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Search for charged-lepton flavor violation in $\Upsilon(2S) \to \ell^{\mp}\tau^{\pm}$ ($\ell = e, \mu$) decays at Belle

The Belle collaboration

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Abstract: We report a search for the charged-lepton flavor violation in $\Upsilon(2S) \to \ell^{\mp}\tau^{\pm}$ ($\ell = e, \mu$) decays using a $25\,\mathrm{fb}^{-1}$ $\Upsilon(2S)$ sample collected by the Belle detector at the KEKB e^+e^- asymmetric-energy collider. We find no evidence for a signal and set upper limits on the branching fractions ($\mathcal{B}$) at 90% confidence level. We obtain the most stringent upper limits: $\mathcal{B}(\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}) < 0.23 \times 10^{-6}$ and $\mathcal{B}(\Upsilon(2S) \to e^{\mp}\tau^{\pm}) < 1.12 \times 10^{-6}$.

Keywords: Beyond Standard Model, e^+-e^- Experiments, Flavour Physics

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Contents

1 Introduction

The lepton flavor conservation is one of the accidental symmetries of the Standard Model (SM). The observation of neutrino oscillation [1, 2] manifests the lepton flavor violation in the neutral lepton sector. In the minimal extension of the SM that explains neutrino oscillation [1, 2], the charged-lepton flavor violating (CLFV) transitions are mediated by $W^{\pm}$ bosons and massive neutrinos. This makes CLFV decays to be heavily suppressed on the order of m_ν^2/m_W^2 such as the branching fraction $\mathcal{B}(\mu \to e\gamma) \sim 10^{-54}$ [3, 4]. Various new physics models, namely leptoquark and supersymmetry, allow enhanced decay rates for CLFV transitions [5, 6]. Therefore, the observation of enhanced charged-lepton flavor violation would be clear evidence for new physics. The experimental limit on the two-body CLFV quarkonium decay provides complementary constraints on the Wilson coefficients of the effective Lagrangian of new physics models [7].

CLEO and BaBar studied the CLFV $\Upsilon(nS)$ ($n = 1, 2, 3$) decay modes [8, 9], and recently Belle searched for $\Upsilon(1S) \to \ell^{\mp}\ell'^{\pm}$ and $\Upsilon(1S) \to \gamma\ell^{\mp}\ell'^{\pm}$ ($\ell = e, \mu; \ell' = e, \mu, \tau$) decay modes [10]. In this paper, we present a search for the CLFV $\Upsilon(2S) \to \ell^{\mp}\tau^{\pm}$ decays using 25 fb^{-1} of the data collected at the $\Upsilon(2S)$ resonance with the Belle detector [11, 12] at the KEKB asymmetric-energy e^+e^- collider [13, 14]. The current most stringent upper limits for CLFV $\Upsilon(2S)$ decays are $\mathcal{B}(\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}) < 3.3 \times 10^{-6}$ and $\mathcal{B}(\Upsilon(2S) \to e^{\mp}\tau^{\pm}) < 3.2 \times 10^{-6}$ as set by BaBar [9].

2 Belle experiment

The Belle detector is a large solid-angle magnetic spectrometer that is comprised of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) composed of 8736 CsI(Tl) crystals, all located inside a superconducting solenoid providing a magnetic field of 1.5 T. An iron flux-return yoke placed outside the solenoid coil is instrumented with resistive plate chambers to detect K_L^0 mesons and muons (KLM). Belle has accumulated the world's largest data

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sample of e^+e^- collision at the center-of-mass (c.m.) energy of 10.02 GeV, which corresponds to 158 million $\Upsilon(2S)$ decays.

We perform the background study and the optimization of selection criteria using Monte Carlo (MC) simulated events. We use the EVTGEN [15] package to generate MC events, and the detector simulation is performed with GEANT-3 [16]. The analysis is performed in the B2BII software framework [17], which converts the Belle to Belle II data format. We generate 5 million signal MC events of $\Upsilon(2S) \to \ell^\mp\tau^\pm$. For background study, we use MC samples of $e^+e^- \to e^+e^-$ (Bhabha) [18], $e^+e^- \to \mu^+\mu^-$ [19, 20], $e^+e^- \to \tau^+\tau^-$ [19, 20], $e^+e^- \to e^+e^-\mu^+\mu^-$ [21], $e^+e^- \to e^+e^-e^+e^-$ [21], inclusive $\Upsilon(2S)$ decays [15, 22], and $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) processes generated with an initial state radiation (ISR) photon [15, 22] at the energy of the $\Upsilon(2S)$ resonance. They correspond to 25 fb^{-1} of integrated luminosity except for the sample of Bhabha events, which corresponds to 2.5 fb^{-1} of integrated luminosity.

3 Reconstruction and event selection

We search for decays $\Upsilon(2S) \to \ell_1^\mp\tau^\pm$ with $\tau^+ \to \ell_2^+\nu_{\ell_2}\overline{\nu}_\tau$ or $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$. Hereafter, the primary non-tau lepton is referred to as ℓ_1 and the lepton from τ as ℓ_2, and charge conjugation is implied. Due to copious background contributions from Bhabha and $e^+e^- \to \mu^+\mu^-$ events, we do not take the combination of the same flavored ℓ_1 and ℓ_2. These background components also have a large contribution to the channel with $\tau^+ \to \pi^+\overline{\nu}_\tau$ owing to the pion misidentification, and we do not use this channel. Therefore, our search strategy includes only $\Upsilon(2S) \to \mu^\mp\tau^\pm$ with $\tau^+ \to e^+\nu_e\overline{\nu}_\tau$ (μ-e mode) or $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ (μ-$\pi\pi^0$ mode), and $\Upsilon(2S) \to e^\mp\tau^\pm$ with $\tau^+ \to \mu^+\nu_\mu\overline{\nu}_\tau$ (e-μ mode) or $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ (e-$\pi\pi^0$ mode).

We require the charged particles to originate from the interaction point (IP); their distances of closest approach from the IP must be within 2.0 cm in the transverse plane and within 5.0 cm along the beam direction. Charged particles are identified based on the information from various sub-detectors [23]. Muon candidates [24] are identified using a likelihood ratio $\mathcal{R}_\mu = \mathcal{L}_\mu/(\mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K)$, where $\mathcal{L}_\mu$, $\mathcal{L}_\pi$, and $\mathcal{L}_K$ are the likelihoods for μ, π, and K based on the information from the KLM. All charged tracks satisfying $\mathcal{R}_\mu > 0.8$ are identified as muons with an efficiency of above 70% and a misidentification rate of less than 3%. An analogous likelihood ratio $\mathcal{R}_e$ is defined for electrons [25], based on the specific ionization from the CDC, the ratio of the energy deposited in the ECL to the momentum measured by the CDC and SVD combined, the shower shape in the ECL, hit information from the ACC, and matching between the position of the charged track and the ECL cluster. We require $\mathcal{R}_e > 0.8$ to distinguish electrons from charged hadrons with an efficiency of above 90% and a misidentification rate of less than 3%. The energy loss of an electron via bremsstrahlung is recovered by adding back the energy of each photon found within 50 mrad of the direction of the electron track into the latter momentum. For charged pions, we use a binary likelihood ratio $\mathcal{R}(\pi|K) = \mathcal{L}_\pi/(\mathcal{L}_\pi + \mathcal{L}_K)$ where $\mathcal{L}_\pi$ and $\mathcal{L}_K$ are the likelihoods for π and K, respectively determined from the specific ionization in the CDC, information from the TOF, and response of the ACC. We require $\mathcal{R}(\pi|K) > 0.6$ to identify charged pions that are above 87% efficient with a kaon misidentification rate of less than 5%.

Neutral pions (π^0) are reconstructed from photon pairs detected as ECL clusters without associated charged particles. The energy of each photon is required to be: greater than

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50 MeV if detected in the barrel ($32.2^\circ < \theta < 128.7^\circ$), greater than 100 MeV if detected in the forward endcap ($12.4^\circ < \theta < 31.4^\circ$), and greater than 150 MeV if detected in the backward endcap ($130.7^\circ < \theta < 155.1^\circ$), where θ is the polar angle with respect to the direction opposite to the e^+ beam. The invariant mass of each photon pair is required to be within 125 and 145 MeV/c^2, corresponding to three standard deviations ($\pm 3\sigma$) in the π^0 mass resolution [26].

As signal events have only two charged particles, they do not always pass the online trigger condition. The effect of finite trigger rate is studied with a trigger simulation, and only events passing the trigger simulation are chosen for simulated samples. Events of μ-e, μ-$\pi\pi^0$, and e-μ modes are mostly selected online by a trigger with two tracks and a KLM hit; in addition, ECL energy and cluster triggers contribute to the μ-e and μ-$\pi\pi^0$ modes. The e-$\pi\pi^0$ mode relies only on the ECL cluster trigger. In this analysis, we use a data sample with the following pre-selections for τ-pair events: $2 \leq N_{\rm trk} \leq 8$, where $N_{\rm trk}$ is the number of good charged tracks; the sum of the charge of the tracks is between -2 and 2; the maximum transverse momentum of the tracks is greater than 0.5 GeV/c; the sum of ECL energy associated with tracks is less than 5.3 GeV when $2 \leq N_{\rm trk} \leq 4$ and the number of tracks in the barrel is less than 2 [27]. These pre-selections are applied to the MC samples too.

The signature of $\Upsilon(2S) \to \ell_1^\mp \tau^\pm$ signal is a high-momentum lepton ℓ_1 of momentum around 4.85 GeV/c in the c.m. frame. We take the highest momentum lepton in an event as ℓ_1. For the μ-e and e-μ modes, we consider a secondary lepton ℓ_2 with momentum in the c.m. frame (p_2^*) to be greater than 0.5 GeV/c. For the μ-$\pi\pi^0$ and e-$\pi\pi^0$ modes, we combine a π^+ with $0.3 < p_{\pi^+}^* < 4.0$ GeV/c and a π^0 with $p_{\pi^0}^* > 0.4$ GeV/c, where $p_{\pi^+}^*$ and $p_{\pi^0}^*$ are the π^+ and π^0 momenta in the c.m. frame, and require that their invariant masses lie between 0.5 and 1.0 GeV/c^2. In the search for $\Upsilon(2S) \to e^\mp \tau^\pm$, we require the total visible energy of the event in the c.m. frame ($E_{\rm vis}^*$), which is the sum of the energy of all neutral clusters and charged tracks, to be less than 9.8 GeV in order to suppress the background from Bhabha events.

Figure 1 shows the p_1^* distributions, where p_1^* is the momentum of ℓ_1 in the c.m. frame with the selections mentioned above. The signal region is chosen to be $4.78 < p_1^* < 4.93$ GeV/c, which corresponds to 2σ around the expected p_1^* that peaks at 4.85 GeV/c. The signal reconstruction efficiencies after the aforementioned selection criteria are 8.6% (μ-e), 8.3% (μ-$\pi\pi^0$), 5.9% (e-μ), and 4.9% (e-$\pi\pi^0$). After the initial selections, the dominant background contribution comes from the Bhabha, $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \tau^+\tau^-$, and $e^+e^- \to e^+e^-\mu^+\mu^-$ samples. The distribution for e-$\pi\pi^0$ has a large discrepancy between the data and the MC sample, and there exists a small discrepancy in μ-e and e-μ modes as well. These discrepancies may be due to an imperfect simulation of Bhabha events since these modes have a potential contribution from Bhabha events.

A multivariate analysis (MVA) is performed to suppress the background further. We form a FastBDT [28] classifier trained with simulated samples using $E_{\rm ECL}$, $E_{\rm vis}^*$, $M_{\rm miss}^{*2}$, $\cos\theta_{12}^*$, and $\cos\theta_{\rm miss}^*$ as input discriminating variables. Here, $E_{\rm ECL}$ is the sum of the energy of neutral ECL clusters that are related to the particles in the rest of the event in the lab frame, $M_{\rm miss}^{*2}$ is the invariant-mass squared of the missing momentum in the c.m. frame, $\cos\theta_{12}^*$ is the cosine of the angle between p_1^* and p_2^* for μ-e and e-μ modes or between p_1^* and $p_{\pi^+}^* + p_{\pi^0}^*$ for μ-$\pi\pi^0$ and e-$\pi\pi^0$ modes in the c.m. frame, and $\cos\theta_{\rm miss}^*$ is the cosine of the polar angle of the missing momentum in the c.m. frame. We require $4.5 < p_1^* < 5.3$ GeV/c for the MVA training.

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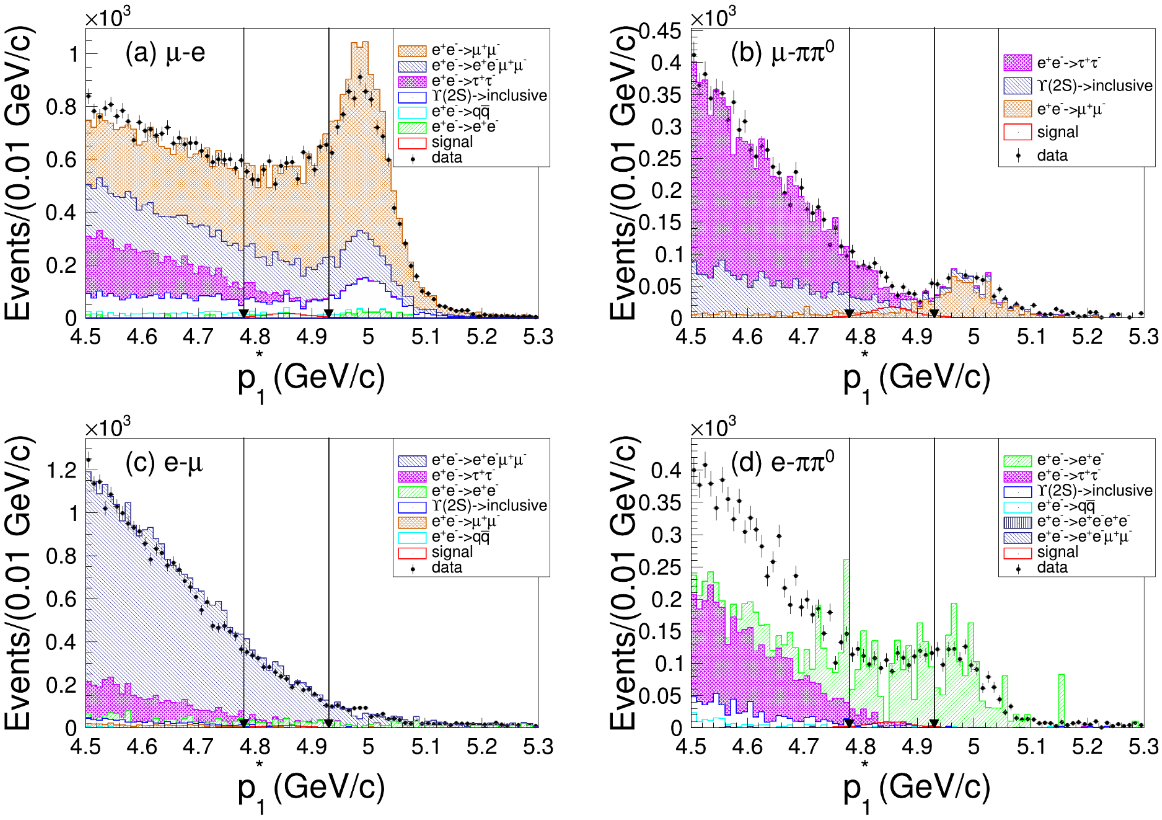

Figure 1. Distributions of p_1^* without the FastBDT output requirement for (a) μ-e, (b) μ-$\pi\pi^0$, (c) e-μ, and (d) e-$\pi\pi^0$. The downward arrows represent the signal window and we assume a high signal branching fraction $\mathcal{B} = 1 \times 10^{-5}$ to make that component visible.

Figure 2 shows the output of the FastBDT classifier $\mathcal{O}_{\rm FBDT}$, which ranges from 0.0, for background-like events, to 1.0, for signal-like events. There exists a small discrepancy between data and background MC distributions at high $\mathcal{O}_{\rm FBDT}$, which may be partly due to an imperfect simulation of Bhabha events. Since the background components do not peak in the signal region of p_1^* distribution, it does not introduce any bias in the signal yield estimated from p_1^* distribution.

At this stage, the average number of candidates in an event is 1.0 for the μ-e and e-μ modes and 1.1 for the μ-$\pi\pi^0$ and e-$\pi\pi^0$ modes. We perform the best candidate selection on the $\mathcal{O}_{\rm FBDT}$ and retain the one with the highest $\mathcal{O}_{\rm FBDT}$ value.

We use the figure-of-merit [29] defined as $\epsilon_{\rm sig}/(3/2 + \sqrt{B})$, where $\epsilon_{\rm sig}$ is the signal reconstruction efficiency and B is the expected number of background events, to optimize the $\mathcal{O}_{\rm FBDT}$ selection. The optimization is done separately for all four modes, and the optimal value depends on the mode. However, for simplicity, we choose $\mathcal{O}_{\rm FBDT} > 0.94$ for all modes, which is slightly looser than the optimal values. This selection rejects more than 99% of the background events for all the modes while retaining 86%, 66%, 89%, and 66% of the signal events for the μ-e, μ-$\pi\pi^0$, e-μ, and e-$\pi\pi^0$ modes, respectively. The signal reconstruction efficiencies after the selection on $\mathcal{O}_{\rm FBDT}$ are 7.4%, 4.8%, 5.3%, and 2.8% for the μ-e, μ-$\pi\pi^0$, e-μ, and e-$\pi\pi^0$ modes, respectively. Figure 3 shows the p_1^* distributions for each mode after

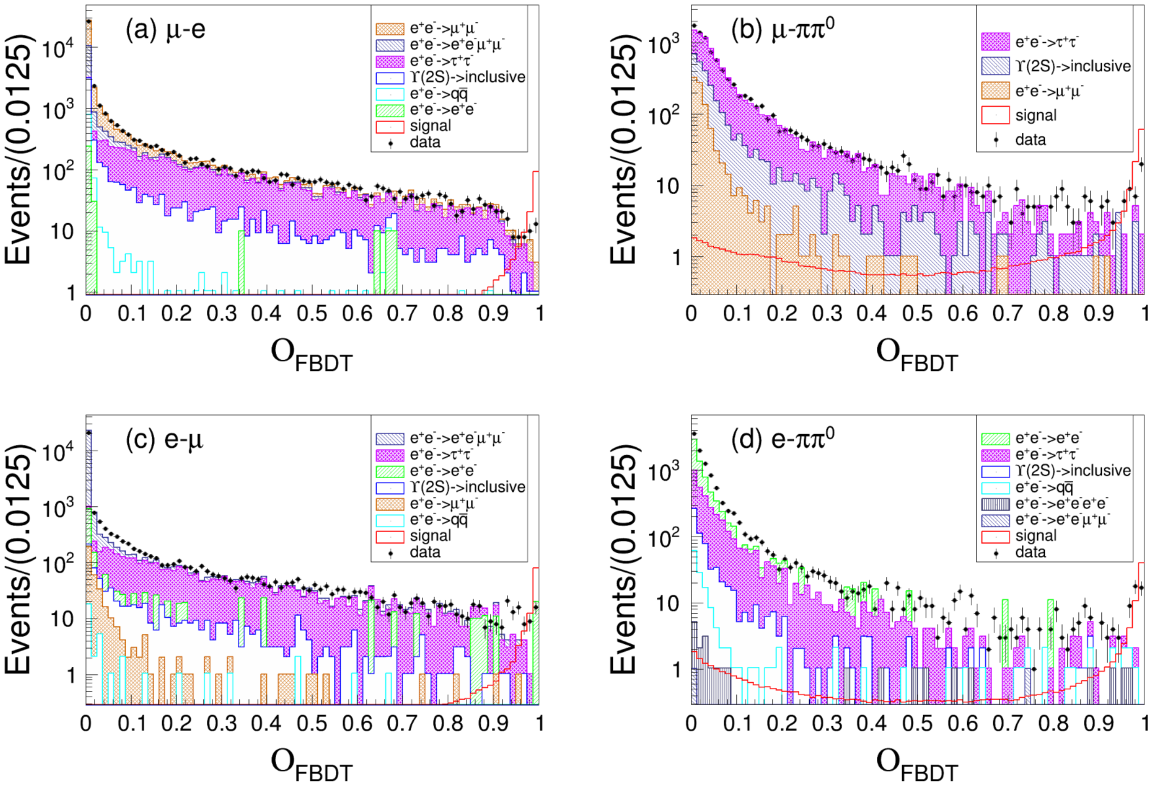

Figure 2. Distributions of $\mathcal{O}_{\rm FBDT}$ for (a) μ-e, (b) μ-$\pi\pi^0$, (c) e-μ, and (d) e-$\pi\pi^0$ on a semi-logarithmic scale. The signal component assumes $\mathcal{B} = 1 \times 10^{-5}$.

Source	Systematic uncertainty (%)	
	$\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$	$\Upsilon(2S) \to e^{\mp}\tau^{\pm}$
Number of $\Upsilon(2S)$	2.3	2.3
Tracking	0.7	0.7
Particle identification and π^0 reconstruction	3.4	3.3
τ branching fraction	0.2	0.2
MVA selection	5.1	5.0
Trigger	2.3	11.9
Total	7.0	13.5

Table 1. Summary of systematic uncertainties.

all the selection criteria. We find three events for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ and twelve events for $\Upsilon(2S) \to e^{\mp}\tau^{\pm}$ modes in the p_1^* signal region in the data.

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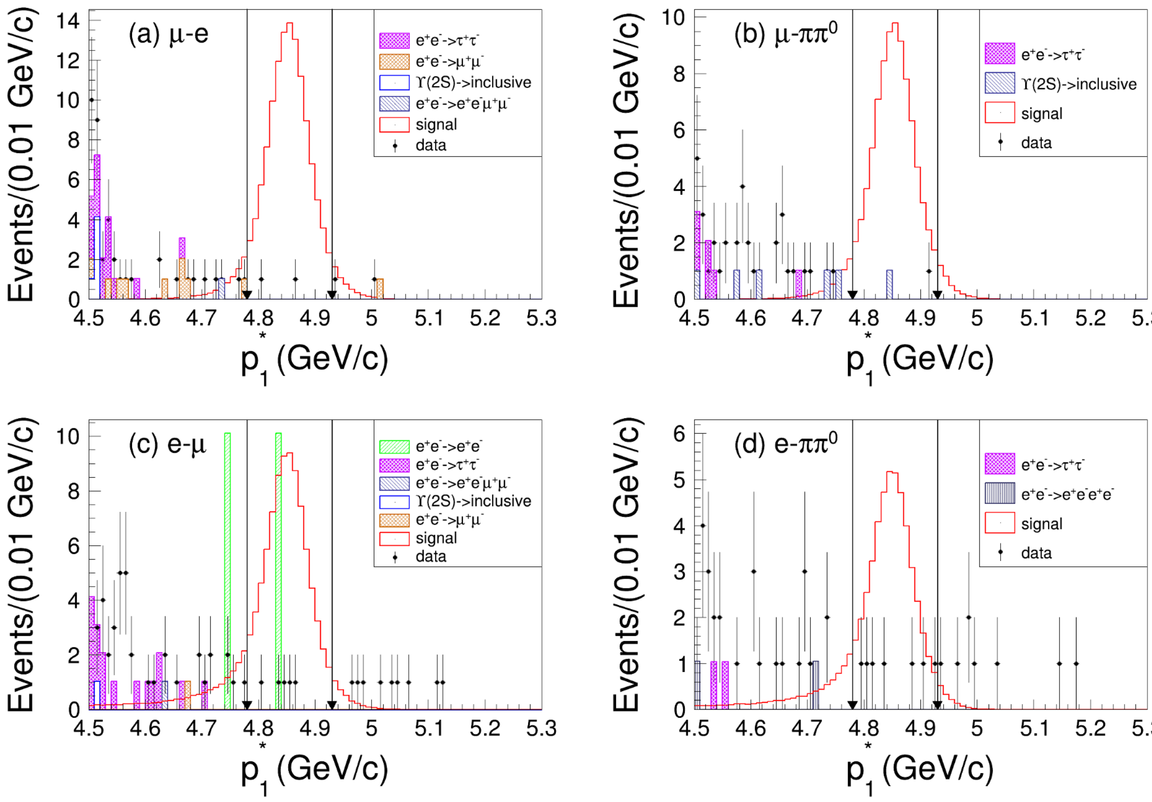

Figure 3. Distributions of p_1^* with the FastBDT output requirement, $\mathcal{O}_{\text{FBDT}} > 0.94$ for (a) μ-e, (b) μ-$\pi\pi^0$, (c) e-μ, and (d) e-$\pi\pi^0$. The downward arrows represent the signal window and the signal component assumes $\mathcal{B} = 1 \times 10^{-5}$.

4 Systematic uncertainty

Table 1 summarizes the systematic uncertainty from various sources. The number of $\Upsilon(2S)$ ($N_{\Upsilon(2S)}$) is estimated to be $(157.8 \pm 3.6) \times 10^6$ with an uncertainty of 2.3%. The systematic uncertainty on the track finding efficiency is estimated to be 0.35% per track from the study of partially reconstructed $D^{*+} \to D^0\pi^+$, $D^0 \to K_S^0\pi^+\pi^-$, $K_S^0 \to \pi^+\pi^-$ decays.

The systematic uncertainty due to lepton identification is studied using the control samples of $J/\psi \to \ell\ell$ and $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\ell^+\ell^-$. The systematic uncertainty due to charged pion identification is studied using $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ decays. The systematic uncertainty due to π^0 reconstruction is determined to be 2.3% from the study on $\tau^- \to \pi^-\pi^0\nu_\tau$ decays. After combining these uncertainties considering the efficiency for each τ decay channel, we obtain that the uncertainty from $\Upsilon(2S) \to \mu^\mp\tau^\pm$ ($\Upsilon(2S) \to e^\mp\tau^\pm$) from particle identification and π^0 reconstruction to be 3.4% (3.3%). The systematic uncertainty from τ branching fraction is 0.2% for both $\Upsilon(2S) \to \mu^\mp\tau^\pm$ and $\Upsilon(2S) \to e^\mp\tau^\pm$ modes.

We use the control sample $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S) \to \ell^-\ell^+$ to estimate the systematic uncertainty from MVA. We require $0.25 < M_{\pi^+\pi^-} < 0.35$ GeV/c^2, where $M_{\pi^+\pi^-}$ is the invariant mass of the two charged pions. We form a FastBDT classifier from the input variables $\hat{E}^*_{\text{vis}}$, $\hat{E}^*_{\text{miss}}$, E_{ECL}, and $\cos\theta^*_{\text{miss}}$, where $\hat{E}^*_{\text{vis}}$ and $\hat{E}^*_{\text{miss}}$ are the visible energy and missing energy calculated neglecting the positively charged lepton from $\Upsilon(1S)$ in order to mimic the topology of the signal $\Upsilon(2S) \to \ell^{\mp}\tau^{\pm}$ event. The FastBDT classifier is retrained using the simulated control sample applying the selection $9.3 < M_{\ell^-\ell^+} < 9.7$ GeV/c^2, where $M_{\ell^-\ell^+}$ is the dilepton invariant mass. We only select the best candidate with the highest $\mathcal{O}_{\rm FBDT}$ as mentioned earlier. We extract the signal yields from an unbinned maximum likelihood fit to $M_{\ell^-\ell^+}$ with and without the FastBDT selection, for the data and MC samples. For the data, the FastBDT selection efficiency including the best candidate is estimated to be $(11.5 \pm 0.5)\%$ and $(14.5 \pm 0.3)\%$ for the muon and electron mode, respectively, and the corresponding numbers for the MC samples are $(11.3 \pm 0.2)\%$ and $(14.0 \pm 0.3)\%$. We take the quadratic sum of the data and MC uncertainty, i.e., 5.1% and 5.0% respectively for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ and $\Upsilon(2S) \to e^{\mp}\tau^{\pm}$ modes, as the systematic uncertainty due to MVA.

The trigger efficiency for signal events that pass all the selection criteria is estimated to be 97.6% (88.0%) for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ ($\Upsilon(2S) \to e^{\mp}\tau^{\pm}$) from the trigger simulation. The efficiency for the electron mode is lower than for the muon mode because the former mainly relies on a single trigger condition (two tracks with a KLM hit for e-μ and ECL cluster trigger for e-$\pi\pi^0$ as described in section 3). We take the difference from unity, i.e., 2.3% (11.9%) as the systematic uncertainty for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ ($\Upsilon(2S) \to e^{\mp}\tau^{\pm}$).

Taking a quadratic sum, the total systematic uncertainty is 7.0% (13.5%) for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ ($\Upsilon(2S) \to e^{\mp}\tau^{\pm}$) decay modes.

5 Upper limit estimation

We estimate the upper limits on the branching fractions with the Feldman-Cousin method, which incorporates the systematic uncertainties into this method [30, 31]. We obtain the branching fractions using $\mathcal{B} = (N_{\rm obs} - N_{\rm exp}^{\rm bkg})/(\epsilon_{\rm sig} N_{\Upsilon(2S)})$, where $N_{\rm obs}$ is the number of observed events and $N_{\rm exp}^{\rm bkg}$ is the expected number of background events. We estimate $N_{\rm exp}^{\rm bkg}$ by $N_{\rm data}^{\rm SB} \times N_{\rm MC}/N_{\rm MC}^{\rm SB}$, where $N_{\rm data}^{\rm SB}$ and $N_{\rm MC}^{\rm SB}$ are the numbers of data and background MC events in the sideband defined as $4.5 < p_1^* < 4.7$ GeV/c or $5.0 < p_1^* < 5.3$ GeV/c, and $N_{\rm MC}$ is the number of background MC events in the signal region. We apply a loose selection of $\mathcal{O}_{\rm FBDT} > 0.4$ to estimate $N_{\rm MC}^{\rm SB}$ and $N_{\rm MC}$, rather than the standard selection $\mathcal{O}_{\rm FBDT} > 0.94$, and obtain the nominal value of $N_{\rm exp}^{\rm bkg} = 3.9 \pm 1.2$ for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ and $N_{\rm exp}^{\rm bkg} = 5.9 \pm 2.6$ for $\Upsilon(2S) \to e^{\mp}\tau^{\pm}$. We also estimate $N_{\rm exp}^{\rm bkg}$ requiring $0.2 < \mathcal{O}_{\rm FBDT} < 0.4$ for $N_{\rm MC}^{\rm SB}$ and $N_{\rm MC}$ and take the difference from the nominal value of $N_{\rm exp}^{\rm bkg}$, 1.28 and 0.46 for the $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ and $\Upsilon(2S) \to e^{\mp}\tau^{\pm}$ modes, respectively, as a systematic uncertainty of $N_{\rm exp}^{\rm bkg}$. As a result, we obtain $N_{\rm exp}^{\rm bkg} = 3.9 \pm 1.8$ for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ and $N_{\rm exp}^{\rm bkg} = 5.9 \pm 2.6$ for $\Upsilon(2S) \to e^{\mp}\tau^{\pm}$ modes.

We find $N_{\rm obs} = 3$ for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$, which is consistent with the expectation, and $N_{\rm obs} = 12$ for $\Upsilon(2S) \to e^{\mp}\tau^{\pm}$. The latter is larger than the background expectation but the signal is not significant; the probability of obtaining 12 or more events with $N_{\rm exp}^{\rm bkg} = 5.9 \pm 2.6$ is 8.1%. We calculate the upper limits on branching fractions at 90% confidence level (CL) using the POLE (POissonian Limit Estimator) program [32, 33]. The estimated upper limits are $\mathcal{B}(\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}) < 0.23 \times 10^{-6}$ and $\mathcal{B}(\Upsilon(2S) \to e^{\mp}\tau^{\pm}) < 1.12 \times 10^{-6}$ as listed in table 2. We obtain 14 (3) times better upper limits for $\Upsilon(2S) \to \mu^{\mp}\tau^{\pm}$ ($\Upsilon(2S) \to e^{\mp}\tau^{\pm}$) as compared to previous results from BaBar [9]. This is the first measurement on CLFV $\Upsilon(2S)$ decays from Belle.

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Modes	$\epsilon_{\rm sig}$ (%)	$N_{\rm exp}^{\rm bkg}$	$N_{\rm obs}$	$\mathcal{B}$ @ 90% CL
$\Upsilon(2S) \to \mu^\mp\tau^\pm$	12.3 ± 0.8	3.9 ± 1.8	3	$< 0.23 \times 10^{-6}$
$\Upsilon(2S) \to e^\mp\tau^\pm$	8.1 ± 1.1	5.9 ± 2.6	12	$< 1.12 \times 10^{-6}$

Table 2. Final results for $\Upsilon(2S) \to \mu^\mp\tau^\pm$ and $\Upsilon(2S) \to e^\mp\tau^\pm$ modes.

6 Summary

In this paper, we have conducted a search for charged-lepton flavor violation in $\Upsilon(2S) \to \ell^\mp\tau^\pm$ decays using 25 fb^{-1} data collected at the $\Upsilon(2S)$ resonance with the Belle detector. Without any evidence for such a signal, we set the upper limits on the branching fractions at 90% CL on $\Upsilon(2S)$ decays. Table 2 summarizes the results obtained for these decays. Our upper limits are more stringent than the previous world's best results from the BaBar collaboration [9].

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