Constraints on Lepton Flavour Triality from Charged LFV.

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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)**

A_4 tetrahedral group

Residual Z_3

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

- Triality sums modulo 3

$\mu^- \to e^- \gamma$ $\quad \Delta T \neq 0$ ✗

T=2 T=1

$\tau^- \to \mu^+ e^- e^-$ $\quad \Delta T = 0$ ✓

T=3 T=-2 T=1 T=1

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

Lepton Triality and Tau decays

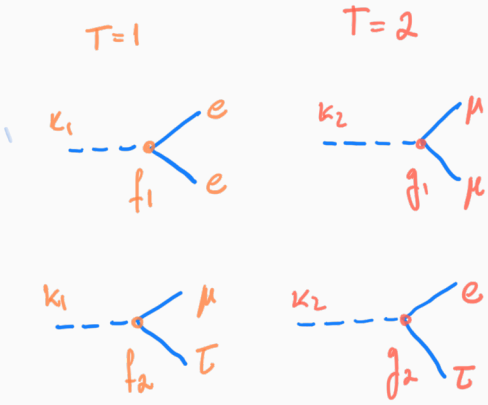
Bigaran, He, Schmidt, Valencia, Volkas, (2022) 2212.09760.

Two possible models T = 1, 2 for the doubly charged singlet $k_{1,2}$

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

while for k_2 the interactions are

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



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
$\mathrm{BR}(\tau^- \to \mu^-\mu^- e^+)$	1.7×10^{-8} *	2.6×10^{-10} **
$\mathrm{BR}(\tau^- \to \mu^+ e^- e^-)$	1.5×10^{-8} *	2.3×10^{-10} **

*** Belle Collaboration (2010) 1001.3221**

**** Snowmass (2022) 2203.14919**

SMEFT

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

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

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

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

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

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:

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

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

Experimental Constraints

LHC Direct bounds

ATLAS searches for doubly charged Higgs from 2017 analysis, rescaled with new ATLAS(2211.07505) data:

$m_{k1} > 650$ GeV, $m_{k1} > 770$ GeV for 50% and 100% branching ratio to electrons;

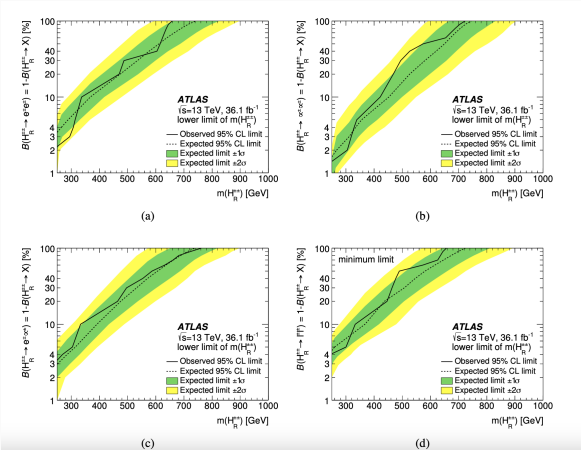
$m_{k2} > 660$ GeV, $m_{k2} > 830$ GeV for 50% and 100% branching ratio to muons;

DELPHI

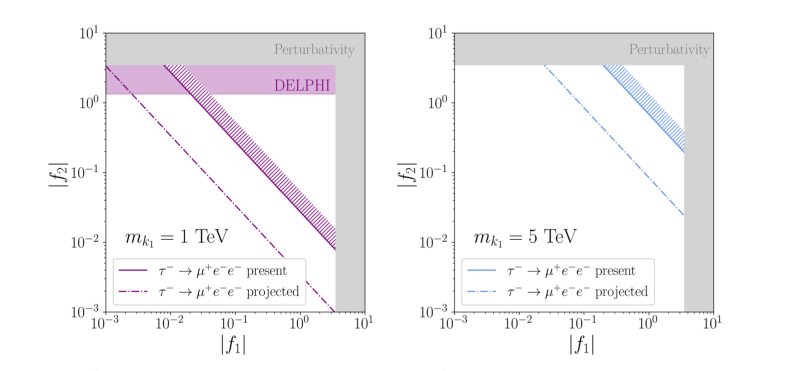
elastic e^+e^- puts bounds on $\frac{m_{k1}}{|f_1|} > 0.74$ TeV ;

$e^+e^- \to \tau^+\tau^-$ puts lower bounds on $\frac{m_{k2}}{|g_2|} > 0.15$ TeV

ATLAS(2017) 1710.09748

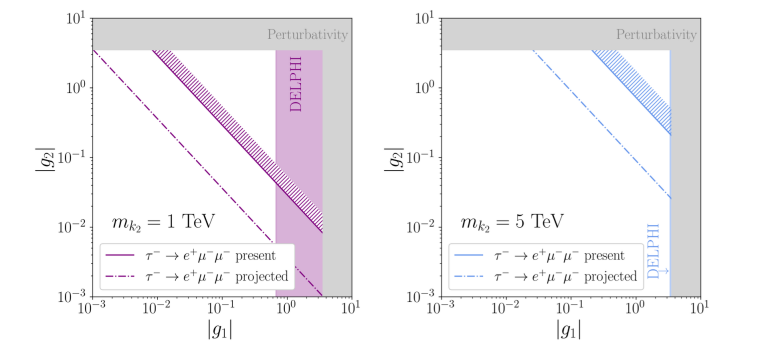


Belle II sensitivity on cLFV tau decays from Triality T=1



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

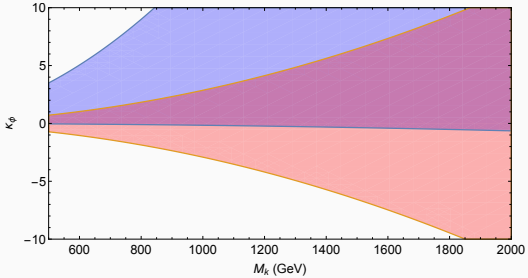
Belle II sensitivity on cLFV tau decays from Triality T=2



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

Other constraints: $H \to \gamma\gamma$

$$V \supset \kappa_\phi \phi^\dagger \phi |k_i|^2,$$
$$R_{\gamma\gamma} = \frac{\Gamma(H\to\gamma\gamma)}{\Gamma(H\to\gamma\gamma)_{SM}}$$



PRELIMINARY

$m_{k_i} - \kappa_\phi$ parameter space currently allowed at 1σ

blue shaded region: current ATLAS Run 2 measurements, $R_{\gamma\gamma} = 1.088^{+0.095}_{-0.09}$ **ATLAS:(2022) 2207.00092**

red shaded region: future sensitivity corresponding to 3000 fb^{-1} at the HL-LHC,
$\Delta\kappa_\gamma = 1.8\%$ with $R_{\gamma\gamma} = \kappa_\gamma^2$ **ATLAS and CMS (2019) 1902.10229**.

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	$\mu^+ \mu^- \to \mu^+ \mu^-$	$\mu^+ \mu^-$

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.

μ^+ beams up to 1 TeV

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

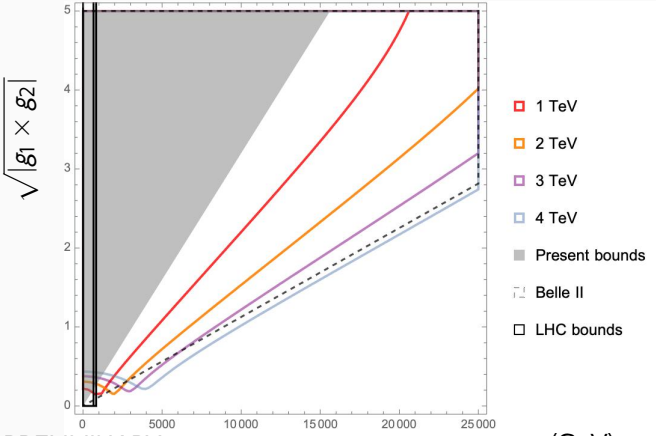
μ^+e^- proposal with asymmetric beam energies.

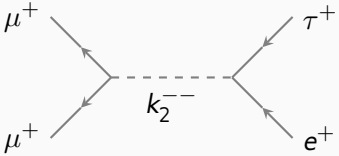
μ^+ beams up to 1 TeV

e^- beams from Tristan at 30 GeV

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

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





μTRISTAN expected luminosity of 12 fb^{-1}/year;

Limits for 50 events/year.

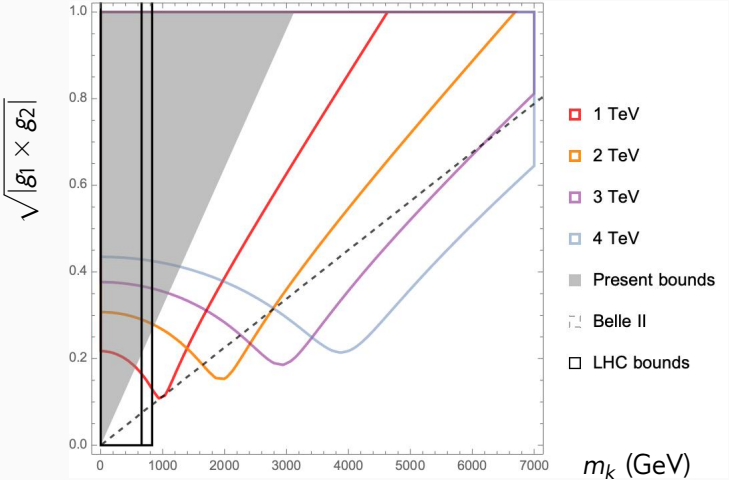
Present bounds:

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

future sensitivity:

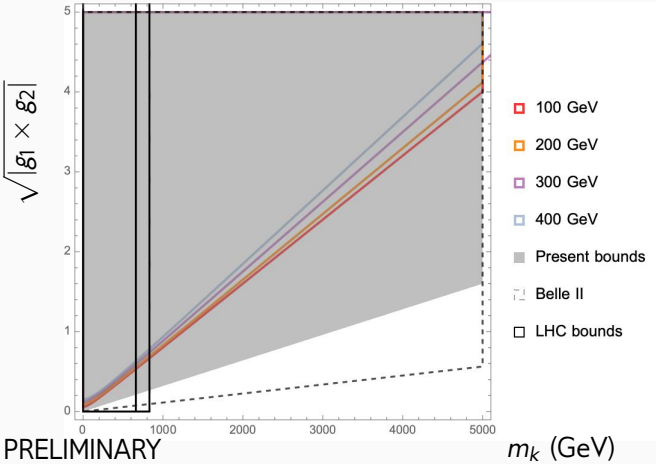
$$\sqrt{|g_1 \times g_2|} < 0.06 \frac{m_{k2}}{TeV}$$

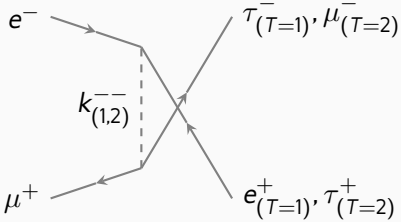
Resonance searches at same sign muon collider



PRELIMINARY

LFV u-channel at μ^+e^-





μTRISTAN luminosity of 100 fb^{-1}/year;

Limits for 50 events/year.

Present bounds:

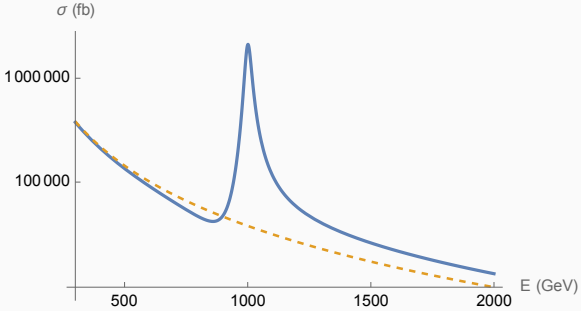
$\sqrt{|f_1 \times f_2|} < 0.17 \frac{m_{k2}}{TeV}$

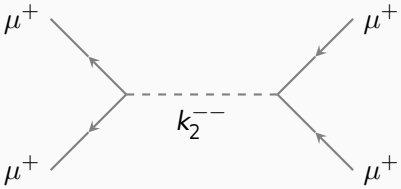
future sensitivity:

$\sqrt{|f_1 \times f_2|} < 0.06 \frac{m_{k2}}{TeV}$

Resonances in elastic scattering

$$\mu^+\mu^+ \to \mu^+\mu^+$$

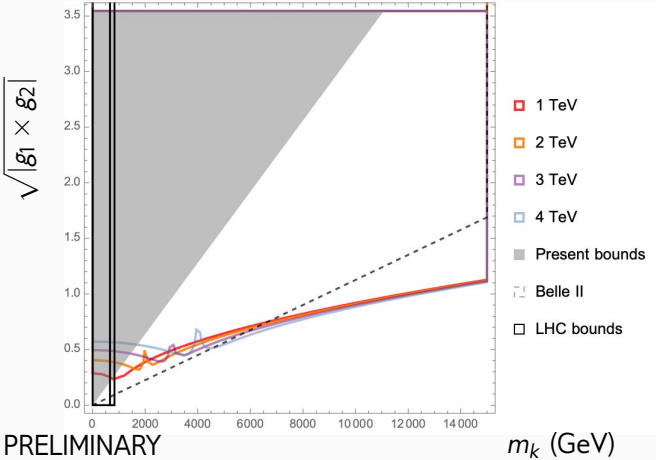




PRELIMINARY

Resonances in elastic scattering

$$\mu^+\mu^+ \to \mu^+\mu^+$$



μTRISTAN expected luminosity of 12 fb^{-1}/year;

Limits for 50 events/year.

$N = |\sigma_{SM} - \sigma_{NP}| \times$ *luminosity*

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 will be able to probe cLFV at same-sign muon collider. It can be competitive to Belle II for one year integrated luminosity and center of mass energy at TeV scale.

Also sensitive to resonances of doubly charged scalars;

References

- E. Ma, "Quark and Lepton Flavor Triality," *Phys. Rev. D*, vol. 82, p. 037301, 2010.
- I. Bigaran, X.-G. He, M. A. Schmidt, G. Valencia, and R. Volkas, "Lepton-flavor-violating tau decays from triality," *Phys. Rev. D*, vol. 107, no. 5, p. 055001, 2023.
- K. Hayasaka *et al.*, "Search for Lepton Flavor Violating Tau Decays into Three Leptons with 719 Million Produced Tau+Tau- Pairs," *Phys. Lett. B*, vol. 687, pp. 139–143, 2010.
- S. Banerjee *et al.*, "Snowmass 2021 White Paper: Charged lepton flavor violation in the tau sector," 3 2022.
- Y. Hamada, R. Kitano, R. Matsudo, H. Takaura, and M. Yoshida, "μTRISTAN," *PTEP*, vol. 2022, no. 5, p. 053B02, 2022.