Non-standard interactions and the $\tau^- \to (K\pi)^- \nu_\tau$ decays

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[1] J. Rendón, P. Roig and G. Toledo Sánchez, Phys. Rev. D **99**, 093005 (2019).

Motivation to do this study

- There is a 2.8 σ discrepancy between the $\tau^+ \to \pi^+ K_s \bar{\nu}_\tau$ rate asymmetry measured by BaBar ($A_{CP}^{\tau,exp} = -3.6(2.3)(1.1) \times 10^{-3}$) [2] and the one coming from the expected value due to $K^0 - \bar{K}^0$ mixing ($A_{CP}^{\tau,SM} = 3.6(1) \times 10^{-3}$) [3], where

$$A_{CP}^{\tau} = \frac{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu_\tau}) - \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu_\tau}) + \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}$$

- The $K_s \pi^-$ spectrum, particularly the first few Belle data points cannot be explained within the SM.

[2] J. P. Lees *et al.* [BaBar Collaboration], Phys. Rev. D **85**, 031102 (2012) Erratum: [Phys. Rev. D **85**, 099904 (2012)].

[3] I. I. Bigi and A. I. Sanda, Phys. Lett. B **625**, 47 (2005).

$\tau^- \to K_S \pi^- \nu_\tau$ spectrum

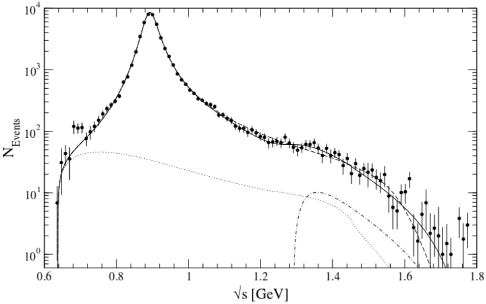

Figure: Distribution of $\tau^- \to K_S \pi^- \nu_\tau$ events measured by Belle[4]

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[4] Belle Collaboration, Phys. Lett. B 654 (2007) 65.
[5] A. Pich, Prog. Part. Nucl. Phys. **75**, 41 (2014)

Motivation to do this study

- See if the bounds of NP coming from the effective couplings are competitive with the bounds coming from Kaon and Hyperon decays[6].

[6] M. González-Alonso and J. Martin Camalich, JHEP **1612**, 052 (2016).

Effective theory analysis of $\tau^- \to \nu_\tau \bar{u} s$

The effective lagrangian density constructed with dimension six operators and invariant under the $SU(2)_L \otimes U(1)$ group has the following form,

$$\mathcal{L}^{(eff)} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2} \sum_i \alpha_i O_i$$

Effective theory analysis of $\tau^- \to \nu_\tau \bar{u} s$

We can explicitly construct the low-scale O(1GeV) effective lagrangian for semi-leptonic transitions as follows:

$$\mathcal{L}_{cc} = -\frac{G_F V_{us}}{\sqrt{2}}(1+\epsilon_L+\epsilon_R)$$
$$\times \Big[\bar{\tau}\gamma_\mu(1-\gamma_5)\nu_\tau \cdot \bar{u}[\gamma^\mu - (1-2\hat{\epsilon}_R)\gamma^\mu\gamma^5]s$$
$$+ \bar{\tau}(1-\gamma_5)\nu_\tau \cdot \bar{u}[\hat{\epsilon}_s - \hat{\epsilon}_p\gamma_5]s$$
$$+ 2\hat{\epsilon}_T \bar{\tau}\sigma_{\mu\nu}(1-\gamma_5)\nu_\tau \cdot \bar{u}\sigma^{\mu\nu}s\Big] + h.c\,,$$

where $\hat{\epsilon}_i = \epsilon_i/(1+\epsilon_L+\epsilon_R)$ for $i = R, S, P, T$.

Amplitude

Due to the parity of pseudoscalar mesons, only the vector, scalar and tensor currents give a non-zero contribution to the decay amplitude [7]

$$
\begin{aligned}
\mathcal{M} =& \mathcal{M}_V + \mathcal{M}_S + \mathcal{M}_T \\
&= \frac{G_F V_{us} \sqrt{S_{EW}}}{\sqrt{2}} (1 + \epsilon_L + \epsilon_R) \\
&\times \left[L_\mu H^\mu + \hat{\epsilon}_S L H + 2 \hat{\epsilon_T} L_{\mu\nu} H^{\mu\nu} \right],
\end{aligned}
$$

where the leptonic currents have the following structure,

$$
\begin{aligned}
L_\mu &= \bar{u}(p^{'}) \gamma_\mu (1 - \gamma_5) u(p) \, , \\
L &= \bar{u}(p^{'}) (1 + \gamma_5) u(p) \, , \\
L_{\mu\nu} &= \bar{u}(p^{'}) \sigma_{\mu\nu} (1 + \gamma_5) u(p) \, ,
\end{aligned}
$$

[7] E. A. Garcés, M. Hernández Villanueva, G. López Castro and P. Roig, JHEP **1712**, 027 (2017).

Amplitude

The Hadronic matrix elements for $\tau^- \to \bar{K}^0 \pi^- \nu_\tau$ are given as follows,

$$
\begin{aligned}
H^\mu =& \langle \pi^- \bar{K}^0 | \bar{s}\gamma^\mu u | 0 \rangle = Q^\mu F_+(s) + \frac{\Delta_{K\pi}}{s} q^\mu F_0(s)\,, \\
H =& \langle \pi^- \bar{K}^0 | \bar{s} u | 0 \rangle = F_s(s)\,, \\
H^{\mu\nu} =& \langle \pi^- \bar{K}^0 | \bar{s}\sigma^{\mu\nu} u | 0 \rangle = iF_T(s)(p_K^\mu p_\pi^\nu - p_\pi^\mu p_K^\nu)\,,
\end{aligned}
$$

where $q^\mu = (p_\pi + p_K)^\mu$, $Q^\mu = (p_K - p_\pi)^\mu - \frac{\Delta_{K\pi}}{s} q^\mu$, $s = q^2$, and $\Delta_{ij} = m_i^2 - m_j^2$.

Amplitude

Similarly for the $\tau^- \to K^-\pi^0\nu_\tau$ decay we have,
$\sqrt{2}F_{0,+,T}^{K^-\pi^0}(s) = F_{0,+,T}^{\bar{K}^0\pi^-}(s)$.

Simplifications in the leptonic part

The vector and the scalar currents are related through the Dirac equation in the following way,

$$L = \frac{L_\mu q^\mu}{M_\tau}$$

Simplifications in the Hadronic part

Similarly one can find a relation between the scalar and the vector hadronic matrix elements by taking the four-divergence of the vector matrix element,

$$F_s(s) = \frac{\Delta_{K\pi}}{m_s - m_u} F_0(s)$$

Total simplification

We conclude that the scalar and vector contributions can be treated jointly by doing the convenient replacement:

$$\frac{\Delta_{K\pi}}{s} \to \frac{\Delta_{K\pi}}{s}\left[1 + \frac{s\hat{\epsilon}_s}{M_\tau(m_s - m_u)}\right]$$

Squared amplitude

The unpolarized spin-averaged squared amplitude is given by:

$$|\bar{\mathcal{M}}|^2 = \frac{G_F^2 |V_{us}|^2 S_{EW}}{2} (1 + \epsilon_L + \epsilon_R)^2 \times (M_{0+} + M_{T+} + M_{T0} + M_{00} + M_{++} + M_{TT})$$

Vector and Scalar Form Factors

Here we benefit from previous works for the VFF and SFF cases. The VFF is taken from ref. [8] and the SFF is taken from ref. [9].

[8] D. R. Boito, R. Escribano and M. Jamin, Eur. Phys. J. C **59**, 821 (2009).
[9] M. Jamin, J. A. Oller and A. Pich, Phys. Rev. D **74**, 074009 (2006).

Tensor Form Factor

For the TFF we obtain its normalization at zero momentum transfer using χPT with tensor sources [10] and Lattice data [11] and its energy dependence using a dispersion relation[12].

$$i\langle\pi^- \bar{K}^0|\frac{\delta\mathcal{L}}{\delta\bar{t}_{\alpha\beta}}|0\rangle = \frac{\Lambda_2}{F^2}\left(p_K^\alpha p_0^\beta - p_0^\alpha p_K^\beta\right) .$$

$$\frac{F_T(s)}{F_T(0)} = exp\left[\frac{s}{\pi}\int_{s_{\pi K}}^{s_{cut}} ds^{'}\,\frac{\delta_T(s^{'})}{s^{'}(s^{'}-s-i\epsilon)}\right] ,$$

where $s_{\pi K} = (m_{\bar{K}^0} + m_{\pi^-})^2$.

[10] O. Cata and V. Mateu, JHEP **0709**, 078 (2007).

[11] I. Baum, V. Lubicz, G. Martinelli, L. Orifici and S. Simula, Phys. Rev. D **84**, 074503 (2011).

[12] J. A. Miranda and P. Roig, JHEP **1811**, 038 (2018).

Tensor Form Factor

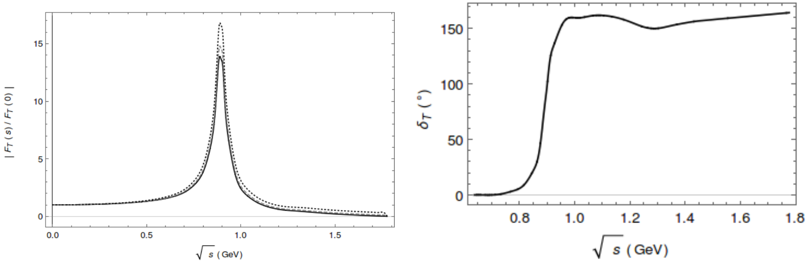


Figure: Modulus and phase, $|F_T(s)|$ (left) and $\delta_T(s) = \delta_+(s)$ (right), of the tensor form factor, $F_T(s)$. On the left plot, the dotted line corresponds to $s_{cut} = 9$ GeV^2, the dashed one to $s_{cut} = 4$ GeV^2, and the solid one to $s_{cut} = M_\tau^2$.

Dalitz Plots

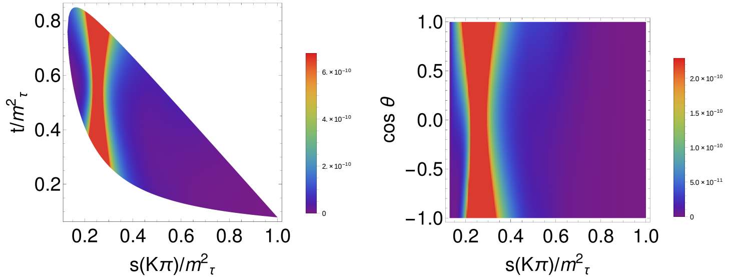


Figure: Dalitz plot distribution $\overline{|\mathcal{M}|^2}_{00}$ in the SM: Differential decay distribution for $\tau^- \to K_S \pi^- \nu_\tau$ in the (s, t) variables (left), and in the $(s, \cos\theta)$ variables (right)

Dalitz Plots

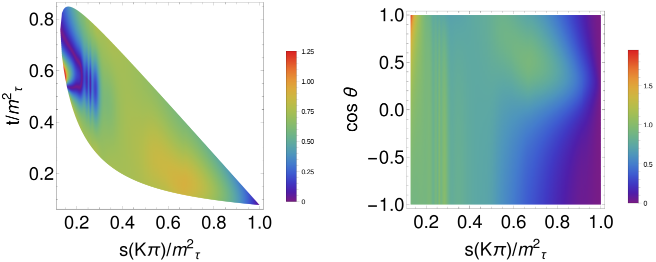


Figure: Dalitz plot distribution $\tilde{\Delta}(\hat{\epsilon}_S, \hat{\epsilon}_T)$ in the $\tau^- \to K_S \pi^- \nu_\tau$ decays: left-hand side corresponds to the (s, t) variables and the right-hand side corresponds to the differential decay distribution in the $(s, \cos\theta)$ variables, both with $(\hat{\epsilon}_S = 0, \hat{\epsilon}_T = 0.6)$.

In the previous plot we have defined,

$$\tilde{\Delta}(\hat{\epsilon}_S, \hat{\epsilon}_T) = \frac{\left| \overline{|\mathcal{M}(\hat{\epsilon}_S, \hat{\epsilon}_T)|^2} - \overline{|\mathcal{M}(0,0)|^2} \right|}{\overline{|\mathcal{M}(0,0)|^2}} .$$

Forward-backward asymmetries

$$\mathcal{A}_{K\pi}(s) = \frac{\int_0^1 d\cos\theta \frac{d^2\Gamma}{ds d\cos\theta} - \int_{-1}^0 d cos\theta \frac{d^2\Gamma}{ds d\cos\theta}}{\int_0^1 d\cos\theta \frac{d^2\Gamma}{ds d\cos\theta} + \int_{-1}^0 d\cos\theta \frac{d^2\Gamma}{ds d\cos\theta}} \,.$$

$$\mathcal{A}_{K\pi} = \frac{3\sqrt{\lambda(s), m_\pi^2, m_K^2)}}{2s^2[X_{VA} + \hat{\epsilon}_S X_S + \hat{\epsilon}_T X_T + \hat{\epsilon}_S^2 X_{S^2} + \hat{\epsilon}_T^2 X_{T^2}]}$$

$$\left(1 + \frac{s\hat{\epsilon}_S}{M_\tau(m_s - m_u)}\right) \Delta_{\pi K} \left[-Re[F_0(s)F_+^*(s)] + \frac{2s\hat{\epsilon}_T}{M_\tau} Re[F_T(s)F_0^*(s)]\right]$$

Forward-backward asymmetries

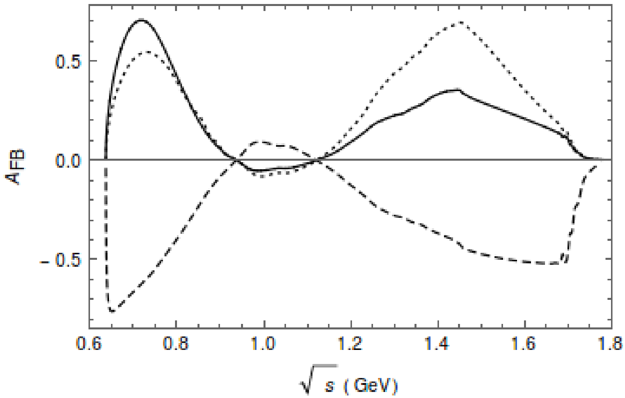


Figure: FB asymmetries: SM (solid line), $\hat{\epsilon}_S = -0.5$, $\hat{\epsilon}_T = 0$ (dashed line) and $\hat{\epsilon}_S = 0$, $\hat{\epsilon}_T = 0.6$ (dotted line).

Limits on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$

$$\Delta \equiv \frac{\Gamma - \Gamma^0}{\Gamma^0} = \alpha\hat{\epsilon}_S + \beta\hat{\epsilon}_T + \gamma\hat{\epsilon}_S^2 + \delta\hat{\epsilon}_T^2 \,,$$

where we obtained the following results for the coefficients: $\alpha \in [0.30, 0.34]$, $\beta \in [-2.92, -2.35]$, $\gamma \in [0.95, 1.13]$ and $\delta \in [3.57, 5.45]$.

Limits on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$

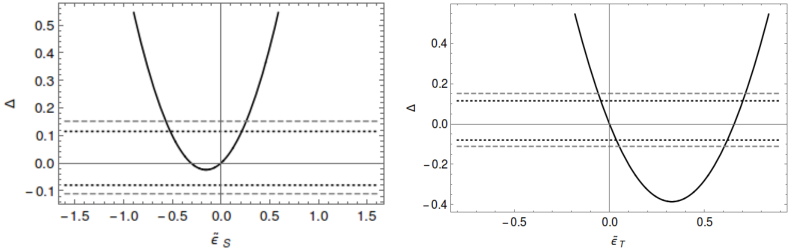


Figure: Δ as a function of $\hat{\epsilon}_S$ for $\hat{\epsilon}_T = 0$ (left hand) and of $\hat{\epsilon}_T$ for $\hat{\epsilon}_S = 0$ (right hand) for $\tau^- \to K_S \pi^- \nu_\tau$ decays. Horizontal lines represent the values of Δ according to the current measurement and theory errors (at three standard deviations) of the branching ratio (dashed line) and in the hypothetical case where the measured branching ratio at Belle-II has a three times reduced uncertainty (dotted line).

Limits on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$

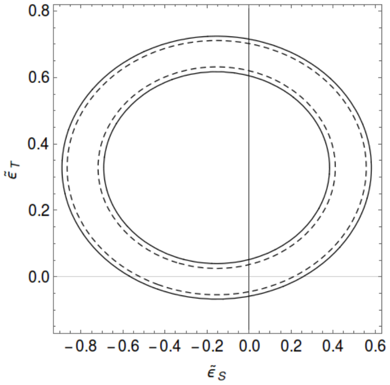


Figure: Constraints on the scalar and tensor couplings obtained from $\Delta(\tau^- \to K_S \pi^- \nu_\tau)$ using theory and the measured value reported in the PDG, with their corresponding uncertainties at three standard deviations (solid line). The dashed line ellipse corresponds to the case where the measurements error was reduced to a third of the current uncertainty.

Limits on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$

Δ limits	$\hat{\epsilon}_S(\hat{\epsilon}_T = 0)$	$\hat{\epsilon}_T(\hat{\epsilon}_S = 0)$	$\hat{\epsilon}_S$	$\hat{\epsilon}_T$
Current bounds	$[-0.57, 0.27]$	$[-0.059, 0.052] \cup [0.60, 0.72]$	$[-0.89, 0.58]$	$[-0.07, 0.72]$
Future bounds	$[-0.52, 0.22]$	$[-0.047, 0.036] \cup [0.62, 0.71]$	$[-0.87, 0.56]$	$[-0.06, 0.71]$

Table: Constraints on the scalar and tensor couplings obtained through the limits on the current branching ratio at three standard deviations using the current theory and experimental errors and assuming the latter be reduced to a third ('Future bounds').

Limits on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$

When we make the fit to the whole spectrum we obtain,

Best fit values	$\hat{\epsilon}_S$	$\hat{\epsilon}_T$	χ^2	χ^2 in the SM
No $i = 5, 6, 7$ bins	$(1.3 \pm 0.9) \times 10^{-2}$	$(0.7 \pm 1.0) \times 10^{-2}$	$[72, 73]$	$[74, 77]$
$i = 5, 6, 7$ bins	$(0.9 \pm 1.0) \times 10^{-2}$	$(1.7 \pm 1.7) \times 10^{-2}$	$[83, 86]$	$[91, 95]$

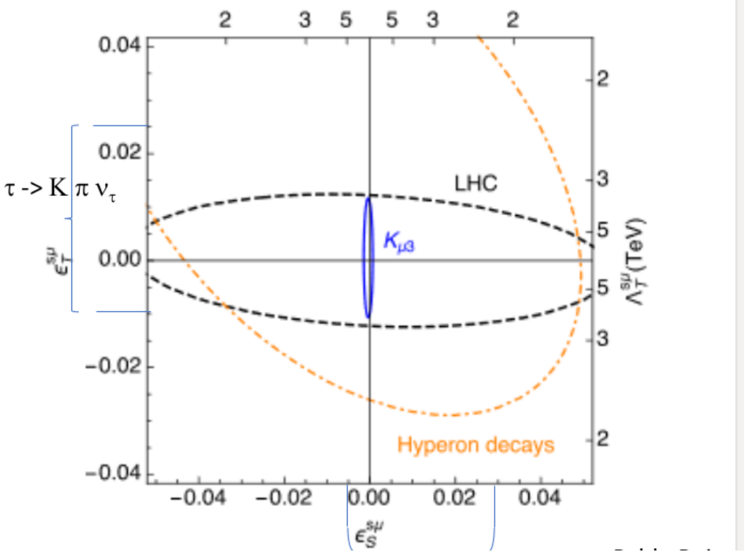
Table: Best fit values to the Belle spectrum and branching ratio of the $\tau^- \to K_S \pi^- \nu_\tau$ decays

[13] The previous limits translate into bounds of the corresponding NP scale $\Lambda \approx [2, 5]$Tev, while Kaon physics may reach $\mathcal{O}(500)$Tev [14]

$$\Lambda \sim v(V_{us}\hat{\epsilon}_{S,T})^{-1/2}$$

[13] D. Epifanov *et al.* [Belle Collaboration], Phys. Lett. B **654**, 65 (2007).
[14] M. González-Alonso and J. Martin Camalich, JHEP **1612**, 052 (2016).

Limits on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$



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[15] M. González-Alonso and J. Martin Camalich, JHEP **1612**, 052 (2016).

What about CP violation?

$$A_{CP}^{BSM} = \frac{2\sin\delta_T^W |\hat{\epsilon}_T| G_F^2 |V_{us}|^2 S_{EW}}{256\pi^3 M_\tau^2 \Gamma(\tau \to K_S \pi \nu_\tau)} \times$$
$$\int_{s_{\pi K}}^{M_\tau^2} \mathrm{d}s |f_+(s)||F_T(s)| \sin\left(\delta_+(s) - \delta_T(s)\right) \frac{\lambda^{3/2}(s, m_\pi^2, m_K^2)(M_\tau^2 - s)^2}{s^2},$$

In agreement with Ref. [16] we confirmed that it is not possible to understand the BaBar A_{CP} measurement.

$$A_{CP}^{BSM} \lesssim 8 \cdot 10^{-7}, \quad (1)$$

which is a slightly weaker bound than the one reported in the previous reference ($A_{CP}^{BSM} \lesssim 3 \cdot 10^{-7}$)

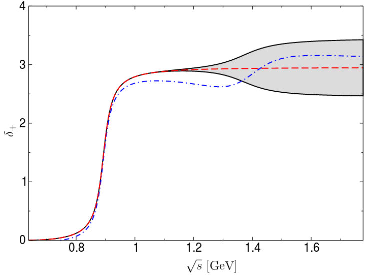
[16] V. Cirigliano, A. Crivellin and M. Hoferichter, Phys. Rev. Lett. **120**, no. 14, 141803 (2018).

Conclusions

- Both the BaBar A_{CP} anomaly and the $i = 5, 6, 7$ Belle data points cannot be explained by heavy NP contributions.
- Using tau decays we have set bounds on $\hat{\epsilon}_S$ and $\hat{\epsilon}_T$ similar to those on hyperon decays (a few Tev NP energy scale) but not competitive with (semi)leptonic Kaon decays ($\mathcal{O}(500)$ Tev).
- **However Tensor interactions are probed with similar NP energy reach than in (semi)leptonic Kaon decays and LHC data.**

Backup

Estimation of inelasticities in the phase of the TFF [17]



[17] V. Cirigliano, A. Crivellin and M. Hoferichter, Phys. Rev. Lett. **120**, no. 14, 141803 (2018)

Effective theory analysis of $\tau^- \to \nu_\tau \bar{u} D$ ($D = d, s$)

We can explicitly construct the low-scale O(1GeV) effective lagrangian for semi-leptonic transitions as follows: [18] [19]:

$$
\begin{aligned}
\mathcal{L}_{CC} \;=\; & -\frac{G_F V_{uD}}{\sqrt{2}} \Big[(1+\epsilon_L^\tau)\bar{\tau}\gamma_\mu(1-\gamma^5)\nu_\tau \cdot \bar{u}\gamma^\mu(1-\gamma^5)D \\
& +\epsilon_R^\tau \bar{\tau}\gamma_\mu(1-\gamma^5)\nu_\tau \cdot \bar{u}\gamma^\mu(1+\gamma^5)D \\
& +\bar{\tau}(1-\gamma^5)\nu_\tau \cdot \bar{u}(\epsilon_S^\tau - \epsilon_P^\tau\gamma^5)D \\
& +\epsilon_T^\tau \bar{\tau}\sigma_{\mu\nu}(1-\gamma^5)\nu_\tau \, \bar{u}\sigma^{\mu\nu}(1-\gamma^5)D \Big] + h.c.\,, \qquad (2)
\end{aligned}
$$

[18] T. Bhattacharya, V. Cirigliano, S. D. Cohen, A. Filipuzzi, M. Gonzalez-Alonso, M. L. Graesser, R. Gupta and H. W. Lin, Phys. Rev. D **85**, 054512 (2012).

[19] S. González-Solís, A. Miranda, J. Rendón and P. Roig, Phys. Lett. B **804**, 135371 (2020).

One-meson decay modes $\tau^- \to P^- \nu_\tau$ ($P = \pi, K$).

$$\Gamma(\tau^- \to \pi^- \nu_\tau) = \frac{G_F^2 |\tilde{V}_{ud}^e|^2 f_\pi^2 m_\tau^3}{16\pi} \left(1 - \frac{m_\pi^2}{m_\tau^2}\right)^2 \times \left(1 + \delta_{\rm em}^{\tau\pi} + 2\Delta^{\tau\pi} + \mathcal{O}(\epsilon_i^\tau)^2 + \mathcal{O}(\delta_{\rm em}^{\tau\pi}\epsilon_i^\tau)\right), \tag{3}$$

where f_π is the pion decay constant, the quantity $\delta_{\rm em}^{\tau\pi}$ accounts for the EM radiative corrections and the term $\Delta^{\tau\pi}$ contains the tree-level NP corrections that arise from $\mathcal{L}_{eff}$ that are not absorbed in $\tilde{V}_{ud}^e$.

One-meson decay modes $\tau^- \to P^- \nu_\tau$ ($P = \pi, K$).

The product $G_F V_{uD}$ in $\mathcal{L}_{eff}$ denotes that its determination from the superallowed nuclear Fermi β decays carries implicitly a dependence on ϵ_L^e and ϵ_R^e that is given by [20]

$$G_F \tilde{V}_{uD}^e = G_F \left(1 + \epsilon_L^e + \epsilon_R^e\right) V_{uD} \, , \qquad (4)$$

For the channel $\tau^- \to K^- \nu_\tau$, the decay rate is that of Eq. (3) but replacing $\tilde{V}_{ud}^e \to \tilde{V}_{us}^e$, $f_\pi \to f_K$, $m_\pi \to m_K$, and $\delta_{\mathrm{em}}^{\tau\pi}$ and $\Delta^{\tau\pi}$ by $\delta_{\mathrm{em}}^{\tau K}$ and $\Delta^{\tau K}$, respectively.

[20] M. González-Alonso and J. Martin Camalich, JHEP **12**, 052 (2016)

New Physics bounds from $\Delta S = 0$ decays

from the $\tau^- \to \pi^- \nu_\tau$ decay rate alone, we obtain the following constraint,

$$\epsilon_L^\tau - \epsilon_L^e - \epsilon_R^\tau - \epsilon_R^e - \frac{m_\pi^2}{m_\tau(m_u + m_d)}\epsilon_P^\tau = (-0.12 \pm 0.68) \times 10^{-2}\,, \quad (5)$$

The bounds for the non-SM effective couplings resulting from the global fit are found to be (in the $\overline{\mathrm{MS}}$ scheme at scale $\mu = 2$ GeV)

$$\begin{pmatrix} \epsilon_L^\tau - \epsilon_L^e + \epsilon_R^\tau - \epsilon_R^e \\ \epsilon_R^\tau + \frac{m_\pi^2}{2m_\tau(m_u+m_d)}\epsilon_P^\tau \\ \epsilon_S^\tau \\ \epsilon_T^\tau \end{pmatrix} = \begin{pmatrix} 0.5 \pm 0.6^{+2.3}_{-1.8}{}^{+0.2}_{-0.1} \pm 0.4 \\ 0.3 \pm 0.5^{+1.1}_{-0.9}{}^{+0.1}_{-0.0} \pm 0.2 \\ 9.7^{+0.5}_{-0.6} \pm 21.5^{+0.0}_{-0.1} \pm 0.2 \\ -0.1 \pm 0.2^{+1.1}_{-1.4}{}^{+0.0}_{-0.1} \pm 0.2 \end{pmatrix} \times 10^{-2}, \quad (6)$$

New Physics bounds from $|\Delta S| = 1$ decays

from the $\tau^- \to K^- \nu_\tau$ decay rate alone, we obtain the following constraint,

$$\epsilon_L^\tau - \epsilon_L^e - \epsilon_R^\tau - \epsilon_R^e - \frac{m_K^2}{m_\tau(m_u + m_s)}\epsilon_P^\tau = (-0.41 \pm 0.93) \times 10^{-2}\,. \quad (7)$$

In this case, the limits for the NP effective couplings are found to be (in the $\overline{\mathrm{MS}}$ scheme at scale $\mu = 2$ GeV)

$$\begin{pmatrix} \epsilon_L^\tau - \epsilon_L^e + \epsilon_R^\tau - \epsilon_R^e \\ \epsilon_R^\tau + \frac{m_K^2}{2m_\tau(m_u+m_s)}\epsilon_P^\tau \\ \epsilon_S^\tau \\ \epsilon_T^\tau \end{pmatrix} = \begin{pmatrix} 0.5 \pm 1.5 \pm 0.3 \\ 0.4 \pm 0.9 \pm 0.2 \\ 0.8^{+0.8}_{-0.9} \pm 0.3 \\ 0.9 \pm 0.7 \pm 0.4 \end{pmatrix} \times 10^{-2}, \quad (8)$$

New Physics bounds from a global fit to both $\Delta S = 0$ and $|\Delta S| = 1$

The resulting limits for the NP effective couplings are found to be (in the $\overline{\mathrm{MS}}$ scheme at scale $\mu = 2$ GeV)

$$\begin{pmatrix} \epsilon_L^\tau - \epsilon_L^e + \epsilon_R^\tau - \epsilon_R^e \\ \epsilon_R^\tau \\ \epsilon_P^\tau \\ \epsilon_S^\tau \\ \epsilon_T^\tau \end{pmatrix} =$$

$$\begin{pmatrix} 2.9 & \pm 0.6 & {}^{+1.0}_{-0.9} & \pm 0.6 & \pm 0.0 & \pm 0.4 & {}^{+0.2}_{-0.3} \\ 7.1 & \pm 4.9 & {}^{+0.5}_{-0.4} & {}^{+1.3}_{-1.5} & {}^{+1.2}_{-1.3} & \pm 0.2 & {}^{+40.9}_{-14.1} \\ -7.6 & \pm 6.3 & \pm 0.0 & {}^{+1.9}_{-1.6} & {}^{+1.7}_{-1.6} & \pm 0.0 & {}^{+19.0}_{-53.6} \\ 5.0 & {}^{+0.7}_{-0.8} & {}^{+0.8}_{-1.3} & {}^{+0.2}_{-0.1} & \pm 0.0 & \pm 0.2 & {}^{+1.1}_{-0.6} \\ -0.5 & \pm 0.2 & {}^{+0.8}_{-1.0} & \pm 0.0 & \pm 0.0 & \pm 0.6 & \pm 0.1 \end{pmatrix} \times 10^{-2}, \tag{9}$$

Conclusions

- This work highlights that hadronic tau lepton decays remain to be not only a privileged tool for the investigation of the hadronization of QCD currents but also offer an interesting scenario as New Physics probes.
- In general, our bounds on the NP couplings, are competitive. This is specially the case for the combination of couplings $\epsilon_L^\tau - \epsilon_L^e + \epsilon_R^\tau - \epsilon_R^e$, which is found to be in accord with [21] and ϵ_T^τ, that can even compete with the constraints set by the theoretically cleaner $K_{\ell 3}$ decays.
- As for ϵ_S^τ, it is impossible to compete with the limits coming from $K_{\ell 3}$ decays (the decay $\tau^- \to \pi^- \eta \nu_\tau$ has not been taken into account because the lack of data).

[21] V. Cirigliano, A. Falkowski, M. González-Alonso and A. Rodríguez-Sánchez, Phys. Rev. Lett. **122**, no.22, 221801 (2019).