POLARIZED QUARK DISTRIBUTIONS FROM SCATTERING OF REAL GAMMA BEAM ON NUCLEAR TARGETS

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We discuss the possible experiments to determine the polarized valence and strange sea quark distributions in nucleons through the polarized real gamma-proton(deuteron) collision. We give various asymmetry expressions obtained from the processes $\gamma + p \rightarrow \gamma + h + X$ and $\gamma + p \rightarrow \gamma + X$ and estimate the related number of events.

After the interesting and surprising results obtained by EMC group [1] and other collaborations [2] for the proton's spin dependent structure functions, the knowledge of the individual polarized quark distributions in nucleons has been of fundamental importance and needed to be reconsidered. Theoretical explanations of this result have lead to the possibility of the unexpected size of the gluon polarization and the negative large sea quark polarization [3]. Several polarized parton distributions in the proton have been developed in the framework of the latest relevant experiments [2,3]. All of these are compatible with some of the data, but they depend on theoretical assumptions or experimental data used to determine the values. Thus, it is clear that more tests are necessary.

Recently, an experiment [4,5] has been proposed to measure the gluon polarization in nucleons through the collision of almost fully polarized high energy real photons with polarized nuclear targets.

In this work, we show that the same experiment can also provide information on the valence and the strange sea spin distributions in the proton. Before going into details, it is useful to give the main points of the proposed experiment from ref. [5]. Circularly polarized laser beams with photon energy $\omega_0 \approx 1$ eV and helicity $\lambda_0 = 1$ are scattered off the electrons from a ring-type accelerator like LEP, TRISTAN or HERA. Through the process of the Compton back-scattering one obtains a high energy photon beam which closely follows the trajectory of electrons in the conversion region. After a certain distance the photon beam comes to a wall with a slit which selects photons with the highest energy and consequently with polarization close to 1. Selected photons strike on the polarized nuclear target.

Here, we are interested in two processes $\gamma + p \rightarrow \gamma + h + X$ and $\gamma + p \rightarrow \gamma + X$ where elastic gamma quark scattering $\gamma q \rightarrow \gamma q$ is considered as the subprocess.

i) $\gamma + p \rightarrow \gamma + h + X$: The number of events N^h in a given bin of x and z variables and related polarized cross section can be found as follows:

$$N_{11}^h - N_{11}^h \sim \Delta \frac{d\sigma(\gamma p \rightarrow \gamma h X)}{dy_1 dy_2 d^2 P_T^{(2)}} \equiv \frac{d\sigma(\gamma p \rightarrow \gamma h X)_{11}}{dy_1 dy_2 d^2 P_T^{(2)}} - \frac{d\sigma(\gamma p \rightarrow \gamma h X)_{11}}{dy_1 dy_2 d^2 P_T^{(2)}} \\ = \sum_i Q_i^4 \frac{x}{\pi z} \Delta q_i(x) D_i^h(z) \Delta \frac{d\hat{\sigma}}{dt} \quad (1)$$

with

$$x = \frac{e^{-y_1} + e^{-y_2}}{e^{y_1} + e^{y_2}}, \quad z = \frac{P_T^{(2)}(e^{y_1} + e^{y_2})}{\sqrt{s}} \quad (2)$$

$$\hat{s} = xs, \quad \hat{t} = -\frac{\sqrt{s} P_T^{(2)} e^{-y_1}}{z}, \quad \hat{u} = -\frac{x \sqrt{s} P_T^{(2)} e^{y_1}}{z} \quad (3)$$

where h stands for hadrons (π^+, π^-, K^+, K^-), up and down arrows indicate photon and proton helicities and Q_i are quark charges. $\Delta q_i(x)$ is the difference of quark distributions with helicity parallel and antiparallel to the helicity of the proton, where i runs over light quarks (u, d and s) and their antiquarks. y_1, y_2 and $P_T^{(2)}$ represent the outgoing photon and hadron rapidities and hadron transverse momentum, respectively. We use the assumption that the hadron fragmentation functions $D_q^h(z)$ do not depend on quark helicity. When quark masses are neglected the difference of cross section for the subprocesses is given in terms of the invariant Mandelstam variables $\hat{s}$ and $\hat{t}$ by

$$\Delta \frac{d\hat{\sigma}}{d\hat{t}} \equiv \frac{d\hat{\sigma}(\gamma q \rightarrow \gamma q)_+}{d\hat{t}} - \frac{d\hat{\sigma}(\gamma q \rightarrow \gamma q)_-}{d\hat{t}} = \frac{4\pi\alpha^2}{\hat{s}^3} \frac{\hat{t}^2 + 2\hat{t}\hat{s}}{\hat{s} + \hat{t}} \quad (4)$$

where $+$ ($-$) sign refers to quark helicity parallel(antiparallel) to the photon helicity.

In the case of pion production we obtain the following asymmetries for proton and deuteron targets

$$A_p^\pi(x, z) \equiv \frac{(N^{\pi^+} - N^{\pi^-})_{||} - (N^{\pi^+} - N^{\pi^-})_{\perp||}}{(N^{\pi^+} - N^{\pi^-})_{||} + (N^{\pi^+} - N^{\pi^-})_{\perp||}} = \frac{(Q_u^4 \Delta u^v - Q_d^4 \Delta d^v) \Delta \frac{d\hat{\sigma}}{d\hat{t}}}{(Q_u^4 u^v - Q_d^4 d^v) 2 \frac{d\hat{\sigma}}{d\hat{t}}} \quad (5)$$

$$A_d^\pi(x, z) \equiv \frac{(N^{\pi^+} - N^{\pi^-})_{||} - (N^{\pi^+} - N^{\pi^-})_{\perp||}}{(N^{\pi^+} - N^{\pi^-})_{||} + (N^{\pi^+} - N^{\pi^-})_{\perp||}} = \frac{(\Delta u^v + \Delta d^v) \Delta \frac{d\hat{\sigma}}{d\hat{t}}}{(u^v + d^v) 2 \frac{d\hat{\sigma}}{d\hat{t}}} \quad (6)$$

where

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{1}{2} \left(\frac{d\hat{\sigma}(\gamma q \rightarrow \gamma q)_+}{d\hat{t}} + \frac{d\hat{\sigma}(\gamma q \rightarrow \gamma q)_-}{d\hat{t}} \right) \quad (7)$$

When $K^+(K^-)$ production is taken into account the same definition of asymmetries take the form

$$A_p^K(x, z) = \frac{\Delta u^v \Delta \frac{d\hat{\sigma}}{d\hat{t}}}{u^v 2 \frac{d\hat{\sigma}}{d\hat{t}}} \quad (8)$$

$$A_d^K(x, z) = A_d^\pi(x, z) \quad (9)$$

In obtaining the above asymmetries we have used the standard relations between the fragmentation functions below

$$D_u^{\pi^+} = D_d^{\pi^-} = D_d^{\pi^+} = D_u^{\pi^-} \quad (10)$$

$$D_d^{\pi^+} = D_u^{\pi^-} = D_u^{\pi^+} = D_d^{\pi^-} \quad (11)$$

$$D_s^{\pi^+} = D_s^{\pi^-} = D_s^{\pi^+} = D_s^{\pi^-} \quad (12)$$

and

$$D_u^{K^+} = D_u^{K^-}, \quad D_s^{K^-} = D_s^{K^+} \quad (13)$$

$$D_s^{K^+} = D_d^{K^+} = D_d^{K^+} = D_u^{K^+} = D_s^{K^-} = D_d^{K^-} = D_d^{K^-} = D_u^{K^-} \quad (14)$$

The use of the ratios of these asymmetries, for example

$$\frac{A_p^\pi}{A_p^K} = \frac{(Q_u^4 \Delta u^v - Q_d^4 \Delta d^v) u^v}{(Q_u^4 u^v - Q_d^4 d^v) \Delta u^v} = \frac{16 - \Delta d^v / \Delta u^v}{16 - d^v / u^v} \quad (15)$$

$$\frac{A_d^\pi}{A_p^K} = \frac{1 + \Delta d^v / \Delta u^v}{1 + d^v / u^v} \quad (16)$$

will give required information to measure the polarized valence quark distributions Δu^v and Δd^v in the proton when u^v and d^v are known from experiments with unpolarized targets.

ii) $\gamma + p \rightarrow \gamma + X$: For this case we follow a similar way to get the number of events $N_{||}^\gamma - N_{\perp||}^\gamma$ in a certain x bin which is proportional to the difference of the polarized cross section given by

$$\Delta \frac{d\sigma(\gamma p \rightarrow \gamma X)}{dy d^2 P_T} = \sum_i Q_i^4 \frac{x}{\pi} \Delta q_i(x) \frac{\sqrt{s}}{(\sqrt{s} - P_T e^y)} \Delta \frac{d\hat{\sigma}}{d\hat{t}} \quad (17)$$

where

$$x = \frac{P_T e^{-y}}{\sqrt{s} - P_T e^y}, \quad \hat{s} = xs, \quad \hat{t} = -P_T \sqrt{s} e^{-y}, \quad \hat{u} = -x P_T \sqrt{s} e^y \quad (18)$$

In this process y and P_T are the rapidity and transverse momentum of the outgoing photon. Using the above expressions and assuming SU(2) symmetric sea quark distributions we can easily obtain the following asymmetries

$$A_p^\gamma(x) \equiv \frac{N_{11}^\gamma - N_{1\bar{1}}^\gamma}{N_{11}^\gamma + N_{1\bar{1}}^\gamma} = \frac{(Q_u^4 \Delta u^v + Q_d^4 \Delta d^v + 2Q_s^4 \Delta s + 2\Delta \bar{q}(Q_u^4 + Q_d^4)) \Delta \frac{d\hat{\sigma}}{d\hat{t}}}{(Q_u^4 u^v + Q_d^4 d^v + 2Q_s^4 s + 2\bar{q}(Q_u^4 + Q_d^4)) 2 \frac{d\hat{\sigma}}{d\hat{t}}} \quad (19)$$

$$A_{p-d}^\gamma(x) \equiv \frac{(N_p^\gamma - N_d^\gamma)_{11} - (N_p^\gamma - N_d^\gamma)_{1\bar{1}}}{(N_p^\gamma - N_d^\gamma)_{11} + (N_p^\gamma - N_d^\gamma)_{1\bar{1}}} = \frac{(\Delta u^v - \Delta d^v) \Delta \frac{d\hat{\sigma}}{d\hat{t}}}{(u^v - d^v) 2 \frac{d\hat{\sigma}}{d\hat{t}}} \quad (20)$$

where $\Delta \bar{q}$ indicates the polarized sea with $\Delta u_s = \Delta \bar{u}_s = \Delta d_s = \Delta \bar{d}_s$ and Δs polarized strange quark distribution. $\bar{q}$ and s are their unpolarized counterparts. If polarized valence quark distributions are assumed to be known the ratio of the above asymmetries can be used to extract sea quark polarization. Since the sea quark contribution is more important at small x one should take into account $x < 0.1$ values to reduce the valence quark contribution.

In order to determine the number of events at LEP energy region $s = 2E_\gamma m_p = 90 \text{ GeV}^2$, $\kappa = 7$, see ref. [5], we plot the integrated cross section

$$\Delta d\sigma^\pi \equiv \int P_T^\pi dP_T^\pi \Delta \frac{d\sigma(\gamma p \rightarrow \gamma \pi^+ X)}{dy_1 dy_2 d^2 P_T^\pi} \quad (21)$$

over the bin $1.5 < P_T^\pi < 1.7 \text{ GeV}$ in Fig. 1 as a function of rapidity $y_1 = y_2 = y$. Here the fragmentation functions D_q^h are taken from ref. [6]. Integrated cross section

$$\Delta d\sigma^\gamma \equiv \int P_T dP_T \Delta \frac{d\sigma(\gamma p \rightarrow \gamma X)}{dy d^2 P_T} \quad (22)$$

over the bin $1.5 < P_T^\gamma < 1.7 \text{ GeV}$ is shown in Fig. 2 against the rapidity of the photon. The integrated luminosity of polarized gamma beam for LEP can be taken as 1 fb^{-1} per year [5]. Thus the number of events $(N_{11}^{\pi^+} - N_{1\bar{1}}^{\pi^+})$ at $y = 0.6$ from Fig. 1 is about 1.6×10^3 per year. As expected from Fig. 2 the event number $(N_{11}^\gamma - N_{1\bar{1}}^\gamma)$ at $y=0.7$ has the value 4.5×10^4 which is much higher than the pion production case.

Fig. 3 shows the asymmetry A_p^γ as a function of rapidity of the photon at $P_T = 1 \text{ GeV}$ for the two sets of the polarized parton distributions of Ref. [7] with and without polarized strange sea quark distributions. In this figure we prefer the y range corresponding to small x , $0.04 \leq x \leq 0.09$, where the sea effect is more distinguished. For unpolarized quark distributions we use the set from ref. [8].

In conclusion, from the measurement of pion and kaon asymmetries in the semi-inclusive polarized real gamma-proton scattering it is possible to determine the polarized valence quark distributions. The asymmetry measurement of the photon could be an additional tool to search for polarization of the quark sea in the proton. Practical difficulties such as statistical accuracy, pion and kaon identification should be considered in a more detailed investigation in experimental conditions including detector parameters.

ACKNOWLEDGMENTS

We are grateful to S. Sultansoy for suggesting the problem and stimulating discussions. This research was supported in part by TUBITAK under TBAG-1247.

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FIG. 1. The integrated cross section $\Delta d\sigma^\pi$ over the bin $1.5 < P_T^{\pi^+} < 1.7$ GeV at LEP, $s=90$ GeV² versus rapidity $y_1 = y_2 = y$.

FIG. 2. The integrated cross section $\Delta d\sigma^\gamma$ over the bin $1.5 < P_T < 1.7$ GeV at LEP, $s=90$ GeV² against the rapidity of the photon.

FIG. 3. Asymmetry A_p^γ against the rapidity of the photon. Tiny line corresponds to the set of polarized quark distributions with strange sea quark polarization from the reference given in the text. Solid line indicates the second set of distributions without strange sea quark polarization.

Fig.1

Fig.2

Fig.3