PROCEEDINGS OF SCIENCE

PoS(Beauty 2013)033

$B \to \tau\nu$ and $B \to D^{(*)}\tau\nu$ at Belle and BaBar

Yasuyuki Horii
Nagoya University
E-mail: `yhorii@hepl.phys.nagoya-u.ac.jp`

The leptonic $B \to \tau\nu$ decay and the semileptonic $B \to D^{(*)}\tau\nu$ decays provide opportunities for testing the Standard Model and for searching for new physics. These decays are sensitive to extended models including the charged Higgs bosons. In this report, recent results obtained at the B factories are reviewed. The comparison between the experimental results and the Standard Model predictions is shown. The constraints on the type II two-Higgs doublet model are reported. The measurements play a role complementary to the studies at the energy frontiers.

14th International Conference on B-Physics at Hadron Machines,
April 8-12, 2013
Bologna, Italy

1. Introduction

The leptonic $B \to \tau\nu$ decay and the semileptonic $B \to D^{(*)}\tau\nu$ decays provide opportunities for testing the Standard Model (SM) and for searching for new physics. Extended models including the charged Higgs bosons are sensitive to these decays [1, 2, 3, 4, 5, 6, 7, 8, 9]. In this report, recent results obtained at the B factories are reviewed. A comparison between the experimental results and the SM predictions is made. New constraints on the type II two-Higgs doublet model are reported.

2. $B \to \tau\nu$

It is challenging to identify the $B \to \tau\nu$ decay experimentally, since it includes multiple neutrinos in the final state. At the e^+e^- B factories, the exclusive production of a B meson pair in the process $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ is exploited. We reconstruct one of the B mesons (“B_{tag}”) and identify the signal decays in the other B mesons (“B_{sig}”). Two independent types of B meson decays are employed for reconstructing B_{tag}: hadronic decays such as $B^- \to D^0\pi^-$ (“hadronic tag”) and semileptonic decays such as $B^- \to D^{*0}\ell^-\bar{\nu}_\ell$ (“semileptonic tag”), where ℓ indicates μ or e. The efficiency for reconstructing B_{tag} is higher for the semileptonic tag while the purity is higher for the hadronic tag.

2.1 Belle results

The first evidence for $B \to \tau\nu$ was reported by the Belle collaboration using a hadronic tag and a data sample corresponding to 449×10^6 $B\bar{B}$ events [10]. This was followed by a measurement using a semileptonic tag and a data sample corresponding to 657×10^6 $B\bar{B}$ events [11]. The branching fraction obtained by the semileptonic-tag analysis is $\mathscr{B}(B \to \tau\nu) = [1.54^{+0.38}_{-0.37}(\mathrm{stat})\,^{+0.29}_{-0.31}(\mathrm{syst})] \times 10^{-4}$, where the significance is 3.6σ. The hadronic-tag result has been updated using Belle’s final data sample corresponding to 772×10^6 $B\bar{B}$ events [12]. The branching fraction is found to be $\mathscr{B}(B \to \tau\nu) = [0.72^{+0.27}_{-0.25}(\mathrm{stat}) \pm 0.11(\mathrm{syst})] \times 10^{-4}$, where the significance is 3.0σ (Figure 1). Here, by employing a neural network-based method for the hadronic tag and a two-dimensional fit for the signal extraction, along with a larger data sample, both statistical and systematic precisions are significantly improved. Combining the semileptonic-tag and hadronic-tag results taking into account all the correlated systematic uncertainties, the branching fraction is found to be $\mathscr{B}(B \to \tau\nu) = (0.96 \pm 0.26) \times 10^{-4}$ with a significance of 4.0σ [12].

2.2 BaBar results

The BaBar collaboration also reported results for $B \to \tau\nu$ using hadronic and semileptonic tags. Using the semileptonic tag and a data sample corresponding to 459×10^6 $B\bar{B}$ events, the branching fraction is measured to be $\mathscr{B}(B \to \tau\nu) = [1.7 \pm 0.8(\mathrm{stat}) \pm 0.2(\mathrm{syst})] \times 10^{-4}$ [13]. Evidence for $B \to \tau\nu$ is obtained with a significance of 3.8σ using the hadronic tag and a data sample corresponding to 468×10^6 $B\bar{B}$ events [14]. The branching fraction is found to be $\mathscr{B}(B \to \tau\nu) = [1.83^{+0.53}_{-0.49}(\mathrm{stat}) \pm 0.24(\mathrm{syst})] \times 10^{-4}$. Combining the two results, the branching fraction is found to be $\mathscr{B}(B \to \tau\nu) = (1.79 \pm 0.48) \times 10^{-4}$, where both statistical and systematic errors are combined in quadrature [14].

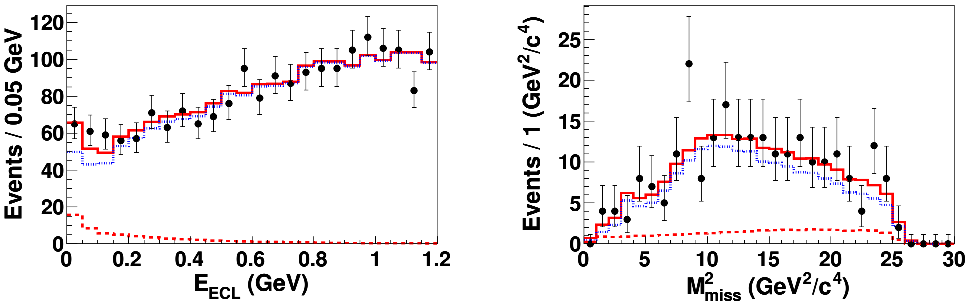


Figure 1: Signal extraction for $B \to \tau\nu$ in the most recent analysis from the Belle experiment [12]. The extra energy after removing detected particles $E_{\rm ECL}$ and the missing mass squared variable $M^2_{\rm miss}$ are employed. The $M^2_{\rm miss}$ distribution is shown for a signal region of $E_{\rm ECL} < 0.2$ GeV. The solid circles with error bars are data. The red solid histograms show the projections of the fits. The red dashed and blue dotted histograms show the signal and background components, respectively.

2.3 Interpretation

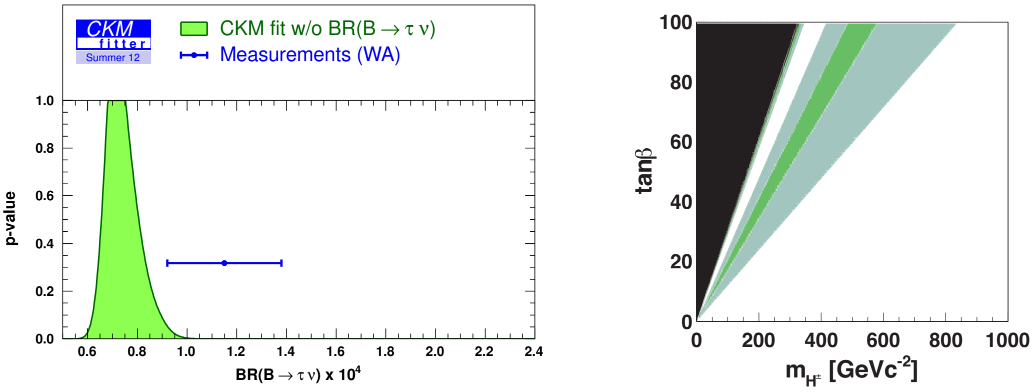
A world average for $\mathscr{B}(B \to \tau\nu)$ is calculated to be $\mathscr{B}(B \to \tau\nu) = (1.15 \pm 0.23) \times 10^{-4}$. For this calculation, we neglect the correlation in the systematic errors between the Belle and BaBar results since the statistical errors are dominant and the correlated parts in the systematic errors are relatively small.

An estimate of $\mathscr{B}(B \to \tau\nu) = (0.73^{+0.12}_{-0.07}) \times 10^{-4}$ is obtained by using f_B and $|V_{ub}|$ provided by a global fit to the CKM matrix elements assuming the SM [15]. Figure 2 (a) shows the comparison between the direct measurement and the prediction from the CKM global fit. The deviation is found to be 1.6σ.

In the type II two-Higgs doublet model [1], the branching fraction of $B \to \tau\nu$ is described by $\mathscr{B}(B \to \tau\nu) = \mathscr{B}(B \to \tau\nu)_{\rm SM} \times r_H$, where $\mathscr{B}(B \to \tau\nu)_{\rm SM}$ is the SM value of the branching fraction and r_H is a modification factor $r_H = (1 - m^2_{B^\pm} \tan^2\beta / m_{H^\pm}{}^2)^2$ with $m_{B^\pm}$ to be the charged B meson mass, $m_{H^\pm}$ to be the charged Higgs mass, and $\tan\beta$ to be the ratio of the two vacuum expectation values. Conservatively using $f_B = (191 \pm 9)$ MeV from the lattice calculation provided by the HPQCD collaboration [16] and $|V_{ub}| = (4.15 \pm 0.49) \times 10^{-3}$ from the $b \to u$ transitions provided by the PDG group [17], we privately evaluate excluded regions in the $\tan\beta$-$m_{H^\pm}$ plane as shown in Figure 2 (b). Stringent constraints are obtained for relatively higher $\tan\beta$.

3. $B \to D^{(*)}\tau\nu$

The semileptonic $B \to D^{(*)}\tau\nu$ decays also include multiple neutrinos in the final states. The results shown to date are based on tags using hadronic B decays. Here, the relative rates $R(D^{(*)}) = \mathscr{B}(B \to D^{(*)}\tau\nu)/\mathscr{B}(B \to D^{(*)}\ell\nu)$, which are independent of the CKM element $|V_{cb}|$ and of the parameterization of the strong interaction to a large extent, are reported. With larger statistics, the q^2 distributions and the angular distributions of the τ and $D^{(*)}$ decays could also provide useful information for testing the SM and constraining New-Physics models.



(a) Comparison of $\mathscr{B}(B \to \tau\nu)$ between a world average of the direct measurements and a SM estimate based on the CKM global fit. The deviation is 1.6σ. The figure and the deviation are provided by the CKMfitter group [15].

(b) Constraint on $\tan\beta$ and $m_{H^\pm}$ in the type II two-Higgs doublet model [1]. The light green, green, and black regions indicate the excluded regions at 2σ, 3σ, and 5σ levels, respectively, where the levels correspond to the probabilities for one-dimensional Gaussian function.

Figure 2: A comparison of $\mathscr{B}(B \to \tau\nu)$ between the direct measurement and the SM estimate, and a constraint on the type II two-Higgs doublet model.

3.1 Belle results

The $\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau$ decay was first observed by the Belle collaboration using the 535×10^6 $B\bar{B}$ data sample [18]. The Belle collaboration also obtained results for charged B meson decays to $D^{(*)}\tau\nu$ using the 657×10^6 $B\bar{B}$ data sample [19]. These measurements are performed by inclusively reconstructing the B_{tag} candidates using all the remaining particles after selecting the B_{sig} decay products. The Belle collaboration also obtained a preliminary result by exclusively reconstructing the B_{tag} candidates and the B_{sig} decay products using the 657×10^6 $B\bar{B}$ data sample [20]. The naive averages of $R(D^{(*)})$ for the above results are $R(D) = 0.430 \pm 0.091$ and $R(D^*) = 0.405 \pm 0.047$ [21]. For these calculations, the correlations in the statistical errors between the different tagging analyses are neglected as the event overlap is very limited. The correlation in the systematic errors between the different tagging analyses is assumed to be 60%.

3.2 BaBar results

The BaBar collaboration has shown the most recent results for the $B \to D^{(*)}\tau\nu$ decays using hadronic tag and the full 471×10^6 $B\bar{B}$ data sample [22]. This analysis includes an increase in signal efficiency of more than a factor of 3 compared to the previous analysis [23]. This improvement is provided by adding more B_{tag} decay chains and using a looser charged lepton selection. The background events are subtracted by employing the boosted decision tree multivariate method. Figure 3 shows the distributions of the kinematic variables used for the signal extraction. Combining the results for the neutral and charged B decays to $D^{(*)}\tau\nu$, the $R(D^{(*)})$ factors are found to be $R(D) = 0.440 \pm 0.058(\text{stat}) \pm 0.042(\text{syst})$ and $R(D^*) = 0.332 \pm 0.024(\text{stat}) \pm 0.018(\text{syst})$. A negative correlation of -0.27 between $R(D)$ and $R(D^*)$ is obtained, including systematic uncertainties.

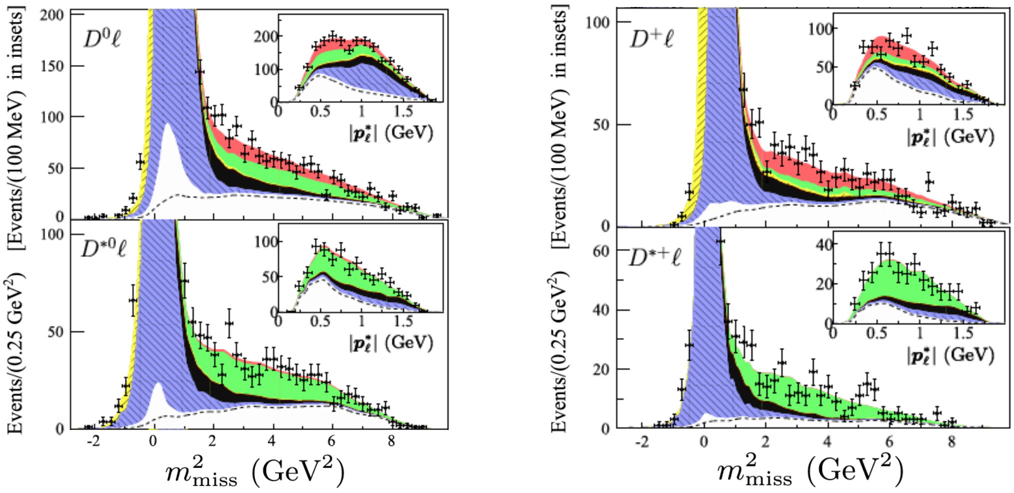


Figure 3: Signal extraction for $B \to D^{(*)}\tau\nu$ in the most recent analysis from the BaBar experiment [22]. The missing mass squared variable $m^2_{\rm miss}$ and the magnitude of the lepton momentum in the B rest frame $|p^*_\ell|$ are employed. The $|p^*_\ell|$ distributions are shown for $m^2_{\rm miss} > 1$ GeV^2. The solid circles with error bars are data. The $B \to D\tau\nu$ and $B \to D^*\tau\nu$ components are shown in red and green, respectively. The $B \to D\ell\nu$ and $B \to D^*\ell\nu$ components are shown in yellow and blue, respectively. The background components are shown as other colors.

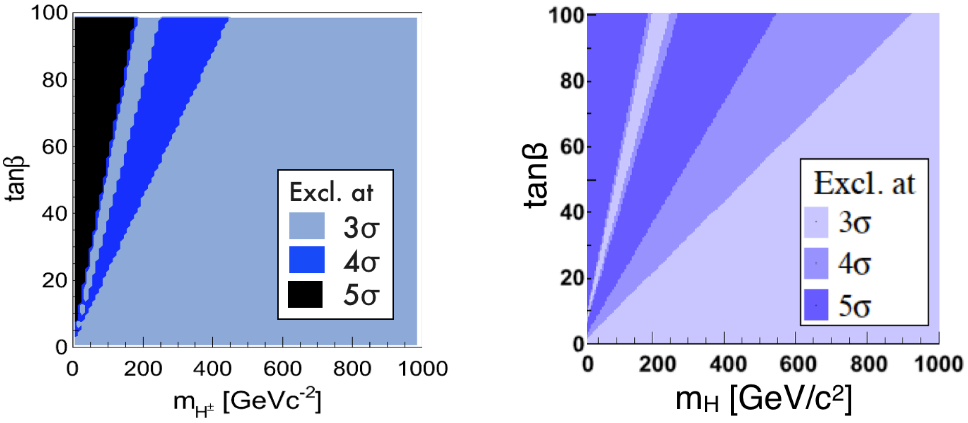
3.3 Interpretation

The results for $R(D^{(*)})$ are consistent between the Belle and BaBar experiments. The Belle results exceed the SM predictions $R(D) = 0.297 \pm 0.017$ and $R(D^*) = 0.252 \pm 0.003$ [8] by 1.4σ and 3.0σ, respectively [21]. The BaBar results exceed these SM predictions by 2.0σ and 2.7σ, respectively [22]. The combined disagreement of the discrepancy is 4σ level [21].

In the type II two-Higgs doublet model, there is a substantial impact on the ratios $R(D^{(*)})$ due to the charged Higgs contribution [7, 9]. Figure 4 shows the constraints on $m_{H^\pm}$ and $\tan\beta$ evaluated from the $R(D^{(*)})$ results. The result for Belle has been obtained privately by ignoring the correlation between the experimental $R(D)$ and $R(D^*)$ results and the dependency of the experimental $R(D^{(*)})$ results on $m_{H^\pm}$ and $\tan\beta$. The BaBar result includes both of them [22]. Both results disfavor the type II two-Higgs doublet model at a level of more than 3σ for all $\tan\beta/m_{H^\pm}$ region.

4. Conclusion

Exploiting the large number of events and the clean environment at the B factories, the measurements of the leptonic $B \to \tau\nu$ decay and the semileptonic $B \to D^{(*)}\tau\nu$ decays are provided with good precision despite the existence of multiple neutrinos in the final states. Stringent constraints on the charged Higgs mass $m_{H^\pm}$ and the vacuum-expectation-value ratio $\tan\beta$ are set for the type II two-Higgs doublet model. These measurements play a role that is complementary to the studies at the energy frontiers. Further investigation at the next-generation B factories is important for testing the SM and for constraining New-Physics models.



(a) Constraint obtained from Belle results [21]. (b) Constraint obtained from BaBar results [22].

Figure 4: Constraint on $\tan\beta$ and $m_{H^\pm}$ in the type II two-Higgs doublet model [7, 9] obtained from the measured $R(D^{(*)})$ values. The colored regions indicate the excluded regions at 3σ, 4σ, and 5σ levels, respectively, where the levels correspond to the probabilities for one-dimensional Gaussian function.

References

[1] W. S. Hou, Phys. Rev. D **48**, 2342 (1993).
[2] S. Baek and Y. G. Kim, Phys. Rev. D **60**, 077701 (1999).
[3] H. Baer *et al.*, Phys. Rev. D **85**, 075010 (2012).
[4] M. Tanaka, Z. Phys. C **67**, 321 (1995).
[5] H. Itoh, S. Komine, and Y. Okada, Prog. Theor. Phys. **114**, 179 (2005).
[6] U. Nierste, S. Trine, and S. Westhoff, Phys. Rev. D **78**, 015006 (2008).
[7] M. Tanaka and R. Watanabe, Phys. Rev. D **82**, 034027 (2010).
[8] S. Fajfer, J. F. Kamenik, and I. Nisandzic, Phys. Rev. D **85**, 094025 (2012).
[9] M. Tanaka and R. Watanabe, Phys. Rev. D **87**, 034028 (2013).
[10] K. Ikado *et al.* (Belle Collaboration), Phys. Rev. Lett. **97**, 251802 (2006).
[11] K. Hara *et al.* (Belle Collaboration), Phys. Rev. D **82**, 071101(R) (2010).
[12] K. Hara *et al.* (Belle Collaboration), Phys. Rev. Lett. **110**, 131801 (2013).
[13] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **81**, 051101(R) (2010).
[14] J. P. Lees *et al.* (BaBar Collaboration), arXiv:1207.0698.
[15] J. Charles *et al.* (CKMfitter Group), Eur. Phys. J. C **41**, 1 (2005), and preliminary results as of winter 2012 at http://ckmfitter.in2p3.fr/.
[16] H. Na *et al.* (HPQCD Collaboration), Phys. Rev. D **86**, 034506 (2012).
[17] J. Beringer *et al.* (Particle Data Group), Phys. Rev. D **86**, 010001 (2012).
[18] A. Matyja *et al.* (Belle Collaboratoin), Phys. Rev. Lett. **99**, 191807 (2007).
[19] A. Bozek *et al.* (Belle Collaboration), Phys. Rev. D **82**, 072005 (2010).
[20] I. Adachi *et al.* (Belle Collaboration), arXiv:0910.4301.
[21] A. Bozek, presentation at the 2nd KEK Flavor Factory Workshop.
[22] J. P. Lees *et al.* (BaBar Collaboration), Phys. Rev. Lett. **109**, 101802 (2012); arXiv:1303.0571.
[23] B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **100**, 021801 (2008).