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

SEARCH AND STUDY OF EXOTIC BARYON RESONANCES WITH ISOTOPIC SPIN I = 5/2 IN THE REACTION $np \to p\pi^+\pi^+\pi^-\pi^-n$ AT $P_n = (5.10 \pm 0.17)$ GeV/c

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* Leninabad State Pedagogical Institute, Leninabad, USSR.

** Bucharest University, Bucharest, Romania.

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The present paper is devoted to a search for and an in-
vestigation of the exotic baryon resonances with isotropic
spin I $=5/2$ in $p\pi^+\pi^+$ and $n\pi^-\pi^-$ combinations. The reaction

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

was used that was picked out from 5-prong stars of np-in-
teractions in the 1 m hydrogen bubble chamber of the High
Energy Laboratory, JINR. The chamber was exposed to a mono-
chromatic neutron beam with a momentum of (5.10 ± 0.17)GeV/c /1/
The methods of separation of the reaction channels are desc-
ribed in ref./2/. The total number of events of the reaction
(1) was equal to 3088. The isotopic invariance of the reac-
tion (1) allowed two interesting combinations of particles
($p\pi^+\pi^+$ and $n\pi^-\pi^-$) to be studied and the distribution of
isotopic symmetrical combinations to be added simultaneously.
A small momentum spread of the incident beam and a suffici-
ent precision in measuring the secondary particles in the
chamber allowed one to reconstruct the secondary neutron so
goot that there were no considerable differences in the iso-
topic symmetrical distributions of combinations with proton
and neutron within the statistic errors.

The analysis of the two-dimensional plot of $M_{p\pi^+}$ versus
$M_{n\pi^-}$ shows that the reaction (1) proceeds via four subtrac-
tions:

$$np \to p\pi^+\pi^+\pi^-\pi^-n \qquad (13.6\pm8.2)\% \qquad (1a)$$

$$\to \Delta^{++}\pi^+\pi^-\pi^-n \qquad (30.5\pm8.0)\% \qquad (1b)$$

$$\to p\pi^+\pi^+\pi^-\Delta^- \qquad (30.5\pm8.0)\% \qquad (1c)$$

$$\to \Delta^{++}\pi^+\pi^-\Delta^- \qquad (25.4\pm8.0)\% \qquad (1d)$$

Their percentage is shown on the right of the subtractions.
Each of subreactions (1a)-(1d) with the Δ_{33}-resonance of
a 1214 MeV/c mass and a 110 MeV/c^2 width was simulated using
the FOWL program. The peripherality of reaction (1) was taken
into account by multiplying the phase space by the factor

$$\exp\{-B|y_{max}-y_1|\}\cdot\exp\{-B|y_2-y_{min}|\},$$

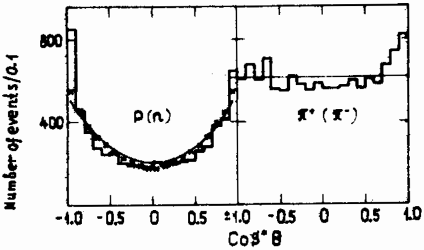

Fig.1

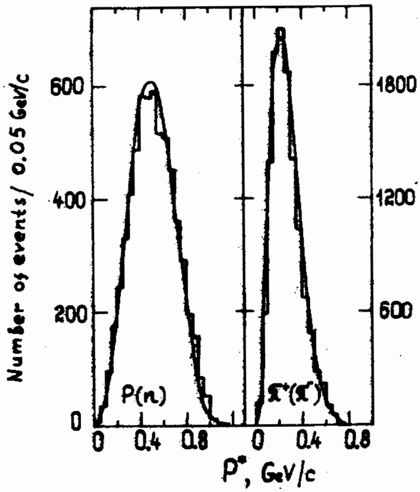

Fig.2

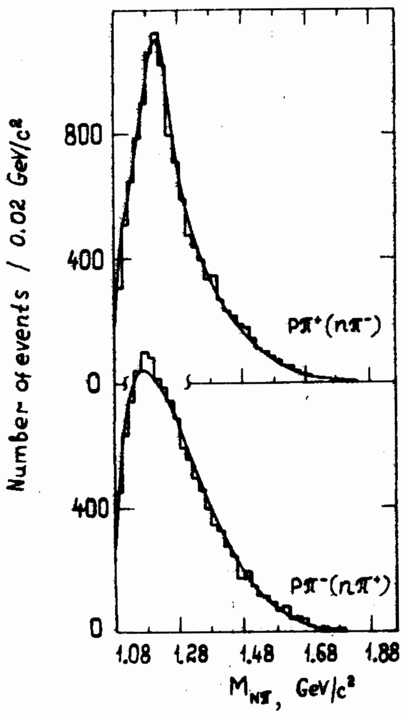

Fig.3

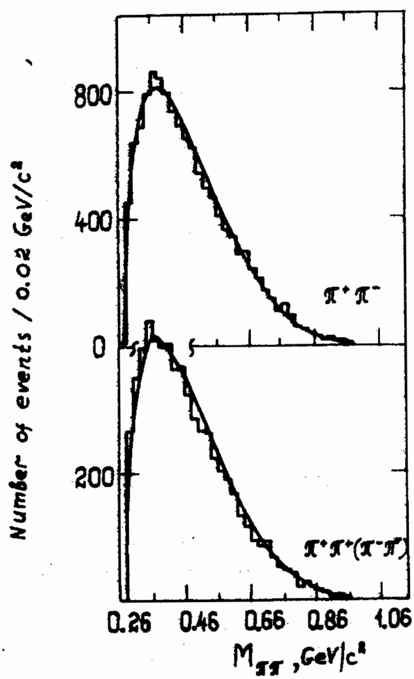

Fig.4

where y_{max} (y_{min}) is the maximum (minimum) possible longitudinal rapidity of nucleon in the reaction (1) at a given energy, $y_1(y_2)$ are the values of the maximum (minimum) rapidity of nucleon for concrete simulated event /3/. The coefficient was determined from the best agreement between the simulated and experimental mass and angular distributions in the CMS of reaction (1). Within a range of 1.61÷1.91 the values of B allow one to get a good description of the angular distributions of nucleons and the effective mass distributions of $N\pi$, $N\pi\pi$ and $\pi\pi$ combinations by the respectively weighted subreactions (1a)-(1d), except the events considered below.

Figure 1 presents the angular distributions of nucleons and π-mesons in the CMS of reaction (1). The solid line corresponds to the description by subreactions (1a)-(1d) at B=1.61, and the crosses are the same at B=1.91. Figure 2 shows the momentum distributions of nucleons and π-mesons and their description by the subreactions (solid line). Figures 3 and 4 show the effective mass distributions of $N\pi$ and $\pi\pi$ combinations. Note that the variation of the percentage of the subreactions within the errors does not change the form of the simulated distributions.

From Figs.3 and 4 it follows that there are no noticeable production of Δ_{33} (and heavier) resonances in $p\pi^-(n\pi^+)$combinations and of ρ° meson in $\pi^+\pi^-$ combinations in the reaction (1) at P_n=5.10 GeV/c.

Figure 5 presents the effective mass distributions of $p\pi^+\pi^+$ (added to $n\pi^-\pi^-$), $p\pi^+\pi^-(n\pi^+\pi^-)$, $p\pi^-\pi^-(n\pi^+\pi^+)$ combinations. The background from the subreactions (1a)-(1d), normalized to the total number of combinations, is denoted by the solid lines. No essential deviations from the background are observed in these distributions.

Figure 6 shows the effective mass distributions of $\Delta^{++}\pi^+(\Delta^-\pi^-)$, $\Delta^{++}\pi^-(\Delta^-\pi^+)$ and $\Delta^\circ\pi^-(\Delta^+\pi^+)$ combinations. Such an $N\pi$-combination is assumed to be Δ_{33} resonance the effective mass of which is within $1174 \le M_{N\pi} \le 1254$ MeV/c^2. The solid lines correspond to the background separated on the same condition as for experimental data.

The effective mass distributions of $\Delta^{++}\pi^-(\Delta^-\pi^+)$and $\Delta^\circ\pi^-(\Delta^+\pi^+)$ combinations are in good agreement with the background, and the deviations do not exceed two standard deviations everywhere. However, the effective mass distribution of $\Delta^{++}\pi^+(\Delta^-\pi^-)$ combinations differs sharply from the background. This distribution was approximated by the sum of the background and three resonance curves with masses of 1438, 1522 and 1894 MeV/c^2 and widths of 30, 30 and 40 MeV/c^2, respectively. The approximating curve is shown by the dotted line; the solid line is the

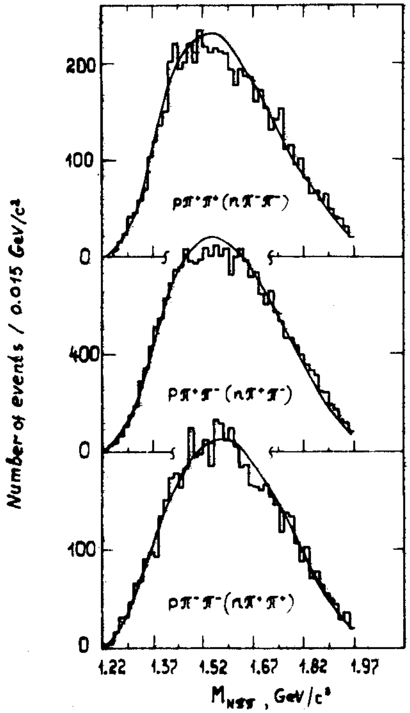

Fig.5. The effective masses of $N\pi\pi$ combinations of reaction (1).

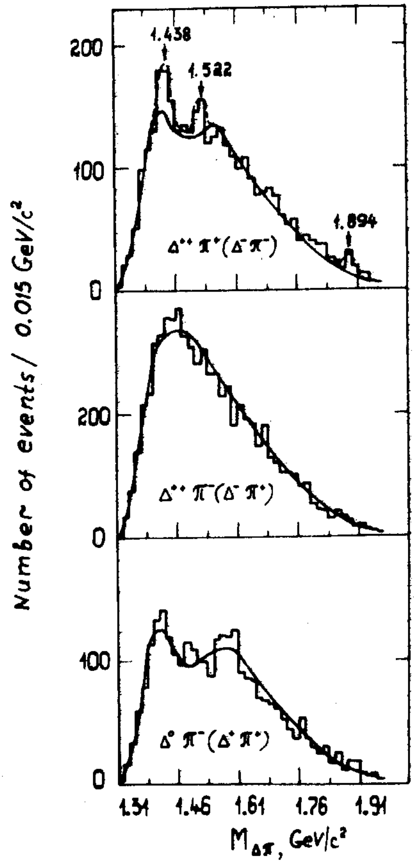

Fig.6. The effective masses of $\Delta\pi$ combinations of reaction (1). $M_{\Delta} = (1214 \pm 40)$ MeV/c^2.

background normalized to the number of background combinations remaining after the fit. The first resonance is described by the Breit-Wigner form in the approximation, and the two others - by the Gauss form corresponding to the experimental mass resolution equal to 9.6 MeV/c^2 in the first resonance region, 11 MeV/c^2 in the second one and 23 MeV/c^2 for the masses greater than 1800 MeV/c^2.

To study the problem of real connection between the observed anomalies and $\Delta^{++}(\Delta^-)$ resonance abundantly produced in reaction (1), the effective mass distribution of $\Delta^{++}\pi^+(\Delta^-\pi^-)$ - combinations was constructed when the Δ_{33}-resonance was

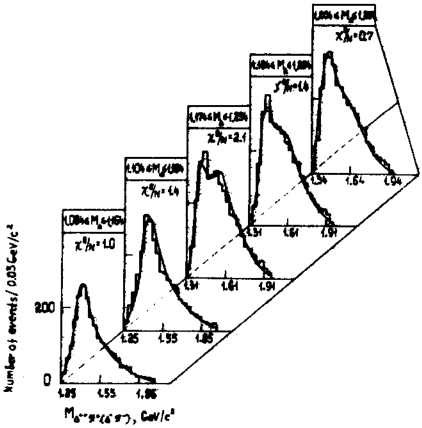

Fig.7. The effective masses of $\Delta^{++}\pi^{+}(\Delta^{-}\pi^{-})$ combinations of reaction (1), M varies, the width of Δ-resonance is equal to 80 MeV/c^2.

the combination of $p\pi^{+}(n\pi^{-})$ with masses within various intervals. The result is shown in fig.7. The intervals of $N\pi$ masses being taken as a Δ-resonance region are shown at the top of each figure; the solid lines are the background of the subreactions (1a)-(1d). The values of χ^2/N are shown to describe the background in each figure. One can see that the worst description by the background corresponds to an interval of $1174 \leq M_{\Delta} \leq 1254$ MeV/c^2. This result is in agreement with that in fig.3 for $\Delta^{++}(\Delta^{-})$-resonance, where as is seen, the maximum of the $p\pi^{+}(n\pi^{-})$ mass distribution belongs to an interval from 1200 to 1220 MeV/c^2 (a more precisely defined value of M_{Δ}= 1214 MeV/c^2 for our condition). The width of cutting the Δ-resonance equal to 80 MeV/c^2 is also found experimentally: a wider band around 1214 MeV/c^2 includes a larger number of background $p\pi^{+}(n\pi^{-})$ combinations, and a relative part of real Δ's decreases; a more narrow band decreases the total number of events in the Δ band. In both cases the precision in determining the production cross section for possible resonances gets worse though the effect is not very strong.

As is seen from the above pictures, there is no question on some kinematic mechanism of arising peculiarities in $\Delta^{++}\pi^{+}(\Delta^{-}\pi^{-})$ systems (the production of ρ-meson and heavy resonances in $N\pi$, $N\pi\pi$, $\Delta\pi$ systems), because there is no essential information concerning the production of known resonances in reaction (1) at our energies.

Table 1 shows the production cross sections of resonances with isotopic spin 5/2 in reaction (1) decaying into $\Delta^{++}\pi^{+}(\Delta^{-}\pi^{-})$ and their masses and widths at P_n = 5.10 GeV/c. The central value of resonance masses is determined with an accuracy of about 10 MeV/c^2.

The existence is possible of two more resonances with masses of 1698 and 1826 MeV/c^2 and widths of approximately 30÷40 MeV/c^2 the production cross sections of which are about 3 mb. Based on the available statistics, the accuracy in de-

Table 1

$M_{rez.}$, MeV/c²	$\Gamma_{rez.}$, MeV/c²	σ, μb
1438	23	9.9 ± 2.7
1522	≤ 20	4.8 ± 1.7
1894	≤ 40	3.3 ± 0.8

termining their cross sections is no better than 40%, and larger material is required to determine them more precisely.

To estimate the pair production cross sections of the resonances, the $\Delta^-\pi^-(\Delta^{++}\pi^+)$ mass distribution was constructed for events selected on condition that the masses of $\Delta^{++}\pi^+(\Delta^-\pi^-)$ combinations were inside the mass bands 1415÷1460 MeV/c² or 1505÷1535 MeV/c² or 1865÷1910 MeV/c², i.e., inside the mass bands of the studied resonances. The obtained distribution was approximated by the background and three resonance curves with masses of 1438, 1522 and 1894 MeV/c² and widths of 30, 20 and 40 MeV/c². The results are presented in fig.8. The summary part of the resonances in fig.8 is the same as in the total distribution of $\Delta^{++}\pi^+(\Delta^-\pi^-)$ combinations (fig.6). Therefore one can conclude that the pair production of the resonances is not observed within the accuracy of the present experiment though the statistical confidence of this result is rather insufficient.

To estumate the spins of the resonances, the angular distribution of nucleons from the decay of Δ-resonance was constructed in the rest system of Δ-resonance included in a new resonance relative to the direction of Δ-resonance in the new resonance rest system. All quantities were transformed into the CMS of Δ-resonance.

The singular distribution for the first resonance ($1415 \leq M_{res} \leq 1460$) is presented at the top of fig.9 by black points. The expected distribution is also shown for the case when the resonance spin is equal to $1/2^{\pm}$ (dotted line) and for the case of the isotropic distribution expected for spin $>1/2$ (point-dotted line). The averaged distribution from the mass bands on the left and right of the resonance ($1340 \leq M \leq 1385$ and $1475 \leq M \leq 1490$) was taken as a background. Taking a 15% limit for the probability of agreement between the hypothesis and the experiment, one can reject the value of spin equal to $1/2^{\pm}$. Thus, the spin of the resonance with M = 1438 MeV/c² can be assumed to be equal to $3/2^{\pm}$, $5/2^{\pm}$.

The same distributions for the resonance with a mass of 1522 MeV/c² ($1505 \leq M_{res} \leq 1535$) are shown at the bottom of fig.9. The background was averaged over the neighbouring mass bands ($1475 \leq M \leq 1490$ and $1550 \leq M \leq 1580$). In this case one can choose the spin-parity of the resonance equal to $1/2^{\pm}$, $3/2^{-}$, $5/2^{+}$ with the same confidence level as for the first resonance. The expected theoretical distributions were obtained by R.Led-

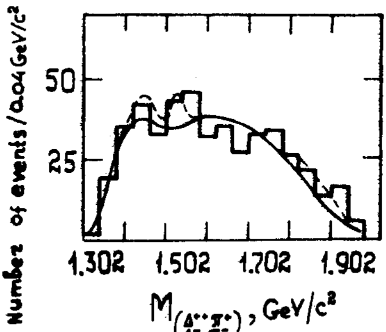

Fig.8. The $\Delta^{++}\pi^{+}(\Delta^{-}\pi^{-})$ effective mass distribution of reaction (1) on condition that $M_{\Delta^{-}\pi^{-}}(M_{\Delta^{++}\pi^{+}})$ is within some of the three observed resonances.

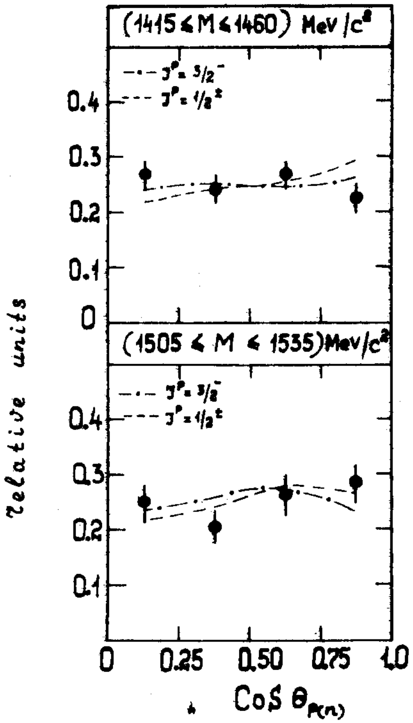

Fig.9. The angular distribution of nucleons from the decay of Δ--resonance relative to the direction of its flight in the new resonance rest system. All quantities are in the rest system of Δ-resonance.

nicky and V.L.Lyuboshitz on the assumption of taking into account the least orbital momentum required to form J^P of the resonance using spin-particles of Δ-resonance and π-meson.

Another distribution, i.e., the angular distribution between the normal to the plane of resonance decay into 3 particles and, the normal to the plane of resonance production, does not contradict to obtained values of spin-particles but does not give any additional information because of a large background (80% for the first and 82% for the second resonances).

In general, statistics should be significantly increased to draw more detailed conclusions about the spin-parities of the resonances.

Table 2

	$M_{rez.}$ (MeV/c²)	$\Gamma_{rez.}$ (MeV/c²)	J^P	Mode
Experiment	1438	23	$3/2^{\pm}, 5/2^{\pm}$	$\Delta\pi$
	1522	≤ 20	$1/2^{\pm}, 3/2^{-}, 5/2^{+}$	$\Delta\pi, N\pi\pi$
	1894	≤ 40	—	$\Delta\pi, N\pi\pi$
B.M. [4,5]	2000	—	$5/2^{-}$ [5]	—
JSM [6]	1450÷1470	—	$1/2^{-}$	—
	1550	—	$3/2^{-}$	
	1900	—	$1/2^{+}, 3/2^{+}, 5/2^{+}$	
SSR [7]	1400÷1700	≈30 for $M_{rez.}$ = 1438	$5/2^{+}$	$\Delta\pi$

Note that the use of the simulated angular distributions of the subreactions (1a)-(1d) as a background results in the same conclusions about spin-parity sets for the above resonances.

The baryon resonances with isotopic spin 5/2 are the exampl of multiquark states the existence of which is not forbidden by QCD. Systems $\Delta^{++}_{33}\pi^{+}(\Delta^{-}_{33}\pi^{-})$ can be constructed of four quarks and 1 antiquark.

Some predictions concerning the existence and the characteristics of the baryon resonances with isotopic spin $I = 5/2$ have been obtained from the "bag model" (BM) /4,5/, the "joint string model" (JSM) /6/ and the superconvergence sum rules for reggeon-reggeon scattering (SSR) /7/. Table 2 shows the experimental data for the resonances with $I = 5/2$ and the predictions of the above-mentioned models.

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