BRANCHING RATIO $\Gamma(\eta \to 3\pi^0)/\Gamma(\eta \to 2\gamma)$ MEASURED USING A 4π SPARK CHAMBER*

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(Received 6 November 1967)

Recently the neutral decay modes of the eta meson have received a great deal of attention both theoretically and experimentally. Experimentally, ratios between the decay modes (a) $\eta \to 2\gamma$, (b) $\eta \to 3\pi^0$, and (c) $\eta \to \pi^0\gamma\gamma$ have been measured by several counter and spark-chamber groups[1-4] with varying techniques, yielding values of

$$R_1 = \Gamma(\eta \to 3\pi^0)/\Gamma(\eta \to 2\gamma)$$

and

$$R_2 = \Gamma(\eta \to \pi^0\gamma\gamma)/\Gamma(\eta \to 2\gamma)$$

in apparent disagreement with one another. In particular, one experiment (Ref. 1) obtained $R_2 = 0.90 \pm 0.10$ whereas in another (Ref. 2), it was concluded that $R_2 \leq 0.50$ (90% confidence level). Furthermore, measurements of the three-pion eta-decay ratio

$$R_3 = \Gamma(\eta \to 3\pi^0)/\Gamma(\eta \to \pi^+\pi^-\pi^0)$$

in hydrogen bubble chambers[5-7] and heavy-liquid bubble chambers[8] yield values of R_3 as low as 0.38[5] and as high as 1.2.[7] The $3\pi^0$ rate obtained from Ref. 1 may be combined with the eta-decay charged/neutral ratio to give $R_3 = 0.68 \pm 0.14$. The primary area of experimental uncertainty is the rate of $\eta \to \pi^0\gamma\gamma$ relative to $\eta \to 3\pi^0$, which enters directly or indirectly into all determinations of R_3. The basic experimental problem is to detect multiphoton events with known but high efficiency so as to separate accurately decay modes overlapping in numbers of observed showers or pairs.

Theoretically the estimates for R_3 also vary widely depending upon assumptions made in the calculations. Adler's original prediction[10] that $I=3$ three-pion final states are required if $R_3 < 1$ now seems less compelling. Price and Crawford[11] have shown that R_3 as low as 0.5 is perfectly consistent with existing Dalitz plots of $\eta \to \pi^+\pi^-\pi^0$ as long as a matrix element including cubic terms in pion energy is allowed, even with pure $I=1$. Earlier estimates for a pure $I=1$ final state included $R_3 = 1.63$ without final-state interaction and $R_3 = 1.35$ assuming a σ^0 meson of 400-MeV mass.[12] The present theoretical estimates appear to be able to accommodate any value of R_3 between 0.5 and 1.6.

In view of theoretical interest in eta decay and the widely spread experimental values for branching ratios to the mode $\eta \to 3\pi^0$, we wish to report an independent measurement of the branching ratio $R_1 = \Gamma(\eta \to 3\pi^0)/\Gamma(\eta \to 2\gamma)$. It is based on 4π spark-chamber observation of five- (5s) and six-shower (6s) events produced in $\pi^- p \to \eta n$ and other $\pi^- p \to$ neutrals both below and above η threshold. No confusion with $\pi^0\gamma\gamma$ decays occurs. Our result is that

$$R_1 = \frac{\Gamma(\eta \to 3\pi^0)}{\Gamma(\eta \to 2\gamma)} = 1.1 \pm 0.2,$$

where the error is primarily due to uncertainty in separating $3\pi^0 n$ from $\eta^0(\to 3\pi^0)$ final states. Combined with the latest compilation[9] of branching ratios (weighted values)

$$R_4 = \Gamma(\eta \to 2\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0) = 1.40 \pm 0.15,$$

we obtain

$$R_3 = R_1 R_4 = 1.5 \pm 0.3.$$

Our result is not inconsistent with a pure $I=1$ three-pion final state in eta decay.

Our experiment does not appear to be capable of measuring the $\pi^0\gamma\gamma/\gamma\gamma$ ratio due to a large background of $2\pi^0$ events.

Our data are drawn from a study of pion charge-exchange[13] and eta production[14] at nine pion energies between 0.5 and 1.3 BeV. The detector was a 4π-solid-angle cubical spark chamber of 6 radiation lengths total thickness on each side using $\frac{1}{8}$-in. steel plates.

The important points are that (a) multishower events were observed with good efficiency, and (b) the frequency of 5s and 6s events rises abruptly at the eta production threshold.

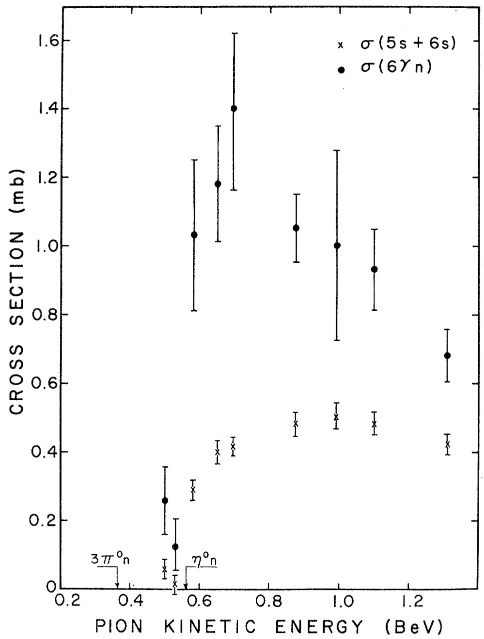

FIG. 1. Measured π^-p cross sections for production of five- and six-shower events (x) as a function of laboratory π^- kinetic energy. The $6\gamma n$ cross sections are obtained by dividing by detector efficiency.

(See Fig. 1.) This sudden rise must be primarily due to $\pi^-p \to \eta(\to 3\pi^0)n$ since the yield increases by a factor of 7 within 70 MeV in passing over eta threshold (at 560 MeV). Although $3\pi^0n$ events are kinematically indistinguishable from $\eta(\to 3\pi^0)n$ events, the low 5s + 6s yield just below η threshold establishes the size of this background.

The detection efficiency for 5s + 6s events from $3\pi^0n$ or $\eta(\to 3\pi^0)n$ depends sensitively upon the single-photon detection efficiency as a function of photon energy, $\epsilon_1(k)$. Two-photon events from π^0n and $\eta(\to 2\gamma)n$ final states yielding 2s and 1s events were used to construct an empirical $\epsilon_1(k)$.[13] The function $\epsilon_1(k) = C\{1-\exp[-(k-k_0)/\Delta k]\}$ was adopted, with k_0 the "threshold energy" (~15 MeV for three sparks), and $C = 0.975$ and Δk adjusted to fit the observed ratios 1s/2s. A single value $\Delta k = 72 \pm 7$ MeV gave a good fit at all nine energies. At $T_\pi = 600$ MeV, 94% of the $\eta(\to 2\gamma)n$ events and 75% of the $\pi^0(\to 2\gamma)n$ events gave two showers.

Monte Carlo predictions of the probability of seeing $\eta(\to 3\pi^0)n$ as a 5s or 6s event were made for all nine incident pion energies. The observed ratio 5s/6s was used to check whether or not the same chamber response function deduced from two-photon events would also describe six-photon events. Figure 2 demonstrates that both the magnitude and π^- energy dependence of the observed ratio 5s/6s are fitted well with $\Delta k = 60 \pm 10$ MeV which is compatible with $\Delta k = 72 \pm 7$ MeV obtained from 1s/2s ratios independently. The Monte-Carlo-calculated probability $P(3\pi^0 \to 5s + 6s)$ increases linearly from 29% at T_{π^-} 500 MeV to 63% at $T_{\pi^-} = 1310$ MeV.

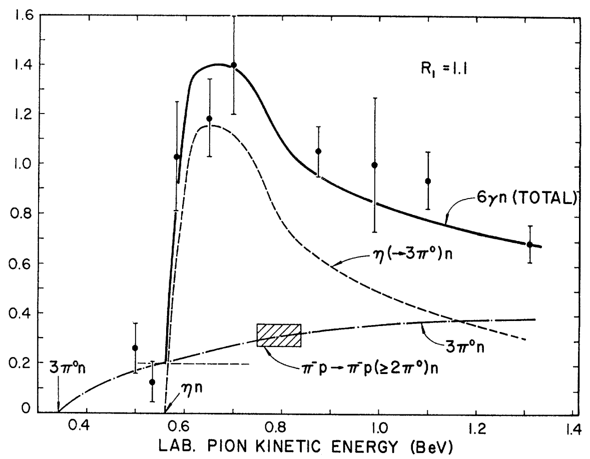

FIG. 2. Comparison of observed and predicted (five-shower)/(six-shower) ratios, for various parameters of spark-chamber efficiency function.

The resulting cross section for the processes $\sigma[\pi^-p \to 6\gamma n]$ is also shown in Fig. 1, assuming that $3\pi^0 \to 6\gamma$. We assume that the only important processes yielding six photons are $\pi^-p \to \eta(\to 3\pi^0)n$ and $\pi^-p \to 3\pi^0n$. We already know the shape of the production cross section $\sigma(\pi^-p \to \eta n)$ from previous measurements using the 2γ decay.[14,15] The parameter R_1 is used to adjust the magnitude of the partial cross section $\sigma[\pi^-p \to \eta(\to 3\pi^0)n]$ as will be described below. The remaining $6\gamma n$ yield we ascribe to the "background" cross section $\sigma(\pi^-p \to 3\pi^0n)$.

We are unaware of any direct measurements of $\sigma(\pi^-p \to 3\pi^0n)$. The most relevant data appear to be recent preliminary bubble-chamber cross-section measurements[16] for $\pi^-p \to \pi^-p\pi^0 + x\pi^0 (x \geq 1)$ in the incident-pion energy range 750–840 MeV (see Fig. 3). We assume these cross sections to represent an upper bound for the $\pi^-p \to 3\pi^0n$ cross section. Our two $\sigma(6\gamma n)$ points below eta threshold constitute another upper limit. We can thus construct an approximate $\sigma(\pi^-p \to 3\pi^0n)$ in Fig. 3.

The scale of $\sigma[\pi^-p \to \eta^0(\to 3\pi^0)n]$ is established

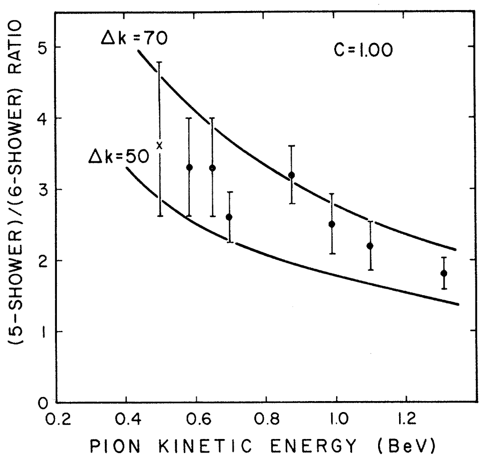

FIG. 3. Total $6\gamma n$ cross section resolved into $\eta(\rightarrow 3\pi^0)n$ and $3\pi^0 n$ components. The shape of ηn cross section was determined from $\eta(\rightarrow 2\gamma)n$ measurements.

by subtracting $3\pi^0 n$ background just above eta production threshold. The curves in Fig. 3 correspond to $R_1 = 1.1$, the best fit. A compute fit to the data was felt to be unnecessary in view of the errors involved. The value $\sigma(3\pi^0 n) = 0.2$ mb near 600 MeV is sufficient to fix R_1; assuming a gradually rising background adequately fits both $\sigma(6\gamma n)$ and the bubble-chamber data, as shown in Fig. 3.

The plotted errors include uncertainties in detection efficiency as well as statistics (2700 total 5s + 6s events). From attempts to fit the data with various values of R_1, we conclude that the uncertainty in R_1 is ±0.2.

*Work supported in part by the U. S. Atomic Energy Commission at both University of California Lawrence Radiation Laboratory (Atomic Energy Commission Contract No. W-7405-eng-48) and Hawaii [Atomic Energy Commission Contract No. AT(04-3)-511].

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