The $A_{LL}$ asymmetry in diffractive reactions and structure of quark-pomeron vertex

S.V.Goloskokov, O.V.Selyugin
Bogolubov Laboratory of Theoretical Physics,
Joint Institute for Nuclear Research, Dubna

Abstract

Theoretical predictions for the behavior of $A_{LL}$ asymmetry determined by the pomeron-hadron vertex are done. Strong dependence of the asymmetry on the mass creating quarks and transfer momenta is shown.

1 Introduction

The spin effects in high energy reactions are still an open problem of perturbative QCD. Like in the framework of the standard perturbative QCD, there is no way to explain many spin phenomena revealed in different processes at high energies.

The spin-flip effects do not exist in the massless limit in hard processes where all quark masses must be omitted. If we do not neglect the quark masses, the spin-flip amplitudes are suppressed as a power of $s$ with respect to the spin-non-flip ones.

The $t$-channel exchange with vacuum quantum numbers (pomeron) gives a fundamental contribution to high energy reactions at fixed momenta transfer ($s \to \infty$, $t$-fixed). The calculations of diagrams and their summations are usually performed in the leading logarithmic approximation (see e.g. [2]). However, the spin-flip amplitudes are absent in this approximation.

As has been intimated, the most part of spin experimental data at high energies are obtained at fixed momenta transfer. So, the theoretical research of the pomeron spin structure is very important. The vacuum $t$-channel amplitude is usually associated in QCD with the two-gluon exchange [3]. The properties of the spinless pomeron were analysed in [4, 5] on the basis of a QCD model with taking account of nonperturbative properties of the theory.
A similar model was used to investigate the spin effects in pomeron exchange. It was demonstrated that different contributions determined by a gluon ladder [6] and quark loops [7] may lead to the spin-flip amplitude growing as $s$ in the limit $s \to \infty$. Factorization of the $qq$ amplitude was shown into the spin-dependent large-distance part and the high-energy spinless pomeron. This permits us to define the quark-pomeron vertex and to discuss the results of summation of the pomeron ladder graphs in higher orders of QCD. It has been shown that the obtained amplitude leads to the ratio of spin-flip and non-flip amplitudes being perhaps independent of the energy [8]. This result should modify different spin asymmetries and lead to new effects in high energy diffractive reactions which can be measured in future experiments in the RHIC at Brookhaven [9].

2 Pomeron and spin phenomena

It was demonstrated in the soft momentum transfer region in [6] within the qualitative QCD analysis that the $qq$ spin-flip amplitude growing as $s$ can be obtained in the $\alpha_s^3s$ order. Factorization of the spin-flip amplitude has been shown into the spin-dependent large-distance part (quark-pomeron vertex) and the high-energy spinless pomeron. The quantitative calculations of the spin effects in $qq$ scattering were performed in the $\alpha_s^3$ order in the half-hard region $s \to \infty$, $|t| > 1GeV^2$ [10] where the perturbative theory can be used.

It was shown that the quark-pomeron vertex (Fig.1) in the perturbative region has a form

$$V_{qqP}^\mu(k, q) = \gamma_\mu u_0(q) + 2mk_\mu u_1(q) + 2k_\mu k_\nu u_2(q) + i\frac{u_3(q)}{2}\epsilon^{\mu\alpha\beta\rho}k_\alpha q_\beta \gamma_\rho \gamma_5 + im \frac{u_4(q)}{2} \sigma^{\mu \alpha} q_\beta.$$  \hspace{1cm} (1)

In (1) $u_i(q)$ are the vertex functions. The term proportional to $\gamma_\mu$ corresponds to the standard spinless pomeron that reflects the well-known fact that the spinless quark-pomeron coupling is like a $C = +1$ isoscalar photon [4]. We use the simple form of the $u_0(q)$ vertex function

$$u_0(q) = \frac{\mu_0^2}{\mu_0^2 + Q^2}, \hspace{0.5cm} q^2 = -Q^2,$$

with $\mu_0 \sim 1Gev$ introduced in [5]. The functions $u_1(q) \div u_4(q)$ at large $Q^2$ were calculated in perturbative QCD [10]. Their magnitudes are not very small. Additional spin-flip contributions to the quark pomeron vertex can be connected with instanton effects (see [11], [12] e.g.). The magnitude of these effects is not very well defined because they are model dependent.

Note that the structure of the quark-pomeron vertex function (1) is drastically different from the standard spinless pomeron. Really, the terms $u_1(q) - u_4(q)$ lead to the spin-flip in the quark-pomeron vertex in contrast to the term proportional to $u_0(q)$ which is spin-non-flip one. As a result the new terms can modify different spin asymmetries and lead to new effects in high energy reactions.

To show this, let us investigate the quark pair productions in diffractive hadron reactions This sort of reactions was investigated by different authors (see [13] e.g.).
We shall estimate the longitudinal double spin asymmetries in the reaction (Fig.2) as an example. Note that to extract this process, we must detect the final proton with the longitudinal momenta $p'_2 = x_f p_2$. The angle of this final proton in the c.m.s. is determined by the relation $\sin(\theta_{p'_2}) = \sqrt{Q^2/(x_f s)}$ and for $\sqrt{s} = 100$GeV, $Q^2 = 10$GeV, $x_f = .7$ we have $\sin(\theta_{p'_2}) \sim 0.04$.

The resulting asymmetry looks as follows

$$A_{UL} = C_g \frac{(1 - x_f^2)\{4u_0^2 + Q^2 u_3[2u_0 + 4m^2 u_1 + 2m^2 u_2 + m^2 u_4]\}}{(1 + x_f^2)\ln(s(1 - x_f)/Q^2)[4u_0^2 + u_3^2 Q^4/2]}.$$  \hspace{1cm} (2)

Here

$$C_g = \frac{\int_0^1 \Delta g(y)dy}{(yg(y))|_{y=0}}.$$  \hspace{1cm} (3)

$m$ is the quark mass. For the simple form of the gluon structure function

$$g(y) = \frac{3}{y}(1 - y)^5$$

we have for the coefficient (3)

$$C_g = \frac{\int_0^1 \Delta g(y)dy}{3}.$$  \hspace{1cm} (4)

It is well known that $\int_0^1 \Delta g(y)dy \sim 3$ is necessary for the explanation of different spin effects \hspace{0.5cm} [14]. In this case $C_g \sim 1$.

## 3 The $A_{UL}$ asymmetry for the energy of RHIC and AGS

It is easy to see from (2) that for the standard spinless pomeron that contains the $u_0$ term, only the asymmetry (2) has a slow $Q^2$ dependence on the logarithmic term in the denominator. However, we must observe a strong $Q^2$ dependence in the $A_{UL}$ asymmetry for the pomeron vertex with the spin-flip part. The resulting asymmetry is equal to zero for $x_f = 1$. The $A_{UL}$ asymmetry for energy of RHIC $\sqrt{s} = 100$GeV estimated on the basis of perturbative results for vertex functions for $x_F = .7$ and $C_g = 1$ is shown in Fig.3. The resulting asymmetry can reach $10 \div 12\%$ in the case of large magnitude for the integral (4). As can be seen, from Fig. 3, we have an insignificant negative asymmetry for light quarks and positive for quarks with large mass. However, for low energies the asymmetry of light quarks can be sufficiently large.

Similar experiments can be performed at AGS energies ($\sqrt{s} = 7$GeV). In this case we can analyse the production of light and charm quarks. The predictions for the pomeron contribution to the $A_{UL}$ asymmetries in this case for $x_F = .7$ and $C_g = 1$ are shown in Fig. 4. The asymmetry is large and reaches 40% because in this case we have no large suppression by the $\ln[\sqrt{s}(1 - x)/Q^2]$ term in (2). We can see that asymmetry of light quarks can reach 15%. The maximum asymmetry strongly depends on scattering energies, $Q^2$ and quark mass. So, for $\sqrt{s} = 100$GeV we have the maximum asymmetry at $Q^2 = 20 \div 25$GeV$^2$ for the quark mass equal to 1.3GeV and at $Q^2 = 45 \div 50$GeV$^2$ for the quark mass equal to 4.6GeV.
4 Conclusion

So, the $A_{LL}$ asymmetry can be measured and the information about the spin structure of the quark-pomeron vertex can be extracted. Therefore, the experiment has been carried out to determine the dependence of asymmetry $A_{LL}$ on $Q^2$ for separate mass quark, for example, $m_q = 1.3 GeV$, or the dependence of asymmetry on the quark mass at separate $Q^2$, for example, for $\sqrt{s} = 100 GeV$ $Q^2 = 20 \div 25 GeV^2$ This asymmetry can be used for the evaluation in RHIC of

$$\int_0^1 \Delta g(y)dy$$

if the magnitudes of vertex functions $u_1(q) \div u_4(q)$ are known from other experiments or in the opposite case (when the $\Delta g(y)$ is known) for the determination of the vertex functions $u_1(q) \div u_4(q)$. This permits one to determine a relative magnitude of the nonperturbative instanton contribution.

Moreover, using the handedness method $[5]$ the final quark-spin correlations with the spin of initial hadrons can be observed.

Acknowledgement. The authors express their deep gratitude to S.P.Kuleshov and A.N. Sissakian for support of this work and to A.V. Efremov, O.V.Teryaev, M.V.Tokarev and Yu.A. Panebratzev for fruitful discussions.

References

[1] S.J.Brodsky, G.P.Lepage, Phys.Rev. 1980, D22, 2157.

[2] E.A.Kuraev, L.N.Lipatov, S.V.Fadin, Zh.Eksp.Teor.Fiz., 1977, 72, 377.

[3] F.E.Low, Phys.Rev., 1975, D12, 163; S.Nussinov, Phys.Rev.Lett., 1975, 34, 1286.

[4] P.V.Landshoff, O. Nachtmann, Z.Phys.C-Particles and Fields 1987, 35, 405.

[5] A.Donnachie, P.V.Landshoff, Nucl.Phys., 1989, B311 509.

[6] S.V.Goloskokov, Yad.Fis., 1989, 49, 1427.

[7] S.V.Goloskokov, Z.Phys. C-Particles and Fields 1991, 52, 329; S.V.Goloskokov, J.Phys. G:Nucl.Part.Phys., 1993, 19, 67.

[8] S.V.Goloskokov, Phys.Lett., 1993, B315, 459.

[9] G.Bunce et al., Phys. World, 1992, 3, 1.

[10] S.V.Goloskokov, O.V. Selugin, Yad. Fiz., 1994, 57.

[11] A.E Dorokhov, N.I.Kochelev, Yu.A.Zubov, Int.Journ.Mod.Phys., 1993, A8,603.

[12] M.Anselmino, S.Forte, Phys.Rev.Lett., 1993, 71, 223.
[13] E.L. Berger et al., Nucl.Phys., 1987, B286, 704;  
S. Catani et al., Nucl.Phys., 1991, B366, 135;  
A. Donnachie, P.V. Landshoff, Phys.Lett., 1992, B285, 172;  

[14] J. Soffer, Proc. of the 10 Int. Symp. on High Energy Spin Phys. p 49 (Nagoya, 1992).  

[15] A.V. Efremov, L. Mankiewicz, N.A. Tornqvist, Phys.Lett., 1992, B284, 394;  

Figure Captions  

Fig. 1 Quark - pomeron vertex.  

Fig. 2 Diagram for the production of a quark pair in pomeron-hadron interaction.  

Fig. 3 $A_H$ - asymmetry in the case of the pomeron-hadron interaction at the RHIC energies.  
(for the spinless vertex - solid curve;  
for the spin-flip vertex and different mass of creating quarks:  
dotted line - $m = 0.005 GeV$, dot-dashed line - $m = 1.3 GeV$,  
short dashed line - $m = 4.6 GeV$).  

Fig. 4 $A_H$ - asymmetry in the case of the pomeron-hadron interaction at the AGS energies.  
(for the spinless vertex - solid curve;  
for the spin-flip vertex and different mass of creating quarks:  
dotted line - $m = 0.005 GeV$, dot-dashed line - $m = 1.3 GeV$,  
short dashed line - $m = 4.6 GeV$).
This figure "fig1-1.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9403377v1
This figure "fig1-2.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9403377v1
This figure "fig1-3.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9403377v1
This figure "fig1-4.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9403377v1