$B \to \tau\nu$ & $B \to D^{(*)}\tau\nu$ decays at Belle

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We present measurements of the decays $B \to \tau\nu_\tau$ and $B \to D^{(*)}\tau\nu_\tau$ in a large data sample recorded with the Belle detector at the KEKB asymmetric energy e^+e^- collider. We obtain the branching fractions for these decays. The resulting constraints on a charged Higgs boson are also discussed.

35th International Conference of High Energy Physics
July 22-28, 2010
Paris, France

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[†]On behalf of the Belle collaboration and supported by the Polish Ministry of Education and Science grant No N N202 287138.

1. Introduction

B meson decays with τ leptons in the final state, despite of experimental difficulties, are of great importance. In the Standard Model (SM) scenario measurement of the tauonic B decay can provide direct experimental determination of B meson decay constant, which can be compared to the lattice QCD calculations. Semitauonic B decays provide access to form-factors that cannot be measures in other semileptonic B decays. Due to large τ lepton mass both decay modes are sensitive to extended Higgs sector, $B \to \tau\nu_\tau$ through branching fraction (BF) effects while $B \to D^{(*)}\tau\nu_\tau$ mostly through other observables such as *e.g.* polarizations.

These analysis are based on a data samples recorded at the $\Upsilon(4S)$ resonance with the Belle detector [1] at the KEKB collider [2].

1.1 Experimental techniques

A decay with 2 or 3 neutrinos can be observed using kinematic constraints available only at B-factories which are clean sources of exclusive $B\overline{B}$ pairs. To ensure that we have missing four-momentum consistent with multi neutrino hypothesis we take the advantage of the accompanying B meson referred to as $B_{\rm tag}$. The $B_{\rm tag}$ can be reconstructed in several exclusive modes first and then checks whether remaining particles are consistent with the signal B ($B_{\rm sig}$) decay can be done. We refer to this method as an "exclusive $B_{\rm tag}$ reconstruction". The $B_{\rm tag}$ can be also reconstructed inclusively from all the particles that remain after selecting $B_{\rm sig}$ candidate. We refer to this method as an "inclusive $B_{\rm tag}$ reconstruction". The analyses presented here exploit both mentioned approaches depending on the final state.

2. $B \to \tau\nu$

In the SM a leptonic B decay is a W-mediated annihilation with the decay rate simply related to B meson decay constant f_B and the quark-mixing amplitude V_{ub}:

$$\mathscr{B}(B^+ \to l^+\nu_l)\Big|_{\rm SM} = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B, \tag{2.1}$$

where G_F is the Fermi constant, m_B and m_l are the B meson and lepton masses while τ_B is the B meson lifetime. The decay is helicity suppressed thus the τ mode is favoured in comparison with the light lepton modes. This decay is also sensitive to charged Higgs which would modify the branching. *E.g.* in the type-II two-Higgs doublet model (2HDM) we have

$$\mathscr{B} = \mathscr{B}\Big|_{\rm SM} \times r_H, \qquad r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2, \tag{2.2}$$

where m_H is the charged Higgs mass and $\tan\beta$ is the ratio of Higgs vacuum expectation values [3].

Belle previously reported the first evidence of $B^+ \to \tau^+\nu_\tau$[1] decay with the "exclusive $B_{\rm tag}$ reconstruction" in hadronic modes [4]. The signal is extracted from a fit to the remaining energy in the electromagnetic calorimeter ($E_{\rm ECL}$), which is the sum of the energies of neutral clusters

[1]Charge conjugate modes are implied throughout this report unless otherwise stated.

	$\mathcal{B}(B^+ \to \tau^+\nu_\tau)$
Belle hadronic tag	$[1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})] \times 10^{-4}$
Belle semileptonic tag	$[1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$
SM – Eq. (2.1)	$[1.2 \pm 0.25] \times 10^{-4}$
SM – CKM fitter	$[0.763^{+0.113}_{-0.061}] \times 10^{-4}$

Table 1: Summary of $B \to \tau\nu$ results at Belle with a comparison to SM predictions from Eq. (2.1) with $|V_{ub}|$ taken from [6], f_B taken from [7] and from CKM fitter results with $B \to \tau\nu$[8].

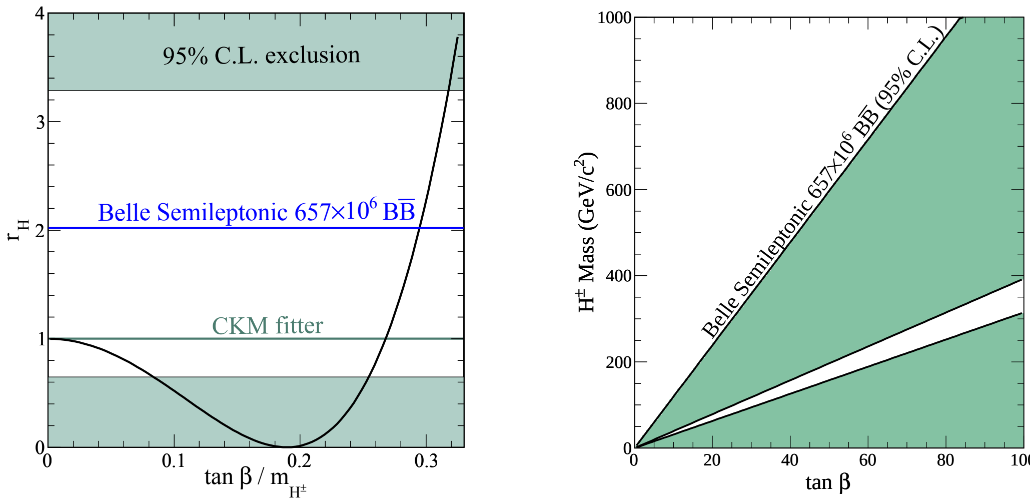

Figure 1: Constraints on the type-II two-Higgs doublet model placed by Belle semileptonic tag result.

that are not associated with either the B_{tag} or the π^0 candidate from the $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ decay. For signal events, E_{ECL} must be either zero or a small value arising from beam background hits while background events are distributed toward higher E_{ECL} due to the contribution from additional neutral clusters. To better establish this decay mode and determine the BF with greater precision we have done a measurement where B_{tag} is reconstructed in semileptonic modes [5]. This result is consistent with the previous one and with the SM predictions (Table 1). Figure 1 shows the constraints placed by our recent result on the 2HDM.

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

Semitauonic B decays are complementary to and competitive with tauonic ones due to different theoretical uncertainties and more observables. In $B \to D^{(*)}\tau\nu$ we are free from f_B and $|V_{ub}|$ which have large uncertainties. We have a dependence on the formfactors and $|V_{cb}|$ instead however the latter cancels out in the ratio

$$R = \frac{\mathcal{B}(B \to D\tau\nu_\tau)}{\mathcal{B}(B \to Dl\nu_l)}. \tag{3.1}$$

The exclusive semitauonic decay was first observed by Belle in the $B^0 \to D^{*-}\tau^+\nu_\tau$ mode [9] using "inclusive B_{tag} reconstruction". At large missing masses most of background components behave combinatorial in the beam constrained mass $M_{\text{tag}} = \sqrt{E^2_{\text{beam}} - p^2_{\text{tag}}}$, where E_{beam} is the

Decay mode	BF&significance from inclusive tag	BF&significance from exclusive tag
$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$	$[2.12^{+0.28}_{-0.27} \pm 0.29]\%$ 8.1σ	$[3.04^{+0.69+0.40}_{-0.66-0.47}]\%$ 3.9σ
$B^0 \to D^{*-}\tau^+\nu_\tau$	$[2.02^{+0.40}_{-0.37} \pm 0.37]\%$ 5.2σ	$[2.56^{+0.75+0.31}_{-0.66-0.22}]\%$ 4.7σ
$B^+ \to \overline{D}^0\tau^+\nu_\tau$	$[0.77 \pm 0.22 \pm 0.12]\%$ 3.5σ	$[1.51^{+0.41+0.24}_{-0.39-0.19}]\%$ 3.8σ
$B^0 \to D^-\tau^+\nu_\tau$	$[1.01^{+0.46+0.13}_{-0.41-0.11}]\%$ 2.6σ	—

Table 2: Summary of $B \to D^{(*)}\tau\nu$ results at Belle along with statistical and systematical uncertainties.

beam energy and $p_{\rm tag}$ is the momentum of $B_{\rm tag}$ candidate (residual particles). On the other hand the signal is visible as a well reconstructed $B_{\rm tag}$ and thus was extracted from a fit to $M_{\rm tag}$. Recently we have done a next-step analysis which includes simultaneous extraction of signals in charged B decays to $D^*\tau\nu$ and to $D\tau\nu$ taking into account D^*D cross-feeds [10]. All the results including preliminary one using "exclusive $B_{\rm tag}$ reconstruction"[11] are summarized in Table 2.

These results are consistent within experimental uncertainties with SM [12] and provide constraints on 2HDM complementary to those from purely tauonic B decays [13].

4. Summary

The studies of B decays to τ at Belle brought significant advances in this field, providing the first evidence of the purely leptonic $B^+ \to \tau^+\nu_\tau$ mode, semi-tauonic $B \to D\tau^+\nu_\tau$ modes and the observation of semi-tauonic B decays in the $B \to D^*\tau^+\nu_\tau$ channels. These results are consistent with the SM but, given the uncertainties, there is still a room for a sizeable non-SM contribution. Belle II experiment on SuperKEKB Super B-factory with ≈ 50 times higher statistics should measure these modes with much higher precision.

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