# Rare and forbidden B and tau decays in Belle

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**Abstract.** Search for the purely leptonic decays $B^+ \to e^+\nu_e$ and $B^+ \to \mu^+\nu_\mu$ is performed using the 772 million $B\overline{B}$ pairs collected by the Belle detector at the KEKB asymmetric-energy $e^+e^-$ collider. Hadronic tagging method based on hierarchical neutral network is used and there is no evidence of a signal in both decay modes. A heavy neutral lepton-like new particle and heavy neutrino searches are also performed and as a result, there are no significant signals. Lepton flavor violation in $\tau$ decays is studied with almost full data sample and obtained upper limits are in order of $10^{-8}$. In this paper, the recent results that can give any constraints to new physics are briefly described.

## 1. Introduction

710 fb$^{-1}$ data sample which contains 772 million $B$ meson pairs is collected at the $\Upsilon$(4S) resonance with the Belle detector [1] at the KEKB accelerator. The KEKB is an energy asymmetric $e^+e^-$ (3.5 on 8.0 GeV) collider [2] operating at the energy of $\Upsilon$(4S). The beams collide at a single interaction point with a crossing angle of $\pm$11 mrad. The $\Upsilon$(4S) decays exclusively to $B^0\overline{B^0}$ or $B^+B^-$.

The Belle detector is a large-solid-angle magnetic spectrometer consisting of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of silica Aerogel threshold Cherenkov Counters (ACC), Time-of-Flight scintillation counters (ToF), and a CsI(Tl) crystal electromagnetic calorimeter (ECL). These subdetectors are located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. The Belle detector covers $4\pi$ and the initial state is well known. Therefore, this is perfect environment for studies of $B$ decays with neutrinos in final state.

In here, the study results of the leptonic decays, and new particle searches such as lepton-like neutral particle and heavy neutrino which are based on 710 fb$^{-1}$ data sample will be desribed. Lepton flavor violation is highly suppressed in the SM is studied in $\tau$ decays and the result is also breifly written.

## 2. Leptonic decays: $B^+ \to e^+\nu_e$ and $B^+ \to \mu^+\nu_\mu$

The purely leptonic decays proceed via annihilation of the charged $B$ meson's constituent quarks into a lepton and a neutrino of the same generation. In the SM, this process is mediated by a $W^+$ boson leading to a branching fraction [3] as follows.

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$$\mathcal{B}(B^+ \to l^+ \, \nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi} \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B,$$

where $G_F$ is the Fermi coupling constant, $m_l$ is the mass of the charged lepton, $m_B$ is the mass of the $B^+$ meson, $\tau_B$ is the $B^+$ meson lifetime, $V_{ub}$ is the element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [4] and $f_B$ is the $B$ decay constant. New physics (NP) contributions might interfere with the SM and modify the expectation. Most prominent is the charged Higgs from two-Higgs-doublet model [5] and the branching fraction of the $B$ to $l\nu_l$ can be greatly enhanced as much as (1-tan$^2 \beta \frac{m_B^2}{m_H^2}$)$^2$. Therefore, this decay can either test the SM or measure the product of the least well-known parameters, $f_B^2|V_{ub}|^2$. The expected branching fractions in the SM using achieved value and world average for each parameter [6][7] are in order of $10^{-11}$, $10^{-7}$, and $10^{-4}$ for $B^+ \to e^+\nu_e$ ($e$ mode), $B^+ \to \mu^+\nu_\mu$ ($\mu$ mode), and $B^+ \to \tau^+\nu_\tau$ ($\tau$ mode), respectively. Due to helicity suppression in the SM, $e$ mode and $\mu$ mode have relatively small branching fractions. On the other hand, $\tau$ mode has larger branching fraction and has been measured previously by the Belle [8] and BABAR [9] experiments, resulting in order of $10^{-4}$.

For studying the leptonic decays of $e$ and $\mu$ modes [10], hadronic tagging method based on hierarchical neural network [11] is used. The signal events are extracted from the signal lepton's momentum ($p_l^B$) in the rest frame of the B$_{sig}$. Due to the two body decay of the signal, we can expect signal events to peak sharply around 2.64 GeV/c and very clean signal with low background. The background in signal region (2.6 GeV/c $< p_l^B <$ 2.7 GeV/c) is estimated by fitting the sideband of $p_l^B$ and extrapolating the background into the signal region. For peaking background, Monte Carlo (MC) modeling is studied.

After all background subtracted, the signal event is investigated. In the $p_l^B$ signal region, there are no observed signal events for both searches as shown in Fig. 1. The upper limits at 90% C.L. are set to be $3.4 \times 10^{-6}$ and $2.7 \times 10^{-6}$ for $B^+ \to e^+\nu_e$ and $B^+ \to \mu^+\nu_\mu$, respectively. These are by far the most stringent limits.

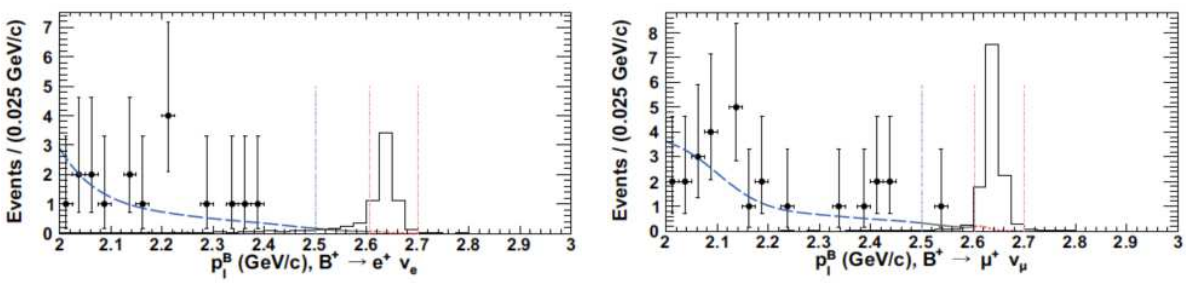


**Figure 1.** The unbinned maximum likelihood fits of the total background PDF to data for $B^+ \to e^+\nu_e$ (left) and $B^+ \to \mu^+\nu_\mu$ (right). The points with error bars are the experimental data. The dashed and the dotted lines show the background PDF in the sideband and signal regions, respectively. The distributions of the signal MC, displayed as the histogram, are scaled by $10^6$ and 40 times the SM expectation for $B^+ \to e^+\nu_e$ and $B^+ \to \mu^+\nu_\mu$, respectively.

## 3. Search for massive invisible particle

Figure 2 shows Feynmann diagram for $B^+ \to l^+X$. There is no well matched theoretical model for an $X$ particle and we assume massive particle replaces a neutrino at the pure leptonic $B$ decay. A $X$ particle may be a candidate of dark matter or light neutralino in the supersymmetry

(SUSY). We expect the $X$ to have no electric charge and to be a spin 1/2 particle. We assume a range of possible mass for the $X$ from 0.1 GeV/c$^2$ to 1.8 GeV/c$^2$ in steps of 100 MeV/c$^2$.

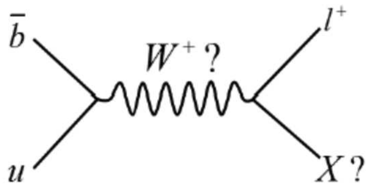


**Figure 2.** Feynmann diagram of $B^+ \to l^+ X$.

The analysis method is similar to $B^+$ to $l^+\nu_l$ that is described in Sect. 2 and systematics is also similar. But, loose momentum cut and loose impact parameter selection are applied. Depending on the mass of the $X$ particle, the peak of $p_l^B$ is changed, therefore cuts should be optimized for each $X$ mass and different cuts are applied for each $X$. After all cuts applied and background is subtracted, the signal region of $p_l^B$ is investigated for each $X$ mass and preliminary upper limits in branching fractions at 90% C.L. are obtained to be in order of $10^{-6}$.

## 4. Search for heavy neutrino

The masses of particles in the SM are generated by the coupling of the Higgs field to the left- and right- handed components of a given particle. There are no right-handed neutrino in the SM, neutrinos in the SM are strictly massless. However, experimental data on neutrino oscillations show that neutrinos are not massless [6]. Many models beyond the SM suggest various explanations and some models assume a heavy neutrino's existence [12]. The direct search for heavy neutrino in $B \to X l \nu_h$ ($\nu_h \to l^\pm \pi^\mp$) is described in Ref [13].

The mass range to search a heavy neutrino is 0.5 GeV/c$^2$ $\leq M(\nu_h) \leq$ 5.0 GeV/c$^2$ and approach is divided depending on the mass as follows.

- $M(\nu_h) <$ 2.0 GeV/c$^2$: look for $X = D$ or $D^*$ using recoil mass
- $M(\nu_h) \geq$ 2.0 GeV/c$^2$: look for $X = D^{(*)}$, light meson and nothing

Various background is suppressed by using number of tracks requirement, strict lepton identification, vertex quality, distance of lepton-pion vertex, and distance between the closest associated hit in SVD/CDC to vertex of $\nu_h$. By using number of neutrinos detected, upper limit of branching fraction on $\nu_h$-$\nu_l$ mixing are obtained and the results with other experiment results are shown in Fig. 3. Corresponding upper limit for the product branching fraction for heavy neutrino mass (2.0 GeV/c$^2$) is in order of $10^{-7}$.

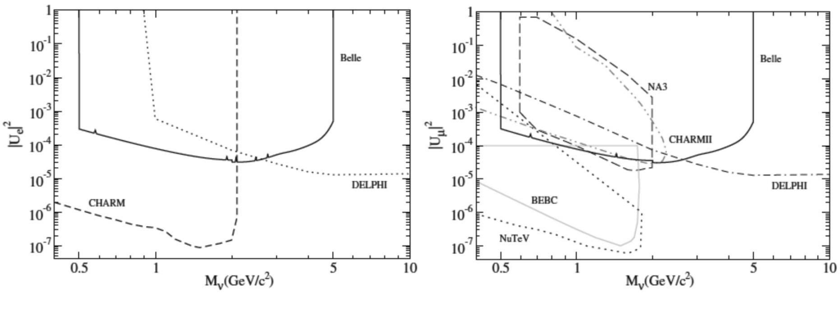


**Figure 3.** Comparison of the obtained upper limits for $|U_e|^2$ (left) and $|U_\mu|^2$ with existing experimental results.

## 5. Lepton flavor violation in tau decays

Lepton flavor violation (LFV) in charged lepton decays is forbidden in the SM or highly suppressed even if neutrino mixing is taken into account. On the other hand, extension of the SM and many other new models predict LFV with branching fractions as large as $10^{-8}$ [14]. $\tau$ lepton is a good tool to search for the LFV decays due to enhanced coupling to the NP as well as large number of LFV decay modes. The study result of the LFV in $\tau \to lhh$, $l$ is electron or muon and $h$ is charged pion or kaon, is described in Ref [15].

A 854 fb$^{-1}$ data sample collected at or below $\Upsilon$(4S) and $\Upsilon$(5S) resonances is used and a total of 14 modes are investigated. Blind analysis is performed as searching the signal events on the $\tau$ mass-$\Delta$E plane and tagging method is used. $\tau_{tag}$ and $\tau_{sig}$ are required to be 1 prong decay and LFV final state, respectively. For background suppression, various observables are used, for example, an opening angle between missing momentum and charged track on the tag side, thrust $T$, and missing mass ($m^2_{miss}$). To evaluate branching fraction, elliptical signal regions that contain $\pm 3\sigma$ of the signal MC satisfying all selection criteria are used for each decay mode. As a result, one event is found for $\tau \to \mu\pi h$. For other 12 modes, no event is observed in the signal regions. The number of observed signal events for all modes agrees with number of expected background events. The upper limits at 90% C.L. are obtained to be $(2.0 \sim 8.6) \times 10^{-8}$, which are improved upon previously published upper limits [16] by factors of about 1.8 on average.

## 6. Summary

Most stringent upper limits at 90% C.L. on $B^+ \to e^+(\mu^+)\nu$ are obtained to be 3.4 (2.7) $\times 10^{-6}$. Search for a heavy neutral lepton-like new particle is performed with $B^+ \to l^+X$, where $X$ can be any invisible fermion particle, and preliminary results in the upper limits are in order of $10^{-6}$ for 0.1 GeV/c$^2$ $< M_X <$ 1.8 GeV/c$^2$. Heavy neutrino search is also performed and upper limit on mixing of $\nu_h$-$\nu_l$ is set in the mass range of 0.5 GeV/c$^2$ $\sim$ 5.0 GeV/c$^2$. Up to now, there are no hints for NP contribution from leptonic $B$ decays. We study 48 different LFV modes in $\tau$ decays, 46 of them are analyzed with almost full data sample and obtained upper limits on the branching fractions are in order of $10^{-8}$. Especially, improved upper limits by factors of about 1.8 on average are obtained for $\tau \to l^+hh'$.

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