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Search for Lepton Flavor Violation in τ decays at Belle Experiment

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We review recent searches for lepton flavor violation in τ^- decays, $\ell^- K_S^0$, $\ell^- K_S^0 K_S^0$ and $\ell^- \ell'^+ \ell''^-$ ($\ell = e$ or μ) based on 671, 671 and 782 fb^{-1} of data collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. No evidence for these decays is observed and we set 90% confidence level upper limits on the branching fractions at the $O(10^{-8})$ level.

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1. Introduction

Lepton flavor violating (LFV) decays of the charged leptons are expected to have negligible rates even including neutrino oscillations in the Standard Model (SM), (for example, $\mathscr{B}(\tau \to \gamma) < 10^{-50}$). Therefore, it is impossible to observe LFV decays in current experiments. However, many extensions of SM, such as supersymmetry (SUSY) and large extra dimensions, predict enhanced LFV decays with branching fractions close to the current experimental sensitivity. Therefore, an observation of LFV decay would be a clear signature for new physics beyond the SM. τ leptons are expected to be coupled strongly with new physics and have many possible LFV decay modes due to their large mass, so their LFV decays are an ideal place to search for new physics. We use $\tau^+\tau^-$ data samples collected with the Belle detector [1] at the KEKB asymmetric-energy e^+e^- collider [2]. Experiments at the KEKB 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. Belle detector is the multi-purpose detector which has good track reconstruction and particle identification ability.

2. Analysis methods

All searches for LFV τ decays follow a similar pattern. We search for $\tau^+\tau^-$ events in which one τ (signal side) decays into an LFV mode under study, while the other τ (tag side) decays into one charged particle with any number of additional photons and neutrinos. To search for exclusive decay modes, we select low multiplicity 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 dominated by $e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$, generic $\tau^+\tau^-$, two-photon, $\mu^+\mu^-$ and Bhabha events. To achieve good sensitivity, we optimize the event selection using particle identification and kinematic information for each mode separately.

After signal selection criteria are applied, signal candidates are examined in the two-dimensional space of the invariant mass, $M_{\rm inv}$, and the difference of their energy from the beam energy in the center-of-mass (CM) system, ΔE. A signal event should have $M_{\rm inv}$ close to the τ-lepton mass and ΔE close to 0. We blind a region around the signal region in the $M_{\rm inv} - \Delta E$ 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 candidate 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, Feldman-Cousins or maximum likelihood approaches.

3. Results

Earlier we have reported searches for various LFV τ decays, e.g., to $\ell hh'$ and $\ell f_0(980)$ ($\ell = e$ or μ and $h = \pi^\pm$ or $K^\pm$) [3, 4], with the upper limits on the branching fractions of about 10^{-8} at the 90% confidence level. Here we review recent searches for ℓK_S^0, $\ell K_S^0 K_S^0$ and $\ell\ell'\ell''$ decays based on data samples of 671, 671 and 782 fb^{-1}, respectively, collected with the Belle detector.

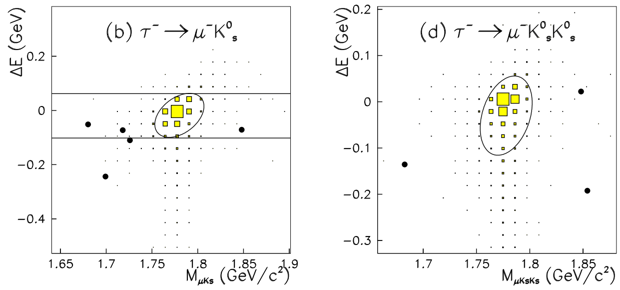

Figure 1: Scatter-plots in the $M_{\rm inv} - \Delta E$ plane: (a) and (b) correspond to the $\pm 20\sigma$ area for the $\tau^- \to \mu^- K_S^0$ (left) and $\tau^- \to \mu^- K_S^0 K_S^0$ (right) modes, respectively. The data are indicated by the solid circles. The filled boxes show the MC signal distribution with arbitrary normalization. The elliptical signal regions shown by a solid curve are used for evaluating the signal yield.

3.1 $\tau \to \ell K_S^0$ and $\ell K_S^0 K_S^0$

Previously, we obtained 90% confidence level (C.L.) upper limits for $\tau^- \to \ell^- K_S^0$ branching fractions ($\mathscr{B}$) using 281 fb^{-1} of data; the results were in the range (4.9$-$5.6) $\times$ 10^{-8} [5]. The BaBar collaboration has recently used 469 fb^{-1} of data to obtain 90% C.L. upper limits in the range (3.3$-$4.0) $\times$ 10^{-8} [6]. We update searches for the LFV decays $\tau^- \to \ell^- K_S^0$ based on 671 fb^{-1} with K_S^0 reconstructed from $\pi^+\pi^-$. We find no signal in either mode and obtain the following 90% C.L. upper limits on the branching fractions: $\mathscr{B}(\tau^- \to e^- K_S^0) < 2.6 \times 10^{-8}$ and $\mathscr{B}(\tau^- \to \mu^- K_S^0) < 2.3 \times 10^{-8}$ These results improve the search sensitivity by factors of 2.2 and 2.1 for eK_S^0 and μK_S^0, respectively, compared to our previous published limits [5].

For the $\ell K_S^0 K_S^0$ modes, the best $90\mathscr{B}(\tau^- \to e^- K_S^0 K_S^0) < 2.2 \times 10^{-6}$ and $\mathscr{B}(\tau^- \to \mu^- K_S^0 K_S^0) < 3.4 \times 10^{-6}$ were set by CLEO using 13.9 fb^{-1} of data [7]. We use 671 fb^{-1} for this search. No evidence for a signal was found in either of the decay modes, and we set the following upper limits for the branching fractions: $\mathscr{B}(\tau^- \to e^- K_S^0 K_S^0) < 7.1 \times 10^{-8}$ and $\mathscr{B}(\tau^- \to \mu^- K_S^0 K_S^0) < 8.0 \times 10^{-8}$. These results improve the search sensitivity by factors of 31 and 43 for $eK_S^0 K_S^0$ and $\mu K_S^0 K_S^0$, respectively, compared to previous limits from CLEO [7].

3.2 $\tau^- \to \ell^- \ell^+ \ell^-$

The following τ^- decays into three leptons are considered: $e^-e^+e^-$, $\mu^-\mu^+\mu^-$, $e^-\mu^+\mu^-$, $\mu^-e^+e^-$, $\mu^-e^+\mu^-$ and $e^-\mu^+e^-$. In the previous analysis, we reached 90% C.L. upper limits on the branching fractions in the range $(2.0 - 4.1) \times 10^{-8}$ [8], based on about 543 fb^{-1} of data. We update this analysis using 782 fb^{-1}. For the signal region, we use an elliptical region which contains 90% of signal events in the $M_{\rm inv} - \Delta E$ plane. The signal efficiencies are kept in the range of (6.0-11.5)%. We observe no events after event selection in the signal region for all modes while the expected background is less than 0.2 events. No evidence for these decays is observed and we set 90% C.L. upper limits on the branching fractions between (1.5-2.7)$\times 10^{-8}$. We improve the best previously upper limits by factors from 1.3 to 1.6.

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Table 1: The signal efficiency (ε), the number of the expected background events ($N_{\rm BG}$) estimated from the sideband data, total systematic uncertainty ($\sigma_{\rm syst}$), the number of the observed events in the signal region ($N_{\rm obs}$), and 90% confidence level upper limit on the branching fraction ($\mathscr{B}$) for each individual mode. For $\tau \to \ell K_0^0$ and $\ell K_S^0 K_S^0$ modes, signal efficiencies are not included the branching fraction($\mathscr{B}(K_S^0 \to \pi^+\pi^-) = 0.6920 \pm 0.005$ [9]).

Mode	ε (%)	$N_{\rm BG}$	$\sigma_{\rm syst}$ (%)	$N_{\rm obs}$	$\mathscr{B}$
$\tau^- \to e^- K_S^0$	10.2	0.18±0.18	6.6	0	2.6×10^{-8}
$\tau^- \to \mu^- K_S^0$	10.7	0.35±0.21	6.8	0	2.3×10^{-7}
$\tau^- \to e^- K_S^0 K_S^0$	5.82	0.07±0.07	11.2	0	7.1×10^{-7}
$\tau^- \to \mu^- K_S^0 K_S^0$	5.08	0.12±0.08	11.3	0	8.0×10^{-8}
$\tau^- \to e^- e^+ e^-$	6.0	0.21±0.15	9.8	0	2.7×10^{-8}
$\tau^- \to \mu^- \mu^+ \mu^-$	7.6	0.13±0.06	7.4	0	2.1×10^{-8}
$\tau^- \to e^- \mu^+ \mu^-$	6.1	0.10±0.04	9.3	0	2.7×10^{-8}
$\tau^- \to \mu^- e^+ e^-$	9.3	0.04±0.04	7.8	0	1.8×10^{-8}
$\tau^- \to e^+ \mu^- \mu^-$	10.1	0.02±0.02	7.6	0	1.7×10^{-8}
$\tau^- \to \mu^+ e^- e^-$	11.5	0.01±0.01	7.7	0	1.5×10^{-8}

4. Summary

The observation of lepton flavor violation is a clear signature of new physics. We report recent searches for lepton flavor violating in τ decays, in particular, into ℓK_S^0, $\ell K_S^0 K_S^0$ and $\ell \ell' \ell''$ ($\ell = e$ or μ) based on using > 600 fb^{-1} of data collected with the Belle detector at the KEKB asymmetric-energy e^+e^- collider (see Table 1). No evidence for these decays is observed, and we set 90% confidence level upper limits on the branching fractions at the $O(10^{-8})$ level. These more stringent upper limits can be used to constrain the space of parameters in various models beyond the SM.

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