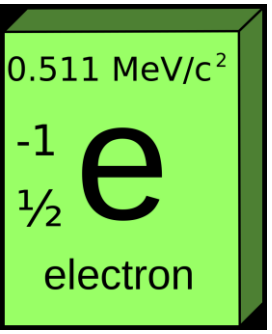
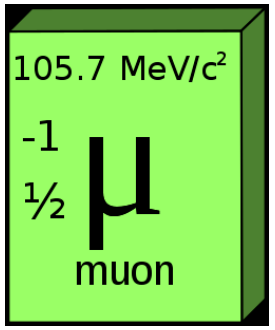
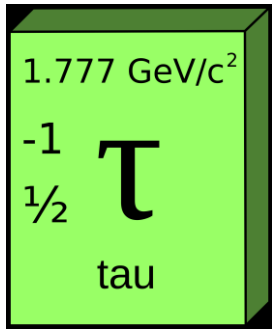
Some recent highlights in lepton Physics:







Pablo Roig
Dpto. de Física Cinvestav

Cinvestav

6thComHEP: Colombian Meeting on High-Energy Physics

November 29- December 3 2021 Hybrid

Contents

Big complementarity with Pedro Podesta's talk Monday!

Contents

- Motivation

- Michel parameters in presence of Majorana neutrinos (Juan Márquez Ms. Th.)

  (Work in progress)

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- Motivation

RadCor in tau to (pi/K) nu & related LU, CKM and NSI tests in Marco Arroyo's talk later on this morning
Phys.Rev.D 104 (2021) 9, L091502

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Phys.Rev.D 102 (2020) 114017

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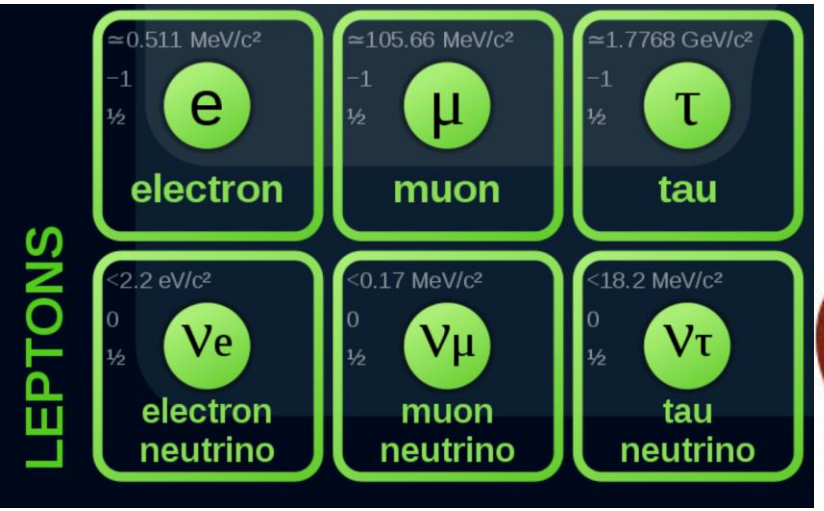
2110.03737 [hep-ph]

- Lepton flavor violating decays including two photons (Fabiola Fortuna & Marcela Marín Ph. D. Th.)
(To appear soon)

(Work in progress) 2110.03711 [hep-ph]

- LFV within Little Higgs models (Enrique Ramírez & Iván Pacheco Ph. D. Th.) & bounds on NSI using semileptonic tau decays (Javier Rendón & Álex Miranda Ph. D. Th.) **not discussed today.**
JHEP 11 (2018) 038, *Phys.Rev.D* 99 (2019) 9, 093005, *Phys.Rev.D* 101 (2020) 3, 034010, *Phys.Lett.B* 804 (2020) 135371

Motivation

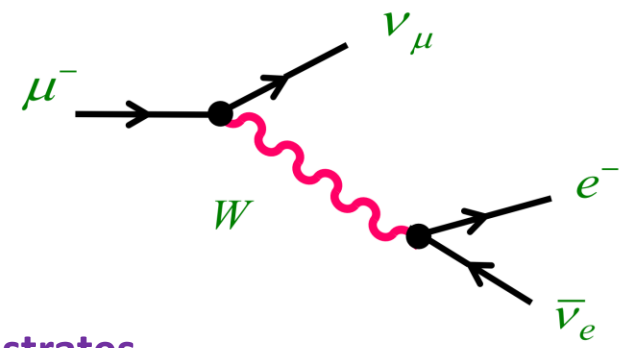


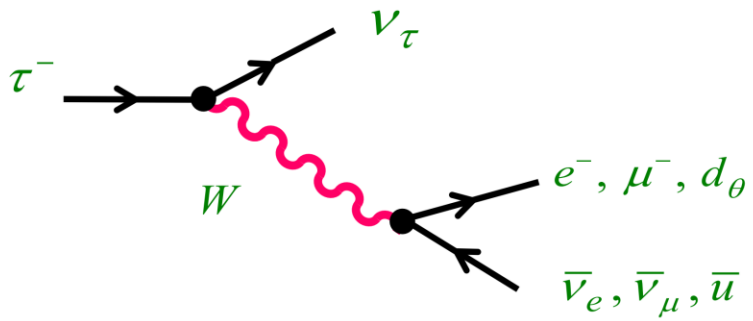
Looking for NP, go as leptonic (clean) as possible

Michel parameters in presence of Majorana neutrinos (Juan Márquez Ms. Th.)

(With Gabriel López Castro)

Weak Decays





'Fundamental' Theory — Λ

This illustrates how an EFT works

$$T(l \to \nu_l\, l' \bar{\nu}_{l'}) \sim \frac{g^2}{M_W^2 - q^2} \xrightarrow{q^2 << M_W^2} \frac{g^2}{M_W^2} = 4\sqrt{2}\, G_F$$

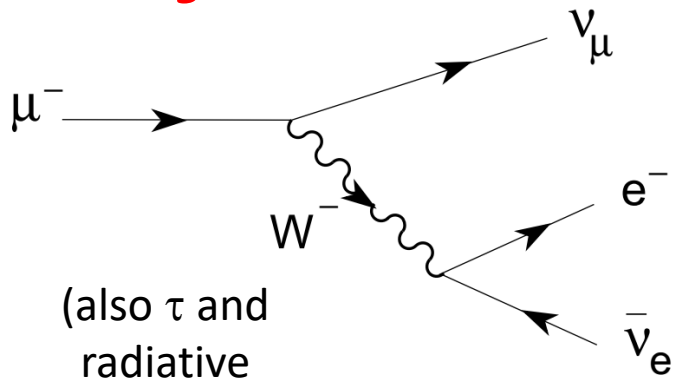
E — **EFT**

This dependence is fundamental for LU tests

$$\frac{1}{\tau_\mu} = \frac{G_F^2 m_\mu^5}{192\pi^3} f(m_e^2/m_\mu^2)\, r_{EW} \Rightarrow G_F = (1.166\,378\,7 \pm 0.000\,000\,6) \times 10^{-5}\ \text{GeV}^{-2}$$

Michel parameters in presence of Majorana neutrinos (Juan Márquez Ms. Th.)

(With Gabriel López Castro)



(also τ and radiative decays)

$$n = S, V, T$$

$$\Gamma^S = 1,\ \Gamma^V = \gamma^\mu,\ \Gamma^T = \frac{i}{2\sqrt{2}}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$$

$$\mathcal{H} = 4\frac{G_{\ell'\ell}}{\sqrt{2}} \sum_{n,\epsilon,\omega} g^n_{\epsilon\omega} \left[\overline{\ell'_\epsilon}\Gamma^n(\nu_{\ell'})_\sigma\right] \left[\overline{(\nu_\ell)_\lambda}\Gamma_n\ell_\omega\right]$$

$\epsilon, \omega, \sigma, \lambda$ label the chiralities

$$\frac{d^2\Gamma_{\ell\to\ell'}}{dx\, d\cos\theta} = \frac{m_\ell\,\omega^4}{2\pi^3} G^2_{\ell'\ell} \sqrt{x^2 - x_0^2} \left\{F(x) - \frac{\xi}{3}\mathcal{P}_\ell \sqrt{x^2 - x_0^2}\cos\theta\, A(x)\right\},$$

$E_{l'}^{max}$

$x \equiv E_{\ell'}/\omega$

$x_0 \equiv m_{\ell'}/\omega$

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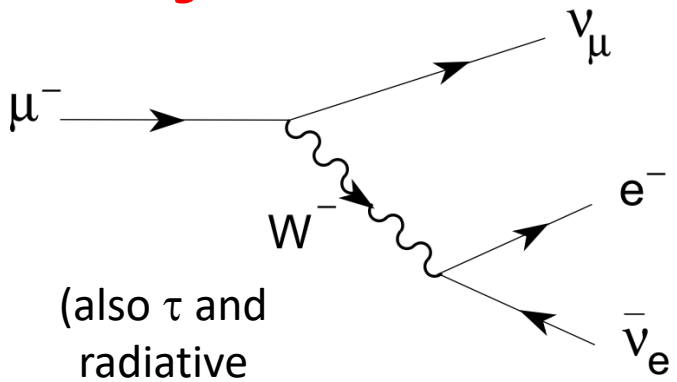

(also τ and radiative decays)

(With Gabriel López Castro)

(Our) Michel parameters for L → 3l 2ν decays **not discussed today.**
JHEP 04 (2016) 185

This measurement will be improved at present and future experiments. Also important in several NP searches as bkg.

Belle II Cinvestav

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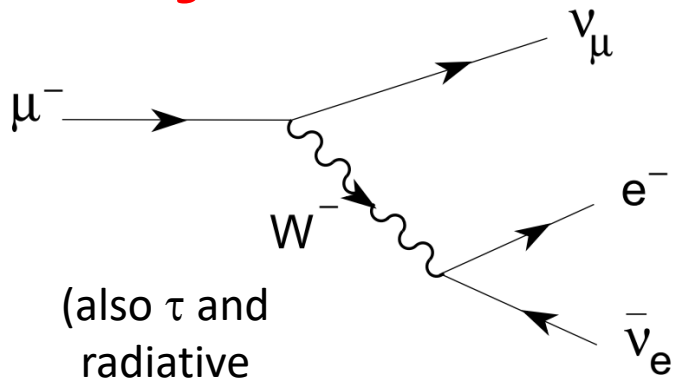

(also τ and radiative decays)

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With TeV scale Majorana neutrinos, modifications to the Michel spectrum could be as large as permille effects in τ decays!!

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The anomalous magnetic moment of the muon (SM, Álex Miranda Ph. D. Th.)

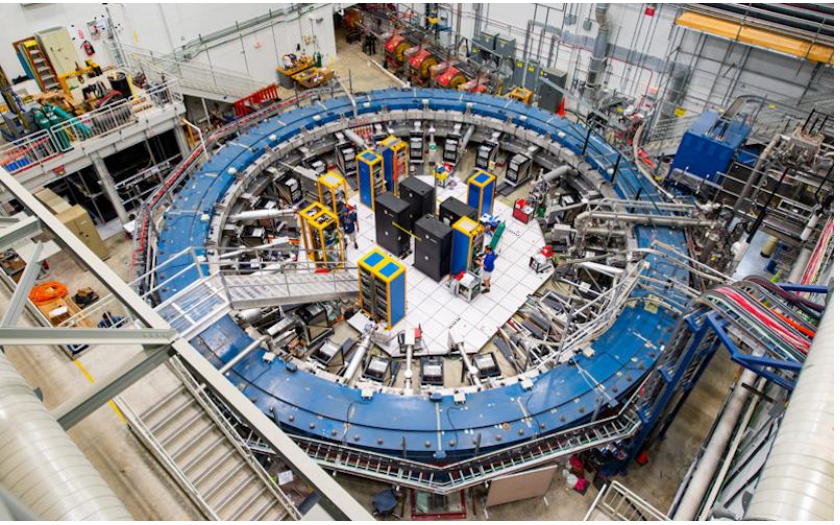
Phys.Rev.D 102 (2020) 114017

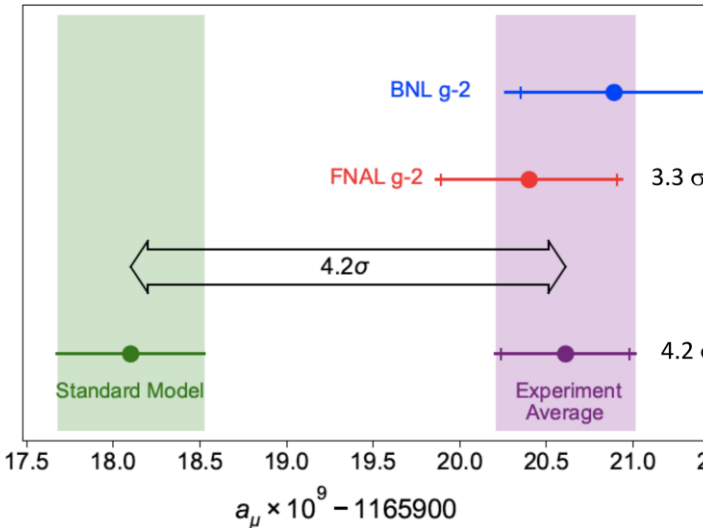
Muon g-2 Theory Initiative

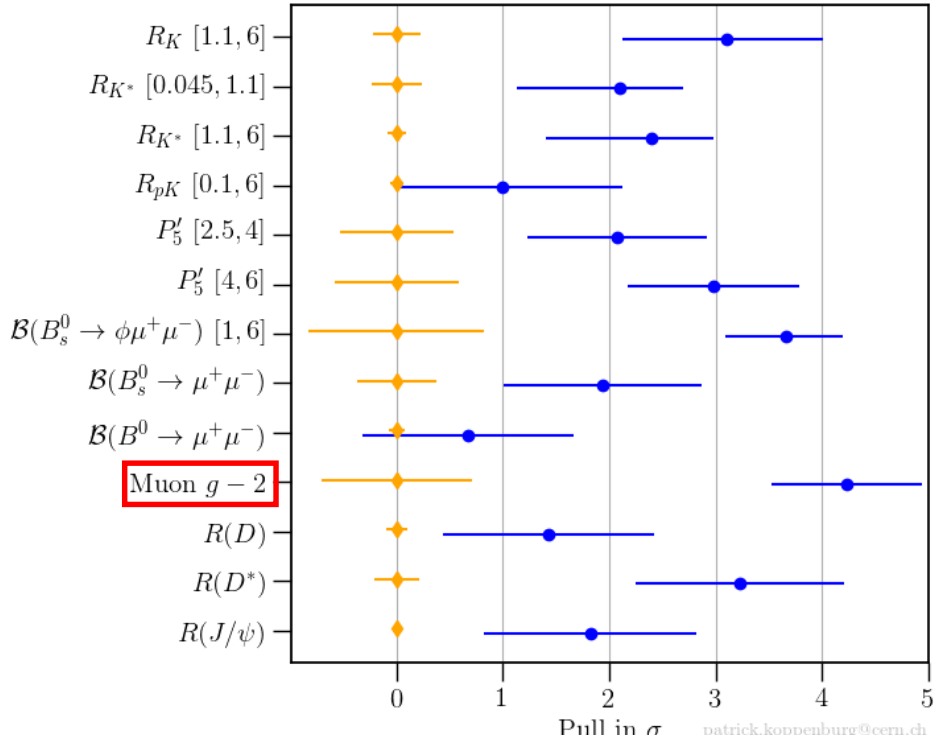
https://doi.org/10.1016/j.physrep.2020.07.006 (SM prediction, '**White Paper**')

See opening talk by David Tarazona and Rodolfo Capdevilla's & Laura Muñoz's talks later on today.

To avoid disagreement between the 'Glasgow consensus' (Prades-de Rafael-Vainshtein, *Adv.Ser.Direct.High Energy Phys.* 20 (2009) 303-317) vs. the Jegerlehner-Nyffeler number in their review, *Phys.Rept.* 477 (2009) 1-110.







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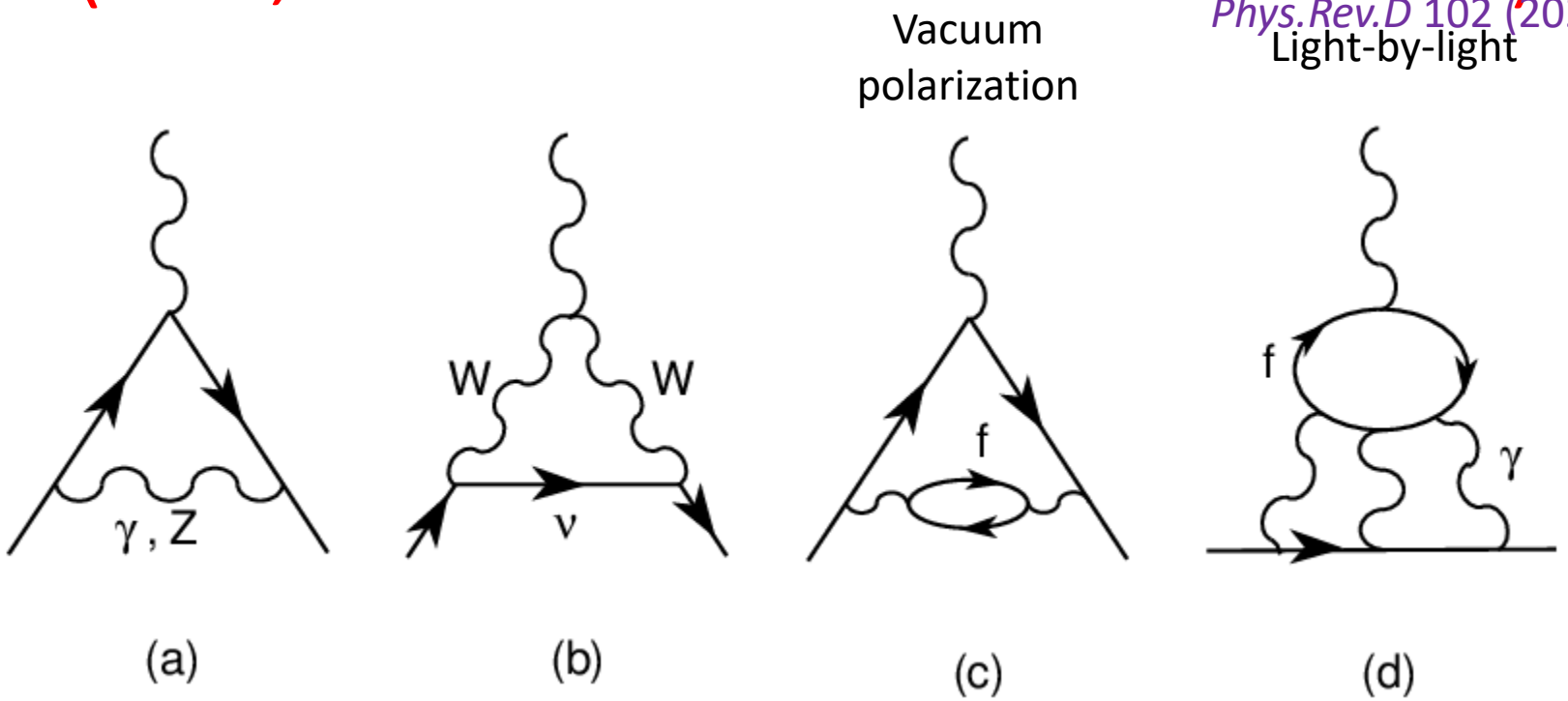
Phys.Rev.D 102 (2020) 114017

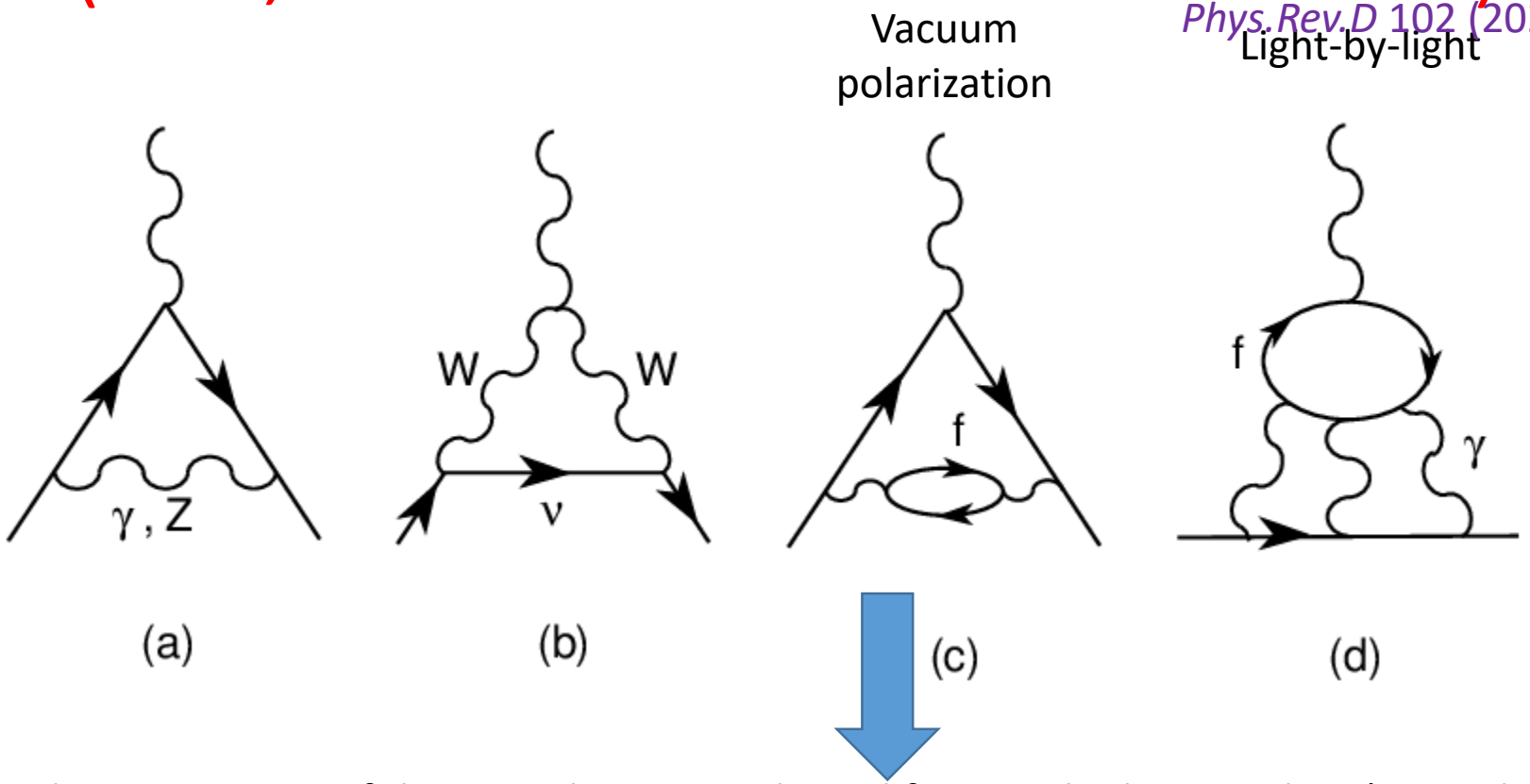


$$a_{\underset{\mu}{e}} = a_{\underset{\mu}{e}}(\mathrm{QED}) + a_{\underset{\mu}{e}}(\mathrm{hadronic}) + a_{\underset{\mu}{e}}(\mathrm{electroweak}),$$

$\vec{\mu}_l = g_l\, e/(2\, m_l)\, \vec{S}_l$, $\quad g_l = 2\,(1+a_l)$, $\quad a_l = \alpha/(2\,\pi)+\ldots$

The anomalous magnetic moment of the muon (SM, Álex Miranda Ph. D. Th.)

Phys.Rev.D 102 (2020) 114017

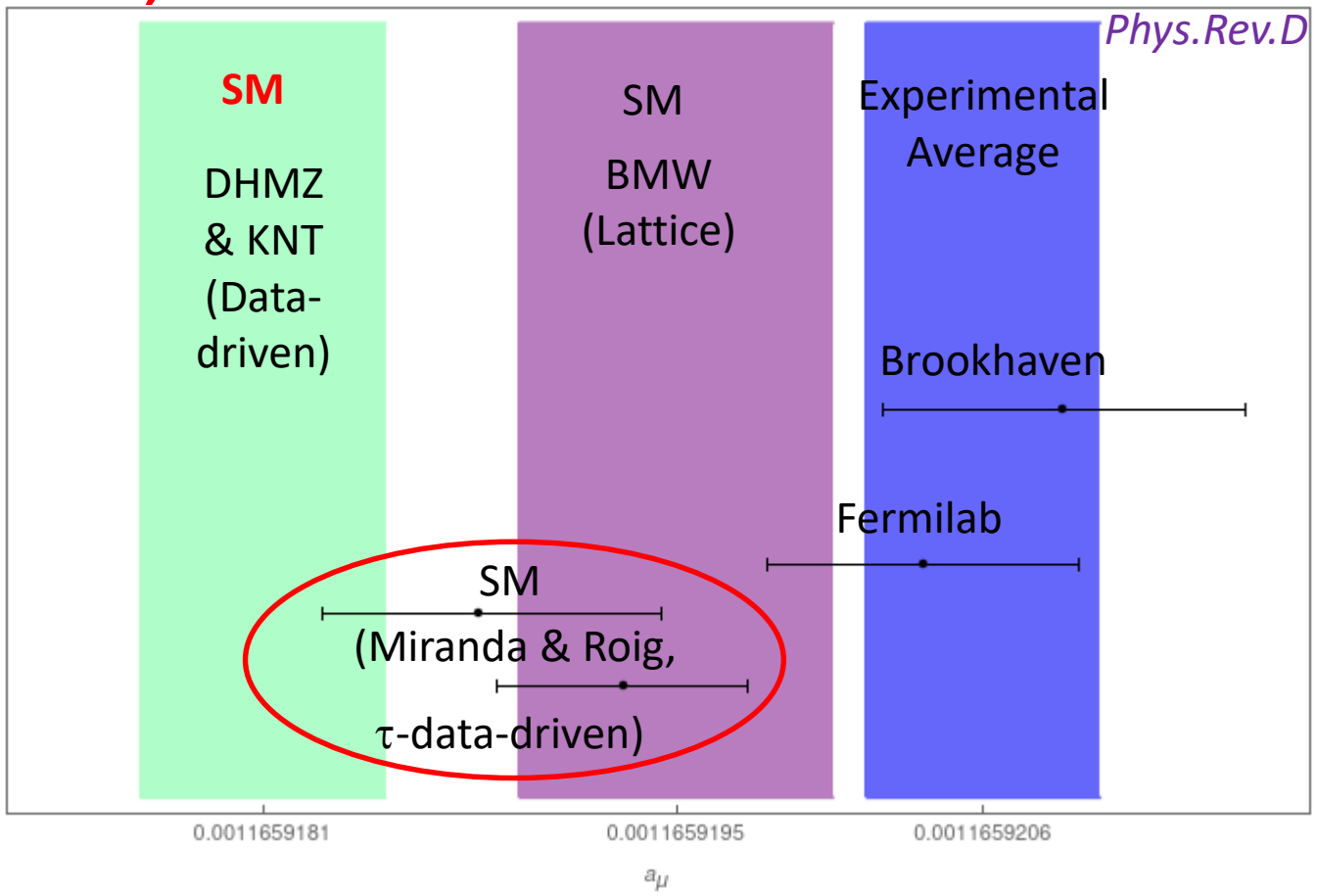


Álex has focused on the dominant piece of this contribution, evaluated from $\tau \to$ hadrons ν_τ data (instead of $e^+e^- \to$ hadrons data), which required computing isospin corrections beyond previous literature.

Our contributions to HLbL (RChT, DSE) **not discussed today.**

Related Álex work on axials contributions to HFS in muonic H (with Pablo Sánchez Puertas) **not discussed today.**

The anomalous magnetic moment of the muon (SM, Álex Miranda Ph. D. Th.)



Phys.Rev.D 102 (2020) 114017

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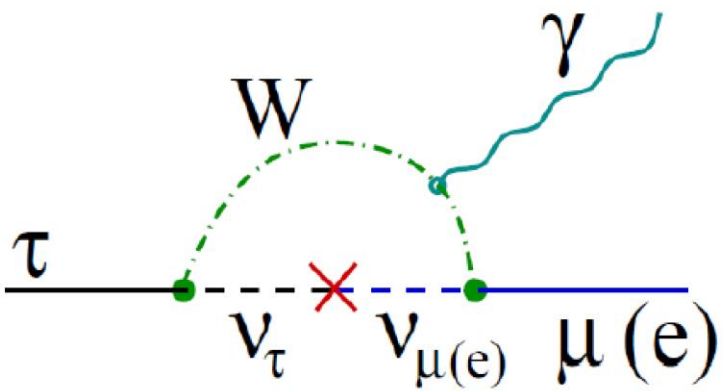
A significant deviation between exp & SM should be New Physics!!

Lepton flavor violating decays

Cinvestav

CHARGED LEPTON FLAVOR VIOLATION (cLFV):

Any observation is New Physics



cLFV is forbidden in the limit of massless neutrinos (Lepton flavor is conserved).
cLFV smallness is due to neutrinos running in the loop (GIM suppression) and the KLN theorem (no IR divs associated with intermediate or final-state particles can appear).

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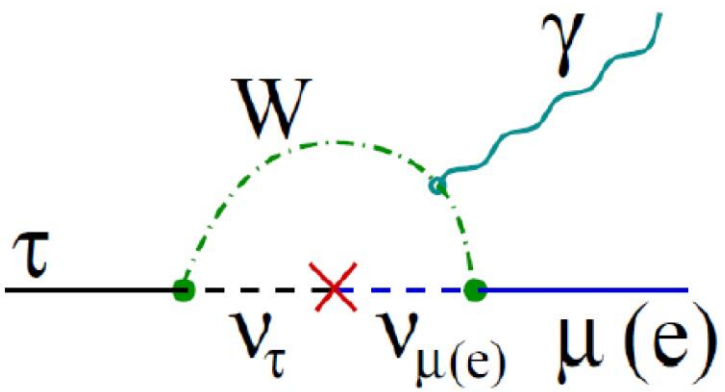

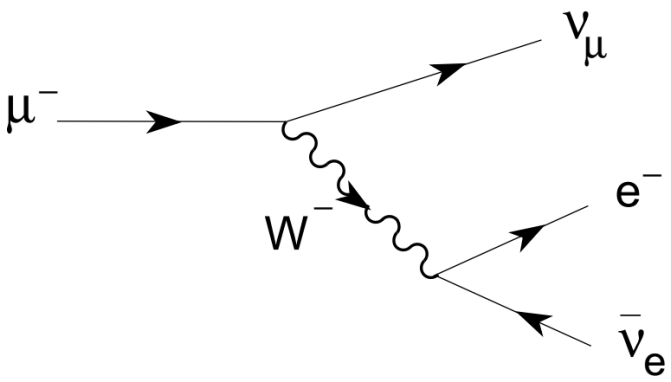

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$$BR(\mu \to e\gamma) \simeq \frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu\bar{\nu})} = \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} \frac{U_{\mu k} U_{ek}^* m_{\nu k}^2}{m_W^2} \right|^2 \sim 10^{-54}.$$

- T. P. Cheng and L. F. Li, Gauge Theory Of Elementary Particle Physics

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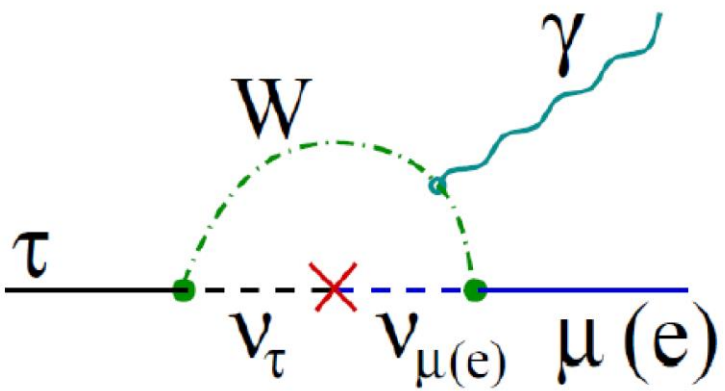

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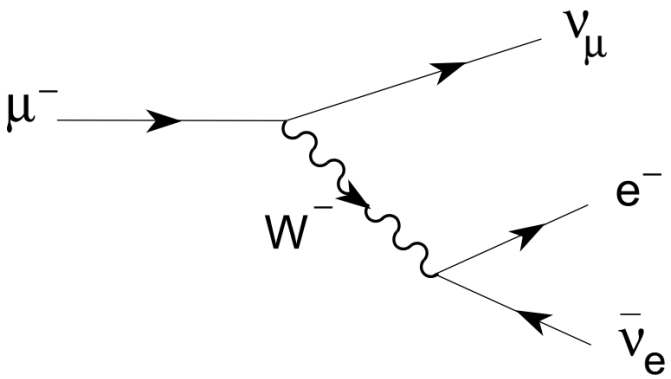

Analogously, a similar suppresion **has to** arise in other cLFV processes.

$BR(Z \to \ell'\ell) \sim 10^{-54}$

- Phys. Rev. D 63, 053004 (2001)

$BR(h \to \ell'\ell) \sim 10^{-55}$

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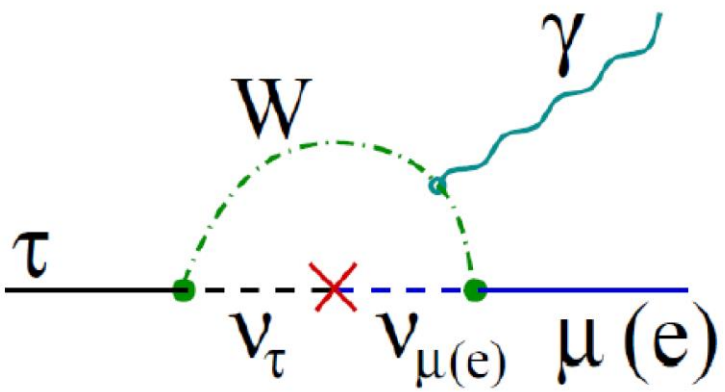

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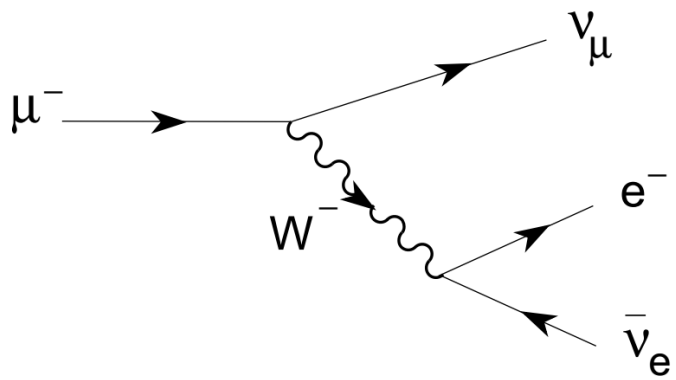

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- Phys. Rev. D 71, 035011 (2005)

$\mathrm{BR}(\mu^\pm \to e^\pm e^\pm e^\mp) \sim 10^{-53}$ (updated input)

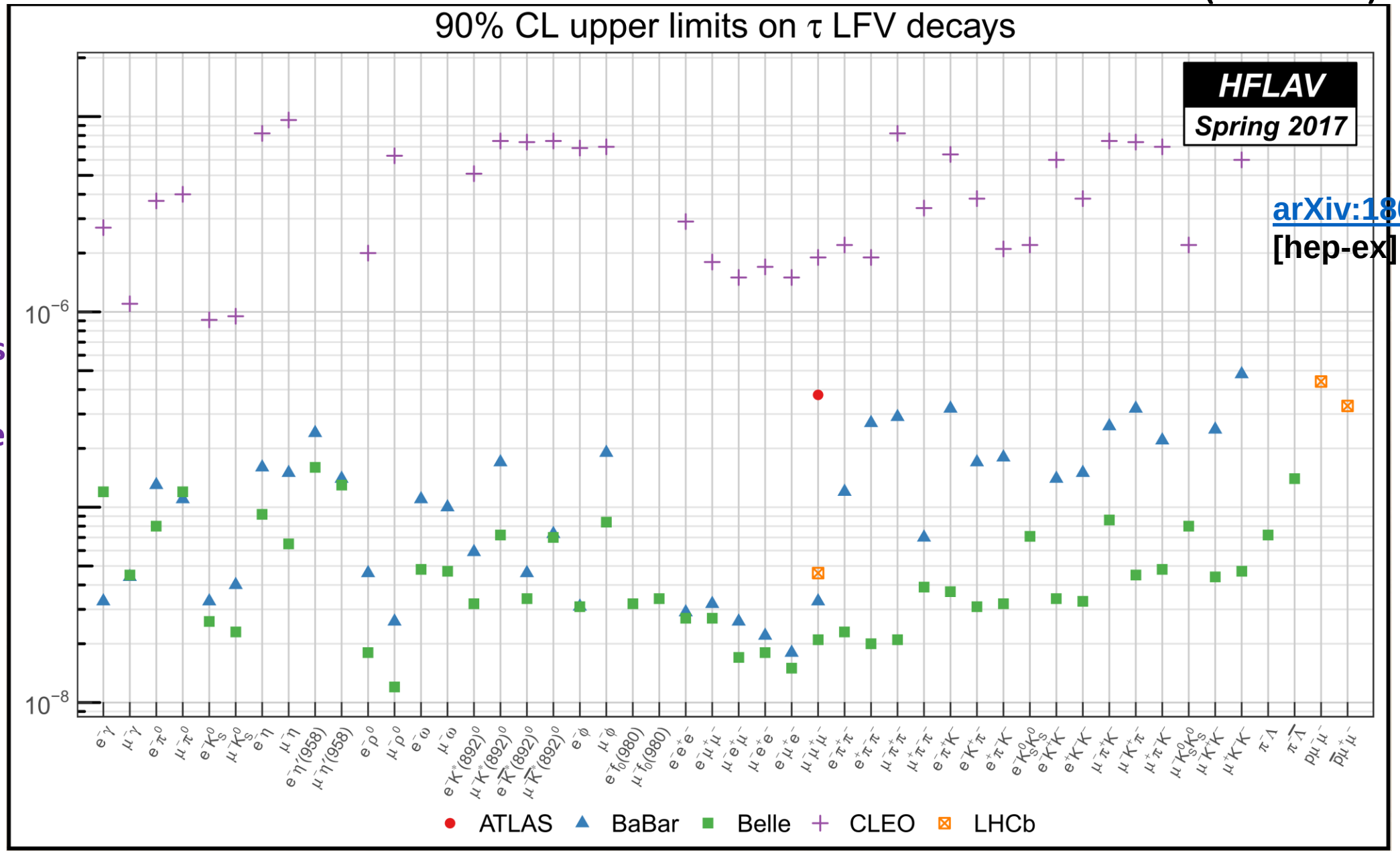
- S. T. Petcov, Sov. J. Nucl. Phys. 25, 340 (1977).

$$\mathcal{M} \sim \sum_{j=1}^{3} U^*_{ej}U_{\mu j}\frac{m^2_j}{m^2_W}\log\left(\frac{m^2_W}{m^2_j}\right)$$

10^{-54}<**BR(τ → 3l)**<10^{-56}, G. Hernández-Tomé, G. López-Castro & P. Roig, **EPJ C 79 (2019) no.1, 84**

CHARGED LEPTON FLAVOR VIOLATION (cLFV):

Belle-II should improve two orders of magnitude w.r.t. BaBar & Belle (it depends on the channel)



arXiv:1808.10567 [hep-ex]

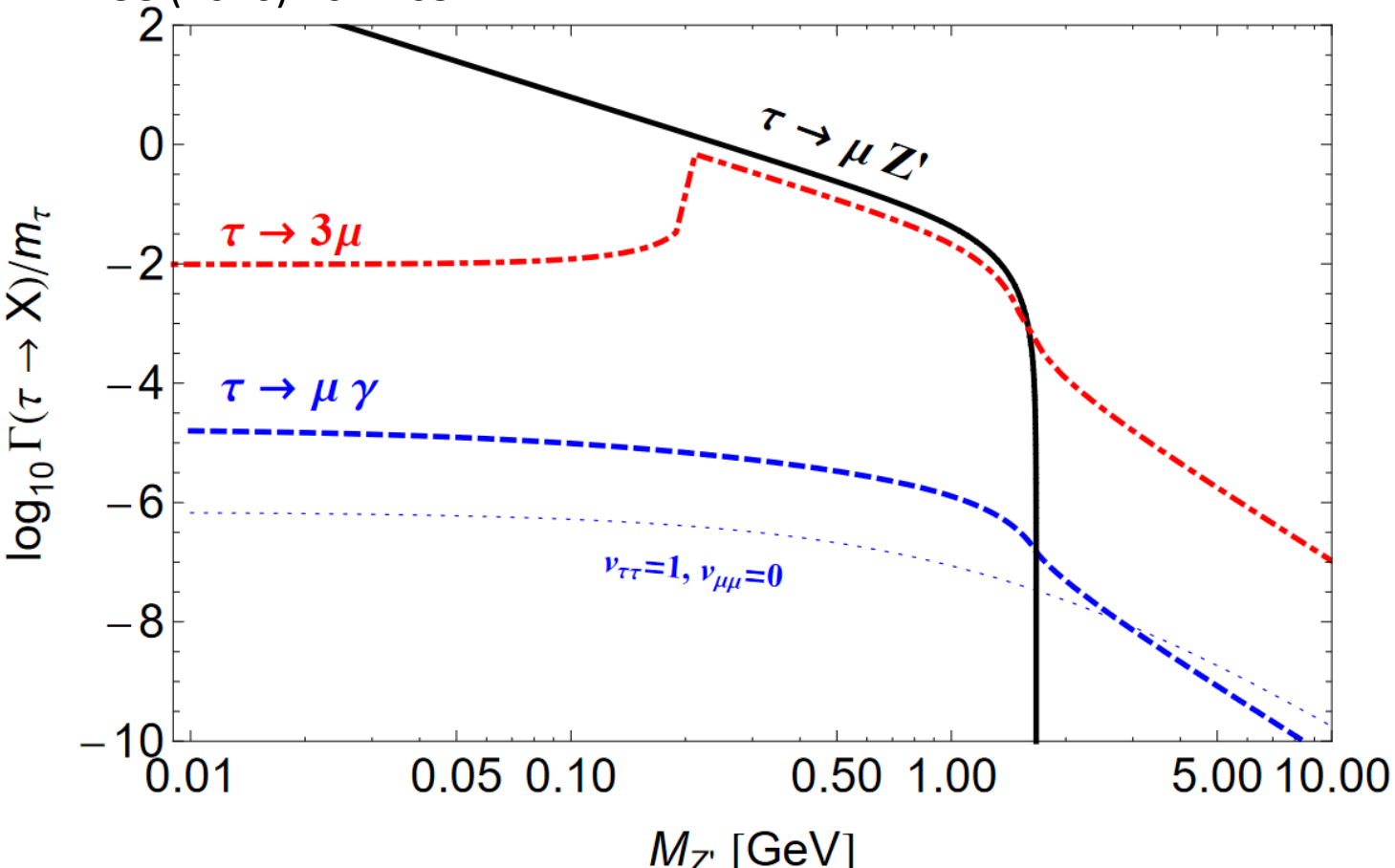
Belle-II Physics Book

Lepton flavor violating decays including an invisible light boson (Marcela Marín Ph. D. Th.)

(With Alejandro Ibarra)

From Heeck, J.
PLB 758 (2016) 101-105

$v_{\mu\mu} = v_{\mu\tau} = 1,\ a_{\mu\mu} = a_{\mu\tau} = 0$



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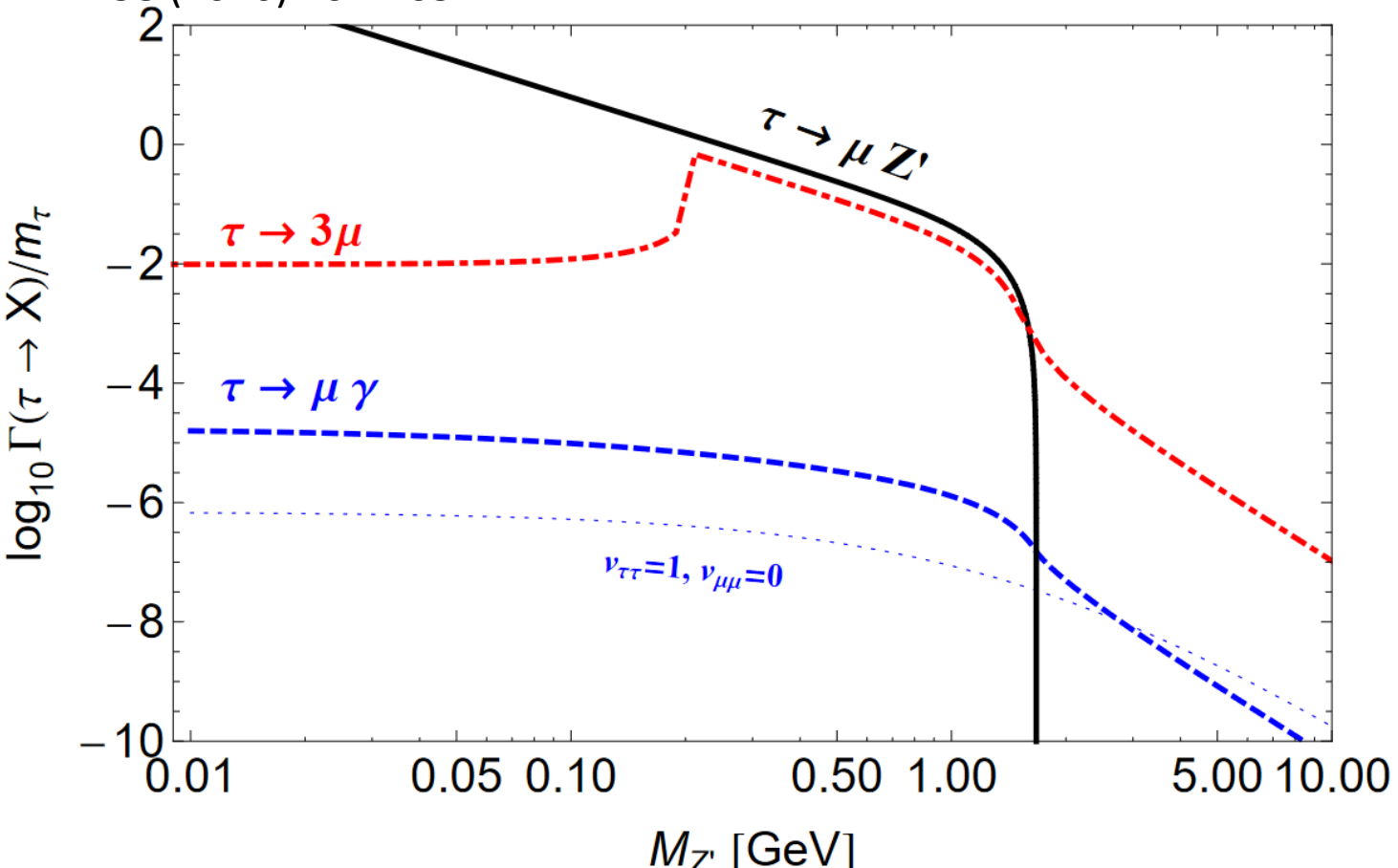

The behaviour of $\tau \to \mu\ Z'$ for low $M_{Z'}$ is clearly unphysical.

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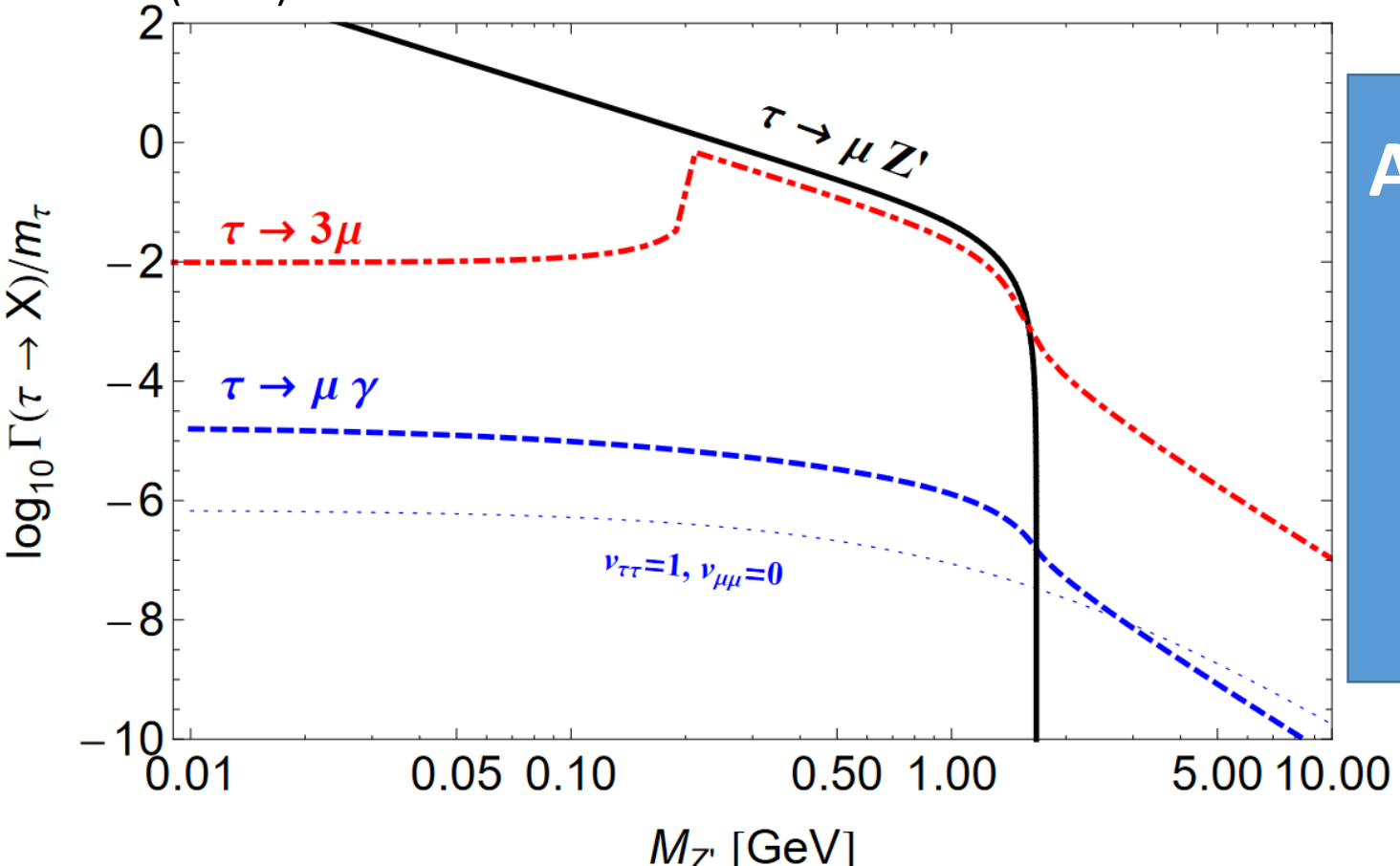


Applying gauge symmetry we have solved this puzzle!! This has profound implications for light spin-1 boson searches!!

Lepton flavor violating decays with two photons (Fabiola Fortuna & Marcela Marín Ph. D. Th.)

To appear soon

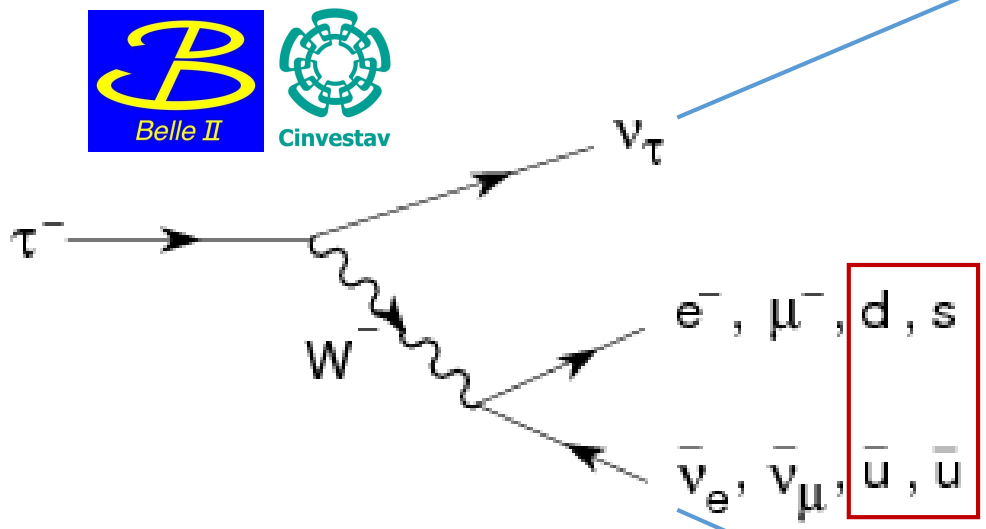
(With Alejandro Ibarra & Xabi Marcano)

- Using a low-E EFT, bounds can be derived on L → l γ γ processes, **which are stronger than the direct searches.**
- Work in progress in a couple of specific model realizations in which L → l γ γ can be more likely than L → l γ.
- Interesting connections with l → τ conversion in nuclei.
- Obviously, one or both photons can be a light Z', which connects to the previous work.

LFV in Little Higgs models (Enrique Ramírez & Iván Pacheco Ph. D. Th.) & bounds on NSI using hadron τ decays (Javier Rendón & Álex Miranda Ph. D. Th.) not discussed today.

(With Sergi González-Solís)

JHEP 12 (2017) 027, *JHEP* 11 (2018) 038, *Phys.Rev.D* 99 (2019) 9, 093005, *Phys.Rev.D* 101 (2020) 3, 034010, *Phys.Lett.B* 804 (2020) 135371



LHC EWPO

K & μ decays $0^+ \rightarrow 0^+$

SMEFT

NEW PHYSICS

Interesting bounds on LFV process with TeV Majorana neutrinos within LH models **not discussed today.**

(With Marco Arroyo, Gerardo, Gabriel & Natxo Rosell)

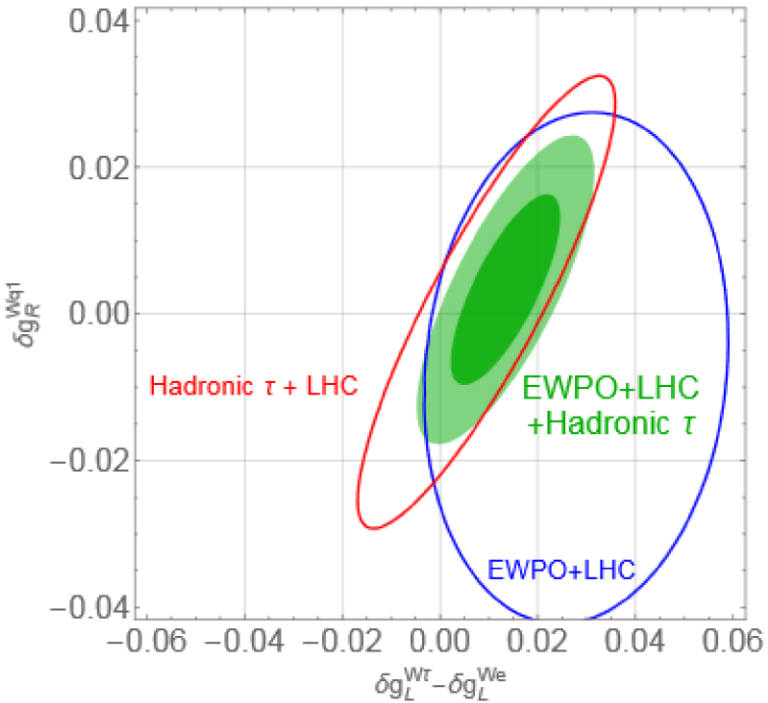
See also our recent *Phys.Rev.D* 104 (2021) 9, L091502 in **Marco's talk later on today**

LFV in Little Higgs models (Enrique Ramírez & Iván Pacheco Ph. D. Th.) & bounds on NSI using hadron τ decays (Javier Rendón & Álex Miranda Ph. D. Th.) not discussed today.

From ηπ channel: $-0.83\ 10^{-2} \leq \varepsilon_S \leq 0.37\ 10^{-2}$ (Garcés et al. '17)

From ππ channel: $\hat{\epsilon}_T = \left(-1.3^{+1.5}_{-2.2}\right) \cdot 10^{-3}$ (Miranda & Roig '18)

Limits from Cirigliano et al. '18:

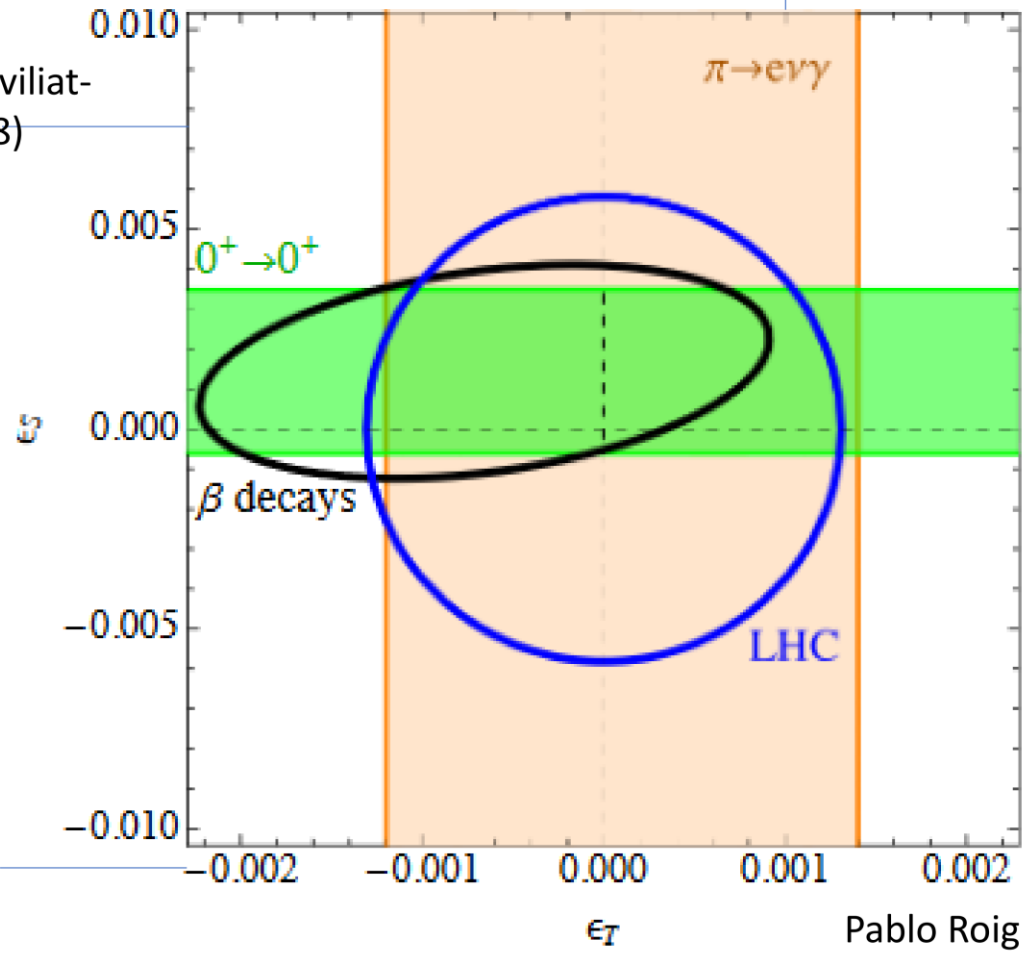


(González-Alonso, Naviliat-Cuncic & Severijns '18)

$\Lambda \approx [5,6]$TeV

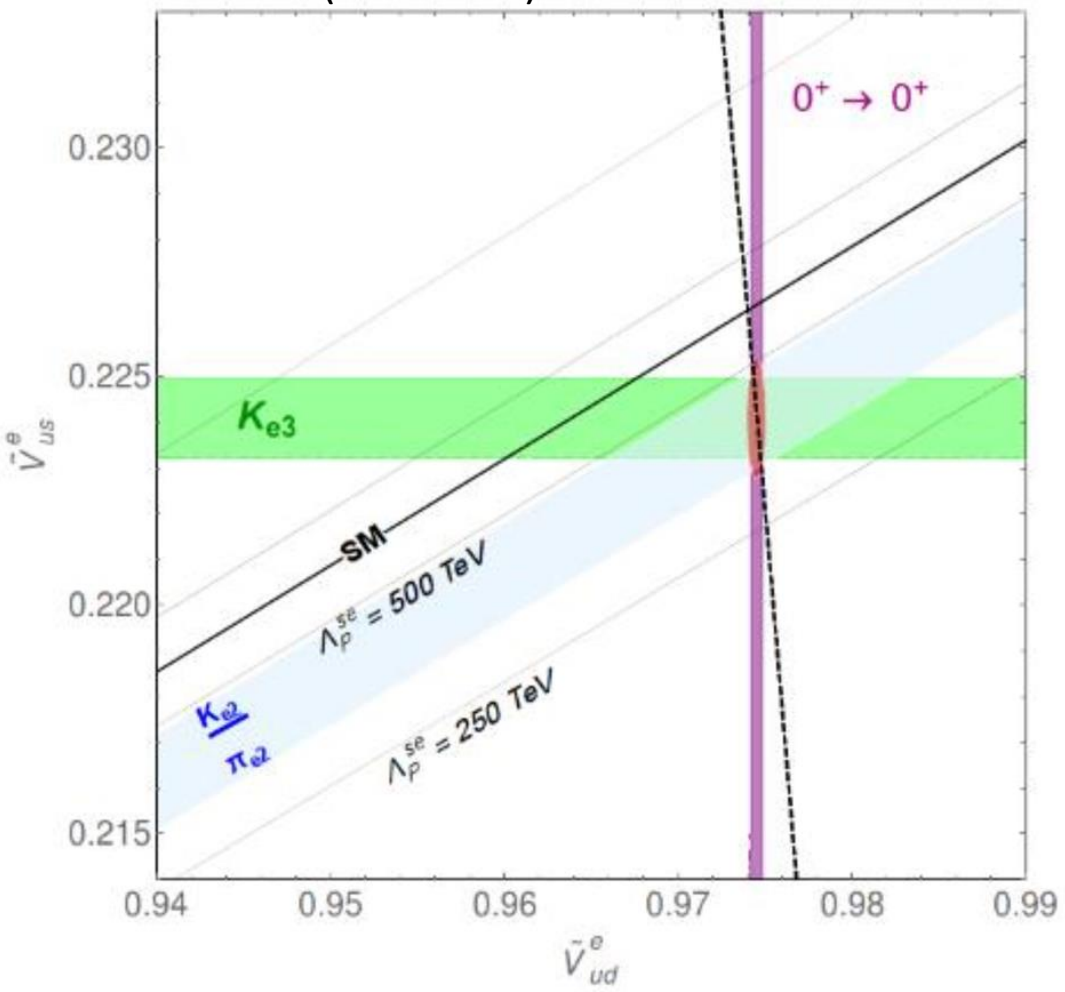
Non-trivial constraints from τ decay!!

$\Lambda \approx v\ (V_{ud}\ \varepsilon_{S,T})^{-1/2}$



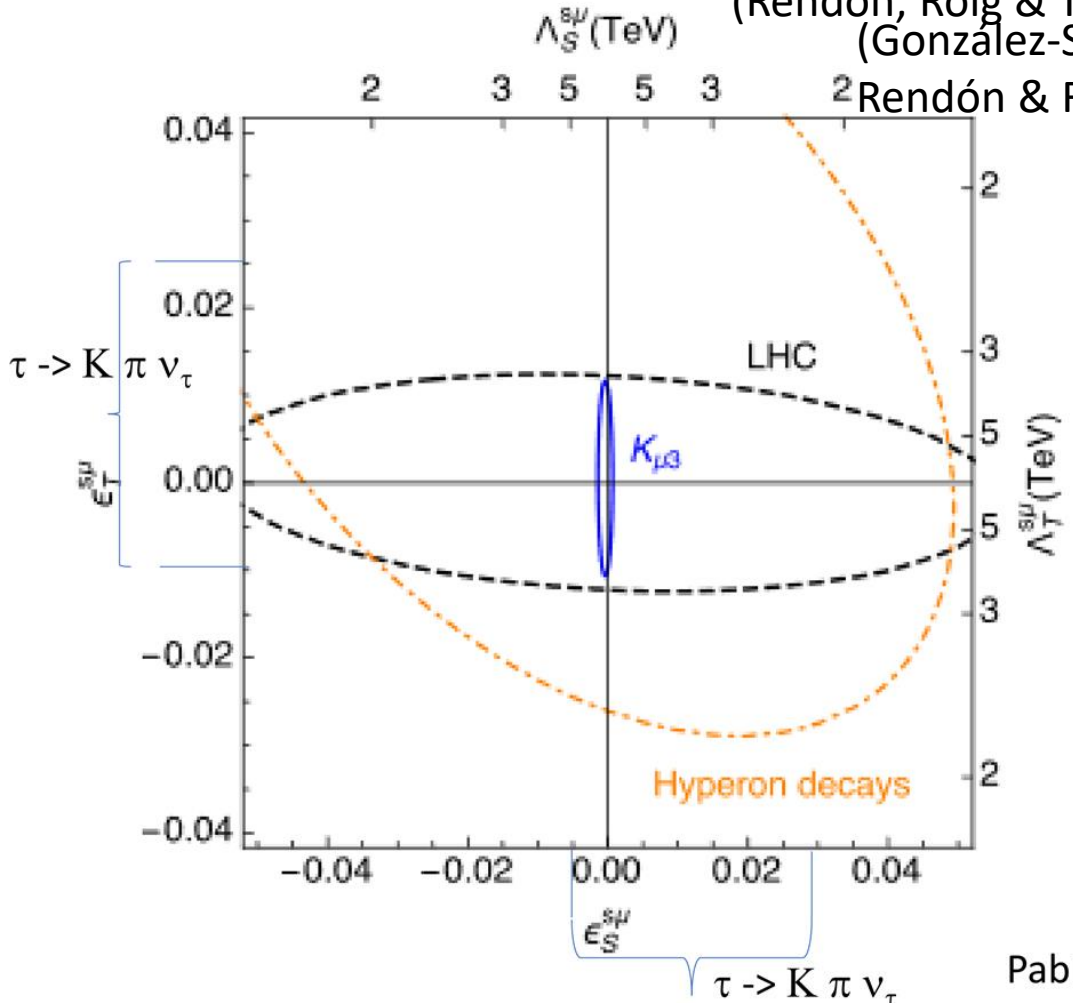
LFV in Little Higgs models (Enrique Ramírez & Iván Pacheco Ph. D. Th.) & bounds on NSI using hadron τ decays (Javier Rendón & Álex Miranda Ph. D. Th.) not discussed today.

Kaon Physics may reach O(500) TeV (González-Alonso et al. '15, '16, '17)
(scalar NSI)



$\Lambda \sim v(V_{us}\hat{\epsilon}_{S,T})^{-1/2}$

(Rendón, Roig & Toledo'19)
(González-Solís, Miranda, Rendón & Roig'20)



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DISCLAIMER

I have not discussed other very interesting NP searches that can be performed through charged leptons physics. Namely:

- **Electron & muon electric dipole moments**
- **$\mu e \rightarrow \mu e$ for $a_\mu^{HVP,LO}$**
- **Dark photons**

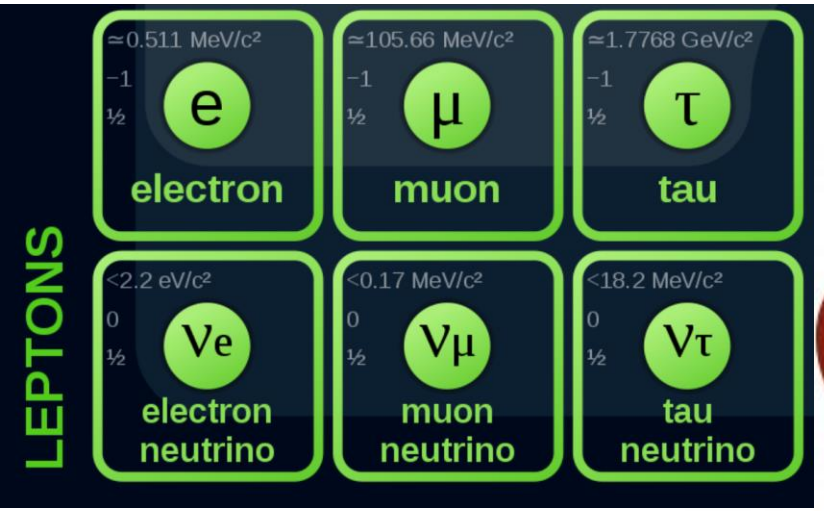
- **LU anomalies in semileptonic decays of heavy mesons**
- **Antimatter gravity with muonium**
- **LNV**

- **LFV in nuclei**
- **Baryogenesis through leptogenesis**
- **…**

arXiv:1808.10567
[hep-ex]

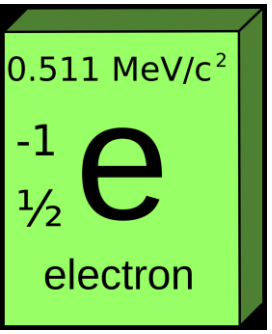
Belle-II Physics Book

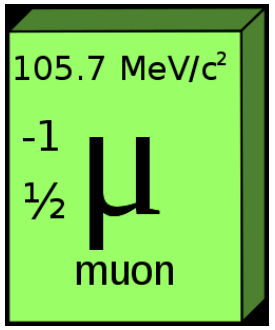
Motivation

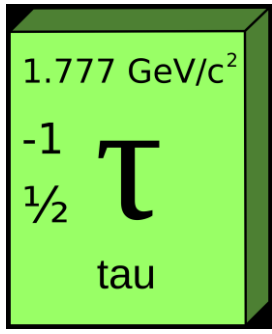


Looking for NP, go as leptonic (clean) as possible

Some recent highlights in lepton Physics:







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6thComHEP: Colombian Meeting on High-Energy Physics

November 29- December 3 2021 Hybrid