Rare B decays with leptons at Belle

K. Hara for the Belle Collaboration
Nagoya University, Furou-cho Chikusa-ku Nagoya, Aichi, 464-8602, Japan

We present a new measurement of the purely leptonic decay $B^{-} \rightarrow \tau^{-} \nu_{\tau}$, with a semileptonic $B$ tagging method, using a data sample containing $657 \times 10^{6}$ $B \bar{B}$ pairs collected with the Belle detector at the KEKB asymmetric $e^{+}e^{-}$ collider. A sample of $B \bar{B}$ pairs are tagged by reconstructing one $B$ meson decaying semileptonically. We detect the $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ candidate in the recoil. We obtain a signal with a significance of 3.8 standard deviations including systematics, and measure the branching fraction to be $(3.8 \pm 0.35^{+0.23}_{-0.28}) \times 10^{-4}$. This result confirms the evidence for $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ obtained in the previous Belle measurement with a hadronic $B$ tagging method. The $B$ meson decay constant $f_B$ and constraint on charged Higgs are obtained using the measured branching fraction.

1. Introduction

The purely leptonic decay $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ [1] is of particular interest since it provides a direct measurement of the product of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $V_{ub}$ [2] and the $B$ meson decay constant $f_B$. In the Standard Model (SM), the branching fraction of the decay $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ is given by

$$B(B^{-} \rightarrow \tau^{-}\nu_{\tau})_{SM} = \frac{G_F^2 m_B m_{\tau}^2}{8\pi} \left(1 - \frac{m_B^2}{m_{\tau}^2}\right)^2 |f_B| |V_{ub}|^2 \tau_{B},$$

where $G_F$ is the Fermi coupling constant, $m_{\tau}$ and $m_B$ are the $\tau$ lepton and $B$ meson masses, and $\tau_{B}$ is the $B$ lifetime. Physics beyond the SM, such as supersymmetry or two-Higgs doublet models, could suppress or enhance $B(B^{-} \rightarrow \tau^{-}\nu_{\tau})$ to levels several times as large as the SM expectation through the introduction of a charged Higgs boson [3, 4]. The charged Higgs effect is described as

$$B(B^{-} \rightarrow \tau^{-}\nu_{\tau}) = B(B^{-} \rightarrow \tau^{-}\nu_{\tau})_{SM} \times r_{H},$$

$$r_{H} = \left(1 - \frac{M_{H}^2}{m_{H}^2}\right)^2,$$

where $m_{H}^2$ is the charged Higgs mass and $\tan \beta$ is the ratio of the two Higgs vacuum expectation values. The expected SM branching fraction from other experimental constraints is $(0.78^{+0.09}_{-0.13}) \times 10^{-4}$ [5]. No statistically significant enhancement relative to the SM expectation has been observed in previous experimental studies. The previous Belle measurement [6] reported the first evidence of $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ decay with a significance of 3.5 standard deviations ($\sigma$), and measured the branching fraction to be $B(B^{-} \rightarrow \tau^{-}\nu_{\tau}) = (1.79^{+0.56}_{-0.49}(stat) \pm 0.46(syst)) \times 10^{-4}$, using a full reconstruction tagging method. The BaBar Collaboration has reported a search for $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ decay with hadronic tagging [7] and semileptonic tagging [8] using $383 \times 10^{6} B \bar{B}$ pairs. They report a 2.6 $\sigma$ excess, combining the two measurements. To establish the $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ signal, test consistency with the SM and search for a charged Higgs boson effect, we need more statistics.

In this report, we present a new measurement of $B^{-} \rightarrow \tau^{-}\nu_{\tau}$ from the Belle experiment with a semileptonic tagging method, based on a $605$ $fb^{-1}$ data sample containing $657 \times 10^{6}$ $B \bar{B}$ pairs collected with the Belle detector at the KEKB asymmetric energy $e^{+}e^{-}$ (3.5 on 8 GeV) collider [9] operating at the $\Upsilon(4S)$ resonance ($\sqrt{s} = 10.58$ GeV).

2. Measurement of $B^{-} \rightarrow \tau^{-}\nu_{\tau}$, with a semileptonic $B$ tagging method

The strategy adopted for this analysis is same as in the previous measurements. We reconstruct one of the $B$ mesons decaying semileptonically (referred to hereafter as $B_{tag}$) and compare the properties of the remaining particle(s) in
We require that no charged particle or \( \pi \) remain in the event (\( B \)). Background levels and the background components are mode-dependent. The details of the selection criteria are described elsewhere [11].

The most powerful variable for separating signal and background is the remaining energy in the electromagnetic calorimeter (ECL), denoted \( E_{\text{ECL}} \), which is the sum of the energies of ECL clusters that are not associated with particles from the \( B_{\text{tag}} \) and \( B_{\text{sig}} \) candidates. The number of signal events is extracted from an extended maximum likelihood fit to the \( E_{\text{ECL}} \) distribution. We combine \( \tau \) decay modes by constraining the ratios of the signal yields to the ratio of reconstruction efficiencies obtained from MC. Figure 1 shows the \( E_{\text{ECL}} \) distribution with the fit results. We see a clear excess of signal events in the region near \( E_{\text{ECL}} \sim 0 \). Table I summarizes the signal yields and the branching fractions obtained from separate fits for each \( \tau \) decay mode and fits with all three modes combined.

Systematic errors for the measured branching fraction are associated with the uncertainties in the signal yield, efficiencies and number of \( B^+B^- \) pairs. The systematic errors for the signal yield arise from the uncertainties in the PDF shapes for the signal (\( \pm 3.1\% \)) and for the background (\( \pm 11.8\% \)) which are dominated by MC statistics. For the latter, uncertainties in the branching fractions of \( B \) decay modes that peak at \( E_{\text{ECL}} = 0 \) such as \( B^- \to D^0 \ell^+\nu \) with \( D^0 \to K_{L}^0\pi^0, K_{L}^0K_{L}^0 \) and so on (\( \pm 4.2\% \)), as well as uncertainties in the background from rare \( B \) decays and \( \tau \) pair events (3.8%) are also taken into account. We take a 11.6% error as the systematic error associated with the tag reconstruction efficiency from the difference of yields between data and MC for the control sample. This value...
and isospin symmetry. The systematic error in the signal effic iencies arises from the uncertainty in tracking efficiency.

The systematic error due to the uncertainty in the number of $B\bar{B}$ pairs is 1.4%. The total fractional systematic uncertainty is $\pm 21\%$. We obtain the branching fraction to be

$$B(B^\rightarrow \tau^-\bar{\nu}_\tau) = (1.65^{+0.38}_{-0.37}(\text{stat})^{+0.35}_{-0.37}(\text{syst})) \times 10^{-4}. \quad (3)$$

The significance of the observed signal is estimated to be $3.8\sigma$ including systematic errors.

### 3. Determination of $f_B$ and Constraint on Charged Higgs

Using the measured branching fraction and known values of $G_F$, $m_B$, $m_\tau$ and $\tau_B$ [12], the product of the $B$ meson decay constant $f_B$ and the magnitude of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$ is determined to be $f_B|V_{ub}| = (9.7 \pm 1.1^{+1.0}_{-1.1}) \times 10^{-4}$ GeV. Combining it with $|V_{ub}| = 3.99^{+0.35}_{-0.30}$ by HFAG [13] based on BLNP model [14], we obtain $f_B = 242^{+28}_{-27} \pm 0.33$ MeV. The obtained $f_B$ value is consistent with the unquenched lattice QCD calculation by HPQCD collaboration $f_B = 216 \pm 22$ MeV [15].

The SM expectation for the branching fraction of $B \rightarrow \tau\nu$ from other experimental constraints is obtained by CKMfitter group to be $B(B^\rightarrow \tau^-\bar{\nu}_\tau) = (0.78^{+0.09}_{-0.13}) \times 10^{-4}$ [5]. Comparing our result to it, we obtain $r_H = 2.11 \pm 0.75$, where error include both statistical and systematic errors. Constraint on charged Higgs is obtained using Eq. (2). Figure 2 shows the constraint on $\tan\beta$ and $m_H^\pm$. The solid line in the left plot shows the expected $r_H$ as a function of $\tan\beta/m_H^\pm$ given by Eq. (2). The shaded areas are the excluded region with a confidence level of 95%.

![Figure 2](image)

Figure 2: Constraint on charged Higgs in $r_H$-$\tan\beta/m_H^\pm$ plane (left) and $m_H^\pm$-$\tan\beta$ plane (right). The black line in the right plot shows the expectation for $r_H$ as a function of $\tan\beta/m_H^\pm$ given by Eq. (2). The shaded areas indicate the excluded region with a confidence level of 95%.
4. Summary

In summary, we have measured the decay $B^- \to \tau^- \bar{\nu}$ with $B\bar{B}$ pair events tagged by semileptonic $B$ decays using a data sample containing $657 \times 10^6 B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric $e^+e^-$ collider. We measure the branching fraction to be $(1.65^{+0.38}_{-0.37}(\text{stat})^{+0.37}_{-0.37}(\text{syst})) \times 10^{-4}$ with a significance of 3.8 standard deviations. We confirm the evidence reported in the previous Belle measurement with $B\bar{B}$ pair events tagged by hadronic $B$ decays. The measured branching fraction is consistent with the SM expectation from other experimental constraints. The $B$ meson decay constant $f_B$ and constraint on charged Higgs are obtained using the measured branching fraction.

Acknowledgments

We thank the KEKB group for excellent operation of the accelerator, the KEK cryogenics group for efficient solenoid operations, and the KEK computer group and the NII for valuable computing and SINET3 network support. We acknowledge support from MEXT and JSPS (Japan); ARC and DEST (Australia); NSFC (China); DST (India); MOEHRD and KOSEF (Korea); KBN (Poland); MES and RFAAE (Russia); ARRS (Slovenia); SNSF (Switzerland); NSC and MOE (Taiwan); and DOE (USA).

References

[1] Throughout this paper, the inclusion of the charge conjugate mode decay is implied unless otherwise stated.
[2] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. 49, 652 (1973);
    N. Cabibbo, Phys. Rev. Lett. 8, 214 (1964).
[3] W. S. Hou, Phys. Rev. D 48, 2342 (1993).
[4] S. Back and Y. G. Kim, Phys. Rev. D 60, 077701 (1999).
[5] J. Charles et al. (CKMfitter Group) Eur. Phys. J. C 41, 1 (2005); Preliminary results as of summer 2008, [http://ckmfitter.in2p3.fr/plots_Summer2008/](http://ckmfitter.in2p3.fr/plots_Summer2008/)
[6] K. Ikado et al. (Belle Collaboration) Phys. Rev. Lett. 97, 251802 (2006).
[7] B. Aubert et al. (BABAR Collaboration) Phys. Rev. D 77, 011107(R) (2008).
[8] B. Aubert et al. (BABAR Collaboration) Phys. Rev. D 76, 052002 (2007).
[9] A. Abashian et al., Nucl. Instr. and Meth. A 479, 1 (2003); Z. Natkaniec et al. (Belle SVD2 group), Nucl. Instr. and Meth. A 560, 1 (2006).
[10] S. Kurokawa and E. Kikutani, Nucl. Instr. and Meth. A 499, 1 (2003), and other papers included in this volume.
[11] I. Adachi et al. (Belle Collaboration) [arXiv:0809.3834](http://arxiv.org/abs/0809.3834)
[12] W.-M. Yao et al., Journal of Physics, G 33, 1 (2006)
[13] E. Barberio et al. (Heavy Flavor Averaging Group), [hep-ex/0603003](http://arxiv.org/abs/hep-ex/0603003) Updates of Semileptonic Results for PDG 2008, [http://www.slac.stanford.edu/xorg/hfag/semi/pdg08/home.shtml](http://www.slac.stanford.edu/xorg/hfag/semi/pdg08/home.shtml)
[14] B.O. Lange, M. Neubert and G. Paz, Phys. Rev. D 72, 073006 (2005)
[15] A. Gray et al. (HPQCD Collaboration), Phys. Rev. Lett. 95, 212001 (2005).