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R. Querzoli, V. Silvestrini: ON THE QUANTUM NUMBERS OF THE η -PARTICLE.

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On the Quantum Numbers of the η-Particle.

R. QUERZOLI and V. SILVESTRINI
Laboratori Nazionali di Frascati del C.N.E.N. - Roma

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Recent experimental work has led to the conclusion that the η has quantum numbers 0^{-+} (spin 0, parity -1, G-parity $+1$). This assignement, however, originates a well known puzzle: the decay of the η into $\pi^+\pi^-\pi^0$, which violates G, should be strongly unfavoured with respect to the not observed decay into $\pi^+\pi^-\gamma$ (1).

On the other hand the assignment 1^{--}, which was considered as the alternative possibility untill a few months ago, does not seem to give rise to any difficulty for the observed branching ratios in the decay modes of the η: the large abundance of neutral decays could be attributed to the $\pi^0+\gamma$ decay mode which, though radiative, is enhanced with respect to the 3π decay by phase space and centrifugal barrier factors (2).

It is the purpose of this letter to discuss the experimental basis on which the 0^{-+} assignment to the η is made.

The evidence in favour of this assignment can be summarized in the following points:

a) the branching ratio

$$\frac{\rho \to \eta + \pi}{\rho \to \pi + \pi},$$

is less than 0.6% (3);

b) it has been observed (4,5) a radiative decay mode of the η which has been identified (5) as the $\gamma+\gamma$ decay;

c) the Dalitz-Fabri plot of the decay $\eta \to \pi^+\pi^-\pi^0$ shows a flat radial distribution (6).

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(1) P. L. BASTIEN, J. P. BERGE, O. I. DAHL, M. FERRO-LUZZI, D. H. MILLER, J. J. MURRAY, A. H. ROSENFELD and M. B. WATSON: *Phys. Rev. Lett.*, **8**, 114 (1962).

(2) A. FUJII: *Progr. Theor. Phys.*, **27**, 1274 (1962).

(3) A. H. ROSENFELD, D. D. CARMONY and R. T. VAN DE WALLE: *Phys. Rev. Lett.*, **8**, 293 (1962).

(4) C. MENCUCCINI, R. QUERZOLI, G. SALVINI and V. SILVESTRINI: Laboratori Nazionali di Frascati, Rapporto LNF-62/62 (presented to the 1962 International Conference in High Energy Physics at CERN).

(5) M. CHRETIEN, F. BULOS, H. R. CROUCH, R. E. LANOU, J. T. MASSIMO, A. M. SHAPIRO, J. A. AVERELL, C. A. BORDNER, A. E. BRENNER, D. R. FIRTH, M. E. LAW, E. E. RONAT, K. STRAUCH, J. C. STREET, J. J. SZYMANSKI, A. WEINBERG, B. NELSON, I. A. PLESS, L. ROSENSON, G. A. SALANDIN, R. K. YAMAMOTO, L. GUERRIERO and F. WALDNER: *Phys. Rev. Lett.*, **9**, 217 (1962).

(6) C. ALFF, D. BERLEY, D. COLLEY, N. GEL'FAND, U. NAUENBERG, D. MILLER, J. SCHULTZ, J. STEINBERGER, T. H. TAN, H. BRUGGER, P. KRAMER and R. PLANO: *Phys. Rev. Lett.*, **9**, 325 (1962).

As the authors of the quoted letter (3) put in evidence, point *a*) cannot be considered as a sharp argument in favour of the 0^{-+} assignement, due to the uncertainties in the crude evaluations of the branching ratio *a*) for the 1^{--} case.

We will discuss in some detail point *b*).

Using a methil-iodide bubble chamber, CHRETIEN *et al.* (5) (we will hereafter refer to this letter with S) have measured the distribution of the relative angle between γ-rays emerging from the reaction:

$$\pi^- + p \to \text{neutrals} .$$

Looking at this distribution for those events in which only two γ's convert in the chamber, they observe a peak which (after subtraction of the background from events with more than two γ's) is in excellent agreement with the angular distribution expected from the process $\eta \to \gamma + \gamma$.

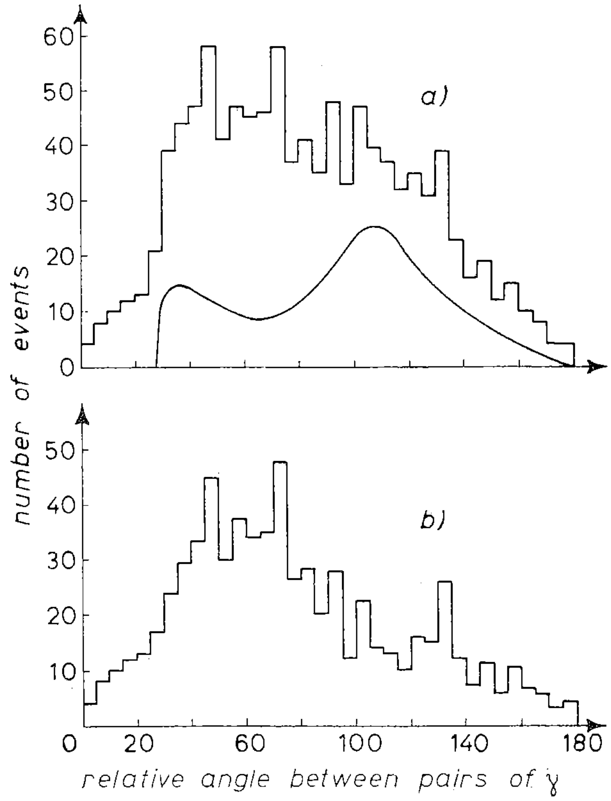

Fig. 1. – *a*) Histogram of the opening angles of the combinations from all 3γ and 4γ events as measured in S. *b*) The histogram of Fig. 1*a* after subtraction of the contribution of the $\pi^0 + \gamma$ decay of the η.

We will try to show that the experimental results of S can perhaps be explained also by the presence of the process $\eta \to \pi^0 + \gamma$.

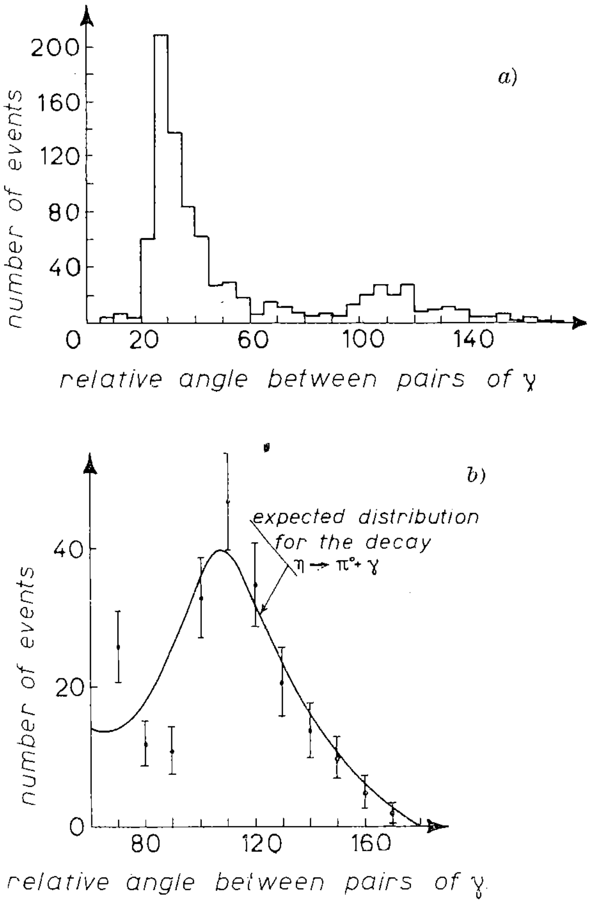

Fig. 2. – *a*) The opening angle distribution of Fig. 2*a* of S, after subtraction of the background (Fig. 1*b*) scaled as in S. *b*) The opening angle distribution of Fig. 2*a*, for angles $\geqslant 60°$, compared with the expected distribution for the decay $\eta \to \pi^0 + \gamma$.

The angular distribution of two γ's from the decay $\eta \to \pi^0 + \gamma$ has been computed by us and is shown in Fig. 1*a* (solid curve). This process should contribute to the angular distribution of the events in which two or three γ's are seen in the chamber.

The hystogram of Fig. 1*a* is the distribution given in S (Fig. 2*b* of S) of the events in which three or four γ's are seen in the chamber. Figure 1*b* is the distribution obtained by subtraction of the solid curve (which represents the contribution of the $\pi^0+\gamma$ decay) from the hystogram of Fig. 1*a*.

By subtraction of distribution 1*b* (scaled as in S) from the experimental angular distribution of the 2γ's events, one gets the distribution shown in Fig. 2*a*). In Fig. 2*b* we make the comparison of this distribution with the expected curve for the $\pi^0+\gamma$ decay, for relative angles $\geqslant 60°$, where the contribution of the γ's from the charge exchange process $\pi^-+p\to\pi^0+n$ is small. To get the relative normalization between the two solid curves of Fig. 1*a* and 2*b* we have assumed that the probability of observing one γ-ray in S was 0.56 (which his the same figure used by the authors to scale the background for subtraction).

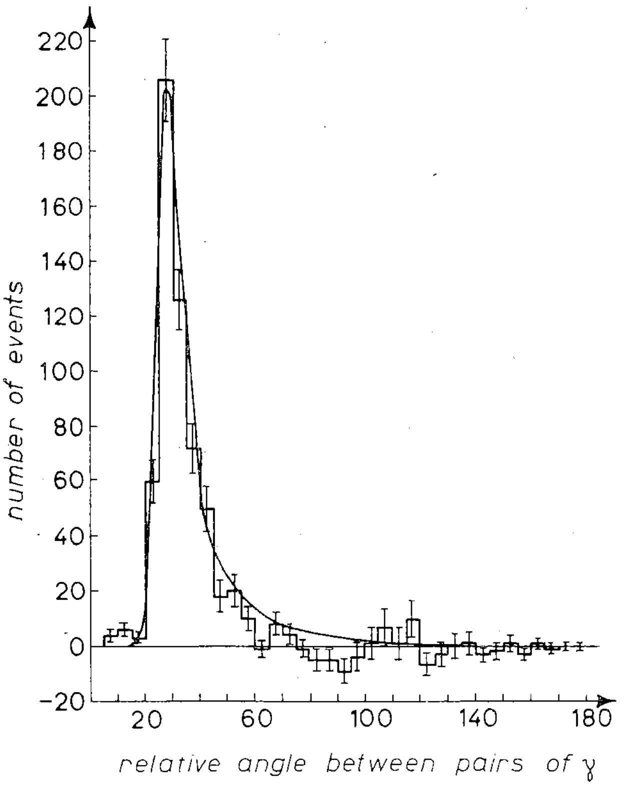

Fig. 3. – The opening angle distribution of Fig. 2*a* after subtraction of the $\eta\to\pi^0+\gamma$ contribution. The solid curve is the expected distribution from the reaction $\pi^-+p\to\pi^0+n$.

Fig. 3 shows what is left, after subtraction of the $\pi^0+\gamma$ contribution, to the γ's from the process $\pi^-+p\to\pi^0+n$. As a conclusion, we think that the experimental results of S are the demonstration of the presence of a radiative decay of the η which is likely to be the $\gamma+\gamma$ decay, but do not exclude the $\pi^0+\gamma$ decay.

Let us now discuss the Dalitz-Fabri plot argument. Such a diagram for all of the events $\eta\to\pi^+\pi^-\pi^0$ to-day available has been published in a recent paper [6]. As the authors put in evidence, a peculiar feature of it is a rather strong final state interaction between the charged pions. Owing to that (and to the fact that the «η's» observed contain a background of uncorrelated 3π production) a connection between the distribution of the points in the diagram and the initial state is rather difficult: as a matter of fact, the experimental results are in disagreement with both of the assignments 0^{-+} and 1^{--} (*).

Information on the quantum numbers of η can however be drawn by an analysis of the final state interaction of the pions. This is experimentally established by the fact that the energy spectrum of the π^0's is modified with respect to the phase-space distribution; this modification is not apparent in the energy spectra of π^+'s and π^-'s. The simplest way of explainihg this fact, is to attribute it to an interaction in the $\pi^+\pi^-$ system, which is absent in the $\pi^+\pi^0$ and $\pi^-\pi^0$ systems [6,7]. It should therefore be a $T=0$ interaction.

If it is so, the 1^{--} assignement is excluded. In fact the 3π's resulting from the η decay should be in a $T=1$ state, and have therefore charge conjugation number $C=+1$. If the η has quantum number 1^{--}, it has $C=-1$ ($C=G$, since for the η $T=0$). The 1^{--} assignement excludes therefore a two-pion $T=0$ interaction in the final state. (The same argument holds for the 1^{+-} assignement.)

(*) See, for instance, BASTIEN *et al.* [1]: the discussion made in this paper is still valid for the complete statistics to-day available.

(7) K. C. WALI: *Phys. Rev. Lett.*, **9**, 120 (1962).

We must say that another possibility is perhaps not escluded: namely that the observed modification of the spectrum is due to a $T=2$ interaction, which should be present in the $\pi^-\pi^0$ and $\pi^+\pi^0$ systems with a factor of 3 with respect to the $\pi^-\pi^+$ system.

If the 3π system is also in a $T=2$ state, this is consistent with the 1^{--} assignement. (This is possible, provided the angular momentum of the interacting pions is $L=2$.)

It is however hard to understand why the η should go into a final state with $T=2$ (violating T), instead of a final state with $T=0$, which is allowed.

In conclusion, we think that the 0^{-+} assignement is strongly suggested by experiment, but that the 1^{--} possibility is not strictly excluded.

A sharp identification of the observed radiative decay of the η would close definitely the question.

This can perhaps be done by the authors of S. In fact, if the radiative decay mode of the η is the $\pi^0+\gamma$, this should result in:

a) a rather large abundance of the 3γ-events with respect to the 4γ-events;

b) the distribution of the relative angle of two γ's from the 3γ-events should contain — overimposed on the rather flat distribution due to the $2\pi^0$ production — the peculiar curve of Fig. 1*a*, with a weight of about 50%.

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