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Λp-DIBARYONS

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The invariant mass spectra of fourty nine hadronic systems with hypercharge, strangeness and baryon number, varied in the limits $0 \leq y \leq 6$, $-2 \leq S \leq +1$, $0 \leq B \leq 6$, have been studied. Resonance-like peaks have been found in the invariant mass spectra of $Y \leq 1$ systems only. The same inequality holds for all established resonances [1]. Thus, a hypercharge selection rule is suggested: "The hypercharge of hadronic resonances in weak gravitational fields cannot exceed one: $Y \leq 1$". This rule defines the conditions and selects the classes of interactions which make possible the formation of hadrons in weak gravitational fields. Thus, one cannot exclude that it is based on a new symmetry principle unknown up to now [2].

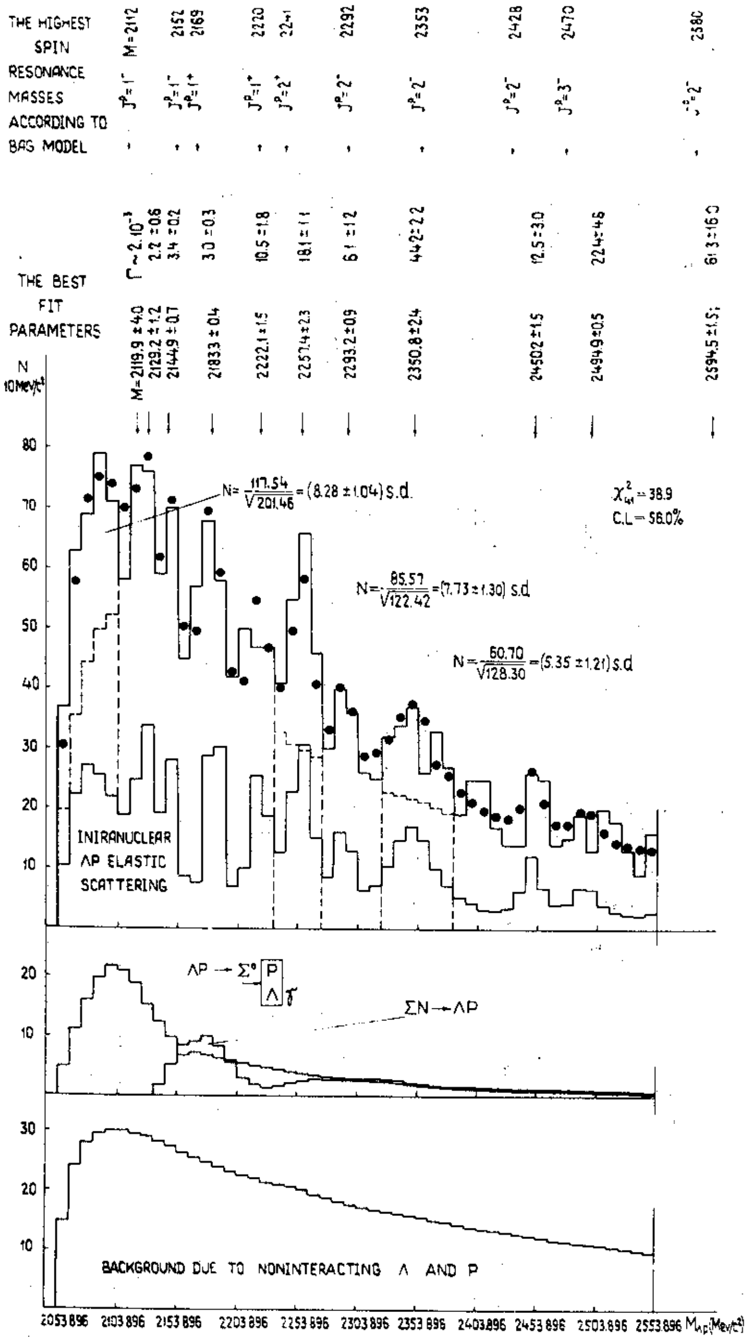
On the other hand, recently a number of theoretical investigations of multiquark hadrons and states have appeared [3-23]. The masses of peaks and enhancements found in the effective mass spectra of $Y \leq 1$ exotic systems, studied in this paper, are in striking agreement with the predictions made in the papers by J.J. de Swart and co-workers [3,5-8,11-13, 20-23]. Below this comparison is presented. This work has been performed by means of the JINR propane bubble chamber exposed to the neutron of $\langle p_n \rangle = 7.0$ GeV/c and negative pion of $p_{\pi^-} = 4.0$ GeV/c momenta beams. The production of possible multiquark-hadrons on ^{12}C nuclei has been studied. The details of the experiment and of the analysis are given elsewhere [2h-p]. Nevertheless, let us remind that the masses of Λ° and K° particles as well as of the well-known $\Sigma(1385)$ and $K^*(892)$ resonances found in this experiment are very close to the tabular values. Besides, the Λp invariant mass resolution (r.m.s. deviation) is 3.00 MeV/c^2 in the initial part of the spectrum, 4.25 MeV/c^2 around the 2128 MeV/c^2 peak and 6.40 MeV/c^2 in the vicinity of the 2256 MeV/c^2 peak. The $\Lambda\Lambda$ invariant mass resolution in the 2365 MeV/c^2 peak region is $\Delta M_{\Lambda\Lambda} = (10.0 \pm 2.4)$ MeV/c^2.

THE Λp-DIBARYON ($I = \frac{1}{2}$, $Y = 1$, $B = 2$, $S = -1$)

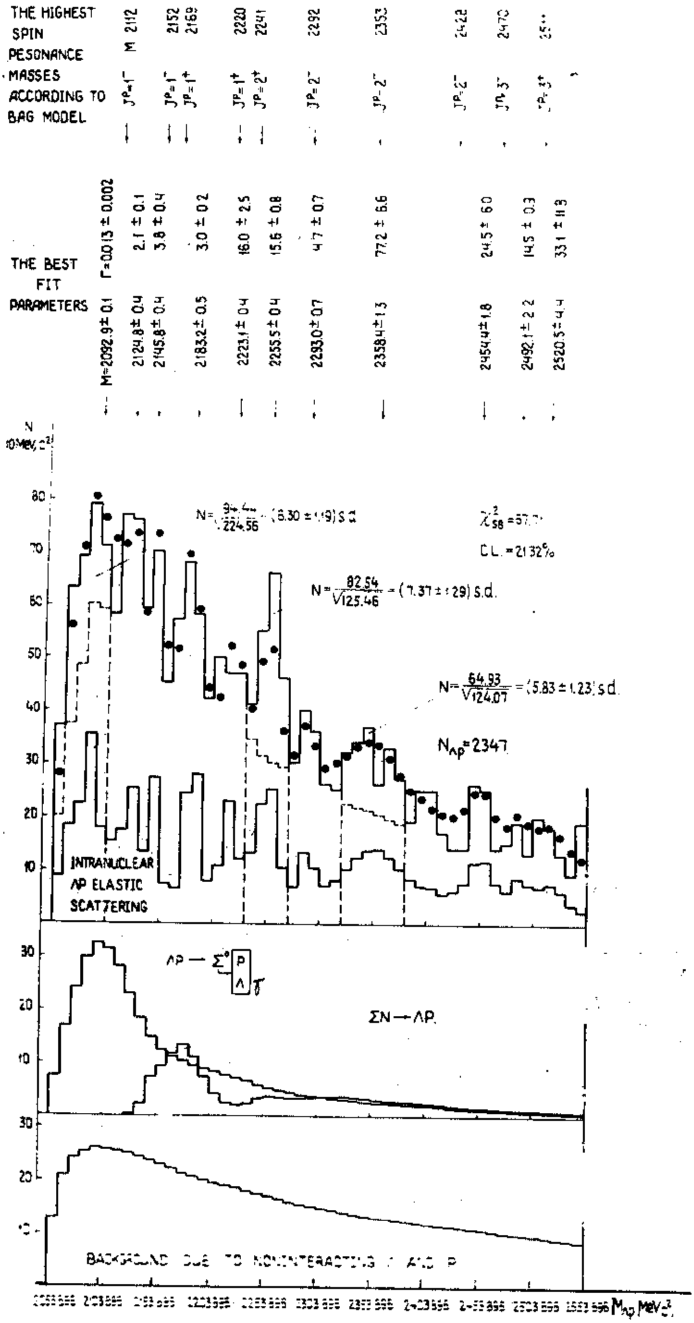
Necessary information on this class of dibaryons has been obtained in a successful analysis of the Λp-invariant mass spectra, particularly of the one due to the neutron exposure. For this purpose a model of the neutron-carbon interaction, able to imitate all final states observed in our experiments, has been developed. It is based on two fundamental hypotheses. The first one is the correctness of impulse approximation at

$\langle p_n \rangle$=7.0 GeV/c. According to the second hypothesis, any peak or enhancement observed in the Λp invariant mass spectrum is due to the intranuclear hyperon-nucleon interaction. Therefore the Λp elastic scattering effective cross section, which dominates the inelastic one in the energy region considered, has been parametrized as a sum of the low energy scattering cross section in effective range approximation, the potential and resonance scattering cross sections at eleven Λp mass values. The last eleven Breit-Wigner terms depend on the resonance spin and orbital momenta what in principle can give information on these quantum numbers. According to the above-mentioned second hypothesis, the Λp elastic scattering effective cross sections, computed using the best-fit parameters, due to the Λp invariant mass spectrum fit, have to fit the corresponding cross sections directly measured. Therefore the simultaneous fit of the Λp invariant mass spectrum up to 2553.8796 MeV/c^2 and the directly measured Λp elastic scattering effective cross sections in the momentum range of P_Λ = = (0.1-2.0) GeV/c using a common χ^2_n functional has been performed. The details of this procedure as well as of the modelling have been described in previous publications [21-p]. The Λp invariant mass spectrum has been fitted simultaneously 1) with the Λp elastic scattering effective cross sections taken from the experiments [24-26] and 2) with the data from both the experiments [24-26] and [27]. The fitting was performed by means of the MINUIT program. The black points in figs.1 and 2 represent the best fit histograms computed taking into account the detection efficiency and the errors of particle momenta. Below are shown the experimental and best-fit histograms as well as the best-fit components of the black-point histogram: the intranuclear Λp elastic scattering, the backgrounds due to noninteracting Λ-hyperons and protons and to the $\Lambda p \to \Sigma^\circ p$, $\Sigma^\circ \to \Lambda\gamma$ and $\Sigma^\pm N \to \Lambda p$ conversion processes. The goodness of the first fit is characterized by X^2_{41}= 38.9 and a confidence level (C.L.) of 56.00%. In the second fit one has X^2_{58} = 67.71 and C.L. = 21.32%. In the Λp invariant mass spectrum up to ~ 2600 MeV/c^2, twelve enhancements have been revealed. Ten of them fit well the resonance mass values predicted by the Bag model [20,22]. But only two of these ten candidates for six-quark hadrons are statistically significant in our experiments. Below, for convenience, the results of two fits are labelled by indices 1 and 2.

Fig.1. Simultaneous fit of the Λp invariant mass spectrum from $n^{12}C$ interactions at $\langle p_n \rangle$=7.0 GeV/c and the Λp elastic scattering effective cross sections measured in the experiments [24-26]. ▶



THE HIGHEST SPIN RESONANCE MASSES ACCORDING TO BAG MODEL
THE BEST FIT PARAMETERS
N 10MeV/c²
N = 117.54 / √201.46 = (8.28 ± 1.04) s.d.
N = 85.57 / √122.42 = (7.73 ± 1.30) s.d.
N = 60.70 / √128.30 = (5.35 ± 1.21) s.d.
χ²₄₁ = 38.9
C.L = 56.0%
INTRANUCLEAR ΛP ELASTIC SCATTERING
ΛP → Σ° P Λ γ
ΣN → ΛP
BACKGROUND DUE TO NONINTERACTING Λ AND P
M_Λp (MeV/c²)


THE HIGHEST SPIN PESONANCE MASSES ACCORDING TO BAG MODEL
THE BEST FIT PARAMETERS
M=2092.9± 0.1
Γ=0.013 ± 0.002
2124.8± 0.4
2.1 ± 0.1
2145.8± 0.4
3.8 ± 0.4
2183.2± 0.5
3.0 ± 0.2
2223.1± 0.4
16.0 ± 2.5
2255.5± 0.4
15.6 ± 0.8
2293.0± 0.7
2358.4±1.3
77.2 ± 6.6
2454.4±1.8
24.5 ± 6.0
2492.1± 2.2
14.5 ± 0.3
N = 82.54 / √125.46 = (7.37 ± 1.29) s.d.
N = 64.93 / √124.07 = (5.83 ± 1.23) s.d.
C.L. = 21.32%
INTRANUCLEAR ΛP ELASTIC SCATTERING
ΣN → ΛP
M_ΛP MeV/c²

1) The peak at $M_1 = (2257.4 \pm 2.3)$ MeV/c^2, $\Gamma_1 = (18.1 \pm 1.1)$MeV/$c^2$ or $M_2 = (2255.5 \pm 0.4)$ MeV/c^2, $\Gamma_2 = (15.6 \pm 0.8)$ MeV/c^2 is established with the statistical significance defined by $N_1 = \frac{85.57}{\sqrt{122.43}} = (7.73 \pm 1.30)$ s.d. and $N_2 = \frac{82.54}{\sqrt{125.46}} = (7.37 \pm 1.29)$ s.d. (85.57 (82.54) events are seen in this signal against a background of 122.43 (125.46)). Most probably, this peak has to be identified with the 2241 MeV/c^2, $J^P = 2^+$ resonance predicted by J.J. de Swart and his colleagues [20,22]: $B^2(\frac{1}{2}, 2255.5) \equiv (\frac{1}{2}, 2^+; 2241)$.

2) The peak at $M_1 = (2350.8 \pm 2.4)$ MeV/c^2, $\Gamma_1 = (44.2 \pm 2.2)$ MeV/c^2 or $M_2 = (2358.4 \pm 1.3)$ MeV/c^2, $\Gamma_2 = (77.2 \pm 6.6)$ MeV/c^2 is established with a statistical significance of $N_1 = \frac{60.70}{\sqrt{128.30}} = (5.36 \pm 1.21)$ s.d. and $N_2 = \frac{64.93}{\sqrt{124.07}} = (5.83 \pm 1.23)$ s.d. Again one can claim: $B^2(\frac{1}{2}, 2358.4) \equiv D(1/2, 2^-; 2353)$.

The well-known peak, situated near the ΣN threshold, aquires in our fits $M_1 = (2129.2 \pm 1.2)$ MeV/c^2, $\Gamma_1 = (2.2 \pm 0.6)$ MeV/c^2 and $M_2 = (2124.8 \pm 0.4)$ MeV/c^2, $\Gamma_2 = (2.1 \pm 0.1)$ MeV/c^2. In the π^--exposure it is established with a significance of 10 standard deviations (fig.3). Most probably, this peak is due to the antibound ΣN state, which reveals itself as a Λp resonance at the ΣN threshold [2,28,29]. But this experiment cannot exclude the genuine Λp 2128 MeV/c^2 resonance. According to the abovementioned fundamental hypothesis on the mechanism of creation of multiquark states, the intensity of a resonance peak must depend on the momentum corresponding to the maximum of the Λ-hyperon momentum spectrum. If such a mechanism is true, one can easily see that with increasing the incident particle momentum the maximum of this spectrum has to tend to higher momenta. In turn, in the invariant mass spectra, it has to reduce the intensity of smaller mass resonances and to increase the intensity of higher mass ones. The following facts seem to demonstrate the correctness of these ideas. The maximum of the Λ-hyperon momentum spectrum in the reaction $\pi^- N \to \Lambda X$ at 4.0 GeV/c is situated in a (0.5-0.7) GeV/c momentum interval. According to the first of our hypotheses, the same must be true also in the case of our nuclear (^{12}C) target. Thus, the resonance momentum $p_\Lambda = 0.62$ GeV/c for the creation of the

◀ Fig.2. The same as in fig.1 invariant mass spectrum fitted simultaneously with the cross sections measured in the experiments [24-26] and by Hauptmann et al. [27].

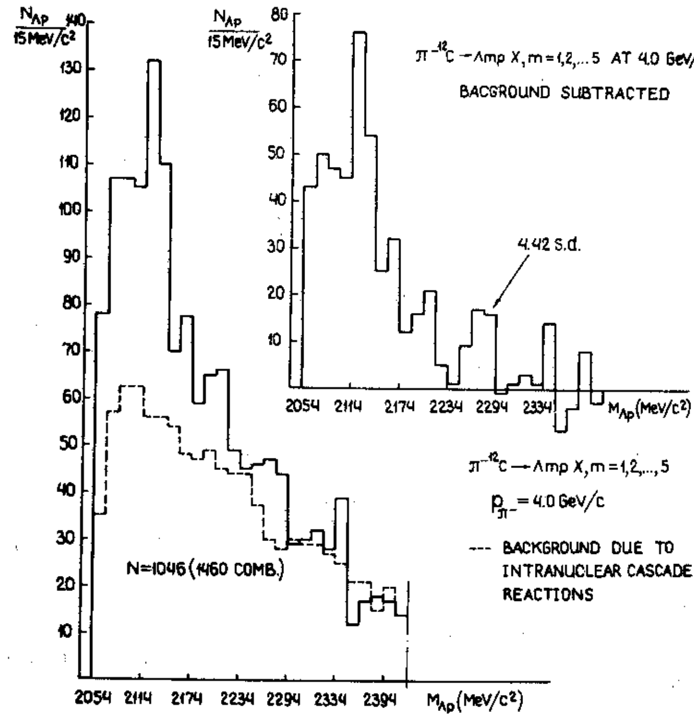


Fig.3. Λp invariant mass spectrum from $\pi^{-}\,{}^{12}C$ interactions at 4.0 GeV/c.

2128 MeV/c^2 enhancement in the intranuclear reaction $\Lambda p \to \Lambda p$ is very close to the maximum of the Λ-hyperon spectrum. At the same time the intensity of the same momentum spectrum in the domain of (1.0÷1.2) GeV/c, including a resonance momentum of 1.12 GeV/c necessary for the creation of the 2256 MeV/c^2 resonance in the intranuclear reaction $\Lambda p \to \Lambda p$, is several times lower. Correspondingly, the 2128 MeV/c^2 peak at 10 standard deviations over the background is seen in the Λp invariant mass spectrum from the $\pi^{-}\,{}^{12}C$ interactions at 4.0 GeV/c, whereas only a "shoulder" is seen in the domain of the 2256 MeV/c^2 resonance (fig.3).The situation is quite opposite in the Λp invariant mass spectrum from $n\,{}^{12}C$ interactions at 7.0 GeV/c. In this case the broad maximum of the Λ-hyperon spectrum embraces the (1.0÷1.2) GeV/c momentum interval and is several times more intensive than at (0.5÷0.7) GeV/c interval. Correspondingly, in this case the 2128 MeV/c^2 peak is less prominent than the 2256 MeV^2 one which is 7.73(7.37) s.d. over the background (figs.1 and 2). Let us stress one more circumstance. The inclusive Λp invariant mass spectra coming mostly from many-particle final states, have been studied in both our experiments.

The situation with the Λp invariant mass spectra from K^-D -interactions is quite analogous to the described one. Until the three-particle $\Lambda p \pi^-$ final states at low energies (less than 0.8 GeV/c) are studied, only the 2128 MeV/c^2 peak and the (2140-2180) MeV/c^2 "shoulder" are observed [30-34]. However, the peaks at 2180 and 2256 MeV/c^2 in the Λp invariant mass spectrum from the five-particle final states $K\bar{D} \to \Lambda p \pi^- \pi^+ \pi^-$ at p_{K^-}=1.5 GeV/c, are observed and thereby this mass spectrum becomes very similar to ours (ref. [35] and figs.1 and 2).

The Λp elastic scattering effective cross sections, computed in the processes of simultaneous fits 1 and 2 are presented by open and hatched circles in figs.4 and 5. The crosses in both figures refer to earlier experiments [24-26], whereas the black points in fig.5 are due to a more recent experiment [27]. It is partinent to note here that the precision of modern, very difficult experiments on the direct measurement of low energy (up to several GeV/c) elastic Λp-scattering effective cross sections are quite unsufficient to detect reliably the 2128 MeV/c^2 resonance. Its width is only several MeV/c^2 (2.2 and 2.1 MeV/c^2 in this experiment, see figs. 1 and 2) whereas in the [24-27] experiments the Λ-hyperon momenta are averaged over (0.5-0.6) GeV/c or over 22.0 MeV/c^2 in the invariant mass scale, i.e., the momentum interval in the mass scale is by an order of magnitude larger than the resonance natural width (figs.4,5). The 2256 MeV/c^2 resonance is under more favourable conditions. In ref.[24] it is averaged over 58 MeV/c^2 corresponding to the momentum interval (1.0÷1.2)GeV/c, i.e., this interval is about four times larger than its natural width (fig.4). In the more recent experiment[27] the momentum interval is (1.0-1.1) GeV/c or 29 MeV/c^2 in the mass scale, i.e., nearly twice as large as its natural width. Thus, the spikes due to this resonance are observed both in[24-26] and in[27] experiments, in the second case the spike being more prominent. At the same time the observation of the 2128 MeV/c^2 peak in the earlier experiment[24] and its absence in the recent experiment[27] cannot serve as an argument against the existence of the 2128 MeV/c^2 enhancement. For similar arguments the broad 2358 MeV/c^2 resonance manifests itself in the recent data[27] as a rather prominent spike, whereas it is almost completely smeared out in the earlier experiment[24].

The significance of all other peaks, except the one at ~2098 MeV/c^2 is defined by less than five standard deviations. The candidate for the peak $D(\frac{1}{2}, 1^-; 2112)$ in the first fit has parameters $M_1 = (2119.9 \pm 4.0)$ MeV/c^2, $\Gamma_1 = (0.0002 \pm 4.2)$ MeV/c^2,

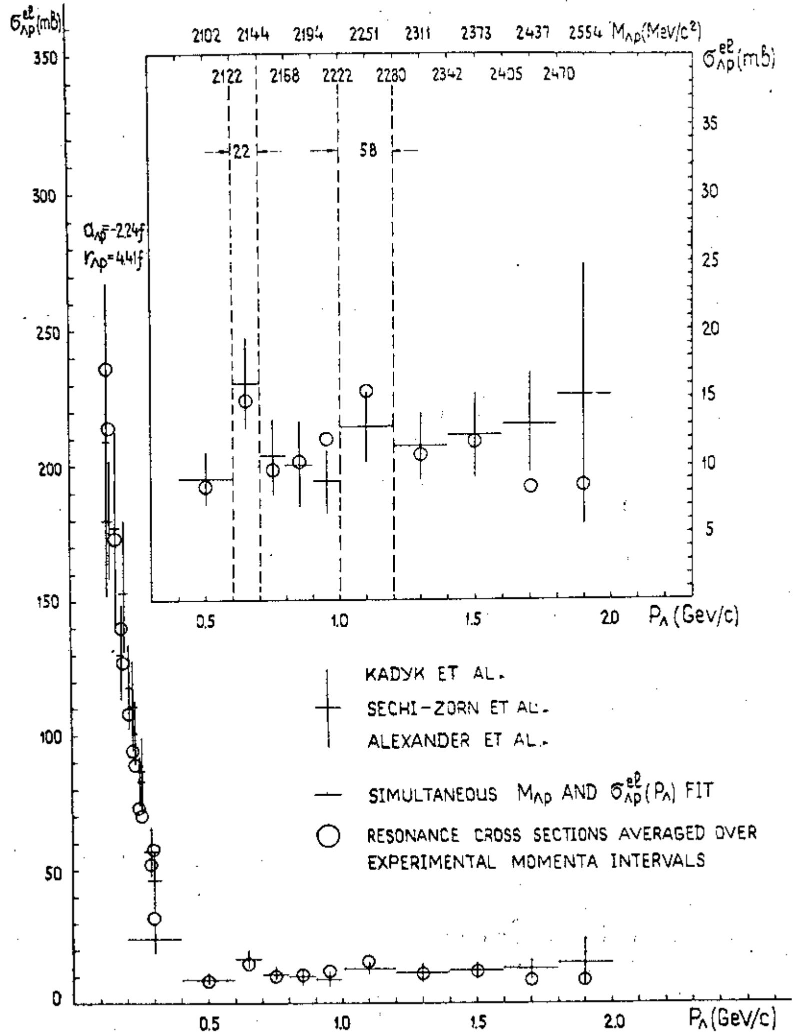


Fig.4. Λp elastic scattering effective cross sections measured in /24-26/ experiments (shown by crosses) and the best-fit cross sections (circles) computed and averaged over the same momentum intervals as in these experiments.

i.e., its width has not been defined. The second fit leads to a more meaningful result: $M_2 = (2092 \pm 0.1)$ MeV/c^2, $\Gamma_2 = (0.013 \pm 0.002)$ MeV/c^2. Thus, our results indicate that if such a resonance does exist at all, it is extremely narrow. Higher statistics combined with the precision of the invariant mass measurements not lower than in our experiments, is of decisive importance either for the resonance in question or for all others represented in the Λp invariant mass spectrum by insignificant spikes. It is worthy to note that in our paper of 1966 [2a,b] we observed in the Λp invariant mass spectrum a 2573 MeV/c^2 peak, $\Gamma < 80$ MeV/c^2 in width, three standard deviations against the background. It is interesting to note that the Bag model predicts several resonant states of close masses.

The broad maximum peaked at 2093 MeV/c^2 is due to low energy Λp scattering. Its significance is defined by $N_1 = (8.28 \pm 1.04)$ s.d. and $N_2 = (6.30 \pm 1.19)$ s.d. The parameters of the low energy Λp scattering defined in our analysis agree well with the ones directly measured [25,26]. The Λp low energy scattering length is firmly established to be negative. Thus, the existence of the Λ-hyperdeuteron is excluded. The scattering parameters are shown in figs.4 and 5 and Table 1.

Finally, let us note that during the process of fitting the contribution of potential Λp scattering tended to zero because the parameter R [2m-q] tended to zero, so further it was fixed equal to zero.

In Table 1 the best parameters obtained in the first and second fits are presented. A, B, C are the contributions of the $\Lambda p \to \Lambda p$, $\Lambda p \to \Sigma^0 p$, $\Sigma^0 \to \Lambda \gamma$, $\Sigma^{\pm}_0 N \to \Lambda p$ two-body processes, respectively, and D is the contribution of the background which is due to noninteracting Λ-hyperons and protons.

Finally the total probability of the following intranuclear cascade process was calculated: an incident 7 GeV/c neutron creates a Λ-hyperon on a bound nucleon; the hyperon, in turn, suffers elastic scattering on another bound nucleon. Using this calculated probability one can show that the 2347 Λp combinations contributing the invariant spectrum should involve $N_{calc.} = 655.5$ events of intranuclear Λp elastic scattering. The same number, obtained using the best-fit contribution A is $N_1 = 649.8 \pm 13.4$ and $N_2 = 632.2 \pm 18.7$ according to the first and second fits respectively.

Thus, according to our model, the Λp elastic scattering can be successfully parametrized as the sum of the low energy scattering effective cross section in the effective range approximation and the Breit-Wigner resonance cross sections predicted by the Bag model. Besides, this model has permitted

Table 1

The best-fit parameters from fits 1 and 2

M_1 (MeV/c^2)	Γ_1 (MeV/c^2)	J_1^P	M_2 (MeV/c^2)	Γ_2 (MeV/c^2)	J_2^P
2119.9 ± 4.0	$2\cdot10^{-3}$ ± 4.2	1^-	2092.9 ± 0.1	0.013 ± 0.002	1^-
2129.2 ± 1.2	2.2 ± 0.6	1^+	2124.8 ± 0.4	2.1 ± 0.1	1^+
2144.9 ± 0.7	3.4 ± 0.2	1^-	2145.8 ± 0.4	3.8 ± 0.4	1^-
2183.3 ± 0.4	3.0 ± 0.3	1^+	2183.2 ± 0.5	3.0 ± 0.2	1^+
2222.1 ± 1.5	10.5 ± 1.8	1^+	2223.1 ± 0.4	16.0 ± 2.5	1^+
2257.4 ± 2.3	18.1 ± 1.1	2^+	2255.5 ± 0.4	15.6 ± 0.8	2^+
2293.2 ± 0.9	6.1 ± 1.2	2^-	2293.0 ± 0.7	4.7 ± 0.7	2^-
2350.8 ± 2.4	44.2 ± 2.2	2^-	2358.4 ± 1.3	77.2 ± 6.6	2^-
2450.2 ± 1.5	12.5 ± 3.0	2^-	2454.4 ± 1.8	24.5 ± 6.0	2^-
2494.9 ± 0.5	22.4 ± 4.6	3^-	2492.1 ± 2.2	14.5 ± 0.9	3^-
2594.5 ± 1.5	61.3 ± 16.0	2^-	2520.5 ± 4.4	33.1 ± 11.8	3^+
$a_{\Lambda p_1}$ (fm)	-2.24 ± 0.12		$a_{\Lambda p_2}$ (fm)	-2.29 ± 0.03	
$r_{\Lambda p_1}$ (fm)	4.41 ± 0.18		$r_{\Lambda p_2}$ (fm)	4.54 ± 0.10	
A_1 ($\Lambda p\to\Lambda p$)	0.277 ± 0.002		A_2 ($\Lambda p\to\Lambda p$)	0.264 ± 0.006	
B_1 ($\Lambda p\to\Sigma^0 p$)	0.112 ± 0.002		B_2 ($\Lambda p\to\Sigma^0 p$)	0.167 ± 0.005	
C_1 ($\Sigma^{\pm}N\to\Lambda p$)	0.048 ± 0.003		C_2 ($\Sigma^{\pm}N\to\Lambda p$)	0.064 ± 0.004	
D_1 (backgr.)	0.563 ± 0.005		D_2 (backgr.)	0.485 ± 0.009	
χ^2_{41}	38.90		χ^2_{58}	67.71	
C.L. %	56.00		C.L. %	21.32	

us to describe the totality of the data on hyperon-nucleon interactions in a noncontradictory way. The analysis performed has shown that light nuclei (not heavier than ^{12}C) can serve as nucleon targets of nuclear density when studying the interactions of unstable particles with nucleons. Resuming one can state that two Λp -dibaryons have been established in this experiment: M =(2255.5±0.4)MeV/c^2, Γ = (15.6±0.8) MeV/c^2, σ_{prod} = = (85.3±20.0) μb and M = (2358.4±1.3) MeV/c^2, Γ = (77.2±

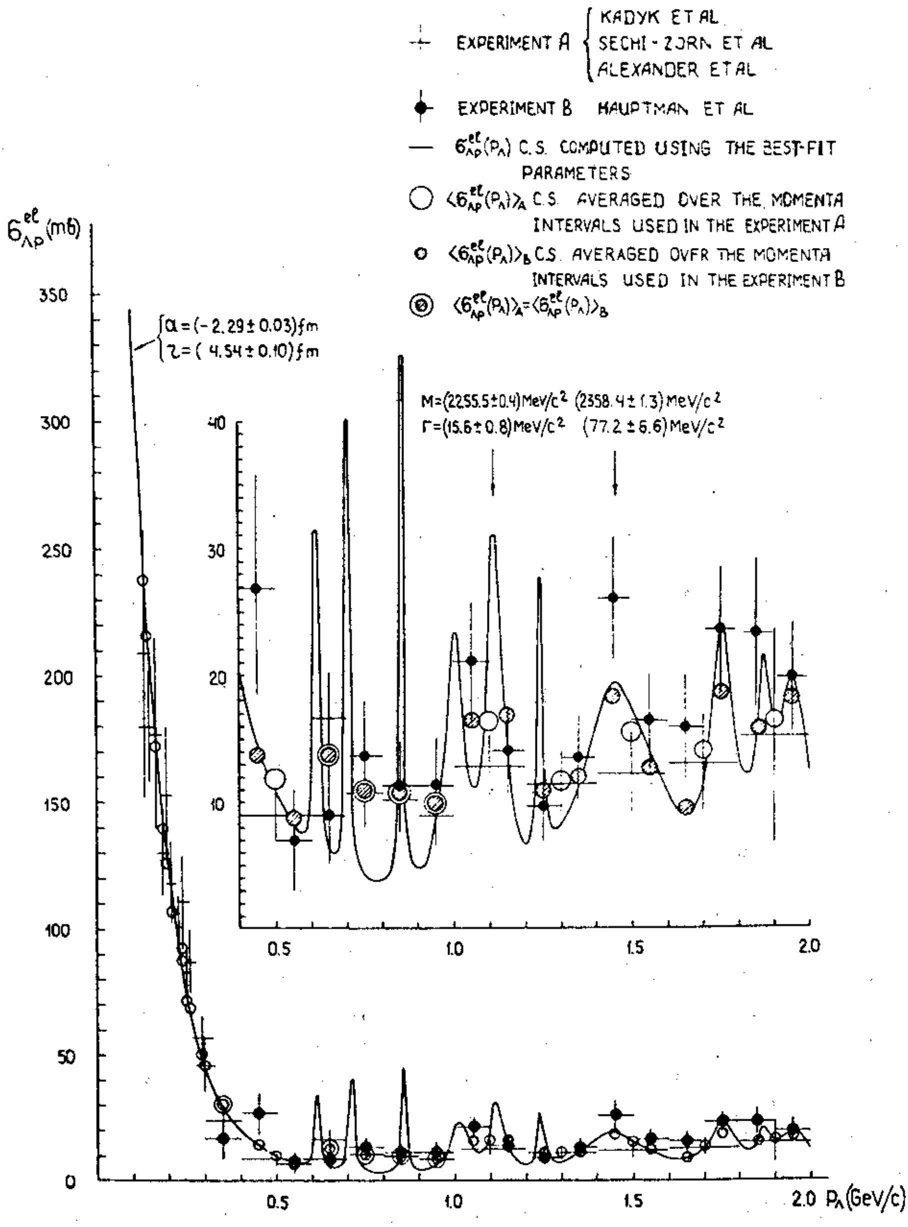


Fig.5. Same as in fig.4 for [24-26] and [27] experiments. Continuous line is the best-fit curve, unaveraged over the momenta intervals.

± 6.6) MeV/c^2, σ_{prod} = (65.0$\pm$17.0) μb. The production cross section of the 2128 MeV/c^2 enhancement amounts σ_{prod} = (22.0$\pm$7.0) μb /20-q/. The cross sections are computed using the data from the neutron exposure and are given per carbon nucleus. The measured and computed Λp elastic scattering cross sections are presented in Table 2.

Authors express their deep gratitude to Prof. A.M.Baldin for his continuous interest to this work.

Table 2

Λp elastic scattering average effective cross sections according to /24-27/ references and to the simultaneous fit

$\langle p_\Lambda \rangle$ (MeV/c)	$\langle (\sigma_{\Lambda p} \pm \Delta\sigma_{\Lambda p})_{meas} \rangle$ (mb)	$\langle \sigma^{comp}_{\Lambda p} \rangle$ (mb)	$\langle p_\Lambda \rangle$ (MeV/c)	$\langle (\sigma_{\Lambda p} \pm \Delta\sigma_{\Lambda p})_{meas} \rangle$ (mb)	$\langle \sigma^{comp}_{\Lambda p} \rangle$ (mb)
135 a	209.0 $\pm$ 58.0	238.5	750 b	13.6 $\pm$ 4.5	10.8
140 a	180.0 $\pm$ 22.0	216.2	850 a	10.2 $\pm$ 2.7	10.7
165 a	177.0 $\pm$ 38.0	172.7	850 b	11.3 $\pm$ 3.6	10.7
185 a	130.0 $\pm$ 17.0	139.7	950 a	8.9 $\pm$ 2.4	9.9
195 a	153.0 $\pm$ 27.0	125.9	950 b	11.3 $\pm$ 3.8	9.9
210 a	118.0 $\pm$ 16.0	107.6	1050 b	21.1 $\pm$ 4.8	16.4
225 a	111.0 $\pm$ 18.0	92.7	1100 a	12.8 $\pm$ 2.4	16.4
230 a	101.0 $\pm$ 12.0	88.0	1150 b	14.0 $\pm$ 3.4	16.8
250 a	83.0 $\pm$ 9.0	72.5	1250 b	9.6 $\pm$ 2.9	11.0
255 a	87.0 $\pm$ 13.0	69.3	1300 a	11.4 $\pm$ 2.4	11.5
290 a	57.0 $\pm$ 9.0	50.8	1350 b	13.5 $\pm$ 3.4	12.0
300 a	46.0 $\pm$ 11.0	46.4	1450 b	26.0 $\pm$ 4.8	18.4
350 a	24.0 $\pm$ 5.0	31.0	1500 a	12.2 $\pm$ 3.2	15.5
350 b	17.2 $\pm$ 8.6	31.0	1550 b	16.4 $\pm$ 3.7	12.7
450 b	26.9 $\pm$ 8.7	14.7	1650 b	15.9 $\pm$ 4.1	9.6
500 a	9.0 $\pm$ 2.0	11.8	1700 a	13.0 $\pm$ 3.8	14.1
550 b	7.0 $\pm$ 4.0	8.8	1750 b	23.5 $\pm$ 5.0	18.6
650 a	16.7 $\pm$ 3.6	13.8	1850 b	23.3 $\pm$ 6.0	15.8
650 b	9.0 $\pm$ 4.0	13.8	1900 a	15.2 $\pm$ 8.4	16.5
750 a	10.7 $\pm$ 2.8	10.8	1950 b	19.9 $\pm$ 4.4	17.2

[a] refers to /24-26/ experiments.

[b] refers to /27/ experiment.

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