New Physics Search at Near Detectors of Neutrino Oscillation Experiments

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Preface

Tau signal at a near detector

Flavour violating 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

MINSIS proposal @FNAL
http://www-off-axis.fnal.gov/MINSIS/

MINSIS meeting @Madrid
http://www.ft.uam.es/workshop/neutrino/default.html

Signal for what?

- Sterile neutrino — mixing with light neutrals
- Non-unitary PMNS matrix — mixing with heavy neutrals
- Non-standard neutrino interactions — exotic four-Fermi int

Outline

1. Introduction
   - Non-standard neutrino interactions in experiments
   - Gauge invariant effective interactions
2. Bounds from charged LFV
   - Simplified case
   - General case
   - Implication to near detector signal
3. Conclusion and Discussion
   - Small remarks on theoretical interpretations

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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.

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

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

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 at near det exps.

NSI in near detector experiments

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

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

Three (coherent) contributions to the signal

- Source NSI in pion decays

NSI in near detector experiments

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 to the signal

- Source NSI in pion decays
- Detection NSI in neutrino-nucleon scattering

NSI in near detector experiments

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

$\downarrow$ osc

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

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

Three (coherent) contributions to the signal

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

NSI in near detector experiments

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

$$\downarrow$$

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

Tau signal rate =

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

Three (coherent) contributions to the signal

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

$\longrightarrow$ We will see source NSI is an interesting possibility...

Parametrize the relevant effective interactions

- Including $(\bar{\nu}_\tau \mu)(\bar{d} u)$ or $(\bar{\tau} \nu_\mu)(\bar{u} d)$
- SM gauge invariant
  Buchmuller Wyler Nucl Phys **B268** (1986) 621

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

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.

With component fields, the eff. Lagrangian looks...

- Decompose $SU(2)_L$ doublets with component fields

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\nu\ell} + \mathscr{L}_{\ell\ell} + \mathscr{L}_{\nu\nu}$$

Relevant part for near detector experiments is...

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

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

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

With component fields, the eff. Lagrangian looks...

- Decompose $SU(2)_L$ doublets with component fields

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\nu\ell} + \mathscr{L}_{\ell\ell} + \mathscr{L}_{\nu\nu}$$

Unavoidable charged LFV

$$\begin{aligned}
\mathscr{L}_{\ell\ell} = \\
\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] \\
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& + \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}$$

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Effective Lagrangian for Charged LFV

$$\mathscr{L}_{\ell\ell} = \frac{G_F}{\sqrt{2}} \Big[\Big\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} - (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \Big\} [\bar{\mu}\gamma^{\rho}\tau][\bar{u}\gamma_{\rho}u] + \Big\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} + (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \Big\} [\bar{\mu}\gamma^{\rho}\tau][\bar{d}\gamma_{\rho}d]$$
$$- \Big\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} - (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \Big\} [\bar{\mu}\gamma^{\rho}\gamma^{5}\tau][\bar{u}\gamma_{\rho}u] - \Big\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau} + (\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau} \Big\} [\bar{\mu}\gamma^{\rho}\gamma^{5}\tau][\bar{d}\gamma_{\rho}d]$$

$$+ \cdots \Big].$$

Corresponding cLFV depends on the Lorenz strc. of $\bar{q}q$

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

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

Effective Lagrangian for Charged LFV

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

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$$- \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau - (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5\tau][\bar{u}\gamma_\rho u] - \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau + (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5\tau][\bar{d}\gamma_\rho d]$$
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$$+ \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau - (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5\tau][\bar{u}\gamma_\rho\gamma^5 u] + \left\{ (\mathcal{C}^{\mathbf{1}}_{LQ})_\mu{}^\tau + (\mathcal{C}^{\mathbf{3}}_{LQ})_\mu{}^\tau \right\} [\bar{\mu}\gamma^\rho\gamma^5\tau][\bar{d}\gamma_\rho\gamma^5 d]$$
$$- \left\{ (\mathcal{C}_{ED})_\mu{}^\tau - (\mathcal{C}^\dagger_{ED})_\mu{}^\tau \right\} [\bar{\mu}\tau][\bar{d}\gamma^5 d] - \left\{ (\mathcal{C}_{EU})_\mu{}^\tau - (\mathcal{C}^\dagger_{EU})_\mu{}^\tau \right\} [\bar{\mu}\tau][\bar{u}\gamma^5 u]$$
$$- \left\{ (\mathcal{C}_{ED})_\mu{}^\tau + (\mathcal{C}^\dagger_{ED})_\mu{}^\tau \right\} [\bar{\mu}\gamma^5\tau][\bar{d}\gamma^5 d] - \left\{ (\mathcal{C}_{EU})_\mu{}^\tau + (\mathcal{C}^\dagger_{EU})_\mu{}^\tau \right\} [\bar{\mu}\gamma^5\tau][\bar{u}\gamma^5 u]$$
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Corresponding cLFV depends on the Lorenz strc. of $\bar{q}q$

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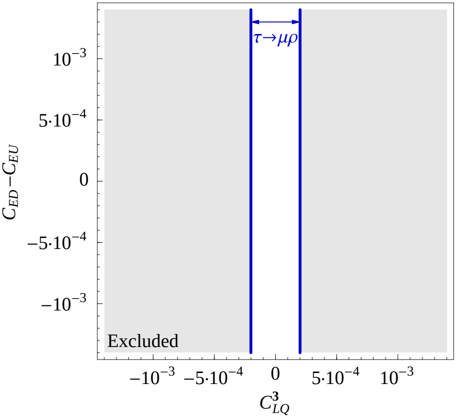
Vector: $\tau \to \mu\rho$ and $\tau \to \mu\omega$

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 first...

- Assume the all coeffs are real and Hermite, $\mathcal{C}_{EX} \equiv (\mathcal{C}_{EX})_{\mu}{}^{\tau} = (\mathcal{C}_{EX})_{\tau}{}^{\mu}$



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

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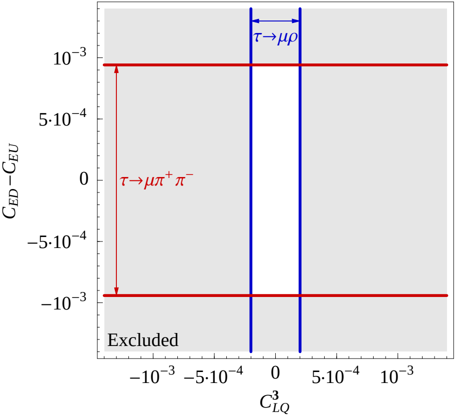

- Br($\tau \to \mu\rho$)<$6.8 \cdot 10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$

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

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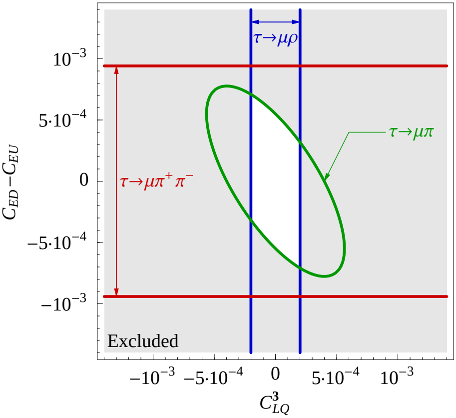

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- Br$(\tau \to \mu\pi^+\pi^-)$<$2.9 \cdot 10^{-7}$
  $|\mathcal{C}_{ED} - \mathcal{C}_{EU}|$
- Br$(\tau \to \mu\pi)$<$1.1 \cdot 10^{-7}$
  $\mathcal{C}^{\mathbf{3}}_{LQ}$ and $(\mathcal{C}_{ED} - \mathcal{C}_{EU})$

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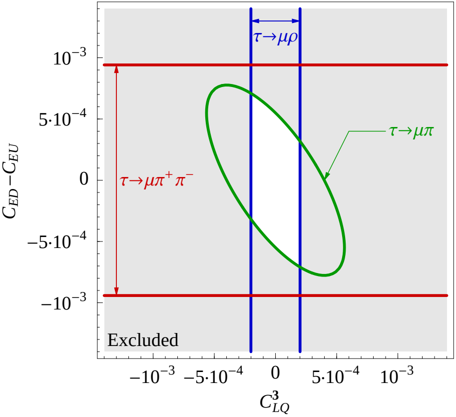

- $\mathrm{Br}(\tau \to \mu\rho) < 6.8 \cdot 10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$
- $\mathrm{Br}(\tau \to \mu\pi^+\pi^-) < 2.9 \cdot 10^{-7}$
  $|\mathcal{C}_{ED} - \mathcal{C}_{EU}|$
- $\mathrm{Br}(\tau \to \mu\pi) < 1.1 \cdot 10^{-7}$
  $\mathcal{C}^{\mathbf{3}}_{LQ}$ and $(\mathcal{C}_{ED}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

$\longrightarrow$ Next let us consider the bounds in general...

- Bound to 6 (complex) parameters
  $(\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau}$, $(\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau}$, $(\mathcal{C}_{ED})_{\mu}{}^{\tau}$, $(\mathcal{C}_{EU})_{\mu}{}^{\tau}$, $(\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau}$, and $(\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau}$
- Bounded from 8 processes
  $\tau \to \mu \Pi$ with $\Pi \in \{\rho, \omega, \phi, \pi^0, \eta, \pi^+\pi^-, K^+K^-, K^0\bar{K}^0\}$

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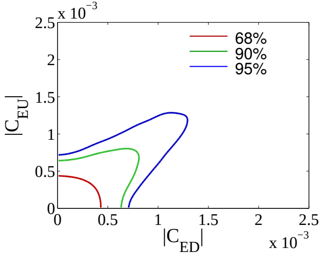
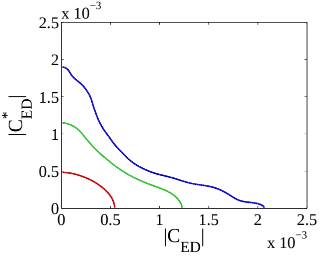
  $\tau \to \mu\Pi$ with $\Pi \in \{\rho, \omega, \phi, \pi^0, \eta, \pi^+\pi^-, K^+K^-, K^0\bar{K}^0\}$





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Blennow and
Fernandez-Martinez

$(\mathcal{C}^{\mathbf{1}}_{LQ})_{\mu}{}^{\tau}$	$(\mathcal{C}^{\mathbf{3}}_{LQ})_{\mu}{}^{\tau}$	$(\mathcal{C}_{ED})_{\mu}{}^{\tau}$	$(\mathcal{C}_{EU})_{\mu}{}^{\tau}$	$(\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau}$	$(\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau}$	@90%
2.1	1.7	7.2	7.2	6.2	6.2	$\times 10^{-4}$

Tau-signal at a near detector

The coeffs with $\mathcal{O}(10^{-4})$ imply Tau-signal/SM$\lesssim \mathcal{O}(10^{-7}$-$10^{-8})$...

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Chiral enhancement in π decays

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Vainshtein Shifman Zakharov JETP Lett **22** (1975) 55, Gross Treiman Wilczek Phys Rev **D19** (1979) 2188

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

with the chiral enhancement factor $\omega_\mu \equiv \frac{m_\pi}{m_\mu} \frac{m_\pi}{m_u + m_d} \simeq 21$.

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$$\longrightarrow \Gamma(\pi^+ \to \mu^+ \nu_\tau)/\Gamma_{\text{SM}} < 7.9 \cdot 10^{-5}$$

which is within the scope of MINSIS$> \mathcal{O}(10^{-6})$.

Outline

1. Introduction
   - Non-standard neutrino interactions in experiments
   - Gauge invariant effective interactions
2. Bounds from charged LFV
   - Simplified case
   - General case
   - Implication to near detector signal
3. Conclusion and Discussion
   - Small remarks on theoretical interpretations

With gauge inv. effective NSI

- Source NSI — Pion decay process with $\mathscr{O}_{ED}$ and $\mathscr{O}_{EU}$ gets the chiral enhancement
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$\mathscr{O}_{ED}$ 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)