The Polarized Semi-inclusive Lepton-Nucleon DIS with Charged Current

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Abstract

This paper discusses the polarization asymmetry of semi-inclusive deep inelastic scattering of leptons on nucleons. Numerical results of asymmetries and radiative corrections to lepton current are provided.

1 Introduction

A study of the spin structure of the nucleon is one of the main problems of particle physics [1]. This problem is called "spin crisis". Semi-inclusive processes are sources are new data on the spin structure of the nucleon. Using data that can give these experiments can provide information for each quark flavor quark. Spin nucleon problem is not yet solved completely and therefore further research of all the contributions into nucleon spin is necessary.

2 The semi-inclusive deep inelastic lN-scattering

Consider the process of semi-inclusive lepton-nucleon deep inelastic scattering of leptons on nucleons with a charged current

$$\ell + N \to \nu + h + X. \tag{1}$$

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The differential cross section for scattering of a lepton is defined as
case of a lepton:

$$\Big(\frac{d^3\sigma_{\ell^-}}{dxdydz}\Big)^h = \tag{2}$$

$$= 2\rho x \left\{ \sum_{q_i,q_j} q_i(x,Q^2) D^h_{q_j}(z,Q^2) + y_1^2 \sum_{\bar{q}_j,\bar{q}_i} \bar{q}_j(x,Q^2) D^h_{\bar{q}_i}(z,Q^2) + \right.$$

$$\left. P_N \left(\sum_{q_i,q_j} \Delta q_i(x,Q^2) D^h_{q_j}(z,Q^2) - y_1^2 \sum_{\bar{q}_j,\bar{q}_i} \Delta \bar{q}_j(x,Q^2) D^h_{\bar{q}_i}(z,Q^2) \right) \right\},$$

where $q_i = d,s,b, q_j = u,c,t, \bar{q}_i = \bar{d},\bar{s},\bar{b},\ \bar{q}_j = \bar{u},\bar{c},\bar{t};$
the case of antilepton

$$\Big(\frac{d^3\sigma_{\ell^+}}{dxdydz}\Big)^h = \tag{3}$$

$$2\rho x \left\{ y_1^2 \sum_{q_i,q_j} q_i(x,Q^2) D^h_{q_j}(z,Q^2) + \sum_{\bar{q}_j,\bar{q}_i} \bar{q}_j(x,Q^2) D^h_{\bar{q}_i}(z,Q^2) + \right.$$

$$\left. + P_N \left(\sum_{q_i,q_j} \Delta q_i(x,Q^2) D^h_{q_j}(z,Q^2) - \sum_{\bar{q}_j,\bar{q}_i} \Delta \bar{q}_j(x,Q^2) D^h_{\bar{q}_i}(z,Q^2) \right) \right\}$$

where $q_i = u,c,t, q_j = d,s,b,\ \bar{q}_i = \bar{u},\bar{c},\bar{t}, \bar{q}_j = \bar{d},\bar{s},\bar{b}.$

Here $\rho = \frac{G^2 s}{2\pi}\left(\frac{m_w^2}{m_w^2+Q^2}\right)^2$, $y_1 = 1-y$, G is Fermi constant, m_w is the W-boson mass, $x = \frac{Q^2}{2p\cdot q}$, $y = \frac{p\cdot q}{p\cdot k}$, $Q^2 = -q^2 = -(k-k')^2$, $s = 2p\cdot k$, $k(k')$ and p are the initial (final) lepton and proton 4-momenta, respectively, P_N is the degree of longitudinal polarization of proton,

$$q(x)(\Delta q(x))/\bar{q}(x)(\Delta\bar{q}(x))$$

are the unpolarized (polarized) quark/antiquark distribution functions, $D^h_q(z,Q^2)(D^h_{\bar{q}}(z,Q^2))$ are the fragmentation functions of quark (antiquark) with flavor q to the hadron h.

Consider the asymmetry. These asymmetries have been offered in the [3]. We consider the asymmetry, which are constructed as a combination of different cross-sections in the following form [2]

$$A^{h^+-h^-}_{\ell^-} = \frac{\Big(\frac{d^3\sigma^{\downarrow\uparrow}_{ell^-}}{dxdydz}\Big)^{h^+-h^-} - \Big(\frac{d^3\sigma^{\downarrow\downarrow}_{ell^-}}{dxdydz}\Big)^{h^+-h^-}}{\big(\frac{d^3\sigma^{\downarrow\uparrow}_{ell^-}}{dxdydz}\Big)^{h^+-h^-} + \Big(\frac{d^3\sigma^{\downarrow\uparrow}_{ell^-}}{dxdydz}\Big)^{h^+-h^-}}, \tag{4}$$

$$A^{h^+-h^-}_{\ell^+} = \frac{\Big(\frac{d^3\sigma^{\uparrow\uparrow}_{el^+}}{dxdydz}\Big)^{h^+-h^-} - \Big(\frac{d^3\sigma^{\uparrow\downarrow}_{ell^+}}{dxdydz}\Big)^{h^+-h^-}}{\big(\frac{d^3\sigma^{\uparrow\uparrow}_{ell^+}}{dxdydz}\Big)^{h^+-h^-} + \Big(\frac{d^3\sigma^{\uparrow\downarrow}_{ell^+}}{dxdydz}\Big)^{h^+-h^-}}, \tag{5}$$

$$A^{h^+-h^-}_{\pm} = \tag{6}$$

$$= \frac{\Big[\big(\frac{d^3\sigma^{\downarrow\uparrow}_{l^-}}{dxdydz}\big)^{h^+-h^-} \pm \big(\frac{d^3\sigma^{\uparrow\uparrow}_{l^+}}{dxdydz}\big)^{h^+-h^-}\Big] - \Big[\big(\frac{d^3\sigma^{\downarrow\downarrow}_{l^-}}{dxdydz}\big)^{h^+-h^-} \pm \big(\frac{d^3\sigma^{\uparrow\downarrow}_{l^+}}{dxdydz}\big)^{h^+-h^-}\Big]}{\Big[\big(\frac{d^3\sigma^{\downarrow\uparrow}_{l^-}}{dxdydz}\big)^{h^+-h^-} \pm \big(\frac{d^3\sigma^{\uparrow\uparrow}_{l^+}}{dxdydz}\big)^{h^+-h^-}\Big] + \Big[\big(\frac{d^3\sigma^{\downarrow\downarrow}_{l^-}}{dxdydz}\big)^{h^+-h^-} \pm \big(\frac{d^3\sigma^{\uparrow\downarrow}_{l^+}}{dxdydz}\big)^{h^+-h^-}\Big]},$$

where $\sigma^{h^+-h^-} = \sigma^{h^+} - \sigma^{h^-}$.

The first arrow corresponds to the helicity of the initial lepton ($\downarrow$) or antilepton ($\uparrow$) and the second – to the polarization degree of the proton: $\uparrow$ ($P_N = +1$), $\downarrow$ ($P_N = -1$).

Let us consider the case π-meson.With the correlations for $\pi-$ meson fragmentation functions [3]

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

$$D^{\pi^+-\pi^-}_s = D^{\pi^+-\pi^-}_{\bar{s}} = 0, D^{\pi^+-\pi^-}_c = D^{\pi^+-\pi^-}_{\bar{c}} = 0,$$

we obtain for the proton target asymmetry in the form of

$$A^{\pi^+-\pi^-}_{\ell^-p} = \frac{\Delta u(x,Q^2) - y_1^2\Delta\bar{d}(x,Q^2)}{u(x,Q^2) + y_1^2\bar{d}(x,Q^2)}, \tag{7}$$

$$A^{\pi^+-\pi^-}_{\ell^+p} = \frac{y_1^2\Delta d(x,Q^2) - \Delta\bar{u}(x,Q^2)}{y_1^2 d(x,Q^2) + \bar{u}(x,Q^2)}, \tag{8}$$

$$A^{\pi^+-\pi^-}_{+,p} = \frac{\Delta u(x,Q^2) + \Delta\bar{u}(x,Q^2) - y_1^2(\Delta d(x,Q^2) + \Delta\bar{d}(x,Q^2))}{u_V(x,Q^2) - y_1^2 d_V(x,Q^2)}, \tag{9}$$

$$A^{\pi^+-\pi^-}_{-,p} = \frac{\Delta u_V(x,Q^2) + y_1^2\Delta d_V(x,Q^2)}{u(x,Q^2) + \bar{u}(x,Q^2) + y_1^2(d(x,Q^2) + \bar{d}(x,Q^2))}, \tag{10}$$

where $u_V(x,Q^2) = u(x,Q^2) - \bar{u}(x,Q^2)$, $d_V(x,Q^2) = d(x,Q^2) - \bar{d}(x,Q^2)$.

For the case of the neutron

$$
\begin{aligned}
A^{\pi^+-\pi^-}_{\ell^- n} &= \frac{\Delta d(x,Q^2) - y_1^2 \Delta\bar{u}(x,Q^2)}{d(x,Q^2) + y_1^2 \bar{u}(x,Q^2)}, && (11)\\
A^{\pi^+-\pi^-}_{\ell^+ n} &= \frac{y_1^2 \Delta u(x,Q^2) - \Delta\bar{d}(x,Q^2)}{y_1^2 u(x,Q^2) + \bar{d}(x,Q^2)}, && (12)\\
A^{\pi^+-\pi^-}_{+,n} &= \frac{\Delta d(x,Q^2) + \Delta\bar{d}(x,Q^2) - y_1^2(\Delta u(x,Q^2) + \Delta\bar{u}(x,Q^2))}{d_V(x,Q^2) - y_1^2 u_V(x,Q^2)}, && (13)\\
A^{\pi^+-\pi^-}_{-,n} &= \frac{\Delta d_V(x,Q^2) + y_1^2 \Delta u_V(x,Q^2)}{d(x,Q^2) + \bar{d}(x,Q^2) + y_1^2(u(x,Q^2) + \bar{u}(x,Q^2))}. && (14)
\end{aligned}
$$

With the help of these asymmetries can be obtained distribution function. The expressions for $(\Delta u + \Delta\bar{u})$, $(\Delta d + \Delta\bar{d})$ we obtain from asymmetries (9),(13); for $\Delta\bar{d}$, Δu from (7) and (12); for $\Delta\bar{u}$, Δd from (8) and (11); for Δu_V, Δd_V from (10), (14). The considered asymmetries have no dependence on fragmentation function which is very useful for the analysis of proton spin structure.

Of interest are the limiting cases for y. We consider the case when $y \to 1$. Asymmetry (7)-(14) take the form of

$$
\begin{aligned}
A^{\pi^+-\pi^-}_{\ell^- p} &= \frac{\Delta u(x,Q^2)}{u(x,Q^2)}, \quad A^{\pi^+-\pi^-}_{+,p} = \frac{\Delta u(x,Q^2) + \Delta\bar{u}(x,Q^2)}{u_V(x,Q^2)},\\
A^{\pi^+-\pi^-}_{\ell^+ p} &= \frac{-\Delta\bar{u}(x,Q^2)}{\bar{u}(x,Q^2)}, \quad A^{\pi^+-\pi^-}_{-,p} = \frac{\Delta u_V(x,Q^2)}{u(x,Q^2) + \bar{u}(x,Q^2)},\\
A^{\pi^+-\pi^-}_{\ell^- n} &= \frac{\Delta d(x,Q^2}{d(x,Q^2)}, \quad A^{\pi^+-\pi^-}_{+,n} = \frac{\Delta d(x,Q^2) + \Delta\bar{d}(x,Q^2)}{d_V(x,Q^2)},\\
A^{\pi^+-\pi^-}_{\ell^+ n} &= \frac{-\Delta\bar{d}(x,Q^2)}{\bar{d}(x,Q^2)}, \quad A^{\pi^+-\pi^-}_{-,n} = \frac{\Delta d_V(x,Q^2)}{d(x,Q^2) + \bar{d}(x,Q^2)}.
\end{aligned}
$$

For the analysis of nucleon spin structure we introduce the first moments of parton distributions as follows

$$
\Delta q(Q^2) = \int_0^1 \Delta q(x,Q^2)dx,
$$

$$
\Delta\bar{q}(Q^2) = \int_0^1 \Delta\bar{q}(x,Q^2)dx,
$$

which correspond to the quark q(antiquark $\bar{q}$) contributions to the spin of nucleon.

With the first moments of parton distributions can be obtained quark contributions to the nucleon spin. Semi-inclusive process is interesting because it can be individually receive contributions of quarks.

3 Numerical results and conclusions

To analyze the distribution of the nucleon spin structure used distribution quarks and antiquarks in the nucleon [6]. The numerical results of obtained asymmetries are presented on Fig.1, Fig.2. The asymmetry $A_{\ell^- p}^{\pi^+ - \pi^-}$ shows a significant dependence on y in the $x \leq 0.5$. The asymmetry $A_{\ell^+}^{\pi^+ - \pi^-}$ in almost the entire region depend on y and the measured region reaches about $60\% - 80\%$. The asymmetry $A_{\ell^- n}^{\pi^+ - \pi^-}$ is negative, weakly dependent on the y. The asymmetry $A_{\ell^+ n}^{\pi^+ - \pi^-}$ is largely dependent on the y at low and medium x. The asymmetries $A_{+,p}^{\pi^+ - \pi^-}$ and $A_{-,p}^{\pi^+ - \pi^-}$ are of the order of 70%, the asymmetry $A_{-,p}^{\pi^+ - \pi^-}$ has a significant dependence on the y in the all kinematic region.

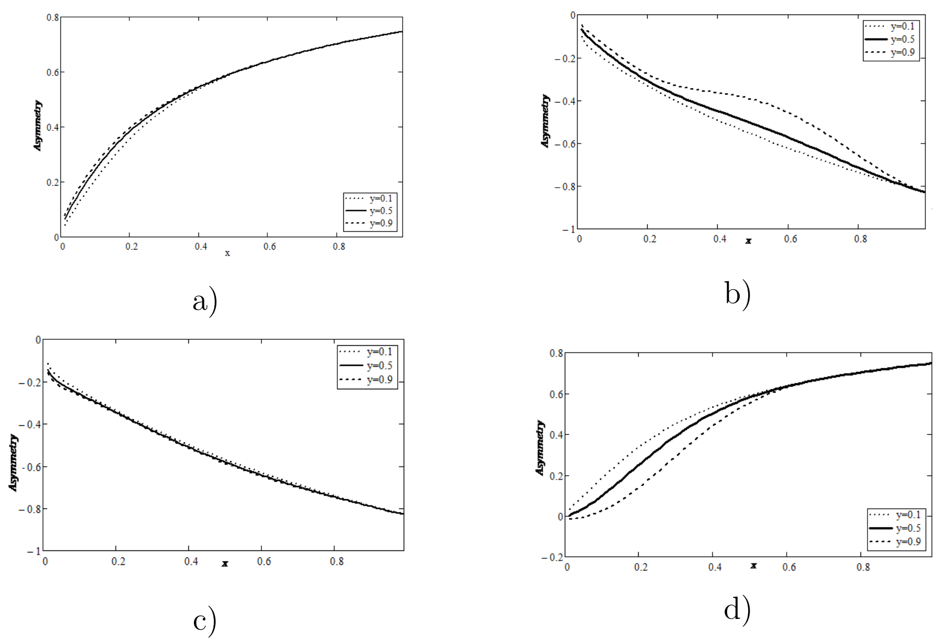
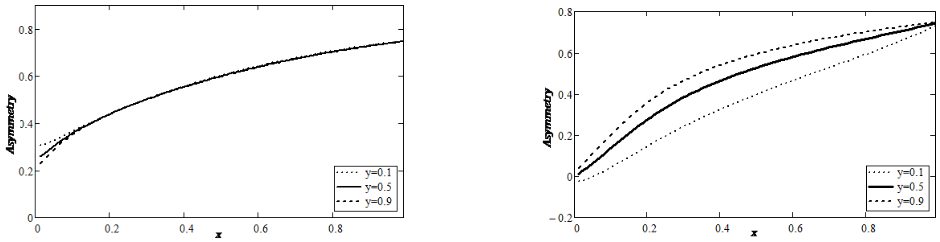


Figure 1: Obtained asymmetries a) $A_{\ell^- p}^{\pi^+ - \pi^-}(x, y)$, b) $A_{\ell^+ p}^{\pi^+ - \pi^-}(x, y)$, c) $A_{\ell^- n}^{\pi^+ - \pi^-}(x, y)$, d) $A_{\ell^+ n}^{\pi^+ - \pi^-}(x, y)$.

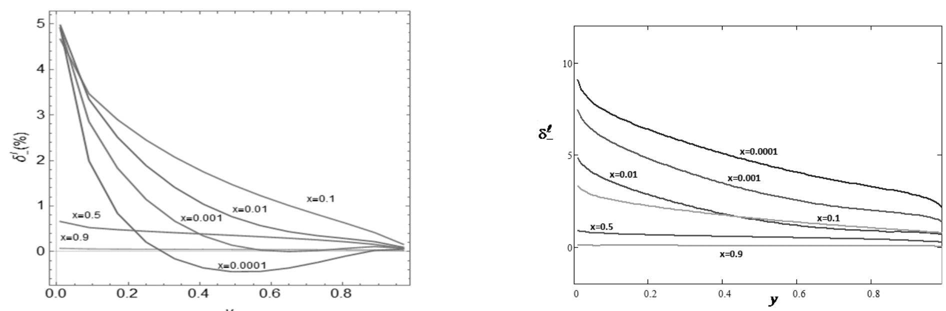
We discuss the radiative corrections. Calculated the electromagnetic corrections to lepton current. Numerical results are presented in Fig. 3. It can be seen that the correction for asymmetry $A_{\ell^- p}^{\pi^+ - \pi^-}$ decreases rapidly for large values of x and less than 1%, and for small values of x, it is heavily



a) b)

Figure 2: Obtained asymmetries: a) $A_{+,p}^{\pi^+-\pi^-}(x,y)$, b) $A_{-,p}^{\pi^+-\pi^-}(x,y)$.

dependent on y. A similar behavior of a correction for asymmetry $A_{\ell-n}^{\pi^+-\pi^-}$. For large values of x, it is insignificant, but for small x up to $4-10\%$. QCD corrections were evaluated in the work [7] and appeared small. The amendments can be neglected, and the main contribution electromagnetic corrections.



a) b)

Figure 3: QED correction $\delta_-^\ell(\%)$ a)for $A_{\ell^-,p}^{\pi^+-\pi^-}(x,y)$, b)for $A_{\ell^-,n}^{\pi^+-\pi^-}(x,y)$.

In this paper we consider the asymmetry that do not depend on the fragmentation functions. With the help of these asymmetries can be obtained of the distribution function, and then deposits quarks and antiquark in the nucleon spin. The advantage of semi-inclusive processes is the ability to receive individual contributions quarks and antiquarks. Radiative corrections were evaluated and they were small except for small values x.

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