The Polarization of the Valence Quarks and the Strange Sea in the Neutrino Experiments on the Polarized Deuterons

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An expressions for the contributions of the strange quarks and antiquarks, the valence quarks in the nucleon spin with help the polarization inclusive and semi-inclusive asymmetries of the DIS the neutrino and the antineutrino of the polarized deuterons were obtained.

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The spin structure of the nucleon has the fundamental interest in the modern hadron physics [1]. The current understanding of the structure nucleon spin is that it consists from the contribution spins quarks and the gluons and its orbital angular moments.

For the longitudinally polarized nucleon its spin can be decomposed into

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_q + L_g, \tag{1}$$

where $\Delta\Sigma$ and Δg are the contributions of the quarks, antiquarks and the gluons respectively; L_q, L_g are the orbital angular moments of the quarks and the gluons.

The numerous polarization experiments of DIS the electrons and the muons on the fixed targets show, that the contribution of the quarks and the antiquarks $\Delta\Sigma$ make up not more $\frac{1}{3}$ the nucleon spin. In the last decade the proton-proton experiments on RHIC for the first time discovered a positive polarization of the gluons Δg in the region of $x > 0,05$. However Δg is not large enough to make up the missing contribution in the nucleon spin. This is clear indication of a nonzero contribution of the orbital angular moments the quarks and the gluons.

The numerical values for $\Delta\Sigma$ and Δg have the large uncertainties because not the information about the parton helicity distributions for $x < 0,005$.

For the understanding spin structure of the nucleon important meaning has a separation of the contributions the quarks and the antiquarks [2].

Now the Δq and $\Delta\bar{q}$ are obtained separately from semi-inclusive lN-DIS [3]. Here the data dependent essentially from the fragmentation functions [2, 4], that carry the complementary uncertainties. The separation Δq and $\Delta\bar{q}$ is possibly in the processes DIS the neutrino and the antineutrino on the polarized targets with the charged current [5, 6]. The neutrino experiments have the real perspective in future because the project muon collider.

The possibility appears to obtain here the high focused neutrino beams from the decays of muons (neutrino factories), for which already can be to create the polarized targets [6–10].

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Therefore it is actual a study of the spin structure nucleon in DIS the neutrino and the antineutrino on the polarized nucleons [5, 11].

In this paper we consider the possibilities of the receipt contributions quarks and antiquarks in the nucleon spin from measurable asymmetries of the DIS the neutrino and the antineutrino on the polarized deuterons.

The cross sections of DIS the neutrino and antineutrino off the polarized deuterons

$$\nu(\bar{\nu}) + d \longrightarrow l^-(l^+) + X \tag{2}$$

represent as

$$\sigma_{\nu(\bar{\nu})d} = \sigma^a_{\nu(\bar{\nu})d} + P_N \sigma^{Pol}_{\nu(\bar{\nu})d} \tag{3}$$

where $\sigma^{a,Pol}_{\nu(\bar{\nu})d}$ are unpolarized and polarization parts of the cross sections respectively; $\sigma = \frac{d^2\sigma}{dxdy}$; x, y are the scaling variable; P_N is the degree of the longitudinal polarization of the deuterons.

In leading order QCD cross sections (3) are obtained for the neutrino in following form

$$\sigma^a_{\nu d} = \frac{\sigma^a_{\nu p} + \sigma^a_{\nu n}}{2} = \sigma_0 x\Big[u(x,Q^2) + d(x,Q^2) + 2s(x,Q^2) + y_1^2\big(\bar{u}(x,Q^2) + \bar{d}(x,Q^2)\big)\Big], \tag{4}$$

$$\begin{aligned}\sigma^{Pol}_{\nu d} &= \frac{\sigma^{Pol}_{\nu p} + \sigma^{Pol}_{\nu n}}{2}\Big(1 - \frac{3}{2}\omega\Big) = \\ &= \sigma_0 x\Big[\Delta u(x,Q^2) + \Delta d(x,Q^2) + 2\Delta s(x,Q^2) - y_1^2\big(\Delta\bar{u}(x,Q^2) + \Delta\bar{d}(x,Q^2)\big)\Big]\Big(1 - \frac{3}{2}\omega\Big)\end{aligned} \tag{5}$$

and the antineutrino

$$\sigma^a_{\bar{\nu}d} = \sigma_0 x\Big[y_1^2\big(u(x,Q^2) + d(x,Q^2)\big) + \bar{u}(x,Q^2) + \bar{d}(x,Q^2) + 2\bar{s}(x,Q^2)\Big], \tag{6}$$

$$\begin{aligned}\sigma^{Pol}_{\bar{\nu}d} = \sigma_0 x\Big[&y_1^2\big(\Delta u(x,Q^2) + \Delta d(x,Q^2)\big) - \\ &- \Delta\bar{u}(x,Q^2) - \Delta\bar{d}(x,Q^2) - 2\Delta\bar{s}(x,Q^2)\Big]\Big(1 - \frac{3}{2}\omega\Big).\end{aligned} \tag{7}$$

Here $q(\bar{q})(x,Q^2), \Delta q(\Delta\bar{q})(x,Q^2) (q = u, d, s)$ are unpolarized and helicity parton distributions; $y_1 = 1 - y$, Q^2 is squared transfer momentum from neutrino (antineutrino) to lepton (antilepton), $\omega \simeq 0,05$ is the probability of D-state in wave function of the deuteron; $\sigma_0 = \frac{G}{\pi}ME$, G is Fermi constant, E is energy neutrino (antineutrino), M is mass deuteron.

The polarization asymmetries of processes (2) are

$$A_{\pm d} = \frac{\big(\sigma^{\downarrow\uparrow}_{\nu d} \pm \sigma^{\uparrow\uparrow}_{\bar{\nu}d}\big) - \big(\sigma^{\downarrow\downarrow}_{\nu d} \pm \sigma^{\uparrow\downarrow}_{\bar{\nu}d}\big)}{\big(\sigma^{\downarrow\uparrow}_{\nu d} \pm \sigma^{\uparrow\uparrow}_{\bar{\nu}d}\big) + \big(\sigma^{\downarrow\downarrow}_{\nu d} \pm \sigma^{\uparrow\downarrow}_{\bar{\nu}d}\big)}, \tag{8}$$

where first arrow corresponds of the helicity neutrino ($\downarrow$) or antineutrino ($\uparrow$), second arrow is the spin of deuteron $\uparrow$ ($P_N = 1$) and $\downarrow$ ($P_N = -1$).

For (3) the asymmetries $A_{\pm d}$ are

$$A_{\pm d} = \frac{\sigma^{Pol}_{\nu d} \pm \sigma^{Pol}_{\bar{\nu}d}}{\sigma^a_{\nu d} \pm \sigma^a_{\bar{\nu}d}}. \tag{9}$$

In view of the cross sections (3)-(7) for the asymmetries (9) we obtain

$$A_{+d} = \frac{\big(1+y_1^2\big)\big[\Delta u_V(x,Q^2)+\Delta d_V(x,Q^2)\big]}{\big(1+y_1^2\big)\big[u(x,Q^2)+\bar{u}(x,Q^2)+d(x,Q^2)+\bar{d}(x,Q^2)\big]+2\big(s(x,Q^2)+\bar{s}(x,Q^2)\big)}\cdot \cdot\Big(1-\frac{3}{2}\omega\Big), \quad (10)$$

$$A_{-d} = = \frac{\big(1-y_1^2\big)\big[\Delta u(x,Q^2)+\Delta d(x,Q^2)+\Delta\bar{u}(x,Q^2)+\Delta\bar{d}(x,Q^2)\big]+2\big(\Delta s(x,Q^2)+\Delta\bar{s}(x,Q^2)\big)}{\big(1-y_1^2\big)\big[u_V(x,Q^2)+d_V(x,Q^2)\big]}\cdot \cdot\Big(1-\frac{3}{2}\omega\Big) \quad (11)$$

where $\Delta q_V(q_V) = \Delta q(q) - \Delta\bar{q}(\bar{q})$ are the valence parton distributions.

Now we consider the semi-inclusive $\nu(\bar{\nu})d$-DIS

$$\nu(\bar{\nu}) + d \longrightarrow l^-(l^+) + \pi^\pm + X. \quad (12)$$

The cross sections of this processes (3), (4), (5) have the form for the neutrino

$$\begin{aligned}
\sigma^{a\pi}_{\nu d} &= \sigma_0 x\big[d(x,Q^2)D^\pi_u(z) + y_1^2\bar{u}(x,Q^2)D^\pi_{\bar{d}}(z) + u(x,Q^2)D^\pi_u(z) + y_1^2\bar{d}(x,Q^2)D^\pi_{\bar{d}}(z)\big],\\
\sigma^{Pol\pi}_{\nu d} &= \sigma_0 x\big[\Delta d(x,Q^2)D^\pi_u(z) - y_1^2\Delta\bar{u}(x,Q^2)D^\pi_{\bar{d}}(z) + \Delta u(x,Q^2)D^\pi_u(z) - \\
&\qquad - y_1^2\Delta\bar{d}(x,Q^2)D^\pi_{\bar{d}}(z)\big]\Big(1-\frac{3}{2}\omega\Big).
\end{aligned} \quad (13)$$

and antineutrino

$$\begin{aligned}
\sigma^{a\pi}_{\bar{\nu} d} &= \sigma_0 x\big[y_1^2 u(x,Q^2)D^\pi_d(z) + \bar{d}(x,Q^2)D^\pi_{\bar{u}}(z) + y_1^2 d(x,Q^2)D^\pi_d(z) + \bar{u}(x,Q^2)D^\pi_{\bar{u}}(z)\big],\\
\sigma^{Pol\pi}_{\bar{\nu} d} &= \sigma_0 x\big[y_1^2\Delta u(x,Q^2)D^\pi_d(z) - \Delta\bar{d}(x,Q^2)D^\pi_{\bar{u}}(z) + y_1^2\Delta d(x,Q^2)D^\pi_d(z) - \\
&\qquad - \Delta\bar{u}(x,Q^2)D^\pi_{\bar{u}}(z)\big]\Big(1-\frac{3}{2}\omega\Big).
\end{aligned} \quad (14)$$

where $D^\pi_{q(\bar{q})}(z)$ is the fragmentation function of the quark q (antiquark $\bar{q}$) in π-meson.

The semi-inclusive asymmetries $A^{\pi^+-\pi^-}_{\pm d}$ we obtained from (8), (9) through the replacement $\sigma \to \sigma^{\pi^+-\pi^-} = \sigma^{\pi^+} - \sigma^{\pi^-}$ and to taking account (13), (14) have

$$A^{\pi^+-\pi^-}_{+d} = \frac{\Delta u(x,Q^2)+\Delta d(x,Q^2)+\Delta\bar{u}(x,Q^2)+\Delta\bar{d}(x,Q^2)}{u_V(x,Q^2)+d_V(x,Q^2)}\Big(1-\frac{3}{2}\omega\Big), \quad (15)$$

$$A^{\pi^+-\pi^-}_{-d} = \frac{\Delta u_V(x,Q^2)+\Delta d_V(x,Q^2)}{u(x,Q^2)+\bar{u}(x,Q^2)+d(x,Q^2)+\bar{d}(x,Q^2)}\Big(1-\frac{3}{2}\omega\Big), \quad (16)$$

In (15), (16) the fragmentation functions cancel because the following correlations

$$D^{\pi^+-\pi^-}_{\bar{d}} = D^{\pi^+-\pi^-}_u, D^{\pi^+-\pi^-}_d = -D^{\pi^+-\pi^-}_u, D^{\pi^+-\pi^-}_{\bar{u}} = -D^{\pi^+-\pi^-}_u.$$

From the asymmetries A_{-d} (11) and $A^{\pi^+-\pi^-}_{+d}$ (15) we obtained the contribution of the strange quarks and antiquarks in the nucleon spin

$$\Delta s + \Delta\bar{s} = \int_0^1 \big[\Delta s(x) + \Delta\bar{s}(x)\big]dx = \frac{1-y_1^2}{2-3\omega}\int_0^1 \big[u_V(x)+d_V(x)\big]\big(A_{-d} - A^{\pi^+-\pi^-}_{+d}\big)dx.$$

From the asymmetry $A_{-d}^{\pi^+ - \pi^-}$ (A_{+d}) can to obtain the contribution of the valence quarks

$$\Delta u_V + \Delta d_V = \frac{1}{1 - \frac{2}{3}\omega} \int\limits_0^1 A_{-d}^{\pi^+ - \pi^-} \left[u(x) + \bar{u}(x) + d(x) + \bar{d}(x)\right] dx.$$

The asymmetries (10) and (16) give an access to the distribution of the strange sea

$$s(x) + \bar{s}(x) = \frac{1}{2}\left(1 + y_1^2\right)\left[u(x) + d(x) + \bar{u}(x) + \bar{d}(x)\right]\left(\frac{A_{-d}^{\pi^+ - \pi^-}}{A_{+d}} - 1\right).$$

Thus, an expressions for the contributions of the strange quarks and antiquarks ($\Delta s + \Delta \bar{s}$), the valence quarks ($\Delta u_V + \Delta d_V$) were obtained through the polarization inclusive and semi-inclusive asymmetries DIS neutrino and antineutrino on polarized deuterons with charged current.

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