Searches for lepton flavor violation in meson decays at Belle

Sourav Patra
(on behalf of Belle Collaboration)

University of Louisville
sourav@post.kek.jp

June 20, 2024

The 17th International Workshop on Tau Lepton Physics
Louisville, USA, 4-8 December 2023
doi:10.21468/SciPostPhysProc.?

Abstract

We present the recent results on searches for charged lepton flavor violations (CLFV) using the Belle data. In the first section, we present a search for CLFV decays $B_s^0 \to \ell^\mp \tau^\pm$, where $\ell = e, \mu$, using 121 fb^{-1} data collected at the $\Upsilon(5S)$ resonance. We also report the results on searches for CLFV $B^+ \to K^+\tau^\pm\ell^\mp$ decays, with $\ell = (e, \mu)$, using 711 fb^{-1} $\Upsilon(4S)$ data sample. Finally, we present a search for $\Upsilon(1S) \to \ell^\pm\ell'^\mp$ and radiative CLFV $\Upsilon(1S) \to \gamma\ell^\pm\ell'^\mp$ [$\ell, \ell' = e, \mu, \tau$] decays using 25 fb^{-1} data recorded at $\Upsilon(2S)$ resonance. This search uses $\Upsilon(1S)$ mesons produced in $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ transitions.

Contents

---

1 Introduction

Over the last decade, studying the leptoquark operators in light of discrepancies in semi-leptonic B-decays [1] has become more interesting. Standard Model (SM) gauge couplings are the same for different generations of leptons. But, several new physics (NP) models like leptoquarks [2], Z' model [3], predict different couplings for different generations of leptons, which indicates the violation of lepton flavor universality (LFU). Also, the violation of LFU generically implies the violation of lepton flavor [4, 5]. Thus, one can study NP models predicting LFU violations using the results of searches for charged lepton flavor violations (CLFV).

The Wilson coefficients of the NP operators, such as vector, axial-vector, and tensor operators, can be probed using the results of two CLFV interactions [6]. Axial-vector, scalar, and pseudoscalar operators are not easily accessible in the two-body decays. One can use Radiative lepton-flavor-violating (RLFV) transitions to probe such operators in a more efficient way [6].

We use e^+e^- collision data collected by the Belle detector at the KEKB asymmetric-energy collider [7] operating at an energy of 10.8 GeV in the center-of-mass frame. The Belle detector includes several subdetector systems: a silicon vertex detector, a central drift chamber, aerogel Cherenkov counters, time-of-flight counters, and an electromagnetic calorimeter. Also, a few layers of resistive plate chambers are located outside the solenoid for detecting K_L^0 mesons and muons (KLM). The detailed description of the Belle detector can be found elsewhere [8].

2 Search for $B_s^0 \to \ell^\mp\tau^\pm$

The predicted branching fraction for $B_s^0 \to \ell^-\tau^+$ decays in various NP models involving leptoquarks is in the order of 10^{-5} [9, 10]. Previously, no experimental results for $B_s^0 \to e^\mp\tau^\pm$ have been reported while an upper limit (UL) $\mathcal{B}(B_s^0 \to \mu^\mp\tau^\pm) < 3.4 \times 10^{-5}$ at 90% CL [11] is reported by LHCb. We search for $B_s^0 \to \ell^\mp\tau^\pm$ decays using 121 fb^{-1} of data collected by the Belle detector collected at $\Upsilon(5S)$ resonance. Hereafter, B_s refers to either B_s^0 or $\bar{B}_s^0$. We include the charge conjugate modes in this analysis. We reconstruct one of the B_s mesons (tag side) in a semileptonic decay mode $\bar{B}_s^0 \to D_s^+\ell^-(x)\overline{\nu}_\ell$, here x implies π or $\pi\pi$, and the signal $B_s \to \ell^-\tau^+$ is searched for in the mode $\tau^+ \to \ell^+\overline{\nu}_\tau\nu_\ell$. We label the primary lepton from signal B_s as ℓ_1 and the lepton from the τ decay ℓ_2. The lepton on the tag side is labeled as ℓ_3. D_s mesons have been reconstructed from the five decay modes: $D_s^+ \to \phi\pi^+$, $\overline{K}^{*0}K^+$, $\phi\rho^0\pi^+$, $K_s^0K^+$ and $\phi\rho^+$.

The background arises from $e^+e^- \to q\overline{q}$ process and $e^+e^- \to B_s^{(*)0}\overline{B}_s^{(*)0}, B^{(*)}\overline{B}^{(*)}X$. We prepare a FastBDT [12] classifier to suppress the background events.

We found 3 events for $B_s \to e^-\tau^+$ and 1 for $B_s \to \mu^-\tau^+$. To calculate this limit, we use the POLE program [13] with the relation $\mathcal{B} = (N_{\rm tot} - N_{\rm bkg})/(N_{\rm B_s} \times \epsilon_{\rm sig})$, where $N_{\rm tot}$ is the total number of observed events, the number of produced B_s mesons ($N_{\rm B_s}$) in experiment $(16.6 \pm 2.7) \times 10^6$, and $\epsilon_{\rm sig}$ is the signal efficiency including the branching fraction of τ. Since the uncertainty in f_s is significant, we report the UL on the branching fractions with and without f_s. Obtained results are summarized in Table 1.

Table 1: Efficiency (ϵ), the expected number of backgrounds ($N_{\rm bkg}^{\rm exp}$), observed events ($N_{\rm tot}$) and the UL at 90% CL on $\mathcal{B}$ and $f_s \times \mathcal{B}$

	ϵ (%)	$N_{\rm bkg}^{\rm exp}$	$N_{\rm tot}$	$\mathcal{B}$ ($\times 10^{-4}$)	$f_s \times \mathcal{B}$ ($\times 10^{-4}$)
$B_s \to e^-\tau^+$	0.0312 ± 0.0071	0.68 ± 0.69	3	< 14.1	< 5.5
$B_s \to \mu^-\tau^+$	0.0303 ± 0.0068	0.77 ± 0.78	1	< 7.3	< 2.9

3 Search for $B^+ \to K^+\tau^\pm\ell^\mp$

ULs on the branching ratios for $B^+ \to K^+\tau^\pm\ell^\mp$ decays have been previously set at the 90% CL using hadronic B-tagging by the BaBar collaboration between 1.5×10^{-5} and 4.5×10^{-5} [14]; the LHCb collaboration has studied a single mode, using B^+ mesons from $B^{*0}_{s2} \to B^+K^-$ decays, setting a limit $\mathcal{B}(B^+ \to K^+\tau^+\mu^-) < 3.9\times10^{-5}$ at the 90% CL [15].

$B^+ \to K^+\tau^+\mu^-$ and $B^+ \to K^+\tau^+e^-$ defined as $OS_{\mu,e}$ modes because the kaon and the primary lepton have opposite charge, and $B^+ \to K^+\tau^-\mu^+$ and $B^+ \to K^+\tau^-e^+$, defined as $SS_{\mu,e}$ modes. For all the modes, τ leptons have been reconstructed in $\tau \to e\nu\overline{\nu}$, $\tau \to \mu\nu\overline{\nu}$, and $\tau \to \pi\nu$.

When primary lepton is oppositely charged to the $B_{\rm sig}$, the dominant background comes from semileptonic D decays: $B^+ \to \overline{D}^0(\to K^+\ell^-\overline{\nu}_\ell)X^+$. On the other hand, semileptonic B^+ decays like $B^+ \to \overline{D}^0(\to K^+X^-)X\ell^+\nu_\ell$ is the major source of background for SS configurations. A BDT classifier is optimized to reduce the $B\overline{B}$ background events. Another BDT classifier has been prepared to suppress the background from $q\overline{q}$ ($q = u,d,s,c$) events, which survive after applying selection on the first BDT output.

We perform unbinned maximum likelihood fit on $M_{\rm recoil}$ distributions to obtain the signal yields for $B \to K\tau\ell$ decays. The fitted signal yields are summarized in Table 2. The UL on the branching ratio is then derived using the formula: $\mathcal{B}^{\rm UL} = \dfrac{N^{\rm UL}_{\rm sig}}{N_{B\overline{B}}\times 2\times f^{+-}\times\varepsilon}$, where $N_{B\overline{B}}$ is the number of $B\overline{B}$ pairs $= (772\pm11)\times10^6$, f^{+-} is the branching fraction $\mathcal{B}(\Upsilon(4S)\to B^+B^-)$ for charged B decays (using 0.514 ± 0.006 [16]), and ε is the signal reconstruction efficiency. By default, ε is obtained with signal phase space MC [17] samples, while we also consider a NP model with a combination of the effective operators $\mathcal{O}_{S,P}$ by reweighting the $q^2 = m^2_{\tau\ell}$ distribution which gives the smallest efficiency.

Table 2: Upper limits of branching fractions at the 90% CL for PHSP (and NP) cases.

Mode	ε (%)	$\varepsilon^{\rm NP}$ (%)	$N_{\rm sig}$	$\mathcal{B}^{\rm UL}$ (10^{-5})
$B^+ \to K^+\tau^+\mu^-$	0.064	0.058	-2.1 ± 2.9	0.59 (0.65)
$B^+ \to K^+\tau^+e^-$	0.084	0.074	1.5 ± 5.5	1.51 (1.71)
$B^+ \to K^+\tau^-\mu^+$	0.046	0.038	2.3 ± 4.1	2.45 (2.97)
$B^+ \to K^+\tau^-e^+$	0.079	0.058	-1.1 ± 7.4	1.53 (2.08)

4 Search for $\Upsilon(1S) \to \ell^\pm\ell'^\mp$ and $\Upsilon(1S) \to \gamma\ell^\pm\ell'^\mp$

The CLEO collaboration has published a result on $\Upsilon(1S) \to \mu^\pm\tau^\mp$ decay [18]. There were no available results on $\Upsilon(1S) \to e^\pm\mu^\mp$ and $\Upsilon(1S) \to e^\pm\tau^\mp$ decays. We use the $\Upsilon(1S)$ produced in $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ decays to remove the QED background by taking advantage of 4 charged tracks in the final state. Previously, no existing results were available for $\Upsilon(nS) \to \gamma\ell^\pm\ell'^\mp$ decays. We perform the first search for RLFV in $\Upsilon(1S) \to \gamma\ell^\pm\ell'^\mp$ decays using the $\Upsilon(2S)$ data sample.

For $\Upsilon(1S) \to e^\pm\mu^\mp$ decays, we extract the signal yield from a UML fit to the $\Delta M = M_{\pi\pi e\mu} - M_{e\mu}$ variable. We fit ΔM distribution using a sum of two Gaussians (for the signal component) and a 1st-order Chebyshev polynomial (for background components).

For $\Upsilon(1S) \to \ell^\pm\tau^\mp$ decays, we extract the signal from a UML fit to the recoil mass of $\pi\pi\ell$ ($M^{\rm recoil}_{\pi\pi\ell}$), where $\ell = \mu, e$. Dominant backgrounds come from $\Upsilon(1S) \to \tau^+\tau^-$ and $\Upsilon(1S) \to \ell^\pm\ell'^\mp$

Decay	ϵ (%)	$N_{\text{sig}}^{\text{fit}}$	$N_{\text{sig}}^{\text{UL}}$	$\mathcal{B}^{\text{UL}}$	PDG result
$\Upsilon(1S) \to e^{\pm}\mu^{\mp}$	32.5	-1.3 ± 3.7	3.6	3.9×10^{-7}	–
$\Upsilon(1S) \to \mu^{\pm}\tau^{\mp}$	8.8	-1.5 ± 4.3	6.8	2.7×10^{-6}	6.0×10^{-6}
$\Upsilon(1S) \to e^{\pm}\tau^{\mp}$	7.1	-3.5 ± 2.7	5.3	2.7×10^{-6}	–
$\Upsilon(1S) \to \gamma e^{\pm}\mu^{\mp}$	24.6	$+0.8 \pm 1.5$	2.9	4.2×10^{-7}	–
$\Upsilon(1S) \to \gamma\mu^{\pm}\tau^{\mp}$	5.8	$+2.1 \pm 5.9$	10.0	6.1×10^{-6}	–
$\Upsilon(1S) \to \gamma e^{\pm}\tau^{\mp}$	5.0	-9.5 ± 6.3	9.1	6.5×10^{-6}	–

Table 3: Summary table for fitted signal yield ($N_{\text{sig}}^{\text{fit}}$), UL of signal yield ($N_{\text{sig}}^{\text{UL}}$), and UL of branching fraction ($\mathcal{B}^{\text{UL}}$).

decays. To extract the signal for $\Upsilon(1S) \to \gamma\ell^{\pm}\tau^{\mp}$ decays, we fit recoil mass of $\pi\pi\gamma\ell$ ($M_{\pi\pi\ell\gamma}^{\text{recoil}}$).

One can estimate UL of branching fraction: $\mathcal{B}[\Upsilon(1S) \to \ell^{\pm}\ell'^{\mp}] < \frac{N_{\text{sig}}^{\text{UL}}}{N_{\Upsilon(2S)} \times \mathcal{B}[\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)] \times \epsilon}$, where $N_{\text{sig}}^{\text{UL}}$ is the UL on the signal yield after including systematic uncertainty. We summarize the results in Tab. 3.

5 Conclusion

We search for charged lepton flavor violations in a few decays motivated by several new physics models using the data collected by the Belle experiment. We did not find any evidence of charged lepton flavor violation. Apart from $B_s^0 \to \mu^{\pm}\tau^{\mp}$ decay, obtained upper ULs of branching fractions are the most stringent to date.

References

[1] R. Aaij *et al.* (LHCb Collaboration), Nature Phys. **18**, 3 (2022) 277.

[2] T. Faber *et al.*, PLB, **787**, (2018).

[3] S. Dwivedi *et al.*, EPJ C **80**, 263 (2020).

[4] S.L. Glashow *et al.*, PRL **114**, 091801 (2015).

[5] A. Crivellin *et al.*, PRD **97**, 015019 (2018).

[6] D.E. Hazard and A.A. Petrov, PRD **94**, 074023 (2016).

[7] S. Kurokawa *et al.*, NIMPR A **499**, 001 007 (2003).

[8] A. Abashian *et al.*, NIMPR A **479**, 117 232 (2002).

[9] A. D. Smirnov, Mod. Phys. Lett. A **33** (2018) 1850019.

[10] I. M. Varzielas *et al.*, JHEP **6** (2015) 72.

[11] R. Aaij *et al.* (LHCb Collaboration), PRL. **123**, 211801 (2019).

[12] T. Keck, Comput Softw Big Sci **1**, 2 (2017).

[13] J. Conrad *et al.*, PRD **67**, 012002 (2003).

[14] J. P. Lees *et al.* (BaBar Collaboration), PRD **86** (2012) 012004.

[15] R. Aaij *et al.* (LCHb Collaboration), JHEP **06** (2020) 129.

[16] R. L. Workman *et al.*, PTEP **2022**, 083C01 (2022).

[17] D.J. Lange *et al.*, NIMPR A **462**, 152 (2001).

[18] W. Love *et al.* (CLEO Collaboration), PRL **101**, 201601 (2008).