Transversity Distributions and Drell-Yan Spin Asymmetries

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We discuss transversity distributions and Drell-Yan transverse double spin asymmetries. First, the antiquark flavor asymmetry $\Delta_T\bar{u}/\Delta_T\bar{d}$ is discussed by using two different descriptions, a meson-cloud model and a Pauli exclusion model. We find that both calculations produce a significant $\Delta_T\bar{d}$ excess over $\Delta_T\bar{u}$. Next, we study its effects on the transverse spin asymmetry A_{TT} and on the Drell-Yan proton-deuteron asymmetry $\Delta_T\sigma^{pd}/2\Delta_T\sigma^{pp}$. We find that the ratio $\Delta_T\sigma^{pd}/2\Delta_T\sigma^{pp}$ is very useful for investigating the flavor asymmetry effect.

1. INTRODUCTION

Since the discovery of a serious spin problem, the internal spin structure of the nucleon has been a popular topic. Using many experimental data on g_1, we have a rough idea on the longitudinally polarized parton distributions. On the other hand, the transversity distributions $\Delta_T q$ have not been measured at all because they cannot be measured in the usual inclusive deep inelastic scattering. They are expected to be measured in the transversely polarized Drell-Yan process at RHIC and semi-inclusive process at HERA. We should try to understand the properties of $\Delta_T q$ before the experimental data are taken.

The Q^2 evolution of the transversity distributions has been already investigated in detail including the next-to-leading-order (NLO) effects [1]. Using these results, we investigate the antiquark flavor asymmetry in the transversity distributions [2]. Now, it is well known that light antiquark distributions are not flavor symmetric [3] according to the NMC, NA51, E866, and HERMES experimental data. In particular, the recent E866 result revealed the x dependence of the ratio $\bar{d}/\bar{u}$ by measuring the Drell-Yan proton-deuteron asymmetry. The antiquark flavor asymmetry in the polarized distributions is also expected to exist. However, it is not known at this stage except for a few theoretical predictions [4,5]. Because the polarized antiquark distributions are measured at RHIC, it is important to investigate a possible asymmetric distribution. In this paper, we calculate the transversity flavor asymmetry by using the nonperturbative models. Then, obtained results are used for calculating the transverse double spin asymmetry A_{TT} at a RHIC energy. Furthermore, we discuss the flavor asymmetry effects on the Drell-Yan proton-deuteron asymmetry $\Delta_T\sigma^{pd}/2\Delta_T\sigma^{pp}$.

2. ANTIQUARK FLAVOR ASYMMETRY

The contribution from the perturbative QCD is considerably small [1] as far as the Q^2 evolution in the range $Q^2 \geq 1$ GeV^2 is concerned. Therefore, we expect the antiquark flavor asymmetry comes almost from the non-perturbative mechanisms. As such mechanisms, a meson-cloud and a Pauli exclusion principle models are typical in discussing the unpolarized $\bar{u}/\bar{d}$ asymmetry [3]. We try to apply these mechanisms to the polarized distributions [2]. Since we have no experimental information about transversity distributions, we calculate the flavor asymmetry in the longitudinally polarized distributions at first. Then, we assume the transversity distributions are equal to the longitudinal distributions at small Q^2 by using the prediction of the nonrelativistic quark model.

First, we discuss the meson-cloud model. In this model, we calculate the meson-nucleon-baryon (MNB) process in which the initial nucleon splits into a virtual meson and a baryon, then the virtual photon from lepton interacts with

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this meson. Because the lightest vector meson is the ρ meson, we calculate the ρ-meson contribution to the flavor asymmetry in the polarized distributions. The contributions from this kind of process can be expressed by the following convolution integral:

$$\Delta\overline{q}(x,Q^2)=\int_x^1\frac{dy}{y}\Delta f_{\rho NB}(y)\Delta\overline{q}_\rho(\frac{x}{y},Q^2)\ , \quad (1)$$

where the function $\Delta f_{\rho NB}$ represent the ρ-meson momentum distribution due to the ρNB process and the function $\Delta\overline{q}_\rho$ represent the polarized antiquark distribution in the ρ meson. In our analysis, nucleon and Δ are taken into account as a final state baryon and all the possible ρNB processes are considered. Since the dominant contribution comes from the ρ^+ meson which has a valence $\bar{d}$ quark, the meson-cloud contribute $\Delta\bar{d}$ excess over $\Delta\bar{u}$. Note that the ρ-meson effects are also studied in Ref. [5] by using the slightly different method from ours in the calculation of $\Delta f_{\rho NB}$.

Next, we discuss the Pauli exclusion model. Because there already exist some studies on this mechanism in the polarized case [4], we simply use their results. According to the SU(6) quark model, we have each quark state probability as $u^\uparrow=5/3$, $u^\downarrow=1/3$, $d^\uparrow=1/3$, and $d^\downarrow=2/3$ in the proton spin-up state. Since the probability of $u^\uparrow$ ($d^\downarrow$) is much larger than that of $u^\downarrow$ ($d^\uparrow$), it is more difficult to create $u^\uparrow$ ($d^\downarrow$) sea than $u^\downarrow$ ($d^\uparrow$) sea because of the Pauli exclusion principle. Then, assuming that the exclusion effect is the same as the unpolarized, $(u_s^\downarrow-u_s^\uparrow)/(u_v^\uparrow-u_v^\downarrow)=(d_s-u_s)/(u_v-d_v)$ and a similar equation for $d_s^\uparrow-d_s^\downarrow$, we have $\Delta\overline{u}=-0.13$ and $\Delta\overline{d}=+0.05$. As a result, we find that the flavor asymmetry from this mechanism.

The both models should be valid only at small Q^2, so that the GRSV parametrization at Q^2=0.34 GeV^2 is chosen in our calculation. The obtained results for the $\Delta_T\bar{u}-\Delta_T\bar{d}$ distribution are shown at $Q^2=10$ GeV^2 in Figure 1. From this figure, we find that both model predictions have similar tendency, namely, $\Delta_T\bar{d}$ excess over $\Delta_T\bar{u}$. However, the meson contributions seems to be smaller than those of the exclusion model. Recently, a flavor asymmetric distribution was proposed by analysing deep inelastic semi-inclusive data [6]. Our distributions are consistent with their result because the accuracy of the present semi-inclusive data is insufficient to find accurate flavor asymmetry.

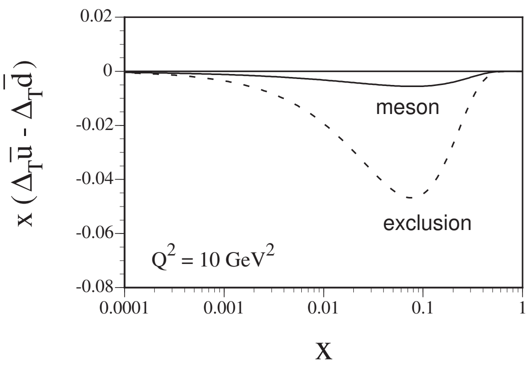

Figure 1. Flavor asymmetric distribution.

3. TRANSVERSE DOUBLE SPIN ASYMMETRIES

The transversity distributions will be studied by measuring the Drell-Yan transverse double spin asymmetries A_{TT} at RHIC. In this section, we discuss the flavor asymmetry effects on A_{TT}. We calculate A_{TT} with NLO contributions at the RHIC energy $\sqrt{s}=200$ GeV by using the flavor symmetric and the flavor asymmetric parton distributions.

The results are shown in Figure 2 as the function of dimuon mass square. The solid, dashed, and dotted curves represent the flavor symmetric, meson-cloud, and Pauli exclusion results, respectively. From this figure, we find that the magnitude of A_{TT} is about 1% in the dimuon mass region $100<M_{\mu\mu}^2<500$ GeV^2. Furthermore, we find that the flavor asymmetric results are considerably different from the flavor symmetric one. However, the differences are not enough to find the flavor asymmetry effects because we may change the magnitude of the transversity distributions so as to agree with the experimental data. Although the longitudinal flavor asymmetry $\Delta\bar{u}/\Delta\bar{d}$ should be investigated by the $W^{\pm}$ production processes, the transversity asymmetry cannot be measured by the $W^{\pm}$. Therefore, we should think about possible measurements in order to investigate the $\Delta_T\bar{u}/\Delta_T\bar{d}$ asymmetry.

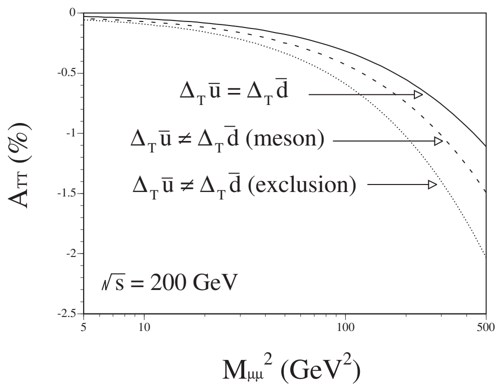

Figure 2. Transverse double spin asymmetry.

4. DRELL-YAN PROTON-DEUTRON ASYMMETRY

As the alternative candidate for finding the transversity flavor asymmetry $\Delta_T\bar{u}/\Delta_T\bar{d}$, we propose to use the polarized proton-deuteron Drell-Yan process in combination with the polarized pp process [2,7]. Recently, a general formalism for the polarized pd reactions was completed [7]. From their parton model analysis, the Drell-Yan proton-deuteron asymmetry $\Delta_T\sigma^{pd}/2\Delta_T\sigma^{pp}$ is expressed by transversity distributions in the proton and the deuteron. If we neglect the nuclear effects in the deuteron and assume the isospin symmetry, the Drell-Yan p-d asymmetry in the large x_F $(=x_A - x_B)$ region is approximately given by the following equation:

$$\frac{\Delta_T\sigma^{pd}}{2\Delta_T\sigma^{pp}} \approx \frac{\left[1+\frac{1}{4}\frac{\Delta_T d(x_A)}{\Delta_T u(x_A)}\right]\left[1+\frac{\Delta_T\bar{d}(x_B)}{\Delta_T\bar{u}(x_B)}\right]}{2\left[1+\frac{1}{4}\frac{\Delta_T d(x_A)}{\Delta_T u(x_A)}\frac{\Delta_T\bar{d}(x_B)}{\Delta_T\bar{u}(x_B)}\right]}, \quad (2)$$

where the x_A and x_B represent the momentum fractions in the hadron A (proton) and the hadron B (deuteron). From this equation, the ratio clearly becomes one if $\Delta_T\bar{u}$ is equal to $\Delta_T\bar{d}$. Therefore, if we find that the data which is different from one, it suggests the flavor asymmetry.

We calculate the ratio $\Delta_T\sigma^{pd}/2\Delta_T\sigma^{pp}$ by using the flavor symmetric and the flavor asymmetric distributions [2]. As a result, we find that the flavor symmetric result becomes almost one in the large x_F region as discussed above although the meson-cloud and the Pauli exclusion results are significantly different from one. From this analysis, we conclude that the Drell-Yan p-d asymmetry is very useful for investigating the light antiquark flavor asymmetry in the transversity distributions. We mention that the p-d asymmetry should be also used for studying the flavor asymmetry in the longitudinally polarized distributions in a similar way. At this stage, there are no project to measure the polarized proton-deuteron Drell-Yan process. However, we expect it is possible in the future RHIC, FNAL, or HERA experiment.

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