DETERMINATION OF THE BRANCHING RATIOS AMONG THE NEUTRAL DECAY MODES OF THE η PARTICLE

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The branching ratios among the neutral decay modes of the η particle have been measured at CERN using a counter technique. Strong evidence for the presence of the mode $\eta\to\pi^0+\gamma+\gamma$ is obtained. The results are

$$R_1=\frac{\eta\to\gamma+\gamma}{\eta\to\text{all neutrals}}=(41.6\pm2.2)\%,$$

$$R_2=\frac{\eta\to3\pi^0}{\eta\to\text{all neutrals}}=(20.9\pm2.7)\%,$$

$$R_3=\frac{\eta\to\pi^0+\gamma+\gamma}{\eta\to\text{all neutrals}}=(37.5\pm3.6)\%.$$

The quoted errors are only statistical. A reasonable estimate of our over-all uncertainty, including systematic errors, would, in our opinion, at most double the statistical errors. From these ratios we deduce

$$R=\frac{\eta\to\gamma+\gamma}{\eta\to(3\pi^0\text{ and }\pi^0+\gamma+\gamma)}=0.7\pm0.7.$$

This is in good agreement with the Frascati result[1] of $R=0.80\pm0.25$. The disagreement with other results[2-4] on this ratio is only apparent, since in all measurements of this ratio (except in the Frascati experiment) the efficiency of detection of the multibody neutral decays was evaluated on the hypothesis of always having six γ rays in the final state.

The remainder of this Letter is devoted to a description of the experimental method. The experimental arrangement is shown in Fig. 1. A 1.2-GeV/c momentum π^- beam from the CERN proton synchrotron is incident upon a 20-cm long hydrogen target, where the reaction

$$\pi^-+p\to\eta+n \qquad (1)$$

is produced among others. The beam is monitored by the coincidence $S_1S_2\bar{S}_3$. S_3 is a scintillator counter with a hole (2.5 cm diam) in the center. The hut of counters S_4, in anticoincidence, allows to detect pions interacting in the target, producing only neutrals in the final state.

At 48° [the maximum angle allowed by kinematics to neutrons from Reaction (1)] a neutron counter C_N (15 cm thick × 10 cm wide × 50 cm high) protected by anticoincidences (S_5 and S_6), 3 m from the H_2 target, detects neutrons and gives their time-of-flight spectrum in a multichannel analyzer.

On the line of flight of the η (19°), a lead glass Cherenkov counter C (cylinder, 35 cm diam, 30 cm thick) at 80 cm from the target detects γ rays in coincidence with neutrons. In front of C, a lead collimator reduces its useful area to a diameter of 25 cm in order to minimize edge effects. Between the collimator and C there is a counter in anticoincidence (S_7).

When a coincidence ($S_1S_2\bar{S}_3\bar{S}_4\bar{S}_5\bar{S}_6\bar{S}_7C_NC$) between a neutron and a γ ray occurs, we print the time of flight of the neutron, the pulse height in C_N, and the pulse height in C. We use the time of flight of the neutron to separate Reaction (1), and the pulse-height spectrum on C to determine the branching ratios. The pulse height in C_N is used as a check.

The time-of-flight spectra of the neutrons are shown in Fig. 2. In Fig. 2(a) the spectra of neutrons not in coincidence with C are shown. The unshaded spectrum has been taken with C_N at 48°, and the η peak appears clearly. The shaded spectrum has been collected with C_N at 52°, where neutrons from Reaction (1) cannot go, and is a background measurement.

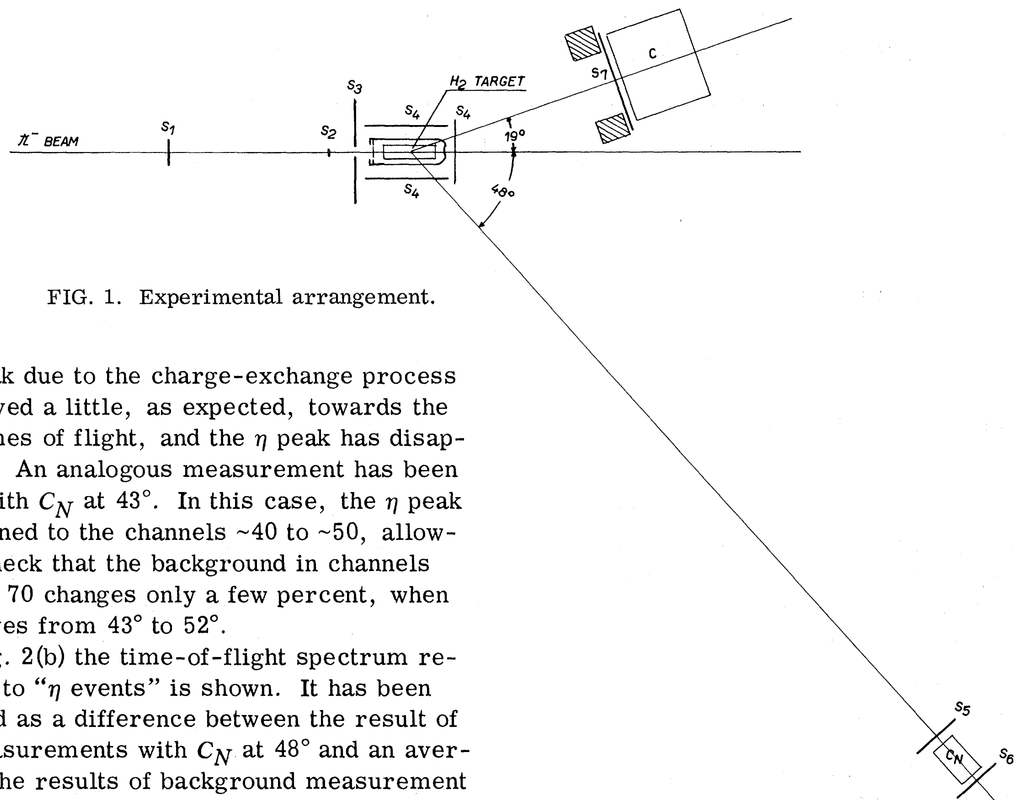

FIG. 1. Experimental arrangement.

The peak due to the charge-exchange process has moved a little, as expected, towards the high times of flight, and the η peak has disappeared. An analogous measurement has been made with C_N at 43°. In this case, the η peak is confined to the channels ~40 to ~50, allowing a check that the background in channels is 50 to 70 changes only a few percent, when C_N moves from 43° to 52°.

In Fig. 2(b) the time-of-flight spectrum referring to "η events" is shown. It has been obtained as a difference between the result of the measurements with C_N at 48° and an average of the results of background measurement at 43° and 52°. The experimental spectrum of Fig. 2(b) is also compared with the expected shape calculated in the hypothesis that the angular distribution of Reaction (1) is flat in the center-of-mass system in the small interval concerned.

Figures 2(c) and 2(d) have the same meaning as Figs. 2(a) and 2(b), showing now spectra of neutrons in coincidence with a γ ray in C. "η measurements" and background measurements were always alternately made, changing from one situation to the other every ~3 hours.

For the events of Fig. 2(c) which have a time of flight between channel 50 and channel 70, we make a pulse-height spectrum on C, as shown in Fig. 3(a). The Cherenkov counter has been calibrated with photons, using the fact that π^-'s interacting in the target produce at 0° a photon spectrum with a sharp cutoff at the momentum of the π^- beam. Calibration with electrons was also performed at 200, 400, 600, 800, 1000, 1200, and 1400 MeV in order to get the resolution of C. The results of the calibration are shown in Fig. 3(c). The stability of the Cherenkov calibration was checked every ~3 hours, and turned out to be constant within ±2%. In order to check that edge effects do not distort the spectra, we have also made a spectrum of γ rays from the decay of π^0's. The kinematical situation of the process

$$\pi^- + p \to \pi^0 + n \qquad (2)$$

has been selected by the neutron counter in such a way that the γ spectrum from the π^0 in C was expected in the same position and with about the same width as the γ-ray spectrum from the decay $\eta \to \gamma + \gamma$ during the actual measurements.

The result of this check measurement is shown in Fig. 3(d) and fits very well the computed spectrum. This check has been repeated also in a kinematical situation such that the γ-ray energy spectrum from the π^0 was expected to be centered around ~600 MeV; the fit with the expected shape was also in this case very good.

In Fig. 3(b) the expected energy spectra in C from the different decay modes of the η are shown. They were computed by the Monte Carlo method. The possibility that more than one γ ray from the decays $\eta \to 3\pi^0$ and $\eta \to \pi^0 + \gamma + \gamma$ enter the Cherenkov has of course been taken into account. The model chosen for the calculation is the statistical one. The experimental resolution has been folded in.

In Fig. 4 the γ-ray energy spectrum from

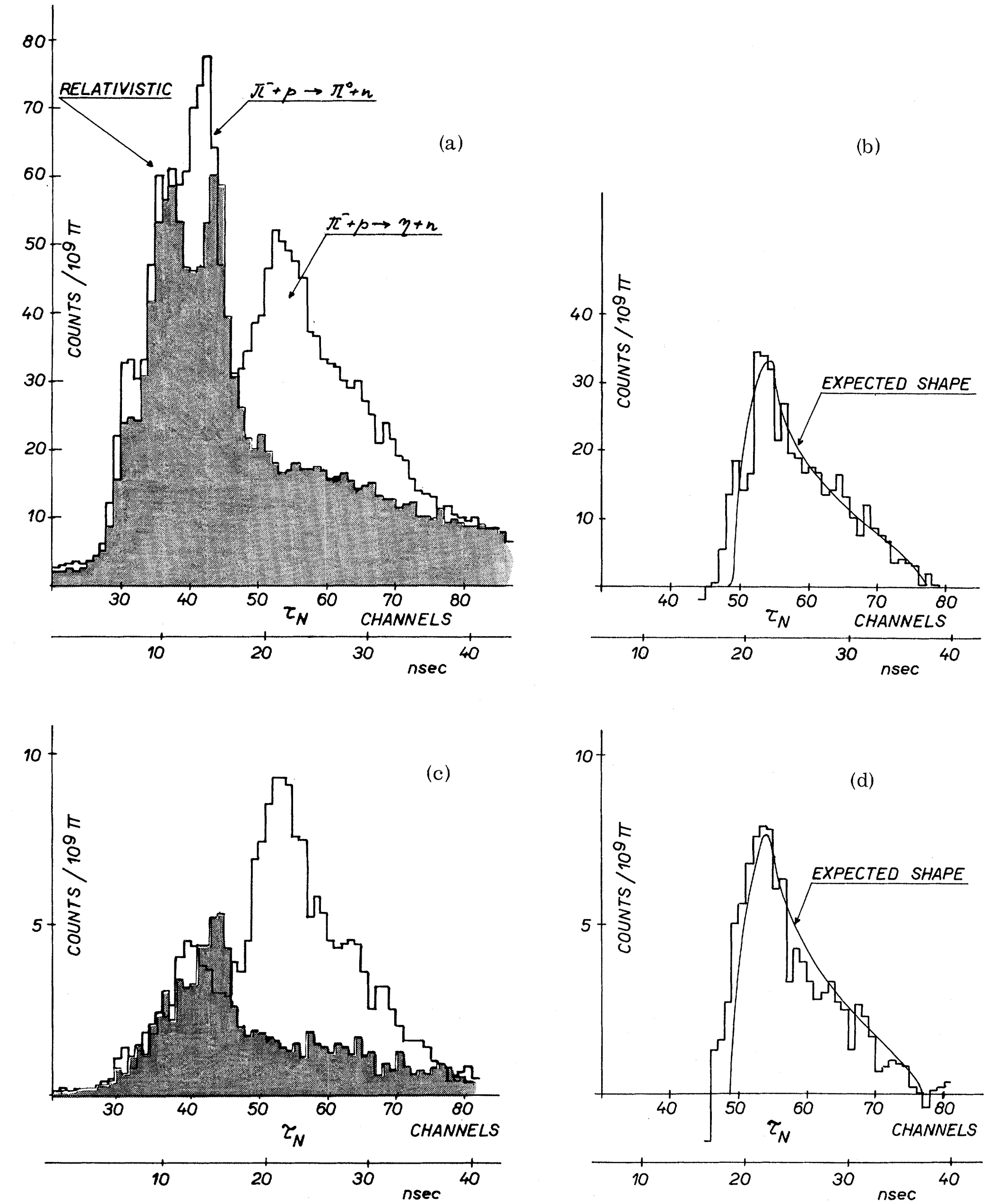

FIG. 2. Time-of-flight (τ_N) spectra of neutrons. (a) Time-of-flight spectra of neutrons not in coincidence with a γ ray in C. Unshaded spectrum: C_N at 48°; shaded spectrum: C_N at 52°. (b) Difference between the unshaded spectrum of Fig. 2(a) ("η spectrum") and an average of background measurements taken with C_N at 52° and 43°. Comparison is made with the expected spectrum. (c) and (d) Same as (a) and (b), but referring now to neutrons in coincidence with a γ in C. The ordinates are counts/10^9 incident pions. The total flux of π^- used to collect the data is $\sim 25\times 10^9$ for the "η measurements" and $\sim 21\times 10^9$ for "background measurements" with C_N at 52°.

the η decays, as obtained in the experiment, is shown. It is obtained as a difference between the spectra of Fig. 3(a) and transforming from channels to γ-ray energy by the results of the calibration. It is not possible to fit (dotted line) the spectrum of Fig. 3 using only the spectra from the decays $\eta \rightarrow \gamma + \gamma$ and $\eta \rightarrow 3\pi^0$. χ^2/n comes out to be ~5, and $f(\chi^2) < 1$ pro mille. A good fit (solid line) is obtained when the mode $\eta \rightarrow \pi^0 + \gamma + \gamma$ is included [$\chi^2/n = 0.70$; $f(\chi^2) \simeq 85\%$]

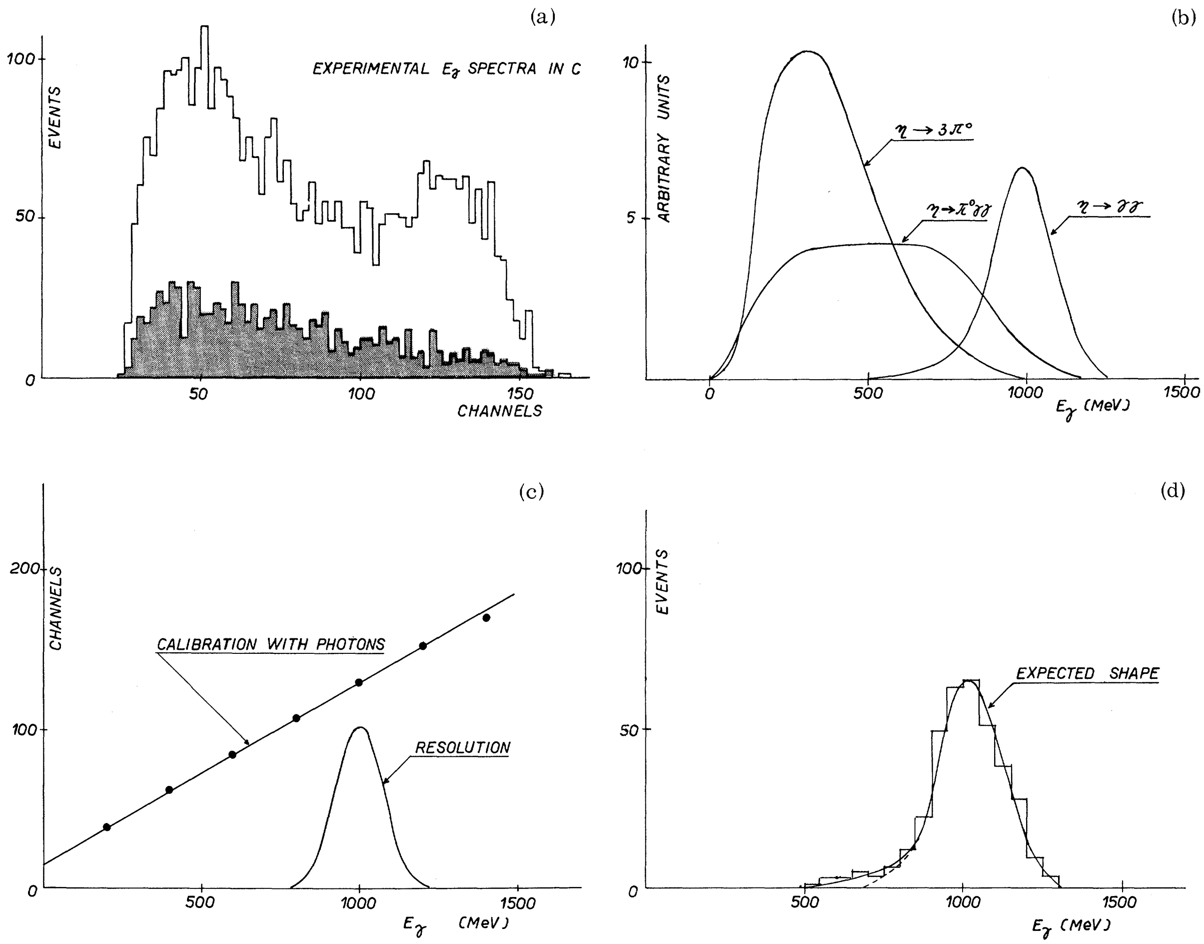

FIG. 3. (a) Pulse-height spectra in C for events with τ_N between channel 50 and channel 70. Unshaded spectrum: η events (C_N at 48°); shaded spectrum: background events (C_N at 52°). (b) Expected energy spectra in C of γ rays from the decays $\eta \to \gamma+\gamma$, $\eta \to 3\pi^0$, $\eta \to \pi^0+\gamma+\gamma$. The relative normalization refers to equal probability for the three decay modes. Experimental resolution folded in. (c) Results of the calibration of C with photons. The spectra obtained with monochromatic electrons of 1 BeV is also given to show the resolution of C. (d) γ-ray energy spectrum from process $\gamma+p \to \pi^0+n(\pi^0 \to \gamma+\gamma)$. The experimental spectrum is compared with the expected one.

providing the branching ratios quoted at the beginning of this Letter.

χ^2 increases rapidly as one tries to fit the spectrum with wrong calibration parameters (slope or resolution) of the Cherenkov counter C. We have also checked that an error in the evaluation of the background in the γ-ray spectra would not distort essentially the result: A ±20% error in the background (much larger than the possible uncertainty in our measurements) would leave unchanged the ratio $(\eta \to 3\pi^0/\eta \to \pi^0+\gamma+\gamma)$ and shift by ~5% the ratios $(\eta \to \gamma+\gamma/\eta \to 3\pi^0)$ and $(\eta \to \gamma+\gamma/\eta \to \pi^0+\gamma+\gamma)$.

An internal check of our measurements is in the following point: The efficiency ϵ_η of detection[5] of the η by C [ratio between the events of Figs. 2(d) and 2(b)] depends on the branching ratios. With the quoted branching ratios, we expect $\epsilon_\eta = 27.5\%$. We find $\epsilon_\eta = (26.3 \pm 1)\%$.

We want to stress that our results are valid on the hypothesis that the γ-ray energy spectra from the different decay modes of the η can be computed in the statistical model. We have, however, built several possible models, introducing a final-state interaction. As a result, the branching ratios never changed more than ~5%. In particular, the γ-ray energy spectrum from the decay $\eta \to 3\pi^0$ is very insensitive to the model, due to the symmetry of the Dalitz plot among the pions. As far as the $\pi^0\gamma\gamma$ mode is concerned, even with very unlikely models built ad hoc and not connected with any

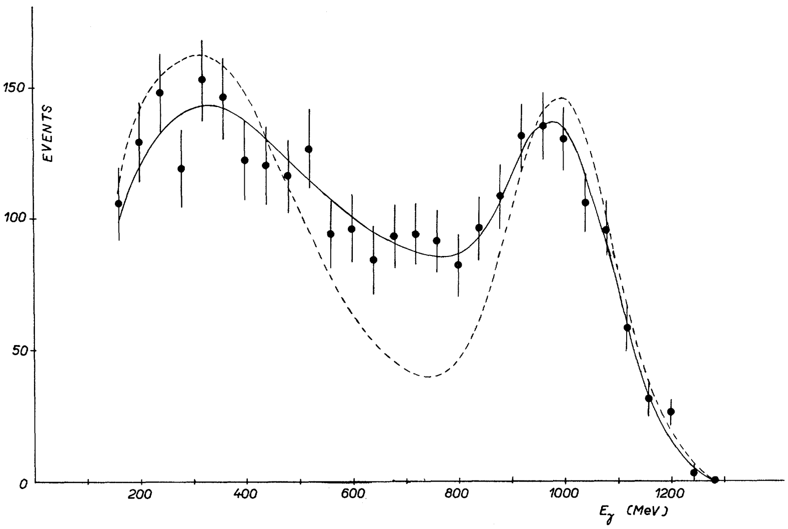

FIG. 4. γ-ray energy spectrum in C of photons from η events (difference between the spectra of Fig. 3(a), after transformation from channels to γ-ray energy). The solid line is the best fit with the expected spectra from the decays $\eta \to \gamma + \gamma$, $\eta \to 3\pi^0$, $\eta \to \pi^0 + \gamma + \gamma$. The dotted line is the best fit using only the spectra from the decays $\eta \to \gamma + \gamma$ and $\eta \to 3\pi^0$.

reasonable physical hypothesis, we could not succeed in reducing the ratio $(\eta \to \pi^0 + \gamma + \gamma)/(\eta \to \text{all neutrals})$ to less than 30%.

It is a pleasure to thank the CERN staff for the warm hospitality we received. The kindness of all of them made our stay at CERN very pleasant, and our work efficient. In particular, we would like to thank Professor G. Fidecaro and his group. Without his assistance, and the help of his technicians Mr. Renevey and Mr. Dechelette, this work could hardly have been performed.

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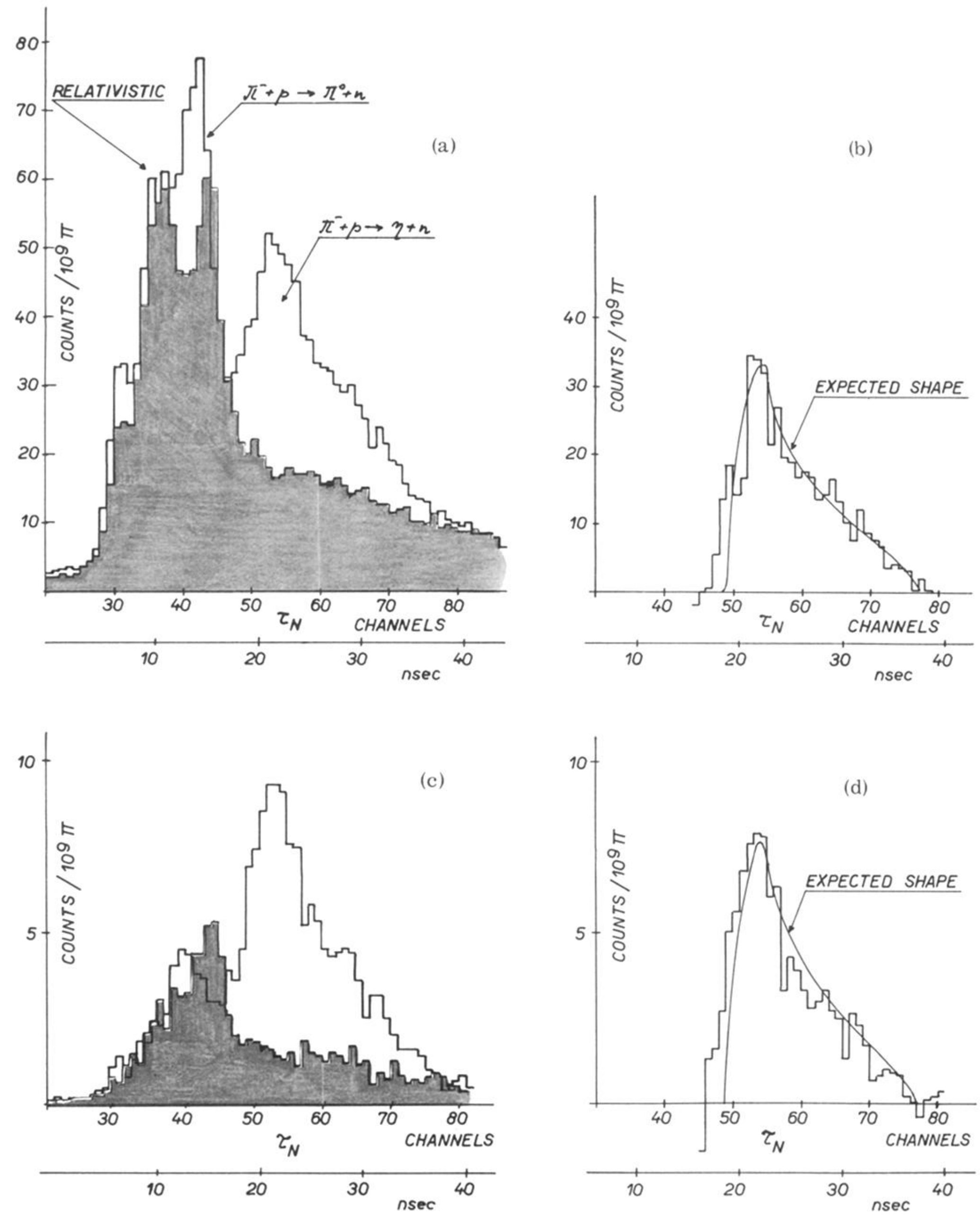
[5]The efficiencies of our Cherenkov to detect the different decay modes of the η are

$$\epsilon_{\gamma\gamma} = 16.6\%; \ \epsilon_{\pi^0\gamma\gamma} = 32\%; \ \epsilon_{3\pi^0} = 44.5\%.$$



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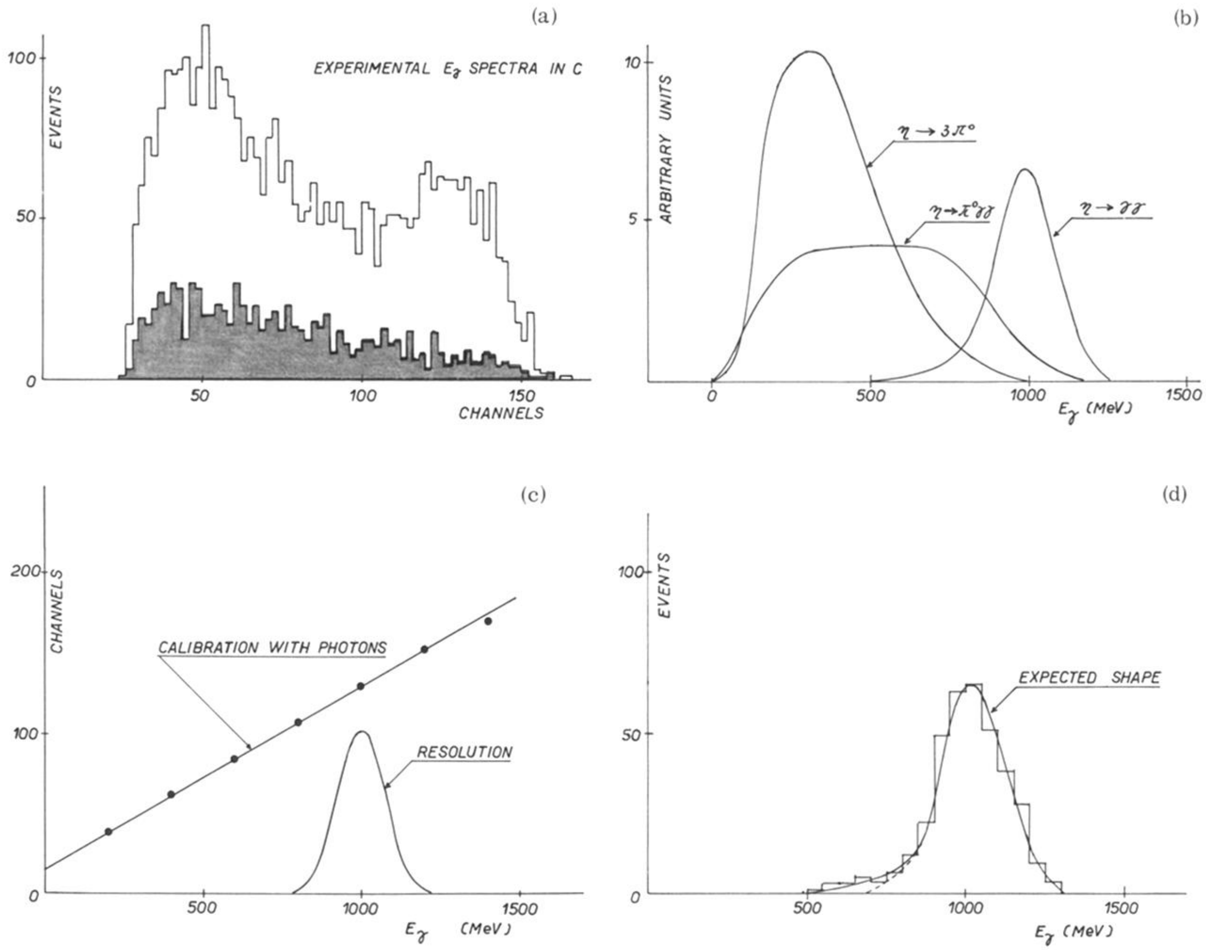

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