Searching for New Physics with $b \to s\tau^+\tau^-$ Processes

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In recent years, intriguing hints for the violation of lepton flavor universality (LFU) have been accumulated in semileptonic B decays, both in the charged-current transitions $b \to c\ell^-\bar{\nu}_\ell$ (i.e., R_D, R_{D^*}, and $R_{J/\psi}$) and the neutral-current transitions $b \to s\ell^+\ell^-$ (i.e., R_K and R_{K^*}). Hints for LFU violation in $R_{D^{(*)}}$ and $R_{J/\psi}$ point at large deviations from the standard model (SM) in processes involving tau leptons. Moreover, LHCb has reported deviations from the SM expectations in $b \to s\mu^+\mu^-$ processes as well as in the ratios R_K and R_{K^*}, which together point at new physics (NP) affecting muons with a high significance. These hints for NP suggest the possibility of huge LFU-violating effects in $b \to s\tau^+\tau^-$ transitions. In this Letter, we predict the branching ratios of $B \to K\tau^+\tau^-$, $B \to K^*\tau^+\tau^-$, and $B_s \to \phi\tau^+\tau^-$, taking into account NP effects in the Wilson coefficients $C_{9(')}^{\tau\tau}$ and $C_{10(')}^{\tau\tau}$. Assuming a common NP explanation of R_D, $R_{D^{(*)}}$, and $R_{J/\psi}$, we show that a very large enhancement of $b \to s\tau^+\tau^-$ processes, of around 3 orders of magnitude compared to the SM, can be expected under fairly general assumptions. We find that the branching ratios of $B_s \to \tau^+\tau^-$, $B_s \to \phi\tau^+\tau^-$, and $B \to K^{(*)}\tau^+\tau^-$ under these assumptions are in the observable range for LHCb and Belle II.

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Introduction.—While the LHC has not observed any new fundamental particle beyond the standard model (SM) ones directly so far, several intriguing hints of new physics (NP) in semileptonic B decays arose recently.

On the one hand, measurements of the $b \to c\ell^-\bar{\nu}_\ell$ charged current have shown interesting hints, even though these are tree-level processes in the SM which are, in general, not very sensitive to NP. The ratios $R_{D^{(*)}}$, which compare tau and light-lepton (e, μ) modes, differ from their SM predictions by a combined significance of approximately 4σ [1]. While the e, μ channels are consistent with the assumption of lepton flavor universality (LFU) [2], the effect related to tau leptons in $R_{D^{(*)}}$ corresponds to an $O(10\%)$ effect at the amplitude level, assuming that it interferes with the SM. Recently, LHCb released results for the ratio $R_{J/\psi}$ [3]. Again, even though the error is large, the experimental central value significantly exceeds the SM prediction which is in agreement with the LFU violation in $R_{D^{(*)}}$ [4–7].

On the other hand, the flavor-changing neutral current $b \to s\mu^+\mu^-$ is loop suppressed in the SM and therefore very sensitive to NP. A collection of deviations from the SM in angular observables and branching ratios has been observed. Moreover, the comparison of $b \to s\mu^+\mu^-$ and $b \to se^+e^-$ through R_K [8] and R_{K^*} [9] suggests a significant violation of LFU. The pattern of these deviations can be explained consistently in a model-independent approach by NP contributions to Wilson coefficients associated with $b \to s\mu^+\mu^-$ operators. A recent combined analysis [10] indeed singles out some NP scenarios preferred over the SM with a significance at the 5σ level (confirming scenarios identified in earlier analyses, mainly restricted to $b \to s\mu^+\mu^-$ processes [11–14]). The significance for these NP scenarios considering only the LFU-violating observables R_K and R_{K^*} (and excluding other $b \to s\mu^+\mu^-$ processes) is at the 3σ–4σ level [15–19]. The violation of LFU between muons and electrons is indeed significant, around 25% at the level of some of the Wilson coefficients.

We might thus expect a large violation of LFU in $b \to s\tau^+\tau^-$ transitions. An enhancement of up to 3 orders of magnitude can be expected compared to the SM predictions in $b \to s\tau^+\tau^-$ processes if one aims at explaining the central value of $R_{D^{(*)}}$ [20–22]. So far, among the possible processes, only LHCb searched for $B_s \to \tau^+\tau^-$ [23]:

$$\mathrm{Br}(B_s \to \tau^+\tau^-)_{\mathrm{EXP}} \leq 6.8 \times 10^{-3}, \tag{1}$$

and *BABAR* performed an analysis of $B \to K\tau^+\tau^-$ [24]:

$$\mathrm{Br}(B \to K\tau^+\tau^-)_{\mathrm{EXP}} \leq 2.25 \times 10^{-3}. \tag{2}$$

There are good experimental prospects for these transitions at LHCb and Belle II.

On the theory side, $b \to s\tau^+\tau^-$ processes have received limited attention so far. Within the SM, the $B_s \to \tau^+\tau^-$ branching ratio is known very precisely [25,26]:

$$\mathrm{Br}(B_s \to \tau^+\tau^-)_{\mathrm{SM}} = (7.73 \pm 0.49) \times 10^{-7}, \qquad (3)$$

whereas the $b \to s\tau^+\tau^-$ processes $B \to K^*\tau^+\tau^-$, $B \to K\tau^+\tau^-$, and $B_s \to \phi\tau^+\tau^-$ have not been considered in detail until recently, especially concerning the impact of NP contributions. While the upper limits on $B_s \to \tau^+\tau^-$ were studied in Refs. [27–29], the branching ratio for $B \to K\tau^+\tau^-$ was estimated in Ref. [30] including NP effects. Recently, an analysis of branching ratios and tau polarizations in $b \to s\tau^+\tau^-$ was performed to determine the sensitivity to NP contributions to the Wilson coefficients [31].

Within the SM, the branching ratios for $B \to K^*\tau^+\tau^-$ and $B_s \to \phi\tau^+\tau^-$ are known to be of $O(10^{-7})$ [31–33], and the inclusive $B \to X_s\tau^+\tau^-$ process was assessed in Refs. [30,34]. Reference [30] also studied the indirect constraints on $b \to s\tau^+\tau^-$ operators, which are very loose once the effects in $b \to s\tau^+\tau^-$ and $b \to d\tau^+\tau^-$ transitions are correlated such that the stringent bounds from $\Delta\Gamma_s/\Delta\Gamma_d$ are avoided. Interestingly, sizable effects in analogous $b \to d\tau^+\tau^-$ operators [35] could help explaining the like-sign dimuon asymmetry measured by the D0 experiment [36,37].

In this Letter, we look in detail at the $b \to s\tau^+\tau^-$ processes $B_s \to \tau^+\tau^-$, $B \to K^*\tau^+\tau^-$, $B \to K\tau^+\tau^-$, and $B_s \to \phi\tau^+\tau^-$. We will express their branching ratios in terms of the Wilson coefficients $C_{9(')}$ and $C_{10(')}$ using the same approach as in Ref. [12]. Since the mass of the tau leptons cannot be neglected compared to the B meson, the allowed kinematic region is much smaller than for decays to light leptons, corresponding to the high-q^2 region (or low recoil).

In the next section, we consider the generic effects of NP originating from vector operators. Then we correlate the effects in $b \to s\tau^+\tau^-$ to R_D and R_{D^*} and study the impact on branching ratios, before we conclude in the final section.

Effective Hamiltonian approach to $b \to s\tau^+\tau^-$.—In this section, we express the branching ratios for our $b \to s\tau^+\tau^-$ processes as functions of $C^{\tau\tau}_{9(')}$ and $C^{\tau\tau}_{10(')}$ and calculate the SM predictions. We define our effective Hamiltonian in the following way, focusing on the relevant operators for our discussion:

$$H_{\mathrm{eff}}(b \to s\tau\tau) = -\frac{4G_F}{\sqrt{2}} V_{tb}V^*_{ts} \sum_a C_a O_a, \qquad (4)$$

$$O^{\tau\tau}_{9(10)} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_L b][\bar{\tau}\gamma_\mu(\gamma^5)\tau], \qquad (5)$$

$$O^{\tau\tau}_{9'(10')} = \frac{\alpha}{4\pi}[\bar{s}\gamma^\mu P_R b][\bar{\tau}\gamma_\mu(\gamma^5)\tau], \qquad (6)$$

where $C^{\mathrm{SM}}_9 \approx 4.1$ and $C^{\mathrm{SM}}_{10} \approx -4.3$ at the scale $\mu = 4.8$ GeV [38–40], $P_{L,R} = (1 \mp \gamma_5)/2$, and the chirality-flipped coefficients have negligible contributions in the SM. We perform the splitting between SM and NP contributions $C_{9(10)} = C^{\mathrm{SM}}_{9(10)} + C^{\mathrm{NP}}_{9(10)}$, whereas $C_{9'(10')} = C^{\mathrm{NP}}_{9'(10')}$.

Here we neglected the effects of scalar and tensor operators whose presence is preferred neither by $b \to s\ell^+\ell^-$ data nor by $b \to c\tau^-\bar{\nu}$ processes. Concerning $b \to s\ell^+\ell^-$, global analyses of $\ell = e, \mu$ data [11–14] show that the operators $O^{\mu\mu}_{9,10}$ (and potentially their primed counterparts) are sufficient, since stringent constraints on scalar operators come from $\mathrm{Br}(B_s \to \mu^+\mu^-)$. Furthermore, tensor operators are not generated at the dimension-6 level for $b \to s\ell^+\ell^-$ once $SU(2)_L$ gauge invariance is taken into account [41,42]. Concerning $b \to c\tau^-\bar{\nu}_\tau$ transitions, the constraints on the scalar and pseudoscalar couplings from the total lifetime of the B_c meson [43–45] and from differential distributions in $B \to D^{(*)}\tau^-\bar{\nu}_\tau$ [46,47] are in tension with a simultaneous explanation of $R(D)$ and $R(D^*)$ [48,49] (these constraints could be avoided with right-handed couplings [43], including possibly right-handed neutrinos [50]). However, no interference with the SM appears for such solutions, which require very large couplings close to the perturbativity limit. Moreover, ultraviolet complete models with an additional neutral spin-0 particle are ruled out by LHC direct searches for resonances in the $\tau^+\tau^-$ channel [51]. It is thus natural to assume that NP in $b \to s\tau^+\tau^-$ transitions should come dominantly from operators with a similar structure than those favored by the anomalies in $b \to s\ell^+\ell^-$ ($\ell = e, \mu$) and $b \to c\tau^-\bar{\nu}$ transitions.

Besides $\mathrm{Br}(B_s \to \tau^+\tau^-)_{\mathrm{SM}}$ given in Eq. (3), we use the approach and inputs in Refs. [10,12,52,53] to compute the other processes of interest. Averaging over the charged and the neutral modes for $B \to K^{(*)}\tau^+\tau^-$ and $B_s \to \phi\tau^+\tau^-$, we find

$$\mathrm{Br}(B \to K\tau^+\tau^-)^{[15,22]}_{\mathrm{SM}} = (1.20 \pm 0.12) \times 10^{-7}, \qquad (7)$$

$$\mathrm{Br}(B \to K^*\tau^+\tau^-)^{[15,19]}_{\mathrm{SM}} = (0.98 \pm 0.10) \times 10^{-7}, \qquad (8)$$

$$\mathrm{Br}(B_s \to \phi\tau^+\tau^-)^{[15,18.8]}_{\mathrm{SM}} = (0.86 \pm 0.06) \times 10^{-7}. \qquad (9)$$

The superscript denotes the q^2 range for the dilepton invariant mass. This broad bin is chosen to leave out the $\psi(2S)$ resonance, allowing the use of quark-hadron duality.

We may include NP contributions and parametrize both the central value and uncertainty of the branching ratio in each channel as quadratic polynomials in the NP contributions C^{NP}_9, C^{NP}_{10}, $C_{9'}$, and $C_{10'}$ in the ranges $[-2, 2]$, $[-2, 2]$, $[-1, 1]$, and $[-0.2, 0.2]$, respectively:

$$\begin{aligned}10^7\times \mathrm{Br}(B\to K\tau^+\tau^-)^{[15,22]} &= (1.20+0.15C_9^{\mathrm{NP}}-0.42C_{10}^{\mathrm{NP}}+0.15C_{9'}-0.42C_{10'}+0.04C_9^{\mathrm{NP}}C_{9'}\\ &\quad +0.10C_{10}^{\mathrm{NP}}C_{10'}+0.02C_9^{\mathrm{NP}2}+0.05C_{10}^{\mathrm{NP}2}+0.02C_{9'}^2+0.05C_{10'}^2)\\ &\quad \pm(0.12+0.02C_9^{\mathrm{NP}}-0.04C_{10}^{\mathrm{NP}}+0.01C_{9'}-0.04C_{10'}\\ &\quad +0.01C_{10}^{\mathrm{NP}}C_{10'}+0.01C_{10}^{\mathrm{NP}2}+0.08C_{10'}^2),\end{aligned} \tag{10}$$

$$\begin{aligned}10^7\times \mathrm{Br}(B\to K^*\tau^+\tau^-)^{[15,19]} &= (0.98+0.38C_9^{\mathrm{NP}}-0.14C_{10}^{\mathrm{NP}}-0.30C_{9'}+0.12C_{10'}-0.08C_9^{\mathrm{NP}}C_{9'}\\ &\quad -0.03C_{10}^{\mathrm{NP}}C_{10'}+0.05C_9^{\mathrm{NP}2}+0.02C_{10}^{\mathrm{NP}2}+0.05C_{9'}^2+0.02C_{10'}^2)\\ &\quad \pm(0.09+0.03C_9^{\mathrm{NP}}-0.01C_{10}^{\mathrm{NP}}-0.03C_{9'}-0.01C_9^{\mathrm{NP}}C_{9'}\\ &\quad -0.01C_{9'}C_{10'}+0.01C_{9'}^2-0.01C_{10'}^2),\end{aligned} \tag{11}$$

$$\begin{aligned}10^7\times \mathrm{Br}(B_s\to \phi\tau^+\tau^-)^{[15,18.8]} &= (0.86+0.34C_9^{\mathrm{NP}}-0.11C_{10}^{\mathrm{NP}}-0.28C_{9'}+0.10C_{10'}-0.08C_9^{\mathrm{NP}}C_{9'}\\ &\quad -0.02C_{10}^{\mathrm{NP}}C_{10'}+0.05C_9^{\mathrm{NP}2}+0.01C_{10}^{\mathrm{NP}2}+0.05C_{9'}^2+0.01C_{10'}^2)\\ &\quad \pm(0.06+0.02C_9^{\mathrm{NP}}-0.02C_{9'}+0.02C_{10'}^2).\end{aligned} \tag{12}$$

As expected, there is a limited dependence of the uncertainties on the values of the Wilson coefficients. In order to shorten the equations, we dropped the superscript $\tau\tau$ in the Wilson coefficients here. Comparing our results with Ref. [31], we find slightly lower central values for the SM [Eqs. (7)–(9)]. On the other hand, we obtain the same dependence of the central values on the NP contributions to the Wilson coefficients [Eqs. (10)–(12)].

Correlation with $R_{D^{(*)}}$ and $R_{J/\psi}$.—It is interesting to correlate these results with the tree-level $b\to c\tau^-\bar{\nu}_\tau$ transition. A solution of the $\sim 4\sigma$ anomaly in $R_{D^{(*)}}$ and $R_{J/\psi}$ requires a NP contribution of $\mathcal{O}(20\%)$ to the branching ratio of $B\to D^{(*)}\tau^-\bar{\nu}_\tau$, which is rather large given that these decays are mediated in the SM already at the tree level. While scalar and tensor solutions are disfavored as discussed in the previous section, a contribution to the SM operator $[\bar{c}\gamma^\mu P_L b][\bar{\tau}\gamma_\mu P_L \nu_\tau]$ is favored such that there is interference with the SM. Since a NP contribution to the Wilson coefficient of the SM $V-A$ operator amounts only to changing the normalization of the Fermi constant for $b\to c\tau^-\bar{\nu}_\tau$ transitions, one predicts in this case $R_{J/\psi}/R_{J/\psi}^{\mathrm{SM}}=R_D/R_D^{\mathrm{SM}}=R_{D^*}/R_{D^*}^{\mathrm{SM}}$, which agrees well with the current measurements.

If NP generates this contribution from a scale much larger than the electroweak symmetry breaking scale [54,55], the semileptonic decays involving only left-handed quarks and leptons are described by the two $SU(2)_L$-invariant operators

$$O_{ijkl}^{(1)}=[\bar{Q}_i\gamma_\mu Q_j][\bar{L}_k\gamma^\mu L_l], \tag{13}$$

$$O_{ijkl}^{(3)}=[\bar{Q}_i\gamma_\mu\sigma^I Q_j][\bar{L}_k\gamma^\mu\sigma^I L_l], \tag{14}$$

where the Pauli matrices σ^I act on the weak-isospin components of the quark (lepton) doublets Q (L). There are no further dimension-6 operators involving only left-handed fields, and dimension-8 operators can be neglected for NP around the TeV scale. This approach has been used to correlate Wilson coefficients of the effective Hamiltonian for both charged- and neutral-current transitions in various broad classes of NP models [20,56–58].

After electroweak symmetry breaking, these operators contribute to semileptonic $b\to c(s)$ decays involving charged tau leptons and tau neutrinos. Working in the down basis when writing the $SU(2)$ components of the operators $O^{(1)}$ and $O^{(3)}$ (i.e., in the field basis with diagonal down-quark mass matrices), we obtain

$$\begin{aligned}C^{(1)}\mathcal{O}^{(1)} &\to C_{23}^{(1)}([\bar{s}_L\gamma_\mu b_L][\bar{\tau}_L\gamma^\mu\tau_L]+[\bar{s}_L\gamma_\mu b_L][\bar{\nu}_\tau\gamma^\mu\nu_\tau]),\\ C^{(3)}\mathcal{O}^{(3)} &\to C_{23}^{(3)}(2V_{cs}[\bar{c}_L\gamma_\mu b_L][\bar{\tau}_L\gamma^\mu\nu_\tau]+[\bar{s}_L\gamma_\mu b_L][\bar{\tau}_L\gamma^\mu\tau_L]\\ &\qquad -[\bar{s}_L\gamma_\mu b_L][\bar{\nu}_\tau\gamma^\mu\nu_\tau])+C_{33}^{(3)}(2V_{cb}[\bar{c}_L\gamma_\mu b_L][\bar{\tau}_L\gamma^\mu\nu_\tau]),\end{aligned} \tag{15}$$

where $C_{ij}^{(n)}$ denote the Wilson coefficients for $\mathcal{O}_{ij33}^{(n)}$.

We neglect the effect of $C_{13}^{(3)}$ which would enter $b\to c\tau^-\bar{\nu}_\tau$ processes with a factor proportional to V_{cd}. But it would contribute even more dominantly to $b\to d\tau^+\tau^+$ and $b\to u\tau^-\bar{\nu}_\tau$ processes such as $B^-\to\tau^-\bar{\nu}_\tau$, where no deviation from the SM is observed [59,60]. We will thus not consider this contribution anymore.

As a consequence, we see that $b\to c\tau^-\bar{\nu}_\tau$ processes receive a NP contribution from $C_{33}^{(3)}$ also in scenarios with a flavor-diagonal alignment to the third generation, which would avoid any effects in down-quark flavor-changing neutral currents. However, due to the Cabibbo-Kobayashi-Maskawa (CKM) suppression of this contribution, a solution of the $R_{D^{(*)}}$ anomaly via this contribution requires a rather large $C_{33}^{(3)}$ coming into conflict with bounds from electroweak precision data [61] and direct LHC searches for $\tau^+\tau^-$ final states [51].

The $R_{D^{(*)}}$ anomaly can thus be solved only via $C_{23}^{(1,3)}$, which then must generate huge contributions to $b \to s\tau^+\tau^-$ and/or $b \to s\nu_\tau\bar{\nu}_\tau$ processes. The severe bounds on NP from $B \to K^{(*)}\nu\bar{\nu}$ (e.g., Ref. [62]) rule out large effects in $b \to s\nu\bar{\nu}$, requiring an approximate cancellation between $C_{23}^{(3)}$ and $C_{23}^{(1)}$ through $C_{23}^{(1)} \approx C_{23}^{(3)}$ [58]. Such a situation can, for instance, be realized by a vector leptoquark singlet [20,22,56,63–65] or by combining two scalar leptoquarks [21]. Neglecting small CKM factors, the assumption $C_{23}^{(1)} \approx C_{23}^{(3)}$ implies that contributions to $b \to c\tau^-\bar{\nu}_\tau$ and $b \to s\tau^+\tau^-$ are generated together in the combination

$$[\bar{c}_L\gamma_\mu b_L][\bar{\tau}_L\gamma^\mu\nu_\tau] + [\bar{s}_L\gamma_\mu b_L][\bar{\tau}_L\gamma^\mu\tau_L]. \tag{16}$$

This correlation means that effects in $b \to s\tau^+\tau^-$ are of the same order as the ones required to explain $R_{D^{(*)}}$, i.e., of the order of a tree-level SM process. Therefore, a NP contribution for $b \to c\tau^-\bar{\nu}_\tau$ which is of the order of 10% compared to the SM tree-level contribution is connected to a NP contribution for $b \to s\tau^+\tau^-$ of a similar size, which is very large compared to the SM loop-level contribution.

Taking into account that the operators in Eq. (16) involve left-handed fields and, thus, contribute to both vector and axial couplings to the τ leptons, we find the relation

$$C_{9(10)}^{\tau\tau} \approx C_{9(10)}^{\rm SM} - (+)\Delta, \tag{17}$$

with

$$\Delta = \frac{2\pi}{\alpha}\frac{V_{cb}}{V_{tb}V_{ts}^*}\left(\sqrt{\frac{R_X}{R_X^{\rm SM}}} - 1\right), \tag{18}$$

where we have neglected Cabibbo-suppressed contributions. In our framework, Δ is independent of the exclusive $b \to c\ell^-\bar{\nu}_\ell$ channel chosen. Note that this prediction for the Wilson coefficients $C_9^{\tau\tau}$ and $C_{10}^{\tau\tau}$ is model independent, in the sense that the only ingredients in the derivation are the assumptions that NP affects only left-handed quarks and leptons and that it couples significantly to the second generation in such a way that experimental constraints can be avoided.

We stress that the factor multiplying the bracket in Eq. (18) is very large (around 860). Using the current values for $R_{D^{(*)}}$, we obtain a positive (respectively, negative) NP contribution to the Wilson coefficient $C_9^{\tau\tau}$ (respectively, $C_{10}^{\tau\tau}$) parametrized by $\Delta = O(100)$ which overwhelms completely the SM contribution to these Wilson coefficients. For instance, by taking $R_X/R_X^{\rm SM} = 1.3$, the corresponding Wilson coefficients are $C_{9(10)}^{\tau\tau} \simeq -(+)116$. Such large values of the Wilson coefficients are not in contradiction with the constraints obtained in Ref. [30] (when comparing with the results of this reference, one must be aware of the different normalizations of the operators in the effective Hamiltonian).

In view of these huge coefficients, we provide predictions for the relevant decay rates assuming that they are completely dominated by the NP contribution Δ and, thus, neglecting both short- and long-distance SM contributions. We obtain the branching ratios of the various $b \to s\tau^+\tau^-$ channels:

$$\mathrm{Br}(B_s \to \tau^+\tau^-) = \left(\frac{\Delta}{C_{10}^{\rm SM}}\right)^2 \mathrm{Br}(B_s \to \tau^+\tau^-)_{\rm SM}, \tag{19}$$

$$\mathrm{Br}(B \to K\tau^+\tau^-) = (8.8 \pm 0.8) \times 10^{-9}\Delta^2, \tag{20}$$

$$\mathrm{Br}(B \to K^*\tau^+\tau^-) = (10.1 \pm 0.8) \times 10^{-9}\Delta^2, \tag{21}$$

$$\mathrm{Br}(B_s \to \phi\tau^+\tau^-) = (9.1 \pm 0.5) \times 10^{-9}\Delta^2, \tag{22}$$

where the last three branching ratios are considered over the whole kinematic range for the lepton pair invariant mass q^2 (i.e., from $4m_\tau^2$ up to the low-recoil end point). We neglect the contributions only due to the SM. In the above expressions, the uncertainties quoted come from hadronic contributions multiplied by the short-distance NP contribution Δ. A naive estimate suggests that the contribution of the $\psi(2S)$ resonance to this branching ratio amounts to 2×10^{-6}, which is negligible in the limit of very large NP contributions considered here. We thus may calculate the branching ratios for the whole kinematically allowed q^2 region, from the vicinity of the $\psi(2S)$ resonance up to the low-recoil end point, assuming that the result is completely dominated by the NP contribution.

Since we neglected all errors related to the SM contribution for the semileptonic processes, we do the same for $\mathrm{Br}(B_s \to \tau^+\tau^-)_{\rm SM}$ in Eq. (19), considering only the uncertainties coming from the B_s decay constant and decay width as well as the different scales used to compute the Wilson coefficients here and in Ref. [25], leading to a relative uncertainty of 4.7% [to be compared with the larger 6.4% uncertainty in Eq. (3) that includes other sources of uncertainties irrelevant under our current assumptions].

In Fig. 1, we indicate the corresponding predictions as a function of $R_X/R_X^{\rm SM}$ (assumed to be independent of the $b \to c\ell^-\bar{\nu}_\ell$ hadronic decay channel X in our approach). We have also indicated the current experimental range for $R_X/R_X^{\rm SM}$, obtained by performing the weighted average of R_D, R_{D^*}, and $R_{J/\psi}$ without taking into account correlations. We see that the branching ratios for semileptonic decays can easily reach 3×10^{-4}, whereas $B_s \to \tau^+\tau^-$ can be increased up to 10^{-3}.

Up to now, we have discussed the correlation between NP in $b \to c\tau\bar{\nu}_\tau$ and $b \to s\tau^+\tau^-$ under a fairly model-independent set of assumptions. If we assume that the same

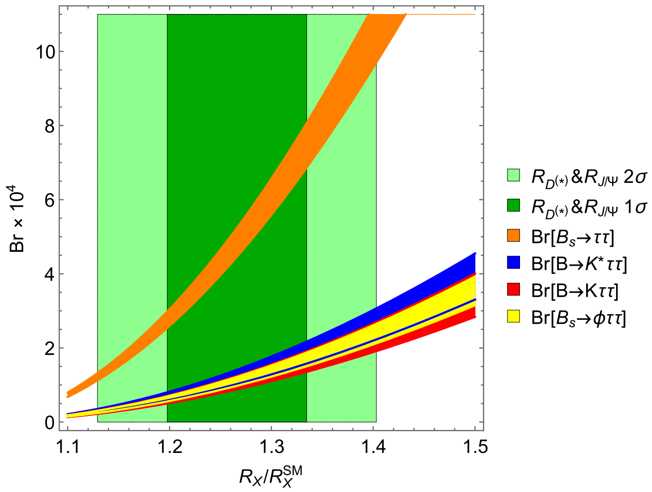

FIG. 1. Predictions of the branching ratios of the $b \to s\tau^+\tau^-$ processes (including uncertainties) as a function of $R_X/R_X^{\rm SM}$.

mechanism is at work for muons and taus, we obtain also a correlation between $b \to s\mu^+\mu^-$ and $b \to c\mu^-\bar{\nu}_\mu$: The $O(25\%)$ shift needed in $C_9^{\mu\mu}$ and $C_{10}^{\mu\mu}$ to describe $b \to s\mu^+\mu^-$ data [10] translates into a very small positive Δ for muons (compared to the very large negative Δ for taus), leading to a decrease of $b \to c\mu^-\bar{\nu}_\mu$ decay rates compared to the SM by a negligible amount of only a few per mille, and there would be no measurable differences between electron and muon semileptonic decays.

Conclusions.—In this Letter, we have studied the possibility of finding NP in $b \to s\tau^+\tau^-$ processes motivated by the converging experimental evidence for LFU violation in both $b \to s$ and $b \to c$ transitions. We have updated the SM predictions for $B \to K\tau^+\tau^-$, $B \to K^*\tau^+\tau^-$, and $B_s \to \phi\tau^+\tau^-$ and calculated the expression of these branching ratios in terms of NP contributions to the $b \to s\tau^+\tau^-$ Wilson coefficients $C^{\tau\tau}_{9,10,9',10'}$.

We have also analyzed the correlation between NP contributions to $b \to s\tau^+\tau^-$ and $b \to c\tau^-\bar{\nu}_\tau$ under general assumptions in agreement with experimental indications: The deviations in $b \to c\tau^-\bar{\nu}_\tau$ decays come from a NP contribution to the left-handed four-fermion vector operator, this NP contribution is due to physics coming from a scale significantly larger than the electroweak scale, and the resulting contribution to $b \to s\nu_\tau\bar{\nu}_\tau$ is suppressed.

Under these assumptions, an explanation of $R_{D^{(*)}}$ requires an enhancement of all $b \to s\tau^+\tau^-$ processes by approximately 3 orders of magnitude compared to the SM. In this case, the predictions for the branching ratios are completely dominated by NP contributions when integrated over the whole kinematic region allowed for the dilepton invariant mass. The corresponding enhancement yields branching ratios between 10^{-4} and 10^{-3} for these modes, as illustrated in Fig. 1.

There are many models which aim at explaining the $b \to c\tau\nu$ anomalies, including charged Higgs bosons [66–73], W' gauge bosons [74–77], and leptoquarks [20,43,50,56,63,64,78–88]. However, models with charged Higgs bosons produce scalar currents which are disfavored as discussed earlier. W' models are mostly in conflict with LHC searches [51,74] and also leptoquarks are bounded by high energy analysis [51]. In leptoquark models, the bounds can be avoided by assuming a large coupling to the second generation [20–22]. This latter class of leptoquark models, which survives all the constraints, leads exactly to the setup outlined in the introduction and a large enhancement of $b \to s\tau^+\tau^-$ processes. Probing these transitions would thus help to discard or confirm this promising class of models.

Our study thus confirms the potential of $b \to s\tau^+\tau^-$ decays in the current and forthcoming experiments studying b decays such as LHCb and Belle II, which will provide complementary analyses of these decays with the exciting opportunity to discover NP in these transitions.

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