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A MODEL PREDICTION FOR POLARIZED ANTIQUARK FLAVOR ASYMMETRY

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Polarized flavor asymmetry $\Delta\bar{u}/\Delta\bar{d}$ is investigated in a meson-cloud model. A polarized nucleon splits into a ρ meson and a baryon, then the polarized ρ meson interacts with the virtual photon. Because of the difference between the longitudinally polarized distributions $\Delta\bar{u}$ and $\Delta\bar{d}$ in ρ, the polarized flavor asymmetry is produced in the nucleon. In addition, we show that the g_2 part of ρ contributes to the asymmetry especially at medium x with small Q^2.

1. Introduction

Spin structure of the nucleon has been investigated extensively for the last ten years, and now we have a rough idea on the internal spin structure. The experimental information comes mainly from inclusive lepton scattering experiments. Although there are polarized semi-inclusive data, they are not accurate enough to pose a strong constraint, for example, on the polarized flavor asymmetry $\Delta\bar{u}/\Delta\bar{d}$. However, it will be clarified experimentally in the near future by W production experiments at RHIC and also semi-inclusive measurements by the COMPASS collaboration.

Most theoretical papers on the unpolarized asymmetry $\bar{u}/\bar{d}$ are written after the NMC discovery on Gottfried-sum-rule violation. Therefore, the unmeasured $\Delta\bar{u}/\Delta\bar{d}$ is an appropriate quantity for testing various theoretical models. In this sense, it is desirable to present model predictions before the experimental data will be taken. There are already some model predictions by Pauli-exclusion, chiral-soliton, and meson-cloud models. The meson models are successful in explaining the unpolarized asymmetry,[1] so that we try to investigate the details of the model in the polarized asymmetry.[2−5] The following discussions are based on Ref. 4.

2. ρ meson contributions

We explain the outline of the formalism for calculating ρ meson contributions to the flavor asymmetric distribution $\Delta\bar{u} - \Delta\bar{d}$. The polarized nucleon splits into a ρ meson and a baryon, then the virtual photon interacts with the polarized ρ meson. The ρ meson is a spin-1 hadron, and ρ^+ or ρ^- has difference between $\bar{u}$ and $\bar{d}$. Therefore, it affects the polarized flavor asymmetry $\Delta\bar{u} - \Delta\bar{d}$ in the nucleon.

The contribution to the nucleon tensor $W_{\mu\nu}$ from the splitting process into a vector meson V and a baryon B is expressed as[4]

$$W_{\mu\nu}(p_N, s_N, q) = \int \frac{d^3 p_B}{(2\pi)^3} \frac{2 m_V m_B}{E_B} \sum_{\lambda_V, \lambda_B} |J_{VNB}|^2 \, W_{\mu\nu}^{(V)}(k, s_V, q). \tag{1}$$

Here, m_V and m_B are the meson and baryon masses, p_N, p_B, k, and q are the nucleon, baryon, meson, and virtual photon momenta, s_N and s_V are the nucleon and meson spins, J_{VNB} is the VNB vertex multiplied by the meson propagator, and $W_{\mu\nu}^{(V)}$ is the meson tensor. Polarized structure functions g_1 and g_2 are defined in the antisymmetric part of the nucleon tensor:

$$W_{\mu\nu}^{A}(p_N, s_N, q) = i\, \varepsilon_{\mu\nu\rho\sigma}\, q^{\rho} \left[s_N^{\sigma} \frac{g_1}{p_N \cdot q} + (p_N \cdot q\, s_N^{\sigma} - s_N \cdot q\, p_N^{\sigma}) \frac{g_2}{(p_N \cdot q)^2} \right]. \tag{2}$$

In order to separate g_1 from g_2, the projection operator

$$P^{\mu\nu} = - \frac{m_N^2}{2\, p_N \cdot q}\, i\, \varepsilon^{\mu\nu\alpha\beta}\, q_\alpha\, s_{N\,\beta}, \tag{3}$$

is multiplied in both sides of Eq. (2), then longitudinal and transverse polarizations are considered. The derivation is too lengthy to be written here, so that the details should be found in Ref. 4. As a result, we obtain

$$\begin{aligned} g_1(x, Q^2) = \frac{1}{1+\gamma^2} \int_x^1 \frac{dy}{y} \, [\, & \{ \Delta f_{1L}(y) + \Delta f_{1T}(y) \} \, g_1^V(x/y, Q^2) \\ & - \{ \Delta f_{2L}(y) + \Delta f_{2T}(y) \} \, g_2^V(x/y, Q^2) \,], \end{aligned} \tag{4}$$

where the function $\Delta f_i^{VN}(y)$ with i=$1L$, $2L$, $1T$, or $2T$ is defined by

$$\Delta f_i(y) = f_i^{\lambda_V=+1}(y) - f_i^{\lambda_V=-1}(y). \tag{5}$$

The factor γ^2 is defined by $\gamma^2 = 4\, x^2\, m_N^2/Q^2$. The function $f_{1L}^{\lambda_V}(y)$ is the ordinary meson momentum distribution with the momentum fraction y in the longitudinally polarized nucleon. There are, however, new contributions from the $2L$, $1T$, and $2T$ terms. The function $f_{1T}^{\lambda_V}(y)$ is the distribution in the transversely polarized nucleon. The functions $f_{2L}^{\lambda_V}(y)$ and $f_{2T}^{\lambda_V}(y)$ are the distributions associated with g_2 of the vector meson. Explicit expressions of $f_i^{\lambda_V}$ are given in the appendix of Ref. 4. Our studies are intended to investigate a role of the additional terms, $2L$, $1T$, and $2T$.

In order to estimate the g_2^V effects, we approximate it by the Wandzura-Wilczek (WW) relation:

$$g_2^{V(WW)}(x, Q^2) = - g_1^V(x, Q^2) + \int_x^1 \frac{dy}{y} g_1^V(y, Q^2). \tag{6}$$

Then, the leading-order expression of g_1^V is used for obtaining

$$g_2^{V(WW)}(x, Q^2) = \frac{1}{2} \sum_i e_i^2 \, [\, \Delta q_i^{V(WW)}(x, Q^2) + \Delta \bar{q}_i^{V(WW)}(x, Q^2) \,], \tag{7}$$

where the WW distributions are defined by

$$\Delta\bar{q}_i^{V(WW)}(x,Q^2) = -\Delta\bar{q}_i^{V}(x,Q^2) + \int_x^1 \frac{dy}{y}\,\Delta\bar{q}_i^{V}(y,Q^2), \tag{8}$$

and the same equation for $\Delta q_i^{V(WW)}(x,Q^2)$. In this way, the vector-meson contribution to $\Delta\bar{q}_i$ in the nucleon becomes

$$\Delta\bar{q}_i^{VNB}(x,Q^2) = \frac{1}{1+\gamma^2}\int_x^1 \frac{dy}{y}\,\Big[\,\big\{\Delta f_{1L}(y)+\Delta f_{1T}(y)\big\}\,\Delta\bar{q}_i^{V}(x/y,Q^2) \\ -\big\{\Delta f_{2L}(y)+\Delta f_{2T}(y)\big\}\,\Delta\bar{q}_i^{V(WW)}(x/y,Q^2)\,\Big]. \tag{9}$$

This equation is used for calculating the ρ meson contributions to $\Delta\bar{u}-\Delta\bar{d}$. The new terms $2L$, $1T$, and $2T$, are proportional to γ^2, namely $1/Q^2$, so that they vanish in the limit $Q^2\to\infty$. Then, Eq. (9) agrees on those in Refs. 2 and 3.

3. Results

For calculating the obtained expression numerically, the splitting processes $N\to\rho N$ and $N\to\rho\Delta$ are included with the vertex couplings

$$V_{VNN} = \widetilde{\phi}_V^{*}\cdot\widetilde{T}\,F_{VNN}(k)\;\overline{u}_{N'}\,\varepsilon^{\mu\,*}\left[g_V\gamma_\mu - \frac{f_V}{2m_N}\,i\,\sigma_{\mu\nu}\widehat{K}^{\nu}\right]u_N, \tag{10}$$

$$V_{VN\Delta} = \widetilde{\phi}_V^{*}\cdot\widetilde{T}\,F_{VN\Delta}(k)\;\overline{U}_{\Delta,\nu}\,\frac{f_{VN\Delta}}{m_V}\,\gamma_5\,\gamma_\mu\,\big[\,\widehat{K}^{\mu}\,\varepsilon^{\nu\,*} - \widehat{K}^{\nu}\,\varepsilon^{\mu\,*}\,\big]\,u_N. \tag{11}$$

Here, $\widetilde{\phi}_V^{*}\cdot\widetilde{T}$ indicates the isospin coupling, $F_{VNN}(k)$ and $F_{VN\Delta}(k)$ are form factors, u_N is the Dirac spinor, U_Δ^{μ} is the Rarita-Schwinger spinor, ε^{μ} is the polarization vector of ρ, g_V, f_V, and $f_{VN\Delta}$ are coupling constants, and $\widehat{K}^{\mu}$ is a vertex momentum. The momentum $\widehat{K}^{\mu}$ could be taken either (A) $(E_V,\vec{k})$ or (B) $(E_N-E_B,\vec{k})$; however, the prescription (B) is used in the following results. For F_{VNN} and $F_{VN\Delta}$, exponential form factors are used with the 1 GeV cutoff. Using these vertices, we calculate the polarized meson momentum distributions in Eq. (9).

Obtained meson momentum distributions are convoluted with the polarized distributions in ρ. The charge symmetry is used for relating the valence quark distributions in ρ^-, ρ^0, and ρ^+:

$$(\Delta\bar{u})_{\rho^-}^{val} = (\Delta\bar{d})_{\rho^+}^{val} = 2(\Delta\bar{u})_{\rho^0}^{val} = 2(\Delta\bar{d})_{\rho^0}^{val} = \Delta V_\rho. \tag{12}$$

Actual parton distributions are not known in ρ, so that they are assumed as $\Delta V_\rho = 0.6\,V_\pi$ by considering a lattice QCD estimate. The distribution in the pion is taken from the GRS (Glück, Reya, and Schienbein) parametrization. Taking into account the isospin factors at the ρNN and $\rho N\Delta$ vertices, we obtain

$$(\Delta\bar{u}-\Delta\bar{d})_{p\to\rho B} = \left[\,-2\,\Delta f_{1L+1T}^{\rho NN} + \frac{2}{3}\,\Delta f_{1L+1T}^{\rho N\Delta}\right]\otimes\Delta V_\rho \\ -\left[\,-2\,\Delta f_{2L+2T}^{\rho NN} + \frac{2}{3}\,\Delta f_{2L+2T}^{\rho N\Delta}\right]\otimes\Delta V_\rho^{WW}\,, \tag{13}$$

where $\otimes$ indicates the convolution integral.

The ρNN and $\rho N\Delta$ are separately calculated and numerical results are shown in Figs. 1 and 2, respectively, at Q^2=1 GeV^2. The ordinary longitudinal contributions are denoted as $1L$, and other new contributions are denoted as $2L$, $1T$, and $2T$. Among the new terms, $2L$ is the largest one, which becomes comparable magnitude with $1L$ at medium x ($x > 0.2$). We notice that the distributions from $\rho N\Delta$ are fairly small in comparison with those from ρNN. All the distributions in these figures are mainly negative, which means that $\Delta\bar{d}$ excess is produced over $\Delta\bar{u}$ by the meson-cloud mechanism. Because W production and semi-inclusive processes will be investigated experimentally, our prediction should be tested in the near future.

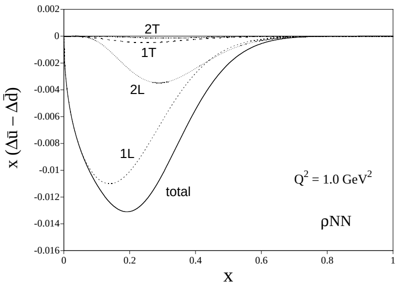

Fig. 1. $\Delta\bar{u} - \Delta\bar{d}$ from the process $N \to \rho N$.

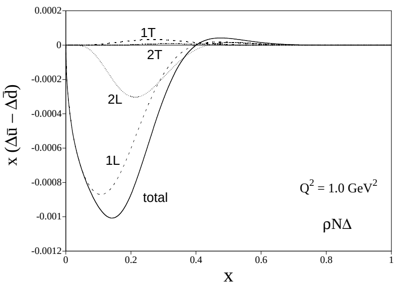

Fig. 2. $\Delta\bar{u} - \Delta\bar{d}$ from the process $N \to \rho\Delta$.

4. Summary

The ρ meson contributions to the polarized antiquark flavor asymmetry $\Delta\bar{u} - \Delta\bar{d}$ have been investigated in a meson-cloud picture. We pointed out especially the existence of additional terms from the g_2 part of ρ. The additional terms become important at medium x with small Q^2. The obtained $\Delta\bar{u} - \Delta\bar{d}$ distributions are mostly negative, namely the model indicates $\Delta\bar{d}$ excess over $\Delta\bar{u}$, and it should be tested by future experiments.

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