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THE DISCOVERY OF RESONANCES IN MULTIBARYON SYSTEMS.

Part III. Λp-Resonances

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Part III. Λp-Resonances

ОИЯИ
БИБЛИОТЕКА

Шахбазян Б.А. и др. **E1 - 11877**

Обнаружение резонансов в мультибарионных системах. Часть III. Λp -резонансы

Обнаружен дибарионный Λp резонанс с массой 2256 МэВ/с², шириной $\Gamma < 15$ МэВ/с² (в зависимости от спина $J_{\Lambda p}$) и спин-четностью $J^P > 0^+$. Статистическая значимость соответствующего пика определяется более чем пятью стандартными отклонениями. Сечение его рождения в $n^{12}C$ столкновениях при $\langle P_n \rangle = 7{,}0$ ГэВ/с оценивается в $\sigma_{pr}(2256) = (85{,}3 \pm 20{,}0)$ мкбн, тогда как сечение образования в процессах $\Lambda p \to \Lambda p$ равно $\sigma_f(2256) = 5{,}3(2J_{\Lambda p}+1)$ мб. Спектры эффективных масс Λp, исследованные в этом эксперименте, кроме известных уже при $\sim(M_\Lambda + M_p)$ МэВ/с² и 2128 МэВ/с² пиков, проявляют особенности, включая и пик 2256 МэВ/с², при значениях масс большинства резонансов, предсказываемых моделью массачусетского мешка. Обсуждаются возможные механизмы образования мультибарионных резонансов. Показано, что, согласно правилу отбора по гиперзаряду $Y \le 1$, мультибарионные резонансы являются сверхплотными сверхстранными объектами.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Shahbazian B.A. et al. **E1 - 11877**

The Discovery of Resonances in Multibaryon Systems. Part III. Λp -Resonances

Dibaryon Λp resonance of 2256 MeV/c² mass, $\Gamma < 15$ MeV/c² (depending on the spin $J_{\Lambda p}$) width, and $J^P > 0^+$ spin-parity assignements is discovered. The statistical significance of the corresponding peak in Λp effective mass spectra is defined by more than five standard deviations. Its production effective cross section in $n^{12}C$ collisions at $\langle P_n \rangle = 7.0$ GeV/c is estimated to be $\sigma_{pr}(2256) = (85.3 \pm 20.0)$ μb, wherease the formation effective cross section in $\Lambda p \to \Lambda p$ interactions is $\sigma_f(2256) = 5.3(2J_{\Lambda p}+1)$ mb.

The Λp effective mass spectra which have been investigated in this experiment reveal, apart the well known $\sim(M_\Lambda + M_p)$ MeV/c² and 2128 MeV/c² peaks, enhancements including 2256 MeV/c² peak near the most of the resonance mass values predicted by MIT Bag Model. Possible mechanisms of multibaryon resonance formation are discussed. According to the hypercharge selection rule $Y \le 1$ multibaryon resonances are shown to be ultra-high density superstrange objects.

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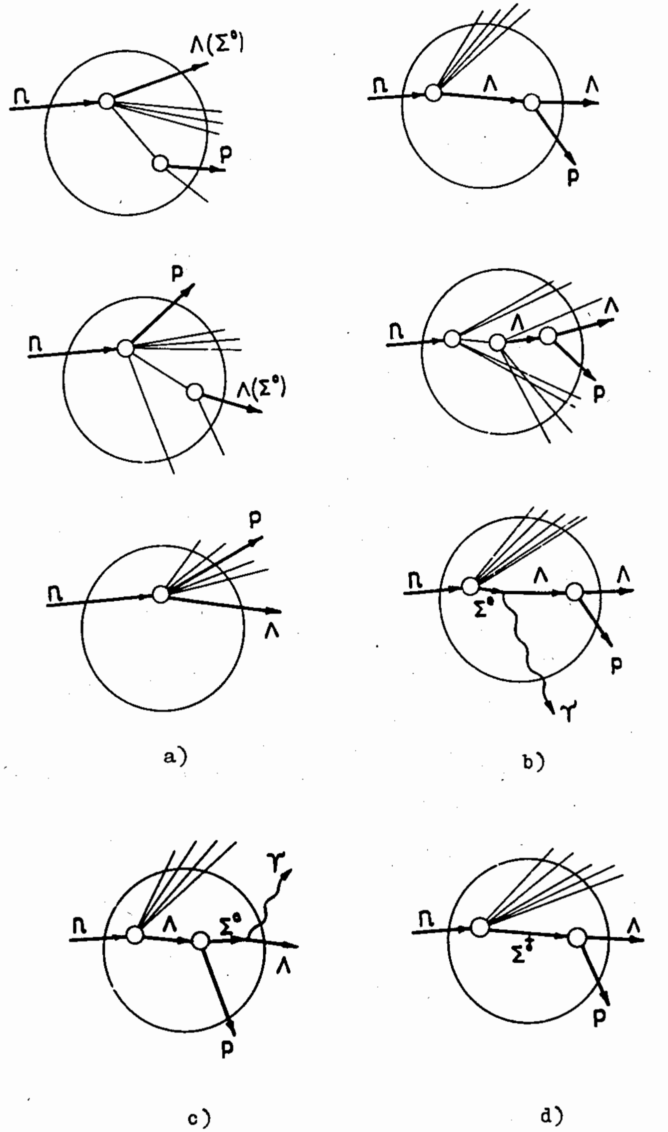
Below we present the recent results of research on the Λp effective mass spectra in $n^{12}C$ and $\pi^{-12}C$ interactions at $\langle P_n \rangle = 7.0$ and $P_{\pi^-} = 4.0$ GeV/c, respectively.

Presently the total statistics of events with and without V^0- particles is 6904 and more than 16000, respectively.

Λp System (Y=1, I=1/2, B=2, S= -1)

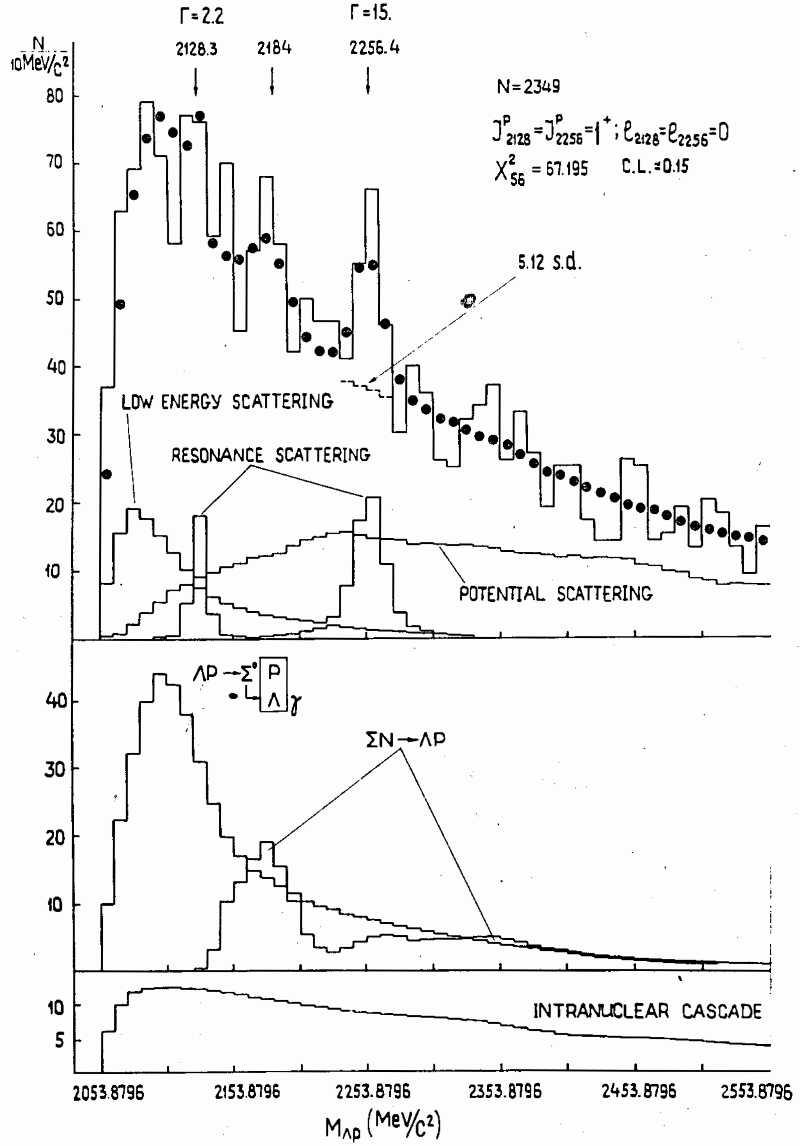
The final state with one Λ- hyperon, one, two and more protons and lighter particles can be formed in a number of various interactions of a fast neutron passing through a ^{12}C nucleus (fig.1). The effective mass spectrum of Λp systems from reactions $n^{12}C \to \Lambda mpX$, m = 1,2 is shown in fig.2. Four enhancements are seen: a peak near the sum of masses $M_\Lambda + M_p$, a peak at 2128 MeV/c², an enhancement at 2184 MeV/c², and a peak at 2256 MeV/c². Note that the first two peaks are confirmed in K^-D experiments /2-6/. The peak at 2256 MeV/c² is confirmed in the Λp elastic scattering effective cross section /7,10/.

By the present time the total combination of experimental facts - independence of the positions and widths of the above three peaks of the nature and energy of projectile particle and of the nucleus mass (light nuclei not heavier than ^{12}C) suggests that they are formed in final state Λp resonance interactions. This means that the resonance ehancements should be peculiar to the Λp effective cross section and, first of all, to the Λp elastic scattering effective cross section. It has been already shown /1l, m/ that the Λp effective mass spectrum can be satisfactorily described (i) using the above hypothesis, (i i) considering the target nuc-



a)
b)
c)
d)

Fig. 1



Γ=2.2
Γ=15.
2128.3
2184
2256.4
N=2349
5.12 s.d.
LOW ENERGY SCATTERING
RESONANCE SCATTERING
POTENTIAL SCATTERING
ΣN→ΛP
INTRANUCLEAR CASCADE
2053.8796
2153.8796
2253.8796
2353.8796
2453.8796
2553.8796

Fig. 2

leus as a Fermi gas of independent nucleons of the known momentum distribution and (iii) making use of the c.m.s. angular distributions and effective cross sections measured in the reactions $\Lambda p \to \Lambda p$ and $\Lambda p \to \Sigma^{\circ} p$.

Because of a rather fast decrease of the Λp effective mass spectrum, only the (2053.8796 - 2553.8796) MeV/c^2 interval was used for analysis. It corresponds to lambda momenta of P_Λ = (0. - - 2.0) GeV/c in the proton rest frame.

As a model of Λ- hyperons created on quasi-free protons at various stages of intranuclear cascade processes, 1322 lambdas (69 of them come from $\Sigma^{\circ} \to \Lambda \gamma$ decays) created on free or quasi-free protons were used. The sample of protons from the events constituting the experimental Λp effective mass spectrum was served as a model of intranuclear cascade protons. Such a sample contains protons created in reactions initiated both by hyperons and by any other type of cascade particles. But it should be noted that in this experiment the momentum spectra of recoil protons from the binary processes $\Lambda p \to \Lambda p$, $\Lambda p \to \Sigma^{\circ} p$, $\Sigma^{\pm} N \to \Lambda p$ are very similar to the momentum spectra of protons from the reactions $n^{12}C \to (mp)X$, $\pi^{-12}C \to (mp)X$, m=1,2,... . This fact was stated by comparing the recoil proton momentum spectra from modelled binary processes and from the measured inelastic ones. Thus the chosen sample of protons rather adequately represents the model of protons created by primary or any cascade particles apart from hyperons. The effective mass spectrum of chance combinations of the mentioned 1322 lambdas and protons has been accepted as the background $\Phi(M'_{\Lambda p})$ due to intranuclear cascade noninteracting lambdas and protons. We state that $\Phi(M'_{\Lambda p})$ is a model of the largest background of noninteracting lambdas and protons in the initial part of the effective mass spectrum. First, this is stipulated by the restricted momentum range $0.150 \leq P_p < 1.000$ GeV/c in which the identification of protons is feasible in this experiment. Second, though lambdas can be identified in a much wider momentum range $P_\Lambda > 0.150$ GeV/c their detection efficiency decreases with increasing momentum. Thus the maximum of $\Phi(M'_{\Lambda p})$ is shifted to the threshold $M_\Lambda + M_p$ as compared to the genuine background of this sort. In the following we use this background normalized to one - $\varphi(M'_{\Lambda p})$.

Among all hyperon-nucleon reactions which are in a relative

momentum range of P_Λ = (0.0 - 2.0) GeV/c the binary processes proceed with the highest effective cross sections. The thresholds of three- and multiparticle processes are situated behind the 2256 MeV/c^2 peak, and the corresponding effective cross sections up to the right bound of the effective mass range remain negligibly small as compared to those of binary processes. Their account would not be justified in view of large experimental errors in this mass region. We have also neglected the contributions of the interference terms in the expression for the Λp elastic scattering effective cross section because the ratio of the peak widths to the widths of intervals between them is much smaller than one. Thus, the Λp elastic scattering effective cross section is written as:

$$\sigma^{el}_{\Lambda p}(M'_{\Lambda p}) = \sum_{k=1}^{4} \sigma_k(M'_{\Lambda p}) \ . \qquad (1)$$

Here the first term

$$\sigma_1(M'_{\Lambda p}) = \frac{4\pi}{\left(-\frac{1}{a} + \frac{r}{2} k^2(M'_{\Lambda p})\right)^2 + k^2(M'_{\Lambda p})} \qquad (2)$$

accounts for the S- wave Λp-scattering in low energy range in the effective range approximation assuming no dependence of the cross section on particle spin, i.e. $a_s = a_t = a$; $r_s = r_t = r$.

In order to describe the peaks at 2128 and 2256 MeV/c^2, two Breit-Wigner terms /13/ in the isolated resonance approximation /14/ have been introduced into the Λp elastic scattering channel:

$$\sigma_{2,3}(M'_{\Lambda p}) = \frac{4\pi (\hbar c)^2 (2J_{\Lambda p}+1) M^2_{2,3}\, p^{4\ell}\, \Gamma^2_{2,3}}{(2J_\Lambda+1)(2J_p+1)\left\{p_{2,3}^{2(2\ell+1)}\left(M'^2_{\Lambda p} - M^2_{2,3}\right)^2 + M^2_{2,3}\Gamma^2_{2,3}\, p^{2(2\ell+1)}\right\}} \qquad (3)$$

$$p^2 = \frac{1}{4M'^2_{\Lambda p}} \left\{ \left(M'^2_{\Lambda p} - M^2_\Lambda - M^2_p\right)^2 - 4M^2_\Lambda M^2_p \right\} . \qquad (4)$$

Everywhere indicies 2,3 indicate the resonance values of the corresponding quantities; P is the momentum in the Λp rest system; $J_{\Lambda p}$, J_Λ, J_p are the spins of the resonance and of its decay products; ℓ is the orbital angular momentum. The approximation $\Gamma_{tot} \simeq \Gamma_{el} = \Gamma_{1,3}$ is justified due to small values of the inelastic effective cross sections in narrow regions of the 2128 and 2256 MeV/c^2 resonances. The matrix element of the potential scattering varies with the relative momentum or the effective mass much slower than the resonance ones do. The potential scattering effective cross section was assumed to be proportional to the Λp phase space volume – $R_2(M'_{\Lambda p})$:

$$\sigma_4(M'_{\Lambda p}) = \pi R^2 R_2(M'_{\Lambda p}) \tag{5}$$

$$R_2(M'_{\Lambda p}) = \frac{\pi p}{M'_{\Lambda p}}$$

p is defined from (4) and R is an average range of the Λp interaction force. The probability of detection of intranuclear scattering events occurred in the bubble chamber volume the effective masses of which contribute to the Λp effective mass spectrum bin ($M_i^{\Lambda p}$, $M_{i+1}^{\Lambda p}$) at finite mass resolution is expressed as

$$W_{el}^{i,i+1}(M_{\Lambda p}) = N_{el}\left\{\int_{M_i^{\Lambda p}}^{M_{i+1}^{\Lambda p}} dM_{\Lambda p} \sum_{k=1}^{3} \int_{M^{\Lambda p}-3\Delta_K}^{M^{\Lambda p}+3\Delta_K} \sigma_K(M'_{\Lambda p}) J(M'_{\Lambda p})\, G(M_{\Lambda p}, \Delta_K, M'_{\Lambda p})\, dM'_{\Lambda p} + \int_{M_i^{\Lambda p}}^{M_{i+1}^{\Lambda p}} \sigma_4(M'_{\Lambda p}) J(M'_{\Lambda p})\, dM'_{\Lambda p}\right\} \tag{6}$$

Here N_{el} is the normalization factor;

$$G(M_{\Lambda p}, \Delta_K, M'_{\Lambda p}) = \frac{1}{\sqrt{2\pi\Delta_K^2}} \exp\left(-\frac{(M'_{\Lambda p} - M_{\Lambda p})^2}{2\Delta_K^2}\right) \tag{7}$$

is the resolution function; $\Delta_1 = 3.00$, $\Delta_2 = 4.25$, $\Delta_3 = 6.40$ MeV/c^2 are its standard deviations in the regions of peaks.

The probability of detection of a Λp elastic scattering event in a chamber of restricted dimensions depends not only on four-momenta $\mathcal{P}_\Lambda$ and $\mathcal{P}_p$ but also on a number of statistical variables such as coordinates of creation and decay, azimuthal angle of the lambda decay plane, Λp scattering plane, etc., i.e.,

$$g = g\left(j(\mathcal{P}_\Lambda, \mathcal{P}_p), x_1, \ldots, x_n\right), \tag{8}$$

$$j(\mathcal{P}_\Lambda, \mathcal{P}_p) = \frac{\sqrt{(\mathcal{P}_\Lambda \cdot \mathcal{P}_p)^2 - \mathcal{P}_\Lambda^2 \cdot \mathcal{P}_p^2}}{\mathcal{P}_\Lambda^0 \mathcal{P}_p^0}, \tag{8a}$$

$j(\mathcal{P}_\Lambda, \mathcal{P}_p)$ is the number of scatters in a unit four-dimensional volume at the collision of lambda and proton beams of $\mathcal{P}_\Lambda$ and $\mathcal{P}_p$ four-momenta and $n_\Lambda = 1$ cm^{-3}, $n_p = 1$ cm^{-3} densities in the laboratory system. But the physical meaning could have only probabilities which depend only on four-momenta $\mathcal{P}_\Lambda$ and $\mathcal{P}_p$ like the effective cross sections. Thus the sought $J(M'_{\Lambda p})$ is an integral of (8) over all statistical variables in corresponding limits expressed as a function of the effective mass of colliding lambda and proton. The integration has been performed using the Monte-Carlo method. Elastic scattering of each of 1322 lambdas with more than 1000 isotropically moving protons of the known momentum spectrum for the ^{12}C nucleus has been modelled using the known Λp c.m.s. angular distributions /7/. After corresponding Lorentz transforms to the laboratory system, only the events survived satisfying all prescribed kinematical, geometrical and measurment criteria. The histogram of survived events of (8a) weights as a function of the lambda-proton effective mass in 1 MeV/c^2 bins is $J(M'_{\Lambda p})$. The last integrand in (6) is a slowly varying function and thereby does not need Gaussian convolution.

The probability of occurrence and detection in the bubble chamber volume of a sequence, the intranuclear $\Lambda p \to \Sigma^0 p$ conversion and $\Sigma \to \Lambda\gamma$ decay processes as a function of the final state Λp effective mass values, contributing to the ($M_i^{\Lambda p}$, $M_{i+1}^{\Lambda p}$) histogram bin with the finite effective mass resolution taken into account, is expressed as

$$W_{\Lambda\Sigma\Lambda}^{i,i+1}(M_{\Lambda p}) = N_{\Lambda\Sigma\Lambda} \int_{M_i^{\Lambda p}}^{M_{i+1}^{\Lambda p}} dM_{\Lambda p} \int_{M^{\Lambda p}-3\Delta_1}^{M^{\Lambda p}+3\Delta_1} \sigma_{\Lambda\Sigma}(M'_{\Lambda p}) J_{\Lambda\Sigma\Lambda}(M'_{\Lambda p})\, G(M_{\Lambda p}, \Delta_1, M'_{\Lambda p})\, dM'_{\Lambda p}. \tag{9}$$

Here $N_{\Lambda\Sigma\Lambda}$ is the normalization factor; the product $\sigma_{\Lambda\Sigma}(M'_{\Lambda p})J_{\Lambda\Sigma\Lambda}(M'_{\Lambda p})$ is the probability of occurrence and detection in the chamber volume of a sequence of processes $\Lambda p \to \Sigma^{\circ} p, \Sigma^{\circ} \to \Lambda\gamma$ as a function of the $M'_{\Lambda p}$ effective mass of the final state proton and Λ- hyperon. In order to calculate $J_{\Lambda\Sigma\Lambda}(M'_{\Lambda p})$, the angular distributions in the c.m.s. /7/ and in the Σ° - rest systems have been modelled. The computational procedure for this is analogous to that of $J(M'_{\Lambda p})$.

For the probability of the last considered process we have

$$W^{i,i+1}_{\Sigma\Lambda}(M_{\Lambda p})=N_{\Sigma\Lambda}\int_{M_i^{\Lambda p}}^{M_{i+1}^{\Lambda p}} dM_{\Lambda p}\int_{M^{\Lambda p}-3\Delta_2}^{M^{\Lambda p}+3\Delta_2}\frac{P_\Lambda}{P_\Sigma}\sigma_{\Lambda\Sigma}(M'_{\Lambda p})J_{\Sigma\Lambda}(M'_{\Lambda p})G(M_{\Lambda p},\Delta_2,M'_{\Lambda p})dM'_{\Lambda p} \quad (10)$$

Here $N_{\Sigma\Lambda}$ is the normalization factor; $G(M_{\Lambda p},\Delta_2, M'_{\Lambda p})$ is the resolution fuction; the product $\frac{P_\Lambda}{P_\Sigma}\sigma_{\Lambda\Sigma}(M'_{\Lambda p})J_{\Sigma\Lambda}(M'_{\Lambda p})$ is the probability of conversion of $\Sigma^{\pm}_{\circ}$ - hyperon to lambda and the detection of the final Λp-pair in the chamber. The $\Sigma^{\pm}$ - hyperon conversion effective cross section in the necessary energy range as well as the corresponding angular distributions are absent. We have used 69 Σ° - hyperons for modelling. It is known/15/ that

$$\frac{d\sigma(\Sigma^{\circ}p\to\Lambda p)}{d\Omega_{c.m.s.}}=\frac{P_\Lambda}{P_\Sigma}\frac{d\sigma(\Lambda p\to\Sigma^{\circ}p)}{d\Omega_{c.m.s.}},$$

where P_Λ and P_Σ are the Λ- and Σ- hyperon momenta in the reaction c.m.s. It is supposed that

$$\frac{d\sigma(\Sigma^{+}n\to\Lambda p)}{d\Omega_{c.m.s.}}\approx\frac{d\sigma(\Sigma^{\circ}p\to\Lambda p)}{d\Omega_{c.m.s.}}=\frac{d\sigma(\Sigma N\to\Lambda p)}{d\Omega_{c.m.s.}}=\frac{d\sigma_{\Lambda\Sigma}}{d\Omega_{c.m.s.}}\frac{P_\Lambda}{P_\Sigma}$$

$$\sigma(\Sigma^{+}n\to\Lambda p)\approx\sigma(\Sigma^{\circ}p\to\Lambda p)=\sigma_{\Lambda\Sigma}(M'_{\Lambda p})\frac{P_\Lambda}{P_\Sigma}.$$

Finally, we have

$$\frac{d\sigma_{\Sigma\Lambda}}{d\Omega_{c.m.s.}}=\frac{P_\Lambda}{P_\Sigma}\frac{d\sigma_{\Lambda\Sigma}}{d\Omega_{c.m.s.}} \quad (11)$$

for any kind Σ- hyperons interacting with nucleons. $J_{\Sigma\Lambda}(M'_{\Lambda p})$

is expressed by the histogram versus the Λ p effective masses of the modelled and detected events of weights

$$j_{\Sigma\Lambda}(M'_{\Lambda p})=\frac{P_\Lambda}{P_\Sigma}\frac{\sqrt{(\mathcal{P}_\Sigma\cdot\mathcal{P}_\Lambda)^2-\mathcal{P}_\Sigma^2\cdot\mathcal{P}_p^2}}{\mathcal{P}_{\Sigma^\circ}\cdot\mathcal{P}_p^\circ} \quad (12)$$

in 1 MeV/c^2 bins.

The coupling of $\Lambda p \to \Lambda p$ and $\Lambda p \to \Sigma^{\circ} p$ channels was not considered in this model.

If the total number of Λp combinations in the effective mass spectrum is N_0, the number of events contributing to the ($M_i^{\Lambda p}$, $M_{i+1}^{\Lambda p}$) mass bin is expressed as

$$N^{Th}_{i,i+1}(M_{\Lambda p})=N_0\left\{AW^{i,i+1}_{el}(M_{\Lambda p})+BW^{i,i+1}_{\Lambda\Sigma\Lambda}(M_{\Lambda p})+CW^{i,i+1}_{\Sigma\Lambda}(M_{\Lambda p})+\mathcal{D}\varphi^{i,i+1}(M_{\Lambda p})\right\}. \quad (13)$$

The contributions A, B, C, $\mathcal{D}$ of the processes considered as well as the parameters a, τ, M_2, Γ_2, M_3, Γ_3, R were computed for the minimum of the functional uniting the data on the Λp effective mass spectra and Λp elastic scattering cross sections/15-17/:

$$\chi^2_n=\sum_{i=1}^{m}\frac{(N^{Th}_{i,i+1}-N^{exp}_{i,i+1})^2}{N^{exp}_{i,i+1}}+\sum_{j=1}^{\ell}\frac{(\sigma^{el}_{\Lambda p}(\bar{P}^j_\Lambda)-\sigma^{Th}_{\Lambda p}(\bar{P}^j_\Lambda))^2}{(\Delta\sigma^{el}_{\Lambda p}(\bar{P}^j_\Lambda))^2}+2(1-Q)\alpha \quad (14)$$

Here $Q=A+B+C+\mathcal{D}$; $N^{exp}_{i,i+1}(M_{\Lambda p})$ is the content of the column of the histogram in the $(M_i^{\Lambda p}, M_{i+1}^{\Lambda p})$ bin ; α is the Lagrange multiplier; $\sigma^{el}_{\Lambda p}(\bar{P}^j_\Lambda)$ and $\sigma^{Th}_{\Lambda p}(\bar{P}^j_\Lambda)$ are the Λp elastic scattering effective cross sections at average momenta $\bar{P}^j_\Lambda$. The number of bins of the Λp effective mass spectrum from one- and two-proton events is m=45 whereas the number of measured cross sections is ℓ = 23. Thus the number of degrees of freedom at 12 unknown parameters is n = 56. In the case of one-proton events n = 42.

We have attempted to extract information on spin and parity of resonant states. States of S=1; $\ell=J_{\Lambda p}+1$ are permitted for a boson resonance of positive parity whereas states of $\ell=J_{\Lambda p}$; S= 0,1 for negative parity. All possible combinations for $J_{\Lambda p}$ =0-3 have been investigated. The confidence levels of $J_{2128}>0, J_{2256}>0$ hypotheses appeared to be three times higher than for $J_{2128}=J_{2256}=0$ hypothesis. This result for the peak of higher mass -2256 MeV/c^2 turned out to be more critical than for the peak of lower mass-2128 MeV/c^2. This can be a consequence of the following law: the spins of hadron resonances increase with increasing their masses. The determination of the spins and parities of Λp resonances reduces to the spin-parity analysis for bosons decaying into spin-1/2 pairs/16/. The conditions for determining uniquely the spin and parity of the Λp - system require the measurement of some spin-correlation terms in the full triple angular distribution. If the spin projections of Λ- hyperons and protons are not measured, the spin and parity of the Λp system cannot in general be fixed. These conditions could not be fulfilled in this experiment. Only the components of the average polarization of lambdas presumed to be daughters of the Λp - system along the beam direction P_z, normal to the Λp-production plane - P_y and normal to both these direction - P_x have been measured. All three components turned out to be zero within the limits of errors/11/. The solutions obtained at various fixed values of $J_{\Lambda p}>0$ and ℓ for one - and one - and two-proton events are shown in Table 1.

As one can see in figs.2 and 6, our model reproduces the experimental effective mass spectra quite well. The blackened and open circles represent the fitted theoretical histograms. Their components due to all processes considered in the model in the lower part of fig.2 are shown. Let us note that the experimental histograms in both figures are not corrected for detection efficiency. It should be noted that the c.m.s. angular distributions of the $\Lambda p \to \Lambda p$, $\Lambda p \to \Sigma^{\circ} p$ binary processes and total cross section of the process $\Lambda p \to \Sigma^{\circ} p$ used in the model suffer from large experimental errors. Then a quite natural question arises how the final results would change if these angular distributions were substantially changed. In order to answer this question, we changed the angular distributions taken from article/7/ for isotropic ones and, using them, computed the quantities $J(M'_{\Lambda p})$, $J_{\Lambda\Sigma\Lambda}(M'_{\Lambda p})$, $J_{\Sigma\Lambda}(M'_{\Lambda p})$ once more and newly fitted the experimental data. As is seen in table 3, the new parameters coincide with "natural" ones within the limits of errors. This result has to be expected by the following two reasons. First, because of

Table 1 Solutions at Various Spin-Parity Assignements

Parameters	$J^P_{2128} = 1^+$; $J^P_{2256} = 1^+$;	$\ell_{2128} = \ell_{2256} = 0$
	One-proton events	One- and two-proton events
	$\chi^2_{42} = 49.379$; CL=0.203	$\chi^2_{56}=67.195$; CL = 0.146
a (f)	-2.35 ± 0.32	-2.37 ± 0.05
r (f)	4.79 ± 0.15	4.69 ± 0.10
M_2 (MeV/c^2)	2126.60 ± 1.65	2128.40 ± 1.00
Γ_2 (MeV/c^2)	2.32 ± 0.57	2.20 ± 0.49
M_3 (MeV/c^2)	2255.70 ± 2.39	2256.40 ± 1.33
Γ_3 (MeV/c^2)	22.29 ± 4.19	15.06 ± 2.68
A ($\Lambda p \to \Lambda p$)	0.322± 0.009	0.429 ±0.016
B ($\Lambda p \to \Sigma^{\circ} p$)	0.229± 0.032	0.223 ±0.007
C ($\Sigma N \to \Lambda p$)	0.036± 0.022	0.091 ±0.006
D (backgr.)	0.416± 0.085	0.250 ±0.012
R (f)	0.59 ± 0.04	0.61 ±0.05
	$J^P_{2128}= 1^+$; $J^P_{2256}= 2^+$;	$\ell_{2128}= 0$; $\ell_{2256}= 1$;
	$\chi^2_{42}= 47.067$; CL=0.270;	$\chi^2_{56}=67.240$; CL=0.145;
a	- 2.45 ± 0.08	- 2.31 ± 0.08
r	4.92 ± 0.12	4.70 ± 0.12
M_2	2127.80 ± 2.32	2129.40 ± 0.61
Γ_2	2.47 ± 0.55	2.47 ± 0.23
M_3	2256.60 ± 0.82	2256.50 ± 0.90
Γ_3	6.25 ± 1.55	10.77 ± 1.20
A	0.487± 0.132	0.324± 0.008
B	0.268± 0.035	0.204± 0.006
C	0.051± 0.041	0.076± 0.006
D	0.187± 0.136	0.407± 0.018
R	0.63 ± 0.017	0.60 ± 0.01

Table 1 Continued

Parameters	$J^P_{2128}=1^+$; $J^P_{2256}=3^+$; $\chi^2_{42}=47.056$; CL=0.270;	$\ell_{2128}=0$; $\ell_{2256}=2$; $\chi^2_{56}=66.483$; CL = 0.159
a	-2.45 ± 0.08	-2.39 ± 0.07
r	4.92 ± 0.12	4.79 ± 0.15
M_2	2127.80 ± 2.32	2129.80 ± 1.12
Γ_2	2.47 ± 0.55	2.46 ± 0.51
M_3	2256.60 ± 0.82	2255.70 ± 1.35
Γ_3	6.25 ± 1.55	$6.72+\pm 0.90$
A	0.487 ± 0.131	0.353 ± 0.047
B	0.268 ± 0.035	0.219 ± 0.022
C	0.051 ± 0.041	0.087 ± 0.023
D	0.187 ± 0.136	0.343 ± 0.097
R	0.63 ± 0.02	0.61 ± 0.03

Table 2 Solutions with Isotropic YN c.m.s. Angular Distributions

Parameters	$J^P_{2128}=1^+$; $J^P_{2256}=1^+$; $\chi^2_{42}=47.746$; CL=0.226;	$\ell_{2128}=\ell_{2256}=0$; $\chi^2_{56}=65.351$; CL=0.195
a	-2.32 ± 0.02	-2.43 ± 0.07
r	4.95 ± 0.03	4.86 ± 0.23
M_2	2126.60 ± 0.47	2128.30 ± 2.74
Γ_2	2.68 ± 0.62	2.28 ± 1.00
M_3	2257.00 ± 0.87	2256.30 ± 2.94
Γ_3	16.75 ± 2.25	14.62 ± 4.06
A	0.457 ± 0.066	0.362 ± 0.046
B	0.129 ± 0.058	0.167 ± 0.040
C	0.061 ± 0.014	0.066 ± 0.017
D	0.405 ± 0.062	0.408 ± 0.037
R	0.62 ± 0.02	0.62 ± 0.05

the low detection efficiency of fast lambdas, our bubble chamber selects from two different, isotropic and measured distributions in the YN c.m.s. and creates in the laboratory system two samples only slightly different in momentum and angular distributions. This must lead to small differences in $J(M'_{\Lambda p})$, $J_{\Lambda\Sigma\Lambda}(M'_{\Lambda p})$ and $J_{\Sigma\Lambda}(M'_{\Lambda p})$ for two kinds of c.m.s angular distributions. Second, the Gaussian convolutions and integrations over the histogram bins performed in formulae (6), (9), (10) smooth over the differences still more. Thus, the differences between the results of two fits wear off when comparing the Tables 1 and 2.

In order to investigate the necessity of accounting for the processes considered, a simultaneous ($\sigma^{el}_{\Lambda p}$ + $M_{\Lambda p}$)- fit, just as in formula (14) but with "turned off" various processes, has been performed. The results are presented in Table 3 in which one can see that the model not accounting for the background from noninteracting lambdas and protons and the model without the second peak (2128 MeV/c^2) are the most significant. Their absence (separately) may be compensated by an increase of contributions of other processes of acceptable χ^2_n and CL. It should be stressed that only the significance of the model in total and by no means the significance of separate peaks is tested by the last procedure of "cutting off" various processes considered in the complete model.

Table 3 Significance of Various Models ($J^P_{2128}=J^P_{2256}=1^+$; $\ell_{2128}=\ell_{2256}=0$)

Without low energy scattering	$\chi^2_{58}=598.880$	CL = 0.
-"- 2128 MeV/c^2 peak	$\chi^2_{58}=74.792$	CL = 0.0577
-"- 2256	$\chi^2_{58}=85.900$	CL = 0.0101
-"- potential scattering	$\chi^2_{57}=103.986$	CL = 0.0004
-"- noninteracting Λ and P background	$\chi^2_{57}=70.756$	CL = 0.11
-"- $\Lambda p \to \Sigma^0 p$	$\chi^2_{57}=98.224$	CL = 0.0005
-"- $\Sigma N \to \Lambda P$	$\chi^2_{57}=80.000$	CL = 0.0048

The analysis of Λp effective mass spectra leads us to the following conclusions.

1. The peak near the Λp threshold is due to the negative S-wave scattering length effect at low energy. This excludes the possibility of the existence of Λp bound states. An unsuccessful up to now search for the Λ- hyperdeuteron confirms this result. The necessity of negative sign of the S-wave scattering length was proved by starting the fitting procedure at a positive scattering length value. The minimum has been reached only at negative sign values. When the error of the positive starting scattering length was set very small, the χ^2_{42}, χ^2_{56} decreased tending to saturation at about 300 and $z \approx 10$ f. But for larger errors, the Λp scattering length suddenly changed the sign to the negative one and χ^2_n reached the minimum of $\chi^2_{56} \approx 67$ and $\chi^2_{42} \approx 47$ for one - and two-proton and one-proton events respectively.

2. The peak at 2128 MeV/c^2, $\Gamma < 3$ MeV/c^2, $J^P > 0^+$ may be due to a number of effects. First, it can be due to the resonance in the Λp elastic scattering channel at a c.m.s. energy of 2128 MeV/c^2. Then in view of the proximity of this mass to the ΣN threshold it can be a manifestation of the ΣN antibound state pole in the amplitude of the reaction $\Sigma N \to \Lambda p$ close to its threshold, i.e., at infinitesimal relative momenta. Finally, the peak at 2128 MeV/c^2 can be a manifestation of both above effects if the coupling between the elastic and inelastic scattering channels is essential.

3. The enhancement near 2184 MeV/c^2 is due to the effect of $\Sigma N \to \Lambda p$ conversion at large relative momenta. As is seen from fig.3, this enhancement, modelled for K^-D-interactions at P_{K^-} =0 and 1.5 GeV/c and for our case, moves with increasing energy from 2143 MeV/c^2 at P_{K^-}= 0 to 2184 MeV/c^2 at $\langle P_n \rangle$ = 7.0 GeV/c incessantly broadening.

This circumstance completely rules out the possibility of kinematical orgin of the 2128 MeV/c^2 peak. Moreover, the "shoulder" at 2138 MeV/c^2 observed in the Λp effective mass spectrum in the $K^-D \to \Lambda p \pi^-$ reaction initiated by stopping K^--mesons /2/ may be well due to the same kinematical effect as seen in fig.3.

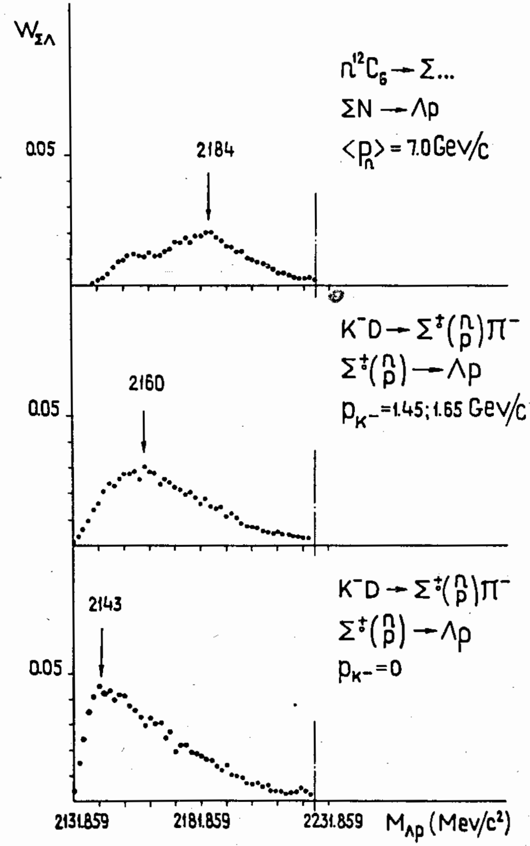


Fig. 3

4. No threshold effects can account for the 2256 MeV/c^2 peak because such a mechanism would need the existence of a new hyperon with a mass of 1318 MeV/c^2 and S= - 1 unobserved up to now.

The only possible interpretation of the 2256 MeV/c^2 peak is the Λp resonance in the elastic scattering channel at 1120 MeV/c in the proton rest system.

Let us note that, unlike the first two peaks confirmed in a series of K^-D experiments /2-6/, the peak at 2256 MeV/c^2 could not be found in these experiments, from our point of view, by the following reasons. Firstly, Λ - hyperons produced in the reaction $K^-n \rightarrow \Lambda \pi^-$ are emitted predominantly in the backward hemisphere of the c.m.s., and therefore their momenta in the laboratory are mainly smaller than the resonance one. Moreover, such a high momentum could be attained only in one of all K^-D experiments performed up to now /5/. Secondly, the collision of not many fast lambdas with the remaining protons is improbable because these hyperons are emitted in the forward hemisphere both in the c.m. and in the laboratory systems. Thereby their collisions with protons need strong spatial correlations of nucleons in the deuteron. The two-nucleon absorption of K^--mesons $K^-D \rightarrow YNm\pi$, m = 0,1,2... seems kinematically more advantageous for the creation of higher mass resonances. But the requirements of spatial correlations should be no less if no more rigid what inevitably reduces the magnitude of the effective cross section.

In our case the maximum of a broad momentum spectrum of Λ - hyperons created in the reaction $n^{12}C \rightarrow \Lambda mp...$ at $\langle P_n \rangle = 7.0$ GeV/c is close to a 1.0 GeV/c momentum. These lambdas with a much higher probability can interact with one of six protons of the ^{12}C nucleus which practically does not correlate with the target nucleon on which the hyperon has been created.

In $\pi^{-12}C$ collisions at 4.0 GeV/c the maximum of the hyperon momentum spectrum is close to 0.5 GeV/c. This means that the spectrum is poorer in momenta close to a resonance momentum of 1.120 GeV/c (2256 MeV/c^2 peak) but it is richer in momenta close to 0.620 GeV/c which corresponds to the 2128 MeV/c^2 resonance peak. It is natural, from this point of view, that the 2128 MeV/c^2 peak is much more intensive than in $n^{12}C$ interactions, and the peak at 2256 MeV/c^2 is degenerated into "shoulder" (fig.4). Besides, the momentum spectra of Σ^+ and Σ^0 -hyperons created in π^-N interactions in the laboratory system are much more rich in slow particles than the corresponding spectra from nN interactions at 7.0 GeV/c. Therefore the contribution of the very slow

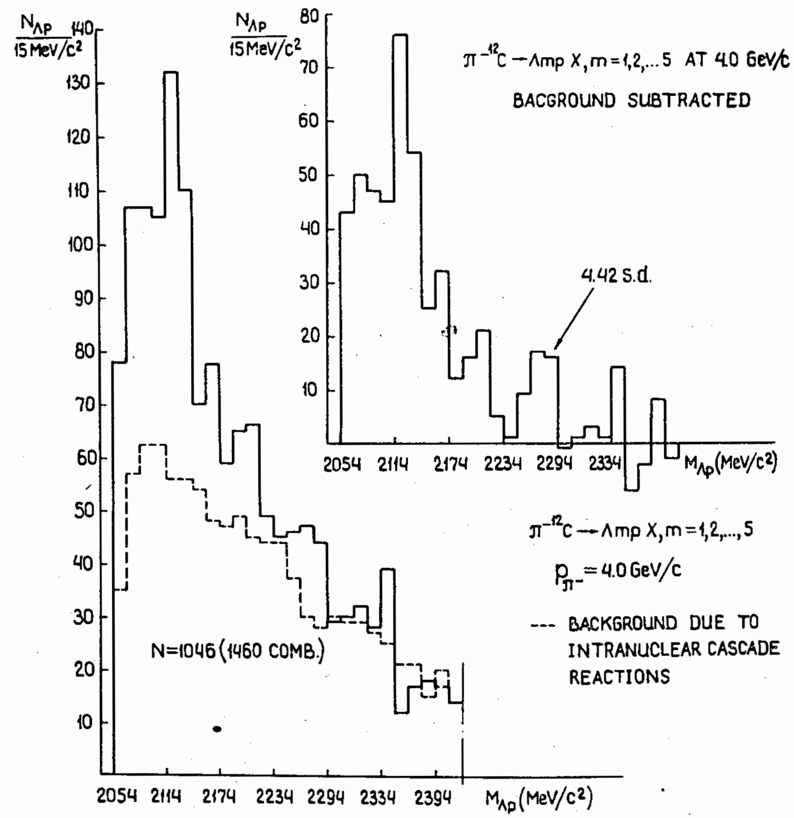


Fig. 4

$\Sigma^{\pm}$ - hyperon conversion mechanism to the 2128 MeV/c^2 peak in $\pi^{-12}C$ is larger than in $n^{12}C$ interactions, i.e., there exists one more reason for a higher intensity of the 2128 MeV/c^2 peak in $\pi^{-12}C$ in comparison with that in $n^{12}C$-interactions.

5. One of the fundamentals of the model /1ℓ,m/ - the possibility to describe the Λp elastic scattering in the region of

0 < P ≤ 2.0 GeV/c relative momenta as a sum of four effective cross sections for potential, low energy and two resonance elastic scattering processes, formula (1), - well agrees with experiment. In fig.5 the crosses represent the measured Λp elastic scattering effective cross sections /7-10/ . The solid line is the calculated Λp elastic scattering cross section using the best fit parameters. And the circles are the same cross sections averaged over the same momentum intervals as in experiments /7-10/. Averaging of the peak at 0.620 MeV/c over 0.6 - 0.7 GeV/c corresponds to averaging over the 22 MeV/c^2 mass interval at a resonance width of 1-3 MeV/c^2. For the peak at 1.120 GeV/c the corresponding values are 1.0 - 1.2 GeV/c and 58 MeV/c^2 at $\Gamma < 15$ MeV/c^2. Nevertheless, the spikes of the effective cross section at the corresponding momenta are observed. The calculated cross sections averaged over the momentum intervals correspond to the spikes and are denoted by circles. The spike corresponding to the 2256 MeV/c^2 peak is confirmed in the recent paper on Λp elastic scattering /10/.

6. We see that the considered realistic model, taking into account the formation of Λp systems in $n^{12}C$ interactions, permitted us to extract from the effective mass spectra more detailed information about the dependence of the Λp elastic scattering effective cross section on energy than that obtained in direct measurements by the present time. Thus, in the absence of monoenergetic beams of unstable particles the ^{12}C nucleus can serve as a high density target for studying their scattering on nucleons. Correspondingly, a propane bubble chamber can serve as a detector of these processes.

But using heavier nuclei as a target, one should expect a heavy smearing of peaks up to their complete dissappearence due to much larger probabilities of intranuclear rescatterings of the Λp - resonance decay products - lambdas and protons. These considerations have been confirmed by the authors of paper /17/ devoted to an investigation of the Λp effective mass spectra in K^--meson collisions at 2.1 GeV/c with ^{12}C, ^{19}F, $^{79-81}Br$ nuclei in the

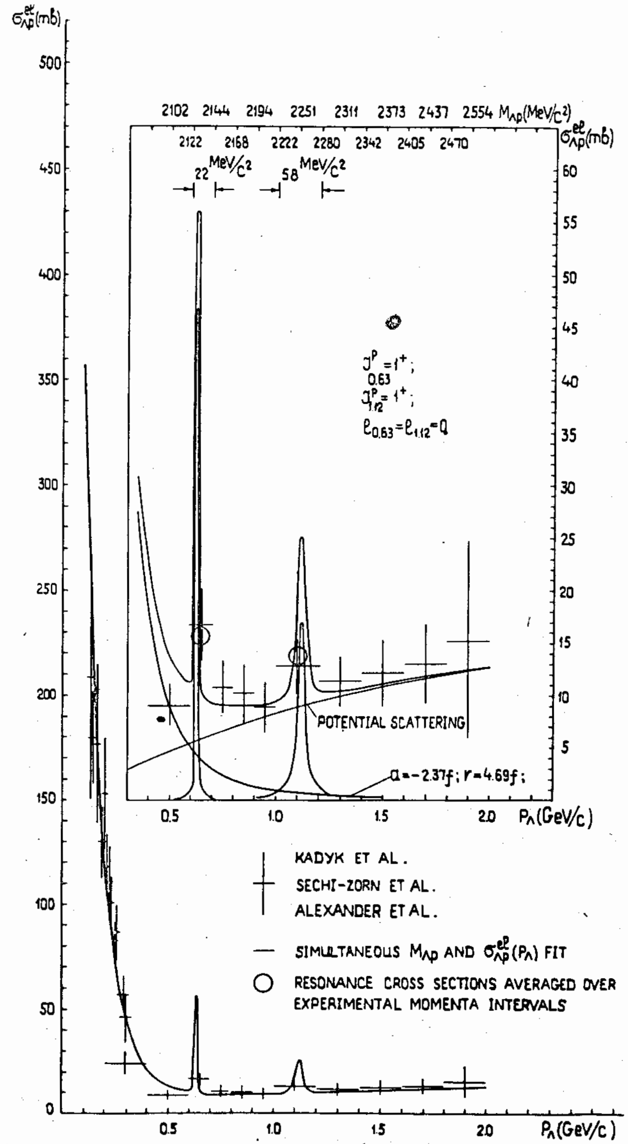


Fig. 5

RHL/UCL bubble chamber filled with a propane - heavy freon mixture. Neither of the enhancements found in all other works has been observed by these authors.

The statistical significance of peaks found in effective mass spectra is a question of principle importance but it cannot be strictly solved yet because of the absence of the theory of strong interactions. At the present time it can be answered only crudely in the frame of a definite model. Thus, the significance of the peak at 2256 MeV/c^2 from one- and two-proton events is defined by 5.12 s.d. over the backrgound which represents the summary effect of all intranuclear processes (see the lower part of fig.2) except the hypothetical Breit-Wigner resonance searched for at this mass (see the dotted histogram in the peak region in fig.2). In this case the confidence level, according to paper /18/, is CL= $5.62\cdot 10^{-6}$. The significance of the same peak from one-proton events estimated in the same way is 4.37 s.d. (fig.6), CL being $1.5\cdot 10^{-4}$. But it seems promising to get rid of a considerable part of the background selecting only the events which could not be produced by an 11 GeV/c neutron (maximum momentum of protons circulating in the machine) on a free proton. For this purpose out of all 1108 one-proton events only those have been selected for which the cos of the Λp system emission angle was smaller than that of the maximal emission angle of the system with mass ($M_\Lambda + M_p$) produced by an 11 GeV/c neutron on a free proton in the three-particle final state reaction np $\rightarrow \Lambda K^0 p$. The effective mass spectrum of 492 events survived after selection is shown in fig.7. The significance is defined by 5.68 s.d. over the background (solid line drawn by hand) with a confidence level of $1.87\cdot 10^{-7}$ /18/.

In the Λp mass spectrum from $\pi^- {}^{12}C$ interactions only the background created in intranuclear cascade processes has been considered. It was imitated by the effective mass spectrum obtained from chance combinations of Λ- hyperons from the most important π^-p channels weighted over the channel cross sections with protons from the main statistics. The statistical significance of events in the enhancement above this background is defi-

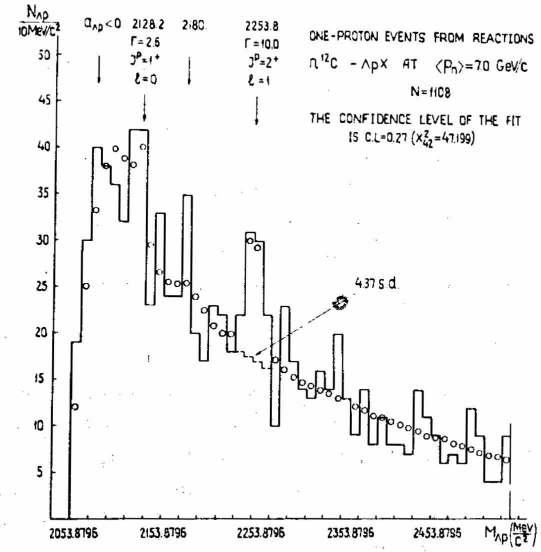


Fig. 6

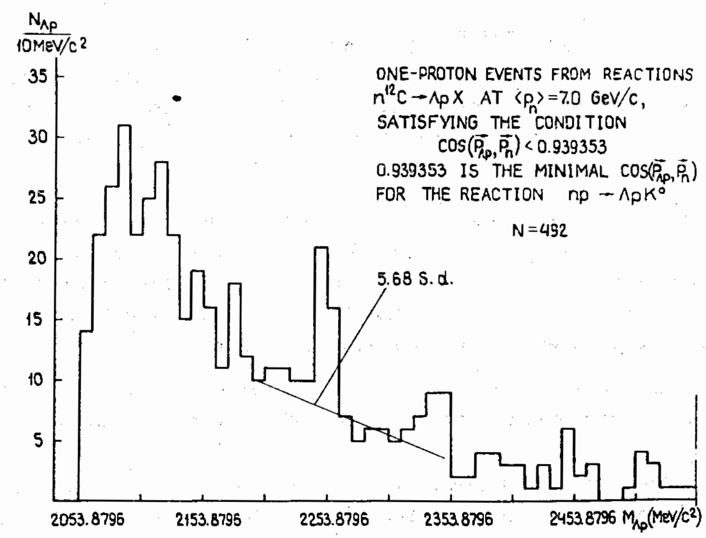


Fig. 7

ned by 4.42 s.d. and CL = $1.33\cdot10^{-4}$. A possible presence of other resonances such as those predicted in paper/12/ makes the above correct estimates of statistical significance more difficult.

Let us state that the statistical significance of the 2256 MeV/c^2 peak is defined by more than five standard deviations in $n^{12}C$ interactions at $\langle P_n \rangle$= 7.0 GeV/c. It is confirmed in $\pi^{-12}C$ collisions at 4.0 GeV/c (4.42 s.d.) and in the Λp elastic scattering effective cross section/7,10/. Thus, with good reason this peak is considered to be statistically significant and is due to the Λp resonance at 2256 MeV/c^2.

7. Crude estimates of the production effective cross sections in $n^{12}C$ collisions of the 2256 and 2128 MeV/c^2 resonances turned out to be (85.3±20) μb and (22.0±7.0) μb, respectively.

According to our model, the formation effective cross section of the 2256 MeV/c^2 resonance in the Λp elastic scattering channel is given by the expression

$$\sigma_f(2256) = 5.3\ (2J_{\Lambda p} + 1)\ \text{mb}.$$

The formation effective cross section of the 2128 MeV/c^2 resonance in the Λp elastic scattering channel, if it is formed only via this channel, is equal to 47 mb for $J^P_{\Lambda p} = 1^+$(fig.5).

8. Our analysis shows that all enhancements observed in Λp effective mass spectra, whether they are of resonance nature or not, are due to hyperon-nucleon interactions in the final state. But one can imagine another mechanism of multibaryon ($B \geqslant 2$) resonance formation which will be discussed below.

9. The average range of the Λp interaction force R, determined in this experiment is within the expected limits.

10. The low energy $\Lambda\Lambda$, like the Λp scattering length is estimated to be of negative sign /1e-j/. This fact possibly rules out the existence of the predicted/11/ bound dilambda state.

Multibaryon Resonances are Ultra High Density, Superstrange Objects.

For the following it is important to clear up possible mechanisms of creation of these resonances. Let us compare a number of facts.

1. The Λp, $\Lambda\Lambda$, $\Lambda\Lambda$p resonance production effective cross sections $\sigma^{\Lambda p}_{pr}$ (2256) = (85.3±20.0) μb, $\sigma^{\Lambda\Lambda}_{pr}$ (2365) =(24.2±7.0) μb/1m,n/ and $\sigma^{\Lambda\Lambda p}_{pr}$ (3568)=(16.1±5.2) μb/1m,n/ differ by less than one order of magnitude in $n^{12}C$ collisions at $\langle P_n \rangle$ = 7.0 GeV/c.

2. The Fermi gas model of nuclei cannot ensure the creation of multibaryon resonances of B > 2 with sensible probabilities.

3. The Λp (figs 2,4,6,7), $\Lambda\Lambda$ and $\Lambda\Lambda$p/1n/ effective mass spectra reveal peaks and spikes at almost all predicted/11,12/ resonance mass values.

These facts suggest that apart from the considered above there should exist a second mechanism which can be either complementary or alternative to the first one depending on experimental conditions. We mean the hyperonization of highly compressed nuclear matter. Such phase transitions are possible in collisions of relativistic particles and nuclei with nuclei. The form and the contribution of the background in this case will substantially differ from the ones estimated above. This means that all above estimates of statistical significance are very conventional and even perhaps incorrect because of our ignorance of the strong interaction theory and the mechanism of multibaryon resonance production.

A relativistic particle (or a nucleus) at cp=(8-10) GeV/n penetrating at small impact parameters into a nucleus, even into a light one like ^{12}C, may produce a rather high compression of nuclear matter in a time interval about an order of magnitude shorter than the mean lifetime of a $\Gamma \sim 10$ MeV/c^2 wide multibaryon resonance. The compressed nuclear matter may become a source of secondary particles/22/. If the relativistic nuclear fluid dynamics/23/ were applicable to our case, then the maximal compression would achieve n/n_o= 14-18, where n_o is the normal nuclear matter density. This would be far enough for a partial hyperonization of the compressed nuclear matter providing thus a small number of dilambda states. Moreover, this possible mechanism could ensure di- and multibaryon, especially multihyperon, resonance formation. If multibaryon resonances could be formed via only two possible mechanisms: nuclear matter compression and final sate hyperon-nucleon resonant interaction, then the possible tribaryon $\Lambda\Lambda p$ resonance would be formed only via the first one, predominantly in central collisions, whereas the Λp and $\Lambda\Lambda$ resonances could be formed via both mechanisms.

The occurrence of a definite mechanism for dibaryon resonance production should depend on the magnitude of the impact parameter occurred in the collision act.

The above remarkable proximity of the di- and tribaryon resonance production effective cross sections proves an important role of the compression mechanism. Most probably, multibaryon resonances $(B>2)$ can be created practically only via this mechanism.

The detection of enchancements at almost all the predicted Λp, $\Lambda\Lambda$ and $\Lambda\Lambda p$ resonance mass values/11,12/, the forms of the Λp (figs 2,4,6,7), $\Lambda\Lambda$ and $\Lambda\Lambda p$ effective mass spectra themselves shown in figs 1 and 2 of/1n/ suggest that the compression mechanism at certain conditions can excite practically only pure resonant multibaryon states with negligibly small contribution of nonresonant background states. The background due to the adjacent resonances attain about 30% of both $\Lambda\Lambda$ 2365.3 MeV/c^2 and $\Lambda\Lambda p$ 3568.3 MeV/c^2 peaks. The significance of the $\Lambda\Lambda p$ peak is defined then by 4.5 s.d. with C.L.$=6.10^{-5}$, whereas the significance of the $\Lambda\Lambda$ peak is defined by 6.0 s.d. and with C.L.$=1.8\cdot10^{-8}$. The significance of the Λp 2256 MeV/c^2 peak would be even higher.

Multibaryon resonances formed via the compression mechanism in light nuclei survive the ultra-high density short lifetime environment and decay if fast enough in free or if slow in a rather rarefied nuclear matter without substantial rescattering of resonance decay products. Thus, multibaryon resonances produced in light nuclei are detectable. In the extreme case of very light nuclei such as deutron or helium, this mechanism should be very improbable. Perhaps, this reason together with that discussed in/1m,n/ could explain the absence of the 2256 MeV/c^2 peak in the Λp spectra from the K^-d experiments/2-6/. In the controversial extreme case of heavy nuclei such as Br or Pt the ultra-high density states could exist during the time intervals comparable to multibaryon mean lifetimes. On the other hand, in this case the dimensions of the compressed nuclear matter volume should be larger than in light (^{12}C) nuclei. These reasons result in heavy rescattering of resonance decay products smearing out the peaks in the Λp and $\Lambda\Lambda$ spectra from the heavy liquid bubble chamber experiment/17,19,20/ and the $\Lambda\Lambda$ peak from the K^-Pt experiment/21/.

Thus, we state the following:

1. The formation of all hadronic resonances, including the multibaryon ones, is governed by the hypercharge selection rule/1f-n/: "The hypercharge of hadronic resonances cannot exceed one $(Y\leq 1)$". This rule governs the above phase transition also.

2. The narrowness of the discovered Λp, $\Lambda\Lambda$ and $\Lambda\Lambda p$ resonances is a direct experimental demonstration that they are single multibaryon hadron states. But hadron states require the geometrical volume of all hadrons, including the multibaryon resonances $(B>1)$, to be a universal constant. The quark confinement, asymptotic freedom and infrared slavery concepts are the manifestations of this fact.

Thus, at the same time multibaryon resonances are ultra-high density, superstrange objects or states of hadronic matter.

In terrestrial conditions, high pressures and compressions of the nuclear matter can be attained bombarding nuclei with relativistic particles and nuclei. The droplets of ultra-high density hadron matter, multibaryon or multihyperon resonances thus obtained, can live at most 10^{-21} - 10^{-20} sec in the absence of corresponding external pressures. Thus, the most direct way to detect ultra-high density states in laboratory conditions is the detection of multibaryon resonances. Other ways seem to be hopeless.

In conclusion we note that the exciting program of study of multibaryon resonances and ultra-high density superstrange states requires machines, accelerating heavy ions up to tens of GeV/n or even higher energies, because both the hyperon production effective cross section and the hyperonization via the compression of the nuclear matter increase with the energy of bombarding projectiles.

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