# 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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The production and properties of baryon resonances with the strangeness $S=+1$ in the $nK^+$ system have been studied in the reaction $np \to npK^+K^-$ at the momentum of incident neutrons $P_n = (5.20 \pm 0.12) GeV/c$. A number of peculiarities have been found in the effective mass spectrum of the above system. All these resonances have a large statistical significance. Their widths are comparable with the mass resolution. The estimation of spins of the resonances has been carried out, and the rotational band connecting the resonance masses and their spins has been constructed.

## 1. Introduction

In the papers [1, 2] D.Diakonov, V.Petrov and M.Polyakov have suggested the extension of a $SU(3)$ symmetry scheme for states with the strangeness $S=+1$. It was claimed the existence of antidecuplet $\overline{10}$, which includes states consisting of five quarks $(uudd\bar{s})$. The dynamics of new resonances was based on the model of chiral scliton. This made it possibly to estimate the masses, widths and quantum numbers of expected new states, to propose a formula of the rotational band that give a dependence of the resonance masses to their spins. In the paper [1], $\Theta$-resonance at the mass $M = 1.530 GeV/c^2$, width $\Gamma \le 15 MeV/c^2$ and with quantum numbers $Y=2$, $I=0$, $J^P = 1/2^+$ is on the top of antidecuplet.

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

Papers of D.Akhers [8] represents a rotation-vibration model giving a set of predicts about masses and other quantum numbers of discussing resonances. In review of A.Arkhipov [9] these effects are rated on unified structure of hadronic spectrum.

The properties of the particles from antidecuplet predicted in [1,2] allow a direct search for effects. These are both comparatively low masses and widths accessible for a direct measurement. This simulated a number of experimental works [10] in which a resonance with the mass of $\sim 1.540$ $GeV/c^2$ and width from 3 to 25 $MeV/c^2$ was discovered in $nK^+$ or $pK_s^0$ system.

But none of these experimental works observe the rotational band or more than one resonance state. Also neither spin of resonance nor its parity was determined. This is primarily due to the small statistics of the experiments, insufficient accuracy and some kinds of samplings.

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

## 2. Experiment

The study was carried out using data obtained in the exposure of 1-*m* $H_2$ bubble chamber (HBC) of JINR's LHE to a quasi-monochromatic neutron beam, constructed in 1972 due to the acceleration of deuterons by the LHE Synchrophasotron. The purpose of the neutron experiment was to study pentaquarks in $\Delta^{++}\pi^+$ system (described below).

Quasi-monochromatic neutrons $(\Delta P_n / P_n \approx 2.5\%)$ were generated due to the stripping of accelerated deuterons in a 1 *cm* Al target placed inside the vacuum chamber of the Synchrophasotron. The neutrons were extracted from the accelerator at the angle of 0° to the direction of accelerated deuterons.

The cleaning of the neutron beam from charged particles was provided by the magnetic field of the accelerator in which the neutrons passed about 12 meters before leaving the Synchrophasotron. The bubble chamber was at a distance of 120 *m* from the Al target. The neutron beam was well collimated and had an angular spread of $\Delta\Omega_n \approx 10^{-7}$ st. The beam had no admixture from either charged particles or $\gamma$ quanta. The detailed description of the neutron channel was made in [11].

The 1-*m* HBC was placed in a magnetic field of $\sim$ 1.7 T. As a result we have had a good accuracy for 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 $\leq 0.5°$.

The reaction channels were separated by the standard $\chi^2$ method with regard to the corresponding constraints [12]. For the reaction $np \to npK^+K^-$ there is only one constraint for the parameters (energy conservation law), and the experimental $\chi^2$ distribution must follow the theoretical $\chi^2$ distribution with one degree of freedom.

The experimental (histogram) and theoretical (solid curve) $\chi^2$ distributions for the above reaction are shown in fig. 1a. 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 $\chi^2 \leq 1$ (limit is marked off by an arrow) for the further analysis. 15% of events with this cut satisfy the two hypotheses: the channel $np \to npK^+K^-$ and the channel $np \to np\pi^+\pi^-$. In this case $\chi^2$ value for the *K*-mesons hypothesis ("*K*") is always less than $\chi^2$ value for the $\pi$-mesons hypothesis ("$\pi$"). All these events are attributed to the "*K*" hypothesis. No difference was observed between some test distributions for single-valued ($\chi^2_{"K"} < 1$, $\chi^2_{"\pi"} > 6.5$) and two-valued ($\chi^2_{"K"} < 1$, $\chi^2_{"\pi"} < 1$) events.

Figure 1b shows missing mass distribution for the $\chi^2 \leq 1$ events. One can see that the distribution has a maximum at the missing mass equal to the neutron mass with an accuracy of 0.1 $MeV/c^2$ and is symmetric about the neutron mass. Subsequently a small number of events with missing masses outside the range marked off in the plot by arrows were excluded for higher purity of data.

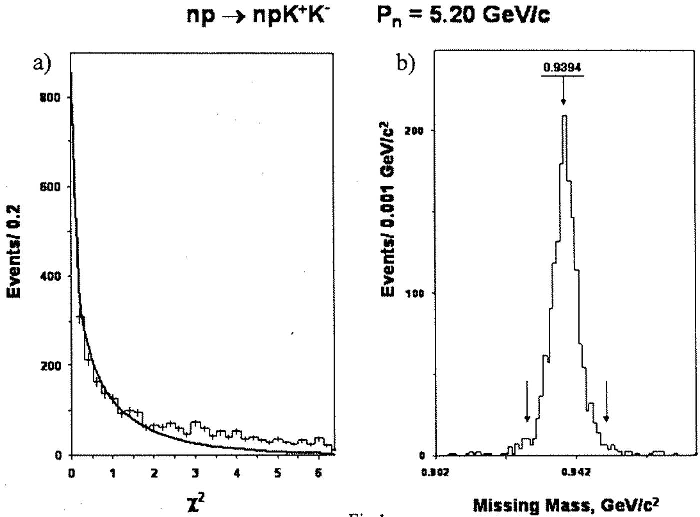



Fig.1.

a) - The experimental (histogram) and the theoretical (solid curve) $\chi^2$-distribution for the reaction $np \to npK^+K^-$;

b) - missing mass distribution for the events of $\chi^2 \leq 1$

As a result, 1558 events were selected from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12) GeV/c$ under the $4\pi$ geometry (the absence of any angular selections).

## 3. 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 $8^{th}$ power, inclusive) and by 10 resonance curves taken in the Breight-Wigner form. The contribution of the background to this distribution is 75.8 %. The requirements to the background curve are the following: firstly, the errors of the coefficients must be no more than 50 % for each term of the polynomial; secondly, the polynomial must describe the experimental distribution after "deletion" of the resonance regions with $\overline{\chi^2} = 1.0$ and $\sqrt{D} = 1.4$ (the parameters of $\chi^2$ 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 values for the background curve normalized to 100 % of events (with resonance regions 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 SD.

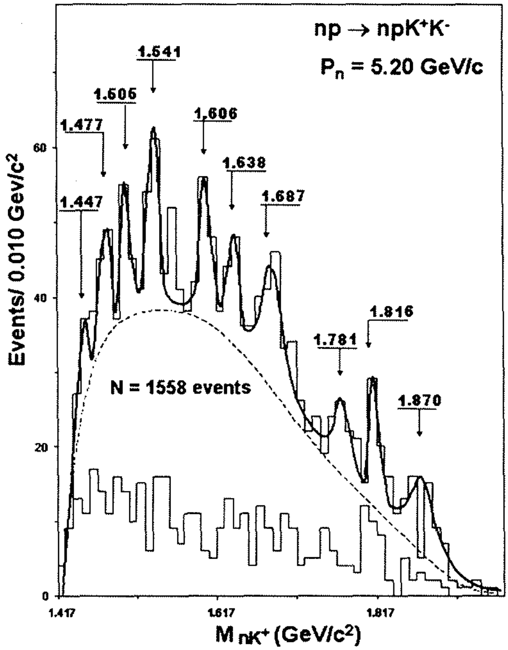



Fig.2.

The effective mass distribution of $nK^+$ combinations for all events from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12) GeV/c$.

The dotted line is the background curve taken in the form of Legendre polynomial of $8^{th}$ power.

The solid line is the sum of the background curve and the ten resonance curves taken in the Breight-Wigner form.

The histogram in the bottom is the effective mass distribution of $nK^+$ combinations selected under condition $\{\cos\Theta_n^* < -0.85 \cup \cos\Theta_n^* > 0.85\}$

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

Fig. 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 $8^{th}$ power and by eight resonance curves taken in the Breight-Wigner form. The statistical significance increased slightly for resonances to the right of the mass $M = 1.541 GeV/c^2$ and decreased slightly for the narrow resonances to the left of it.

To gain a better understanding of low–masses resonances, the distribution of the effective masses of $nK^+$ combinations was constructed with bins of 5 $MeV/c^2$ (up to a 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 $4^{th}$ power and by six resonance curves taken in the Breight-Wigner form.

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

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 $P_n = (5.20 \pm 0.12) GeV/c$.
The dotted line is the background curve taken in the form of Legendre polynomial of $8^{th}$ power.
The solid line is the sum of the background curve and the eight resonance curves taken in the Breight-Wigner form

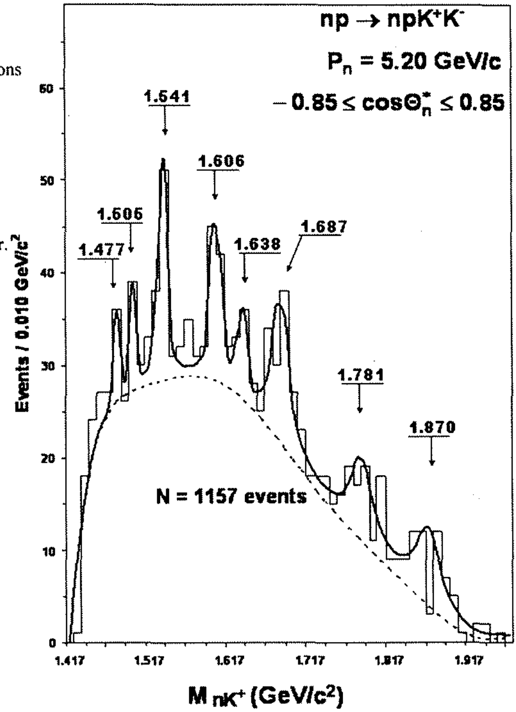
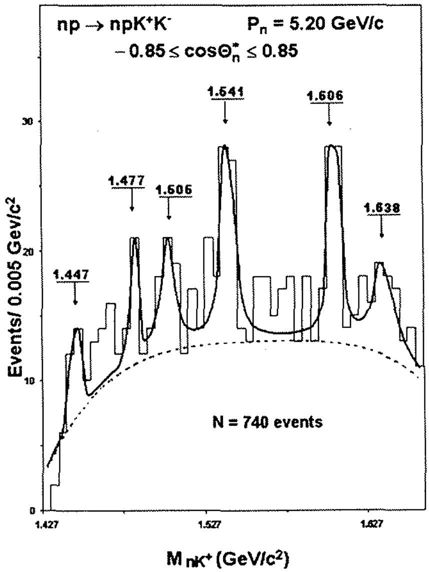



Fig.4.

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



We made an effort to increase the statistical significances of some resonances. This attempt was based under the assumption that resonances are generated by means of $K$-exchange mechanism: a well known resonance ($\Sigma^*$ or $\Lambda^*$) decaying trough $pK^-$ mode is produced in one of the vertices of the corresponding diagram and a resonance in the $nK^+$ system was produced in another vertex. The $K^-$ meson from the decay of the known resonance can be correlated kinematically with the resonance in the $nK^+$ system. In consequence kinematically produced peaks can occur in the effective mass distribution of $nK^+K^-$ system.

Figure 5 shows the effective mass distribution of $nK^+K^-$ combinations. A number of peculiarities can be clearly seen in this distribution. No corresponding resonances decaying through the mode $R \to NK\overline{K}$ are available in PDG tables. These are just the kinematic reflections mentioned above. Fig. 5 also shows the effective masses distribution of $nK^+K^-$ combinations selected so that the effective mass of the $nK^+$ system lies within the range of the $M = 1.541 GeV/c^2$ resonance. Two clusters are readily apparent in this distribution in the $nK^+K^-$ mass region from 2.020 to 2.150 and from 2.240 to 2.280 ($GeV/c^2$). The corresponding clusters exist also for resonances in $nK^+$ system with $M = 1.606 GeV/c^2$ and $M = 1.678 GeV/c^2$.

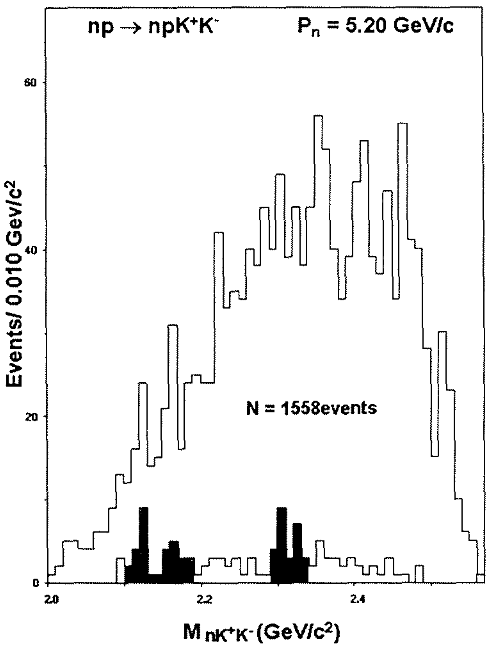



Fig.5.
The effective mass distribution of $nK^+K^-$ combinations from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12) GeV/c$.
The bottom histogram corresponds to the effective mass distribution of $nK^+K^-$ combinations selected so that the effective mass of $nK^+$ combinations is within the resonance range at $M = 1.541 GeV/c^2$

Selecting the mass region of $nK^+K^-$ combinations that correspond to the resonance reflections in the $nK^+$ system at these masses, we obtain distributions of the effective masses of $nK^+K^-$ combinations (Fig. 6).

The selected mass bands of $nK^+K^-$ combinations and additional cuts on the emission angles of the secondary neutron in the general c.m.s. are given under each plot. The additional cuts on emission angle somewhat decrease the background but the major effect of enhancement results from the sample on masses of $nK^+K^-$ combinations.

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

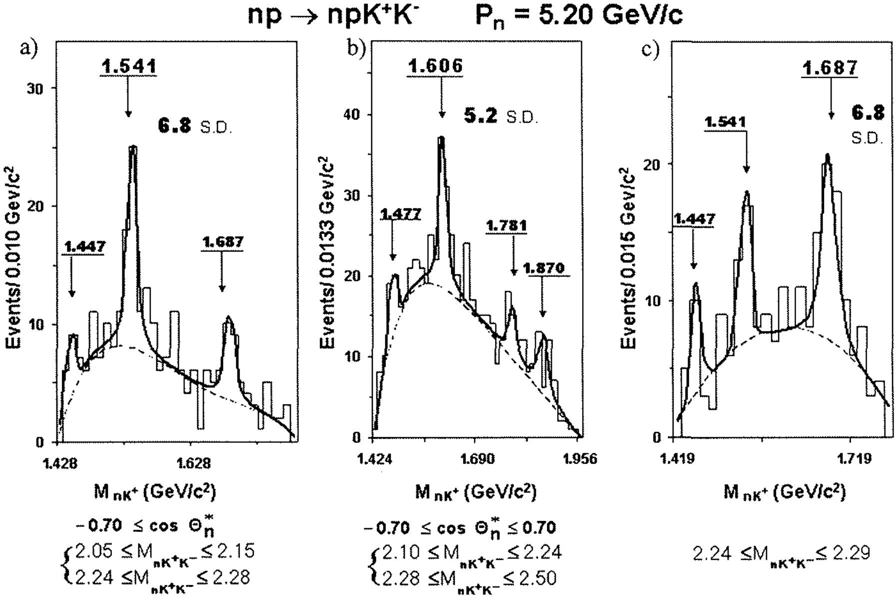



Fig. 6.

The effective mass distribution of $nK^+$ combinations from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12) GeV/c$ for the resonances at:

(a) $M = 1.541 GeV/c^2$; (b) $M = 1.606 GeV/c^2$, (c) $M = 1.678 GeV/c^2$.

Selected mass regions of $nK^+K^-$ combinations and the additional cuts for emission angles of secondary neutrons in the general c.m.s. are presented under the plot.

Dotted lines denote background curves. Solid lines are approximating curves

As a consequence, we get a considerable enhancement of the effects of three resonances processed in this manner (the values of SD are listed in the plot of Fig. 6). In this case, the number of events in the peaks does not decrease as compared with the processed data shown in Fig. 2-4.

Figure 7 presents the distributions of the effective masses of $pK^-$ combinations under the same sampling conditions as in Fig. 6. Peculiarities are evident in the distribution of the effective masses of $pK^-$ combinations corresponding to the known $\Sigma^*$ or $\Lambda^*$ resonances (these peculiarities are also easily observed in the distributions of the effective masses of $pK^-$ combinations constructed without cuts mentioned above).

We have tried to estimate the values of spins of the observed resonances in $nK^+$ system. To do this, we constructed distributions of emission angles of neutrons from the resonance decay with respect to the direction of resonance emission in general c.m.s of the reaction. All values are taken in the rest system of resonance (helicity coordinate system). In the helicity coordinate system, the angular distributions have to be described by a sum of even-power Legendre polynomials with maximum power being equal to $(2J-1)$, where $J$ is a spin of the resonance (for half-integer spins). In such a manner the value of lower limit of the resonance spin is estimated. The authors are grateful to Dr. V.L.Luboshits for the arrangement of the corresponding formulas.

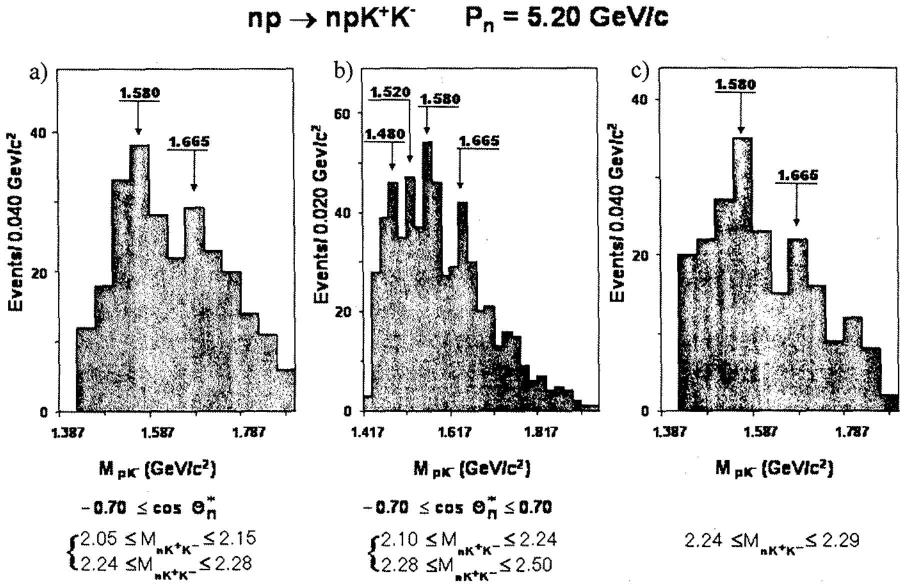



Fig. 7. The effective mass distribution of $pK^-$ combinations from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12) GeV/c$. Selected mass intervals of $nK^+K^-$-combinations and the additional cuts of emission angles of secondary neutron in the general c.m.s. are given under the histogram (a-c correspond to fig. 6)

Figure 8 presents the angular distributions for six resonances whose masses are in the ranges given in the plots. The background distributions are constructed on the intervals to the left and to the right of the corresponding resonance band and subtracted with a factor corresponding to the background fraction in the resonance region. No cuts on emission angles of secondary particles were used in constructing these distributions (cuts on the emission angle of secondary neutron leave the results unchanged). When approximating it was essential that errors in coefficients of the selected Legendre polynomials should be less then 50%.

From the plots presented in fig. 8 one can see that the distribution for the resonance at $1.467 < M < 1.487 GeV/c^2$ is isotropic and polynomials of high power are not needed for an approximation. Therefore, its spin is $J \geq 1/2$. The most likely spin value for the resonance at $1.500 < M < 1.510 GeV/c^2$ is $J \geq 3/2$, although the value $J \geq 1/2$ also has enough large confidence level. The spin value $J \geq 1/2$ for the resonance at $1.530 < M < 1.550 GeV/c^2$ (the most widely discussed in papers) has a confidence level significantly less than the higher ones. Of the highest confidence level is the spin value $J \geq 5/2$. The resonance at $1.595 < M < 1.615 GeV/c^2$ has a rather confident estimation for the spin value $J \geq 7/2$.

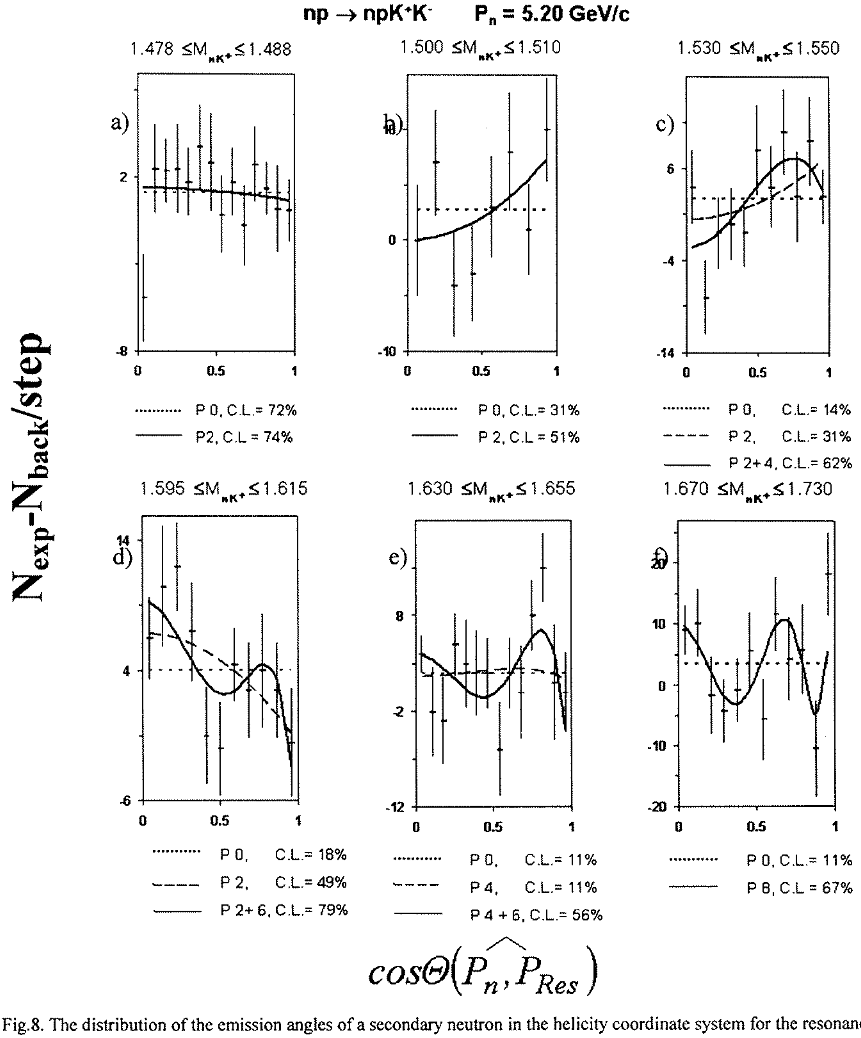



Fig.8. The distribution of the emission angles of a secondary neutron in the helicity coordinate system for the resonances with mass equal to: (a) $M = 1.477GeV/c^2$, (b) $M = 1.505GeV/c^2$, (c) $M = 1.541GeV/c^2$, (d) $M = 1.606GeV/c^2$, (e) $M = 1.638GeV/c^2$, (f) $M = 1.687GeV/c^2$

Qualitative estimation can be made by examining the shape of the plots: they must have $(2J-3)/2$ extrema and a "trivial" one at $\cos\Theta = 0$. That is, for spin $J \geq 7/2$ there must be two extrema and a "trivial" extremum at $\cos\Theta = 0$, which is reasonably well exemplified by the plot of fig. 8d.

Figures 8e and 8f present the results of spin studies for heavier resonances. The resonance at $1.630 < M < 1.655 GeV/c^2$ has a spin value $J \geq 7/2$ with a good confidence level, the resonance at $1.670 < M < 1.730 GeV/c^2$ has the spin value $J \geq 9/2$ with an even larger confidence level. The high-mass resonance has week estimation, which is due to a rather low mass resolution at this region and the growing effect of the background on spin estimation in this region.

The results of the present work are presented in Tab. I.

Table I

| $M_{exp} \pm \Delta M_{exp}$ $GeV/c^2$ | $\Gamma_{exp} \pm \Delta\Gamma_{exp}$ $GeV/c^2$ | $\Gamma_R \pm \Delta\Gamma_R$ $GeV/c^2$ | $J_{exp}$ | *S.D.* |
|---|---|---|---|---|
| $1.447 \pm 0.007$ | $0.005 \pm 0.004$ | $0.004 \pm 0.004$ | | 3.2 |
| $1.467 \pm 0.003$ | $0.008 \pm 0.003$ | $0.008 \pm 0.004$ | | 2.3 |
| $1.477 \pm 0.002$ | $0.005 \pm 0.003$ | $0.002^{+0.006}_{-0.002}$ | 1/2 | 3.0 |
| $1.505 \pm 0.004$ | $0.008 \pm 0.003$ | $0.005 \pm 0.005$ | 3/2 | 3.5 |
| $1.541 \pm 0.004$ | $0.011 \pm 0.003$ | $0.008 \pm 0.004$ | 5/2 | 6.8 |
| $1.606 \pm 0.005$ | $0.014 \pm 0.005$ | $0.011 \pm 0.006$ | 7/2 | 5.2 |
| $1.638 \pm 0.005$ | $0.016 \pm 0.011$ | $0.012^{+0.015}_{-0.012}$ | 7/2 | 3.6 |
| $1.687 \pm 0.007$ | $0.027 \pm 0.007$ | $0.024 \pm 0.008$ | 9/2 | 6.8 |
| $1.781 \pm 0.008$ | $0.029 \pm 0.012$ | $0.023 \pm 0.015$ | | 4.1 |
| $1.870 \pm 0.019$ | $0.036 \pm 0.010$ | $0.032 \pm 0.011$ | | 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 widths of the resonances are found by a quadratic subtraction of the value of the mass resolution from the experimental value of the width. The mass resolution function [13] grows with increasing mass as:

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

where $M$ – the mass of the resonance, $m_i$ – the rest mass 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 instance, the value of the total width of the resolution function for the resonance with $M = 1.541 GeV/c^2$ is found to be $\approx 7\ MeV/c^2$.

*The fourth column* contains the values of the resonance spins. These are the lower limits of spins as explained in the discussion of the spin estimation procedure.

*The fifth column* lists 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 production cross section for the resonance at $M = 1.541 GeV/c^2$ in the $nK^+$ system from the reaction $np \to npK^+K^-$ at $P_n = (5.20 \pm 0.12) GeV/c$ is $\sigma = (3.5 \pm 0.7)\ \mu b$.

## 4. Discussion

We have attempted to systematize the obtained results using the formula for rotational bands suggested by Diakonov et al. [1, 2]:

$$M_J = M_0 + kJ(J+1), \qquad (1)$$

*where*: $M_J$ – the mass of the resonance, $J$ – its spin, $M_0$ – rest mass of the soliton, $k$ – the inverse of twice the soliton moment of inertia (we use the terminology of paper [2]).

Under closer examination, the plots of the effective mass distribution of $nK^+$ combinations (especially those in Fig. 4 constructed with a bin of 5 $MeV/c^2$) one can observe that strong peculiarities are accompanied by weaker ones: a weak peculiarity at $M = 1.467 GeV/c^2$, the bump in the mass region of $M = 1.565 GeV/c^2$ etc. That is why we performed the approximation of the mass distributions versus spin using two variants. Both of them are given in Tab. II, which shows good agreement between the experimental data and the formula (1). In Tab. IIa 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 in experiments at a lower mass. In Tab. IIb no experimental values of masses and spins are available in the third and fifth lines. There are only bumps at these masses that are not provided statistically as resonances.

Table II

a)

| $M_0$ = 1.462 $GeV/c^2$ $k$ = 0.0090 | | | |
|---|---|---|---|
| $J$ | $M_J$ | $M_{exp} \pm \Delta M_{exp}$ | $J_{exp}$ |
| 1/2 | 1.469 | $1.467 \pm 0.003$ | |
| 3/2 | 1.496 | $1.505 \pm 0.004$ | 3/2 |
| 5/2 | 1.541 | $1.541 \pm 0.004$ | 5/2 |
| 7/2 | 1.604 | $1.606 \pm 0.005$ | 7/2 |
| 9/2 | 1.685 | $1.687 \pm 0.007$ | 9/2 |
| 11/2 | 1.784 | $1.781 \pm 0.008$ | |
| 13/2 | 1.901 | $1.870 \pm 0.019$ | |

b)

| $M_0$ = 1.471 $GeV/c^2$ $k$ = 0.0107 | | | |
|---|---|---|---|
| $J$ | $M_J$ | $M_{exp} \pm \Delta M_{exp}$ | $J_{exp}$ |
| 1/2 | 1.479 | $1.477 \pm 0.002$ | 1/2 |
| 3/2 | 1.511 | $1.505 \pm 0.004$ | 3/2 |
| 5/2 | 1.565 | | |
| 7/2 | 1.640 | $1.638 \pm 0.005$ | 7/2 |
| 9/2 | 1.736 | | |
| 11/2 | 1.854 | $1.870 \pm 0.019$ | |

Taking the moments of inertia in the form of $I = M_0 \cdot r^2$ and using the value of $k = 1/2I$ from Tab. II one can determine the radius of the soliton. It proves to be approximately $1.2 fm$, which is close to the π-meson radius $(\approx 1.35\ fm)$.

We have carried out another approximation of the observed rotational bands where the mass of an exited state depends not on of a resonance spin but on its orbital moment $l$:

$$M_l = M_0 + kl(l+1). \qquad (2)$$

The results are presented in Tab. III: (a) – for "strong" resonances and (b) – for "weak" ones (as in Table II). The values of orbital moments are taken arbitrarily but so that they do not contradict the estimations of the spins. This approximations gives a better agreement with the experimental data. In addition, it takes in account the resonance with $M = 1.447 GeV/c^2$, which is observed in most of presented distributions and is widely discussed in theoretical analisys.

With the assumption made about the orbital moments, the parity of the resonance at $M = 1.541 GeV/c^2$ is negative. When the value of its spin $J = 5/2$ is also considered, it may be concluded that this resonance is not located on the top of the antidecuplet suggested in [1, 2].

But there exists a probability that on the top occurs the resonance with $M = 1.501 GeV/c^2$, with positive parity and spin equal to ½. Our determination of the spin for the resonance with $M \approx 1.505 GeV/c^2$ does not contradict to the fact that there can be found a resonance with $M = 1.501 GeV/c^2$ ($J^P = 1/2^+$) and a resonance with $M = 1.507 GeV/c^2$ ($J^P = 3/2^-$). In this case both of them are very narrow and are shifted relative to each other. This results in an average value of the experimental mass equal to $M = 1.505 GeV/c^2$. Thus, it is necessary to carry out very precise experiments both in mass resolution and in terms of the statistics.

Table III

a)

| $M_0 = 1.481\ GeV/c^2$ $k = 0.0100$ | | |
|---|---|---|
| $\ell$ | $M_\ell$ | $M_{exp} \pm \Delta M_{exp}$ |
| 0 | 1.481 | $1.477 \pm 0.002$ |
| 1 | 1.501 | $1.505 \pm 0.004$ |
| 2 | 1.541 | $1.541 \pm 0.004$ |
| 3 | 1.601 | $1.606 \pm 0.005$ |
| 4 | 1.681 | $1.687 \pm 0.007$ |
| 5 | 1.781 | $1.781 \pm 0.008$ |
| 6 | 1.901 | $1.870 \pm 0.019$ |

b)

| $M_0 = 1.447\ GeV/c^2$ $k = 0.0100$ | | |
|---|---|---|
| $\ell$ | $M_\ell$ | $M_{exp} \pm \Delta M_{exp}$ |
| 0 | 1.447 | $1.447 \pm 0.007$ |
| 1 | 1.467 | $1.467 \pm 0.003$ |
| 2 | 1.507 | $1.505 \pm 0.004$ |
| 3 | 1.567 | |
| 4 | 1.647 | $1.638 \pm 0.005$ |
| 5 | 1.747 | |
| 6 | 1.867 | $1.870 \pm 0.019$ |

***One further remark needs to be made.***

The problem of pentaquarks evolved as early as the 1960s. Ya.B.Zel'dovich and A.D.Saharov [14] were the first in interpreting the effects observed at that time in the $p\pi^+\pi^+$ system as a manifestation of pentaquark states. Our first investigations [15] concerning this problem have given an impetus to the creation of a unique neutron beam [11] for 1-m HBC of LHE upon acceleration of deuterons at LHE's Synchrophasotron. In 1979 we reported [16] the observation of a rather narrow $(\Gamma = 43 MeV/c^2)$ resonance in the effective masses of $\Delta^{++}\pi^+$ $(\Delta^-\pi^-)$ combinations with $M = 1.440 GeV/c^2$ with a statistical significance of 5.5 SD. These resonances could be interpreted as five-quark states — $uuuu\bar{d}$ $(dddd\bar{u})$ for $\Delta^{++}\pi^+$ $(\Delta^-\pi^-)$. Also, in [16] a Regge trajectory was constructed for the states with $J$=$T$ and $N$, $\Delta$, $E_{55}$ (observed by us at $M = 1.440 GeV/c^2$) were shown to be on this trajectory. The slope of the trajectory was about 1.680 $(GeV/c^2)^{-2}$.

The existence of such new resonances with $J = T$ was predicted by A.Grigorian and A.Kaidalov in their studies of superconverged sum rules for Reggeon-particle scattering [17]. Their predictions agreed with our data.

In 1983 we have published another study with increased statistic [18]. Two more states were observed at $M = 1.522 GeV/c^2$ and $M = 1.894 GeV/c^2$. Thus, the problem of states with more than three quarks is discussed for a long time and there are theories predicting them.

The problem of the number of quarks is, in our opinion, of no importance in the assumptions made by D.Diakonov, V.Petrov and M.Polyakov. The symmetry approach does not use the notion "quark" at all. This approach is very general and thus is much more important that the model approach.

As regards the experimental situation, we think of it as being very complicated. All experiments investigated the effects in the systems $nK^+$ or $pK_S^0$ reveal only one peak at the mass region from 1.530 to 1.540 $GeV/c^2$. This is likely due to low incident energy, insufficient mass resolution, small statistics and a variety of samples in the experiments.

It seems to be now of crucial importance to observe at least one more resonance, to determine spins of at least two resonances and to estimate precisely their widths. The predicted law of increase in resonance width with an increase in its spins $\Gamma \sim J^3 / M^2$ [2] is very stringent. The width increases 125 times as the spin increases by a factor of 5, and the experiment will give some observations only if the masses of resonances do increase considerably, which is difficult for an observation and provokes a question as to whether the nonrelativistic approach used in the model of chiral soliton is valid.

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