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Evidence for two pion-pion resonances

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Recent experimental evidence for the detailed behaviour of the total $\pi^+ - p$ cross-section (σ^+) with energy has appeared¹⁾.

In this note we want to point out that a careful analysis of the existing experimental information on high energy $\pi^+ p$ scattering suggests the existence of two pion-pion resonances in the isotopic spin states $I=1$ and $I=2$. First of all we will discuss the 0.9 BeV maximum in σ^- .

We will see that the only explanation of it, which does not contradict any existing experimental fact is in terms of a strong pion-pion interaction in the $I=1$ state, in full agreement with current theoretical ideas²⁾.

Noting furthermore the striking similarity between this maximum and the one in σ^+ at 1.3 BeV, we will deduce that also a $I=2$ $\pi\pi$ resonance should exist.

Maximum in σ^- at 0.9 BeV - Elastic and inelastic cross-sections for $\pi^- p$ scattering show both a maximum at 0.9 BeV³⁾. Our discussion will be concerned only with the inelastic part. In view of the experimental angular distributions⁴⁾ it seems reasonable to believe that the bump in the elastic part is nothing but diffraction scattering. Whether it is so or not, is, however, unimportant for our interpretation of the inelastic part. The latter is $\sim 85\%$ composed of single pion production^{5), 3)} and our discussion will thus regard only this process.

The idea that the 0.9 BeV maximum in σ^- is due to the $\pi\pi$ interaction is an old one, and was firstly suggested by Piccioni. Dyson⁶⁾ noted that a $I=0$ resonance for the $\pi\pi$ system would have had no effect at all on $\pi^+ p$ scattering while it could have enhanced strongly the $\pi^- p$ total cross-section. Takeda⁷⁾ remarked that also a $I=1$ resonance could have explained the 0.9 BeV hump. Indeed it would have scarcely influenced the behaviour of σ^+ .

Fig. 1

The simple model that the incoming meson hits a meson of the cloud and shakes it off without any further interaction (see Fig.1) permitted definite predictions to be made both on the branching ratios for single pion production and on the qualitative behaviour for the spectra of the final state particles (for example a maximum in the c.m. energetic spectrum of the nucleons, corresponding to the formation of the pion-pion isobar, was expected). More detailed experimental analysis⁸⁾ completely disproved these predictions, while on the other hand fully confirmed the predictions of the Lindenbaum-Sternheimer isobar model⁹⁾. This seemed to rule out a strong contribution of pion-pion interaction to single pion production. In favour of this explanation there remained the fact that the radius of the nucleon considered as an absorbing sphere was found to be of the same order of the Compton wave length of the π -meson⁴⁾. Let us see now how a careful analysis of experiments brings to the conclusion that the $\pi\pi$ interaction must be responsible of the 0.9 BeV maximum. The known features about π^-p scattering at these energies are

- i) Isobar model predicts energetic spectra in good agreement with the experimental ones, especially for the reaction

- ii) Evidence of a contribution from the diagram of fig. 1 to the process

has been found^{10),11)}.

- iii) At 1 BeV reaction (2) has a cross-section of ~ 7 mb. In it the diagram of Fig. 1 plays an important role¹¹⁾. Roughly speaking one can say that its contribution is surely more than 50 % at this energy.
- iv) At the same energy no evidence at all in favour of this diagram is found in the case of reaction (1)¹²⁾.

It is not difficult to understand that the idea that only $\pi\pi$ interaction contributes to pion production is not necessarily in disagreement with the fact that the 3,3 isobar model seems to explain experimental facts. Indeed let us suppose that the primary interaction has taken place in the cloud. The wave length of the final state pions is much bigger than that of the incoming one because there has been a loss of energy in the production of one pion and because the energy is now divided on three particles. It happens that the relative energy of each pion and the nucleon is in the range where the 3,3 resonance dominates. Furthermore the wave packets of the pions have such dimensions that they partially overlap upon the nucleon core, immediately after having been produced. Thus a secondary interaction between the pions and the nucleon is to be expected and it is not surprising that the 3,3 isobar model gives a good description of the experimental data. If this idea works, however, we do not expect the 3,3 final state interaction always to be present. From the above picture it follows indeed that the two pions have a certain probability of interacting, but also a certain probability of not having any further interaction with the nucleon, the latter being greater when the strength of the pion-nucleon interaction is smaller. Thus we expect that of the two reactions (1) and (2) the second would be more suitable for the observation of the simple Dyson-Takeda $\pi\pi$ interaction (i.e. a $\pi\pi$ interaction without final state interaction) owing to the fact that in the final state of the first reaction the π^-n system is in the pure isotopic spin $\frac{3}{2}$ and thus has a much bigger probability of interacting. All this is in full qualitative agreement with points ii) - iv).

Let us now refer to Fig. 1 and discuss the probability of having the incoming and virtual mesons in different isotopic spin states, starting from the initial π^+p systems. As it has been shown in ¹⁰⁾ the cross-section predicted by this diagram is

$$\frac{\partial^2 \sigma}{\partial \Delta^2 \partial w^2} = \alpha \sigma_{\pi\pi}(w) F(w^2, \Delta^2) \quad (3)$$

where Δ is the 4-momentum transfer to the nucleon, w is the total energy of the two π 's in their c.m.s., $\alpha = 2$ (1) if in the lower vertex a charged (uncharged) pion is emitted, $\sigma_{\pi\pi}$ is the total $\pi\pi$ cross-section, $F(w^2, \Delta^2)$ is a function independent from the charge states of the pions. The various $\pi\pi$ cross-sections for "physical" processes can be written in terms of cross-sections for pure isotopic spin states in this way

$$\sigma(\pi^+ + \pi^+ \rightarrow \pi^+ + \pi^+) = \sigma_2 \quad (4)$$

$$\sigma(\pi^\pm + \pi^0 \rightarrow \pi^\pm + \pi^0) = \frac{1}{4} \sigma_2 + \frac{1}{4} \sigma_1 + \frac{1}{2} \sqrt{\sigma_2 \sigma_1} \cos \theta_{21} \quad (5)$$

$$\begin{aligned} \sigma(\pi^- + \pi^+ \rightarrow \pi^- + \pi^+) &= \frac{1}{36} \sigma_2 + \frac{1}{4} \sigma_1 + \frac{1}{9} \sigma_0 + \frac{1}{6} \sqrt{\sigma_2 \sigma_1} \cos \theta_{21} + \frac{1}{9} \sqrt{\sigma_2 \sigma_0} \cos \theta_{20} + \\ &+ \frac{1}{6} \sqrt{\sigma_1 \sigma_0} \cos \theta_{10} \end{aligned} \quad (6)$$

$$\sigma(\pi^- + \pi^+ \rightarrow \pi^0 + \pi^0) = \frac{1}{9} \sigma_2 + \frac{1}{9} \sigma_0 - \frac{2}{9} \sqrt{\sigma_2 \sigma_0} \cos \theta_{20} \quad (7)$$

where σ_a is the cross-section for the $I=a$ state and θ_{ab} is the phase difference between the amplitudes for $I=a$ and $I=b$ states. The θ 's are chosen so as to satisfy $\theta_{21} + \theta_{20} + \theta_{10} = 0$. In the following table the values of the cross-sections for single pion production as obtained from (3) - (7) are given, in the extreme case where only one isotopic spin state is important. The quantity $J_I = \int \sigma_I(w) F(\Delta^2, w^2) d\Delta^2 dw^2$ is taken as unit.

TABLE 1

	J_I as unit		
	only $I=0$	only $I=1$	only $I=2$
$\sigma(p^+ \rightarrow n^{++})$	0	0	2
$\sigma(p^+ \rightarrow p^{+0})$	0	$\frac{1}{4}$	$\frac{1}{4}$
$\sigma(p^- \rightarrow n^{+-})$	$\frac{2}{9}$	$\frac{1}{2}$	$\frac{1}{18}$
$\sigma(p^- \rightarrow p^{-0})$	0	$\frac{1}{4}$	$\frac{1}{4}$
$\sigma(p^- \rightarrow n^{00})$	$\frac{1}{9}$	0	$\frac{1}{9}$

As it is easily seen from the preceding table if we want a big effect on σ^- only we are forced to take the $\pi\pi$ interaction in the $I=1$ state, the possibility of it being in $I=0$ being ruled out by the fact that point ii) could not have been observed in reaction (2). In this case, however, an effect is expected also on σ^+ . This could be in agreement with the fact that a smaller bump in σ^+ seems to exist at 0.9 BeV¹⁾.

We note that if the existence of this bump should be confirmed it would constitute another strong evidence in favour of $\pi\pi$ interaction in the sense that it would exclude the cause of the 0.9 BeV bump in σ^- to be in the $I=\frac{1}{2}$ state of the pion nucleon system. Thus the idea that the inelastic channel for π^-p scattering goes mainly through the diagram of fig. 1 followed by a possible final state interaction is in qualitative agreement with all the experimental data listed above. We will now see that such an agreement cannot be given by other possible explanations.

One can imagine that the pion production goes through different channels one of which given by fig. 1 (the inclusion of the latter is necessary to get agreement with point ii)), and that the validity of isobar model is determined not by final state interaction effects, but by the contribution of other channels. Once one has given up the possibility of final state interaction to explain points iii) and iv) one is obliged to assume that the $\pi\pi$ interaction is much stronger in the state $I=2$ as in the other states (see table 1). We can say that if the diagram of fig. 1 could act alone at 1 BeV it would give a cross-section of at least 4 mb for the reaction (2). But then its contribution to the reaction

should be of about 32 mb (see table 1) which is surely in disagreement with the total σ^+ of 28 mb. Thus it is not possible to assume that the part of the inelastic channel going through the diagram of fig. 1 is determined by a strong $I=2$ $\pi\pi$ interaction. The state $I=0$ is excluded because it could not affect reaction (2). There remains only $I=1$. But in this state as it results from table 1, the $\pi\pi$ interaction should give a double contribution to reaction (1), in disagreement with point iv). Thus the many channels model gives always a contradiction with the experimental facts. All the above discussion is in our opinion rather convincing in favour of the proposed model that only diagram of fig. 1 is responsible for the inelastic bump at 0.9 BeV, once one has included possible final state interactions in it. Detailed calculations in this sense are being carried out.

Maximum in σ^+ at 1.3 BeV. The first experimental evidence indicates a striking similarity between this maximum and the one at 0.9 BeV in σ^+ . In fact it is essentially composed of inelastic scattering and the elastic differential cross-section shows a forward diffraction-like peak giving for the nucleon radius 1 fermi, that is to say a value very similar to the Compton wave-length of the pion¹³⁾. Also if direct experimental evidence of $\pi\pi$ interaction is lacking here, let us suppose that this interaction is responsible for this bump. It follows then from table 1 that this interaction must be particularly strong in the $I=2$ state.

To say something about the energy of this resonance let us again discuss before the 0.9 BeV bump in σ^- . One may suspect the maximum of σ^- to be strongly determined by the position of the $\pi\pi$ resonance. If one assumes that this maximum is attained when the cross-section has the maximum average value one gets the result that the position of the T=1 $\pi\pi$ resonance must be 4.8μ (μ = meson mass) in full agreement with the values deduced by the structure of the nucleon¹⁴⁾ and by the spectra of the nucleons in π production¹¹⁾. Thus one is tempted to do the same for the 1.3 BeV σ^+ bump. The result being

$$w^{\text{res.}} = 6.4 \mu$$

If such a resonance exists it could not have any direct effect neither on pion-nucleon and nucleon-nucleon elastic scattering, nor on the electro-magnetic structure of the nucleon, in the sense that a nucleon cannot undergo the virtual emission of a system with I=2. However the following experimentally detectable effects are to be expected.

1. No bump corresponding to the one at 1.3 BeV in π^+p scattering should be found in the cross-section for double photoproduction.
2. An experiment of single pion production in pion-nucleon collision around 1.3 BeV analysed as done in¹⁰⁾, should give a strong evidence of $\pi\pi$ interaction for the events

$$\pi^+ + p \rightarrow n + \pi^+ + \pi^+$$

due to the fact that energetic and isotopic-spin considerations exclude in this case the final state interaction to be important.

Furthermore the branching ratio
$$R = \frac{\sigma(p^+ \rightarrow n^{++})}{\sigma(p^+ \rightarrow p^{+0})}$$

is expected to be rather bigger than 1. The simple diagram of fig. 1 with the $\pi\pi$ interaction in I=2 would give R=8, but the final state interactions and the still important effect of the I=1 resonance could considerably lower it. This prediction is very different from those of the isobar model ($R = \frac{2}{13}$) and of the statistical theory ($R = \frac{2}{3}$).

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R E F E R E N C E S

- 1) T.J. Devlin et al., Phys. Rev. Letters 4, 242 (1960).
- 2) G.F. Chew and S. Mandelstam, UCRL 8728.
W.R. Frazer and J.R. Fulco, Phys. Rev. Letters 2, 365 (1959).
W.R. Frazer and J.R. Fulco, UCRL 8880.
- 3) R.R. Crittenden et al, Phys. Rev. Letters 2, 121 (1959).
- 4) A.R. Erwin and J.K. Kopp, Phys. Rev. 109, 1364 (1958).
- 5) V. Alles-Borelli et al, Nuovo Cimento 14, 211 (1959).
- 6) F.J. Dyson, Phys. Rev. 99, 1037 (1955).
- 7) G. Takeda, Phys. Rev. 100, 440 (1955).
- 8) e.g. see ref. ⁵⁾.
- 9) R.B. Sternheimer and S.J. Lindenbaum, Phys. Rev. 109, 1723 (1958).
- 10) F. Bonsignori and F. Selleri, Nuovo Cimento 15, 465 (1960).
- 11) I. Derado, Nuovo Cimento, to be published.
- 12) I. Derado, private communication.
- 13) L.O. Roellig and D.A. Glaser, Phys. Rev. 116, 1001 (1959).
- 14) J. Bowcock, W.N. Cottingham and D. Lurié, Nuovo Cimento, to be published.