Eur Phys J C **33**, s01, s297–s299 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2003-03-209-y

EPJ C direct
electronic only

Rare decays of tau-lepton

Takayoshi Ohshima

Department of Physics, Nagoya University, Chikusa, Nagoya, 464-8602 Japan

Received: 15 October 2003 / Accepted: 12 November 2003 /
Published Online: 1 December 2003 –

Abstract. We have searched for the Lepton Flavor Violating decays $\tau^- \to \mu^-\gamma$ and $\tau^- \to \mu^-\eta$ using ∼85 fb^{-1} of data accumulated by the Belle detector at KEKB, and attained preliminary upper limits for the branching fraction $Br(\tau^- \to \mu^-\gamma) < 3.2 \times 10^{-7}$ and $Br(\tau^- \to \mu^-\eta) < 3.4 \times 10^{-7}$, respectively, at the 90% confidence level. These are the first data that reach to the sensitivity of 10^{-7} level, and provide some constraints on the parameter spaces of $\tan\beta$ vs. SUSY mass and $\tan\beta$ vs. Higgs mass.

PACS. number(s) 13.35.Dx, 11.30.Fs, 14.60.Fg

1 Introduction

B factory performs also τ factory. KEKB is an asymmetric energy e^+e^- collider built primarily to study CP violation of B-mesons. It has been successfully operating since 1999 and has now attained the world highest peak luminosity of $1 \times 10^{34} cm^{-2} sec^{-1}$ this May. Belle is the general purpose 4π detector with good momentum and energy resolutions and particle identification ability. KEKB-Belle has so far accumulated about 160 fb^{-1} luminosity, corresponding to about $1.4{\times}10^8$ τ-pair production at $\sqrt{s} = 10.58$ GeV. Such a hugh amount of data enables us to search for Lepton Flavor Violation (LFV) τ decay in a much more sensitive way than the previous experiments. Among many of the possible LFV decays, the latest Belle results on $\tau^- \to \mu^-\gamma$ and $\tau^- \to \mu^-\eta$ are here presented. The detail description on KEKB and Belle should be referred to [1].

2 $\tau^- \to \mu^-\gamma$

This process is forbidden in the Standard Model (SM), but is allowed in new physics beyond the SM such as supersymmetric (SUSY) models, left-right symmetry models and others [2]. Some of these models predict a rather large branching fraction (Br) of 10^{-7}-10^{-9} accessible at Belle. The best limit is so far achieved by CLEO [3] as Br $= 1.1 \times 10^{-6}$.

From our previous study, it becomes obvious that background (BG) is composed of mostly radiative τ-pair ($\gamma\tau^+\tau^-$) and radiative μ-pair ($\gamma\mu^+\mu^-$); and non-zero candidate events are found in a signal region so that not only reduction of background but also reliable knowledge of its distribution is quite substantial to correctly extract the number of signal events. We have made intensive efforts in our analysis to thoroughly understand background properties.

We search for a $\tau^+\tau^-$ event using 86.3 fb^{-1} of data (78.5 M $\tau^+\tau^-$ production): One τ decays to μ and γ, and the other τ decays to a charged particle, but not μ, and any number of photons with neutrino(s). See, detail description of the event selection in [4]. One of characteristic features in our analysis is a newly introduced criterion on the relation between missing momentum ($p_{\rm miss}$) and missing mass-squared ($m^2_{\rm miss}$), as illustrated in Fig. 1. This cut removes 98% of generic $\tau^+\tau^-$ and 86% of $\mu^+\mu^-$, while 76% of signals is remained. The sensitivity is resultantly improved by a factor of ∼1.5 apart from the enhancement of the accumulated luminosity, compared to CLEO [3].

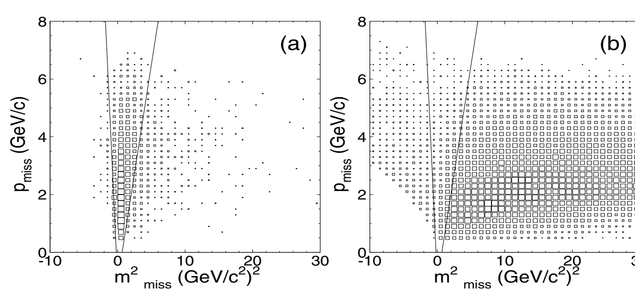

Fig. 1. A newly introduced selection criterion in the $m^2_{\rm miss}$-$p_{\rm miss}$ plane. The cut bounbary is indicated by lines for **a** signal and **b** $\tau^+\tau^-$ MC events

Signal yield is finally evaluated in ΔE-$M_{\mu\gamma}$ plane, where $\Delta E{=}E^{CM}_{\mu\gamma}$-$E^{CM}_{beam}$, and $E^{MC}_{\mu\gamma}$ and $M_{\mu\gamma}$ are a center-of-mass energy and the invariant mass of signal $\mu\gamma$ system, respectively. The ΔE and $M_{\mu\gamma}$ resolutions are estimated by MC as σ=65.4±0.6 MeV and σ=20.3±0.9 MeV/c^2, respectively. In order to avoid introducing bias into analysis, we blind a region over $M_{\mu\gamma} = 1.7 - 1.85$ GeV/c^2.

Background is expressed as

$$N_{\rm BG}(\Delta E, M_{\mu\gamma}) = N^{\gamma\tau\tau}(\Delta E, M_{\mu\gamma}) \cdot (1 + \Lambda) + N^{\gamma\mu\mu}(\Delta E, M_{\mu\gamma}) \cdot \kappa, \quad (1)$$

where $N^{\gamma\tau\tau}(\Delta E, M_{\mu\gamma})$ is a contribution from generic τ-pair decays and Λ is a small uds continuum fraction. The first term is obtained by MC. The second one is a contribution from μ-pairs and evaluated from $\mu^+\mu^-$ data by multiplying a μ identification inefficiency, κ. Thus obtained background spectrum is expressed by a combination of Gaussian and Landau functions with $1 + \Lambda = 1.14 \pm 0.09$ and $\kappa = 0.14 \pm 0.04$, and its expected distribution at the signal region is indicated by the dots curve in Fig. 2. $\gamma\tau\tau$ yields the dominant contribution, while $\gamma\mu\mu$ does a smaller one but not insignificant. The Λ and κ can be also determined by comparing $N_{\rm BG}(\Delta E, M_{\mu\gamma})$ to the actual data distribution outside the blind region; $1 + \Lambda = 1.22$ and κ=0.11 are resulted in as the optimized parameters, and its spectrum is indicated by the real curve in Fig. 2. Furthermore, the background spectrum at the signal region is simply inferred by averaging their distributions at both side-bands, as indicated by the histogram. Curves and histogram agree very well.

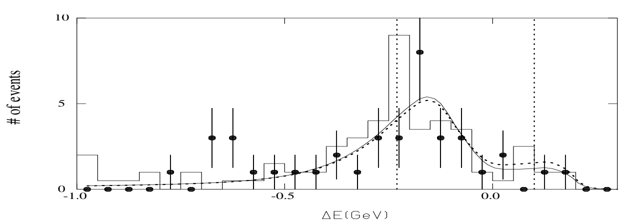

Fig. 2. Background ΔE-distributions in the signal region, $1.71 < M_{\mu\gamma} < 1.82$ GeV/c^2. The first term of (1) produces the dominant distribution with a peak at $\Delta E \sim -0.25$ GeV, while the second term appears as a small structure around $\Delta E \simeq 0.1$ GeV. See the text for description

Data points in Fig. 2 are the actual remaining data when the blind is unveiled. Very good agreement between the data and the expected backgrounds is seen, and no appreciable signal behavor is found. Figure 3 shows the remaining data event distribution on ΔE-$M_{\mu\gamma}$ plane. Because of the initial radiation and energy leakage from the calorimeter, the signal MC distribution exhibits a long low energy tail.

By taking $\pm 5\sigma$ region for ΔE and $M_{\mu\gamma}$, an unbinned extended maximum likelihood fit is performed with a Likelihood defined as [3]

$$\mathcal{L} = \frac{e^{-(s+b)}}{N!} \prod_{i=1}^{N} (sS_i + bB_i), \quad (2)$$

where S_i and B_i are the signal and background probability densities at i-th event, respectively, s and b are the number of signal and background events, and N is the total number of events. Result of fit for $N = 54$ events gives us $s = 0$ signal events. An upper limit on the number of

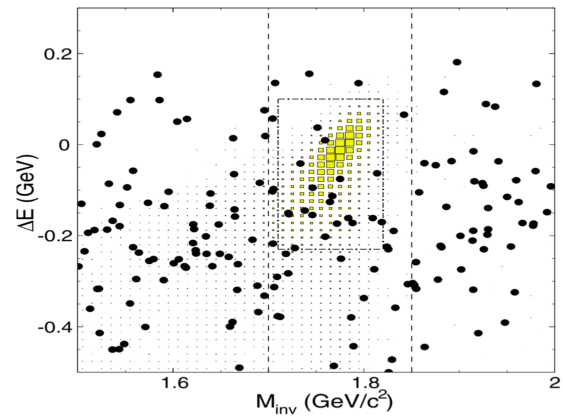

Fig. 3. Remaining event distributions in the data (dots) and signal MC (square) in ΔE-$M_{\mu\gamma}$ plane. The domain between the dashed lines is kept blinded during the analysis

signal events at 90% confidence level (CL) is obtained as $s_{90} = 5.1$ events with use of a Toy MC. An upper limit on the branching fraction at 90% CL is then calculated as 2.9×10^{-7} via

$$Br(\tau^- \to \mu^-\gamma) < \frac{s_0}{2\epsilon N_{\tau\tau}}, \quad (3)$$

where $N_{\tau\tau}$ is the total number of τ-pairs produced, 7.85×10^7, and ϵ is the detection efficiency, 10.5%.

Systemtic uncertainties are considered both on s_{90} and the detection sensitivity $2\epsilon N_{\tau\tau}$: The detail description is referred in [4]. The incorporation of all systemtic uncertainties increases the upper limit by 6.3%: The upper limit is therefore

$$Br(\tau^- \to \mu^-\gamma) < 3.1 \times 10^{-7} \quad \text{at 90\% CL.} \quad (4)$$

3 $\tau^- \to \mu^-\eta$

This is an attractive process to obtain the most stringent bound on Higgs-mediated LFV in MSSM [5]. It is pointed out that a flavor non-diagonal lepton-lepton-Higgs Yukawa coupling could be induced if slepton mixing is large: μ-τ-Higgs coupling is specifically anticipated so, since left-handed smuons and staus are usually supposed to be large. The color factor and the mass-squared dependent Higgs coupling at the Higgs-s-$\bar{\rm s}$ vertex would enhance the branching fraction by a factor of 8.4 in $\tau^- \to \mu^-\eta$ compared to $\tau \to 3\mu$. Current limit is $Br(\tau^- \to \mu^-\eta) < 9.6 \times 10^{-6}$ by CLEO [8].

We analyze 84 fb^{-1} of data by detecting η in $\gamma\gamma$ and $\pi^+\pi^-\pi^0$ modes. Our analysis is essentially very similar to that of $\tau^- \to \mu^-\gamma$: We search for a $\tau^+\tau^-$ events containing exactly two oppositely charged tracks and two or more photons, two of which form an η in a case of $\eta \to \gamma\gamma$ mode; or containing four charged tracks with zero net charge and two or more photons, among which a π^0 and in succession an η are resonstructed in $\eta \to \pi^+\pi^-\pi^0$ mode. The signal side is composed the thus reconstructed η and a track to be identified as a μ, while the tag side has a track, but not

μ, and plural number of photons with missing momentum and energy. Detail is referred to [9]. As an example of kinematic reconstruction, Fig. 4 shows a resolution normalized η-mass in $\gamma\gamma$ mode ($S^{\eta}_{\gamma\gamma}$) and π^0-mass ($S^{\pi^0}_{\gamma\gamma}$) and η-mass (m_η) in 3π modes.

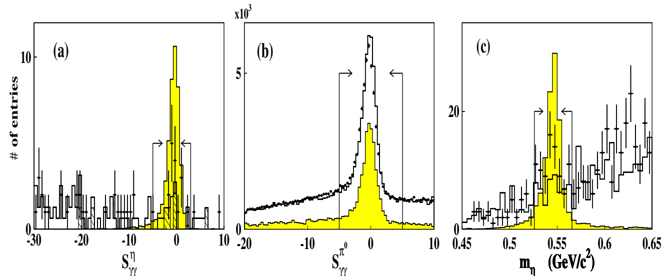

Fig. 4. Resolution normalized invariant masses of $\gamma\gamma$, **a** $S^{\eta}_{\gamma\gamma}$ and **b** $S^{\pi^0}_{\gamma\gamma}$, and (c) η-mass, m_η, from $\pi^+\pi^-\pi^0$ reconstruction

Blind analysis is performed in the same as the case of $\tau^- \to \mu^-\gamma$, but the signal region is defined at this time by an ellipse with a 90% acceptance in ΔE-$M_{\mu\gamma}$ plane, as found in Fig. 5. When the blind region is opened after all kinematical cuts, there are 7 and 2 remaining events in $\gamma\gamma$ and 3π modes, respectively, within $\pm 10\sigma$ region, but outside the ellipse, in the ΔE-$M_{\mu\eta}$ plane, where σ means the resolution of ΔE or $M_{\mu\eta}$ measurement. On the other hand, MC predicts 3.7 and 0 events. No events are found in the ellipse for both modes: Therefore, a 90% CL upper limit of signal events is set as 2.3 events.

With the detection efficiency of $\epsilon = 8.37\%$ and 5.04% for $\gamma\gamma$ and 3π modes, respectively, and $N_{\tau\tau} = 76.9 \times 10^6$, we obtaine 90% CL upper limits on Br as 4.5×10^{-7} and 13.6×10^{-7}. Systematic uncertainty amounts to 8.1% for $\gamma\gamma$ and 7.3% for 3π. Including these systematic errors into the Br following [10] and combining two modes, we finally obtain

$$Br(\tau^- \to \mu^-\eta) < 3.4 \times 10^{-7} \quad \text{at 90\% CL.} \qquad (5)$$

4 Summary

We attain upper limits on $\tau^- \to \mu^-\gamma$ as $Br < 3.2 \times 10^{-7}$ and on $\tau^- \to \mu^-\eta$ as $Br < 3.4 \times 10^{-7}$ at 90% CL. as

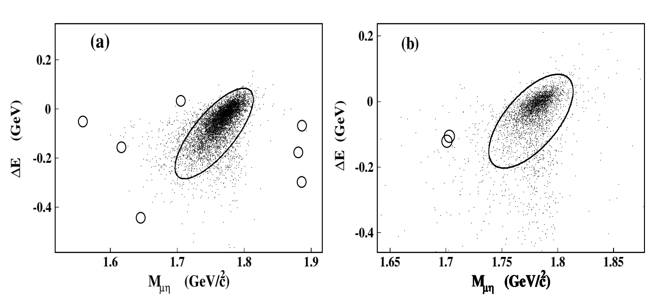

Fig. 5. Remaining event distributions over $\pm 10\sigma$ region on the ΔE-$M_{\mu\eta}$ plane for **a** $\eta \to \gamma\gamma$ and **b** $\eta \to \pi^+\pi^-\pi^0$ modes. The ellipses are the signal regions with an acceptane of 90%. Data are indicated by the open circles, and the signal MC are plotted by dots

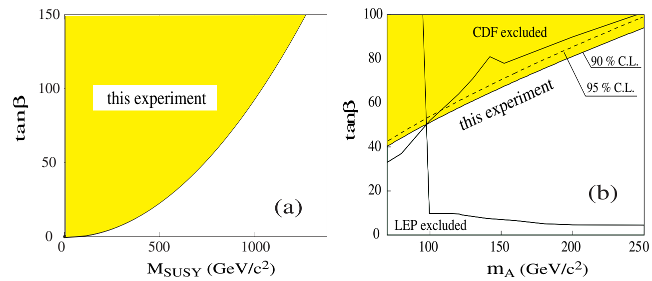

Fig. 6. Excluded parameter space by this experiment for **a** $\tan\beta$-M_{SUSY} by $\tau^- \to \mu^-\gamma$ decay and **b** $\tan\beta$-m_A by $\tau^- \to \mu^-\eta$

the preliminary results. These are the first data reaching sensitivity of 10^{-7} level. They provide constraints on the physics beyond the SM.

Figure 6(a) shows an excluded region by this $\tau^- \to \mu^-\gamma$ data on the relation between $\tan\beta$ and SUSY particle mass (M_{SUSY}) following the paper by Dedes *et al.* [7], and 6(b) shows an excluded region by this $\tau^- \to \mu^-\eta$ data on the relation between $\tan\beta$ and Higgs mass (m_A) following the paper by Babu and Kolda [6]. Our result on the latter constraint has sensitivity close to that achieved by CDF experiment [11].

As additional data of 75 fb^{-1} are made available, these sensitivities will be soon improved.

References

1. About KEKB, see S. Kurokawa and E. Kikutani: Nucl. Instr. and Meth. A **499**, 1 (2003); about Belle spectrometer, see Belle Collaboration, A. Abashian et al.: Nucl. Instr. and Meth. A **479**, 117 (2002)
2. For instance, see J. Hisano and D. Nomura: Phys. Rev. D **59**, 116005 (1999); K.S. Babu, B. Dutta, and R.N. Mohapatra: Phys. Rev. D **60**, 0350033 (1999)
3. CLEO Collaboration, S. Ahmed et al.: Phys. Rev. D **61**, 071101 (2000)
4. Belle Collaboration: Contributed paper to this Conference, EPS-ID:558
5. M. Sher: Phys. Rev. D **66**, 057301 (2002)
6. K.S. Babu and C. Kolda: Phys. Rev. Lett. **89**, 241802 (2002)
7. A. Dedes, J. Ellis, and M. Raidal: Phys. Lett. B **549**, 159 (2002)
8. CLEO Collaboration, G. Bonvicini et al.: Phys. Rev. Lett. **79**, 1221 (1997)
9. Belle Collaboration: Contributed paper to this Conference, EPS-ID:560
10. R. Cousins and V. Highland: Nucl. Instr. and Meth. A **320**, 331 (1992)
11. CDF Collaboration, T. Affolder et al.: Phys. Rev. Lett. **86**, 4472 (2001)