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BRANCHING RATIOS WITHIN THE NEUTRAL DECAYS OF THE η^0 MESON*

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(Received 10 November 1969)

We have studied the neutral decays of η^0 mesons produced in a hydrogen bubble chamber. Utilizing the conversion within the chamber of one photon from each decay, we obtain the following percentages of the neutral decays: $(\eta^0\to\gamma\gamma)/(\eta^0\to\text{neutrals})=(48.6\pm3.6)$ %, $(\eta^0\to\pi^0\gamma\gamma)/(\eta^0\to\text{neutrals})=(12.2\,^{+5.2}_{-4.4})$ %, and $(\eta^0\to3\pi^0)/(\eta^0\to\text{neutrals})=(39.2\pm4.2)$ %. With the assumption of no $\pi^0\gamma\gamma$ contribution, we obtain the ratio $(\eta^0\to3\pi^0)/(\eta^0\to\gamma\gamma)=0.91\pm0.14$.

Several recent experiments[1-7] have reported results concerning the branching ratios within the all-neutral decays of the η^0 meson. In this experiment we have measured these ratios using a hydrogen bubble chamber to observe the reaction sequence

$$K^-+p\to\Lambda+y^0,\ \Lambda\to p+\pi^-,\ y^0\to\gamma+x^0,$$

where the γ is detected and measured by its conversion to e^+e^- within the chamber. We have utilized both internal and external conversion to e^+e^- and find good agreement between the two after making a significant correction for the detection efficiency of the external events. A small detection-efficiency correction was also calculated for the internal sample. From the observed distribution of the invariant mass $M^2(x^0)$ for 248 events with $M(y^0)$ in the η^0 mass region, and making the assumption that the only neutral decays of the η^0 are to $\gamma\gamma$ and $3\pi^0$, we find:

$$R_1=(\eta\to3\pi^0)/(\eta\to\gamma\gamma)=0.91\pm0.14.$$

This result is in excellent agreement with the reported results of Baltay et al. in a similar experiment performed with a deuterium chamber.[1]

However, our data are not consistent with the assumption of only two decay modes. In the region $0.05\ \text{BeV}^2<M^2(x^0)<0.10\ \text{BeV}^2$ we expect only seven events from the $\gamma\gamma$, $3\pi^0$, and non-η^0 background contributions; we observe 18 events. Under the assumption that the controversial $\pi^0\gamma\gamma$ mode can also contribute to the decay, we obtain the following percentages of the neutral decays:

$$(\eta^0\to\gamma\gamma)/(\eta^0\to\text{neutrals})=(48.6\pm3.6)\ \%,$$

$$(\eta^0\to\pi^0\gamma\gamma)/(\eta^0\to\text{neutrals})=(12.2\,^{+5.2}_{-4.4})\ \%,$$

$$(\eta^0\to3\pi^0)/(\eta^0\to\text{neutrals})=(39.2\pm4.2)\ \%.$$

With these results the value for R_1 is 0.81 ± 0.14 which is smaller than but still consistent with the direct measurement of Baglin et al.[2]

These events were obtained from a 500 000-picture exposure[8] of the BNL-Columbia 30-in. hydrogen-filled bubble chamber to a separated K^- beam of 730- to 760-MeV/c incident momentum at the BNL alternating gradient synchrotron. We obtained approximately 25 K^- and approximately 5 π^- and μ^- per picture. The entire film has been double scanned for the topology 2-prong + vee (internal sample) and 0-prong + 2-vee (external sample). After measuring and reconstructing 38 000 2-prong + vee events with TVGP, we were able to select 422 possible Dalitz pair events by requiring: (1) that $M(y^0)$ in the SQUAW fit $K^-p \to \Lambda y^0$, $\Lambda \to p\pi^-$ was greater than 440 MeV, and (2) that the invariant mass of the two charged tracks at the production vertex was less than 50 MeV, assuming them to be e^+e^-. The events meeting these requirements were then re-examined on the scanning table. We were able to select as the internal sample 138 events which had a clear signature for the e^+ or the e^- track by examination of the track's ionization and curvature. The external sample was obtained from 4680 events of the 0-prong + 2-vee topology found in scanning. This sample contains 967 events which fit the hypothesis of a Λ decay and a gamma conversion with a common origin at the point of disappearance of a K^--beam track.

Both the internal and external samples were constained to the two-vertex hypothesis (a) $K^-p \to \Lambda y^0$, $\Lambda \to p\pi^-$. In addition, the internal sample was constrained to the two-vertex hypothesis (b) $K^-p \to \Lambda e^+e^-x^0$, $\Lambda \to p\pi^-$, and the external sample to the similar three-vertex hypothesis (c) $K^-p \to \Lambda + \gamma + x^0$, $\Lambda \to p\pi^-$, $\gamma p \to e^+e^-p$. In these hypotheses y^0 and x^0 are simply relativistically invariant masses which conserve energy and momentum in the reaction. In Fig. 1 we show the scatter plot of $M^2(y^0)$ vs $M^2(x^0)$ for the combined samples. Note that we include only those events with $M(y^0)$ above 440 MeV. This excludes that part of the $M(y^0)$ spectrum where direct production of $\Lambda\pi^0$ and $\Sigma^0\pi^0$ can contribute.

In general the detection efficiency for both samples can be expected to vary as a function of the photon energy E_γ in the laboratory. For the Dalitz pair events we use the conversion coefficient of Kroll and Wada[9] which is given as a function of both the invariant mass and the energy partition of the e^+e^- pair. It has been pointed out earlier[10] that if one integrates over all energy partitions and over the invariant mass from 0 to 50 MeV, one finds essentially the same detection probabilities for $\eta^0 \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$. However, in this experiment we only detect the Dalitz pair if one lepton has a momentum less than 125 MeV/c thereby assuring that it can be distinguished from a pion of the same momentum. This means that as the laboratory energy of the virtual photon increases we expect to miss events which have nearly an equipartition of this energy between the two leptons. This loss significantly reduces the detection efficiency of $\eta^0 \to \gamma\gamma$ in the internal sample but has little effect on the other decay modes.

The detection efficiency for the externally converted photons can be obtained experimentally since the production and conversion of the photons are separate events connected only by the photon momentum. We have been able to determine empirically this overall detection efficiency from the observed energy distribution of 651 photons arising mainly from the reactions $K^- + p \to \Lambda + \pi^0$ and $K^- + p \to \Sigma^0 + \pi^0$.

In order to determine the behavior of the background simulating η^0 production and decay, we take the $M(y^0)$ interval between 440 and 542 MeV to be the control region. In this region we expect only events arising from $\Lambda\pi^0\pi^0$ and $\Sigma^0\pi^0\pi^0$ production. Since we are just above threshold for η^0 production, we define the η^0 region as $M(y^0)$ greater than 542 MeV. The experimental distributions in $M(x^0)$, $M(y^0)$, and $M(\Lambda\gamma)$ for events in the control region can be matched by assuming the events arise from the produc-

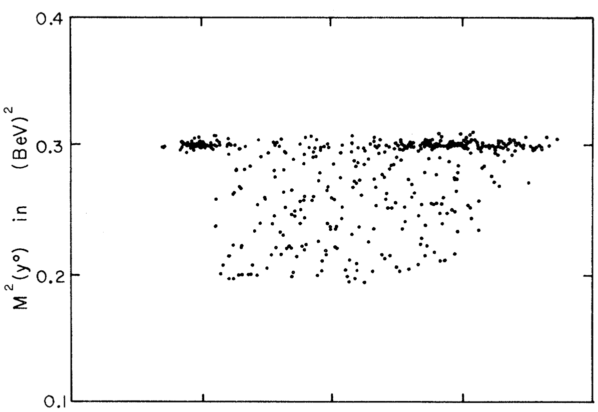

FIG. 1. Scatter plot of both internal and external events from the fits $K^-p \to \Lambda + y^0$ and $K^-p \to \Lambda + \gamma + x^0$. Within the region of $M(y^0)$ plotted, only η^0 decays to all neutrals and background production of $\Lambda\pi^0\pi^0$ and $\Sigma^0\pi^0\pi^0$ can contribute.

tion of 25% $\pi^0\Lambda(1405)$, $\Lambda(1405)\to\Sigma^0\pi^0$ and 75% $\pi^0\Sigma^0(1385)$, $\Sigma^0(1385)\to\Lambda\pi^0$. Other contributions have been considered, but only $\Lambda\pi^0\pi^0$ picked from phase space results in noticeably different $M(x^0)$ and $M(y^0)$ distributions.

Using Monte Carlo techniques and isotropic angular distributions, we have generated the expected contributions to the $M^2(x^0)$ spectrum from (1) non-η^0 events in the control region, (2) non-η^0 events in the η^0 region, and (3) η^0 events in the η^0 region from three decay modes: $\gamma\gamma$, $\pi^0\gamma\gamma$, and $3\pi^0$. For the $\pi^0\gamma\gamma$ mode we take the simplest gauge-invariant matrix element used by Baltay et al.[1]; and for the $3\pi^0$ mode we take a constant matrix element. The choice of $3\pi^0$ matrix elements has a negligible effect on the generated $M^2(x^0)$ spectrum.

Since the internal and the external samples have different photon detection efficiencies and different measurement errors on the quantity $M^2(x^0)$, the above set of five expected $M^2(x^0)$ distributions was determined separately for each sample. Using errors propagated by SQUAW for only those events within the η^0 region, we obtain a resolution function for the quantity $M^2(x^0)$ in each of seven $M^2(x^0)$ intervals between -0.05 and 0.30 BeV^2. These resolution functions, each a sum of Gaussians, were folded into the generated distributions for $M^2(x^0)$; the excellent agreement between the generated and experimental width of the $\eta^0\to\gamma\gamma$ peak in Fig. 2(b) is evidence of the correctness of this method.

The extended maximum-likelihood method[11] was used to determine the contributions from each of these generated distributions. Figure 2 shows the simultaneous fit to the η^0 region and the control region obtained by holding the $\pi^0\gamma\gamma$ contribution to zero. The likelihood for this fit is 120 times less than that obtained by including a $\pi^0\gamma\gamma$ contribution. The difference in the fits arises entirely from the cluster of experimental events in the region $0.05 < M^2(x^0) < 0.10$ BeV^2 seen in Fig. 2(b). In Fig. 3 we show all events from this $M^2(x^0)$ region projected on the $M^2(y^0)$ axis. It is clear from this plot that this region certainly contains some eta events. We have considered the possibility that η^0 decays to $\gamma\gamma$ or $3\pi^0$ could populate this region due to poor measurement or kinks in the electron and positron tracks. All 18 events in this region were carefully examined and then measured a second time; all 18 events remained in this $M^2(x^0)$ region. The non-η^0 contribution to these fits was assumed to arise from the neutral decays of the resonance

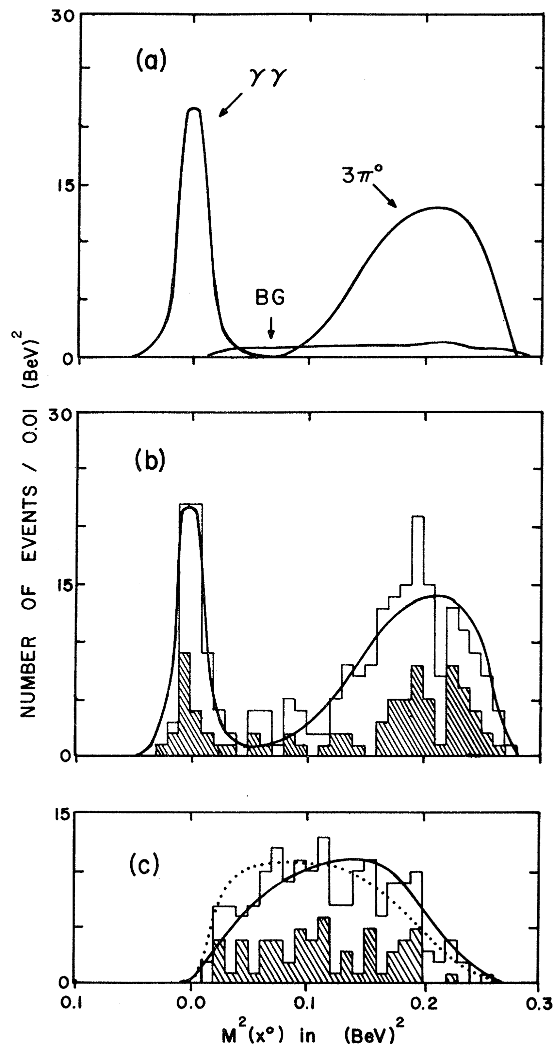

FIG. 2. Plot of $M^2(x^0)$ distribution for events in η^0 region (b) and control region (c). Events with internally converted photons are shown cross hatched. The smooth curves in (b) and (c) are the result of a maximum-likelihood fit to both regions simultaneously. The contributions of $\eta^0\to\gamma\gamma$, $\eta^0\to 3\pi^0$, and background to the fit in the η^0 region are shown in (a). The background contribution in the η^0 region is largely determined by the fit in the control region. The dotted curve in (c) is an alternate fit to a $\Lambda\pi^0\pi^0$ phase-space contribution.

states $\Sigma^0(1385)$ and $\Lambda(1405)$ as discussed above. This assumption predicts more non-η^0 events in the η^0 region than would be obtained from $\Lambda\pi^0\pi^0$ and $\Sigma^0\pi^0\pi^0$ uniformly distributed in phase space. The major effect resulting from the alternate use of this phase-space contribution is to increase, by about 2%, the fraction of neutral η^0 decays attributed to $\pi^0\gamma\gamma$.

We conclude that our data are not compatible

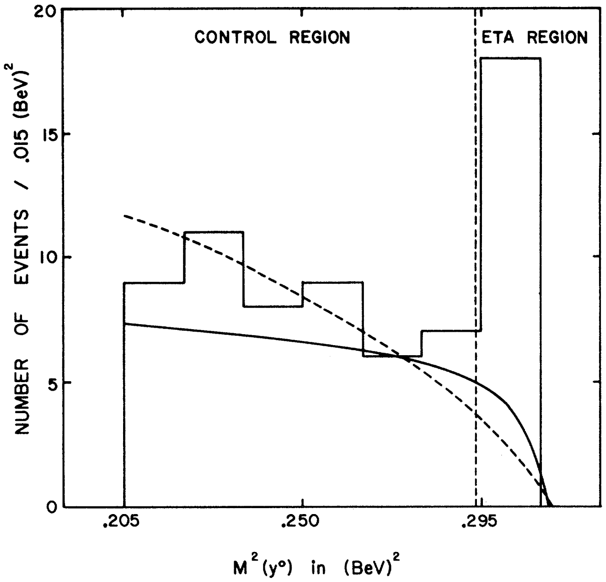

FIG. 3. Plot of $M^2(y^0)$ for those events in the region $0.05\ \mathrm{BeV}^2 < M^2(x^0) < 0.100\ \mathrm{BeV}^2$. The solid curve shows the contribution of the $\Sigma^0(1385)+\pi^0$ and $\Lambda(1405)+\pi^0$ reactions as determined by the maximum-likelihood fit. The dashed curve shows the fitted contribution of the alternate reaction, $\Lambda\pi^0\pi^0$ uniformly distributed in phase space.

with the assumption that the neutral decays of the η^0 meson are limited to the final states $\gamma\gamma$ and $3\pi^0$. We note that this result is insensitive to our detection efficiency for photons and that the significance of the result is independent of the details of the $\pi^0\gamma\gamma$ state. Conversely, we cannot insist that the decay is to $\pi^0\gamma\gamma$. Rather, the observation of an excess of η^0 events in the $0.05 < M^2(x^0) < 0.10\ \mathrm{BeV}^2$ region requires only that there be a final state containing no more than two neutral pions.

It is a pleasure to acknowledge the advice and support of Earle C. Fowler throughout this experiment. We are indebted to Lawrence E. Evans for helpful discussions concerning electromagnetic decays and to Morris E. Binkley, Dwight W. Carpenter, and Carl M. Rose for discussions during the analysis of this experiment. In addition, we acknowledge the many contributions of our technical personnel to the various phases of this experiment.

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*The research leading to this report was carried out at the Brookhaven National Laboratory and Duke University with partial financial support of the U. S. Atomic Energy Commission.

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