Analyzing Powers in Inclusive Pion Production at High Energy and Nucleon Spin Structure

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Against naive predictions of perturbative QCD, significant polarizations of produced hyperons and large analyzing powers in produced pions from a transversely polarized nucleon are observed at low transverse momentum p_T and high Feynman $x_F(=2p_L/\sqrt{s}$ in CM, p_L is the longitudinal momentum of the observed hadron) region. These data indicate some non-perturbative mechanism being intact for these spin phenomena. These subjects have been studied experimentally and theoretically for a long time. We conducted research on polarizations and analyzing powers in inclusive hadron productions based on the quark recombination mechanism. This model is a simple relativistic model for recombinations of quarks and/or diquarks to produce a final state hadron with quark distribution functions in incident hadrons and wave functions in the final state hadron. This model reproduces the empirical rule of DeGrand and Miettinen(DM)[1], and calculated polarizations and asymmetries are in good agreement with experiments[2].

In this work, we concentrate on the transverse single spin asymmetry in $\vec{p}+p\rightarrow\pi^a+X$ (the analyzing power of a produced pion) at high x_F. The original QRC Model as well as DM rule predict the relative magnitudes of analyzing powers in π^+, π^- and π^0 as $A_N(\pi^+)$: $A_N(\pi^-)$: $A_N(\pi^0)$ = 2 : −1 : 1, and cannot describe the experimental data $A_N(\pi^+)$: $A_N(\pi^-)$: $A_N(\pi^0) \sim 2:-2:1$. Our aim is to improve of QRC model to so as to account for the experimental data.

We outline the QRC model which is designed to describe the inclusive pion production for low p_T and high x_F. In this model, a fast valence quark in projectile proton picks up one of the slow antiquarks created by the collision in order to form a final state pion. This difference of momenta of quark and antiquark is indispensable to induce the spin dependence of the production cross section. Our model is based on the following assumptions; [*a.*]The produced hadron is formed by direct recombination process, since significant polarizations are observed in the high x_F region. [*b.*]Each parton which participates in this reaction has the intrinsic transverse momentum distribution. [*c.*]Quark and antiquark are recombined by the scalar confinement interaction in the hadronization process. [*d.*]$SU(6)$ spin-flavor symmetry is assumed for the initial and final state hadron structure.

The pion production probability in the Infinite Momentum Frame(IMF) is given by

$$S_{p\rightarrow\pi}=\int[dx_idy_idz_i/x_i]G_\pi(x_3,x_4,y_3,y_4,z_3,z_4)$$
$$\times|M(x_i,y_i,z_i)|^2 f_{\bar{q}}(x_2,y_2,z_2)G_{q/p}(x_1,y_1,z_1)\Delta^3\Delta^4 \qquad (1)$$

where we choose the x-axis as the beam direction and z as the orientation of the initial proton spin , Δ^3 and Δ^4 express the delta functions which correspond to energy-momentum conservation in this process. x_i are the longitudinal momentum fraction ($0\leq x_i\leq 1$) and y_i, z_i the transverse momentum fractions. M is the scattering amplitude of $q_1+\bar{q}_2\rightarrow q_3+\bar{q}_4$ process under the confining color field. For the valence quark momentum distribution in proton, we assume the factorization form; $G_{q/p}(x_1,y_1,z_1)=q_{q/p}(x_1)\ \exp[-(y_1^2+z_1^2)]$, where the longitudinal momentum distribution $q_{q/p}(x_1)$ is the quark distribution function in the proton extracted from deep inelastic scattering experiments. $f_{\bar{q}}$ is the momentum distribution of the picked-up antiquark and G_π the pion wave function. The π^+ production is dominated by the valence u-quark in proton $q_{q/p}(x_1) = u(x_1)$, and π^- case by the valence d-quark.

Finally, we obtain the analyzing power of the final state pion as follow;

$$A_N(\pi) \quad = \quad R\frac{\int[dx_i\ dy_i\ dz_i/x_i]G_\pi\ \sigma_{dep}\ f_{\bar{q}}\ \delta G_{q/p}\ \Delta^4\Delta^3}{\int[dx_i\ dy_i\ dz_i/x_i]G_\pi\ \sigma_{ind}\ f_{\bar{q}}\ G_{q/p}\ \Delta^4\Delta^3} \tag{2}$$

where σ_{dep} and σ_{ind} denote the spin-dependent scattering and the spin-independent amplitudes, respectively. R involves *unknown* underlying dynamics of the confinement force, and is simply assumed to be a constant parameter which will be fixed to reproduce the π^+ analyzing power. $\delta G_{q/p}(x,y,z) = \delta q_{q/p}(x)\ \exp[-(y^2+z^2)]$, $\delta q_{q/p}(x)(\equiv q_{q_\uparrow/p}(x) - q_{q_\downarrow/p})$ is the spin dependent momentum distribution function.

In eq.(2), resulting analyzing powers are rather insensitive to the shapes of G_π and $f_{\bar{q}}$, because we take the ratio. Therefore, we point out that the large Bjorken x behavior of the quark distribution functions of the incoming proton, $q(x_1)$ and $\delta q(x_1)$, mainly controls the analyzing power of pions. In other words, $A_N(\pi^+)$ is sensitive to the shape of $\delta u(x)/u(x)$ of the proton and so on. If we assume the $SU(6)$ spin-flavor asymmetry for the proton, $\delta q(x)$ are written by $\delta u(x) = (2/3)u(x)$, $\delta d(x) = (-1/3)d(x)$ with $u(x) = 2d(x)$ for unpolarized distribution functions. Inserting them into eq. (2), one easily finds $A_N(\pi^+) : A_N(\pi^-) = 2 : -1$, which disagrees with experiments. However, it is well known from deep inelastic experiments that valence quark distribution functions of the nucleon at large Bjorken x are clearly different from the $SU(6)$ symmetry expectations. Here, we introduce the spin dependent distribution function $\delta q(x)$ in the following simplified form to mimic the shapes of the experimental data on the ratio of the spin-dependent to spin-independent structure functions of the proton $g_1^p(x)/f_1^p(x)$; $\delta u(x)/u(x) = \sqrt{x}$, $\delta d(x)/d(x) = -\sqrt{x}$. Results of our calculation with these distribution are showed in Fig.1. For π^0 production case, details are found in ref. [3].

In conclusion, we have studied the analyzing powers in inclusive pion productions $\vec{p} + p \to \pi^a + X$ at high x_F in terms of the quark recombination model. We have particularly emphasized that the analyzing power is sensitive to the large Bjorken x dependence of the spin distribution function in the nucleon. Once we take into account the realistic quark distribution functions which deviate from the $SU(6)$ predictions at large Bjorken x, as suggested by the deep inelastic scattering and effective quark model calculations, resulting analyzing powers show reasonable agreement with the data. These results may indicate that the spin dependent inclusive hadron production at the high x_F region, which are accessible at RHIC and HERA-N, is a complemental tool to probe the valence quark spin structure of the nucleon at large x.

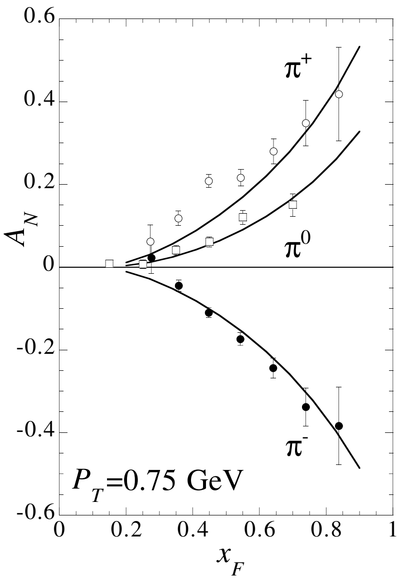

Figure 1: *Analyzing powers of pions produced by $\vec{p}p$ collision.*

References

[1] T.A. DeGrand and H.I. Miettinen, Phys. Rev. **D23** (1981) 1227.
[2] Y. Yamamoto, K.-I. Kubo, H. Toki, Prog. Theor. Phys. **98** (1997) 95
[3] K. Suzuki, N. Nakajima, H. Toki and K.-I. Kubo, to appear in Mod. Phys. .Lett. A