Nonlinear Dynamics and Applications. Vol. 29 (2023) 435 - 437

The Quark Contributions to the Proton Spin at the Neutrino Experiments with Polarized Targets

E.S. Timoshin* and S.I. Timoshin†
Sukhoi State Technical University of Gomel
Prospect Octiabria, 48, 246746, Gomel, Republic of Belarus

The expressions for the contributions light quark flavors (u, d, s) in the nucleon spin were obtained using the measurable polarization asymmetries A_{-p} and A_{-n} at deep inelastic scattering the (anti)neutrino on polarized protons and neutrons. The asymmetries A_{+p} and A_{+n} give the access to the polarization of the valence quarks $\Delta u_V, \Delta d_V$ without use additional measurable quantities.

PACS numbers: 13.88.+c, 13.15.+g , 13.40.Ks , 13.60.Hb , 14.20.Dh
Keywords: quark, nucleon spin, structure function, asymmetry

In the deep inelastic scattering (DIS) (anti)neutrino on polarized targets is a possibility to separate the contributions of the valence quarks and the quark sea in the nucleon spin unlike traditional lepton-nucleon DIS. A perspective is to obtain high-focused neutrino beams from neutrino factories [1, 2]. In this case the polarized targets need that already can to create. Therefore the neutrino experiments with polarized targets become real.

Here we consider the method the receipt of the quark contributions in nucleon spin from measurable quantities in neutrino DIS on polarized targets.

The differential cross-sections of the inclusive processes

$$\nu(\bar{\nu}) + \vec{N} \longrightarrow \nu(\bar{\nu}) + X, \qquad (1)$$

neutrino DIS on the polarized nucleons with the neutral weak current were obtained in the following form:

$$\sigma_{\nu,\bar{\nu}} = \sigma^a_{\nu,\bar{\nu}} + P_N \sigma^p_{\nu,\bar{\nu}}, \qquad (2)$$

where $\sigma = \frac{d^2\sigma}{dxdy}$, $P_N = \pm 1$ is degrees longitudinal polarization of nucleon,

$$\sigma^a_{\nu,\bar{\nu}} = \frac{x\sigma_0}{2}\Big[\sum_q (y_1^+ a_q \pm 2y_1^- b_q) q(x) + \sum_q (y_1^+ a_q \mp 2y_1^- b_q)\bar{q}(x)\Big], \qquad (3)$$

$$\sigma^p_{\nu,\bar{\nu}} = \frac{x\sigma_0}{2}\Big[\sum_q (2y_1^+ b_q \pm y_1^- a_q)\Delta q(x) + \sum_q (-2y_1^+ b_q \pm y_1^- a_q)\Delta\bar{q}(x)\Big], \qquad (4)$$

$\sigma_0 = \frac{G^2}{\pi} ME$, $a_q = (g_V^2 + g_A^2)_q$, $b_q = (g_V g_A)_q$; $q = u, d, s$; $g_{Vu} = \frac{1}{2} - \frac{4}{3}\sin^2\Theta_W$, $g_{Au} = \frac{1}{2}$, $g_{Vd} = g_{Vs} = \frac{1}{2} + \frac{2}{3}\sin^2\Theta_W$, $g_{Ad} = g_{As} = -\frac{1}{2}$, Θ_W is Weinberg angle. $y_1^{\pm} = 1 \pm y_1^2$, $y_1 = 1 - y$, M is target mass of nucleon, E is energy initial neutrino (antineutrino), G is Fermi constant; x, y are scaling variables; $q(x), (\bar{q}(x))$ and $\Delta q(x), (\Delta\bar{q}(x))$ are distribution functions unpolarized and polarized quarks (antiquarks) respectively. $\sigma^a_{\nu,\bar{\nu}}$ and $\sigma^p_{\nu,\bar{\nu}}$ are unpolarized and polarization parts of cross section (2).

The polarization asymmetries we determine as the following combinations of cross sections (2):

$$A_{\pm} = \frac{(\sigma_\nu^{\downarrow\uparrow} \pm \sigma_{\bar{\nu}}^{\uparrow\uparrow}) - (\sigma_\nu^{\downarrow\downarrow} \pm \sigma_{\bar{\nu}}^{\uparrow\downarrow})}{(\sigma_\nu^{\downarrow\uparrow} \pm \sigma_{\bar{\nu}}^{\uparrow\uparrow}) + (\sigma_\nu^{\downarrow\downarrow} \pm \sigma_{\bar{\nu}}^{\uparrow\downarrow})}. \qquad (5)$$

*E-mail: etimoshin@gstu.by
†E-mail: timoshin@gstu.by

The first arrow correspond the helicity of neutrino ($\downarrow$) or antineutrino ($\uparrow$), and the second - direction spin of nucleon $\uparrow$ ($P_N = +1$) and $\downarrow$ ($P_N = -1$). Substituting cross sections (2) to (5) we have for asymmetries

$$A_{\pm} = \frac{\sigma_{\nu}^{p} \pm \sigma_{\bar{\nu}}^{p}}{\sigma_{\nu}^{a} \pm \sigma_{\bar{\nu}}^{a}}. \tag{6}$$

With the help (3), (4) the polarization asymmetries (5) for the proton we obtain in the following form:

$$A_{-p} = \frac{a_u\left[\Delta u(x) + \Delta\bar{u}(x)\right] + a_d\left[\Delta d(x) + \Delta\bar{d}(x)\right] + a_s\left[\Delta s(x) + \Delta\bar{s}(x)\right]}{2\left[b_u u_V(x) + b_d d_V(x)\right]}, \tag{7}$$

$$A_{+p} = \frac{2\left[b_u \Delta u_V(x) + b_d \Delta d_V(x)\right]}{a_u\left[u(x) + \bar{u}(x)\right] + a_d\left[d(x) + \bar{d}(x)\right] + a_s\left[s(x) + \bar{s}(x)\right]}. \tag{8}$$

The polarization SF of the neutron have measure in DIS on the deutrons and the nuclei ^3He (SLAC, COMPASS, HERMES). They necessary for the separation of the parton distributions on the flavors in the combination with the data DIS on the protons.

The possibilities measurements SF neutron will expand in the experiments at EIC and in JLab 12 GeV. We consider such the approach for the neutrino DIS (1). For the scattering off the neutrons the asymmetries (5) are

$$A_{-n} = \frac{a_d\left[\Delta u(x) + \Delta\bar{u}(x)\right] + a_u\left[\Delta d(x) + \Delta\bar{d}(x)\right] + a_s\left[\Delta s(x) + \Delta\bar{s}(x)\right]}{2\left[b_d u_V(x) + b_u d_V(x)\right]}, \tag{9}$$

$$A_{+n} = \frac{2\left[b_d \Delta u_V(x) + b_u \Delta d_V(x)\right]}{a_d\left[u(x) + \bar{u}(x)\right] + a_u\left[d(x) + \bar{d}(x)\right] + a_s\left[s(x) + \bar{s}(x)\right]}. \tag{10}$$

In (7) and (9) we cross to the first moments of the parton distributions

$$a_u(\Delta u + \Delta\bar{u}) + a_d(\Delta d + \Delta\bar{d}) + a_s(\Delta s + \Delta\bar{s}) = \int_0^1 2A_{-p}\left[b_u u_V(x) + b_d d_V(x)\right]dx, \tag{11}$$

$$a_d(\Delta u + \Delta\bar{u}) + a_u(\Delta d + \Delta\bar{d}) + a_s(\Delta s + \Delta\bar{s}) = \int_0^1 2A_{-n}\left[b_d u_V(x) + b_u d_V(x)\right]dx. \tag{12}$$

For the separation of quark flavors in (11), (12) we use the octet axial charge $a_8 = 3F - D = 0,579 \pm 0,025$, that in QPM is

$$a_8 = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s}). \tag{13}$$

Therefore, from (11), (12), (13)

$$\Delta u + \Delta\bar{u} = $$
$$= \frac{(2a_d + a_s)\int_0^1 A_{-p}\left[b_u u_V(x) + b_d d_V(x)\right]dx - (2a_d + a_s)\int_0^1 A_{-n}\left[b_d u_V(x) + b_u d_V(x)\right]dx}{(a_u - a_d)(a_u + a_d + a_s)} +$$
$$+ \frac{a_s a_8}{2(a_u + a_d + a_s)},$$

$$\Delta d + \Delta\bar{d} = $$
$$= \frac{(2a_u + a_s)\int_0^1 A_{-n}\left[b_d u_V(x) + b_u d_V(x)\right]dx - (2a_d + a_s)\int_0^1 A_{-p}\left[b_u u_V(x) + b_d d_V(x)\right]dx}{(a_u - a_d)(a_u + a_d + a_s)} +$$
$$+ \frac{a_s a_8}{2(a_u + a_d + a_s)},$$

$$\Delta s+\Delta\bar{s}=\frac{\int_0^1 A_{-p}\left[b_u u_V(x)+b_d d_V(x)\right]dx-\int_0^1 A_{-n}\left[b_d u_V(x)+b_u d_V(x)\right]dx-\frac{a_8(a_u+a_d)}{2}}{a_u+a_d+a_s}.$$

These the contributions of the quark flavors in the spin nucleon can to obtain from the data on the proton (11) and the apply quantities a_8 (13) and a_3:

$$a_3=(\Delta u+\Delta\bar{u})-(\Delta d+\Delta\bar{d}) \qquad (14)$$

$$\Delta u+\Delta\bar{u}=\frac{2\int_0^1 A_{-p}\big(b_u u_V(x)+b_d d_V(x)\big)dx+a_d a_3+a_s(a_3+a_8)/2}{a_u+a_d+a_s},$$

$$\Delta d+\Delta\bar{d}=\frac{2\int_0^1 A_{-p}\big(b_u u_V(x)+b_d d_V(x)\big)dx-a_u a_3+a_s(a_8-a_3)/2}{a_u+a_d+a_s}, \qquad (15)$$

$$\Delta s+\Delta\bar{s}=\frac{2\int_0^1 A_{-p}\big(b_u u_V(x)+b_d d_V(x)\big)dx-a_u a_3-(a_u+a_d)(a_8-a_3)/2}{a_u+a_d+a_s}.$$

The analogous expressions can to obtain for the neutron, if in (15) to make the replacements $A_{-p}\to A_{-n}, a_u\leftrightarrow a_d, b_u\leftrightarrow b_d$. The first moments distributions of the valence quarks Δu_V and Δd_V from A_{+p} (8) and A_{+n} (10) we perform as

$$b_u\Delta u_V+b_d\Delta d_V=\frac{1}{2}\int_0^1 A_{+p}\Big[\sum_{q=u,d,s} a_q\big(q(x)+\bar{q}(x)\big)\Big]dx$$

$$b_d\Delta u_V+b_u\Delta d_V=$$
$$=\frac{1}{2}\int_0^1 A_{+n}\Big[a_d\big(u(x)+\bar{u}(x)\big)+a_u\big(d(x)+\bar{d}(x)\big)+a_s\big(s(x)+\bar{s}(x)\big)\Big]dx.$$

Therefore the polarization of the valence quarks we obtain the expressions

$$\Delta u_V=\frac{\frac{b_u}{2}\int_0^1 A_{+p}\Big[\sum_{q=u,d,s} a_q\big(q(x)+\bar{q}(x)\big)\Big]dx-\frac{b_d}{2}\int_0^1 A_{+n}\Big[a_d\big(u(x)+\bar{u}(x)\big)+a_u\big(d(x)+\bar{d}(x)\big)+a_s\big(s(x)+\bar{s}(x)\big)\Big]dx}{b_u^2-b_d^2},$$

$$\Delta d_V=\frac{\frac{b_u}{2}\int_0^1 A_{+n}\Big[a_d\big(u(x)+\bar{u}(x)\big)+a_u\big(d(x)+\bar{d}(x)\big)+a_s\big(s(x)+\bar{s}(x)\big)\Big]dx-\frac{b_d}{2}\int_0^1 A_{+p}[\sum_{q=u,d,s} a_q\big(q(x)+\bar{q}(x)\big)\Big]dx}{b_u^2-b_d^2}$$

Thus, with the help the polarization asymmetries A_{-p} and A_{-n} DIS the neutrino and the antineutrino on the longitudinally polarized protons and the neutrons the expressions were obtained for the quark contributions $(\Delta u+\Delta\bar{u})$, $(\Delta d+\Delta\bar{d})$, $(\Delta s+\Delta\bar{s})$ in the nucleon spin. The asymmetries A_{+p} and A_{+n} give the access at the polarization valence quarks Δu_V and Δd_V without the using complementary measurable quantities.

References

[1] Harris, D.A. A Small Target Neutrino Deep-Inelastic Scattering Experiment at the First Muon Collider / D.A. Harris, K.S. McFarland // AIP Conf. Proc. - 1998. - Vol.435, No.1. - P.505-510.

[2] Physics at a Neutrino Factory / C. Albright [et al.]. - ArXiv: hep-ex/0008064.