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In ref.[1] we reported the preliminary results of the studies of the radiative effects in Λ^0 -hyperon production by 7 ÷ 8 GeV/c negative pions in propane. Those data were obtained from an analysis of the events in which, along with the V^0, at least one electron pair was observed from the conversion of γ -rays generated in the same interaction. The effective mass distribution, $M_{\Lambda\gamma}$, obtained in this article for the $\Lambda\gamma$ combinations (see Fig. 1) exhibits two enchancements, one of which lies in the region of 1150-1200 MeV and is due to the Σ^0, while the second being in the region of 1300-1400 MeV shows evidence for the production of the previously unknown resonance $\Lambda\eta^0$ with $M = 1680$ MeV and $T = 0$.

The present paper reports the additional results of the investigation of this phenomenon at a primary π^- momentum of 4.0 GeV/c.

We used the pictures taken in the JINR 24-liter propane bubble chamber[2] exposed to (4.00 ± 0.06) GeV/c π^- -mesons in a constant magnetic field of 14, 300 Oe. The detailed description of the channel and some information about the pion beam were given in ref.[3].

The pictures were scanned twice. We selected the interaction events in which V^0 production was accompanied by at least one electron pair from the γ -ray conversion and which satisfied the selection criteria for $\pi^- p$ interactions in propane[4]. The average efficiency of the two-stage scanning was equal to $(88 \pm 2)\%$. Simi-automatic devices of the High Energy Laboratory were employed to carry out the measurements.

All the events selected and measured were computed on the electronic computers of the JINR Computing Centre using special programmes[5]. The programmes provided for the identification of the events and calculation of various geometric and energetic characteristics of charged and neutral particles and γ -rays. In the γ -ray momentum calculations, corrections were made for the energy losses of electrons and positrons due to radiation and ionization. The average error in the γ -ray momentum measurements was 10-15% for the interval of γ-ray momenta of 0.1 ÷ 1.0 GeV/c, respectively[6]. The final identification of the events was made after obtaining the results of the measurements and computations.

Scanning devices were employed to visually establish the fact that the γ-ray was related to a given event. A better accuracy was obtained by measuring the angle θ between the direction of the γ-ray momentum and the line which connects the interaction point with the vertex of the electron pair. The γ-ray was not considered to belong to a given event if $\theta > 5^\circ$. The requirement was not imposed on the γ-rays which were less than 2 mm in length and whose electron pairs had very small momenta $P_\gamma < 50$ MeV or short tracks $\ell \leq 4$ cm. The distribution of the γ-rays over the angle is shown in Fig. 2. It is seen that the majority of the γ-rays have the angles θ not exceeding 5°. The events which occurred in the fiducial volume of the chamber were taken for further investigation. The efficiency of the detection of the γ-rays in this volume was 10%.

A total of 120 thousand pictures were studied. The preliminary results obtained from the analysis of the experimental data are presented below. The events selected contained the following types: 1) with one or two γ-rays, 2) with or without charged secondaries and 3) with one or two V^0-particles. The numbers of the events of different types are given in table 1.

Table I

n_s	0		2		4	
Particle type / Number of γ-rays	Λ	$\Lambda + K^0$	Λ	$\Lambda + K^0$	Λ	$\Lambda + K^0$
γ	40	3	65	2	4	-
2γ	3	-	4	-	-	1
Totals	43	3	69	2	4	1

For the events studied, the $M_{\Lambda\gamma}$ effective masses $\Lambda + \gamma$ of the combinations were calculated. The interval in the histogram was chosen to be 50 MeV because an average error in the effective mass determination was 30 MeV. The histogram of the effective masses, $M_{\Lambda\gamma}$ is given in Fig. 3. As in ref.[1], this histogram exhibits two peaks in the mass regions of 1150-1200 and 1300-1400 MeV.

In order to determine the background from reactions with the Σ^0's and π^0's, all events were analysed using the fitting program[7]. The results of the analysis enabled us to assign the events to one of the following reactions[x]:

$$\pi^- + p \to \Sigma^0 + K^0 + \pi^+ + \pi^- \qquad (1)$$

$$\to \Lambda + K^+ + \pi^- + \pi^0 \; . \qquad (2)$$

In addition to the fitting program, the results of ionization measurements[8] and the picture of the charged particle decays in the chamber were used to identify these reactions.

The $M_{\Lambda\gamma}$ effective mass distribution for reaction (1) has a narrow peak in the region of the Σ^0 hyperon mass of (1150-1200) MeV, while the $M_{\Lambda\gamma}$ distribution for reaction (2) is very broad (see Fig. 4a). The summarized histogram of the effective masses, $M_{\Lambda\gamma}$, for reactions (1) and (2) is fitted by a smooth curve which was considered to be the background one for the reactions with the Σ^0 and π^0 involved. The background curve is plotted on the effective mass distribution $M_{\Lambda\gamma}$ in Fig. 3. The curve was normalized to the background, that is to the number of the $\Lambda + \gamma$ combinations outside the region of (1300-1400) MeV. A comparison of the experimental histogram of the effective masses with the background curve shows that the latter describes the background well. In addition, in the region of the effective masses of (1300-1400) MeV, a peak is observed which is two intervals broad and is 2½ standard deviations above the background. According to the Kolmogorov-Smirnov criterion[9], the effective mass distribution gives a fit to the background histogram with a probability of 7.5%, while this probability for the histogram without the peak in the region of $M_{\Lambda\gamma}$ = (1300-1400) MeV is 90%. Fig. 4(b) shows the distribution of the $M_{\Lambda\gamma}$ effective masses without the events assigned to reactions (1) and (2). It is seen that the event fraction in the peak in the region of (1300-1400) MeV increases compared to the background. However, some part of the events is still left in the Σ^0 mass region and there is a small background due to the reactions with π^0 mesons. It was impossible to separate these background events by the fitting program because of the fact that, in addition to the Σ^0 and π^0 they involved at least one neutral particle which was not detected in the

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[x] In the analysis by the fitting program, no reactions of the types $\pi p \to \Sigma K \pi \, (\to \Lambda(\Sigma^0) K^0)$ were singled out.

chamber, K^0 -meson in particular. Appropriate calculations[*] made in ref.[1] indicated that the $M_{\Lambda\gamma}$ distribution for the Λ's and γ -rays emitted from the decay of π^0 mesons, which are produced by the decay of the known resonances, cannot exhibit such a peak in the region of (1300-1400) MeV. The $Y_0^*(1405)$ gives a kinematic contribution to the $M_{\Lambda\gamma}$ distribution, which is completely contained in the region of $M_{\Lambda\gamma} < 1300$ MeV. The same can be said about the Y_1^* (1385). These distributions for the Y_0^* (1520) and Y_1^* (1660) have no sharp peak in the region of $M_{\Lambda\gamma}$ = (1300-1400) MeV. The calculations show that only the distribution of the γ -rays emitted from the decay of the η^0 arising from the decay of the $\Lambda\eta^0$ with a mass of about 1680 MeV, has its kinematic peak in the region of $M_{\Lambda\gamma}$ = (1300-1400) MeV (see Fig. 5). Since there are no precise experimental data presently available on the production of the mentioned resonances in $\pi^- p$ interactions at the energies we used, it is impossible to quantitatively estimate their contribution to the $M_{\Lambda\gamma}$ distribution. However, it is known[10] that the portion of the $\pi^- p$ reactions in which these resonances are generated, does not exceed (10-12)%. Therefore their contribution to the distribution in the region of (1300-1400) MeV is very small. Similar conclusions can be made regarding the role of the resonances decaying into K and π^0 mesons. Thus, it is impossible to explain the peak in the region of (1300-1400) MeV as being due to the known resonances. One can assume the peak in the histogram at $M_{\Lambda\gamma}$ = 1300-1400 MeV to be due to the existence of the $\Lambda\eta^0$ resonance. The estimates in ref.[11] indicate that the mass of this resonance is close to the sum of the rest masses of the Λ and η^0 ($M_{\Lambda\eta} = 1680$ MeV). The laboratory momentum distributions of γ -rays of different origin favour this interpretation. Fig. 6 shows the momentum distributions for the γ -rays emitted from the decay of the π^0 mesons in reaction (2), of Σ^0 hyperons in reaction (1) and the γ -rays from the region of the second peak in the histogram. It is clearly seen that all the distributions are different and the γ -ray momentum distribution in the peak region does not contradict the expected distribution for the γ -rays from the decay of the η^0 meson.

We have made an attempt to determine the $\Lambda\eta^0$ resonance spin. For this

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[*] These calculations took account of the Π -shape of the momentum distribution of the γ -rays emitted from the decay of π^0 or η^0 mesons, in a certain counting system with momentum within the limits of

$$(P_\gamma)^{max.}_{min.} = \frac{1}{2}\left(\frac{E}{c} + P\right)$$

and the centre at $(P_\gamma) = \frac{1}{2}\frac{E}{c}$, where E and P are the energy and momentum of π^0 or η^0 mesons in this counting system respectively. The distribution over $M^2_{\Lambda\gamma}$ at a fixed energy of π^0 or η^0 mesons in the Λ hyperon rest system has the following form $M^2_{\Lambda\gamma} = M^2_{\Lambda} + 2M_{\Lambda}P_{\gamma}/c$.

purpose, it is necessary to separate the background from the peak in the region of $M_{\Lambda\gamma}$ = 1300–1400 MeV. On the basis of the kinematics of $\Lambda\eta^0$ production in the two-body reaction of the type

$$\pi^- + p \to (\Lambda\eta^0) + K \tag{3}$$

the momentum in the reaction c.m.s. did not exceed $(P^*_\Lambda)_{max}$. The upper $(P^*_\Lambda)_{min}$ and lower $(P^*_\Lambda)_{min}$ limits of the Λ momentum in this reaction are given by the following expression

$$(P^*_\Lambda)^{max}_{min} = (\beta\gamma)^*_{\Lambda\eta^0}\, E^{**}_\Lambda \pm \gamma^*_{\Lambda\eta}\, P^{**} ,$$

where $\gamma^*_{\Lambda\eta}$ is a Lorentz factor of the $\Lambda\eta^0$ in the reaction c.m.s., and E^{**} and P^{**} are the energy and momentum of the Λ in the $\Lambda\eta^0$ rest system, respectively. $\gamma^*_{\Lambda\eta}$ will have its maximum value in the reaction with $m = m_{K^0}$ = 498 MeV, $(P^*_\Lambda)_{min}$ = 730 MeV, and $(P^*_\Lambda)_{min}$ = 470 MeV. For another possible channel of the reaction, in which both the $\Lambda\eta^0$ and $K^*(890)$ are produced, $m = m_{K^*}$ = 890 MeV, $(P^*_\Lambda)_{max}$ = 580 MeV, and $(P^*_\Lambda)_{min}$ = 330 MeV. The momentum distribution of the Λ's from the peak at $M_{\Lambda\gamma}$ = 1300–1400 MeV in the c.m.s. is shown in Fig. 7. With the account of the error in the momentum determination of ± 10%, we take $(P^*_\Lambda)_{max}$ to be equal to 800 MeV. The Λ's with momentum of $P^*_\Lambda > 800$ MeV are considered to be background ones.

Because of a small binding energy of the $\Lambda\eta^0$ resonance (≈20 MeV), it is natural to expect its spin to have a small value, say 1/2 or 3/2. Then the angular distribution of the Λ's in the $\Lambda\eta^0$ rest system should be either isotropic or of the form $a + b\cos^2\theta$, respectively. By converting it into the $\Lambda\gamma$ rest system (since we detect usually only one γ-ray from the decay of the η^0), we obtain the distribution presented in Fig. 8 (the smooth curves). The same figure shows the experimental histogram for the Λ's from the peak at (1300–1400) MeV of Λ momentum of $P^*_\Lambda < (P^*_\Lambda)_{max}$ = 800 MeV, which is in good agreement with the theoretical curve for the $\Lambda\eta^0$ resonance spin 1/2. According to the Kolmogorov-Smirnov criterion, the experimental histogram shows a fit to the theoretical curve with a probability of 81%. Note that the distribution corresponding to the spin 3/2 $(0.5 + 1.5\cos^2\theta)$ gives a fit to the experimental angular distribution converted into the $\Lambda\gamma$ rest system with a probability of 15%.

Thus, the results of this paper confirm the conclusions made in ref./1/ about the existence of the $\Lambda\eta^0$ resonance with $T = 0$ and $J = ½$.

The Brookhaven group/12/ has proved the existence of the $\Lambda\eta^0$ resonance by another method consisting in an analysis of the shape of the η^0 production cross section for the reaction $K^- p \to \Lambda\eta^0$ near threshold. The authors have come to the conclusion that this reaction cross section is best of all explained by the existence of the $\Lambda\eta^0$ resonance rather than $S_{1/2}$ or $P_{1/2}$ scattering[x]. They have found the mass of this resonance to be equal to 1675 MeV, the width being $\Gamma = 15$ MeV and spin $J = 1/2$.

Experiments reported during the last time/14/ give evidence for the presence of anomalies in the cross sections for the reactions $\pi N \to N\eta^0$ and $K^- d \to \Sigma^- \eta^0 p$ with η^0 meson generation near threshold. An analysis of the dependence of the η^0 production cross section for these reactions upon the momentum of an incident particle leads to the conclusion about the existence of near - threshold resonances between the final reaction products. The existence of the new resonances in the baryon - η^0 system made it possible for the authors of/15/ to postulate the existence of the η - baryon octet with $J = 1/2$ whose members should correspond to the octet mass formula.

$$\frac{1}{2}(\tilde{N} + \tilde{\Xi}) = \frac{1}{4}(3\tilde{\Lambda} + \tilde{\Sigma}),$$

where $\tilde{B} = B\eta$ and $B = (N, \Lambda, \Sigma, \Xi)$.

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[x] A similar conclusion is drawn in ref./13/.

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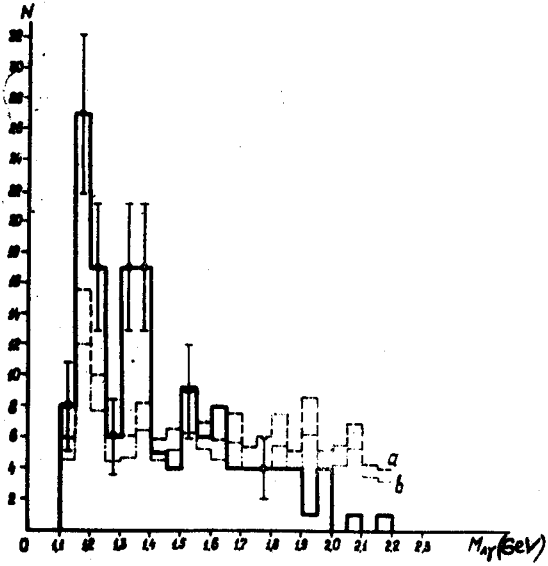

Fig. 1. The spectrum of the effective masses $M_{\Lambda\gamma}$ obtained from the experiment at (7 - 8) GeV/c.

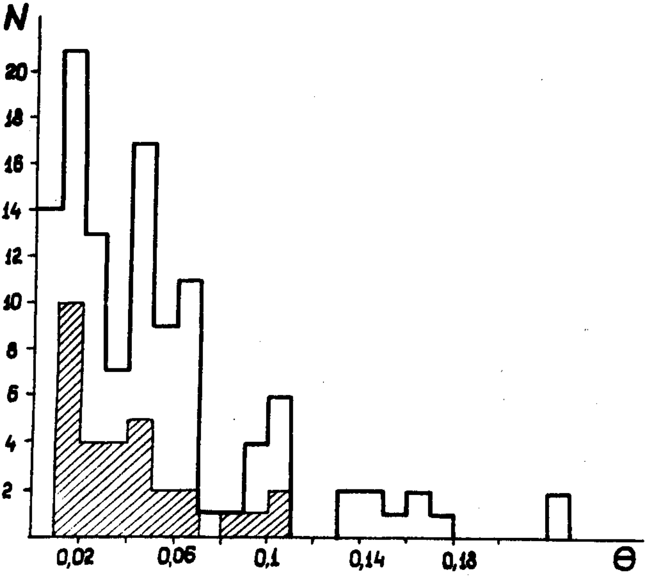

Fig. 2. The distribution of the γ-rays over the angle θ. The shaded region corresponds to γ-rays from the peak at $1300 \leq M_{\Lambda\gamma} \leq 1400$ MeV.

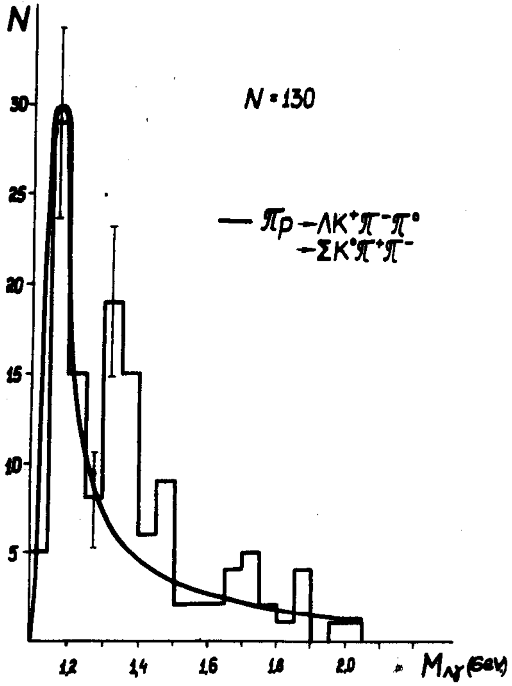

Fig. 3. The $M_{\Lambda\gamma}$ effective mass distribution in the present experiment. The solid curve is a background one.

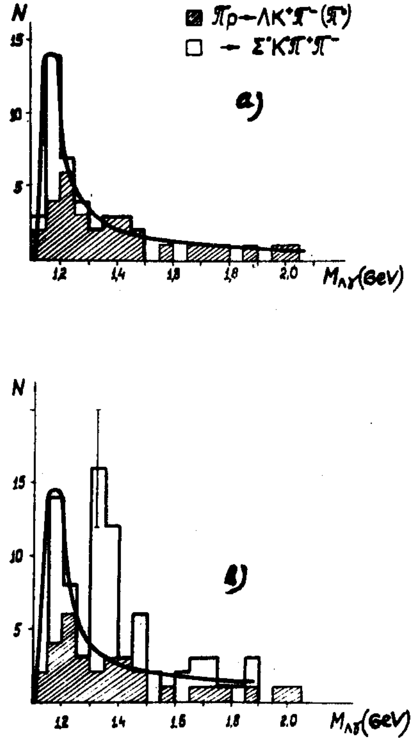

Fig. 4. a) The $M_{\Lambda\gamma}$ effective mass histogram for the events from the reactions $\pi^- + p \to \Sigma^0 + K^0 + \pi^+ + \pi^-$ (1) and $\pi^- p \to \Lambda + K^+ + \pi^- + \pi^0$ (2). b) The $M_{\Lambda\gamma}$ effective mass histogram with subtraction of the events attributed to reactions (1) and (2). The solid curve is normalized to the background.

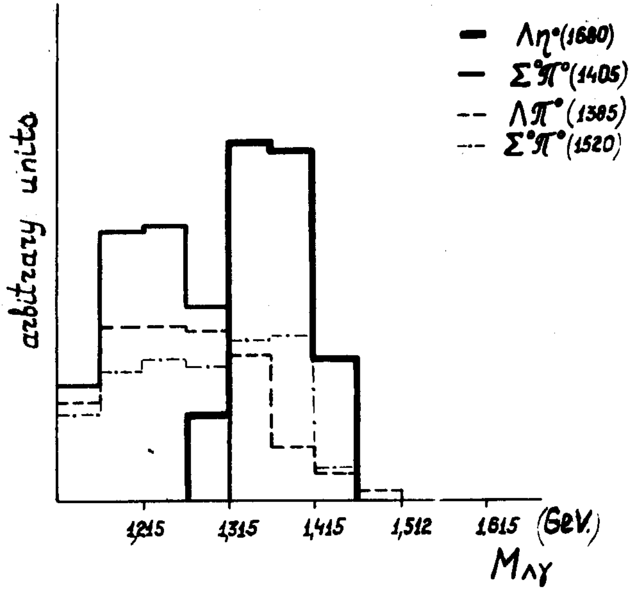

Fig. 5. The theoretical distribution on the effective masses $M_{\Lambda\gamma}$ for some of the known resonances.

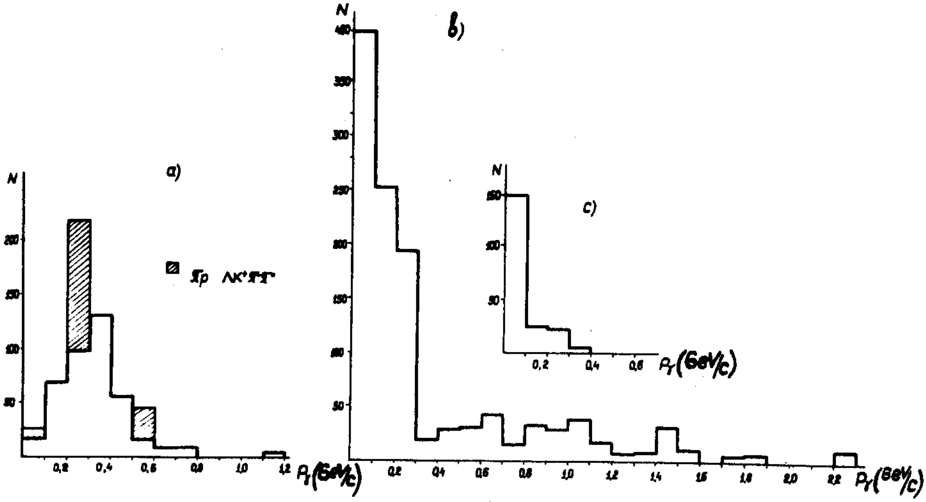

Fig. 6. The lab.momentum distribution of the γ -rays a) from the peak at $M_{\lambda\gamma}$ = 1300–1400 MeV, b) from the π^0 mesons, c) from the Σ^0 hyperons.

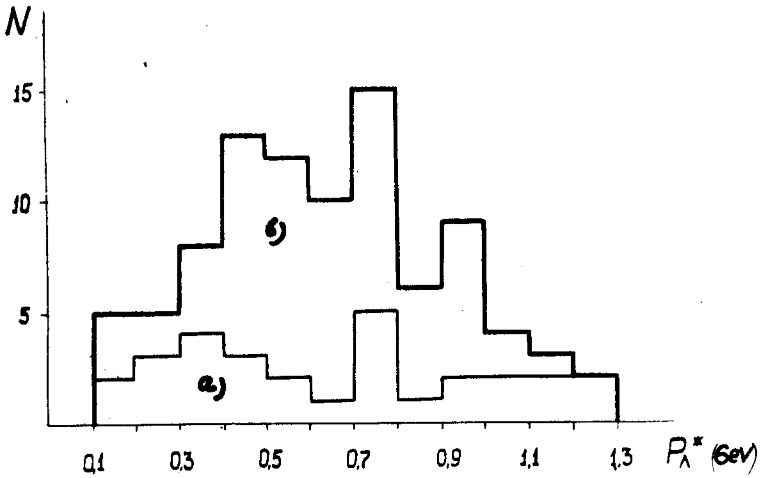

Fig. 7. The c.m.s. momentum distribution of Λ hyperons a) from the peak at 1300 < $M_{\Lambda\gamma} \leq$ 1400 MeV, b) for all the Λ particles.

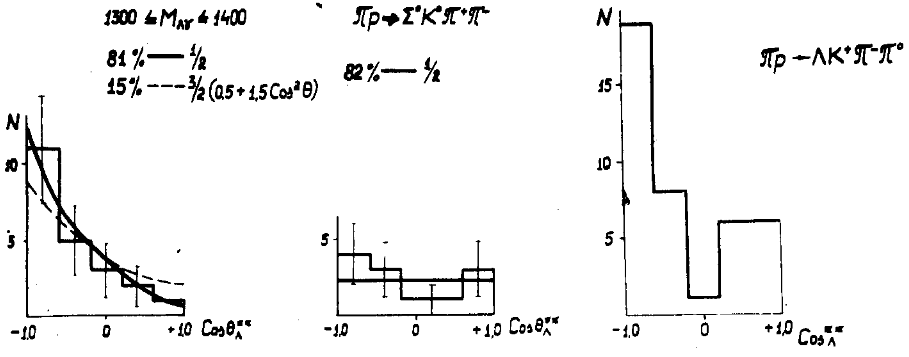

Fig. 8. The angular distribution of Λ hyperons in the Λγ rest system a) from the peak at $M_{\Lambda\gamma}$ = 1300-1400 MeV, b) from Σ^0 hyperons and c) from the reaction $\pi^- p \to \Lambda K \pi\pi$.