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THE A_{LL} ASYMMETRY IN DIFFRACTIVE REACTIONS AND STRUCTURE OF QUARK-POMERON VERTEX

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Theoretical predictions for the behaviour 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.

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

A_{LL}-асимметрия в дифракционных реакциях и структура кварк-померонной вершины

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Представлены теоретические предсказания поведения A_{LL} асимметрии, определяемой структурой кварк-померонной вершины. Показана сильная зависимость величины асимметрии от массы рождающихся кварков и переданного момента.

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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 [1] 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 order 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

In 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 α_s^3 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 α_s^3 order in the half-hard region $s \to \infty$, $|t| > 1$ GeV^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

$$V^{\mu}_{qqP}(k, q) = \gamma_\mu u_0(q) + 2mk_\mu u_1(q) + 2k_\mu \not{k} u_2(q) + \\ + i\frac{u_3(q)}{2}\varepsilon^{\mu\alpha\beta\rho}k_\alpha q_\beta \gamma_\rho \gamma_5 + im\frac{u_4(q)}{2}\sigma^{\mu\alpha}q_\alpha . \quad (1)$$

In (1) $u_i(q)$ are the vertex functions. The term proportional to γ_μ corresponds to the standard spinless pomeron that reflects the well-known fact

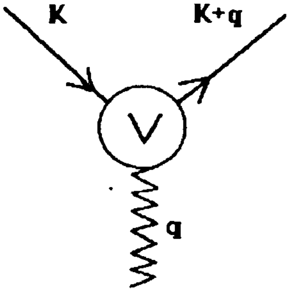

Fig.1. Quark-pomeron vertex

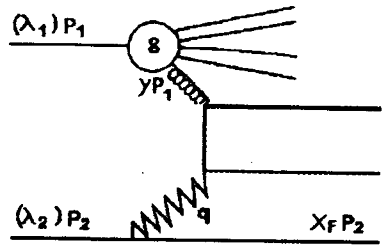

Fig.2. Diagram for the production of a quark pair in pomeron-hadron interaction

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

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

with $\mu_0 \sim 1$ GeV 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, $x_f = 0.7$ we have $\sin(\theta_{p_2'}) \sim 0.04$.

The resulting asymmetry looks as follows

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

Here

$$G_g = \frac{\int_0^1 \Delta g(y)\, dy}{(y g(y))|_{y=0}}, \quad (3)$$

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)

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

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

3. The A_{LL} 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_{ll} asymmetry for the pomeron vertex with the spin-flip part. The resulting asymmetry is equal to zero for $x_f = 1$. The A_{ll} asymmetry for energy of RHIC $\sqrt{s} = 100$ GeV estimated on the basis of perturbative results for vertex functions for $x_F = 0.7$ 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

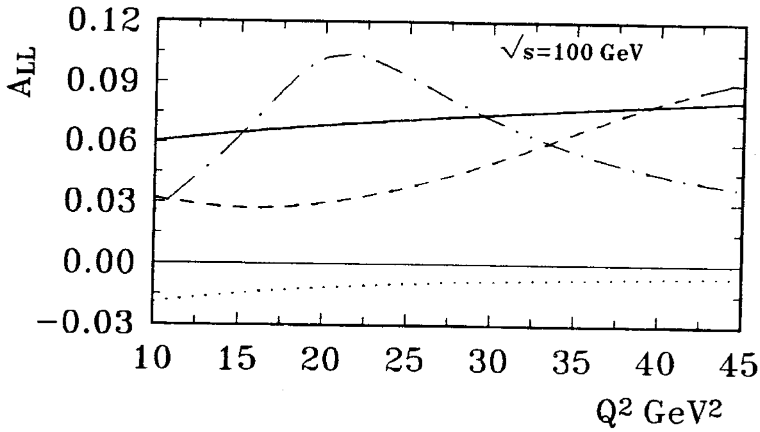

Fig.3. A_{ll} — asymmetry in the case of the pomeron-hadron interaction at the RHIC energies (for the spinless vertex — solid curve; for the spin-flip vertex and different mass of creating quarks: dotted line — $m = 0.005$ GeV, dot-dached line — $m = 1.3$ GeV, short dashed line — $m = 4.6$ GeV)

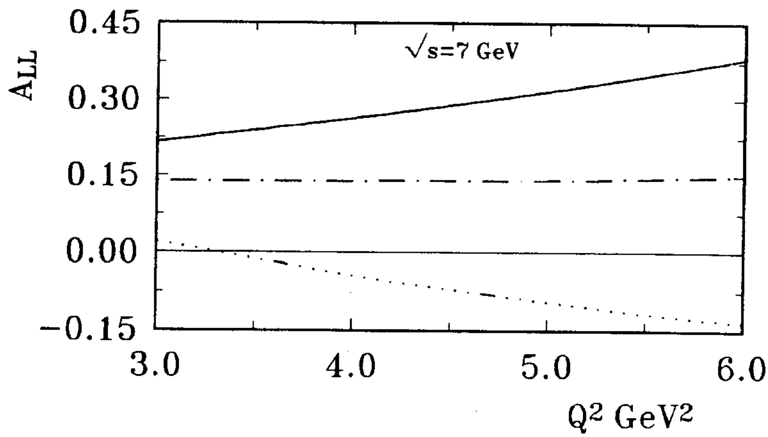

Fig.4. A_{ll} — asymmetry in the case of the pomeron-hadron interaction at the AGS energies (for the spinless vertex — solid curve; for the spin-flip vertex and different mass of creating quarks: dotted line — $m = 0.005$ GeV, dot-dached line — $m = 1.3$ GeV)

predictions for the pomeron contribution to the A_{LL} asymmetries in this case for $x_F = 0.7$ 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 $\ln\,[s(1-x)/Q^2]$ 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 1.3 GeV and at $Q^2 = 45 \div 50$ GeV^2 for the quark mass equal to 4.6 GeV.

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 [15] the final quark-spin correlations with the spin of initial hadrons can be observed.

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