Spin Effects In Diffractive High-Energy Reactions
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Abstract

Spin effects in diffractive $pp$ and $lp$ reactions are analyzed. It is shown that the structure of the pomeron coupling can be studied in future polarized experiments.

Diffractive processes at high energies have common properties. They lead to the events with large rapidity gap between produced particles. The observation of these events at CERN and DESY [1, 2] has revived interest in the study of the pomeron and reactions where its properties can be investigated. Future experiments at RHIC and HERA [3, 4] and proposed FELIX experiment at LHC [5] will permit one to study different aspects of polarized diffractive $pp$ and $lp$ reactions. In some experiments, the diffractive contributions might be an important background effect. All these processes should carefully be analyzed to obtain information on what kind of dynamics at large distances can be studied in future experiments and what effects in physical observables should be expected. In this report we shall discuss the effects of spin-dependent pomeron coupling in elastic $pp$ scattering and diffractive $Q\bar{Q}$ leptoproduction. Similar problems have been discussed in [7].

The "standard" approaches [8] to the pomeron exchange do not lead to the spin-flip part in the pomeron coupling. However, some model approaches predict nonzero spin effects in the $s \to \infty$, $|t|/s \to 0$ limit (see [9, 10, 11] e.g.). This means that the pomeron might not conserve the $s$-channel helicity. The "new" property of the pomeron can provide very definite predictions at high energies. This conclusion is especially important for the diffractive scattering of polarized particles where the complicated spin structure of the pomeron should be manifested.

I shall discuss here some predictions of the meson-cloud model (MCM) [11]. They now become actual for the polarized PP2PP experiment at RHIC [12] where the spin asymmetries near the diffraction minimum should be studied and for the proposed FELIX experiment at LHC [13] where elastic $pp$ scattering might be analyzed up to $|t| \sim 20GeV^2$.

The MCM [14] provide the following form of the pomeron-proton coupling:

$$V^\mu_{pp}\pi(p, r) = mp_\mu A(r) + \gamma_\mu B(r),$$

where $m$ is the proton mass and $r$ is the momentum transfer ($t = r^2$). The $\gamma_\mu B(r)$ term is a standard pomeron coupling that determines the spin-non-flip amplitude. The term $mp_\mu A(r)$ leads to the spin-flip in the pomeron vertex which is caused by the meson-cloud effects and does not vanish in the $s \to \infty$ limit. Really, we can estimate the Born terms of the spin-non-flip and spin-flip effects from the pomeron-proton vertex (1):

$$|T^{B+}(s, t)| \propto s |B(r)|;$$

$$|T^{B-}(s, t)| \propto m \sqrt{|t| s} |A(r)|.$$
So, both the amplitudes have the same energy dependence.

The model predicts the following ratio for spin-flip and non-flip amplitudes:

\[
\frac{|T^B_{-}(s,t)|}{|T^B_{+}(s,t)|} \simeq \frac{m \sqrt{|t|} |A(r)|}{|B(r)|} \approx 0.05 \div 0.07 \text{ for } |t| \sim 0.5 \text{GeV}^2
\]  

(3)

that is consistent with the estimations of Ref. \[12\].

The spin-non-flip and spin-flip amplitudes in MCM have the eikonal form

\[
T_{++}(s,t) \propto i s \int \rho d\rho J_0(r\rho) (1 - \exp [2i\chi_0(s,\rho)]);
T_{+-}(s,t) \propto i s \int \rho^2 d\rho J_1(r\rho) \chi_1(s,\rho) \exp [2i\chi_0(s,\rho)],
\]  

(4)

where

\[
\chi_0(s,\rho) \propto \chi^\text{center}_0(s,\rho) + \frac{\sqrt{s}}{2} \int dz \alpha^2(s, R);
\]

\[
\chi_1(s,\rho) \propto \frac{d}{d\rho} \int dz \alpha(s, R).
\]  

(5)

Here \(\chi^\text{center}_0\) is determined by the \(B\) term in \((1)\), \(\alpha(s, R)\) being proportional to the \(A\) term in the coordinate space. In MCM this amplitude is determined by the large-distance structure of the hadron. Just the \(\alpha(s, R)\) contribution defines the spin-flip amplitude at high energies and gives the predominant contribution to the \(\chi_0(s,\rho)\) eikonal phase at superhigh energies \(\sqrt{s} > 100 \text{GeV}\) because of the coefficient growing as \(\sqrt{s}\). Thus, the MCM predicts the strong correlation between the polarization phenomena at high energies and differential cross section behaviour at superhigh energies.

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Fig.1 The predicted \(A_N\) asymmetry of the \(pp\)-elastic scattering: full line -for \(\sqrt{s} = 50 \text{GeV}\); short-dashed line -for \(\sqrt{s} = 120 \text{GeV}\). The expected statistical errors are shown for PP2PP experiment.
The spin asymmetries are determined as a ratio of spin-dependent and spin-average cross section. Thus, spin asymmetries in PP scattering might be large near the diffraction minimum ($|t| \sim 1 GeV^2$) where the spin-average cross section is quite small.

The MCM model prediction for polarization at RHIC energies with the expected statistical errors for PP2PP experiment [13] are shown in Fig.1. The expected errors are quite small and the information about the spin-flip part of the proton-pomeron coupling can be obtained experimentally.

Fig.1 Predictions for polarization at RHIC energies with the expected statistical errors for PP2PP experiment [13].

The model predictions for elastic proton-proton scattering at LHC up to $|t| = 20 GeV^2$ are shown in Fig.2. The differential cross section increasing at superhigh energies is caused by the term growing as $\sqrt{s}$ in the eikonal phase $\chi_0$ (5).

So, the future PP2PP and FELIX experiments will give an excellent possibility to test the spin structure of the pomeron-proton coupling and the possible rapid growth of the eikonal phase $\chi_0$ determined by the meson-cloud effects.

The future polarized diffractive experiments at DESY [3] and CERN [5] might give the possibility to study the spin structure of the pomeron in diffractive lepton proton reactions

$$e + p \rightarrow e' + p' + X$$  \hspace{1cm} (6)

It has been shown in [15, 16] that in addition to the diagrams where gluons interact with one quark in the hadron [8], the large-distance gluon-loop effects should complicate the structures of the pomeron coupling. The perturbative calculations [13] give the following form for this vertex:

$$V^\mu_{\gamma q F}(k, r) = \gamma^\mu u_0 + 2 M_Q k^\mu u_1 + 2 k^\mu k u_2 + i u_3 \epsilon^{\mu \alpha \beta \rho} k_\alpha r_\beta \gamma_\rho \gamma_5 + i M_Q u_4 \sigma^{\mu \alpha} r_\alpha.$$ \hspace{1cm} (7)

where $M_Q$ is the quark mass. We shall call the form (7) the spin-dependent pomeron coupling. If we consider only the $\gamma^\mu u_0$ contribution, it will be called a standard coupling.
Here we analyze the effects of the quark–pomeron coupling in the polarized diffractive $e + p \to e' + p' + \bar{Q}Q$ reaction based on \[17, 18, 19\] and estimate the longitudinal double-spin $A_{ll}$ asymmetry for light and heavy quark production at energy $\sqrt{s} = 20 \text{GeV}$.

The difference of the polarized cross section can be written in the form

$$
\Delta \sigma(t) = \frac{d^5 \sigma(\uparrow)}{dxdydx_pdt dk^2_\perp} - \frac{d^5 \sigma(\downarrow)}{dxdydx_pdt dk^2_\perp} = \frac{3(2 - y)\beta_0^4 F(t)^2[9 \sum_i e_i^2]\alpha^2}{128x_p^{2\alpha_p(t)-1}Q^2\pi^3} \frac{A(\beta, k^2_\perp, x_p, t)}{\sqrt{1 - 4k^2_\perp\beta/Q^2(k^2_\perp + M^2_Q)}}. \tag{8}
$$

Here $\sigma(\uparrow)$ and $\sigma(\downarrow)$ are the cross sections with parallel and antiparallel longitudinal polarization of the leptons and protons, $\beta_0$ is the quark–pomeron coupling, $F(t)$ is the pomeron-proton form factor and $e_i$ are the quark charges.

The function $A$ is determined by the trace over the quark loop. The contribution of the standard pomeron vertex to $A^s$ looks like

$$
A^s(\beta, k^2_\perp, t) = 16(2(1 - \beta)k^2_\perp - |t|\beta - 2M_Q^2(1 + \beta))|t|. \tag{9}
$$

Similar forms can be written for the spin–average cross sections. In both the cases the strong dependence of the cross sections on the mass of the produced quarks has been found.

We calculate the cross section integrated over momentum transfer because it is usually difficult to detect the recoil proton in diffractive experiments

$$
\sigma[\Delta \sigma] = \int_{t_m}^{0} dt \sigma(t)[\Delta \sigma(t)], \quad |t_m| = 7(\text{GeV})^2. \tag{10}
$$

The exponential form of the proton form factor $F(t) = e^{bt}$ with $b = 1.9 (\text{GeV})^{-2}$ has been used.

![Fig.3 k^2_\perp – dependence of A_{ll} asymmetry at $\sqrt{s} = 20 (\text{GeV})$. Solid line -for the standard vertex; dot-dashed line -for the spin-dependent quark-pomeron vertex.](image-url)
The asymmetry of the diffractive light $Q\bar{Q}$ production is shown in Fig. 3. It is sensitive to the spin structure of the pomeron coupling. The asymmetry for the standard quark–pomeron vertex is very simple in form

$$A_{ll} = \frac{yx_p(2-y)}{2-2y+y^2}. \quad (11)$$

There is no any $k_{\perp}$ and $\beta$ dependence here. For the spin–dependent pomeron coupling the $A_{ll}$ asymmetry is smaller than for the standard pomeron vertex and depends on $k_{\perp}^2$. Thus, the $A_{ll}$ asymmetry can be used to test the quark-pomeron coupling structure.

The $A_{ll}$ asymmetry for diffractive open charm ($c\bar{c}$) production has been calculated for the standard pomeron coupling only.

The predicted $A_{ll}$ asymmetry is not small. The open charm prediction is proposed to be used by COMPASS [5] to study $\Delta G$. It has been shown in [19] that the produced diffractive $Q\bar{Q}$ jets should be detected by the COMPASS spectrometer. So, we can conclude that the diffractive events might be an important background here.

We have found that the spin structure of the pomeron coupling should modify the spin average and spin–dependent cross section in elastic and diffractive processes. It can be studied in single and double transverse spin asymmetries in elastic $pp$ scattering. The $A_{ll}$ asymmetry in diffractive $Q\bar{Q}$ leptoproduction is convenient to test the pomeron coupling structure. The asymmetry is free from normalization factors and is sensitive to the dynamics of pomeron interaction. We have predicted large $A_{ll}$ asymmetry for the diffractive $Q\bar{Q}$ production. This conclusion can be important in the analysis of $\Delta G/G$ in the COMPASS spectrometer.

Thus, we can conclude that the pomeron coupling structure can be studied in different diffractive processes. Note that the spin–structure of the pomeron vertex is determined by the large–distance gluon-loop correction or by the effects of the hadron wave function. So, the important test of the spin structure of QCD at large distances can be carried out by studying diffractive reactions in future polarized experiments at HERA, RHIC and LHC accelerators.
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