Spin effects in elastic scattering in the region of large momentum transfer

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The importance of taking into account the spin degrees of freedom in order to understand effects in the region of large values of t is discussed.

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Recent experiments in which polarization effects were studied have shown that these effects cannot be regarded as negligible at currently available energies. The most interesting result[1] was obtained in the experiments using the AGS, where in studying the pp scattering an increase in the polarization parameters was observed with increasing momentum transfer.

An analysis of the experimental data on elastic scattering of hadrons at high energies using relations that take into account the spin of the interacting particles[2,3,5] shows that spin effects play an important role in the region of small momentum transfer,[2] where the properties of the asymptotically dominant (vacuum) contribution to the amplitude are evident, and in the region of values of $|t| > 1$ GeV^2.

This paper is devoted to the discussion of the role of the spin degree of freedom in elastic scattering of hadrons in the region of large values of the square of the momentum transfer.

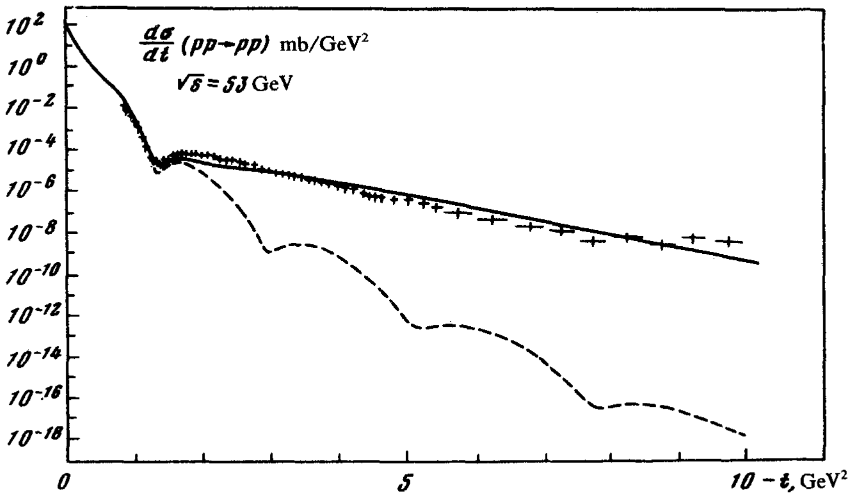

Fig. 1. Differential cross section of elastic pp scattering at $\sqrt{s} = 53$ GeV. The solid curve describes the differential cross section with allowance for the spin structure of the amplitude[3] and the dashed curve does not take into account the amplitudes with double helicity flip.

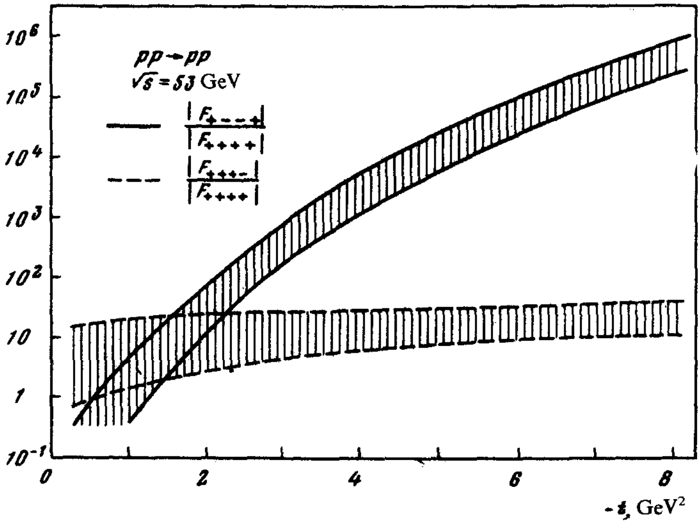

Fig. 2. The range of variation of the ratios of amplitudes with a helicity flip to those without such a flip.

Although the main source of experimental information are the direct polarization studies, certain interesting conclusions can be made on the basis of the analysis of angular distributions data. It is known that lack of experimental evidence of the second minimum in the angular distributions of *pp* scattering to $|t| = 10\ \mathrm{GeV}^2$ at ISR energies is inconsistent with the conclusions of most of the models that describe elastic scattering. It appears that by allowing for the spin of the interacting protons[3] we can go over from a picture of the distribution with a characteristic sequence of maxima and minima to a dependence that is observed experimentally (Fig. 1). Analysis[3] of *pp* scattering by the method of the generalized scattering matrix[4] leads to the following conclusions.

1. The amplitudes without a helicity flip F_{++++}, F_{+-+-} and the amplitude with a single helicity flip F_{+++-} have a characteristic sequence of maxima and minima and are close in absolute value in the entire region of momentum transfer $0 \leqslant |t| \leqslant 10\ \mathrm{GeV}^2$ (Fig. 2).

2. The amplitudes with a double helicity flip F_{++--} and F_{+--+} are small compared to those without a helicity flip in the region of small momentum transfer and are relatively large for the values $3 \leqslant |t| \leqslant 10\ \mathrm{GeV}^2$. The appropriate ratios are cited in Fig. 2. In the region of momentum transfer from 3 to 10 GeV^2 the amplitudes with a double spin flip have smooth behavior (without maxima or minima).

Therefore, the angular distributions of elasitic *pp* scattering in the indicated region of momentum transfer have a smooth behavior corresponding to the experimental results (Fig. 1). Allowance for the spin structure of the scattering amplitude, which results in filling of the second minimum, should produce a noticeable polarization parameter at ISR energies ($\sim 10\%$ at $-t = 2\ \mathrm{GeV}^2$).

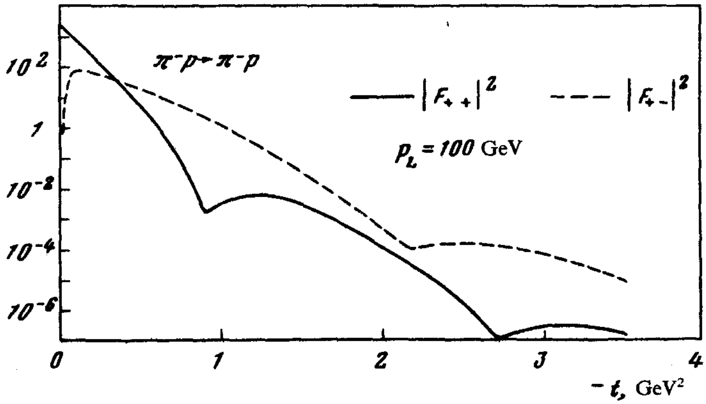

Fig. 3. Helicity amplitudes of elastic $\pi^- p$ scattering.

Note that for asymptotically large energies, when the amplitudes with a helicity flip vanish, the diffraction maxima and minima of amplitudes without a helicity flip should alternate in the angular distributions.

It would be of interest to compare the conclusions about the behavior of different amplitudes with the corresponding analysis of πN scattering.[5] The t dependence of the amplitudes without a helicity flip F_{++} and with a helicity flip F_{+-} appears to be similar to the behavior of the F_{++++} and F_{+++-} amplitudes in the pp scattering. The amplitudes in $\pi^{\pm} p$ scattering have a characteristic sequence of maxima and minima (Fig. 3), which leads to a corresponding structure in the angular distributions. Therefore, it would be extremely interesting to measure the differential cross sections of elastic $\pi^{\pm} p$ scattering at high energies in a wide range of momentum transfer.

Let us now turn to geometric characteristics and calculate the interaction radii for different (interaction) amplitudes:

$$R_i(s) = \sqrt{\langle b^2 \rangle_i} = \left[\int_0^\infty b^3 db\, f_i(s,b) \Big/ \int_0^\infty b\, db\, f_i(s,b) \right]^{1/2},$$

where $f_i(s,b)$ are the corresponding helicity amplitudes in the impact-parameter representation. The indices 0, 1, or 2 denote one of the amplitudes without a helicity flip and with a single or double helicity flip, respectively. In calculating the quantities $R_i(s)$ we used the results of Refs. 3 and 5. It appears that $R_0(s) \sim R_1(s) \sim 1$ F for the pp and πN scattering, whereas the average radius of the interactions responsible for the double helicity flip (pp scattering) is about 1/3 of this value: $R_2(s) \sim \frac{1}{3} R_0(s) \sim 0.3$ F. This result is in agreement with the conclusion that the $F_2(s,t)$ amplitude has no oscillations in the range $3 \leqslant |t| \leqslant 10$ GeV^2. In fact, an estimate of the $F_i(s,t)$ amplitudes when $s \to \infty$ and $t \neq 0$ gives the following expression $F_i(s,t) = \Phi_i(s,t) \cos\left[R_i(s)\sqrt{-t} + \phi_i(s)\right]$, where the $F_i(s,t)$ functions have no zeros. Therefore, the distances Δ_i between the zero amplitudes (according to the variable $\sqrt{-t}$) are inversely proportional to the interaction radii: $\Delta_i \sim 1/R_i(s)$. It follows from the preceding estimates of $R_i(s)$ that the distance between the minima of the

$F_2 (s,t)$ amplitude is larger by approximately an order of magnitude than that between the minima of the $F_i (s,t)$ amplitudes, where $i = 0.1$.

Such behavior of the amplitudes may indicate that the proton has an inner region 0.3 F in dimension, for example, a localization region of the valence quarks. In this case the difference between the $R_1 (s)$ and $R_2 (s)$ radii, which are associated with the spin degrees of freedom, can be explained. In fact, if the valence quarks are confined to distances of 0.3 F, then the contribution to the pp scattering from the interaction due to exchange of the valence quarks also has a characteristic dimension of $\sim$0.3 F. This mechanism contributes to the $F_2 (s,t)$ amplitude but does not contribute to the scattering with a single helicity flip. Other interactions, such as those involving gluons and $q\bar{q}$ pairs, which have a more peripheral contribution compared to the valence components, must contribute to the $F_1 (s,t)$ amplitude.

This investigation shows that, although the spin effects are vanishingly small at superhigh energies, allowance for the spin degrees of freedom at present-day energies is important for understanding the effects in the region of large momentum transfer. Investigation of the spin effects in this region is certainly of interest for a deeper understanding of the internal structure of hadrons. Apart from direct determination of the polarization parameters, it is very important to measure the angular distributions of elastic scattering in the region of large values of $|t|$.

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