Polarized light-flavor antiquark distributions from Drell-Yan process with produced lepton helicities

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In 1988, measurements of the polarized nucleon structure functions in the polarized deep-inelastic scattering (polarized DIS) showed that only a small part of the nucleon spin is carried by quarks, and the polarization of the strange sea-quark is negative and quite large[1]. Those results were not anticipated by conventional theories, and are often referred to as '*the proton spin crisis*'[2]. However, in these data analyses the polarized light sea-quarks were assumed to be symmetric. The experimental data for the longitudinally polarized semi-inclusive DIS [3]-[5] have been reanalyzed recently for $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$ [6], and also several models taking into account of the behaviour of the polarized light flavor sea-quark were proposed[7, 8]. The reanalysis from the experimental data of the semi-inclusive DIS had ambiguities because of insufficient information on the fragmentation functions and of statistical error. Therefore, at present we cannot derive any conclusion on $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$ from data. In addition, unfortunately, in the DIS analysis we have no idea to estimate the first moment of $\Delta\bar{u} - \Delta\bar{d}$ such as the Gottfried sum rule for the unpolarized light sea-quark flavor asymmetry. It makes the analysis on the light flavor sea-quark polarization difficult. Thus, it is important to find a formula for the first moment of $\Delta\bar{u} - \Delta\bar{d}$, and to measure it directly without ambiguites.

Here we propose a formula for the first moment of $\Delta\bar{u} - \Delta\bar{d}$ from the Drell-Yan (DY) process with longitudinally polarized nucleon targets and unpolarized hadron beams by measuring the helicity of one of the produced pair lepton.

Let us consider a process of $h + \vec{N} \to \vec{\ell^{\pm}} + \ell^{\mp} + X$. The spin-dependent cross section is expressed as

$$
\begin{aligned}
\frac{d^3\Delta\sigma}{dx_1 dx_2 d\cos\theta_\mu} &= K_{pol}\, \frac{d\Delta\hat{\sigma}}{d\cos\theta_\mu} \sum_i e_i^2 \left\{ \bar{q}_i^h(x_1, Q^2)\Delta q_i^N(x_2, Q^2) + q_i^h(x_1, Q^2)\Delta \bar{q}_i^N(x_2, Q^2) \right\} \\
&\equiv K_{pol}\, \frac{d\Delta\hat{\sigma}}{d\cos\theta_\mu} \Delta P^{hN}(x_1, x_2, Q^2) \ , \qquad (1)
\end{aligned}
$$

where

$$
\begin{aligned}
\Delta P^{hp}(x_1, x_2, Q^2) = &\ \frac{4}{9}\left\{ \bar{u}^h(x_1, Q^2)\ \Delta u^p(x_2, Q^2) - u^h(x_1, Q^2)\ \Delta\bar{u}^p(x_2, Q^2) \right\} \\
&+ \frac{1}{9}\left\{ \bar{d}^h(x_1, Q^2)\ \Delta d^p(x_2, Q^2) - d^h(x_1, Q^2)\ \Delta\bar{d}^p(x_2, Q^2) \right\} \\
&+ \frac{1}{9}\left\{ \bar{s}^h(x_1, Q^2)\ \Delta s^p(x_2, Q^2) - s^h(x_1, Q^2)\ \Delta\bar{s}^p(x_2, Q^2) \right\} \\
&+ (\text{contributions from heavy quark distributions}) \ . \qquad (2)
\end{aligned}
$$

Assuming the isospin symmetry for the target nucleon, one has an interesting equation such as,

$$
\begin{aligned}
&\int_0^1 \int_0^1 \frac{d^3\Delta\sigma^{hp}/dx_1dx_2d\cos\theta_\mu - d^3\Delta\sigma^{hn}/dx_1dx_2d\cos\theta_\mu}{K_{pol}\ d\Delta\hat{\sigma}/d\cos\theta_\mu} dx_1dx_2 \\
&= \frac{1}{9}\left[\Delta u_v^p(Q^2) - \Delta d_v^p(Q^2) + 2\left\{\Delta\bar{u}^p(Q^2) - \Delta\bar{d}^p(Q^2)\right\}\right]\left\{4\ \bar{u}^h(Q^2) - \bar{d}^h(Q^2)\right\} \\
&\quad - \frac{1}{9}\left\{\Delta\bar{u}^p(Q^2) - \Delta\bar{d}^p(Q^2)\right\}\left[4\ u_v^h - d_v^h + 2\left\{4\ \bar{u}^h(Q^2) - \bar{d}^h(Q^2)\right\}\right] \\
&= \frac{1}{9}\left|\frac{g_A}{g_V}\right|\left\{4\ \bar{u}^h(Q^2) - \bar{d}^h(Q^2)\right\} - \frac{1}{9}\left\{\Delta\bar{u}^p(Q^2) - \Delta\bar{d}^p(Q^2)\right\}\left[4\ u_v^h - d_v^h + 2\left\{4\ \bar{u}^h(Q^2) - \bar{d}^h(Q^2)\right\}\right]
\end{aligned}
\tag{3}
$$

for the measurement of the ℓ^+ helicity. In the eq.(3), g_A and g_V are the nucleon axial and vector coupling constants, respectively, and u_v^h and d_v^h are numbers of the valence u- and d-quarks in the beam particle h, respectivley. Here, we drop the label Q^2, since the valence quark numbers in the hadron are independent of Q^2. Therefore, appraising $4\bar{u}^h(Q^2) - \bar{d}^h(Q^2)$ in the unpolarized beam hadron h and the K-factor of this polarized DY process, we get information on the first moment of $\Delta\bar{u}^p - \Delta\bar{d}^p$ from the cross sections for $h + \{\vec{p}\ \text{ and }\ \vec{n}\} \rightarrow \vec{\ell^\pm} + \ell^\mp + X$ with wide ranges of both x_1 and x_2.

In conclusions, we have proposed a formula for the difference between the polarized light flavor sea-quark density, $\Delta\bar{u}^p - \Delta\bar{d}^p$, from DY processes. It is given by a combination of the cross sections with an unpolarized hadron beam and a longitudinally polarized proton target by measuring one of the produced lepton helicity and that with a neutron target. Then, the formula is described in terms of the neutron β-decay constant and the difference between $\Delta\bar{u}^p$ and $\Delta\bar{d}^p$. As coefficients of these terms depend on u- and d-quark numbers in the unpolarized beam hadron, we can independently get information on the behavior of $\Delta\bar{u}^p$ and $\Delta\bar{d}^p$ by changing the beam hadron.

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