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Search for the Decay $\tau^- \to 4\pi^- 3\pi^+ (\pi^0) \nu_\tau$

CLEO Collaboration

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Abstract

We have searched for the decay of the τ lepton into seven charged particles and zero or one π^0. The data used in the search were collected with the CLEO II detector at the Cornell Electron Storage Ring (CESR) and correspond to an integrated luminosity of 4.61 fb^{-1}. No evidence for a signal is found. Assuming all the charged particles are pions, we set an upper limit on the branching fraction, $B(\tau^- \to 4\pi^- 3\pi^+ (\pi^0) \nu_\tau) < 2.4 \times 10^{-6}$ at the 90% confidence level. This limit represents a significant improvement over the previous limit.

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The decay of the τ lepton into final states with seven or more pions is of particular interest since it may provide a sensitive probe of the ν_τ mass due to the limited phase space. There are several experimental upper limits on the branching fractions (at the 90% confidence level). The HRS experiment [1] published an upper limit of $B(\tau^- \to 4\pi^- 3\pi^+ \geq 0 \text{ neutrals } \nu_\tau) < 1.9 \times 10^{-4}$ [2]. Recently, the OPAL experiment [3] set an upper limit of $B(\tau^- \to 4\pi^- 3\pi^+ (\pi^0) \nu_\tau) < 1.4 \times 10^{-5}$. For comparison, the upper limit on the branching fraction for the decay $\tau^- \to 3\pi^- 2\pi^+ 2\pi^0 \nu_\tau$ as determined by the CLEO II experiment [4] is 1.1×10^{-4}. In this paper, we present the result of a search for the decay into seven charged particles and zero or one π^0 using the CLEO II detector with the assumption that all charged particles are pions.

The data used in this search were collected from e^+e^- collisions at a center-of-mass energy ($\sqrt{s}$) of 10.6 GeV with the CLEO II detector [5] at the Cornell Electron Storage Ring (CESR). The total integrated luminosity of the sample is $4.61 fb^{-1}$, corresponding to the production of $N_{\tau\tau} = 4.21 \times 10^6$ τ-pairs. CLEO II is a general purpose spectrometer with excellent charged particle and electromagnetic shower energy detection. The momenta and specific ionization (dE/dx) of charged particles are measured with three cylindrical drift chambers between 5 and 90 cm from the e^+e^- interaction point that have a total of 67 layers. These are surrounded by a scintillation time-of-flight system and a CsI(Tl) calorimeter with 7800 crystals. These detector systems are installed inside a superconducting solenoidal magnet (1.5 T), surrounded by an iron return yoke instrumented with proportional tube chambers for muon identification.

The event selection criteria were designed to maintain a high detection efficiency while suppressing the τ migration and hadronic ($e^+e^- \to q\bar{q}$) background. The τ migration is primarily from the decays $\tau^- \to 2\pi^-\pi^+2\pi^0\nu_\tau$ and $\tau^- \to 3\pi^-2\pi^+\pi^0\nu_\tau$, in which the π^0's decay via the Dalitz mechanism or via the $\gamma\gamma$ decay channel with photon conversion at the beam pipe or drift chamber walls. Each $\tau^+\tau^-$ candidate event is required to contain eight charged tracks with zero net charge. The distance of closest approach of each track to the e^+e^- interaction point must be less than 1 cm in the plane transverse to the beam axis and 10 cm along the beam axis; this requirement suppresses the τ migration background from photon conversions. Each track must have a momentum of at least $0.02E_{beam}$ ($E_{beam} = \sqrt{s}/2$) and be in the central region of the detector, $|\cos\theta| < 0.90$, where θ is the polar angle with respect to the beam axis.

The event is divided into two hemispheres using the plane perpendicular to the thrust axis [6], where the thrust axis is calculated using both charged tracks and photons. A photon candidate is defined as a calorimeter cluster with a minimum energy of 60 MeV in the barrel region ($|\cos\theta| < 0.80$) or 100 MeV in the endcap region ($0.80 < |\cos\theta| < 0.95$). The photon candidate must be isolated by at least 30 cm from the projection of any charged track on the surface of the calorimeter *and* have either an energy which is above 300 MeV or a lateral profile of energy deposition consistent with that of a photon. There must be one charged track in one hemisphere recoiling against seven charged tracks in the other (1 vs. 7 topology) with no more than two photons in the 1-prong hemisphere. These requirements select the dominant one-charged-particle decays of the τ lepton as tags, $\tau^- \to e^-\bar{\nu}_e\nu_\tau$, $\mu^-\bar{\nu}_\mu\nu_\tau$, $\pi^-\nu_\tau$, $\rho^-\nu_\tau$, while suppressing the hadronic background. There is no photon multiplicity requirement in the 7-prong hemisphere in order to minimize the dependence on the Monte Carlo simulation (see below) of charged pions interacting in the calorimeter that may mimic photon showers. We also do not attempt to reconstruct the π^0 meson in the decay $\tau^- \to 4\pi^-3\pi^+\pi^0\nu_\tau$. The migration background is further reduced by restricting the number of electron candidates in the 7-prong hemisphere to be no more than two [7]. An electron candidate is defined as a charged track with a shower energy to momentum ratio in the range, $0.85 < E/p < 1.1$, and, if available, with a specific ionization loss (dE/dx) consistent with that of an electron.

Two kinematic requirements are used to further reduce the hadronic background. The total invariant mass of charged tracks and photons in each hemisphere must be less than the τ mass ($M_1, M_7 < M_\tau = 1.777$ GeV/c^2) [8]. The magnitude of the total momentum of the 7-prong hemisphere in the τ rest frame, P^*, must be less than 0.2 GeV/c. In calculating P^*, we assume the energy of the τ is the same as that of the beam by ignoring initial state radiation and approximate the τ direction by the direction of the 7-prong momentum vector. The P^* requirement selects events with tau-like kinematics while suppressing the hadronic background. It also reduces the τ migration background from lower multiplicity decays in which the 7-prong jet momentum is not as good of an approximation of the τ direction. Figures 1(a) and 1(b) show the P^* vs. M_7 distribution for the data and hadronic background before the P^* and M_7 requirements are imposed. The hadronic sample is selected from the data using the criteria described above, except that $M_1 > 1.8$ GeV/c^2 and, to increase statistics, there is no restriction on the photon multiplicity in the 1-prong hemisphere. The hadronic background shows a cluster of events in the large P^* vs. M_7 region. However, the Monte Carlo (see below) predicts an enhancement of events with low P^* and M_7 for the signal decay $\tau^- \to 4\pi^-3\pi^+\nu_\tau$ as shown in Fig. 1(c). The P^* distribution for the data events with $M_7 < M_\tau$ is shown in Fig. 2. It is evident from both Fig. 1(a) and Fig. 2 that no events satisfy the selection criteria described above.

The detection efficiencies (ϵ) for the signal decays are estimated by Monte Carlo simulation. The KORALB generator is used to create τ pairs according to the standard electroweak theory, including α^3 radiative corrections [9]. The decays $\tau^- \to 4\pi^-3\pi^+\nu_\tau$ and $4\pi^-3\pi^+\pi^0\nu_\tau$ are modeled using phase space with a V-A interaction. The GEANT program [10] is used to simulate the detector response. The estimated detection efficiencies are given in Table I. The two efficiencies are comparable, as expected, since the same selection criteria were imposed on these two kinematically similar decays. As a test of the validity of the analysis, we compare the zero events observed with the expected number of events from the τ migration and hadronic background. The migration background is determined using the Monte Carlo technique. The hadronic background is empirically estimated from Fig. 1(b) with the assumption that M_1 and M_7 are not strongly correlated; this is evident from the similarity of Figs. 1(a) and 1(b) in the large P^* vs. M_7 region. The number of hadronic events with $M_7 < M_\tau$ is determined by normalizing the number of events in Fig. 1(b) with $M_7 > 1.8$ GeV/c^2 to that in Fig. 1(a). The estimated background is summarized in Table I. The observation of zero events is consistent with the background expectation.

The upper limit of the branching fraction is determined from the upper limit on the number of candidate events λ by

$$B(\tau^- \to 4\pi^-3\pi^+(\pi^0)\nu_\tau) = \frac{\lambda}{2\epsilon B_{tag} N_{\tau\tau}}$$

where $B_{tag} = (73.0 \pm 0.3)\%$ is the sum of branching fractions of the tags [8]. Since the efficiencies for $4\pi^-3\pi^+$ and $4\pi^-3\pi^+\pi^0$ are the same within 1%, we choose the lower efficiency for the former decay to derive a more conservative upper limit. Using $\lambda = 2.3$ events for the zero candidate events observed, the result is $B(\tau^- \to 4\pi^-3\pi^+(\pi^0)\nu_\tau) < 2.3 \times 10^{-6}$ at the 90% confidence level.

The systematic error contains contributions from several sources. These include the 1% uncertainty in the luminosity, 1% uncertainty in the $\tau^+\tau^-$ production cross-section, 12% uncertainty in the tracking efficiency, 0.3% uncertainty in the branching fraction of the tag as well as the 0.1% statistical error in the detection efficiency due to limited Monte Carlo statistics. The systematic error in the tracking efficiency is estimated from a study of the charged particle multiplicity distribution of hadronic events. Since the tracks from 7-prong τ decays are more collimated, we also study the ability of the Monte Carlo to simulate reconstruction of collimated tracks by comparing the minimum opening angle distribution of like-sign tracks in 5-prong τ decays from the data with that of the Monte Carlo. The reproduction by the Monte Carlo is quite satisfactory. The total systematic error is calculated by adding all errors in quadrature. The final result at the 90% confidence level is

$$B(\tau^- \to 4\pi^-3\pi^+(\pi^0)\nu_\tau) < 2.4 \times 10^{-6},$$

where Gaussian statistics were used to include the systematic error [11].

In conclusion, we find no evidence for the decay $\tau^- \to 4\pi^-3\pi^+(\pi^0)\nu_\tau$ and set an upper limit on the decay branching fraction. The upper limit is significantly more stringent than those of the previous experiments [1], [3].

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TABLE I. Summary of signal, background, efficiency, and branching fraction (at the 90% confidence level). All errors are statistical.

Data	0
τ migration	0.88 ± 0.23
$q\bar{q}$ background	1.95 ± 1.40
$4\pi^-3\pi^+$ efficiency (%)	15.7 ± 0.1
$4\pi^-3\pi^+\pi^0$ efficiency (%)	15.9 ± 0.3
$B(\tau^- \to 4\pi^-3\pi^+(\pi^0)\nu_\tau)$	$< 2.3 \times 10^{-6}$

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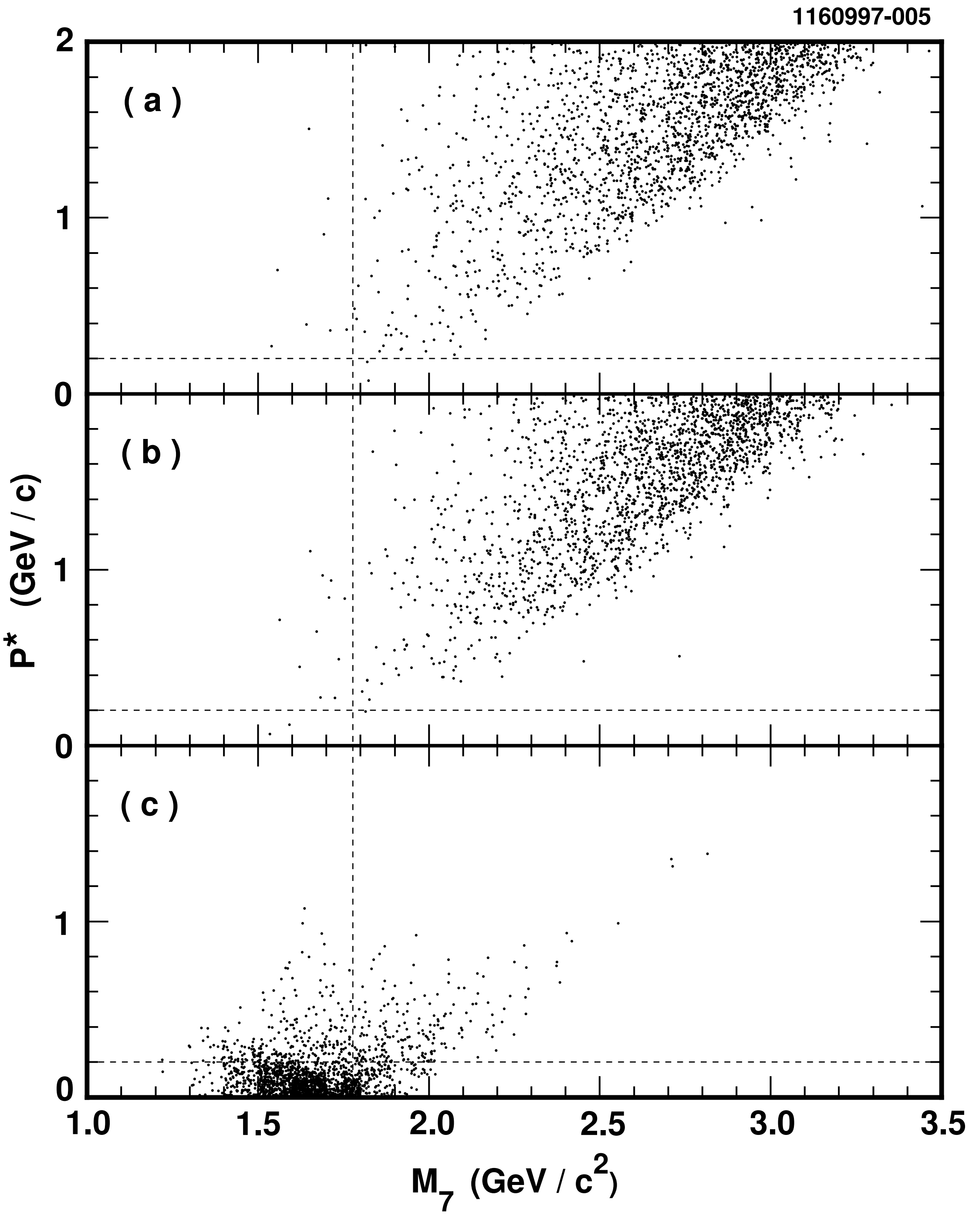

FIG. 1. Center-of-mass momentum vs. invariant mass of the 7-prong hemisphere for the (a) data, (b) hadronic background, and (c) signal Monte Carlo for $\tau^- \to 4\pi^- 3\pi^+ \nu_\tau$. The hadronic background is obtained with a high mass tag, $M_1 > 1.8$ GeV/c^2. The dashed lines indicate the values at which the respective cuts were imposed.

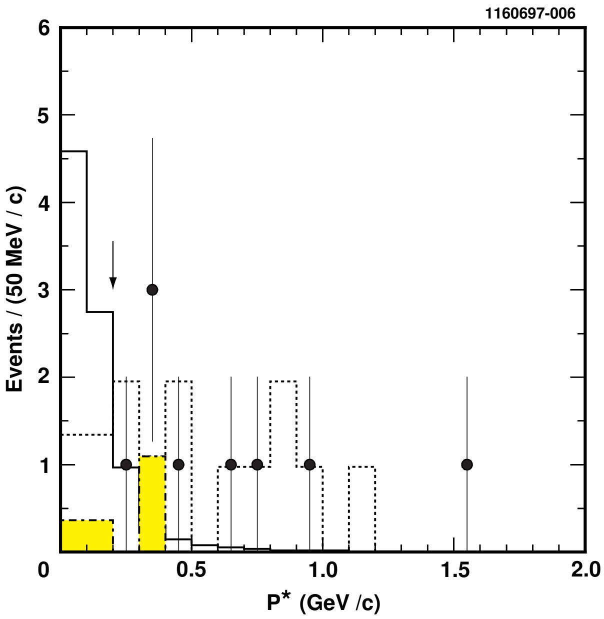

FIG. 2. Center-of-mass momentum spectra of the 7-prong hemisphere for the data, signal Monte Carlo for $\tau^- \to 4\pi^- 3\pi^+ \nu_\tau$ (solid), and background (dashed), which includes the τ migration (shaded) and hadronic background. The arrow indicates the value at which the cut was imposed. The signal Monte Carlo is normalized to the number of events in the data.