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TAU DECAY EVENTS INVOLVING η MESONS

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Abstract: The characteristics of tau decays to final states involving η mesons are presented. The data sample, which corresponds to an integrated luminosity of 300 pb^{-1}, was taken at the PEP e^+e^- colliding beam facility using the High Resolution Spectrometer. The storage ring was operated at $\sqrt{s} = 29$ GeV. The η production appears to be only compatible with the decay $\tau^+ \to \pi^+\eta\bar{\nu}$, which violates isospin and G-parity conservation. This decay, thus, proceeds via a second-class vector current. The branching ratio $(5.1 \pm 1.5)\%$ explains much of the current discrepancy between the one-prong topological branching ratio and the sum of the individual one-prong modes.

In this talk we discuss the characteristics of tau decays to final states involving η mesons. The observation of such events in the one-prong topology is reported elsewhere [1]). Although τ-decays to hadronic final states are dominated by the low-mass $J^P = 1^-, 0^-$ and 1^+ particles $\rho(770)$, π and $a_1(1270)$, the nature of τ decays to hadronic systems of high mass (for example, those which lead to the final states, $5\pi^+$ and $5\pi^\pm\pi^0$) is not well understood [2]).

The decay $\pi^+ \to \pi^+\eta\bar{\nu}$ is of particular significance since the G parity of $(\pi^+\eta)$ is odd, but the J^P must be 0^+ or 1^-, so that, in the conventional picture, the decay violates CVC and occurs via a second-class vector current [3]). The decay mode $\tau^+ \to \pi^+\eta\pi^0\bar{\nu}$ is allowed and is expected to occur at a low level [2]).

The rates for more complicated decay modes involving η mesons such as $\pi^+\eta\eta\bar{\nu}$ and $\pi^+\eta\pi^0\pi^0\bar{\nu}$ are constrained by the low branching ratios for the $5\pi^\pm\bar{\nu}$ and $5\pi^+\pi^0\bar{\nu}$ final states of $5.1 \cdot 10^{-4}$ and the non-observation of the $5\pi^\pm 2\pi^0\bar{\nu}$ final state [4]). The η has a 23.7% decay branching ratio to $\pi^+\pi^-\pi^0$, and isospin conservation gives $B(\tau^\pm \to \pi^\pm\eta\pi^0\pi^0\bar{\nu}) \leq B(\tau^\pm \to \pi^\pm\eta\pi^+\pi^-\bar{\nu})$. We do not further consider these higher multiplicity modes in this talk.

In order to clarify some of these questions, we have studied the inclusive production of η mesons in τ-decay. The results come from data collected by the High Resolution Spectrometer (HRS) operated at the PEP e^+e^- colliding beam facility.

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The center-of-mass energy was 29 GeV, and the data correspond to an integrated luminosity of 300 pb^{-1}. The characteristics of the detector and the event selection procedures are described elsewhere [1]).

The $\gamma\gamma$ mass distribution for the 374 combinations from 3432 events is shown in fig. 1a. The data exhibit a clear enhancement of the η mass over a slowly falling background. There is also a low mass peak at 155 MeV that originates from the $\tau^+ \to \rho^+ \bar{\nu} \to \pi^+ \pi^0 \bar{\nu}$ decay. This π^0 peak is shifted upwards in mass since the clustering

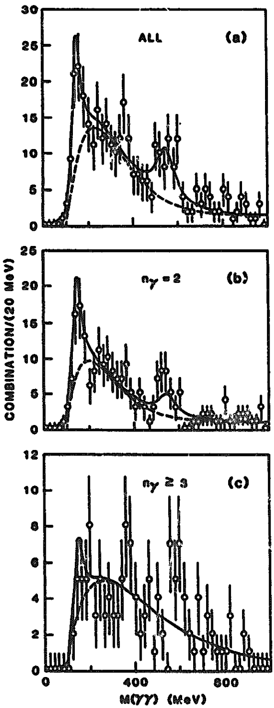

Fig. 1. Effective mass distribution for $\gamma\gamma$ combinations: (a) all events; (b) events with two and only two photon clusters; (c) events with three or more photon clusters. The dashed lines show the background. The full line shows the best fits, including signals for the π^0 and η decays.

algorithm favors events in which the reconstructed opening angles are increased, due to fluctuations in the shower development.

The data are subdivided into 229 events with two and only two neutral clusters in fig. 1b, and 145 $\gamma\gamma$ combinations from 113 events with three or more neutral clusters in fig. 1c. A minimum energy cut of 100 MeV was applied in defining a separate cluster. The enhancement at the η mass in the inclusive data of Fig. 1a persists in the events with only two photons. As expected from the photon selection criteria, there are fewer events with $n_\gamma \geq 3$, and there is no significant signal near 550 MeV for this selection.

The shape of the mass distribution of the events populating the region between the π^0 and η peaks and above the η peak in fig. 1 has been studied using the Monte Carlo technique. The main contribution comes from the $\pi^+ 2\pi^0 \bar{\nu}$ final state when the two photons from the π^0 are not resolved by the shower counter, but there is also a large effect coming from misidentified photons from the $\pi^+\pi^0\bar{\nu}$ final state, since the branching ratio is large at 21.8%. An interacting pion or a photon from initial state radiation can be mistaken for a photon from a final state decay in calculating the $\gamma\gamma$ effective mass. In addition, a photon occasionally converts to an e^+e^- pair in the Cerenkov counter system. The magnetic field bends the resulting e^+ and e^- tracks and two apparent neutral clusters can result. The events in fig. 1c with $n_\gamma \geq 3$ come predominantly from these background processes, and there is also a smaller contribution from the $\tau^+ \to \pi^+ 3\pi^0 \bar{\nu}$ decay.

The best fit lines on fig. 1, which represent the data well, have contributions at the π^0 and η masses, plus a background. The masses and widths (FWHM), which are fixed in the fits are: $M_{\pi^0} = 155$ MeV, $\Gamma_{\pi^0} = 42$ MeV and $M_\eta = 549$ MeV, $\Gamma_\eta =$ 100 MeV. The χ^2 for a fit of the data of fig. 1a to the background term, plus the π^0 contribution is 46.4. The six data points in the η mass region contribute 112.7 to this χ^2, so that significance of the signal is 3.4 standard deviations. The fit shown by the solid line, including π^0 and η contributions, has a χ^2 of 34.9 for 44 degrees of freedom. The data of fig. 1c are well represented by the background term, plus a very small contribution for the π^0. No contribution at the η mass is required.

The number of signal events in the η mass region, 480 MeV $< M_{\gamma\gamma} <$ 620 MeV, are listed in table 1 for the three data selections shown in fig. 1.

TABLE 1

Tau decay branching ratios

γ selection	Events above		Branching ratios for assumed final states	
	figure	background	$\pi^+\eta\bar{\nu}$	$\pi^+\eta\pi^0\bar{\nu}$
all	2a	39±8	4.9±1.0%	>35% at 90% CL
$n_\gamma = 2$	2d	26±6	5.3±1.3%	>11% at 90% CL
$n_\gamma \geq 3$	2e	10±5		16±8%

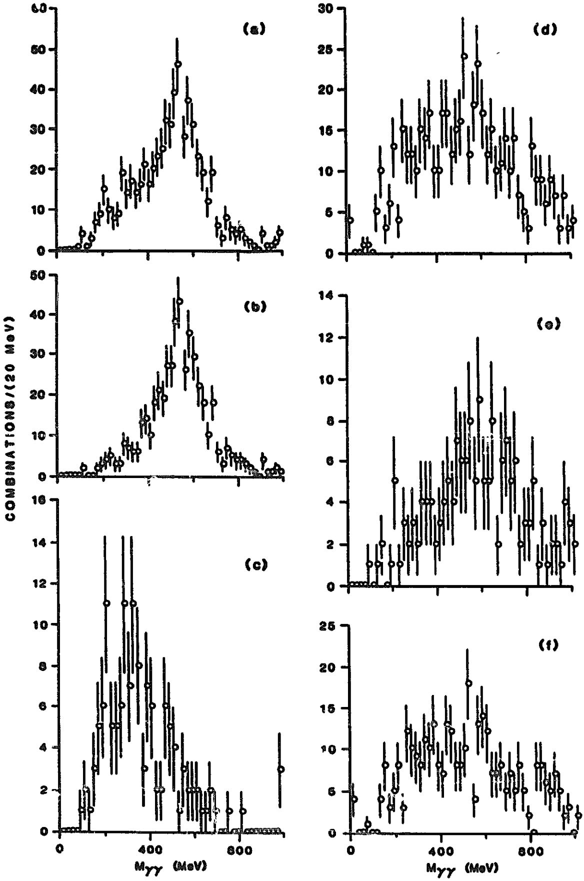

Fig. 2. Effective mass distributions for $\gamma\gamma$ combinations from $\eta \to \gamma\gamma$ and $\eta \to 3\pi^0 \to 6\gamma$ decays according to the Monte Carlo simulation: (a) $\tau^+ \to \pi^+ \eta \bar{\nu}$ decay, all events; (b) $\tau^+ \to \pi^+ \eta \bar{\nu}$ decay, events with two and only two photon clusters; (c) $\tau^+ \to \pi^+ \eta \bar{\nu}$ decay, events with three or more photon clusters; (d) $\tau^+ \to \pi^+ \eta \pi^0 \bar{\nu}$ decay, all events; (e) $\tau^+ \to \pi^+ \eta \pi^0 \bar{\nu}$ decay, events with two and only two photon clusters; (f) $\tau^+ \to \pi^+ \eta \pi^0 \bar{\nu}$ decay, events with three or more photon clusters.

Fig. 2 shows the $\gamma\gamma$ mass spectra with equivalent cuts to those used for the data but applied to events resulting from a MC simulation of the decays $\tau^+ \to \pi^+\eta\bar{\nu}$ (fig. 2a–c) and $\tau^+ \to \pi^+\eta\pi^0\bar{\nu}$ (fig. 2d–f). The two neutral decay modes, $\eta \to \gamma\gamma$ and $\eta \to 3\pi^0$, were allowed with the known branching ratios. The *MC* simulation, shown in fig. 2, corresponds to about eight times the number of $\tau \to \eta$ events observed in the data.

There is no π^0 peak in these *MC* samples since the $\eta \to 3\pi^0$ decay usually gives a π^0 with momentum below the 2 GeV/c cut. The opening angle of a 2-GeV $\pi^0 \to \gamma\gamma$ decay is also typically below 10°, so that the requirement of two clusters in separate modules results in a low π^0 detection efficiency.

As expected, the *MC* simulation of the $\pi^+\eta\bar{\nu}$ final state shows a strong enhancement in the $\gamma\gamma$ mass spectrum near 550 MeV in fig. 2a and fig. 2b. The shoulder at lower masses comes from $\gamma\gamma$ combinations with photons from separate π^0's from the $\eta \to 3\pi^0$ decay. Only a small fraction of the events satisfy the selection $n_\gamma \geq 3$ and, as seen in fig. 2c, there is no η signal in these data.

The *MC* simulation of the $\pi^+\eta\pi^0\bar{\nu}$ final state, shown in Figs. 2d–f, has a poor signal-to-noise ratio at the η peak because of the combinatorial background with one photon from the η decay combining with one from the π^0. For this final state, few events satisfy the $n_\gamma = 2$ selection, and most of the $\eta \to 2\gamma$ decay events are found in fig. 2f which has $n_\gamma \geq 3$. However, even with this cut, the η peak is difficult to see.

The comparison of the data of fig. 1 with the *MC* simulations of the $\pi^+\eta\bar{\nu}$ and $\pi^+\eta\pi^0\bar{\nu}$ final states shown in fig. 2 clearly indicates that the signal results from the decay $\tau^+ \to \pi^+\eta\bar{\nu}$. We emphasize that the probability of missing both π^0 decav photons from the $\pi^+\eta\pi^0\bar{\nu}$ final state is at the several percent level, so although some $\tau^+ \to \pi^+\eta\pi^0\bar{\nu}$ decays cannot be ruled out, the predominant decay mode observed is $\tau^+ \to \pi^+\eta\bar{\nu}$.

This point is quantified in the decay branching ratios corresponding to the data of fig. 1a and fig. 1b for assumed $\pi^+\eta\bar{\nu}$ and $\pi^+\eta\pi^0\bar{\omega}$ final states, which are given in table 1. The two values for the $\pi^+\eta\bar{\nu}$ final state are consistent within errors and agree with the $(5.1 \pm 1.5)\%$ value reported previously [1]), whereas the $\pi^+\eta\pi^0\bar{\nu}$ hypothesis gives unreasonably large (and inconsistent) decay branching ratios for the two data selections.

Since the final state $\pi^+\eta\bar{\nu}$ has been observed, the question arises if the decay occurs through the intermediate $a_0(980)$ scalar meson: $\tau^+ \to a_0^+(980)\bar{\nu} \to \pi^+\eta\bar{\nu}$. The $\pi^+\eta$ mass spectrum is consistent with the possibility of an intermediate $a_0(980)$ state. However, with the present number of events, we are unable to establish this decay mode.

There have been many searches for second-class currents, both in nuclear β decay and in muon capture [5]). In the n–p transition, the vector (axial-vector) current is expressed in terms of three form factors of which the scalar (tensor) has the symmetry corresponding to the second-class current. Since the second-class form factors are proportional to the momentum transfer, the effects are small and no convincing evidence has been established. These experiments are primarily sensitive to the axial current since the scalar form factor is proportional to the lepton mass and so suppressed in β decay processes. The resulting limit [6]) on the scalar form factor is very weak and not in conflict with the present result. Second-class currents also contribute to quasi-elastic neutrino scattering [7]), and some fits have been made, including a second-class tensor form factor [8]), although the data do not require such a contribution.

Some theoretical estimates [9]) of the magnitude of the $\tau^+ \to \pi^+ \eta \bar{\nu}$ decay branching ratio, based on current algebra and the SU(2)×SU(2) σ model, gives values of 4–6% in agreement with our measurement.

If a second-class vector current exists, there is additional interest in a study of the decay $\tau^+ \to \pi^+ \omega^0 \bar{\nu}$ where the intermediate state $\tau^+ \to b_1(1235)\bar{\nu}$ can occur through a second-class axial-vector current [9,10]). The $\pi^+ \omega \bar{\nu}$ final state can also result from the decay of the $\rho(1600)$, so a detailed analysis is required to establish the presence the $b_1(1235)$ intermediate state.

In summary, we report the observation of η production in one-prong τ decays and give evidence for the decay $\tau^+ \to \pi^+ \eta \bar{\nu}$. The branching ratio of 5.1% gives a 3.6% contribution to the one-prong topology since the branching ratio of η to neutrals is 71%. This result goes far in accounting for the one-prong deficit. The dicrimination between the $\pi^+ \eta \bar{\nu}$ and $\pi^+ \eta \pi^0 \bar{\nu}$ final states rests on: (i) the absence of additional photons in the events in which the $\eta \to \gamma\gamma$ decay is detected, (ii) the overall consistency of the data with characteristics expected from the $\tau^+ \to \pi^+ \eta \bar{\nu}$ decay, and (iii) the difference of the data from the simulation of the $\tau^+ \to \pi^+ \eta \pi^0 \bar{\nu}$ decay leading to a low detection efficiency and a correspondingly large and unreasonable branching ratio.

Second-class currents are not included in the known parts of the Standard Model of electroweak interactions. Since the statistics of our data sample is limited, it is important that the present results be confirmed or refuted by other, independent experiments on τ decay.

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Note added in proof: After the completion of this paper, we have studied the inclusive η production in τ decays using the invariant mass spectrum of $\pi^+\pi^-$ in the decay of $\eta \to \pi^+\pi^-\pi^0$ [ref. [11])]. The result is an upper limit on the process $\tau^+ \to \pi^+ \eta X$ of 2.1% at 90% confidence level. This new limit is not in agreement with our previously published result of $(5.1 \pm 1.5)\%$ for the branching ratio of $\tau^+ \to \pi^+ \eta \bar{\nu}$. Since the previous result is only three deviation effect as stated in this text, it is most probably due to a statistical fluctuation.

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