Production of η and ω Mesons in τ Decay and a Search for Second-Class Currents

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The production of η and ω mesons in τ decay has been studied with the CLEO detector. A sample of 42000 $e^+e^- \rightarrow \tau^+\tau^-$ events at a mean $\sqrt{s}$ of 10.5 GeV is used in the analysis. The branching ratio $B(\tau^- \rightarrow \omega\pi^-\nu_\tau)$ is measured to be $(1.60\pm0.27\pm0.41)\%$. No signal for η production from τ decay is observed, resulting in 95%-confidence-level upper limits of 1.8% for $B(\tau^- \rightarrow \eta\pi^-\nu_\tau)$, 2.1% for $B(\tau^- \rightarrow \eta\pi^-\pi^0\nu_\tau)$, and 2.1% for inclusive η production in τ decay. No evidence is found for decays proceeding via second-class currents.

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The study of η and ω meson production in τ decay is of particular interest since it could provide evidence for second-class currents,[1,2] which are not included in the standard model of the electroweak interaction. In addition, because 70.9% of η mesons decay into all neutral particles,[3] the presence of a large amount of η production in τ decay could help explain the discrepancy between the measured one-prong topological branching ratio and the sum of the exclusive one-prong decay modes.[4] However, if inclusive η production occurs in more than 2% of one-prong τ decays, an inconsistency develops between other existing e^+e^- annihilation data and the standard model.[5] The exclusive decay channel $\tau^- \rightarrow \omega\pi^-\nu_\tau$ was recently observed by Albrecht *et al.* (ARGUS Collaboration),[6] and no evidence was seen for a second-class axial-vector current ($J^{PG}=1^{++}$) in the $\omega\pi^-$ system. Derrick *et al.* (HRS Group)[7] have reported evidence for the exclusive decay $\tau^- \rightarrow \eta\pi^-\nu_\tau$ with a branching ratio of $(5.1\pm1.5)\%$, in which the η was seen in the decay mode $\gamma\gamma$. The decay to $\eta\pi^-\nu_\tau$ can arise from a first-class current only through isospin violation in final-state strong interactions, which is expected to produce this final state in less than 0.5% of τ decays.[8]

In this Letter we present results of a search for τ decays to final states containing η or ω mesons using the CLEO detector[9,10] at the Cornell Electron Storage Ring. This analysis relies primarily on two devices: a seventeen-layer drift chamber in a 1-T magnetic field which provides a momentum resolution of $(\sigma_p/p)^2=(0.007p)^2+(0.006)^2$ (p in GeV/c), and a lead-PWC (proportional wire chamber), electromagnetic-shower detector which is located at a mean distance of 2.4 m from the beam interaction point and which has a photon-energy resolution of $\sigma_E/E=20\%/\sqrt{E}$ (E in gigaelectronvolts).

The data sample corresponds to 308 pb^{-1} of e^+e^- annihilation events at an average center-of-mass energy of 10.5 GeV. The criteria used to select the sample of

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42000 $e^+e^- \rightarrow \tau^+\tau^-$ events in the one-versus-three topology have been described previously.[11] The contamination from hadronic events is estimated to be $(15 \pm 5)\%$ by an analysis of the invariant-mass distribution of the three charged prongs.[10] This sample is used to search for the ω via its decay to $\pi^+\pi^-\pi^0$ and for the η in the $\pi^+\pi^-\pi^0$ and $\gamma\gamma$ decay modes. The η is also sought with use of the $\pi^+\pi^-$ invariant-mass distribution.

In order to reconstruct the η and ω decays to $\pi^+\pi^-\pi^0$, we must first identify the photons from the π^0 decays. Photons are defined as showers which have deposited energy of greater than 150 MeV in the electromagnetic calorimeter and which do not lie on the extrapolated path of any charged track. Although this energy cut allows minimum ionizing showers which have failed the charged track-matching algorithm to be mistakenly identified as photons (such showers give a peak at 220 MeV), it is necessary in order to keep our ω efficiency reasonable. Below 150 MeV, the observed energy spectrum of unmatched showers is dominated by noise. A large peak at the π^0 mass is observed when the invariant mass is computed for pairs of photons, where both photons are in the hemisphere (as defined by the thrust axis) of the three-prong τ decay. Photon pairs satisfying $90 < m_{\gamma\gamma} < 180$ MeV are chosen as π^0 candidates, and the photon energies are adjusted in a kinematic fit to the π^0 mass. These π^0 candidates are then combined in turn with each of the two pairs of oppositely charged drift-chamber tracks, assumed to be pions, from the three-prong τ decay. In Fig. 1(a) is shown the resulting $\pi^+\pi^-\pi^0$ invariant-mass distribution. A clear signal is observed in the ω region, but none is seen near the η mass. For the measurement of $B(\tau^- \rightarrow \omega\pi^-\nu_\tau)$, the ω signal is enhanced, as shown in Fig. 1(b), by selecting $\pi^+\pi^-\pi^0$ combinations from the interior half of the three-pion Dalitz plot.[12] With the fit of the distributions to Gaussian signals for the η and ω plus a polynomial background, the 95%-confidence-level upper limit on the number of η mesons is 36 [from Fig. 1(a)], and the number of observed ω mesons is 139 ± 25 [from Fig. 1(b)]. The fit to the ω peak in Fig. 1(b) gives a mass of 789 ± 5 MeV, and a measured rms width of 25 ± 5 MeV, in good agreement with Monte Carlo predictions. In the extraction of the limit on $\eta \rightarrow \pi^+\pi^-\pi^0$, the mass and width of the signal were taken from Monte Carlo calculations to be 550 and 30 MeV, respectively. The width is dominated by the experimentally determined π^0 mass resolution.

A Monte Carlo procedure is used to determine our detection efficiencies for events containing $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\omega \rightarrow \pi^+\pi^-\pi^0$ relative to the average one-versus-three τ event.[13] The world-average three-prong topological branching fraction, $B_3 = (13.1 \pm 0.3)\%$,[14] is used to convert the ω and η yields into an upper limit on $B(\tau^- \rightarrow \eta\pi^- X^0 \nu_\tau)$ and a measurement of $B(\tau^- \rightarrow \omega\pi^- X^0 \nu_\tau)$, where by X^0 we mean either zero or one π^0.[15] The B_3-normalized branching ratio we obtain from the ω signal depends somewhat on X^0. The measured ω momentum spectrum and the number of photons observed in the three-prong hemisphere are consistent with the hypothesis that the ω's arise only from $\tau^- \rightarrow \omega\pi^-\nu_\tau$. Therefore, in making the efficiency corrections, it is assumed that all ω's produced in τ decay come via this exclusive decay mode, giving $B(\tau^- \rightarrow \omega\pi^-\nu_\tau) = (1.60 \pm 0.27 \pm 0.41)\%$, where the first error is statistical and the second systematic. This value is consistent with the ARGUS measurement[6] of $B(\tau^- \rightarrow \omega\pi^-\nu_\tau) = (1.5 \pm 0.3 \pm 0.3)\%$. If the ω signal were due entirely to $\tau^- \rightarrow \omega\pi^-\pi^0\nu_\tau$, our branching ratio would increase by 14%. The systematic error includes uncertainties in the detection efficiencies, in the fitting functions used in extracting the signal, and in the normalization of the data. Studies of background events with a one-versus-three topology, but with a three-prong invariant-mass greater than the τ mass, indicate that the contribution to the ω signal from the hadronic background in the τ sample is negligible.

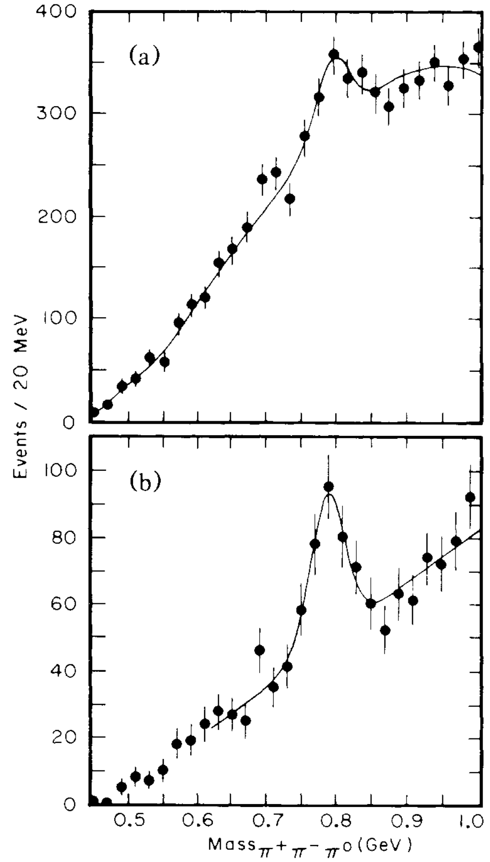

FIG. 1. $\pi^+\pi^-\pi^0$ invariant-mass distribution from the three-prong τ events for (a) combinations from the full Dalitz plot and (b) combinations in the interior half of the Dalitz plot. The solid curves show the fits described in the text.

We examine the $\omega\pi^-$ system for resonant effects. Al-

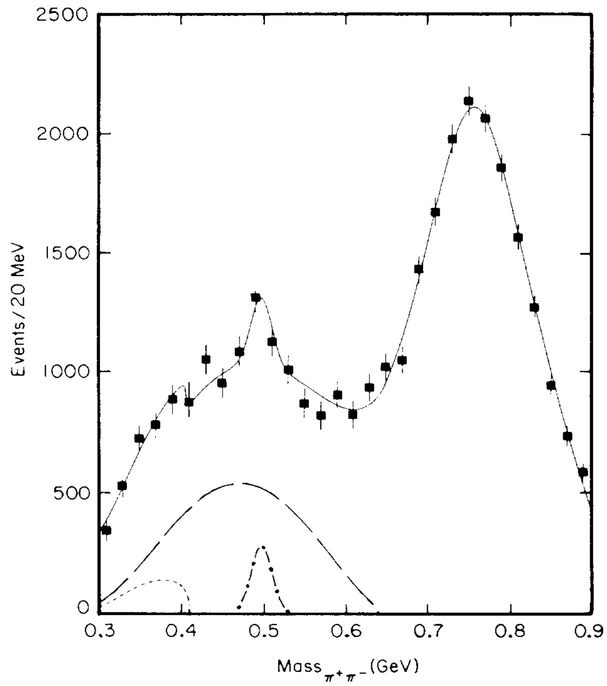

FIG. 2. $\pi^+\pi^-$ invariant-mass distribution from three-prong τ decays with the like-sign background subtracted. The solid curve represents a fit which includes shapes for the η, ω, ρ^0, and K^0 plus a polynomial background. The contributions to the fit from the η, ω, and K^0 are shown by the short-dashed, long-dashed, and dot-dashed curves, respectively.

though no structure is observed in the $\omega\pi^-$ invariant-mass spectrum, the spin and parity of this system can, in principle, be determined, allowing us to distinguish between a first-class current and a second-class current. The ψ distribution is measured, where ψ is the angle in the ω rest frame between the normal to the ω decay plane and the bachelor π^- direction.[16] The fit to the $1-\cos^2\psi$ shape, which represents the first-class current ($J^{PG}=1^{-+}$), gives a confidence level of 85% (χ^2 of 0.9 for three degrees of freedom), whereas the flat $\cos\psi$ shape, which represents the second-class current ($J^{PG}=1^{++}$, $I=0$), has a confidence level of 32% (χ^2 of 3.2 for three degrees of freedom).[17] The first-class current interpretation is therefore slightly preferred.

The 95%-confidence-level upper limit we obtain for $B(\tau^-\rightarrow\eta\pi^-X^0\nu_\tau)$ changes smoothly from 1.8% to 2.1%, as we vary the mix of the two exclusive states from all $\tau^-\rightarrow\eta\pi^-\nu_\tau$ to all $\tau^-\rightarrow\eta\pi^-\pi^0\nu_\tau$. Therefore there is no evidence for η production in τ decay at a level which would be inconsistent with the standard model,[5] nor is there evidence for the second-class vector-current decay $\tau^-\rightarrow\eta\pi^-\nu_\tau$.

As an alternative approach, we search for an η signal in the $\pi^+\pi^-$ invariant-mass spectrum. Because of its small Q value, and a decay matrix element which favors low π^0 energies in the η rest frame,[18] the η decays give a narrow, asymmetric peak near 380 MeV in the $\pi^+\pi^-$ invariant-mass distribution. A measurement of this peak in our three-prong τ sample provides a truly inclusive measurement of η production as it is relatively insensitive to the number of additional π^0's in the τ decay. However, the method suffers from systematic uncertainties because other resonances (most notably the K^0, ρ^0, and the $\pi^+\pi^-$ from the ω decay) resulting from τ decay, as well as the underlying hadronic background, can contribute to this region of the $\pi^+\pi^-$ mass distribution. The decay $\eta\rightarrow\pi^+\pi^-\gamma$ makes a negligible contribution to the η signal as measured in the fit described below.

Figure 2 shows the invariant-mass distribution obtained from three-prong τ decays by subtracting the $\pi^\pm\pi^\pm$ (one entry per event) from the $\pi^\pm\pi^\mp$ mass spectrum (two entries per event). No peak is observed near 380 MeV, whereas this peak is clearly evident in Monte Carlo events when the decay $\tau^-\rightarrow\eta\pi^-\nu_\tau$ or $\tau^-\rightarrow\eta\pi^-\pi^0\nu_\tau$ is included. The data are fitted with the Monte Carlo predicted shapes for the η and ω decays, a Gaussian distribution for the K^0, a spin-1 Breit-Wigner form for the ρ^0,[19] and a polynomial background shape. The contributions to the fit from the η, ω, and K^0 are indicated in Fig. 2. The 95%-confidence-level upper limit on the number of η mesons in this distribution is 1040. Correcting for the relative detection efficiency between these events involving η and an average one-versus-three τ event, adding a 37% systematic error in quadrature to the statistical error, and normalizing to the world average for B_3, we find a 95%-confidence-level upper limit of 2.1% on the inclusive branching ratio of τ to η for the sum of all exclusive channels containing a single η. These data give an upper limit on τ decays to states containing two η's of 1.5%. After efficiency corrections, the number of ω's in Fig. 2 is consistent, within the systematic uncertainties, with expectations from the branching ratio measured above.

As a further check on these results, we have used the one-prong side of the one-versus-three events to search for the decays $\tau^-\rightarrow\eta\pi^-X^0\nu_\tau$ in which $\eta\rightarrow\gamma\gamma$. Only one-prong τ decays with exactly two photons in the one-prong hemisphere are used, with each photon having a measured energy in excess of 300 MeV. When the invariant mass of these photon pairs is plotted for $x>0.6$, where $x=p_{\gamma\gamma}/E_{\text{beam}}$, a large π^0 signal (166 ± 12 events) consistent with $\tau^-\rightarrow\pi^-\pi^0\nu_\tau$ is observed as shown in Fig. 3, but no enhancement is seen in the region of the η mass. With use of the same photon-selection procedure and the same x region, an η signal is observed in a continuum ($\sqrt{s}=10.5$ GeV) hadronic-event sample, with a mass and width of 552 ± 9 and 82 ± 15 MeV, respectively. By our fixing the η mass and width to these values, the τ data are fitted as shown in Fig. 3. At the 95% confidence level, fewer than 21.1 η's are contained in the plot. Monte Carlo simulations are used to integrate over the unobserved x region and to compute the relative detection efficiency between the decays $\tau\rightarrow\pi^-\pi^0\nu_\tau$ and

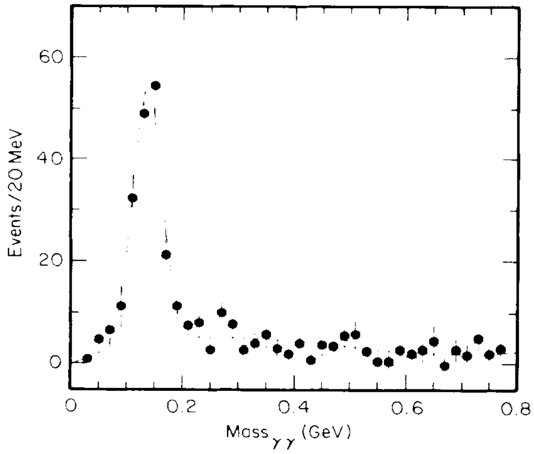

FIG. 3. $\gamma\gamma$ invariant-mass distribution with $\chi > 0.6$ for one-prong τ candidates. The solid line shows the fit described in the text.

$\tau^- \rightarrow \eta\pi^-\nu_\tau$. With use of the observed number of π^0's and $B(\tau \rightarrow \pi^-\pi^0\nu_\tau) = (22.1 \pm 0.4)\%$ [3] as the normalization, the 95%-confidence-level upper limit on $B(\tau^- \rightarrow \eta\pi^-\nu_\tau)$ is 4.8%.[20]

To summarize, we have searched for τ's decaying to final states which include either an η or an ω meson. The branching ratio $B(\tau^- \rightarrow \omega\pi^-\nu_\tau)$ is found to be $(1.60 \pm 0.27 \pm 0.41)\%$. No η production is observed in either the $\pi^+\pi^-\pi^0$ or $\gamma\gamma$ decay mode. The 95%-confidence-level upper limits of $B(\tau^- \rightarrow \eta\pi^-\nu_\tau) < 1.8\%$ and $B(\tau^- \rightarrow \eta\pi^-\pi^0\nu_\tau) < 2.1\%$ are determined. An analysis of the $\pi^+\pi^-$ invariant-mass distribution gives an upper limit of 2.1% for inclusive η production. Comparable limits have recently been reported by other experiments.[21] No evidence is found for second-class currents or for inclusive η production in τ decay at a level which would be inconsistent with the standard model.[5] However, this also implies that η production cannot explain the discrepancy between the measured one-prong topological branching fraction and the sum of the exclusive one-prong decay modes.

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[13] Typically, the relative efficiencies are 3.4% for the η and 3.2% for the ω, including the effect of the Dalitz cut for the case of the ω. These values do not include the branching ratios for each particle into $\pi^+\pi^-\pi^0$.

[14] P. Burchat, in *Proceedings of the Twenty-Third International Conference on High Energy Physics, Berkeley, California, 1986,* edited by Stewart C. Loken (World Scientific, Singapore, 1987), p. 756.

[15] Other exclusive modes which contribute to η or ω production in τ decay can be related either directly or through isospin arguments to the measured five-prong topological branching fraction and so are expected to be very small. See Ref. 5.

[16] This analysis depends on our assumption that no additional π^0's are present.

[17] The second-class current, $J^P = 1^+$ $(I = 2)$, interpretation gives a χ^2 of 9.5 for three degrees of freedom.

[18] J. Layter *et al.*, Phys. Rev. D **7**, 2565 (1973).

[19] The measured η signal is insensitive to the form used to describe the shape of the ρ^0.

[20] This limit assumes that $\tau^- \rightarrow a_0^-(980)\nu_\tau$; $a_0^-(980) \rightarrow \eta\pi^-$. If the decay mode is actually $\tau^- \rightarrow \eta\pi^-\nu_\tau$ (nonresonant), the upper limit changes to 3.8%.

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