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A STUDY OF ONE-PION EXCHANGE MODEL MATRIX ELEMENT OF THE $pp \to np\pi^+$ REACTION AT INITIAL PROTON ENERGY OF 800 MeV

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The $NN\to NN\pi$ reactions represent a traditional source of an information on strong interactions. Since a theory of strong interactions is not constructed as yet, any results of investigations of the $NN\to NN\pi$ reactions are greatly important in selecting some preferable approaches between various proposed theoretical assumptions for these interactions. It is obvious, by the way, that a possible amount of information which has to be related to the $2\to 3$ reactions (five independent kinematical variables) may be much more diverse and fundamental in comparison with that related to the $2\to 2$ reactions (two independent variables) which previously attracted a lot of attention. The very important recent achievement consists in realisation namely for reaction $pp\to np\pi^+$ of detection at the initial energy T=800 MeV in coincidence of (any) two final particles, which permits then to extract an information of differential cross section densities of the highest admissible order of differentiality $\eta=5$ [20,21], directly connected with the squared matrix element of this reaction. In what follows we analyse these new and very important data.

In tentative approaches to explain the pp-interactions at intermediate energies in the region from 0.6 to 1 GeV there exists an important problem of applicability of the one-pion exchange model (OPEM) propositions [1].

As it is known, the main idea on which the OPEM is based consists of a proposition that for the collision reactions $NN\to NN\pi$ there correspond any set of Feynman pole diagrams containing a pion as an intermediate virtual particle. Namely, it means that for the reaction

$$p+p\to n+p+\pi^+ \qquad (1)$$

there correspond four Feynman pole diagrams of Fig. 1, in which full lines represent nucleons, the dashed ones represent pions and p_1, p_2, q_2, q_1, q are 4-momenta corresponded to particles in (1), and $\mathcal{T}_i$ is πN-scattering amplitude ($i = 1,2,3,4$).

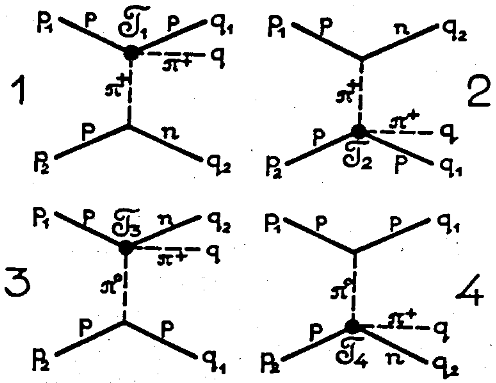

Fig. 1. Four Feynman pole diagrams corresponded to reaction (1) according to the OPEM version in /19/.

In the energy region under consideration, the applicability of the OPEM version in which every contribution from four Feynman pole diagrams of Fig. 1 and the most valuable interferences between them are taken into account, was demonstrated in refs /2-6/ especially, as an example, for reaction (1). Furthermore, the improved OPEM version /6-8,19/, in which every interferences are exactly taken into account, was used to analyse a variety of the 3-rd order experimental information consisted of the energy and/or momentum spectra of positive pions detected in reaction (1) at their different outgoing angles. The given OPEM version /19/ contains only one free parameter A entering into a function of the so-called "pion-nucleon form factor" $G(K_i^2)$, which cannot be determined in a frame of the OPEM. A shape of this function can be established by comparison with experimental data collected at any energy fixed inside a range of applicability of the OPEM basing on a statement that in the case of dominance of the one-pion exchange the form factor $G(K_i^2)$ has to depend on the transferred momentum K_i^2 only and thus not to depend on the initial energy T.

In /2-6/ it was established, that a function of the shape

$$G(K_i^2) = A\mu^2 / \left[K_i^2 + (A+1)\mu^2\right], \qquad (2)$$

where μ is pion mass, at A=8÷9 can be used to describe well the whole amount of experimental data on reaction (1) inside the initial energy range T=0.6÷1 GeV. Namely, the general result of comparison of the improved OPEM version /19/ with the

experimental data for ${}^3\sigma_\pi^L$ at T=660, 730, 800, 991 and 1000 MeV /4,5,9,13-18/ claims that within the 10-15% accuracy at A=9 in (2) a good agreement with experiment is stated, i.e. the "pion-nucleon form factor" extracted from experimental data has the following shape /2-6,19/:

$$G(K_i^2) = 9\mu^2 / (K_i^2 + 10\mu^2)\ . \qquad (3)$$

New and the most important stage in studying reaction (1) starts with collecting the experimental data of the 5-th order of differentiality which directly correspond to the squared matrix element $|\mathcal{M}_{fi}|^2$ of the $pp \to np\pi^+$ reaction. Therefore, our OPEM version /19/, which has successfully described the 3-rd order data in the energy range T=0.6-1.0 GeV, was also used /22,23/ to analyse a new set of the 5-th order experimental data up to now collected only at T=800 MeV /20,21/. The 5-th order data collected in /20,21/ contains 16 measurements when in coplanar geometry there were detected in coincidence final protons and positive pions produced in reaction (1) and there are obtained the 5-th order distributions

$$ {}^5\sigma_{p\pi}^{L\,exp} \equiv d^5\sigma / dq_p^L\, d\cos\Theta_p^L\, d\cos\Theta_\pi^L\, d\varphi_p^L\, d\varphi_\pi^L \simeq \qquad (4)$$
$$ \simeq \{\text{phase space density}\} \cdot |\mathcal{M}_{fi}|^2 $$

at fixed angles Θ_p^L, φ_p^L for protons, and $\Theta_\pi^L, \varphi_\pi^L$ for pions within their "smearing" accuracies of ±3°.

For every experimental distribution ${}^5\sigma_{p\pi}^{L\,exp}$ we have calculated nine theoretical functions ${}^5\sigma_{p\pi}^{L\,theor}$ corresponding to the pair of angles $(\Theta_p^L, \Theta_\pi^L)^{exp}$ and their "smearing" limits equal to ±3°. A part of our calculation is shown in Figs 2 and 3. As a result, it follows that:

a) inside the given ranges of angles there are considerable variations in magnitude and positions of maxima for ${}^5\sigma_{p\pi}^{L\,theor}$;

b) inside the given "smearing" limits ±3° for every ${}^5\sigma_{p\pi}^{L\,exp}$ measured in /20/ and /21/ there are some calculated functions ${}^5\sigma_{p\pi}^{L\,theor}$ which are near by their behaviour and magnitudes to the experimental one;

c) by such a way of analysis, from our calculations related to the 5-th (i.e. maximal) order data and, therefore, to the matrix element squared of the reaction (1), an applicability of

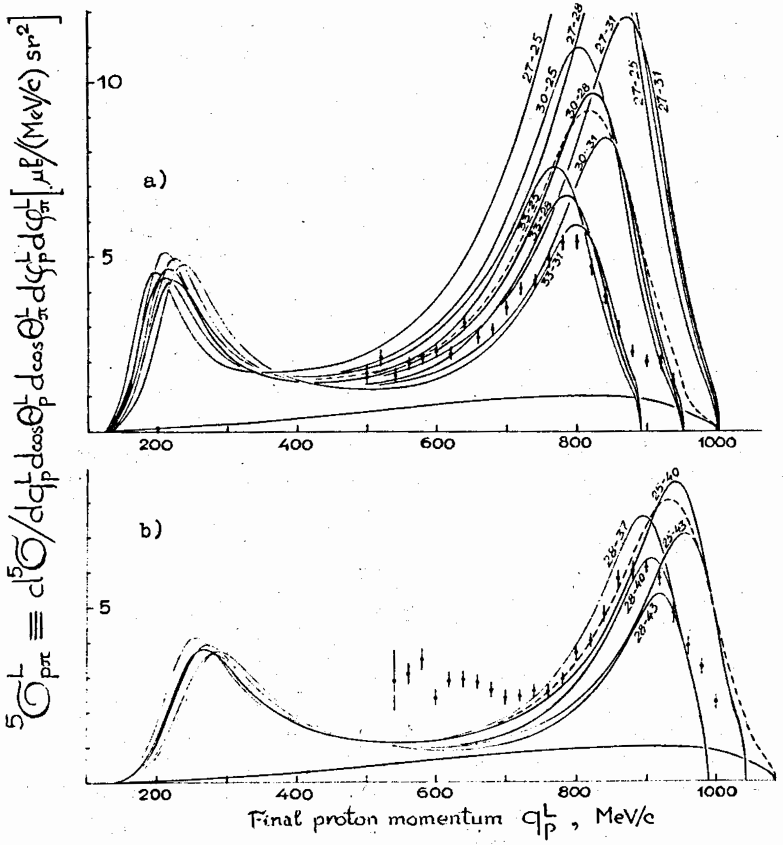

Fig. 2. Comparison of results of our OPEM calculations with the 5-th order experimental data obtained in ref. /20/: a) the experimental distribution $^5\sigma^{L\,exp}_{p\pi}$ obtained by measuring $p\pi$-coincidences at $\Theta^L_p=30^o$ and $\Theta^L_\pi=28^o$, and nine theoretical curves calculated taking into account the "smearing" limits of $\pm 3^o$, b) another distribution for $\Theta^L_p=25^o$ and $\Theta^L_\pi=40^o$ and theoretical curves which are the most close to experimental distribution. Two dashed curves are the averaged values $\{^5\sigma^{L\,theor}_{p\pi}\}_{Av}$.

our OPEM version and, consequently, a dominant contribution of one-pion exchange are clearly shown;

d) the results of calculations in ref. /21/ mentioned there as related to "peripheral model" sharply disagree with experimental data and cannot be reconciled with our calculations

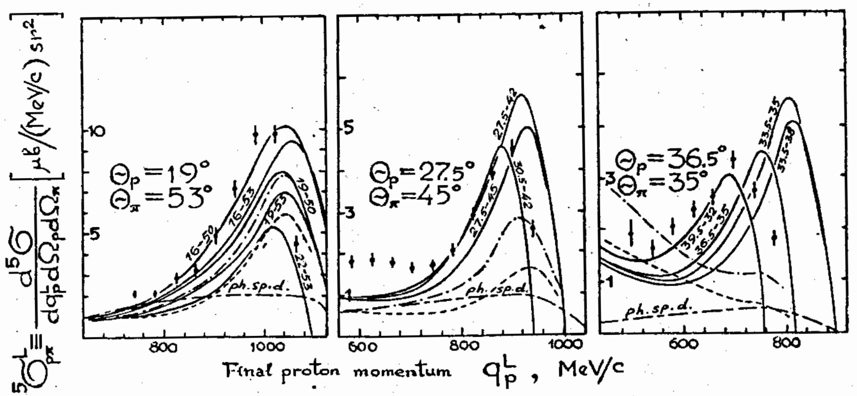

Fig. 3. Our theoretical distributions analogous to those in Fig. 2 represented in comparison with experimental data of ref. /21/. Dashed curves are calculations in accord to "peripheral model" proposed in ref. /21/. Dot-dashed curves contain an input of dibarion intermediate state/21/.

according to the improved OPEM version /19/ (see Fig. 3);

e) the previously extracted "pion-nucleon form factor" $G(K_i^2)=9\mu^2/(K_i^2+10\mu^2)$ can be also reconciled with the recent 5-th order experimental information /20,21/.

Also, we have to mention that to extract the so-called "pion-nucleon form factor" $G(K_i^2)$ it is necessary to know the "off-shell correction function" $\Gamma(K_i^2)$ included in the amplitude $\mathcal{T}_i$. Because throughout all our calculations only 33-amplitude of πN-scattering was taken into account in $\mathcal{T}_i$, we have used the off-shell correction $\Gamma_{33}(K_i^2)$, derived in ref. /11/ using dispersion relations corresponding to the case (see Fig. 4). Earlier it was shown /6/ that an approximation of taking into account the 33-amplitude only does not exceed few percents.

The important result of study presented consist in that, in particular for reaction (1), using the 33-amplitude approximation and experimental data of all admissible orders, it is possible to maintain successive and complete differential analysis resulted in extraction of the "pion-nucleon form factor" $G(K_i^2)=9\mu^2/(K_i^2+10\mu^2)$ which reflects the behaviour of strong interactions in pp-collisions at "large" distances and can be used in constructing QCD models for confinement problem.

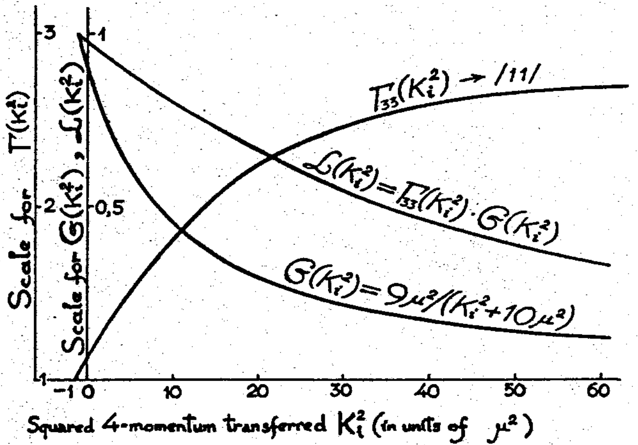

Fig. 4. Behaviour of the "off-shell" correction function $\Gamma_{33}(K_i^2)$ derived in ref. /11/, the pion-nucleon form factor $G(K_i^2) = 9\mu^2/(K_i^2+10\mu^2)$ and the function $\mathcal{L}(K_i^2)=\Gamma_{33}(K_i^2)\cdot G(K_i^2)$ represented in dependence on the 4-momentum squared K_i^2, transferred to virtual pion according to diagrams of Fig. 1.

Finally, it is convenient to stress that the widespread opinion that one-pion exchange mechanism cannot contribute at "small" distances (that correspond to high momenta) is not confirmed by behaviour of the form factor $G(K_i^2)$ extracted here. Namely, from (3) it follows that for reaction (1) at T=1 GeV for the highest admissible 4-momentum value $K_{i\,max} \simeq 8.5\mu =$ 1300 MeV/c (that corresponds to distance ~0.2 fm) the magnitude of $G(K_{i\,max}^2)$ is not smaller than 10%.

So, it is clearly shown that in the given region of intermediate energies from 0.6 up to 1 GeV our OPEM version /19/ can be effectively used to explain the experimental data of any admissible order. As a consequence, agreement of our OPEM version with experiment and behaviour of the pion-nucleon form factor $G(K_i^2)$ extracted by us from a lot of experimental data means that the one-pion exchange mechanism for reaction (1) dominates elsewhere for any permissible values of the squared 4-momentum transferred to a virtual pion K_i^2 from 0 up to its upper limit $K_{i\,max}^2 \simeq 70\mu^2$ at T = 1 GeV.

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