PROCEEDINGS OF SCIENCE

Rare tau decays at Belle

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We report results of a search for tau lepton decays strongly suppressed in the Standard Model based on the world-largest data sample accumulated with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. The decays include: lepton flavor and lepton number violating tau decays into a lepton (e or μ) and two charged mesons (K or π) as well as lepton and baryon number violating tau decays into a Λ and a charged meson (K or π). The sensitivity to the branching fractions is significantly improved compared to our previous results and reaches $\mathscr{O}(10^{-8})$.

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1. Introduction

Generally, the tau lepton is expected to have a strong coupling to the new physics (NP) since it has the heaviest mass among the leptons. We search for many kinds of the signature for the NP and lepton-flavor violation (LFV) is one of the clear signatures because it is forbidden in the standard model (SM) and its probability is very small even if the neutrino oscillations are taken into account. Thus, a tau-lepton-flavor violating (τ LFV) decay is promising and many possible τ LFV modes are considered: not only merely lepton-flavor-violating processes but also lepton-number- or baryon-number-violating processes.

Here, we report the recent results for $\tau \to \ell h h'$ and Λh using around a 1000 fb^{-1} data sample obtained by the Belle collaboration, where $\ell = e, \mu$ and $h = \pi, K$.

2. Method

All searches for τ LFV decays follow a similar procedure. 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 and any number of additional photons and neutrinos. To search for exclusive LFV decay modes, we select low multiplicity events with zero net charge, and separate an event into two hemispheres (signal and tag) using a thrust axis. The backgrounds in such searches are dominated by $q\overline{q}$ $(q = u, d, s, c)$, generic $\tau^+\tau^-$, two-photon, $\mu^+\mu^-$ and Bhabha events. To obtain a good sensitivity, we optimize the event selection using particle identification and kinematic information for each mode separately. Because every τ LFV decay is a neutrinoless one, the information from missing tracks is very powerful to reject the background from generic $\tau^+\tau^-$ events. 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 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 τ LFV decay or set an upper limit (UL) at 90% confidence level (CL) by applying counting approach. [1]

3. Results

3.1 $\tau \to \ell h h'$ ($\ell = e, \mu$, $h = \pi, K$)

Although $\tau^- \to \ell^- h^+ h'^-$ violates only the lepton flavor, $\tau^- \to \ell^+ h^- h'^-$ violates the lepton number as well. Here, we search for 8 modes of $\tau^- \to \ell^- h^+ h'^-$ and 6 modes of $\tau^- \to \ell^+ h^- h'^-$. The former ones are expected to be enhanced by the Higgs-mediated model while the latter are motivated by the Majorana neutrino model.

We have updated the analysis for these modes with an 854 fb^{-1} data sample. Main backgrounds come from $\tau \to \pi\pi\pi\nu$ for $\ell = \mu$ and $\tau \to \pi\pi^0\nu$ for $\ell = e$, where the photon, that is a daughter of π^0, converts to e^+e^-. To reduce them, $\tau \to \pi\pi\pi\nu$ veto, using $M_{\pi\pi\pi}$, and γ-conversion veto are newly introduced for $\mu\pi K$ modes and $\ell = e$ modes, respectively. As a result, we have found

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Table 1: Summary of ULs for recently updated modes. The signal efficiency (ε), the number of expected background events ($N_{\rm BG}$) estimated from the sideband data, the number of observed events in the signal region ($N_{\rm obs}$) and 90% CL UL on the branching fraction ($\mathscr{B}_{90}$) for each individual mode.

Mode ($\tau^- \to$)	ε (%)	$N_{\rm BG}$	$N_{\rm obs}$	$\mathscr{B}_{90}$ (10^{-8})	Mode ($\tau^- \to$)	ε (%)	$N_{\rm BG}$	$N_{\rm obs}$	$\mathscr{B}_{90}$ (10^{-8})
$\mu^-\pi^+\pi^-$	5.83	0.63 ± 0.23	0	2.1	$e^-\pi^+\pi^-$	5.45	0.55 ± 0.23	0	2.3
$\mu^+\pi^-\pi^-$	6.55	0.33 ± 0.16	1	3.9	$e^+\pi^-\pi^-$	6.56	0.37 ± 0.18	0	2.0
$\mu^-K^+K^-$	2.85	0.51 ± 0.18	0	4.4	$e^-K^+K^-$	4.29	0.17 ± 0.10	0	3.4
$\mu^+K^-K^-$	2.98	0.25 ± 0.13	0	4.7	$e^+K^-K^-$	4.64	0.06 ± 0.06	0	3.3
$\mu^-\pi^+K^-$	2.72	0.72 ± 0.27	1	8.6	$e^-\pi^+K^-$	3.97	0.18 ± 0.13	0	3.7
$\mu^-K^+\pi^-$	2.62	0.64 ± 0.23	0	4.5	$e^-K^+\pi^-$	4.07	0.55 ± 0.31	0	3.1
$\mu^+K^-\pi^-$	2.55	0.56 ± 0.21	0	4.8	$e^+K^-\pi^-$	4.00	0.46 ± 0.21	0	3.2
$\Lambda\pi^-$	4.39	0.31 ± 0.18	0	3.0	ΛK^-	3.16	0.42 ± 0.19	0	4.2
$\overline{\Lambda}\pi^-$	4.80	0.21 ± 0.15	0	2.8	$\overline{\Lambda}K^-$	4.11	0.31 ± 0.14	0	3.1

1 event for $\mu^+\pi^-\pi^-$ and $\mu^-\pi^+K^-$ modes while no events are observed in the other modes. Since this is consistent with the expected number of the backgrounds, we set the UL on the branching fraction. The evaluated numbers to set the UL and the number of observed events in the signal region are summarized in Table 1. The ULs for this mode are the most sensitive. (preliminary)

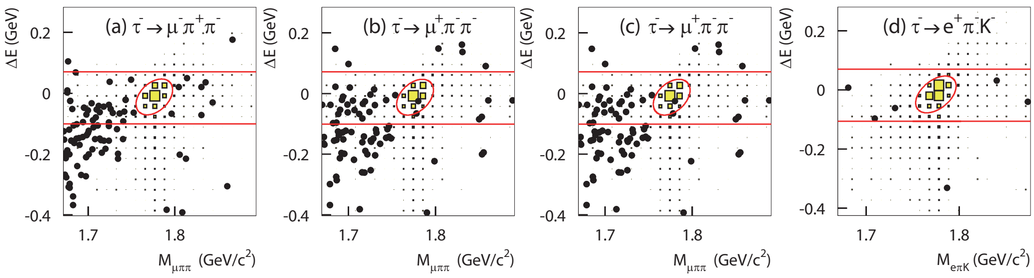

Figure 1: Resulting plots on the $M_{\rm inv}$ – ΔE plane for $\tau^- \to \mu^-\pi^+\pi-$ (a), $\tau^- \to \mu^+\pi^-\pi^-$ (b), $\tau^- \to \mu^-\pi^+K^-$ (c) and $\tau^- \to e^+\pi^-K^-$ (d). Here, black dots show the data and yellow boxes indicate the density for the signal events.

3.2 $\tau \to \Lambda h$ $(h = \pi, K)$

This mode violates the lepton number (L) as well as the baryon number (B): $\tau^- \to \overline{\Lambda}h^-$ conserves $(B-L)$ while $\tau^- \to \Lambda h^-$ violates $(B-L)$. Some GUTs can make $(B-L)$ conserving decays while a more complicated model is necessary to induce $(B-L)$ violating decays.

We have searched for these decays with a 906 fb^{-1} data sample. Main backgrounds come from $\tau \to \pi K_S^0 \nu$ and $q\overline{q}$ $(q = u,d,s)$ events having Λ and π. In the former background, K_S^0 is misidentified as Λ. This can be rejected by a K_S^0 veto using $M_{\pi\pi}$. On the other hand, the latter is likely to have a proton as a charged track on the tag side because of the baryon number conservation. Therefore, we veto the proton for the tag-side track. As a result, no events are observed for each mode; no excess is found for the signal. Thus, we set the UL on the branching fraction. The obtained numbers are summarized in Table 1. We obtain the most stringent ULs. (preliminary)

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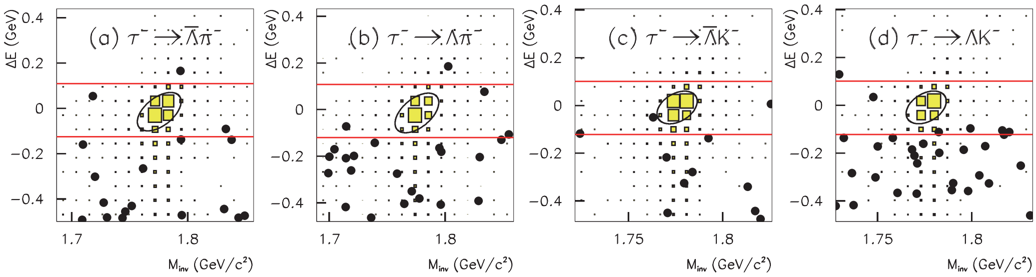

Figure 2: Resulting plots on the $M_{\rm inv} - \Delta E$ plane for $\tau^- \to \mu^-\pi^+\pi^-$ (a), $\tau^- \to \mu^+\pi^-\pi^-$ (b), $\tau^- \to \mu^-\pi^+K^-$ (c) and $\tau^- \to e^+\pi^-K^-$ (d). Here, black dots show the data and yellow boxes indicate the density for the signal events.

4. Summary

We have searched for 46 major modes of lepton flavor violating τ decays with a 1000 fb^{-1} data sample, reported the recently updated results for $\tau \to \ell h h'$ and Λh here and obtained the most sensitive results for them so far. The current status of the τ LFV searches in $B-$factory experiments is summarized in Fig. 3. No evidence for these decays is observed and we set 90% CL ULs on the branching fractions at the $O(10^{-8})$ level. The sensitivity for the LFV search is 100 times improved in comparison with CLEO's one due to the effective background rejection and increase of the data sample.

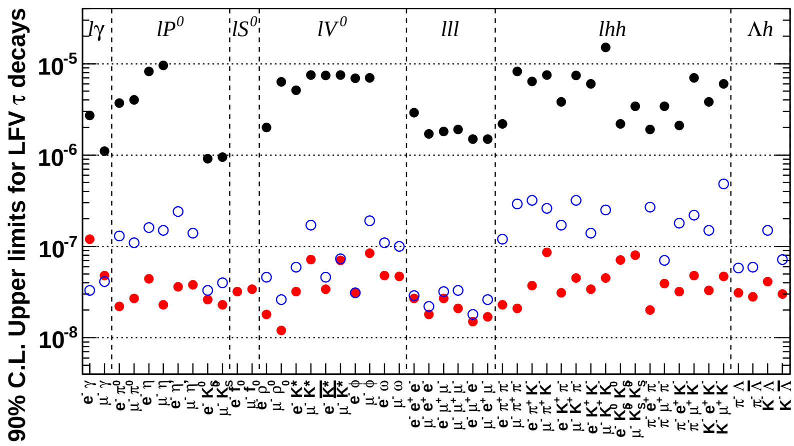

Figure 3: Current 90% CL ULs for the branching fraction of τ LFV mode. Red, blue and black circles show Belle, BaBar and CLEO results, respectively.

References

[1] G. J. Feldman and R. D. Cousins, Phys. Rev. D **57**, 3873 (1998).