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POLARIZATION EFFECTS IN MESON-NUCLEON SCATTERING AT HIGH ENERGY

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At present the theoretical and experimental research leads to the conclusion about the essential role of the spin of particles in the high energy scattering[1]. Thus, the available experimental data point to the absence of the energy dependence of polarization at small transfer momenta in a number of processes in a wide energy interval of scattering. This makes a basis for the hypothesis about the existence of a non-zero polarization in the limit $s \to \infty$. Thus, the polarization research on the future accelerators will provide information about the structure of the hadron interaction at large distances.

At present QCD can't consistently regard the hadron interaction at large distances, especially the spin phenomena. We have only a hint of the possibility to obtain the non-zero spin effects at superhigh energy, see e.g.[2]. Using different hypotheses about the property of the hadron interaction at large distances a number of model approaches lead to the nondisappearing polarization in high energy processes at small transfer momenta.[3] Our model allows us to calculate the contribution of the quark-antiquark pair, surrounding a hadron, in the spin-flip amplitude. The appearing effects change slowly with growing energy.

In this paper we regard the model results for the polarization effects of meson-nucleon scattering. Early, it was shown[5] that the calculated in the model real and imaginary parts of the leading asymptotic term of the spin-flip amplitude of the charge-exchange reaction $\pi^- p \to \pi^0 n$ agree sufficiently well with the amplitude reconstructed by the model-independent approach from the experimental data. This result allows us to suppose that the contribution of the nucleon and Δ_{33}-isobar in diagram in fig.1 contribute to the main terms in the spin-flip amplitude. This hypothesis will be proved in this work.

In the spin-flip amplitude of meson-nucleon scattering, determined by the diagram, fig.1, with the fixed amplitude $T_{\pi\pi}$- of pion-pion

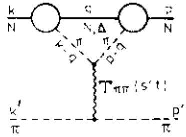

Fig.1. The contribution of two-meson exchange to hadron- hadron processes at long distances.

interaction the only free parameters will be the coupling constants and the parameters β in form factors determined in a dipole form

$$\varphi_{N(\Delta)}(l^2, q^2 \simeq M^2_{N(\Delta)}) = \frac{\beta^4_{N(\Delta)}}{(\beta^2_{N(\Delta)} - l^2)^2} . \qquad (1)$$

It is important to emphasize that in the case of the nucleon-nucleon scattering the leading asymptotic terms of the spiral amplitudes are also determined by the contribution of the diagram fig.1 with the evident replacement of $T_{\pi\pi}$ by the pion-nucleon scattering amplitude. Then, the basic parameters of the model stay without change. This permits us to determine them from any suitable reaction and latter to use in the calculation for another reaction. Here we shell use the values of the coupling constants

$$\frac{g^2_{\pi NN}}{4\pi} = 14.6 \quad ; \quad \frac{g^2_{\pi N\Delta}}{4\pi} = 21 \ (\mathrm{GeV}^{-2})$$

and parameters β

$$\beta^2_N = 3.4(\mathrm{GeV}^2), \quad \beta^2_\Delta = 1.5(\mathrm{GeV}^2), \qquad (2)$$

determined from the best description of the differential cross sections in the proton-proton elastic scattering/7/. In the calculation of the spin-flip amplitude of the charge-exchange reaction $\pi^- p \to \pi^0 n$ we used the same values of coupling constants and parameters β as shown in (2).

Use of the spin-non-flip amplitude of the charge-exchange reaction $\pi^- p \to \pi^0 n$, obtained from the results/8/ of the description of the elastic $\pi^+ p$ -scattering accurate to $1/\sqrt{s}$ terms, permits us to calculate the correct picture of polarization at p_L= 40 GeV, however without the structure at $|t| \approx 0.25$ GeV^2 /9/. Note that in work/8/ it was supposed for simplicity that the form of the cross-even amplitudes of pion-nucleon scattering is equal to the cross-odd part. We cannot determine the form of the cross-odd part of the scattering amplitude only from the experimental data on the elastic $\pi^\pm p$-scattering.

Using the experimental data of the differential cross-section and polarization of the charge-exchange reaction $\pi^- p \to \pi^0 n$ at p_L= 40 GeV permits us to obtain that form independently. However, at this energy one should take into account also the 1/s terms of the scattering amplitude which can be essential in the range of small energies.

The corresponding Born cross-odd amplitude was chosen in the following form:

$$T1^{nf}_{Born} = \sqrt{s}\ (1+i)\ T_1(s,t) + i\ T_2(s,t) \ ; \qquad (3)$$

$$T_1(s,t) = h_1\ e^{\alpha\ (\ln s - i\pi/2)t} \ ; \quad \alpha = 0.85\ \mathrm{GeV}^{-2}. ;$$

$$T_2(s,t) = h_2(1 + b_1 t + b_2 t^2)\ e^{(b_0 + \alpha\ (\ln s - i\pi/2))t} \ ;$$

In the language of the Regge-model, the first term in (3) corresponds to the ρ-meson exchange with $\alpha(0) = 0.5$; and the second, to the ρ'-

exchange with $\alpha(0) = 0$. Note that the simplest choice of the form of the amplitude of ρ -exchange is dictated by that the $T_{\pi\pi}$ - amplitude of pion-pion interaction was chosen in the Gauss form in the calculation of the spin-flip amplitude of the charge- exchange reaction.

In the eikonal representation of the spiral amplitude of charge-exchange reaction $\pi^- p \to \pi^0 n$

$$T^0_{+,+}(s,t) = \int \rho \, J_0(\rho\Delta) e^{-\chi_0(s,\rho)} (\chi_\rho(s,\rho)) + \chi_{\rho'}(s,\rho)) * (1 - 1/\sqrt{s}\, \chi^+(s,\rho)) \, d\rho \; ;$$

$$T^0_{+,-}(s,t) = \int \rho^2 \, J_1(\rho\Delta) \; e^{-\chi_0(s,\rho)} \; \chi^1_\rho(s,\rho) * (1 - 1/\sqrt{s} \;\; \chi^+(s,\rho)) \, d\rho \; ; \qquad (4)$$

for the spin-flip and spin-non-flip amplitudes all the rescatterings up to $1/s$ terms were taken into account. Here:

$\chi_0(s,\rho)$ - the asymptotic term of the eikonal spin-non-flip phase;

$\chi^+(s,\rho)$ - the cross-even $1/\sqrt{s}$ term of the eikonal phase;

$\chi_{\rho(\rho')}(s,\rho)$ - the term of the eikonal phase corresponding to the Born amplitude with the $\rho(\rho')$-meson exchange in the t-channel;

$\chi^1_\rho(s,\rho)$ - the asymptotic term of the spin-flip eikonal phase including the exchange of the N and Δ_{33}-isobar in the s-channel;

The leading and $1/\sqrt{s}$ terms of the cross-even amplitude were used from work[9]. With the following values of the parameters:

$h_1 = 0.1176$ GeV^{-1}; $\quad h_2 = -0.1327$;

$b_0 = 4.9$ GeV^{-2}; $\quad b_1 = 4.36$ GeV^{-2}; $\quad b_2 = 13$ GeV^{-4} ;

a sufficient description was obtained both for the data of differential cross-sections and the data of polarization, fig.2 and 3.

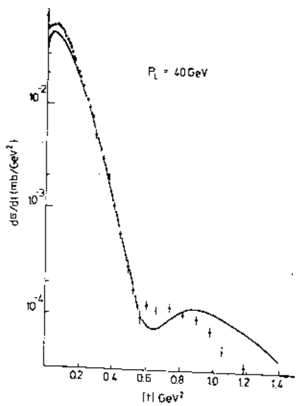

Fig.2. The differential cross sections of the charge-exchange reaction $\pi^- p \to \pi^0 n$ at $p_L = 40$ GeV.

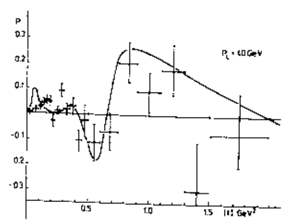

Fig.3. The polarization of the charge-exchange reaction $\pi^- p \to \pi^0 n$ at $p_L = 40$ GeV.

Ī - the experimental data from works[11,12].

It should be noted that the account of 1/s corrections in the spin-flip amplitude allows us to significantly improve the coincidence of the theoretical calculation with experiment, fig.4.

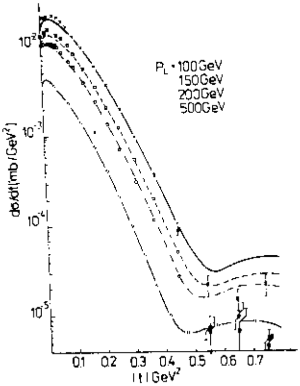

Fig.4.

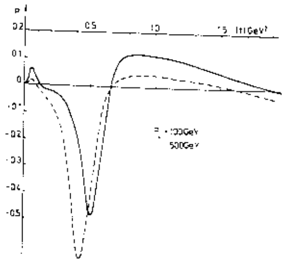

Fig.5.

The predictions of the model for (Fig.4) the differential cross sections and (Fig.5) the polarization of the charge-exchange reaction $\pi^- p \to \pi^0 n$ at high energies. ⫯ - the experimental data from works [13,14]

The analysis shows that when the preasymptotic corrections are absent, we naturally have the zero polarization. If eikonal corrections to the ρ-meson exchange are taken into account, a large negative polarization follows at $|t| \cong 0.5$ GeV^2, and the inclusion of 1/s corrections creates a complicated structure with a double zero at $|t| \cong 0.25$ GeV^2. It means that the corresponding structure has to disappear at higher energies.

Really, our calculations show that this already occurs at energy p_L= 100 GeV (fig.5). At a still higher energy, the picture of polarization changes very weakly (fig.5), which signifies that at this energy the 1/s corrections are nonessential. The model predicts a large negative polarization near 60% at $|t| \cong 0.5$ GeV^2, which can be verified in the future polarization experiment. This result is close to predictions of the model[10]. The correctness of the energy dependence found in the model for the scattering amplitude of the charge-exchange reaction $\pi^- p \to \pi^0 n$ is confirmed by a good coincidence of the model predictions with the available experimental data on the differential cross-sections up to p_L=200 GeV (fig.4).

A great interest is the use of the obtained here cross-odd contributions to the spin-flip and spin-non-flip amplitudes of πp- scattering. The amplitudes of elastic processes we have obtained are accurate to $1/\sqrt{s}$- terms. The analysis performed shows that in this case the reliable results of the predicted spin effects should be expected at an energy above p_L= 100 GeV. At a lower energy, the $1/s$ terms are essential and the agreement of the theory with experiment can be only qualitative.

The model predictions for the polarization of π p-scattering, corresponding to the experimental data at p_L= 100 GeV are shown in fig.6. The predictions at higher energies are shown in fig 7.

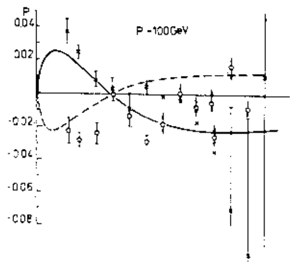

Fig.6. The polarization of elastic $\pi^{\pm}p$ -scattering at p_L= 100 GeV. ⫯, ⫯ - the experimental data of π^+p- and π^-p-scattering from work[14].

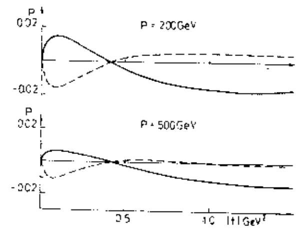

Fig.7. The prediction for the polarization of $\pi^{\pm}p$ -scattering at p_L= 200 GeV and p_L= 500 GeV.

Note that the model predicts a large polarization at high energies in the range of the diffraction peak. Thus, at energy p_L= 200 GeV and transfer momenta $|t| \cong 3.5$ GeV^2, the calculations give the following values of the polarization parameters:

$$P(\pi^+p) \simeq 10\% \; ; \quad P(\pi^-p) \simeq -15\% \; .$$

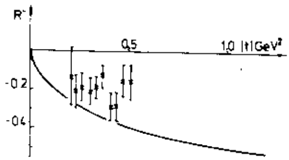

Fig.8. The prediction of the model for the parameter $R(\pi^-p)$ at p_L= 40 GeV, ⫯ -the experimental data from work[15].

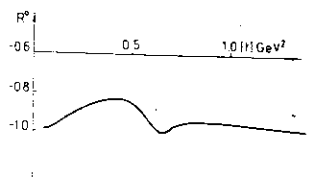

Fig.9. The prediction of the model for the parameter $R^0_{th}(\pi^0p)$ of charge-exchange reaction $\pi^-p \to \pi^0 n$ at p_L= 40 GeV.

Let us show that the model leads to good results at comparatively low energies $p_L < 100$ GeV. Thus, the results of the model for the parameter $R(\pi^- p)$ are shown in fig.8 at energy $p_L = 40$ GeV, and these results qualitatively agree with the experimental data. For $R(\pi^+ p)$ in this energy range we have only one experimental point: $R^+_{ex} = -0.220 \pm 0.160$ ($\pi^+ p$-scattering at $p_L = 45$ GeV and $|t| = 0.315$). For this point our calculations give $R^+_{th} = -0.22$. The predictions of our model for the parameter R^0_{th} of the charge-exchange reaction $\pi^- p \to \pi^0 n$ are shown in fig.9 at $p_L = 40$ GeV.

Thus, the model with taking account of the N and Δ contribution provides a self-consistent picture of the spin-flip scattering of different hadron processes at high energies. Really, the parameters in the spin-flip amplitude determined from one reaction, for example, elastic pp-scattering, allow us to obtain a wide circle of results for the polarization effects of elastic meson-nucleon scattering and charge-exchange reaction $\pi^- p \to \pi^0 n$ at high energies. The results obtained here can be used in planning future polarization experiments.

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