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Search for baryon and lepton number violating decays of the τ lepton

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We have searched for five decay modes of the τ lepton that simultaneously violate lepton and baryon number: $\tau^-\to\bar{p}\gamma$, $\tau^-\to\bar{p}\pi^0$, $\tau^-\to\bar{p}\eta$, $\tau^-\to\bar{p}2\pi^0$, and $\tau^-\to\bar{p}\pi^0\eta$. The data used in the search were collected with the CLEO II detector at the Cornell Electron Storage Ring. The integrated luminosity of the data sample is 4.7 fb^{-1}, corresponding to the production of 4.3×10^6 $\tau^+\tau^-$ events. No evidence is found for any of the decays, resulting in much improved upper limits on the branching fractions for the two-body decays and first upper limits for the three-body decays. [S0556-2821(99)50209-9]

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Baryon and lepton number conservation are experimentally observed phenomena. In the standard model, both numbers are assumed to be conserved. Baryon and lepton number violations are expected in many extensions of the standard model such as supersymmetry and superstring inspired models [1]. In some of the models, there is a new symmetry associated with the conservation of the baryon minus lepton number, $B-L$, even though both baryon and lepton numbers are not conserved. Decays with this new symmetry have been searched for in nucleon decays [2]. The lower limits on the nucleon lifetimes imply that the corresponding decays involving the τ lepton are below the current experimental sensitivity [3]. Nevertheless, experimenters have searched for this type of decay because the τ lepton provides a clean laboratory for the search [4]. The previous upper limits [5] on the branching fractions for the decays into an anti-proton [6] and a photon, π^0 or an η meson are in the range of $10^{-4}-10^{-3}$. There are no published results for the decays involving two neutral mesons, $\tau^-\to\bar{p}2\pi^0$ and $\tau^-\to\bar{p}\pi^0\eta$. The CLEO II experiment, with its large sample of τ events, provides an opportunity to search for decays that violate lepton and baryon numbers, but conserve $B-L$. In this paper, we present the result of a search in five decay modes: $\tau^-\to\bar{p}\gamma$, $\tau^-\to\bar{p}\pi^0$, $\tau^-\to\bar{p}\eta$, $\tau^-\to\bar{p}2\pi^0$, and $\tau^-\to\bar{p}\pi^0\eta$.

The data used in this analysis were collected with the CLEO II detector from e^+e^- collisions at the Cornell Electron Storage Ring (CESR) at a center-of-mass energy $\sqrt{s}\sim10.6$ GeV. The total integrated luminosity of the data sample is 4.7 fb^{-1}, corresponding to the production of $N_{\tau\tau}=4.3\times10^6$ $\tau^+\tau^-$ events. CLEO II is a general purpose spectrometer [7] with excellent charged particle and shower energy detection. The momenta of charged particles are measured with three drift chambers between 5 and 90 cm from

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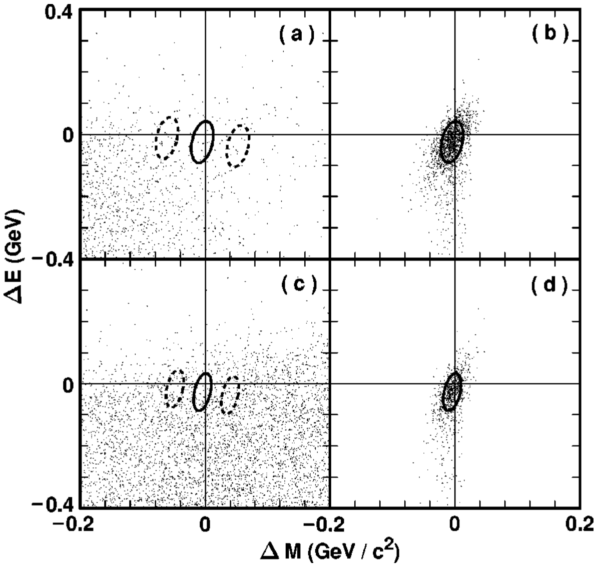

FIG. 1. ΔE vs ΔM distribution of the data (a) and signal Monte Carlo (b) for the decay $\tau^- \to \bar{p}\pi^0$. (c) and (d) show the corresponding distributions for $\tau^- \to \bar{p}2\pi^0$. The normalization of the signal Monte Carlo is arbitrary. The ellipses indicate the signal (solid) and sideband (dashed) regions.

the e^+e^- interaction point (IP), with a total of 67 layers. The specific ionization (dE/dx) of charged particles is also measured in the main drift chamber. 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 $\tau^+\tau^-$ candidate events must contain two charged tracks with zero net charge. To reject beam-gas events, the distance of closest approach of each track to the IP must be within 0.5 cm transverse to the beam and 5 cm along the beam direction. Photons are defined as energy clusters in the calorimeter with at least 60 MeV in the barrel ($|\cos\theta|<0.80$) or 100 MeV in the endcap ($0.80<|\cos\theta|<0.95$), where θ is the polar angle defined with respect to the beam axis. We further require every photon to be separated from the projection of any charged track on the surface of the calorimeter by at least 30 cm unless its energy is greater than 300 MeV.

We divide each event into two (signal and tag) hemispheres, each containing one charged track, using the plane perpendicular to the thrust axis [8], which is calculated from both charged tracks and photons. The charged track in the tag (signal) hemispheres is assumed to be a pion (an antiproton). The invariant mass of the particles in the tag hemisphere must be less than the τ mass, $M_\tau = 1.777$ GeV/c^2 [2]. To suppress the background from radiative Bhabha and μ-pair events, the direction of the missing momentum of the event is required to satisfy $|\cos\theta_{missing}|<0.90$, where $\theta_{missing}$ is the angle of the missing momentum defined with respect to the beam axis. Because there is no neutrino in the signal hemisphere, while there is at least one neutrino undetected in the tag hemisphere, the missing momentum of the event must point toward the tag hemisphere, $0<\cos\alpha<1.0$, where α is the angle between the missing momentum and the total momentum of the particles in the tag hemisphere.

Several additional selection criteria are imposed on the decays $\tau^- \to \bar{p}\gamma$ and $\tau^- \to \bar{p}\pi^0$ to suppress the background. For the decay $\tau^- \to \bar{p}\gamma$, we further impose the restriction $\cos\alpha<0.99$ to reduce the background from radiative Bhabha and μ-pair events. The background is further reduced by requiring the net transverse momentum of each event with respect to the beam axis to be greater than 300 MeV/c. The Bhabha background is further suppressed by rejecting events with an electron in the tag hemisphere. An electron is defined as a particle having a shower energy-to-momentum ratio with $E/p>0.85$ and a specific ionization loss (dE/dx) within 3 standard deviations of the expectation. The migration background from other τ decays is suppressed by restricting the angle between the momentum vectors of the $\bar{p}$ and γ, $0.35<\cos\theta_{\bar{p}\gamma}<0.92$. For the decay $\tau^- \to \bar{p}\pi^0$, the $\bar{p}$ momentum must be greater than 2.5 GeV/c to reduce further the background from τ migration.

We reconstruct π^0 and η mesons with photons in the barrel using the $\gamma\gamma$ decay channel. In order to maintain a high detection efficiency, while minimizing the dependence on the Monte Carlo simulation of electromagnetic showers, there is no explicit cut on the maximum number of photons in the signal hemisphere. However, photons that are most likely to be real must be used in the signal decay reconstruction. These are photons passing the 30 cm isolation cut and having either an energy above 300 MeV or a lateral profile of energy deposition consistent with that expected of a photon.

The $\gamma\gamma$ invariant mass spectrum is expressed in standard deviations from the nominal π^0 or η mass,

$$S_{\gamma\gamma} = (M_{\gamma\gamma} - M_{\pi^0,\eta})\sigma_{\gamma\gamma},$$

where $\sigma_{\gamma\gamma}$ is the mass resolution calculated from the energy

TABLE I. Summary of detection efficiencies, signal yields, expected backgrounds, and 90% C.L. upper limits on the signal yields and branching fractions.

Mode	$\tau^- \to \bar{p}\gamma$	$\tau^- \to \bar{p}\pi^0$	$\tau^- \to \bar{p}\eta$	$\tau^- \to \bar{p}2\pi^0$	$\tau^- \to \bar{p}\pi^0\eta$
ϵ (%)	10.7±0.2	8.4±0.2	14.0±0.2	4.3±0.1	4.6±0.1
N_{ob}	1	14	2	41	1
N_{bg}	6.0	13.5	4.0	50.5	0.5
N	2.8	8.8	3.5	10.0	3.5
$\mathcal{B}$ (10^{-6})	3.5	15	8.9	33	27

and angular resolution of each photon. The signal region is defined as $-3<S_{\gamma\gamma}<2$; the asymmetric cut is used to account for shower leakage.

To search for the decay candidates, we select τ candidates with invariant mass and total energy consistent with expectations. The following kinematic variables are used to select the candidate events:

$$\Delta E = E - E_{beam}$$

$$\Delta M = M - M_{\tau},$$

where E_{beam} is the beam energy, and E and M are the reconstructed τ candidate energy and mass, respectively. The decay candidates are required to have both kinematic variables within 1.28σ of the expectations (80% efficiency for each variable). For the decays involving η mesons, which have a smaller τ migration background, the requirement is loosened to 1.64σ (90% efficiency for each variable). The σ's are estimated from the Monte Carlo simulations of the signal decays (see below). As an example, we show in Fig. 1 the ΔE vs ΔM distributions of the candidate events for the decays $\tau^- \rightarrow \bar{p}\pi^0$ and $\tau^- \rightarrow \bar{p}2\pi^0$ [9].

The numbers of events observed (N_{ob}) in the signal region and the detection efficiencies (ϵ) are listed in Table I. The efficiencies are estimated from a Monte Carlo simulation. In the Monte Carlo program, one τ lepton decays according to a two- or three-body phase space distribution for the mode of interest and the other τ lepton decays generically according to the KORALB τ event generator [10]. The detector response is simulated with the GEANT program [11].

The background (N_{bg}) is estimated from the sideband regions in the ΔE vs ΔM distribution assuming that the background shape is linear. Each sideband is separated from the signal region by 6.0σ (see Fig. 1 as an example). The numbers of events observed are consistent with the background expectations as shown in Table I. There is therefore no evidence for a signal. To understand the origin of the background, we also estimate the τ migration background using the KORALB program and the hadronic background using the Lund program [12]. The simulation programs can account for the background and indicate that most of the background is from τ migration. The large backgrounds in the decays $\tau^- \rightarrow \bar{p}\pi^0$ and $\tau^- \rightarrow \bar{p}2\pi^0$ originate from the copious decays $\tau^- \rightarrow \pi^-\pi^0\nu_\tau$ and $\tau^- \rightarrow \pi^-2\pi^0\nu_\tau$.

The upper limit on the branching fraction is related to the upper limit N on the number of signal events by

$$\mathcal{B}=\frac{N}{2\epsilon N_{\tau\tau}\mathcal{B}_1\mathcal{B}^{m}_{\pi^0}\mathcal{B}^{n}_{\eta}},$$

where $\mathcal{B}_1$ is the inclusive 1-prong branching fraction [2], $\mathcal{B}_{\pi^0}$ ($\mathcal{B}_\eta$) is the branching fraction [2] for $\pi^0 \rightarrow \gamma\gamma$ ($\eta \rightarrow \gamma\gamma$), and m (n) is the number of π^0 (η) mesons in the final state. The 90% confidence level upper limits on the signal are summarized in Table I. We estimate the upper limits using a Monte Carlo calculation, which incorporates both the Poisson statistics of the signal and the systematic errors. The systematic errors include the statistical uncertainty in the background estimate due to limited statistics in the sideband regions. This statistical uncertainty is incorporated using Poisson statistics [13]. All other sources of systematic errors are incorporated using Gaussian statistics. These include the uncertainties in the $\tau^+\tau^-$ cross section (1%), luminosity (1%), track reconstruction efficiency (3%), photon detection efficiency (2.5%), $p/\bar{p}$ detection efficiency (10%), branching fraction of $\eta \rightarrow \gamma\gamma$ (0.8%) [2], and the statistical uncertainties in the detection efficiencies due to limited Monte Carlo samples (1–2 % for the two-body modes and 2–3 % for the three-body modes). These uncertainties are added in quadrature in computing N.

In conclusion, we have searched for τ decays that violate lepton and baryon numbers, but conserve baryon minus lepton number. We find no evidence for a signal, resulting in much improved upper limits for the two-body decays and first upper limits for the three-body decays.

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