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POLARIZATION PHENOMENA IN HARD HADRON SCATTERING AND STRONG INTERACTION AT LARGE DISTANCES

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Quantum chromodynamics (QCD) plays an important role in the modern theory of strong interaction. The hypotheses about colour quarks[1] and local gauge-invariance make the basis of QCD. The most important results in QCD are obtained for the processes where an approximate separation of long and short distances is achieved. However, there are some troubles in QCD for elastic hadron-hadron scattering and polarization phenomena. For example, QCD models lead to a zero value for the polarization parameter. This difficulty is essential. Really, the vector interaction in QCD leads to the scattering amplitude which obeys the γ_5 -invariance[3] for the massless-quark limit. In this case the polarization is zero. When we take into account the quark masses, a small polarization $\mathcal{P} \sim m_q/\sqrt{|t|}$ is possible in contradiction with the experiment. Most models of hard scattering obey the γ_5 -invariance at short distances. So, the polarization is zero in these models.

We want to emphasize that in high-energy large-angle scattering one must take into account soft rescatterings which occur at the same collision. The following physical picture of scattering is true for every hard scattering model. Soft rescatterings of particles take place before and after a hard scattering process[4]. These effects of long distances caused by particle interaction in initial and final states lead to a large polarization at finite energies[5] for every γ_5 -invariant model.

In this paper, following ref.[5] we thoroughly investigate the spin effects in large-angle pp -scattering. As a result, we explain the behaviour of different spin correlation functions and obtain the information about the properties of hadron interaction at short distances.

Consider the elastic hadron scattering at large angles. The investigation of these processes is not possible in QCD in a model-independent way. In QCD diagrams describing the hard scattering are some nonplanar graphs with "pinch" singularities[6,7]. They have quark masses as dimensional parameters. If the contribution of these diagrams to the scattering amplitude is sufficiently small, the dimensional parameters are unimportant in the asymptotic region. As a result, the scattering amplitude obeys the γ_5 -invariance.

Below we shall use the following representation for the γ_5 -invariant asymptotical amplitude of large-angle pp -scattering[4]:

$$T_{as}(s,t) = V(s,t)\,\gamma_\mu^{(1)}\gamma^{\mu(2)} + A(s,t)(\gamma_5\gamma_\mu)^{(1)}(\gamma_5\gamma^\mu)^{(2)}, \tag{1}$$

where $V(s,t)$ and $A(s,t)$ are vector-vector and axial-axial parts of interaction, respectively. Other matrix structures in the NN -scattering amplitude[8] are not γ_5 -invariant. They must be suppressed as a power of s with growing energy.

It is easily seen that amplitude (1) leads to the following asymptotic forms of the helicity proton-proton scattering amplitude:

$$\begin{aligned}
\Phi_1(s,t) &= \langle ++|++\rangle = 2[V(s,t)+V(s,u)-A(s,t)-A(s,u)];\\
\Phi_3(s,t) &= \langle +-|+-\rangle = (1+\cos\theta)[V(s,t)+A(s,t)];\\
\Phi_4(s,t) &= \langle +-|-+\rangle = -(1-\cos\theta)[V(s,u)+A(s,u)];\\
\Phi_2(s,t) &= \langle ++|--\rangle \equiv 0\ ;\ \Phi_5(s,t) = \langle ++|+-\rangle \equiv 0.
\end{aligned} \tag{2}$$

As a result of γ_5 -invariance, at short distances the amplitude Φ_5 and polarization are zero.

A consistent calculation of long-distance contributions[4,5] to the hard scattering amplitude can be done on the basis of the Logunow-Tavkhelidze quasipotential method. It leads to the preasymptotic corrections of orders $1/p$, $1/p^2$ and so on where p is the c.m.s. momentum of colliding particles. For the helicity amplitudes we have

$$\Phi_{i\,(i=1,3,4)}(s,t) = \Phi_i^{(0)}(s,t) + \frac{1}{p}\Phi_i^{(1)}(s,t) + \frac{1}{p^2}\Phi_i^{(2)}(s,t) + \dots, \tag{3}$$

where $\Phi_i^{(0)}$ is the asymptotic term (2) $\Phi_i^{(1,2)}$ are first-and second-order corrections to the leading contribution. These corrections contain the contributions of long distances. They were calculated and summed up in[5], where one may find their explicit form.

The correction terms contain the hadron masses and other dimensional parameters, which leads to the violation of γ_5 -invariance of interaction at finite energies. It can be shown that this effect leads to the spin-flip amplitude of the order m_N/p [5].

We shall consider a particular example with $V(s,t)$ and $A(s,t)$ in (1) that obey the dimensional quark-counting rule (9). They have a power behaviour in t and u variables:

$$\begin{aligned}
V(s,t) &= \frac{1}{s^5}\left(B_1\left|\frac{s}{t-d}\right|^{n_1} + B_3\left|\frac{s}{u-d}\right|^{n_3}\right),\\
A(s,t) &= \frac{1}{s^5}\left(B_2\left|\frac{s}{t-d}\right|^{n_2} + B_4\left|\frac{s}{u-d}\right|^{n_4}\right).
\end{aligned} \tag{4}$$

In (4) an approximate consideration of higher-order corrections to the hard part of interaction is achieved by the parameter d . We obtain the following expression for the helicity-flip amplitude

$$\begin{aligned}
\Phi_5(s,t) = \frac{e^{2i\chi(0)}}{s^5}\sqrt{1-\cos^2\theta}\,\Big\{&B_1\Big[\left|\frac{s}{t-d}\right|^{n_1} - \left|\frac{s}{u-d}\right|^{n_1}\Big]F(n_1)\\
&+ B_2\Big[\left|\frac{s}{t-d}\right|^{n_2} - \left|\frac{s}{u-d}\right|^{n_2}\Big]F(n_2) + B_3\Big[\left|\frac{s}{t-d}\right|^{n_3} - \left|\frac{s}{u-d}\right|^{n_3}\Big]\times\\
&\times F(n_3) + B_4\Big[\left|\frac{s}{t-d}\right|^{n_4} - \left|\frac{s}{u-d}\right|^{n_4}\Big]F(n_4)\Big\},
\end{aligned} \tag{5}$$

where the function

$$F(n) = \frac{m_N}{2p} + \frac{2m_N}{ip^2}(n-1/2)a \tag{6}$$

contains the preasymptotic contributions. The coefficient a and the eikonal factor $\exp(2i\chi(0))$ depend on the soft part of interaction. As a result, for the hadron interaction in initial and final states we obtaine the helicity-flip amplitude Φ_5 of the order m_N/p . It can be shown that the polarization for different models of hard scattering at $p_L \sim$ 10 GeV is 10 - 40%[5] and decreases with energy as $1/s$.

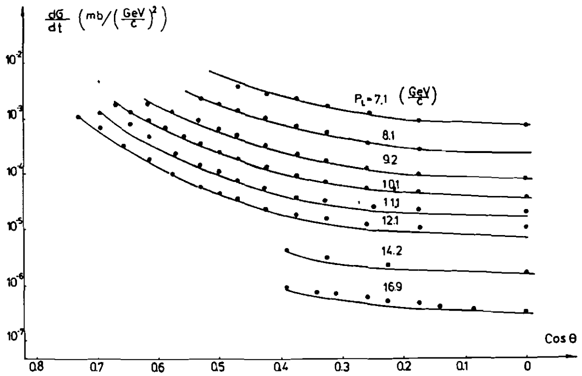
The calculations show that the long-distance effects don't change the amplitude Φ_2 which is equal to zero as in the asymptotic limit (2).

The experimental information about pp -polarization at large angles at p_L = 28 GeV[10] permits us to determine the form of hard part of the scattering amplitude. To solve this problem, we use experimental data for $d\sigma/dt$ at cos $\theta \lesssim$ 0.7 and $p_L <$ 7 GeV[11], for the polarization at P_L = 28 GeV, for spin correlation parameters A_{LL} at P_L = 11.75 GeV /12/ and $A_{NN}(90^o)$ at $P_L > 6$ GeV /13/.

Only the hard part of interaction was fitted when we analysed the experimental data. The soft part which determines the preasymptotic effects to the helicity amplitudes (3,5) was fixed on the basis of the small-angle scattering analysis. So, this does not lead to additional freedom in the scattering amplitude.

The best description of the experimental data was obtained for the following values of parameters in (3)

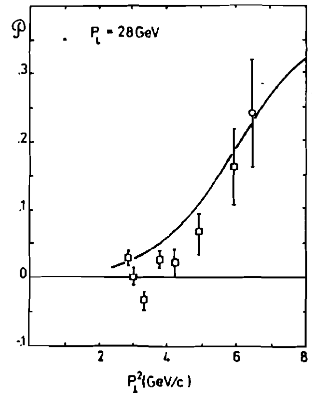
$$B_1 = -[162{,}3 \pm 14]\,(GeV^2)^4 \qquad n_1 = 4$$
$$B_2 = [8235 \pm 94]\,(GeV^2)^4 \qquad n_2 = 1$$
$$B_3 = [1586 \pm 300]\,(GeV^2)^4 \qquad n_3 = 1$$
$$B_4 = [1938 \pm 260]\,(GeV^2)^4 \qquad n_4 = 2$$
$$d = (2{,}5 \pm 0{,}1)\,(GeV^2)$$



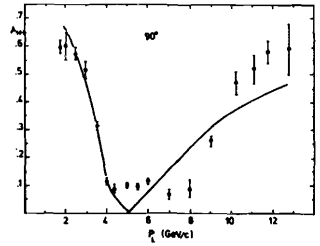
F i g. 1. Differential cross-section of pp -scattering.

Theoretical curves for differential pp -cross-sections at large angles are shown in fig. 1. The obtained results for polarization and $A_{NN}(90^o)$ are presented in figs. 2,3. The polarization at P_L = 28 GeV^2 and $\theta_{cm} = 55^o$ is of order 35%.

We want to note that the preasymptotic terms of the scattering amplitudes are approximately equal to the main asymptotic term at P_L = 5GeV. As a result, they compensate leading contribution to ϕ_3 at $P_L \sim 5$ GeV and $\theta = 90^o$. This leads to a dip at $A_{NN}(90^o)$ in this energy region (fig.3). At lower energies the behaviour of $A_{NN}(90^o)$ is determined by preasymptotic terms. It is interesting that the theory predictions are in accordance with experiment at very low energies $P_L \sim 2$ GeV (fig. 3).



F i g. 2. Description of pp - polarization at P_L = 28 GeV

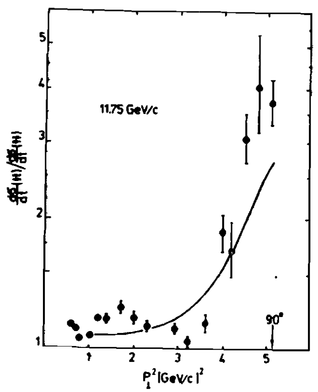


F i g. 3. Energy dependence of $A_{NN}(90^o)$.

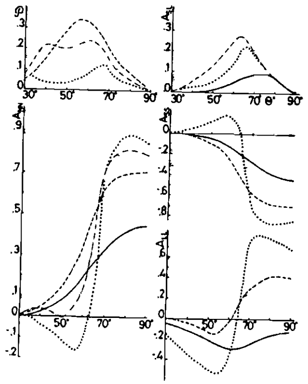
In fig. 4 the ratio of cross sections with parallel and antiparallel spins is shown. The obtained angular and energy dependences of different spin-correlation parameters at P_L from 12 GeV to 100 GeV are plotted in fig.5. A rapid change of A_{SS}, A_{LL}, A_{NN} at $\theta \sim 60^o$ is connected with the zero asymptotic amplitude ϕ_3. The preasymptotic terms smooth this effect at low energies. Like the polarization, the parameter A_{SL} is determined by the preasymptotic effects and decreases with energy as $1/\sqrt{s}$.

So the dynamical mechanism which is connected with the long-distance effects discussed here leads to important conclusions about the energy dependence of spin-correlation functions. The functions A_{SS}, A_{LL}, A_{NN} must go to their nonzero asymptotic limits when $s \to \infty$. At the same time the polarization and A_{SL} must decrease with energy as

$$\mathcal{P} \sim 1/s \; ; \; A_{SL} \sim 1/\sqrt{s}.$$



F i g. 4. The obtained ratio for cross-sections with parallel and antiparallel spins.

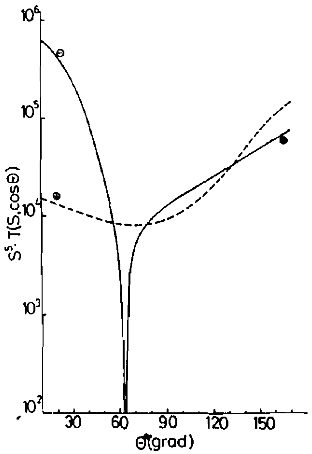


F i g. 5. Predictions for the energy dependence of spin correlation functions A_{SS} , A_{SL}, A_{LL}, A_{NN} and polarization at —·P_L= 12 GeV; ---- - P_L = 28 GeV; —·— - P_L = 50 GeV; ····· - P_L= 100 GeV.

The large-angle polarization experiments in pp- scattering at sufficiently high energies are needed in order to check these predictions.

The information about the form of asymptotic terms of vector-vector and axial-axial parts of pp interaction at short distances can now be obtained; they are shown in fig.6. The vector-vector part of interaction is largest near $\theta \sim 0^\circ$. In this case the hard parts of helicity amplitudes ϕ_1 and ϕ_3 are approximately equal at $\theta \sim 0^\circ$ to each other in accordance with experiment. This vector-vector part of interaction has zero at $\theta \sim 60^\circ$. This leads to zero of the helicity amplitude ϕ_3 that was discussed above.

The obtained hard part of interaction explains all physical effects in large angle pp -scattering with taken into account preasymptotic corrections caused by the soft rescattering of hadrons in initial and final states. So, such a behaviour of vector-vector and axial-axial parts of interaction shown in fig.6 should take place in all realistic γ_5 -invariant models of hard hadron scattering including QCD.



F i g. 6. Asymptotic angular dependences of hadron interaction at short distances:
—— - vector-vector part at interaction,
--- - axial-axial part of interaction.

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Голоскоков С.В., Кулешов С.П., Селюгин О.В.   E2-86-383
Роль взаимодействия на больших расстояниях
в поляризационных эффектах в жестком рассеянии адронов

Показано, что учет в жестком рассеянии адронов эффектов больших расстояний позволяет количественно объяснить поведение поляризации и спиновых корреляционных параметров в pp-рассеянии на большие углы. Извлечена информация о свойствах вектор-векторной и аксиал-аксиальной частей взаимодействия протонов на малых расстояниях при высоких энергиях. Сделан вывод, что такие условия зависимости должны получаться во всех реалистических γ_5-инвариантных моделях жесткого столкновения адронов, в том числе и в КХД.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Goloskokov S.V., Kuleshov S.P., Seljugin O.V.   E2-86-383
Polarization Phenomena in Hard Hadron Scattering
and Strong Interaction at Large Distances

It is shown thaz making allowance for the large-distance effects hard hadron scattering provides a quantitative description of the polarization behaviour and of spin-correlation parameters in large-angle pp-scattering. The information about vector-vector and axial-axial parts of proton-proton high-energy interaction at small distances is obtained. The conclusion has been drawn that such conditions of dependence could take place in all realistic γ_5-invariant models of hard hadron scattering including QCD.

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

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