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Information on their research is available at http://www.cc.saga-u.ac.jp /saga-u/riko/physics/quantum1/structure.html.

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SPIN ASYMMETRIES AT RHIC AND POLARIZED PARTON DISTRIBUTIONS

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We discuss polarized parton distributions and their effects on spin asymmetries at RHIC. In particular, transversity distributions and transverse spin asymmetry are studied. First, we show the Q^2 evolution difference between a transversity distribution and a corresponding longitudinally polarized distribution. The difference could be an important test of perturbative QCD in high-energy spin physics. Then, the transverse spin asymmetry A_{TT} is calculated with possible transversity distributions. Next, we study antiquark flavor asymmetry $\Delta_T \bar{u}/\Delta_T \bar{d}$ in the transversity distributions by using a simple model. Its effects on the transverse spin asymmetry are also discussed.

1 Introduction

It is important to test the proton spin structure through transversely polarized structure functions, particularly the leading-twist structure function h_1. There are three major reasons for investigating the transversity distribution h_1, which is often denoted as $\Delta_T q$ or δq. The first reason is to test our knowledge of high-energy spin physics in another spin observable in addition to the longitudinally polarized ones. The second is to study a relativistic aspect of nucleon structure. Because nonrelativistic quark models predict the same transversity distribution as the longitudinally polarized one, the difference could reflect the relativistic aspect. The third could be more important. Because the transversity Q^2 evolution is very different from the longitudinal one as shown in section 3, the difference is a good test of perturbative QCD in spin physics.

The transversity distributions are expected to be measured in the transversely polarized Drell-Yan process at RHIC. We should try to understand the properties of h_1 before the experimental data are taken. In this paper, we discuss the Q^2 evolution of the transversity distributions [1,2] and compare its results with those of the longitudinally polarized ones. [3] Then, the transverse spin asymmetry A_{TT} is investigated in connection with the transversity distributions. [3,4] Next, a possible antiquark flavor asymmetry $\Delta_T \bar{u}/\Delta_T \bar{d}$ is studied in a simple quark model, and its effects on A_{TT} are shown.

[a] Information on their research is available at http://www.cc.saga-u.ac.jp/saga-u/riko /physics/quantum1/structure.html.

2 Q^2 evolution equation for transversity distributions

The transversity distribution $\Delta_T q$ can be expressed in the parton model. It is given by the probability to find a quark with spin polarized along the transverse spin of a polarized proton minus the probability to find it polarized oppositely: $\Delta_T q = q_\uparrow - q_\downarrow$. Its leading-order (LO) Q^2 evolution equation was derived in 1990,[1] and the next-to-leading-order (NLO) form was completed in 1997.[2]

Because of the chiral-odd nature of the transversity distribution, the gluon does not participate in the evolution equation. Therefore, the DGLAP evolution equation is very different from the ones for the longitudinal evolution. It is simply given by a single integrodifferential equation,

$$\frac{\partial}{\partial \ln Q^2} \Delta_T q^{\pm}(x, Q^2) = \frac{\alpha_s(Q^2)}{2\pi} \int_x^1 \frac{dz}{z} \Delta_T P_{q^\pm}(z) \, \Delta_T q^{\pm}\left(\frac{x}{z}, Q^2\right) , \qquad (1)$$

where $\Delta_T P_{q^\pm}$ is the splitting function for the transversity distribution. The notation $q^\pm$ in the splitting function indicates the $\Delta_T q^+ = \Delta_T q + \Delta_T \bar{q}$ or $\Delta_T q^- = \Delta_T q - \Delta_T \bar{q}$ distribution type. The $\alpha_s(Q^2)$ is the running coupling constant. The transversity NLO evolution is the same in the MS and $\overline{MS}$ schemes. Even though the distribution may not be flavor nonsinglet, the evolution equation looks like the "usual" nonsinglet one without coupling to the gluon term.

Dividing the variables x and Q^2 into small steps, we solve the DGLAP integrodifferential equation by the Euler method in the variable Q^2 and by the Simpson method in the variable x.[3] Numerical results indicate that accuracy is better than 1% in the region $10^{-5} < x < 0.8$ if more than fifty Q^2 steps and more than five hundred x steps are taken. Our Q^2 evolution program could be obtained upon email request.[b]

3 Q^2 evolution results

Because the transversity distributions themselves are not measured yet, it takes time for finding their scaling violation. On the other hand, the Q^2 dependence is important for predicting spin asymmetries. In particular, the transversity evolution is very different from the longitudinal one as we show in this section. We discuss the evolution results for the flavor singlet transversity distribution $\Delta_T q_s = \sum_i (\Delta_T q_i + \Delta_T \bar{q}_i)$.[3] The evolution of the flavor asymmetric distribution $\Delta_T \bar{u} - \Delta_T \bar{d}$ is discussed in section 4. There is a problem in studying the transversity evolution in the sense that the input distribution is not available at this stage. However, it is known within quark models that the transversity

[b] See http://www.cc.saga-u.ac.jp/saga-u/riko/physics/quantum1/program.html.

distributions are almost the same as the corresponding longitudinally polarized distributions. Therefore, we may use a longitudinal distribution as an input transversity distribution at small Q^2.

The singlet evolution results are shown in Fig. 1. The initial transversity and longitudinally polarized distributions are assumed as the same GS-A distribution at Q^2=4 GeV^2, and they are shown by the dotted curve. It is evolved to the distributions at Q^2=200 GeV^2 by the transverse or longitudinal evolution equation. The LO and NLO evolution results are shown by the dashed and solid curves. Because the evolution is from Q^2=4 GeV^2 to 200 GeV^2, the NLO contributions are not so large. It is known that the NLO effects are significant in the small Q^2 region, $Q^2 < 2$ GeV^2. The transversity NLO effects increase the evolved distribution at medium-large x and also at small x (<0.01), and they decrease the distribution in the intermediate x region ($0.01 < x < 0.1$). The transversity NLO effects are different from the longitudinal NLO ones; however, it is more interesting to find large differences between the evolved transversity and longitudinally-polarized distributions. For example, the evolved transversity distribution $\Delta_T q_s$ is significantly smaller than the longitudinal one Δq_s in the region $x \sim 0.1$. The magnitude of $\Delta_T q_s$ itself is also smaller than that of Δq_s at very small x (< 0.07). Therefore, as we mentioned in the introduction, the study of the transversity distributions is important for testing the perturbative aspect of QCD in spin physics.

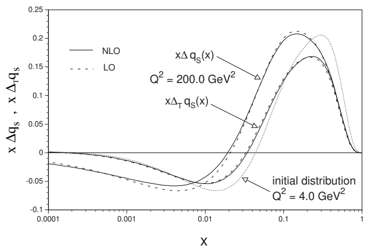

Figure 1: Q^2 evolution of the singlet transversity and longitudinally polarized distributions.

4 Antiquark flavor asymmetry and transverse spin asymmetry

It is now well known that light antiquark distributions are not flavor symmetric [5] according to the NMC, NA51, and E866 experimental data. In particular, the recent E866 Drell-Yan data revealed the x dependence of the $\bar{u} - \bar{d}$ distribution. [6] The mechanisms for producing the asymmetry are virtual meson clouds, Pauli exclusion principle, and others. On the other hand, the antiquark flavor asymmetry in the polarized distributions is not known at this stage except for a few theoretical predictions. Because the polarized antiquark distributions are measured at RHIC, it is important to investigate a possible asymmetric distribution. In the following, we study the flavor asymmetry in the transversity distributions.

First, we discuss the perturbative contributions. They are expected to be small[5] because there is no LO contribution. Due to the difference between the splitting functions $\Delta_T P_{q^\pm}$ in Eq. (1), there is a finite perturbative contribution to $\Delta_T \bar{u} - \Delta_T \bar{d}$.[7] We choose the GRSV distributions at Q^2=0.34 GeV^2 as the initial ones although perturbative calculations may not be valid in such a small Q^2 region. Despite the initial distributions are flavor symmetric, the NLO evolution produces finite distributions in Fig. 2. However, because the magnitude is rather small, the perturbative mechanism would not be the major source for the flavor asymmetry.

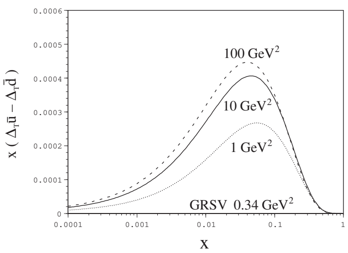

Figure 2: Q^2 evolution of $x(\Delta_T \bar{u} - \Delta_T \bar{d})$ distribution. The initial distribution is $\Delta_T \bar{u} - \Delta_T \bar{d} = 0$ at $Q^2 = 0.34$ GeV^2.

Many theoretical papers are written on the unpolarized flavor asymmetry $\bar{u} - \bar{d}$. Although the meson-cloud mechanism is most successful among the models, the polarized asymmetry is not well studied. In order to estimate the order of magnitude of $\Delta_T \bar{u} - \Delta_T \bar{d}$ and its effects on the transverse spin asymmetry, we use a simple picture based on the Pauli exclusion principle.[8] Because the proton spin-up state is described in the SU(6) quark model as $|p_+\!>=(1/\sqrt{6})[2|u_+u_+d_-\!>-|u_+u_-d_+\!>-|u_-u_+d_+\!>]$, we have each quark state probability as $u_+ = 5/3$, $u_- = 1/3$, $d_+ = 1/3$, and $d_- = 2/3$. These equations indicate that it is more difficult to create the spin-up u (spin-down d) quark than the spin-down u (spin-up d) according to the 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 $\Delta_{(T)}\overline{u} = -0.13$ and $\Delta_{(T)}\overline{d} = +0.05$.[8] This exclusion model should be valid only at very small Q^2, so that the GRSV parametrization is chosen in our analysis. In order to estimate the distributions and the spin asymmetry A_{TT}, the GRSV distributions are modified to have the first moments: $\Delta_T\overline{u} = -0.13$ and $\Delta_T\overline{d} = +0.05$. The initial $\Delta_T \bar{u} - \Delta_T \bar{d}$ distribution and its Q^2 evolution results are shown in Fig. 3. Because the polarization excess is larger in the u quark, the exclusion effect is dominated by the negative $\bar{u}$ quark polarization.

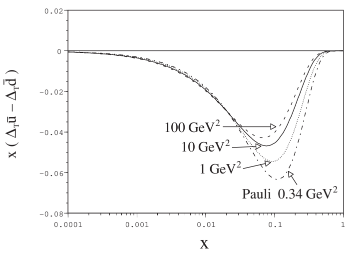

Figure 3: Q^2 evolution of $x(\Delta_T \bar{u} - \Delta_T \bar{d})$ distribution. The initial distribution is suggested by the Pauli exclusion model.

We have also calculated the transverse spin asymmetries at the RHIC energy $\sqrt{s} = 200$ GeV. In the flavor symmetric case, the Drell-Yan spin asymmetry A_{TT} is of the order of 0.5∼1% in the dimuon mass region $100 < M^2_{\mu\mu} < 500$ GeV^2. If the flavor asymmetry is taken into account, it increases to 1∼2%. There is an indication of the $\Delta_T \bar{u}/\Delta_T \bar{d}$ asymmetry in A_{TT}; however, the valence quark distributions have to be fixed first in order to find $\Delta_T \bar{u}$ and $\Delta_T \bar{d}$. Because A_{TT} is rather small, we had better try other processes such as Z^0 and jet production processes or semi-inclusive muon scattering.[9] Because the transverse asymmetry $\Delta_T \bar{u}/\Delta_T \bar{d}$ *cannot* be measured through the $W^{\pm}$ production processes, we should think about possible measurements.[3]

5 Summary

We have discussed the transversity distributions, in particular their Q^2 evolution. Because the evolved transversity distribution is very different from the longitudinally polarized one, the difference could be an important test of perturbative QCD. Next, we studied possible flavor asymmetric distributions $\Delta_T \bar{u} - \Delta_T \bar{d}$ and their Q^2 evolution. Because the perturbative QCD effects are rather small, we should investigate nonperturbative mechanisms for creating the flavor asymmetry. Calculated spin asymmetries A_{TT} are rather small, which suggests that we had better rely also on other measurements for finding the accurate transversity distributions.

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