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NARROW DIBARYON RESONANCES WITH ISOTOPIC SPIN $I = 2$

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Narrow enhancements were observed in the effective mass spectrum of $pp\pi^+$-combinations at (2511±5), (2607±2) and (2716±4) MeV/c^2 in the reaction $np \to pp\pi^+\pi^-\pi^-$ at an incident momentum of P_n = 5.2±0.16 GeV/c, studied in the 1m bubble chamber, LHE, JINR. The total experimental widths of the resonances are equal to 46, 27 and 36 MeV/c^2 and are completely determined by the resolution of the apparatus. The enhancements above background are 4.0; 6,8 and 3.4 standard errors. The most probable value of the spin for the resonance with a mass of 2607 MeV/c^2 was found to be $J \geq 2$. The resonance with such a mass decays with a probability of 48% via the mode $\to \Delta_{33}p$, with a probability of 14% via $\to (BB)^{++}_{2090}\pi^+$ and 38% via other modes. Here $(BB)^{++}_{2090}$ is a dibaryon in a 2-proton system with a mass around 2090 MeV/c^2.

The investigation has been performed at the Laboratory of High Energies and at the Laboratory of Computing Techniques and Automation, JINR.

Узкие дибарионные резонансы с изотопическим спином $I = 2$

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В реакции $np \to pp\pi^+\pi^-\pi^-$ при импульсе первичных нейтронов P_n = 5,2±0,16 ГэВ/с на материалах с 1-метровой водородной пузырьковой камеры ЛВЭ ОИЯИ обнаружены узкие особенности в спектре эффективных масс $pp\pi^+$-комбинаций при значениях (2511±5), (2607±2) и (2716±4) МэВ/с^2. Полные экспериментальные ширины резонансов равны 46, 27 и 36 МэВ/с^2 и целиком определяются аппаратурным разрешением. Превышение над фоном составляет 4,0; 6,8 и 3,4 стандартных отклонения соответственно. Наиболее вероятное значение спина резонанса с массой 2607 МэВ/с^2 оказалось равным $J \geq 2$. Этот резонанс распадается с вероятностью около 48% по каналу $\to \Delta_{33}p$, с вероятностью около 14% по каналу $\to (BB)^{++}_{2090}\pi^+$ и с вероятностью около 38% по другим каналам. Здесь $(BB)^{++}_{2090}$ — дибарион в системе 2-х протонов с массой в районе 2090 МэВ/с^2.

Работа выполнена в Лаборатории высоких энергий и Лаборатории вычислительной техники и автоматизации ОИЯИ.

The presented results were obtained by processing the films in an exposure of 1m hydrogen bubble chamber, LHE, JINR, to monochromatic neutrons ($\Delta P_n/P_n \approx 3\%$) at a momentum of 5.20 GeV/c. The characteristics of the beam, methods of the selection of reaction channels, the reaction cross-sections, etc., were described earlier ([1], see refs.). The following reactions were identified from 5-prong stars:

$$np \to pp\pi^+\pi^-\pi^- \quad (10356 \text{ events}) \tag{1}$$

$$np \to pp\pi^+\pi^-\pi^-\pi^0 \quad (6357 \text{ events}). \tag{2}$$

Figure 1 shows the distribution of effective masses of $pp\pi^+$-combinations: 1) — from reaction (2), 1) — from reaction (1), 3) — sum of

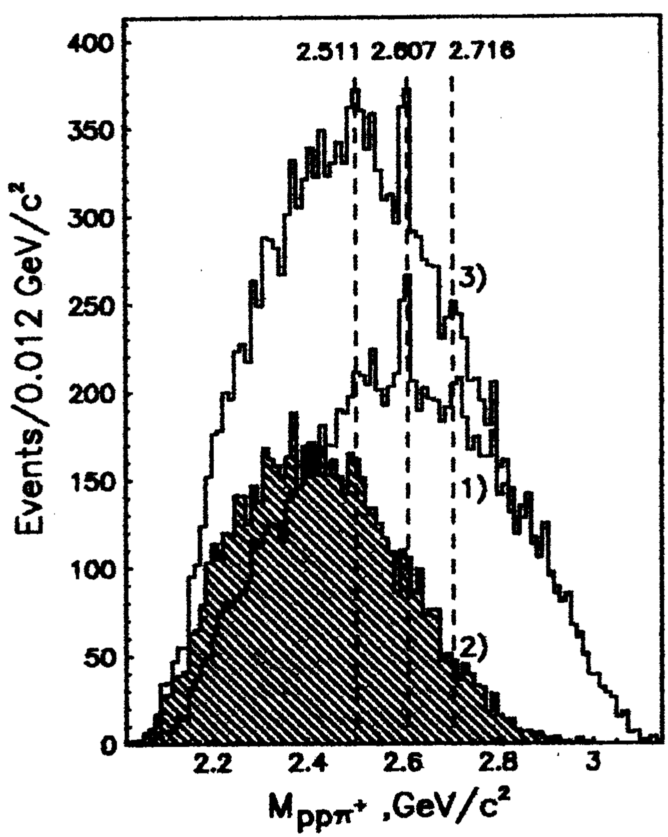


Fig.1. The effective mass distribution of $pp\pi^+$-combinations at P_n=5.2 GeV/c: 1) — reaction $np \to pp\pi^+\pi^-\pi^-$; 2) — reaction $np \to pp\pi^+\pi^-\pi^-\pi^0$; 3) — sum of (1) and (2)

these reactions. One can easily note an enhancement near masses of 2500, 2600 and 2700 MeV/c^2, which repeats for all distributions.

The further analysis is concerned mainly with reaction (1).

Figure 2 shows the distribution of effective masses of $pp\pi^+$-combinationns from reaction (1). The distribution is approximated by an incoherent sum of the background curve taken in the form of a superposition of Legendre polynomials of up to the second power inclusive (coefficients of higher power polynomials are negligible), and by three Breit — Winger resonance curves. The background contributes up to 95.3%. The

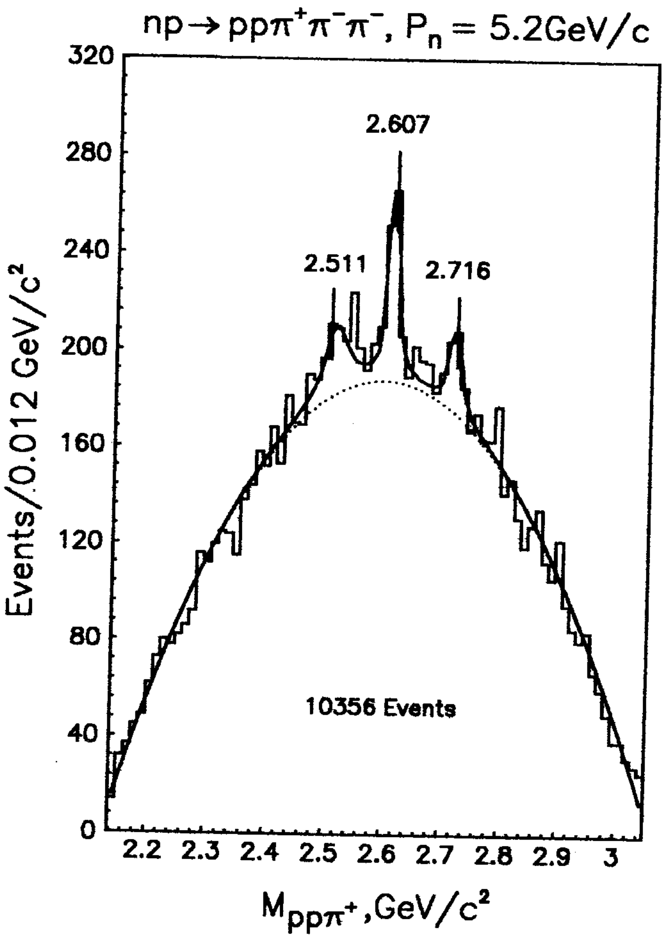


Fig.2. The effective mass distribution of $pp\pi^+$-combinations from reaction (1) at $P_n = 5.2$ GeV/c. The solid line — the approximation by the background curve and three Breit — Wigner curves; dotted line — the contribution of the background (Legendre polynomial of second power)

background describes the regions outside the resonances with $\chi^2 = 0.8 \pm 0.18$, $\sqrt{D} = 1.57 \pm 0.12$, that is close to the pure statistical distribution with $\chi^2 = 1.0$, $\sqrt{D} = 1.41$.

The central values of the masses of the observed resonances are equal to (2511±5), (2607±2), (2716±4) MэB/c^2. The exceedings over the background are equal to 4.0, 6.8 and 3.4 standard deviations, respectively. More detailed data are presented in the final table.

The analysis showed the reaction (1) proceeded largely through a production of Δ_{33}-isobar in the $p\pi^+$-system and was characterized by a strong anisotropy of protons emission in the general c.m.s. For the subsequent analysis the events of this reaction were therefore simulated with and without production of Δ_{33}-isobar using the FOWL program. Moreover, the periphericity of protons emission was taken into account by introducting the factor $\exp B \mid y^*_{p_1} - y^*_{p_{min}} \mid * \exp B \mid y^*_{p_2} - y^*_{p_{max}} \mid$ into the phase spase, $y^*_{p_1(p_2)}$ — the rapidity of the first (second) proton, and $y^*_{\min(\max)}$ — the minimum (maximum) possible rapidity of proton in reaction (1) at present energy. All values were taken in c.m.s. of the reaction. The value of factor B, the contribution of the peripheral processes as well as the contribution of the Δ_{33}-production channel were defined from a comparison of simulated event with a number of experimental distributions of reaction (1) (angle distribution of protons in c.m.s. of the reaction, distributions of effective masses of pp-, $p\pi^+$- and $pp\pi^+$-combinations). It was obtained that reaction (1) proceeded in 50% of events via isobar production; factor $B = 3.3$, the contribution of the peripheral processes ≈ 57%.

With simulated events at hand we have attempted to determine the relative weights of various decay modes of the resonance with a 2607 MeV/c^2 mass.

Figure 3a shows the distribution of the effective masses of $p\pi^+$-combinations from the mentioned resonance. This distribution was obtained by constructing the $pp\pi^+$ effective masses under the condition that at least one of the $p\pi^+$-combinations was placed within the Δ_{33}-isobar region, and by subtracting the background distributions from left and right sides of the band of 2607 MeV/c^2 resonance with the corresponding weights determined by the background contribution in the resonance band. The distribution is described by the curve composed by 70% due to resonance curve of Δ_{33}-resonance and by 30%, due to phase space curve.

Figure 3b shows the effective mass distribution of two protons from mentioned resonance, obtained in the same way. The distribution is described by the curve with 40% due to the curve of *pp*-resonance with a mass around 2090 MeV/c^2 and 60%, due to the background curve caused by the sum of processes in reaction (1) (with — and without Δ_{33}-production, and taking into account the periphericity of protons). The narrow *pp*-resonances with masses around 2090 MeV/c^2 were observed in a number of experiments [2]

In consequence, the following values were obtained for the relative contributions of various decay modes of the resonance in $pp\pi^+$-system at the 2607 MeV/c^2 mass:

$$(BB)^{+++}_{2607} \rightarrow \Delta_{33}p \qquad (38 \pm 9)\ \%$$

$$(BB)^{+++}_{2607} \rightarrow (BB)^{++}_{2090}\pi^+ \qquad (14 \pm 5)\ \%$$
$$\quad \hookrightarrow pp$$

$$(BB)^{+++}_{2607} \rightarrow pp\pi^+ \qquad (38 \pm 9)\ \%$$

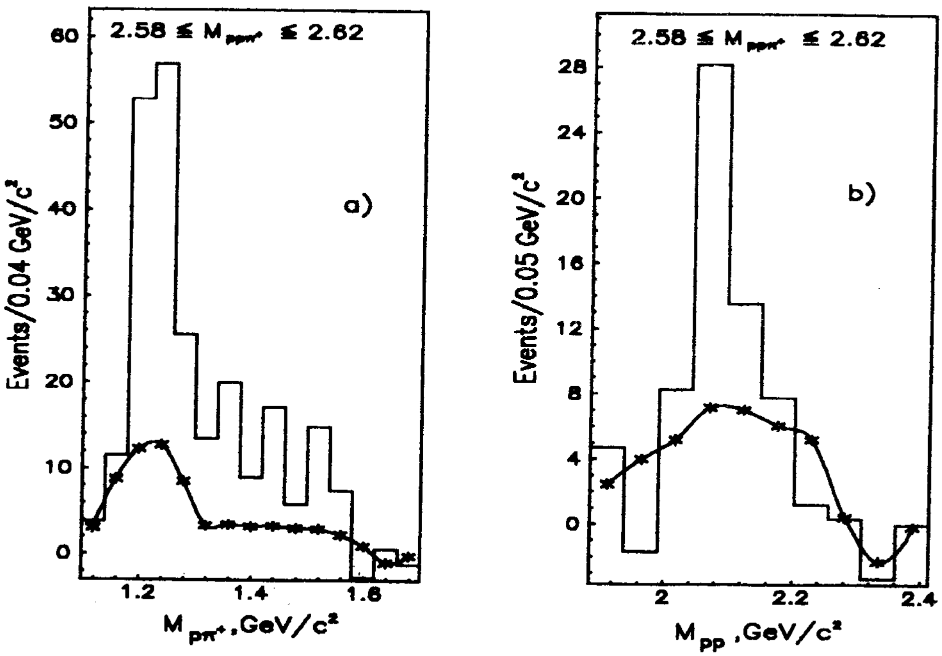


Fig.3. a) — The effective mass distribution of $p\pi^+$-combinations for $pp\pi^+$-resonance with 2607 MeV/c^2 mass. Crosses — the contribution of the background due to the periphericity of phase space. b) — The effective mass distributions of *pp*-combinations for $pp\pi^+$-resonance with 2607 MeV/c^2 mass. Crosses — the contribution of the background due to processes of Δ_{33}-production and periphericity of phase space

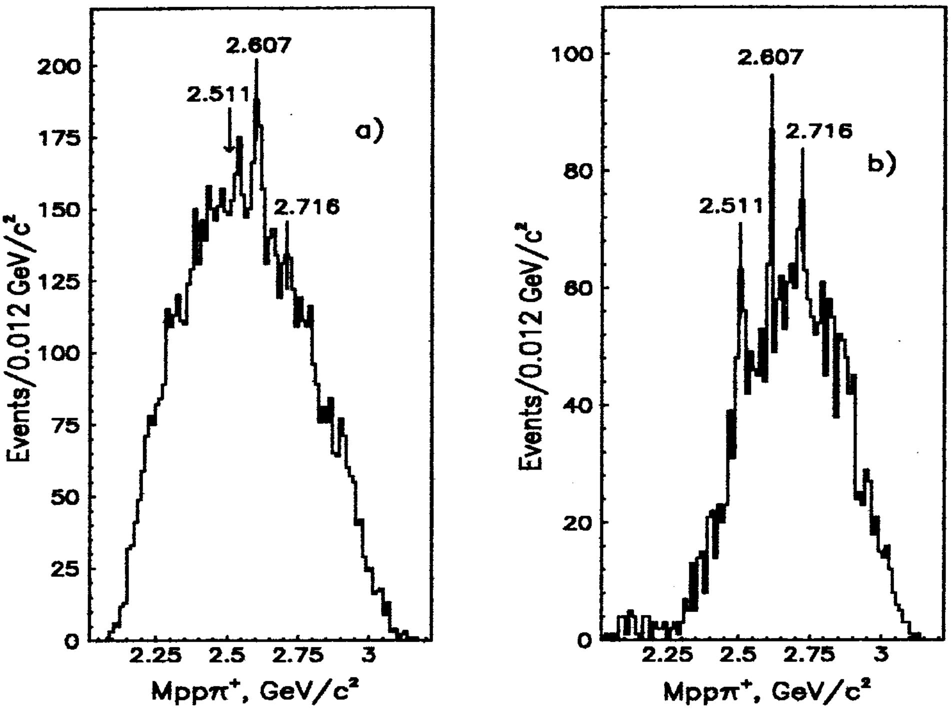
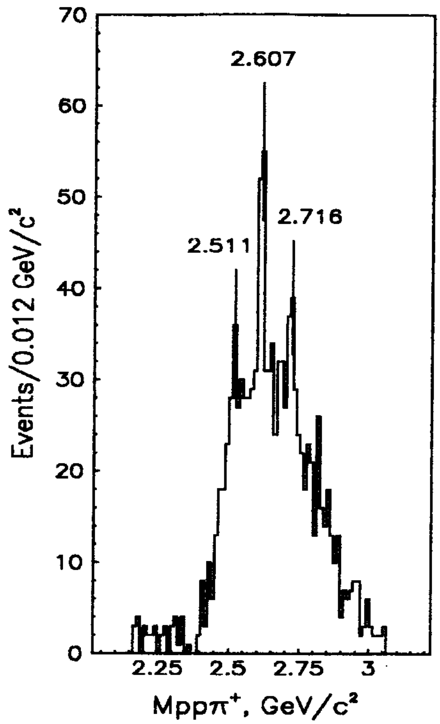


Fig.4. a) — The distribution of $pp\pi^+$ effective masses under the condition that at least one of the $p\pi^+$-combinations belongs to Δ_{33}-isobar region ($1.130 \le M_{p\pi^+} \le 1.296$ GeV/c^2). b) — The distribution of $pp\pi^+$ effective masses under the condition that none of $p\pi^+$-combinations belongs to Δ_{33}-isobar region ($M_{p\pi^+} > 1.296$ or $M_{p\pi^+} < 1.130$ GeV/c^2)

Figures 4 and 5 show the distributions of effective masses of $pp\pi^+$-combinations from reaction (5) for the events under some conditions for two — particle masses. The distribution of fig.4a was obtained by constructing $pp\pi^+$ effective masses under the condition that at least one of the $p\pi^+$-combinations belongs to Δ_{33}-isobar region ($1.130 \le M_{p\pi^+} \le 1.296$ GeV/c^2). The distribution of fig.4b was obtained by constructing $pp\pi^+$ effective masses under the condition that none of $p\pi^+$-combinations belongs to Δ_{33}-isobar region ($M_{p\pi^+} > 1.296$ or $M_{p\pi^+} < 1.130$ GeV/c^2). The distribution of fig.5 was obtained by constructing $pp\pi^+$ effective masses under the condition that none of $p\pi^+$-combinations belongs to Δ_{33}-isobar region and under the additional condition that the effective masses of pp-combinations belong to the region of pp-resonance with a mass around 2.090 GeV/c^2

Fig.5. The distribution obtained by constructing $pp\pi^+$ effective masses under the condition that none of $p\pi^+$-combinations belongs to Δ_{33}-isobar region and under the additional condition that the effective masses of pp-combinations belong to the region of pp-resonance with a mass around 2.090 GeV/c^2 ($2.00 \le M_{pp} \le 2.20$ GeV/c^2)



($2.00 \le M_{pp} \le 2.20$ GeV/c^2). This distributions enable to research in more detail the discussion effects and to produce the quantitative marks of the probabilities of the different modes of decays.

To determine the spin of the 2607 MeV/c^2 resonance, there was constructed and analysed the distribution of the angle between the normal of the resonance decay plane and the direction of resonance motion in general c.m.s. Such distributions are known to be described in strong decays by a sum of Legendre polynomials of an even power with the maximum power of $2J$, where J — the resonance spin, [3] (the angle is calculated in the resonance rest system). The distribution of $\cos\Theta_{\vec{n},\hat{\vec{p}}_{res.}}$ is shown in fig.6. There the dotted

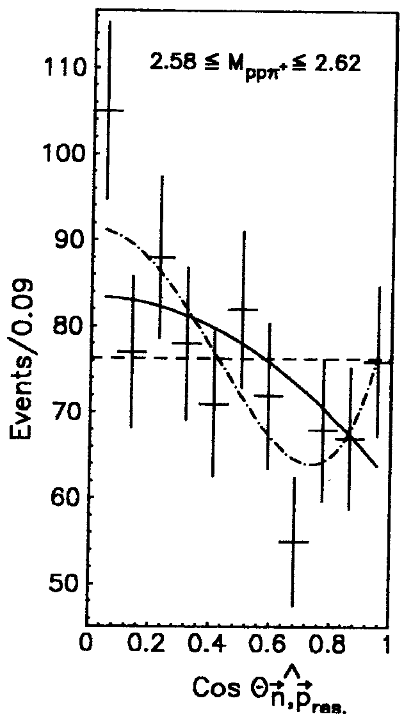


Fig.6. The distribution of $\cos\Theta_{\vec{n},\hat{\vec{p}}_{res.}}$ — angle between the normal of decay plane of $pp\pi^+$-resonance with a mass 2607 MeV/c^2 and the direction of its flight in general c.m.s. $np \to pp\pi^+\pi^-\pi^-$. All values are taken in resonance rest system. The dotted line — isotopic distribution, the solid line — the description by Legendre polynomials of up to second power inclusive, the dot-and-dash line — the description by Legendre polynomials of up to fourth power inclusive

line is an isotopic distribution, the solid line — the description by Legendre polynomials of up to second power inclusive, the dot-and-dash line — the description by Legendre polynomials of up to fourth power inclusive. The corresponding distribution for left and right sides is essentially isotopic, therefore the background subtraction was not carried out. The corresponding confidence levels are equal to 4%, 12% and 55%. Hence one may infer the spin of $pp\pi^+$ — resonance at the mass 2607 MeV/c^2 as $J \geq 2$.

The final data about the observed resonances are given in the Table.

Table

$M_e \pm \Delta M_e$, MeV/c^2	$\Gamma_e \pm \Delta\Gamma_e$, MeV/c^2	$\Gamma_R \pm \Delta\Gamma_R$, MeV/c^2	$\sigma \pm \Delta\sigma$, μb	*S.D.*	*P*
2511±5	46±21	24±21	8.4±3.0	4.0	$5.0 \cdot 10^{-4}$
2607±2	27±7	7±7	10.3±2.4	6.8	$2.0 \cdot 10^{-9}$
2716±4	36±16	22±16	4.9±2.2	3.4	$1.4 \cdot 10^{-2}$

The first column contains the central value of the resonance mass; the second one — the experimental full width of the resonance; the third one — the true resonance width, obtained by quadratic subtractiion of the widths of the resolution function for the masses of $pp\pi^+$-combinations (these are equal to 23, 26 and 29 MeV/c^2 for the corresponding resonances) from the experimental widths. In the fourth column the cross-section of the resonance production in reaction (1) is given along with the errors, including the error of determination of the channel (1) cross-section (see [[1]); in the fifth column — number of standard deviations above the background, in the sixth column — the probability that observed enhancements are background fluctuations.

There were too few experimental data concerning searches and investigations of similar resonances in the previously published reports. The evidence about weak enchancements in the effective mass spectra of $pp\pi^+$-combinations at 2160 MeV/c^2 were obtained in [4,5]. In [6] no enhancements were found, but there either bound states of $nn\pi^-$-system or a region of the effective masses of the same system near the threshold of $NN\pi$ were studied. A number of papers (see, e.g., [7] and references therein) was concerned with the investigations of the resonances production of π^+-mesons from the interactions of protons with various nuclei at $T \approx 350$ MeV. This effect can be interpreted from the point of view of a production and a following decay of resonances with isotopic spin $I = 2$ proton-nuclei interactions, but there exist not less convincing alternative explanations.

One can note that all the above effects are observed in the mass regions placed considerably lower than that studied in our experiment.

Theoretical predictions about resonances with isotopic spin $I = 2$ are made in the models using quite different approaches. There are predictions base on quark models [8], Skyrme model [9], the general quantum-mechanical approach in a model of semiopen resonator [10].

The very diversity of approaches with the whole spectrum of predictions signifies that the problem of the nature of the studied effect remains to be still open and requires considerably more experimental data to explain it. On the other hand it is very hard to overrate the significance of resonance effects in multihadronic (multiquark) systems, especially for the investigations of the relativistic nuclei interactions.

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