Search for the decay $\tau^{-}\rightarrow 4\pi^{-} 3\pi^{+}(\pi^{0})\nu_{\tau}$

K.W. Edwards  
Carleton University

Kenneth A. Bloom  
University of Nebraska-Lincoln, kbloom2@unl.edu

CLEO Collaboration

Follow this and additional works at: http://digitalcommons.unl.edu/physicsbloom

Part of the Physics Commons

Edwards, K.W.; Bloom, Kenneth A.; and Collaboration, CLEO, "Search for the decay $\tau^{-}\rightarrow 4\pi^{-} 3\pi^{+}(\pi^{0})\nu_{\tau}$" (1997). Kenneth Bloom Publications. 154.  
http://digitalcommons.unl.edu/physicsbloom/154

This Article is brought to you for free and open access by the Research Papers in Physics and Astronomy at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Kenneth Bloom Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
Search for the decay $\tau^- \rightarrow 4\pi^- 3\pi^+(\pi^0)\nu_\tau$


(CLEO Collaboration)
RAPID COMMUNICATIONS

The decay of the $\tau$ lepton into final states with seven or more pions is of particular interest since it may provide a sensitive probe of the $\nu_\tau$ 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 $B(\tau^- \to 4\pi^- 3\pi^+ 0 \nu_\tau) < 1.9 \times 10^{-4}$ [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 $1.1 \times 10^{-4}$. In this paper, we present the result of a search for the decay into seven charged particles and zero or one $\pi^0$ 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 $4.61 \times 10^6 \, \text{fb}^{-1}$, corresponding to the production of $N_{\tau\tau} = 4.21 \times 10^6 \, \tau$ 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 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 $\tau$ migration and hadronic ($e^+e^- \to q\bar{q}$) background. The $\tau$ 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 $\pi^0$'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 $\tau$ migration background from photon conversions. Each track must have a momentum of at least $0.02E_{\text{beam}}/(\sqrt{s}/2)$ and be in the central region of the detector, $|\cos \theta| < 0.90$, where $\theta$ is...
Search for the Decay \( \tau^+ \rightarrow 4 \pi^- 3 \pi^+ (\pi^0) \nu_{\tau} \)

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 \( \tau \) lepton as tags, \( \tau^- \rightarrow e^- \nu_e \nu_{\tau}, \mu^- \nu_\mu \nu_{\tau}, \pi^- \nu_\pi \nu_{\tau}, \rho^- \nu_{\rho} \), while suppressing the hadronic background. There is no photon multiplicity requirement in the 1-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 \( \pi^0 \) meson in the decay \( \tau^+ \rightarrow 4 \pi^- 3 \pi^+ \pi^0 \nu_{\tau} \). 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, a measured 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 \( \tau \) mass (\( M_1, M_7 < M_\tau = 1.777 \text{ GeV}/c^2 \)) [8]. The magnitude of the total momentum of the 7-prong hemisphere in the \( \tau \) rest frame, \( P^* \), must be less than 0.2 GeV/c. In calculating \( P^* \), we assume the energy of the \( \tau \) is the same as that of the beam by ignoring initial state radiation and approximate the \( \tau \) 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 \( \tau \) migration background from lower multiplicity decays in which the 7-prong jet momentum is not as good of a \( \tau \) 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 \( M_1 > 1.8 \text{ GeV}/c^2 \) and, to increase statistics, there is no restriction on the photon.

![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 \( \tau^+ \rightarrow 4 \pi^- 3 \pi^+ \nu_{\tau} \). The hadronic background is obtained with a high mass tag, \( M_7 > 1.8 \text{ GeV}/c^2 \). The dashed lines indicate the values at which the respective cuts were imposed.](image)

![FIG. 2. Center-of-mass momentum spectra of the 7-prong hemisphere for the data, background (dashed), signal Monte Carlo (solid) for \( \tau^+ \rightarrow 4 \pi^- 3 \pi^+ \nu_{\tau} \). The background is the sum of the \( \tau \) 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.](image)

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

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>( \tau ) migration</th>
<th>( q \bar{q} ) background</th>
<th>( 4 \pi^- 3 \pi^+ ) efficiency (%)</th>
<th>( 4 \pi^- 3 \pi^+ \pi^0 ) efficiency (%)</th>
<th>( B(\tau^+ \rightarrow 4 \pi^- 3 \pi^+ (\pi^0) \nu_{\tau}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0.88 ± 0.23</td>
<td>1.95 ± 1.40</td>
<td>15.7 ± 0.2</td>
<td>15.9 ± 0.3</td>
<td>(&lt; 2.38 \times 10^{-6})</td>
</tr>
</tbody>
</table>
ton multiplicity in the 1-prong hemisphere. The hadronic background shows a cluster of events in the region of large \( P^* \) vs \( M_\gamma \). However, the Monte Carlo (see below) predicts an enhancement of events with low \( P^* \) and \( M_\gamma \) for the signal decay \( \tau^- \rightarrow 4\pi^- 3\pi^+ \nu_e \), as shown in Fig. 1(c). The \( P^* \) distribution for the data events with \( M_\gamma < M_\tau \) 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 \( (\epsilon) \) for the signal decays are estimated by Monte Carlo simulation. The KORALB-TAUOLA generator is used to create \( \tau \) pairs according to the standard electroweak theory, including \( \alpha^3 \) radiative corrections [9]. The decays \( \tau^- \rightarrow 4\pi^- 3\pi^+ \nu_e \) and \( 4\pi^- 3\pi^- \pi^0 \nu_e \) 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 observation of zero events is consistent with the background expectation.

It is evident from both Fig. 1 and Fig. 2 that no events satisfy the selection criteria described above.

The detection efficiencies \( (\epsilon) \) for the signal decays are estimated by Monte Carlo simulation. The KORALB-TAUOLA generator is used to create \( \tau \) pairs according to the standard electroweak theory, including \( \alpha^3 \) radiative corrections [9]. The decays \( \tau^- \rightarrow 4\pi^- 3\pi^+ \nu_e \) and \( 4\pi^- 3\pi^- \pi^0 \nu_e \) 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 observation of zero events is consistent with the background expectation.

The migration background is determined using the Monte Carlo simulation of charged pions interacting in the calorimeter that may mimic electrons.

\[ B(\tau^- \rightarrow 4\pi^- 3\pi^+ (\pi^0) \nu_e) < 2.4 \times 10^{-6}, \]

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

In conclusion, we find no evidence for the decay \( \tau^- \rightarrow 4\pi^- 3\pi^+ (\pi^0) \nu_e \) 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].

We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Department of Energy, the Heisenberg Foundation, the Alexander von Humboldt Stiftung, Research Corporation, the Natural Sciences and Engineering Research Council of Canada, and the A.P. Sloan Foundation.

---

[2] In this paper charge conjugate states are implied.
[7] We allow up to two electron candidates in the 7-prong hemisphere in order to minimize the dependence on the Monte Carlo simulation of charged pions interacting in the calorimeter that may mimic electrons.