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STUDY OF NEUTRAL BOSONS DECAYING INTO π^0 MESONS AND γ QUANTA

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STUDY OF NEUTRAL BOSONS DECAYING INTO π^0 MESONS AND γ QUANTA

The present work has been carried out jointly by the scientific workers of the following Institutes:

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I. Introduction

In film obtained in an exposure of the JINR 23-inches xenon bubble chamber to a 2.34 BeV/c π^+ beam, we have searched for production and decays of neutral bosons decaying into π^0 -mesons and γ -quanta.

There are many physical topics concerning such decays of bosons. These are connected, for example, with the problems of the existence of new neutral mesons /1,2/, with the examination of the consequences of SU_6 theory /3/, and with the verification of the possible C, T noninvariance in the electromagnetic interactions of strongly interacting particles /4-6/. It is important also to obtain the complete set of informations concerning the neutral decays of η^0 , ω^0 and χ^0 .

We present in this paper the preliminary experimental results which can be attributed to some of the above mentioned problems. Our results are based on a very small part of photographs available disigned for this investigation. The experimental data were analysed and discussed.

II. Experimental Procedure

The scanning for interactions of beam particles occuring in a chosen central region of the bubble chamber has been made twice in succession. The interactions with 1 and 2 prongs and with some number $k = 0,1,2, \ldots$ of γ -rays ascribed to these interactions are searched.

The lower limit of energy for γ -rays detectable in the chamber with nearly constant efficiency was about 15 MeV. The recording probability of γ-rays generated in the chosen central region of the chamber and recorded within the fiducial volume equals 80–95%[x]. The energy E_γ of γ rays was estimated according to the method worked out[8–11]. The accuracy of energy measurement in the energy interval 10–9000 MeV is 12–30%. The accuracy of the measurement of the angle $\Theta_{\gamma\gamma}$ between any two γ rays is equal to 0.5–2 degrees.

Thus, it is possible to estimate the invariant mass $M_{k\gamma}$ combining some number k of γ. It was found that k can be equal up to 8 and it is still possible to distinguish single γ and to evaluate E_γ. The γ quanta used for the evaluation of $M_{k\gamma}$ are observed as generated in the point of interaction of incident π^+. Thus, the mass $M_{k\gamma}$ can be expressed by the formula

$$M^2_{k\gamma} = \sum_{\substack{i,j=1 \\ i\neq j}}^{n} M^2_{\gamma_i \gamma_j} \qquad (1)$$

irrespectively whether the γ are generated independently by the radiative decay of some particle X or by decays of X via, for example, π^0 or $\eta \to 2\gamma$. The accuracy in $M_{k\gamma}$ determination depends on the accuracy of the $\theta_{\gamma\gamma}$ and E_γ estimation, and is different for different values of k. For events with $k = 2$ this accuracy reaches in average 10–12%, for events with $k = 3$ about 9–10%, and for events with $k = 4$ about 8–10%.

The minimum energy value for detectable protons in stars with a small number of prongs (less than 4) is about 5 MeV. There exist the indications that in the high-energy interactions with a small number of prongs the pion-nucleon interactions of π with the quasi-free nucleons in the nuclei play a predominant role[12–13].

Confining oneself to the investigation only the interactions with one observed secondary track stopping in the chamber, we can assume the selected interactions to be in general the process

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[x] This probability depends on both the energy of γ and on the geometrical factors[7].

$$\pi^{+} + n \to \underset{\hookrightarrow k\gamma}{X} + p, \qquad (2)$$

n being quasi-free neutron in the periphery of the xenon nucleus[x/]. The energy of the secondary charged particle, assumed as the proton, can be estimated by means of the range-energy relation. It is possible to select in this way the reaction of type (2) in which the total energy of secondary products, γ quanta and p , is equal (in the frame of accuracy of determination of E_γ and E_p) to the energy of the incoming π^+.

III. Experimental Data

Out of 150000 photographs about 2500 events with one prong and about 4000 events with two prongs were selected. 573 events of type (2) with stopped secondary track were singled out. Later on only these events will be analysed in detail. Table 1. presents the distribution of events according to the number of γ-rays.

Table 1
The Distribution of Events of Type (2) According to the Number of γ -Rays

Number of γ	Number of events	Recording efficiency for $k\gamma$ events (%)
1	25	-
2	265	93.0
3	85	85.4
4	165	81.9
5	22	73.4
6	11	60.5

The events containing observable V particles are not placed in the

x/ This follows from previous investigations[12,13].

Table 1. 40 events with one γ and 12 events with two γ were found.

In each event the geometry of interaction was twice measured by means of UIM-21 microscope and also no less than twice the E_γ of each γ was estimated. Thus, for any event the momenta of γ rays, the energy of secondary charged particle, assumed as proton, were estimated, and also the invariant mass $M_{k\gamma}$ were evaluated for all possible combinations of 2,3,4,... γ rays.

A. Two γ Events

We have plotted in Fig. 1 the distribution of the effective mass $M_{\gamma\gamma}$. Here you see the important peak at the π^0 -value, as it must. A second group of events is present in the region of the η. The solid line represents the background, and was obtained by the Monte-Carlo method for the two γ -events and normalized to the total number of events with the values $M_{\gamma\gamma} \leq 90$ MeV. It is also worth pointing out that the shapes of the $M_{\gamma\gamma}$ distributions obtained by the Monte-Carlo method for three and four γ events are also similar.

The distribution of the opening angle $\theta_{\gamma\gamma}$ in the laboratory system is shown in Fig. 2. In this histogram two groups of events are presented. A first is present in the region of $\theta^{min}_{\gamma\gamma}$ value for π^0, and the second by $\theta^{min}_{\gamma\gamma}$ value for η. The distributions of the events in these two groups are in good agreement with the theoretical distribution for π^0 (curve 1) and for η (curve 2).

With our statistics to date it is not possible to say whether other resonances decaying into two γ are presented or not.

B. Three γ Events

Fig. 3 shows the spectrum of the effective mass $M_{3\gamma}$ of the 85 three γ events and does not exhibit any peak in the region of the ω^0 mass. The solid curve is the $M_{3\gamma}$ background obtained by the Monte-Carlo method and normalized in the region of $M_{3\gamma}$ values no higher than 0.5 GeV.

The histogram in Fig. 4 represents the spectrum of the effective mass $M_{\gamma\gamma}$ of two γ in the three γ events, and shows a significant peak at the π^0 value. The solid curve is evaluated by the Monte-Carlo method and normalized to the total number of events with $M_{\gamma\gamma} \leq 90$ MeV.

C. Four γ Events

For 165 events that fit the reaction (2) we have computed the effective mass of four γ system, $M_{4\gamma}$. Figure 5 shows the mass spectra obtained after taking into account the recording probability for four γ events. The solid curve gives the distribution expected from phase space for the reaction $\pi^+ + n \to \pi^0 + \pi^0 + p$.

The spectrum of the effective mass of two γ in the four γ events is shown in Fig. 6. The smooth curve was calculated by the Monte-Carlo method and normalized to the total number of events with $M_{\gamma\gamma} \leq 90$ MeV. In this histogram you can see an important peak at the π^0 value.

The sample of four γ events contains 68 such events in which two (of six possible) independent $\gamma - \gamma$ combinations give the values of mass $M_{\gamma\gamma}$ within the mass interval 90-180 MeV. Those remaining independent pairs of $\gamma - \gamma$ combinations contain $M_{\gamma\gamma}$ values which lie either outside the interval 90-180 MeV or 400-700 MeV. The first interval corresponds to the possible $M_{\gamma\gamma}$ value for π^0 and the second to the possible $M_{\gamma\gamma}$ value for η within the mass estimation accuracy of about 30%. The events satisfied the above criteria were attributed to the two γ events. The designation $M_{\pi^0\pi^0}$ will be used in the course of this paper for effective mass $M_{4\gamma}$ in this group of $\pi^0\pi^0$ events.

The second group of four γ events, containing 86 events, is such a sample in which only one of the possible $\gamma - \gamma$ combinations lies into $M_{\gamma\gamma}$ interval 90-180 MeV and the other independent $M_{\gamma\gamma}$ values lie outside the allowed, within 30% accuracy, values for mass of π^0 or η . The designation $M_{\pi^0\gamma\gamma}$ for $M_{4\gamma}$ will be used here.

It is possible to select also the groups containing $\eta\pi^0$, $\eta\eta$ and $\eta\gamma\gamma$ events. Our statistics are not big enough to give any significant results concerning possible samples. We confine oneself to study the $\pi^0\pi^0$ and $\pi^0\gamma\gamma$ events.

Fig. 7 shows the distribution of $M_{\pi^0\pi^0}$. The solid curve 1 superimposed on the histogram represents the phase-space for reaction $\pi^+ + n \to \pi^0 + \pi^0 + p$ normalized to the total number of events. The curve 2 represents the background computed by the Monte-Carlo method, and normalized to the total number of events with values of $M_{\pi^0\pi^0} \lesssim 0.5$ GeV.

The effective mass $M_{\pi^0\pi^0}$ · distribution deviate from the expectation from phase space and from the background. This distribution shows the presence of two groups of particles. The first can be attributed to the mass value $M_{\pi^0\pi^0} = 709 \pm 18$ MeV and the second to the value $M_{\pi^0\pi^0} = 1250 \pm 30$ MeV.

In Fig. 8 the mass $M_{\pi^0\gamma\gamma}$ distribution is shown. Solid curve representing the background is normalized to the total number of events with mass $M_{\pi^0\gamma\gamma} \leq 0.45$ GeV. The distribution shows evidence of two groups of particles. One group contains the events with the weighted mean mass $M_{\pi^0\gamma\gamma} = 560 \pm 16$ MeV and the second with the mass $M_{\pi^0\gamma\gamma} = 945 \pm 24$ MeV.

The all possible effective mass distributions $M_{3\gamma}$, in all four γ events and in the samples of $\pi^0\pi^0$ and $\pi^0\gamma\gamma$ events are shown in Figs. 9, 10, 11, respectively.

Figs. 12 and 13 show the $M_{\gamma\gamma}$ distributions in $\pi^0\pi^0$ and $\pi^0\gamma\gamma$ events.

D. Five γ-Events

For 28 events with five γ rays that fit the reaction (2) we have computed the effective mass $M_{5\gamma}$, $M_{4\gamma}$, $M_{3\gamma}$, $M_{2\gamma}$. Results are presented in Figs. 14,15,16 and 17.

E. Six γ Events

The effective mass distributions of $M_{6\gamma}$, $M_{5\gamma}$, $M_{4\gamma}$, $M_{3\gamma}$, $M_{2\gamma}$ in six γ events are shown in Figs. 18, 19, 20, 21, and 22, respectively.

IV. Results and Discussion

The analysis of $M_{\gamma\gamma}$ distributions in any sample of $k\gamma$ events of type (2) shows the existence of an important peak at the π^0 mass value. The number of π^0 observed in any $M_{\gamma\gamma}$ distribution is equal always to the member of π^0 expected, which can be ascribed to the corresponding reaction (2). This result shows strong evidence for correctness of our method and indicates the possibility of direct study of particles decaying into π^0 mesons, γ rays, η mesons and so on.

The 14 events with values of mass $M_{\gamma\gamma}$ within the interval 400-700 MeV in the $M_{\gamma\gamma}$ distribution of the two γ events (Fig. 1) can be attributed to the generation of $\eta \to 2\gamma$. The 124 events with mass in the interval 90-180 MeV can be also ascribed to π^0. Approximately the same number of events are obtained, within the statistical fluctuations, from the distribution of the opening angle $\theta_{\gamma\gamma}$ (Fig. 2).

In average, the ratio $R_{\frac{\eta}{\pi^0}}$ of number of $\eta \to 2\gamma$ to the number of π^0 generated in the reaction $\pi^+ + n \to X + p$, $X \to 2\gamma$ is equal to

$$R_{\frac{\eta}{\pi^0}} = 12.1 \pm 4.0\,\% \,. \qquad (3)$$

The distribution of $M_{3\gamma}$ in three γ events (Fig. 3) does not exhibit any peak in the region of the ω^0 mass. Taking into account the possible intensity of $\omega^0 \to \pi^0 + \gamma$ production in reaction under consideration, we expect to observe 6 ω^0 events. These events can be unobservable in the sample of three γ events in which the background reached about 85% of the total number of the three γ combinations.

In the sample of four γ events, containing $\pi^0\pi^0$ and $\pi^0\gamma\gamma$ events (Fig. 6,7) there are some indications for the existence of the following particles$^{x/}$:

$\eta \to \pi^0 + \gamma + \gamma$, $M_{\pi^0\gamma\gamma} = 560 \pm 16$ MeV, 12 events;

$X \to \pi^0 + \gamma + \gamma$, $M_{\pi^0\gamma\gamma} = 945 \pm 24$ MeV, 21 events;

$S^0 \to \pi^0 + \pi^0$, $M_{\pi^0\pi^0} = 709 \pm 18$ MeV, 20 events;

$f^0 \to \pi^0 + \pi^0$, $M_{\pi^0\pi^0} = 1250 \pm 30$ MeV, 7 events.

We evaluate now the decay branching ratio for $\eta \to$ neutrals.

$$R_1 = \frac{\eta \to \pi^0 + \gamma + \gamma}{\eta \to \gamma + \gamma} = 0.86 \pm 0.47 \,. \qquad (4)$$

Assuming the six γ events with $M_{6\gamma}$ within the interval value 400-700 MeV to be $\eta \to \pi^0 + \pi^0 + \pi^0$, we estimate the upper limit for the

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$^{x/}$The numbers of events were estimated in assumption that the values of mass of particles lie within the $\pm 20\%$ intervals around average values of $M_{\pi^0\pi^0}$ or $M_{\pi^0\gamma\gamma}$ in the corresponding peaks.

$$R_2 = \frac{\eta \to \pi^0 + \pi^0 + \pi^0}{\eta \to 2\gamma} \leq 0.42 \,. \qquad (5)$$

It should be noted that our results are very similar to those obtained with electronic technique /14/. The authors give $R_1 = 0.90 \pm 0.14$ and $R_2 = 0.50 \pm 0.09$.

Ascribing the 21 events with the mass $M_{\pi^0\gamma\gamma} = 945 \pm 24$ MeV to the X^0 particle /15-17/, to be surprising seems the very big intensity of production of $X^0 \to \pi^0 + \gamma + \gamma$ in comparison with previous results concerning other decay modes of X^0 /15-17/.

We have performed a more detailed analysis of the events from the peak at $M_{\pi^0\gamma\gamma} = 945 \pm 24$ MeV. For all these events the correlation $\pi^0\gamma$ of the π^0 with the γ was performed. There are two possible independent combinations of π^0 with γ rays from $\pi^0\gamma\gamma$ four γ event. The distribution of these $M_{\pi^0\gamma}$ mass is shown in Fig. 23. From this distribution there appears an indication that the possible cascade decay of X

$$X \to \omega^0 + \gamma, \qquad \omega^0 \to \pi^0 + \gamma$$

is not excluded.

Other significant hint about this mode can follow the $M_{3\gamma}$ distribution in all four γ events and in $\pi^0\gamma\gamma$ four γ events (Fig. 9,11) in cimparison with the $M_{3\gamma}$ distribution in $\pi^0\pi^0$ events with four γ (Fig. 10).

At present we must consider this result as an useful indication only. In order to get definite informations concerning this problem the statistics of experimental material sould be enlarged.

The statistics of the five and six γ events are not big enough presently to give any significant results.

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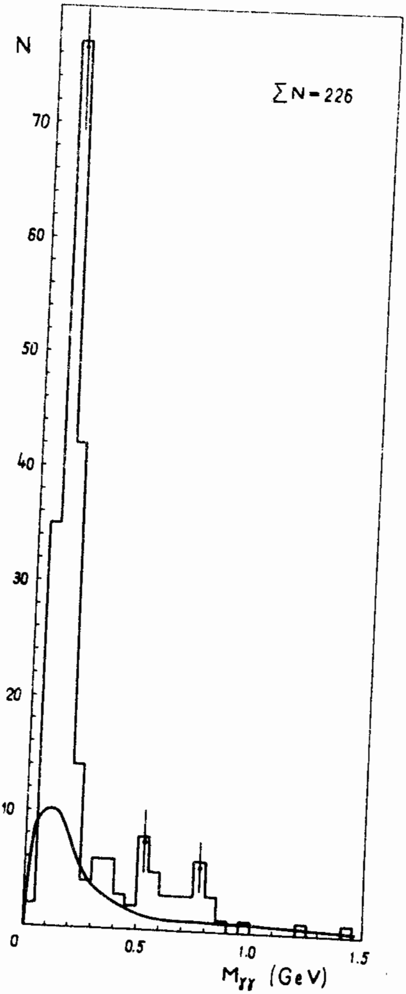

Fig. 1. Distribution of the effective mass $M_{\gamma\gamma}$ in the two γ events. The solid curve represents the background.

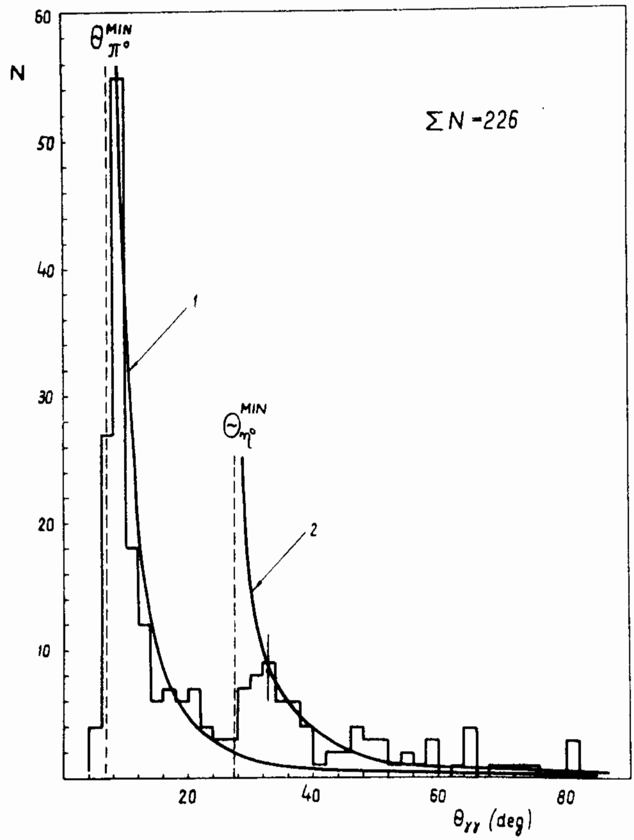

Fig. 2. Distribution of the opening angle $\Theta_{\gamma\gamma}$ in the two γ events (lab. syst.). The curves 1 and 2 represents the theoretical distributions.

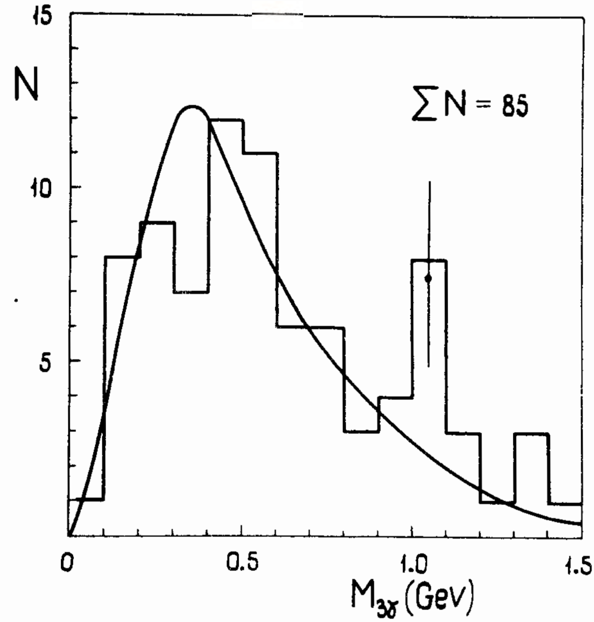

Fig. 3. Distribution of $M_{3\gamma}$ in the three γ events. The solid curve superimposed on the histogram represents the background.

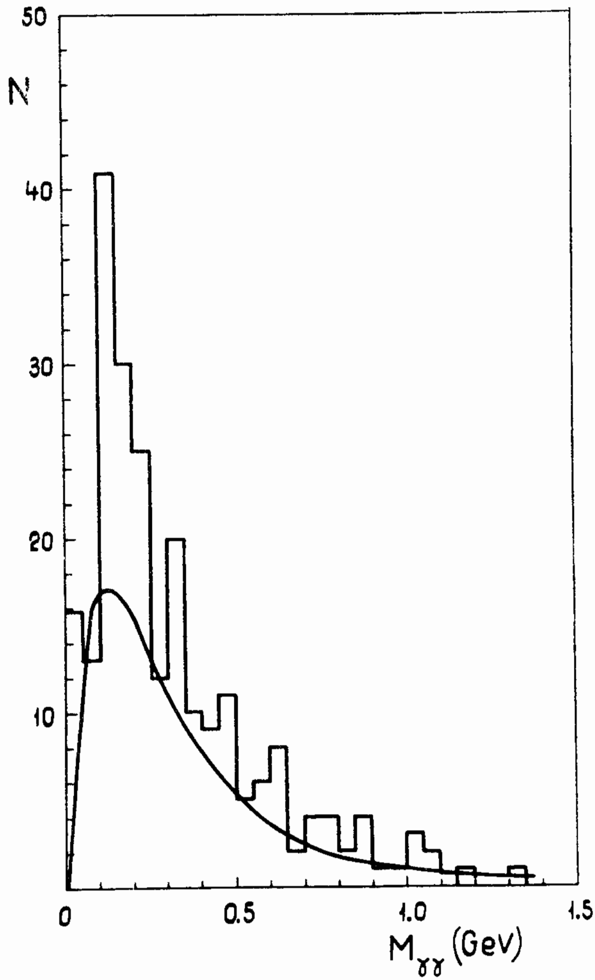

Fig. 4. Distribution of $M_{\gamma\gamma}$ in events with three γ . The solid curve represents the background.

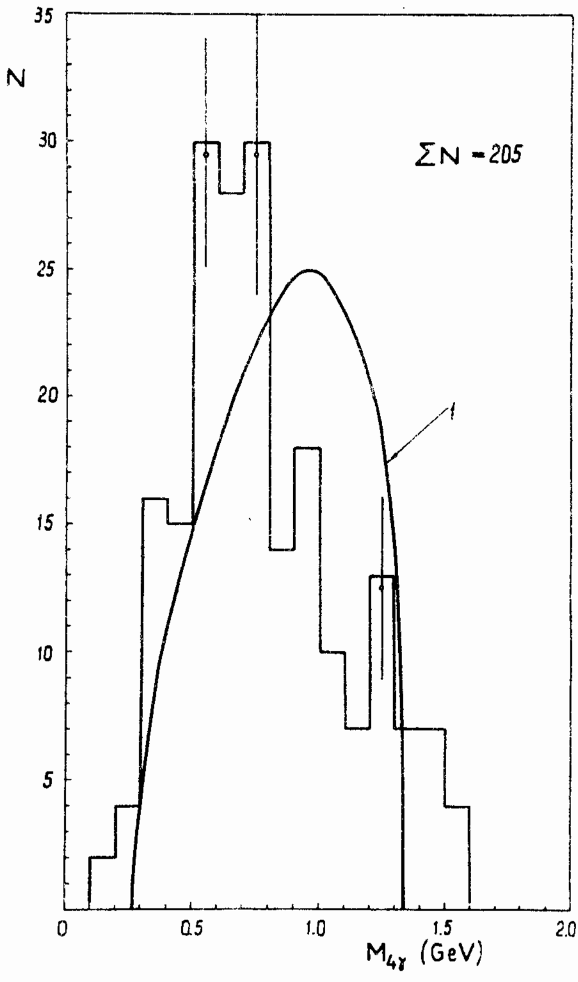

Fig. 5. Distribution of the effective mass $M_{4\gamma}$ in the four γ events. The curve 1 represents phase-space for reaction $\pi^{+}+n \to \pi^{0}+\pi^{0}+p$.

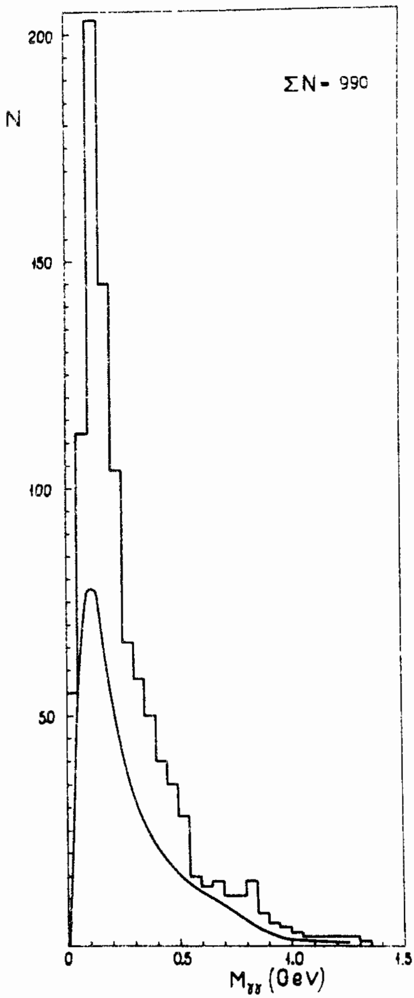

Fig. 6. Distribution of the $M_{\gamma\gamma}$ in the four γ events. The background is shown by the solid curve.

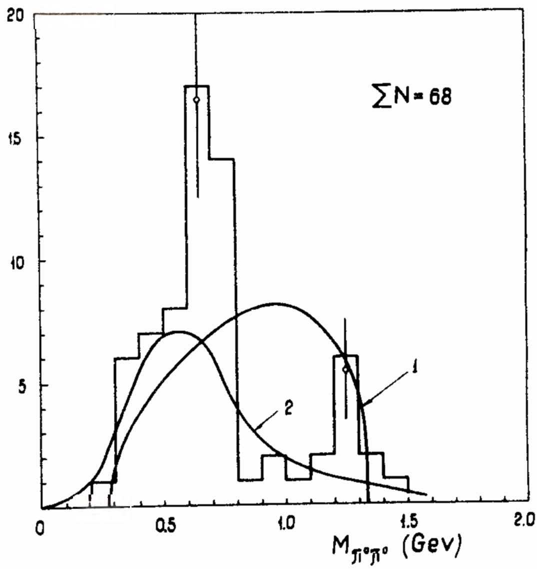

Fig. 7. Distribution of the mass $M_{\pi^0\pi^0}$ in the four γ events. The curve1 represents the phase-space for reaction $\pi^+ + n \to \pi^0 + \pi^0 + p$, the curve 2 represents the background.

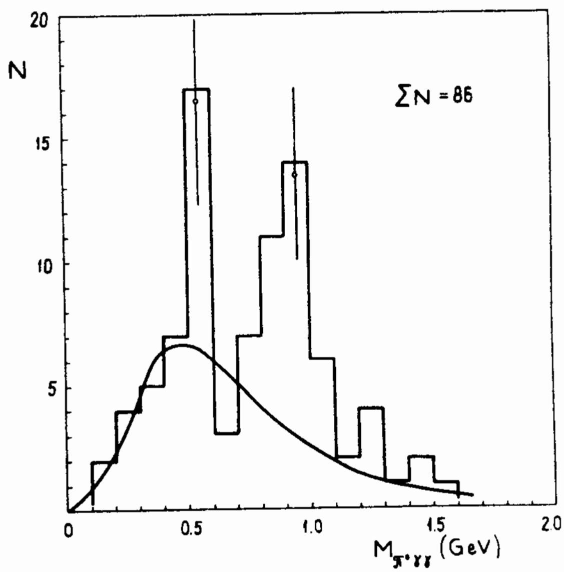

Fig. 8. Distribution of the mass $M_{\pi^0\gamma\gamma}$ in the four γ events. The solid curve represents the background.

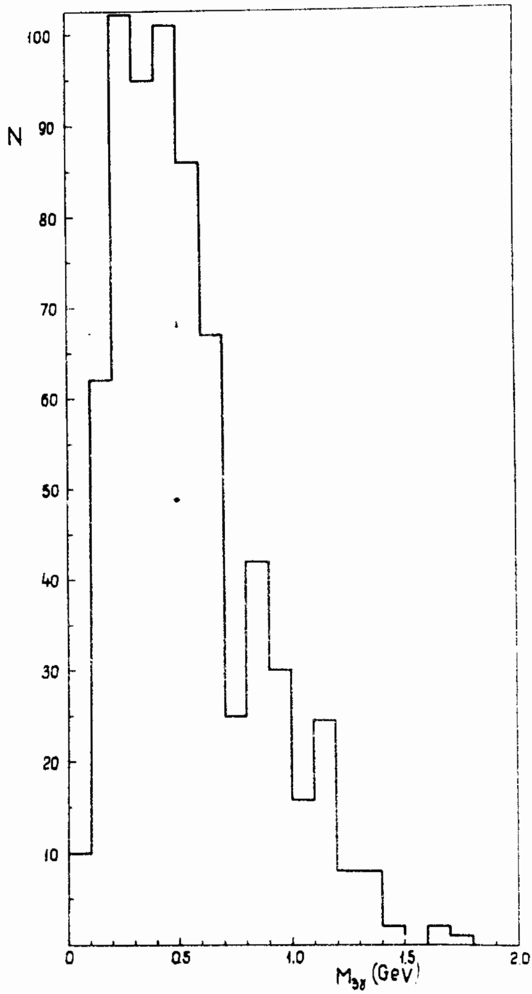

Fig. 9. Distribution of $M_{3\gamma}$ in the all four γ events.

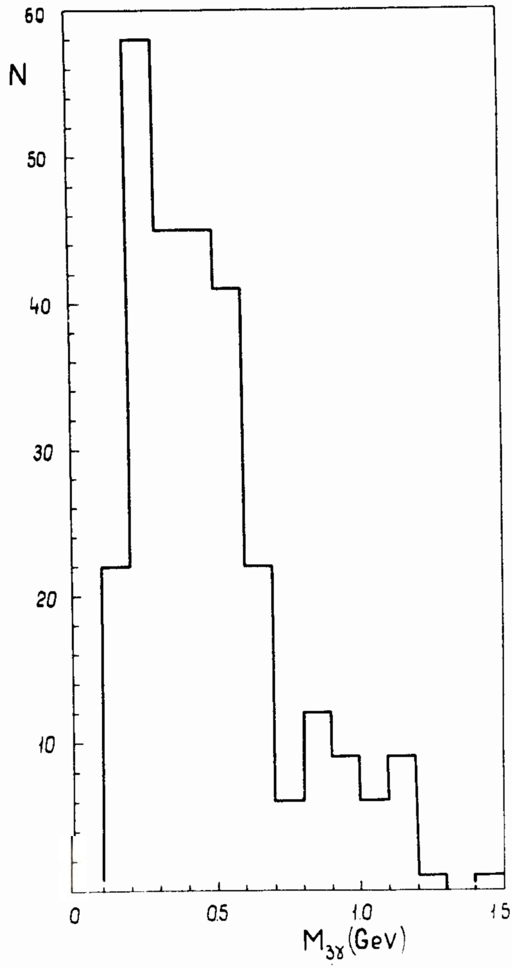

Fig. 10. Distribution of $M_{3\gamma}$ in the four γ events with two π^0.

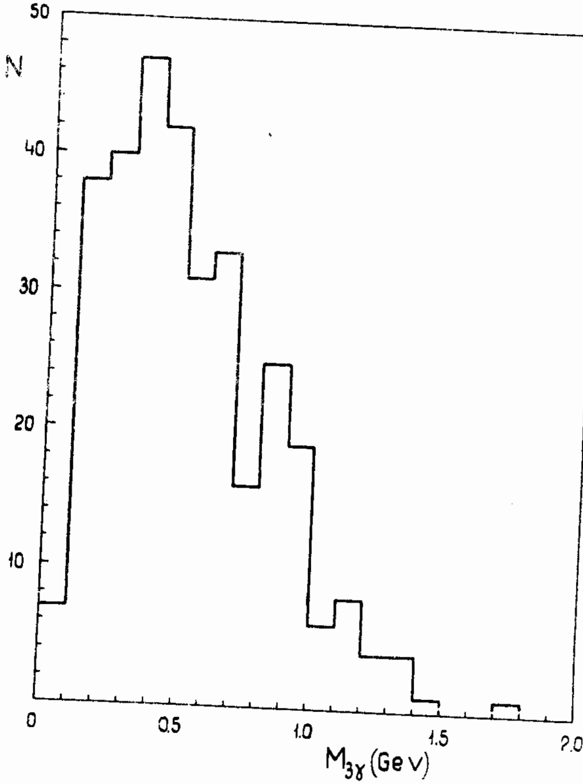

Fig. 11. Distribution of $M_{3\gamma}$ in the four γ events containing one π^0 ($\pi^0\gamma\gamma$ events).

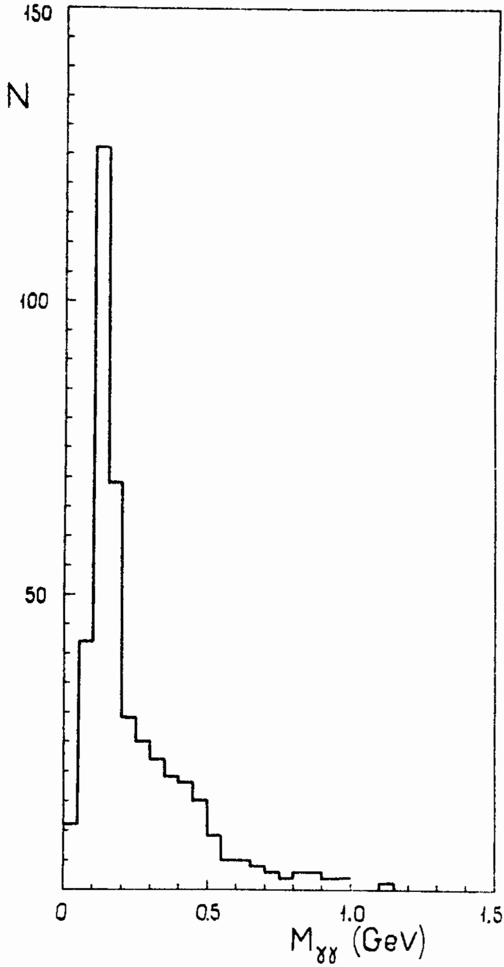

Fig. 12. Distribution of $M_{\gamma\gamma}$ in the four γ events in which the two π^0 are present.

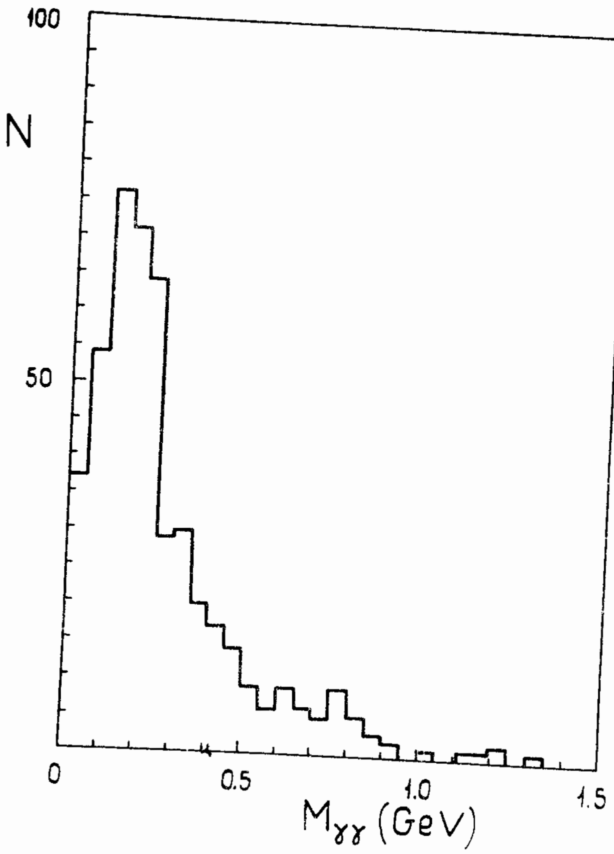

Fig. 13. Distribution of $M_{\gamma\gamma}$ in four γ events with only one π^0

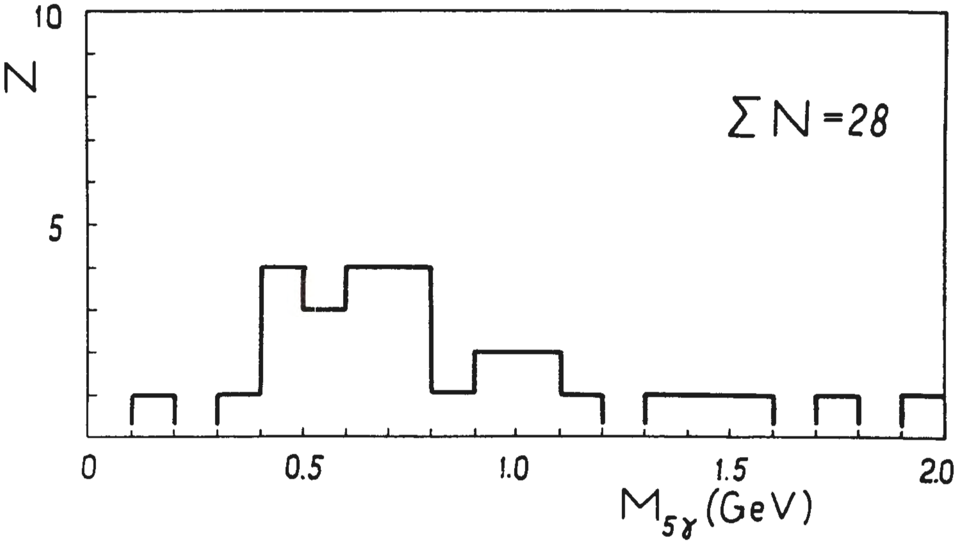

Fig. 14. Distribution of $M_{5\gamma}$ in the five γ events.

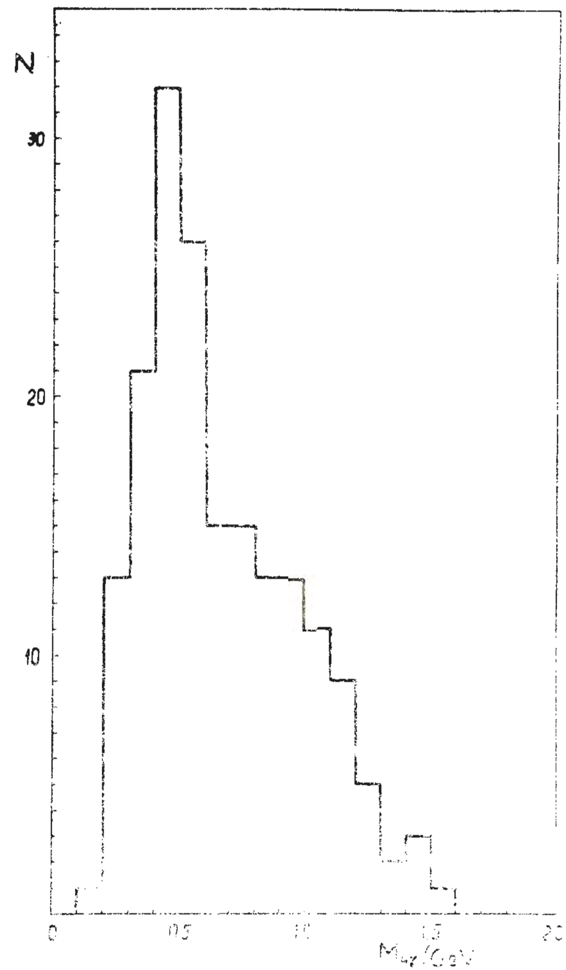

Fig. 15. Distribution of $M_{4\gamma}$ in the five γ events.

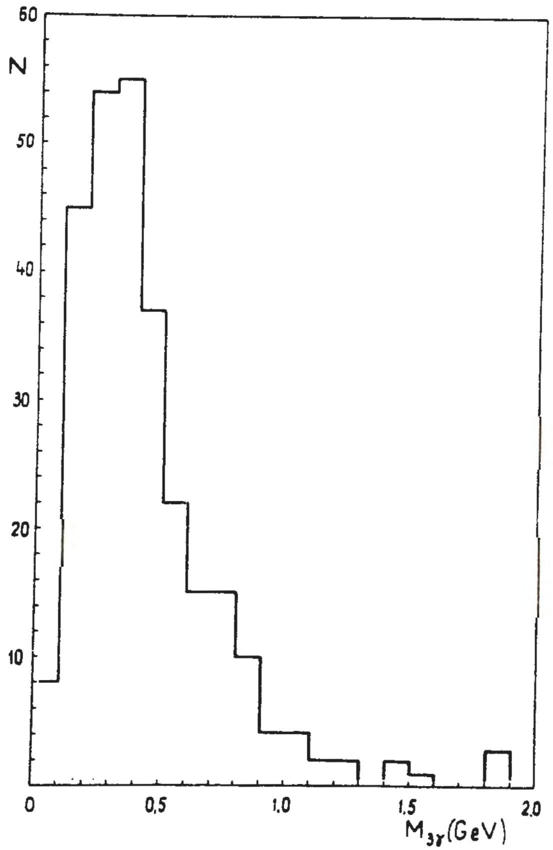

Fig. 16. Distribution of $M_{3\gamma}$ in the five γ events.

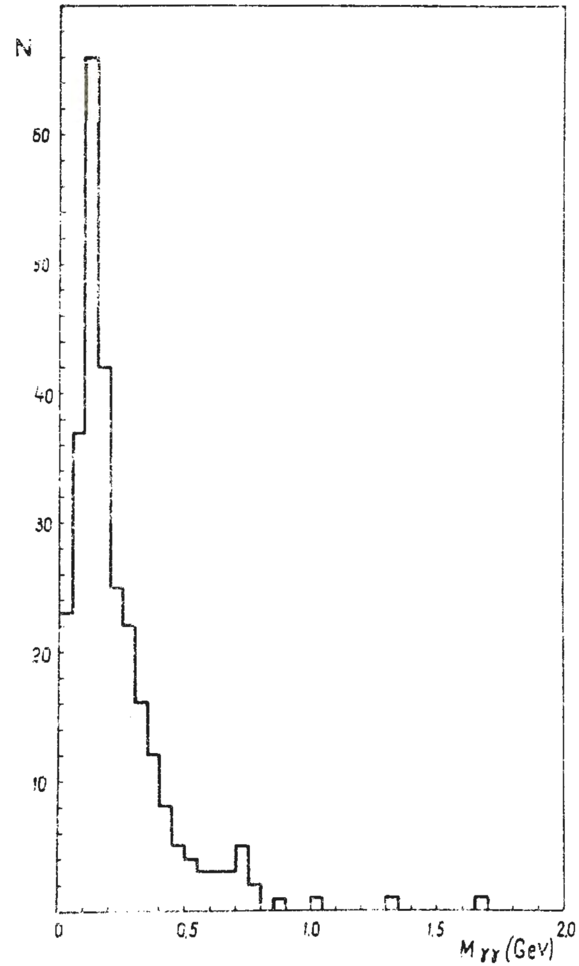

Fig. 17. Distribution of $M_{\gamma\gamma}$ in the five γ events.

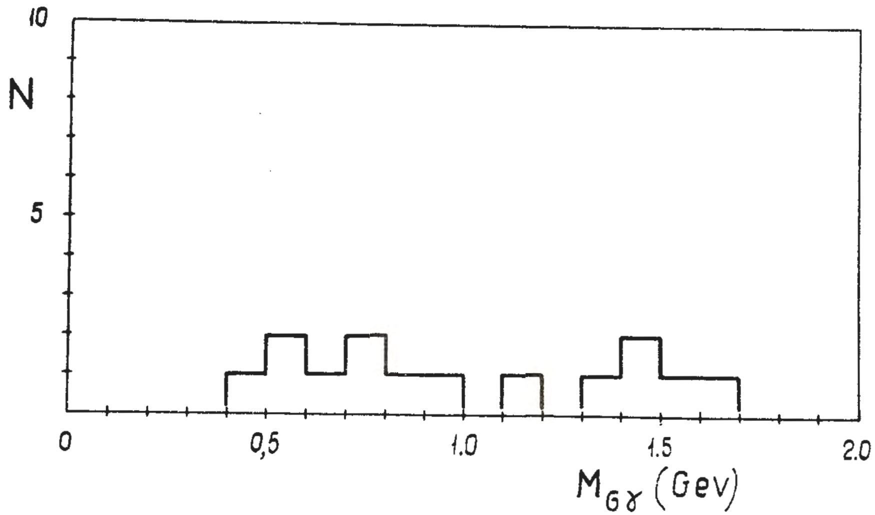

Fig. 18. Distribution of $M_{6\gamma}$ in the six γ events.

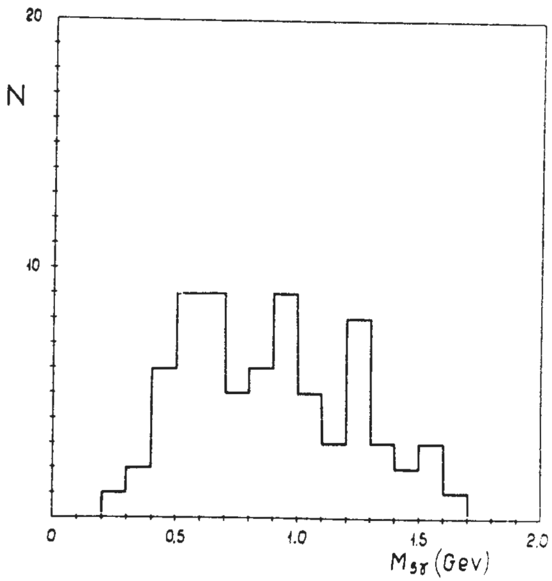

Fig. 19. Distribution of $M_{5\gamma}$ in the six γ events.

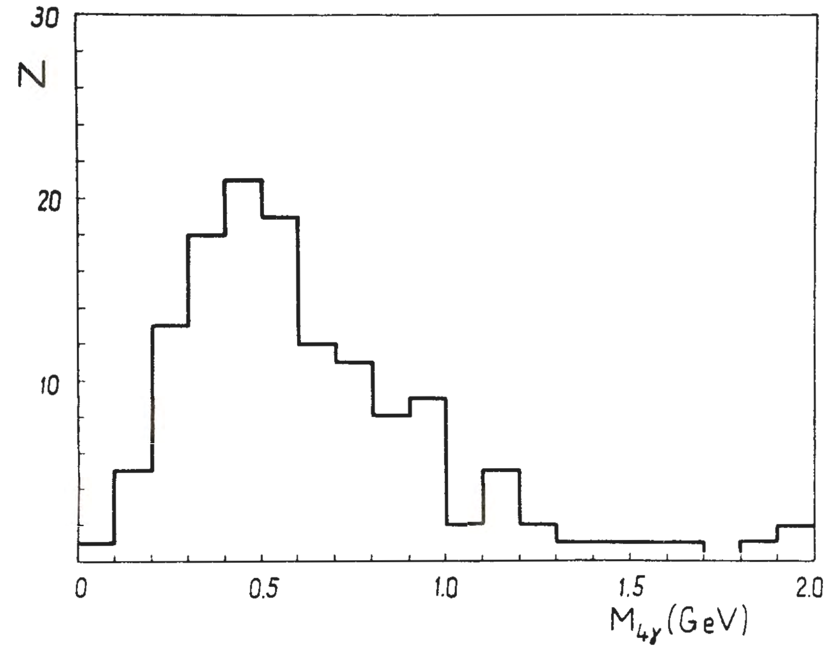

Fig. 20. Distribution of $M_{4\gamma}$ in the six γ events.

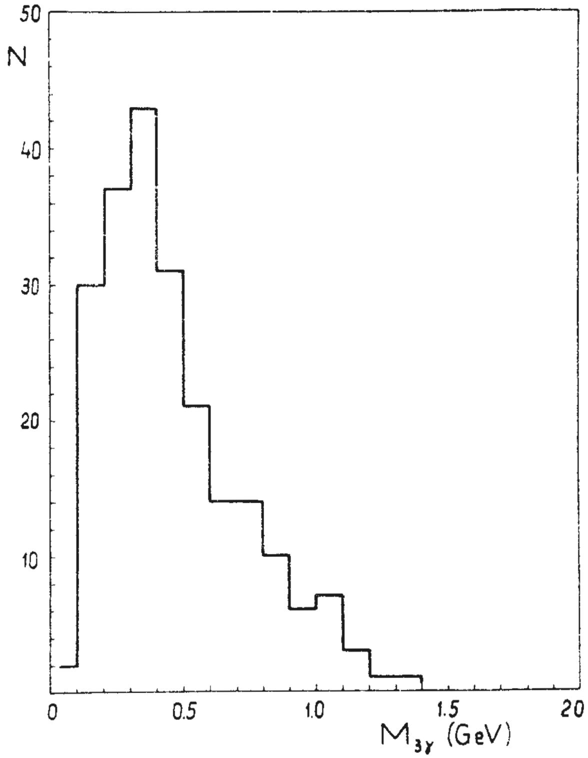

Fig. 21. Distribution of $M_{3\gamma}$ in the six γ events.

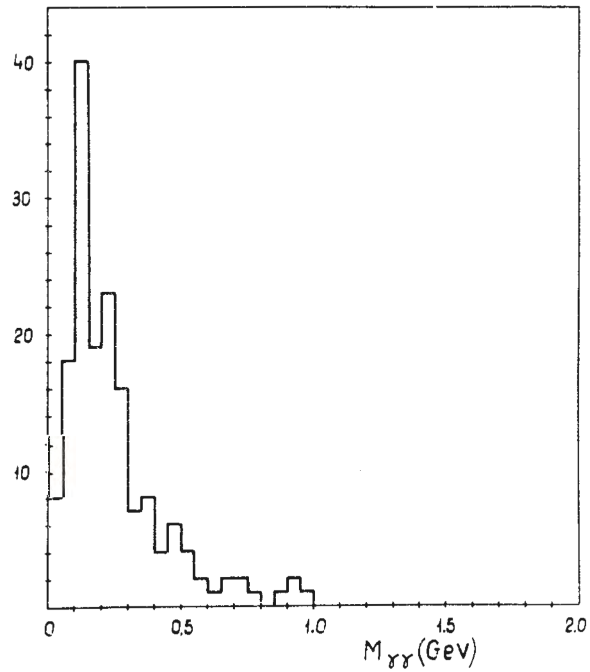

Fig. 22. Distribution of $M_{\gamma\gamma}$ in the six γ events.

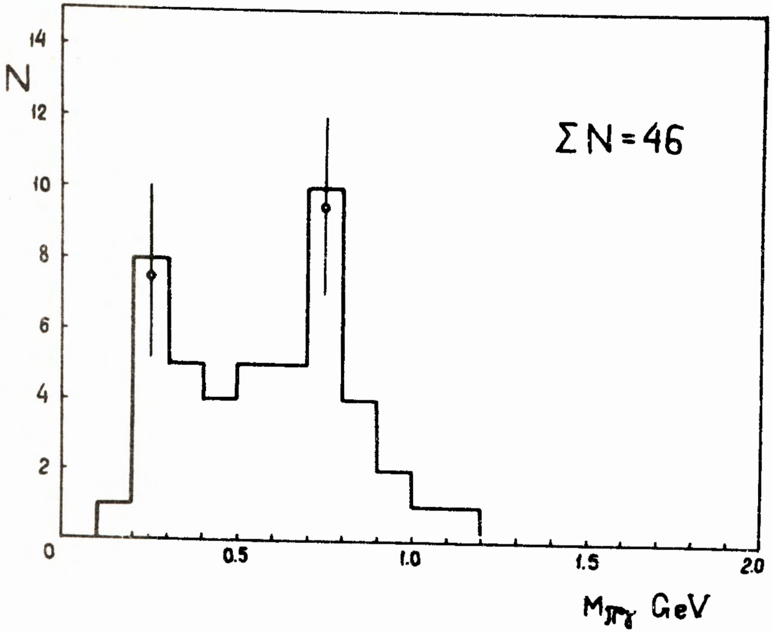

Fig. 23. Distribution of $M_{\pi^0\gamma}$ in $\pi^0\gamma\gamma$ four γ events with $M_{\pi^0\gamma\gamma}$ in the mass value interval 800–1100 MeV.