ETA-MESON BRANCHING RATIO INTO $\pi^0+\gamma+\gamma$*

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An upper limit of 0.50 (90% confidence level) is set for the branching ratio $(\eta\rightarrow\pi^0+\gamma+\gamma)/(\eta\rightarrow\gamma+\gamma)$ in a spark-chamber experiment measuring $\pi^-+p\rightarrow(n+4\gamma$ and $n+2\gamma)$ at 10 BeV/c. This disagrees with a recent measurement of 0.90 ± 0.10 for the same ratio.

A recent determination of the neutral branching ratios of the η meson[1] gave the ratios $(\eta\rightarrow\gamma+\gamma)/(\eta\rightarrow\text{all neutrals})=(41.6\pm2.2)\%$ and $(\eta\rightarrow\pi^0+\gamma+\gamma)/(\eta\rightarrow\text{all neutrals})=(37.5\pm3.6)\%$. Dividing these gives

$$r\equiv\frac{\eta\rightarrow\pi^0+\gamma+\gamma}{\eta\rightarrow\gamma+\gamma}=0.90\pm0.10.$$

This error in r may be an underestimate due to possible correlation errors in their statistical analysis, about which we have no information.

In a recent experiment at the alternating-gradient synchrotron, we investigated final states in $\pi^-+p\rightarrow n+\text{gammas}$ at an incident π^- momentum of 10 BeV/c. Some results of the final states with two gammas and with four gammas have already been published[2,3] and these articles contain descriptions of the hydrogen target, spark chamber, etc. We have determined an upper limit for the ratio r using pictures of 2γ events and 4γ events in the same sample of film:

$$r\leqslant0.50\ \text{(90\% confidence level)}.$$

The number of $\eta\rightarrow2\gamma$ events is determined from the spectrum of γ-γ opening angles, θ, which is shown in Fig. 1(a). After subtracting out π^0 events from the tail of the π^0 opening-angle peak, and also contamination from $m\gamma$ events ($m\geqslant3$) where only two out of the m gammas have appeared in the spark chamber, there are 1535 ± 100 $\eta\rightarrow2\gamma$ events.

The number of $\eta\rightarrow\pi^0+\gamma+\gamma$ events is determined from the opening-angle spectrum of 4γ events by comparison with Monte Carlo–generated $\pi^0\pi^0$ phase-space events and $\eta\rightarrow\pi^0+\gamma+\gamma$ events. The 4γ data, analyzed as if all events were $\pi^0\pi^0$ events, are presented in Fig. 1(b). Monte Carlo–generated $\eta\rightarrow\pi^0+\gamma+\gamma$ events, analyzed this same way, appear as a peak 200 MeV wide, centered between 500 and 550 MeV. Accordingly, only events with values of $M_{\pi\pi}$, the calculated $\pi^0\pi^0$ invariant mass, between 350 and 725 MeV are selected for further analysis. The 4γ data surviving this cut, 998 events, include $(76.5\pm3.0)\%$ of any $\eta\rightarrow\pi^0+\gamma+\gamma$ events.

An opening-angle spectrum of these 4γ events, of the form $(1/\theta_1+1/\theta_2)\equiv\Theta^{-1}$, where θ_1 is the

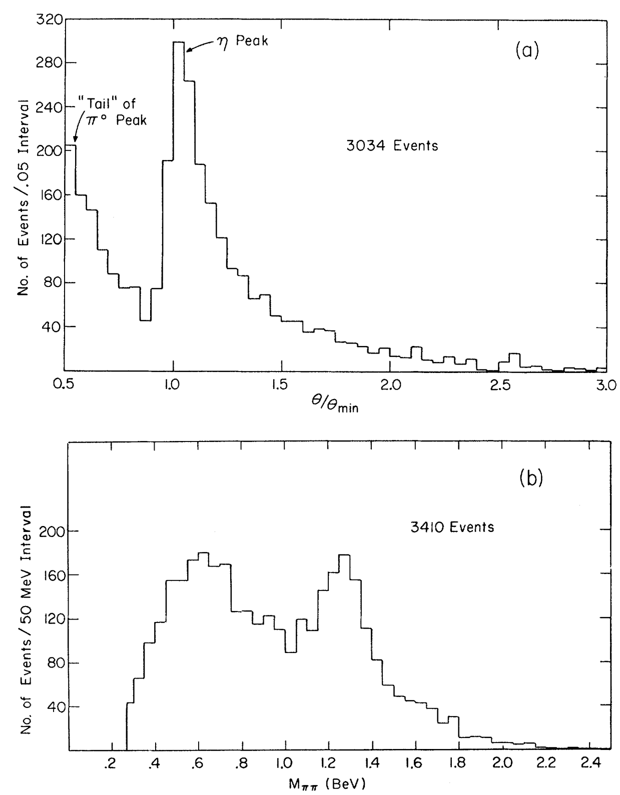

FIG. 1. (a) Distribution of γ-γ opening angles, θ, for the 2γ events, normalized to $\theta_{min}\approx2m_\eta/p_\eta$, where m_η and p_η are the η mass and momentum; θ_{min} is the minimum allowed γ-γ opening angle for η's. (b) The $\pi^0\pi^0$ mass spectrum of the 4γ events, analyzed as if all events were $\pi^0\pi^0$ events, showing a broad peak at low masses and the f^0 peak at 1.27 BeV.

opening angle between two of the γ's and θ_2 is the opening angle between the other two γ's, is shown in Fig. 2. Also shown are curves of the same function for Monte Carlo–generated $\pi^0\pi^0$ phase-space events and $\eta\to\pi^0+\gamma+\gamma$ events. Assuming that the experimental data consist of only $\pi^0\pi^0$ and $\eta\to\pi^0+\gamma+\gamma$ events, a least-squares fit of these two distributions to the experimental histogram gives 275 ± 75 $\eta\to\pi^0+\gamma+\gamma$ events. The upper limit (90% confidence level) is 430 $\eta\to\pi^0+\gamma+\gamma$ events. Because of the presence of background (i.e., non-$\pi^0\pi^0$ and non-η) events in the 4γ data, these numbers of η events must be taken as upper limits.

The detection efficiency of the spark chamber for $\eta\to\pi^0+\gamma+\gamma$ events relative to $\eta\to\gamma+\gamma$ events is 0.726 ± 0.030. Combining these results, we obtain $r\leq 275/(0.726\times0.765\times1535)$, or

$$r\leq 0.32\pm0.09 \quad (\text{peak of } \chi^2 \text{ probability})$$

and

$$r\leq 0.50 \quad (90\% \text{ confidence level}).$$

We now discuss (a) the method of pairing the γ's, (b) the input functions for the Monte Carlo programs, (c) the cause of the difference between the Θ^{-1} distributions for the $\pi^0\pi^0$ and η events, and (d) the effect of background events in the 4γ data.

(a) To pick the "best" pairing, the relationship $\theta_{\rm min}\approx 2m/p$ is used, where $\theta_{\rm min}$ is the minimum allowed γ-γ opening angle from the decay of a digamma particle of mass m and momentum p. For each of the three pairings, the quantity $(2m/\theta_1+2m/\theta_2)$ is calculated, where θ_1 (θ_2) is the γ-γ opening angle of the first (second) set of γ's, and m is the π^0 mass. If both sets of γ's arise from π^0's decaying near the minimum allowed angles, this quantity is approximately equal to p_1+p_2, the sum of the π^0 momenta. That pairing is chosen which has p_1+p_2 closest to the incident π^- momentum. This pairing method is used for all Monte Carlo and experimental events.

(b) The $\pi^0\pi^0$ Monte Carlo events were generated so as to approximate closely the experimental shapes of both the di-pion mass distribution inside the 350- to 725-MeV mass cut and the t distribution, where t is the four-momentum transfer squared. Accordingly, these Monte Carlo events were generated using a three-body $\pi^0\pi^0n$ phase-space calculation, except that the production angular distribution of the $\pi^0\pi^0$ system was taken as $\sim e^{10t}$. Various mass and t distributions (e.g., with e^{4t} instead of e^{10t}) produce only negligible changes in the Θ^{-1} distribution.

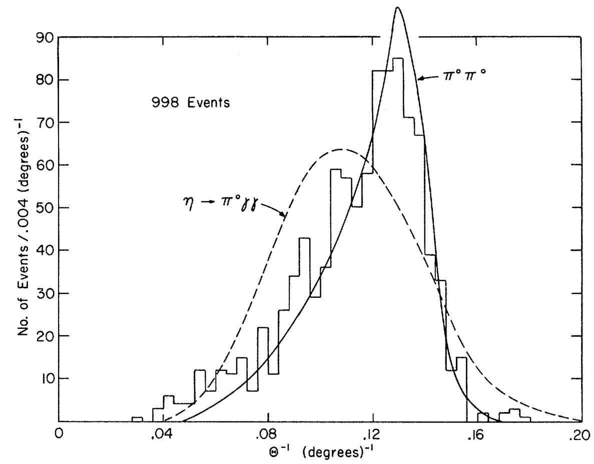

FIG. 2. Experimental histogram of the sum of inverse γ-γ opening angles, $(1/\theta_1+1/\theta_2)\equiv\Theta^{-1}$, where θ_1 is the γ-γ opening angle between one set of gammas and θ_2 is the same for the other set of gammas, measured in the π^-p c.m. system. The method of pairing the gammas into sets is described in the text. The curves show Monte Carlo–generated Θ^{-1} distributions for $\pi^0\pi^0$ events (solid line) and $\eta\to\pi^0+\gamma+\gamma$ events (dashed line). The curves are normalized to the same number of events as the experimental histogram within the region used for the least-squares fit, 0.080 to 0.152 deg^{-1}.

The $\eta\to\pi^0+\gamma+\gamma$ Monte Carlo events were generated with a fixed η mass of 549 MeV. The production angular distribution was taken as $\sim e^{4t}$, which approximates the observed t dependence of the $\eta\to2\gamma$ events in our 2γ data and also that of Guisan et al.[4] In the η rest frame, the $\pi^0\gamma\gamma$ decay distribution is taken via three-body phase space, producing a phase-space spectrum of digamma masses, $M_{\gamma\gamma}$.

(c) The different $M_{\gamma\gamma}$ spectra of the $\pi^0\pi^0$ and $\eta\to\pi^0+\gamma+\gamma$ events is the cause of the difference between their Θ^{-1} distributions. (For $\pi^0\pi^0$ events, of course, the equivalent $M_{\gamma\gamma}$ spectrum is simply a spike at 135 MeV.) This can be explained as follows:

Consider the function $(m/\theta_1+M_{\gamma\gamma}/\theta_2)$, where m is the π^0 mass, and θ_1 and θ_2 have been defined above. If both θ_1 and θ_2 are near their minimum allowed values, then this function is approximately equal to $P/2$, where P is the incident π^- momentum (2.12 BeV/c in the π^-p c.m. system). For $\pi^0\pi^0$ events, $M_{\gamma\gamma}=m$, giving $(1/\theta_1+1/\theta_2)\equiv\Theta^{-1}\approx P/2m=0.137$ deg^{-1}, and the Θ^{-1} distribution of Fig. 2 peaks near this value. For $\eta \to \pi^0+\gamma+\gamma$ events, the phase-space spectrum of $M_{\gamma\gamma}$ produces a corresponding spread of θ_2 values, thus smearing out the Θ^{-1} distribution as shown in Fig. 2.

Clearly, any model of the decay $\eta \to \pi^0+\gamma+\gamma$ which seriously distorts the $M_{\gamma\gamma}$ phase-space spectrum will affect our upper limit for r. One particular model of η decay has been considered.[5] Taking the η as an initial quark-antiquark state, it is assumed to decay via two successive magnetic dipole transitions: $\eta \to \rho^0+\gamma$, $\rho^0 \to \pi^0+\gamma$, where the ρ^0 represents a virtual 1^- intermediate state (the ρ^0, ω^0, or φ^0). This model produces a flattening of the $M_{\gamma\gamma}$ spectrum compared to pure phase space, but leaves unchanged the upper limit for r.

(d) It has been determined[3] that there is a background of 15 to 40% in the low-mass region of the 4γ data [threshold to 1.0 BeV in Fig. 1(b)], due to feed-down from $3\pi^0$ events in which two of the six gammas have escaped detection. We have not been able to predict all the detailed properties of such feed-down events, but reasonable models predict Θ^{-1} distributions which are broader than the observed experimental Θ^{-1} distribution. Therefore, introduction of these background events into the fits to the 4γ data will decrease the number of $\eta \to \pi^0+\gamma+\gamma$ events in the best fit; in fact, a reasonable fit can be obtained using only $\pi^0\pi^0$ events plus $3\pi^0$ feed-down events, with no η's. For this reason, the value of r determined above, which assumed the existence of only $\pi^0\pi^0$ and $\eta \to \pi^0+\gamma+\gamma$ events in the data, is considered an upper limit rather than an exact determination.

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MEASUREMENT OF THE Σ^+ MAGNETIC MOMENT*

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This paper presents the results of a measurement of the magnetic moment of the Σ^+ hyperon. In addition to providing a test of current baryon symmetry schemes, the experiment also demonstrates the feasibility of several new techniques in experimental high-energy physics. Spark chambers were operated directly in very high (165 kG) magnetic fields, and spark-chamber observations were made of the complete production and decay event of the short-lived sigma hyperon (see Fig. 1). The general method for measuring the magnetic moment was the same as that employed in several Λ^0 magnetic-moment measurements.[1-5] The precession of polarized sigmas in a magnetic field was measured by observing the asymmetric decay,

$$\Sigma^+ \to \pi^0 + p. \tag{1}$$

In this experiment the polarization vector was nearly perpendicular to the magnetic field ($\vec{B}$), while the Σ^+ momentum ($\vec{P}_\Sigma$) was directed along $\vec{B}$. For this case, a Σ that moves a distance L_Σ in the field will have its magnetic moment precess through an angle

$$\epsilon = \mu_\Sigma \Gamma; \quad \Gamma = 2\bar{B}L_\Sigma m_\Sigma/\hbar P_\Sigma, \tag{2}$$

where $\bar{B}$ is the average value of the field along L_Σ, μ_Σ is the magnetic moment in units of