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Searches for Leptonic B-decays and $B \to D^{(*)}\tau\nu_\tau$ at the B-factories

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We report the recent results from BABAR and Belle on leptonic decays of B mesons including: $B^+ \to \tau^+\nu_\tau$, $B^+ \to \ell^+\nu_\ell$, and $B^+ \to \ell^+\nu_\ell\gamma$. We also report the recent results on $B \to D^{(*)}\tau\nu_\tau$.

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1. Introduction

The asymmetric *B*-factories, PEP-II and KEKB, and their companion detectors, BABAR [1] and Belle [2] respectively, collide electrons and positrons with a center-of-mass (CM) energy at the $\Upsilon(4S)$ resonance of 10.58 GeV, just above the threshold for *B*-meson pair production. Together, the two experiments have produced over 1.5 ab^{-1} of $B\bar{B}$ decays, performed stringent studies of heavy quarks and lepton decays, and successfully confirmed Standard Model (SM) predictions in the flavour sector. Although no major deviations from the SM have yet been found at current sensitivities, evidence of New Physics (NP) can nevertheless reveal itself through virtual effects in the decays of SM particles. For example, the decay processes of $B^+ \to \tau^+\nu_\tau$, $B^+ \to \ell^+\nu_\ell$ (where $\ell = e, \mu$), and $B \to D^{(*)}\tau\nu_\tau$ can be mediated at tree-level by a Charged Higgs boson in place of the SM W^+ boson[1]. By precisely measuring these decays, we hope to discover NP and/or significantly constrain its parameters. This paper will discuss the latest searches for the $B^+ \to \tau^+\nu_\tau$, $B^+ \to \ell^+\nu_\ell(\gamma)$, and $B \to D^{(*)}\tau\nu_\tau$ decays.

1.1 *B*-Meson Reconstruction

With one to three neutrinos in their final-state, the $B^+ \to \tau^+\nu_\tau$, $B^+ \to \ell^+\nu_\ell$, or $B \to D^{(*)}\tau\nu_\tau$ decays cannot be fully reconstructed. Instead, we exploit the closed kinematics of the initial e^+e^- state and the clean $\Upsilon(4S) \to B\bar{B}$ production by reconstructing the recoiling B meson ($B_{\rm tag}$). Depending on the analysis, this is done either "exclusively" or "inclusively." An inclusive analysis first selects the detectable signal decay products and then checks if the remaining particles in the event are consistent with a $B_{\rm tag}$. This method provides a higher signal efficiency ($\sim 5\%$ for the $B^+ \to \ell^+\nu_\ell$ analysis, after signal selection) but results in larger backgrounds. Conversely, an exclusive analysis first reconstructs the $B_{\rm tag}$ and then checks if the remaining particles in the event are consistent with the signal decay products. The $B_{\rm tag}$ is reconstructed using one of two tagging methods: hadronic tag which reconstructs $B_{\rm tag} \to D^{(*)0}X_{\rm had}$ or $J/\Psi X_{\rm had}$ where $X_{\rm had}$ is a combination of kaons and/or pions, or semi-leptonic (SL) tag which reconstructs $B_{\rm tag} \to D^{(*)0}\ell$ and assumes an undetected neutrino. This method results in a low signal efficiency ($\sim 0.3\%$ for hadronic-tag analyses and $\sim 1\%$ SL-tag analyses, before signal selection) but it compensates by providing a highly pure sample of B mesons with comparatively little non-$B\bar{B}$ (continuum) background. In addition, because the hadronic $B_{\rm tag}$ uses only fully-detectable hadronic decay modes, the missing four-vector of the otherwise undetectable signal neutrino is fully determined.

Several kinematic variables are useful in the $B_{\rm tag}$ reconstruction. For exclusive hadronic-tag and inclusive analyses, we require $|\Delta E| \equiv |E_{B_{\rm tag}} - \frac{\sqrt{s}}{2}|$ to be consistent with zero, where $\sqrt{s}$ is the total energy of the e^+e^- system and $E_{B_{\rm tag}}$ is the $B_{\rm tag}$ candidate energy, both in the CM frame. In addition, since the beam energy has better resolution than individual particle resolution, we define the "energy-substituted" mass of the $B_{\rm tag}$ as $m_{\rm ES} \equiv \sqrt{\frac{s}{4} - \vec{p}^{\,2}_{B_{\rm tag}}}$, where $\vec{p}_{B_{\rm tag}}$ is the $B_{\rm tag}$ three-momentum in the CM frame. A well-reconstructed $B_{\rm tag}$ candidate will have an $m_{\rm ES}$ consistent with the nominal B-meson mass, while "combinatorial" background from misreconstructed $B_{\rm tag}$ candidates will populate the "sidebands," the region below the B-meson peak in $m_{\rm ES}$. In exclusive SL-tag analyses, the direction of the $B_{\rm tag}$ cannot be fully determined due to the presence of the neutrino in the $B_{\rm tag}$

[1] Charge conjugate modes are included implicitly throughout this paper.

decay. However, four-momentum conservation requires the $B_{\rm tag}$ momentum to lie on a cone around the flight direction of the $D^{(*)0}\ell$ system in the CM frame. Thus, for SL-tag analyses, we use the cosine of the angle between the $B_{\rm tag}$ and the $D^{(*)0}\ell$ flight directions: $\cos\theta_{B,D\ell} \equiv \frac{\sqrt{s}E_{D\ell} - m^2_{B_{\rm tag}} - m^2_{D\ell}}{2|\vec{p}_{B_{\rm tag}}|\cdot|\vec{p}_{D\ell}|}$ where $E_{D\ell}$ is the energy sum of the $D^{(*)0}$ and lepton, $|\vec{p}_{D\ell}| \equiv \sqrt{\frac{s}{4} - m^2_{B_{\rm tag}}}$, and $m_{B_{\rm tag}}$ and $m_{D\ell}$ are the invariant masses of the $B_{\rm tag}$ and $D^{(*)0}\ell$ system respectively. For a well-reconstructed $B_{\rm tag}$, $\cos\theta_{B,D\ell}$ will be between -1 and 1.

2. Recent Searches for $B^+ \to \tau^+\nu_\tau$

The leptonic decays $B^+ \to \tau^+\nu_\tau$ and $B^+ \to \ell^+\nu_\ell$ proceed via an annihilation of b and u quarks into a virtual W^+ boson. Leptonic decays can provide clean theoretical predictions of SM parameters without the QCD-based uncertainties arising from hadrons in the final state. Specifically, these decay modes provide experimental sensitivity to the B-meson decay constant f_B and the Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{ub}|$, both of which dominate the SM uncertainty in the branching fraction, given as $BR(B^+ \to \ell^+\nu_\ell)_{\rm SM} = \frac{G_F^2 m_B}{8\pi}|V_{ub}|^2 f_B^2 \tau_B m_\ell^2 \left(1 - \frac{m_\ell^2}{m_b^2}\right)^2$ where G_F is the Fermi constant, m_B and τ_B are the B-meson mass and lifetime respectively, and m_ℓ and m_b are the masses of the lepton and b-quark respectively. Because the leptonic decays are helicity suppressed, the decay rates for the lighter leptons are inaccessible at the current B-factories, having branching fractions of the order 10^{-7} and 10^{-11} for the muon and electron modes respectively. However, the SM branching fraction of the tau mode is $(1.2 \pm 0.25) \times 10^{-4}$ assuming $|V_{ub}| = (4.32 \pm 0.3) \times 10^{-3}$ [3] and $f_B = (190 \pm 13)$ MeV [4].

A virtual Charged Higgs boson can replace the W^+ boson in the annihilation diagram, which could significantly enhance or suppress the SM rate. In the type-II two Higgs doublet model (2HDM) [5] the SM branching fraction is multiplied by an additional factor of $\left(1 - \tan^2\beta\frac{m_B^2}{m_H^2}\right)^2$, where m_H is the mass of the charged Higgs and $\tan\beta$ is the ratio of the vacuum expectation values. Thus measuring the $B^+ \to \tau^+\nu_\tau$ branching fraction can constrain NP parameters.

A recent search for $B^+ \to \tau^+\nu_\tau$ at *BABAR*, which uses an exclusive hadronic tag analysis with 468 million $B\bar{B}$ events [6], first reconstructs a $B_{\rm tag}$ and selects the signal decay by reconstructing $e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $\pi^+\nu$, or $\rho\nu \to \pi^+\pi^0\nu$ which constitute 70% of tau decays. These tau modes are reconstructed by requiring exactly one correctly-charged track within the rest of the event and by applying requirements on the CM momentum for the e, μ, and π modes and a four-variable likelihood ratio (LHR) for the ρ mode. The continuum background is further suppressed using three event-shape variables since the lighter $e^+e^- \to q\bar{q}$, $\tau^+\tau^-$ events tend to decay in a more jet-like manner than the isotropically symmetric decays of a $B\bar{B}$ event.

After reconstructing the $B_{\rm tag}$ and signal decays, there should be no additional particles in the event. Thus, the most discriminating variable in this analysis is $E_{\rm extra}$, the sum of the remaining energy in the electromagnetic calorimeter, which should be zero. Although this variable peaks at zero for signal events, additional energy is typically present from such sources as particle shower fragments, low-energy neutrals from the $B_{\rm tag}$, and beam-related photons in the detector. Therefore, the MC modelling of the $E_{\rm extra}$ variable is validated with data using "double-tagged" samples in which a second tagged-B is reconstructed, either hadronically or semi-leptonically, opposite the first hadronic $B_{\rm tag}$. Finally, the branching fraction is extracted using an unbinned maximum likelihood fit to $E_{\rm extra}$. The probability density functions (PDF) of the signal and peaking background are taken from MC and validated with the data using the $m_{\rm ES}$ distribution. The PDF for the combinatorial background is taken from the $m_{\rm ES}$ sidebands in on-resonance data. After unblinding the data in the signal region, a significant excess at low $E_{\rm extra}$ is seen, corresponding to an exclusion of the null hypothesis at 3.3σ. This analysis measures $BR(B^+ \to \tau^+\nu_\tau) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$ where the uncertainties are statistical and systematic respectively.

Another $B^+ \to \tau^+\nu_\tau$ analysis at BABAR was published recently, which uses exclusive SL $B_{\rm tag}$ candidates in 459 million $B\bar{B}$ events [7], thus providing a measurement from a dataset that is statistically independent from the hadronic tag analysis. After reconstructing a $B_{\rm tag}$ and the four tau decay modes mentioned above, this analysis uses a variety of signal, $B_{\rm tag}$, and event-shape variables, such as lepton momentum and $\cos\theta_{B,D\ell}$, to produce three LHRs: for signal, continuum, and $B\bar{B}$ background. $E_{\rm extra}$ is used to extract the branching fraction and is validated using a SL double-tagged sample. The MC background prediction is calibrated using data in the $E_{\rm extra}$ sideband. This analysis measures $BR(B^+ \to \tau^+\nu_\tau) = (1.7 \pm 0.8 \pm 0.2) \times 10^{-4}$ at 2.3σ. When combined with the hadronic tag measurement, $BR(B^+ \to \tau^+\nu_\tau) = (1.76 \pm 0.49) \times 10^{-4}$ [6].

A similar analysis from Belle was recently published using exclusive SL tags and 657 million $B\bar{B}$ events [8]. After reconstructing the $B_{\rm tag}$, exactly one e, μ, or π track is selected for the tau decay and requirements are applied on the tau momentum and $\cos\theta_{B,D\ell}$. A SL double-tagged $E_{\rm extra}$ distribution is used to correct the signal MC to the data. The signal and background PDFs are taken from MC, while the continuum MC is corrected using off-resonance data. This analysis measures $BR(B^+ \to \tau^+\nu_\tau) = (1.54^{+0.38}_{-0.37}\,^{+0.29}_{-0.31}) \times 10^{-4}$ at 3.6σ. Belle also performed an hadronic tag analysis using 449 million $B\bar{B}$ events in 2006 [9], which resulted in the first evidence of $B^+ \to \tau^+\nu_\tau$ at 3.5σ with $BR(B^+ \to \tau^+\nu_\tau) = (1.79^{+0.56}_{-0.49}\,^{+0.46}_{-0.51}) \times 10^{-4}$.

Although these measurements are consistent with each other, combining to an average [3] of $BR(B^+ \to \tau^+\nu_\tau) = (1.64 \pm 0.34) \times 10^{-4}$, there is discrepancy from the SM expectation as quoted above. In addition, when extracting $BR(B^+ \to \tau^+\nu_\tau)$ from other experimental values fit to the CKM matrix and Unitarity Triangle, the directly measured $BR(B^+ \to \tau^+\nu_\tau)$ value is almost 3σ larger than the fit values: $(0.805 \pm 0.071) \times 10^{-4}$ [10] and $(0.763^{+0.114}_{-0.061}) \times 10^{-4}$ [11] as determined by that UTfit and CKMfitter collaborations respectively. Neglecting the possibility of significant statistical fluctuation in the measurements, the discrepancy between $BR(B^+ \to \tau^+\nu_\tau)$ and the other CKM measurements suggests two possibilities: the lattice estimate of f_B is significantly inconsistent with experiment or we are seeing evidence of NP in either $B^+ \to \tau^+\nu_\tau$ or $\sin(2\beta)$ of the Unitarity Triangle. Nevertheless, the measurements of $BR(B^+ \to \tau^+\nu_\tau)$ have already excluded at 90% confidence level (CL) much of the NP parameter values on the m_H versus $\tan\beta$ plane.

3. Recent Searches for $B^+ \to \ell^+\nu_\ell$ (γ)

Although the leptonic decays $B^+ \to \ell^+\nu_\ell$ where $\ell = e, \mu$ are less accessible than $B^+ \to \tau^+\nu_\tau$ due to the branching fraction's proportionality to the square of the lepton mass, these two-body decay modes can provide cleaner measurements since the lepton is monoenergetic at about $2.64\,\mathrm{GeV}/c$. A recent BABAR result, which uses the inclusive analysis method and 468 million $B\bar{B}$ events [12], first finds a high momentum electron or muon within an event. This lepton along with any missing energy within the event are assigned as the signal decay, and the rest of the event is then assigned as the B_{tag}. Events with more than one lepton are rejected, the B_{tag} is required to satisfy ΔE and transverse momentum criteria, and the background is further suppressed using a Fisher discriminant of kinematic and event shape variables. Finally, a yield is extracted from a two-dimensional fit to m_{ES} and p_{fit}, the latter being a linear combination of the lepton momenta in the CM and B_{tag} rest frames. Although no signal decays are observed, the extrapolated upper limit of $BR(B^+ \to \mu^+\nu_\mu) < 1.0\times10^{-6}$, at 90% CL, approaches the SM expectation of $\sim 5\times10^{-7}$. An upper limit of $BR(B^+ \to e^+\nu_e) < 1.9\times10^{-6}$ is also determined, but this is superseded by a previous Belle result [13] of $BR(B^+ \to e^+\nu_e) < 0.98\times10^{-6}$ and is still orders of magnitude above the SM expectation of 10^{-11}.

Although the radiative leptonic mode, $B^+ \to \ell^+\nu_\ell\gamma$, does not provide as clean of a measurement of $|V_{ub}|f_B$ as the purely leptonic mode, the presence of the photon removes the helicity suppression, resulting in a more accessible decay rate at an order of 10^{-6}. The decay rate depends on the $B\to\gamma$ form factor, but can be approximated as $BR(B^+ \to \ell^+\nu_\ell\gamma) \approx \frac{\alpha_{\text{em}}G_F^2|V_{ub}|^2}{288\pi^2} f_B^2 m_B^5 \tau_B \left(\frac{Q_u}{\lambda_B} - \frac{Q_b}{m_b}\right)^2$ [14], where α_{em} is the fine-structure constant, Q_i is the quark charge, and λ_B is the first inverse moment of the B-meson wave function which is present in the $B\to\pi$ form factor and two-body $B\to\pi X$ decays. However, this parameter has large theoretical uncertainty, making $B^+ \to \ell^+\nu_\ell\gamma$ a crucial decay for obtaining a clean measurement of λ_B.

A recent BABAR result for $BR(B^+ \to \ell^+\nu_\ell\gamma)$ was obtained from a cut-and-count hadronic-tag analysis using 465 million $B\bar{B}$ events [15] by first reconstructing a B_{tag} and then suppressing continuum background using event-shape variables. The signal decay is reconstructed by selecting the highest energy photon within the rest of the particles, requiring exactly one electron or muon, and restricting the angle between the lepton momentum and the event's missing momentum to that of a three-body decay. In addition, π^0 vetoes are applied to remove the largest background of $B\to\pi^0\ell\nu_\ell$. Finally, requirements are applied to the calculated neutrino mass, $m_\nu^2 \equiv |p_{\Upsilon(4S)} - p_{B_{\text{tag}}} - p_\ell - p_\gamma|^2$ where p_i is the four-momentum of particle i, which peaks at zero for signal events. Because no requirements are applied to the lepton or photon kinematics, this analysis is the world's first measurement that is independent of the $B\to\gamma$ form factor models. A measurement of $BR(B^+ \to \ell^+\nu_\ell\gamma) = (6.5^{+7.6}_{-4.7}{}^{+2.8}_{-0.8})\times10^{-6}$ is obtained at 2.1σ, as well an upper limit of $BR(B^+ \to \ell^+\nu_\ell\gamma) < 15.6\times10^{-6}$ at 90% CL which approaches the SM expected value and is the most stringent reported limit to date. Finally, this analysis also provides tighter, model-dependent results by restricting the $\gamma-\nu$ and $\gamma-\ell$ angles.

4. Recent Searches for $B \to D^{(*)}\tau\nu_\tau$

Like $B^+ \to \tau^+\nu_\tau$, the decay $B\to D^{(*)}\tau\nu_\tau$ is also sensitive to a Charged Higgs coupling at the tree level and is complementary to $B^+ \to \tau^+\nu_\tau$ in that it can restrict NP parameter-space on the m_H versus $\tan\beta$ plane that is inaccessible by $B^+ \to \tau^+\nu_\tau$. However, $B\to D^{(*)}\tau\nu_\tau$ also has additional advantages, including a SM-predicted decay rate that is four orders of magnitude larger than $B^+ \to \tau^+\nu_\tau$, at $BR(B^0 \to D^-\tau\nu_\tau)_{\text{SM}} = 0.69\pm0.04$ and $BR(B^0 \to D^{*-}\tau\nu_\tau)_{\text{SM}} = 1.41\pm0.07$ [16]. There is also less SM uncertainty due to no dependence on $|V_{ub}|^2 f_B^2$, but instead depends on $|V_{cb}|^2$ which is better known than $|V_{ub}|^2$ and cancels out in the ratio $R(D) \equiv \frac{BR(B\to D\tau\nu)}{BR(B\to D\ell\nu)}$. The SM branching fraction of $B\to D\tau\nu$ also depends on a vector and a scalar form factor; the former can be measured from $B \to D\ell\nu$ while the latter can be constrained by Heavy Quark Effective Theory. A dependence on $tan^2\beta \frac{m_B^2}{m_H^2}$ also exists for the 2HDM. Finally, because $B \to D^{(*)}\tau\nu_\tau$ is a three-body decay, it permits the study of other observables that are potentially sensitive to NP, such as the transferred momentum (q^2) and the D^* and τ polarization.

Belle recently expanded on a previous inclusive analysis of $B^0 \to D^{*-}\tau\nu_\tau$ to include the $D^{(*)0}$ modes, using 535 and 675 million $B\bar{B}$ events respectively [17, 18]. In these two analyses, first $D^0 \to K^+\pi^-(\pi^0)$ and $D^* \to D^0\pi$ are reconstructed. Next, an electron, muon, or pion track are selected for the tau decay, and the rest of the event is assigned as the B_{tag}. Requirements on ΔE and m_{ES} are applied, as well as on additional variables such as q^2, missing energy, and visible energy within the event. The largest background for $B \to D^{(*)}\tau\nu_\tau$ measurements is from $B \to D^{(*)}\ell\nu_\ell$, which has only one neutrino instead of the two or three in a $B \to D^{(*)}\tau\nu_\tau$ decay. Therefore, the most discriminating variable for a $B \to D^{(*)}\tau\nu_\tau$ analysis is M^2_{miss}, the square of the missing mass in the event, which peaks at zero for $B \to D^{(*)}\ell\nu_\ell$ while extending to 8 GeV for $B \to D^{(*)}\tau\nu_\tau$. However, since the B_{tag} is not exclusively reconstructed, this analysis uses the variable $X_{\text{miss}} \equiv (E_{\text{miss}} - |\vec{p}_{D^{(*)}} + \vec{p}_{\ell,\pi}|)/|\vec{p}_{B_{\text{tag}}}|$ where $\vec{p}_i$ is the three-momentum of particle i, which is similar to M^2_{miss} but with no dependence on m_{ES}. Finally, in the $B^0 \to D^{*-}\tau\nu_\tau$ analysis, a fit to m_{ES} is applied, and in the new analysis, a two-dimensional fit is applied to m_{ES} and $|\vec{p}_{D^{(*)0}}|$ in the CM frame while taking into account cross-feed between signal modes. The $B^0 \to D^{*-}\tau\nu_\tau$ analysis claims the first observation of an exclusive $b \to c\tau\nu$ decay at 5.2σ, while the new analysis claims the first observation of $B^+ \to D^0\tau\nu_\tau$ at 3.5σ. The branching fraction results are provided in Table 1.

Two hadronic tag analyses were also performed by BABAR and Belle respectively [19, 20]. After reconstructing the B_{tag}, a $D^{(*)}$ candidate is reconstructed in approximately ten modes and exactly one lepton is allowed within the event. Combinatorial background is suppressed using E_{extra} and lepton momentum in both analyses, and BABAR additionally applies requirements on q^2 and the missing momentum in the event. All four $B \to D^{(*)}\tau\nu_\tau$ modes are then simultaneously extracted from a two-dimensional fit to $M^2_{\text{miss}} \equiv |p_{\Upsilon(4S)} - p_{B_{\text{tag}}} - p_{D^{(0)}} - p_\ell|^2$, where p_i is the four-momentum of particle i, and either E_{extra} for the Belle analysis or the lepton momentum in the B_{tag} rest frame for the BABAR analysis. BABAR also simultaneously fits to $B \to D^{**}\ell\nu$ control samples, while Belle uses MC to estimate the $B \to D^{**}\ell\nu$ contribution. Both analyses use $B \to D^{(*)}\ell\nu_\ell$ samples for yield normalization. The BABAR analysis provides the first measurements of kinematic distributions for NP studies, and both analyses provide measurements of the ratio $R(D^{(*)})$. The results of the various $B \to D^{(*)}\tau\nu_\tau$ branching fractions are consistent with the SM predictions and are given in Table 1.

	Belle Inclusive	Belle Hadronic Tag	BABAR Hadronic Tag
$B^+ \to D^{*0}\tau\nu_\tau$	$2.12^{+0.28}_{-0.27} \pm 0.29$ (8.1σ)	$3.04^{+0.69}_{-0.66}{}^{+0.40}_{-0.47}$ (3.9σ)	$2.25 \pm 0.48 \pm 0.22$ (5.3σ)
$B^0 \to D^{*-}\tau\nu_\tau$	$2.02^{+0.40}_{-0.37} \pm 0.37$ (5.2σ)	$2.56^{+0.75}_{-0.66}{}^{+0.31}_{-0.22}$ (4.7σ)	$1.11 \pm 0.51 \pm 0.04$ (2.7σ)
$B^+ \to D^0\tau\nu_\tau$	$0.77 \pm 0.22 \pm 0.12$ (3.5σ)	$1.51^{+0.41}_{-0.39}{}^{+0.24}_{-0.19}$ (3.8σ)	$0.67 \pm 0.37 \pm 0.11$ (1.8σ)
$B^0 \to D^-\tau\nu_\tau$	–	$1.01^{+0.46}_{-0.41}{}^{+0.13}_{-0.11}$ (2.6σ)	$1.04 \pm 0.35 \pm 0.15$ (3.3σ)

Table 1: Measured branching fraction values for the recent $B \to D^{(*)}\tau\nu_\tau$ analyses.

PoS(HQL 2010)017

5. Conclusions

Having been observed at both BABAR and Belle, $B^+ \to \tau^+\nu_\tau$ and $B \to D^{(*)}\tau\nu_\tau$ are now well-established decays. Although $B^+ \to \mu^+\nu_\mu$ and $B^+ \to \ell^+\nu_\ell\gamma$ have not yet been observed, the sensitivity of the these decays are near SM predictions, with the expectation of observing these decays at the next generation *B*-factories. Although all the branching fractions measured for the decays discussed in this paper are consistent with the SM predictions within uncertainties, there is room for NP, especially with the $B^+ \to \tau^+\nu_\tau$ decay. Future *B*-factories, such as SuperB [21] and Belle-II [22], are expected to have exclusion and discovery potentials competitive with the LHC by continuing indirect searches of the Higgs with decays such as $B^+ \to \tau^+\nu_\tau$, $B^+ \to \ell^+\nu_\ell$, and $B \to D^{(*)}\tau\nu_\tau$.

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