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EFFECTS OF THE REAL PART OF HIGH ENERGY ELASTIC NUCLEON-NUCLEON SCATTERING

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The behaviour of the differential cross sections and polarization in the range of the diffraction structure was obtained by the model analysis of the high energy amplitude of proton-proton and proton-antiproton scattering. A number of new effects, depending on the behaviour of the real part of the scattering amplitude with t and s are predicted.

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

Эффекты вещественной части амплитуды высокоэнергетического нуклон-нуклонного упругого рассеяния

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На основе модельного анализа амплитуды высокоэнергетического протон-протонного и протон-антипротонного упругого рассеяния получено объяснение поведения дифференциальных сечений и поляризации в области дифракционной структуры. Предсказывается ряд новых эффектов, зависящих от поведения вещественной части амплитуды рассеяния по t и s.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

A great amount of experimental and theoretical researches of high energy elastic proton-proton and proton-antiproton scattering at small angles/1/ provide a rich information on these processes, which allows us to narrow the circle of examined models and at the same time to set a number of difficult problems which are not yet solved concerning mainly the energy dependence of number of characteristics of these reactions.

So the dependence of the polarization on energies s at different transfer momenta remains unclear. It is known that QCD predicts the disappearance of the spin-flip amplitudes at sufficiently large energies. However, experimentally, polarization turns out to be large/2/ at least in the range of the diffraction minimum at p_L = 200 and 300 GeV and it does not disappear probably with growing energy/3, 4/. Some models/5/ lead to spin effects which do not disappear as $s \to \infty$. It has been shown in [6] that there is the possibility of obtaining such amplitudes in the framework of QCD.

Whether the hypothesis of geometrical scaling[7] is fulfilled or violated is not yet established. In the energy range of ISR the experiment shows the value of the correlations following from the hypothesis but in the energy range of SPS there occurs its large violation.

In mainly aspects these questions are connected with the dependence of the spin-non-flip phase of hadron-hadron scattering on s and t. Most of the models define the real part of the scattering amplitude phenomenologically. Some models make use of the local dispersion relations[8] and the hypothesis of geometrical scaling. As is known, with the use of some simplifying assumption, the information about the phase of the scattering amplitude can be obtained from the experimental data at small momentum transfers where the interference of the coulomb and hadron amplitudes takes place. On the whole, the obtained information confirms the dispersion relations, with the exception of the recent data at $\sqrt{s} = 900$ GeV. On the base of these recent data in [9] the conclusion is drawn that, if the data are correct, the large magnitude of the real part of the scattering amplitude can be explained in the frame work of the hypothesis of the odderon[10].

More complicated is the question about the dependence of the phase of the scattering amplitude on t. It is shown in [11] that a consistent description of the experimental data in the range of ISR and SPS can be obtained in the case of rapidly changing phase, when the real part of the scattering amplitude grows quickly in the range of small t and becomes dominating. In the conventional picture of the scattering of hadrons the real part manifests itself in the range of the diffraction minimum where it defines the magnetude of the differential cross sections. The essentially different energy dependence of the differential cross sections of proton-proton and proton-antiproton scattering from $p_L = 50$ GeV up to $p_K = 1850$ GeV was considered in [12] as the proof of the hypothesis of odderon.

In this work we show that the existing experimental data, without the point $\rho(t=0) = 0.24$ at $\sqrt{s} = 900$ GeV, can be understood in the framework of the ordinary picture with the real part defined by the local despersion relations. Then we consider a number of consequences which can be verified in the future experiments.

In[13-15] the dynamic model of hadron-hadron interaction with a small number of free parameters and of additional hypotheses was developed. It permits us to quantitatively reproduce a wide set of the experimental data and to predict a number of physical effects, for example, the position of the diffraction minimum of πp-scattering, confirmed experimentally. The model takes into account the contribution of surrounding hadron quark-antiquark pairs to the scattering amplitude. In the framework of this model we can carry out the calculation of the asymptotic spin-flip amplitudes. They have the same asymptotics as the spin-non-flip amplitudes. The efficiency of the model was shown in/16/ for the process of charge exchange $\pi^- p \to \pi^\circ n$. The calculated spin flip amplitudes of this process agree sufficiently well with the amplitudes reconstructed by the model-independent approach/17/ form the experimental data.

It should be noted that the Born terms of the spin-flip and spin-non-flip amplitudes have the zero relative phase, so the amplitudes calculated in the model of elastic scattering are purely imaginary. The real part of these amplitudes appears only when the energy dependence of the effective mass and interaction radius is considered, for which we have used the local dispersion relations. The change of the phase appears between the spin-flip and spin-non-flip amplitudes when rescattering is taken into account. As a result, polarization will arise in the hadron-hadron scattering, especially significant in the range of the diffraction minimum where it has a large negative magnitude up to superhigh energirs in all hadron-hadron reactions we have investigated.

The leading and $I/\sqrt{s}$ terms of the spin-flip and spin-non-flip amplitudes were taken into account for the description of the experimental data. The asymptotic terms are $s \to u$ crossing-symmetric, which leads to the equality of the physical value for particles and antiparticles at sufficiently high energies. The difference of results in the preasymptotic range is connected with the role of the $I/\sqrt{s}$ terms.

It should be noted that the contribution of the $I/\sqrt{s}$ terms is most noticeable in the real part of the scattering amplitude because the real part of the asymptotic term is small. In the following we regard a number of the physical effects defined by Re T (s, t).

In/18/ is shown that in the framework of the model the change of differential cross sections in the range of the diffraction minimum of pp- and $p\bar{p}$-scattering is defined entirely by the real part of the scattering amplitude. Thus the magnitude of the real part at $t \cong -1.5$ GeV is connected in the model with its magnitude at $t = 0$ GeV, then at $p_L = 50$ GeV the real part of the $p\bar{p}$-scattering is near zero and we have a sharp diffraction minimum. In the case of pp-scattering at this energy the real part is essentially enlarged by the contribution of $I/\sqrt{s}$ terms and in the differential cross sections we have a "shoulder". At $p_L = 1850$ GeV the real part of $p\bar{p}$-scattering is larger than that of pp-scattering, and accordingly the diffraction minimum is less seen. The same picture appears in experiments.

This explanation of the experimental picture shows that the $I/\sqrt{s}$ terms of the scattering amplitude give a noticeable contribution at ISR energies. Experimentally observed change of the ratio of particle and antiparticle cross sections, especially large near the diffraction minimum, is defined entirely by the $1/\sqrt{s}$ terms in this energy range. And, accordingly, that effect is not connected with the contribution of the odderon.

From our view point an approximate fulfillment of the relation following from the hypothesis of geometrical scaling

$$B(0)/\sigma_{tot} \cong \text{const}; \quad d\sigma/dt\,(2-\max)/\sigma^2_{tot} \cong \text{const}.$$

is due to the fact that these constants decrease for falling $1/\sqrt{s}$ terms and increase for the asymptotic amplitudes. If we have for the asymptotic amplitudes the exact fulfillment of geometrical scattering, then these relations must strongly break in the range of ISR; thus the $1/\sqrt{s}$ terms give a sufficiently large contribution in this energy range. Naturally, these relations must break when $1/\sqrt{s}$ terms disappear, which we can see from the experimental data obtained at SPS.

Further information about the change of the real part of the spin-non-flip scattering amplitude can be obtained from the research of the energy dependence of the polarization in these reactions in the range of the diffraction minimum.

$$P = -2\,\frac{\text{Im}\,T_{nf}(s,t)\,\text{Re}\,T_f(s,t) - \text{Re}\,T_{nf}(s,t)\,\text{Im}\,T_f(s,t)}{T^2_{nf}(s,t) + 2T^2_f(s,t)}\,. \tag{1}$$

The asymptotic spin-flip amplitude calculated in the model is crossing-symmetric and slowly changes with t. $\text{Im}T_{nf}(s,t)$ changes in sign in this range. $\text{Im}T_f(s,t)$ is a slowly changing function of s and t, roughly equal for pp- and $p\bar{p}$-scattering therefore it can be shown from the comparison of the model results with the experimental data that the contribution of the $1/\sqrt{s}$ terms becomes sufficiently small when $p_L > 100$ GeV. This result follows from the analysis of the experimental data carried out in/3/. Thus, the difference in the energy dependence of the polarization of pp- and $p\bar{p}$-scattering will mainly be defined by the change of the real part of the spin-non-flip amplitude of these reactions.

The calculated polarization of pp- and $p\bar{p}$-scattering at different energies and the existing experimental data are shown in fig. 1(a,b,c,d). As is seen from fig. 1, the curve quite well reproduces the experimental data on proton-proton scattering. There are no avaiable experimental data on the proton-antiproton scattering in this energy range.

The model predicts that at superhigh energies the polarization effects of particles and antiparticles are the same, whereas at smaller

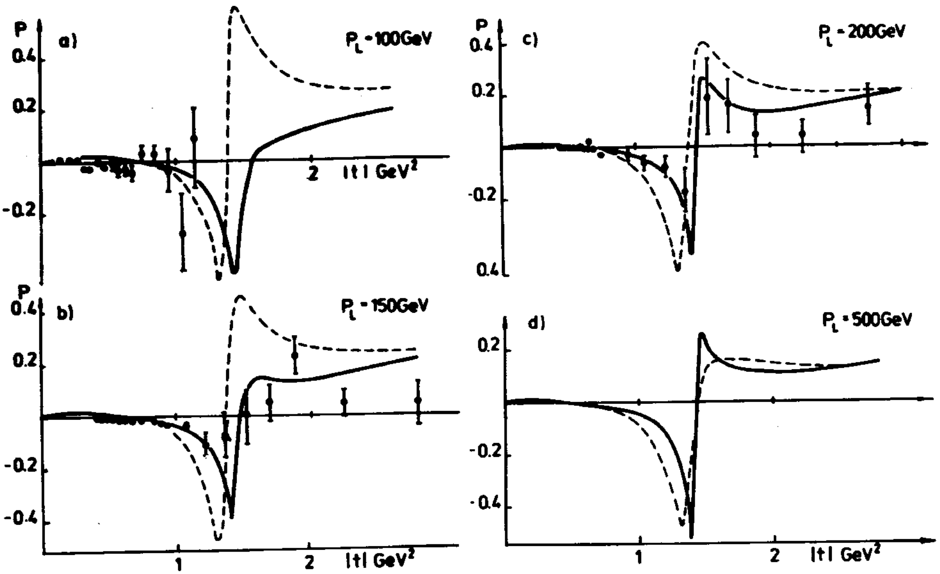

Fig.1. The polarization of the proton-proton (solid curves) and the proton-antiproton (dashed currves) scattering a) 100 GeV, b) 150 GeV, c) 200 GeV, d) 500 GeV.

energies they are essectially different. The largest difference of the polarization of pp- and $p\bar{p}$-scattering is in the range of the diffraction minimum at $p_L = 100$ GeV. Here the polarization of proton- antiproton scattering amounts to 60% at $t = -1.45$ GeV^2. The polarization of proton-proton scattering is near zero and the experimental data at $p_L = 150$ GeV confirm this. The reason is that the real part of the spin-non-flip amplitude of the proton-antiproton scattering changes in sign in the range of the diffraction minimum and the second term of (1) increases essentially the magnitude of the polarization. The polarization of proton-proton scattering is decreased behind the diffraction minimum by the negative contribution of the second term of (1). This difference gets smaller with growing energy. Thus the model predicts the same behavior of the polarization of pp- and $p\bar{p}$-scattering up to the diffraction minimum and the different behavior after it, where the polarization of pp-scattering increases, going to an asymptotic value from below, whereas the polarization of $p\bar{p}$-scattering is going to it from above.

The energy dependence of the polarization of pp- and $p\bar{p}$-scattering is shown in figs. 2 and 3 at $t = -0.2$ GeV^2 and $t = -2.0$ GeV^2. It can be seen that the polarization in the range of small transfer momenta is small though one can observe the difference in the polarization of pp- and $p\bar{p}$-scattering in the range $p_L = 100 \div 200$ GeV. At $t = 2.0$ GeV^2

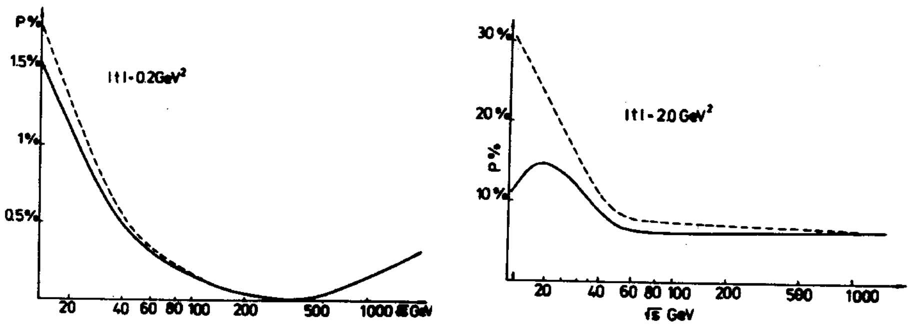

Fig. 2. The dependence of the polarization of the proton-proton (solid curves) and the proton-antiproton (dashed currves) scattering with s at a) $t = -0.2$ GeV^2, b) $t =$ $= -2.0$ GeV^2.

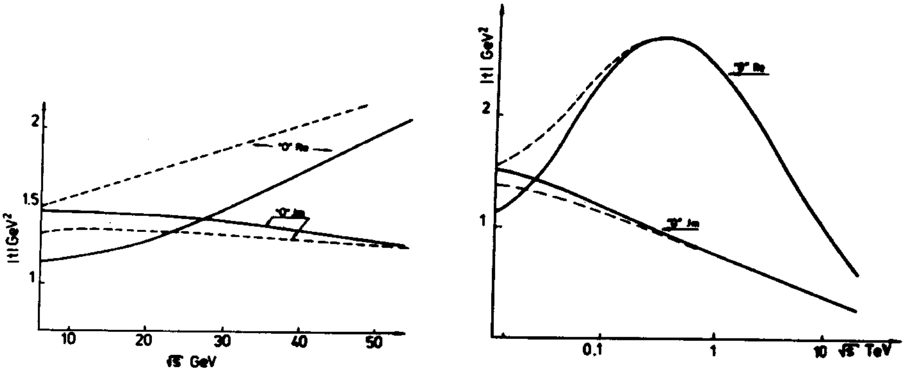

Fig. 3. The dependence of the "zeros" of the real and imagin part of the spin-non-flip amplitude of the proton-proton (solid curves) and the proton-antiproton (dashed currves) scattering with t and s.

the difference in the polarization of pp- and $p\bar{p}$-scattering is sufficiently large and it can be observed in a more wide energy interval.

The change of "zeros", when the real and imaginary parts of pp- and $p\bar{p}$-scattering change in sign, is shown in fig. 3. As is seen, "zeros" of the real and imaginary parts of pp-scattering coincide at $p_L \cong$ $\cong 400$ GeV where the sharp diffraction minimum exists, but for $p\bar{p}$-scattering this picture is not observed. Thus, we see that the sharp form of the diffraction minimum of pp-scattering in a wide energy region is due to two reasons: — the decrease in the real part at $t = 0$ and the coincidence of "zeros" of the real and imaginary parts of spin-non-flip amplitude. In the range of superhigh energies, "zeros" of the real and imaginary parts draw together and at energy $\sqrt{s} = 20$ TeV again a pronounced diffraction minimum must be seen for pp- and $p\bar{p}$-scattering experimentally.

Thus, many peculiarities of the differential cross sections and the polarization of pp- and $p\bar{p}$- elastic scattering can be understood from a unique viewpoint. No additional hypotheses such as the hypothesis of the odderon should be introduced. Our model predicts a number of new effects, on the whole dependent on the change of the real part of the scattering amplitude with s and t. It is shown that the information about the energy dependence of the real part of the scattering amplitude can be obtained from the experiments at superhigh energies in the range $t \cong 1.5$ GeV^2 and also from the investigation of the polarization at $p_L = 100 \div 200$ GeV.

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