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STUDY OF THE ENHANCEMENTS IN THE Λp INVARIANT MASS SPECTRUM IN $\pi^- \, {}^{12}C \to \Lambda p \, K(n\pi) \, {}^{10}B$ INTERACTION AT 4 GEV/C

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STUDY OF THE ENHANCEMENTS IN THE Λp INVARIANT MASS SPECTRUM IN $\pi^- \, {}^{12}C \rightarrow \Lambda p \; K(n\pi) \; {}^{10}B$ INTERACTION AT 4 GEV/C

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In the last time the search for dibaryon resonances with strangeness - 1 has been an attractive problem.

Significant enhancements in the Λp invariant mass spectra have been observed. These results come from the experiments on interactions of high energy neutrons and negative pions with carbon nuclei [1-4] as well as of low energy K^--mesons with deuterium [5,6].

In the experiments performed in Dubna [1-4] with 7 GeV neutrons and 4 GeV/c π^--mesons interacting with carbon nuclei in the propane bubble chamber strong peaks at 2058, 2127 and 2252 MeV/c^2 in the Λp invariant mass spectra have been observed.

The analysis performed in [1-4] have led the authors to the following conclusions.

The peak at 2058 MeV/c^2 is due to the final state Λp interaction with the low energy scattering parameters $a_{\Lambda p} = -(2.0 \pm 0.6)f$ $r_{\Lambda p} = (2.5 \pm 0.8)f$. The peak at 2127 MeV/c^2 can be due either to the ΣN final state interaction with the subsequent $\Sigma N \to \Lambda p$ conversion or to the Λp resonant state.

The peak at 2252 MeV/c^2 is due to Λp resonance.

Some indications on the existence of the resonances at 2125 MeV and about 2236 MeV Λp center of mass energy have been got from the Λp scattering data [7].

However, these data are scare because one has no low energy Λ-hyperon beams.

The Λp invariant mass spectrum obtained in π^--meson-carbon interactions [2,3], is shown in Fig. 1.

In the present paper we try to determine the character of the enhancements in the Λp invariant mass spectrum.

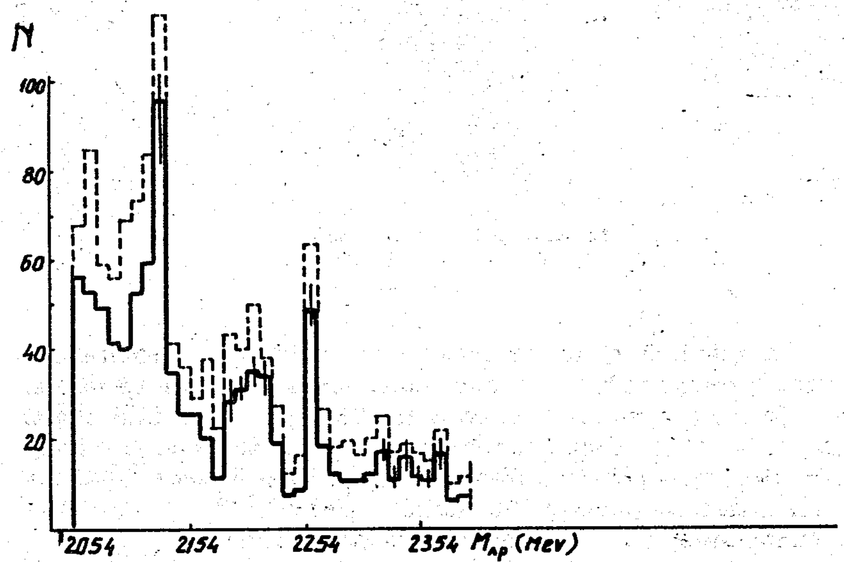

Fig. 1. The experimental [2,3] invariant mass spectrum obtained in the interaction of 4 GeV/c π^--mesons with carbon nuclei.

With that end in view we shall consider three possibilities: 1/There are no any interactions in the final state (impulse approximation). 2/ There is the Λp interaction in the final state with a possibility of the conversion process $\Sigma N \to \Lambda p$. The scattering amplitude a/ has no any resonant peaks, b/ contains resonant peaks.

A basic assumption of our analysis is that π^--mesons interact with two-nucleon cluster in carbon nuclei. The supposed mechanism of the reaction $\pi^- {}^{12}C \to \Lambda p K(n\pi)\,{}^{10}B$/ (n is the total number of π°'s), when the Λp interaction exists, is represented by the graph shown in Fig. 2.

The vertices in the diagram presented in Fig. 2 correspond respectively to the following transitions.

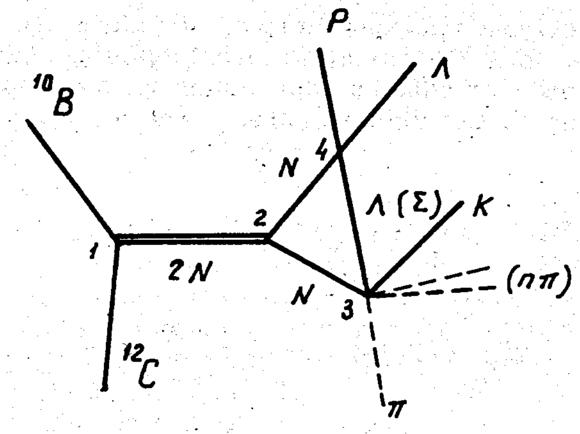

Fig. 2. The diagram representing the $\pi^- {}^{12}C \to \Lambda p K(n\pi)\,{}^{10}B$ reaction.

1. ${}^{12}C \to d + {}^{10}B$, ${}^{12}C \to 2p + {}^{10}Be$
2. $d \to p + n$, $2p \to p + p$
3. $\pi^- p \to \Lambda K^\circ$
   $\Sigma^\circ K^\circ$
   $\Lambda K^+ \pi^-$
   $\Lambda K^\circ \pi^\circ$
   $\Sigma^+ K^+ \pi^- \pi^-$
   $\Sigma K^\circ \pi^\circ \pi^-$
   $\Sigma^\circ K^\circ \pi^+ \pi^-$
   $\Lambda K^+ \pi^\circ \pi^-$
   $\Lambda K^\circ \pi^+ \pi^-$
   $\Sigma^+ K^+ \pi^\circ \pi^- \pi^-$
   $\Sigma^\circ K^+ \pi^+ \pi^- \pi^-$
   $\Sigma^+ K^\circ \pi^+ \pi^- \pi^-$
   $\Lambda K^+ \pi^+ \pi^- \pi^-$
   $\Lambda K^\circ \pi^+ \pi^- \pi^\circ$ (1)
4. $\Lambda p \to \Lambda p$
   $\Sigma^+ n \to \Lambda p$
   $\Sigma^\circ p \to \Lambda p$

If the nucleons in the intermediate state are taken on the mass shell (the small internal binding energy of clusters allows for such an approximation) the amplitude corresponding to the diagram presented in Fig. 2 could be written as

$$A(\pi^- {}^{12}C \to \Lambda p K(n\pi)\,{}^{10}B) \propto F_d(P_d) F_{N-N}(p_{N-N}) \times$$

$$\times \int d_4 p_\Lambda\, \delta(p_1^2+M_N^2)\,\delta(p_2^2+M_N^2) \frac{A(\pi^- p \to \Lambda K(n\pi))\, A(\Lambda p \to \Lambda p)}{p_\Lambda^2 + M_\Lambda^2} +$$

$$+ \int d_4 p_\Sigma\, \delta(p_1^2+M_N^2)\,\delta(p_2^2+M_N^2) \frac{A(\pi^- p \to \Sigma K(n\pi))\, A(\Sigma N \to \Lambda p)}{p_\Sigma^2 + M_\Sigma^2}), \qquad (2)$$

where p_1, p_2 are the four-momenta of the nucleons composing a cluster, p_Λ, p_Σ denote the four momenta of the Λ and Σ hyperons, respectively, P_d is the three-momentum of the center of mass of the cluster, p_{N-N} is the relative-momentum of the nucleons in the cluster. M_N, M_Λ, M_Σ denote the masses of the nucleon, Λ-hyperon and Σ-hyperon, respectively. The function $F_d(P_d)$ describes the motion of the cluster in the carbon nucleus, $F_{N-N}(p_{N-N})$ is the form factor of the cluster. The amplitudes of the defined processes are denoted by the letter A with corresponding index. From the energy-momentum conservation relation we obtain

$$p^2_{\Lambda(\Sigma)} = -M_N^2 - M_\pi^2 - M_K^2 - P^2_{\pi s} - E_{ds} E_{\pi s} +$$
$$+ 2E_{Ks}\left(\frac{E_{ds}}{2} + E_{\pi s}\right) + P_s P_{\pi s} \cos\theta \qquad (3)$$

with

$$E_{ds} = \sqrt{P^2_{\pi s} + M_d^2}\,,\quad E_{\pi s} = \sqrt{P^2_{\pi s} + M_\pi^2}\,,\quad E_{Ks} = \sqrt{P_s^2 + M_K^2}\,,$$

$$\vec{P}_s = \vec{P}_{\Lambda s} + \vec{P}_{ps}\,,\quad \cos\theta = \frac{P_s P_{\pi s}}{P_s P_{\pi s}}\,.$$

M_d denotes the mass of the cluster. All the momenta in (3) are taken in the center of mass system of the cluster.

In the formula (2) the integrals over $d_4 p_{\Lambda(\Sigma)}$ are evaluated in the manner described in the paper /8/, that is we charge the integration variable from $d_4 p_{\Lambda(\Sigma)}$ to the $dp_1^2\, dp_2^2\, dp^2_{\Lambda(\Sigma)}\, d\phi$ (ϕ is the azimuthal angle of $\vec{p}_\Lambda$). The integrals over $d\,p^2_{\Lambda(\Sigma)}$ we approximate by the product of the average value of the integrand and the width of the integral, which is proportional to the square root of the cluster binding energy. From (2) we obtain the following expression for the Λp invariant mass distribution

$$\rho(M_{\Lambda p}) \propto Ps \left| \frac{A(\pi^- p \to \Lambda K(n\pi))\, A(\Lambda p \to \Lambda p)}{p_\Lambda^2 + M_\Lambda^2} + \right. \qquad (4)$$

$$\left. + \frac{A(\pi^- p \to \Sigma K(n\pi))\, A(\Sigma N \to \Lambda p)}{p_\Sigma^2 + M_\Sigma^2} \right|^2.$$

In the formula (2) the factor F_{N-N} has been taken as a constant, this can be done because the $\Lambda(\Sigma)$-hyperon momentum is greater than the Fermi momentum of the cluster (deuteron). F_d does not depend on the Λp relative energy. In (4) an integration over some kinematic variables is not shown explicitly. The factor PS is connected with the phase-space. It is estimated in the following way: all particles emerging in the vertex 3 are considered as one particle with an effective mass M_K defined by the conservation relation for energy-momentum in the vertex 3

$$p_K^2 = (p_I^2 + p_\pi - p_\Lambda)^2$$

and

$$M_K^2 = -p_K^2 = M_N^2 + M_\pi^2 + M_\Lambda^2 + 2M_N\sqrt{P_\pi^2 + M_\pi^2} -$$
$$-2(M_N + \sqrt{P_\pi^2 + M_\pi^2})(\sqrt{P_\Lambda^2 + M_\Lambda^2}) + 2P_\pi P_\Lambda \cos\theta_{\Lambda\pi}, \quad (5)$$

where

$$\cos\theta_{\Lambda\pi} = \frac{\vec{P}_\pi \vec{P}_\Lambda}{P_\pi P_\Lambda}, \quad M_\Lambda^2 = -p_\Lambda^2 .$$

In (5) P_Λ and P_π are three-momenta of the Λ -hyperon and π-meson in the cluster rest system. For a fixed M_K the kinematics is just that given by the three-body system (the recoil of the nucleons is neglected). Consequently we have

$$PS = P_{\Lambda p} P_{K s}, \quad (6)$$

where

$$P_{Ks} = -(P_{\Lambda s} + P_{ps}),$$

and $P_{\Lambda p}$ is the Λ-hyperon momentum in the Λp c.m.s., in (6) $P_{\Lambda s}$ and P_{ps} are the final state Λ -hyparon and proton momenta in the center of mass system of the cluster and π^--meson. In order to determine the phase-space the amplitudes $A(\pi^- p \to \Lambda K(n\pi))$ and $A(\pi^- p \to \Sigma K(n\pi))$ have to be expressed as functions of angles and momenta of the $\Lambda(\Sigma)$ -hyperons created in the elementary processes $\pi^- p \to \Lambda K(n\pi)$ and $\pi^- p \to (\Sigma K(n\pi))$. In our work those amplitudes are defined by the experimental differential cross section $\frac{d^2\sigma}{\partial P_\Lambda \partial\theta_\Lambda}$ evaluated in JINR (Dubna) /2-4/.

The probability defined by the formula (4) as a function of the Λp invariant mass $M_{\Lambda p}$, which can be written as

$$M_{\Lambda p}^2 = -(p_2 + p_{\Lambda(\Sigma)})^2,$$

hence

$$M_{\Lambda p}^2 = M_{\Lambda(\Sigma)}^2 + M_N^2 + 2M_N\sqrt{P_{\Lambda(\Sigma)}^2 + M_{\Lambda(\Sigma)}^2}, \quad (7)$$

where $P_\Lambda(\Sigma)$ is three momentum of the $\Lambda(\Sigma)$ -hyperon in the cluster rest system.

In the formula (2) the Λp interaction in the final state is described by the amplitudes $A(\Lambda p \to \Lambda p)$ and $A(\Sigma N \to \Lambda p)$. These amplitudes are taken from the paper /7/, where low energy scattering has been calculated in a potential model by solving the multichannel ($\Lambda p, \Sigma^+ n, \Sigma^0 p$) Schrödinger equation. In the paper /7/ it has been shown that a resonance with charge 1 could exist below the ΣN threshols, giving a cusp in Λp scattering amplitude at 3 MeV below the $\Sigma^+ n$ threshold. The Λp scattering amplitude which we have used corresponded to the following scattering parameters:

1) $a_s = -1.8$ fm., $a_t = -1.7$ fm., which give the resonance, and
2) $a_s = -1.8$ fm., $a_t = -1.3$ fm for a case without a resonance; a_s and a_t are, respectively, the singlet and triplet scattering lengths.

Also in the papers /7/ it has been discussed a possibility for the existence of the Λp resonant state at about 2236 MeV. If we take the Λp scattering amplitude with a resonance at 2252 which reaches the elastic unitarity limit, we will obtain the Λp invariant mass spectrum shown in Fig. 3. Since we did not know the phases of the amplitudes we have considered two boundary cases, when the two terms in (4) had the same or opposite phases. Fig. 4 presents the Λp invariant mass distribution calculated without involving any resonances in the Λp scattering amplitude. The curve corresponding to the case in which there are no any interaction in the final state is presented in Fig. 3 (the dashed-line curve). The vertex functions which we have used were the physical amplitudes, consequently, in numerical calculations the $\Lambda(\Sigma)$ -hyperon was taken on the mass shell.

From Fig. 3 we see that near the ΣN threshold two effects can be important: the Λp final state scattering with a resonant state and the $\Sigma N \to \Lambda p$ conversion process. The third peak in the invariant mass spectrum presented in Fig. 1 would have been created only by the resonance in the Λp scattering amplitude if such a resonance at about 2252 MeV existed. As was mentioned, the Λp scattering data and some theoretical considerations /7/ indicate that the existence of such a resonant state is possible. Fig. 3 shows also that without inclusion of the Λp final state interaction the Λp invariant mass spectrum is represented by the quite smooth curve (The dashed-line curve).

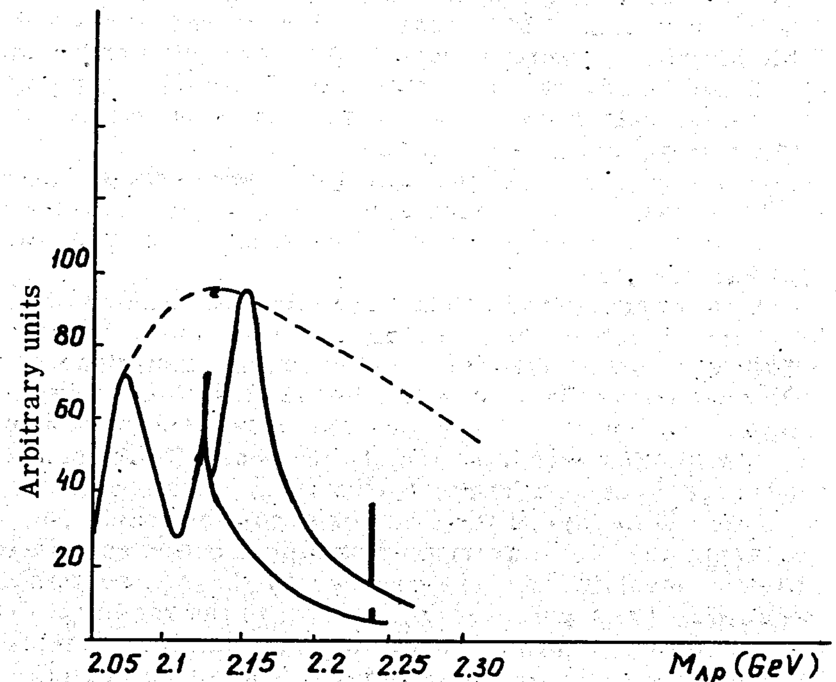

Fig. 3. The Λp invariant mass distributions in the reaction $\pi^- {}^{12}C \to \Lambda p K (n\pi)\ {}^{10}B$. The solid curves represent the case with the inclusion of the Λp interaction with resonances in the Λp system. (The lines 1 and 2 correspond to the same and opposite sign, respectively, of the two terms in the formula (4)).

The model considered in this work qualitatively reproduces the experimental Λp invariant mass spectra obtained in the papers /1-4/. The experimental evidence

for the validity of the model were discussed in the paper /1/.

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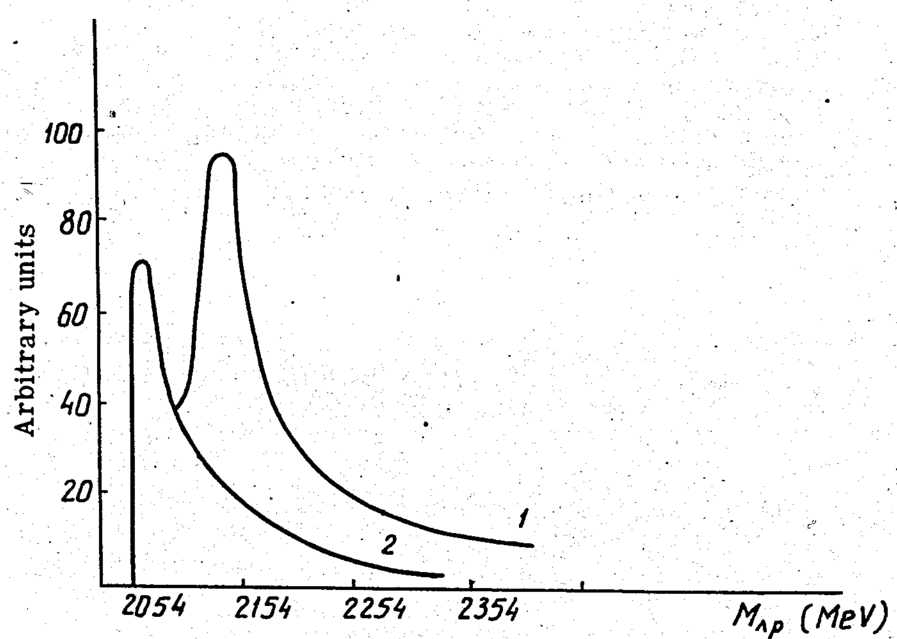

Fig. 4. The Λp invariant mass distributions calculated with the inclusion of the Λp interaction without invoking any resonances in the Λp scattering amplitude. The denotation is the same as in Fig. 3.

References

1. B.A.Shahbazian, V.I.Moroz. JINR Preprint E1-4022, Dubna, 1968.
2. B.A.Shahbazian. JINR Preprint E1-4584, Dubna, 1969; High Energy Physics and Nuclear Structure, 524, N.Y.-London, 1970; IV Int.Conf. on High Energy Physics and Nuclear Structure, 57, Dubna, 1971.

3. B.A.Shahbazian and A.A.Timonina. JINR Preprint E1-5935, Dubna, 1971; Nucl.Phys., B53, 19 (1973).
4. B.A.Shahbazian, A.A.Timonina and N.A.Kalinina. Lett. al Nuovo Cimento, 6, No. 2, 63 (1973); JINR preprint E1-6704, Dubna, 1972.
5. D.Cline, R.Laumann and J.Mapp. Phys.Rev.Lett., 22, 1452 (1968).
6. T.H.Tan. Phys.Rev.Lett., 23, 395 (1969).
7. J.J.de Swart, M.M.Nagels, T.K.Rijkne, P.A.Verhoeven. Hyperon-Nucleon Interaction, Nijmegen - The Netherlands (1971); M.M.Nagels, T.A.Rijken, J.J.de Swart. A Potential Model for Hyperon-Nucleon Scattering. Nijmegen - The Netherlands (1972).
8. N.S.Craigie and C.Wilkin. Nucl.Phys., B14, 477 (1968).

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