DIFFRACTIVE HADRON PRODUCTION AND POMERON COUPLING STRUCTURE
S.V.Goloskokov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research,
141980 Dubna, Russia

Large-distance effects, which lead to the spin-flip part of the hadron-pomeron coupling in QCD-models, are discussed. We study spin asymmetries in exclusive reactions and in diffractive $Q\bar{Q}$ and vector meson production which are sensitive to the spin-dependent part of the pomeron coupling.

Investigation of hard diffractive processes is now a problem of topical interest. Experimental study of reactions with a large rapidity gap [1] gives information on the pomeron structure. Theoretically, it is important to find a possible way to test different model approaches which have been proposed for the pomeron and its couplings with quarks and hadrons. The pomeron has mainly the gluon contents and can be represented in QCD as a two-gluon exchange [2]. Thus, the diffractive reactions may be a significant tool to study the gluon distributions in the nucleon at small x [3]. Actually, these processes can be expressed in terms of skewed gluon distribution in the nucleon $\mathcal{F}_X(X + \Delta X)$, where $X + \Delta X$ is a fraction of the proton momentum carried by the outgoing gluon ($\Delta X \ll X$) and the difference between the gluon momenta (skewedness) is equal to X [4].

The pomeron is a color singlet object which describes high energy reactions at fixed momentum transfer. Usually, the pomeron exchange is written in the factorized form as a product of the function $\boldsymbol{P}$, which absorbs s-dependence of the amplitude, and the pomeron-hadron vertices $V^{h\boldsymbol{P}}$

$$\hat{T}(s,t) = i\boldsymbol{P}(s,t)V_{h_1\boldsymbol{P}} \otimes V^{h_2\boldsymbol{P}}. \tag{1}$$

The model approaches [5, 6] lead to the quark-pomeron couplings in a simple form:

$$V_{h\boldsymbol{P}}^{\mu} = B_{h\boldsymbol{P}}(t)\,\gamma^{\mu}, \tag{2}$$

which looks like a $C = +1$ isoscalar photon vertex [7]. In this case, the spin-flip effects are suppressed as a power of s.

In QCD-based models, which consider large-distance contributions in hadrons, a more general form of the pomeron coupling with the proton has been obtained. In the model [8], which was found to be valid for momentum transfer

$|t| <$ few GeV^2, the $Q\bar{Q}$ sea effects have been approximated by a meson cloud of the hadron. The model results in the pomeron-hadron coupling in the form

$$V_{p\mathbb{P}}^{\mu}(p,t,x_P) = 2p^{\mu}A(t,x_P) + \gamma^{\mu}B(t,x_P). \qquad (3)$$

Here x_P is a fraction of the initial pomeron momentum carried by the pomeron ($x_P = 0$ for elastic scattering). The large-distance meson cloud contributions in the nucleon produce the A term in (3). It leads to the transverse spin effects in the pomeron coupling which does not vanish at high energies. This means that the pomeron might not conserve the s-channel helicity. Within this model, a quantitative description of meson-nucleon and nucleon-nucleon polarized scattering at high energies has been obtained [8]. The model predictions for polarization at RHIC energies are shown in Fig. 1 [9]. Error bars in the Figure indicate expected statistical errors for the PP2PP experiment at RHIC. The expected errors are quite small and the information about the spin-flip part of the proton-pomeron coupling can be obtained experimentally.
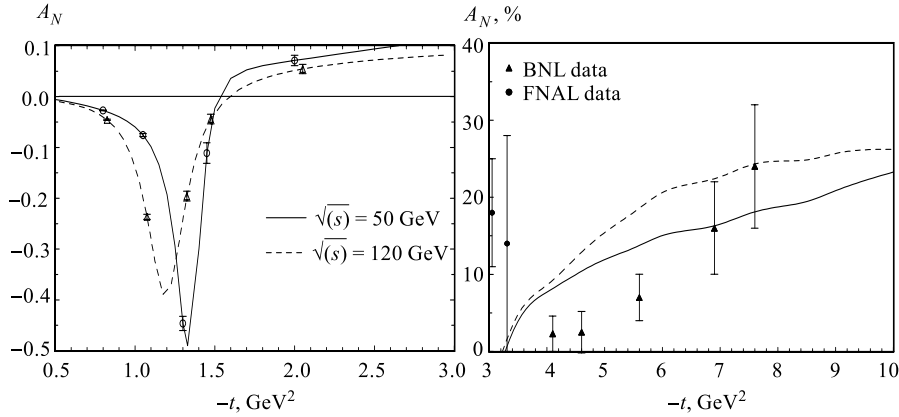

Fig. 1. Meson cloud model predictions for single-spin transverse asymmetry of the pp scattering at RHIC energies

Fig. 2. Diquark model predictions for single-spin asymmetry at high energy pp scattering

The similar structure of the proton coupling with the two-gluon system has been found for moderate momentum transfer in a QCD-based diquark model [10]. Diquarks provide an effective description of nonperturbative effects in the proton. The spin-dependent A contribution in (3) is determined in the model by the effects of vector diquarks. The predicted A_N asymmetry (Fig. 2) is of the same order of magnitude as has been observed in the model [8, 9] for $|t| \sim 3\text{GeV}^2$ and found in the BNL [11] and FNAL experiments [12]. A similar form of the proton-pomeron coupling has been used in [13]. Generally, the spin-dependent

pomeron coupling (3) can be obtained if one considers together with the Dirac the Pauli form factors [14] in the electromagnetic nucleon current. In all the cases, the spin-flip A contribution is determined by the nonperturbative effects in the proton.

Let us analyze now what polarized diffractive experiments might be sensitive to the pomeron coupling structure (3). We shall consider double spin asymmetry of the J/Ψ and $Q\bar{Q}$ production. The cross section of these reactions can be decomposed into the following important parts: leptonic and hadronic tensors and the amplitude of the $\gamma^\star P \to J/\Psi(Q\bar{Q})$ transition. The hadronic tensor for the vertex (3) can be written as

$$W^{\mu;\nu}(s_p) = \sum_{s_{fin}} \bar{u}(p', s_{fin})V_{pgg}^\mu(p, t, x_P)u(p, s_p)\bar{u}(p, s_p) \tag{4}$$

$$\times V_{pgg}^{\star\,\nu}(p, t, x_P)u(p', s_{fin}),$$

where p and p' are the initial and final proton momenta, and s_p is a spin of the initial proton.

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

$$\sigma(\pm) = \frac{1}{2}\left(\sigma(\overset{\rightarrow}{\leftarrow}) \pm \sigma(\overset{\rightarrow}{\Rightarrow})\right). \tag{5}$$

These cross sections can be expressed in terms of spin-average and spin dependent values of the leptonic and hadronic tensors. The structure of the leptonic tensor is well known [15]. For the hadronic tensor one can write

$$W^{\mu;\nu}(\pm) = \frac{1}{2}(W^{\mu;\nu}(+\frac{1}{2}) \pm W^{\mu;\nu}(-\frac{1}{2})), \tag{6}$$

where $W(\pm\frac{1}{2})$ are the hadronic tensors with the helicity of the initial proton equal to $\pm 1/2$. The explicit forms of the hadronic tensors can be found in [16].

A simple model is considered for the amplitude of the $\gamma^\star \to J/\Psi$ 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 [3]. In this approximation, quarks have the same momenta equal to half of the vector meson momentum and $m_c = m_J/2$. The gluons from the pomeron are coupled to the single and different quarks in the $c\bar{c}$ loop. This ensures gauge invariance of the final result.

The cross section of the J/Ψ leptoproduction can be written in the form

$$\frac{d\sigma^\pm}{dQ^2 dy dt} = \frac{|T^\pm|^2}{32(2\pi)^3 Q^2 s^2 y}. \tag{7}$$

For the spin-average amplitude square we find

$$|T^+|^2 = N((2 - 2y + y^2)m_J^2 + 2(1-y)Q^2)s^2[|B + 2mA|^2 + |A|^2|t|]I^2. \quad (8)$$

Here N is a known normalization factor and I is the integral over transverse momentum of the gluon

$$I = \frac{1}{(m_J^2 + Q^2 + |t|)} \int \frac{d^2l_\perp(l_\perp^2 + \vec{l}_\perp\vec{\Delta})}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{\Delta})^2 + \lambda^2)[l_\perp^2 + \vec{l}_\perp\vec{\Delta} + (m_J^2 + Q^2 + |t|)/4]}. \quad (9)$$

The term proportional to $(2 - 2y + y^2)m_J^2$ in (8) represents the contribution of the virtual photon with transverse polarization. The $2(1-y)Q^2$ term describes the effect of longitudinal photons.

The spin-dependent amplitude square looks like

$$|T^-|^2 = N(2-y)s|t|[|B|^2 + m(A^\star B + AB^\star)]m_J^2 I^2. \quad (10)$$

As a result, we find the following form of asymmetry [16]:

$$A_{ll} = \sigma(-)/\sigma(+) \sim \frac{|t|}{s} \frac{(2-y)[|B|^2 + m(A^\star B + AB^\star)]}{(2 - 2y + y^2)[|B + 2mA|^2 + |t||A|^2]}. \quad (11)$$
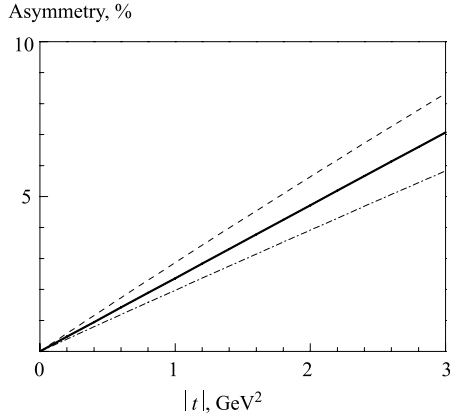

Asymmetry, %

$|t|$, GeV^2

Fig. 3. The predicted A_{ll} asymmetry of the J/Ψ production at HERMES: solid line — for $\alpha = 0$; dot-dashed and dashed lines — for $\alpha = \pm 0.1$ GeV^{-1}

The A_{ll} asymmetry of vector meson production is equal to zero for the forward direction ($t = 0$). It depends on the ratio of the spin-flip to the nonflip parts of the pomeron coupling $\alpha = A/B$. The absolute value of α is proportional to the ratio of helicity-flip and nonflip amplitudes which have been found in [8,10] to be of about 0.1 and weakly dependent on energy. The predicted asymmetry at HERMES energies is shown in Fig. 3. At HERA energies, the asymmetry will be negligible. The value of asymmetry for $\alpha = 0$ is not equal to zero. This term of the asymmetry is determined by the γ_μ part of the pomeron coupling (3). It gives the predominated contribution to the asymmetry of vector meson production in our model.

Let us pass now to spin effects in $Q\bar{Q}$ leptoproduction. In the two-gluon picture of the pomeron, we consider all the graphs where the gluons from the

pomeron couple to a different quark as well to the single one. The spin-average and spin-dependent cross section can be written in the form

$$\frac{d^5\sigma(\pm)}{dQ^2 dy dx_p dt dk_\perp^2} = \left(\begin{smallmatrix}(2-2y+y^2)\\(2-y)\end{smallmatrix}\right) \frac{N(x_p,Q^2)\,C(\pm)}{\sqrt{1-4k_\perp^2\beta/Q^2}}. \qquad (12)$$

Here, $N(x_p,Q^2)$ is a normalization function which is common for spin average and spin dependent cross section and

$$C(\pm) = \int \frac{d^2l_\perp d^2l'_\perp\, D^\pm(t,Q^2,l_\perp,l'_\perp,\cdots)}{(l_\perp^2+\lambda^2)((\vec{l}_\perp+\vec{r}_\perp)^2+\lambda^2)(l'^2_\perp+\lambda^2)((\vec{l'}_\perp+\vec{r}_\perp)^2+\lambda^2)}, \qquad (13)$$

where $D^\pm$ function comprises a sum of the $\gamma P \to Q\bar{Q}$ production diagrams and the corresponding crossed contributions convoluted with the spin average and spin-dependent tensors. The obtained diffractive A_{ll} asymmetry has weak energy dependence and is proportional to x_p which is typically of about $.05 - .1$. The predicted asymmetry is quite small and does not exceed 1-1.5% [17]. We find that the asymmetry is not equal to zero for $\alpha = 0$. The value of the asymmetry for nonzero α is determined by the spin–dependent part of the pomeron coupling. However, as in the case of J/Ψ production, sensitivity of the asymmetry to α is not very strong.

Another object, which can be studied at polarized $Q\bar{Q}$ production, 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 transverse jet momentum. Thus, the asymmetry integrated over the azimuthal jet angle 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 estimated Q^2 dependence of the A_{lT} asymmetry integrated over t for $\alpha = 0.1 \text{GeV}^{-1}$ is shown in Fig. 4. The predicted asymmetry is huge and has a strong $k_\perp^2$ dependence. The large value of A_{lT} asymmetry is caused by the fact that it does not have a small factor x_p as a coefficient.
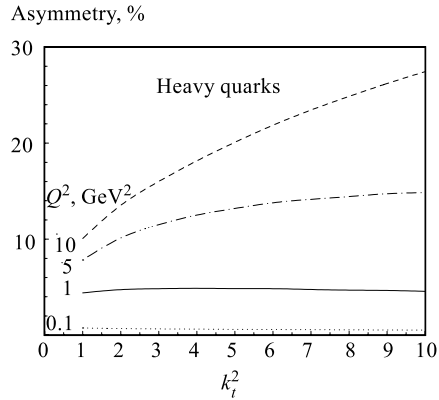

Fig. 4. The predicted Q^2 dependence of A_{lT} asymmetry for the $c\bar{c}$ production at HERA for $\alpha = 0.1 \text{ GeV}^{-1}$, $x_p = 0.1$, $y = 0.5$

In the present report, the polarized cross section of the diffractive hadron leptoproduction at high energies has been studied. The spin asymmetries are expressed in terms of the A and B structures of the pomeron coupling (3). Generally, the function B should be determined by the spin–average and the function A — by the polarized skewed gluon distribution in the proton. The $B\gamma^\mu$ term of the pomeron coupling (3) contributes to both $\sigma(+)$ and $\sigma(-)$ cross sections which for $\alpha = 0$ are proportional to B^2. This gives the nonzero $A_{ll}(\alpha = 0)$ asymmetry which is independent of the gluon density. We predict not small value of the A_{ll} asymmetry of the diffractive vector meson production at the HERMES energy. The obtained asymmetry is independent of the mass of a produced meson. So, we can expect a similar value of the asymmetry in the polarized diffractive ϕ –meson leptoproduction. The predicted A_{ll} asymmetry in the $Q\bar{Q}$ leptoproduction is smaller than 1.5%. The $A_{ll}(\alpha = 0)$ contribution is predominated in asymmetry, and sensitivity of the asymmetry on α for $\alpha \neq 0$ is rather weak. Thus, the A_{ll} asymmetry in diffractive reactions is not a good tool to study polarized gluon distributions of the proton and the spin structure of the pomeron. Otherwise, it has been found not small A_{lT} asymmetry in diffractive $Q\bar{Q}$ production. This asymmetry is proportional to α and can be used to obtain direct information about the spin–dependent part A of the pomeron coupling. Experimental analyses of energy dependence of the A_{lT} asymmetry as well as of the A_N asymmetry in elastic pp scattering, which have a weak energy dependence in the model, can throw light on the spin structure of the pomeron coupling. They are appropriate objects to study the polarized gluon structure of the proton too. Thus, the pomeron coupling structure can be investigated in diffractive processes. This gives important information on the spin structure of QCD at large distances.

REFERENCES

1. ZEUS Collaboration, **Derrick M. et al.** — Z. Phys., 1995, v.C68, p.569;
   H1 Collaboration, **Ahmed T. et al.** — Phys. Lett., 1995, v.B348, p.681.

2. **Low F.E.** — Phys. Rev., 1975, v.D12, p.163;
   Nussinov S. — Phys. Rev. Lett., 1975, v.34, p.1286.

3. **Ryskin M.G.** — Z. Phys., 1993, v.C57, p.89;
   Brodsky S.J. et al. — Phys. Rev., 1994, v.D50, p.3134.

4. **Radyushkin A.V.** — Phys. Rev., 1997, v.D56, p.5524;
   Ji X. — Phys. Rev., 1997, v.D55, p.7114.

5. **Landshoff P.V., Nachtmann O.** — Z. Phys., 1987, v.C35, p.405.

6. **Kuraev E.A., Lipatov L.N., Fadin V.S.** — Sov. Phys. JETP, 1976, v.44, p.443.

7. **Donnachie A., Landshoff P.V.** — Nucl. Phys., 1984, v.B244, p.322.

8. **Goloskokov S.V., Kuleshov S.P., Selyugin O.V.** — Z. Phys., 1991, v.C50, p.455.

9. **Akchurin N., Goloskokov S.V., Selyugin O.V.** — Int. J. Mod. Phys., 1999, v.A14, p.253.

10. **Goloskokov S.V., Kroll P.** — Phys. Rev., 1999, v.D60, p.014019.

11. **Peaslee D.C. et al.** — Phys. Rev. Lett., 1983, v.51, p.2359.

12. **Fidecaro G. et al.** — Phys. Lett., 1981, v.B105, p.309.

13. **Klenner J., Schäfer A., Greiner W.** — Z. Phys., 1995, v.A352, p.203.

14. **Arens T., Diehl M., Nachtmann O., Landshoff P.V.** — Z. Phys., 1997, v.C74, p.651.

15. **Anselmino M., Efremov A., Leader E.** — Phys. Rep., 1995, v.C261, p.1.

16. **Goloskokov S.V.** — Eur. Phys. J, 1999, v.C11, p.309.

17. **Goloskokov S.V.** — to appear in Proc. of the Workshop on Polarized Protons at High Energies — Accelerator Challenges and Physics Opportunities, Hamburg, Germany, 17-20 May 1999, e-Print: hep-ph/9907429.