Polarization effects in two-particle processes at high energies in quantum chromodynamics

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The cross sections for $2 \to 2$ spin-flip processes do not decrease with increasing s. In several cases, they are not suppressed at large $|t|$ in comparison with the cross sections for processes without spin flip. A method is proposed for calculating seed amplitudes for $2 \to 2$ processes.

The literature has lacked a correct analysis of the behavior of the amplitudes for $2 \to 2$ spin-flip scattering at high energies and at large momentum transfer in quantum chromodynamics (QCD). In the present paper we adopt the example of meson–meson scattering to show that, in contrast with naive expectations, such processes have a differential cross section which does not fall off with increasing energy. It is also shown here that in several cases the amplitudes for spin-flip processes fall off no more rapidly than the amplitudes for processes without spin flip with increasing t.

We begin with a calculation of the parametricity of the helicity amplitudes for meson–meson scattering at $s \gg |t| \gg \mu^2$, where $\mu^2 \sim 1$ GeV^2. We assume that there exists a region of momentum transfer and energy in which logarithmic perturbative corrections are unimportant.[1)] We will carry out a calculation on the parametricity of the helicity amplitudes in this region. This parametricity is determined by the short-range component. In the scattering problem, there is no factorization of the regime of short and long ranges.[1] Accordingly, in a calculation of the short-range component we should restrict the range of integration in such a way that the virtualities of the propagators satisfy the condition $|\chi_1^2| \gtrsim 1$ GeV^2. For definiteness we consider the behavior of the helicity amplitudes A_{00}^{00} and $A_{00}^{+1\pm1}$ for $\rho\rho$ scattering. The parametrically leading component of A_{00}^{00} is known to be determined by the quark–quark scattering mechanism[2,3] (Fig. 1), and in the region of interest here it has a behavior $\sim st^{-2.5}$. It can be seen from an analysis of the corresponding diagrams that the behavior of the amplitudes $A_{00}^{+1\pm1}$ is determined by the same mechanism. Calculating the main components (Fig. 1), we find

$$A_{00}^{+1\pm1} \sim C_{\pm} f_\rho^4 (m_\rho^2/\mu^3)(st^{-2,5}) \sim A_{00}^{00} \sim C_0 f_\rho^4 \mu^{-1}(st^{-2,5}). \quad (1)$$

Since the result depends on the cutoff parameter, this calculation method cannot lead to anything approaching reliable numerical values for the amplitudes, although it does guarantee the correct asymptotic behavior of the helicity amplitudes as functions of s and t.

The parametrically leading contribution (Fig. 1) to the amplitude comes from the region in which the virtualities of the gluons satisfy $\chi_{1,2}^2 \sim \mu^2$. It is thus clear that a correct calculation corresponds to a calculation with the "total" meson wave function.

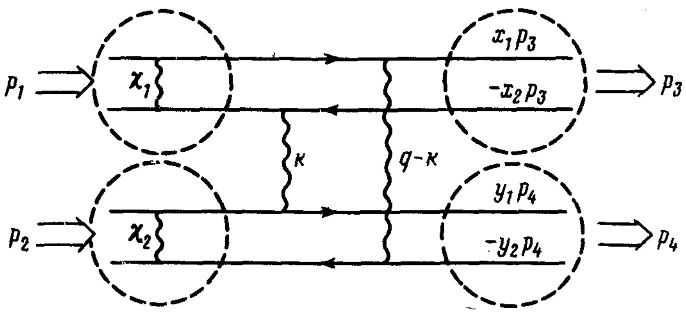

FIG. 1.

A similar situation arises in QCD in a calculation of the hadron form factors with a small momentum transfer. As was shown in Ref. 4, the duality approximation in the QCD sum rules simulates well the incorporation of the total hadron wave function, and it leads to fairly good results on the hadron form factors even at the perturbative level if the correction function is chosen appropriately. In the scattering problem in the region $s \gg |t|$, the Euclidean version of the sum rules is not applicable, but here one can use sum rules in an exclusive kinematics, which have proved successful in calculations on soft and semihard processes with heavy and light quarks.[5,6] We believe that the accuracy of these sum rules is slightly poorer (30–50% for light quarks) but completely acceptable for our purposes. Noting that if the correlation function is chosen correctly, and the leading parametric behavior is found even at the perturbative level,[5] we will not attempt to calculate the corrections to the leading contributions. We thus have a correct qualitative behavior of the amplitudes in the region $s \gg |t| \gtrsim 1\ \mathrm{GeV}^2$, which agrees with (1).

To calculate the $\rho\rho \to \rho\rho$ amplitude we consider the correlation function

$$K^{\mu\nu} = \int d^4x e^{ip_1x} \langle \rho_L(p_3)\rho_L(p_4)|J_\mu(x)J_\nu(0)|0\rangle, \tag{2}$$

where J_μ is the isovector component of the vector current. In lowest-order perturbation theory, the contribution to (2) which is the leading contribution in terms of s is determined by diagrams of the type in Fig. 2, with two-gluon exchange in the t channel. In Fig. 2, p_1 and p_2 are the momenta of the vector currents, p_3 and p_4 are the momenta of the ρ_L mesons, $q = p_3 - p_1$, $q^2 = t \simeq -\mathbf{q}_\perp^2$, and k is the integration momentum. It is convenient to carry out the calculations in terms of Sudakov variables $\tilde{p}_1 = p_1 - p_1^2 s^{-1} p_2$, $\tilde{p}_2 = p_2 - p_2^2 s^{-1} p_1$, writing all the vectors of the problem in the form $a = \alpha \tilde{p}_2 + \beta p_1 + a_\perp$. As a result of the calculations, we find

$$K^{\mu\nu} = \frac{is}{18\pi^2} \int \frac{d^2k_\perp}{\mathbf{k}_\perp^2(\mathbf{k}_\perp - \mathbf{q}_\perp)^2} [B^\mu(k_\perp) - B^\mu(k_\perp = 0)][B^\nu(k_\perp) - B^\nu(k_\perp = 0)], \tag{3}$$

$$B^\lambda = if_\rho(4\pi\alpha_s)\int_0^1 dx \frac{\phi(x)}{x(1-x)} \left[\frac{p_1^\lambda 2x(1-x) + (2x-1)(k_\perp^\lambda - xq_\perp^\lambda)}{p_1^2 - \dfrac{(\mathbf{k}_\perp - x\mathbf{q}_\perp)^2}{x(1-x)}} \right]. \tag{4}$$

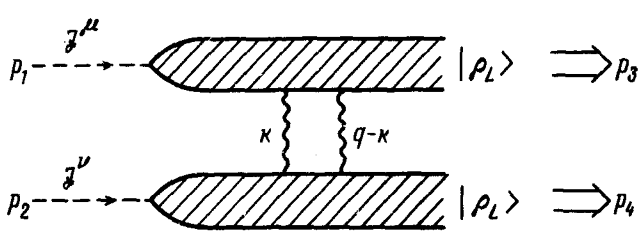

FIG. 2.

Here x is the fraction of the longitudinal momentum of the quark in the ρ_L meson, $\phi(x)$ is the wave function of the leading ρ_L twist, which was determined in Ref. 7, and $f_\rho \simeq 200$ MeV. In the case $p_{1,2}^2 = 0$, expression (3) becomes the result of Refs. 7 and 8.

Using (3) and working in the duality approximation, we can derive sum rules for the helicity amplitudes. We will omit the lengthy equations involved and simply summarize the results. For the region $s \gg |t| \gg \mu^2$ we find

$$A_{00}^{00} \to \frac{8}{9}\alpha_s^2 \pi s_0^{1,5}(st^{-2,5}), \qquad A_{00}^{+1\pm1} \to \frac{\pi\alpha_s^2}{30m_\rho^2} s_0^{2,5}(st^{-2,5}). \tag{5}$$

Here $s_0 \simeq 1.5$ GeV^2 is the duality interval of the ρ meson, and m_ρ is its mass. We see that (5) agrees parametrically with (1).

We wish to emphasize that the sum-rule method can be used not only to calculate the asymptotic behavior but also to construct a scattering amplitude over the wide region $|t| \gtrsim 1$. The contribution found as a result of these calculations is formally defined and finite for all t. Estimates show that the corrections become a key factor at $|t| \lesssim 1$ GeV^2 and that the results found at such values of t should not be taken seriously.[2)]

We thus reach the important conclusion that the spin-flip amplitudes not only do not decrease with increasing energy but are also unsuppressed in terms of powers of t in comparison with the amplitudes without spin flip. However, it can be seen from (5) that in this particular example there is a definite numerical suppression.

We note in conclusion that in the scattering mechanism which has been discussed here, which does not lead to additional suppressions, the flip of the hadron helicity occurs in the course of the hadronization of the partons and is not directly related to the existence of a mass of the light quarks. We have selected the $\rho\rho$ scattering process as the simplest one to illustrate the method. Preliminary estimates show that the amplitudes with helicity flip in NN scattering again do not decrease with increasing energy. These results will be published in detail separately.

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[1)] Incorporating such corrections can evidently lead to only an increase in the rate of growth of the amplitudes with s.

[2)] We believe that the scattering amplitude in this kinematic region is determined by a qualitatively different mechanism: the gluon components of the hadron wave functions. This question will be taken up in a separate paper.

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