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SEARCH FOR DECAY MODES $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$ AND $\eta \rightarrow \pi^+\pi^-\gamma\gamma$

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UCRL-17569
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
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AEC Contract No. W-7405-eng-48

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LeRoy R. Price and Frank S. Crawford, Jr.

May 16, 1967

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On the basis of 219 observed eta decays of the type

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

and on zero observed candidates for decays of the type

$$\eta \to \pi^+\pi^-\pi^0\gamma \tag{2}$$

or of the type

$$\eta \to \pi^+\pi^-\gamma\gamma, \tag{3}$$

we find the experimental upper limits

$$R \equiv \frac{\Gamma(\pi^+\pi^-\pi^0\gamma)}{\Gamma(\pi^+\pi^-\pi^0)} < 0.9\%, \tag{4}$$

and

$$R' \equiv \frac{\Gamma(\pi^+\pi^-\gamma\gamma)}{\Gamma(\pi^+\pi^-\pi^0)} < 0.9\%. \tag{5}$$

Simple arguments based on phase space and powers of α give the predictions $R \simeq 1$, and $R' \simeq 10^{-2}$, in contrast with our result in Eq. (4).

Using a model based on the effective decay $\eta \to \pi\rho\gamma$, Singer[1] predicts $\Gamma(\pi^+\pi^-\pi^0\gamma)/\Gamma(\pi^0\gamma\gamma) \simeq 0.2\%$. If we assume $\Gamma(\pi^0\gamma\gamma)$ to be about equal[2] to $\Gamma(\pi^+\pi^-\pi^0)$, then Singer's model predicts $R \simeq 0.2\%$.

Our initial sample of four-prong events, produced in the 72-inch hydrogen bubble chamber, consists of: 4000 events[3,4,5] from 1170-MeV/c π^+; 5000 events from 1170-MeV/c π^-; and 2000 events from 1050-MeV/c π^+. The eta decays of type (1) were previously extracted

from the sample under the assumption that decays of types (2) and (3) do not occur. These events were contributed to the eta compilation paper.[6] They are practically free of non-eta-decay background. In the present experiment to search for decays of types (2) and (3) we have reprocessed the entire sample of four-pronged events. We apply the following uniform criteria to the complete sample:

1. Four-constraint (4C) fit. All events are fit to the reaction

$$\pi^{\pm} p \rightarrow \pi^{\pm} p \pi^{+} \pi^{-} .$$

If χ^2 for this reaction is less than 35, the event is rejected.

2. Cut on eta mass. The mass recoiling against the final $\pi^{\pm} p$ is calculated from unfit measured quantities. If this mass is inside the eta-mass region $[0.28 \leq m_{\eta}^2 \leq 0.32 (\mathrm{BeV})^2]$, the event is retained; otherwise it is discarded.[7]

3. Mass plot of missing neutral. The missing mass recoiling against all four final charged tracks is calculated. A plot of the spectrum appears in Fig. 1. The figure shows clear peaks at the γ and π^0 masses.

At that stage the sample is not yet "cleaned up," in the sense that it includes some events that are not actually of the desired type

$$\pi^{\pm} p \rightarrow \pi^{\pm} p \pi^{+} \pi^{-} (x^0) . \qquad (6)$$

It also includes some events of the types

$$\pi^{\pm} p \rightarrow \pi^{\pm} p e^{+} e^{-} (x^0) ,$$
$$\pi^{\pm} p \rightarrow \pi^{\pm} \pi^{+} n \pi^{+} \pi^{-} (x^0) ,$$

where x^0 denotes missing neutrals. It also includes events of type (6) for which the proton has not yet been identified on the scanning table.

4. Scanning-table examination. All events with $m^2(x^0) > 0.03$ are carefully examined on the scanning table. The five shaded events in Fig. 1

were determined to be from reactions other than type (6) and were removed from the sample. (Three events involved Dalitz-pair electrons; the other two were not four-pronged events.) The scanning-table examination was not pursued for $m^2(x^0) < 0.03$, since the entire sample of etas[6] was previously cleaned up on the scanning table, and since the radiative decays of types (2) and (3) cannot easily be separated from the normal charged eta decays, for $m^2(x^0) < 0.03$.

Curve (a) in Fig. 1 is calculated from Singer's[1] matrix element for $\eta \to \pi^+\pi^-\pi^0\gamma$. Curve (b) is calculated from the "simplest" gauge-invariant matrix element for $\eta \to \pi^+\pi^-\gamma\gamma$, which is

$$M(\eta \to \pi^+\pi^-\gamma\gamma) = (\underline{\epsilon}_1 \cdot \underline{\epsilon}_2)(\underline{k}_1 \cdot \underline{k}_2) - (\underline{\epsilon}_1 \cdot \underline{k}_2)(\underline{\epsilon}_2 \cdot \underline{k}_1),$$

where $\underline{\epsilon}_1$, $\underline{\epsilon}_2$, $\underline{k}_1$, $\underline{k}_2$ are the four-vector polarizations and momenta of the photons.[8] From Fig. 1 we find that a cut off at $m^2(x^0) = 0.038$ gives a detection efficiency of 43% for $\eta \to \pi^+\pi^-\pi^0\gamma$ and 42% for $\eta \to \pi^+\pi^-\gamma\gamma$. There are no other correction factors for these two modes.[9]

The corrected number of decays $\eta \to \pi^+\pi^-\pi^0$ in our sample is 255. On the basis of observing zero events above $m^2(x^0) = 0.038$, we find the upper limits (which would correspond to observing a single event) to be

$$R < (1/0.43)/255 = 0.9\%$$

$$R' < (1/0.42)/255 = 0.9\%.$$

A previous measurement by Flatté[10] gave $R < 7\%$.

We are grateful to Earle C. Fowler, Ronald A. Grossman, and L. J. Lloyd for their contributions to the data analysis, and to Luis W. Alvarez for his interest and support.

FOOTNOTES AND REFERENCES

†Work done under the auspices of the U. S. Atomic Energy Commission.

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7. Since there are always two pions of the same charge in the final state, and either one of them could have come from an eta decay, there are actually two missing masses calculated for each event. If either (or both) mass is in the eta region, the event is retained.

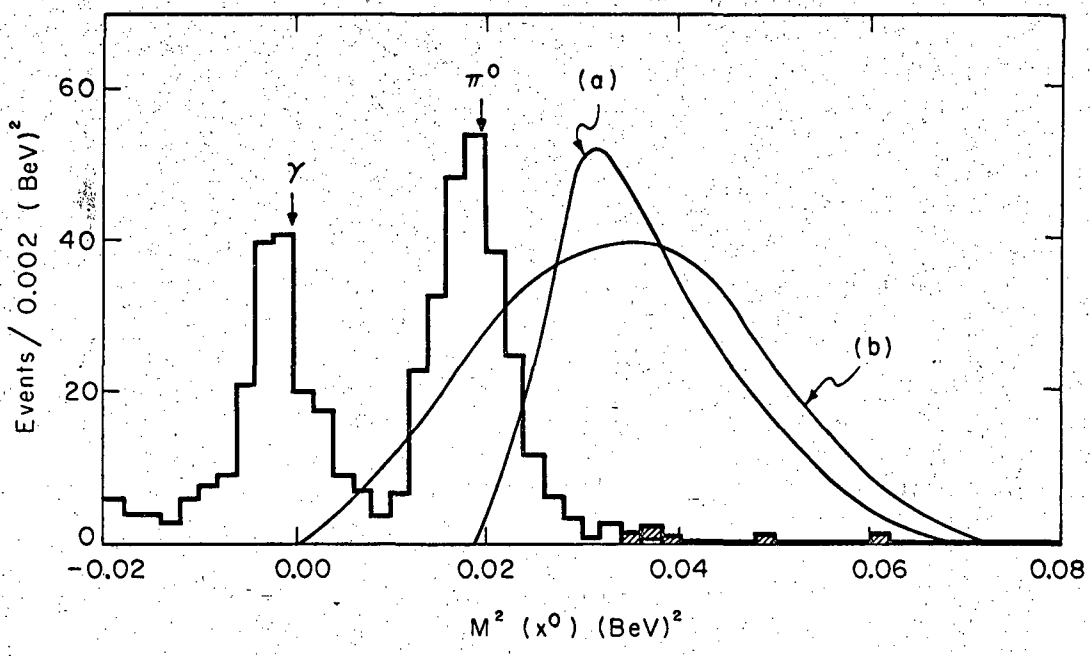
8. We thank S. M. Flatté for the results of his calculation of curves (a) and (b).

9. The only other way events could have been lost is through the 4C cutoff. Using the event-simulating program FAKE (G. R. Lynch, Lawrence Radiation Laboratory Report No. UCRL-10335, 10 July 1962, unpublished), we estimate that less than 1% of the events with $m^2(x^0) > 0.038$ for either mode would be removed by this 4C cut.

10. S. M. Flatté, Search for $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$. (to be published in Phys. Rev. Letters).

FIGURE CAPTION

Fig. 1. Spectrum of $(\text{mass})^2$ of missing neutral for $\eta \rightarrow \pi^+\pi^-(x^0)$. At this stage the 4C events have been removed, but the remaining events have not been examined on the scanning table. The shaded events were found upon examination at the scanning table to be spurious and were removed. Curves (a) and (b) correspond to the expected spectra for eta decay into $\pi^+\pi^-\pi^0\gamma$ and $\pi^+\pi^-\gamma\gamma$, respectively.



XBL675-3195

Fig. 1

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