Spin effects in large-angle meson-baryon scattering

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We remark that recent data on large-angle meson-baryon scattering at high energies are nicely accounted for by the massive-quark model and quark-geometrodynamic model developed a few years ago. In particular we reproduce the correct size and ρ-alignment properties of the reaction $\pi^- p \to \rho^- p$. We also predict a very small scattering cross section for the reaction $\pi N \to \pi\Delta$.

Large-angle hadron-hadron scattering at high energies has, for a long time, been given much attention, both experimental and theoretical, due to its important role in clarifying the dynamics of color interactions at very short distances.

The picture that emerges from the commonly accepted theory of strong interactions, quantum chromodynamics (QCD), is that, at large angles, the scattering amplitudes for hadron-hadron scattering are built from the convolution of short-distance hadronic wave functions (whose structure is intimately related to the dynamics of form factors) with the basic perturbative scattering amplitudes, which are dominated by single-gluon exchange.

It should be pointed out that, while this picture contains many aspects that are basically sound (and are in fact even more generally accepted), the possibility to neglect, even at short distances, the effects of confinement dynamics, and therefore to approximate the basic interaction with the exchange of a perturbative gluon, appears to be questionable. In particular, the development of a research strategy going from the massive-quark model (MQM) to the quark geometrodynamics (QGD) has been questioned all along.[1]

Without entering into a detailed discussion of the points of perturbative QCD that, in our opinion, are unsatisfactory, we would like to stress that in the analysis of the spin effects in high-energy large-angle hadron-hadron scattering, one can put to experimental test the perturbative assumption of single-gluon exchange. Indeed, one fundamental feature of the perturbative QCD interaction is the quark helicity conservation implied by the vector-gluon coupling when all masses are neglected, which predicts that at short distances the scattering amplitudes must obey the helicity-conservation rule

$$\lambda_a + \lambda_b = \lambda_c + \lambda_d \tag{1}$$

for all the processes $a + b \to c + d$ involving light mesons and baryons.[2]

On the other hand, if one follows the research strategy of the MQM and QGD model, Eq. (1) is, in general, not true, and even though one obtains qualitatively similar behaviors for the differential cross sections, one expects important differences when spin effects are considered. This is the case, for example, of proton-proton elastic scattering, where one observes a large value of the spin-spin asymmetry near 90°, which at the present energies is definitely in disagreement with Eq. (1) (Ref. 3).

The physics of large-angle scattering in the MQM/QGD framework has been discussed and analyzed in detail in a series of papers.[4–6] Based on our previous work we would like to make a few comments on two important reactions

$$\pi^- p \to \rho^- p \ , \tag{2}$$

$$\pi^- p \to \pi^- \Delta^+ \tag{3}$$

that are the object of experimental investigation at Brookhaven[7] and have the virtue of shedding further light on the important issue of the possible violation of the helicity-conservation relation (1).

The MQM/QGD approach, which is discussed at length in Ref. 1, displays many features of the naive quark model, but incorporates quark confinement explicitly. In this model we construct the helicity amplitudes for two-body reactions at large angles by considering a set of diagrams corresponding to either meson exchange [Fig. 1(a)] or to baryon exchange [Fig. 1(b)]. The building blocks of these

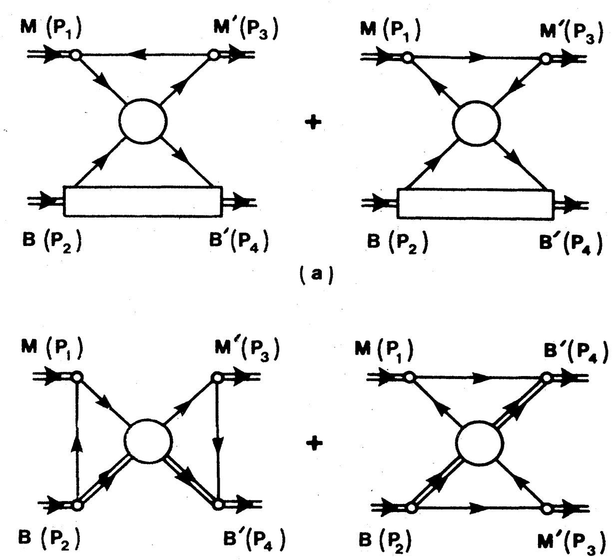

FIG. 1. Graphs contributing to large-angle meson-baryon scattering. (a) is the "meson exchange" and (b) is the "baryon exchange."

diagrams, which are, on the one hand, the vertex functions, and on the other, the quark-quark and quark-diquark scattering amplitudes have been explicitly given in Ref. 6. We will only report formulas which are relevant to the channels (2) and (3).

For the sake of completeness we first consider the elastic channel $\pi^- p \to \pi^- p$; the differential cross section will be given by

$$\frac{d\sigma}{dt}(\pi^- p \to \pi^- p) = \frac{N}{s^9}\ln^2\frac{s}{m_0^2}\left\{\cos^2\theta/2\left[\lambda\left(9\frac{1+\cos^2\theta/2}{\sin^3\theta}+\frac{2\sin^2\theta/2(2+\cos\theta)}{(1-\cos\theta)^3}\right)\right.\right.$$
$$\left.+\frac{6}{(1-\cos\theta)^{3/2}}-\frac{4(1+2\cos\theta-4\sin^2\theta/2)}{\sin^3\theta(1+\cos\theta)^{1/2}}\right]^2$$
$$+\sin^2\theta/2\left[\lambda\left(9\frac{1+\cos^2\theta/2}{\sin^3\theta}+\frac{\sin^2\theta}{(1-\cos\theta)^3}\right)+\frac{6}{(1-\cos\theta)^{3/2}}\right.$$
$$\left.\left.+\frac{4(1-2\cos\theta-4\cos^2\theta/2)}{\sin^3\theta(1+\cos\theta)^{1/2}}\right]^2+\frac{36\pi^2}{\ln^2(s/m_0^2)(1-\cos\theta)^3}\right\} . \tag{4}$$

This formula depends on two parameters N and λ, giving absolute (N) and relative (λ) normalization between diagrams of Figs. 1(a) and 1(b); m_0 is a typical hadronic mass; $m_0^2=2$ GeV^2. One could fix these constants from the existing $\pi^+ p \to \pi^+ p$ data at $p_{\rm LAB}=20$ GeV and $\theta \simeq 60°$,[8] which are rather accurate; it is worth stressing that, in view of our assumption, natural in any quark model, of SU(6) wave functions, this determination fixes N and λ for all the channels $MB \to M'B'$, with M,M' belonging to the **35** and B,B' to the **56** representation of SU(6). However, experimental uncertainties do not allow definite conclusions on the value of λ, even though data seem to favor large values of this parameter;[6] in any case, ρ-alignment properties of the reaction (2), to be discussed below, strongly suggest a large value of λ, thus we have fixed it to be $=10$, which leads to $N=0.75\times10^{-26}$ cm^2 GeV^{16}. In Fig. 2 we give our theoretical predictions for three different values of θ, $\theta=100°, 90°, 80°$ for the elastic channel.

Next we investigate the $\pi^- p \to \rho^- p$ channel; the differential cross section can be written as[9]

$$\frac{d\sigma}{dt}\equiv\sigma=\sigma_0+\sigma_++\sigma_- , \tag{5}$$

and a straightforward calculation of the diagrams in Fig. 1 gives the result:

$$\sigma_{0,+}=\frac{16N}{s^9}\ln^2\frac{s}{m_0^2}\left[\frac{\sin^2\theta/2}{\sin^6\theta}\left((1+\cos\theta)^{3/2}+(1+\cos\theta)^{-1/2}\mp\frac{3\lambda}{2}\sin^2\theta/2\right)^2\right.$$
$$\left.+\frac{\cos^2\theta/2}{\sin^6\theta}\left((1+\cos\theta)^{3/2}+(1+\cos\theta)^{-1/2}\pm\frac{3\lambda}{2}\sin^2\frac{\theta}{2}\right)^2+\frac{\pi^2}{\ln^2(s/m_0^2)(1-\cos\theta)^3}\right] , \tag{6}$$

$$\sigma_-=\frac{N}{s^9}\ln^2\frac{s}{m_0^2}\left\{\sin^2\frac{\theta}{2}\left[2\lambda\left(1+\cos^2\frac{\theta}{2}\right)\left(\frac{\cos\theta-4-6\cos^2\theta/2}{\sin^3\theta}+\frac{4+2\cos\theta}{(1-\cos\theta)^3}\right)+\frac{2\cos^2\theta/2-5-\cos\theta}{(1-\cos\theta)^{3/2}}+\frac{4}{\sin^3\theta(1+\cos\theta)^{1/2}}\right]^2\right.$$
$$+\cos^2\frac{\theta}{2}\left[2\lambda\left(1+\cos^2\frac{\theta}{2}\right)\left(\frac{3\cos\theta-6+2\sin^2\theta/2}{\sin^3\theta}+\frac{4\sin^2\theta/2}{(1-\cos\theta)^3}\right)\right.$$
$$\left.+\frac{5+\cos\theta-2\sin^2\theta/2}{(1-\cos\theta)^{3/2}}+\frac{4\cos\theta}{\sin^3\theta(1+\cos\theta)^{1/2}}\right]^2$$
$$\left.+\frac{\pi^2}{\ln^2(s/m_0^2)(1-\cos\theta)^3}[\sin^2\theta/2(5+\cos\theta-2\cos^2\theta/2)^2+\cos^2\theta/2(5+\cos\theta-2\sin^2\theta/2)^2]\right\} .$$

Our theoretical predictions are presented in Fig. 3 for $\theta=100°$, $90°$, $80°$ and $\lambda=10$. Let us now calculate the ratio

$$R=\frac{d\sigma(\pi^- p\to\rho^- p)}{d\sigma(\pi^- p\to\pi^- p)} . \tag{7}$$

At $P_{\rm LAB}=10$ GeV and $\lambda=10$ we find

$$R=0.11 \quad (\theta=80°) ,$$
$$R=0.41 \quad (\theta=90°) , \tag{8}$$
$$R=0.85 \quad (\theta=100°) ,$$

and these results are almost independent of $P_{\rm LAB}$ and λ for $P_{\rm LAB}\geq 10$ GeV/c and $\lambda\geq3$. Our result should be compared with the experimental value $R\simeq1$ with some uncertainties due to the background.[10]

We can make another comparison of our model with presently available data for the channel $\pi^- p\to\rho^- p$: preliminary results[10] give in the ρ helicity frame, an angular distribution of the type $\sin^2\tilde\theta\sin^2\phi$ ($\tilde\theta$ is the polar angle and ϕ is the azimuth of the charged pion produced in the ρ decay). It is easily shown that such an angular distribution is reproduced if σ_- in Eq. (6) is large as compared to σ_+ and

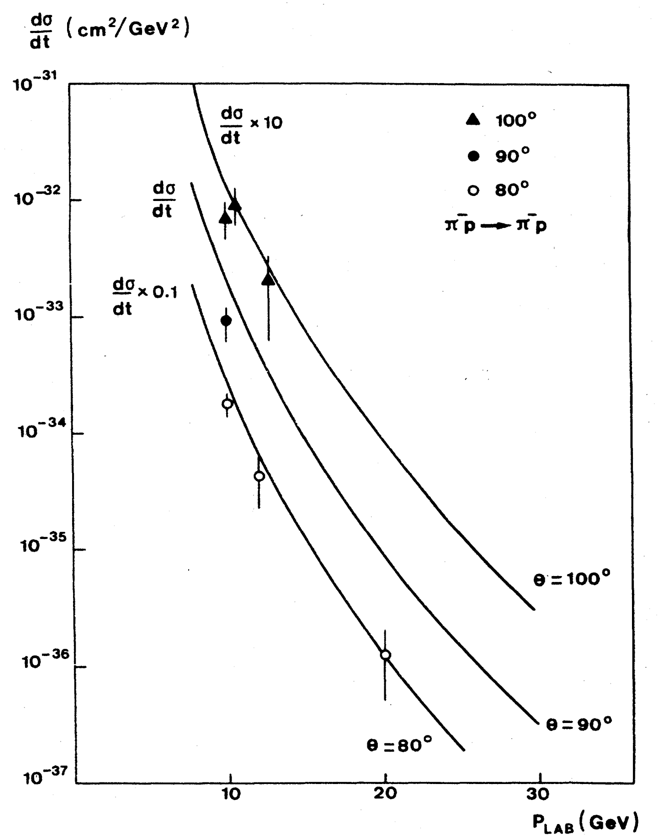

FIG. 2. Comparison of our predictions for $\pi^- p \to \pi^- p$ at large fixed angle vs laboratory momentum (data points are from Ref. 8).

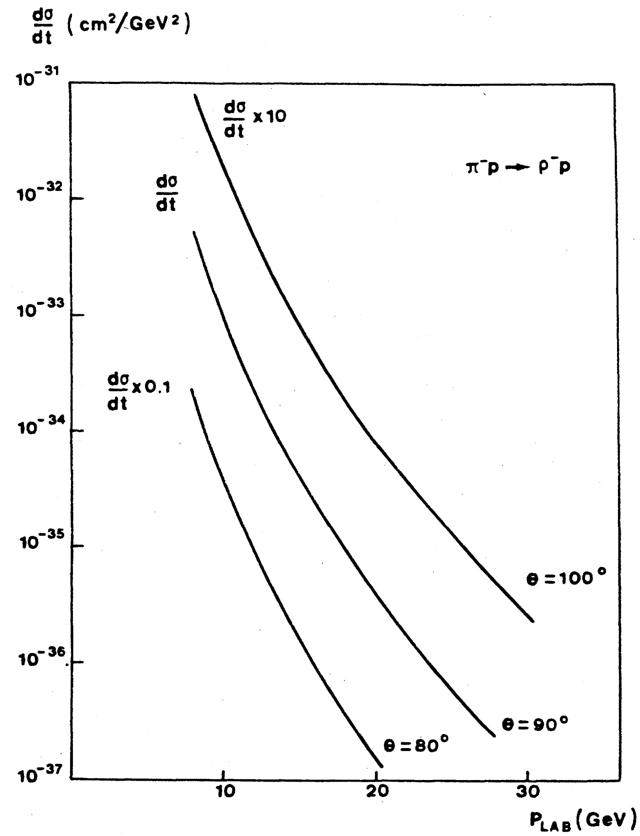

FIG. 3. Absolute predictions of our model for the reaction $\pi^- p \to \rho^- p$.

σ_0. In fact the angular distribution in the ρ region in terms of density matrix expansion is

$$\frac{d^2\sigma}{d\cos\tilde{\theta}\, d\phi} \sim \sigma_0 \cos^2\tilde{\theta} + \sigma_+ \sin^2\tilde{\theta}\cos^2\phi + \sigma_- \sin^2\tilde{\theta}\sin^2\phi - \sqrt{2}\sigma_{10}\sin 2\tilde{\theta}\sin\phi . \quad (9)$$

If we now evaluate our expression for σ_0, σ_+, σ_-, as well as σ_{10} (for its definition see Ref. 9) we find for $P_{\rm LAB} \gtrsim 10$ GeV and $\lambda = 10$

$$\frac{\sigma_0}{\sigma_-} = \frac{\sigma_+}{\sigma_-} = 0.12, \quad \frac{\sigma_{10}}{\sigma_-} = -0.02 \ , \quad (10)$$

in good agreement with the experimental results. Our findings are almost independent of λ for $\lambda \geqslant 3$, whereas they change drastically for smaller values of λ; for instance, when $\lambda = 1$ we would obtain $\sigma_0/\sigma_- = \sigma_+/\sigma_- = 0.94$ and $\sigma_{10}/\sigma_- = -0.15$ which disagrees with the experimental results. For the sake of comparison we might wonder what is the prediction of perturbative QCD, according to the helicity-conservation rule (1).

For the process $\pi^- p \to \rho^- p$ Eq. (1) implies that four helicity amplitudes will vanish and only $H_{0+,0+}$ and $H_{1-,0+}$ will remain; as a result $\sigma_+ = \sigma_-$ and the expected angular distribution will be of the type

$$\frac{d\sigma}{d\cos\tilde{\theta}\, d\phi} \sim 1 + a\cos^2\tilde{\theta} \ , \quad (11)$$

which seems to be inconsistent with presently available data.

Finally we consider the channel $\pi^- p \to \pi^- \Delta^+$; we limit our analysis to this particular channel because this reaction might be measured at the Brookhaven Alternating Gradient Synchrotron; on the other hand, other channels in $0^- \frac{1}{2}^+ \to 0^- \frac{3}{2}^+$, such as $\pi^- p \to \pi^+ \Delta^-$ and $\pi^- p \to K^+ Y^{*-}$, are suppressed in our model.[11]

The differential cross section at large angles is easily evaluated and it reads

$$\frac{d\sigma}{dt}(\pi^- p \to \pi^- \Delta^+) = \frac{8N}{s^9} \ln^2\frac{s}{m_0^2} \frac{1}{\sin^4\theta(1+\cos\theta)} \ . \quad (12)$$

Using the aforementioned value of N we find at $P_{\rm LAB} = 10$ GeV a very small cross section, i.e., $d\sigma/dt \sim 10^{-36}$ $\rm cm^2/GeV^2$ at $\theta = 90°$, which leads to the conclusion that all the large-angle high-energy two-body reactions with a $\frac{3}{2}^+$ baryon in the final state are suppressed in our model.

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[11]Explicit calculations (Ref. 6) show that also the $\pi^- p \rightarrow K^+ \Sigma^-$ channel, which is currently under study at Brookhaven, is suppressed in our model.