Double-Spin Asymmetries in Diffractive Heavy-Quark Production

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The longitudinal double spin asymmetry $A_{LL}$ in polarized diffractive heavy quark production for a standard and a spin-dependent effective quark-pomeron vertex is calculated. It is shown that for the open charm production in proton-proton and lepton-proton reactions this asymmetry is large and sensitive to the form of the pomeron coupling.

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The study of pomeron properties has attracted considerable interest due to the observation of high $p_T$ jets in diffractive collisions [1,2] that can be interpreted in terms of partonic structure of the pomeron [3]. Besides this effect, the contributions can be important where all the pomeron energy is spent for the production of a quark and antiquark pair [4,5], as confirmed experimentally [2].

Two well-known models are usually used in investigations of the pomeron: the perturbative BFKL pomeron [6] and nonperturbative two-gluon model [7,8]. They have some similar properties. Really, this standard pomeron exchange leads to the mainly imaginary helicity-conserving scattering amplitude due to the simple form of the quark-pomeron coupling

$$V_{\mu}^{QP} \propto \gamma_{\mu}.$$  \hspace{1cm} (1)

So, the pomeron vertex here is like a C = $1$ isoscalar photon coupling (see e.g. [8]).

However, the spin structure of the quark-pomeron interaction may not be so simple. The perturbative calculations of the gluon-loop effects show that they are factorized into the effective pomeron coupling [9]. In the semi-hard region where the perturbative theory can be used it has the form [9]

$$V_{\mu}^{QP}(k,r) = \gamma_\mu u_0(r) + 2m k_u u_1(r) + 2 k_\mu k_\nu u_2(r) + i \epsilon_{\mu\nu\sigma\rho} k_\sigma r_\rho r_\tau$$

$$+ i m a_4(r) \sigma^{\mu\nu} r_\alpha.$$  \hspace{1cm} (2)

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Here $k$ is a quark momentum, $\tau$ is a momentum transfer.

The obtained quark-pomeron coupling (2) has a complicated spin structure. Really, only the term proportional to $\gamma_4$ corresponds to the standard helicity-conserving pomeron. The terms $u_3(\tau) - u_4(\tau)$ lead to the spin-flip in the quark-pomeron vertex. These functions for $\tau^2 = |t| > 1 GeV^2$ were calculated perturbatively [10]. Their magnitudes are not very small. As a result, the spin-dependent quark-pomeron vertex should modify different spin asymmetries and lead to new effects in high energy diffractive reactions that can be measured in future spin experiments at HERA and RHIC [11].

A simple way to test the pomeron coupling is to study the diffractive $Q\bar{Q}$ production by polarized protons [12]. The quark-pomeron vertex (2) is mass-dependent. It is important to check the effects caused by these new terms in the pomeron coupling for heavy quark production.

In this report, the longitudinal double spin asymmetries in the diffractive open charm production in processes $p\uparrow p\uparrow - p + Q\bar{Q} + X$ and $l\uparrow p\uparrow - l + Q\bar{Q}$ are studied. They can be detected as $p(l) + p\rightarrow p(l) + p + 2H$ events. We shall here analyze the contributions where all the pomeron energy is spent for the heavy $Q\bar{Q}$ production (see e.g. [4]) shown by the diagram of Fig. 1. It has been shown [12] that the longitudinal double-spin asymmetry does not depend practically on the pomeron proton vertex structure. We shall use the form (1) for simplicity.

The longitudinal double spin asymmetry is determined by the relation

$$A_{UL} = \frac{\Delta \sigma}{\sigma} = \frac{\sigma(z_1) - \sigma(z_2)}{\sigma(z_1) + \sigma(z_2)} \quad (3)$$

For the spin-average (cr) and spin-dependent ($\Delta \sigma$) cross sections integrated over all the $Q\bar{Q}$ phase space we find

$$\sigma(\Delta \sigma) = F(P) \int_{x_p}^{\infty} dy g(y)|\Delta g(y)| \int_{0}^{\gamma_{max}} \frac{d^2k_{\perp} N^s(z_p, k_{\perp}^2, u_1, |t|)}{1 - 4k_{\perp}^2 / s\gamma_p (k_{\perp}^2 + M_{Q\bar{Q}}^2)^2} \quad (4)$$

**FIG. 1.** Diffractive $Q\bar{Q}$ production in pp reaction.
Here $g(Ag)$ are the gluon spin-average and spin structure function of the proton, $k_\perp$ is a transverse part of the momentum in the loop, $M_Q$ is a quark mass, $N^{\sigma_{\Delta \sigma}}$ is a trace over the quark loop. In (4) $F(\beta P)$ is a function determined by the pomeron contribution. This function is the same for $\sigma$ and $Au$ in (3) and cancels in $A_{\eta}$.

The main contribution to $\Delta \sigma$ is proportional to the first moment of $Ag$

$$A_g = \int_0^1 dy \Delta g(y),$$

which is unknown now. However, the magnitude of $Ag$ can be large, $Ag \sim 3$. This large magnitude of $Ag$ is important in the explanation of the proton spin [13].

In calculation of $\sigma$ we use the simple form of the gluon structure function

$$g(y) = \frac{R}{y}(1 - y)^5, \quad R = 3.$$

The resulting asymmetry depends on the ratio

$$C_g = \frac{\Delta g}{R}.$$  \hspace{1cm} (6)

For $Ag \sim 3$ we find that $C_g \sim 1$. This magnitude will be used in what follows.

For a standard form of the pomeron vertex (1) we have

$$A_{\Delta f} = -2x_P \left( \ln \frac{|1|}{M_Q^2} - 3 \right) \ln \frac{H}{M_Q^2} \left( \frac{2 \ln x_P}{4|1|} + \ln \frac{|1|}{M_Q^2} \right).$$  \hspace{1cm} (7)

Thus, $A_{\Delta f}$ is proportional to $x_P$ because $N^{\Delta g} \propto \varepsilon^{\mu \nu \rho \sigma} f_{\rho \sigma} \propto x_P$ where $x_P$ is a part of the proton momentum $p$ carried off by the pomeron. As a result, additional $x_P$ appears in $\Delta \sigma$. For the pomeron vertex (2) the axial-like term $V^{\mu}(k, \tau)\alpha_0(\tau)\varepsilon^{\rho \sigma \lambda \delta} f_{\lambda \delta} \gamma_5$ is extremely important in asymmetry. The formula for asymmetry is more complicated in this case.

Our predictions for $A_{\Delta f}$ asymmetry at $\sqrt{s} = 40$ GeV and $x_P = 0.2$ for the standard quark-pomeron vertex ($\gamma_\mu$) and the spin-dependent quark-pomeron vertex (2) are shown in Fig. 2 for the open charm production. It is easy to see that the obtained asymmetry strongly depends on the structure of the quark-pomeron vertex. For the spin-dependent quark-pomeron vertex, $A_{\Delta f}$ asymmetry is smaller by factor 2 because $\sigma$ in (3) is larger in this case. This is connected with the contribution of other $u_i$ structures.

Let us study now the open charm production in diffractive lepton-proton reaction. It is determined at small $x_P$ by a diagram similar to that shown in Fig. 1 with the lepton and photon instead of the gluon structure function of the proton in the upper part of Fig. 1. Now there is no unknown spin gluon structure function $Ag$ of the proton at the asymmetry and we can obtain a more explicit result.

The asymmetry is determined by formula (3). For the spin-average ($\sigma$) and spin-dependent ($\Delta \sigma$) cross sections we find
FIG. 2. $A_{ll}$ asymmetry of the open charm production in $pp$ diffractive reaction. Solid line-for standard; dot-dashed line-for spin-dependent quark-pomeron vertex.

FIG. 3. $Q^2$ dependence of $A_{ll}$ asymmetry of the open charm production in $lp$ diffractive reaction at fixed $|t|=3 GeV^2$. Solid line-for standard; dot-dashed line-for spin-dependent quark-pomeron vertex.

The notations here are the same as in (4). The main contributions to $A_{ll}$ asymmetry in the discussed region are determined by the $uu$ and $d$ structures in (2). For a standard form of the pomeron vertex (1) the asymmetry looks as follows

$$
\sigma(\Delta\sigma) = F(\delta p) \frac{c}{x_p} \int_{-t}^{y_{max}} \frac{d^2 k_\perp N_{eV}(x_p,k_\perp^2,m_\perp^2)}{\sqrt{1-4k_\perp^2/sy \pi^2 (1+M_\perp^2)^2}} .
$$

(8)

The contributions of the effective quark-pomeron coupling (2) discussed here modify different spin asymmetries that have some common properties:

$A_{ll} = -z_p y \frac{Q^2 (2-y) \ln([y^2 - (1-y) ln(\frac{1+y}{m_Q})])}{[2] t(1-y)^2 \ln(\frac{Q^2}{[y^2] t} y^2 (2-y) ln(\frac{Q^2}{m_Q}))} .
$$

(9)

We use here the standard set of kinematical variables determined in [2]. Note that $\Delta\sigma$ is proportional to the photon virtuality $Q^2$. As a result, the asymmetry (9) must increase with $Q^2$.

Our predictions for $A_{ll}$ the asymmetry were made for energy $\sqrt{s} = 300 GeV$, $y = 0.5$ and $x_p = 0.2$ for the standard and spin-dependent quark pomeron vertices. In Fig. 3 the $Q^2$ dependence of $A_{ll}$ for fixed $|t|=3 GeV^2$ is shown. The obtained asymmetry is not small and strongly depends on the spin structure of the quark-pomeron vertex. The asymmetry decreases with $|t|$ growing and increases with $Q^2$ growing.

The contributions of the effective quark-pomeron coupling (2) discussed here modify different spin asymmetries that have some common properties:
• Asymmetry for open charm production is sufficiently large.
• Asymmetry decreases with energy only logarithmically $A_{ll} \sim 1/\ln(sz/4|t|)$.
• Asymmetry is equal to zero at $z_p = 0$. So, it is better to study it at $z_p = 0.1 - 0.2$.
• The obtained asymmetry strongly depends on the structure of the quark-pomeron vertex.

To summarize, we have presented, in this report, the QCD analysis of the longitudinal double spin asymmetry in diffractive 2-jet production in $lp$ and $pp$ processes using the effective pomeron coupling. It is shown that for the open charm production this asymmetry is large and sensitive to the form of the pomeron coupling. Relevant asymmetry in the diffractive $J/\Psi$ production can be large too. The model prediction shows that the $A_{ll}$ asymmetry in high energy diffractive reactions can be studied in future spin experiments at HERA and RHIC accelerators. This gives information about the spin structure of the quark-pomeron vertex and spin properties of QCD at large distances.

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References