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C.Besliu, A.P.Ierusalimov, F.Kotorobai,
V.I.Moroz, A.V.Nikitin, D.Pantea,
V.N.Pechenov, A.P.Stelmakh, Yu.A.Troyan

MULTIQUARK RESONANCES IN np-INTERACTIONS AT ENERGIES OF (1-5) GeV

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In this paper we study resonances in various systems with baryon numbers equal to 2,1,0. As will be shown below, these resonances are characterized by narrow widths. They are evidently produced by the mechanism of baryon exchange. All the resonances under study have an exotic set of quantum numbers and can be considered as a system consisting of more than three quarks.

Data have been obtained in an exposure of the 1m HBC of the Laboratory of High Energies of the Joint Institute for Nuclear Research to monochromatic neutrons with various energies from the synchrophasotron. The momentum spread of incident neutrons is no more than 3% [1] for all energies.

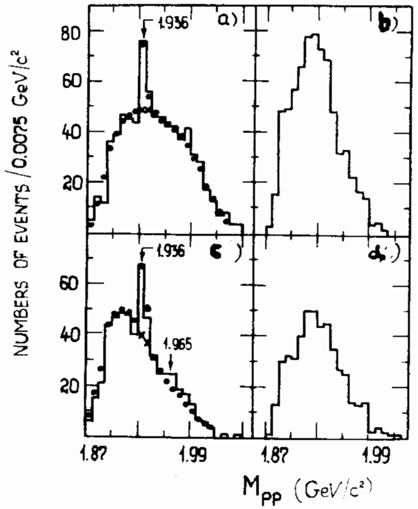
1. DIBARYON RESONANCES

The study of resonances in a two-nucleon system is described in a number of papers. Some of the experiments have been carried out using electronic methods with an investigation of the behaviour of the scattering cross sections of polarized protons, the reaction of deuteron photodesintegration, the energetic behaviour of the reaction $\pi^+ d \to pp$ and so on. The conclusion of all these experiments based on the use of phase analysis lies in an evidence for the existence of four resonances in a two-proton system with masses near 2.14-2.50 GeV/c^2 and widths of 50-200 MeV/c^2. A detailed survey of this type experiments is given in paper [2].

Another group of experiments is concerned with a direct observation of the effective masses of two protons produced in hadron-nucleus interactions. These studies have been carried out by chamber method using chambers having different fillers and various hadron beams. Peculiarities are observed in the effective mass distributions of two protons with widths from 5 to 50 MeV/c^2. To explain the effects, various mechanisms are used because it is difficult to interpret unambiguously the data obtained in nuclear interactions. To acquaint oneself with the situation, it would be useful to pay attention to papers [3,4], which have detailed references to the experiments performed in this way.

In this paper we present first results of a study of the effective masses of two protons from the reaction $np \to pp\pi^-$ at

Fig.1. The effective mass distribution of two protons from the reaction $np \to pp\pi^-$ at $P_n = 1.25$ GeV/c; a) events with $\Delta^2_{n\to\pi^-} < -0.45$ (GeV/c^2)^2; b) events with $\Delta^2_{n\to\pi^-} >$ > -0.45 (GeV/c); c) events with $x^*_{\pi^-} > 0.1$; d) events with $x^*_{\pi^-} < 0.1$. Dots - approximation curve, crosses - background.



$P_n = 1.25$ GeV/c (1448 events) and $P_n = 2.23$ GeV/c (2678 events) and from the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ at $P_n = 5.10$ GeV/c (3684 events).

Figure 1a shows the effective mass distribution of two protons from the reaction $np \to pp\pi^-$ at $P_n = 1.25$ GeV/c. This distribution is constructed on condition that the 4-momentum transfer squared from incident neutron to π^--meson $\Delta^2 = -(E^*_n - E^*_{\pi^-})^2 + (P^*_n - P^*_{\pi^-})^2$ is smaller than -0.45 (GeV/c^2)^2. All values are calculated in the c.m.s.

Figure 1b shows the effective mass distribution of two protons for the events with $\Delta^2 > -0.45$ (GeV/c^2)^2. If a sharp peak is observed for a mass of 1936 MeV/c^2 in fig.1a, no peculiarities are observed in fig.1b.

Figure 1c shows the M^{eff}_{pp} distribution of the events with $x^*_{\pi^-} = P^*_{\pi^-} / P^*_n$ greater than 0.1.

Figure 1d shows the same distributions for the events with $x^*_{\pi^-} < 0.1$. The peak with a mass of 1936 MeV/c^2 is observed only in fig.1c. The analysis of the double-plot distribution of Δ^2 versus $x^*_{\pi^-}$-confirms an agreement between the limits of Δ^2 and $x^*_{\pi^-}$ ($\Delta^2 < -0.45$ corresponds to $x^*_{\pi^-} > 0.1$).

Thus, one can conclude that the sharp resonance is observed in the two-proton system for the events with a large modules of 4-momentum transfer squared from incident neutron to π^--meson (or, the same, from proton-target to the system of two final protons).

The effective mass distribution was approximated by the resonance curve taken in the Breit-Wigner form and by the background curve constructed of a phase space curve (35%) and a curve obtained from the OPER-model [5] (65%). The result of the approximation is shown in fig.1 by dots; the background is denoted by crosses.

The values of the mass and the experimental width of the resonance $M_{res} = (1932 \pm 2)$ MeV/c^2 and $\Gamma^{exp}_{res} = (6 \pm 1.4)$ MeV/c^2, respectively, have been calculated using the maximum likelihood method. The experimental resolution was $\Gamma^{resol} = 6$ MeV/c^2 in the case of using the mass resolution function in the Breit-Wigner form for the approximation. Then the real width of the resonance was $\Gamma^{real}_{res} = (0.0 \pm 1.4)$ MeV/c^2.

The production cross section of the resonance having a mass of 1936 MeV/c^2 was (63 ± 18) μb for the total cross section of the reaction $np \to pp\pi^-$ equal to (1.45 ± 0.06) mb at $P_n = 1.25$ GeV/c.

Figure 2 shows the effective mass distributions of two protons from the reaction $np \to pp\pi^-$ at $P_n = 2.23$ GeV/c. The events with $|x^*_{\pi^-}| < 0.15$ are shown in fig.2a; and the events with $|x^*_{\pi^-}| > 0.15$, in fig.2b. The average values of the modulus of 4-momentum transfer squared from incident neutron to π^--meson $|\Delta^2|$ are equal to 0 for the first case and 0.5 (GeV/c^2)^2 for the second one.

The distribution in fig.2a is well described by the background curve constructed of a curve obtained from the OPER-model (85%) and a curve from the process of diffractive production and decay of the isobar with a mass of 1470 MeV/c^2 and a width of 200 MeV/c^2 (15%).

The peak for a mass of 1960 MeV/c^2 is clearly observed in fig.2b. The approximation by the above background and the Breit-Wigner curve (the result of the approximation pictured by dots) gives $M_{res} = (1965 \pm 2)$ MeV/c^2 and $\Gamma^{exp}_{res} = (9.0 \pm 2.0)$ MeV/c^2. The experimental resolution is equal to $\Gamma^{resol} = 8$ MeV/c^2. Then the real width of the resonance is $\Gamma^{real}_{res} = (1.0 \pm 2.0)$ MeV/c^2. The production cross section of the resonance is $\sigma_{res} = (48 \pm 14)$ μb for the total cross section of the reaction $np \to pp\pi^-$ equal to (3.41 ± 0.18) mb at $P_n = 2.23$ GeV/c.

Figure 3 shows the effective mass distribution of two protons from the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ at $P_n = 5.10$ GeV/c. Figure 3a is for the events with $\Delta^2_{n\to\Sigma\pi} < 2$ (GeV/c^2)^2 and figure 3b for the events Δ^2 greater than 2 (GeV/c^2)^2. The distribution in fig.3a is rather well described by the background curve (except a small difference near masses of 1936 and 1960 MeV/c^2). A sharp peak is observed in fig.3b near a mass of 1960 MeV/c. The maximum likelihood method gives $M_{res} = (1959 \pm 2)$ MeV/c^2 and $\Gamma^{exp}_{res} = (6.5 \pm 2.0)$ MeV/c^2 for this resonance that leads to the real width of the resonance $M^{real}_{res} = (0 + 2)$ MeV/c^2 at $\Gamma^{resol} = 6.5$ MeV/c^2. The approximation by the resonance curve in the Breit-Wigner form and by the background curve (denoted by crosses) gives $\sigma_{res} = (3.9 \pm 1.1)$ μb for the production cross section of the resonance at the total cross section of the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ equal to (0.39 ± 0.03) mb at $P_n = 5.10$ GeV/c.

The simulated background consists of a number of subprocesses, via which the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ proceeds (this is

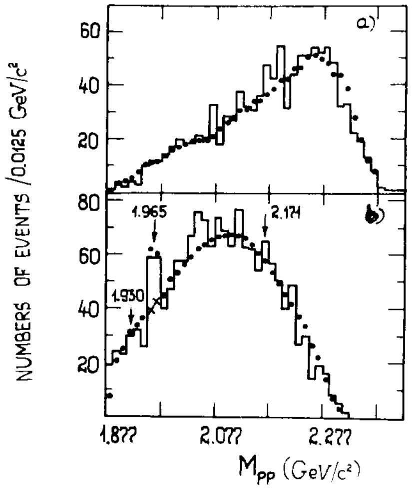
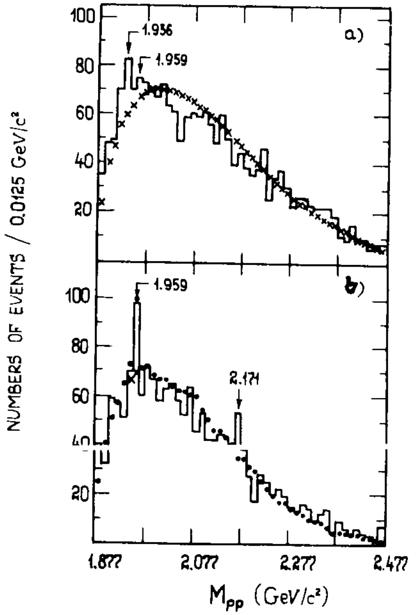


Fig.2. The effective mass distribution of two protons from the reaction $np \to pp\pi^-$ at P_n = = 2.23 GeV/c: a) events with $|x^*_{\pi^-}| < 0.15$; b) events with $|x^*_{\pi^-}| > 0.15$. Dots - approximation curve, crosses - background.

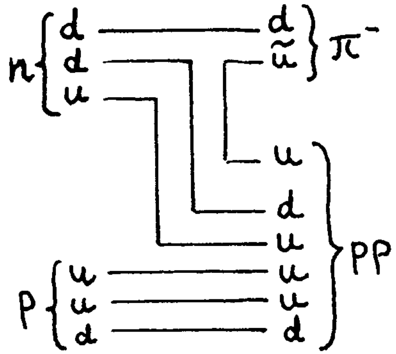
Fig.3. The effective mass distribution of two protons from the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ at P_n = 5.10 GeV/c: a) events with $\Delta^2_{n \to \Sigma\pi} < 2$ $(GeV/c^2)^2$; b) events with $\Delta^2_{n \to \Sigma\pi} > 2 (GeV/c^2)^2$. Dots - approximation curve, crosses - background.



mainly the production of Δ_{33} -isobar in various isotopic states), and takes into account a peripheral character of this reaction. The background curve is discussed in more detail in Chapter II.

The joint processing of the data from the reactions $np \to pp\pi^-$ at P_n = 2.23 GeV/c and $np \to pp\pi^+\pi^-\pi^-\pi^0$ at P = 5.10 GeV/c gives M_{res} = (1962±3) MeV/c^2 and Γ^{real}_{res} = (0.5 ± 1.4) MeV/c^2. In addition, an indication (see fig.3b) should be noted of the existence of the peculiarity in the effective masses of two protons at 2171 MeV/c^2.

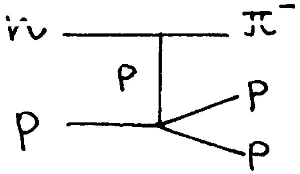
The method of resonance separation, when the events of reactions are selected with large 4-momentum transfer squared from proton-target to two-proton system (or from incident neutron to π-meson system), can testify that the reaction $np \to pp\pi^-$ is due to the quark diagram (Ia):



(Ia)

The d- and u-quarks from the neutron are joined with the uud-quarks of the proton-target. The u-quark is joined to them from the uū-pair pulled out of vacuum. The 6-quark uuuudd system is formed which produces the resonance, one of the decay modes of which is the decay into two protons. The remaining ū- and d-quarks are united into π^--meson.

In terms of field theory diagrams we deal with diagrams of the baryon exchange type



(Ib)

For reactions with a large number of π-mesons a greater number of quark-antiquark pairs can be pulled out of vacuum, but as a whole the mechanism of diproton resonance production is the same as for the case of the production of the only π-meson.

If the uū-pair is replaced by the s$\bar{s}$-pair in the process shown in diagram Ia, the reaction $np \to \Lambda pK^0$ will be obtained with a resonance in the Λp-system for sufficiently large 4-momentum transfers. The masses of these strange dibaryon resonances can differ from those we have found by the difference between the masses of strange and nonstrange valent quarks:

$$\Delta(M^{res}_{\Lambda p} - M^{res}_{pp}) = \Delta(M_s - M_u) = \Delta(M_\Lambda - M_p) = 177 \text{ MeV/c}^2.$$

The comparison of our results with the data on Λp-resonances [6,7] is shown in the Table (the masses of the resonances are units of MeV/c^2):

Table

M^{res}_{pp} present paper	M^{res}_{pp} + 177	$M^{res}_{\Lambda p}$
1936	2113	2098 [6]
1962	2139	2130 [6,7]
2171	2348	2352 [6]

This agreement between the predicted and found masses of the Λp-resonances can testify to the 6-quark structure of Λp-resonances (note that their widths are also of the order of some MeV/c^2) and similar mechanisms of resonance production in the pp- and Λp-systems.

The small width of the resonances found makes us examine an interesting question concerning hadron-nucleus interactions.

To form the resonance with a mass of 1936 MeV/c^2 in a system of two nucleons, it is sufficient to collide two nucleons having momenta of 0.23 MeV/c with one another. Such nucleons are in nuclei where the Fermi-momenta may stretch farther than the above value.

Then a rather considerable part of long-lived (as compared to the time of strong interaction) 6-quark dinucleon states can exist in nuclei. They can be knocked out of the nuclei and observed as peaks in the effective mass distributions of two not very fast nucleons. Such formations can be observed in chambers with heavy liquids. The energy and the type of incident hadron are of no significance. A similar picture is observed in experiments (see [3,4]). If the considered model is correct, the yield of correlated nucleon pairs will be approximately proportional to the A-atomic number of nucleus-target (the cross section is normalized to A) for sufficiently heavy nuclei and will weakly depend on the type and energy of incident hadron.

From the foregoing some conclusions can be drawn:

1). The resonances with masses of (1936$\pm$2) and (1962$\pm$2) MeV/c^2 and widths of the order of several MeV/c^2 are found in the system of two protons from np-interactions for energies of (1-5) GeV;

2). The resonances are produced in processes of the baryon exchange type. A fraction of these resonances amounts to some per cent of the total cross section of the corresponding reaction.

II. RESONANCES WITH ISOTOPIC SPIN I = 5/2

Since 1964 [8] many authors have studied exotic baryon resonances with isotopic spin I = 5/2 using, mainly the bubble chamber method. Our investigations have been and are being carried out on neutron beams. Our recent results described in paper [9] are devoted to the study of the reaction

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

at incident neutron momenta $P_n = (5.10 \pm 0.17)$ GeV/c. The resonances with masses of 1438, 1522 and 1894 MeV/c^2 and widths of ≈ 23, $\lesssim 20$ and $\lesssim 40$ MeV/c^2, respectively, were found in the $\Delta^{++}_{33}\pi^+(\Delta^-_{33}\pi^-)$ systems. The production cross sections of these resonances were equal to several μb with an accuracy of $\pm$25%. No double resonance production was found. An attempt was made to determine the spin and parity of the new particles observed. In this paper we try, using larger statistics, to study the production of the same resonances with other projections of isotopic spin, namely the systems with I = 5/2, $I_3 = \pm 3/2$. We also discuss the production mechanism of the resonances with I = 5/2 for the reactions studied.

Figure 4 shows the effective mass distribution of $\Delta^{++}_{33}\pi^+(\Delta^-_{33}\pi^-)$-combinations from the reactions $np \to np\pi^+\pi^+\pi^-\pi^-$ at $P_n = (5.10 \pm 0.17)$ GeV/c. The $N\pi$ combination is believed to be Δ_{33}-isobar if its mass is $M_{N\pi} = (1214 \pm 40)$ MeV/c^2.

The result of the best approximation of the distribution by the background and two resonance curve taken in the Breit-Wigner form with $M_{01} = 1441$, $\Gamma_{01} = 7$ MeV/c^2, $M_{02} = 1515$ and $\Gamma_{02} = 7$ MeV/c^2 is shown in fig.4 by points. The background curve is constructed of various subprocesses of the reaction (1) taking into account peripheral characteristics of nucleons in the c.m.s. [9].

The production cross sections of the resonances with masses $M_{01} = 1441$ and $M_{02} = 1515$ MeV/c^2, having the mode of decay $N^{+++} \to \Delta^{++}_{33}\pi^+$, are equal to $\sigma_1 = (6.0 \pm 1.6)$ and $\sigma_2 = (2.0 \pm 1.3)$ μb, respectively.

At the same time the effective mass distribution of $\Delta^0_{33}\pi^-(\Delta^+_{33}\pi^+)$-combinations from the reaction (1) is completely described by the background.

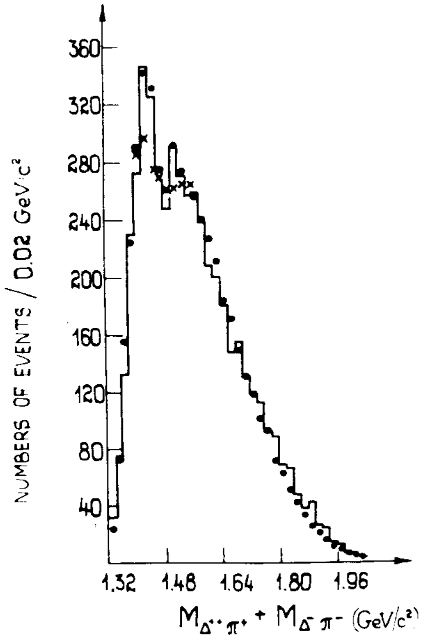


Fig.4. The effective mass distribution of $\Delta^{++}_{33}\pi^+(\Delta^-_{33}\pi^-)$ - combinations from the reaction $np \to p\pi^+\pi^+\pi^-\pi^- n$ at $P_n = 5.10$ GeV/c. Dots - approximation curve, crosses - background.

Let us consider the reaction

$$np \to pp\pi^+\pi^-\pi^-\pi^0 \qquad (2)$$

at P_n = 5.10 GeV/c. The investigation of various combinations of secondary particles from this reaction shows that it proceeds mainly via three subprocesses with the production of Δ_{33}-isobars in various isotopic states:

$$np \to \Delta^{++}_{33}p\pi^-\pi^-\pi^0 \quad 50\% \qquad (2a)$$

$$\to \Delta^{0}_{33}p\pi^+\pi^-\pi^0 \quad 25\% \qquad (2b)$$

$$\to \Delta^{+}_{33}p\pi^+\pi^-\pi^- \quad 25\% . \qquad (2c)$$

Moreover, ω^0 and η^0-mesons are produced in ~6% of events from this reaction.

The reaction (2), much like the reaction (1), is peripheral in character. The peripheral character of nucleons in this reaction is taken into account in the same manner as for the reaction (1) by inserting into the matrix elements of subprocesses (2a ÷ 2c) the factor:

$$\exp\{-B|Y_{max} - Y_1|\} \cdot \exp\{-B|Y_2 - Y_{min}|\},$$

where $Y_{max}(Y_{min})$ is the maximum (minimum) longitudinal rapidity of the proton in the reaction (2), and $Y_1(Y_2)$ the most (the least) longitudinal rapidity of the proton for a given simulated event. The coefficient B = 1.41.

Later on the background for any distributions is constructed of subreactions (2a ÷ 2c) taking into account their percentage mentioned above and the peripheral character of nucleons.

Figure 5 shows the effective mass distribution of $\Delta^0_{33}\pi^-$-combinations from the reaction (2). This distribution is approximated by the background curve and the two resonance curves taken in the Breit-Wigner form with masses and widths M_{01} = 1422, Γ_{01} = 11 and M_{02} = 1539, Γ_{02} = 10 MeV/c^2. The production cross sections of the corresponding resonances are equal to $\sigma_1 = (11 \pm 2.4)$ μb and $\sigma_2 = (2.7 \pm 2.2)$ μb, respectively. The background is pictured in fig.5 by crosses; and the result of the best approximation, by dots.

At the same time the effective mass distribution of $\Delta^+_{33}\pi^+$-combinations from the reaction (2) is completely described by the background.

Thus, one can conclude that the resonance peaks in the $\Delta_{33}\pi$-system are observed both with $|I_3| = 5/2$ and $I_3 = -3/2$ in the vicinity of effective masses of 1430 ± 10 and 1525 ±

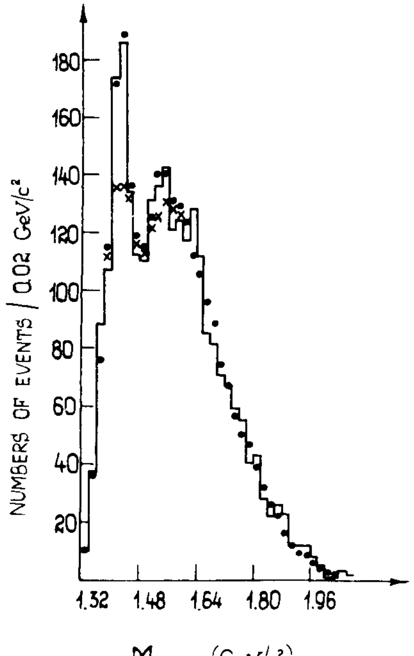
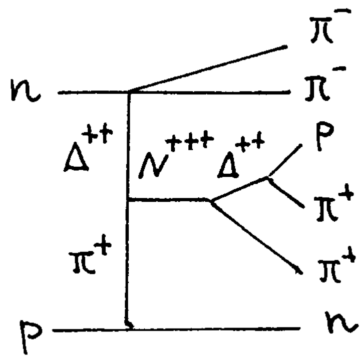


Fig.5. The effective mass distribution of $\Delta^0_{33}\pi^-$-combinations from the reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$ at P_n = 5.10 GeV/c. Dots - approximation curve, crosses - background.

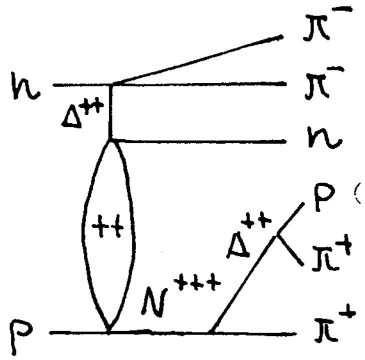
± 10 MeV/c^2. The effective mass distribution of $\Delta^{++}_{33}\pi^0$-combinations (not shown) does not contradict the existence of such peculiarities, but this distribution is less informative because the decay of resonances with I = 5/2 via this mode is 1.5 times less probable than via the mode $\Delta^0_{33}\pi^-$.

The set of the above facts from the reactions (1) and (2) combined with no significant double resonance production leads to the conclusion that the resonances with I = 5/2 are produced by mechanisms of the baryon exchange type.

To produce resonances with I = 5/2, $I_3 = \pm 5/2$ in the reaction (1), the corresponding diagrams of baryon exchange can be shown as follows (consider the combination of $p\pi^+\pi^+$):



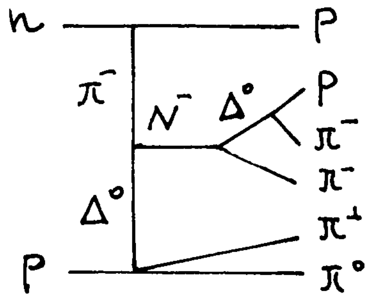
(IIa)



(IIb)

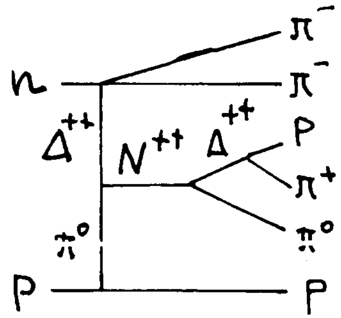
The diagrams with two identical pions produced in the same vertex cannot be written for $\Delta^0_{33}\pi^-$ ($\Delta^+_{33}\pi^+$)-combinations of this reaction. Both the absence of double production of the resonances with I = 5/2 and effects in the $\Delta^0_{33}\pi^-$ ($\Delta^+_{33}\pi^+$)-combinations can be explained by processes (IIa) and (IIb).

For the reaction (2) the following diagram is suitable for $\Delta^{\circ}_{33}\pi^{-}$ -combinations:



(IIc)

There is also a diagram for the production of resonance with $I = 5/2$, $I_3 = +3/2$ decaying via the mode $N^{++} \to \Delta^{++}_{33}\pi^{\circ}$:



(IId)

However, isospin branching ratios give no definite prediction concerning relative fractions of the diagrams (IIc) and (IId).

At the same time similar diagrams cannot be plotted for the production of N^{++} decaying into $\Delta^{+}_{33}\pi^{+}$. Therefore the $\Delta^{+}\pi^{+}$ effective mass distributions form the reaction (2) are completely described by the background.

Taking into account the above mechanism, an increase of resonance production effects can be expected for the events selected kinematically in accordance with the diagrams considered above.

In the reaction (1) the diagrams (IIa) and (IIb) are characterized by the emission of both π^{-} -mesons into the forward hemisphere in the c.m.s. for $\Delta^{++}_{33}\pi^{+}$ -combinations (or by the emission of both π^{+}-mesons into the backward hemisphere for isotopically conjugated $\Delta^{-}_{33}\pi^{-}$ -combinations).

Figure 6 shows the result of plotting the effective mass distribution of $\Delta^{++}_{33}\pi^{+}$ (added to $\Delta^{-}_{33}\pi^{-}$)-combinations providing $\theta^{*}_{\pi^{-}_{1}} > 0$ and $\cos\theta^{*}_{\pi^{-}_{2}} > 0$ ($\cos\theta^{*}_{\pi^{+}_{1}} < 0$ and $\cos\theta^{*}_{\pi^{+}_{2}} < 0$). This distribution is approximated by the background curve from the

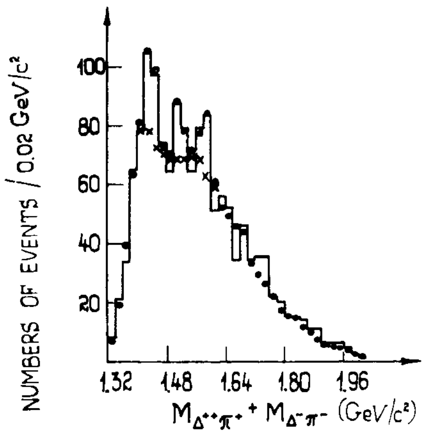


Fig.6. The effective mass distribution of $\Delta^{++}_{33}\pi^{+}(\Delta^{-}_{33}\pi^{-})$-combinations from the reaction $np \to p\pi^{+}\pi^{+}\pi^{-}\pi^{-}n$ at $P_n = 5.10$ GeV/c for events provided that $\cos\theta^{*}_{\pi^{-}_{1}} > 0$, $\cos\theta^{*}_{\pi^{-}_{2}} > 0$, ($\cos\theta^{*}_{\pi^{+}_{1}} < 0$, $\cos\theta^{*}_{\pi^{+}_{2}} < 0$). Dots - approximation curve, crosses background.

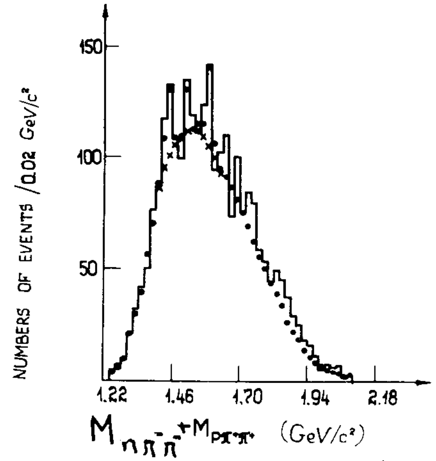


Fig.7. The effective mass distribution of $p\pi^{+}\pi^{+}(n\pi^{-}\pi^{-})$ - combinations from the reaction $np \to p\pi^{+}\pi^{+}\pi^{-}\pi^{-}n$ at $P_n = 5.10$ GeV/c for events selected on condition that $\cos\theta^{*}_{\pi^{-}_{1}} > 0$, $\cos\theta^{*}_{\pi^{-}_{2}} > 0$ ($\cos\theta^{*}_{\pi^{+}_{1}} < 0$, $\cos\theta^{*}_{\pi^{+}_{2}} < 0$). Dots - approximation curve, crosses - background.

subprocesses of the reaction (1) [9] with $\cos\theta^{*}$ limitations for π-mesons and by three resonance curves with masses and widths equal to $M_{01} = 1440$, $\Gamma_{01} = 9$; $M_{02} = 1517$, $\Gamma_{02} = 9$; and $M_{03} = 1583$, $\Gamma_{03} = 7$ MeV/c^2. Under these conditions the production cross sections of the resonances with the corresponding masses are equal to $\sigma_1 = (3.3 \pm 0.9)$ μb, $\sigma_2 = (1.8 \pm 0.8)$ μb and $\sigma_3 = (1.8 \pm 0.8)$ μb.

Figure 7 shows the effective mass distribution of $p\pi^{+}\pi^{+}$ (added to $n\pi^{-}\pi^{-}$)-combinations from the reaction (1) for events with $\cos\theta^{*}_{\pi^{-}_{1}} > 0$ and $\cos\theta^{*}_{\pi^{-}_{2}} > 0$ (or $\cos\theta^{*}_{\pi^{+}_{1}} < 0$ and $\cos\theta^{*}_{\pi^{+}_{2}} < 0$ for $n\pi^{-}\pi^{-}$). The masses and real widths of the resonances calculated by the maximum likelihood method are equal to $M_{01} = 1443 \pm 3$, $\Gamma^{real}_{res01} = (4.5 \pm 6.5)$; $M_{02} = (1509 \pm 4)$, $\Gamma^{real}_{res02} = (0 \pm 8.4)$; $M_{03} = (1592 \pm 3)$, $\Gamma^{real}_{res03} = (0 \pm 5)$ MeV/c^2. Note that the experimental mass resolution becomes worse with increasing resonance masses: $\Gamma^{resol} = 10$ MeV/c^2 near the first resonance, $\Gamma^{resol} = 17$ MeV/c^2 near the second resonance, and $\Gamma^{resol} = 24$ MeV/c^2 near the third one. Therefore the calculated values of the resonance widths must be considered only within the indicated errors.

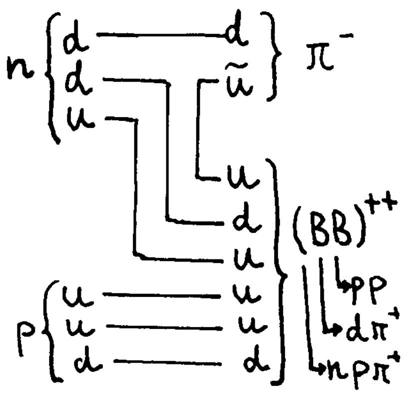
The production cross section of the resonance decaying via the mode $N^{+++} \to p\pi^+\pi^+$ are equal to $\sigma_1 = (3.1 \pm 0.9)$ μb, $\sigma_2 = (1.5 \pm 0.9)$ μb and $\sigma_3 = (2.4 \pm 0.9)$ μb. The comparison of these cross sections with those obtained for the decay mode $N^{+++} \to \Delta_{33}^{++}\pi^+$ indicates that the resonances with $I = 5/2$ decay mainly via Δ_{33}^{++}-isobar.

As a conclusion one can say that the decay of the resonances is observed for the total isotopic spin $I = 5/2$ and projections $I_3 = +5/2$ and $I_3 = -3/2$. This is a strong evidence for the actual existence of those systems. The widths of the resonances are within 20 MeV/c^2. A possible production mechanism for such system is the baryon exchange with Δ_{33}-nucleon scattering in the final state. The resonances decay mainly via Δ_{33}-isobar.

The results conforming to our data have been recently obtained at ITEP [10] for the reaction $\pi^+p \to p\pi^+\pi^+\pi^-\pi^0$ (with the emission of π^- backward in the lab.sys.) at $P_{\pi^+} = 4.37$ GeV/c.

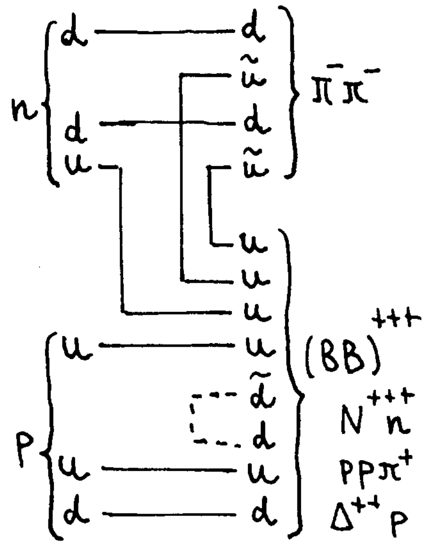
III. A POSSIBLE PRODUCTION MECHANISM FOR MULTI-QUARK RESONANCES AND $(\pi^-\pi^-)$-RESONANCE

Let us consider quark diagrams for the formation of dinucleon resonances associated with the production of one or two π^--mesons. For reactions such as $np \to \pi^-(BB)^{++}$ (e.g., $np \to pp\pi^-$, $np \to d\pi^+\pi^-$, $np \to np\pi^+\pi^-$) the following diagrams can be written:



(IIIa)

For reaction such as $np \to \pi^-\pi^-(BB)^{+++}$ (e.g., $np \to pp\pi^+\pi^-\pi^-$, $np \to pp\pi^+\pi^-\pi^-\pi^0$, $np \to np\pi^+\pi^+\pi^-\pi^-$):



(IIIb)

As is seen, the diagrams (IIIa) and (IIIb) have many common properties: in both of them one or two quarks are pulled out of the incident nucleon, and one or two quark-antiquark pairs are produced from vacuum. A six-quark state is produced in the vertex decaying later in a variety of ways. It is important that the six quark state is formed by the capture of free quarks. This capture process can be a "soft" one what means a small excitation transferred from one part of the six-quark state to another. If resonances are possible between these two parts, their masses will be small.

Small excitation resonances are not subjected to any external forces because all quark regrouping in interaction has been finished. At the same time the decay phase is small for low masses. Perhaps, this is the reason why narrow widths of the resonances in question are observed.

From this point of view the upper vertex of the diagram (IIIb) is of interest where two π^--mesons have been formed from two "spectator" d-quarks of incident neutron. The detachment of u-quark from neutron can induce oscillations of a system of two "spectator" d-quarks that may be resonant in character. From the above considerations the mass of this state (after "soft" hadronization) can be small, and this state can be long-lived enough. If the potential of interquark interaction is an oscillator-like, one can expect a series of resonances in a $(\pi^-\pi^-)$ system placed equidistantly.

Figure 8 shows the effective mass distribution of two π^--mesons from the reaction $np \to pp\pi^+\pi^-\pi^-$ at $P_n = (5.10 \pm 0.17)$ GeV/c (5735 events). A clear peak is observed in the vicinity of a mass of 390 MeV/c^2. The result of approximation

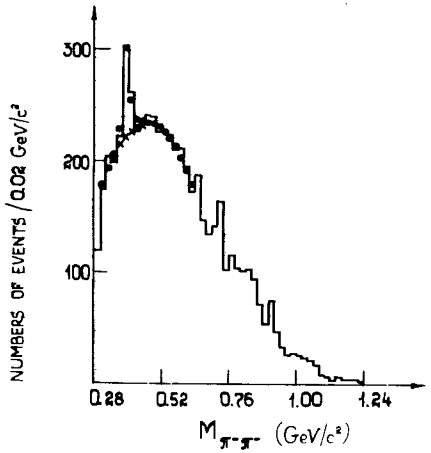


Fig.8. The $(\pi^-\pi^-)$ effective mass distribution from the reaction $np \to pp\pi^+\pi^-\pi^-$ at $P_n = 5.10$ GeV/c. Dots - approximation curve, crosses - background.

of the distribution in the resonance region using a resonance curve in the Breit-Wigner form and a second-degree polynomial curve as a background is shown in fig.8 (dotted line). In this case the experimental mass resolution is equal to $\Gamma^{resol} = 7$ MeV/c^2. The experimental width is equal to $\Gamma^{exp}_{res} = (18 \pm 5)$ MeV/c^2. Therefore for the real width of the resonance we have $\Gamma^{real}_{res} = (11 \pm 5)$ MeV/c^2 and $M_{res} = (393 \pm 3)$ MeV/c^2. The production cross section is equal to $\sigma_{res} = (13 \pm 3)$ μb for this resonance.

Thus, one can conclude that there is a solid evidence for the existence of six-, five- and four-quark resonances in various reactions of np-interactions. A mechanism of the baryon exchange type is probable to produce such states. The widths of all produced resonances are at least of an order less than those we deal with in strong interactions. All the observed effects account for no more than some per cent of the total cross sections of the corresponding reactions.

To study similar states, considerably larger statistics is certainly required. Note, however, that experiments of this type which can be suggested do not require very high energies and can be carried out using an available equipment. The most important requirement for such experiments lies in increasing the measurement accuracy of effective masses due to small resonance widths. Of course, the condition of minimum background must be fulfilled for these experiments that can be easily understood referring to the above mechanism of resonance production.

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Бешлиу К. и др. Д1-83-815

Многокварковые резонансы в np-взаимодействиях при энергиях /1÷5/ ГэВ

В различных реакциях np-взаимодействий при энергиях нейтронов /1÷5/ ГэВ исследуются резонансы в системах из 6,5 и 4 кварков. Обнаружены резонансы в системе двух протонов с массами 1936 и 1962 МэВ/c^2, в системах $p\pi^+\pi^+(n\pi^-\pi^-)$ и $p\pi^-\pi^-$ с массами в районе 1430, 1520 и 1580 МэВ/c^2, в системе двух π^--мезонов с массой 390 МэВ/c^2. Все резонансы имеют ширины порядка 10 МэВ/c^2. Сечения образования резонансов составляют несколько микробарн; они определены с точностью /25÷40/%. Обсужден механизм барионного обмена, который, с нашей точки зрения, объясняет образование изучаемых систем.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1983

Besliu C. et al. D1-83-815

Multiquark Resonances in np-Interactions at Energies of (1- 5) GeV

Resonances in systems of 6,5 and 4 quarks have been studied in various reactions of np-interactions for the energies of incident neutrons (1÷5) GeV. The resonances have been found in a system of 2 protons with masses of 1936 and 1962 MeV/c^2, in $p\pi^+\pi^+(n\pi^-\pi^-)$ and $p\pi^-\pi^-$ systems with masses near 1430, 1520 and 1580 MeV/c^2 and in a system of $2\pi^-$-mesons with a mass of 390 MeV/c^2. The widths of all these resonances are of the order of 10 MeV/c^2. The production cross sections of the resonances are equal to some microbarns and determined with an accuracy of (25÷40)%. The mechanism of baryon exchange, which, from our point of view, explains the production of the systems studied, is discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1983