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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

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YEREVAN PHYSICS INSTITUTE

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Sh.S. EREMIAN

πN ELASTIC SCATTERING AND CHARGE EXCHANGE REACTIONS IN MODIFIED "QUASIEIKONAL" MODEL

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Ш.С.ЕРЕМЯН

УПРУГОЕ πN - РАССЕЯНИЕ И ПЕРЕЗАРЯДКА В МОДИФИЦИРОВАННОЙ КВАЗИЭЙКОНАЛЬНОЙ МОДЕЛИ

Проводится анализ экспериментальных данных по упругому $\pi^{\pm}p$ рассеянию и $\pi^{-}p$ -перезарядке в рамках метода комплексных моментов при учете движущихся ветвлений с коэффициентами ливневого усиления, зависящими от переданного импульса. Показывается, что для описания данных при $/t/ >$ 0,7 (Гэв/с)^2 необходимо учитывать зависимость функций вычетов от переданного импульса. Получено хорошее согласие с экспериментом в области $0 \leq /t/ \leq 2$(Гэв/с)^2

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The analysis of the experimental data on elastic $\pi^{\pm}p$ - scattering and $\pi^{-}p$ - charge exchange reactions within the frameworks of the method of the complex angular momentum taking into account the moving cuts with "shower" factors depending on momentum transfer is given. It is shown, that in order to describe the data at $/t/ > 0.7(GeV/c)^2$ one must introduce an especial dependence of the residue functions on the momentum transfer in form of the two different exponents. A good agreement with the experimental data is obtained in the region $0 \leq |t| \leq 2(GeV/c)^2$.

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Introduction

The high energy πN-scattering reactions are theoretically and experimentally studied sufficiently well. A great number of works /1-11/ has been devoted in the last years to the theoretical analysis of this process. Many of these works are based on Regge poles method taking into account the absorption in one or another way. However, a class of models which simply take into consideration the P,P' and ρ-poles and their Regge-cuts did not explain all the set of the experimental data. In particular the polarization data at $(t) > 0.7(GeV/c)^2$ were described non-satisfactorily. This concerns to the models as with strong /1-2/ as well as with weak /3/ absorption. Some authors used the dual-absorption model either by combining it with the dispersion sum rules in order to obtain the real part of the amplitude /4/ or by introducing the ρ'-trajectory /5/ or the "Regge-Regge"cuts /6/. The vast majority of these works is devoted to the description of a certain process, either the elastic $\pi^{\pm} p$ - scattering, or the $\pi^- p \to \pi^0 n$ charge exchange reaction, however their application to other related reactions results in disagreement with the experimental data. The authors of some works /5,6/ obtain correct results for all related processes at low energies taking into account ρ' or $R \otimes R$ contributions; increasing the energy these additional contributions rapidly vanish and one obtains results which are in disagreement with experimental ones at energies $E \gtrsim$ 13GeV and $|t| \gtrsim 0.8(GeV/c)^2$.

In the preceding work /7/ we have made an attempt to extend the region of the description of the experimental data for $/t/ > 0.8\ (GeV/c)^2$ complicating the residue functions of the poles.

Correct expressions have been obtained for the differential cross sections up to $/t/ \lesssim 1.5$ $(GeV/c)^2$. However, as the analysis carried out by us in the work /8/ has shown the models considered in /1-7/ are principle unable to give correct description of all the set of the experimental data on πN-scattering, namely, a bad description is obtained for the polarizations and spin correlation parameters.

In this work it is suggested a model taking into account the P, P' and ρ -trajectories and related cuts with certain parametrization of the residue functions of poles and certain modification of the "quasieikonal" model /9/ (QEM). It is shown, tha[illegible]ch an approach provides a successful description of all the set of the experimental data on πN -scattering.

In Section I we define the modified "quasieikonal" model (MQEM) differing from QEM by the fact, that the "shower" factors /10/ in it depend on momentum transfer.

In Section 2 it is given the parametrization of the contributions of P and P' vacuum trajectories and shown, that in order to describe correctly the differential cross sections of elastic $\pi^{\pm}$ p-scattering at $0.7 \leqslant /t/ \leqslant 1.6$ it is necessary to introduce two exponents having various t-dependence in the residue functions of the vacuum poles.

In Section 3 the parametrization of the isovector amplitudes is described. It is shown, that the correct spin-flip amplitude is obtained if one takes a pole residue with second order zero and a "shower" factor strongly depending on momentum transfer.

In Section 4 the determination of the theoretical parameters by means of the experimental data is given. The obtained results, the limits of the applicability and the possibility of the modification of the used model are discussed in Section 5. The predictions of the theory at high energies are also given.

I. The Modified "Quasieikonal" Model (MQEM)

The reactions of πN-scattering are described by two amplitudes: F_0 the non-spin flip and F_1 the spin-flip amplitudes. The normalization of the amplitudes and all the observable magnitudes is such as in the work /8/.

In MQEM the amplitudes taking into account all the rescatterings have the following form (in more details see /9/):

$$F_0(s,t) = \int f_0(s,b)\, e^{i\vec{\varkappa}\vec{b}} \frac{d^2 b}{2\pi}, \tag{1}$$

$$F_1(s,t) = \int f_1(s,b)\, e^{i\vec{\varkappa}\vec{b}} \cos\varphi \frac{d^2 b}{2\pi i}, \tag{2}$$

where $\varkappa^2 = -t$, $\vec{b}$ – is the impact parameter and $f_{0,1}(s,b)$ are the partial amplitudes given by the expressions:

$$f_0^{el}(s,b) = \frac{1}{2iC'}\left[e^{\chi_0'} ch\,\chi_1' - 1 - \chi_0' + C'\chi_0\right], \tag{3}$$

$$f_1^{el}(s,b) = \frac{1}{2iC'}\left[e^{\chi_0'} sh\,\chi_1' - \chi_1' + C'\chi_1\right] \tag{4}$$

for elastic scattering and

$$f_0^{CEX}(s,b) = \frac{1}{2iC'}\left\{e^{\chi_0'^{I=0}}\left(\chi_0'^{I=1} ch\,\chi_1'^{I=0} + \chi_1'^{I=1} sh\,\chi_1'^{I=0}\right) - \chi_0'^{I=1} + C'\chi_0^{I=1}\right\}, \tag{5}$$

$$f_1^{cex}(s,b)=\frac{1}{2ic'}\Big\{e^{\chi_0'^{I=0}}\big(\chi_0'^{I=1}\, sh\,\chi_1'^{I=0}+ \quad (6)$$
$$+\chi_1'^{I=1}\, ch\,\chi_1'^{I=0}\big)-\chi_1'^{I=1}+C'\chi_1^{I=1}\Big\}$$

for charge exchange reaction. Here

$$\chi'_{0,1}=\sum_a \chi'_{a_{0,1}}\ ;\quad a=P,P',\rho, \qquad (7)$$
$$\chi'^{I=0}_{0,1}=\sum_{i=P,P'}\chi'_{i_{0,1}}\ ;\quad \chi'^{I=1}_{0,1}=\chi'_{\rho_{0,1}},$$

$$\chi'_{a,0}=2i\int C_{a_0}(t)\,F_0^a(s,t)\,e^{-i\vec{\varkappa}\vec{b}}\,\frac{d^2\varkappa}{2\pi}, \qquad (8)$$

$$\chi'_{a_1}=2i\int C_{a_1}(t)\,F_1^a(s,t)\,e^{-i\vec{\varkappa}\vec{b}}\cos\varphi\,\frac{d^2\varkappa}{2\pi}, \qquad (9)$$

$$\chi_{a_0}=2i\int F_0^a(s,t)\,e^{-i\vec{\varkappa}\vec{b}}\,\frac{d^2\varkappa}{2\pi}, \qquad (10)$$

$$\chi_{a_1}=2i\int F_1^a(s,t)\,e^{-i\vec{\varkappa}\vec{b}}\cos\varphi\,\frac{d^2\varkappa}{2\pi}. \qquad (11)$$

In eqs (7-11) $\chi_{0,1}$ and $\chi'_{0,1}$ are the eikonals and quasieikonals, respectively. As has been noted the main difference between our model and QEM is the fact that we do not neglect the momentum transfer dependence of the "shower" factors $C_{a_{0,1}}(t)$.

2. The Parametrization of the Vacuum Amplitudes

The S -channel pole amplitudes for the exchange by a trajectory $\alpha_a(t)$ have the following form /2,7,9,11/

$$F_{0,1}^{(a)}(s,t)=\varepsilon_a\,\eta_a(t)\,\gamma_{0,1}^{a}(t)\left(\frac{s-u}{2s_0}\right)^{\alpha_a(t)}, \tag{12}$$

where

$$\eta_a(t)=i\sigma_a\,\frac{\exp\left(i\frac{\pi}{2}\left(\frac{\sigma_a+1}{2}-\alpha_a(t)\right)\right)}{\cos\frac{\pi}{2}\left(\frac{\sigma_a+1}{2}-\alpha_a(t)\right)} \tag{13}$$

is the signature factor and σ_a is the signature for the trajectory a and

$$\varepsilon_a=\left(\frac{s-u}{2s_0}\right)^{\alpha_a(0)-1} \tag{14}$$

Let us choose the residue function $\gamma_{0,1}^{a}(t)$ in the form

$$\gamma_{0,1}^{a}(t)=\frac{\cos\frac{\pi}{2}\left(\frac{\sigma_a+1}{2}-\alpha_a(t)\right)}{\cos\frac{\pi}{2}\left(\frac{\sigma_a+1}{2}-\alpha_a(0)\right)}\,\beta_{0,1}^{a}(t), \tag{15}$$

then the pole amplitude will be written in the form

$$F_{0,1}^{(a)}(s,t)=\varepsilon_a\,\eta_a(0)\,\beta_{0,1}^{a}(t)\,e^{-i\frac{\pi}{2}\alpha_a' t}\left(\frac{s-u}{2s_0}\right)^{\alpha_a' t} \tag{16}$$

where /11/

$$\eta_a(0)=\eta_a(\alpha_a(0)). \tag{17}$$

As it has been shown in the work /2/ one may describe the differential cross sections for elastic $\pi^{\pm}$ P-scattering at small t using one exponent in the residue functions of P and P' trajectories. However, it is impossible to describe the region $|t| \approx 1$ in this model. In particular, a dip in the region $/t/ \approx 1$ has been obtained due to the large destructive contribution of the vacuum cuts into the elastic scattering differential cross sections.

In the paper /7/ we have shown , that one can overcome these difficulties parametrizing the residues of the vacuum poles in the form of two exponents:

$$\beta_0^a(t) = a_a e^{R_{a1}^2 t} + |t| b_a e^{R_{a2}^2 t}. \qquad (18)$$

Then the non-flip P and P' poles amplitudes take the form

$$F_0^{0(a)}(s,t) = \varepsilon_a \eta_a(0) \left(a_a e^{\lambda_{a1} t} + |t| b_a e^{\lambda_{a2} t} \right), \qquad (19)$$

where

$$\lambda_{ai} = R_{ai}^2 + \alpha_a'(0) \left(\ln \frac{s-u}{2s_0} - i \frac{\pi}{2} \right). \qquad (20)$$

In the case of such parametrisation of the amplitude $F_0^{0(a)}$, the term $|t| b_a e^{\lambda_{a2} t}$ gives a large contribution at $|t| \approx 1$ and compensates the destructive contribution of the vacuum cuts which allows to obtain correct values for elastic $\pi^{\pm}$p-scattering differential cross sections up to $/t/ \approx 1.6 (GeV/c)^2$.

From the amplitude analysis/8/ of the experimental data it is known, that in πN-scattering a partial conservation of the S-channel helicity takes place for vacuum exchanges. Therefore, the spin-flip pole amplitude for P and P' trajectories has been parametrized in the following form

$$F_1^{0(a)}(s,t)=\sqrt{|t|}\,\varepsilon_a\,\eta_a(\nu)\,\Delta_a\,e^{\lambda_{a3}t}, \tag{21}$$

where Δa is a small magnitude showing the degree of the violation of the S-channel helicity conservation for vacuum exchanges.

Such a parametrization of the pole amplitudes for vacuum exchanges taking into account all the elastic rescattering by the formulae (3) and (4) allows to approximate with enough accuracy the results of the amplitude analysis given in the work /8/ assuming that the "shower" factors $C_0^{P,P'}$ depend weakly on momentum transfer.

3. The Parametrization of Isovector Amplitudes.

The results of the amplitude analysis /8/ have shown, that the amplitude F_1^1 must have a minimum at $/t/\geqslant 0.7(GeV/c)^2$ somewhat shifted from zero. Besides the Argand plot of this amplitude has a sharply expressed loop in the interval $0.55 \leqslant /t/ \leqslant 1(GeV/c)^2$. When the energy increases the minimum in F_1^1 goes to zero and the loop flattens, i.e , the amplitude begins to take a form characteristic for residue with second order zero

From the above given consideration it is seen that the ρ pole residue $\beta_1^1(t)$ of the amplitude F_1^1 must consist of the sum of two terms at least

$$\beta_1^1(t)=\beta_{11}^1(t)+\beta_{12}^1(t). \tag{22}$$

To obtain the loop on Argand plot at $0.55 \leqslant t \leqslant 1(GeV/c)^2$ it is necessary that $\beta_{11}^1(t)$ would have two zeros in near but not coinciding points: at $/t/ = 0.7\ (GEV/c)^2$ and $/t/ = 0.6\ (GeV/c)^2$ (therefore the parametrization $\beta_{11}^1(t) \sim \alpha_\rho^2(t)$ gives not correct results). Let us present $\beta_{11}^1(t)$ in the form:

$$\beta_{11}^1(t) = \alpha_\rho(t)\left(a_1^\rho e^{R_{\rho3}^2 t} - b_1^\rho e^{R_{\rho4}^2 t}\right), \qquad (23)$$

where the first zero at the point $/t/ = 0.7\ (GeV/c)^2$ is obtained due to the factor $\alpha_\rho(t)$ while the second zero is obtained at $/t_0/ = 0.6(GeV/c)^2$ if

$$a_1^\rho = b_1^\rho e^{t_0(R_{\rho4}^2 - R_{\rho3}^2)}. \qquad (24)$$

Such a residue gives correct phase relations at small momentum transfers, however, the real part of the total amplitude F_1^1 becomes negative at $/t/ > 0.7\ (GeV/c)^2$ despite of the fact that the real part of contribution of reggeon cuts changes its sign and becomes positive in case of such parametrization of ρ -pole residue at $/t/ \geqslant 0.7$. Increasing the contribution of the cuts (by increasing C_1) it is not possible to get the correct result since their imaginary part does not change the sign and remaining negative it leads to a sharp decrease of the imaginary part of the total amplitude in disagreement with the data of the analysis /8/ from which it is known that $ReF_1^1 > 0$ up to $/t/ = 1.15\ (GeV/c)^2$ and $\Im m F_1^1$ is positive and sufficiently large.

The term $\beta_{12}^1(t)$ must compensate all these disadvantages of the residue $\beta_{11}^1(t)$: it must give a contribution into the total amplitude which has a positive real and imaginary parts. Besides, $\beta_{12}^1(t)$ must provide a necessary shift of the imaginary part of the amplitude F_1^1 from zero, i.e. it must have no zeros in this momentum transfer region. And, finally, its contribution at $|t| < 0.5(\mathrm{GeV}/c)^2$ must be small in order to maintain the correct phase relations given by the residue $\beta_{11}^{1}(t)$. The following form of the residue function satisfies all these requirements

$$\beta_{12}^{1}(t) = |t| \left(C_1^{\rho} - |t| d_1^{\rho} \right) e^{R_{\rho 1}^2 t} \tag{25}$$

if

$$\beta_{12}^{1}(|t_1| \sim 0.05) = 0, \tag{26}$$

i.e

$$C_1^{\rho} = |t_1| d_1^{\rho} . \tag{27}$$

The contribution of $\beta_{12}^{1}(t)$ to the cuts when the condition (26) is fulfilled is anomaly large with regard to the contribution of the pole itself and has a phase sharply differing from its phase. At small momentum transfers it gives sufficiently small contribution due to the common factor t and, therefore, it does not violate the phase relations of the amplitude in the whole. The properties of the cuts connected with $\beta_{12}^{1}(t)$ begin to appear only at sufficiently large "shower" factor which, however, would violate strongly the correct picture at small momentum transfers. Therefore, we have chosen the shower factors in the form

$$C_{0,1}^{a}(t) = A_{0,1}^{a} + |t| B_{0,1}^{a} \tag{28}$$

The contribution of β_{12}^{1} into the cuts grows due to the growth of $C_1^{\rho}(t)$ at large $|t|$ provides the correct phase of the amplitude F_1^{1} for all values of t.

It has appeared that when the condition (26) is fulfilled the cuts of the term $\beta_{12}^{1}(t)$ have the same phase characteristics in MQEM as the hypothetical ρ'-trajectory has

Let us recall that the contribution of the later one "dies" as $S^{-3/2}$ with the increase of the energy. In difference from this case the β_{12}^{1} contribution decreases as $(S^{\frac{1}{2}} \ln^2 S)^{-1}$.

Thus, we have shown, that the pole amplitude must be of the form:

$$F_1^{1(\rho)}(s,t) = \varepsilon_\rho \eta_\rho(0)\sqrt{|t|}\Big\{\alpha_\rho(t)\big(a_1^\rho e^{\lambda_{\rho 3}t} - b_1^\rho e^{\lambda_{\rho 4}t}\big) + |t|\big(c_1^\rho - |t| d_1^\rho\big) e^{\lambda_{\rho 5}t}\Big\}, \tag{29}$$

where the parameters a_1^ρ and c_1^ρ are connected by the conditions (25) and (27).

Choosing the "shower" factor in the form (28) (taking into account only the first rescattering) one may present the structure of the total amplitude in MQEM in the following form:

$$F_1^1(s,t) = \eta_\rho(t)\,|F_1^{1(\rho)}(s,t)| + \sum_{i,j=1,2}\Big(A_1^\rho + \frac{B_1^\rho}{\lambda_{\rho j}+\lambda_{\rho i}} * L_1\Big(t\,\frac{\lambda_{\rho i}}{\lambda_{\rho j}+\lambda_{\rho i}}\Big)\Big)|F_1^{1(\rho\rho)}(s,t)|\, e^{i(\frac{\pi}{2} - \varphi^{cut}(t))} \tag{30}$$

where $F_1^{1(\rho)}$ is the pole amplitude, $F_1^{1(\rho\rho)}$ is the amplitude corresponding to the first cut, $L_1(x)$ is Legger's polynom, and $\varphi^{cut}(t)$ is the phase of the first cut.

As shown in /8/ when $B_1^\rho = 0$ no form of the residue function may give the correct phase for the amplitude F_1^1. An additional dependence of the phase on the momentum transfer which allows to obtain correct amplitude for isovector exchanges appears in MQEM due to the fact, that the "shower" factor depends on t. The amplitude parametrized in the form (29) gives a good agreement with the results of the amplitude analysis at all energies.

Now let us consider the amplitude F_0^1. It is known from the results of the amplitude analysis /8/:

1) In order to obtain the correct "crossover" point of the elastic $\pi^{\pm}p$ - scattering differential cross sections we have

$$\mathrm{Im}\, F_0^1(|t| \approx 0.15) = 0,$$

2) In order to obtain positive polarization for $\pi^- p \to \pi^0 n$ charge exchange reaction it is necessary, that the sign of $\mathrm{Re}\, F_0^1$ would not be changed in the region $0 < /t/ < 0.5 (\mathrm{GeV}/c)^2$.

The first condition is easily obtained /1,2/ by parametrizing the residue in the form:

$$\beta_{01}^1(t) = a_0^{\rho} e^{R_{\rho 1}^2 t}. \tag{31}$$

However, in the case of such residue $\mathrm{Re}\, F_0^1$ changes its sign at $/t/ \gtrsim 0.2\ (\mathrm{GeV}/c)^2$ and the polarization of the $\pi^- p$ charge exchange reaction have a deep dip at $/t/ \approx 0.4\ (\mathrm{GeV}/c)^2$. Many authors /5/ have suggested to introduce ρ'-trajectory in order to obtain correct polarization. As it has been mentioned above a residue of the form

$$\beta_{02}^1(t) = |t|(c_0^{\rho} - |t| d_0^{\rho}) e^{R_{\rho 2}^2 t} \tag{32}$$

gives a contribution into the cuts which have all the phase characteristics of ρ'-trajectory. Therefore, we shall parametrize the pole amplitude F_0^1 in a form of sum of the residues β_{01}^1 and β_{02}^1 i.e.

$$F_0^{1(\rho)}(s,t)=\mathcal{E}_\rho \eta_\rho(0)\left[C_0^\rho e^{\lambda_{\rho 1}t}+|t|(C_0^\rho-|t|d_0^\rho)e^{\lambda_{\rho 2}t}\right] \quad (33)$$

Meanwhile the following condition (see (27)) must be satisfied

$$C_0^\rho=|t_1|d_0^\rho \quad (34)$$

We have already mentioned, that the residue $\beta_{\rho 2}^1(t)$ gives a contribution similar to one from ρ' only for sufficiently large "shower" factor, therefore, $C_0^\rho(t)$ will have the form (28).

The amplitude F_0^1 determined in such manner completely corresponds to the results of the amplitude analysis. The charge exchange polarization on the whole depends on the magnitude and sign of the parameters C_0^ρ and B_0^ρ and it may be charged toward any direction by the choice of these parameters.

4. The Determination of the Parameter of the Model

Because of the absence of sufficient number of accurate experimental data at large momentum transfers the t-dependent parameters in the "shower" factors for vacuum exchanges are determined with large errors. Therefore, we have accepted

$$B_{0,1}^{P,P'}=0. \quad (35)$$

The parameter C_0^P is the most important among $C_i^{P,P'}$ since the contribution of the P'-pole and vacuum terms into the spin-flip amplitude usually is small. For this reason all the remained "shower" parameters of the vacuum group was asumed equal to unity in the numerical calculations, i.e they are equal to their "eikonal" values. The value of the parameter $C_0^P = A_{0P} = 1.56$ has been taken from the work /10/. The parameter C' has been taken equal to 1.6 in order to provide the correspondence of the value of the coefficient in front of the second vacuum cut to that one of the work/10/.

Since the observable magnitudes appeared to be insensitive to the parameters $R_3^{(P,P')^2}$, $R_{\rho 4}^2$ and $R_{\rho 5}^2$ and therefore they were determined with large errors we assumed, that

$$R_2^{(P,P')^2} = R_3^{(P,P')^2}; \quad R_{\rho 1}^2 = R_{\rho 4}^2; \quad R_{\rho 2}^2 = R_{\rho 5}^2. \tag{36}$$

The parameters for the trajectories have been taken from the work /2/. Besides we have accepted $B_0^\rho = B_1^\rho$ because of the absence of good experimental data on polarization for charge exchange reaction. The parameters a_1^ρ, C_1' and C_0^ρ are connected by the relations (25), (27) and (34). Thus, we have 20 parameters remained free which were determined by the method of the sequential analysis of the statistical hypotheses /12/, in which the necessary number of the observations is not fixed earlier, but it is determined during the process of analysis itself. This allows to limit oneself by a not large number of experimental points, namely, by results of the amplitude analysis from the work /8/. The parameters obtained in such manner were corrected and controlled by the available data which were not entered directly into the amplitude analysis. For instance, the parameters $a_{P,P'}$, C_{0P} were corrected by the sum of the total cross sections /13/ at high energies; the parameters $b_{P,P'}$, $R_{\rho i}^2$, $R_{\rho' i}^2$ were controlled by the elastic $\pi^\pm p$-scattering differential cross sections /14/ and by the parameters of the diffraction slope /15/; the parameters $a_{o\rho}, R^2_{\rho i}, A^\rho_o$ were corrected by the difference of the total cross sections/16/; all the remained parameters were determined from the amplitude analysis. After obtaining the values of the parameters χ^2-value were computed over all the set of the experimental data at $0 \leq |t| \leq 2(GeV/c)^2$. The χ^2-value appeared to be equal to 1.25 per experimental point which characterized a sufficiently good description of the experimental data, especially in comparison with the results of other authors /1-11/. The obtained values of the parameters and corresponding errors are given in Table I. The χ^2-values for each observable magnitude separately are given in Table II. The predictions of the observable magnitudes for these values of the parameters are presented in Figs 1-12.

5. The Discussion of the Results.

The total cross sections for $\pi^\pm p$-interactions are shown in Fig.1. The agreement with the experimental data is very good. The rise of the total cross section for $\pi^+ p$ and $\pi^- p$ interactions begins at E $\approx$ 70 and 200 GeV, respectively, which is in good agreement with the last NAL experimental data /17/ (this point has become known to us after the finishing of computations and it was not included in the minimization procedure). In the model under consideration this rise takes place much rapidly than in the other models /2/ which is due to the presence of the term $|t| b_P e^{\lambda_{P2} t}$ in the P-pole residue. This term at t =0 gives a contribution to the elastic rescattering of the form $(-1/\ln^2 S)$ which rapidly "dies" with the increase of energy and results in a sharper rise of the total cross sections the asymptotic value of which is equal to 30mb.

The ratio $\alpha^{\pm} = Re\, F_0^{\pm}(S,0) / Im\, F_0^{\pm}(S,0)$ and the diffraction slope b(S) for elastic $\pi^{\pm}p$ scattering are shown in Figs.2 and 3. The agreement with the experiment is good for both the magnitudes. In Fig.3 the values of b(S) are shown for two values of t: /t/=0 and 0.2(Gev/c)^2. The shrinkage effect is noticeably masked by the contribution of the P'-pole and reggeon cuts. As a result the effective cone width is almost not changed with the growth of in the energy region E=10÷ 100GeV.

The differential cross sections for elastic $\pi^{\pm}p$-scattering are shown in Fig.4. The term proportional to t in the residue of P and P' poles compensates the destructive contribution of elastic rescatterings at large momentum transfers. Otherwise the cross sections would have a dip at /t/$\approx$1(GeV/c)^2 (see/2/). The theoretical curves of our model correctly describe the experiment in a sufficiently wide interval of momentum transfers up to /t/$\approx$ 1.5 (GeV/c)^2. One may extend the description up to /t/$\approx$3(GeV/c)^2 introducing an additional term proportional to $t^2 e^{R^2 t}$ into the P-pole residue. We have not considered this problem since the parameters connected with this term would be determined with large errors due to the absence of sufficient experimental data.

Especially good description of the data is obtained at 40GeV It is correctly predicted the "crossover" point of the differential cross section for elastic $\pi^{\pm}$p-scattering. The "crossover" point slowly moves toward the higher momentum transfers when the energy increases.

Fig. 5 represents the differential cross sections for th charge exchange reaction $\pi^- p \to \pi^0 n$. A possibility to describe the cross sections up $/t/ \approx 2 (GeV/c)^2$ has been appeared due to the presence of the terms of the form (28) in the ρ-pole residue.

The polarization in elastic $\pi^{\pm}p$-scattering and charge exchange $\pi^- p \to \pi^0 n$ reactions is presented in Fig.6. The error corridor is shaded. Elastic polarization is in good agreement with the experimental data for all the intervals of energy and momentum transfer. Charge exchange polarization has not been included into the minimization because of the contradictoriness of the experimental data /21/; and the curve shown in Fig.6 is the model's prediction. The shape and the sign of this curve may be varied depending on the magnitude and sign of the parameters of the residue $\beta^{1}_{02}(t)$ (see (32)) and B^{ρ}_{0} which are determined with large errors from the existing experimental data.

In Fig.7 the spin correlation parameters are shown. The corridor of the theoretical errors for the magnitude T is large because of inaccurate determination of the spin-flip vacuum amplitude.

The Argand plots for the amplitudes by means of which the observable magnitudes have been built are given in Fig.8. These amplitudes coincide well with the results of the amplitude analysis /8/. The plots of the real and imaginary parts of each amplitude separately are given in the same figure.

The rapid rise of the elastic polarization after $/t/ \gtrsim 0.7$ $(GeV/c)^2$ takes place due to the existence of a loop in the amplitude $F_1^{\,1}$ at $0.6 \lesssim /t/ \lesssim 1.1 (GeV/c)^2$. This loop has been appeared due to the fact that in the residue of this amplitude the zero of $\alpha_\rho(t)$ and the zero of the term $a_1^{\rho} e^{\lambda_{\rho 1} t} - b_1^{\rho} e^{\lambda_{\rho 2} t}$

does not coincide(just for this reason a residue of the type $\alpha_{\rho}^{2}(t)$ does not give the required growth of polarization)

The decrease of the elastic polarization after $/t/>1.5$ $(GeV/c)^2$ takes place due to the change of the sign of $ReF_1^{\ 1}$ and the rapid decrease of $/F_1^{\ 1}/$. As it is shown in /8/ in the frameworks of QEM it is impossible to obtain such phase relations for the amplitudes.

Some predictions of the model for the region of higher energies 40 - 1000GeV are given in the remained figures.

Fig. 9 shows the predictions on the elastic $\pi^{\pm}p$-scattering differential cross sections*) at energies 70,200 and 1000 GeV as well as on the charge exchange reaction $\pi^- p \to \pi^0 n$ at energies corresponding to the experimental data of the work /24/. It is seen that the dip of the elastic cross sections shifts toward the region of small /t/; from $/t/ = 1.7$ $(GeV/c)^2$ at E = 6 GeV to $/t/ = 0.9$ at E = 1000 GeV. The differential cross section are almost equal each to other and their crossover point slowly moves when the energy increases; from $/t/ = 0.15$ up to $/t/= 0.3$ $(GeV/c)^2$ at E = 1000 GeV. The experimental data on the charge exchamge reaction differential cross sections /24/ have become known to us after the finishing of the computations so our curves are the predictions of the model for the energies 21,25,32,5,40 and 48 GeV.

*) The experimental data /17/ on π^-p- scattering differential cross sections at 200 GeV have appeared when this article was in the process of preparation and they are shown together with the predicted curve.

The predictions for the elastic $\pi^{\pm}p$ polarization at energies 70, 200 and 1000 GeV are given in Fig.10. As it is seen from the figure the behaviour of the $\pi^{+}p$- Polarization does not depend almost on the energy, while the $\pi^{-}p$-Polarization changes its sign at $/t/\geqslant 0.8$ and $E\geqslant 100$ $(GeV/c)^2$. This takes place since at such energies the contribution of the isovector part of the amplitude F_1 becomes much smaller than the isoscalar one which leads to a difference in the behaviours of $\pi^{\pm}p$ - polarizations

If at $E>30$ GeV the $\pi^{+}p$-scattering polarization will change its sign at $/t/\gtrsim 0.7(GeV/c)^2$ then this would mean that it is necessary to take a term with first order zero at such /t/ for ρ -pole residue in the amplitude F_1^1.

The energy dependence of the elastic polarizations at /t/= 0.2 and 1 $(GeV/c)^2$ are presented in the same figure. It is seen that it essentially differs from the usually predicted power law decrease in the region $10\leqslant E\leqslant 100$ GeV. In order to find finally the structure of the residues of the ρ -pole and vacuum exchanges in the spin-flip amplitude it is necessary to carry out more detailed measurements of the energy dependence of the elastic polarization in the available energy interval from 10 to 40 GeV. Besides, $\pi^{+}p$-scattering polarization measurements are required at energies higher than 30 GeV.

In Fig.11 the predictions for the spin correlation parameter T for elastic $\pi^{\pm}p$ scattering at 40,70, 200 and 1000GeV are presented. Fig. 12 shows the predictions for the polarization and spin correlation parameters T and S for the charge exchange reaction. Despite of the results of the other authors the behaviour of these magnitudes in our model depends very weakly on the energy. Only at $E\gtrsim 100$ GeV a dip in polarization become to be appeared at $/t/ \gtrsim 0,5$ which is characteristic for models with strong absorption.

Thus, taking into account the cuts in MQEM and the complicated form of the pole functions of residues one may describe all the set of the experimental data on all elastic πN-scattering and charge exchange reactions at medium and high energies. An improvement of the models' predictions may be achieved by adjusting more carefully the parametrization of the residues and determining the factors C more accurately.

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Table I

Regge Pole Parameters for πN-Scattering

$a_P = 2.867 \pm 0.01$ (GeV)$^{-2}$	$a_{P'} = 4.414 \pm 1.0$ (GeV)$^{-2}$
$b_P = 3.032 \pm 0.30$ (GeV)$^{-3}$	$b_{P'} = -7.445 \pm 2.0$ (GeV)$^{-2}$
$R^2_{P1} = 2.558 \pm 0.2$ (GeV)$^{-2}$	$R^2_{P'1} = 1.35 \pm 1.0$ (GeV)$^{-2}$
$R^2_{P2} - 0.593 \pm 0.2$ (GeV)$^{-2}$	$R^2_{P'2} = 5.0 \pm 4.0$ (GeV)$^{-2}$
$\Delta_P = 0.091 \pm 0.09$ (GeV)$^{-3}$	$\Delta_{P'} = -0.328 \pm 0.5$ (GeV)$^{-3}$
$R^2_{P3} = 593 \pm 0.5$ (GeV)$^{-2}$ **)	$R^2_{P'3} = 5.0 \pm 5.0$ (GeV)$^{-2}$ **)
$C_{0P} = 1.560 \pm 0.10$ *)	$C_{0P'} = 1.0$ *)
$C_{1P} = 1.0$ *)	$C_{1P'} = 1.0$ *)

$$C' = 1.43 = C^2_{0P}/1.6$$

$a_{0\rho} = 0.676 \pm 0.06$ (GeV)$^{-2}$	$a_{1\rho} = 0.379 + 0.05$ (GeV)$^{-3}$ **)
$c_{0\rho} = -1.109 \pm 0.5$ (GeV)$^{-4}$ *)	$b_{1\rho} = 3.272 \pm 1.0$ (GeV)$^{-3}$
$d_{0\rho} = -15.478 \pm 2.0$ (GeV)$^{-6}$	$c_{1\rho} = -0.456 \pm 0.1$ (GeV)$^{-5}$ **)
$R^2_{\rho 1} = 3.859 \pm 1.0$ (GeV)$^{-2}$	$d_{1\rho} = -6.368 \pm 1.0$ (GeV)$^{-7}$
$R^2_{\rho 2} = 3.503 \pm 1.0$ (GeV)$^{-2}$	$R^2_{\rho 3} = 0.244 \pm 0.1$ (GeV)$^{-2}$
$C_{0\rho} = 1.0 \pm 0.2 + \mathcal{K}^2(3.172 \pm 1.0)$	$R^2_{\rho 4} = 3.859 \pm 1.0$ (GeV)$^{-2}$ **)

$$C_{1\rho} = 0.31 \pm 0,3 + \mathcal{K}^2(3.172 \pm 1.0)^{**)}$$

*) Parameters taken from the works /2,10/.

**) Parameters connected with the relations (24,27,34,36).

Table II

χ^2-Values for the observable magnitudes in πN-scattering

	σ^{+}_{TOT}	σ^{-}_{TOT}	$P^{\pm}(t)$	$d\sigma^{\pm}/dt$	$d\sigma^{CEX}/dt$	summary
n	42	54	236	280	172	784
χ^2	63.83	24.38	297.48	380.8	219.2	985.76
χ^2/n	1,52	0.45	1.26	1.36	1.27	1.25

Figure Captions

Fig. 1. Total cross sections of $\pi^{\pm}$P- Interactions.

Fig. 2. Ratio $\mathrm{Re}F_0^{\pm}(E,0)/\mathrm{Im}F_0^{\pm}(E,0)$ for the elastic $\pi^{\pm}$ P-Scattering.

Fig. 3. Diffraction Slope b(S,t) of the elastic $\pi^{\pm}$ p-Scattering at /t/= 0 and 0.2 $(\mathrm{GeV/c})^2$.

Fig. 4. Elastic $\pi^{\pm}$P-scattering differential cross sections.

Fig. 5. Differential cross sections for $\pi^- p \to \pi^0 n$ charge exchange reaction.

Fig. 6. Elastic $\pi^{\pm}$P- scattering polarization and predictions for the polarization in the reaction $\pi^- p \to \pi^0 n$ at 5 GeV. Corridor of the theoretical errors is shaded.

Fig. 7. Predictions for the spin correlation parameters T(t) and S(t) for elastic $\pi^{\pm}$P-scattering at 6 and 16 GeV. Corridor of theoretical errors is shaded .

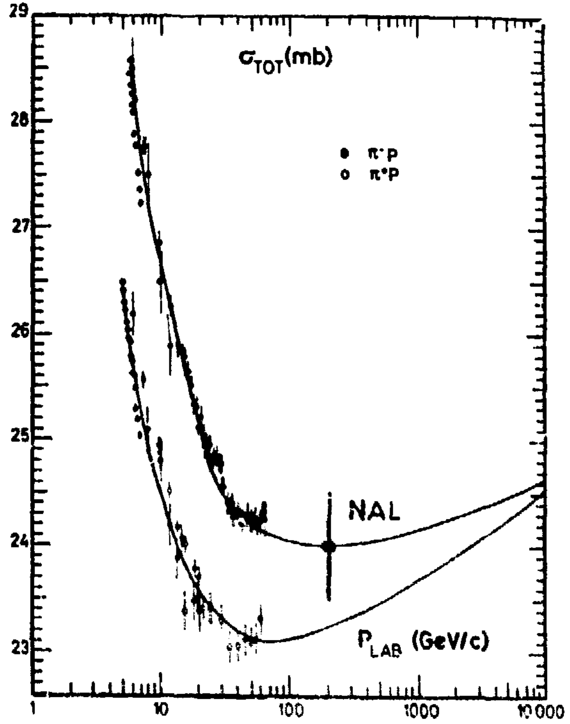
Fig. 8. Amplitudes for πN-scattering at 6 GeV.

Fig. 9. Predictions for elastic $\pi^{\pm}$ P-scattering and $\pi^- p \to \pi^0 n$ charge exchange reaction differential cross sections.

Fig. 10. Predictions for elastic $\pi^{\pm}$ P-scattering Polarization. The t-dependence for various energies as well as the energy dependence at /t/=0,2 and $1(\mathrm{GeV/c})^2$ are shown.

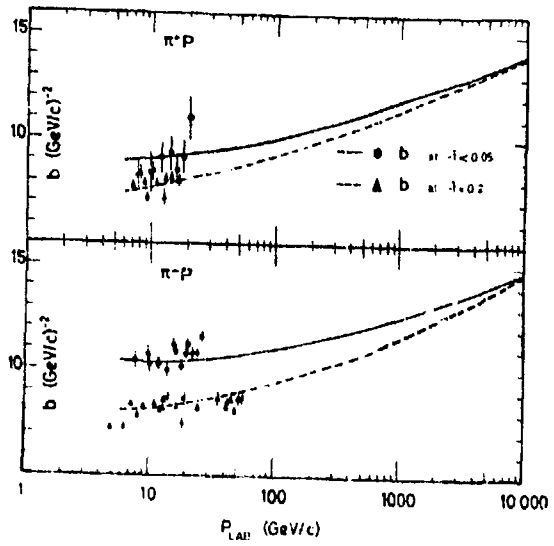
Fig. 11. Predictions for spin correlation parameters T(t) and S(t) in elastic $\pi^{\pm}$ P-Scattering at various energies.

Fig. 12. Predictions for polarization, spin correlation parameters and $\mathrm{Im}\,F_0^{1}(s,t=0)$ in the charge exchange reaction $\pi^- p \to \pi^0 n$ at various energies.



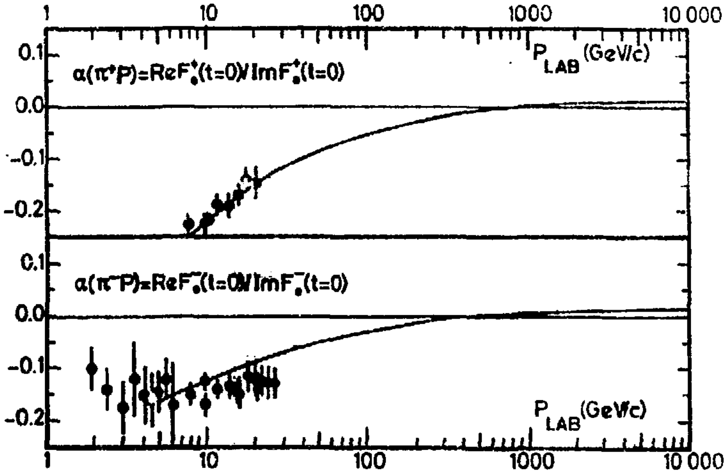
σ_{TOT}(mb)
π^-p
π^+p
NAL
P_{LAB} (GeV/c)
29
28
27
26
25
24
23
1
10
100
1000
10 000

Fig.1



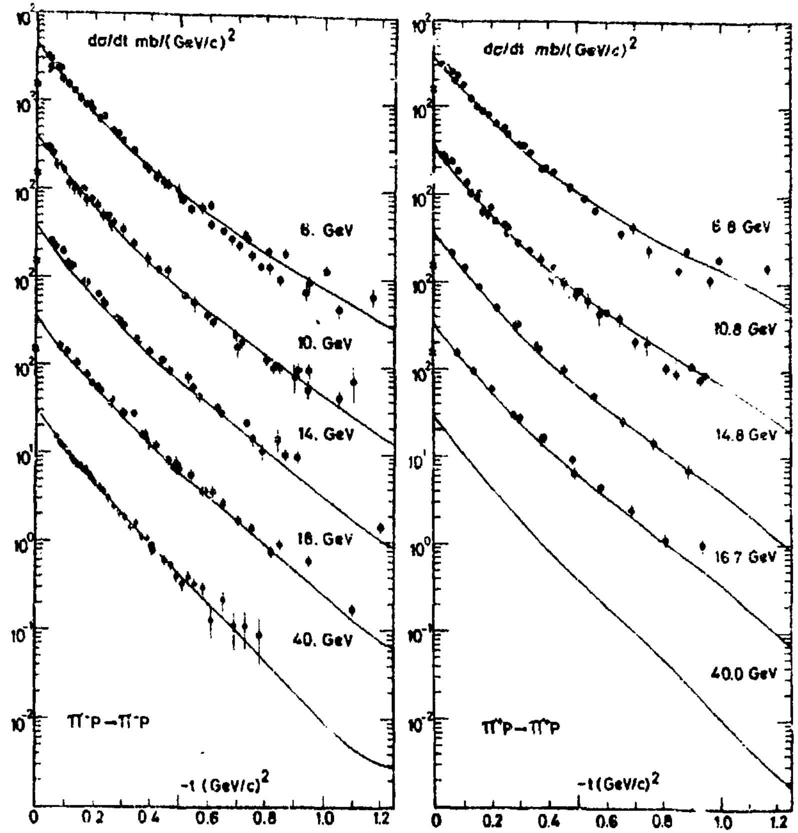
π^+p
π^-p
b $(GeV/c)^{-2}$
b $(GeV/c)^{-2}$
15
10
15
10
1
10
100
1000
10 000
P_{LAB} (GeV/c)

Fig.2



α(π⁺P)=ReF⁺₀(t=0)/ImF⁺₀(t=0)
α(π⁻P)=ReF⁻₀(t=0)/ImF⁻₀(t=0)
P_LAB (GeV/c)
1
10
100
1000
10 000
0.1
0.0
-0.1
-0.2

Fig.3



dσ/dt mb/(GeV/c)²
6. GeV
10. GeV
14. GeV
18. GeV
40. GeV
π⁻p→π⁻p
6.8 GeV
10.8 GeV
14.8 GeV
16.7 GeV
40.0 GeV
π⁺p→π⁺p
-t (GeV/c)²
0
0.2
0.4
0.6
0.8
1.0
1.2

Fig.4

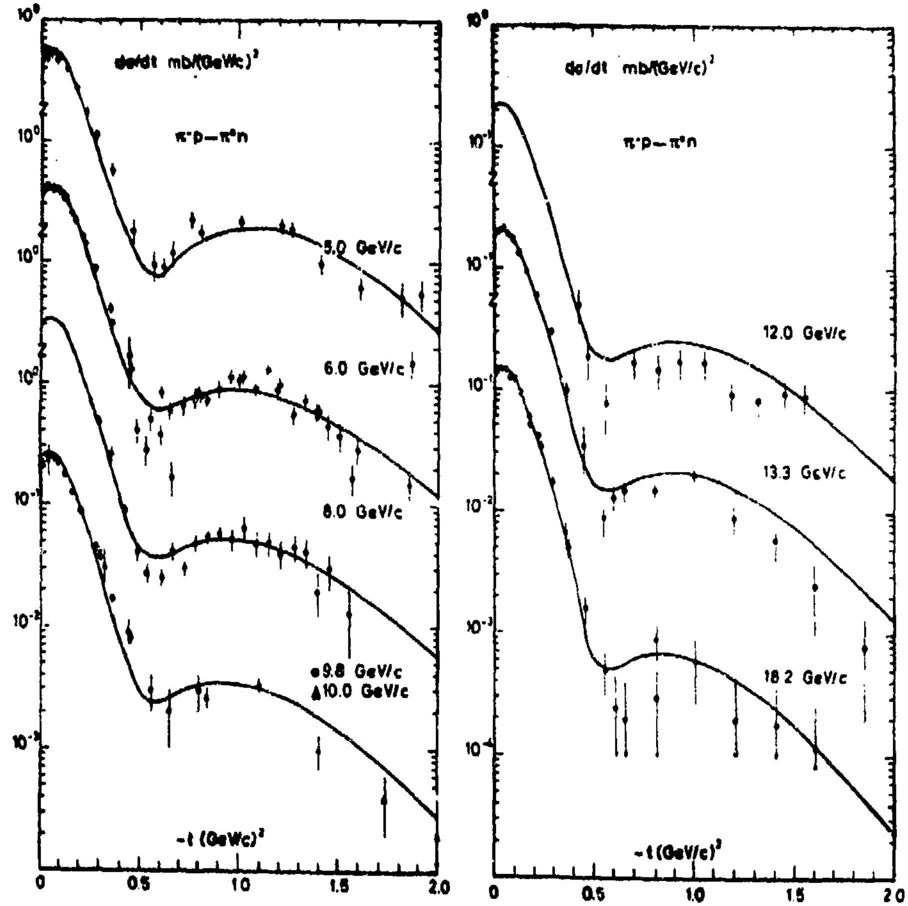

dσ/dt mb/(GeV/c)²
π⁻p → π⁰n
5.0 GeV/c
6.0 GeV/c
8.0 GeV/c
●9.8 GeV/c
▲10.0 GeV/c
-t (GeV/c)²
12.0 GeV/c
13.3 GeV/c
18.2 GeV/c
0
0.5
1.0
1.5
2.0

Fig.5

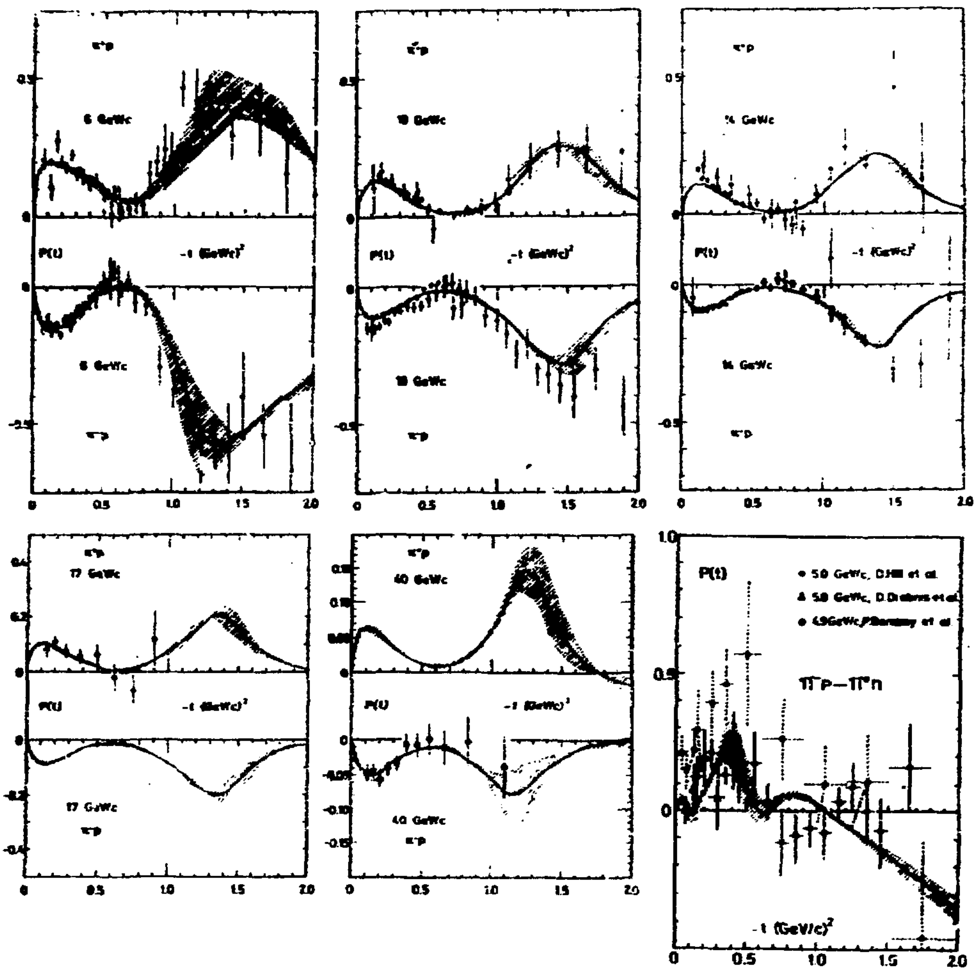


Fig.6

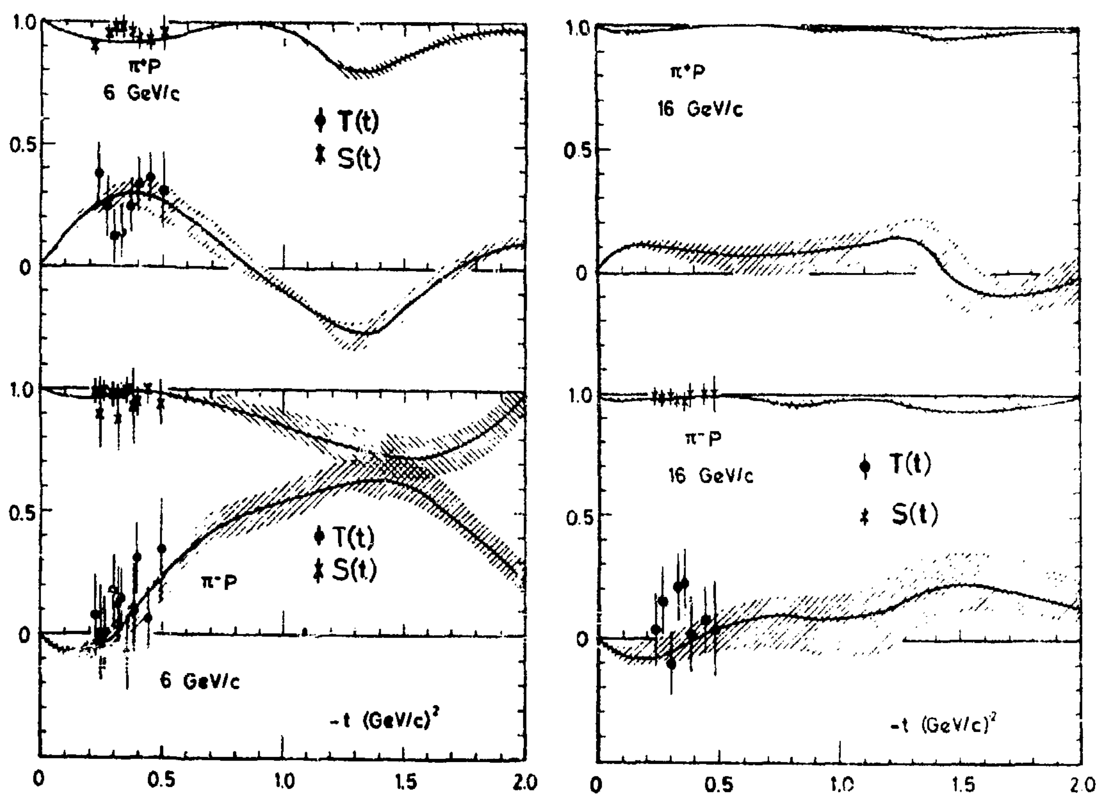
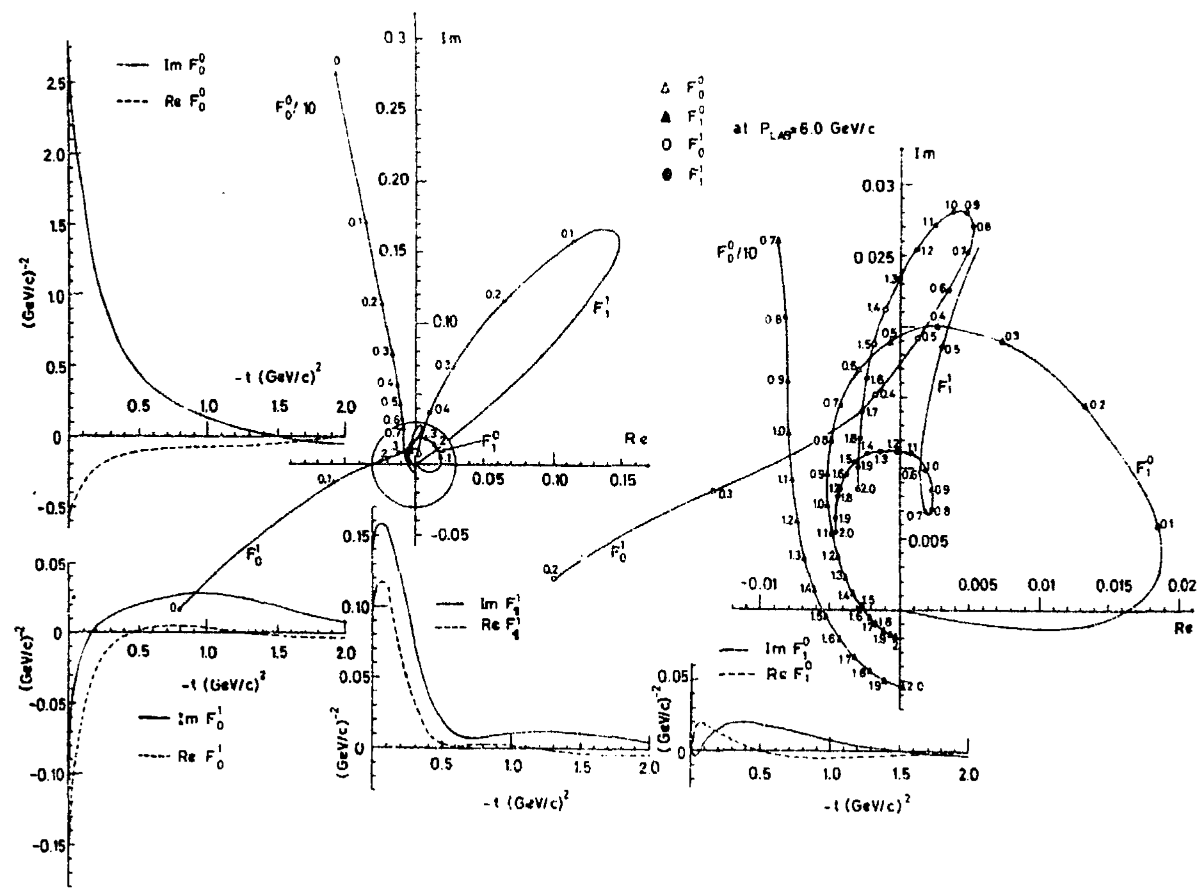

1.0
0.5
0
π^+P
6 GeV/c
T(t)
S(t)
π^-P
6 GeV/c
-t (GeV/c)^2
0
0.5
1.0
1.5
2.0
π^+P
16 GeV/c
π^-P
16 GeV/c

Fig.7



Im F_0^0
Re F_0^0
$F_0^0/10$
(GeV/c)$^{-2}$
-t (GeV/c)^2
Im
Re
F_1^1
F_1^0
F_0^1
Im F_0^1
Re F_0^1
Im F_1^1
Re F_1^1
Im F_1^0
Re F_1^0
at P_{LAB}=6.0 GeV/c

Fig. 8

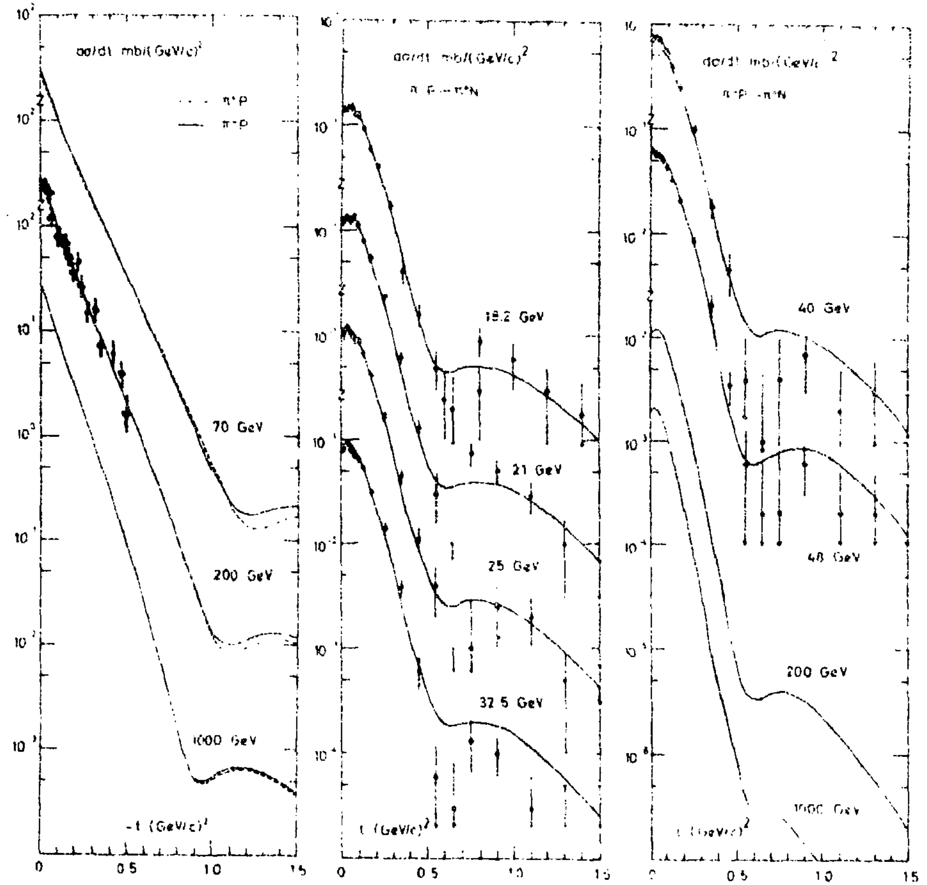

dσ/dt mb/(GeV/c)²
π⁺p
π⁻p
70 GeV
200 GeV
1000 GeV
-t (GeV/c)²
dσ/dt mb/(GeV/c)²
18.2 GeV
21 GeV
25 GeV
32.5 GeV
t (GeV/c)²
40 GeV
48 GeV
200 GeV
t (GeV/c)²
0
0.5
1.0
1.5

Fig.9

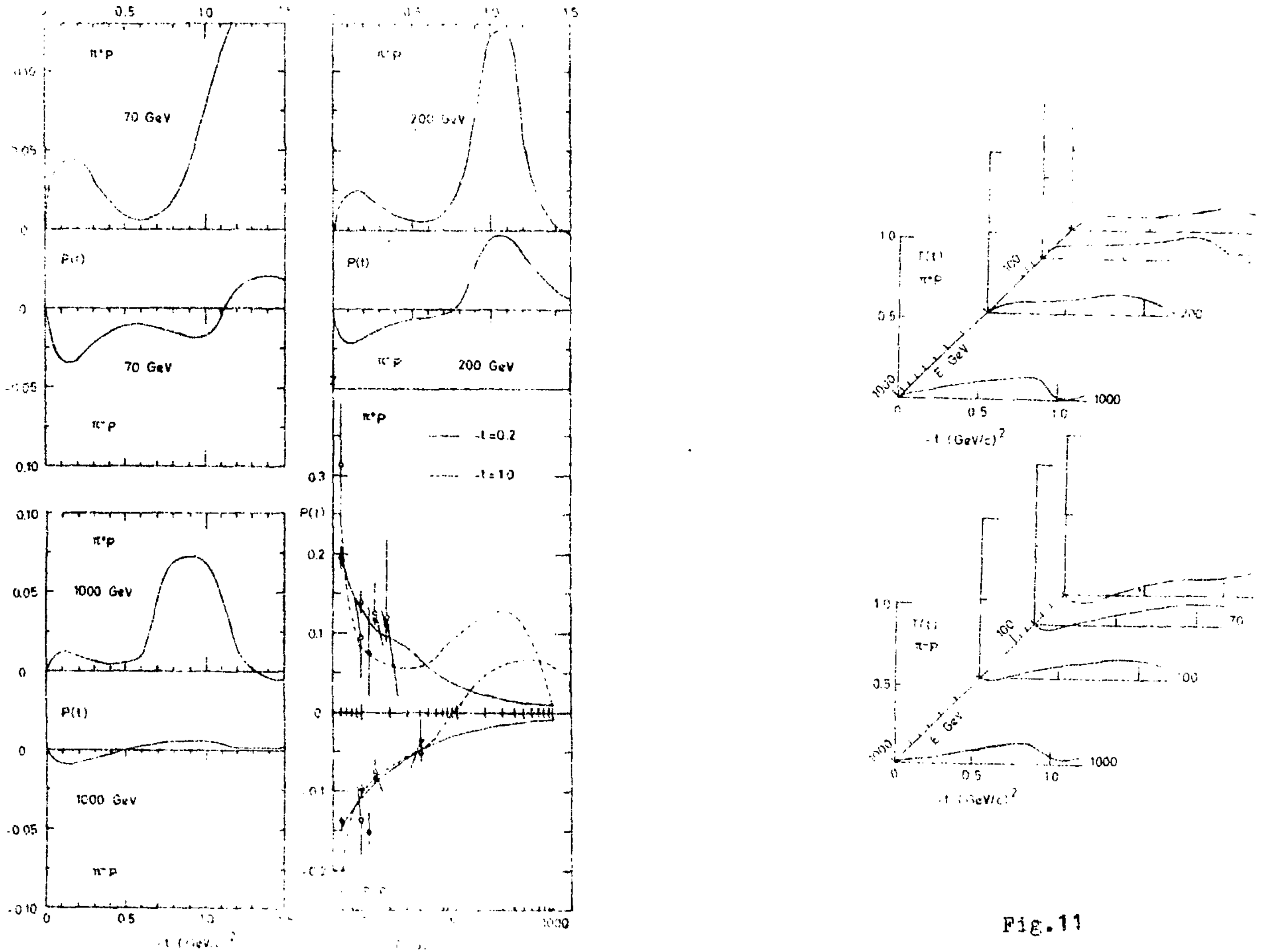

π⁺p
70 GeV
P(t)
70 GeV
π⁻p
π⁺p
200 GeV
P(t)
π⁻p
200 GeV
π⁺p
1000 GeV
P(t)
1000 GeV
π⁻p
π⁺p
-t = 0.2
-t = 1.0
P(t)
-t (GeV/c)²
T(t)
π⁺p
E GeV
-t (GeV/c)²
T(t)
π⁻p
E GeV
-t (GeV/c)²

Fig.11

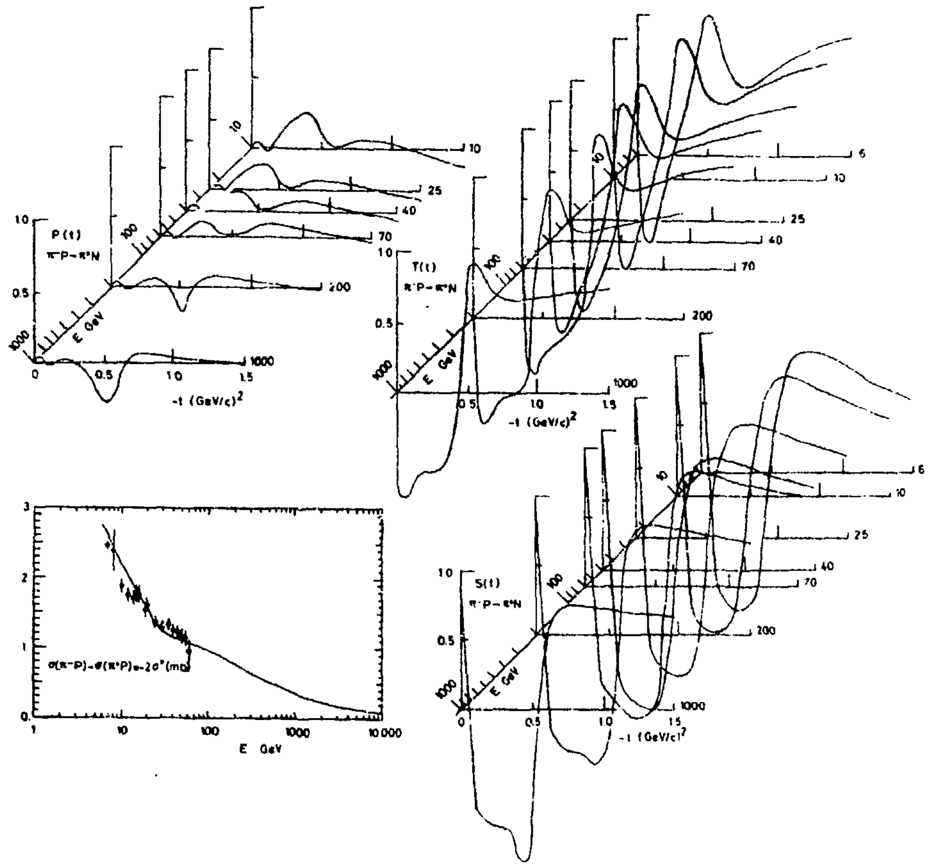


Fig.12

R E F E R E N C E S

1. F.Henyey, G.L.Kane, J Pumplin, M.H.Ross , Phys.Rev., 182, 1579 (1968); Phys.Lett., 21, 946 (1969). M.H.Ross,F.S.Henyey and G.L.Kane, Nucl.Phys. B23, 269(1970); B.J.Hartley, G.L.Kane, Phys.Lett., 39b, 531 (1972).
2. K.G.Boreskov, A.M.Lapidus, S.T.Sukhorukov, K.A.Ter-Martirosian, Yadernaya Fizika, 14, 814 (1971); Nucl.Phys., B36,566 (1972).
3. Richard C.Arnold and Mauris L.Blacman, Phys.Rev., 176, 2082 (1968).
4. H.Harari,Phys.Rev.Lett.,26,1400 (1971);A.Schwimmer, Phys.Rev. D5 ,2780 (1972); A.Martin and P.R Stevens, Phys.Rev. D5, 147, (1972); M.Ross, Phys.Lett., 38B, 321 (1972); R.C.Johnson, Phys.Lett., 38B, 325 (1972); J.W.Coleman and R.C.Johnson, Phys.Rev.D7, 3386(1973) B.J.Hartley, G.L Kane, Nucl.Phys. B57, 157 (1973), F.Schremp, Preprint DESY 71/24 (1971);
5. R.D.Fild, Preprint LBJ-33 (1971); R.W.Hanson, Phys.Rev. D7, 798 (1973); E.Leader, B.Nicolescu, Phys.Rev, D7, 836 (1973).
6. G.Girardi et al., Preprint Saclay DPh-T/72/36 (1972);G.Cohen-Tannoudji et al., Preprint Saclay DPh-T/72-6(1972).
7. G.G.Arakelian, A.P.Garyaka, A.A.Grigorian, Sh.S.Eremian, B I Lisin, Report on XVI Interp. Conf. on High Energy Phys. Chicago, Batavia, 1972.
8. Sh.S.Eremian, Scientific Report EFI -55 (74)
9. K.A.Ter-Martirosian, Pisma v Zhurn Exp. i teor Fiz, 15, 734(1972).
10. A.B.Kaidalov, Yadernaya Fizika, 13, 404 (1971).
11. K.A.Ter-Martirosian, Yadernaya Fisika, 10, 1047 (1969).
12. A.Wald Sequential Analysis, New York 1947.

13. Yu.P.Gorin et al., Yadernaya Fizika, 14, 998 (1971); Phys.Lett., 36B, 415 (1971); J.V.Allaby et al., Yadernaya Fizika, 12, 538 (1970); Phys.Lett., 30B, 500 (1969); L.M.Vasiliev et al., Phys.Lett., 36B. 528 (1971); Yu.P.Gorin et al., Yadernaya Fizika, 15,953 (1972); K.J.Foley et al, Phys.Rev.Lett., 19, 330, 859, (1967).

14. K.J.Foley et al., Phys.Rev.Lett., 11, 425 (1963); ibid, 15, 45(1965); 19, 330 (1967); Phys.Rev., 1775 (1969); O.Harting et al., Phys.Rev.Lett., 29, 1415 (1972). A.R.Dzierba et al., Phys.Rev., D7, 725 (1973), C.ambats et al., Phys.Rev.Lett. 29, 1415 (1972); Yu.M.Antipov et al, Nucl. Phys., B57, 33 (1973).

15. A.A.Nomfilov et al., Binary Reactions, Dubna, 1972 p.219 G.Giacomelli, Rapporteur's Talk at the XVI Intern.Conf.on High Energy Physics, Batavia V.3,p 292,1972.

16. Yu.P.Gorin et al., Yadernaya Fizika, 17, 309 (1973).

17. D.Bogert et al., Phys.Rev.Lett., 31, 1271 (1973).

18. K.J.Foley et al., Phys.Rev., 181, 1775 (1969).

19. G.C.Fox and C.Quigg, UCRL, 20001 (1970).

20. G.Giacomelly, Rapporteur's Talk at the XVI Intern Conf. on High Energy Physics, Batavia, V.3 p.219 (1972).

21. M.Borghini et al , Phys Lett, 31B, 405 (1970); 36B, 493(1971); C.Bruneton et al., Phys Lett., 44B, 471 (1973); J.P.Merlo, R.L.-73-008 (1973) p.67.

22. D.Hill et al. Phys.Rev.Lett., 30,239 (1973); P.Bonamy et al. Nucl.Phys., B16, 335 (1970); P.Bonamy et al., Amsterdam Inter. Conf.on Elementary Particles, 1971; D.O.Drobnis et al., Phys Rev.Lett., 20, 274 (1968).

23. A.de Lesquen et al. Phys.Lett , 40B, 277 (1972).

24. V.N.Bolotov et al. Yadernaya Fizika, 18, 1046 (1973).

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