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

Nota interna: n° 170
22 Novembre 1962

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Recent experimental work has lead to the conclusion that the η has quantum numbers 0^{-+} (spin 0, parity - 1, G-parity + 1). This assignment, 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, do 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 ma de.

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

a) the branching ratio $\frac{e \to \eta + \pi}{e \to \pi + \pi}$ 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).

As the authors of the quoted letter (3) put in evidence, point a) connot be considered as a sharp argument in favour of the 0^{-+} assignment, 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:

$$\pi^- + p \longrightarrow \text{neutrals}$$

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

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

The angular distribution of two γ's from the decay $\eta \to \pi^0 + \gamma$ has been computed by us and it is shown in fig. 1a (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. 1a is the distribution given in S (fig. 2b of S) of the events in which three or four γ's are seen in the chamber. Fig. 1b is the distribution obtained by substraction of the solid curve (which represent the contribution of the $\pi^0 + \gamma$ decay) from the hystogram of fig. 1a.

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

On Fig. 3 it is shown what is left, after substraction of the $\pi^0 + \gamma$ contribution, to the γ's from the process $\pi^- + p \rightarrow \pi^0 + n$. 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 $\eta \rightarrow \pi^+\pi^-\pi^0$ 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 diffucult: as a matter of fact, the experimental results are in disagreement with both of the assignments 0^{-+} and 1^{--}(x).

The assignment of the quantum numbers to the η is therefore left, in our opinion, to the following point: which assignment is consistent with the observed final state interaction of the pions. In this frame we are lead to a rather conclusive argument in favour of the 0^{-+} assignment. Let us consider, in fact, the interaction of the pions: since it is present in the $\pi^+\pi^-$ system, but not in the $\pi^+\pi^0$ and $\pi^-\pi^0$ systems, it must be a $T = 0$ state. The three pions resulting from the η decay are thus in a $T = 1$ state, and have therefore charge conjugation C equal to + 1. If the η has quantum numbers 1^{--}, it has $C = -1$ ($C = G$, since for the η $T = 0$). The observed final state interaction of the pions excludes therefore the 1^{--} assignment, according to the conservation of the C - quantum number.

Although we are not yet able to understand the observed branching ratios of the η decay for the 0^{-+} assignment(1,7)(*), we must conclude that this is the only possibility not ruled out by experiment.

(x) - See, for instance, Bastien et al., Phys. Rev. Lett. 8, 114 (1962): the discussion made in this paper is still valid for the complete statistics to-day available.

(*) - Recent calculations done by H. Shimodaria (to be published) show that the branching ratio puzzle can be overcome in some way.

A sharp identification of the observed radiative decay of the η should be welcome in any case. 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 3 γ-events with respect to the 4 γ -events.

b) The distribution of the relative angle of two γ's from the 3 γ-events should contain - overposed to the rather flat distribution due to the 2 π^0 production -the peculiar curve of fig. 1a), with a weight of about 50%.

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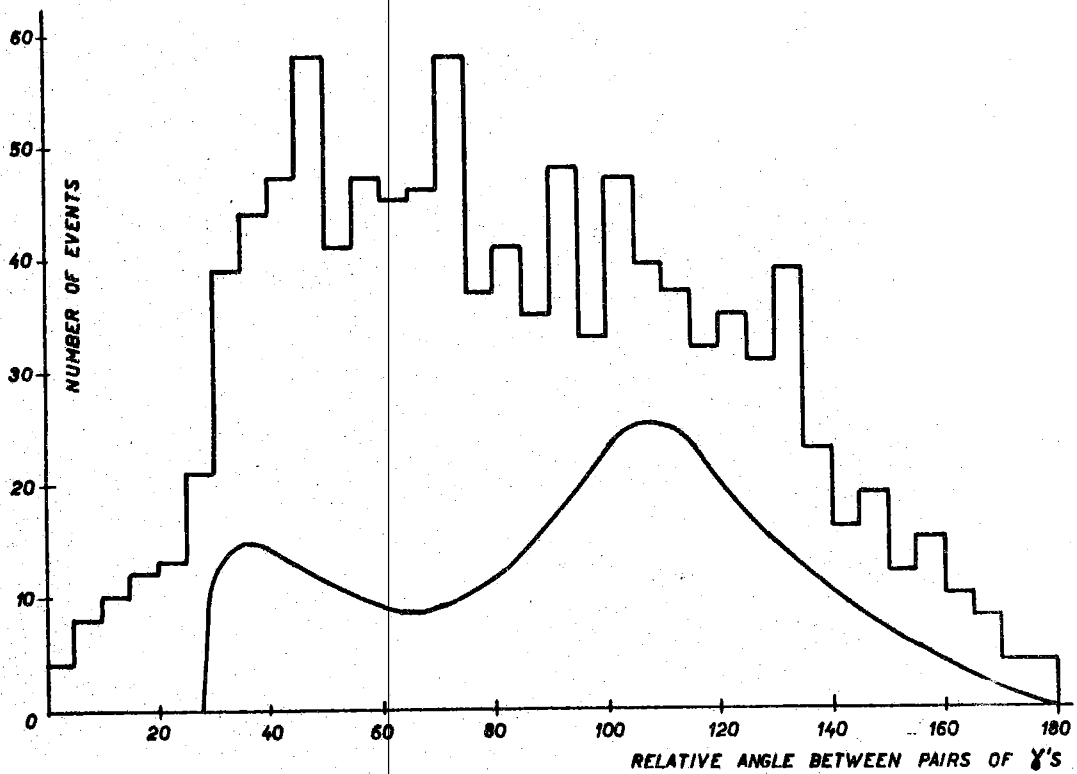

FIG. 1a

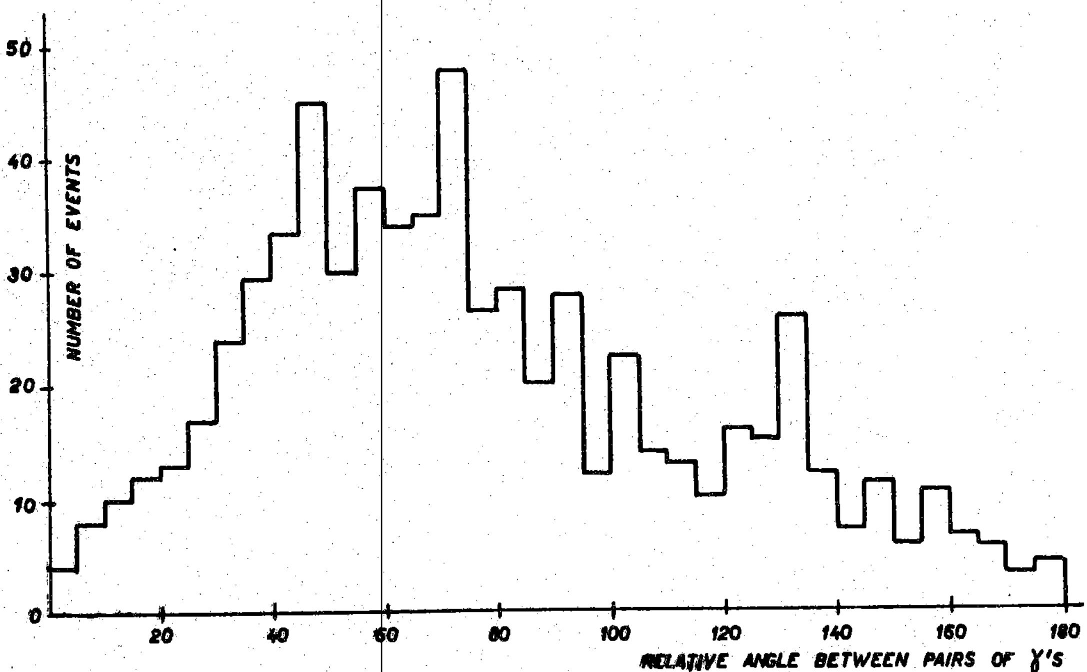

FIG. 1b

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

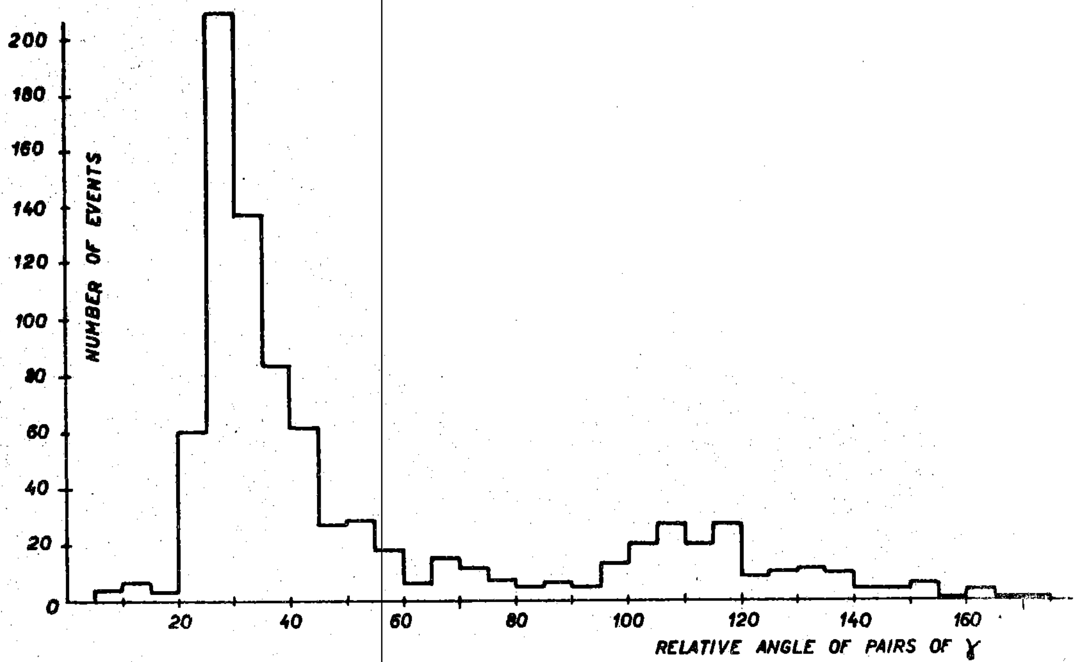

FIG. 2a

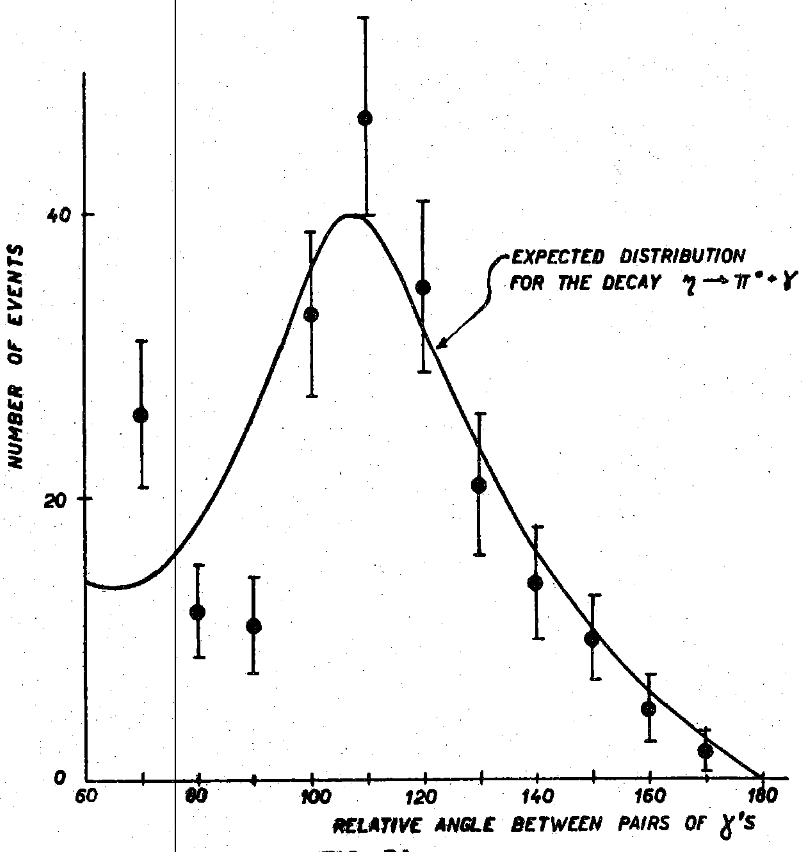

FIG. 2b

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

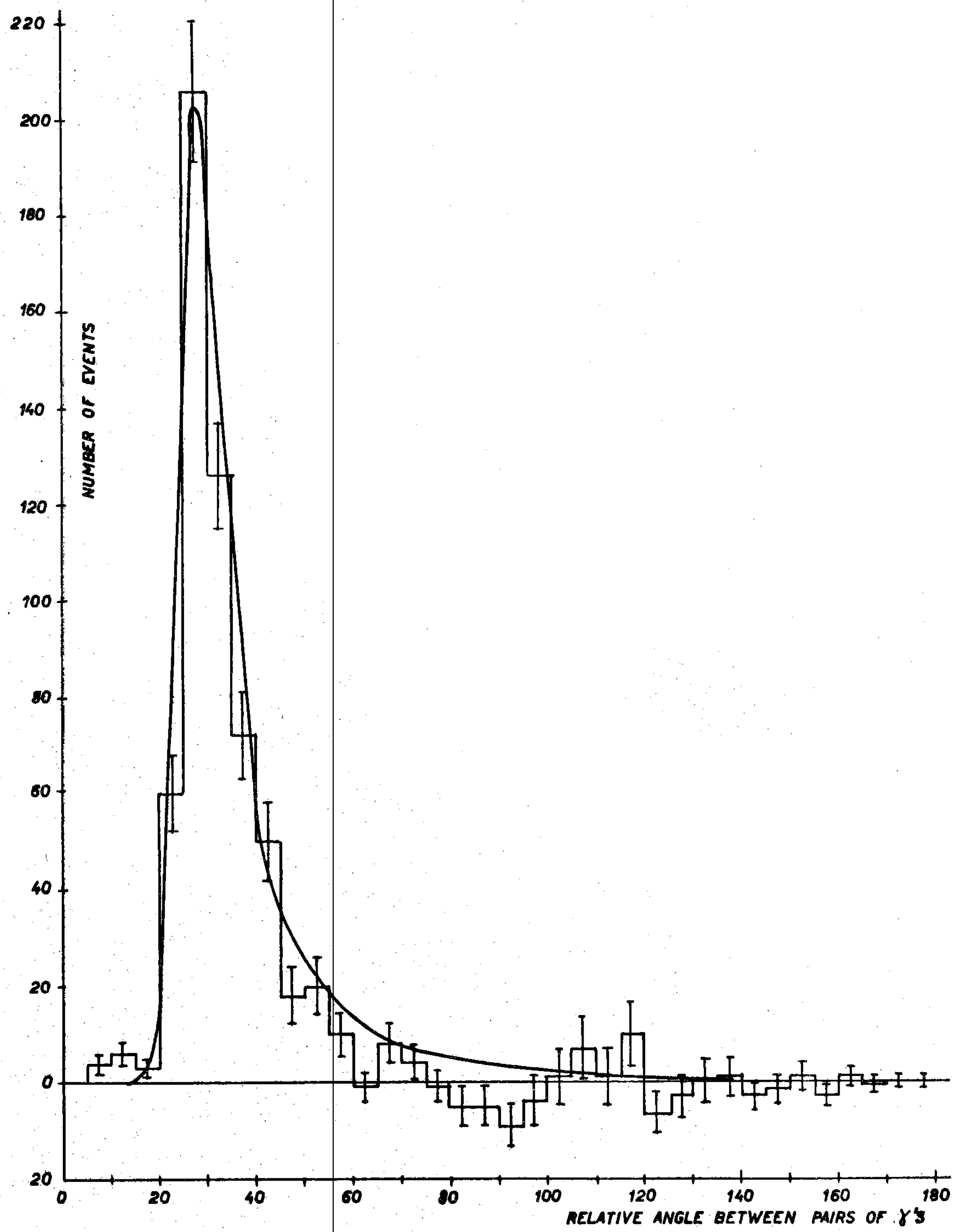

FIG. 3

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