Complementarity of μTRISTAN and Belle II in searches for CLFV.

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Charged Lepton Flavour Violation

Charged Lepton Flavour Violation (LFV) was not observed so far. However, neutrino oscillations show that there are no individual lepton numbers L_e, L_μ, and L_τ conservation.

Several BSM models predict cLFV.

Experimental bounds are stringent, especially on electron-muon cLFV.

- $\mu \to e\gamma$,
- $\mu \to eee$.

cLFV involving τ:

- Data are less constraining; Belle II future sensitivity will increase significantly.

Lepton Triality

Avoids $\mu \leftrightarrow e$ conversions
Allows LFV tau decays.

Ma,(2010) 1006.3524

Motivated by flavour structure models
Tribimaximal mixing of neutrino flavours **Altarelli, Feruglio (2006)**

Residual Z_3 symmetry may emerge from breaking of A_4 flavour symmetry Residual Z_3
He, Keum, Volkas (2006) hep-ph/0601001

Lepton Triality

$L \to \omega^T L$ and $e_R \to \omega^T e_R$,
$\omega = e^{\frac{2\pi i}{3}}$
H, quarks are singlets under triality

$$\mathcal{L}_Y = y_{e_i} L_i e_{R_i} H + h.c.$$

$\mathcal{L}_Y$ is diagonal under Z_3
The leptons e, μ, τ are charged under flavour triality
T = 1, 2, 3

Simple extensions to the SM using scalar bileptons can mediate these triality-preserving interactions

Bigaran, He, Schmidt, Valencia, Volkas, (2022) 2212.09760.

Lepton Triality

Models T = 1, 2, 3 for the doubly charged singlet k_i

$$\mathcal{L}_{k_1} = \frac{1}{2}\left(2f_1\overline{(\tau_R)^c}\mu_R + f_2\overline{(e_R)^c}e_R\right)k_1 + \text{h.c.}$$

$$\mathcal{L}_{k_2} = \frac{1}{2}\left(2g_1\overline{(\tau_R)^c}e_R + g_2\overline{(\mu_R)^c}\mu_R\right)k_2 + \text{h.c.}$$

$$\mathcal{L}_{k_3} = \frac{1}{2}\left(2h_1\overline{(\mu_R)^c}e_R + h_2\overline{(\tau_R)^c}\tau_R\right)k_3 + \text{h.c.}.$$

Tau Decays

Tau LFV decays:

$\tau \to e/\mu + \gamma$,

$\tau \to e/\mu + l^+ l^-$ where $l = e/\mu$.

Observable	Present constraint	Projected sensitivity
$BR(\tau^- \to \mu^- \mu^- e^+)$	1.7×10^{-8} *	2.6×10^{-10} **
$BR(\tau^- \to \mu^+ e^- e^-)$	1.5×10^{-8} *	2.3×10^{-10} **

*** Belle Collaboration (2010) 1001.3221**

**** Belle II (2022) 2203.14919**

SMEFT

$$\mathcal{L}_{6,LFV} = C^{ll}(\bar{L}\gamma_\mu L)(\bar{L}\gamma^\mu L) + C^{ee}(\bar{e}_R\gamma_\mu e_R)(\bar{e}_R\gamma^\mu e_R) + C^{le}(\bar{L}\gamma_\mu L)(\bar{e}_R\gamma^\mu e_R)$$

$$C^{VRR}_{ee,1312} = \frac{f_1 f_2}{4m_{k_1}^2}$$

$$BR(\tau^\pm \to \mu^\mp e^\pm e^\pm) = \frac{f_1^2 f_2^2}{64 G_F^2 m_{k_1}^4} BR(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)$$

$$C^{VRR}_{ee,2321} = \frac{g_1 g_2}{4m_{k_2}^2}$$

$$BR(\tau^\pm \to \mu^\pm \mu^\pm e^\mp) = \frac{g_1^2 g_2^2}{64 G_F^2 m_{k_2}^4} \tilde{I}\left(\frac{m_\mu^2}{m_\tau^2}\right) BR(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)$$

Present bounds:

$$\sqrt{f_1 \times f_2} < 0.17 \frac{m_{k1}}{TeV}$$

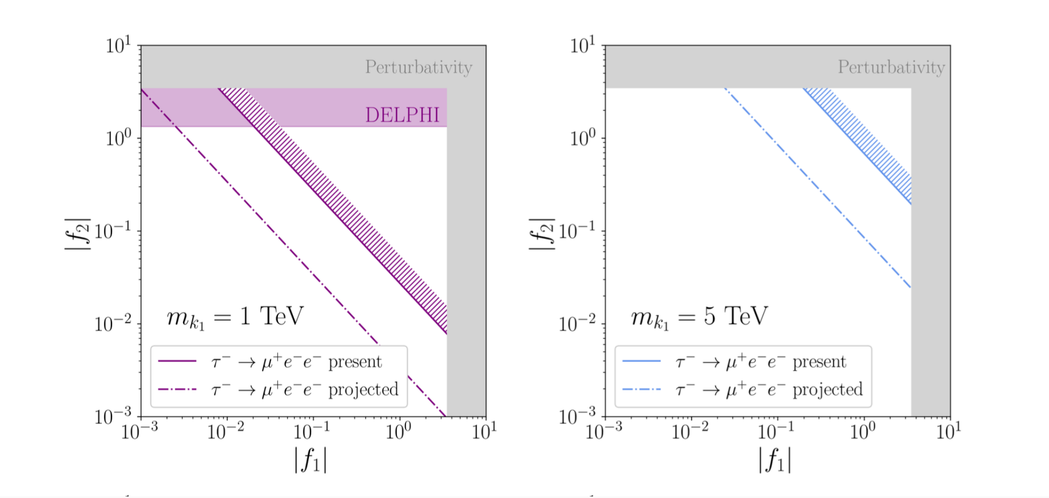
$$\sqrt{g_1 \times g_2} < 0.17 \frac{m_{k2}}{TeV}$$

Prediction for future sensitivity:

$$\sqrt{f_1 \times f_2} < 0.06 \frac{m_{k1}}{TeV}$$

$$\sqrt{g_1 \times g_2} < 0.06 \frac{m_{k2}}{TeV}$$

Belle II sensitivity on cLFV tau decays from Triality T=1



Bigaran, He, Schmidt, Valencia, Volkas, (2022) 2212.09760.

μTRISTAN

Hamada, Kitano, Matsudo, Takaura and Yoshida, (2022) 2201.06664

Ultracold muon technology from g-2 at J-PARC

$\mu^+\mu^+$ proposal $\sqrt{s} = 2$ TeV;

1 TeV μ^+ beams;

expected luminosity of 12 fb^{-1} per year.

$\mu^+ e^-$ proposal with asymmetric beam energies;

μ^+ beams up to 1 to 3 TeV;

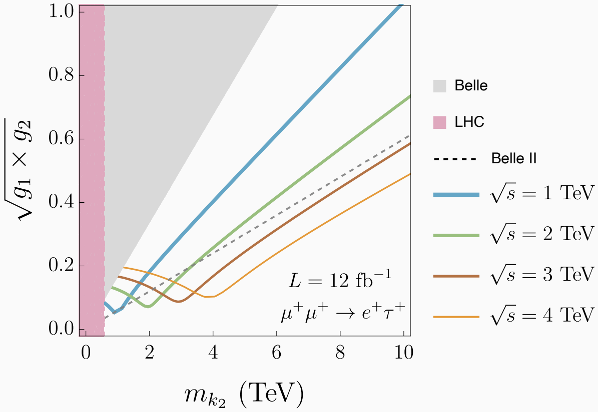
e^- beams from Tristan at 30 to 50 GeV;

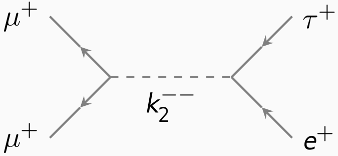
expected luminosity of 100 fb^{-1} per year.

Future lepton Colliders

Model	Process	Lepton Collider
T=1	$\mu^+ e^- \to e^+ \tau^-$	μTRISTAN
T=1	$e^+ e^- \to e^+ e^-$	$e^+ e^-$
T=1	$e^- e^- \to e^- e^-$	-
T=1	$e^- e^- \to \tau^- \mu^-$	-
T=2	$\mu^+ \mu^+ \to \tau^+ e^+$	μTRISTAN
T=2	$\mu^+ \mu^+ \to \mu^+ \mu^+$	μTRISTAN
T=2	$\mu^+ e^- \to \tau^+ \mu^-$	μTRISTAN
T=2	$\mu^+ \mu^- \to \mu^+ \mu^-$	$\mu^+ \mu^-$
T=3	$\mu^+ e^- \to \mu^+ e^-$	μTRISTAN
T=3	$\mu^+ e^+ \to \tau^+ \tau^+$	-

CLFV s-channel at $\mu^+\mu^+$





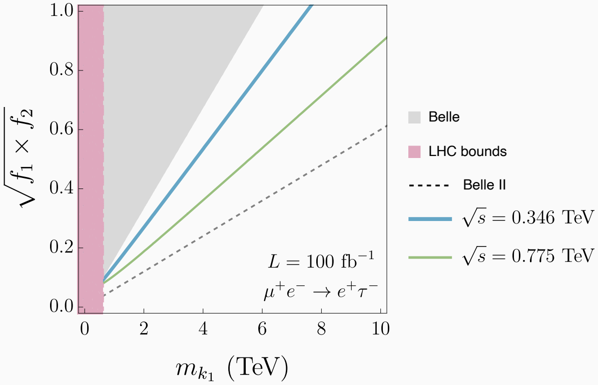
90% C.L. contour
assuming no background
N = 2.44;

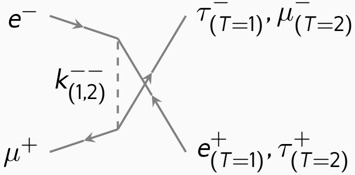
$$\sqrt{g_1 g_2} \lesssim 0.15 \left(\frac{N}{Ls}\right)^{\frac{1}{4}} \frac{m_{k_2}}{\text{TeV}}$$

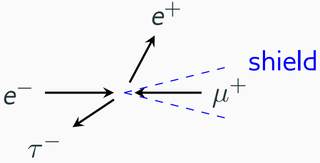
For $\sqrt{s} = 2$ TeV:

$$\sqrt{g_1 g_2} \lesssim 0.17 \frac{m_{k_2}}{\text{TeV}} .$$

CLFV u-channel at $\mu^+ e^-$

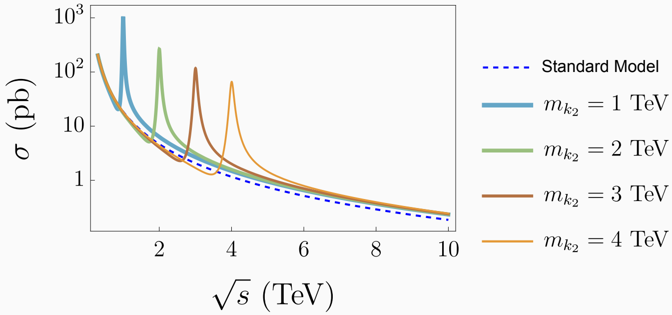


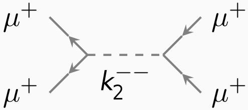




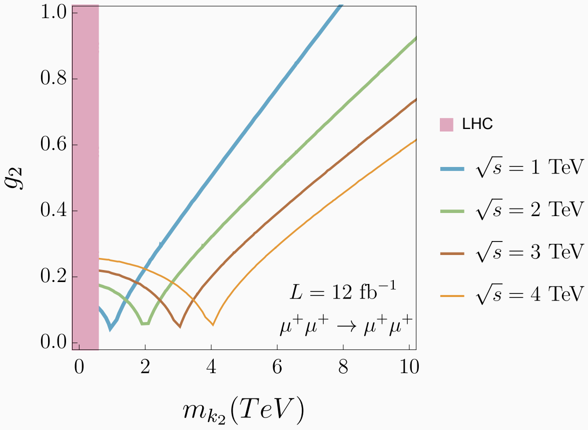
$$\sqrt{f_1 f_2} \lesssim 0.13 \frac{m_{k_1}}{\mathrm{TeV}}$$

Resonances in elastic scattering $\mu^+\mu^+ \to \mu^+\mu^+$





Resonances in elastic scattering $\mu^+\mu^+ \to \mu^+\mu^+$

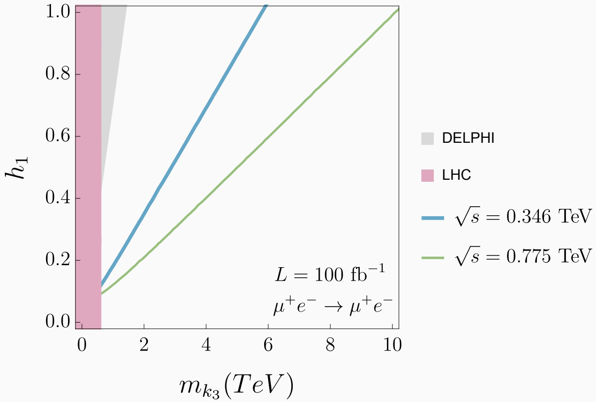


90% C.L. contour;
SM contributions as background;
S = 1.64

$$S = \frac{|\sigma - \sigma_{SM}|}{\sqrt{\sigma_{SM}}}\sqrt{L};$$

$$g_2 \lesssim 0.18 \left(\frac{S^2}{Ls}\right)^{1/4} m_k;$$

$$g_2 \lesssim 0.09 \frac{m_{k_2}}{\text{TeV}}.$$



$$S = \frac{|\sigma - \sigma_{SM}|}{\sqrt{\sigma_{SM}}}\sqrt{L}\ ;$$

$$h_1 \lesssim 0.17 \frac{m_{k_3}}{\text{TeV}}\ .$$

Summary

Lepton Flavour Triality avoids CLFV bounds from muon decays while allowing tau LFV interactions;

Belle II sensitivity to tau LFV processes will increase significantly.

μTRISTAN $\mu^+\mu^+$ collider

Resonances searches

μTRISTAN $\mu^+ e^-$ collider