Model independent analysis of $b \to (c, u) \tau \nu$ leptonic and semileptonic decays

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Abstract

Latest measurement of the ratio of branching ratios $R_D = \mathcal{B}(B \to D \tau \nu)/\mathcal{B}(B \to D l \nu)$ and $R_{D^*} = \mathcal{B}(B \to D^* \tau \nu)/\mathcal{B}(B \to D^* l \nu)$, where $l$ is either an electron or muon, differs from the standard model expectation by $1.9\sigma$ and $3.3\sigma$, respectively. Similar tension has been observed in purely leptonic $B \to \tau \nu$ decays as well. In this context, we consider the most general effective Lagrangian in the presence of new physics and perform a model independent analysis to explore various new physics couplings. Motivated by the recently proposed new observables $R'_D = R_D/\mathcal{B}(B \to \tau \nu)$ and $R'_{D^*} = R_{D^*}/\mathcal{B}(B \to \tau \nu)$, we impose $2\sigma$ constraints coming from $R'_D$ and $R'_{D^*}$ in addition to the constraints coming from $R_D$, $R_{D^*}$, and $\mathcal{B}(B \to \tau \nu)$ to constrain the new physics parameter space. We study the impact of new physics on various observables related to $B_s \to (D_s, D_{s}^*)\tau \nu$ and $B \to \pi \tau \nu$ decay processes.

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I. INTRODUCTION

Although the anomalies in the $B$ meson decays suggest presence of new physics (NP) in the flavor sector, NP is yet to be confirmed. Various model dependent as well as model independent analysis have been carried out to explore different NP scenarios. More specifically, the $b \to u$ and $b \to c$ leptonic and semileptonic decays of $B$ meson such as $B \to (D, D^*) \tau \nu$, $B \to \pi \tau \nu$, and $B \to \tau \nu$ decays have been the center of attraction among the physics communities in the last few years \cite{1-38}. Of late, various baryonic decay modes such as $\Lambda_b \to \Lambda_c \tau \nu$ and $\Lambda_b \to p \tau \nu$ mediated via $b \to (c, u) \tau \nu$ transition processes also got some attention because of the high production of $\Lambda_b$ at the LHC \cite{39-43}. The semileptonic $B$ decays are sensitive probes to search for various NP models such as two Higgs doublet model (2HDM), minimal suppersymmetric standard model (MSSM) and leptoquark model. Exclusive semileptonic $B$ decays was first observed by BELLE collaboration \cite{44}, with subsequent studies reported by BELLE \cite{45, 46} and BABAR \cite{47, 48}. The recent measurement on the ratio of branching ratios $R_D$ and $R_{D^*}$ are

$$
R_D^{\text{BABAR}} = 0.440 \pm 0.058 \pm 0.042, \quad R_{D^*}^{\text{BABAR}} = 0.332 \pm 0.024 \pm 0.018,
$$

$$
R_D^{\text{BELLE}} = 0.375 \pm 0.064 \pm 0.026, \quad R_{D^*}^{\text{BELLE}} = 0.293 \pm 0.038 \pm 0.015,
$$

where the first uncertainty is statistical and the second one is systematic. Very recently LHCb has also measured the ratio $R_{D^*}$ to be $0.302 \pm 0.030 \pm 0.011$ with a semileptonic tagging method \cite{49} which is within 1.6$\sigma$ of the standard model (SM) theoretical expectation. The measured values of $R_D$ and $R_{D^*}$ exceed the SM prediction by 1.9$\sigma$ and 3.3$\sigma$ respectively. Considering the $R_D$ and $R_{D^*}$ correlation, the combined analysis of $R_D$ and $R_{D^*}$ finds the deviation from the SM prediction to be at more than 4.0$\sigma$ level \cite{51}. The combined results from the leptonic and hadronic decays of $\tau$, the BABAR and BELLE measured value of $\mathcal{B}(B \to \tau \nu)$ are $(1.83^{+0.53}_{-0.49}) \times 10^{-4}$ \cite{32} and $(1.25 \pm 0.28) \times 10^{-4}$ \cite{53}, respectively. BELLE measurement is consistent with the SM prediction for both exclusive and inclusive $V_{ub}$, whereas, with the exclusive $V_{ub}$, there is still some discrepancy between the BABAR measured value of $\mathcal{B}(B \to \tau \nu)$ and the SM theoretical prediction.

Very recently, in Ref. \cite{54}, various new observables such as $R_D'$ and $R_{D^*}'$ have been proposed to explore the correlation between the new physics signals in $B \to (D, D^*)\tau \nu$ and $B \to \tau \nu$ decays.
These observables

\[ R_D^\tau = \frac{R_D}{\mathcal{B}(B \to \tau \nu)}, \quad R_D^{\tau*} = \frac{R_D^{\tau*}}{\mathcal{B}(B \to \tau \nu)} \]  

(2)

are obtained by dividing the ratio of branching ratios \( R_D \) and \( R_D^{\tau*} \) by \( B \to \tau \nu \) branching ratio. Although, \( \tau \) detection and identification systematics are present in \( B \to \tau \nu \) and \( B \to (D, D^*)\tau \nu \) decays, it will mostly cancel in these newly constructed ratios. However, these ratios suffer from large uncertainties due to the presence of not very well known parameter \( V_{ub} \) in the denominator. The estimated values are [54]

\[ R_D^{\text{BABAR}} (\times 10^3) = 2.404 \pm 0.838, \quad R_D^{\text{BABAR}} (\times 10^3) = 1.814 \pm 0.582, \]
\[ R_D^{\text{BELLE}} (\times 10^3) = 3.0 \pm 1.1, \quad R_D^{\tau* \text{BELLE}} (\times 10^3) = 2.344 \pm 0.799. \]  

(3)

The estimated values of these new observables from BABAR and BELLE measured values of the ratio of branching ratios \( R_D \), \( R_D^{\tau*} \), and \( \mathcal{B}(B \to \tau \nu) \) are consistent with the SM prediction [54] although the measured values of \( R_D \) and \( R_D^{\tau*} \) itself differ from the SM prediction. It, however, does not necessarily rule out the possibility of presence of NP because even if NP is present, the effect of it may largely cancel in the ratios. In Ref. [54], the authors discuss the constraints on 2HDM parameter space using the constraints coming from the estimated values of \( R_D^\tau \) and \( R_D^{\tau*} \) and find that although the BABAR data does not allow a simultaneous explanation of all the above mentioned deviations, however, for BELLE data, there actually a common allowed parameter space. In this present study, we use the most general effective Lagrangian in the presence of NP to study various NP effects on \( b \to u \) and \( b \to c \) leptonic and semileptonic decays. First, we consider the constraints coming from the measured values of \( R_D \), \( R_D^{\tau*} \), and \( \mathcal{B}(B \to \tau \nu) \) to explore various NP effect. Second, we see whether it is possible to constrain the NP parameter space even further by putting additional constraints coming from the estimated values of \( R_D^\tau \) and \( R_D^{\tau*} \), since the estimated values of these ratios are consistent with the SM values. We also give prediction on other similar observables related to \( B \to \pi \tau \nu \) and \( B_s \to (D_s, D^*_s) \tau \nu \) decays.

In section II we start with a brief description of the effective Lagrangian for the \( b \to (u, c) l \nu \) transition decays in the presence of NP. All the relevant formulas such as the partial decay width of \( B \to l \nu \) decays and differential decay width of three body \( B \to (P, V) l \nu \) decays are reported in section II. We also construct various new observables related to semileptonic \( B \) and \( B_s \) meson decays. In section III we start with the input parameters that are used for our numerical computation. The
SM prediction and the effect of each NP couplings on various observables related to semileptonic $B$ and $B_s$ meson decays are reported in section [III]. We conclude with a brief summary of our results in section [IV].

II. HELICITY AMPLITUDES WITHIN EFFECTIVE FIELD THEORY APPROACH

In the presence of NP, the effective weak Lagrangian for the $b \to q' l \nu$ transition decays, where $q'$ is either a $u$ quark or a $c$ quark, can be written as [55, 56]

$$
\mathcal{L}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{q'b} \left\{ (1 + V_L) \bar{L} \gamma_{\mu} \nu_L \bar{q}' \gamma^\mu b_L + V_R \bar{L} \gamma_{\mu} \nu_L \bar{q}' R \gamma^\mu b_R + \bar{\nu}_L \bar{L} \gamma_{\mu} \nu_R \bar{q}' L \gamma^\mu b_L \\
+ \bar{\nu}_R \bar{L} \gamma_{\mu} \nu_R \bar{q}' R \gamma^\mu b_R + S_L \bar{L} \gamma_{\mu} \nu_L \bar{q}' R b_L + S_R \bar{L} \gamma_{\mu} \nu_L \bar{q}' L b_R + \bar{S}_L \bar{L} \gamma_{\mu} \nu_R \bar{q}' R b_L + \bar{S}_R \bar{L} \gamma_{\mu} \bar{q}' L b_R \\
+ T_L \bar{L} \bar{\sigma}_{\mu\nu} \nu_L \bar{q}' R \sigma^{\mu\nu} b_L + \bar{T}_L \bar{L} \bar{\sigma}_{\mu\nu} \nu_R \bar{q}' L \sigma^{\mu\nu} b_R \right\} + \text{h.c.} ,
$$

(4)

where, $G_F$ is the Fermi coupling constant and $V_{q'b}$ is the CKM matrix element. The vector, scalar, and tensor type NP interactions denoted by $V_{L,R}$, $S_{L,R}$, and $T_L$ are associated with left handed neutrinos, whereas, $\bar{V}_{L,R}$, $\bar{S}_{L,R}$, and $\bar{T}_L$ type NP couplings are associated with right handed neutrinos. We consider all the NP couplings to be real for our analysis. Again, we keep only vector and scalar type NP couplings in our analysis. We rewrite the effective Lagrangian as [25]

$$
\mathcal{L}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{q'b} \left\{ G_V \bar{L} \bar{\gamma}_5 (1 - \gamma_5) \nu_L \bar{q}' \gamma^\mu b - G_A \bar{L} \gamma_{\mu} (1 - \gamma_5) \nu_L \bar{q}' \gamma^\mu \gamma_5 b + G_S \bar{L} (1 + \gamma_5) \nu_L \bar{q}' b \right\} \\
- G_P \bar{L} (1 - \gamma_5) \nu_L \bar{q}' \gamma_5 b + \bar{G}_V \bar{L} \gamma_{\mu} (1 + \gamma_5) \nu_L \bar{q}' \gamma^\mu b - \bar{G}_A \bar{L} \gamma_{\mu} (1 + \gamma_5) \nu_L \bar{q}' \gamma^\mu \gamma_5 b \\
+ \bar{G}_S \bar{L} (1 + \gamma_5) \nu_L \bar{q}' b - \bar{G}_P \bar{L} (1 + \gamma_5) \nu_L \bar{q}' \gamma_5 b \right\} + \text{h.c.} ,
$$

(5)

where

$$
G_V = 1 + V_L + V_R , \quad G_A = 1 + V_L - V_R , \quad G_S = S_L + S_R , \quad G_P = S_L - S_R \\
\bar{G}_V = \bar{V}_L + \bar{V}_R , \quad \bar{G}_A = \bar{V}_L - \bar{V}_R , \quad \bar{G}_S = \bar{S}_L + \bar{S}_R , \quad \bar{G}_P = \bar{S}_L - \bar{S}_R .
$$

The SM contribution can be obtained once we set $V_{L,R} = S_{L,R} = \bar{V}_{L,R} = \bar{S}_{L,R} = 0$ in Eq. (5). In the presence of NP, the partial decay width of $B \to l \nu$ and differential decay width of three body $B_q \to (P, V) l \nu$ decays, where $P$ is a pseudoscalar meson and $V$ is a vector meson can be expressed as [25]

$$
\Gamma(B \to l \nu) = \frac{G_F^2 |V_{ub}|^2 f_B^2 m_l^2 m_B (1 - \frac{m_l^2}{m_B^2})^2}{8\pi} \left\{ \frac{m_B^2}{m_l (m_b(\mu) + m_u(\mu))} G_P \right\}^2
$$

4
transition form factors, we refer to Refs. [25, 57].

\[
\frac{d\Gamma^P}{dq^2} = \frac{8N |\mathcal{F}_P|}{3} \left\{ H_0^2 \left( G_V^2 + \bar{G}_V^2 \right) \left( 1 + \frac{m_t^2}{2q^2} \right) + \frac{3m_t^2}{2q^2} \left[ \left( H_t G_V + \sqrt{q^2/m_t} H_s G_S \right)^2 + \left( H_t \bar{G}_V + \sqrt{q^2/m_t} H_s \bar{G}_S \right)^2 \right] \right\}
\]

(7)

and

\[
\frac{d\Gamma^V}{dq^2} = \frac{8N |\mathcal{F}_V|}{3} \left\{ \mathcal{A}_{AV}^2 + \frac{m_t^2}{2q^2} \left[ 3\mathcal{A}_{ip}^2 + \mathcal{A}_{AV}^2 + \frac{m_t^2}{2q^2} \left[ \mathcal{A}_{AV}^2 + 3\mathcal{A}_{ip}^2 \right]\right] \right\}
\]

(8)

where

\[
|\mathcal{F}_{(P,V)}| = \sqrt{\lambda(m_B^2, m_{(P,V)}^2, q^2)/2m_B}, \quad \lambda(a, b, c) = a^2 + b^2 + c^2 - 2(ab + bc + ca)
\]

\[
N = \frac{G_F^2 |V_{ub}|^2 q^2}{256\pi^3 m_B^2} \left( 1 - \frac{m_t^2}{q^2} \right)^2, \quad H_0 = \frac{2m_B|\mathcal{F}_P|}{\sqrt{q^2}} F_+(q^2),
\]

\[
H_t = \frac{m_B^2 - m_t^2}{\sqrt{q^2}} F_0(q^2), \quad H_s = \frac{m_B^2 - m_t^2}{m_B(m_B - m_Q)}, F_0(q^2),
\]

\[
\mathcal{A}_{AV}^2 = \mathcal{A}_0^2 + \mathcal{A}_I^2 G_A^2 + \mathcal{A}_I^2 G_V^2, \quad \bar{\mathcal{A}}_{AV}^2 = \mathcal{A}_0^2 \bar{G}_A^2 + \mathcal{A}_I^2 \bar{G}_V^2,
\]

\[
\mathcal{A}_{ip} = \mathcal{A}_I G_A + \frac{\sqrt{q^2}}{m_I} \mathcal{A}_P G_P, \quad \bar{\mathcal{A}}_{ip} = \mathcal{A}_I \bar{G}_A + \frac{\sqrt{q^2}}{m_I} \mathcal{A}_P \bar{G}_P.
\]

(9)

and

\[
\mathcal{A}_0 = \frac{1}{2m_V \sqrt{q^2}} \left[ (m_B^2 - m_t^2 - q^2)(m_B + m_V)A_1(q^2) - \frac{4m_B^2 |\mathcal{F}_V|^2}{m_B + m_V} A_2(q^2) \right],
\]

\[
\mathcal{A}_I = \frac{2(m_B + m_V)A_1(q^2)}{\sqrt{2}}, \quad \mathcal{A}_I = -\frac{4m_B^2 V(q^2) |\mathcal{F}_V|^2}{\sqrt{2}(m_B + m_V)},
\]

\[
\mathcal{A}_P = \frac{2m_B^2 |\mathcal{F}_V|^2 \mathcal{A}_0(q^2)}{\sqrt{q^2}}, \quad \mathcal{A}_P = -\frac{2m_B^2 |\mathcal{F}_V|^2 \mathcal{A}_0(q^2)}{(m_B(m_B + m_c))}.
\]

(10)

For the details of the helicity amplitudes, B meson decay constant, and the $B_q \to (P,V)$ meson transition form factors, we refer to Refs. [25, 57].

To study the possibility of correlation in $\tau$ decays, we follow Ref. [54] and define new observables $R_D^r$ and $R_D^{r*}$, as

\[
R_D^r = \frac{R_D}{B(B \to \tau \nu)}, \quad R_D^{r*} = \frac{R_D^{r*}}{B(B \to \tau \nu)}.
\]

(11)

The $\tau$ detection and identification systematics that are present in both $B \to D \tau \nu$ and $B \to D^* \tau \nu$ decays may get cancelled in these new ratios. Semileptonic $B_s$ decays to $D_s \tau \nu$ and $D_s^{*} \tau \nu$ and $B$
decays to $\pi \tau \nu$ are also mediated via $b \rightarrow (u, c) \tau \nu$ quark level transition processes and, in principle, are subject to NP. In this context, we also define ratio of branching ratios in these decay modes similar to $B \rightarrow (D, D^*) \tau \nu$ decays. Those are

$$R_\pi = \frac{\mathcal{B}(B \rightarrow \pi \tau \nu)}{\mathcal{B}(B \rightarrow \pi l \nu)}, \quad R^\tau_{D_s} = \frac{\mathcal{B}(\bar{B}_s \rightarrow D_s \tau^- \bar{\nu}_\tau)}{\mathcal{B}(B \rightarrow \tau \nu)}, \quad R^\tau_{D^*_s} = \frac{\mathcal{B}(\bar{B}_s \rightarrow D^*_s \tau^- \bar{\nu}_\tau)}{\mathcal{B}(B \rightarrow \tau \nu)},$$

(12)

We want to mention that although $R_\pi, R_{D_s}, R_{D^*_s},$ and $R^\tau_\pi$ do not depend on CKM matrix elements $V_{ub}$ and $V_{cb}$, but the newly constructed ratios $R^\tau_D, R^\tau_{D^*}, R^\tau_{D_s}$ and $R^\tau_{D^*_s}$ do depend on the CKM matrix element $V_{ub}$.

We wish to see the effect of various NP couplings on these observables in a model independent way. There are two types of uncertainties in theoretical calculation of the observables. First kind of uncertainties may come from the very well known input parameters such as quark masses, meson masses, and the mean life time of mesons. We ignore such uncertainties as they are not important for our analysis. Second kind of uncertainties may arise due to not very well known parameters such as CKM matrix elements, meson decay constants, and the meson to meson transition form factors. In order to gauge the effect of above mentioned uncertainties on various observables, we use a random number generator and perform a random scan of all the theoretical inputs such as CKM matrix elements, meson decay constants, and the meson to meson transition form factors. We vary all the theoretical inputs within $2\sigma$ from their central values in our random scan. The allowed NP parameter space is obtained by imposing $2\sigma$ constraints coming from BABAR and BELLE measured values of the ratio of branching ratios $R_D, R_{D^*},$ and $\mathcal{B}(B \rightarrow \tau \nu)$. We also use $2\sigma$ constraints coming from the estimated values of the newly constructed ratios $R^\tau_D$ and $R^\tau_{D^*}$ to explore various NP couplings. We now proceed to discuss the results of our analysis.

### III. NUMERICAL CALCULATIONS

For definiteness, let us first give the details of the input parameters that are used for the theoretical computation of all the observables. For the quark mass, meson mass, and the meson life time, we use the following input parameters from Ref. [58].

$$m_b(m_b) = 4.18 \text{ GeV}, \quad m_c(m_b) = 0.91 \text{ GeV}, \quad m_\pi = 0.13957 \text{ GeV}$$
Similarly, for the CKM matrix elements, meson decay constant, and meson to meson transition form factors, we use the inputs that are tabulated in Table I. We refer to Refs. [25, 57] for a detailed discussion on various form factor calculation. The uncertainties associated with both the theory and experimental input parameters are added in quadrature and tabulated in Table I and Table II. The SM prediction for all the observables are reported in Table III. Central values of all the observables are obtained by using the central values of all the input parameters from Eq. (13) and from Table I. The 1σ range in each observable, reported in Table III, is obtained by performing a random scan of all the theory inputs such as B_q meson decay constants, B_q → (P, V) transition form factors and the CKM matrix elements |V_{qb}| within 1σ of their central values. Our main aim is to study NP effects on various new observables such as R_π, R_{D^0}, R_{D_s^0}, R_{D^*}, R_{D_s^*}, R_{D_s^0}, R_{D_s^*} in a model independent way. We consider four different NP scenarios. First, we use 2σ experimental constraint coming from the BABAR and BELLE measured values of the ratio of branching ratios R_D and R_{D^*}, and B(B → τν). Second, we put additional constraint coming from the estimated values of R_{D^0} and R_{D_s^0}. The observables R_{D^0} and R_{D_s^0} are ratios obtained by dividing the ratio of branching ratios R_D and R_{D^*} by branching ratio B(B → τν). Hence the NP effect will be cancelled to a large extent in these ratios. Moreover, the estimated values of these new ratios are consistent with the SM prediction. Although, it does not necessarily rule out the presence of NP, it may, however, constrain the NP parameter space even further. Again, the τ detection systematics will also largely cancel in these ratios. Because of the presence of V_{ub} in these ratios, the estimated errors on both these observables are rather large. However, this could be reduced once more precise data on V_{ub} is available. In view of the anticipated improved precision in the measurement of V_{ub}, we impose 2σ experimental constraint coming from the estimated values of R_{D^0} and R_{D_s^0} in addition to the constraints coming from R_D, R_{D^*}, and B(B → τν) to explore various NP couplings. All the NP parameters are considered to be real for our analysis. We also assume that only the third generation leptons get contributions from the NP couplings in the b → (u, c) lν processes and for l = e^−, μ^− cases, NP is absent. We next discuss the effect of various NP couplings after imposing
| CKM matrix Elements: | Meson Decay constants (in GeV): |
|----------------------|---------------------------------|
| $|V_{ub}|$ (Exclusive) | $(3.61 \pm 0.32) \times 10^{-3}$ [59] | $f_B$ | $0.1906 \pm 0.0047$ [60–62] |
| $|V_{cb}|$ (Average) | $(40.9 \pm 1.1) \times 10^{-3}$ [59] |

Inputs for $(B \to \pi)$ Form Factors:

| $F_+(0) = F_0(0)$ | $0.281 \pm 0.028$ [63] | $h_{A_1}(1)|V_{cb}|$ | $(34.6 \pm 1.02) \times 10^{-3}$ [64] |
| $b_1$ | $-1.62 \pm 0.70$ [63] | $\rho_1^2$ | $1.214 \pm 0.035$ [64] |
| $b_1^0$ | $-3.98 \pm 0.97$ [63] | $R_1(1)$ | $1.401 \pm 0.038$ [64] |

Inputs for $(B \to D)$ Form Factors:

| $V_1(1)|V_{cb}|$ | $(43.0 \pm 2.36) \times 10^{-3}$ [65] | $R_0(1)$ | $1.14 \pm 0.114$ [2] |
| $\rho_1^2$ | $1.20 \pm 0.098$ [65] |

Inputs for $(B_s \to D_s)$ Form Factors: [66]

| $F_+$ | $F_0$ |
|-------|-------|
| $F(0)$ | $0.74 \pm 0.02$ | $0.74 \pm 0.02$ |
| $\sigma_1$ | $0.20 \pm 0.02$ | $0.430 \pm 0.043$ |
| $\sigma_2$ | $-0.461 \pm 0.0461$ | $-0.464 \pm 0.0464$ |

Inputs for $(B_s \to D_s^*)$ Form Factors: [66]

| $V$ | $A_0$ | $A_1$ | $A_2$ |
|------|------|------|------|
| $F(0)$ | $0.95 \pm 0.02$ | $0.67 \pm 0.01$ | $0.70 \pm 0.01$ | $0.75 \pm 0.02$ |
| $\sigma_1$ | $0.372 \pm 0.0372$ | $0.350 \pm 0.035$ | $0.463 \pm 0.0463$ | $1.04 \pm 0.104$ |
| $\sigma_2$ | $-0.561 \pm 0.0561$ | $-0.60 \pm 0.06$ | $-0.510 \pm 0.051$ | $-0.07 \pm 0.007$ |

TABLE I: Theory Input parameters
A. BABAR constraint

We consider four different NP scenarios for our analysis. In the first scenario, we vary new vector couplings $V_L$ and $V_R$ and consider all other NP couplings to be zero. First, we impose 2σ experimental constraint coming from BABAR measured values of the ratio of branching ratios $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ to constrain the new vector type couplings ($V_L$, $V_R$). Second, we impose additional 2σ constraint coming from the estimated values of $R_D^\tau$ and $R_{D^*}^\tau$ to see whether it is possible to constrain the NP parameter space even further. In Fig.[1] we show the NP effect on various observables after imposing the 2σ experimental constraint coming from the BABAR measured values. The allowed ranges in each observable are tabulated in Table.[IV] We find significant deviation of all the observables from SM expectation in this scenario. It is clear that we can constrain the NP parameter space even further by imposing constraints coming from $R_D^\tau$ and $R_{D^*}^\tau$. To illustrate this point, we show with green dots the NP effect on various observables once additional constraints from BABAR and BELLE measurements.
FIG. 1: Allowed ranges in various observables with $V_L$ and $V_R$ type NP couplings once the BABAR 2σ experimental constraint is imposed. The dark (red) region corresponds to the allowed ranges once $R_D$, $R_{D^*}$, and $B(B \rightarrow \tau \nu)$ constraint is imposed, whereas, the light (green) region corresponds to the allowed ranges of the observables once additional 2σ constraint from $R_D^r$ and $R_{D^*}^r$ is imposed.

| Observable | Column I | Column II | Observable | Column I | Column II |
|------------|----------|-----------|------------|----------|-----------|
| $R_D^r (\times 10^3)$ | (1.736, 7.097) | (1.736, 4.080) | $R_{D^*}^r$ | (0.359, 4.422) | (0.472, 3.144) |
| $R_{D^*} (\times 10^3)$ | (1.978, 4.780) | (1.978, 2.978) | $R_\pi$ | (0.560, 1.648) | (0.560, 1.469) |
| $R_{D_s} (\times 10^3)$ | (1.480, 6.973) | (1.480, 4.101) | $R_{D_s}$ | (0.226, 0.601) | (0.226, 0.601) |
| $R_{D_s^*} (\times 10^3)$ | (1.895, 4.599) | (1.895, 2.980) | $R_{D_s^*}$ | (0.246, 0.394) | (0.246, 0.390) |

TABLE IV: Allowed ranges in various observables with $(V_L, V_R)$ NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BABAR measured values of $R_D$, $R_{D^*}$, and $B(B \rightarrow \tau \nu)$ are imposed, whereas, the ranges in Column II represent the allowed values once additional 2σ constraints from $R_D^r$ and $R_{D^*}^r$ are imposed.
FIG. 2: Allowed ranges in various observables with $S_L$ and $S_R$ type NP couplings once the BABAR $2\sigma$ experimental constraint is imposed. Allowed range obtained by imposing $2\sigma$ constraint coming from $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ overlaps with the allowed range once additional $2\sigma$ constraint from $R_D^*$ and $R_{D^*}$ is imposed.

$2\sigma$ constraints coming from $R_D^*$ and $R_{D^*}$ are imposed. It is observed that the allowed ranges in $R_D^*$, $R_{D^*}$, $R_{D_s^*}$, and $R_{\pi}^*$ are considerably reduced whereas there are no or very little changes in $R_{\pi}$, $R_{D_s}$, and $R_{D_s^*}$ allowed ranges once the additional $2\sigma$ constraint from $R_D^*$ and $R_{D^*}$ are imposed. We want to emphasize that since the new observables, $R_{D_1}^{\tau(\pi)}$ and $R_{\pi}^\tau$ are ratios obtained by normalizing $R_{D_1}^{\tau(\pi)}$ and $B(B \to \pi \tau \nu)$ with the branching ratio $B(B \to \tau \nu)$, there must be some cancellation of NP effects. However, the NP effect can not be completely eliminated. NP effect will not be present in these new ratios if only $V_L$ type NP couplings are present. In that case $G_V = G_A$ and the contribution coming from the NP couplings will cancel in $R_{D_1}^{\tau(\pi)}$ and $R_{\pi}^\tau$.

In the second scenario, we study the impact of new scalar couplings $S_L$ and $S_R$ on various observables keeping all other NP couplings to be zero. The effect of $S_L$ and $S_R$ type NP couplings on various observables are shown in Fig. 2 once the $2\sigma$ experimental constraints coming from BABAR measured values are imposed. Significant deviation from the SM expectation is observed in this scenario. Again, putting additional $2\sigma$ constraints from $R_D^*$ and $R_{D^*}$ do not seem to affect any of the observables. The allowed ranges in each observable are tabulated in Table. V.

In the third scenario, we study the impact of new vector couplings $\tilde{V}_L$ and $\tilde{V}_R$, associated with
right handed neutrinos, on various observables. We first restrict the NP parameter space by imposing $2\sigma$ experimental constraints coming from the BABAR measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ are imposed. Column II represents the allowed range in each observable once additional $2\sigma$ constraints from $R_D^*$ and $R_{D^*}$ are imposed.

TABLE V: Allowed ranges in various observables with $(S_L, S_R)$ NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BABAR measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ are imposed. Column II represents the allowed range in each observable once additional $2\sigma$ constraints from $R_D^*$ and $R_{D^*}$ are imposed.

| Observable | Column I | Column II |
|------------|----------|-----------|
| $R_D^r(\times 10^3)$ | (1.285, 3.788) | (1.285, 3.788) |
| $R_{D^*}^r(\times 10^3)$ | (0.955, 2.096) | (0.955, 2.096) |
| $R_{D_s}^r(\times 10^3)$ | (1.125, 3.386) | (1.125, 3.386) |
| $R_{D_s^*}^r(\times 10^3)$ | (0.848, 1.903) | (0.848, 1.903) |

| Observable | Column I | Column II |
|------------|----------|-----------|
| $R_D^l(\times 10^3)$ | (1.521, 7.346) | (1.521, 4.080) |
| $R_{D^*}^l(\times 10^3)$ | (1.889, 4.841) | (1.889, 2.978) |
| $R_{D_s}^l(\times 10^3)$ | (1.323, 7.508) | (1.323, 4.275) |
| $R_{D_s^*}^l(\times 10^3)$ | (1.826, 4.767) | (1.826, 3.008) |

TABLE VI: Allowed ranges in various observables with $(\bar{V}_L, \bar{V}_R)$ NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BABAR measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ are imposed. Column II represents the allowed range in each observable once additional $2\sigma$ constraints from $R_D^*$ and $R_{D^*}$ are imposed.

| Observable | Column I | Column II |
|------------|----------|-----------|
| $R_D^r(\times 10^3)$ | (0.297, 2.542) | (0.297, 2.542) |
| $R_{D^*}^r(\times 10^3)$ | (0.658, 2.933) | (0.658, 2.933) |
| $R_{D_s}^r(\times 10^3)$ | (0.251, 0.480) | (0.251, 0.480) |
| $R_{D_s^*}^r(\times 10^3)$ | (0.240, 0.254) | (0.240, 0.254) |

| Observable | Column I | Column II |
|------------|----------|-----------|
| $R_D^l(\times 10^3)$ | (0.398, 4.538) | (0.414, 3.563) |
| $R_{D^*}^l(\times 10^3)$ | (0.617, 1.669) | (0.617, 1.568) |
| $R_{D_s}^l(\times 10^3)$ | (0.241, 0.628) | (0.241, 0.590) |
| $R_{D_s^*}^l(\times 10^3)$ | (0.239, 0.397) | (0.241, 0.397) |

SM prediction similar to the first scenario. We observe that the ranges in $R_D^r$, $R_{D^*}^r$, $R_{D_s}^r$, $R_{D_s^*}^r$, and
FIG. 3: Allowed ranges in various observables with $\bar{V}_L$ and $\bar{V}_R$ type NP couplings once BABAR $2\sigma$ experimental constraint is imposed. We show in dark (red) the allowed ranges once $2\sigma$ constraints from $R_D$, $R_{D^*}$, and $B(B \to \tau\nu)$ are imposed. Similarly, the allowed ranges are shown in light (green) once additional $2\sigma$ constraints from $R_D^r$ and $R_{D^*}^r$ are imposed.

$R_\pi^r$ do reduce once the additional $2\sigma$ constraints coming from $R_D^r$ and $R_{D^*}^r$ are imposed. However, we see no or very little change in $R_\pi$, $R_{D^r}$, and $R_{D^*}^r$. Again, if only $\bar{V}_L$ type NP couplings were present, then $G_V = G_A$ and the NP effect will cancel in $R_D^{r(s)}$ and $R_\pi^r$.

In the fourth scenario, we vary $\tilde{S}_L$ and $\tilde{S}_R$, new scalar couplings associated with right handed neutrinos, while keeping others to zero. We find that only one set of $\tilde{S}_L$, $\tilde{S}_R$ namely $\tilde{S}_L = 0.467$ and $\tilde{S}_R = 0.003$ satisfy the $2\sigma$ experimental constraint coming from the BABAR measured values of the ratio of branching ratios $R_D$, $R_{D^*}$, and $B(B \to \tau\nu)$. Corresponding values of all the observables are tabulated in Table. VII. Again significant deviation from the SM expectation is observed for all the observables. Imposing the additional $2\sigma$ constraints coming from the new observables $R_D^r$ and $R_{D^*}^r$ do not seem to affect the observables in this scenario.

It is observed that all the NP scenarios can accommodate the existing data on $b \to (u, c)\tau\nu$ decays. However, for $S_L$ and $S_R$ type NP couplings there are very few points that are compatible with the $2\sigma$ constraints coming from BABAR measurements. Similarly, for $\tilde{S}_L$ and $\tilde{S}_R$ type NP couplings there is only one set of points that satisfy the BABAR $2\sigma$ constraints. It is worth
| Observable          | Column I | Column II | Observable | Column I | Column II |
|---------------------|----------|-----------|------------|----------|-----------|
| $R_D^r (\times 10^3)$ | 1.597    | 1.597     | $R_D^r$    | 0.392    | 0.392     |
| $R_{D^*}^r (\times 10^3)$ | 1.052 | 1.052 | $R_\pi$ | 1.060 | 1.060 |
| $R_{D_s}^r (\times 10^3)$ | 1.305 | 1.305 | $R_{D_s}$ | 0.338 | 0.338 |
| $R_{D_s^*}^r (\times 10^3)$ | 0.943 | 0.943 | $R_{D_s^*}$ | 0.244 | 0.244 |

TABLE VII: Allowed values of various observables with $\tilde{S}_L$ and $\tilde{S}_R$ type NP couplings once the BABAR 2\(\sigma\) experimental constraint is imposed. Allowed values (Column I) obtained by imposing 2\(\sigma\) constraint coming from $R_D$, $R_{D^*}$, and $B(B \to \tau\nu)$ overlaps with the allowed values (Column II) once additional 2\(\sigma\) constraint from $R_D^r$ and $R_{D^*}^r$ is imposed.

mentioning that more precise data on $R_D^r$ and $R_{D^*}^r$ will be crucial in distinguishing various NP structures.

B. BELLE constraint

Now we wish to find the effect of $(V_L, V_R)$, $(S_L, S_R)$, $(\tilde{V}_L, \tilde{V}_R)$, and $(\tilde{S}_L, \tilde{S}_R)$ type NP couplings on all the observables using experimental constraint coming from the BELLE measurement. We consider four different NP scenarios similar to BABAR analysis in section. IIIA. Similar to BABAR analysis in section. IIIA we first impose 2\(\sigma\) constraints coming from the BELLE measured values of the ratio of branching ratios $R_D$, $R_{D^*}$, and $B(B \to \tau\nu)$ to explore various NP scenarios. We again impose 2\(\sigma\) constraints coming from $R_D^r$ and $R_{D^*}^r$ that are estimated using the BELLE measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau\nu)$ to see whether it is possible to constrain the NP parameter space even further. Effect of NP on each observable under various scenarios are shown in Fig. 4, Fig. 5, Fig. 6, and Fig. 7.

The deviation from the SM expectation is found to be significant in all the four scenarios. The allowed ranges in each observable for each scenario are reported in Table. VIII Table. IX Table. X and Table. XI We see that for $(V_L, V_R)$ couplings, although, the allowed ranges of $R_D^r$, $R_{D^*}^r$, $R_{D_s}^r$, and $R_{D_s^*}^r$ do reduce, there is no or very little change in the allowed ranges of $R_\pi^r$, $R_\pi$, $R_{D_s}$, and $R_{D_s^*}$ once we impose 2\(\sigma\) constraints from $R_D^r$ and $R_{D^*}^r$. Similar results are observed for $(\tilde{V}_L, \tilde{V}_R)$ NP
FIG. 4: Allowed ranges in various observables with $V_L$ and $V_R$ type NP couplings once BELLE 2σ experimental constraint is imposed. Dark (red) regions represent the allowed range obtained by imposing 2σ constraints coming from BELLE measured values of $R_D$, $R_{D^*}$, and $\mathcal{B}(B \to \tau \nu)$, whereas, the light (green) regions represent the allowed range once 2σ additional constraints from $R_D^\tau$ and $R_{D^*}^\tau$ are imposed.

| Observable   | Column I          | Column II         | Observable | Column I          | Column II         |
|--------------|-------------------|-------------------|------------|-------------------|-------------------|
| $R_D^\tau$   | $(1.417, 7.304)$  | $(1.417, 5.198)$  | $R_{\pi}^\tau$ | $(0.359, 4.382)$  | $(0.359, 4.382)$  |
| $R_{D^*}^\tau$ | $(1.897, 4.856)$  | $(1.897, 3.932)$  | $R_{\pi}$ | $(0.440, 1.369)$  | $(0.440, 1.349)$  |
| $R_{D_s}$    | $(1.212, 7.247)$  | $(1.212, 5.534)$  | $R_{D_s}$ | $(0.180, 0.530)$  | $(0.180, 0.530)$  |
| $R_{D_s}^\tau$ | $(1.880, 4.576)$  | $(1.880, 3.949)$  | $R_{D_s}^\tau$ | $(0.190, 0.377)$  | $(0.192, 0.377)$  |

TABLE VIII: Allowed ranges in various observables with $(V_L, V_R)$ NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BELLE measured values of $R_D$, $R_{D^*}$, and $\mathcal{B}(B \to \tau \nu)$ are imposed, whereas, the ranges in Column II represent the allowed values once additional 2σ constraints from $R_D^\tau$ and $R_{D^*}^\tau$ are imposed.
FIG. 5: Allowed ranges in various observables with $S_L$ and $S_R$ type NP couplings once BELLE $2\sigma$ experimental constraint is imposed. We show in dark (red) the allowed range in each observable once $2\sigma$ constraints coming from BELLE measured values of $R_D$, $R_D^\ast$, and $B(B \to \tau\nu)$ are imposed. Again, we show in light (green) the allowed range once additional $2\sigma$ constraints from $R_D^\tau$ and $R_D^{\ast\tau}$ are imposed.

| Observable | Column I | Column II | Observable | Column I | Column II |
|------------|----------|-----------|------------|----------|-----------|
| $R_D^\tau$ ($\times 10^3$) | (1.336, 7.122) | (1.336, 5.199) | $R_D^\pi$ | (0.207, 11.012) | (0.207, 6.901) |
| $R_D^{\ast\tau}$ ($\times 10^3$) | (1.287, 3.804) | (1.287, 3.804) | $R_\pi$ | (0.496, 4.091) | (0.496, 3.964) |
| $R_D^s$ ($\times 10^3$) | (1.060, 6.669) | (1.060, 5.406) | $R_D^s$ | (0.177, 0.541) | (0.177, 0.541) |
| $R_D^{\ast s}$ ($\times 10^3$) | (1.238, 3.532) | (1.238, 3.532) | $R_D^{\ast s}$ | (0.222, 0.254) | (0.222, 0.254) |

TABLE IX: Allowed ranges in various observables with ($S_L$, $S_R$) NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BELLE measured values of $R_D$, $R_D^\ast$, and $B(B \to \tau\nu)$ are imposed, whereas, the ranges in Column II represent the allowed values once additional $2\sigma$ constraints from $R_D^\tau$ and $R_D^{\ast\tau}$ are imposed.
FIG. 6: Allowed ranges in various observables with $\tilde{V}_L$ and $\tilde{V}_R$ type NP couplings once BELLE 2σ experimental constraint is imposed. Dark (red) regions represent the allowed range obtained by imposing 2σ constraints coming from BELLE measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$, whereas, the light (green) regions represent the allowed range once 2σ additional constraints from $R_D^*$ and $R_{D^*}$ are imposed.

| Observable       | Column I     | Column II    | Observable       | Column I     | Column II    |
|------------------|--------------|--------------|------------------|--------------|--------------|
| $R_D^* (\times 10^3)$ | (1.665, 7.402) | (1.665, 5.200) | $R^\tau_\pi$    | (0.398, 4.471) | (0.398, 4.471) |
| $R_{D^*} (\times 10^3)$ | (1.889, 5.008) | (1.889, 3.942) | $R_\pi$         | (0.616, 1.485) | (0.616, 1.440) |
| $R_{D_s} (\times 10^3)$ | (1.406, 7.168) | (1.406, 5.429) | $R_{D_s}$       | (0.241, 0.550) | (0.241, 0.550) |
| $R_{D_s^*} (\times 10^3)$ | (1.846, 4.675) | (1.846, 3.974) | $R_{D_s^*}$    | (0.233, 0.383) | (0.233, 0.383) |

TABLE X: Allowed ranges in various observables with $(\tilde{V}_L, \tilde{V}_R)$ NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BELLE measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ are imposed, whereas, the ranges in Column II represent the allowed values once additional 2σ constraints from $R_D^*$ and $R_{D^*}$ are imposed.
FIG. 7: Allowed ranges in various observables with $\tilde{S}_L$ and $\tilde{S}_R$ type NP couplings once BELLE 2σ experimental constraint is imposed. We show in dark (red) the allowed range in each observable once 2σ constraints coming from BELLE measured values of $R_D$, $R_{D^*}$, and $\mathcal{B}(B \to \tau \nu)$ are imposed. Similarly, the allowed ranges in each observable are shown in light (green) once additional 2σ constraints from $R_{\tau D}$ and $R_{\tau D^*}$ are imposed.

| Observable | Column I | Column II | Observable | Column I | Column II |
|------------|----------|-----------|------------|----------|-----------|
| $R_D^\tau (\times 10^3)$ | (1.622, 7.301) | (1.622, 5.200) | $R_\pi^\tau$ | (0.229, 4.732) | (0.229, 4.387) |
| $R_{D^*}^\tau (\times 10^3)$ | (1.333, 3.857) | (1.333, 3.857) | $R_\pi$ | (0.616, 2.271) | (0.616, 2.271) |
| $R_{D_s}^\tau (\times 10^3)$ | (1.352, 7.465) | (1.352, 5.564) | $R_{D_s}$ | (0.241, 0.560) | (0.241, 0.544) |
| $R_{D_s^*}^\tau (\times 10^3)$ | (1.297, 3.583) | (1.297, 3.563) | $R_{D_s^*}$ | (0.232, 0.253) | (0.232, 0.253) |

TABLE XI: Allowed ranges in various observables with $(\tilde{S}_L, \tilde{S}_R)$ NP couplings. The ranges reported in Column I represent the allowed values of each observable once constraints coming from BELLE measured values of $R_D$, $R_{D^*}$, and $\mathcal{B}(B \to \tau \nu)$ are imposed, whereas, the ranges in Column II represent the allowed values once additional 2σ constraints from $R_{\tau D}$ and $R_{\tau D^*}$ are imposed.
couplings as well. For $(S_L, S_R)$ type NP couplings, we find considerable reduction in the allowed ranges of $R_D^r$, $R_{D_s}^r$, and $R_\pi^r$, whereas, there is no or very little change in the allowed ranges of $R_{D^*}^r$, $R_{D_s}^r$, $R_{D^*}$, and $R_\pi$ once additional $2\sigma$ constraints from the estimated values of $R_D^r$ and $R_{D^*}^r$ are imposed. Similar results are obtained for $(\tilde{S}_L, \tilde{S}_R)$ NP couplings as well.

It is evident that all the four NP scenarios not only accommodate the existing data on $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$, but also accommodate the newly estimated data on $R_D^r$ and $R_{D^*}^r$. Recent result from BELLE on $B(B \to \pi \tau \nu) < 2.5 \times 10^{-4}$ [67] gives an upper limit on $R_\pi^r < 2.62$ [54]. It is worth mentioning that one can constrain the NP parameter space even further once more precise data on $B(B \to \pi \tau \nu)$ is available. Here too, more precise measurements are required to distinguish various NP structures.

IV. CONCLUSION

Lepton flavor universality violation has been observed in various semileptonic $B$ meson decays. The measured values of $R_D$ and $R_{D^*}$ exceed the SM expectation by $1.9\sigma$ and $3.3\sigma$, respectively. HFAG reported the combined deviation from the SM prediction to be at the level of $4\sigma$. Similar tensions have been observed in $B \to (K, K^*) ll$ and $B_s \to \phi ll$ decays mediated via $b \to s ll$ transition process as well. A lot of phenomenological studies have been performed in order to explain these discrepancies. Measurement of $B \to \tau \nu$ and $B \to (D, D^*) \tau \nu$ decays suffer $\tau$ detection and identification systematics. To examine this possibility, very recently, in Ref. [54], the authors introduced two new observables namely $R_D^r$ and $R_{D^*}^r$, where the $\tau$ detection and identification systematics will largely cancel. The estimated values of $R_D^r$ and $R_{D^*}^r$ are consistent with the SM prediction although there is discrepancy between the measured $R_D$ and $R_{D^*}$ with the SM prediction. This may occur for a class of NP which affect both $R_D$, $R_{D^*}$, and $B \to \tau \nu$ decays. In Ref. [54], the authors consider type II 2HDM model to illustrate these points.

In this paper, we use an effective field theory in the presence of NP to explore various NP couplings in a model independent way. First, we consider the constraints coming from the measured values of $R_D$, $R_{D^*}$, and $B(B \to \tau \nu)$ to see various NP effect on these new observables. Second, we see whether it is possible to constrain the NP parameter space even further by putting additional constraints coming from the estimated values of $R_D^r$ and $R_{D^*}^r$ since these ratios are consistent with the SM values. We study the effect of new physics couplings on various observables related to
$B_s \rightarrow (D_s, D^*_s) \tau \nu$ and $B \rightarrow \pi \tau \nu$ decays as well. The main results of our analysis are summarized below.

We first study the impact of NP couplings on various observables using $2\sigma$ constraints coming from BABAR measured values of $R_D$, $R_{D^*}$, and $\mathcal{B}(B \rightarrow \tau \nu)$. We consider four different NP scenarios. We find significant deviation from the SM prediction in each observable for each scenario. We find that, although, each of the four NP scenarios can simultaneously explain all the existing data on $b \rightarrow u$ and $b \rightarrow c$ leptonic and semileptonic $B$ meson decays, there are very few points that are compatible within the $2\sigma$ constraints coming from BABAR measurements for $(S_L, S_R)$ type NP couplings. Similarly, for $\tilde{S}_L$ and $\tilde{S}_R$ type NP couplings there is only one set of points that satisfy the BABAR $2\sigma$ constraints. Our second point was to see whether it is possible to constrain the NP parameter space even further by imposing constraints coming from the newly constructed observables $R_{\tau D}$ and $R_{\tau D^*}$ in a model independent way. We see that the additional constraint coming from the new observables $R_{\tau D}^r$ and $R_{\tau D^*}^r$ does not constrain $(S_L, S_R)$ and $(\tilde{S}_L, \tilde{S}_R)$ type NP parameter space. However, for $(V_L, V_R)$ and $(\tilde{V}_L, \tilde{V}_R)$ type NP couplings, the allowed ranges in $R_{\tau D}^r$, $R_{\tau D^*}^r$, $R_{D_s}^r$, $R_{D^*_s}^r$, and $R_{\tau \pi}^r$ are considerably reduced once the additional $2\sigma$ constraint from $R_{\tau D}^r$ and $R_{\tau D^*}^r$ are imposed.

We do the same analysis using the BELLE measured values. We first constrain the NP parameter space using $2\sigma$ constraints from BELLE measured values of $R_D$, $R_{D^*}$, and $\mathcal{B}(B \rightarrow \tau \nu)$. The deviation from the SM expectation is found to be significant in all the four scenarios. We find that for $(V_L, V_R)$ couplings, although, the allowed ranges in $R_{\tau D}^r$, $R_{\tau D^*}^r$, $R_{D_s}^r$, and $R_{D^*_s}^r$ do reduce, there is no or very little change in $R_{\tau \pi}^r$, $R_{\tau \pi}^r$, $R_{D_s}^r$, and $R_{D^*_s}^r$ allowed ranges once we impose $2\sigma$ constraints from $R_{\tau D}^r$ and $R_{\tau D^*}^r$. Similar results are obtained for $(\tilde{V}_L, \tilde{V}_R)$ NP couplings as well. For $(S_L, S_R)$ type NP couplings, the allowed ranges in $R_{\tau D}^r$, $R_{D_s}^r$, and $R_{D^*_s}^r$ reduce considerably, whereas, there is no or very little change in $R_{\tau D}^r$, $R_{D_s}^r$, $R_{D^*_s}^r$, and $R_{\tau \pi}^r$ allowed ranges once additional $2\sigma$ constraints from the estimated values of $R_{\tau D}^r$ and $R_{\tau D^*}^r$ are imposed. Similar results are obtained for $(\tilde{S}_L, \tilde{S}_R)$ NP couplings as well.

Although, current measurements from BABAR and BELLE suggest presence of NP, NP is yet to be confirmed. Both experimental and theoretical precision in these $B$ decay modes are necessary for a reliable interpretation of NP signals if NP is indeed present. Retaining our current approach, we could sharpen our estimates once improved measurement of $V_{ub}$ is available. These newly defined observables may, in future, play a crucial role in identifying the nature of NP couplings.
in $b \rightarrow (u, c)\tau\nu$ decays. Again, precise data on $\mathcal{B}(B \rightarrow \pi\tau\nu)$ will put additional constraint on the NP parameter space. Similarly, measurement of $R_{D_s}$ and $R_{D_s^*}$ will also help in identifying the nature of NP couplings in $b \rightarrow c\tau\nu$ decays.

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