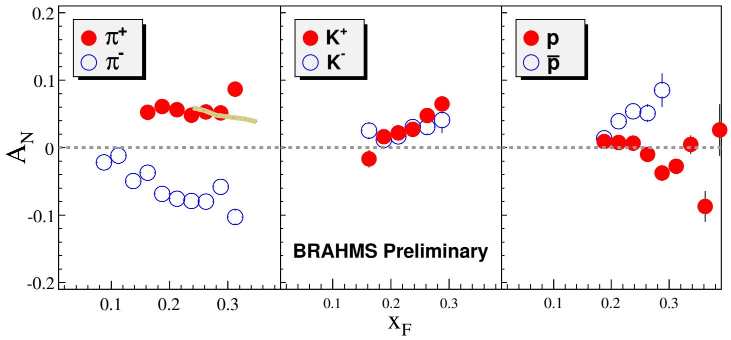


Figure 3. $A_N$ vs $x_F$ for pions, kaons, and protons. Solid symbols are positive particles and open symbols are for negative particles. The curve drawn on $A_N(\pi^+)$ is from "Twist-3" calculations[4]. Errors are statistical only.

Kramer" (AKK) parameterization[10] is utilized. The AKK FF assumes dominance of gluon fragmentation in $p$ and $\bar{p}$ production, but that assumption contradicts to the measurements of $\bar{p}/p$ in this kinematic range[11].

The analyzing power $A_N$ for charged hadrons is a function of $x_F$ are shown in Fig. 3. The systematic error is estimated to be 30% including uncertainties from the beam polarization ($\sim$ 15%). The $A_N$ values are positive for $\pi^+$ and negative for $\pi^-$ increasing with $x_F$ in the range of 2-10%. The asymmetries and their $x_F$-dependence are qualitatively in agreements with the measurements at lower $\sqrt{s}$ and also $A_N(\pi^0)$ measurements at RHIC[1,5].

Figure 3 compares $A_N(\pi^+)$ with one of the pQCD calculations in the range of $p_T > 1$ GeV/$c$ using "Twist-3" parton distributions[4]. The calculation seems to describe the data in the kinematic range compared. The kinematic reach of the measurements is limited by statistics and PID to fully explore the differences among the pQCD-based models, flavor dependence of the $A_N$ measurements will provide extra constraints on theoretical models. $A_N(K^+)$ is measured as positive at the kinematic ranges shown in Fig. 3. The measured non-zero SSAs of $K^-$ and $\bar{p}$ seem to be contradictory to näive expectations[12] that spin asymmetries are mainly carried by valence quarks not sea quarks. This result might imply that the main feature of quark fragmentation which influences the value of the SSA is the relative importance of sea and valence quark contributions. Protons show no significant asymmetries, but requires more understanding on the production mechanism to theoretically describe the behavior because a significant fraction of the protons might still be from the polarized beam fragments under the constraint of baryon conservation at this kinematic range.

In summary, BRAHMS has measured SSAs and cross-sections for inclusive charged hadron production at forward rapidities in $p_{\uparrow}+p$ at $\sqrt{s}$ = 200 GeV. The differential cross-section and $A_N$ of pions are in general consistent with pQCD calculations, but $A_N$ of kaons and protons suggests manifestation of non-pQCD phenomena and/or a call for more theoretical modeling with good understanding of the fragmentation processes. The SSA and cross-section measurements of identified hadrons allow more complete and stringent tests of theoretical models of partonic dynamics in the RHIC energy regime.

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