HEAVY LIQUID CHAMBER ANALYSIS OF $\eta^0 \to 3\pi$ AND $\eta^0 \to \gamma\gamma$ DECAY-MODES

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From 199 $\eta^0 \to 3\pi^0 \to 6\gamma$, 526 $\eta^0 \to \pi^+\pi^-\pi^0$ and 401 $\eta^0 \to \gamma\gamma$ events with all γ-rays reconstructed in a heavy liquid bubble chamber, we obtain direct and independent measurements of the branching ratios: $R_1 = \Gamma(\eta^0 \to 3\pi^0)/\Gamma(\eta^0 \to \pi^+\pi^-\pi^0) = 1.50 {}^{+0.15}_{-0.29}$ and $R_2 = \Gamma(\eta^0 \to \gamma\gamma)/\Gamma(\eta^0 \to \pi^+\pi^-\pi^0) = 1.72 \pm 0.25$. We also study the Dalitz-plots for the modes $\eta^0 \to 3\pi^0$ and $\eta^0 \to \pi^+\pi^-\pi^0$, and find no significant variation of the amplitude of the decay $\eta^0 \to 3\pi^0$.

Previous experiments on eta meson neutral decay modes have yielded often contradictory results [1]. In most of these experiments, the number of γ-rays actually produced in the observed events remained unknown and the relative decay rates were fitted in order to explain some experimental distribution [2-4]. In contrast, for events selected in the present experiment [15], all the γ-rays from the decays $\eta^0 \to 3\pi^0 \to 6\gamma$, $\eta^0 \to \pi^+\pi^-\pi^0(\pi^0 \to \gamma\gamma)$ and $\eta^0 \to \gamma\gamma$ are detected by electron pair production in the Ecole Polytechnique Heavy Liquid Bubble Chamber, and their momenta are measured by the Behr-Mittner method. The branching ratios $R_1 = \Gamma(\eta^0 \to 3\pi^0)/(\Gamma(\eta^0 \to \pi^+\pi^-\pi^0)$ and $R_2 = \Gamma(\eta^0 \to \gamma\gamma)/\Gamma(\eta^0 \to \pi^+\pi^-\pi^0)$ are thus obtained independently of each other and free of background from other possible neutral modes, e.g. $\pi^0\gamma\gamma$. The η^0 mesons were produced via $\pi^- p \to \eta^0 n$ by 950 MeV/c π^- from the Saclay 3 GeV proton synchrotron. The $1 \times \frac{1}{2} \times \frac{1}{2}$ m^3 bubble chamber was filled for a part of the film with pure freon CF_3Br (11 cm radiation length) and for the other part with a mixture of propane C_3H_8 and freon CF_3Br (20 cm radiation length). The experimental procedure is described further elsewhere [5].

I) $R_1 = \Gamma(\eta^0 \to 3\pi^0)/\Gamma(\eta^0 \to \pi^+\pi^-\pi^0)$. The sample of $\eta^0 \to \pi^+\pi^-\pi^0$ decays has been obtained as described in ref. 6. For the numerator sample, we retain only events with all 6 γ's converted. The film was scanned twice for 6 γ-events with a combined scanning efficiency of about 98% for the events surviving the cuts as described below. Events with 4 γ's or 5 γ's simulating 6 γ production by bremsstrahlung of a conversion electron are removed by cut-offs on the angles between pairs of γ-rays [5]. Only 17% of acutal η^0 events are lost by this requirement which eliminates virtually all bremsstrahlung γ-rays as we have confirmed by inspection of the photographs. Other cuts [5] have been applied to suppress background events containing among the six a spurious γ from another source. The background of non 6 γ-events in those surviving our cuts is less than 12% (90% confidence), as estimated by determining the

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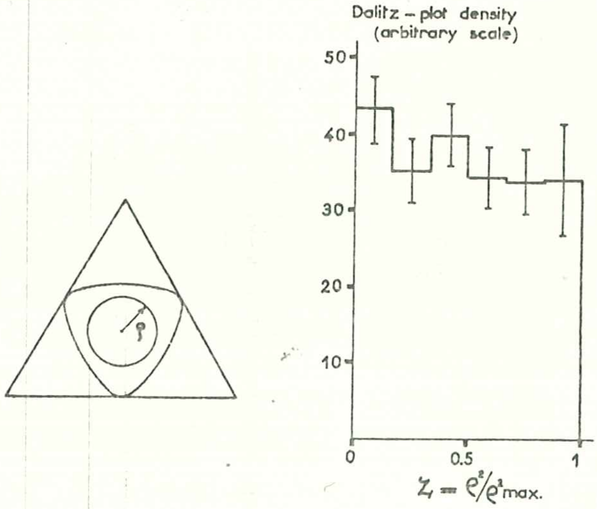

Fig. 1. Dalitz plot apparent density for $\eta^o \rightarrow 3\pi^o$ as a function of

$$z = \frac{2}{3}\sum_{i=1}^{3}\left[\frac{3}{M_\eta - 3m_\pi}(E_i - \tfrac{1}{3}M_\eta)\right]^2$$

By "apparent density", we mean that the actual density is deformed by the measurement errors and by weighting procedure. If α' is the apparent slope of $M^2 = A(1+2\alpha z)$, Monte Carlo calculations show α'/α is of the order of 0.4.

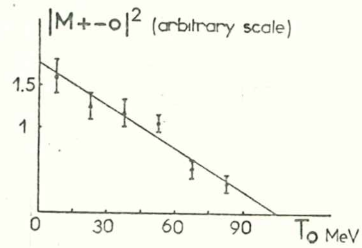

Fig. 2. Dalitz plot density for $\eta^o \rightarrow \pi^+\pi^-\pi^o$ as a function of T_o.

probability for a given interaction to have a spurious γ-ray pointing to it by chance.

The production of more than 3π's is highly improbable at the energy chosen for the beam. Hence, any contamination of our sample of 6 γ-events is due to non eta $3\pi^o$ production. From direct fits of the observed $3\pi^o$ -mass distribution to that expected from the incoherent sum of 3π-phase space production plus eta production, and taking into account measurement errors, we find that the background of non eta $3\pi^o$ events is less than 21% (68% confidence). We have checked previously that the estimated errors on γ-ray momenta account for our observed $\pi^o \rightarrow \gamma\gamma$ mass and χ^2 distributions [5].

Using a theoretical model [14], a similar heavy liquid bubble chamber experiment [8] concludes that the production of non eta $\pi^o\pi^o\pi^o$ events is less favoured than the production of non eta $\pi^+\pi^-\pi^o$ events, the latter being estimated in our experiment to be (13 ± 3)% of $\eta^o \rightarrow \pi^+\pi^-\pi^o$ events from the data of refs. 10 and 11. This order of magnitude is further confirmed by a study in our film of the production of $\pi^+\pi^-\pi^-$ events.

Correcting for γ detection efficiencies ($\sim$ 0.7 per γ in the freon and $\sim$ 0.5 per γ in the mixture) and for the effects of the cuts, we find $R_1 = 15.2^{+0.17}_{-0.33}$ in the freon sample, and $R_1 = 1.45^{+0.29}_{-0.42}$ in the mixture. The agreement between these two results is a check of our estimates of γ detection efficiencies since the ratio of 6 γ to 2 γ detection efficiencies is about three times greater in the freon than in the mixture. Combining these results we find $R_1 = 1.50^{+0.15}_{-0.29}$. The asymmetric error is due mainly to the non eta $3\pi^o$ background uncertainty. This error cannot be compared directly with that of ref. 8 where the amount of non eta $3\pi^o$ background is estimated theoretically.

Our final result confirms our preliminary value 1.3 ± 0.4 presented elsewhere [7]. It agrees well with other recent experiments [3,4,8,9].

II) $R_2 = \Gamma(\eta^o \rightarrow \gamma\gamma)/\Gamma(\eta^o \rightarrow \pi^+\pi^-\pi^o)$. Our measurement of this ratio is based on only a part of our film which contains 401 $\eta^o \rightarrow \gamma\gamma$ and 214 $\eta^o \rightarrow \pi^+\pi^-\pi^o$ events with all γ-rays detected. The $\eta^o \rightarrow \gamma\gamma$ candidates were required to have the angle between the 2 γ- rays projected on the scanning table > 90o. This criterion eliminates 86% of $\pi^o \rightarrow \gamma\gamma$ events.

The main background for $\eta^o \rightarrow \gamma\gamma$ events is due to the reaction $\pi^-p \rightarrow \pi^o\pi^o n$ in which two photons escape detection. This background is easily estimated and removed using distributions obtained from events with 3 γ detected [5]. We then find R_2 = 1.72 ± 0.25.

Combining our two independent measurements we find $R_1 + R_2 = 3.22^{+0.29}_{-0.38}$ compared with the world average [1] deduced from hydrogen bubble chamber experiments $\Gamma(\eta^o \rightarrow$ all neutrals$)/\Gamma(\eta^o \rightarrow \pi^+\pi^-\pi^o)$ = 3.35 ± 0.35. (We do not use the fitted value given in ref.1 which already takes account of experiments on neutral modes.) Our results are thus compatible with the absence of the mode $\eta^o \rightarrow \pi^o\gamma\gamma$, in agreement with recent experiments on this mode [1].

III A) Dalitz plot analysis for $\eta^o \rightarrow 3\pi^o$ decays. The present data on the Dalitz plot of the decay $\eta^o \rightarrow \pi^+\pi^-\pi^o$ are well fitted by a matrix element linear in the kinetic energy of the neutral pion. Upper limits on possible quadratic terms have been reported [12]. Up to now, there has been no investigation of the Dalitz plot of the decay $\eta^0 \to 3\pi^0$, in which the linear term must vanish as a result of the symmetry among the three pions. The matrix element squared can be described to lowest order in the pion energies by a constant plus one quadratic term: $|M_{000}|^2 = A(1 + 2\alpha z)$ where

$$z = \tfrac{2}{3}\sum_{i=1}^{3} y_i^2 \text{ and } y_i = 3(E_i - \tfrac{1}{3}M_\eta)/(M_\eta - 3m_\pi)\ .$$

z varies from 0 to 1 and is proportional to ρ^2, where ρ is the distance to the center of the Dalitz plot.

The measurement of all γ-rays produced in the decay $\eta^0 \to 3\pi^0 \to 6\gamma$ allows the reconstruction of the π^0's and a study of the Dalitz plot for this decay. A priori, there are 15 ways of pairing 6γ's into $3\pi^0$'s. For each of these 15 hypotheses we have fitted the γ-ray momenta and directions to the four constraints that each of the 3 pairs of γ-rays must have the π^0 mass and the six γ-rays must have the η^0 mass. Each hypothesis is then given a weight proportional to its likelihood, calculated as indicated in ref. 5. Typically some three hypotheses make a significant contribution.

From our sample of 199 $\eta^0 \to 3\pi^0 \to 6\gamma$ candidates, we find $\alpha = -0.32 \pm 0.37$ or $-0.86 < \alpha < 0.2$ with 90% confidence. The confidence limits take account of the effect of the measurement errors on γ-ray momenta (calibrated by a study of observed $\pi^0 \to \gamma\gamma$ distributions [5]), and of the effects of the fitting and of the weighting procedures. This result is compatible with a constant matrix element (fig. 1).

III B) Dalitz plot for $\eta^0 \to \pi^+\pi^-\pi^0$. For these events the π^0 kinetic energy T_0 in the η^0 rest-frame is reconstructed with an average precision of 5 MeV in the two constraint unambiguous fit $\eta^0 \to \pi^+\pi^-\pi^0 \to \pi^+\pi^-\gamma\gamma$. Small corrections have been made to the T_0 spectrum to account for effects of our cuts and to remove 13% non-resonant $\pi^+\pi^-\pi^0$ background. These corrections vary by less than 8% accross the T_0 spectrum. The resulting spectrum can be fitted well by a matrix element squared linear in T_0

$$|M_{+-0}|^2 = B\left[1 - 2a\left(\frac{3T_0}{m_\eta - 3m_\pi} - 1\right)\right]$$

with:
$a = 0.41 \pm 0.04$ (fig. 2) in agreement with previous results [11-13].

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15. The work on part I of this letter was done mainly in Paris and Berkeley, part II in Paris, Madrid and Strasbourg, part III in Paris and Strasbourg. The value of R_1 given here supersedes those given in W. Michael, U. C. Berkeley Thesis (1967), and in G. Irwin et al., Bull. Am. Phys. Soc. 13 (1968) 1641.

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