Dynamic model of amplitude with spin flip

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The parameter R in π^-p scattering at 40 GeV/c is calculated on the basis of a model in which a polarized proton is regarded as a "rotating" particle. The sign of the asymmetry is predicted for the $\pi(p, n)2\pi$ reaction on polarized protons.

The question of the possible dynamic interpretation of spin flip in strong interactions has not yet been considered. The spin terms of the scattering matrix are introduced phenomenologically either by adding a spin-orbit term to the central potential, or by introducing corresponding reggeon vertices. We describe below an illustrative model of an amplitude with spin "flip," based on parton concepts. It follows from this model that the spin effects in hadron-hadron scattering, which are connected with $(\sigma, \mathbf{l})$ interaction in first order (polarization, spin flip), should decrease with increasing energy not slower than $(\ln s)^{-2}$ to the line. The model leads also to other qualitative consequences that can be verfied at energies on the order of several GeV.

If it is assumed that both positive and negative parities are realized among the partons that make up the physical nucleon, then such configurations should have odd orbital angular momentum. For example, for a polarized nucleon, the combination

$$\text{physical nucleon } \frac{1}{2}^{(+)} = \text{parton } \frac{1}{2}^{(+)} + \text{parton } 0^{(-)}$$

has a unity orbital momentum $\mathbf{L}_z = \mathbf{r}_x \cdot \mathbf{r}_y = 1$, which has a 2/3 probability of being oriented along the z axis.[1)]

The oriented orbital angular momentum can be set in correspondence with an average polar momentum $\overline{\mathbf{p}_x} = \langle \mathbf{L}_z \cdot \mathbf{r}_{+y}/\mathbf{r}^2\rangle$, which lies in a plane normal to z and is directed tangentially to the orbit. Let us consider the scattering of a fast spinless particle by a polarized nucleon, corresponding to such a "rotating" combination of partons. As is well known, the amplitude M_1 with spin flip[2)] can be represented at large s and at small q in the form

$$M_1 = 2\pi i \int \{ f(+\rho, s) - f(-\rho, s) \} J_1(q\rho)\rho d\rho\,, \tag{1}$$

where $f(\pm\rho, s)$ are the partial amplitudes of particles having an impact parameter ρ and travel "on the right" $(+\rho)$ and "on the left" $(-\rho)$ of the center of the nucleon in the (x, y) plane (the spin is oriented along the z axis). How can the difference $f(+\rho, s) - f(-\rho, s)$ arise?

Since the parton density in the nucleon at rest is at any rate axially symmetrical with respect to the z direction, and therefore cannot depend on the sign of ρ in the (x, y) plane, the reason for the difference may be that on traveling "on the left" $(-\rho)$ the tangential momentum of the rotating partons is directed opposite to the incoming particle; $(-\rho)$ corresponds to $|j| = l - 1/2$, and when traveling "on the right" $(+\rho)$ the particle "catches up" with the parton. At large s and small q, when the contribution of the real part to the amplitude can be neglected, the value of $f(\rho, s)$ takes in the case of scattering of spinless particles, as is well known, the form[1]

$$f(\rho, s) = \frac{\sigma_0}{2\pi\gamma\eta} \exp\left[-\frac{\rho^2}{2\gamma\eta}\right], \tag{2}$$

where $\eta = (1/2)\ln(s/m)$ is the rapidity of the initial partons (colliding particles in the c.m.s.), and $\gamma = 4\alpha_p'(0) \approx 1\ (\text{GeV}/c)^{-2}\delta_0$ is the limiting value of the total cross section.

In our model, the parton corresponding to the polarized nucleon dissociates initially into two partons having unity orbital angular momentum. It is natural to assume that the average tangential momentum of the pair is $\mathbf{p}_x \approx \mathbf{p}_\perp \approx m$ ($p_\perp$ is the transverse momentum of the partons). Thus, the partners acquire in the c.m.s. respective rapidities $\eta_\pm = \eta_0 \pm \Delta/2$, where

$$\Delta = \frac{1}{2}\ln\frac{\sqrt{p_x^2 + m^2} + p_x}{\sqrt{p_x^2 + m^2} - p_x} \approx \frac{1}{2}\ln\frac{\sqrt{2} + 1}{\sqrt{2} - 1} \approx 1\,;$$

and the average distance between the partners in the (x, y) plane is determined by the condition $\overline{\Delta\rho} \approx 1/m$.

The collision of a spinless particle having an impact parameter $+\rho$ with a polarized nucleon can now be represented as the sum of its interaction with the slow partons, the "progeny" of the partner having a rapidity η_- and an impact parameter $\rho - 1/m$, and the "progeny" of the partner η_+ having an impact parameter $\rho + (1/m)$. In accordance with (2) we obtain for the imaginary part of $f(\pm\rho, s)$:

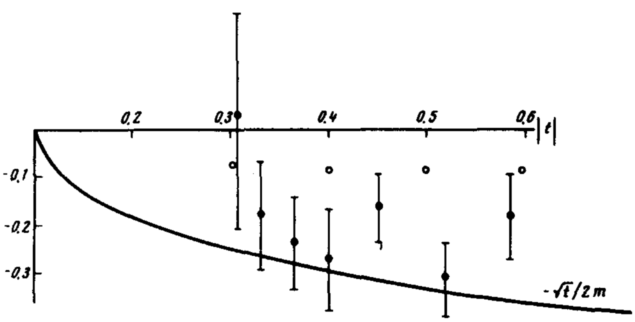

FIG. 1. The parameter R in π^-p at $p_\pi = 40$ GeV/c.

$$f(\pm\rho, s) = \frac{2\sigma_0}{3\cdot 4\pi\eta_{\mp}\gamma} \exp\left[-\frac{\left(\rho - \frac{1}{m}\right)^2}{2\gamma\eta_{\mp}}\right] + \frac{2\sigma_0}{3\cdot 4\pi\gamma\eta_{\pm}} \exp\left[-\frac{\left(\rho + \frac{1}{m}\right)^2}{2\gamma\eta_{\pm}}\right] \quad (3)$$

(the coefficient 2/3 is determined by the contribution of the oriented orbital angular momentum). At $q^2 \ll 1/2\gamma\eta$ and $\eta \gg 1$ we have accurate to terms $\sim\Delta^2$

$$M_1 = i\sigma_0 \frac{q}{2m} \frac{1}{m^2\gamma} \frac{\Delta}{\eta^2}; \qquad M_0 = i\sigma_0 \exp\left[-\frac{\gamma}{2} q^2 \eta\right]. \quad (4)$$

Thus, M_1 does not contain a P pole. This statement pertains to the "s" channel amplitude with change of helicity, which coincides asymptotically with M_1. The Pomeranchuk pole is contained in trivial fashion in the "t" channel amplitude, by virtue of its connection with M_0.[2]

Figure 1 shows the experimental data on the parameter R in $\pi^- p$-scattering at $p_L = 40$ GeV/c.[3] 3) The curve shows the values of R calculated from formulas (1) and (2), with M_1 averaged over two partons masses, 0.14 and 0.938.3) Accordingly, at $p_L = 40$ GeV we used the rapidities $\eta_0(\pi) = 4.1$ and $\eta_0 = 2.2$.

It was shown that the spin-orbit interaction $(\vec{\sigma}, \mathbf{l})$ of hadrons can be reduced, in the parton model, to orbit-orbit interaction $(\mathbf{L}, \mathbf{l})$. Thus, the presence of a strong amplitude M_1 can denote that hadrons with spin 1/2 have "rotation." This raises the question whether it is possible to observe in the reactions a transfer of tangential momentum, in analogy with the transfer of 4-momentum, charge, strangeness, etc. from one vertex to another.

Let us examine the reaction $\pi(p, n)2\pi$ by a polarized proton at $p_\pi \sim 2$ GeV/c from a point of view of the transfer of tangential momentum p from a nucleon vertex to a pion vertex. Some 70–80% of the $\pi(p, n)2\pi$ reaction at these energies goes via ρ-meson production, and the cross section of this reaction is well described by the reggeized one-pion exchange model[4] with allowance for the interaction of one of the pions with a neutron in the final state.

We choose the kinematic variables in such a way that they correspond to opposing motion of the incident pion and the virtual pion. In this case the direction of the neutron momentum should coincide in the laboratory system with the direction of the incident-pion momentum. If the proton is polarized and "rotation" is present, then the choice of the opposing kinematics means that the production of ρ proceeds predominantly in the shaded region (Fig. 2a) under the condition that the spin is directed away from the reader. This fact by itself still does not lead to asymmetry, since such a picture corresponds to allowance for only the one-pion-exchange diagram.

Asymmetry results from allowance for the interaction in the final states. What interacts with a neutron in the final state is predominantly a slow pion traveling at a large angle. This interaction becomes manifest in the

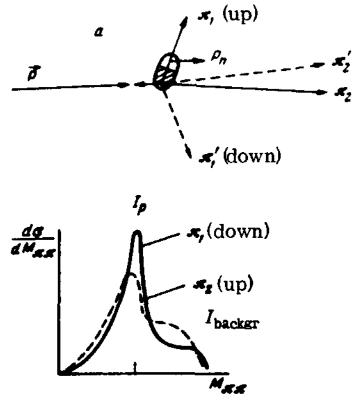

FIG. 2. Asymmetry in the reaction $\pi(p, n)2\pi$.

mass spectrum of the $\pi\pi$ system as an excess background outside the ρ-meson mass (Fig. 2b). As a result of the choice of the "opposing" kinematics, if there is a transfer of the tangential momentum, the neutron interacts predominantly with a slow pion that moves upward in our figure. On the basis of the described qualitative considerations we can expect the transfer of tangential momentum to lead to a definite sign of the asymmetry and the mass spectrum of the $\pi\pi$ system produced on a polarized proton, namely

$$\left(\frac{I_{\text{backgr}}}{I_\rho}\right)_{\pi_1(\text{up})} > \left(\frac{I_{\text{backgr}}}{I_\rho}\right)_{\pi_1(\text{down})},$$

or

$$\frac{(d\sigma/dM_{\pi\pi})_{\text{backgr}}}{(d\sigma/dM_{\pi\pi})_\rho} = A - BP[\mathbf{p}_0 \times \mathbf{p}_{\pi_1}] \quad A, B > 0.$$

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1)We put $\hbar = c = 1$ throughout.

2)In this article we use a scattering matrix expressed in terms of Pauli matrices: $M = M_0 + iM_1\sigma\mathbf{n}$ ($\mathbf{n}$ is a normal to the scattering plane).

3)At $p_L \gg m$, $q^2 \ll 4m^2$, and $m = 0.938$ GeV we have

$$R = -\frac{q}{2m} + \left(\sqrt{\frac{2q^2}{p_L m}} + 2\,\text{Re}\frac{M_1}{M_0}\right)\left(1 - \frac{q^2}{8m^2}\right)$$

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