Constraints on $SU(2)_L$-preserving NSI from hadronic τ decays

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Outline

Motivation Neutrino oscillation

» Since the 2000's, standard *(ish)* neutrino oscillations are found to be mass-driven.

⇓

- Different mass (propagation) and flavour (production/detetction) eigenstates.

» Can be parametrized with the PMNS matrix:

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

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$\Downarrow$

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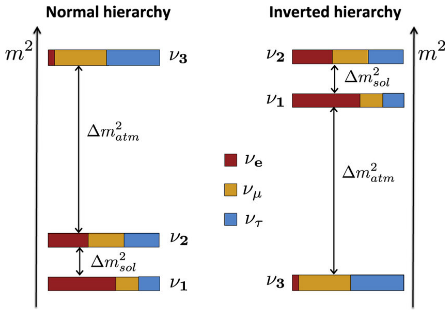
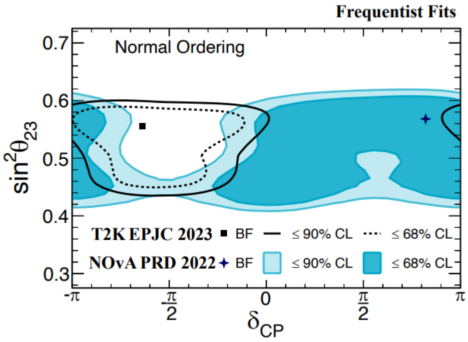
- Oscillation parameters depend on the mass ordering.



S. Adrián-Martínez et al. (KM3NeT) (2016)

Motivation TENSIONS AND NSI

- NSI went from being a possible oscillation origin to a subdominant effect.
- There are some results that are still in tension in the mass-driven mixing.



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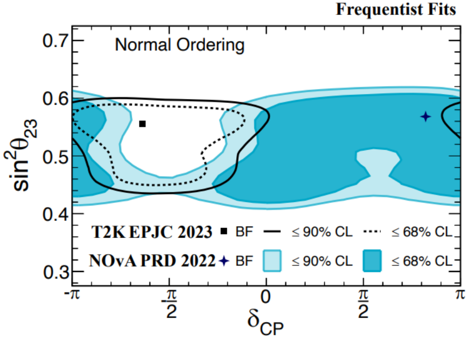

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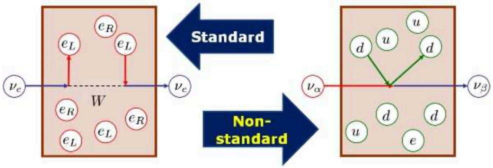

T. Ohlsson (2013)

- They would introduce variations to the Standard matter effects (MSW).

↪ Could be (and are) constrained with ocillation experiments

NSI and symmetries Formalism

» Introducing an effective lagrangian for NC NSI:

$$\mathcal{L}_{\mathrm{NSI(NC)}} = -2\sqrt{2}G_F \sum_{f,X,\alpha,\beta} \epsilon^{fX}_{\alpha\beta} (\overline{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\overline{f}\gamma_\mu P_X f)$$
$$= -\sqrt{2}G_F \sum_{f,\alpha,\beta} (\overline{\nu}_\alpha \gamma^\mu P_L \nu_\beta)\left(\overline{f}\left[\epsilon^{fV}_{\alpha\beta}\gamma_\mu + \epsilon^{fA}_{\alpha\beta}\gamma_\mu\gamma_5\right] f\right)$$

» While CC modifies ν's detection and production, the NC change the propagation.

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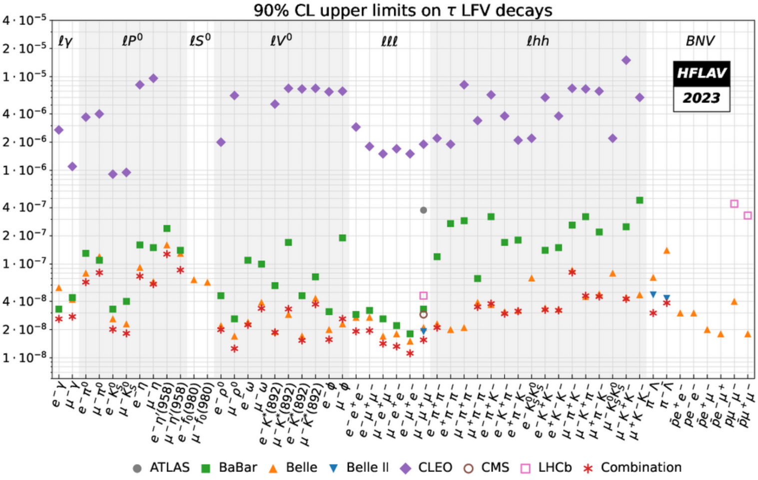
» While CC modifies ν's detection and production, the NC change the propagation.

» We include only vector and axial-vector contributions to the four-fermion operators.

» Similar strengths are expected in V and A contributions for chiral mediators.

τ decays UPDATES IN CLFV BOUNDS



» Improvement of bounds on τ LFV.

S. Banerjee et al. (HFLAV) (2024)

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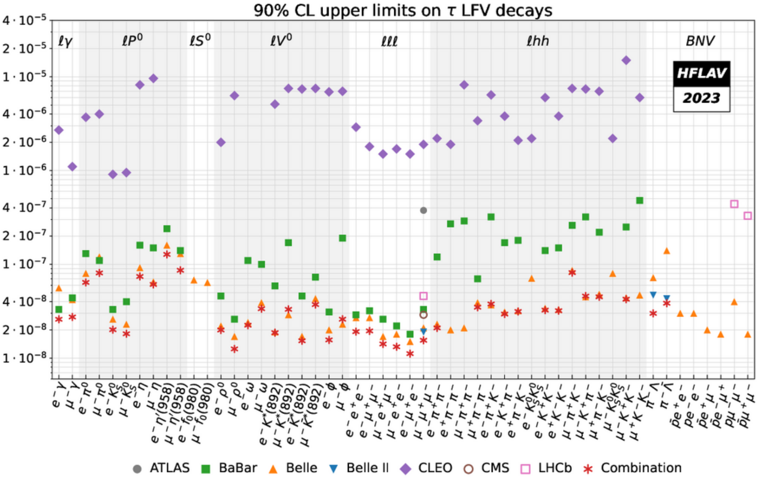

- Improvement of bounds on τ LFV.
- Cleaner observables.

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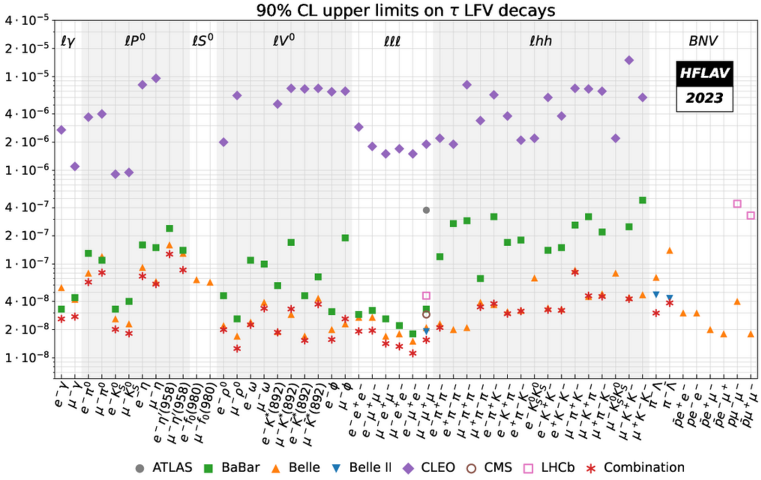

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- Cleaner observables.
- Multiple hadronic channels available.

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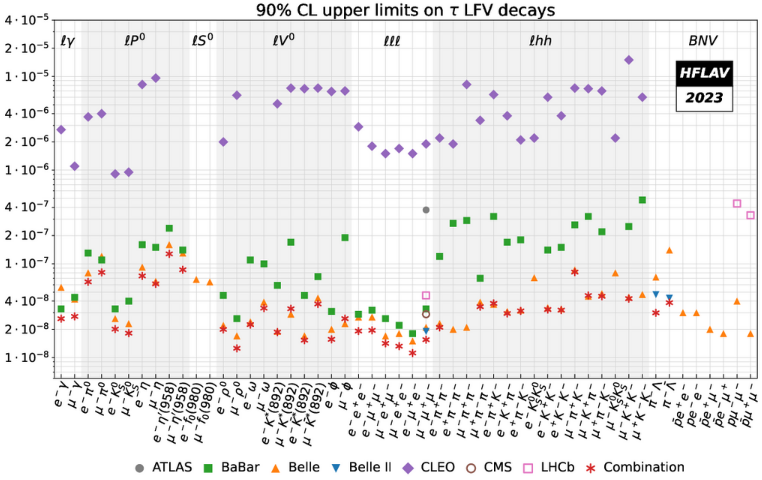


- Improvement of bounds on τ LFV.
- Cleaner observables.
- Multiple hadronic channels available.
- Possible higher sensitivity to NP.

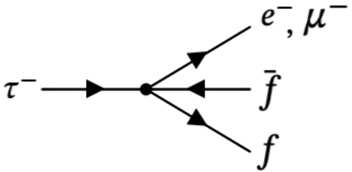
S. Banerjee et al. (HFLAV) (2024)

τ decays Updates in CLFV bounds

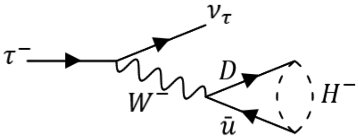
» We aim to update previous analyses and to include more channels:

- S. Bergmann et al. (1999, 2000, 2000)
- M. B. Gavela et al. (2009)
- S. Davidson and M. Gorbahn (2020),

among others.



⇓ Normalized with *(when possible)*



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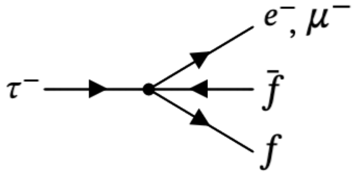

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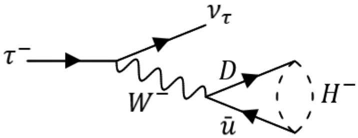

» We consider HFLAV averages for the 95% CL in the following channels:

- $\tau \to \ell P^0$ with $P^0 \in \{\pi^0, \eta, \eta'\} \longrightarrow I = 0, 1;\ \epsilon^{f\,A}_{\ell\tau}$
- $\tau \to \ell P^+ P^-$ with $P \in \{\pi, K\} \longrightarrow I = 0, 1;\ \epsilon^{f\,V}_{\ell\tau}$
- $\tau \to \ell V$ with $V \in \{\omega, \phi\} \longrightarrow I = 0;\ \epsilon^{f\,V}_{\ell\tau}$

τ decays Preliminary results

Process	Dirac Structure	Isospin	$\lvert\epsilon^u_{\mu\tau}\rvert$ Constaint	$\lvert\epsilon^d_{\mu\tau}\rvert$ Constraint	$\lvert\epsilon^s_{\mu\tau}\rvert$ Constraint
$\tau \to \mu\pi^0$	Axial	1	$\leq 1.2 \times 10^{-3}$	$\leq 1.2 \times 10^{-3}$	N/A
$\tau \to \mu\eta$	Axial	0	$\leq 1.4 \times 10^{-3}$	$\leq 1.4 \times 10^{-3}$	$\leq 9.6 \times 10^{-4}$
$\tau \to \mu\eta'$	Axial	0	$\leq 2.6 \times 10^{-3}$	$\leq 2.6 \times 10^{-3}$	$\leq 1.2 \times 10^{-3}$
$\tau \to \mu\pi^+\pi^-$	Vector	1	$\leq 4.0 \times 10^{-4}$	$\leq 4.0 \times 10^{-4}$	N/A
$\tau \to \mu K^+K^-$	Vector	0	$\leq 1.0 \times 10^{-2}$	N/A	$\leq 1.0 \times 10^{-2}$
$\tau \to \mu\omega$	Vector	0	$\leq 5.8 \times 10^{-4}$	$\leq 5.8 \times 10^{-4}$	N/A
$\tau \to \mu\phi$	Vector	0	N/A	N/A	$\leq 4.8 \times 10^{-4}$

Process	Dirac Structure	Isospin	$\lvert\epsilon^u_{e\tau}\rvert$ Constaint	$\lvert\epsilon^d_{e\tau}\rvert$ Constraint	$\lvert\epsilon^s_{e\tau}\rvert$ Constraint
$\tau \to e\pi^0$	Axial	1	$\leq 1.1 \times 10^{-3}$	$\leq 1.1 \times 10^{-3}$	N/A
$\tau \to e\eta$	Axial	0	$\leq 1.5 \times 10^{-3}$	$\leq 1.5 \times 10^{-3}$	$\leq 1.0 \times 10^{-3}$
$\tau \to e\eta'$	Axial	0	$\leq 3.2 \times 10^{-3}$	$\leq 3.2 \times 10^{-3}$	$\leq 1.4 \times 10^{-3}$
$\tau \to e\pi^+\pi^-$	Vector	1	$\leq 4.0 \times 10^{-4}$	$\leq 4.0 \times 10^{-4}$	N/A
$\tau \to eK^+K^-$	Vector	0	$\leq 9.0 \times 10^{-3}$	N/A	$\leq 9.0 \times 10^{-3}$
$\tau \to e\omega$	Vector	0	$\leq 4.7 \times 10^{-4}$	$\leq 4.7 \times 10^{-4}$	N/A
$\tau \to e\phi$	Vector	0	N/A	N/A	$\leq 3.7 \times 10^{-4}$

Conclusions Limitations

» We can build $D > 6$ $SU(2)_L$-preserving operators for ν_ℓ that don't translate to CLFV:

NSI Effective operator example without CLFV

$$\bar{l}_R \left(H^\dagger \sigma^a \ell_L\right) \left(\bar{\ell}_L \sigma^a H\right) l_R \longrightarrow -\frac{1}{2}\langle H\rangle^2 \left(\bar{l}\gamma^\mu P_R l\right) \left(\overline{\nu}_l \gamma_\mu P_L \nu_l\right)$$

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- For non-singlet mediators the constraint is up to the ratio of the masses *(Estimated factor <7)*.

- EFT approach is no longer valid for light mediators!

- We are constraining one coupling at a time
  $\hookrightarrow$ Maybe there is an interference enhancement.

Conclusions Summary

- Flavour changing NC NSI can be *(strongly)* constrained using CLFV experimental bounds.
  $\hookrightarrow$ We obtained $\epsilon^{f}_{\alpha\beta} \sim \mathcal{O}(10^{-3})$ in most channels.

- τ semileptonic and leptonic decays are particularly useful to search for these flavour-violating channels.

- Our bounds can still allow for NSI with different UV theories or in dense atmospheres. *(Effects in supernovae?)*

Thanks for your attention!

Supplementary Material

» Interaction hamiltonian with general NSI

$$\mathcal{H}_F = \frac{1}{2E}\left\{U\begin{pmatrix} 0 & & \\ & \Delta m_{21}^2 & \\ & & \Delta m_{31}^2 \end{pmatrix}U^\dagger + a_{\rm CC}\begin{pmatrix} 1+\epsilon_{ee}^m & \epsilon_{e\mu}^m & \epsilon_{e\tau}^m \\ (\epsilon_{e\mu}^m)^* & \epsilon_{\mu\mu}^m & \epsilon_{\mu\tau}^m \\ (\epsilon_{e\tau}^m)^* & (\epsilon_{\mu\tau}^m)^* & \epsilon_{\tau\tau}^m \end{pmatrix}\right\},$$

M. B. Gavela et al. (2009)

» Non-singlets mediators treatment

$$\epsilon_\nu^f = \frac{\lambda_{\tau f}^*\lambda_{\mu f}}{4\sqrt{2}M_B^2 G_F}$$

$$\epsilon_\nu^f \equiv \frac{G_{\nu_\mu\nu_\tau}^f}{G_F}$$

$$G_{\nu_\alpha\nu_\beta}^f = G_{\alpha\beta}^f\,\frac{M_1^2}{M_2^2}\,.$$

S. Bergmann et al. (2000)

Supplementary Material

Class	Operator	Mediator
$1^{s,t}_{LXLX}$	$(\overline{L^c_\alpha} i\tau^2 L_\beta)(\overline{L^c_\epsilon} i\tau^2 L_\delta)^\dagger$	$S(\mathbf{1},\mathbf{1},\ 1)$
	$(\overline{L^c_\alpha} i\tau^2 \vec{\tau} L_\beta)(\overline{L^c_\epsilon} i\tau^2 \vec{\tau} L_\delta)^\dagger$	$S(\mathbf{1},\mathbf{3},\ 1)$
	$(\overline{L^c_\alpha} i\tau^2 Q_\beta)(\overline{L^c_\epsilon} i\tau^2 Q_\delta)^\dagger$	$S(\bar{\mathbf{3}},\mathbf{1},\ 1/3)$
	$(\overline{L^c_\alpha} i\tau^2 \vec{\tau} Q_\beta)(\overline{L^c_\epsilon} i\tau^2 \vec{\tau} Q_\delta)^\dagger$	$S(\bar{\mathbf{3}},\mathbf{3},\ 1/3)$
2_{LFLF}	$(\overline{L_\alpha}(l_R)_\beta)(\overline{L_\epsilon}(l_R)_\delta)^\dagger$	$S(\mathbf{1},\mathbf{2},\ 1/2)$
	$(\overline{L_\alpha}(u_R)_\beta)(\overline{L_\epsilon}(u_R)_\delta)^\dagger$	$S(\bar{\mathbf{3}},\mathbf{2},\ -7/6)$
	$(\overline{L_\alpha}(d_R)_\beta)(\overline{L_\epsilon}(d_R)_\delta)^\dagger$	$S(\bar{\mathbf{3}},\mathbf{2},\ -1/6)$
$3^{s,t}_{LXYZ}$	$(\overline{L_\alpha}\gamma^\mu L_\beta)_s(\overline{L_\epsilon}\gamma_\mu L_\delta)^\dagger_s$	$V(\mathbf{1},\mathbf{1},\ 0)$
	$(\overline{L_\alpha}\gamma^\mu \vec{\tau} L_\beta)(\overline{L_\epsilon}\gamma_\mu \vec{\tau} L_\delta)^\dagger$	$V(\mathbf{1},\mathbf{3},\ 0)$
	$(\overline{L_\alpha}\gamma^\mu L_\beta)(\overline{Q_\epsilon}\gamma_\mu Q_\delta)^\dagger$	$V(\mathbf{1},\mathbf{1},\ 0)$
	$(\overline{L_\alpha}\gamma^\mu \vec{\tau} L_\beta)(\overline{Q_\epsilon}\gamma_\mu \vec{\tau} Q_\delta)^\dagger$	$V(\mathbf{1},\mathbf{3},\ 0)$
	$(\overline{L_\alpha}\gamma^\mu Q_\beta)(\overline{L_\epsilon}\gamma_\mu Q_\delta)^\dagger$	$V(\bar{\mathbf{3}},\mathbf{1},\ -2/3)$
	$(\overline{L_\alpha}\gamma^\mu \vec{\tau} Q_\beta)(\overline{L_\epsilon}\gamma_\mu \vec{\tau} Q_\delta)^\dagger$	$V(\bar{\mathbf{3}},\mathbf{3},\ -2/3)$

- Classification of constrained operators with its mediator

4_{LLFF}	$(\overline{L_\alpha}\gamma^\mu L_\beta)(\overline{(l_R)_\epsilon}\gamma_\mu (l_R)_\delta)^\dagger$	$V(\mathbf{1},\mathbf{1},\ 0)$
	$(\overline{L_\alpha}\gamma^\mu L_\beta)(\overline{(u_R)_\epsilon}\gamma_\mu (u_R)_\delta)^\dagger$	$V(\mathbf{1},\mathbf{1},\ 0)$
	$(\overline{L_\alpha}\gamma^\mu L_\beta)(\overline{(d_R)_\epsilon}\gamma_\mu (d_R)_\delta)^\dagger$	$V(\mathbf{1},\mathbf{1},\ 0)$
5_{LFLF}	$(\overline{L^c_\alpha}\gamma^\mu (l_R)_\beta)(\overline{L^c_\epsilon}\gamma_\mu (l_R)_\delta)^\dagger$	$V(\mathbf{1},\mathbf{2},\ 3/2)$
	$(\overline{L^c_\alpha}\gamma^\mu (u_R)_\beta)(\overline{L^c_\epsilon}\gamma_\mu (u_R)_\delta)^\dagger$	$V(\bar{\mathbf{3}},\mathbf{2},\ -1/6)$
	$(\overline{L^c_\alpha}\gamma^\mu (d_R)_\beta)(\overline{L^c_\epsilon}\gamma_\mu (d_R)_\delta)^\dagger$	$V(\bar{\mathbf{3}},\mathbf{2},\ 5/6)$