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SEARCH FOR $\eta^0 \rightarrow e^+ + e^- + \pi^0$

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Search for $\eta^0 \rightarrow e^+ + e^- + \pi^0$ *

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It has been suggested that the observed CP violation in K_2^0 decay may be due to the existence of C-violating (but P-conserving) interactions.[1,2] If C is not conserved, the decay

$$\eta^0 \rightarrow \pi^0 e^+ e^- \tag{1}$$

can proceed through one virtual gamma ray γ_v via $\eta^0 \rightarrow \pi^0 \gamma_v \rightarrow \pi^0 e^+ e^-$ with a rate $\Gamma(\pi^0 e^+ e^-)$ proportional to α^2, and hence with $\Gamma(\pi^0 e^+ e^-)$ perhaps comparable to the rate $\Gamma(\gamma\gamma)$ for

$$\eta^0 \rightarrow \gamma\gamma.^{3,4} \tag{2}$$

If C is conserved, reaction (1) can still proceed via two virtual gamma rays through $\eta^0 \rightarrow \pi^0 \gamma_v \gamma_v \rightarrow \pi^0 e^+ e^-$. Then $\Gamma(\pi^0 e^+ e^-)$ is proportional to α^4 and hence perhaps $\Gamma(\pi^0 e^+ e^-) \approx \alpha^2 \Gamma(\gamma\gamma)$.

We have searched for reaction (1) in a sample of etas produced in the reactions

$$\pi^\pm p \rightarrow \pi^\pm p \eta^0, \tag{3}$$

using incident π^+ and π^- of about 1 BeV/c in the Alvarez 72-inch hydrogen chamber. We find one good candidate and three rather poor candidates for the decay (1). All four candidates are also good fits to

$$\eta^0 \rightarrow \pi^+ \pi^- \gamma. \tag{4}$$

To obtain an upper limit for $\Gamma(\pi^0 e^+ e^-)$ we assume that the one good candidate is a real decay (1). Based on 219 observed decays

$$\eta^0 \rightarrow \pi^+\pi^-\pi^0 \tag{5}$$

obtained from the same sample of etas[5,6,7,8] and on a compiled[9] branching ratio for $\Gamma(\gamma\gamma)/\Gamma(\pi^+\pi^-\pi^0)$, we find an upper limit of

$$\Gamma(\pi^0 e^+ e^-)/\Gamma(\gamma\gamma) \leq (0.7 \pm 0.7) \times 10^{-2}. \tag{6}$$

Our result (6) is compatible with C-invariance.

The remainder of this Letter is devoted to experimental details. Our initial sample of events consists of about 4000 four-prongs produced by 1170 MeV/c π^+,[5,6,7] 5000 produced by 1170-MeV/c π^-,[8] and 2000 produced by 1050-MeV/c π^+.[8] Protons are identified on the scanning table by their bubble density. All events are fit to a number of hypotheses (described below) and then a series of cutoffs is applied. For each cutoff we estimate the fractional loss of decays of the type (1) under the assumption that the decay spectrum follows phase space.[10] The estimated corrections are made using the event-simulating program FAKE.[11] The fitted hypotheses and cutoffs are as follows:

1. Four-Constraint (4C) Fit. If χ^2 for the reaction

$$\pi^\pm p \rightarrow \pi^\pm p \pi^+ \pi^- \tag{7}$$

is less than 60, we reject the event. This cutoff removes about 2% of the decays from reaction (1).

2. Coulomb-Scatter Fit. One of the four final tracks is deleted, and the remaining tracks are then fit (1C) to reaction (7). Events for which χ^2 is less than 6 are rejected, provided that $\theta p \beta$ is less than 4000 deg-MeV/c, where θ is the space angle between the fitted and measured momenta of the deleted track, and p is the fitted momentum of this track. About 5% of reaction (1) is removed by this criterion.

3. $\pi^+\pi^-\pi^0$ Production. The events are fit (1C) to the reaction

$$\pi^\pm p \rightarrow \pi^\pm p \pi^+ \pi^- \pi^0 \tag{8}$$

and are rejected if χ^2 is less than 8. This removes all of the etas decaying into $\pi^+\pi^-\pi^0$ and removes about 4% of reaction (1).

4. <u>$e^+e^-\pi^0$ Production.</u> If χ^2 for the fit (1C) to

$$\pi^{\pm}p \rightarrow \pi^{\pm}pe^+e^-\pi^0 \tag{9}$$

is less than 8, the event is kept. This retains 96% of the events of type (1). However, along with the desired events (1) we also expect to retain a background of events which spuriously fit reaction (9) but which are actually due to the Dalitz decay

$$\pi^0 \rightarrow e^+e^-\gamma. \tag{10}$$

The π^0's are produced in one of the reactions

$$\pi^{\pm}p \rightarrow \pi^{\pm}p\pi^0, \tag{11}$$

$$\pi^{\pm}p \rightarrow \pi^{\pm}p\pi^0\pi^0, \tag{12}$$

or

$$\pi^{\pm}p \rightarrow \pi^{\pm}p\pi^0\pi^0\pi^0, \tag{13}$$

where (13) is mostly[6] due to eta decay,

$$\eta^0 \rightarrow 3\pi^0. \tag{14}$$

Another possible source of background π^0's for Dalitz decay (10) is eta production via (3) and decay via[12]

$$\eta^0 \rightarrow \pi^0\gamma\gamma. \tag{15}$$

Another source of background for reaction (9) is eta decay via internal conversion of one of the gamma rays corresponding to the decays (2) and (15), i.e.

$$\eta^0 \rightarrow \gamma\gamma_v \rightarrow \gamma e^+e^- \tag{16}$$

or

$$\eta^0 \rightarrow \pi^0\gamma\gamma_v \rightarrow \pi^0\gamma e^+e^-. \tag{17}$$

The existence of these expected spurious contributions to the fits to reaction (9) is confirmed in a plot of the missing mass recoiling against the final $\pi^{\pm}p$ for the events that fit (9). The plot exhibits a pronounced peak at the π^0 mass,

corresponding to (11), a continuum that we believe corresponds to (12), and a peak at the η mass corresponding to (10) with (14) or (15), and to (16) and (17).

5. Cutoff on $m(e^+e^-)$. For events that fit (9) we calculate the invariant mass $m(e^+e^-)$, using measured (rather than fitted) momenta for the e^+ and e^-. If $m(e^+e^-)$ is less than 100 MeV we reject the event. This cutoff removes essentially all of the background due to internal conversion as discussed in the preceding paragraph.[13] In addition it removes about 40% of the desired reaction (1).[14]

6. 2C Fits to Eta Production. The surviving events are fit to eta production (3) followed by eta decay via $e^+e^-\pi^0$, reaction (1), or $\pi^+\pi^-\gamma$, reaction (4). Only events for which χ^2 is less than 15 for reaction (1) are retained. This cutoff removes about 4% of the desired events (1). No cutoff is imposed on the fits to reaction (4).

7. Scanning-Table Examination. The survivors were examined on the scanning table. Several pions with flat tracks had less than 150 MeV/c and were distinguished from electrons by their bubble density. Several pions were found to interact and were thus distinguished from electrons.

Finally we are left with the four candidates summarized in Table I. (In no case can the possible electrons be distinguished from pions by examination on the scanning table.)

Table I. Summary of the four candidates for reaction (1).

	χ^2 (2C)		
Event	$\eta \to e^+e^-\pi^0$	$\eta \to \pi^+\pi^0\gamma$	$m(e^+e^-)$
974 550	3.4	2.3	339
1 386 444	7.5	2.8	190
2 159 366	11.2	0.7	375
2 198 452	10.8	2.2	139

The second, third, and fourth candidates are rather poor fits to reaction (1) and are good fits to reaction (4). We estimate (using FAKE) that 4% of $\eta \to \pi^+\pi^-\gamma$ should fit $\eta \to e^+e^-\pi^0$ with χ^2 (2C) < 15. Using the measured[5] branching ratio $\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ and the number of etas in our sample, we estimate an a priori expected 2.4 events $\eta \to \pi^+\pi^-\gamma$ contributing to Table I.

As an upper limit we assume that event 974 550 is real. Our overall detection efficiency for reaction (1) as determined from FAKE is 0.39, giving us 2.6 ± 2.6 "corrected" events $\eta \to e^+e^-\pi^0$. The corrected number of decays $\eta \to \pi^+\pi^-\pi^0$ in our sample is 236.4. Thus we find as an upper limit

$$\Gamma(e^+e^-\pi^0)/\Gamma(\pi^+\pi^-\pi^0) \leq 2.6 \pm 2.6/236.4 = (1.1 \pm 1.1) \times 10^{-2},$$

which is equivalent[9] to (6).

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FOOTNOTES AND REFERENCES

*This work was done under the auspices of the U. S. Atomic Energy Commission.

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9. A. H. Rosenfeld, A. Barbaro-Galtieri, W. H. Barkas, P. L. Bastien, J. Kirz, and M. Roos, Lawrence Radiation Laboratory Report UCRL-8030 Part I, March 1965 Edition give $\Gamma(\gamma\gamma)/\Gamma(\pi^+\pi^-\pi^0) = 1.54 \pm 0.20$.
10. According to Ref. 4 the spectrum of the e^+ energy k_+ and e^- energy k_- in the eta rest frame is $dk_+ dk_- [4k_+k_- - 2m_\eta(k_+ + k_-) + (m_\eta^2 - m_\pi^2)]$. This distribution is close enough to that for phase space so that our correction factors based on phase space are not significantly affected.
11. G. R. Lynch, "Program FAKE: Monte Carlo Simulation of Bubble Chamber Events." Lawrence Radiation Laboratory Report UCRL-10335, July 10, 1962.

12. The decay (15) has not been established experimentally; it is not easily distinguished from $\eta^0 \rightarrow 3\pi^0$. In Ref. 6, reaction (15) was assumed to be absent. Its rate may be nonnegligible if the A-invariance postulated by J. B. Bronzan and F. E. Low, Phys. Rev. Letters 12, 522 (1964) actually holds.

13. In the internal-conversion processes (10), (16), and (17) the virtual γ is "almost real" and the distribution in $m(e^+e^-)$ is very strongly peaked towards small values. See N. Kroll and W. Wada, Phys. Rev. 98, 1355 (1955).

14. The decay $\eta \rightarrow \gamma\pi^0$ with a real γ is forbidden by angular-momentum conservation. The internally converted virtual γ in reaction (1) is therefore not "almost real" and thus the distribution in $m(e^+e^-)$ is not strongly peaked towards low values. The cutoff at 100 MeV would remove about 20% of reaction (1) if we could always distinguish electrons from pions. Because we usually cannot distinguish $e^\pm$ from $\pi^\pm$, and because reaction (9) often fits with either of the two possibilities for the electron, we apply the cutoff to both possibilities and lose about 40% of reaction (1).

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