ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2-96-462

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ON POSSIBLE STUDY OF QUARK-POMERON COUPLING STRUCTURE AT THE COMPASS SPECTROMETER

Submitted to «Modern Physics Letters A»

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1996

The diffractive events with a large rapidity gap in deep inelastic lepton–proton scattering

$$e + p \to e' + p' + X \qquad (1)$$

have recently been investigated (see, e.g. [1, 2]). These experiments have given an excellent tool to test the structure of the pomeron and its couplings. As a result, the study of the pomeron properties becomes again popular now.

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

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

where p_l, p_l' 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 this reaction is related to the diffractive structure function

$$\frac{d^4\sigma}{dx dQ^2 dx_p dt} = \frac{4\pi\alpha^2}{xQ^4}[1 - y + \frac{y^2}{2}]F_2^{D(4)}(x, Q^2, x_p, t), \qquad (3)$$

which is determined by the pomeron contribution and usually represented at small x_p in the factorized form

$$F_2^{D(4)}(x, Q^2, x_p, t) = f(x_p, t) F_2^P(\beta, Q^2, t). \qquad (4)$$

Here $f(x_p, t)$ is the pomeron flux factor and $F_2^P(\beta, Q^2, t)$ is the pomeron structure function.

The function $f(x_p, t)$ at small x_p behaves as [3]

$$f(x_p, t) \propto \frac{1}{x_p^{2\alpha_P(t)-1}}, \qquad (5)$$

where $\alpha_P(t)$ is the pomeron trajectory

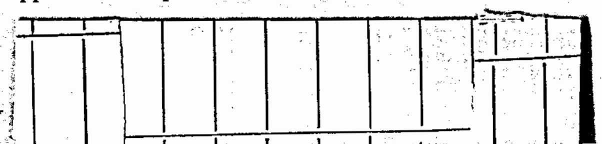
$$\alpha_P(t) = \alpha_P(0) + \alpha' t, \quad \alpha' = 0.25(GeV)^{-2}. \qquad (6)$$

The future polarized diffractive experiments at DESY, CERN and Brookhaven [4] might give the possibility to study the spin structure of the pomeron. One of the places to perform such an experiment is the future detector of the COMPASS collaboration at CERN [5] which will use the polarized muon beam and fixed polarized hadron target. The important feature of COMPASS is the possibility to detect the hadron component of the process within an angle of about 200-250 Mrad.

The question on the value of the spin–flip component of the pomeron should be very important for the diffractive scattering of polarized particles. In the nonperturbative two-gluon exchange model [6] and the BFKL model [7] the pomeron couplings have a simple matrix structure (the standard coupling in what follows):

$$V^{\mu}_{hhP} = \beta_{hhP}\, \gamma^{\mu}. \qquad (7)$$

In this case, the spin-flip effects are suppressed as a power of s.



It was shown in [8, 9] that in addition to the standard pomeron vertex (7) determined by the diagrams where gluons interact with one quark in the hadron [6], the large-distance gluon-loop effects (see Fig.1) should complicate the structures of the pomeron coupling. Really, if we consider the gluon loop correction of Fig.1a for the standard pomeron vertex (7) and the massless quark, we obtain in addition to the γ_μ term, new structures

$$\gamma_\alpha(\not k + \not r)\gamma^\mu \not k \gamma^\alpha \simeq -2[2(\not k + \frac{\not r}{2})k^\mu + i\epsilon^{\mu\alpha\beta\rho}k_\alpha r_\beta \gamma_\rho \gamma_5], \qquad (8)$$

where k is a quark momentum, r is a momentum transfer. The perturbative calculations [8] of both graphs, Fig.1, give the following form for this vertex:

$$V^{\mu}_{qqP}(k, r) = \gamma^\mu u_0 + 2M_Q k^\mu u_1 + 2k^\mu \not k u_2 + iu_3 \epsilon^{\mu\alpha\beta\rho} k_\alpha r_\beta \gamma_\rho \gamma_5 + iM_Q u_4 \sigma^{\mu\alpha} r_\alpha, \qquad (9)$$

where M_Q is the quark mass. We shall call the form (9) the spin-dependent pomeron coupling. It has been shown [10] that the functions $u_1(r) - u_4(r)$ can reach 20 – 30% of the standard pomeron term $\sim \gamma_\mu$ for $|r^2| \simeq$ few GeV^2. Moreover, they result in the spin-flip effect at the quark-pomeron vertex in contrast with the term γ_μ. So, the loop diagrams lead to a complicated spin structure of the pomeron couplings. The phenomenological vertex V^{μ}_{qqP} with the γ_μ and u_1 terms was proposed in [11]. The modification of the standard pomeron vertex (7) might be obtained from the instanton contribution [12].

The test of the spin properties of the pomeron coupling can be done in future polarized experiments. At small x_p, the contribution where all the energy of the pomeron goes into the $Q\bar{Q}$ production [13, 14] might be very important. The role of these contributions in the spin asymmetries of diffractive two–jet production has been studied in [9, 15]. It has been found that the A_{ll} asymmetry in the light quark production in deep inelastic lp scattering, Fig.2, is dependent on the pomeron coupling structure. This asymmetry for cross sections integrated over the transverse momentum of jet could reach 10 – 20% [15]. The dependence of polarized cross sections and double–spin longitudinal asymmetry on the transverse momentum of a produced jet $k_\perp^2$ and their sensitivity to the quark–pomeron coupling structure have been studied in [16].

In this paper, we analyze the effects of the quark–pomeron coupling in the polarized diffractive $e + p \to e' + p' + Q\bar{Q}$ reaction at the energy $\sqrt{s} = 20 GeV$. We estimate the cross section, the longitudinal double–spin asymmetry A_{ll} and the kinematics of the final jet to show that these events can be studied at future spectrometer of the COMPASS Collaboration [5].

The diffractive light $Q\bar{Q}$ production in lepton-proton reaction is determined by the diagram of Fig. 2. The spin-average cross section can be written in the form [16]

$$\sigma(t) = \frac{d^5\sigma(\rightleftarrows)}{dx dy dx_p dt dk_\perp^2} + \frac{d^5\sigma(\rightrightarrows)}{dx dy dx_p dt dk_\perp^2} =$$
$$\frac{3(1 - y + y^2/2)\beta_0^4 F(t)^2 [9 \sum_i e_i^2]\alpha^2}{128 x_p^{2\alpha_P(t)} y Q^2 \pi^3} \frac{N(\beta, k_\perp^2, x_p, t)}{\sqrt{1 - 4k_\perp^2\beta/Q^2}(k_\perp^2 + M_Q^2)^2}. \qquad (10)$$

Here $\sigma(\rightrightarrows)$ and $\sigma(\rightleftarrows)$ are the cross sections with parallel and antiparallel longitudinal polarization of the leptons and protons, β_0 is the quark–pomeron coupling, $F(t)$ is the pomeron-proton form factor, e_i are the quark charges. The leading x_p dependence is extracted in the coefficient of Eq.(10) which is determined by the pomeron flux factor (5). The trace over the quark loop $-N$ may be decomposed as follows

$$N(\beta, k_\perp^2, t) = N^s(\beta, k_\perp^2, t) + \delta N(\beta, k_\perp^2, t). \qquad (11)$$

Here N^s is the contribution of the standard pomeron vertex (7) and δN contains the contribution of the $u_1(r) - u_4(r)$ terms from (9). For N^s in the case of light quarks in the loop and $x_p = 0$ we find

$$N^s(\beta, k_\perp^2, t) = 32[2(1-\beta)k_\perp^2 - \beta|t|]|t|. \qquad (12)$$

The form of δN is more complicated. We have found it in the $\beta \to 0$ limit. For the massless quarks only the u_3 terms contribute to δN:

$$\delta N(k_\perp^2, t) = 32k_\perp^2|t|[(k_\perp^4 + 4k_\perp^2|t| + |t|^2)u_3 - 4k_\perp^2 - 2|t|]u_3. \qquad (13)$$

Note that δN is positive because $u_3 \leq 0$. Higher twist terms of an order of M_Q^2/Q^2 and $|t|/Q^2$ have been dropped in (12,13).

The difference of the cross section for the supercritical pomeron can be written in the form

$$\Delta\sigma(t) = \frac{d^5\sigma(\stackrel{\rightarrow}{\Leftarrow})}{dx dy dx_p dt dk_\perp^2} - \frac{d^5\sigma(\stackrel{\rightarrow}{\Rightarrow})}{dx dy dx_p dt dk_\perp^2} =$$
$$\frac{3(2-y)\beta_0^4 F(t)^2[9\sum_i e_i^2]\alpha^2}{128 x_p^{2\alpha_P(t)-1} Q^2 \pi^3} \frac{A(\beta, k_\perp^2, x_p, t)}{\sqrt{1 - 4k_\perp^2\beta/Q^2}(k_\perp^2 + M_Q^2)^2}. \qquad (14)$$

The notation here is similar to that used in Eqs. (10).

The function A is determined by the trace over the quark loop. It can be written in the $x_p \to 0$ limit as follows:

$$A(\beta, k_\perp^2, t) = A^s(\beta, k_\perp^2, t) + \delta A(\beta, k_\perp^2, t). \qquad (15)$$

Here A^s is the contribution of the standard pomeron vertex (7) and δA is determined by the $u_1(r) - u_4(r)$ terms from (9).

The function A^s for the light quarks looks like

$$A^s(\beta, k_\perp^2, t) = 16(2(1-\beta)k_\perp^2 - |t|\beta)|t|. \qquad (16)$$

We have calculated δA in the $\beta \to 0$ limit. For the massless quarks we have

$$\delta A(\beta, k_\perp^2, t) = -16(3k_\perp^2 + 2|t|)k_\perp^2|t|u_3. \qquad (17)$$

The leading twist terms have been calculated here as previously.

It can be seen that σ has a more singular behaviour than $\delta\sigma$ as $x_p \to 0$. This is determined by the fact that the leading term in $\delta\sigma$ is proportional to $\epsilon^{\mu\nu\alpha\beta} r_\beta ... \propto x_p p$. The same is true for the lepton part of the diagram of Fig.1. As a result, the additional term $y x_p$ appears in $\delta\sigma$.

We calculate the cross section integrated over momentum transfer because it is difficult to detect the recoil proton in COMPASS detector

$$\sigma[\Delta\sigma] = \int_{t_m}^{0} dt \sigma(t)[\Delta\sigma(t)], \quad |t_m| = 7(GeV)^2. \qquad (18)$$

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

As an example, we calculate the cross sections and asymmetry for $\beta = 0.175, y = 0.7, x_p = 0.1$ and $Q^2 = 5GeV^2$. The results for the cross section of the light quark production in diffractive deep inelastic scattering for the pomeron with the pomeron intercept $\alpha_P(0) = 1.1$ are shown in Fig. 3 for the standard and spin-dependent pomeron couplings. The shape of both the curves is very similar and for the spin-dependent pomeron coupling the cross section is almost twice that for the standard pomeron coupling.

The longitudinal double spin asymmetry is determined by the relation

$$A_{ll} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma(\stackrel{\rightarrow}{\Leftarrow}) - \sigma(\stackrel{\rightarrow}{\Rightarrow})}{\sigma(\stackrel{\rightarrow}{\Rightarrow}) + \sigma(\stackrel{\rightarrow}{\Leftarrow})}. \qquad (19)$$

The asymmetry of the diffractive light $Q\bar{Q}$ production is shown in Fig. 4. It can be seen from the cross section (14,10) that the asymmetry for the standard quark–pomeron vertex is very simple in form

$$A_{ll} = \frac{y x_p (2-y)}{2 - 2y + y^2}. \qquad (20)$$

There is no any $k_\perp$ and β dependence here. For the spin-dependent pomeron coupling the asymmetry is more complicated because of different contributions to δA and δN proportional to $k_\perp^2$. In this case the A_{ll} asymmetry is smaller than for the standard pomeron vertex. Thus, the A_{ll} asymmetry can be used to test the quark-pomeron coupling structure.

Let us estimate now the kinematics of jet events. The jet momenta are:

$$j_1 = q - k, \quad j_2 = r + k. \qquad (21)$$

The photon momentum can be written in the center-mass system in the form

$$q = \left(y\sqrt{s}, \frac{-Q^2}{\sqrt{s}}, \vec{q}_\perp\right), \quad |\vec{q}_\perp| = \sqrt{(1-y)Q^2}. \qquad (22)$$

The transverse momentum r can be written as follows

$$r = \left(\frac{-|t|}{\sqrt{s}}, x_p\sqrt{s}, \vec{r}_\perp\right), \quad |\vec{r}_\perp| = \sqrt{(1-x_p)|t|}. \qquad (23)$$

From the mass-shell conditions for jet momenta $j_1^2 = j_2^2 = M_Q^2$ the quark momentum k has been found to be

$$k \simeq \left(\frac{(\vec{r}_\perp + \vec{k}_\perp)^2 + M_Q^2}{\sqrt{s} x_p}, -\frac{yQ^2 + (\vec{q}_\perp - \vec{k}_\perp)^2 + M_Q^2}{\sqrt{s} y}, \vec{k}_\perp\right). \qquad (24)$$

In (22-24) the light-cone variables have been used.

The jet momenta and its angles in the rest system of the initial proton can be expressed in terms of (22-24)

$$P_{J1} \simeq \frac{yx_ps - k_\perp^2 - M_Q^2}{2x_pm}, \; \sin\left(\frac{\theta_{J1}}{2}\right) \simeq \frac{m\sqrt{(\vec{k}_\perp - \vec{q}_\perp)^2}}{ys};$$
$$P_{J2} \simeq \frac{m^2 + M_Q^2 + k_\perp^2}{2x_pm}, \; \sin\left(\frac{\theta_{J2}}{2}\right) \simeq \frac{mx_p}{\sqrt{m^2 + M_Q^2 + k_\perp^2}}. \quad (25)$$

Here m is the proton mass. The invariant mass of a produced system is

$$M_{2Jet}^2 = x_pys. \quad (26)$$

The momenta and jet angles for $\sqrt{s} = 20GeV, x_p = 0.1, y = 0.7$ and $Q^2 = 5GeV^2$ are shown in Figs 5,6 for the azimuth angle between the lepton scattering plane and $k_\perp$ is equal to 90 degree. It is seen that both jets can be detected by the COMPASS detector whose angular acceptance is about 200-250Mrad.

Thus, we have found that the structure of the quark–pomeron coupling should modify the spin average and spin–dependent cross section. The spin–dependent form of V_{qqP} almost twice increases the cross section. However, the shape of the cross sections is very similar for the standard and spin–dependent pomeron vertices. The A_{ll} asymmetry is more 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 found a well-defined prediction for A_{ll} for the standard pomeron vertex. This conclusion is similar to the results of [9] where the single-spin asymmetry in the diffractive $Q\bar{Q}$ production has been studied.

The predicted cross sections are not small for the experimental investigation of this reaction. Our analysis of jet kinematics shows that they might be detectable by the COMPASS spectrometer. There is no possibility to detect the final proton. However, the analysis of the diffractive events similar to that done in HERA experiments [1, 2] can be performed in this case, too.

We can conclude that the study of the longitudinal double spin asymmetry and the cross section of the diffractive deep inelastic scattering at the new spectrometer of the COMPASS Collaboration at CERN can give important information about the complicated spin structure or the pomeron coupling.

The author expresses his deep gratitude to A.V.Efremov, M.Finger, G.Mallot, P.Kroll, W.-D.Nowak, I.A.Savin, A.Schäfer and O.V.Teryaev for fruitful discussions.

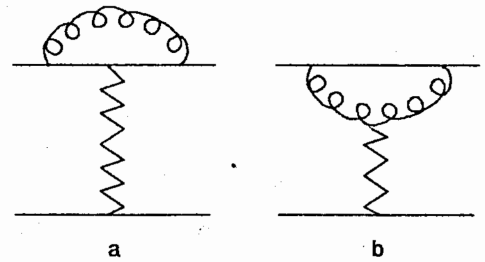


Fig.1 Gluon-loop contribution to the quark-pomeron coupling. Broken line -the pomeron exchange.

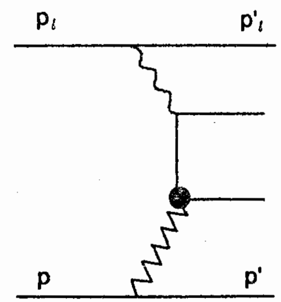


Fig.2 Diffractive $Q\bar{Q}$ production in deep inelastic scattering

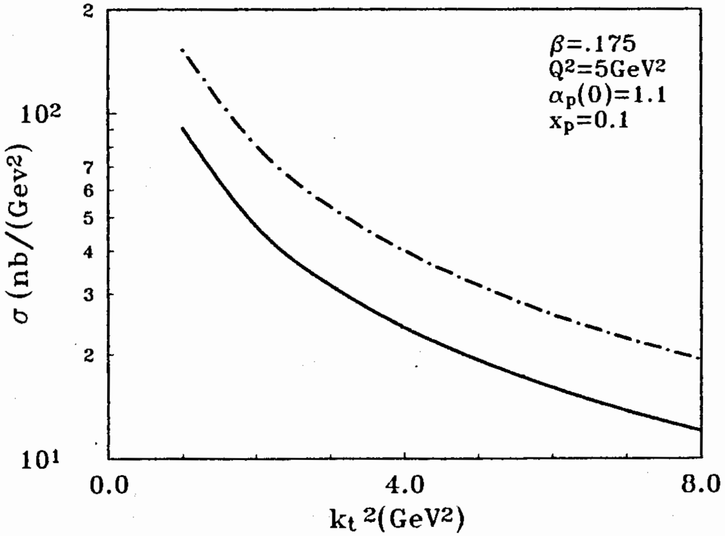


Fig.3. $k_\perp^2$– dependence of cross-sections at $\sqrt{s} = 20(GeV)$. Solid line -for the standard vertex; dot-dashed line -for the spin-dependent quark-pomeron vertex.

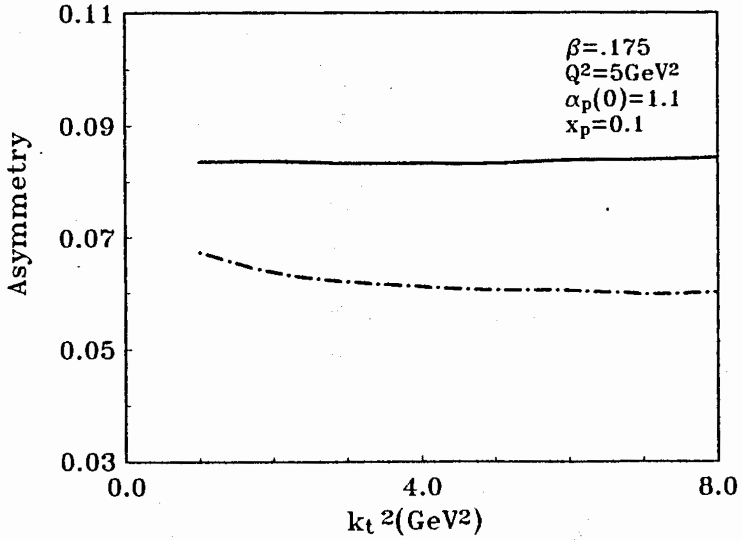


Fig.4. $k_\perp^2$– dependence of A_H asymmetry at $\sqrt{s} = 20(GeV)$. Solid line -for the standard vertex; dot-dashed line -for the spin-dependent quark-pomeron vertex.

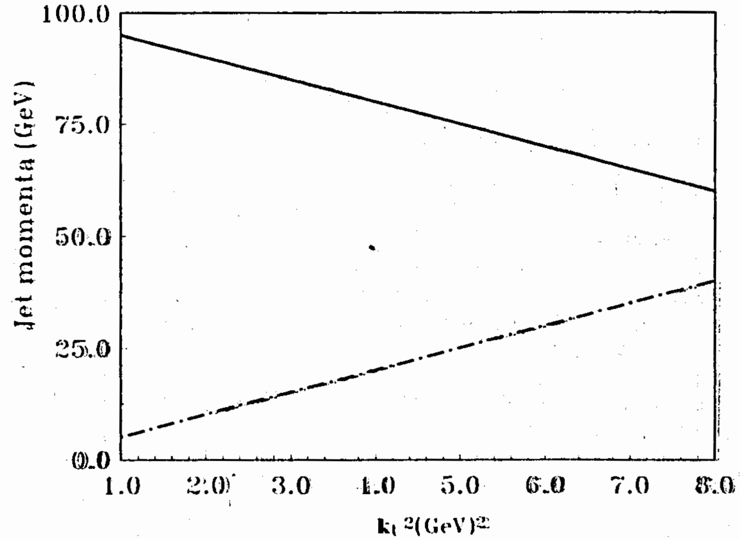


Fig.5 $k_\perp^2$– dependence of jet momenta. Solid and dot-dashed line -for jet1 and jet2 respectively.

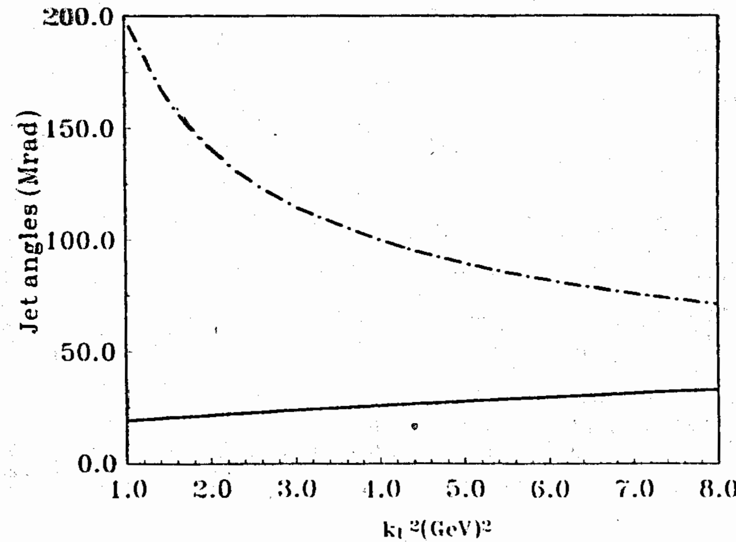


Fig.6 $k_\perp^2$– dependence of jet angles. Solid and dot-dashed line -for jet1 and jet2 respectively.

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Received by Publishing Department
on December 11, 1996.

Голоскоков С.В. E2-96-462
О возможности изучения структуры кварк-померонной вершины на спектрометре COMPASS

Исследовано дифракционное рождение $Q\overline{Q}$ пар и кинематика струй в конечном состоянии в поляризованном глубоконеупругом лептон-протонном рассеянии при энергии $\sqrt{s}=20$ ГэВ. Показано, что эта реакция может быть использована на новом спектрометре COMPASS коллаборации в ЦЕРНе для изучения структуры кварк-померонной вершины.

Работа выполнена в Лаборатории теоретической физики им.Н.Н.Боголюбова ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1996

Goloskokov S.V. E2-96-462
On Possible Study of Quark-Pomeron Coupling Structure at the COMPASS Spectrometer

We analyse the diffractive $Q\overline{Q}$ production and final jet kinematics in polarized deep-inelastic lp scattering at $\sqrt{s}=20$ GeV. We show that this reaction can be used in the new spectrometer of the COMPASS Collaboration at CERN to study the quark-pomeron coupling structure.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1996