Investigation of the proton spin at HERA

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1 Introduction

The experiments HERMES [1], [2]
$0.023 < x < 0.6$ and $1 < Q^2 < 15$ (Gev^2)

- From the inclusive measurements $\rightarrow g_1^p, g_1^d$ [3], [4]

  One observes a good consistency with the measurements of SMC [5] and SLAC. [6] - [8]

  The fraction of the proton's spin which is carried by its quarks and antiquarks

  $$\Delta\Sigma = 0.2 - 0.35.$$

  It corresponds to a negative strange-quark polarization

  $$\Delta s = -0.10 \pm 0.04.$$

- From the semi-inclusive measurements [2], [9], [10] $\rightarrow$ quark polarization extracted separately for the $\bar{u}, \bar{d}, \bar{s}$ flavours.

  In contrast to results based on inclusive data for the**light sea quarks** $(\bar{u}, \bar{d})$ **the polarization is compatible with zero** and the strange sea is **positively** polarized within the measured range. However, within their total uncertainty also the **polarization of the strange quarks is zero.**

- **The future experiments at polarized HERA** $(\vec{e}\vec{p})$ The inclusive reactions DIS

$$e^-(e^+) + p \rightarrow v(\bar{\nu}) + X(CC) \quad (1)$$

$$e^{\pm}+p \xrightarrow{\gamma,z} e^{\pm}+X(NC) \qquad (2)$$

In present talk we propose an approach for the determination the contributions of individual quarks flavours, i.e. $\Delta q + \Delta\bar{q} \quad (q = u, d, s)$, and of sea quarks $\Delta\bar{u}$, $\Delta\bar{d}$, $\Delta\bar{s}$ to the proton's spin from the inclusive measurements (1) . The last is specially important to understanding the internal spin structure of the proton. Moreover this give a possibility to compare with the semi-inclusive measurements HERMES.

Also the polarization of quark flavours and the valence quarks is determined from the observable quantities the processes (2) in frame the electroweak theory.

2 The polarized $ep - DIS$ (charged current)

The cross sections of the reactions (1) are

$$d^2\sigma_{e^-,e^+} \ / \ dxdy = \qquad (3)$$
$$\rho\left[\frac{1}{2}\left(y_1^+ F_2^{e^-,e^+} \pm y_1^- x F_3^{e^-,e^+}\right) + P_N x \left(y_1^+ g_6^{e^-,e^+} \pm y_1^- g_1^{e^-,e^+}\right)\right].$$

Here

$$\rho = \frac{G^2 s}{2\pi}\left(\frac{1}{1+Q^2/m_w^2}\right)^2, \quad y_1^{\pm} = 1 \pm y_1^2, \quad y_1 = 1 - y,$$

$F_{2,3}$and $g_{1,6}$ are the structure functions (SF) of proton; G is Fermi constant, P_N is degree the longitudinal polarization of proton, m_w is mass of W boson; $x = Q^2/2pq$ and $y = pq/pk$; $Q^2 = -q^2 = -(k-k')^2$, k, k', p are the 4-moments of the incoming (outcoming) lepton and proton respectively; $S = 2pk$.

The observable polarized asymmetries are

$$A^{CC}_{e^-,e^+}(x,y) = \frac{\sigma^{\downarrow\uparrow,\uparrow\uparrow}_{e^-,e^+} - \sigma^{\downarrow\downarrow,\uparrow\downarrow}_{e^-,e^+}}{\sigma^{\downarrow\uparrow,\uparrow\uparrow}_{e^-,e^+} + \sigma^{\downarrow\downarrow,\uparrow\downarrow}_{e^-,e^+}}, \qquad (4)$$

where

$$\sigma \equiv d^2\sigma/dxdy;$$

the first arrow : ↓ (electron) or ↑ (positron),

second – proton spin: ↑ ($P_N = +1$), ↓ ($P_N = -1$).

Substituting (3) to (4) obtain

$$A^{CC}_{e^-,e^+}(x,y) = \frac{2x\left(y_1^+ g_6^{e^-,e^+} \pm y_1^- g_1^{e^-,e^+}\right)}{y_1^+ F_2^{e^-,e^+} \pm y_1^- x F_3^{e^-,e^+}}. \quad (5)$$

Analogously (5) determine asymmetries $A_{e^-,e^+}(x)$ with help the cross sections

$$d\sigma_{e^-,e^+}/dx = \int_0^1 \frac{d^2\sigma_{e^-,e^+}}{dxdy} dy = \frac{\varrho}{3}\left[2F_2^{e^-,e^+} \pm xF_3^{e^-,e^+} + \right.$$
$$\left. + 2P_N x \left(2g_6^{e^-,e^+} \pm g_1^{e^-,e^+}\right)\right]. \quad (6)$$

These asymmetries are

$$A^{CC}_{e^-,e^+}(x) = \frac{2x\left(2g_6^{e^-,e^+} \pm g_1^{e^-,e^+}\right)}{2F_2^{e^-,e^+} \pm xF_3^{e^-,e^+}}. \quad (7)$$

Then from (5), (7) can to extract the spin-dependent SF $g_{1,6}^{e^-,e^+}$:

$$g_1^{e^-,e^+} = \pm\frac{1}{2x(3y^2-1)}\left[y_1^+ A^{CC}_{e^-,e^+}(x)\left(2F_2^{e^-,e^+} \pm xF_3^{e^-,e^+}\right) - \right.$$
$$\left. -2A^{CC}_{e^-,e^+}(x,y)\left(y_1^+ F_2^{e^-,e^+} \pm y_1^- xF_3^{e^-,e^+}\right)\right], \quad (8)$$

$$g_6^{e^-,e^+} = \frac{1}{2x(3y^2-1)}\left[A^{CC}_{e^-,e^+}(x,y)\left(y_1^+ F_2^{e^-,e^+} \pm y_1^- xF_3^{e^-,e^+}\right) - \right.$$
$$\left. -y_1^- A^{CC}_{e^-,e^+}(x)\left(2F_2^{e^-,e^+} \pm xF_3^{e^-,e^+}\right)\right].$$

$$g_{1,6}(x) = \sum_q \Delta q(x) \pm \sum_{\bar{q}} \Delta\bar{q}(x), \quad (9)$$

where

$q = u, c, t \quad (q = d, s, b)$and $\bar{q} = \bar{d}, \bar{s}, \bar{b}(\bar{q} = \bar{u}, \bar{c}, \bar{t})$
for electron (positron).
The first moments SF

$$\Gamma_{1,6} = \int_0^1 g_{1,6} dx. \tag{10}$$

Then neglecting the contributions of quarks (c, b, t) with help (9) and (10) obtain for proton

$$\begin{aligned} \Gamma_1^{e^-} &= \Delta u + \Delta\bar{d} + \Delta\bar{s}, \\ \Gamma_6^{e^-} &= \Delta u - \Delta\bar{d} - \Delta\bar{s}, \\ \Gamma_1^{e^+} &= \Delta d + \Delta s + \Delta\bar{u}, \\ \Gamma_6^{e^+} &= \Delta d + \Delta s - \Delta\bar{u}, \end{aligned} \tag{11}$$

where the quantities
$\Delta q(\Delta\bar{q}) = \int_0^1 \Delta q(x)[\Delta\bar{q}(x)]dx \quad (q = u, d, s)$determine in QPM the contributions of quarks (antiquarks) to the protons spin.

Combining the expressions (11) with the supplementary measurable quantity, for example, the axial charge a_8 (or a_3):

$$a_8 = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s}) \tag{12}$$

we determine the quark contributions to the protons spin:
1)

$$\Delta \sum \equiv (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s}) = \Gamma_1^{e^-} + \Gamma_1^{e^+} \tag{13}$$

2) The quark flavours

$$\begin{aligned} \Delta u + \Delta\bar{u} &= \tfrac{1}{2}(\Gamma_1^{e^-} + \Gamma_1^{e^+} + \Gamma_6^{e^-} - \Gamma_6^{e^+}), \\ \Delta d + \Delta\bar{d} &= \tfrac{1}{6}[(2a_8 + \Gamma_1^{e^-} + \Gamma_1^{e^+} + 3(\Gamma_6^{e^+} - \Gamma_6^{e^-})], \\ \Delta s + \Delta\bar{s} &= \tfrac{1}{3}(\Gamma_1^{e^-} + \Gamma_1^{e^+} - a_8). \end{aligned} \tag{14}$$

3) The valence quarks

$$\Delta u_V \equiv \Delta u - \Delta\bar{u} = \tfrac{1}{2}(\Gamma_6^{e^-} + \Gamma_6^{e^+} - \Gamma_1^{e^+} - \Gamma_1^{e^-}),$$
$$\Delta d_V \equiv \Delta d - \Delta\bar{d} = \tfrac{1}{2}(\Gamma_1^{e^+} - \Gamma_1^{e^-} + \Gamma_6^{e^-} + \Gamma_6^{e^+}).$$

4) The sea quarks

$$\begin{aligned} \Delta\bar{u} &= \tfrac{1}{2}(\Gamma_1^{e^+} - \Gamma_6^{e^-}), \\ \Delta\bar{d} &= \tfrac{1}{6}(2\Gamma_1^{e^-} + a_8 - \Gamma_1^{e^+}) - \Gamma_6^{e^-}, \\ \Delta\bar{s} &= \tfrac{1}{6}(\Gamma_1^{e^-} + \Gamma_1^{e^+} - a_8). \end{aligned} \tag{15}$$

Thus, the scheme an extraction the contributions of quarks to proton's spin is proposed by the measurable quantities:

The asymmetries $\left[A^{CC}_{e^-,e^+}(x,y), A^{CC}_{e^-,e^+}(x)\right] \rightarrow g_{1,6}^{e^-,e^+} \rightarrow \Gamma_{1,6}^{e^-,e^+}; a_8 \rightarrow$ The contributions of quarks to the spin of proton.

3 A combination the polarized data HERA and the neutrino experiments

$$A^{CC}_{\nu,\bar{\nu}}(x,y) \sim g_{1,6}^{\nu,\bar{\nu}}; \quad F_{2,3}^{\nu,\bar{\nu}}$$

So $g_{1,6}^{\nu,\bar{\nu}} = g_{1,6}^{e^+,e^-}$ and $F_{2,3}^{\nu,\bar{\nu}} = F_{2,3}^{e^+,e^-}$,

the neutrino asymmetries can to represent as

$A^{CC}_{\nu,\bar{\nu}}(x,y) \sim \quad g_{1,6}^{e^+,e^-}$ and $F_{2,3}^{e^+,e^-}$.

Therefore, may to use the following set of asymmetries: $A^{CC}_{e^+,e^-}(x,y)$ and $A^{CC}_{\nu,\bar{\nu}}(x,y)$.

4 The polarized $ep-$ DIS (neutral current)

Here we consider the following measurable asymmetries:

$$A_{\pm}(x,y) = \frac{(\sigma^{\downarrow\uparrow} \pm \sigma^{\uparrow\uparrow}) - (\sigma^{\downarrow\downarrow} \pm \sigma^{\uparrow\downarrow})}{(\sigma^{\downarrow\uparrow} \pm \sigma^{\uparrow\uparrow}) + (\sigma^{\downarrow\downarrow} \pm \sigma^{\uparrow\downarrow})} \tag{16}$$

and (analogously (4))

$$A_{e^-,e^+}(x,y) = \frac{\sigma^{\downarrow\uparrow,\uparrow\uparrow} - \sigma^{\downarrow\downarrow,\uparrow\downarrow}}{\sigma^{\downarrow\uparrow,\uparrow\uparrow} + \sigma^{\downarrow\downarrow,\uparrow\downarrow}}. \tag{17}$$

In terms SF

$$A_+(x,y) = \frac{2xg_6}{F_2}, \quad A_-(x,y) = \frac{2xg_1}{xF_3} \tag{18}$$

and

$$A_{e^-,e^+}(x,y) = \frac{2x(y_1^+ g_6 \pm y_1^- g_1)}{y_1^+ F_2 \pm y_1^- xF_3}, \tag{19}$$

where

$$g_1 = \sum_{i=\gamma,\gamma z,z} \eta_i g_1^i, \quad g_6 = \sum_{i=\gamma z,z} \eta_i g_6^i,$$

$$\eta_\gamma = 1, \quad \eta_{\gamma z} = \frac{Gm_z^2}{2\sqrt{2}\pi\alpha}(g_V + g_A)\frac{Q^2}{Q^2+m_z^2}, \quad \eta_z = \eta_{\gamma z}^2,$$

$$g_1^\gamma(x) = \tfrac{1}{2} \sum_{q=u,d,s} e_q^2[\Delta q(x) + \Delta\bar{q}(x)],$$

$$g_1^{\gamma z}(x) = \sum_q e_q^(g_V)_q[\Delta q(x) + \Delta\bar{q}(x)],$$

$$g_1^z(x) = \frac{1}{2}\sum_q (g_V^2 + g_A^2)[\Delta q(x) + \Delta\bar{q}(x)],$$

$$g_6^{\gamma z}(x) = \sum_q e_q (g_A)_q[\Delta q(x) - \Delta\bar{q}(x)],$$

$$g_6^z(x) = \sum_q (g_V g_A)_q[\Delta q(x) - \Delta\bar{q}(x)],$$

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

$$(g_A)_{d,s} = -\frac{1}{2}; \quad e_u = \frac{2}{3}; \quad e_{d,s} = -\frac{1}{3}.$$

For the first moments SF g_1, g_6 obtain respectively

$$\Gamma_1 = A(\Delta u + \Delta\bar{u}) + B[(\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})], \tag{20}$$

$$\Gamma_6 = C\Delta u_V + D\Delta d_V, \tag{21}$$

where

$$A = \frac{2}{9} + \frac{2}{3}\eta_{\gamma z}(g_V)_u + \frac{1}{2}\eta_z(g_V^2 + g_A^2)_u,$$

$$B = \frac{1}{18} - \frac{1}{3}\eta_{\gamma z}(g_V)_{d,s} + \frac{1}{2}\eta_z(g_V^2 + g_A^2)_{d,s},$$

$$C = \frac{2}{3}\eta_{\gamma z}(g_A)_u + \eta_z(g_V g_A)_u, \quad D = -\frac{1}{3}\eta_{\gamma z}(g_A)_d + \eta_z(g_V g_A)_d.$$

The individual contributions u, d, s flavours we determine from (20) using a_8 and

$$a_3 = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d}). \tag{22}$$

$$\Delta u + \Delta\bar{u} = \frac{\frac{2\Gamma_1}{B} + a_8 + 3a_3}{2(A + 2B)},$$

$$\Delta d + \Delta\bar{d} = \frac{2\Gamma_1 + -2Aa_3 + B(a_8 - a_3)}{2(A + 2B)},$$

$$\Delta s + \Delta\bar{s} = \frac{(1 - a_8/a_3)(A + B) - 2A + \frac{2\Gamma_1}{a_3}}{2(A + 2B)}.$$

The data HERMES [10] are consistent with an unbroken $_f$ symmetry in the light polarized sea, i.e. $\Delta\bar{u} \approx \Delta\bar{d}$. In this case

$$a_3 = \Delta u_V - \Delta d_V$$

and for the valence quarks have with help 21, 22

$$\Delta u_V = \frac{\Gamma_6 + D a_3}{C + D}, \quad \Delta d_V = \frac{\Gamma_6 - C a_3}{C + D}.$$

The SF $g_{1,6}$ are extracted from asymmetries (18)

$$g_6 = \frac{F_2}{2x} A_+, \quad g_1 = \frac{x F_3}{2x} A_-$$

or (19)

$$g_1 = \frac{y^+ F_2(A_{e^-} - A_{e^+}) + y_1^- x F_3(A_{e^-} + A_{e^+})}{4 x y_1^-},$$

$$g_6 = \frac{y_1^+ F_2(A_{e^-} + A_{e^+}) + y_1^- x F_3(A_{e^-} - A_{e^+})}{4 x y_1^+}.$$

5 Conclusions

1. The scheme for determination the contributions of quarks: $\Delta\Sigma, \Delta q + \Delta\bar{q}$ $(q = u, d, s)$, $\Delta u_V, \Delta d_V, \Delta\bar{u}, \Delta\bar{d}, \Delta\bar{s}$, to spin of protons from observale asymmetries *ep*- DIS by charged current (or a combination $A^{CC}_{e^-,e^+}(x,y)$ and $A^{CC}_{\nu,\bar{\nu}}(x,y)$) is proposed.
2. The quantities $(\Delta q + \Delta q)$, Δu_V, obtained with help the polarized asymmetries $A_\pm$ and A_{e^-,e^+} the processes *ep*-DIS (NC) in frame the electroweak theory.

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