Bounds to Non-standard Neutrino Interactions

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Preface

MINSIS signal

Flavour violation process with a neutrino in μ-τ sector

at the beam source: $\pi^+ \to \mu^+ \nu$

$\nu N \to \tau^- X$:at a (near) detector

Categories of physics at MINSIS — Effective theory-wise

- Sterile neutrino — mixing with light neutrals
  →Li Lopez-Pavon Yasuda
- Non-unitary PMNS matrix — mixing with heavy neutrals
  →Antusch Blennow
- Non-standard neutrino interactions — exotic four-Fermi int
  →Fernandez-Martinez Mena Parke Winter

Outline

1. Introduction
   - Non-standard neutrino interactions in experiments
   - Gauge invariant effective interactions for MINSIS
2. Bounds from charged LFV
   - Under some assumptions for simplicity
   - In general
3. Conclusion and Discussion

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1. Introduction
   - Non-standard neutrino interactions in experiments
   - Gauge invariant effective interactions for MINSIS
2. Bounds from charged LFV
   - Under some assumptions for simplicity
   - In general
3. Conclusion and Discussion

NSI in oscillation experiments

- NSI — Exotic interactions with neutrinos which are parametrized as four-Fermi interactions:

Standard oscillation

$$P_{\nu_\alpha \to \nu_\beta} = \left| \langle \nu_\beta | \mathrm{e}^{-\mathrm{i}HL} | \nu_\alpha \rangle \right|^2$$

NSI in oscillation experiments

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Standard oscillation

$$P_{\nu_\alpha \to \nu_\beta} = \left| \langle \nu_\beta | \mathrm{e}^{-\mathrm{i}HL} | \nu_\alpha \rangle \right|^2$$

With NSI in source and detection

$$P_{\nu_\alpha \to \nu_\beta} = \left| \langle \nu_\beta^d | \mathrm{e}^{-\mathrm{i}HL} | \nu_\alpha^s \rangle \right|^2$$

- CC type NSI — flavour mixture states at source and detection

Grossman PL**B359** (1995) 141.

$$|\nu_\alpha^s\rangle = |\nu_\alpha\rangle + \sum_{\gamma=e,\mu,\tau} \epsilon_{\alpha\gamma}^s |\nu_\gamma\rangle, \qquad \text{e.g., } \pi^+ \xrightarrow{\epsilon_{\mu e}^s} \mu^+ \nu_e$$

$$\langle\nu_\alpha^d| = \langle\nu_\alpha| + \sum_{\gamma=e,\mu,\tau} \epsilon_{\gamma\alpha}^d \langle\nu_\gamma|, \qquad \text{e.g., } \nu_\tau N \xrightarrow{\epsilon_{\tau e}^d} e^- X$$

NSI in oscillation experiments

- NSI — Exotic interactions with neutrinos which are parametrized as four-Fermi interactions:

Standard oscillation

$$P_{\nu_\alpha \to \nu_\beta} = \left| \langle \nu_\beta | \mathrm{e}^{-\mathrm{i}HL} | \nu_\alpha \rangle \right|^2$$

With NSI in propagation

$$P_{\nu_\alpha \to \nu_\beta} = \left| \langle \nu_\beta | \mathrm{e}^{-\mathrm{i}(H + V_{\mathrm{NSI}})L} | \nu_\alpha \rangle \right|^2$$

- NC type NSI — extra matter effect in propagation

e.g., Wolfenstein PR**D17** (1978) 2369. Valle PL**B199** (1987) 432. Guzzo Masiero Petcov PL**B260** (1991) 154. Roulet PR**D44** (1991) R935.

$$(V_{\mathrm{NSI}})_{\beta\alpha} = \sqrt{2} G_F N_e \begin{pmatrix} \epsilon^m_{ee} & \epsilon^m_{e\mu} & \epsilon^m_{e\tau} \\ \epsilon^{m*}_{e\mu} & \epsilon^m_{\mu\mu} & \epsilon^m_{\mu\tau} \\ \epsilon^{m*}_{e\tau} & \epsilon^{m*}_{\mu\tau} & \epsilon^m_{\tau\tau} \end{pmatrix},$$

e.g., $\nu_e \xrightarrow{\epsilon^m_{e\tau}} \nu_\tau$ in propagation

- Source and detection NSIs are relevant to *MINSIS*.

NSI in MINSIS

at the beam source: $\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+ \nu_\tau$

$$\downarrow$$

$\nu_\tau N \xrightarrow{\text{SM}} \tau^- X$:at a detector

$$\mathcal{A}^{\nu N\text{-scat}}_{\text{SM}} \mathcal{A}(\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+ \nu_\tau)$$

Three (coherent) contributions

- Source NSI in pion decay
- Detection NSI at neutrino-nucleon scattering
- Standard(/non-standard) oscillation

NSI in MINSIS

at the beam source: $\pi^+ \xrightarrow{\text{SM}} \mu^+ \nu_\mu$

$$\downarrow$$

$\nu_\mu N \xrightarrow{\epsilon^d_{\mu\tau}} \tau^- X$:at a detector

$$\mathcal{A}_{\text{SM}}^{\nu N\text{-scat}} \mathcal{A}(\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+ \nu_\tau) + \mathcal{A}(\nu_\mu N \xrightarrow{\epsilon^d_{\mu\tau}} \tau^- X) \mathcal{A}_{\text{SM}}^{\pi\text{-decay}}$$

Three (coherent) contributions

- Source NSI in pion decay
- Detection NSI at neutrino-nucleon scattering
- Standard(/non-standard) oscillation

NSI in MINSIS

at the beam source: $\pi^+ \xrightarrow{\text{SM}} \mu^+ \nu_\mu$

$$\nu_\mu \xrightarrow{\text{osc}} \nu_\tau N \xrightarrow{\text{SM}} \tau^- X$$:at a detector

$$\mathcal{A}_{\text{SM}}^{\nu N\text{-scat}} \mathcal{A}(\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+ \nu_\tau) + \mathcal{A}(\nu_\mu N \xrightarrow{\epsilon^d_{\mu\tau}} \tau^- X) \mathcal{A}_{\text{SM}}^{\pi\text{-decay}} + \mathcal{A}_{\text{SM}}^{\nu N\text{-scat}} \langle \nu_\tau | -\mathrm{i} H L | \nu_\mu \rangle \mathcal{A}_{\text{SM}}^{\pi\text{-decay}}$$

Three (coherent) contributions

- Source NSI in pion decay
- Detection NSI at neutrino-nucleon scattering
- Standard(/non-standard) oscillation

NSI in MINSIS

at the beam source: $\pi^+ \longrightarrow \mu^+ \nu$

$$\downarrow$$

$\nu N \longrightarrow \tau^- X$:at a detector

MINSIS signal rate =

$$\left| \mathcal{A}_{\rm SM}^{\nu N\text{-scat}} \mathcal{A}(\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+ \nu_\tau) + \mathcal{A}(\nu_\mu N \xrightarrow{\epsilon^d_{\mu\tau}} \tau^- X) \mathcal{A}_{\rm SM}^{\pi\text{-decay}} + \mathcal{A}_{\rm SM}^{\nu N\text{-scat}} \langle \nu_\tau | - {\rm i} H L | \nu_\mu \rangle \mathcal{A}_{\rm SM}^{\pi\text{-decay}} \right|^2$$

Three (coherent) contributions

- Source NSI in pion decay
- Detection NSI at neutrino-nucleon scattering
- Standard(/non-standard) oscillation

We will see source NSI is an interesting possibility...

Four-Fermi interactions

- including $(\bar{\nu}_\tau \mu)(\bar{d} u)$ or $(\bar{\tau} \nu_\mu)(\bar{u} d)$
- SM gauge invariant

$$\begin{aligned}
\mathscr{L}_{\text{eff}} =& 2\sqrt{2} G_F \sum_{\beta,\alpha} \left[(\mathcal{C}^{\mathbf{1}}_{LQ})_\beta{}^\alpha (\mathscr{O}^{\mathbf{1}}_{LQ})^\beta_\alpha + (\mathcal{C}^{\mathbf{3}}_{LQ})_\beta{}^\alpha (\mathscr{O}^{\mathbf{3}}_{LQ})^\beta_\alpha \right] \\
&+ 2\sqrt{2} G_F \sum_{\beta,\alpha} \left[(\mathcal{C}_{ED})_\beta{}^\alpha (\mathscr{O}_{ED})^\beta_\alpha + (\mathcal{C}_{EU})_\beta{}^\alpha (\mathscr{O}_{EU})^\beta_\alpha + \text{H.c.} \right],
\end{aligned}$$

defined with the operators

$$\begin{aligned}
(\mathscr{O}^{\mathbf{1}}_{LQ})^\beta_\alpha =& [\overline{L}^\beta \gamma^\rho L_\alpha][\overline{Q} \gamma_\rho Q], \\
(\mathscr{O}^{\mathbf{3}}_{LQ})^\beta_\alpha =& [\overline{L}^\beta \gamma^\rho \vec{\tau} L_\alpha][\overline{Q} \gamma_\rho \vec{\tau} Q], \\
(\mathscr{O}_{ED})^\beta_\alpha =& [\overline{L}^\beta E_\alpha][\overline{D} Q], \\
(\mathscr{O}_{EU})^\beta_\alpha =& [\overline{L}^\beta E_\alpha](\mathrm{i}\tau^2)[\overline{Q} U],
\end{aligned}$$

and the corresponding coefficients $\mathcal{C}$s.

Four-Fermi interactions

With component fields, the Lagrangian looks ...

$$\mathscr{L}_{\text{eff}} = \underbrace{\mathscr{L}_{\text{MINSIS}}}_{\nu\ell} + \underbrace{\mathscr{L}_{\text{CLFV}}}_{\ell\ell} + \underbrace{\mathscr{L}_{\text{NSI}}}_{\nu\nu}$$

$$\mathscr{L}_{\text{MINSIS}} = 2\sqrt{2}G_F \Big[2(\mathcal{C}^{\mathbf{3}}_{LQ})_\tau{}^\mu [\bar{\nu}^\tau \gamma^\rho \mathrm{P}_L \mu][\bar{d}\gamma_\rho \mathrm{P}_L u] + 2(\mathcal{C}^{\mathbf{3}}_{LQ})_\tau{}^\mu [\bar{\tau}\gamma^\rho \mathrm{P}_L \nu_\mu][\bar{u}\gamma_\rho \mathrm{P}_L d]$$
$$+ (\mathcal{C}_{ED})_\tau{}^\mu [\bar{\nu}^\tau \mathrm{P}_R \mu][\bar{d}\mathrm{P}_L u] + (\mathcal{C}_{EU})_\tau{}^\mu [\bar{\nu}^\tau \mathrm{P}_R \mu][\bar{d}\mathrm{P}_R u]$$
$$+ (\mathcal{C}^\dagger_{ED})_\tau{}^\mu [\bar{\tau}\mathrm{P}_L \nu_\mu][\bar{u}\mathrm{P}_R d] + (\mathcal{C}^\dagger_{EU})_\tau{}^\mu [\bar{\tau}\mathrm{P}_L \nu_\mu][\bar{u}\mathrm{P}_L d] + \cdots \Big].$$

Source NSI: $(\mathcal{C}^{\mathbf{3}}_{LQ})_\tau{}^\mu$, $(\mathcal{C}_{ED})_\tau{}^\mu$, and $(\mathcal{C}_{EU})_\tau{}^\mu$,

Detection NSI: $(\mathcal{C}^{\mathbf{3}}_{LQ})_\tau{}^\mu$, $(\mathcal{C}^\dagger_{ED})_\tau{}^\mu$, and $(\mathcal{C}^\dagger_{EU})_\tau{}^\mu$.

Note that $(\mathcal{C})_\tau{}^\mu$ and $(\mathcal{C}^\dagger)_\tau{}^\mu$ are independent.

Four-Fermi interactions

With component fields, the Lagrangian looks ...

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{MINSIS}} + \mathscr{L}_{\text{CLFV}} + \mathscr{L}_{\text{NSI}}$$

$$\begin{aligned}
\mathscr{L}_{\text{CLFV}} = \frac{G_F}{\sqrt{2}} \Bigg[& \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} - (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\tau][\bar{u}\gamma_{\rho}u] + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} + (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\tau][\bar{d}\gamma_{\rho}d] \\
& - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} - (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\gamma^{5}\tau][\bar{u}\gamma_{\rho}u] - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} + (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\gamma^{5}\tau][\bar{d}\gamma_{\rho}d] \\
& - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} - (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\tau][\bar{u}\gamma_{\rho}\gamma^{5}u] - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} + (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\tau][\bar{d}\gamma_{\rho}\gamma^{5}d] \\
& + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} - (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\gamma^{5}\tau][\bar{u}\gamma_{\rho}\gamma^{5}u] + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} + (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{\rho}\gamma^{5}\tau][\bar{d}\gamma_{\rho}\gamma^{5}d] \\
& - \left\{ (\mathcal{C}_{ED})_{\mu}{}^{\tau} - (\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau} \right\} [\bar{\mu}\tau][\bar{d}\gamma^{5}d] - \left\{ (\mathcal{C}_{EU})_{\mu}{}^{\tau} - (\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau} \right\} [\bar{\mu}\tau][\bar{u}\gamma^{5}u] \\
& - \left\{ (\mathcal{C}_{ED})_{\mu}{}^{\tau} + (\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{5}\tau][\bar{d}\gamma^{5}d] - \left\{ (\mathcal{C}_{EU})_{\mu}{}^{\tau} + (\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{5}\tau][\bar{u}\gamma^{5}u] \\
& + \left\{ (\mathcal{C}_{ED})_{\mu}{}^{\tau} + (\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau} \right\} [\bar{\mu}\tau][\bar{d}d] - \left\{ (\mathcal{C}_{EU})_{\mu}{}^{\tau} + (\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau} \right\} [\bar{\mu}\tau][\bar{u}u] \\
& + \left\{ (\mathcal{C}_{ED})_{\mu}{}^{\tau} - (\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{5}\tau][\bar{d}d] - \left\{ (\mathcal{C}_{EU})_{\mu}{}^{\tau} - (\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau} \right\} [\bar{\mu}\gamma^{5}\tau][\bar{u}u] + \cdots \Bigg].
\end{aligned}$$

It is impossible to turn off $(\bar{\mu}\tau)(\bar{u}u)$ and $(\bar{\mu}\tau)(\bar{d}d)$ at the same time — MINSIS-NSIs are always constrained from CLFV.

Outline

Effective Lagrangian for Charged LFV

$$\begin{aligned}
\mathscr{L}_{\text{CLFV}} = \frac{G_F}{\sqrt{2}} \Big[& \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau - (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho \tau][\bar{u}\gamma_\rho u] + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau + (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho \tau][\bar{d}\gamma_\rho d] \\
& - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau - (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5 \tau][\bar{u}\gamma_\rho u] - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau + (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5 \tau][\bar{d}\gamma_\rho d] \\
& - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau - (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho \tau][\bar{u}\gamma_\rho\gamma^5 u] - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau + (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho \tau][\bar{d}\gamma_\rho\gamma^5 d] \\
& + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau - (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5 \tau][\bar{u}\gamma_\rho\gamma^5 u] + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau + (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5 \tau][\bar{d}\gamma_\rho\gamma^5 d] \\
& - \left\{ (\mathcal{C}_{ED})_\mu{}^\tau - (\mathcal{C}^\dagger_{ED})_\mu{}^\tau \right\} [\bar{\mu}\tau][\bar{d}\gamma^5 d] - \left\{ (\mathcal{C}_{EU})_\mu{}^\tau - (\mathcal{C}^\dagger_{EU})_\mu{}^\tau \right\} [\bar{\mu}\tau][\bar{u}\gamma^5 u] \\
& - \left\{ (\mathcal{C}_{ED})_\mu{}^\tau + (\mathcal{C}^\dagger_{ED})_\mu{}^\tau \right\} [\bar{\mu}\gamma^5\tau][\bar{d}\gamma^5 d] - \left\{ (\mathcal{C}_{EU})_\mu{}^\tau + (\mathcal{C}^\dagger_{EU})_\mu{}^\tau \right\} [\bar{\mu}\gamma^5\tau][\bar{u}\gamma^5 u] \\
& + \left\{ (\mathcal{C}_{ED})_\mu{}^\tau + (\mathcal{C}^\dagger_{ED})_\mu{}^\tau \right\} [\bar{\mu}\tau][\bar{d}d] - \left\{ (\mathcal{C}_{EU})_\mu{}^\tau + (\mathcal{C}^\dagger_{EU})_\mu{}^\tau \right\} [\bar{\mu}\tau][\bar{u}u] \\
& + \left\{ (\mathcal{C}_{ED})_\mu{}^\tau - (\mathcal{C}^\dagger_{ED})_\mu{}^\tau \right\} [\bar{\mu}\gamma^5\tau][\bar{d}d] - \left\{ (\mathcal{C}_{EU})_\mu{}^\tau - (\mathcal{C}^\dagger_{EU})_\mu{}^\tau \right\} [\bar{\mu}\gamma^5\tau][\bar{u}u] + \cdots \Big].
\end{aligned}$$

Relevant CLFV depends on the Lorenz structure of $\bar{q}q$

cf. Black Han He Sher PR**D66** (2002) 053002

Vector: $\tau \to \mu\rho$ and $\tau \to \mu\omega$

Axial-vector and Pseudo-scalar: $\tau \to \mu\pi$ and $\tau \to \mu\eta$

Scalar: $\tau \to \mu\pi^+\pi^-$, $\tau \to \mu K^+ K^-$, and $\tau \to \mu K^0 \bar{K}^0$.

For simplicity, let us ...

- concentrate on the NSI at source $\pi^+ \to \mu^+ \nu_\tau$
- assume the all coeffs are real and Hermite
  e.g. $\mathcal{C}_{ED} \equiv (\mathcal{C}_{ED})_\mu{}^\tau = (\mathcal{C}_{ED})_\tau{}^\mu$

$$\mathscr{L}_{\text{MINSIS}} = -2\sqrt{2} G_F \left[\mathcal{C}^{\mathbf{3}}_{LQ} [\bar{\nu}^\tau \gamma^\rho \mathrm{P}_L \mu][\bar{d}\gamma_\rho \gamma^5 u] + \frac{1}{2} (\mathcal{C}_{ED} - \mathcal{C}_{EU}) [\bar{\nu}^\tau \mathrm{P}_R \mu][\bar{d}\gamma^5 u] + \cdots \right],$$

$$\Gamma(\pi^+ \to \mu^+ \nu_\tau) = \Gamma_{\text{SM}} \times \left| 2\mathcal{C}^{\mathbf{3}}_{LQ} + \omega_\mu (\mathcal{C}_{ED} - \mathcal{C}_{EU}) \right|^2 .$$

with the chiral enhancement factor $\omega_\mu = \frac{m_\pi}{m_\mu} \frac{m_\pi}{m_u + m_d} \sim 15$.

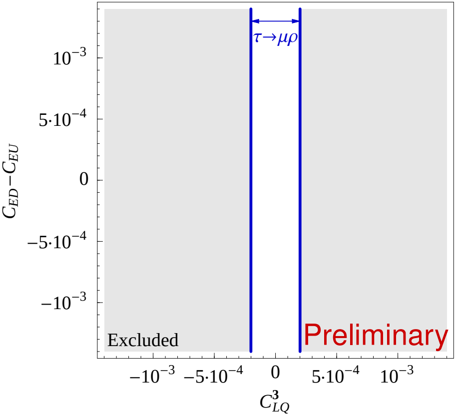
- Two relevant parameters:

$$\mathcal{C}^{\mathbf{3}}_{LQ} \quad \text{and} \quad \mathcal{C}_{ED} - \mathcal{C}_{EU}$$

We will see the constraints to them from CLFV, especially
$\tau \to \mu\rho$, $\tau \to \mu\pi$, and $\tau \to \mu\pi^+\pi^-$.

Bounds from charged LFV

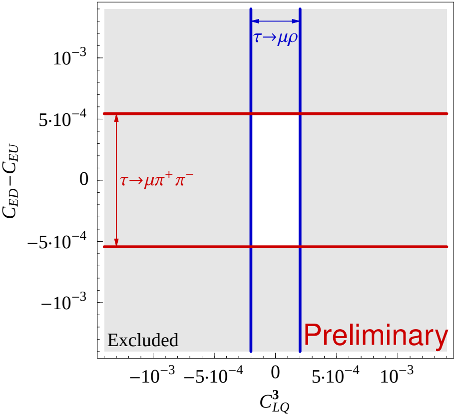
Under some assumptions for simplicity



- $\mathrm{Br}(\tau\to\mu\rho)<6.8\cdot10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$

Bounds from charged LFV

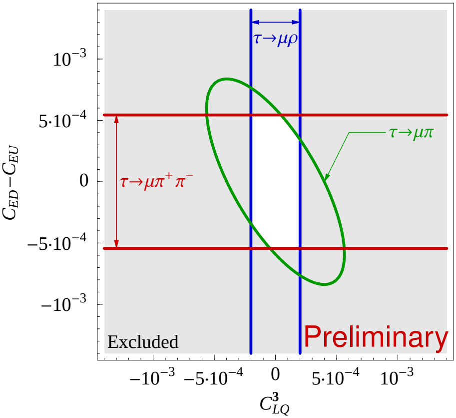
Under some assumptions for simplicity



- Br($\tau \to \mu\rho$)<$6.8 \cdot 10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$
- Br($\tau \to \mu\pi^+\pi^-$)<$2.9 \cdot 10^{-7}$
  $|\mathcal{C}_{ED} - \mathcal{C}_{EU}|$

Bounds from charged LFV

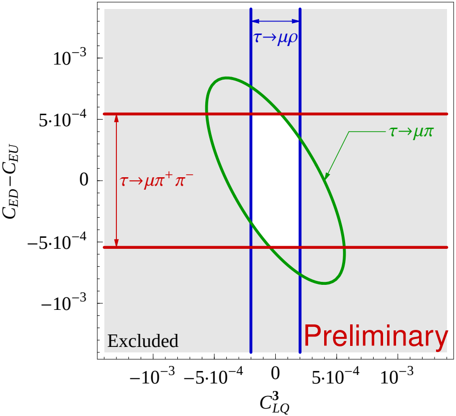
Under some assumptions for simplicity



- Br($\tau \to \mu\rho$)<$6.8 \cdot 10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$
- Br($\tau \to \mu\pi^+\pi^-$)<$2.9 \cdot 10^{-7}$
  $|\mathcal{C}_{ED} - \mathcal{C}_{EU}|$
- Br($\tau \to \mu\pi$)<$1.1 \cdot 10^{-7}$
  $\mathcal{C}^{\mathbf{3}}_{LQ}$ and $(\mathcal{C}_{ED} - \mathcal{C}_{EU})$

Bounds from charged LFV

Under some assumptions for simplicity



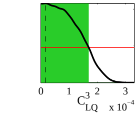
- Br($\tau \to \mu\rho$)<$6.8 \cdot 10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$
- Br($\tau \to \mu\pi^+\pi^-$)<$2.9 \cdot 10^{-7}$
  $|\mathcal{C}_{ED} - \mathcal{C}_{EU}|$
- Br($\tau \to \mu\pi$)<$1.1 \cdot 10^{-7}$
  $\mathcal{C}^{\mathbf{3}}_{LQ}$ and $(\mathcal{C}_{ED} - \mathcal{C}_{EU})$

MINSIS/SM ratio can be

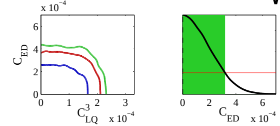
$$\frac{\Gamma(\pi^+ \to \mu^+\nu_\tau)}{\Gamma_{\rm SM}} = \left| 2\,\underbrace{\mathcal{C}^{\mathbf{3}}_{LQ}}_{<10^{-4}} + \underbrace{\omega_\mu}_{\sim 10}\,\underbrace{(\mathcal{C}_{ED} - \mathcal{C}_{EU})}_{<10^{-4}} \right|^2 < 10^{-6}.$$

Bounds from charged LFV

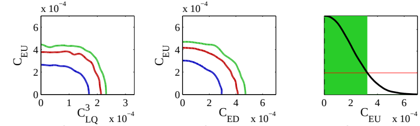
In general



Taking the all CLFV constraints into account, we can show the allowed region for each coefficient.



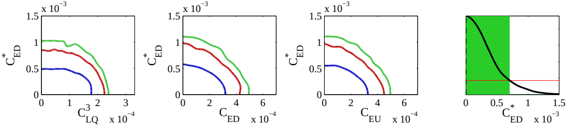
Correlation between two coeffs.
[Preliminary]

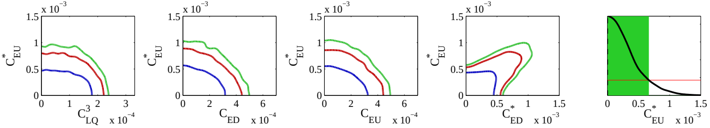


After marginalizing irr. parameters,

$$|(\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau}| < 7.1 \cdot 10^{-4}$$

(90% CL).





The plots produced by Enrique and Mattias.
Gracias and Tack.

Outline

With gauge inv. effective NSI

- Source NSI — The pion decay process with $\mathscr{O}_{ED}$ and $\mathscr{O}_{EU}$ gets the chiral enhancement
$$\frac{\text{MISIS}}{\text{SM}} < 10^{-5}\text{-}10^{-6} \text{ under the CLFV bounds.}$$
- Detection NSIs do not get such an enhancement.

$\mathscr{O}_{ED}$ and $\mathscr{O}_{EU}$ can be mediated by

- Higgs doublet in THDM (type III = FCNC)
- Slepton doublet in R-parity violating SUSY ($W_{\not{R}} = \frac{1}{2}\lambda LLE^c + \lambda' LQD^c$)
- Leptoquarks (V_2, U_1, S_1, R_2)