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Search for Lepton Flavor Violation in τ decays at B-factories

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We review recent searches for lepton flavor violation (LFV) in τ decays at the KEKB and PEPII $B-$factories. No evidence for such decays has been found and upper limits for various decay modes were obtained. A sensitivity to branching fractions of LFV decays is approaching $\sim 10^{-8}$. These results improve by 1-2 orders of magnitude previous upper limits from CLEO and reach the level of some new physics predictions.

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1. Introduction

Lepton flavor violating (LFV) decays of the charged leptons are expected to have very small probability via neutrino oscillations in the Standard Model (SM). Many extensions of SM, such as supersymmetry, large extra dimensions and others predict enhanced LFV decays with branching fractions close to the current experimental sensitivity. Because of its large mass τ leptons can potentially decay to various modes with hadrons. Experiments at the *B*-factories allow searches for such decays with a very high sensitivity since the cross section of $\tau^+\tau^-$ production is $\sigma_{\tau\tau} \simeq 0.9$ nb, close to that of $B\overline{B}$ production, $\sigma_{B\overline{B}} \simeq 1$ nb, and thus, *B*-factories are also τ-factories. By summer 2005 Belle and BaBar detectors currently operating at the KEKB and PEPII *B*-factories, accumulated about $420 \cdot 10^6$ and $260 \cdot 10^6$ $\tau^+\tau^-$ events, respectively, and performed a search for various LFV τ decays. Among various previous searches for LFV decays [1] the best upper limits on the branching fractions $\sim 10^{-6} - 10^{-7}$ at the 90% confidence level were obtained by CLEO with $\sim 10^7$ $\tau^+\tau^-$ pairs [2, 3, 4, 5, 6, 7].

2. Analysis methods

Searches for different LFV τ decays follow a similar pattern. We search for $\tau^+\tau^-$ events in which one LFV τ (signal-side) decays into a mode under study, while the other τ (tag side) decays into one (or three) charged particles with a net charge of opposite sign and any number of additional photons and neutrinos. Thus, the experimental signature is:
$\{\tau^- \to$ LFV decay, e.g. $\ell^-\gamma$, $\ell^-\eta$, $\ell^- K^0_S, \ldots\}$ + $\{\tau^+ \to (\text{a track})^+ + (n_\gamma^{\text{TAG}} \geq 0) + X(\text{missing})\}$.
To search for exclusive decay modes, we select low multiplicity (2 or 4 charged tracks) events with zero net charge, and separate a signal- and tag-side into two hemispheres using a thrust axis. The backgrounds in such searches are dominant by $q\overline{q}$, generic $\tau^+\tau^-$, $\mu^+\mu^-$ and Bhabha events. After signal selection criteria are applied using particle identification and kinematic information for reducing the background, signal candidates are examined in the two-dimensional space of the invariant mass, M_{inv}, and the difference of their energy from the beam energy in the center-of-mass (CM) system, ΔE. A signal event should have M_{inv} close to the τ-lepton mass and ΔE close to 0. We blind a region around the signal region in the $M_{\text{inv}} - \Delta E$ plane so as not to bias our choice of selection criteria. The expected number of background events in the blind region is first evaluated, and then the blind region is opened and candidates events are counted. By comparing the expected and observed numbers of events, we either observe a LFV τ decay or set an upper limit by applying Bayesian, frequentist or maximum likelihood approaches.

3. Results for LFV τ decays

3.1 $\tau \to \ell K^0_S$

Lepton flavor violating decays with K^0_S mesons are in particular discussed in models with either heavy singlet Dirac neutrinos, $R-$parity violation in SUSY or dimension-six effective fermionic operators that induce $\tau - \mu$ mixing. Belle has searched for the τ lepton flavor violating decays $\tau^- \to \ell^- K^0_S$ ($\ell = e$ or μ) using a data sample of 281 fb^{-1}. No evidence for a signal was found in either of the decay modes, and the following upper limits for the branching fractions were set:

$\mathscr{B}(\tau^- \to e^- K_S^0) < 5.6 \times 10^{-8}$ and $\mathscr{B}(\tau^- \to \mu^- K_S^0) < 4.9 \times 10^{-8}$ at the 90% confidence level [8]. These results improve by a factor of 16 and 19, respectively, previously published limits from CLEO [7].

3.2 $\tau \to \ell\gamma$

Searches for $\tau^- \to \mu^-\gamma$ and $e^-\gamma$ decay modes are important in the SUSY seesaw model. The branching fraction for $\tau \to \mu\gamma$ is predicted to be $10^{-6} - 10^{-9}$ and can be observed at the *B*-factory with the current luminosity. Belle and BaBar have searched for the LFV decay $\tau^- \to \mu^-\gamma$ and obtained upper limits for the branching fraction at the 90% confidence level $\mathscr{B}(\tau^- \to \mu^-\gamma) < 3.1 \times 10^{-7}$ [9] and $\mathscr{B}(\tau^- \to \mu^-\gamma) < 6.8 \times 10^{-8}$ [10] , respectively, 16 times more restrictive than that from CLEO [6]. They have also searched for the $\tau^- \to e^-\gamma$ mode and obtained the following upper limits: $\mathscr{B}(\tau^- \to e^-\gamma) < 3.9 \times 10^{-7}$ [11] and $\mathscr{B}(\tau^- \to e^-\gamma) < 1.1 \times 10^{-7}$ [12] , respectively. The new upper limit is by a factor of 25 lower than that from CLEO [3].

3.3 $\tau \to \ell\eta, \ell\eta'$ and $\ell\pi^0$

While the $\tau - \mu$ transition in the case of the $\tau^- \to \mu^-\gamma$ mode can occur via one-loop contributions with SUSY particles in the minimum supersymmetric extension of the SM (MSSM), the Higgs mediated diagrams can also contribute. If a typical SUSY mass is larger than $\sim$ 1 TeV, processes via one-loop contributions with SUSY particles are suppressed. In such a case, the decay modes $\tau^- \to \mu^-\eta$, $\tau \to \ell^-\ell'^-\ell''^+$ and $\tau^- \to \ell^- hh$ become important for LFV searches. Belle obtained new upper limits on the branching fractions of semileptonic LFV τ^- decays involving pseudoscalar mesons π^0, η and η' [13]. They range from 1.5×10^{-7} to 10×10^{-7} for the six decay modes studied and are 10 to 64 times more restrictive than previous limits from CLEO [2].

3.4 Three-body LFV τ decays

BaBar and Belle have also searched for various three-body LFV decays. For three-lepton decays the upper limits on the branching fractions vary in the range $(1.1-3.3) \times 10^{-7}$ for BaBar [14] and $(1.9-3.5) \times 10^{-7}$ for Belle [15] improving the CLEO results [4] by one order of magnitude. Both groups also searched for various $\ell hh'$ (where h, $h' = \pi^\pm$ or $K^\pm$) decays including lepton number violation with the range of upper limits $(0.7-4.8) \times 10^{-7}$ and $(2.2-15.5) \times 10^{-7}$ for BaBar [16] and Belle [17], respectively, significantly better than those of CLEO [4].

3.5 LFV τ decays into baryons

Belle has also performed a search for various LFV decays also violating baryon number conservation. Their upper limits for the $\tau^- \to \bar{p}\gamma$ and $\tau^- \to \bar{p}\pi^0$ are 3.0×10^{-7} and 6.5×10^{-7} [18], or 12 and 23 times better, respectively, than those of CLEO [5]. For the first time they studied $\tau^- \to \bar{\Lambda}\pi^-, \Lambda\pi^-$ decays and set upper limits of 1.4×10^{-7} and 0.72×10^{-7}, respectively [19].

4. Summary

Recent results from BaBar and Belle are summarized in Table 1. It is clear that a sensitivity to LFV τ decay branching fractions is approaching 10^{-8}. These results improve by 1-2 orders those of CLEO and reach the level of some new physics predictions.

	Belle		BaBar	
τ^- decay mode	$\mathscr{B}, 10^{-7}$	$\int L\,dt$, fb^{-1}	$\mathscr{B}, 10^{-7}$	$\int L\,dt$, fb^{-1}
$\mu^- K_S^0$	0.49	281	–	–
$e^- K_S^0$	0.56	281	–	–
$\mu^-\gamma$	3.1	87	0.68	232
$e^-\gamma$	3.9	87	1.1	232
$\mu^-\eta, \mu^-\eta', \mu^-\pi^0$	1.5, 4.7, 4.1	154	–	–
$e^-\eta, e^-\eta', e^-\pi^0$	2.4, 10., 1.9	154	–	–
$\ell^- hh'$	2.2-15.5	158	0.7-4.8	221
$\ell^-\ell'^-\ell''^+$	1.9-3.5	87	1.1-3.3	92
$p\gamma, p\pi^0$	3.0, 6.5	87, 154	–	–
$\bar{\Lambda}\pi^-, \Lambda\pi^-$	1.4, 0.72	154	–	–

Table 1: 90% upper limits on the branching fractions of LFV τ decays

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