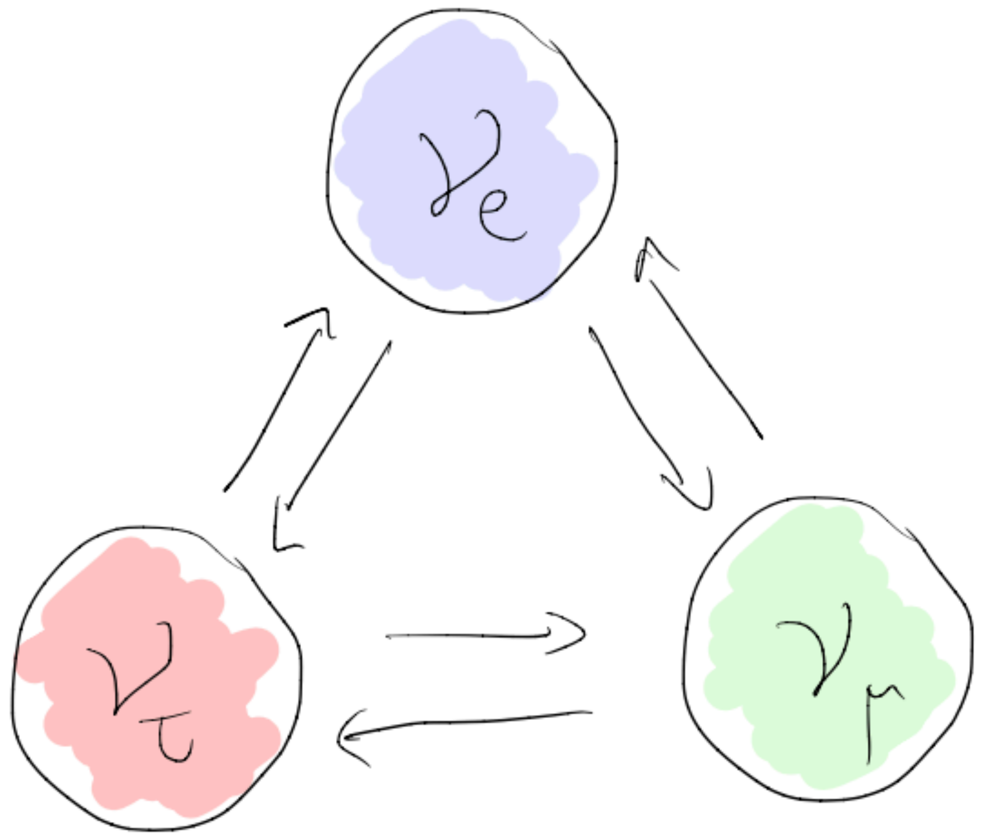
What if cLFV was only manifest in tau decays?

Dr. Innes Bigaran

Based on IB, XG He, M.A. Schmidt, G. Valencia, R.Volkas
Phys.Rev.D 107 (2023) 5, 055001
arXiv: 2212.09760

Lepton flavour violation (LFV)

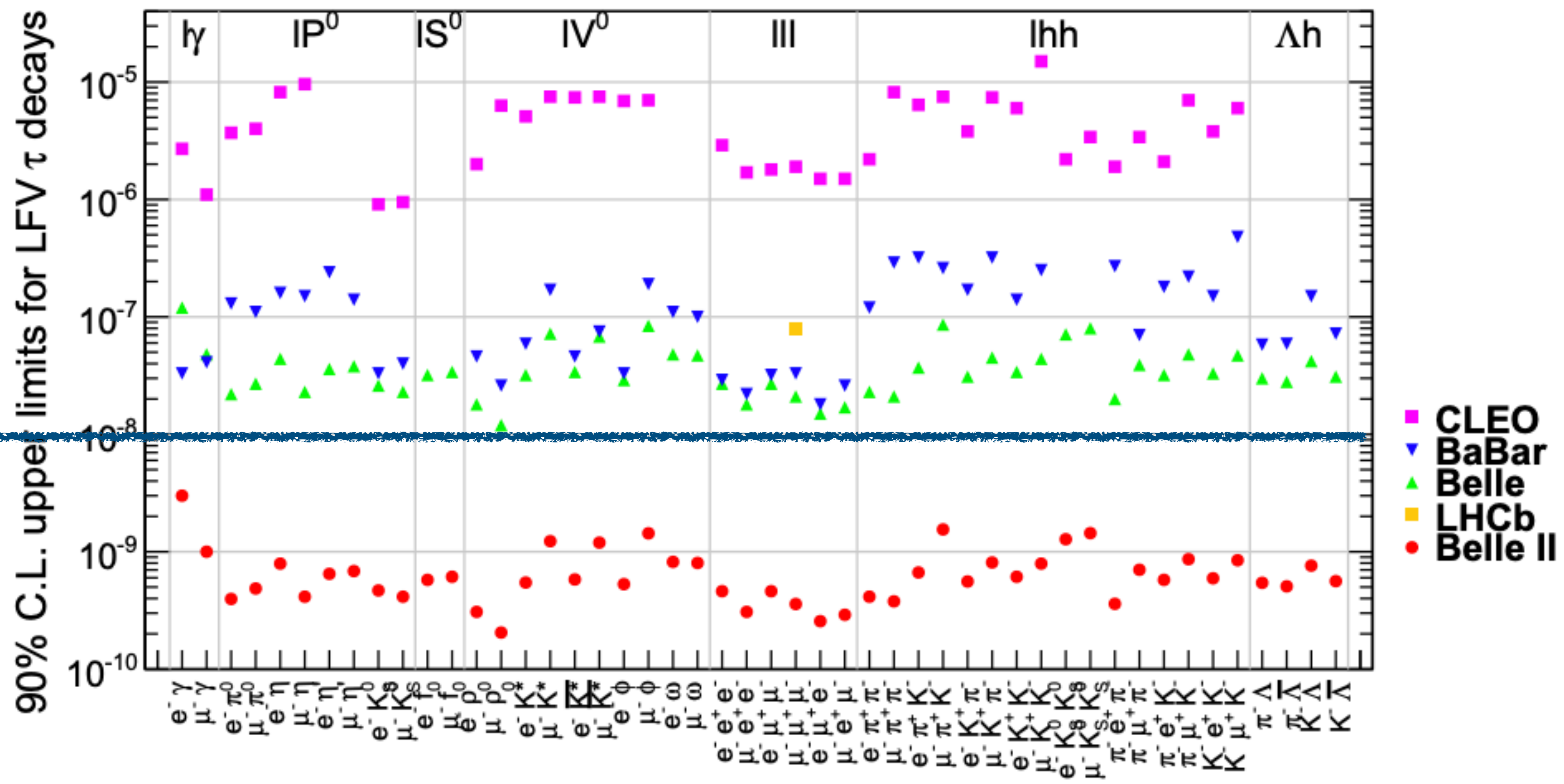


- A *definitive* sign of there being physics beyond the SM is that neutrinos oscillate between flavour eigenstates
- Family lepton numbers are not conserved BSM

$$L = L_\mu + L_e + L_\tau$$

- Neutrinos and charged leptons exist in an isospin doublet: why don't we see charged lepton flavour violation (cLFV) too?

New prospects for tau physics



Present constraints →

Bell II Physics Book, 1808.10567

- The tau is heavy enough to decay into both other lepton flavours
- Strong constraints on μ to e transitions: maybe there is no (sizeable) cLFV to be found this transition?
- Is there any well-motivated physics reason for cLFV to only be visible in decays of the tau?

New prospects for tau physics

Our Focus Here:

Observable	Present constraint	Projected sensitivity
$\mathrm{BR}(\tau^- \to \mu^-\mu^-e^+)$	$< 1.7 \times 10^{-8}$ [1]	2.6×10^{-10} [2]
$\mathrm{BR}(\tau^- \to \mu^+e^-e^-)$	$< 1.5 \times 10^{-8}$ [1]	2.3×10^{-10} [2]

If we were to see cLFV in these decays, what could this say about the rest of the flavour sector?

- The tau is heavy enough to decay into both other lepton flavours
- Strong constraints on μ to e transitions: maybe there is no (sizeable) cLFV to be found this transition?
- Is there any well-motivated physics reason for cLFV to only be visible in decays of the tau?

Lepton flavour triality

[Submitted on 17 Jun 2010]

Quark and Lepton Flavor Triality

Ernest Ma (UC Riverside)

arXiv/1006.3524

Motivated by the success of A_4 in explaining neutrino tribimaximal mixing, and its approximate residual Z_3 symmetry in the quark and charged-lepton sectors, the notion of "flavor triality" is proposed. Under this hypothesis, certain processes such as tau+ to mu+mu+e- and tau+ to e+e+mu- are favored, but tau+ to mu+e+e- and mu+ to e+e+e- are disfavored. Similarly, B0 to tau+e- is favored, but B0 to tau-e+ is disfavored.

- The notion of lepton flavour triality was first introduced inspired by the success of A_4 (tetrahedral group) symmetry group to explain tribimaximal mixing of neutrino flavours (pre 2011 compatible)
- A residual Z_3 symmetry in the charged lepton sector also appears in other (non-Abelian, discrete) flavour models

Idea: each charged lepton is *charged* under this Z_3 (flavour triality) and this guides the observed cLFV

$$\psi_T \to \left(e^{2\pi i/3}\right)^T \psi .$$

T is a triality charge.

Lepton flavour triality

Charge assignments:

L_i has triality $T=i$

$e_{R,i}$ has triality $T=i$

& Triality sums modulo 3

Implications:

✗ $\mu \to e\gamma$

$T=2$ $T=1$

$\Delta T \neq 0$.

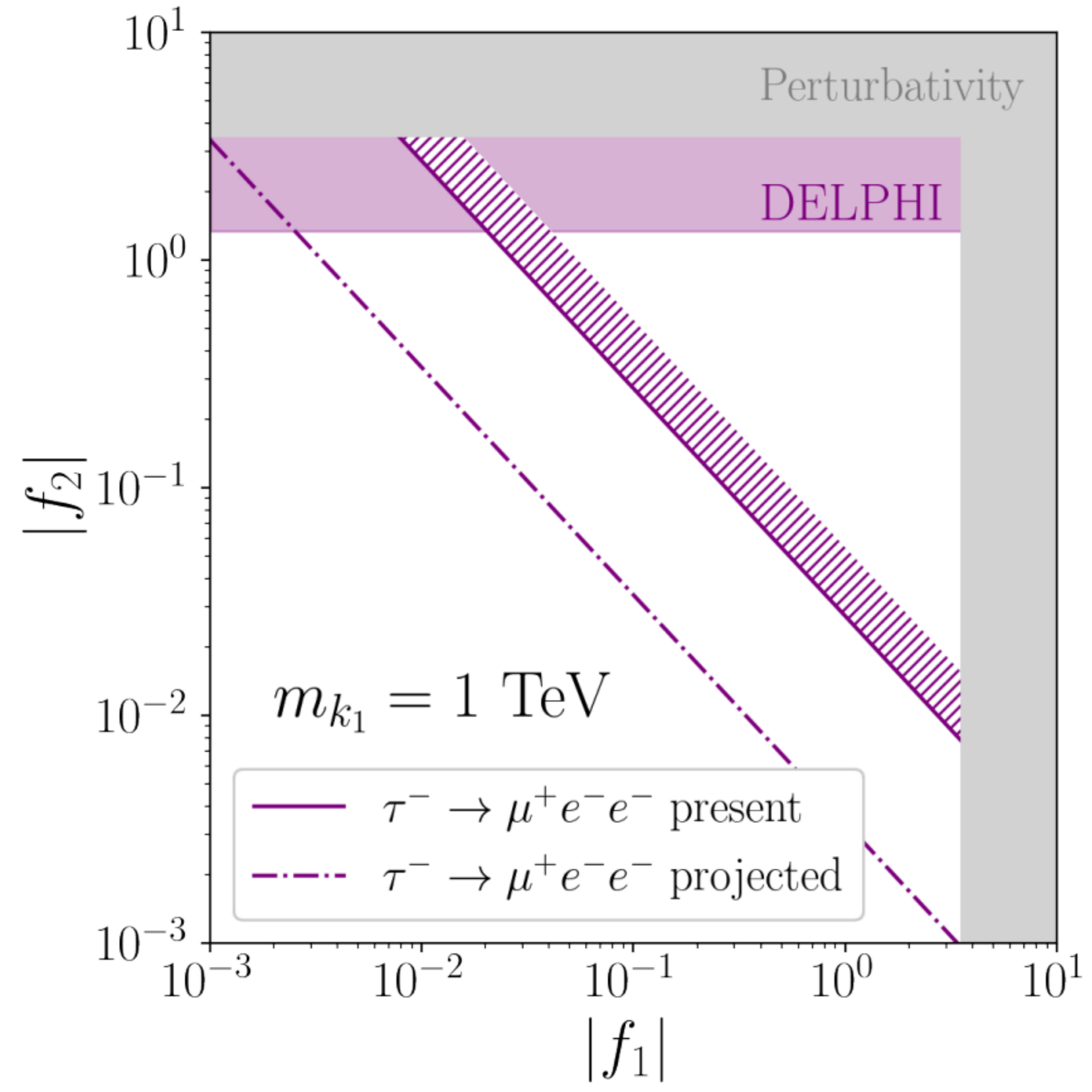
$\tau^- \to \mu^- e^+ e^+$ ✓

$T=3$ $T=2-1-1=0 \bmod 3 = 3$

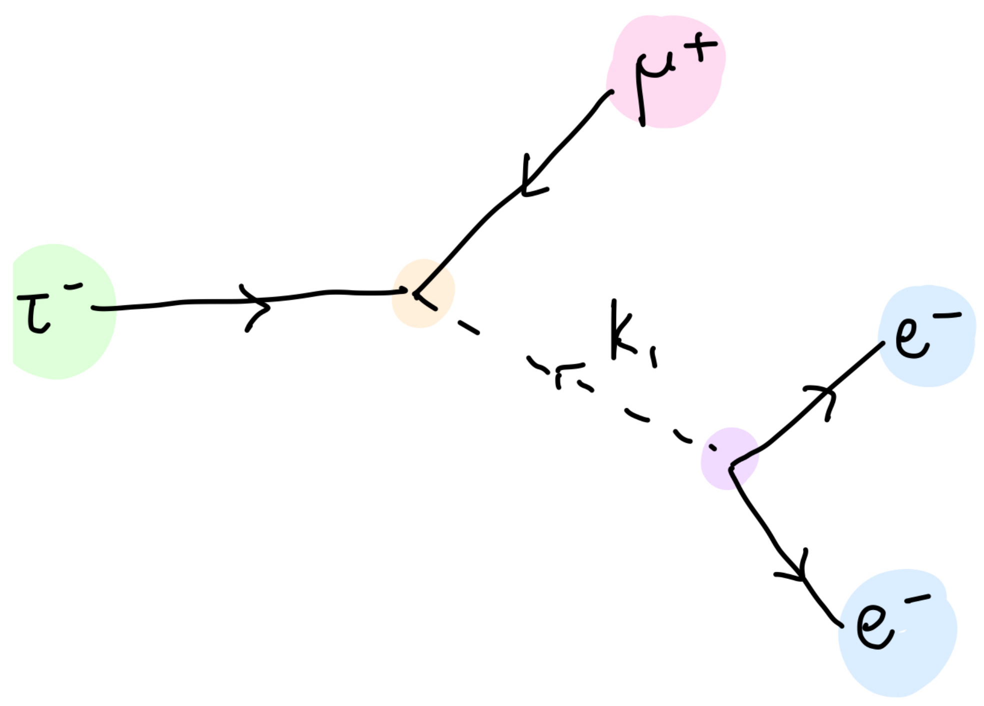
$\Delta T = 0$.

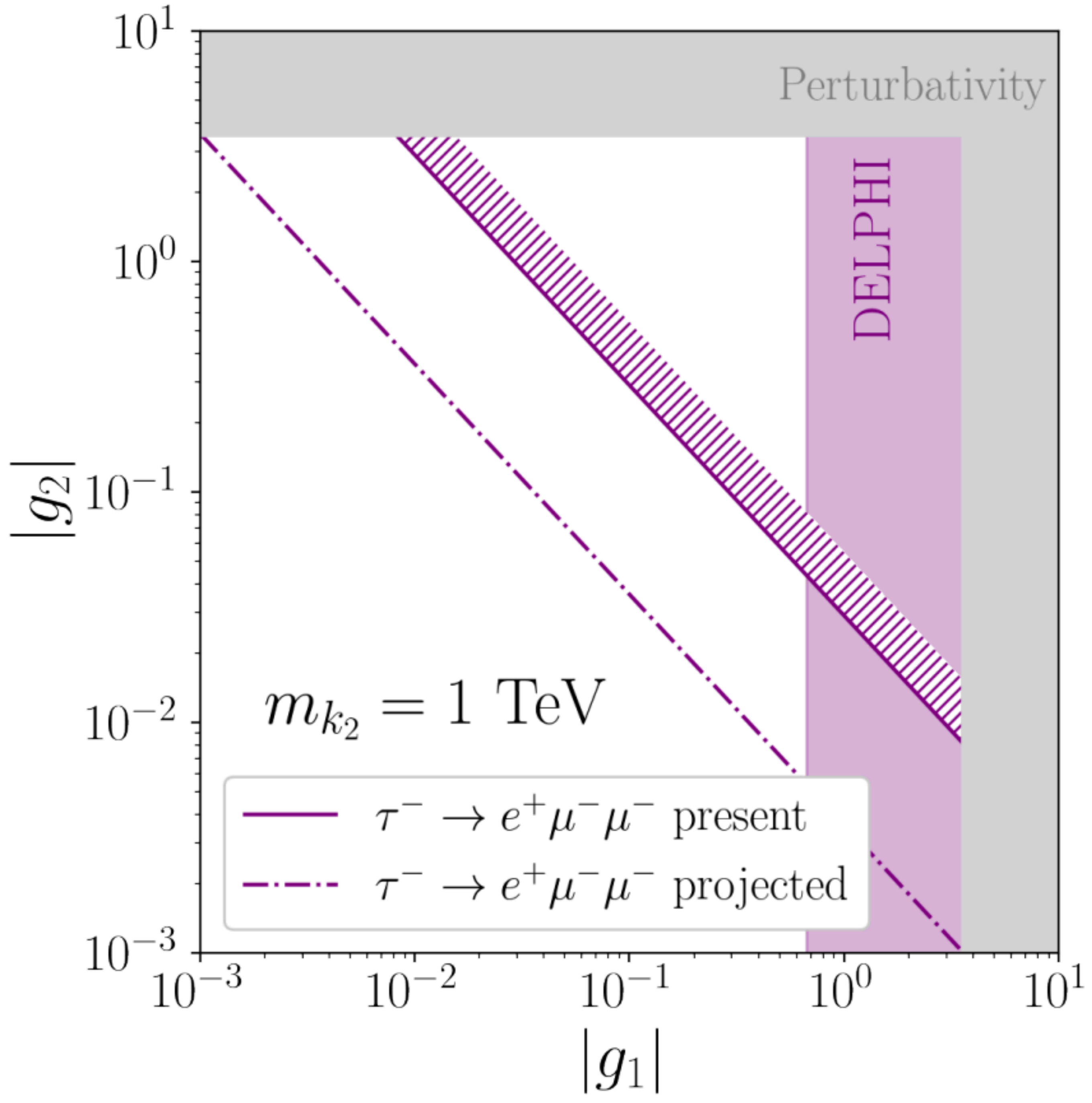
- If triality is conserved in the charged-lepton sector, only a subset of cLFV processes would be detectable
- Simple extensions to the SM using scalar bileptons can mediate these triality-preserving interactions
- Even if triality is softly broken (req. for neutrino mass generation) this motivates which decays we should detect

Electroweak Singlet Scalars

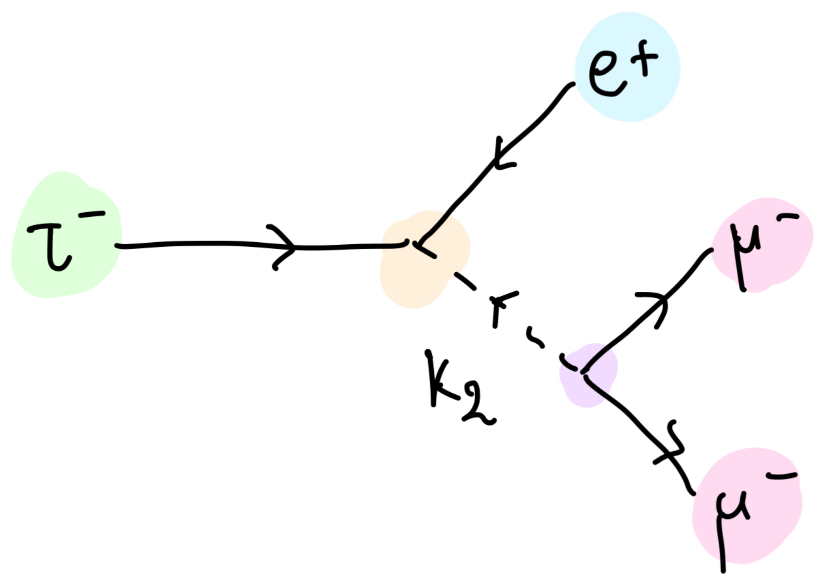


T=1





T=2



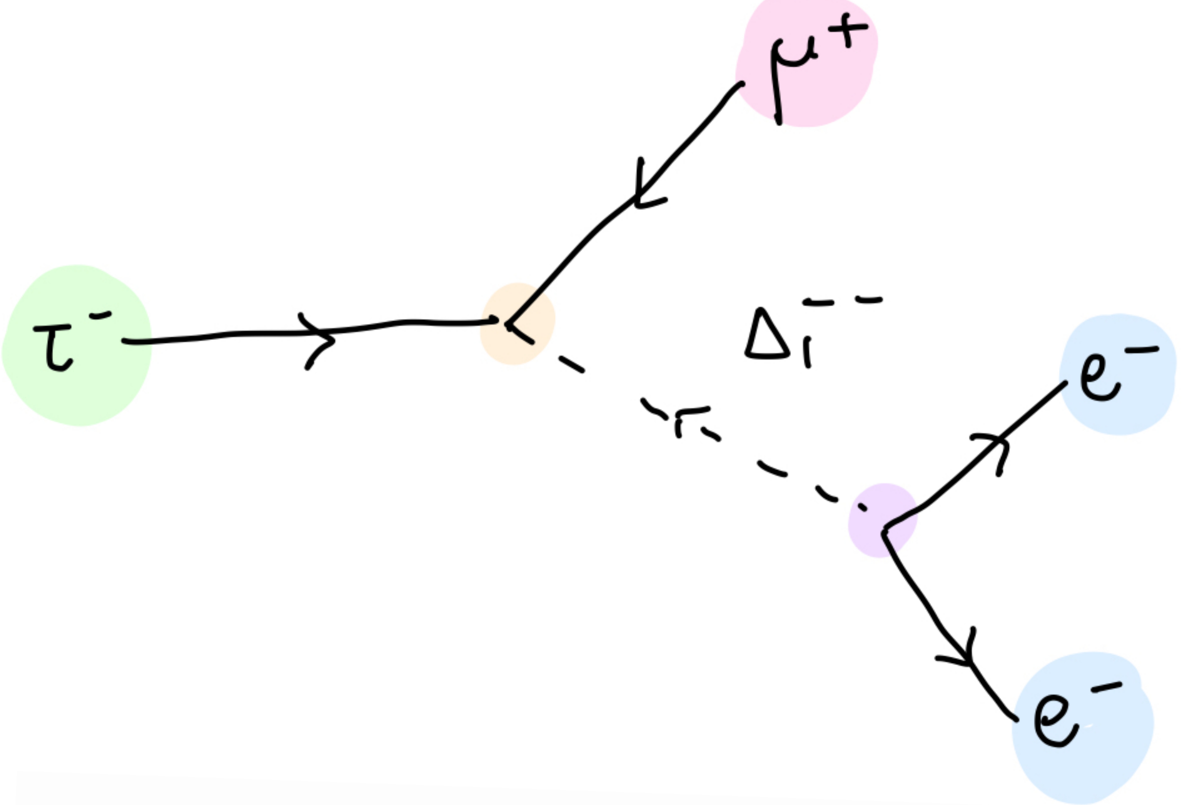
$$\mathcal{L}_{k_1} = \frac{1}{2}\left(2 f_1 \overline{\tau_R^c} \mu_R + f_2 \overline{e_R^c} e_R\right) k_1 + h.c.$$

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

- Doubly-charged scalar bilepton, constrained to be TeV scale by direct searches

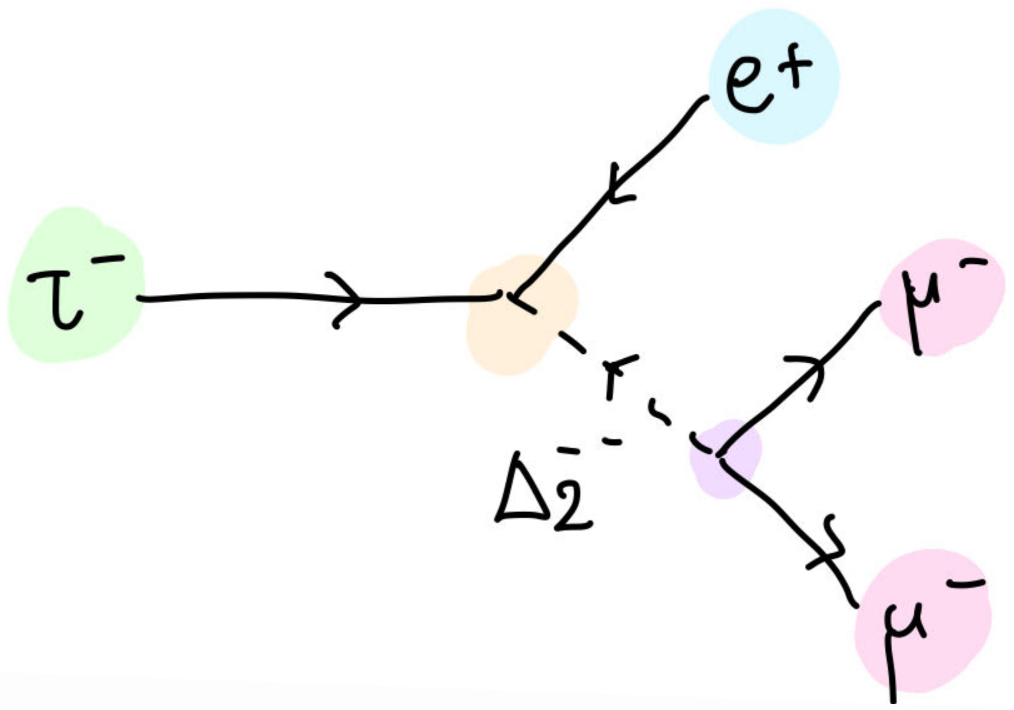
- Contribution from (T=1) [T=2] to e+ e- → (e+ e-) [τ+ τ-] constrained by DELPHI

Electroweak Triplet Scalars



T=1

$$\mathcal{L}_{\Delta_1} = \frac{1}{2}\left(2f_1 \overline{L_3^c}\,\Delta_1 L_2 + f_2 \overline{L_1^c}\,\Delta_1 L_1\right) + h.c.$$



T=2

$$\mathcal{L}_{\Delta_2} = \frac{1}{2}\left(2g_1 \overline{L_3^c}\,\Delta_2 L_1 + g_2 \overline{L_2^c}\,\Delta_2 L_2\right) + h.c.$$

- EW triplet bilepton, richer pheno because of contributions from isospin partners

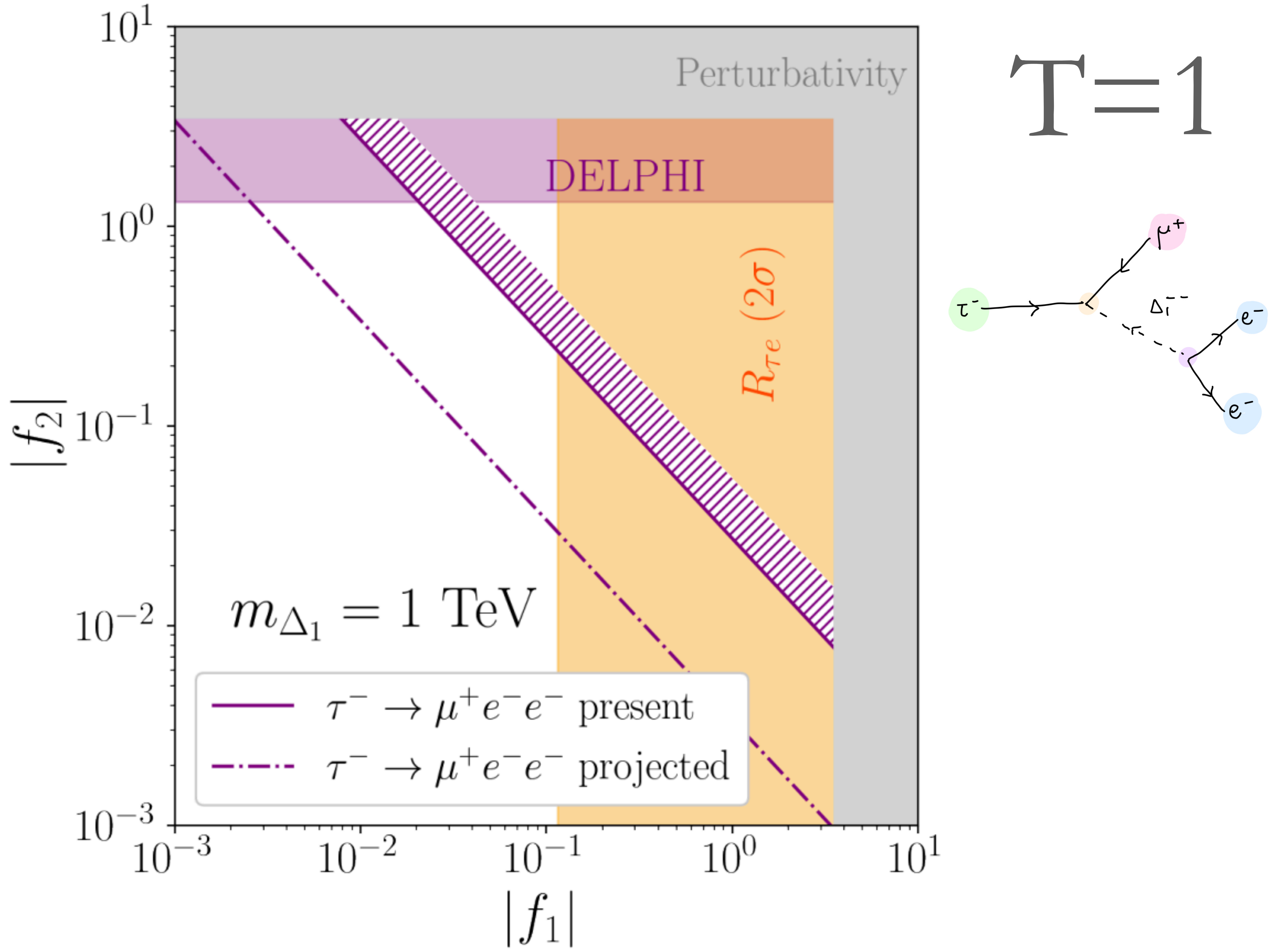
$$\Delta_T \sim \begin{pmatrix} \Delta_T^{+} & \Delta_T^{++} \\ \Delta_T^{0} & -\Delta_T^{+} \end{pmatrix}$$

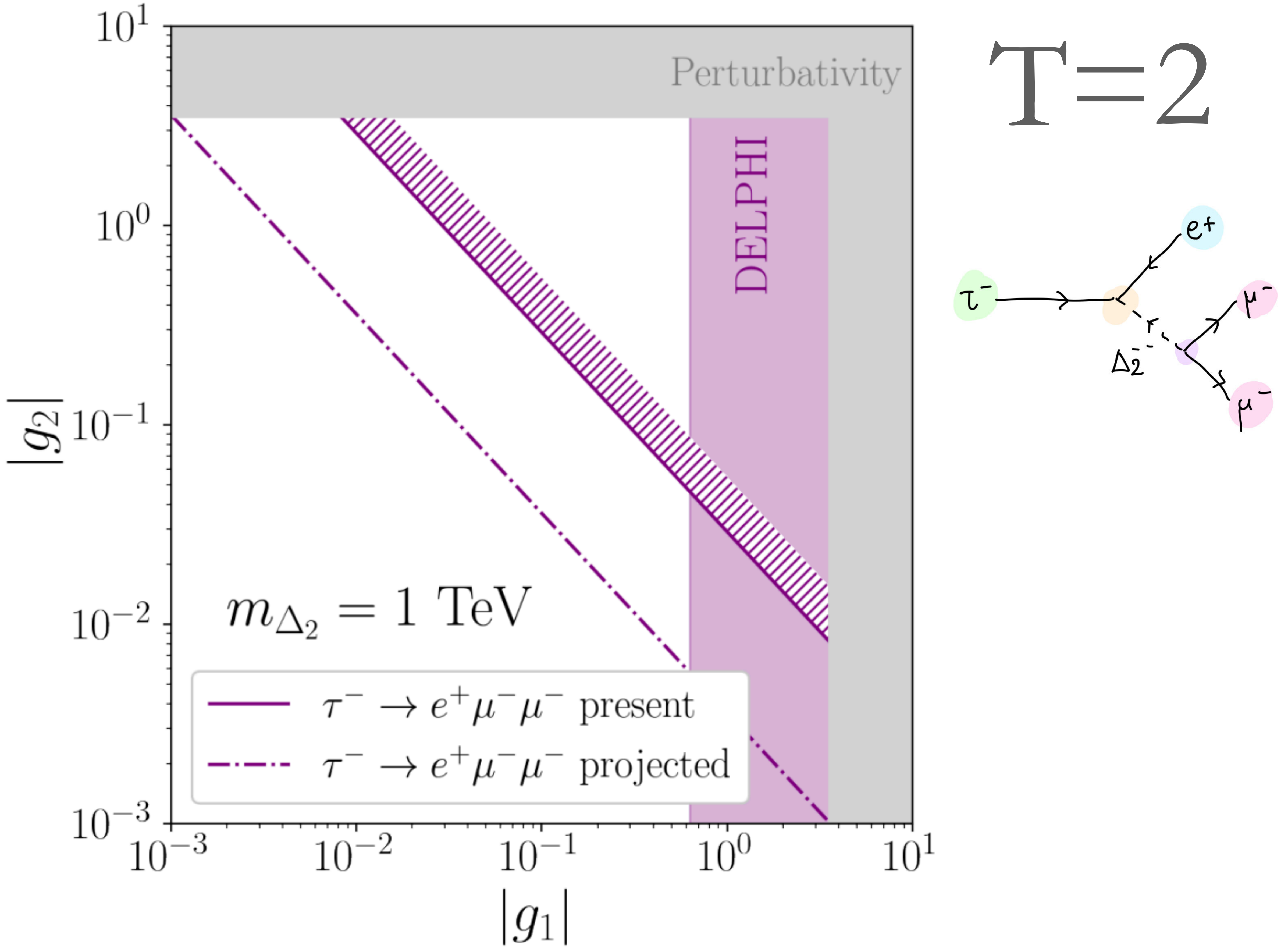
doubly charged scalar.

isospin partners

- Constrained to be TeV scale by doubly-charged bilepton searches
- Leptonic processes to neutrinos also constrain this parameter space, e.g. $$R_{\mu e} = \frac{\Gamma(\tau \to \mu + \text{inv})}{\Gamma(\tau \to e + \text{inv})} \frac{\Gamma_{\text{SM}}(\tau \to e + \text{inv})}{\Gamma_{\text{SM}}(\tau \to \mu + \text{inv})},$$
- Neutrino trident and modified muon decay also provide constraints, though not yet competitive

Electroweak Triplet Scalars

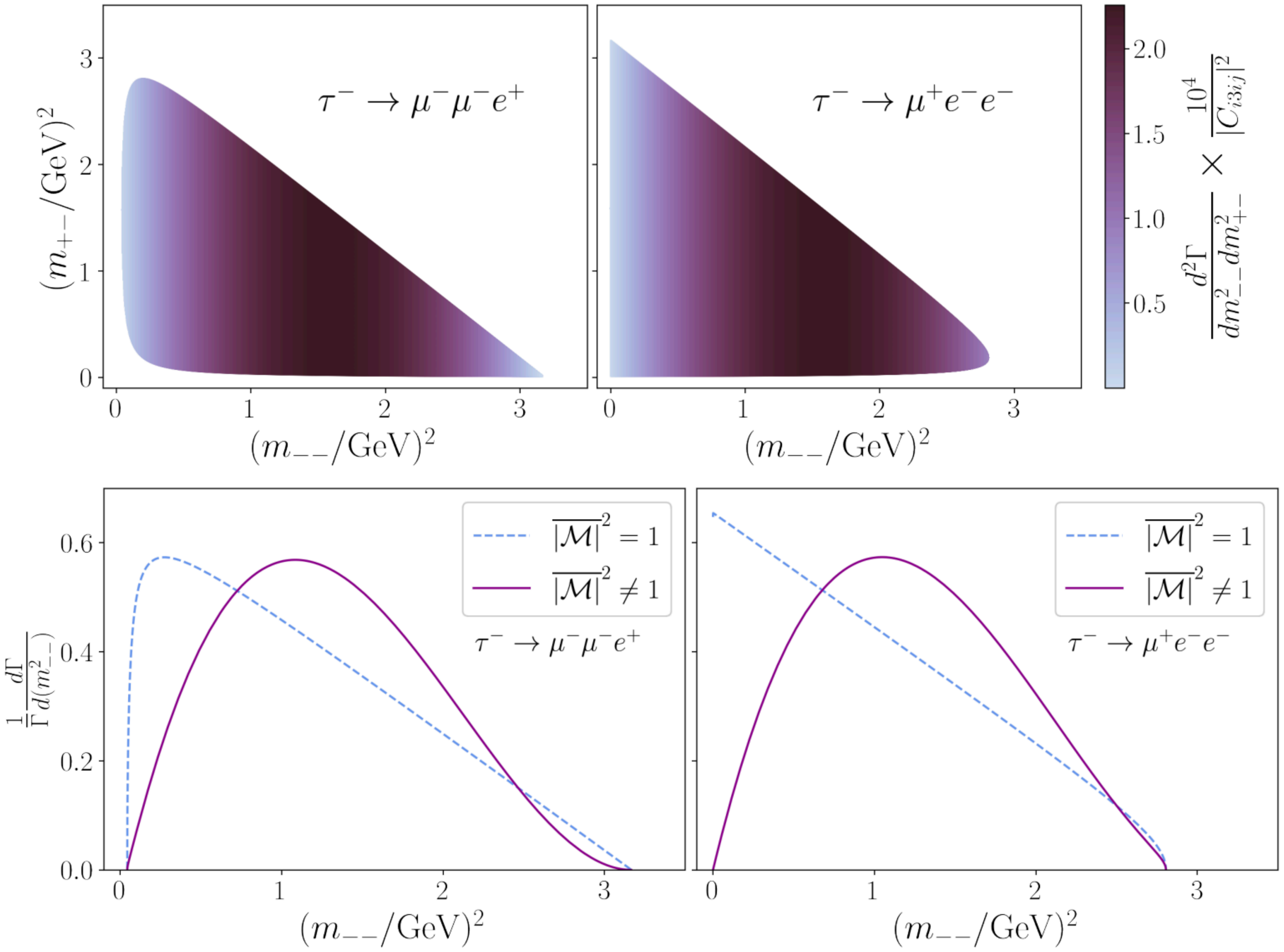




Innes Bigaran. Phenomenology Symposium 2023, 9 May 2023

Kinematic targets: phase space analysis

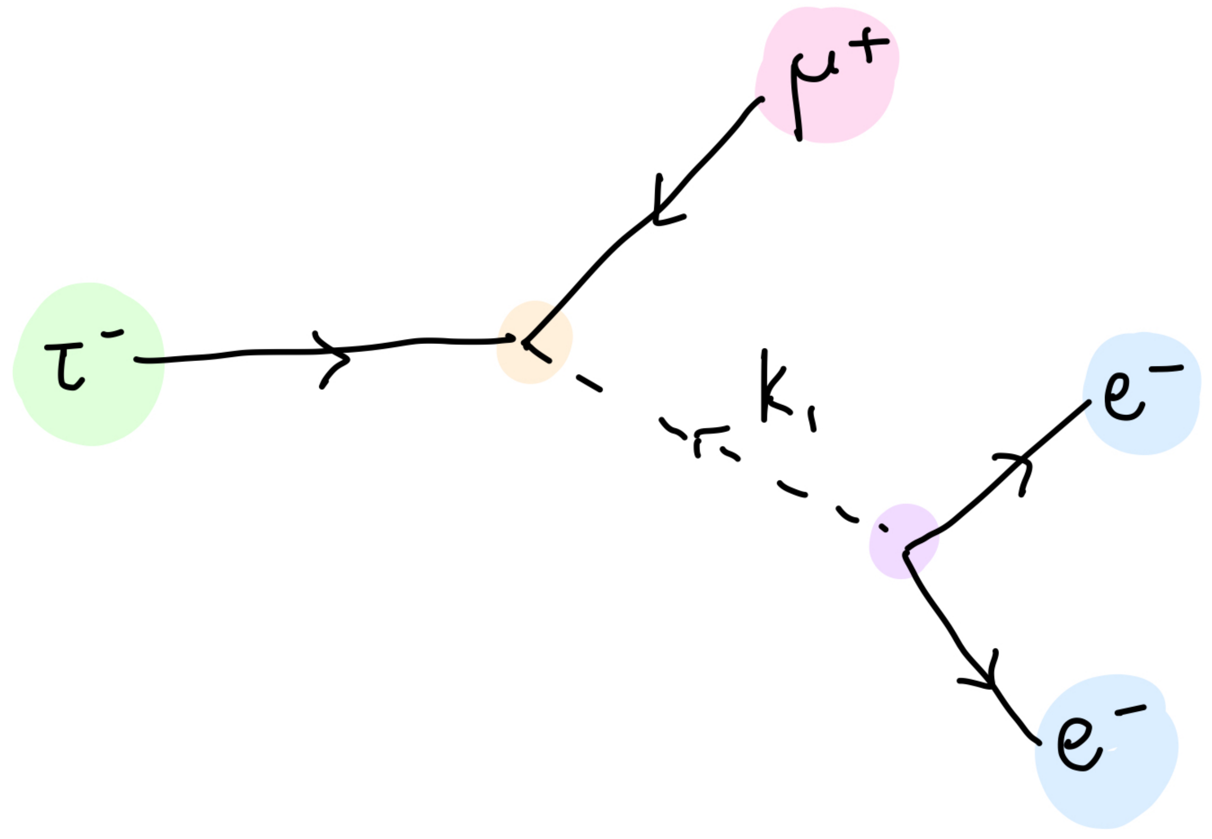
Extension to 1403.5783, 1506.07786 and others



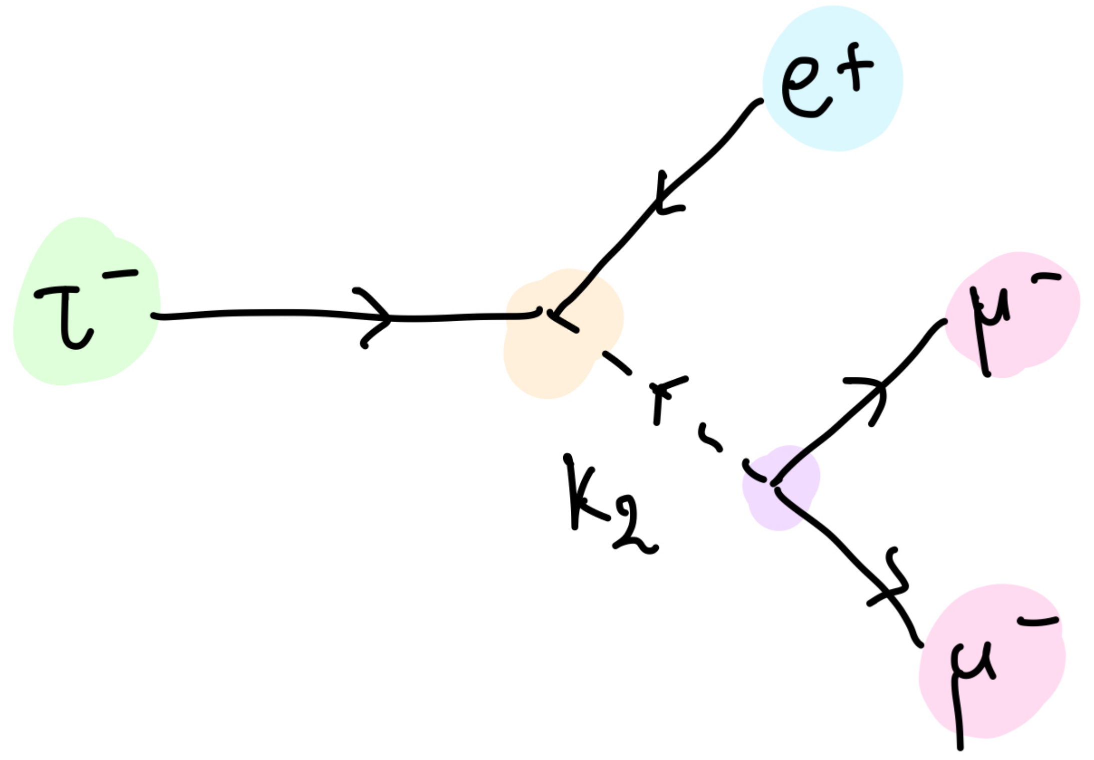
- Kinematic distributions from these decays in which the RH or LH vector interactions dominate
- In calculating projected sensitivities, expt. assumed flat matrix-element dependence (i.e. blue dashed line in bottom plots)
- More likely to observe decays in peaked regions. Req. detector efficiency information to calculate more accurate projected limits

Summary

I. Bigaran , XG He, M.A. Schmidt, G. Valencia, R.Volkas
arXiv: 2212.09760



- Lepton triality: assign lepton flavours different “charges” under a Z_3
- Motivates the search for cLFV signals in tau decays, and explains non-observation of cLFV in μ to e transitions
- Motivated by a residual Z_3 flavour symmetry in the lepton sector: can guide flavour model-building
- Minimal models furnished by EW singlet and triplet bileptons
- Dominant signals of cLFV in models with lepton flavour triality are in tau decays



Thank you!

Backup

Neutrino masses in these models

- If originate with A4, the residual symmetry is Z2 in the neutral lepton sector and Z3 in charged lepton sector (incompatible with present oscillation data, but good benchmark ‘tribimaximal mixing’
- If impose exact lepton flavour triality, and introduce three RH neutrinos:

Dirac masses

$$\mathcal{L} \supset -y_{ij} \bar{L}_i \nu_{R_i} \tilde{H} + h.c.$$

$$y = \begin{pmatrix} y_{11} & 0 & 0 \\ 0 & y_{22} & 0 \\ 0 & 0 & y_{33} \end{pmatrix}$$

Majorana masses

$$\mathcal{L} \supset \kappa_{ij} (L_i H)(L_j H)$$

$$\kappa = \begin{pmatrix} 0 & \kappa_{12} & 0 \\ \kappa_{12} & 0 & 0 \\ 0 & 0 & \kappa_{33} \end{pmatrix}$$

Require either soft or explicit symmetry breaking to be consistent with neutrino oscillation measurements