Abstract

We consider double spin asymmetries for longitudinally polarized leptons and transversally polarized protons in diffractive vector meson and $Q\bar{Q}$ production for the HERMES energy range on the basis of the two-gluon model. The asymmetry predicted for meson production is quite small. Large asymmetry is expected for $Q\bar{Q}$ production.

Study of the hadron structure is a fundamental problem of modern physics. One of the important objects here is skewed parton distributions (SPD) in a nucleon which are the distributions generalized to the case of non-forward scattering [1]. At small $x$, these distributions can be investigated in diffractive processes. In the case of diffractive charm quark production including $J/\Psi$ reactions, the predominant contribution is determined by the two-gluon exchange (gluon SPD). Thus diffractive heavy quark production should play a keystone role in the future study of the gluon distribution $F_x(x)$ at small $x$. Processes where light quarks appear should include the quark distribution functions as well as the gluon one. In future, it will be an excellent possibility to study spin effects with transversally polarized target at HERMES. Such experiments should shed light on the polarized parton distributions responsible for the transverse spin effects in the hadron.

In this report, we consider double spin asymmetries for longitudinally polarized leptons and transversally polarized protons in diffractive vector meson and $Q\bar{Q}$ production in the HERMES energy range. The two-gluon exchange model with the spin-dependent $gg$-proton coupling (1) will be used. We discuss the connection of two-gluon model with skewed gluon distribution.

To study spin effects in the diffractive hadron production, one should know the structure of the two-gluon coupling with the proton at small $x$. We use the form

$$V_{ggg}^{\alpha\beta}(p, t, x_P, l_\perp) = B(t, x_P, l_\perp)(\gamma^\alpha p^\beta + \gamma^\beta p^\alpha) +$$

$$+ \frac{iK(t, x_P, l_\perp)}{2m}(p^\alpha \sigma^{\alpha\gamma} r_\gamma + p^\beta \sigma^{\alpha\gamma} r_\gamma) + iD(t, x_P, l_\perp)e^{\alpha\beta\rho\gamma} \gamma_\rho \gamma_5. \quad (1)$$

Here $m$ is the proton mass, $p$ is the proton momentum, $x_P$ is a part of this momentum carried by the two-gluon system, and $l_\perp$ is the gluon transverse momentum. The first two terms of the vertex (1) are symmetric in $\alpha, \beta$ indices. The structure proportional to $B(t, ...)$ in (1) determines the spin-non-flip contribution. The term $\propto K(t, ...)$ leads to the transverse spin-flip at the vertex. The asymmetric structure in (1) is proportional to $D\gamma_\rho \gamma_5$ and can be associated with $\Delta G$. It should contribute to the double spin longitudinal asymmetry $A_L$. 

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We study a simple model for the amplitude of the $\gamma^* \to V$ transition. The virtual photon is going to the $q\bar{q}$ state, and the $q\bar{q} \to V$ amplitude is described by a nonrelativistic wave function [2]. In this approximation, quarks have the same momenta equal to half of the vector meson momentum and mass $m_q = m_V/2$. A model like that should be applicable for heavy ($J/\Psi$) production. Gluons from the two-gluon-proton structure (1) are coupled with the single and different quarks in the quark loop. This ensures the gauge invariance of the final result.

The spin-average and spin-dependent cross sections of the vector meson leptoproduction with longitudinal polarization of a lepton and different transverse polarization of the proton are determined by the relation

$$d\sigma(\pm) = \frac{1}{2} (d\sigma(-\uparrow) \pm d\sigma(-\downarrow)).$$  \hspace{1cm} (2)$$

The cross section $d\sigma(\pm)$ can be written in the form

$$\frac{d\sigma^\pm}{dQ^2dydt} = \frac{|T^\pm|^2}{32(2\pi)^3Q^2s^2y}.\hspace{1cm} (3)$$

For the spin-average amplitude square we find

$$|T^+|^2 = s^2N\left(1 + (1 - y)^2m_V^2 + 2(1 - y)Q^2\right)\left[|\bar{B}|^2 + |\bar{K}|^2\frac{|t|}{m_V^2}\right].\hspace{1cm} (4)$$

Here $N$ is the normalization factor, the term proportional to $(1 + (1 - y)^2m_V^2)$ represents the contribution of the virtual photon with transverse polarization. The $2(1 - y)Q^2$ term describes the effect of longitudinal photons. The $\bar{B}$ and $\bar{K}$ functions are expressed through the integral over transverse momentum of the gluon. The function $\bar{B}$ is determined by

$$\bar{B} = \frac{1}{4Q^2} \int \frac{d^2l_\perp(l_\perp^2 + l_\perp\Delta)B(t,l_\perp^2,x_P,...)}{(l_\perp^2 + \lambda^2)((l_\perp + \Delta)^2 + \lambda^2)[l_\perp^2 + l_\perp\Delta + \bar{Q}^2]}$$

$$\sim \frac{1}{4Q^4} \int_{0}^{l_\perp^2 < Q^2} \frac{d^2l_\perp(l_\perp^2 + l_\perp\Delta)}{(l_\perp^2 + \lambda^2)((l_\perp + \Delta)^2 + \lambda^2)}B(t,l_\perp^2,x_P,...),\hspace{1cm} (5)$$

with $\bar{Q}^2 = (m_V^2 + Q^2 + |t|)/4$. The term $(l_\perp^2 + l_\perp\Delta)$ appears in the numerator of (5) because of the cancellation between the graphs where gluons are coupled with the single and different quarks. The $\bar{K}$ function is determined by a similar integral. The integral (5) can be connected with the gluon SPD as

$$\mathcal{F}_{x_P}^g(x_P,t) = \int_{0}^{l_\perp^2 < Q^2} \frac{d^2l_\perp(l_\perp^2 + l_\perp\Delta)}{(l_\perp^2 + \lambda^2)((l_\perp + \Delta)^2 + \lambda^2)}B(t,l_\perp^2,x_P,...) \propto \bar{B}.\hspace{1cm} (6)$$

We find that $B(l_\perp^2,x_P,...)$ is the nonintegrated spin-average gluon distribution. The $\bar{K}$ function is proportional to the $\mathcal{K}_{x_P}^g(x_P,t)$ distribution. Determination of the gluon distribution functions can be found e.g. in [3].

The spin-dependent amplitude square looks like

$$|T^-|^2 = s|t|\frac{\bar{Q}S_\perp}{4m} \left(Q^2 + m_V^2 + |t|\right)\left[\bar{B}\bar{K}\right].\hspace{1cm} (7)$$
The $A_{LT}$ asymmetry for vector meson production is determined by

$$A_{LT} = \frac{\sigma(-)}{\sigma(+)} \sim \frac{\vec{Q}\vec{S}_\perp}{4m} \frac{yx_P|t|}{(1 + (1 - y)^2) m_V^2 + 2(1 - y)Q^2} \frac{\tilde{B}\tilde{K}}{|B|^2 + |K|^2|t|/m^2}. \quad (8)$$

This asymmetry is approximately proportional to the ratio of $\tilde{K}/\tilde{B} \propto K_g x_P / F_g x_P$ and generally can be used to obtain information on $K_g$ SPD from experiments with transversely polarized target. The expected value of $\tilde{K}/\tilde{B}$ ratio can be estimated from elastic scattering. It is about .1 in the models [4, 5] which predict asymmetries similar to that observed experimentally [6]. We use $\tilde{K}/\tilde{B} = 0.1$ in our estimation. Unfortunately, it is found that the $A_{LT}$ asymmetry in the diffractive vector meson production contains the small coefficient $x_P = (Q^2 + m_V^2 + |t|)/(ys)$. The asymmetry predicted for $J/\Psi$ production at HERMES energies is shown in Fig. 1 for the case when the transverse part of photon momentum is parallel to the target polarization $S_\perp$. Simple estimations on the basis of (8) for $\rho$ meson production are shown there too. Expected mass dependence is quite weak. However, this result is obtained for the nonrelativistic meson wave function which is not so good approximation for light meson production. At HERA energies, asymmetry will be extremely small.

![Fig. 1. The $A_{LT}$ asymmetry for vector meson production at HERMES ($y=0.5$, $|t| = 1\text{GeV}^2$): solid line -for $J/\Psi$ production; dotted line -for $\rho$ production.](image1)

![Fig. 2. The predicted $Q^2$ dependence of the $A_{LT}$ asymmetry for the $c\bar{c}$ production at HERMES for $x_P=0.1$, $y=0.5$, $|t| = 1\text{GeV}^2$.](image2)

A similar analysis has been done for the case of $Q\bar{Q}$ production [7]. It was found that the asymmetry is proportional, as for vector meson production (8), to the ratio of $\tilde{K}/\tilde{B}$ functions determined in (5) but with the other scale $\vec{k}_\perp^2 = m_q^2 + \vec{k}_\perp^2$ ($k_\perp$ is a transverse part of the quark momentum). Now we find two different terms in $d\sigma(-)$:

$$d\sigma^{QQ}(-) = \left(\vec{k}_\perp\vec{S}_\perp\right) d\sigma_k^{QQ}(-) + x_P \left(\vec{Q}_\perp\vec{S}_\perp\right) d\sigma_k^{QQ}(-) \quad (9)$$

The first term cannot appear for vector meson production. Really in this case, we must integrate the amplitude over the transverse quark momentum with the meson wave function. As a result, the term $\propto \left(\vec{k}_\perp\vec{S}_\perp\right)$ disappears, and only the second term which has $x_P$ smallness contributes. The situation is opposite for $Q\bar{Q}$ production. If we can distinguish quark and antiquark jets, with opposite values of $k_\perp$, the term $\propto \left(\vec{k}_\perp\vec{S}_\perp\right)$ contributes. This
term is large and does not have $x_P$ smallness as the second one in (9). It gives a predominant contribution to $d\sigma^{QQ}(-)$. Note that the $A_{IT}$ asymmetry is proportional to the scalar production of the proton spin vector, and the jet momentum $A_{IT} \propto (\vec{k}_\perp \vec{S}_\perp) \propto \cos(\phi_{Jet})$, and the asymmetry integrated over the azimuthal jet angle $\phi_{Jet}$ is zero. We have calculated the $A_{IT}$ asymmetry for the case when the proton spin vector is perpendicular to the lepton scattering plane and the jet momentum is parallel to this spin vector. The predicted asymmetry is large, about 10%, and shown in Fig. 2.

In the present report, the polarized diffractive hadron leptoproduction at high energies has been studied within the two-gluon exchange model with the spin-dependent $gg$-proton coupling (1). This means that our results should be applicable for reactions which include heavy quarks. For processes with light quarks, our predictions should be valid in high energy range or small $x$ region ($x \leq 0.05$ e.g) where the contribution of quark SPD should be small. The $A_{IT}$ is proportional to the ratio of $\vec{K}/\vec{B}$ structure functions and generally can be used to get information on the transverse distribution $K_{gP}(x_P,t)$ from experiment. There are some difficulties here. The asymmetry for vector meson production is expected to be quite small $A_{IT} < 0.1\%$. Similar asymmetry for $QQ$ production is predicted to be about 10%. It is an excellent object to study transverse effects in the proton coupling with gluons. However, the experimental study of this asymmetry is not so simple. To find nonzero asymmetry in this case, it is necessary to distinguish quark and antiquark jets and to have possibility to study azimuthal asymmetry structure. This is important, because cross sections integrated over $d\phi_{Jet}$ are equal to zero.

It is shown that the gluon SPD $F_{gP}(x_P)$ and distribution $K_{gP}(x_P)$ at small $x_P$ can be studied from the double spin asymmetry in the hadron leptoproduction. The contributions of the quark SPDs are non-negligible for $x$ of about 0.1. Thus, in the case of the $\rho$ production, the quark SPD might be studied in addition to the gluon one in the HERMES experiments. We conclude that important information on the spin–dependent SPD at small $x$ can be obtained from the asymmetries in the diffractive hadron leptoproduction for longitudinally polarized lepton and transversely polarized hadron targets.

References