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Search for New Physics in Lepton Flavor Violating τ Decays at Belle

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We report mainly on a search for lepton-flavor-violating τ decays involving $\pi^0/\eta/\eta'$ final states using a sample of 153.8 fb^{-1}, which was recorded with the Belle detector at the KEKB e^+e^- asymmetric-energy collider. We also present searches for other possible LFV tau decays, and discuss the relationship of our results to SUSY parameters.

Keywords: Lepton Flavor violation; τ lepton; B-factory

1. Introduction

The Lepton Flavor Violating (LFV) decays in the charged sector are prohibited in the Standard Model (SM) even if it is modified by introducing tiny neutrino masses observed in neutrino experiments. In some models beyond the SM, e.g., Minimal Supersymmetric extension of the Standard Model (MSSM), LFV decays in the charged sector can occur. In the MSSM, the $\tau - \mu$ transition can occur via two main contributions, one is from one-loop diagrams involving the exchange of SUSY particles, and the other is from Higgs-mediated diagrams which amplitudes are proportional to $1/(m_{\mathrm{SUSY}})^2$ and $1/(m_{\mathrm{Higgs}})^2$, respectively. If $m_{\mathrm{SUSY}} \sim 1$ TeV, processes via one-loop diagrams, e.g., $\tau^- \to \mu^-\gamma$, are suppressed. In such a case the decay modes $\tau^- \to \mu^-\eta$ or $\tau^- \to 3\mu$ induced by the Higgs-mediated diagram become important. In addition, the $\tau^- \to \mu^-\eta$ decay has larger decay probability than the $\tau^- \to 3\mu$ because of phase space and color effects in the Higgs-$s\bar{s}$ or Higgs-$\mu^+\mu^-$ vertex.

We have searched for LFV τ decays involving $\pi^0/\eta/\eta'$ based on a data sample of 153.8 fb^{-1}, equivalent to 140.3M $\tau^+\tau^-$ pairs, collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric e^+e^- collider.

2. Data Analysis

We look for an event with the following particles:

$$\{\tau \to (\ell = e/\mu) + (M^0 = \pi^0/\eta/\eta')\} + \{\tau \to (1\text{ prong}) + (\mathrm{n}_\gamma > 0) + \mathrm{X(missing)}\}.$$

Table 1. Results of the final event selection for the individual modes.

Mode	Subdecay mode	ϵ (%)	$\mathcal{B}_{\pi^0/\eta/\eta'}$ (%)	b_0 (ev.)	s (ev.)	U.L. of $\mathcal{B}$ @ 90% C.L.
$\tau^- \to e^- \eta$	$\eta \to \gamma\gamma$	5.68	39.43	0.15 ± 0.15	0	3.9×10^{-7}
	$\eta \to \pi^+\pi^-\pi^0$	6.84	22.6	0.23 ± 0.23	0	5.6×10^{-7}
	combined					2.3×10^{-7}
$\tau^- \to \mu^- \eta$	$\eta \to \gamma\gamma$	8.03	39.43	3.1 ± 1.0	1	2.4×10^{-7}
	$\eta \to \pi^+\pi^-\pi^0$	7.15	22.6	0.60 ± 0.42	0	5.4×10^{-7}
	combined					1.3×10^{-7}
$\tau^- \to e^- \pi^0$	$\pi^0 \to \gamma\gamma$	4.70	98.798	$0.0^{+0.4}_{-0.0}$	0	1.9×10^{-7}
$\tau^- \to \mu^- \pi^0$	$\pi^0 \to \gamma\gamma$	6.36	98.798	2.7 ± 0.7	5	4.3×10^{-7}
$\tau^- \to e^- \eta'$	$\eta' \to \pi^+\pi^-\eta$	8.51	17.5	0.16 ± 0.16	1	10×10^{-7}
$\tau^- \to \mu^- \eta'$	$\eta' \to \pi^+\pi^-\eta$	8.41	17.5	1.4 ± 0.6	0	4.1×10^{-7}

In other words, events should be consistent with a $\tau^+\tau^-$ event, in which one τ decays to a lepton and $\pi^0(\eta, \eta')$ (signal side) and the other τ decays into a charged track, any number of γ's and neutrino(s) (tag side). When a pseudoscalar meson (denoted hereafter as M^0) is reconstructed from $\gamma\gamma$, the event has a 1-1 prong configuration. When the η is reconstructed from $\pi^+\pi^-\pi^0$, or the η' is reconstructed in $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$, the event has a 1-3 prong configuration. Correspondingly, the signal side should contain at least two photons in both cases. The same principle of the event selection as that in the $\tau \to \mu\eta$ search [1] has been used.

In order to reject the background (BG), various kinematic cuts are applied. The QED BG is efficiently rejected by the total energy cut, the $q\bar{q}$ continuum BG is rejected by the number of γ or the cut on the opening angle between ℓ and $\gamma\gamma$ on the signal side. Important information is provided by the missing particles. Since neutrinos are emitted only on the tag side, the direction of the missing momentum should be contained on the tag side, so the correlation between the missing momentum and the missing mass squared can be used to remove the generic $\tau\tau$ and $q\bar{q}$ continuum contributions.

The yield of signal events is finally determined in the $M_{\ell M^0} - \Delta E$ plane, where $M_{\ell M^0}$ is the invariant mass of the ℓM^0 system and ΔE is the difference between the energy of the ℓM^0 system and the beam energy in the center-of-mass frame. In order to perform the blind analysis, we shaded the signal region over $\pm 5\sigma$ of $M_{\ell M^0}$ and -0.5 $< \Delta E <$ 0.5 GeV, where the resolutions, $\sigma_{M_{\ell M^0}}$ and $\sigma_{\Delta E}$, are evaluated from signal MC. In this analysis we apply the counting method and take an elliptically shaped signal region in the $M_{\ell M^0}$–ΔE plane with a signal acceptance, Ω, of 90%, which is more sensitive than a signal box. The analysis of the BG MC distributions shows that they agree well with the data in the sideband regions, and no peaking BG structures that mimic the signal are observed. The expected number of BG events (b_0) in the signal elliptical region is obtained by assuming a flat distribution over the $M_{\ell M^0} - \Delta E$ plane. The uncertainty of the expected number of BG events is quite large ($\leq 100\%$), particularly in the electron modes, so we set $b_0 = 0$ in the upper limit evaluation if $b_0 < 1$. The resultant b_0 are listed in Table 1.

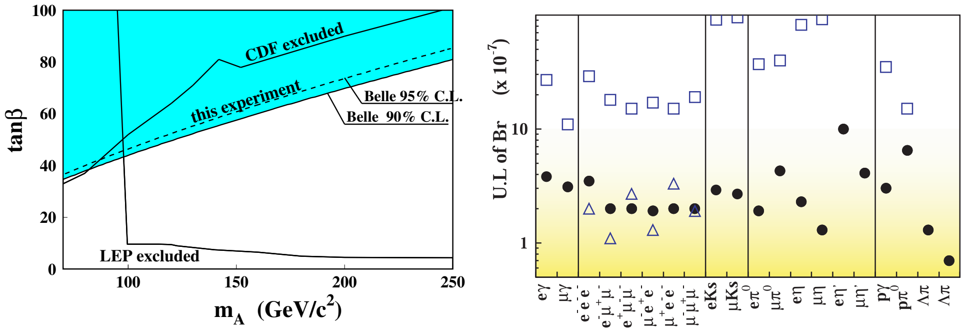

Fig. 1. (Left) Experimentally excluded $m_A - \tan\beta$ parameter space. The 90% and 95% C.L. results of this experiment using [5] are indicated by the shaded region together with the 95% C.L. regions excluded by LEP and the Tevatron. (Right) Results of other LFV decay searches at CLEO, Babar and Belle shown by □, △ and •, respectively.

After opening the blinded region, we find one event in both $\tau^- \to e^-\eta'$ and $\tau^- \to \mu^-\eta$ modes, and five events in the $\tau^- \to \mu^-\pi^0$ mode, however, no events are found for the other modes. The resultant numbers of events s are consistent with the expected BG b_0, so we set a 90% C.L. upper limit on the branching ratio for each decay mode based on Feldman & Cousins method as shown in Table 1.

3. Results and discussion

Using a sample of 153.8 fb^{-1} we obtain new upper limits on the branching fraction of LFV τ decays involving pseudoscalar mesons π^0, η, η'. They range from 1.3×10^{-7} to 10×10^{-7} at 90% C.L for six different modes as shown in Table 1. If we assume the relationship derived by M. Sher [5] $\mathcal{B}(\tau^-\to\mu^-\eta) = 0.84\times10^{-6}\times\left(\frac{\tan\beta}{60}\right)^6\left(\frac{100\ \mathrm{GeV}}{m_A}\right)^4$, where m_A is the pseudoscalar Higgs mass and $\tan\beta$ is the ratio of the vacuum expectation values, we can restrict the allowed parameter space for $m_A - \tan\beta$ as indicated in Fig. 1 (left). Our boundary is indicated by the shaded region for 90% C.L.. Figure 1 (left) also shows the 95% C.L. constraints from high energy collider experiments at LEP [2] and CDF [3]. Figure 1 (right) shows the results of other LFV τ decay searches. We set a 90% C.L. limit of $\mathcal{B}$ in 20 modes. These results are 10 to 70 times better than in the previous CLEO measurements [4] and set new limits on the $\tau\to\ell\eta'$ and $\tau\to\Lambda\pi$ modes.

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