Investigation Spin of Nucleon in Neutrino Reactions

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Abstract

A new way of obtaining spin-dependent structure functions from asymmetries of deep inelastic neutrino scattering on polarized target is proposed. Quark contributions in nucleon's spin have been defined on the basis the first moments of structure functions for scattering on proton and deutron.

Introduction

After the EMC experiment [1] began new stage in a study the spin structure of nucleon. The EMC experimental results indicated, that only a small fraction, $\Delta\Sigma = 0.12 \pm 0.17$, of the proton's spin is due to the spin of quarks and the strange quarks have essential negative polarization $\Delta\Sigma = -0.190 \pm 0.078$. They contradicted to expectations of the naive quark parton model (QPM) ($\Delta\Sigma = 1$, $\Delta s = 1$) or the relativistic QPM ($\Delta\Sigma = 0.58$).

In following years was conducted the series experiments [2]-[9] on the deep inelastic scattering (DIS) polarized electrons and muons on polarized targets. The SLAC, CERN, DESY data confirm conclusions about small $\Delta\Sigma$ with typical value 0.2-0.4, that corresponds the polarization of the strange quarks .

In semi-inclusive experiments [10], [11] was measured the polarization of the sea quarks. For the light sea quarks ($\Delta\bar{u}$, $\Delta\bar{d}$) the polarization is compatible with zero, while for the strange quarks a slightly positive polarization is favoured within the measured range in contrast to results based on inclusive data alone [2]-[9]. However, within their total uncertainty also the polarization of the strange quarks is zero.

Therefore further measurements the quark contributions in the nucleon's spin are necessary. A search new possibilities the receipt the information about the spin structure of the nucleon is actual in connection with this.

The polarized DIS with neutrino beams [12] is highly interesting for a investigation the nucleon's spin as gives access to the flavor structure of the target.

In previous works [13]-[15] a ways were elaborated for the determination the quark contributions in the spin of nucleon with help the different sets of the observable quantities (the asymmetries, the first moments of polarized structure functions) lepton - nucleon DIS.

In this paper we propose a new approach for extraction of the polarized structure functions (SF) from the measurable asymmetries, which not depend from the type of the target. This allows make an analysis the spin structure of the nucleon based on the first moments the polarized SF for the different polarized targets, and not only deutron as in [14], [15].

1 Polarized νN-DIS (charged current)

$$\nu_\mu(\bar{\nu}_\mu) + N \to \mu^-(\mu^+) + X \qquad (1)$$

The cross sections of the reactions (1) are

$$\begin{aligned}\sigma_{\nu\bar{\nu}} &= \sigma_0[xy^2F_1^{\nu\bar{\nu}}(x) + y_1F_2^{\nu\bar{\nu}}(x) \pm xy\left(1-\frac{y}{2}\right)F_3^{\nu\bar{\nu}}(x) + \\ &+ P_N x(y_1^+ g_6^{\nu\bar{\nu}}(x) \pm y_1^- g_1^{\nu\bar{\nu}}(x)) \qquad (2)\end{aligned}$$

Here $\sigma \equiv d^2\sigma/dxdy$; x, y are usual scaling variables, $F_{1,2,3}$ and $g_{1,6}$ are structure functions (SF), $y_1^\pm = 1 \pm y_1^2$, $y_1 = 1-y$, P_N is degree the longitudinal polarization of nucleon.

The asymmetries are necessary measured quantities in the polarized experiments. This asymmetries are a certain combinations of the differential cross sections for the different directions the particl's spin.

For the neutrino processes can definite following the observable asymmetries:

$$A_{\nu\bar{\nu}}(x,y) = \frac{\sigma_{\nu\bar{\nu}}^{\downarrow\uparrow,\uparrow\uparrow} - \sigma_{\nu\bar{\nu}}^{\downarrow\downarrow,\uparrow\downarrow}}{\sigma_{\nu\bar{\nu}}^{\downarrow\uparrow,\uparrow\uparrow} + \sigma_{\nu\bar{\nu}}^{\downarrow\downarrow,\uparrow\downarrow}} \qquad (3)$$

or in terms of SF

$$A_{\nu\bar{\nu}}(x,y) = \frac{y_1^+ g_6^{\nu\bar{\nu}}(x) \pm y_1^- g_1^{\nu\bar{\nu}}(x)}{y_1^+ F_1^{\nu\bar{\nu}}(x) \pm \frac{y_1}{2} F_3^{\nu\bar{\nu}}(x)} \qquad (4)$$

For extraction SF g_1, g_2 determine asymmetries with help $d\sigma_{\nu\bar{\nu}}/dx = \int_0^1 \frac{d^2\sigma}{dxdy}dy$:

$$A_{\nu\bar{\nu}}(x) = \frac{2[2g_6^{\nu\bar{\nu}}(x) \pm g_1^{\nu\bar{\nu}}(x)}{4F_1^{\nu\bar{\nu}}(x) \pm F_3^{\nu\bar{\nu}}(x)}. \quad (5)$$

Then from (4), (5) can to extract spin-dependent SF

$$\begin{aligned} g_1^{\nu\bar{\nu}}(x) &= \pm\frac{1}{1-3y_1^2}\left[2A_{\nu\bar{\nu}}(x,y)\left(y_1^+ F_1^{\nu\bar{\nu}}(x) \pm \frac{y_1}{2}F_3^{\nu\bar{\nu}}(x)\right) - \right. \\ &\left. -y_1^+\left(2F_1^{\nu\bar{\nu}}(x) \pm \frac{1}{2}F_3^{\nu\bar{\nu}}(x)\right)\right] \\ g_6^{\nu\bar{\nu}}(x) &= \frac{y_1^-}{3y_1^2-1}\left[A_{v,\bar{v}}(x,y)\left(\frac{y_1^+}{y_1^-}F_1^{v,\bar{v}}(x) \pm \frac{1}{2}F_3^{v,\bar{v}}(x)\right) - \right. \\ &\left. -A_{v,\bar{v}}(x)\left(2F_1^{v,\bar{v}}(x) \pm \frac{1}{2}F_3^{v,\bar{v}}(x)\right)\right]. \end{aligned} \quad (6)$$

1.1 Spin structure of nucleon: proton's target

The SF $g_{1,6}^{\nu,\bar{\nu}}(x)$ in QPM are

$$g_1^{\nu,\bar{\nu}}(x) = \sum_q \Delta q(x) + \sum_{\bar{q}} \Delta\bar{q}(x), \quad (7)$$

$$g_6^{\nu,\bar{\nu}}(x) = \sum_q \Delta q(x) - \sum_{\bar{q}} \Delta\bar{q}(x), \quad (8)$$

where $q = d, s, b$ ($q = u, c, t$) and $\bar{q} = \bar{u}, \bar{c}, \bar{t}$ ($\bar{q} = \bar{d}, \bar{s}, \bar{b}$) for neutrino (antineutrino). The first moments SF (7), (8), that are $\Gamma_{1,6} = \int_0^1 g_{1,6}dx$, equal

$$\begin{aligned} &\Gamma_1^{\nu p} = \Delta d + \Delta s + \Delta\bar{u},\ \Gamma_6^{\nu p} = \Delta d + \Delta s - \Delta\bar{u}, \\ &\Gamma_1^{\bar{\nu}p} = \Delta u + \Delta\bar{d} + \Delta\bar{s},\ \Gamma_6^{\bar{\nu}p} = \Delta u - \Delta\bar{d} - \Delta\bar{s}, \end{aligned} \quad (9)$$

where

$$\Delta q(\Delta\bar{q}) = \int_0^1 \Delta q(x)(\Delta\bar{q}(x))dx.$$

For extraction the quark contributions from (9) necessary have supplementary measurable quantity, for example, axial charge $a_3 = F + D = 1.267 \pm 0.00035$, that in QPM is

$$a_3 = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d}). \qquad (10)$$

Combining (9), (10) obtain following quark contributions in spin nucleon:

- the quark flavours (u, d, s)

$$\begin{aligned} \Delta u + \Delta\bar{u} &= \frac{1}{2}(\Gamma_1^{\nu p} + \Gamma_1^{\bar{\nu}p} - \Gamma_6^{\nu p} + \Gamma_6^{\bar{\nu}p}), \\ \Delta d + \Delta\bar{d} &= \frac{1}{2}(\Gamma_1^{\nu p} + \Gamma_1^{\bar{\nu}p} - \Gamma_6^{\nu p} + \Gamma_6^{\bar{\nu}p}) - a_3, \\ \Delta s + \Delta\bar{s} &= \Gamma_6^{\nu p} - \Gamma_6^{\bar{\nu}p} + a_3, \end{aligned} \qquad (11)$$

- the valence quarks

$$\Delta u_V = \frac{1}{2}(\Gamma_6^{\nu p} + \Gamma_6^{\bar{\nu}p} - \Gamma_1^{\nu p} + \Gamma_1^{\bar{\nu}p}), \; \Delta d_V = \frac{1}{2}(\Gamma_1^{\nu p} - \Gamma_1^{\bar{\nu}p} + \Gamma_6^{\nu p} + \Gamma_6^{\bar{\nu}p}), \qquad (12)$$

- the total quark contribution
  $\Delta\Sigma = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})$ is

$$\Delta\Sigma = \Gamma_1^{\nu p} + \Gamma_1^{\bar{\nu}p}, \qquad (13)$$

- the antiquarks

$$\begin{aligned} \Delta\bar{u} = \frac{1}{2}(\Gamma_1^{\nu p} - \Gamma_6^{\nu p}), \; \Delta\bar{d} &= \frac{1}{2}(\Gamma_1^{\bar{\nu}p} - \Gamma_6^{\nu p} - a_3), \\ \Delta\bar{s} &= \frac{1}{2}(\Gamma_1^{\nu p} - \Gamma_6^{\bar{\nu}p} + a_3). \end{aligned} \qquad (14)$$

1.2 Spin structure of nucleon: deutron's target

The polarization SF of deutron determine as usually in the form:

$$g_{1,6}^{\nu(\bar{\nu})d} = \frac{g_{1,6}^{\nu(\bar{\nu})p} + g_{1,6}^{\nu(\bar{\nu})n}}{2}(1 - 1.5\omega),$$

where $\omega \approx 0.05$ is the probability D-state in wave function of deutron.

The first moments SF $g_{1,6}^{\nu(\bar{\nu})d}$ are

$$\Gamma_1^{\nu d} = \Gamma_1^{\bar{\nu}d} \equiv \Gamma_1^d = \frac{1}{2}[(\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})](1 - 1.5\omega),$$

$$\Gamma_6^{\nu(\bar{\nu})d} = \frac{1}{2}[\Delta u_V + \Delta d_V \pm (\Delta s + \Delta\bar{s})](1 - 1.5\omega).$$

Hence it follows

$$\Delta\Sigma = \frac{2\Gamma_1^d}{1 - 1.5\omega}, \tag{15}$$

$$\Delta u_V + \Delta d_V = \frac{\Gamma_6^{\nu d} + \Gamma_6^{\bar{\nu}d}}{1 - 1.5\omega}, \tag{16}$$

$$\Delta s + \Delta\bar{s} = \frac{\Gamma_6^{\nu d} - \Gamma_6^{\bar{\nu}d}}{1 - 1.5\omega},$$

$$\Delta u + \Delta\bar{u} = \frac{1}{2}\left(\frac{2\Gamma_1^d - \Gamma_6^{\nu d} + \Gamma_6^{\bar{\nu}d}}{1 - 1.5\omega} + a_3\right) \quad , \tag{17}$$

$$\Delta d + \Delta\bar{d} = \frac{1}{2}\left(\frac{2\Gamma_1^d - \Gamma_6^{\nu d} + \Gamma_6^{\bar{\nu}d}}{1 - 1.5\omega} - a_3\right).$$

1.3 Polarized νN — DIS (neutral current)

Now considere the processes with neutral current

$$\nu_\mu(\bar{\nu}_\mu) + N \to \nu_\mu(\bar{\nu}_\mu) + X. \tag{18}$$

The cross sections of the processes (18) obtain from (??) with help the replacements

$$F_{1,2,3}^{\nu,\bar{\nu}} \to F_{1,2,3}^0; \quad g_{1,6}^{\nu,\bar{\nu}} \to g_{1,6}^0.$$

The polarization asymmetries are

$$A^{NC}_{\nu,\bar{\nu}} = \frac{\sigma^{\downarrow\uparrow,\uparrow\uparrow}_{\nu,\bar{\nu}} - \sigma^{\downarrow\downarrow,\uparrow\downarrow}_{\nu,\bar{\nu}}}{\sigma^{\downarrow\uparrow,\uparrow\uparrow}_{\nu,\bar{\nu}} + \sigma^{\downarrow\downarrow,\uparrow\downarrow}_{\nu,\bar{\nu}}}, \tag{19}$$

$$A^{NC}_{\pm} = \frac{(\sigma^{\downarrow\uparrow}_{\nu} \pm \sigma^{\uparrow\uparrow}_{\bar{\nu}}) - (\sigma^{\downarrow\downarrow}_{\nu} \pm \sigma^{\uparrow\downarrow}_{\bar{\nu}})}{(\sigma^{\downarrow\uparrow}_{\nu} \pm \sigma^{\uparrow\uparrow}_{\bar{\nu}}) + (\sigma^{\downarrow\downarrow}_{\nu} \pm \sigma^{\uparrow\downarrow}_{\bar{\nu}})}. \tag{20}$$

In terms SF:

$$A^{NC}_{\nu,\bar{\nu}} = \frac{2x(y_1^+ g_6^0 \pm y_1^- g_1^0)}{y_1^+ F_2^0 \pm y_1^- x F_3^0}, \tag{21}$$

$$A^{NC}_{+} = \frac{2xg_6^0}{F_2^0}, \quad A^{NC}_{-} = \frac{2g_1^0}{F_3^0}, \tag{22}$$

where

$$\begin{aligned} g_1^0(x) &= \frac{1}{2}\sum_q a_q[\Delta q(x) + \Delta\bar{q}(x)], \\ g_6^0(x) &= \sum_q b_q[\Delta q(x) - \Delta\bar{q}(x)], \end{aligned} \tag{23}$$

$$a_q = (g_V^2 + g_A^2)_q, \quad b_q = (g_V g_A)_q,$$

$$(g_V)_u = \frac{1}{2} - \frac{4}{3}\sin^2\theta_w, \quad (g_A)_u = \frac{1}{2}; \quad (g_V)_{d,s} = -\frac{1}{2} + \frac{2}{3}\sin^2\theta_w,$$

$$(g_A)_{d,s} = -\frac{1}{2},$$

$\theta_w$is Weinberg angle.

In case of the reactions (18) with neutral current SF $g^0_{1,6}$ can determine directly from expressions (21)

$$g_1^0(x) = \frac{1}{4xy_1^-}[y_1^+ F_2^0(A^{NC}_{\nu} - A^{NC}_{\bar{\nu}}) + y_1^- x F_3^0(A^{NC}_{\nu} + A^{NC}_{\bar{\nu}})],$$

$$g_6^0(x) = \frac{1}{4xy_1^+}[y_1^+ F_2^0(A^{NC}_{\nu} + A^{NC}_{\bar{\nu}}) + y_1^+ x F_3^0(A^{NC}_{\nu} - A^{NC}_{\bar{\nu}})]$$

or from (22):

$$g_1^0(x) = \frac{1}{2} F_3^0 A_-^{NC}, \quad g_6^0(x) = \frac{1}{2x} F_2^0 A_+^{NC}.$$

1.4 Proton's target

The first moments SF (23):

$$\Gamma_1^p = \frac{1}{2}[a_u(\Delta u + \Delta\bar{u}) + a_d(\Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})],$$

$$\Gamma_6^p = b_u \Delta u_V + b_d \Delta d_V.$$

Then the quark contributions can to find from following combinations observable quantities:

$$\boxed{\begin{array}{l} \Gamma_1^p, a_3, a_8 = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s}) \\ \qquad\qquad a_8 = 3F - D = 0.585 \pm 0.025 \end{array}} \longrightarrow \qquad (23)$$

$$\longrightarrow \left[\begin{array}{l} \Delta u + \Delta\bar{u} = \dfrac{2\Gamma_1^p + \frac{1}{2}a_d(3a_3 + a_8)}{a_u + 2a_d}, \\ \Delta d + \Delta\bar{d} = \dfrac{2\Gamma_1^p + \frac{1}{2}a_d(a_8 - a_3) - a_3 a_u}{a_u + 2a_d}, \\ \Delta s + \Delta\bar{s} = \dfrac{2\Gamma_1^p - \frac{1}{2}a_u(a_3 + a_8) + \frac{1}{2}a_d(a_3 - a_8)}{a_u + 2a_d} \end{array} \right.$$

$$\boxed{\begin{array}{l} \Gamma_6^p, \ a_3 = \Delta u_V - \Delta d_V \\ \qquad (\Delta\bar{u} = \Delta\bar{d}) \end{array}} \longrightarrow \left[\begin{array}{l} \Delta u_V = \frac{\Gamma_6^p + a_3 b_d}{b_u + b_d}, \\ \Delta d_V = \frac{\Gamma_6^p - a_3 b_u}{b_u + b_d}. \end{array} \right. \qquad (23)$$

1.5 Deutron's target

The first moments SF of deuteron are

$$\Gamma_1^d = \frac{1}{4}[(a_u + a_d)(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d}) + 2a_d(\Delta s + \Delta\bar{s})](1 - 1.5\omega),$$

$$\Gamma_6^d = \frac{1}{2}[(b_u + b_d)(\Delta u_V + \Delta d_V)(1 - 1.5\omega).$$

With help their and a_3, a_8 obtain

$$\boxed{\Gamma_1^d, a_3, a_8}$$

$$\downarrow$$

$$\Delta u + \Delta\bar{u} = \frac{1}{a_u + 2a_d}\left(\frac{2\Gamma_1^d}{1 - 1.5\omega} + \frac{1}{2}a_8 a_d\right) + \frac{a_3}{2},$$

$$\Delta d + \Delta\bar{d} = \frac{1}{a_u + 2a_d}\left(\frac{2\Gamma_1^d}{1 - 1.5\omega} - \frac{1}{2}a_8 a_d\right) - \frac{a_3}{2},$$

$$\Delta s + \Delta\bar{s} = \frac{1}{a_u + 2a_d}\left[\frac{2\Gamma_1^d}{1 - 1.5\omega} - \frac{1}{2}a_8(a_u + a_d)\right].$$

$$\Gamma_6^d \to \Delta u_V + \Delta d_V = \frac{2\Gamma_6^d}{(b_u + b_d)(1 - 1.5\omega)}.$$

2 Conclusions

- νN – **DIS (charged current)**

  the determination polarized SF

$$A_{\nu,\bar{\nu}}(x,y),\ A_{\nu,\bar{\nu}}(x) \to g_1^{\nu,\bar{\nu}}, g_6^{\nu,\bar{\nu}}$$

  the quark contributions to nucleon's spin

$$\Gamma_1^{\nu(\bar{\nu})p}, \Gamma_6^{\nu(\bar{\nu})p}, a_3 \to \left[\begin{array}{l} \Delta u + \Delta\bar{u}, \Delta d + \Delta\bar{d}, \Delta s + \Delta\bar{s} \\ \Delta u_V, \Delta d_V \\ \Delta\Sigma \\ \Delta\bar{u}, \Delta\bar{d}, \Delta\bar{s} \end{array}\right.$$

$$\Gamma_1^d, \Gamma_6^{\nu(\bar{\nu})d}, a_3 \to \left[\begin{array}{l} \Delta u + \Delta\bar{u}, \Delta d + \Delta\bar{d}, \Delta s + \Delta\bar{s} \\ \Delta u_V + \Delta d_V \\ \Delta\Sigma \end{array}\right.$$

- νN – **DIS (neutral current)**

  the determination polarized SF

$$A_{\nu,\bar\nu}^{NC}(x,y) \text{ or } A_{\pm}^{NC}(x,y) \to g_1^0, g_6^0$$

the quark contributions to nucleon's spin for proton and deutron

$$\Gamma_1^p, a_3, a_8 \to \Delta u + \Delta\bar u, \Delta d + \Delta\bar d, \Delta s + \Delta\bar s$$

$$\Gamma_6^p, a_3(\Delta\bar u = \Delta\bar d) \to \Delta u_V, \Delta d_V$$

$$\Gamma_1^d, a_3, a_8 \to \Delta u + \Delta\bar u, \Delta d + \Delta\bar d, \Delta s + \Delta\bar s$$

$$\Gamma_6^d \to \Delta u_V + \Delta d_V.$$

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