Measurement of the Inclusive Branching Fraction $\tau^- \rightarrow \nu_\tau \pi^- \pi^0$ + Neutral Meson(s)

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(Received 1 July 1986)

We measure an inclusive branching fraction of $(13.9 \pm 2.0^{+1.9}_{-2.2})\%$ for the decay $\tau^- \rightarrow \nu_\tau \pi^- \pi^0 + nh^0$ ($n \geq 1$), where h^0 is a π^0 or an η. The data sample, obtained with the time-projection-chamber detector facility at the SLAC e^+e^- storage ring PEP, corresponds to an integrated luminosity of 72 pb^{-1} at 29 GeV center-of-mass energy. The measured branching fraction is somewhat greater than the theoretical prediction and, with errors taken into account, could resolve the present difference between the inclusive and the sum of the exclusive $\tau^\pm$ branching fractions into one charged prong.

PACS numbers: 13.35.+s, 14.60.Jj

Over the past several years, a discrepancy between the inclusive one-prong branching fraction of the $\tau^\pm$ lepton and the sum of its exclusive one-prong decay fractions[1] has sparked interest in further measurement of the exclusive channels. The measured inclusive one-prong branching fraction is $(86.5 \pm 0.6)\%$,[2] while the sum of the measured exclusive decay modes that have only one charged particle is $(68.9 \pm 2.0)\%$.[2,3] Decays involving more than one neutral meson have been excluded from the sum because of the large errors in the measurements.[4] Theory predicts that the sum of the branching fractions of one-prong decays associated with multiple neutral mesons is 8.5%,[1] less than half of the $(17.6 \pm 2.1)\%$ difference between the inclusive and exclusive fractions. In this Letter we report a measurement of the sum of the single-prong branching fractions of the $\tau^\pm$ associated with more than one neutral meson.

The 72 pb^{-1} of data were recorded with the time-projection chamber (TPC) facility at the SLAC e^+e^- storage ring PEP operating at $\sqrt{s} = 29$ GeV/c^2. The TPC[5] tracks charged particles with a momentum resolution of $\sigma_p/p = 0.035p/(1\ \mathrm{GeV}/c)$, while the hexagonal calorimeter (HEX)[6] measures photons with a typical energy resolution of $\sigma_E/E \approx (0.20\ \mathrm{GeV}^{1/2})/E$. The fine segmentation of the HEX (8-mrad projective strips) permits the reconstruction of electromagnetic showers separated by as little as 40 mrad. Cuts applied to the HEX data remove energy clusters due to charged hadron interactions, electron bremsstrahlung, and pattern-recognition fakes. Photons that convert in the 0.2-radiation length beam pipe are reconstructed geometrically with the TPC and added to the photon sample. The γ-γ invariant-mass distribution for all combinations with center-of-mass momentum $P_{\gamma\gamma} \geq 1.5$ GeV/c and center-of-mass decay angle $\cos\theta_{\mathrm{c.m.}} \leq 0.6$ is plotted in Fig. 1, showing a clear π^0 peak.

Charged tracks identified by the TPC are used to select $\tau^+\tau^-$ events in which each $\tau^\pm$ decays into a single charged particle. The selection requires two oppositely charged tracks (excluding off-vertex tracks, poorly measured tracks, and tracks from photon conversions) with acollinearity angle between 3° and 55° and acoplanarity angle (defined using the e^+e^- beam direction) between 1° and 55°. Two-photon and Bhabha events are removed by requiring total charged energy between 7.25 and 22 GeV, and the ionization loss dE/dx in the TPC is used to identify tracks that are not electrons.[5] Radiative Bhabhas are rejected by demanding that at least one track not be an electron, and if only one track is identified as a nonelectron, that its momentum be less than 9.5 GeV/c. Multihadron events are rejected by requiring that the event sphericity be less than 0.06, while two-photon events are removed by requiring that the scalar sum of the charged-track momenta in each event hemisphere be greater than 0.65 GeV/c. This selection results in a sample of 1299 events, of which Monte Carlo simulation estimates 97 ± 20 to be background in roughly equal amounts from radiative Bhabha events, two-photon events, and $\tau^+\tau^-$ events in which one $\tau^\pm$ decays into three charged particles.

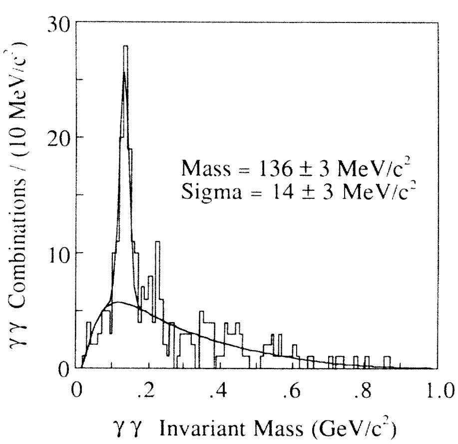

FIG. 1. The γ-γ invariant-mass spectrum in the $\tau^+\tau^-$ event sample.

The predicted decay modes of the τ^- with more than one neutral meson and a one-prong branching fraction greater than 0.1%[1] are[7]

$$\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0, \quad 7\%;$$

$$\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0 \pi^0, \quad 1\%;$$

$$\tau^- \to \nu_\tau \pi^- \pi^0 \eta, \quad 0.5\%.$$

It is difficult to distinguish among these because of low neutral-meson reconstruction efficiency ($\sim 6\%$/meson) and combinatorial background, and so the analysis is primarily sensitive to the sum, rather than the individual branching fractions.

In events with three or more photons in the same hemisphere the invariant mass of each γ-γ combination is fitted (one-constraint) to the π^0 mass. The combination is labeled a π^0 candidate if $\chi^2_{\pi^0} \leq 4$ and $P_{\gamma\gamma} \geq 1$ GeV/c. For each π^0 candidate the energies of all photons in the same hemisphere (excluding the two from the π^0) with $E_\gamma \geq 0.4$ GeV are summed. If this additional energy is greater than 1 GeV, the decay is counted as a multiple-neutral-meson decay. Decays containing more than one π^0 candidate are weighted by the fraction of the π^0 candidates that have more than 1 GeV additional energy. Using this technique, 47.5 multiple-neutral-meson decays are found.

The acceptance and the background are estimated with a Monte Carlo program that simulates both electromagnetic[8] and hadronic[9] showers in the HEX, then processes these showers with the same software as the real data. The Monte Carlo program estimates that 7.6 ± 0.8 of the decays in the multiple-neutral-meson sample are background, mostly from the decay $\tau^- \to \nu_\tau \rho^- \to \nu_\tau \pi^- \pi^0$ accompanied by final-state radiation.[10] The Monte Carlo estimation of the background is checked by searching for the multiple-neutral-meson signal in the 660 three-charged-prong $\tau^\pm$ decays selected by Aihara,[11] as the branching ratio for $\tau^\pm \to \nu_\tau 3\pi^\pm + n\pi^0$ $(n \geq 2)$ decays is predicted to be less than $(0.13 \pm 0.04)\%$.[1,12]

Since three decay modes are expected to contribute to the multiple-neutral-meson signal and the acceptance for each decay mode is slightly different, the $47.5 - 7.6 = 39.9$ multiple-neutral-meson decays are converted into a weighted sum of three branching fractions:

$$B_{\nu_\tau \pi^- \pi^0 \pi^0} + 1.6 B_{\nu_\tau \pi^- \pi^0 \pi^0 \pi^0} + 1.1 B_{\nu_\tau \pi^- \pi^0 \eta} = (13.9 \pm 2.0 \pm 1.9)\%, \quad (1)$$

where the first error is statistical and the second is systematic. The main contributions to the systematic error are the uncertainty in the π^0 reconstruction efficiency (12%) and the background subtraction (5%).[13]

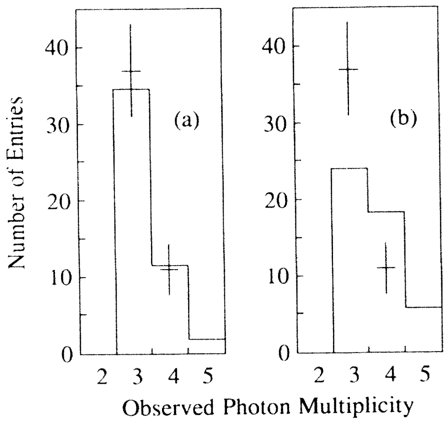

FIG. 2. Photon multiplicity in multiple-neutral-meson events. The points with error bars are the observed distribution, while the solid lines are the Monte Carlo predictions for (a) $\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0$ and (b) $\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0 \pi^0$ decay modes. The predicted distribution for the $\tau^- \to \nu_\tau \pi^- \pi^0 \eta$ decay mode is nearly identical to distribution (b).

In order to convert the weighted sum of branching fractions [Eq. (1)] into an unweighted sum, it is necessary to know the relative contribution of each candidate decay mode. This information is obtained by counting the number of photons observed in multiple-neutral-meson decays. The Monte Carlo program predicts a significantly smaller number of detected photons for $\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0$ decays than for $\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0 \pi^0$ or $\tau^- \to \nu_\tau \pi^- \pi^0 \eta$ decays (Fig. 2). When the observed photon multiplicity is fitted to a linear combination of the distributions predicted for each decay mode, the maximum likelihood is obtained if 100% of the multiple-neutral-meson signal is attributed to $\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0$ decays. However, the statistical error is large, and so this result is expressed as a lower limit of

$$B_{\nu_\tau \pi^- \pi^0 \pi^0} > 8.3\% \quad (95\% \text{ C.L.}), \qquad (2)$$

or, equivalently, as an upper limit on the weighted sum of the remaining branching fractions of

$$1.6 B_{\nu_\tau \pi^- \pi^0 \pi^0 \pi^0} + 1.1 B_{\nu_\tau \pi^- \pi^0 \eta} < 5.6\% \ (95\% \text{ C.L.}). \qquad (3)$$

Using the upper limit given in Eq. (3), the weighted sum of branching fractions [Eq. (1)] is converted into an unweighted sum with modestly increased systematic errors. Since the best fit is obtained when $B_{\nu_\tau \pi^- \pi^0 \pi^0 \pi^0}$ and $B_{\nu_\tau \pi^- \pi^0 \eta}$ are 0%, the most probable value for the unweighted sum is 13.9%. Therefore, we obtain an unweighted sum of multiple-neutral-meson branching fractions of

$$B_{\nu_\tau \pi^- \pi^0 \pi^0} + B_{\nu_\tau \pi^- \pi^0 \pi^0 \pi^0} + B_{\nu_\tau \pi^- \pi^0 \eta} = (13.9 \pm 2.0^{+1.9}_{-2.2})\%, \qquad (4)$$

where the uncertainty in the composition of the multiple-neutral-meson decay modes is now included in the systematic error. The systematic errors in Eq. (4) are asymmetric, as nonzero values for $B_{\nu_\tau \pi^- \pi^0 \pi^0 \pi^0}$ and $B_{\nu_\tau \pi^- \pi^0 \eta}$ can lower the unweighted sum but cannot raise it. The values for the additional systematic error are given by the extreme values for the unweighted sum obtained when the three multiple-neutral-meson branching fractions are independently varied within the one-standard-deviation contour defined by Eqs. (1) and (3).

In conclusion, we have measured the sum of the branching fractions of the single-prong $\tau^\pm$ decay modes that include more than one neutral meson to be $(13.9 \pm 2.0^{+1.9}_{-2.2})\%$. This value is greater than the theoretical prediction of 8.5%, and agrees, within errors, with the $(17.6 \pm 2.1)\%$ difference between the inclusive branching fraction and the sum of the exclusive one-prong branching fractions with at most one neutral meson. Although this experiment has limited power to distinguish between the individual multiple-neutral-meson decay modes, it places a lower limit on $B_{\nu_\tau \pi^- \pi^0 \pi^0}$, or, equivalently, an upper limit on the weighted sum of $B_{\nu_\tau \pi^- \pi^0 \pi^0 \pi^0}$ and $B_{\nu_\tau \pi^- \pi^0 \eta}$.

We acknowledge the efforts of the SLAC e^+e^- storage ring PEP staff, and the engineers, programmers, and technicians who made this work possible. This work was supported by the U.S. Department of Energy under Contracts No. DE-AC03-76SF00098, No. DE-AM03-76FS00034, and No. DE-AC02-76ER03330, by the National Science Foundation, and by the Joint Japan–U.S. Collaboration in High Energy Physics.

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$$B(\tau^- \to \nu_\tau \pi^- \pi^0 \eta) B(\eta \to \text{all neutrals}).$$

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