Hadronic τ Decays as New Physics Probes in the LHC Era

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We analyze the sensitivity of hadronic τ decays to nonstandard interactions within the model-independent framework of the standard model effective field theory. Both exclusive and inclusive decays are studied, using the latest lattice data and QCD dispersion relations. We show that there are enough theoretically clean channels to disentangle all the effective couplings contributing to these decays, with the $\tau \to \pi\pi\nu_\tau$ channel representing an unexpected powerful new physics probe. We find that the ratios of nonstandard couplings to the Fermi constant are bound at the subpercent level. These bounds are complementary to the ones from electroweak precision observables and $pp \to \tau\nu_\tau$ measurements at the LHC. The combination of τ decay and LHC data puts tighter constraints on lepton universality violation in the gauge boson-lepton vertex corrections.

Hadronic tau decays have been extensively used in the last decades to learn about fundamental physics [1,2]. The inclusive decays are used to accurately extract fundamental standard model (SM) parameters such as the strong coupling constant [3–5], the strange quark mass, or the V_{us} entry of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [6,7]. They also represent a valuable QCD laboratory, where chiral parameters or properties of the QCD vacuum can be extracted with high precision in a model-independent fashion through dispersion relations [8,9]. On the other hand, exclusive hadronic tau decays are much harder to predict within QCD with high accuracy, and thus, they are useful for learning about hadronic physics. The only exceptions are the two-body decays $\tau \to \pi\nu_\tau, K\nu_\tau$, thanks to the precise lattice calculations of the pion and kaon decay constants [10].

The agreement between the above-mentioned determinations of SM and QCD parameters with determinations using other processes represents a nontrivial achievement, which is only possible thanks to the impressive effort carried out in several fronts: experimental, lattice, and analytical QCD methods. Needless to say, this agreement is easily spoiled if nonstandard effects are present. However, the use of hadronic tau decays as new physics (NP) probes

has been marginal so far (see, e.g., Refs. [11,12]), with the exception, once again, of the simple $\tau \to \pi\nu_\tau, K\nu_\tau$ channels. The goal of this Letter is to amend this situation presenting an unprecedented comprehensive analysis of the NP reach of CP-conserving hadronic tau decays.

For the sake of definiteness, we focus on the nonstrange decays, which are governed by the following low-energy effective Lagrangian [13,14]

$$
\begin{aligned}
\mathcal{L}_{\text{eff}} = -\frac{G_F V_{ud}}{\sqrt{2}} & [(1 + \epsilon_L^\tau)\bar{\tau}\gamma_\mu(1 - \gamma_5)\nu_\tau \cdot \bar{u}\gamma^\mu(1 - \gamma_5)d \\
& + \epsilon_R^\tau \bar{\tau}\gamma_\mu(1 - \gamma_5)\nu_\tau \cdot \bar{u}\gamma^\mu(1 + \gamma_5)d \\
& + \bar{\tau}(1 - \gamma_5)\nu_\tau \cdot \bar{u}[\epsilon_S^\tau - \epsilon_P^\tau \gamma_5]d \\
& + \epsilon_T^\tau \bar{\tau}\sigma_{\mu\nu}(1 - \gamma_5)\nu_\tau \cdot \bar{u}\sigma^{\mu\nu}(1 - \gamma_5)d] + \text{H.c.}, \quad (1)
\end{aligned}
$$

where we use $\sigma^{\mu\nu} = i[\gamma^\mu, \gamma^\nu]/2$, and G_F is the Fermi constant. The only assumptions are Lorentz and $U(1)_{\text{em}} \times SU(3)_C$ invariance, and the absence of light nonstandard particles. In practice, we also assume that the subleading derivative terms in the effective field theory (EFT) expansion (suppressed by m_τ/m_W) are, indeed, negligible. The Wilson coefficients ϵ_i parametrize nonstandard contributions, and they vanish in the SM leaving the $V - A$ structure generated by the exchange of a W boson. The nonstandard coefficients ϵ_i can be complex, but the sensitivity of the observables considered in this Letter to the imaginary parts of the coefficients is very small. Thus, the results, hereafter, implicitly refer to the real parts of ϵ_i.

Through a combination of inclusive and exclusive τ decays, we are able to constrain all the Wilson coefficients in Eq. (1)—this is the main result of this Letter. In the $\overline{\text{MS}}$ scheme at scale $\mu = 2$ GeV, we find the following central values and 1σ uncertainties:

$$\begin{pmatrix} \epsilon_L^\tau - \epsilon_L^e + \epsilon_R^\tau - \epsilon_R^e \\ \epsilon_R^\tau \\ \epsilon_S^\tau \\ \epsilon_P^\tau \\ \epsilon_T^\tau \end{pmatrix} = \begin{pmatrix} 1.0 \pm 1.1 \\ 0.2 \pm 1.3 \\ -0.6 \pm 1.5 \\ 0.5 \pm 1.2 \\ -0.04 \pm 0.46 \end{pmatrix} \times 10^{-2}, \quad (2)$$

where $\epsilon_{L,R}^e$ parametrize electron couplings to the first generation quarks and are defined in analogy to their tau counterparts. They affect the $G_F V_{ud}$ value obtained in nuclear β decays [16], which is needed in the analysis of hadronic tau decays. The correlation matrix associated to (2) is

$$\rho = \begin{pmatrix} 0.88 & 0 & -0.57 & -0.94 \\ & 0 & -0.86 & -0.94 \\ & & 0 & 0 \\ & & & 0.66 \end{pmatrix}. \quad (3)$$

Below, we summarize how Eqs. (2)–(3) were derived.

Exclusive decays.—The $\tau \to \pi \nu_\tau$ channel [17] gives the following 68% C.L. constraint:

$$\epsilon_L^\tau - \epsilon_L^e - \epsilon_R^\tau - \epsilon_R^e - \frac{B_0}{m_\tau}\epsilon_P^\tau = (-1.5 \pm 6.7) \times 10^{-3}, \quad (4)$$

where $B_0 = m_\pi^2/(m_u + m_d)$. We included the SM radiative corrections [18–20] and the latest lattice average for the pion decay constant, $f_{\pi^\pm} = 130.2(8)$ MeV ($N_f = 2 + 1$) [21], from Refs. [22–24]. We stress that the lattice determinations of $f_{\pi^\pm}$ are a crucial input to search for NP in this channel, and despite its impressive precision, it represents the dominant source of error in Eq. (4), followed by the experimental error (2.4 times smaller) and the radiative corrections uncertainty. Because of this, significant improvement in the bound above can be expected in the near future. Alternatively, as is often seen in the literature [1], one can obtain tighter constraints on the effective theory parameters by considering "theoretically clean" ratios of observables where the f_π dependence cancels out. For example, from the ratio $\Gamma(\tau \to \pi \nu)/\Gamma(\pi \to \mu \nu)$ one can deduce

$$\epsilon_L^\tau - \epsilon_L^\mu - \epsilon_R^\tau + \epsilon_R^\mu - \frac{B_0}{m_\tau}\epsilon_P^\tau + \frac{B_0}{m_\mu}\epsilon_P^\mu = (-3.8 \pm 2.7) \times 10^{-3}. \quad (5)$$

This and similar constraints are not included in Eq. (2), which only summarizes the input from hadronic tau decays without using any meson decay observables. Instead, we later combine Eq. (2) with the results of Ref. [25], which derived a likelihood for the effective theory parameters based on a global analysis of pion and kaon decays. The combination effectively includes constraints from $\Gamma(\tau \to \pi \nu)/\Gamma(\pi \to \ell \nu)$, with correlations due to the common f_π uncertainty taken into account.

The $\tau \to \pi\pi\nu_\tau$ channel, which is sensitive to vector and tensor interactions, is much more complicated to predict within QCD in a model-independent way. However, a stringent constraint can be obtained through the comparison of the spectral functions extracted from $\tau \to \pi\pi\nu_\tau$ and its isospin-rotated process $e^+e^- \to \pi^+\pi^-$, after the proper inclusion of isospin-symmetry-breaking corrections. The crucial point here is that heavy NP effects (associated with the scale Λ) can be entirely neglected in $e^+e^- \to \pi^+\pi^-$ at energy $\sqrt{s} \ll \Lambda$ due to the electromagnetic nature of this process. We can benefit from past studies that exploited this isospin relation to extract from data the $\pi\pi$ component of the lowest-order (LO) hadronic vacuum polarization contribution to the muon $g - 2$, usually denoted by $a_\mu^{\text{had,LO}}[\pi\pi]$, through a dispersion integral. Such an approach implicitly assumes the absence of NP effects, which, however, may contribute to the extraction from tau data. In this way, we find a subpercent level sensitivity to NP effects

$$\frac{a_\mu^\tau - a_\mu^{ee}}{2a_\mu^{ee}} = \epsilon_L^\tau - \epsilon_L^e + \epsilon_R^\tau - \epsilon_R^e + 1.7\epsilon_T^\tau$$

$$= (8.9 \pm 4.4) \times 10^{-3}, \quad (6)$$

where $a_\mu^\tau = (516.2 \pm 3.6) \times 10^{-10}$ [26] and $a_\mu^{ee} = (507.14 \pm 2.58) \times 10^{-10}$ [27] are the values of $a_\mu^{\text{had,LO}}[\pi\pi]$ extracted from τ and e^+e^- data. The $\sim 2\sigma$ tension with the SM reflects the well-known disagreement between both datasets [27,28]. In order to estimate the factor multiplying ϵ_T in Eq. (6), we have (i) assumed that the proportionality of the tensor and vector form factors, which is exact in the elastic region [30,31], holds in the dominant ρ resonance region (as is the case within the resonance chiral theory framework [32]), and (ii) used the lattice QCD result of Ref. [33] for the $\pi\pi$ tensor form factor at zero momentum transfer (see, also, Refs. [34,35]). Inelastic effects impact the estimate 1.7 at the $< 10\%$ level. This small uncertainty can be traced back to the fact that the coefficient 1.7 arises from the ratio of two integrals over the $\pi\pi$ invariant mass, each involving the product of a rapidly decreasing weight function (which deemphasizes the inelastic region) and appropriate form factors (whose uncertainty tends to cancel in the ratio). Details will be provided in Ref. [36].

The constraint above can be strengthened by directly looking at the s dependence of the spectral functions (instead of the a_μ integral), which would also allow us

to disentangle the vector and tensor interactions [37]. Moreover, the $a_\mu^{\tau,ee}$ uncertainties include a scaling factor due to internal inconsistencies of the various datasets [27], which will hopefully decrease in the future. In fact, new analyses of the $\pi\pi$ channel are expected from CMD3, BABAR, and possibly Belle-2 [27,29]. Last, a_μ^τ will benefit from the ongoing calculations of isospin-breaking effects in the lattice [38]. All in all, we can expect a significant improvement in precision with respect to the result in Eq. (6) in the near future.

As recently pointed out in Ref. [12], a third exclusive channel that can provide useful information is $\tau \to \eta\pi\nu_\tau$, since the nonstandard scalar contribution is enhanced with respect to the (very suppressed) SM one. Because of this, one can obtain a nontrivial constraint on ϵ_S^τ even though both SM and NP contributions are hard to predict with high accuracy. Using the latest experimental results for the branching ratio (BR) [17,39] and a very conservative estimate for the theory errors [12,40,41], we find

$$\epsilon_S^\tau = (-6 \pm 15) \times 10^{-3}, \qquad (7)$$

which will significantly improve if theory or experimental uncertainties can be reduced. The latter will certainly happen with the arrival of Belle-II, which is actually expected to provide the first measurement of the SM contribution to this channel [42] (see, also, Ref. [43] for Belle results). This is the only probe in this Letter with a significant sensitivity (via $\mathcal{O}(\epsilon_S^2)$ effects) to the imaginary part of ϵ_i coefficients. Including the latter does not affect the bound in Eq. (7) though.

Inclusive decays.—Summing over certain sets of decay channels, one obtains the so-called inclusive vector (axial) spectral functions $\rho_{V(A)}$ [1,2]. In the SM, they are proportional to the imaginary parts of the associated VV (AA) two-point correlation functions, $\Pi_{VV(AA)}(s)$, but these relations are modified by NP effects [44,45]. Thus, one could directly use the latest measurements of these spectral functions to constrain such effects if we had a precise theoretical knowledge of their QCD prediction. However, perturbative QCD is known not to be valid at $\sqrt{s} < 1$ GeV, especially in the Minkowskian axis, where the spectral function lies. Nevertheless, one can make precise theoretical predictions for integrated quantities exploiting the well-known analytic properties of QCD correlators [3]. Here, we extend the traditional approach to also include NP effects, finding [44,45]

$$\int_{4m_\pi^2}^{s_0} \frac{ds}{s_0} \omega\left(\frac{s}{s_0}\right) \rho_{V\pm A}^{\exp}(s) \approx (1 + 2\epsilon_V) X_{VV}$$
$$\pm (1 + 2\epsilon_A)\left[X_{AA} - \frac{f_\pi^2}{s_0}\omega\left(\frac{m_\pi^2}{s_0}\right)\right] + \epsilon_T^\tau X_{VT}, \quad (8)$$

where $\omega(x)$ is a generic analytic function and $\rho_{V\pm A}^{\exp}(s)$ is the sum or difference of the vector and axial spectral functions, extracted experimentally under SM assumptions [2,26]. We also introduced the NP couplings $\epsilon_{V/A} \equiv \epsilon_{L\pm R}^\tau - \epsilon_{L+R}^e$, where $\epsilon_{L\pm R}^\ell \equiv \epsilon_L^\ell \pm \epsilon_R^\ell$. Last, X_{ij} are QCD objects that can be calculated via the operator product expansion [46]. Equation (8) shows how the agreement between precise SM predictions (rhs) and experimental results (lhs) for inclusive decays can be translated into strong NP constraints.

In the $V + A$ channel, we find two clean NP constraints using $\omega(x) = (1 - x)^2(1 + 2x)$, which gives the total non-strange BR, and with $\omega(x) = 1$. They provide, respectively,

$$\epsilon_{L+R}^\tau - \epsilon_{L+R}^e - 0.78\epsilon_R^\tau + 1.71\epsilon_T^\tau = (4 \pm 16) \times 10^{-3}, \quad (9)$$

$$\epsilon_{L+R}^\tau - \epsilon_{L+R}^e - 0.89\epsilon_R^\tau + 0.90\epsilon_T^\tau = (8.5 \pm 8.5) \times 10^{-3}. \quad (10)$$

The uncertainty in Eq. (9) comes mainly from the non-perturbative corrections, whereas that of Eq. (10) is dominated by experimental and duality violations (DV) uncertainties [46].

In the $V - A$ channel, where the perturbative contribution is absent, two strong constraints can be obtained using $\omega(x) = 1 - x$ and $\omega(x) = (1 - x)^2$

$$\epsilon_{L+R}^\tau - \epsilon_{L+R}^e + 3.1\epsilon_R^\tau + 8.1\epsilon_T^\tau = (5.0 \pm 50) \times 10^{-3}, \quad (11)$$

$$\epsilon_{L+R}^\tau - \epsilon_{L+R}^e + 1.9\epsilon_R^\tau + 8.0\epsilon_T^\tau = (10 \pm 10) \times 10^{-3}. \quad (12)$$

DV dominate uncertainties for the first constraint, while experimental and f_π uncertainties dominate the latter one. This constraint could be improved with more precise data and f_π calculations, but at some point, DV, much more difficult to control, would become the leading uncertainty. The non-negligible correlations between the various NP constraints derived above (due to f_π and experimental correlations) have been taken into account in Eq. (2).

The weight functions chosen above are motivated by simplicity (low-degree polynomials), small nonperturbative corrections, and different enough behavior so that their correlations can be taken into account.

Electroweak precision data.—If NP is coming from dynamics at $\Lambda \gg m_Z$ and electroweak symmetry breaking is linearly realized, then the relevant effective theory at $E \gtrsim m_Z$ is the so-called standard model effective field theory (SMEFT), which has the same local symmetry and field content as the SM, but also contains higher-dimensional operators encoding NP effects [13,65,66]. The SMEFT framework allows one to combine, in a model-independent way, constraints from low-energy measurements with those from electroweak precision observables (EWPO) and LHC searches. Moreover, once the SMEFT is matched to concrete UV models at the scale Λ,

one can efficiently constrain masses and couplings of NP particles. The dictionary between low-energy parameters in Eq. (1) and Wilson coefficients in the Higgs basis [67,68] is

$$\epsilon_L^\tau - \epsilon_L^e = \delta g_L^{W\tau} - \delta g_L^{We} - [c_{\ell q}^{(3)}]_{\tau\tau11} + [c_{\ell q}^{(3)}]_{ee11},$$

$$\epsilon_R^\tau = \delta g_R^{Wq_1},$$

$$\epsilon_{S,P}^\tau = -\frac{1}{2}[c_{lequ} \pm c_{ledq}]_{\tau\tau11}^*,$$

$$\epsilon_T^\tau = -\frac{1}{2}[c_{lequ}^{(3)}]_{\tau\tau11}^*, \tag{13}$$

where we approximate $V_{\mathrm{CKM}} \approx \mathbf{1}$ in these $\mathcal{O}(\Lambda^{-2})$ terms. The coefficients $\delta g_{L/R}^{Wf}$ are corrections to the SM Wff' vertex and c_i/v^2 parametrize four-fermion interactions with different helicity structures ($v \approx 246$ GeV); see the Supplemental Material [46] for their precise definitions [46]. Note that ϵ_R^ℓ is lepton-universal in the SMEFT, up to dimension-eight corrections [13,69]. We perform this matching at $\mu = M_Z$, after taking into account the QED and QCD running of the low-energy coefficients ϵ_i up to the electroweak (EW) scale [70]. Electroweak and QCD running to or from 1 TeV is also carried out in the comparison with LHC bounds below. The running is numerically important for (pseudo-)scalar and tensor operators, influencing the confidence intervals at an $\mathcal{O}(100\%)$ level and introducing mixing between the corresponding Wilson coefficients.

Our results are particularly relevant for constraining lepton flavor universality (LFU) violation, which can be done through a SMEFT analysis with all dimension-six operators present simultaneously. As a matter of fact, Ref. [68] carried out a flavor-general SMEFT fit to a long list of precision observables, which, however, did not include any observable sensitive to $qq\tau\tau$ interactions. As a result, no bound was obtained on the four-fermion Wilson coefficients, $[c_i]_{\tau\tau11}$. From Eq. (13), given that $[c_{\ell q}^{(3)}]_{ee11}$ and the vertex corrections δg are independently constrained, hadronic tau decays imply novel limits on these coefficients. We find

$$\begin{bmatrix} c_{lq}^{(3)} \\ c_{lequ} \\ c_{ledq} \\ c_{lequ}^{(3)} \end{bmatrix}_{\tau\tau11} = \begin{pmatrix} 0.012(29) \\ -0.002(11) \\ 0.009(11) \\ -0.0036(93) \end{pmatrix}$$

$$\rho = \begin{pmatrix} .09 & -.09 & .02 \\ & .37 & .29 \\ & & -.28 \end{pmatrix}, \tag{14}$$

after marginalizing over the remaining SMEFT parameters. These are not only very strong, but also unique low-energy bounds. On the other hand, Ref. [68] did access the right-handed vertex correction: $\delta g_R^{Wq_1} = -(1.3 \pm 1.7) \times 10^{-2}$,

from neutron beta decay [25,71]. Including hadronic tau decays in the global fit improves this significantly: $\delta g_R^{Wq_1} = -(0.4 \pm 1.0) \times 10^{-2}$ [72]. The fact that ϵ_R^τ, probed by tau decays, and ϵ_R^e, probed by beta decays, are connected to one and the same parameter $\delta g_R^{Wq_1}$ is a prediction of the SMEFT, and would not be true in a more general setting where EW symmetry is realized nonlinearly. Thus, comparison between phenomenological determinations of ϵ_R^τ and ϵ_R^e (both consistent with zero currently) provides a test of that SMEFT assumption.

LHC bounds.—It is instructive to compare the NP sensitivity of hadronic tau decays to that of the LHC. While the experimental precision is typically inferior for the LHC, it probes much higher energies and may offer a better reach for the Wilson coefficients whose contribution to observables is enhanced by E^2/v^2. We focus on the high-energy tail of the $\tau\nu$ production. This process is sensitive to the four-fermion coefficients $[c_{\ell q}^{(3)}, c_{\ell equ}, c_{\ell edq}, c_{\ell equ}^{(3)}]_{\tau\tau11}$, which also affect tau decays. Other Wilson coefficients in Eq. (13) do not introduce energy-enhanced corrections to the $\tau\nu$ production and can be safely neglected in this analysis [75].

In Table I, we show our results based on a recast of the transverse mass m_T distribution of $\tau\nu$ events in $\sqrt{s} = 13$ TeV LHC collisions recently measured by ATLAS [76]. We estimated the impact of the Wilson coefficients on the $d\sigma(pp \to \tau\nu)/dm_T$ cross section using the MADGRAPH [77], PYTHIA 8 [78], DELPHES [79] simulation chain. We assign 30% systematic uncertainty to that estimate, which roughly corresponds to the size of the next-to-leading-order QCD corrections to the NP terms (not taken into account in our simulations) [80]. The SM predictions are taken from [76], and their quoted uncertainties in each bin are treated as independent nuisance parameters. We find that, for the chirality-violating operators, the LHC bounds are comparable to those from hadronic tau decays. On the other hand, for the chirality-conserving coefficient $[c_{\ell q}^{(3)}]_{\tau\tau11}$, the LHC bounds are an order of magnitude stronger thanks to the fact that the corresponding operator interferes with the SM $q\bar{q}' \to \tau\nu$ amplitude. Let us stress that SMEFT analyses of high-p_T

TABLE I. 95% C.L. intervals (in 10^{-3} units) at $\mu = 1$ TeV, assuming one Wilson coefficient is present at a time. The third column uses Eq. (2), whereas the fourth one also includes clean LFU ratios such as $\Gamma(\tau \to \pi\nu)/\Gamma(\pi \to \mu\nu)$.

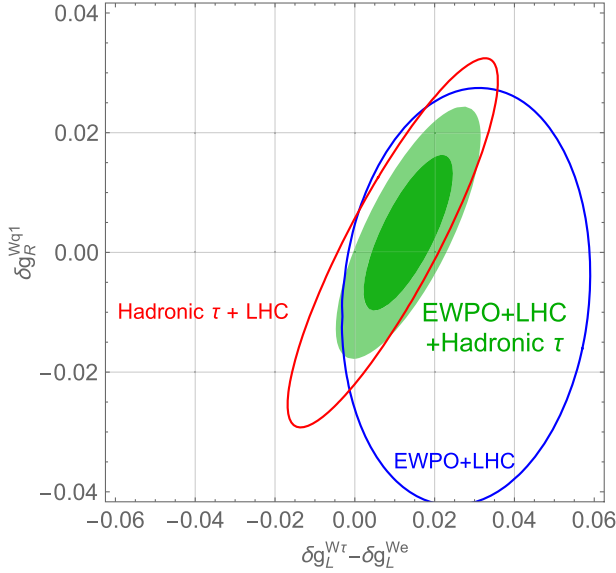| Coefficient	ATLAS $\tau\nu$	τ decays	τ and π decays
$[c_{\ell q}^{(3)}]_{\tau\tau11}$	[0.0, 1.6]	[−12.6, 0.2]	[−7.6, 2.1]
$[c_{\ell equ}]_{\tau\tau11}$	[−5.6, 5.6]	[−8.4, 4.1]	[−5.6, 2.3]
$[c_{\ell edq}]_{\tau\tau11}$	[−5.6, 5.6]	[−3.5, 9.0]	[−2.1, 5.8]
$[c_{\ell equ}^{(3)}]_{\tau\tau11}$	[−3.3, 3.3]	[−10.4, −0.2]	[−8.6, 0.7]

FIG. 1. 68% and 95% C.L. bounds on the vertex corrections $\delta g_L^{W\tau} - \delta g_L^{We}$ and $\delta g_R^{Wq_1}$ (green) after using the LHC input to constrain $[c_{\ell q}^{(3)}]_{\tau\tau 11}$ and $[c_{\ell q}^{(3)}]_{ee 11}$. We also show separate 95% C.L. contours from hadronic τ decays (red) and from previous EWPO [68] (blue), which are correlated, cf. discussion below Eq. (5).

data require additional assumptions though, such as heavier NP scales and suppressed dimension-eight operator contributions. Last, we observe an $\mathcal{O}(2)\sigma$ preference for a nonzero value of $[c_{\ell q}^{(3)}]_{\tau\tau 11}$ due to a small excess over the SM prediction observed by ATLAS in several bins of the m_T distribution.

The LHC and τ decay inputs together allow us to sharpen the constraints on LFU of gauge interactions. From Table I, $[c_{\ell q}^{(3)}]_{\tau\tau 11}$ is constrained by the LHC at an $\mathcal{O}(10^{-3})$ level, and similar conclusions can be drawn with regard to $[c_{\ell q}^{(3)}]_{ee 11}$ [68,81]. Then, hadronic tau decays effectively become a new probe of the vertex corrections: $\epsilon_L^\tau - \epsilon_L^e \approx \delta g_L^{W\tau} - \delta g_L^{We}$ and $\epsilon_R^\tau = \delta g_R^{Wq_1}$, complementing the information from previous low-energy EWPO [68]. The interplay between the two is shown in Fig. 1. The input from hadronic tau decays leads to the model independent constraint on LFU of W boson interactions: $\delta g_L^{W\tau} - \delta g_L^{We} = 0.0134(74)$, which becomes more than two times stronger in the simpler scenario where $\delta g_L^{W\tau} - \delta g_L^{We}$ is the only deformation of the SM.

Conclusions.—We have shown, in this Letter, that hadronic τ decays represent competitive NP probes, thanks to the very precise measurements and SM calculations. This is a change of perspective with respect to the usual approach, which considers these decays as a QCD laboratory where one can learn about hadronic physics or extract fundamental parameters such as the strong

coupling constant. From this new perspective, the agreement between such determinations [3–5] and that of Ref. [10] in the lattice is recast as a stringent NP bound. Our results are summarized in Eq. (2) and can be easily applied to constrain a large class of NP models with the new particles heavier than m_τ. Hadronic τ decays probe new particles with up to $\mathcal{O}(10)$ TeV masses (assuming order 1 coupling to the SM) or even $\mathcal{O}(100)$ TeV masses, for strongly coupled scenarios. They can be readily combined with other EWPO within the SMEFT framework to constrain NP heavier than m_Z. Including this new input in the global fit leads to four novel constraints in Eq. (14), which are the first model-independent bounds on the corresponding $\tau\tau qq$ operators. Moreover, it leads to tighter bounds on the W boson coupling to right-handed quarks. Hadronic τ decays represent a novel sensitive probe of LFU violation (τ vs e), which competes with and greatly complements EWPO and LHC data. This is illustrated in Fig. 1 and Table I for vertex corrections and contact interactions, respectively. Thus, our constraints can be useful in relation with the current hints of LFU violation in certain B meson decays [82–86], or the old tension in W decays [17,87]. For instance, our model-independent $\mathcal{O}(1)\%$ constraints in Eq. (2) imply that the hints for $\mathcal{O}(10)\%$ LFU violation observed in $B \to D^*\tau\nu$ decays [82–84] cannot be explained by NP effects in the hadronic decay of the τ lepton but must necessarily involve (as is the case in most models) nonstandard LFU-violating interactions involving the bottom quark.

The discovery potential of these processes in the future is very promising since the constraints derived in this Letter are expected to improve with the arrival of new data (e.g., from Belle-II) and new lattice calculations. The $\tau \to \pi\pi\nu_\tau$ channel represents a particularly interesting example through the direct comparison of its spectrum and $e^+e^- \to \pi^+\pi^-$ data. Last, the extension of our analysis to strange decays of the tau lepton represents another interesting research line for the future.

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