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Yu. A. Troyan*, A. V. Beljaev, A. Yu. Troyan,
E. B. Plekhanov, A. P. Jerusalimov, G. B. Piskaleva,
S. G. Arakelian[1]

SEARCH AND STUDY OF THE BARYONIC RESONANCES WITH THE STRANGENESS $S=+1$ IN THE SYSTEM OF nK^+ FROM THE REACTION $np \to npK^+K^-$ AT THE MOMENTUM OF INCIDENT NEUTRONS $P_n = (5.20 \pm 0.12)$ GeV/c

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*E-mail: atroyan@jinr.ru
[1] Lebedev Physical Institute of RAS, Moscow

Троян Ю. А. и др. Д1-2004-39

Поиск и исследование барионных резонансов
со странностью $S=+1$ в системе nK^+ в реакции $np \to npK^+K^-$
при импульсе налетающих нейтронов $P_n = (5{,}20 \pm 0{,}12)$ ГэВ/c

В реакции $np \to npK^+K^-$ при импульсе падающих нейтронов $P_n = (5{,}20 \pm 0{,}12)$ ГэВ/c исследовано образование и свойства барионных резонансов со странностью $S=+1$ в системе nK^+.

Обнаружен ряд особенностей в спектре эффективных масс указанной системы. Все резонансы имеют высокую статистическую значимость. Их ширины сравнимы с разрешением по массам. Произведена оценка спинов резонансов и построена ротационная полоса, связывающая массы резонансов с их спинами.

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Search and Study of the Baryonic Resonances
with the Strangeness $S=+1$ in the System of nK^+
from the Reaction $np \to npK^+K^-$ at the Momentum
of Incident Neutrons $P_n = (5.20 \pm 0.12)$ GeV/c

The production and properties of the resonances with the strangeness $S=+1$ in the system of nK^+ were studied in the $np \to npK^+K^-$ reaction at the momentum of incident neutrons $P_n = (5.20 \pm 0.12)$ GeV/c.

A number of peculiarities were found in the effective mass spectrum of the mentioned above system. All these resonances have a large statistical significance. Then widths are comparable with the mass resolution. The estimation of the resonance spin was carried out and the rotational band connecting the resonance masses with spins was constructed.

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

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INTRODUCTION

D. Diakonov, V. Petrov, and M. Polyakov have suggested in the papers [1, 2] the development of the sheme of $SU(3)$ symmetry for states with the strangeness $S = +1$. The existence of anti-decuplet $\overline{10}$, which included states consisting of five quarks ($uudd\bar{s}$), was claimed. The dynamics of new resonances was based on the model of chiral soliton. This fact gave the possibility to estimate masses, widths, and quantum numbers of expected new effects, to suggest the formula of the rotational band that gave a dependence of the resonance masses on their spins. In the paper [1], Θ-resonance at the mass $M = 1.530$ GeV/c^2, width $\Gamma \leqslant 15$ MeV/c^2 and with quantum numbers $Y = 2$, $I = 0$, $J^P = 1/2^+$ is in the vertex of anti-decuplet.

The hypothesis of the authors [1] is discussed in great detail in many theoretical works, the number of which is close to 50. A detailed review of theoretical works one can find in papers [3, 4, and 5] together with a number of critical remarks. The quite different approaches to the problem of these resonances are developed in papers [6, 7]: integration of quarks into diquarks, which is accompanied by a rise of superconducting layers [6]; pure quark picture, where can arise isoscalar, isovector, and isotensor states consisting of five quarks (both usual and strange), which strongly extends possible quantum numbers as well as resonance masses and probability of resonance decays (for example, Θ resonances may have the quantum numbers $1/2^-$, $3/2^-$, $5/2^-$) [7].

The properties of the particles from anti-decuplet predicted in [1, 2] are such that allow the direct search for effects. These properties are both comparatively low masses and accessible for a direct measurement widths. That is why there are a number of experimental works [8] on discovering of a resonance with the mass of ~ 1.540 GeV/c^2 and width of $3{-}25$ MeV/c^2 in nK^+or pK_s^0 system.

But neither of experimental works from the mentioned above have yet observed the rotational band or more than one resonance state. Also neither spin of resonance nor its parity was determined. This fact is first of all due to a small statistics of experiments, insufficient accuracy, and different kinds of samplings.

In present work we have attempted to study the characteristics of the observed effects in more detail.

1. EXPERIMENT

The study was carried out using the data obtained in an exposure of a 1-m H_2 bubble chamber of LHE (JINR) to a quasimonochromatic neutron beam that was constructed in 1972 due to the acceleration of deuterons by synchrophasotron of LHE. The purpose of the neutron experiment was the study of pentaquarks in $\Delta^{++}\pi^+$ system (see below).

Quasimonochromatic neutrons ($\Delta P_n/P_n \approx 2.5\%$) were generated due to the stripping of accelerated deuterons in 1-cm AL target placed inside the vacuum chamber of synchrophasotron. Neutrons were extracted from the accelerator at the angle of 0° to the direction of accelerated deuterons.

Cleaning of the neutron beam from charged particles was provided by the magnetic field of accelerator through which neutrons passed about 12 meters before leaving the synchrophasotron. The bubble chamber was placed at a distance of 120 m from AL target. The neutron beam was good collimated and had an angular spread of $\Delta\Omega_n \approx 10^{-7}$ sterad. The neutron beam had no admixture neither from charged particles nor γ quanta. A detailed description of the neutron channel was made in [9].

The 1-m H^2 bubble chamber was placed inside the magnetic field of ~ 1.7 T. As a result we have had a good accuracy of the momenta of secondary charged particles ($\delta P \approx 2\%$ for protons and $\delta P \approx 3\%$ for K^+ and K^- from the reaction $np \to npK^+K^-$). The angular accuracy was $\leqslant 0.5^\circ$.

The channels of the reactions were separated by the standard χ^2 method taking into account the corresponding coupling equations [10]. There is only one coupling equation for the parameters of the reaction $np \to npK^+K^-$ (energy conservation law) and the experimental χ^2 distribution must be the same as the theoretical χ^2 distribution with one degree of freedom.

Figure 1, *a* shows the experimental (histogram) and the theoretical (solid curve) χ^2 distributions for the reaction $np \to npK^+K^-$. One can see a good agreement between them up to $\chi^2 = 1$ and some difference for $\chi^2 > 1$. Therefore we have used only the events with $\chi^2 \leqslant 1$ (limit is pointed by arrow) for the further analysis. Fifteen percent of events with this limitation satisfy two hypotheses: channel $np \to npK^+K^-$ and channel $np \to np\pi^+\pi^-$. In this case χ^2 value of the hypothesis of K mesons («K») is always less than χ^2 value of the hypothesis of π-mesons («π»). All these events are attributed to the «K» hypothesis. A difference between some test distributions for single hypothesis and double hypothesis events was not observed.

Figure 1, *b* shows missing mass distribution for the events of $\chi^2 \leqslant 1$. One can see that the distribution has the maximum at the value equal to the neutron mass with accuracy of 0.1 MeV/c^2 and is symmetric about the neutron mass. Later on a small number of events with the missing masses out of range pointed by arrows were excluded for more purity of data.

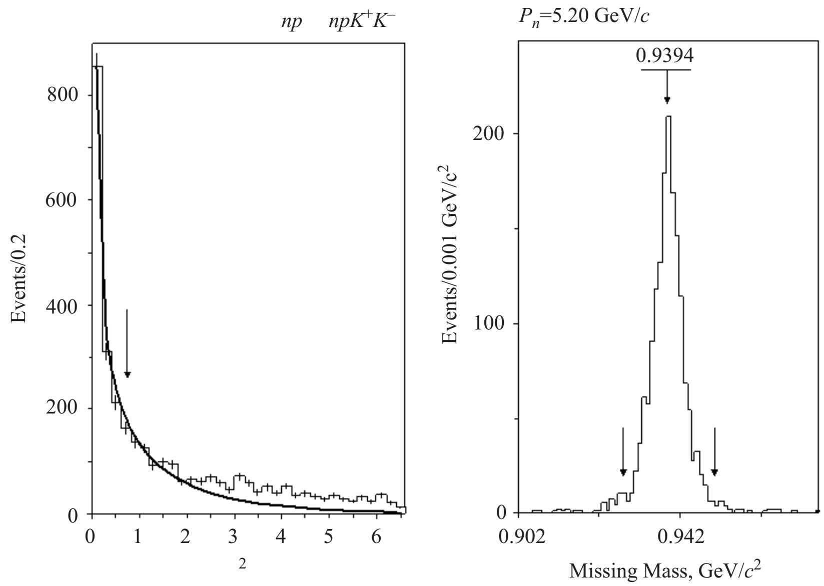

Fig. 1. *a*) the experimental (histogram) and the theoretical (solid curve) χ^2 distribution for the reaction $np \to npK^+K^-$; *b*) missing mass distribution for the events of $\chi^2 \leqslant 1$

In consequence of this 1558 events were selected from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c under condition of 4π geometry (the absence of any angular selections).

2. RESULTS

Figure 2 shows the effective mass distribution of nK^+ combinations for all the events from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c. The distribution is approximated by an incoherent sum of the background curve (taken in the form of a superposition of Legendre polynomials up to the 8th power, inclusive) and by 10 resonance curves taken in the Breit–Wigner form. The part of the background is 75.8% in this distribution. The requirements to the background curve are the following: firstly, the errors of the coefficients must be not more than 50% for each term of the polynomial; secondly, the polynomial must describe the experimental distribution after «deletion» of resonance regions with $\overline{\chi^2} = 1.0$ and $\sqrt{D} = 1.4$ (the parameters of χ^2 distribution with one degree of freedom). The parameters for the distribution in Fig. 2 are $\overline{\chi^2} = 0.92 \pm 0.29$ and $\sqrt{D} = 1.33 \pm 0.20$. The same parameters for the background curve normalized to 100% of events (resonance regions are included) are $\overline{\chi}^2 = 1.40 \pm 0.19$ and $\sqrt{D} = 2.38 \pm 0.14$. The significance level of the resonance at $M = 1.541$ GeV/c^2 is 4.5 S.D.

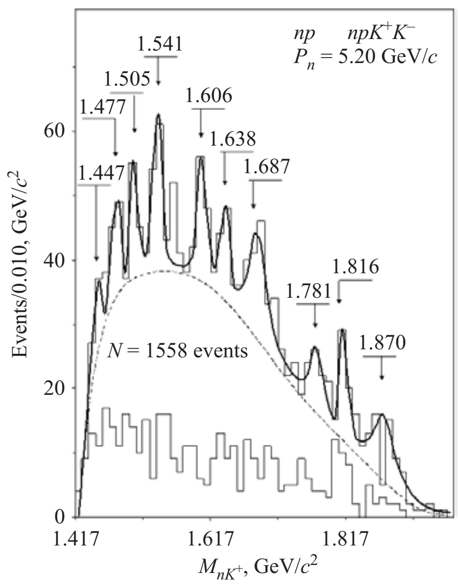

Fig. 2. The effective mass distribution of nK^+ combinations for all the events from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c. Dotted line indicates the background curve taken in the form of Legendre polynomial of the 8th degree. Solid line indicates the sum of the background curve and 10 resonance curves taken in the Breit–Wigner form. Lower histogram is the effective mass distribution of nK^+ combinations selected under condition $\{\cos\Theta_n^* < -0.85 \cup \cos\Theta_n^* > 0.85\}$

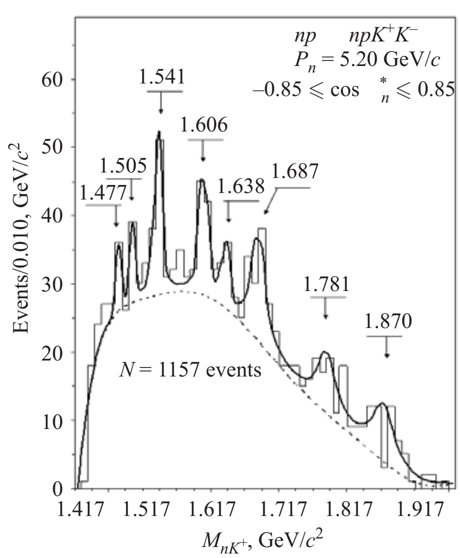

Fig. 3. The effective mass distribution of nK^+ combinations for the events selected under condition $\{-0.85 < \cos\Theta_n^* < 0.85\}$ from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c. Dotted line indicates the background curve taken in the form of Legendre polynomial of the 8th degree. Solid line indicates the sum of the background curve and eight resonance curves taken in the Breit–Wigner form

In the same Fig. 2 the distribution of effective masses is presented for nK^+ combinations selected under condition of $\{\cos\Theta_n^* < -0.85 \cup \cos\Theta_n^* > 0.85\}$, where Θ_n^* is the angle of secondary neutron emission in c.m.s. One can see that this distribution has no essential bumps and a deletion of such kind of events can decrease the background.

Figure 3 shows the distribution of effective masses of nK^+ combinations for the events selected under condition $\{-0.85 < \cos\Theta_n^* < 0.85\}$. The distribution is approximated by an incoherent sum of the background curve taken in the form of superposition of Legendre polynomials up to the 8th power and by eight resonance curves taken in the Breit–Wigner form. The statistical significances somewhat increase for the resonances on the right from the mass $M = 1.541$ GeV/c^2 and somewhat decrease for the narrow resonances on the left one.

For a better study of low-mass resonances, the distribution of effective masses of nK^+ combinations was constructed with bins of 5 MeV/c^2 (up to the mass of ~ 1.663 GeV/c^2). This distribution (Fig. 4) was approximated by an incoherent sum of the background curve taken in the form of a superposition of Legendre polynomials up to the 4th power and six resonance curves taken in the Breit–Wigner form.

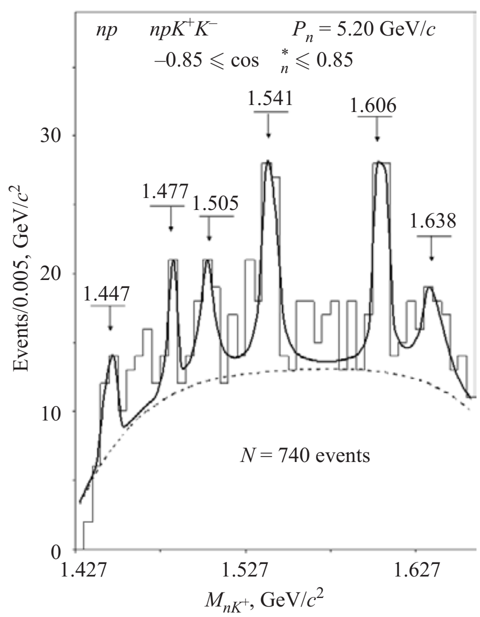

Fig. 4. The effective mass distribution of nK^+ combinations for the events selected under condition $\{-0.85 < \cos\Theta_n^* < 0.85\}$ from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c. Dotted line indicates the background curve taken in the form of Legendre polynomial of the 4th degree. Solid line indicates the sum of the background curve and six resonance curves taken in the Breit–Wigner form

The resonance at $M = 1.541$ GeV/c^2 exceeds the background by 5.2 S.D, the resonance at $M = 1.605$ GeV/c^2 — by 5.4 S.D and the resonance at $M = 1.505$ GeV/c^2 — by 3.1 S.D. The widths of the resonances are more precisely determined by means of this distribution (see Tab. 1).

We undertook an attempt to increase the statistical significances of some resonances. This attempt was based on the assumption that resonances were produced by means of K-exchange mechanism: a well known resonance (Σ^* or Λ^*) decaying through pK^- mode was produced in one of the vertices of the corresponding diagram and the resonance in the nK^+ system was produced in another vertex. K^- meson from decay of a well known resonance could kinematically be correlated with the resonance in the nK^+ system. Consequently, kinematically produced peaks could be formed in the effective mass distribution of nK^+K^- system.

Figure 5 shows the effective mass distribution of nK^+K^- combinations. A number of peculiarities are clearly observed in this distribution. Corresponding resonances decaying through the mode $R \to NK\bar{K}$ are absent in PDG tables. These are just the same kinematic reflections mentioned above. The same Fig. 5 shows the effective mass distribution of nK^+K^- combinations constructed under condition that the effective mass nK^+ system is within the range of the resonance at $M = 1.541$ GeV/c^2. Two clusters are clear seen in this distribution near the following masses of nK^+K^- system: $2.020 \div 2.150$ GeV/c^2 and $2.240 \div 2.280$ GeV/c^2. Corresponding clusters exist for resonances in nK^+ system at $M = 1.606$ GeV/c^2 and $M = 1.678$ GeV/c^2.

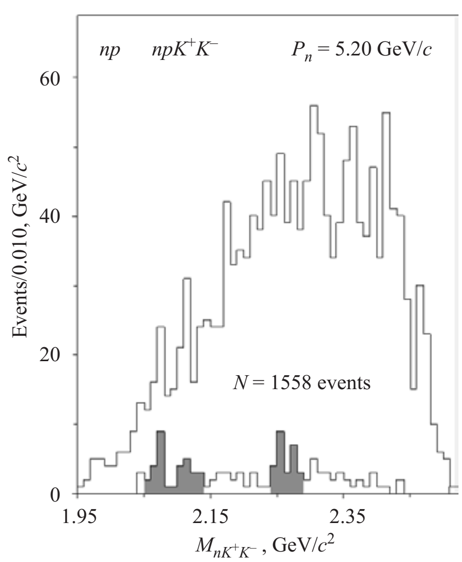

Fig. 5. The effective mass distribution of nK^+ combinations for the events selected under condition $\{-0.85 < \cos\Theta_n^* < 0.85\}$ from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c. Lower histogram is the effective mass distribution of nK^+K^- combinations plotted under condition that the effective mass of nK^+ combinations was in the region of the resonance at $M = 1.541$ GeV/c

Selecting regions of masses of nK^+K^- combinations that correspond to the nK^+ resonances, we obtain distributions of effective masses of nK^+K^- combinations (Fig. 6).

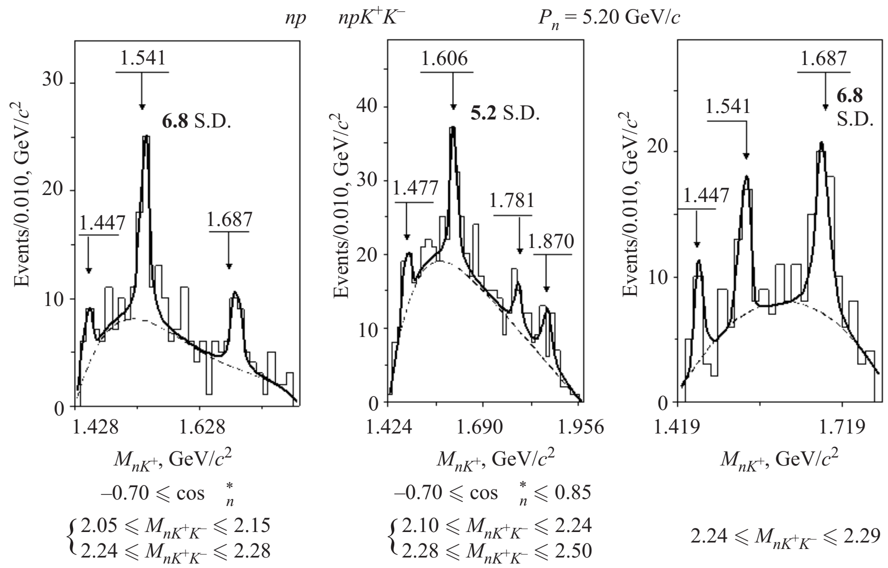

Fig. 6. The effective mass distribution of nK^+ combinations from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/*c*: *a*) for the resonances at $M = 1.541$ GeV/c^2; *b*) for the resonances at $M = 1.606$ GeV/c^2; *c*) for the resonances at $M = 1.678$ GeV/c^2. The selected masses for nK^+K^- combinations and the additional limits of the emission angles of secondary neutrons in c.m.s. are shown under each plot. Dotted lines indicate background curves. Solid lines indicate approximating curves

The selected masses for nK^+K^- combinations and the additional limits of the emission angles of secondary neutrons in c.m.s. are shown under each distribution. The additional cut on emission angle somewhat decrease the background but the main effect of enhancement is due to the cut on masses of nK^+K^- combinations.

Each of the obtained distributions is approximated by an incoherent sum of background curve taken in the form of Legendre polynomial and by resonance curves taken in the Breit–Wigner form.

As a result we get a significant enhancement of effects of three resonances processed in such a manner (the values of S.D. are shown in Fig. 6). In this case the number of events in peaks do not decrease as compared with the data presented in Fig. 2, 3, and 4.

Figure 7 shows the distributions of effective masses of pK^- combinations under the same conditions of sampling as in Fig. 6. One can observe peculiarities in the masses of pK^- combinations corresponding to well known Σ^* or Λ^* reso-

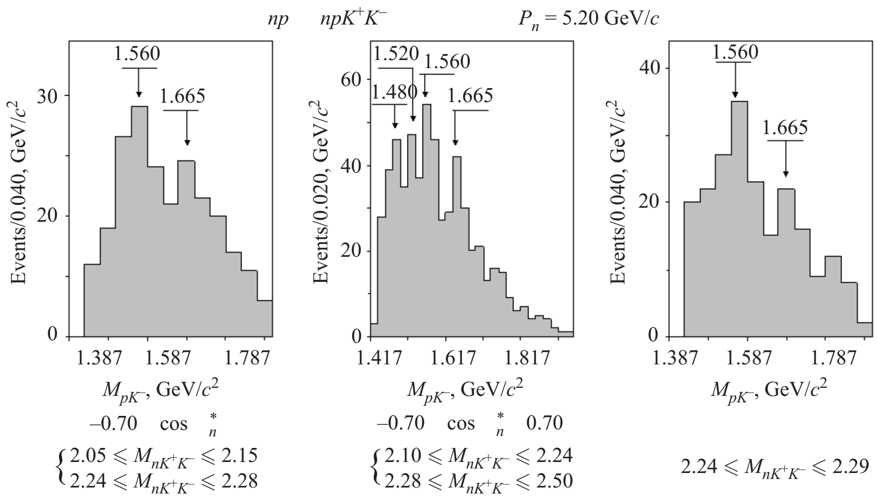

Fig. 7. The effective mass distribution of nK^+ combinations from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12)$ GeV/c. The selected masses for nK^+K^- combinations and the additional limits of the emission angles of secondary neutrons in c.m.s. are shown under each histogram (corresponding to Fig. 6)

nances (these peculiarities are well observed also in the distributions of effective masses of pK^- combinations constructed without limitations mentioned above).

We have tried to estimate the values of spins for the observed resonances in nK^+ system. To do this there were constructed the distributions of emission angles of neutron from resonance decays relative to the direction of resonance emission in general c.m.s. All the quantities were taken in the rest system of resonance (helicity coordinate system). In the helicity coordinate system, the angular distributions must to be described by the sum of Legendre polynomials of even degrees and a maximum degree must to be equal to $(2J - 1)$, where J is a spin of the resonance (for half-integer spins). In this manner the value of low limit of resonance spin was estimated. The authors were grateful to Dr. V. L. Luboshits for his help.

Figure 8 shows the angular distributions for six resonances which masses are within the ranges pointed in plots. The backgrounds are constructed using events on the left and on the right of the corresponding resonance band and subtracted using the weight in proportion to the contribution of a background into resonance region. No limitations on emission angles of secondary particles were used in construction of these distributions (cuts on emission angle of secondary neutron do not change the results). It is necessary during the approximation that errors of coefficients Legendre polynomials do not exceed 50%.

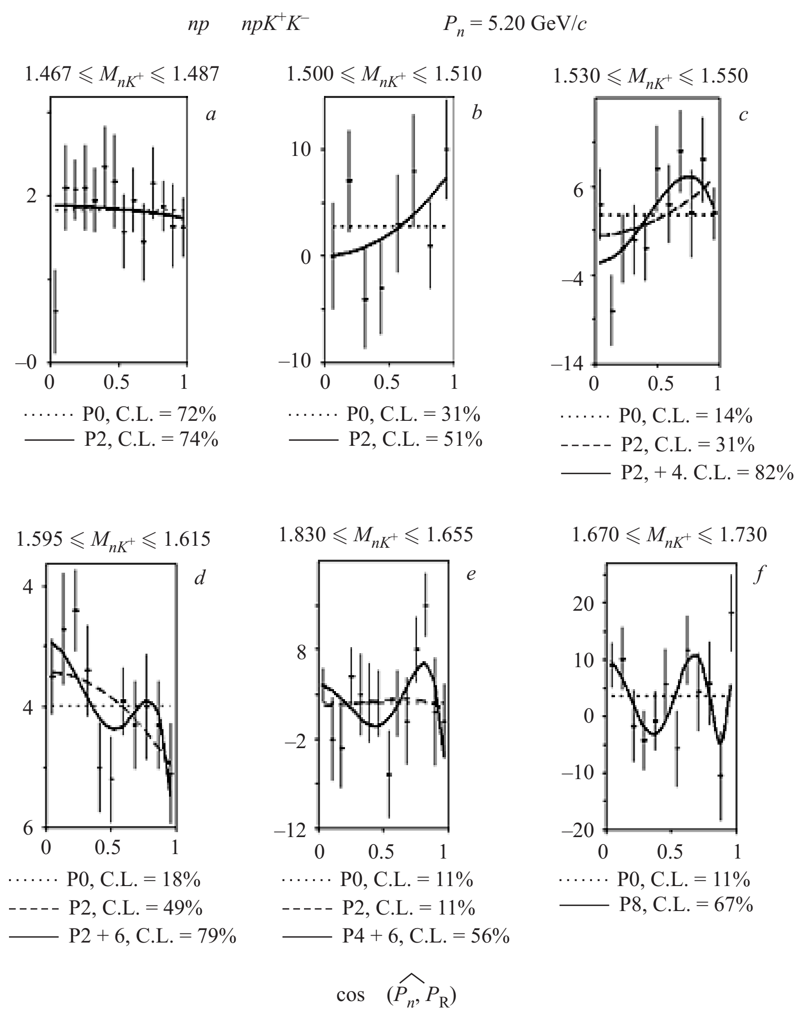

Fig. 8. The distribution of the emission angles of secondary neutrons in helicity coordinate system: *a*) for the resonances at $M = 1.477$; *b*) for the resonances at $M = 1.505$; *c*) for the resonances at $M = 1.541$; *d*) for the resonances at $M = 1.606$; *e*) for the resonances at $M = 1.638$; *f*) for the resonances at $M = 1.687$ GeV/c^2

One can see in the plots presented in Fig. 8 that the distribution for the resonance at $1.467 < M < 1.487$ GeV/c^2 is isotropic and polynomials of a higher power are not necessary for the approximation, and, therefore, its spin is equal to $J \geqslant 1/2$. The most probable value of the spin is $J \geqslant 3/2$ for the resonance at the mass of $1.500 < M < 1.510$ GeV/c^2, although the value $J \geqslant 1/2$ has enough large confidence level. The value of spin $J \geqslant 1/2$ for the resonance at the mass of $1.530 < M < 1.550$ GeV/c^2 (the most widely discussed in papers) has a confidence level significantly less than the highest one. The highest confidence level is for spin of $J \geqslant 5/2$. The resonance at $1.595 < M < 1.615$ GeV/c^2 has a more reliable estimation for the value of spin $J \geqslant 7/2$.

A qualitative estimation can be done by studying the shapes of plots: these plots must have $(2J-3)/2$ extrema and a «trivial» one at $\cos\Theta = 0$ that is quite in agreement with the data in Fig. 8, *d*.

Figures 8, *e* and *f* present results of spin studies for more heavier resonances. The resonance at the mass of $1.630 < M < 1.655$ GeV/c^2 has the value of spin $J \geqslant 7/2$ with a good confidence level, the resonance at the mass of $1.670 < M < 1.730$ GeV/c^2 has the value of spin $J \geqslant 9/2$ with a larger confidence level. The high-mass resonance has a weak estimation because of a much worse mass resolution at this region and a larger influence of the background.

The results are presented in Table 1.

Table 1.

$M_{\rm exp} \pm \Delta M_{\rm exp}$, GeV/$c^2$	$\Gamma_{\rm exp} \pm \Delta\Gamma_{\rm exp}$, GeV/$c^2$	$\Gamma_R \pm \Delta\Gamma_R$, GeV/$c^2$	$J_{\rm exp}$	S.D.
1.447 ± 0.007	0.005 ± 0.004	0.004 ± 0.004		3.2
1.467 ± 0.003	0.008 ± 0.003	0.008 ± 0.004		2.3
1.477 ± 0.002	0.005 ± 0.003	$0.002^{+0.006}_{-0.002}$	1/2	3.0
1.505 ± 0.004	0.008 ± 0.003	0.005 ± 0.005	3/2	3.5
1.541 ± 0.004	0.011 ± 0.003	0.008 ± 0.004	5/2	6.8
1.606 ± 0.005	0.014 ± 0.005	0.011 ± 0.006	7/2	5.2
1.638 ± 0.005	0.016 ± 0.011	$0.012^{+0.015}_{-0.012}$	7/2	3.6
1.687 ± 0.007	0.027 ± 0.007	0.024 ± 0.008	9/2	6.8
1.781 ± 0.008	0.029 ± 0.012	0.023 ± 0.015		4.1
1.870 ± 0.019	0.036 ± 0.010	0.032 ± 0.011		5.9

The first column contains the experimental values of the resonance masses and their errors.

The second column contains the experimental values of the total width of the resonances.

The third column contains the true widths of the resonances and their errors.

The true width of a resonance is obtained by a quadratic subtraction of the value of mass resolution from the experimental value of the width. The function of the mass resolution [11] increases with the increasing of masses:

$$\Gamma_{\rm res}(M) = 4.2 \cdot \left[\left(M - \sum_{i=1}^{2} m_i\right)/0.1\right] + 2.8,$$

where: M is a mass of the resonance, m_i are masses of the particles composing this resonance. M and m_i are in Gev/c^2. Coefficients 4.2 and 2.8 are in MeV/c^2.

For example, the value of the mass resolution is ≈ 7 MeV/c^2 for the resonance at $M = 1.541$ GeV/c^2.

The fourth column contains the values of resonances spins or, in other words, the lower limits of spins as explained during discussion of the procedure of spin estimation.

The fifth column presents the statistical significances of the resonances determined as the ratio of the number of events in the resonance to the square root of the number of background events under the resonance curve.

The estimation of the cross-section for the resonance at $M = 1.541$ GeV/c^2 in the nK^+ system from the reaction $np \rightarrow npK^+K^-$ is $\sigma = (3.5 \pm 0.7)$ mkb at $P_n = (5.20 \pm 0.12)$ GeV/c.

3. DISCUSSION

We have tried to systematize the obtained results using the formula for the rotational bands suggested in papers of Diakonov et al. [1, 2]:

$$M_J = M_0 + kJ(J+1), \tag{1}$$

where: M_J is the mass of the resonance, J is its spin, M_0 is rest mass of the soliton, k is the value equal to the inversed multiplied by twice inertia moment of soliton (we use the terminology of the paper [2])

Looking at the plots of the effective mass distribution of nK^+ combinations one can observe that strong peculiarities are accompanied by more weak ones: weak peculiarity at $M = 1.467$ GeV/c^2, the bump at $M = 1.565$ GeV/c^2 and others. Therefore, we have carried out the approximation of the mass distributions versus spin using two variants. Both of them are presented in Table 2. One can see a good agreement between the experimental data and the formula (1). In Table 2a, the largest predicted mass at 1.901 GeV/c^2 $(J = 13/2)$ can be cut by the phase space on the right and be observed experimentally at the lower mass. In Table 2b, the data about experimental values of masses and spins are absent in the third and fifth lines. There are only bumps at these masses that are not provided statistically as resonances.

Taking the inertia moments $I = M_0 \cdot r^2$ and using the value of $k = 1/2I$ from Table 2 it is possible to determine the radius of soliton. It is approximately equal to 1.2 fm that is close to π-meson radius (≈ 1.35 fm).

We have done another approximation of the observed rotational bands proposing that the mass of an exited state depends not on the resonance spin but on its orbital moment l:

$$M_l = M_0 + kl(l+1). \tag{2}$$

Table 2.

a)				b)			
$M_0 = 1.462$ GeV/c^2		$k = 0.0090$		$M_0 = 1.471$ GeV/c^2		$k = 0.0107$	
J	M_J	$M_{\rm exp} \pm \Delta M_{\rm exp}$	$J_{\rm exp}$	J	M_J	$M_{\rm exp} \pm \Delta M_{\rm exp}$	$J_{\rm exp}$
1/2	1.469	1.467 ± 0.003		1/2	1.471	1.477 ± 0.002	1/2
3/2	1.496	1.505 ± 0.004	3/2	3/2	1.511	1.505 ± 0.004	3/2
5/2	1.541	1.541 ± 0.004	5/2	5/2	1.565		
7/2	1.604	1.606 ± 0.005	7/2	7/2	1.640	1.638 ± 0.005	7/2
9/2	1.685	1.687 ± 0.007	9/2	9/2	1.736		
11/2	1.784	1.781 ± 0.008		11/2	1.854	1.870 ± 0.019	
13/2	1.901	1.870 ± 0.019					

The results are presented in Table 3:

3a — for «strong» resonances and 3b — for «weak» one. The values of orbital moments are taken arbitrarily but so that they do not contradict the estimations of the spins. Such approximations better satisfy the experimental data. In this description, it is necessary to take into account the resonance at $M = 1.447$ GeV/c^2 that was observed in most of the presented distributions and was discussed in some theoretical studies.

Table 3.

a)			b)		
$M_0 = 1.481$ GeV/c^2		$k = 0.0010$	$M_0 = 1.447$ GeV/c^2		$k = 0.0100$
ℓ	M_ℓ	$M_{\rm exp} \pm \Delta M_{\rm exp}$	ℓ	M_ℓ	$M_{\rm exp} \pm \Delta M_{\rm exp}$
0	1.481	1.477 ± 0.002	0	1.447	1.447 ± 0.007
1	1.501	1.505 ± 0.004	1	1.467	1.467 ± 0.003
2	1.541	1.541 ± 0.004	2	1.507	1.505 ± 0.004
3	1.601	1.606 ± 0.005	3	1.567	
4	1.681	1.687 ± 0.007	4	1.647	1.638 ± 0.005
5	1.781	1.781 ± 0.008	5	1.747	
6	1.901	1.870 ± 0.019	6	1.867	1.870 ± 0.019

Taking into account the assumption about the orbital moments, the parity of the resonance at $M = 1.541$ GeV/c^2 is negative. Taking into account the value of its spin $J = 5/2$ in addition one can conclude that this resonance is not placed at the vertex of anti-decuplet suggested in papers [1, 2]. But there is a probability that the resonance at $M = 1.501$ GeV/c^2 (with positive parity and spin equal to 1/2) is placed at the vertex. Our determination of the spin for $M \approx 1.505$ GeV/c^2 does not contradict the fact that there can be placed two resonances at $M = 1.501$ GeV/c^2 ($J^P = 1/2^+$) and at $M = 1.507$ GeV/c^2 ($J^P = 3/2^-$). In this case both of them are very narrow and are shifted relative to each other that gives, as a result, the average value of the experimental mass equal to $M = 1.505$ GeV/c^2. So it is necessary to carry out very precise experiments both on mass resolution and statistics.

It is necessary to do an additional remark.

The problem of pentaquarks arised in early 1860s. Ya. B. Zeldovich and A. D. Saharov [12] were the first to interpret the observed effects in the system of $p\pi^+\pi^+$ as a manifestation pentaquark states. Our first studies [13] concerning this problem have stimulated the realization of the unique neutron beam [9] for the 1-m H_2 bubble chamber of LHE, JINR, due to acceleration of deuterons in synchrophasotron of LHE. In 1979, there was published our paper [14] about observation of a rather narrow ($\Gamma = 43$ MeV/c^2) resonance in the effective masses of $\Delta^{++}\pi^+$ $(\Delta^-\pi^-)$ combinations at $M = 1.440$ GeV/c^2 with statistical significance equal to 5.5 S.D. These resonances could be interpreted as five-quark states-$uuuu\overline{d}(dddd\overline{u})$ for $\Delta^{++}\pi^+$ $(\Delta^-\pi^-)$. In the same paper, there was constructed Regge trajectory for states with $J = T$ and was shown that N, Δ, E_{55} (observed at $M = 1.440$ GeV/c^2) were placed in it. The slope of the trajectory was equal to 1.680 GeV/c^2.

The existence of these new resonances with $J = T$ was predicted in papers of A. Grigorian and A. Kaidalov [15] during the investigation of superconverged sum rules for the reggeon–particle scattering. Their predictions coincide with our data.

In 1983, we have published the paper [16] about this problem using the increased statistics. Two states were additionally observed at $M = 1.522$ GeV/c^2 and $M = 1.894$ GeV/c^2. By this means the question about states containing more than three quarks is discussed for a long time and there are theories predicting them.

In our opinion the question about the number of quarks is not important in the assumptions of D. Diakonov, V. Petrov, and M. Polyakov. The symmetry approach does not use the term «quark» at all. This approach is very general and, therefore, it is more important than the model one.

As far as concerned the experimental situation seems to be very complicate. There is only one peak observed at the mass in the region 1.530–1.540 GeV/c^2 in all experiments where effects in systems nK^+ or pK_S^0 were studied. It seems to be concerned with a low incident energy, insufficient mass resolution, small statistics, and various experimental samples.

It seems to us that the most essential task now is the observation of at least one additional resonance, the determination of spins of at least two resonances and a precise determination of their widths. The predicted law of increasing of resonance widths due to increase of resonance spins $\Gamma \sim J^3/M^2$ [2] is very hard. With increasing of spin by a factor 5, the resonance width increases 125 times. It is possible to observe something experimentally only if the masses of resonances strongly increase, but it is very hard for observation and provokes a question about the correctness of a nonrelativistic approach used in the model of chiral soliton.

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