INSTITUTE OF THEORETICAL
AND EXPERIMENTAL PHYSICS

ITEP - 110

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УДК 539.172.5 М-16

Abstract

~~We have investigated~~ $\Lambda\bar{\Lambda}$ system, produced in the $\pi^- p$ interaction at incident pion momentum 40 GeV/c. The bump with $M(\Lambda\bar{\Lambda}) = 3430$ MeV/c^2, $\Gamma \simeq 40$ MeV/c^2, is observed in the mass spectrum of $\Lambda\bar{\Lambda}$ system. The angular distribution of $\Lambda\bar{\Lambda}$ in this region does not contradict $J^{PC} = 2^{--}$. The spin state and spherical harmonic momenta analysis in mass range 2.23 ÷ 3.0 GeV/c^2 gives strong indications on the existence three ~~more~~ states with the masses of 2400 ± 40 MeV/c^2, 2510 ± 25 MeV/c^2, 2820 ± 40 MeV/c^2 and the widths of 65 ± 50 MeV/c, 124 ± 53 MeV/c^2, 132 ± 80 MeV/c^2. The prefered quantum numbers of these states (J^{PC}) are 3^{+-}, 2^{++} and 4^{++}, respectively.

We have already published [1,2] the preliminary results of investigation of the reaction

$$\pi^- p \rightarrow \Lambda \bar{\Lambda} n \qquad (1)$$

which has been performed by means of 6-m ITEP spectrometer [3] (established at Serpukhov IHEP PS). We have advanced this investigation with the same beam momentum 40 GeV/c. In last runs we used H_2 and polyethelene target, which was placed somewhat nearer to the spectrometer in order to increase the detection efficiency for large masses, $M > 3$ GeV/c^2. Besides, the coincidence between beam telescope and large area scintillation counter placed downstream the spectrometer was introduced in trigger.

Fig. 1 presents the missing mass squared (M^2_X) distribution of observed events. We select the reaction (1) by the condition $-0.2 < M^2 < 2{,}0$ $(GeV/c)^2$. We have already paid attention [1,2] to the existence of isolated group of events in mass interval 3.3 - 3.5 GeV/c^2. Our new data prove the existence of resonance in this mass region. There is signal constituted of 14 events on the effective mass spectrum of the $\Lambda\bar{\Lambda}$ -system (fig.2). The background, determined by the power function approximation of the neighbouring bins, amounts 3 events. The probability of observation these 14 events is therefore $P < 10^{-5}$, which corresponds to more than 5 standard deviations. Mass of this resonance is 3430 ± 20 MeV/c^2, width (uncorrected by experimental resolution) is

< 65 MeV/c^2. Main features of these 14 events are presented in Table 1. To extract quantum numbers of this resonance, we analysed Θ_{G-J} and φ_{T-Y} distributions, and angular correlations between directions of P from Λ decay and $\bar{p}$ from $\bar{\Lambda}$ decay (these directions are taken in Λ and $\bar{\Lambda}$ rest frames respectively). The computed distribution is $(1 + \beta \cos \Theta_{pp})$, with $\beta = \alpha^2$ for S = 0, $\beta =$ $= - \alpha^2/3$ for S = 1, where $\alpha = 0.647$ is the Λ decay asymmetry parameter. Mean values $\overline{\cos \Theta_{p\bar{p}}}$ are + 0.140 and -0.047 respectively. For events in the 3.43 GeV/c^2 region $\overline{\cos \Theta_{p\bar{p}}} = -0.18 \pm 0.15$, which agrees with spin value S = 1.

Fig. 3 illustrates the cos Θ_{G-J} distribution. Best of all it agrees with assumption $J^{PC} = 2^{--}$ (L = 2), e.q. $I(\Theta) = 2\pi \, |Y_2^1|^2$. Fig. 4 presents the t distribution for this resonance. It corresponds to the natural spin-parity exchange ruther well. We have estimated the production cross-section for $\Lambda\bar{\Lambda}$ (3430) to be (6 ± 3) nb for runs with liquid hydrogen target only.

Let us now turn to the analysis of angular distributions in mass interval $2.22 < M_{\Lambda\bar{\Lambda}} < 3.02$ GeV/c^2. There are serious reasons to suppose, that production of $\Lambda\bar{\Lambda}$ system goes predominantely through the one-pion exchange; in the paper /4/ which deals with the analogous reaction $\pi^- p \to p\bar{p}n$ convincing arguments in favour of such dominance were presented. In this case $(\pi^+ \pi^- \to \Lambda\bar{\Lambda})$ the parity conservation demands S=1, J = L ± 1, and as the system of two identical bosons can exist in even orbital states only, so the following quantum states are possible:

$$J^{PC} = 0^{++}\ ,\ 2^{++}\ ,\ 4^{++} \qquad \text{and so on.} \qquad (2)$$

To make the analysis of angular distributions in mass interval $2.22 < M_{\Lambda\bar{\Lambda}} < 3.02$ GeV/c^2 we have refused from M^2_X cut, so our statistics increased approximately by 40% without changing our distributions visibly. On fig. 5 the distribution of all events via $\Lambda\bar{\Lambda}$ transverse momentum squared is shown. This quantity is approximately equal to $-(t-t_{min})$, because the overwhelming majority of events has total $\Lambda\bar{\Lambda}$ -momentum near to incident beam momentum. In the region below 0.4 $(GeV/c)^2$ the data are fitted well to the exponential curve with the slope $b = -7.9\ (GeV/c)^2$, which agrees well with the value -6.7 for the reaction $\pi^- p \to p\bar{p}n$ /4/ . The following analysis is restricted by the condition $P_\perp^2 < 0.4\ (GeV/c)^2$. Fig. 6 illustrates the approximate isotropy of the Treiman-Yang angle distribution. On the same figure the distribution on correlation angle between directions of p from Λ decay and $\bar{p}$ from $\bar{\Lambda}$ decay is shown. One may see, that this distribution agrees well with the assumption that $S = 1$; the mean value $\overline{\cos\theta_{p\bar{p}}} = -0.052 \pm 0.029$ is close to -0.047 for $S=1$. This testifies to the one-pion exchange dominance in the region $P_\perp^2 < 0.4\ (GeV/c)^2$.

Now, the mass scale of the $\Lambda\bar{\Lambda}$ system from threshold 2.22 GeV/c^2 to 3.02 GeV/c^2 was divided into 80 MeV/c^2 bins, and unnormalized moments were computed for each bin

$$N < Y_\ell^m > = \sum_i \frac{Re[Y_\ell^m(\theta_i, \varphi_i)]}{\varepsilon[\theta_i, \varphi_i M_{\Lambda\bar{\Lambda}i}]} . \qquad (3)$$

Here i - the event number, θ_i, φ_i - polar and azimuthal angles in Gottfried-Jackson frame ($\Lambda\bar{\Lambda}$ c.m. frame, Z direction is parallel to incident beam, and Y direction is perpendicular to production plane, as usual), and ε is the spectrometer efficiency, computed by Monte-Carlo technique. On fig. 7 the momenta with $l \leq 6$ and $m \leq 2$ are shown. The momenta with $m=2$ are compatible with zero within error limits, which presents additional argument in favour of one-pion exchange. In the behaviour of moment $N< Y_2^0 >$ the structure is clearly seen: two bumps, the first one (with minor mass) being near in position with the maximum in the mass spectrum, and the other one corresponding to the shoulder in the mass spectrum. In the left bump region the moments $N< Y_4^0 >$ and $N< Y_6^0 >$ are equal to zero, so that here we have the orbital state $L=1$. Probable J values are hence 0 or 2, but $J=0$ leads to $N < Y_2^0 > = 0$, so we atribute to this state $J^{PC} = 2^{++}$. In the right bump region $N < Y_4^0 >$ and $N < Y_6^0 >$ show visible deviations from zero: the higher moments are equal to zero within error limits. This implies the existence of the $L=3$ state in the right bump. From two possible J values: 2 and 4 it is to be chosen the last one, because in the case $J=2$ the moment $N < Y_6^0 >$ would be equal to zero. So we attribute $J^{PC} = 4^{++}$ to this state. The computed relations between

$\langle Y_0^0\rangle : \langle Y_2^0\rangle : \langle Y_4^0\rangle : \langle Y_6^0\rangle$ for 4^{++} are 1: 0.53 : : 0.35 : 0.21, which agrees well with the experimental ones: 1.00 ± 0.15: 0.76 ± 0.22 : 0.55 ± 0.23 : 0.35 ± 0.23.

The shape of N is well fitted to the uncoherent sum of two Breit-Wigner curves with masses 2510 ± 25 MeV/c^2, 2820 ± 40 MeV/c^2 and widths 132 ± 80 MeV/c^2, 124 ± 53 MeV/c^2 (corrected for experimental resolution). On fig. 8 the folded angular distributions are presented, together with computed curves for 2^{++} and 4^{++}, using the formula

$$I(\theta) = 2\pi \sum_{\mu=-1}^{1} \left| C^{J0}_{s\mu\, \ell-\mu}\, Y_\ell^{-\mu} \right|^2.$$

(the one-pion exchange gives M=0 for projections of J on Z direction). The above curves are normalized on total area under the hystogram; quite satisfactory agreement may be seen.

For proving of resonance nature of observed structures, one should assure that the phase goes through $\pi/2$ at the point of maximum, but our statistics doesn't allow us to do such analysis.

As concernes to the region $p_\perp^2 > 0.4$ (GeV/c)^2, here we have only 68 events, but it may be seen (fig.9), that the structure in the N $\langle Y_2^0\rangle$ is completely absent, but the bump in mass spectrum corresponds to the enhancement in the N $\langle Y_6^0\rangle$, that indicates on the existence of L=3 state. In this region $\overline{\cos\theta_{p\bar{p}}}$ = + 0.074 ± 0.066, that is close to the computed value +0.140 for S=0. If it's so, then it follows directly: $J^{PC} = 3^{+-}$. The mass of this structure is 2400 ± ± 40 MeV/c^2, width is 65 ± 50 MeV/c^2.

This mass value is close to the half-established resonance $N\bar{N}_{I=0}$ (2375) /5/ . Recent work /6/ presents evidence of a resonance in channel $p\bar{p} \to \pi^+\pi^-$ with $I^G = 0^+$, $J^{PC} = 4^{++}$, with mass 2310 MeV/c^2 and width 210 MeV/c^2. This latter estimation of quantum numbers does not coincide with our one.

As concernes to our structures in the region $P_\perp^2 < 0.4$ $(GeV/c)^2$: $\Lambda\bar{\Lambda}$ (2510) and $\Lambda\bar{\Lambda}$ (2820), there was published some evidence of resonances in annihilation channel $p\bar{p} \to \pi^+\pi^-$ /7/ with mass 2480 MeV/c^2 and width 264 MeV/c^2 (J = 5), and in reaction $\pi^- p \to p\bar{p}n$ /4/ , that we have already cited, with masses 2460 and 2550 MeV/c^2 and widths 390 and 480 MeV/c^2 (J=4 and 5 respectively).

To conclude, we present the summary of observed structures in the Table 2.

Acknowledgements

We wish to thank professor I.S.Shapiro, L.N.Bogdanova and B.O.Kerbikov for fruitful discussion, and V.E.Tarasov and T.K.Stadnikova for their help during this work.

T a b l e 1

$M_{\Lambda\bar{\Lambda}}$ MeV	P_{Λ} GeV	$P_{\bar{\Lambda}}$ GeV	$\cos\theta_{G-J}$	$\cos\theta_{p\bar{p}}$	t $(GeV/c)^2$
3371	30.32	9.27	0.772	-0.374	-0.191
3374	27.93	11.10	0.567	-0.511	-0.171
3381	28.80	[illegible].28	0.524	-0.964	-0.026
3398	9.09	29.93	-0.677	0.584	-0.121
3402	5.87	33.99	-0.942	-0.855	-0.131
3404	7.12	32.64	-0.939	0.778	-0.168
3416	6.72	34.00	-0.840	-0.701	-0.152
3420	32.44	7.25	0.967	-0.278	-0.351
3433	28.38	13.43	0.826	-0.931	-0.645
3443	23.27	16.77	0.273	0.515	-0.200
3456	32.17	7.62	0.797	-0.031	-0.082
3465	30.99	8.06	0.626	0.998	-1.248
3496	33.56	4.62	0.672	-0.879	-1.789
3498	8.10	33.44	-0.798	0.100	-0.125

Here $M_{\Lambda\bar{\Lambda}}$ - effective mass of $\Lambda\bar{\Lambda}$ -system, P_{Λ} and $P_{\bar{\Lambda}}$ - Λ and $\bar{\Lambda}$ momenta in the lab frame, θ_{G-J} - Gottfried-Jackson angle in $\Lambda\bar{\Lambda}$ c.m. frame, $\theta_{p\bar{p}}$ - angle between p and $\bar{p}$ directions in Λ and $\bar{\Lambda}$ c.m. frame respectively, t - momentum transfer from incident π^- to $\Lambda\bar{\Lambda}$ -system.

Table II Summary of results

Structure	M MeV	Γ MeV	S	L	J^{PC}	Exchange	σ nb
$\Lambda\bar{\Lambda}$ (2400)	2400 ± 40	65 ± 50	0	3	3^{+-}	natural	2 ± 1
$\Lambda\bar{\Lambda}$ (2510)	2510 ± 25	124 ± 53	1	1	2^{++}	π	13 ± 4
$\Lambda\bar{\Lambda}$ (2820)	2820 ± 40	132 ± 80	1	3	4^{++}	π	6 ± 3
$\Lambda\bar{\Lambda}$ (3430)	3430 ± 20	$\leqslant$ 65	1	(2)	(2^{--})	natural	6 ± 3

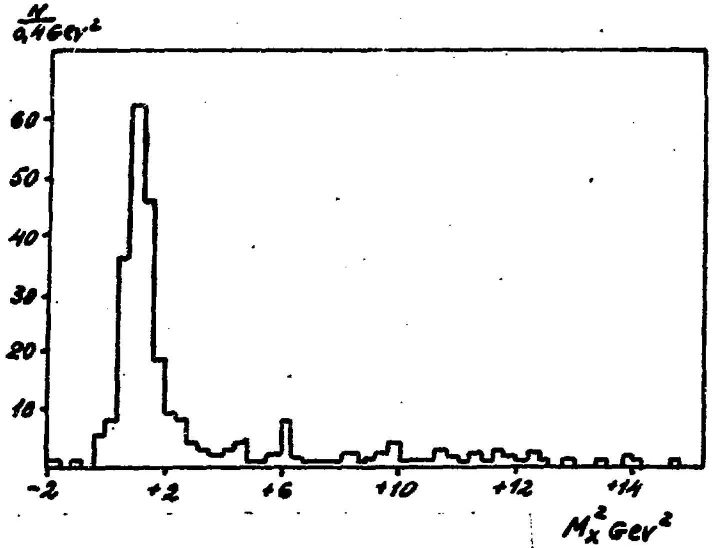

Fig. 1. Missing mass squared distribution of events to $\Lambda\bar{\Lambda}$.

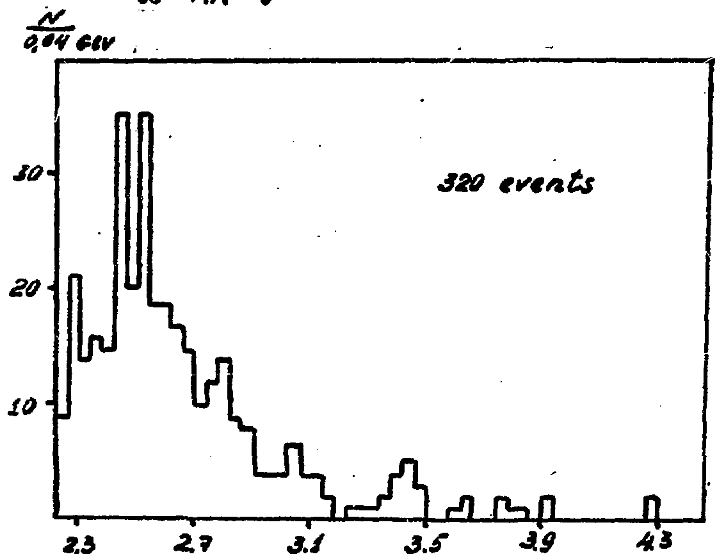

Fig. 2. Effective mass distribution for the $\Lambda\bar{\Lambda}$ system

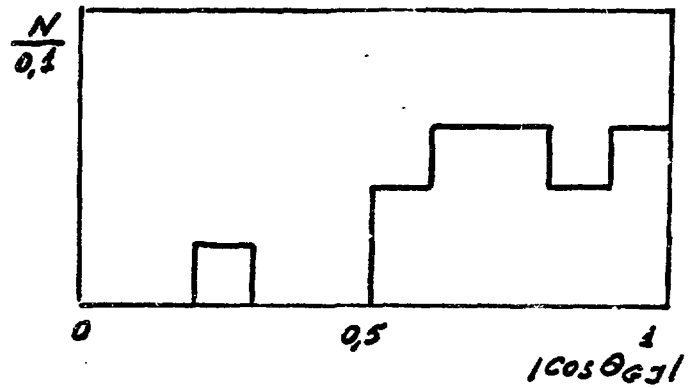

Fig. 3. Gottfried-Jackson angle distribution for the region near 3.43 GeV

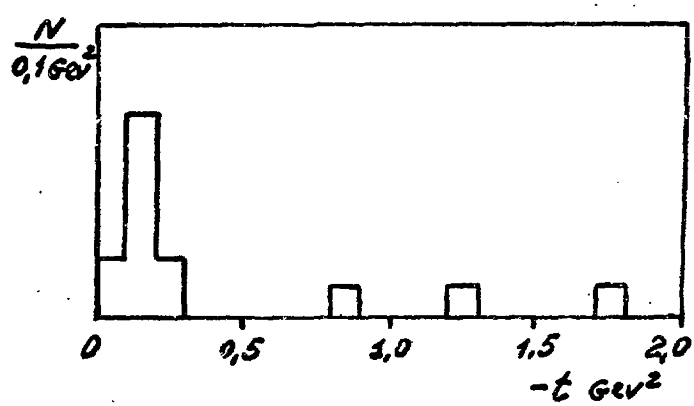

Fig. 4. t distribution for the region near 3.43 GeV

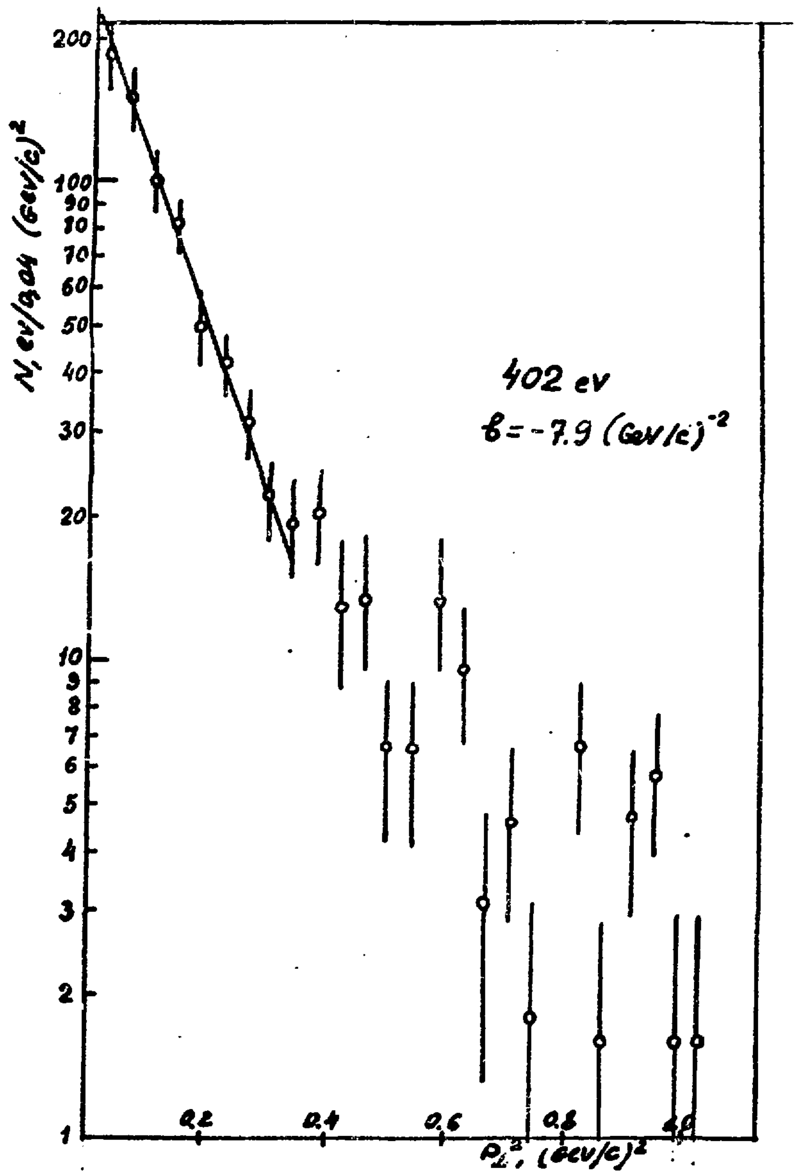

Fig. 5. $P_\perp^2$ distribution

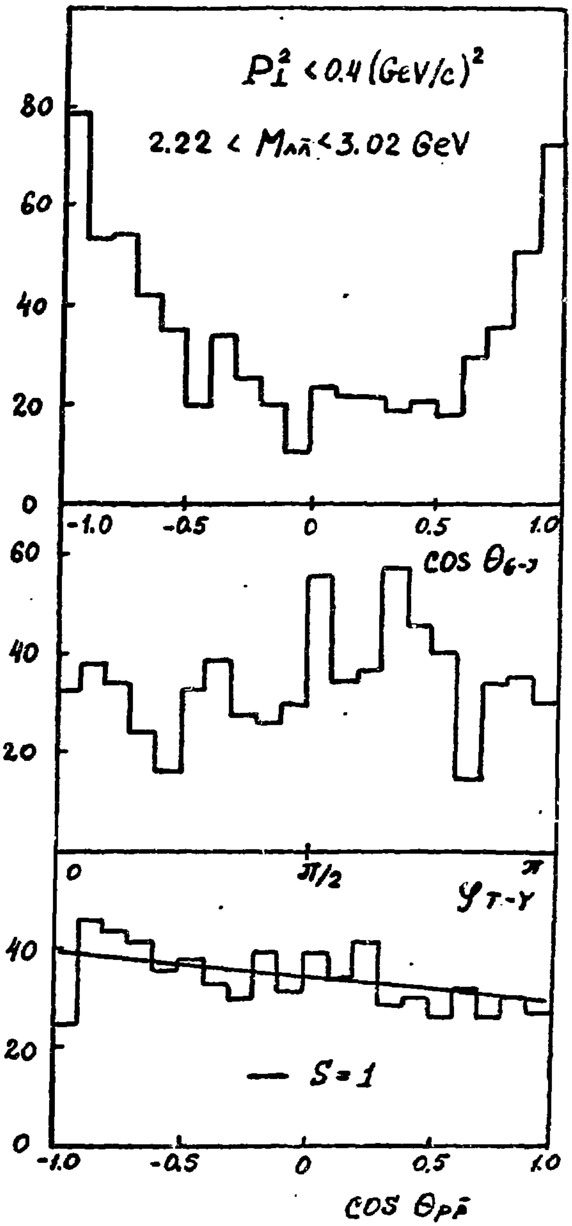

Fig. 6. Angular distributions for $P_\perp^2 < 0.4\ (GeV/c)^2$

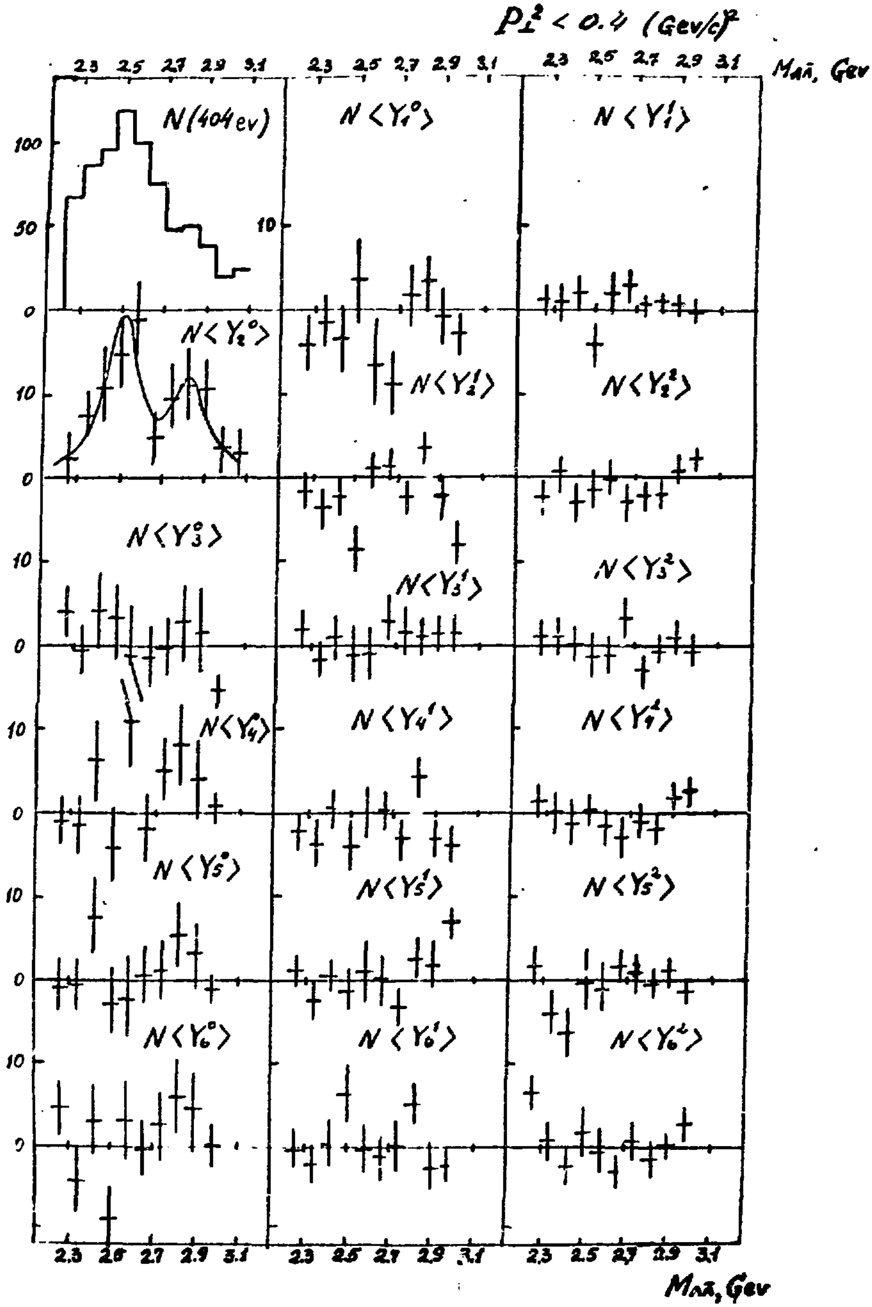

Fig. 7. Unnormalized momenta for $P_\perp^2 < 0.4\ (GeV/c)^2$

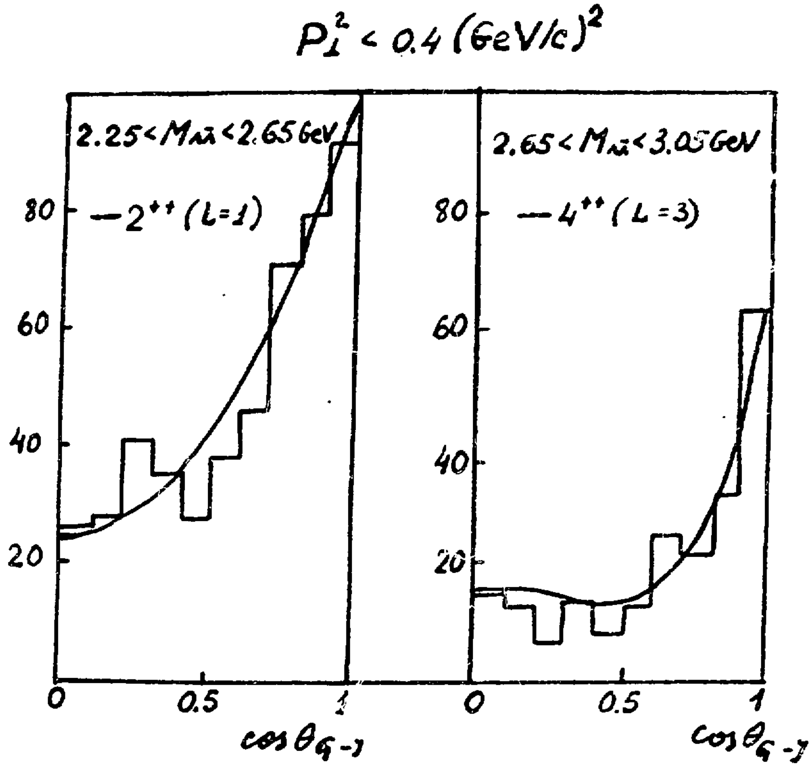

Fig. 8. Angular distributions for structure $\Lambda\bar{\Lambda}$ (2510) and $\Lambda\bar{\Lambda}$ (2820)

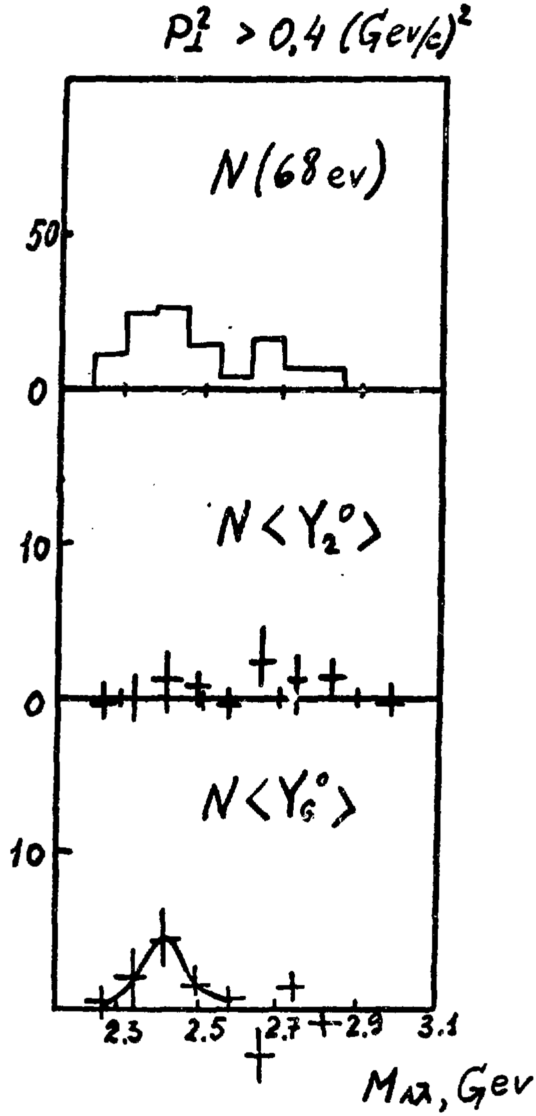

Fig. 9. Unnormalized moments for $P_{\perp}^{2} > 0.4\ (GeV/c)^{2}$.

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О наблюдении новых состояний $\Lambda\bar{\Lambda}$.

Работа поступила в ОНТИ 8/VIII-1977г.

Подписано к печати 6/IX-77г. Т-16619. Формат 70х108 1/16.
Печ.л.1,25.Тираж 290 экз.Заказ 110.Цена 7 коп.Индекс 3624.

Отдел научно-технической информации ИТЭФ, 117259, Москва

Индекс 3624