We calculate the double spin asymmetry of the diffractive $Q\bar{Q}$ and vector meson leptoproduction at COMPASS energies. We analyze dependences of the asymmetry on the structure of the Pomeron-proton coupling. It is shown that it is difficult to study the spin structure of the Pomeron coupling with the proton from the $A_{LL}$ asymmetry. The $A_{LT}$ asymmetry might be an appropriate object for this investigation.

1 Introduction

Now the Pomeron nature is a problem of topical interest due to the progress in analysis of diffractive processes at HERA [1, 2]. Study of the diffractive vector meson and $Q\bar{Q}$ production

$$e + p \rightarrow e' + p' + Q\bar{Q}$$

should give information on the gluon distribution at small $x$ [3, 4] and on the Pomeron structure [5]. The experiments with polarized beams should be used to extract the information on polarized parton distributions. The diffractive $J/\Psi$ and heavy $Q\bar{Q}$ production play a significant role here. The $Q\bar{Q}$ exchange in $t$-channel is not essential in such processes and the predominant contribution is determined by a color singlet $t$-channel exchange (Pomeron).

The $A_{LL}$ asymmetry of the open charm production has been proposed to be used by COMPASS [6] to study $\Delta G$. To determine a possible role of diffractive events at COMPASS energies, the $A_{LL}$ asymmetry of the polarized diffractive $c\bar{c}$ production has been studied in [7]. The model where the Pomeron interacts with a single quark in the loop has been used. The diffractive asymmetry has been found not small in this model. The ratio of diffractive and total events at small $Q^2$ is about 30% [8]. The resulting diffractive contribution to $A_{LL}$ asymmetry might be about 5-10%. The analysis of the final jet kinematics shows that the $c\bar{c}$ production through the photon-gluon fusion and diffractive events should be detected simultaneously by COMPASS. It was mentioned on the basis of these model results [8] that the diffractive contribution might be an important background in the COMPASS experiment. In the present report, the polarized cross section of diffractive hadron leptoproduction at high energies will be studied within a QCD two-gluon model of the Pomeron. We shall investigate the polarized diffractive $Q\bar{Q}$ production at COMPASS. The spin effects in diffractive vector meson production will also be discussed shortly.
2 Structure of hadron leptoproduction in QCD model

Let us study the diffractive hadron leptoproduction. For the open charm production, the leading $t$-channel contribution is determined by the Pomeron exchange. In the Donnachie-Landshoff (D-L) model [8], the Pomeron preferably couples to a single quark in the hadron (Fig. 1a). In the QCD-inspired models, the Pomeron is presented by two gluons [9] which can couple to a different quark in the loop as well as to the single one (Fig 1b, c).

![Fig. 1. Donnachie-Landshoff and two-gluon model of the Pomeron](image)

The diffractive lepton-proton reactions (1) are usually described in terms of the kinematic variables

$$Q^2 = -q^2, \quad t = r^2,$$
$$y = \frac{pq}{p p'}, \quad x = \frac{Q^2}{2 pq}, \quad x_p = \frac{q(p - p')}{qp}, \quad \beta = \frac{x}{x_p},$$

(2)

where $p, p'$ and $p, p'$ are the initial and final lepton and proton momenta, respectively, $q = p_l - p_l'$, $r = p - p'$ are the virtual photon and Pomeron momenta.

The cross section of the hadron leptoproduction can be decomposed into the leptonic and hadronic tensors, the amplitude of the $\gamma^* P \rightarrow \text{Hadrons}$ transition amplitude and the Pomeron exchange. The structure of the leptonic tensor is quite simple [10] because the lepton is a point-like object

$$\mathcal{L}^{\mu\nu}(s_l) = \sum_{\text{spin \ } s_f} \bar{u}(p'_l, s_f)\gamma^\mu u(p_l, s_l)\bar{u}(p_l, s_l)\gamma^\nu u(p'_l, s_f)$$

$$= \text{Tr} \left[ (\not{p}_l + \not{\mu}) \frac{1 + \gamma_5 \not{q}_l}{2} \gamma^\nu (\not{p}_l' + \mu) \gamma^\mu \right].$$

(3)

Here $s_l$ is a spin vector of the initial lepton. The spin-average and spin dependent cross sections with parallel and antiparallel longitudinal polarization of a lepton and a proton are determined by the relation

$$\sigma(\pm) = \frac{1}{2} (\sigma(\leftrightarrow) \pm \sigma(\rightarrow)).$$

(4)
These cross sections can be expressed in terms of the spin-average and spin dependent value of the lepton and hadron tensors. For the first, one can write

\[ \mathcal{L}^{\mu\nu}(\pm) = \frac{1}{2}(\mathcal{L}^{\mu\nu}(+\frac{1}{2}) \pm \mathcal{L}^{\mu\nu}(\mp\frac{1}{2})). \] (5)

For longitudinal polarization, \( \mathcal{L}^{\mu\nu}(\pm\frac{1}{2}) \) are the tensors with the helicity of the initial lepton equal to \( \pm\frac{1}{2} \). The tensors (5) look like

\[ \mathcal{L}^{\mu\nu}(+) = 2(g^{\mu\nu}l \cdot q + 2l^\mu l^\nu - l^\mu q^\nu - l^\nu q^\mu), \]
\[ \mathcal{L}^{\mu\nu}(-) = 2i\mu_\epsilon^{\mu\nu\delta\rho}q_\delta(s_l)\rho. \] (6)

In the QCD-based models, when the gluons from the Pomeron couple to a single quark in the hadron, the effective Pomeron coupling \( V_{hP}^{\mu} = \beta_{hP}\gamma^\mu \) appears which looks like a \( C = +1 \) isoscalar photon vertex \([8]\). The spin-dependent Pomeron coupling can be obtained if one considers in the electromagnetic nucleon current together with the Dirac form factor the Pauli one \([11]\). We use in calculations the following form of the two–gluon coupling with the proton \([12]\)

\[ V_{P}^{\mu\nu}(p, t, x_P) = V_{pgg}^{\mu\nu}(p, t, x_P) = 4p^\mu p^\nu A(t, x_P) + (\gamma^\mu p^\nu + \gamma^\nu p^\mu)B(t, x_P). \] (7)

Here \( x_P \) is a fraction of initial proton momenta carried by the Pomeron. The term proportional to \( B \) represents the Pomeron coupling that leads to the non-flip amplitude. The \( A \) function is the spin–dependent part of the Pomeron coupling that produces spin–flip effects nonvanishing at high-energies \([12]\). The absolute value of the ratio of \( A \) to \( B \) is proportional to the ratio of helicity-flip and non-flip amplitudes. It has been found in \([13, 14]\) that \( \alpha = |A|/|B| \sim 0.1 - 0.2 \) GeV\(^{-1}\) and has weak energy dependence. We shall use in our estimations the value \( \alpha \leq 0.1 \) GeV\(^{-1}\).

The hadronic tensor for the vertex (7) has the form

\[ W^{\alpha\alpha';\beta\beta'}(s_p) = \sum_{s_f} \bar{u}(p', s_f) V_{pgg}^{\alpha\alpha'}(p, t, x_P)u(p, s_p)\bar{u}(p, s_p)V_{pgg}^{\beta\beta'}(p, t, x_P)u(p', s_f). \] (8)

Here \( s_p \) is a spin of the initial proton. The spin-average and the spin dependent hadronic tensor \( W(\pm) \) is determined by

\[ W^{\alpha\alpha';\beta\beta'}(\pm) = \frac{1}{2}(W^{\alpha\alpha';\beta\beta'}(+\frac{1}{2}) \pm W^{\alpha\alpha';\beta\beta'}(-\frac{1}{2})), \] (9)

where \( W(\pm\frac{1}{2}) \) are the hadron tensors with the helicity of the initial proton equal to \( \pm\frac{1}{2} \). The leading term of the spin average hadron tensor looks like

\[ W^{\alpha\alpha';\beta\beta'}(+) = 16p^\alpha p^{\alpha'} p^\beta p^{\beta'}(|B(t)| + 2mA(t))^2 + |t||A(t)|^2). \] (10)

It is proportional to the meson-proton cross section up to a function of \( t \) (\( m \) is a proton mass). The spin-dependent part of the hadron tensor can be written as

\[ W^{\alpha\alpha';\beta\beta'}(-) = \Delta A^\alpha_{\gamma\alpha'};\beta\beta' + \Delta A^1_{\alpha\alpha'};\beta\beta'. \] (11)
Here

$$\Delta A_\gamma^{\alpha':\beta'} = 2im|B|^2,$$

$$\left[ p^\alpha' p^\beta' \epsilon^{\alpha'\gamma\delta}(r_P)_{\gamma}(s_p)_{\delta} + \text{All Permutations} \left( \frac{\left( \alpha \rightarrow \alpha' \right)}{\left( \beta \rightarrow \beta' \right)} \right) \right]$$

(12)

The $\Delta A_\gamma$ contribution is proportional to $|B|^2$. It is equivalent in form to the spin-dependent part of the leptonic tensor (see (6)) and caused by the $\gamma_{\mu\nu}$ term in (6). The $\Delta A_1$ term contains interference of the $A$ and $B$ amplitudes from (7). It is more complicated, and its explicit form can be found in [12].

3 Spin effects in heavy $Q\bar{Q}$ production at COMPASS

The diffractive $Q\bar{Q}$ production in the lepton-proton reaction is determined in the D-L model by the diagram of Fig. 1a. Otherwise, in the two-gluon picture of the Pomeron we consider all the graphs where the gluons from the Pomeron couple to a different quark in the loop (Fig. 1c) as well as to the single one (Fig. 1b). This provides a gauge-invariant scattering amplitude. The spin-average and spin-dependent cross section can be written in the form

$$\frac{d^5\sigma(\pm)}{dQ^2dydx_pdt^2_{\perp}} = \frac{C(x_p,Q^2) N(\pm)}{\sqrt{1-4k^2_{\perp}/Q^2}}$$

(13)

Here $C(x_p,Q^2)$ is a normalization function which is common for the spin average and spin dependent cross section; $N(\pm)$ is determined by the sum of graphs in Fig. 1 b,c integrated over the gluon momenta $l$ and $l'$. The $D^\pm$ function here is a sum of traces over the quark loops of the graphs in Fig. 1b,c and corresponding crossed diagrams convoluted with the spin average and spin-dependent tensors. The calculation shows a considerable cancellation between the nonplanar contribution of the graph in Fig. 1c and the planar contribution from Fig. 1b. As a result, the function $D^\pm$ in (14) is proportional to the gluon momenta $l_{\perp}$ and $l'_{\perp}$. This distinguishes the D-L and the QCD models of the Pomeron. The D-L Pomeron contribution in Fig. 1a is equivalent only to the planar graph of Fig 1b.

We shall discuss here the $A_H = \sigma(-)/\sigma(+)$ asymmetry at COMPASS energy. The obtained asymmetry is proportional to $x_p$ ($x_p$ is typically of about .05 − .1) and has a weak energy dependence. The predicted asymmetry is quite small and does not exceed 1-1.5%. It has a week dependence on the $\alpha = A/B$ ratio and does not vanish for $\alpha = 0$. The $Q^2$ dependence of the $A_H$ asymmetry of the diffractive open charm production can be estimated as $A_H \propto Q^2/(Q^2 + Q^2_0)$ and is shown in Fig. 2. The COMPASS experiment intends to study events at small $Q^2$ where the
diffractive asymmetry will be extremely small. Thus, our calculations within two-gluon model of the Pomeron shows that there is no problem with the diffractive contribution at COMPASS. Note that the smallness of the asymmetry is caused mainly by the strong cancellation in $\Delta \sigma$ between the graphs in Fig 1b,c. Such compensation is absent in the D-L model where only the planar graphs shown in Fig. 1a (Fig. 1b) appear. As a result, the latest model of the Pomeron, provides the diffractive $A_{ll}$ asymmetry which is about 10% \[7\] and is larger by a factor of about 10 than the value obtained here.

The other important object which can be studied at COMPASS is the $A_{lt}$ asymmetry with longitudinal lepton and transverse proton polarization. It has been found that the $A_{lt}$ asymmetry is proportional to the scalar production of the proton spin vector and the jet momentum $A_{lt} \propto (s_\perp \cdot k_\perp) \propto \cos(\phi_{Jet})$. Thus, the asymmetry integrated over the azimuthal jet angle $\phi_{Jet}$ is zero. We have calculated the $A_{lt}$ 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 show in Fig. 3. It is huge and has a drastic $k_\perp^2$ dependence. The large value of the $A_{lt}$ asymmetry is caused by the fact that in contrast to $A_{ll}$, it does not have a small factor $x_p$ as a coefficient.

Note that usually it is impossible to detect the outgoing proton in fixed target experiments. Then, the integration over the momentum transfer $t$ of the cross section (13) should be done. Such integrated asymmetry is smaller by the factor of 1.2–2 with respect to the unintegrated values shown in Figs 2, 3.

4 Spin effects in vector meson production

Similar calculations have been done for the diffractive vector meson lepto-production. The $\gamma^* p \rightarrow V$ transition has been modeled as a conversion of the virtual
photon in a $q\bar{q}$ pair and subsequent $q\bar{q} \rightarrow V$ transition. As previously, we have included in our analysis the graphs where the gluons from the Pomeron couple to a different quark in the loop as well to the single one. The nonrelativistic wave function, when both the quarks have the same momenta equal to half of the meson momentum and the quark mass $m$ is equal to $m_V/2$, have been used in calculation.

The spin-dependent cross section can be written in the form

$$\frac{d\sigma^\pm}{dQ^2dydt} = \frac{|T^\pm|^2}{32(2\pi)^3Q^2s^2y}.$$ (15)

For the spin-average amplitude square we find

$$|T^+|^2 = N((2 - 2y + y^2)m_J^2 + 2(1 - y)Q^2)s^2|B|^2||1 + 2m\alpha|^2 + |\alpha|^2|t||I^2.$$ (16)

Here $N$ is a known normalization factor $\alpha = |A|/|B|$ and $I$ is the integral over transverse momentum of the gluon. The term proportional to $(2 - 2y + y^2)m_J^2$ in (16) represents the contribution of a virtual photon with transverse polarization. The $2(1 - y)Q^2$ term describes the effect of longitudinal photons.

Fig. 4. The differential cross section of the $J/\Psi$ production at HERA energy: solid line - for $\alpha = 0$; dot-dashed line - for $\alpha = 0.1\text{GeV}^{-1}$; dashed line - for $\alpha = -0.1\text{GeV}^{-1}$.

Fig. 5. The predicted $A_{ll}$ asymmetry of the $J/\Psi$ production at COMPASS: solid line - for $\alpha = 0$; dot-dashed line - for $\alpha = 0.1\text{GeV}^{-1}$; dashed line - for $\alpha = -0.1\text{GeV}^{-1}$.

The cross sections (15) integrated over $y$ and $Q^2$ with $Q^2_{\text{max}} \sim 4\text{GeV}^2$

$$\frac{d\sigma^\pm}{dydt} = \int_{y_{\text{min}}}^{y_{\text{max}}} dy \int_{Q^2_{\text{min}}}^{Q^2_{\text{max}}} dQ^2 \frac{d\sigma^\pm}{dQ^2 dydt}.$$ (17)

for the $J/\Psi$ production at HERA energy $\sqrt{s} = 300\text{GeV}^2$ is shown in Fig. 4. The spin-average cross sections are sensitive to $\alpha$ but the shape of all curves is the same. Thus, it is difficult to extract information about the spin-dependent part of
the Pomeron coupling from the spin–average cross section of the diffractive vector meson production.

The spin-dependent amplitude square looks like

$$|T^-|^2 = N(2 - y)s|t||B|^2 + 2m|AB|n_f^2t^2.$$ (18)

As a result, the following form of asymmetry is found [12]:

$$A_{ll} = \frac{\sigma(-)}{\sigma(+)} \sim \frac{|t|}{s} \frac{(2 - \bar{y})(1 + 2\alpha)}{(2 - 2\bar{y} + \bar{y}^2)\left[\left(1 + 2m\alpha\right)^2 + \alpha^2|t|^2\right]}.$$ (19)

The predicted asymmetry of the $J/\Psi$ vector meson production at COMPASS for different $\alpha$ is shown in Fig. 5. The asymmetry is equal to zero in the forward direction. The predicted asymmetry does not vanish for nonzero $|t|$. The value of the asymmetry for $\alpha \neq 0$ is dependent on the $A$–term of the Pomeron coupling. However, the sensitivity of the asymmetry to $\alpha$ is quite weak. Thus, it will not be so easy to study the spin structure of the Pomeron coupling with the proton from the $A_{ll}$ asymmetry of the diffractive vector meson production. The obtained asymmetry is independent of the mass of a produced meson. We can expect a similar value of the asymmetry in the polarized diffractive $\phi$–meson leptoproduction. In this reaction the contribution of the $t$–channel $Q\bar{Q}$ exchange should be quite small. Otherwise, for the $\rho$ meson production the $t$–channel $Q\bar{Q}$ contribution should be significant at COMPASS energies.

5 Conclusion

In the present report, the polarized cross section of the diffractive hadron leptoproduction at high energies has been studied. As a result, connection of the spin–dependent cross section in the diffractive production with the Pomeron coupling has been found. Generally, two–gluon couplings with the proton in diffractive processes at small $x$ can be expressed in terms of the skewed gluon distribution in the nucleon $F_X(X + \Delta)$, where for vector meson production one can find $X \sim (Q^2 + m_V^2)/W^2$, $\Delta \ll X$ [14]. Here $X + \Delta$ is a fraction of the proton momentum carried by the outgoing gluon, and the difference between the gluon momenta (skewedness) is equal to $X$. The function $B$ should be determined by the spin–average and the function $A$ by the polarized skewed gluon distribution in the proton. To find the explicit connection of $A$ with spin–dependent gluon distribution, additional study is necessary.

It has been found that there is no problem with the diffractive contribution to $A_{ll}$ at COMPASS for $Q^2 \rightarrow 0$ because its value is found to be negligible. The predicted $A_{ll}$ asymmetry in the $Q\bar{Q}$ leptoproduction for $Q^2 \geq 1\text{GeV}^2$ is smaller than 1.5%. The nonzero asymmetry for $\alpha = A/B = 0$ is completely determined by the $\gamma^\alpha$ term in the Pomeron coupling [7]. The $A_{ll}$ asymmetry in diffractive processes for nonzero momentum transfer has been found dependent on the $A$ term of the Pomeron coupling which has a spin dependent nature. However, the sensitivity of
asymmetry to the $\alpha$–ratio is quite weak. Thus, the $A_\mu$ asymmetry in diffractive reactions is not a good tool to study the polarized gluon distributions of the proton and spin structure of the Pomeron. Otherwise, the $A_{T\perp}$ asymmetry in diffractive $Q\bar{Q}$ production might be about 10-20%. This asymmetry is proportional to $\alpha$ and might be used to obtain direct information about the spin structure of Pomeron coupling and the skewed polarized gluon structure functions of the proton.

We would like to stress that the spin-dependent amplitude in the diffractive reaction is more sensitive to the model of the Pomeron interaction than the spin-average one. Some tricks in calculations, which restore the gauge invariance of the scattering amplitude, can simplify investigation of $\sigma(+)$ (see e.g. [16]). Unfortunately, they do not work for $\sigma(-)$. We consider the full perturbative calculation which includes all possible $t$-channel gluon exchanges as the most reliable method to study the spin effects in diffractive reactions. Future polarized diffractive experiments might be an important test of the spin structure of QCD at large distances and of the different theoretical approaches to diffractive reactions.

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