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B.A.Shahbazian, A.A.Timonina, N.A.Kalinina

ЛАБОРАТОРИЯ ВЫСОКИХ ЭНЕРГИЙ

INVESTIGATION OF MULTIBARYONIC RESONANCES WITH STRANGENESS EQUAL TO AND DIFFERENT FROM ZERO

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INVESTIGATION OF MULTIBARYONIC RESONANCES WITH STRANGENESS EQUAL TO AND DIFFERENT FROM ZERO

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1. Introduction

The aim of this investigation was an attempt to elucidate to some extent the role which the total hypercharge and strangeness of a system play in the strong interactions of hadrons. Various possible approaches to this problem could be imagined.

We chose the study of the interactions between two or more baryons for two groups of them differing in total strangeness and hypercharge quantum numbers:

i) the group of $S \neq 0 - (\Lambda p), (\Lambda\Lambda), (\Lambda pp), (K^{\circ}p)$,

ii) the group of $S = 0 - (pp), (3p), (4p), (5p), (6p)$.

The most suitable way to do this is, in our view, the search for and investigation of multibaryonic resonances using the study of the effective mass spectra of the above systems.

The experimental information was extracted from photographs of the JINR 55 cm propane bubble chamber exposed to a neutron beam of a 7.07 GeV/c average momentum and to a 4.0 GeV/c momentum π^- -meson beam. The protons were possible to identify using the range and ionization measurements up to 1.0 GeV/c momenta.

About 80% of protons stopped in the bubble chamber volume.

The systematic losses of V° -particles were accounted for computing the detection efficiency and the weight of each event /1/. Each event contributes a histogram with its weight.

2. The (Λp) -System, $Y = 1$, $B = 2$, $S = -1$

In total 1818 neutron-carbon interactions each containing a Λ - hyperon, (1-5) protons and π - and K-mesons were selected in the neutron exposure. 964 of them contained each a Λ -hyperon, one proton and π - and K-mesons. The effective mass spectrum of these one-proton events is shown in fig.I. The background calculated in impulse approximation /2/ is shown by the dotted histogram. Three significant peaks at 2058 MeV (5.8 s.d.), 2127 MeV (5.2 s.d.) and 2252 MeV (4.3 s.d.) are clearly seen.

In the lower part of fig.I the $\bar{\alpha}$ and $\bar{\beta}$ coefficients as a function of the (Λp) effective mass are shown.

These coefficients are defined as

$$\bar{\alpha} = \langle \left(\frac{F-B}{F+B}\right)_{exper.} - \left(\frac{F-B}{F+B}\right)_{backgr.} \rangle,$$

$$\bar{\beta} = \langle \left(\frac{P-E}{P+E}\right)_{exper.} - \left(\frac{P-E}{P+E}\right)_{backgr.} \rangle,$$

Here $F(B)$ is the total number of events in a given (Λp) mass interval Λ - hyperons of which are emitted in the forward (backward) hemisphere of the (Λp) rest system with respect to the (Λp) line of flight, $P(F)$ is the number of events in a given (Λp) mass interval with $|\cos\theta_\Lambda| > 0.5$ (< 0.5) in the (Λp) rest system.

The isotropic angular distribution $(\bar{\alpha} \simeq 0, \bar{\beta} \simeq 0)$ and small relative kinetic energy of Λ -hyperons in the region of the 2058 MeV peak (the maximum is at ~ 4 MeV) suggests that this peak is due to the final state (Λp) interaction. Assuming that the singlet and triplet state contributions are equal and taking into account the background we applied the Watson theory /3/ of the final state interactions and defined the (Λp) scattering parameters:

$$a_{\Lambda p} = -(2.0 \pm 0.6) \times 10^{-13} \text{ cm},$$

$$r_{\Lambda p} = (2.5 \pm 0.8) \times 10^{-13} \text{ cm}.$$

This result is in agreement with the data on elastic (Λp) scattering /4/ . The negative sign of $a_{\Lambda p}$ suggests that the bound (Λp) states are forbidden and explains the unsuccessfulness of the Λ -hyperdeuteron searches. Note that the effective mass resolution for the initial part of the (Λp) spectrum is (3.0 ± 0.5) MeV.

Since the mass of the 2127 MeV peak is very close to the sum of the Σ -hyperon and nucleon masses, it is natural to interpret the second peak as being due to the final state ΣN interaction with the subsequent $\Sigma N \to \Lambda p$ conversion. The small $\bar{\alpha}$ and $\bar{\beta}$ coefficients $(\bar{\alpha} \simeq 0, \bar{\beta} \simeq 0)$ in the region of this peak strongly support this interpretation. The negative (ΣN) scattering length defined in (Σp) scattering experiments excludes the possibility of the (Σp) bound states.

The alternative possibility - the genuine (Λp) resonance of the 2127 MeV mass cannot be excluded for the moment.

The best fit Breit-Wigner parameters with the account for the background and the resolution function /5/ were found to be

$$M_R = (2125.2 \pm 2.5)\ \text{MeV},$$
$$\Gamma = (20.6 \pm 5.2)\ \text{MeV}.$$

Finally the 2252 MeV peak cannot be interpreted as a result of the final state interaction with the subsequent conversion because such a mechanism would need for a baryon of $M \sim 1314$ MeV and $S = -1$ which up to now was not observed.

The apparent unisotropy of the angular distribution of Λ -hyperons in the (Λp) rest system for events from this peak cannot be considered to be statistically significant.

All our attempts to imitate this peak by modelling the creations and decays of various kinds of known resonances were unsuccessful. The enhancements obtained in this way in the (Λp) effective mass spectra which were kinematical reflections of the creation and decays of various known resonances always were very broad (200-300 MeV) and the positions of their flat maxima were moving with the change of the incident neutron momentum. The further integration over the experimental neutron momentum spectrum led to flatter curves.

All these facts suggest that the 2252 MeV peak is due to a (Λp) resonance. The best fit Breit-Wigner parameters of this resonance with the account of background and resolution function (which has in this (Λp) mass region the full width at half height $M = (15.0 \pm 2.0)$ MeV) are equal to

$$M_R = (2251.2 \pm 3.9)\text{MeV},$$

$$\Gamma = (21.1 \pm 5.4)\ \text{MeV}.$$

The (Λp) effective mass spectrum of all 1818 events (3044 combinations) is shown in fig.2. The gap between the first two peaks where the maximum of the background is situated is filled up due to fake (Λp) combinations coming from (2-5) proton events.

But in spite of the grown background the thrid peak, which is situated on the falling part of the background, survives. The (Λp) effective mass spectrum for 1091 events of (1-5) proton multiplicities (1726 combinations) from the pion exposure has a form similar to that from the neutron exposure (fig.3). The 2127 MeV peak is mush strongly pronounced obscuring thereby the 2058 MeV and 2252 MeV peaks. This fact may be due to different energies of the pion and neutron exposures and different mechanisms of the resonance formation.

3. The $(\Lambda\Lambda)$ - System, $Y = 0$, $B = 2$, $S = -2$

Fifty three $(\Lambda\Lambda)$ pairs were identified /2/ . The $(\Lambda\Lambda)$ effective mass spectrum is shown in fig.4. The most pessimistic estimates have shown that the creation of $(\Lambda\Lambda)$ pairs in nuclear cascade processes does not exceed 50% of the experimental sample.

The effective mass spectrum of the background $(\Lambda\Lambda)$ pairs (in /2/ a detailed description of the background calculation is given) normalized to the 50% of the experimental sample is shown by the dotted histogram. As an illustration, the phase space volume distribution over $M_{\Lambda\Lambda}$ for the $(\Lambda\Lambda)$ pair creation in collisions of neutrons and pions with carbon nuclei is shown by the dash-dotted line.

It can be stated that the experimental spectrum cannot be described by the computed spectra. As a background, the dotted histogram (the nuclear cascade process) is taken.

Two enhancements are observed, the first one in a (2291-2471) MeV range with a maximum at 2370 MeV and the second, which is less pronounced, at ~ 2260 MeV.

The first one (2370 MeV) most probably is due to a $(\Lambda\Lambda)$ resonance (2.2 s.d.). The maximum likelihood best fit Breit-Wigner parameters taking into account the $(\Lambda\Lambda)$ mass resolution of (22.0 $\pm$ 4.0) MeV were obtained /2/

$$M_R = (2365.3 \pm 9.6)\ \text{MeV},$$

$$\Gamma = (47.2 \pm 15.1)\ \text{MeV}.$$

The second enhancement at ~ 2260 MeV may be due to the $(\Lambda\Lambda)$ final state interaction. An attempt to estimate the $(\Lambda\Lambda)$ scattering parameters in the frame of the Watson theory was made. The χ^2_2 fit (fig.4) leads to the following bounds on $a_{\Lambda\Lambda}$ and $r_{\Lambda\Lambda}$

$$-1 \times 10^{-13}\ \text{cm} \leq a_{\Lambda\Lambda} < 0,$$

$$1.5\times10^{-13}\ \text{cm} < r_{\Lambda\Lambda} < 3\times10^{-13}\ \text{cm}.$$

The negative scattering length excludes the bound $(\Lambda\Lambda)$ states. Our estimates of $a_{\Lambda\Lambda}$ and $r_{\Lambda\Lambda}$ agree with double hyperfragment data /6/ . The form of the $(\Lambda\Lambda)$ effective mass spectrum observed in this work was further confirmed in an experiment with a heavy liquid bubble chamber exposed to a K^--meson beam /7/

4. *The* (Λpp) *-System,* $Y = 2,\ B = 3,\ S = -1$

The (Λpp) effective mass spectrum for 854 events is shown in fig.5. No significant peaks are observed. An analysis has shown that the irregularities of the spectrum contain events the (Λp) combinations of which fall in the 2058 MeV, 2127 MeV, 2252 MeV peak regions of the (Λp) effective mass spectrum.

5. *The* $(K^{\circ}p)$ *- System,* $Y = 2,\ B = 1,\ S = +1$

The $(K^{\circ}p)$ effective mass spectra from $\Lambda K^{\circ}(\ell p)\ (m\pi)$ final states created in $n^{1}_{0}{}_{6}C^{12}_{6}$ and $\pi_{6}C^{12}_{6}$ interactions are shown in fig.6.

The blackened histograms contain those events the (Λp) combinations of which are in the 2058 MeV, 2127 MeV, 2252 MeV peak regions of the (Λp) spectrum situated. The difference-spectra which now are free of the influence of the (Λp) spectrum form are shown in the lower part of fig.6. The total as well as the difference- $(K^{\circ}p)$ spectra do not reveal any significant enhancement.

6. *The* (pp) *- System,* $Y = 2,\ B = 2,\ S = 0$

The effective mass spectra of this system from 6731 $n^{1}_{0}\ {}_{6}C^{12}_{6}$ and 1097 $\pi^{-}\ {}_{6}C^{12}_{6}$ interactions are shown in the upper part of fig.7. Both the spectra have similar forms and do not reveal any significant enhancement.

The (pp) effective cross-sections either elastic or total are measured rather precisely and no enhancements were observed in the region which corresponds to the maximum of the (pp) effective mass spectrum at 1901 MeV. Therefore one has to consider this maximum as a maximum of the phase space volume distribution.

Besides, the (pp) effective mass spectrum for binary combinations of 1791 four-proton events (10952 combinations), which we adopted as a suitable background (dotted-line histogram), practically coincides with the (pp) effective mass spectrum of two-proton events.

No enhancements were observed when the bin-size was decreased up to 1.0 MeV. Our (pp) effective mass resolution of $\Delta M = 2.0$ MeV could not reveal the maximum at 66 KeV which is due to the large negative (pp) scattering length at low energy. Our results suggest that if even (pp) resonances do exist their widths must be much less than 1.0 MeV and special experiments would be needed to reveal them.

7. Systems: $(3p)$, $Y = 3$, $B = 3$, $S = 0$ (4418 events);

$(4p)$, $Y = 4$, $B = 4$, $S = 0$ (1791 events);

$(5p)$, $Y = 5$, $B = 5$, $S = 0$ (508 events);

$(6p)$, $Y = 6$, $B = 6$, $S = 0$ (100 events)

Figure 7 shows the corresponding effective mass spectra except the $(6p)$-system. No enhancements were observed. This result did not change with decreasing the bin-size up to 1.0 MeV.

Discussion

The results of this investigation are listed in Table I. The systems considered in the growing hypercharge order are arranged. Those systems the effective mass spectra of which do (do not) reveal candidates for resonances by plus (minus) are marked.

It is clearly seen that the candidates for resonances were observed only for systems of hypercharges not exceeding one: $Y \lesssim 1$. The similar condition for all known meson and baryon resonances is fulfilled /8/.

One cannot exclude that this condition is a universal one for all hadronic systems. Then the hypothesis can be formulated that the inequality $Y \leq 1$ would be a necessary but not sufficient condition for the formation of hadronic resonances (if no resonances of widths $\Gamma \ll 1.0$ MeV do exist in hadronic systems of hypercharges $Y > 1$).

Let us note in conclusion that new experiments on the search for an investigation of multibaryonic resonances of hypercharges either less or more than one $Y < 1$ and $Y > 1$ would be desirable. The best suited reactions for the investigation of systems of $Y \leq 1$, in our view, would be the collisions of fast K^- -mesons with light nuclei as well as the collisions of slow and fast hyperons with protons and light nuclei.

In order to obtain reliable results especially on charged multibaryonic systems, one should, in our view, use as targets the nuclei of mass numbers not exceeding $A = 12$.

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Table 1

N°	System	B	S	Y	Candidates for resonances
1.	$(\Lambda\Lambda)$	2	−2	0	+ (> 2 st.dev.)
2.	(Λp)	2	−1	1	+ (> 4 st.dev.)
3.	(Λpp)	3	−1	2	−
4.	$(K^{\circ}p)$	1	+1	2	−
5.	$(2p)$	2	0	2	−
6.	$(3p)$	3	0	3	−
7.	$(4p)$	4	0	4	−
8.	$(5p)$	5	0	5	−
9.	$(6p)$	6	0	6	−

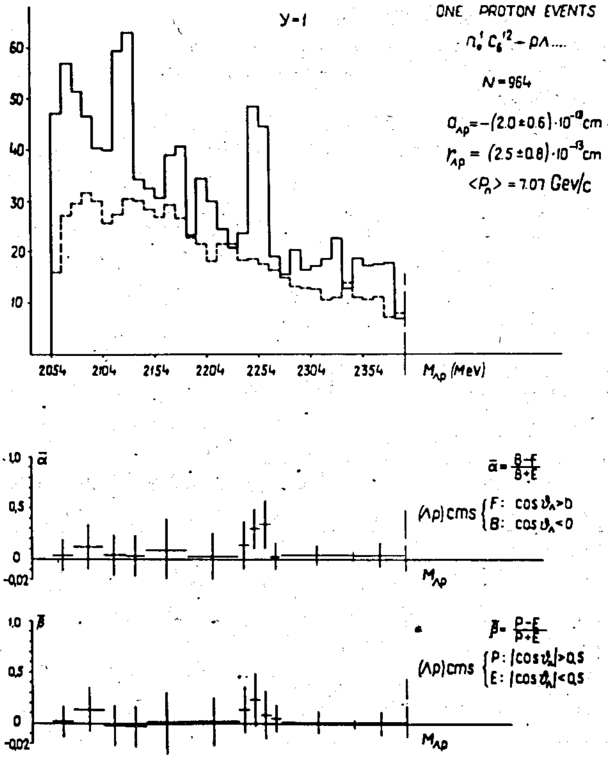

Fig.1. The (Λp) effective mass spectrum of 964 one-proton events ----- is the background calculated in impulse approximation. The asymmetry and polarization coefficients $\bar{\alpha}$ and $\bar{\beta}$ as a function of $M_{\Lambda p}$.

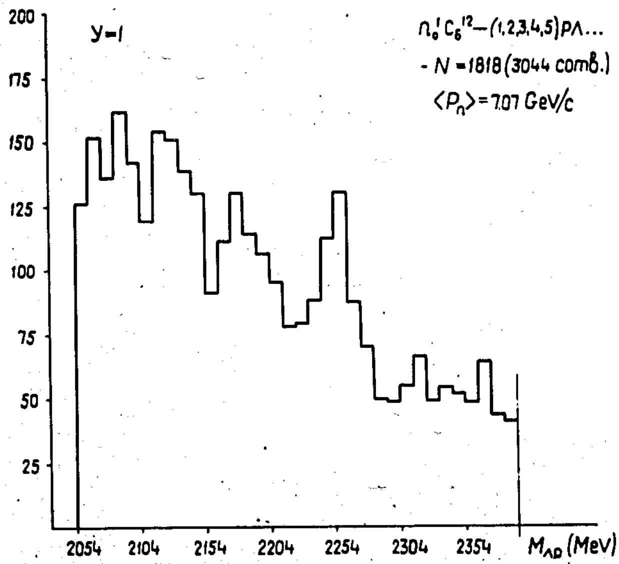

Fig.2. The (Λp) effective mass spectrum of all 1818 events with one Λ -hyperon and (1-5) protons. The neutron exposure.

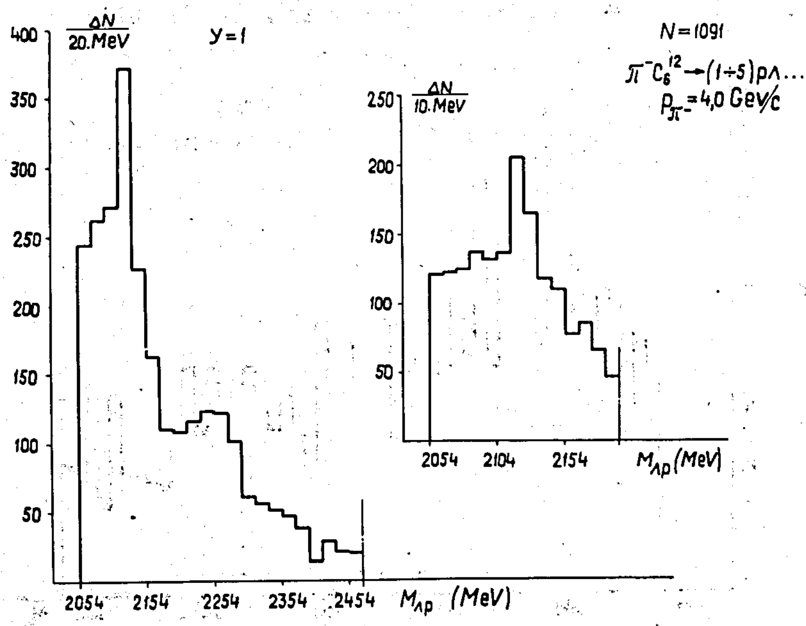

Fig.3. The $(\Lambda\ p)$ effective mass spectrum of events from the pion exposure.

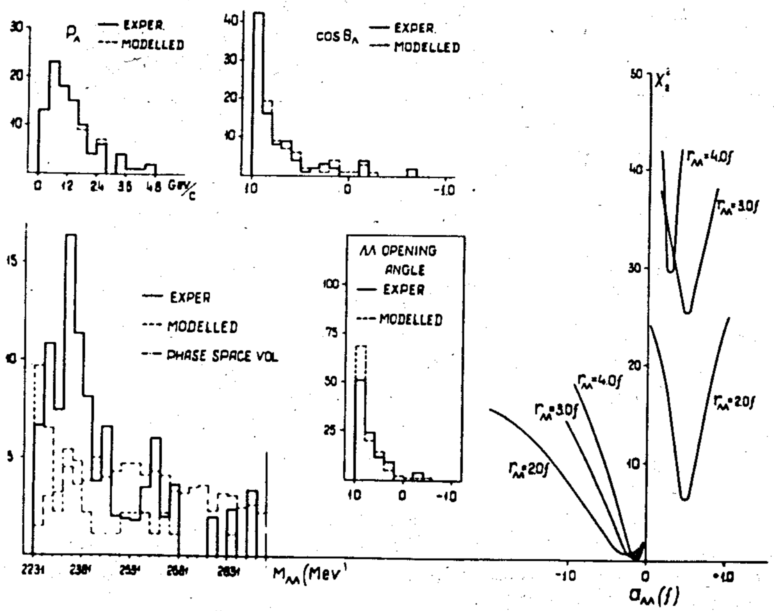

Fig.4. The $(\Lambda\Lambda)$ effective mass spectrum. ------- is the background calculated for the nuclear cascade processes resulting in $(\Lambda\Lambda)$ pair creation.

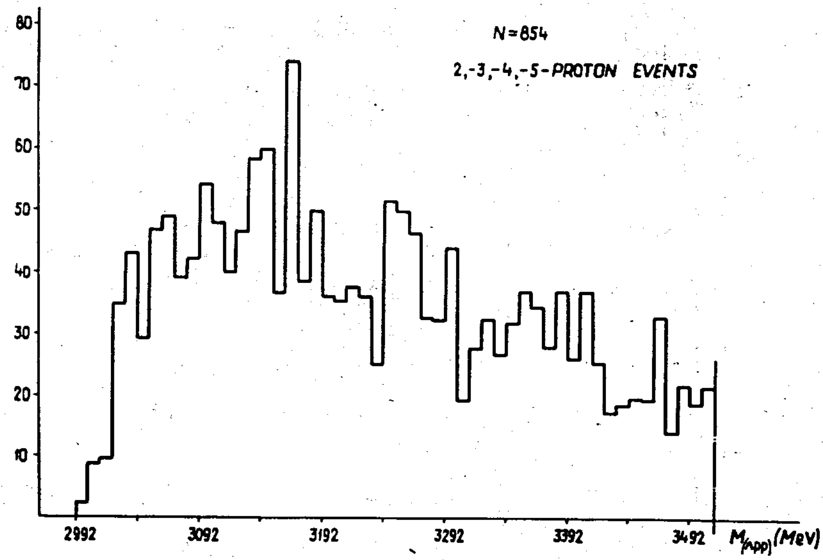

Fig.5. The (Λpp) effective mass spectrum.

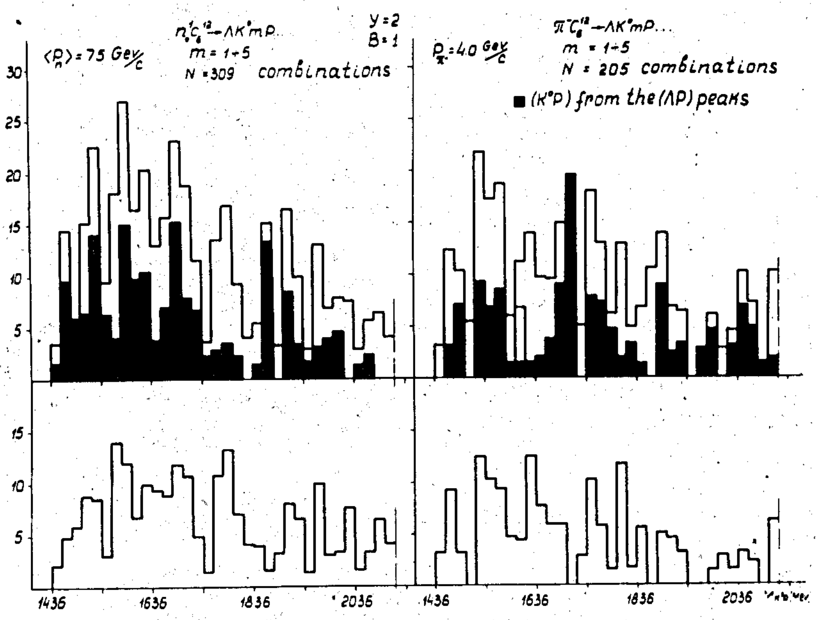

Fig.6. The $(K^0 p)$ effective mass spectra for the neutron and pion exposures. The blackened histograms contain the events, the $(\Lambda\ p)$ combinations of which fall in the 2058, 2127, 2252 MeV peak regions of the (Λp) effective mass spectra. The difference - $(K^0 p)$ spectra are shown in the lower part of the figure.

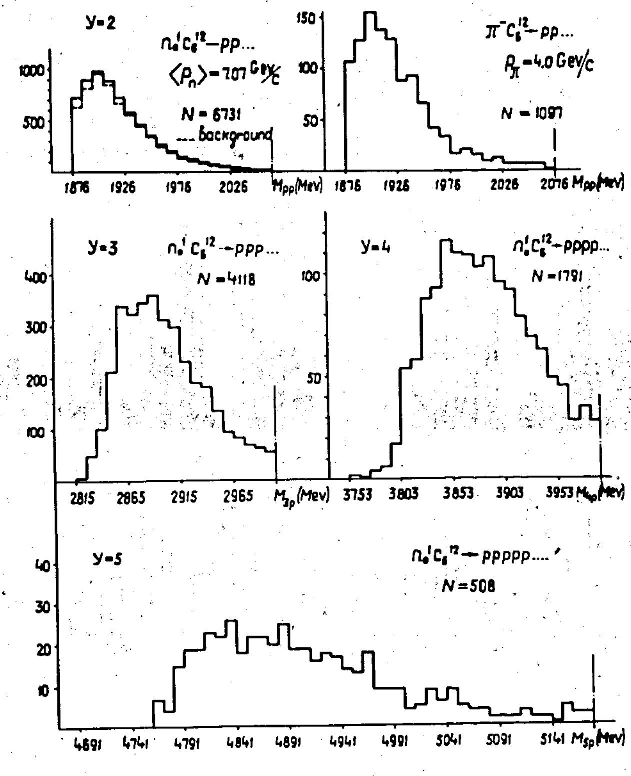

Fig.7. The *(pp)* , *(3p)* , *(4p)* , *(5p)* effective mass spectra.