EL SABOR DE LA FÍSICA

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08/abril/2022

- My academic journey:

- Collaboration work with GLC:

- G-parity breaking in $\tau^- \to \eta^{(\prime)}\pi^-\nu_\tau$ decays induced by the $\eta'\gamma\gamma$ form factor, G. Hernández-Tomé, G. López Castro, P. Roig, Phys.Rev.D 96 (2017) 5, 053003.

- Flavor violating leptonic decays of τ and μ leptons in the Standard Model with massive neutrinos, G. Hernández-Tomé, G. López Castro, P. Roig, Eur.Phys.J.C 79 (2019) 1.

- Effects of heavy Majorana neutrinos on lepton flavor violating processes, G. Hernández-Tomé, J. I. Illana, M. Masip, G. López Castro, P. Roig, Phys.Rev.D 101 (2020) 7, 075020.

- Radiative corrections to $\tau \to \pi(K)\nu_\tau[\gamma]$: A reliable new physics test, M.A. Arroyo-Ureña, G. Hernández-Tomé, G. López-Castro, P. Roig, I. Rosell, Phys.Rev.D 104 (2021) 9, L091502.

- One-loop determination of $\tau \to \pi(K)\nu_\tau[\gamma]$ branching ratios and new physics test, M.A. Arroyo-Ureña, G. Hernández-Tomé, G. López-Castro, P. Roig, I. Rosell, JHEP 02 (2022) 173.

- ΔL=2 hyperon decays induced by Majorana neutrinos and doubly-charged scalars, G. Hernández-Tomé, G. López Castro, D. Portillo-Sánchez, arXiv: 2112.02227.

What is a second class current (SCC)?

- G-parity $G = Ce^{i\pi I_2}$.

$$G|\pi\rangle = -|\pi\rangle\,, \quad G|\eta\rangle = |\eta\rangle\,, \quad G|\rho\rangle = |\rho\rangle\,,$$
$$G|\omega\rangle = -|\omega\rangle\,, \quad G|a_0\rangle = -|a_0\rangle\,.$$

Allowed decays by G-parity

$\rho \to \pi\pi, \quad \omega \to 3\pi, \quad a_0 \to \eta\pi.$

Naturally suppresed by G-parity.

$\rho \to 3\pi, \eta\pi \quad \omega \to 2\pi, 4\pi, \quad a_0 \to 2\pi.$

- In 1958 S. Weinberg established a classification for non-strange weak (V-A) hadronic currents.

First Class Current (FCC)

$$J^{PG} = 0^{++}, 0^{--}, 1^{+-}, 1^{-+}.$$

Second Class Current (SCC)

$$J^{PG} = 0^{+-}, 0^{-+}, 1^{++}, 1^{--}.$$

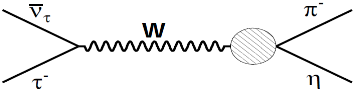
G-parity is not exact! broken by isospin non-conservation ⇒ hadronization of SM currents into states that mimic the effects of a **Genuine SCC**.

- ***For a genuine SCC we mean: effects of NP, for example, the ones induced by the exchange of charged Higgs or leptoquark bosons.***

- A clean test for a SCC is given by $\boxed{\tau \to \eta^{(\prime)}\pi^-\nu_\tau}$ C. Leroy and J. Pestieau, Phys. Lett. 72B, 398 (1978).

The G-parity of the system is -1, opposed to the vector current in the SM.

- *Note that* $\boxed{\tau \to \pi^-\pi^0\nu_\tau}$ *is a FCC. BR=* $\boxed{(25{,}50 \pm 0{,}10) \times 10^{-2}}$.



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Theoretical estimations [3, 4, 5, 6]

$$BR_{SM}\left(\tau \to \pi^- \eta \nu_\tau\right) \sim 10^{-5}$$
$$BR_{SM}\left(\tau \to \pi^- \eta' \nu_\tau\right) \sim 10^{-7} - 10^{-8}$$

Experimental Bounds

$\tau^- \to \eta\pi^- \upsilon_\tau$

BaBar	$9{,}9 \times 10^{-5}$	95 % C.L [7]
Belle	$7{,}3 \times 10^{-5}$	90 % C.L [8]
CLEO	$1{,}4 \times 10^{-4}$	95 % C.L [9]

$\tau^- \to \eta'\pi^- \upsilon_\tau$

BaBar	$7{,}2 \times 10^{-6}$	90 % C.L [10]
CLEO	$7{,}4 \times 10^{-6}$	90 % C.L [11]

- ***Let's think possitive! The discovery of $\tau \to \eta^{(\prime)}\pi\nu_\tau$ decays should be finally possible at Belle-II.***
- ***Since the discovery of genuine SCC would point to the existence of NP it is very important to have a good study of the possible backgrounds sources.***

One loop contribution to decay $\tau \to \eta^{(\prime)}\pi^-\nu_\tau$

PHYSICAL REVIEW D **96,** 053003 (2017)

G-parity breaking in $\tau^- \to \eta^{(\prime)}\pi^-\nu_\tau$ decays induced by the $\eta^{(\prime)}\gamma\gamma$ form factor

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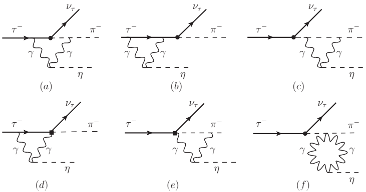
- Electromagnetic interactions also break isospin symmetry and will contribute to $\tau \to \eta^{(\prime)}\pi^-\nu_\tau$.



$$BR_{\eta}^{\gamma\gamma} = 5{,}2\cdot 10^{-13}\,, \quad BR_{\eta'}^{\gamma\gamma} = 0{,}8\cdot 10^{-16}.$$

- It is clear that current searches are not sensitive to effects of two-photon contributions in the $\tau^- \to \eta^{(\prime)}\pi^-\nu_\tau$ decays .

- We verified that:
  - These kinds of contributions are negligible for the $\pi^0\pi^-$ channel.
  - For the $\eta\pi^-$ channel, contribute -at most- with corrections at the 10^{-4} level.
  - And for $\eta'\pi^-$ their maximum relative size can vary between $3\cdot 10^{-4}$ and $3\cdot 10^{-5}$ depending on the value of the tree level BR.

Flavor violating leptonic decays of τ and μ leptons in the Standard Model with massive neutrinos

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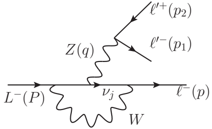
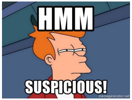
- cLFV in the SM+ν (Dirac):
  - $BR(L' \to \ell\gamma) \sim 10^{-54}$ T. P. Cheng and L. F. Li, Gauge Theory Of Elementary Particle Physics
  - $BR(Z \to \ell'\ell) < 10^{-54}$ J. I. Illana and T. Riemann, Phys. Rev. D 63, 053004 (2001)
  - $BR(h \to \ell'\ell) < 10^{-55}$ E. Arganda, A. M. Curiel, M. J. Herrero and D. Temes, Phys. Rev. D 71, 035011 (2005)
  - BR($\mu^\pm \to e^\pm e^\pm e^\mp$)$\sim 10^{-53}$

    ⋆ S. T. Petcov, Sov. J. Nucl. Phys. 25, 340 (1977).
  - BR($\tau^\pm \to \mu^\pm \ell^\pm \ell^\mp$)$> 10^{-14}$ (4×10^{-16}) † X. Y. Pham, Eur. Phys. J. C 8, 513 (1999).



$$\mathcal{M} \sim \sum_{j=1}^{3} U_{ej}^* U_{\mu j} \log\left(\frac{m_W^2}{m_j^2}\right)$$



- **If the prediction in † were right, there would be a difference of more than 30 orders of magnitude between $L^\pm \to \ell'^\pm\gamma$ and $L^\pm \to \ell'^\pm\ell^\pm\ell^\mp$.**
- **The amplitude won't vanish in the limit of massless neutrino.**
- **There would be no way to cure such infrared behavior.**

Z-Penguin contribution emission from internal neutrino line

- Relevant integral:

$$\Gamma_j^{\lambda} = \int \frac{d^4k}{(2\pi)^4} \frac{\gamma_\rho(1-\gamma_5)i\left[(\not{p}+\not{k})+m_j\right]\gamma^\lambda(1-\gamma_5)i\left[(\not{P}+\not{k})+m_j\right]\gamma_\sigma(1-\gamma_5)(-ig^{\rho\sigma})}{\left[(p+k)^2-m_j^2\right]\left[(P+k)^2-m_j^2\right]\left[k^2-m_W^2\right]}. \quad (1)$$

- Despite we agree with the previous expression reported in † in terms of the Feynman parameters integrals, we disagree with the approximation done in order to extract the relevant dependece on the neutrino mass.
- We highlight that we are studying a process where the lowest scale is the nuetrino mass and q^2 must be non-vanising.
- Take an expansion around $q^2 = 0$ modifies substantially the behavior of the original functions in the interesting physical region for the neutrino masses and, as a consequence, it gives rise to an incorrect infrared logarithmically divergent behavior.

Decay channel	Our Result
$\mu^- \to e^- e^+ e^-$	$7{,}4 \cdot 10^{-55}$
$\tau^- \to e^- e^+ e^-$	$3{,}2 \cdot 10^{-56}$
$\tau^- \to \mu^- \mu^+ \mu^-$	$6{,}4 \cdot 10^{-55}$
$\tau^- \to e^- \mu^+ \mu^-$	$2{,}1 \cdot 10^{-56}$
$\tau^- \to \mu^- e^+ e^-$	$5{,}2 \cdot 10^{-55}$

Effects of heavy Majorana neutrinos on lepton flavor violating processes

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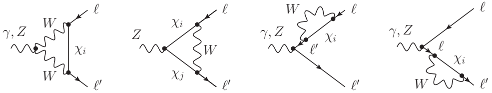
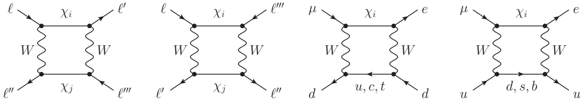


$\ell \to \ell'\gamma$, $\ell \to \ell'\ell''\ell'''$, $Z \to \ell\ell'$, $\mu \to e$ C transition in low-scale *seesaw* models



A minimal parametrization

- Consider five self-conjugate spinors $\chi_i = \chi_{Li} + \chi_{Li}^c$ (($i = 1, 2, 3$) 3 active neutrinos plus two sterile spinors of opposite lepton number ($i = 4, 5$).)
- 5 espinores autoconjugados $\chi_i = \chi_{Li} + \chi_{Li}^c$ ($i = 1, 2, 3$) [3 neutrinos activos + 2 neutrinos estériles de número leptónico opuesto ($i = 4, 5$).]

$$-\mathcal{L} \supset \sum_{i=1}^{3} y_i H \overline{L}_i P_R \chi_5 + M \overline{\chi}_4 P_R \chi_5 + \frac{1}{2} \mu \overline{\chi}_5 P_R \chi_5 + \text{h.c.} \quad (2)$$

- Once the Higgs gets a v.e.v. the Majorana mass matrix for the 5 flavors reads

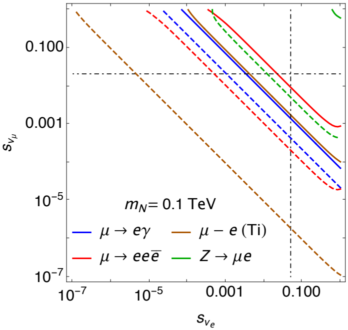
$$\mathcal{M} = \begin{pmatrix} 0 & 0 & 0 & 0 & m_1 \\ 0 & 0 & 0 & 0 & m_2 \\ 0 & 0 & 0 & 0 & m_3 \\ 0 & 0 & 0 & 0 & M \\ m_1 & m_2 & m_3 & M & \mu \end{pmatrix} \quad (3)$$

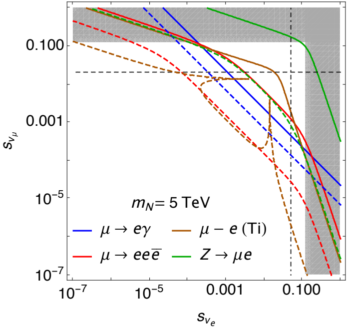
- m_1, m_2, m_3, M Dirac masses
- **μ breaks lepton number. When $\mu = 0$ both states form a heavy Dirac neutrino singlet of mass M.**

- A Dirac fermion has 4 four independent components.
- A Majorana fermion ($\psi^c \equiv \eta^* \psi$) has only two free components.

- We derived direct limits

Reaction	Present Limit		Future Sensitivity
$\mu \to e\gamma$	4.2×10^{-13}	90% C.L.	6×10^{-14}
$\mu \to ee\bar{e}$	1.0×10^{-12}	90% C.L.	10^{-16}
$Z \to \mu e$	7.3×10^{-7}	95% C.L.	10^{-10}
$\mu - e$ (Ti)	4.3×10^{-12}	90% C.L.	10^{-18}

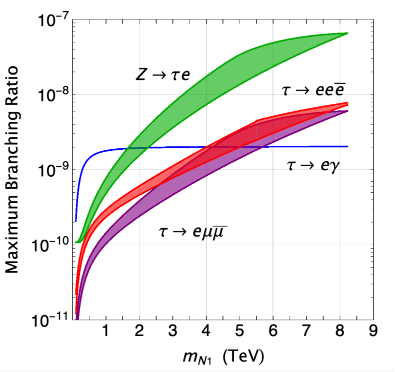


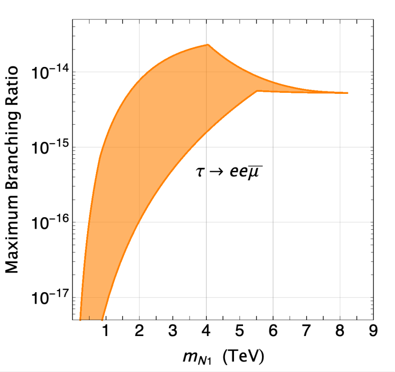


$m_{N_1} = m_{N_2} = m_N = 0{,}1,\ 5$ TeV and considering the current (solid lines) and future limits (dashed lines).

Phys. Rev. D 101 (2020) no.7, 075020 [arXiv:1912.13327]

- Maximal rates for $\tau - e$ consistent with current experimental limits from $\mu \to e\gamma$, $\mu \to 3e$, indirect and perturbative limits. The lower (upper) band corresponds to $r = 1$ ($r \gg 1$).





$$\mathrm{BR}(\tau \to e\gamma) = 2{,}0 \times 10^{-9},$$
$$\mathrm{BR}(Z \to \tau e) = 6{,}0 \times 10^{-8}.$$

$$\mathrm{BR}(\tau \to e e \bar{e}) = 7{,}3 \times 10^{-9},$$
$$\mathrm{BR}(\tau \to e \mu \bar{\mu}) = 6{,}0 \times 10^{-9},$$
$$\mathrm{BR}(\tau \to e e \bar{\mu}) = 2{,}3 \times 10^{-14}$$

ΔL=2 HYPERON DECAYS

ΔL=2 hyperon decays induced by Majorana neutrinos and doubly-charged scalars

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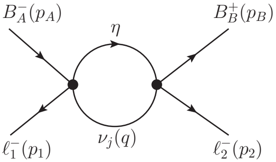
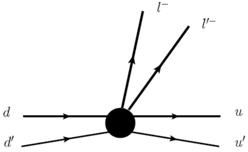




- One-loop mechanism (long distance effects). C. Barbero, GLC. y A. Mariano (2003) C. Barbero, L. F. Li, GLC. y A. Mariano (2007)
- Hadronic states as the relevant degrees of freedom.
- First aprox: constant transition matrix elements. (divergent behaviour).

$$BR(\Sigma^- \to pe^-e^-) \sim \mathcal{O}(10^{-33}).$$

- MIT bag model (Short distance effects). C. Barbero, L. F. Li, GLC. y A. Mariano (2013)
- Considering the most general 6-fermion effective lagrangian
- Considering reasonable values for the Wilson coefficients and the NP scale.

$$BR(\Sigma^- \to pe^-e^-) \sim O(10^{-23}).$$

One-loop mechanism

- First approx, hadronic matrix elements constants at $q^2 = 0$:

$$\langle B_B | j_\mu | B_f \rangle = \bar{u}_B \gamma_\mu \left(f_{fi}(0) + g_{fi}(0)\gamma_5 \right) u_i, \quad (4)$$

$\Rightarrow$ in this approx, the relevant one-loop functions are given by

$$C_{v0}^{\eta j} = i \frac{\kappa_{v_-}(0)}{16\pi^2} B_0(t, m_{\nu_j}^2, m_\eta^2), \quad (5)$$

$$C_{vA}^{\eta j} = -C_{v1}^{\eta j} = i \frac{\kappa_{v_+}(0)}{16\pi^2} \left[B_0(t, m_{\nu_j}^2, m_\eta^2) + B_1(t, m_{\nu_j}^2, m_\eta^2) \right], \quad (6)$$

with $t = (p_A - p_1)^2$, and

$$C_{a0}^{\eta j} = -i \frac{\kappa_{a_-}(0)}{16\pi^2} B_0(t, m_{\nu_j}^2, m_\eta^2), \quad (7)$$

$$C_{aA}^{\eta j} = -C_{a1}^{\eta j} = i \frac{\kappa_{v_+}(0)}{16\pi^2} \left[B_0(t, m_{\nu_j}^2, m_\eta^2) + B_1(t, m_{\nu_j}^2, m_\eta^2) \right], \quad (8)$$

Note that B_0 and B_1 are UV-divergent functions, a simple cut-off procedure was considered in C. Barbero, L. F. Li, GLC. y A. Mariano (2013).

One-loop mechanism

- A better approximation is to model the dependency on q^2 of the hadronic factors:
  - polar approx:

$$f_i(q^2) = f_i(0)\left(1 - \frac{q^2}{m_{f_i}^2}\right)^{-1}, \quad g_i(q^2) = g_i(0)\left(1 - \frac{q^2}{m_{g_i}^2}\right)^{-1}, \qquad (9)$$

$$m_{f_i} = 0{,}84/\sqrt{2}\ (0{,}97/\sqrt{2})\ \text{GeV}, \quad m_{g_i} = 1{,}08/\sqrt{2}\ (1{,}25/\sqrt{2})\ \text{GeV},$$

m_{f_i}, m_{g_i} regulator masses

- Under this approx, the relevant functions are given by:

$$\boxed{C_{v_r}^{\eta j} \sim \frac{i}{16\pi^2} F \cdot D_{\{0,1,2,3\}}(m_{h_A}, m_{h_B})}, \quad (v_r = v_0, v_1, v_2, v_A) \qquad (10)$$

- with F constant factors

$$F \equiv h_{A_\eta}(0) h_{B_\eta}(0) m_{h_A}^2 m_{h_B}^2, \quad (11)$$

($h \equiv f, g$ factores en la ec. 9).

- 4-points Pa-Ve functions Finite and well-defined

- No additional approximation in our computation

$$D_{\{0,1,2,3\}}(m_X, m_Y) \equiv D_{\{0,1,2,3\}}\left(t, m_A^2, s, m_2^2, m_1^2, m_B^2, m_{\nu_j}^2, m_\eta^2, m_X^2, m_Y^2\right)$$

One loop mechanism

- One-loop mechanism:

$$\mathcal{M} \sim G^2 \boxed{\sum_j m_{\nu_j} U_{\ell_1 j} U_{\ell_2 j} \cdot C^{\eta j}_{\{v,a\}_r}(m_{\nu_j})},$$

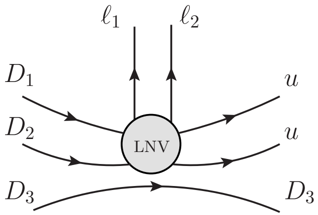
con$(v_r = v_0, v_1, v_2, v_A)$.

Current limits:

$$m_{ee} = 0{,}165\,\text{eV},$$
$$m_{e\mu} = 90\,\text{GeV},$$
$$m_{\mu\mu} = 480\,\text{GeV}.$$

Results:

Canal	Branching Ratio
	Mecanismo de lazo
$\Sigma^- \to \Sigma^+ ee$	1.6×10^{-41}
$\Sigma^- \to pee$	2.2×10^{-34}
$\Sigma^- \to p\mu\mu$	1.7×10^{-10}
$\Sigma^- \to p\mu e$	1.6×10^{-12}
$\Xi^- \to \Sigma^+ ee$	2.1×10^{-36}
$\Xi^- \to \Sigma^+ \mu e$	1.8×10^{-14}
$\Xi^- \to pee$	7.2×10^{-36}
$\Xi^- \to p\mu\mu$	2.5×10^{-11}
$\Xi^- \to p\mu e$	2.3×10^{-12}



Short range contributions:

'Contributions of heavy particles'

Short range contributions

- An appropiate framework to deal with the contributions of heavy particles is an effective field theory (EFT).

- The most general effective lagrangian describing 6-fermion operators is given by:

$$\mathcal{L}_{\text{eff}}^{\Delta \text{L}=2} = \frac{G_F^2}{\Lambda} \sum_{i,X,Y,Z} \left[C_i^{X,Y,Z}\right]_{\alpha\beta} \mathcal{O}_i^{X,Y,Z}, \tag{12}$$

the (dim=9) operators are classified as follows:

$$\begin{aligned}
\mathcal{O}_1^{XYZ} &= 4[\bar{u}_i P_X d_k][\bar{u}_j P_Y d_n](j_Z), \\
\mathcal{O}_2^{XYZ} &= 4[\bar{u}_i \sigma^{\mu\nu} P_X d_k][\bar{u}_j \sigma_{\mu\nu} P_Y d_n](j_Z), \\
\mathcal{O}_3^{XYZ} &= 4[\bar{u}_i \gamma^{\mu} P_X d_k][\bar{u}_j \gamma_{\mu} P_Y d_n](j_Z), \\
\mathcal{O}_4^{XYZ} &= 4[\bar{u}_i \gamma^{\mu} P_X d_k][\bar{u}_j \sigma_{\mu\nu} P_Y d_n](j_Z)^{\nu}, \\
\mathcal{O}_5^{XYZ} &= 4[\bar{u}_i \gamma^{\mu} P_X d_k][\bar{u}_j P_Y d_n](j_Z)_{\mu},
\end{aligned} \tag{13}$$

the leptonic part is given by

$$j_Z = \bar{\ell}_\alpha P_Z \ell_\beta^c, \quad j_Z^\nu = \bar{\ell}_\alpha \gamma^\nu P_Z \ell_\beta^c.$$

Neutrinos pesados

- Heavy neutrino constributions:

$$[C_3^{LLR}]_{\ell_1\ell_2} = -2M_{B_A} V_{uD} V_{uD'} \sum_{j=1}^{2} \frac{B_{\ell_1 N_j} B_{\ell_2 N_j}}{m_{N_j}},$$

$$= \boxed{2V_{uD} V_{uD'} s_{\nu_{\ell_1}} s_{\nu_{\ell_2}} \frac{M_{B_A}}{m_{N_1}} \frac{(r-1)}{(r+r^{1/2})}}.$$

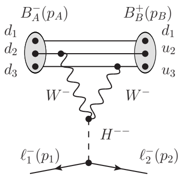
Taking the hadronic matrix elements for $\Sigma \to p\ell\ell'$ reported in previous computation using the so-called MIT bag model en C. Barbero, L. F. Li, GLC. y A. Mariano (2013)

$$BR(\Sigma^- \to pee) = \frac{[C_3^{LLR}]^2_{ee}}{M^2_{\Sigma^-}} (5{,}0 \times 10^{-14})\,\text{MeV}^2 = 4{,}90 \times 10^{-30},$$

$$BR(\Sigma^- \to pe\mu) = \frac{[C_3^{LLR}]^2_{e\mu}}{M^2_{\Sigma^-}} (4{,}52 \times 10^{-14})\,\text{MeV}^2 = 7{,}05 \times 10^{-31},$$

$$BR(\Sigma^- \to p\mu\mu) = \frac{[C_3^{LLR}]^2_{\mu\mu}}{M^2_{\Sigma^-}} (4{,}52 \times 10^{-15})\,\text{MeV}^2 = 1{,}13 \times 10^{-32}.$$

Doubly charged higgs contributions



- Doubly charged higgs contributions in the HTM J. Schechter, J.W.F. Valle (1980).
- Motivation: Seesaw type-II mechanism.

$$\Delta = \begin{pmatrix} \frac{1}{\sqrt{2}}\Delta^+ & \Delta^{++} \\ \Delta^0 & -\frac{1}{\sqrt{2}}\Delta^+ \end{pmatrix}.$$

$$\mathcal{L}_Y = h_{ij}\psi_i^T C i\sigma_2 \Delta \psi_j + \text{H.c.}$$

- Physical spectrum: two CP-even scalars H_1 y H_2, one CP-odd scalar A, two charged scalars $H^{\pm}$, and two doubly charged scalars $H^{\pm\pm}$.

$$\begin{aligned} i\mathcal{M} =& 4\sqrt{2}G^2 \frac{h_{\ell_1\ell_2} v_\Delta}{M^2_{H^{\pm\pm}}} X^{\mu\nu} g_{\mu\nu}\, \bar{u}(p_2)(1-\gamma_5)v(p_1), \\ \equiv& 8\sqrt{2}G^2 \frac{h_{\ell_1\ell_2} v_\Delta}{M^2_{H^{\pm\pm}}} \bar{u}(p_B)\,[A + B\gamma_5]\, u(p_A)\, (j_L^{\ell_2\ell_1}). \end{aligned}$$

- Wilson coefficient:

$$\boxed{[C_3^{LLL}]_{\ell_1\ell_2} = 8\sqrt{2} V_{uD} V_{uD'} M_{B_A} \frac{h_{\ell_1\ell_2} v_\Delta}{M^2_{H^{\pm\pm}}}.}$$

Doubly charged higgs contributions

- Limits on the HTM

$$\rho = M_W^2/M_Z^2 \cos^2\theta_W = \frac{1+2v_\Delta^2/v^2}{1+4v_\Delta^2/v^2}, \tag{14}$$

where $v = 246$ GeV is the v.e.v. associated to the scalar doublet in the SM. Taking the current limit $\rho^{\exp} = 1{,}00038(20)$ we obtain $v_\Delta \lesssim \mathcal{O}(1)$ GeV.

- Limits on the doubly charged scalars

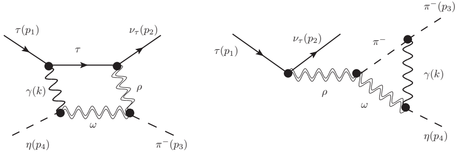
Process	Current data	Constrainsts [GeV^{-2}]
$\mu^- \to eee^+$	$< 1{,}0 \times 10^{-12}$	$\lvert h_{ee}^\dagger h_{e\mu}\rvert/M_{H^{\pm\pm}}^2 < 2{,}3 \times 10^{-12}$
$\mu \to e\gamma$	$< 4{,}2 \times 10^{-13}$	$\sum_{k=e,\mu,\tau} \lvert h_{ek}^\dagger h_{\mu k}\rvert/M_{H^{\pm\pm}}^2 < 2{,}7 \times 10^{-10}$
electron $g-2$	$< 5{,}2 \times 10^{-13}$	$\sum_{k=e,\mu,\tau} \lvert h_{ek}\rvert^2/M_{H^{\pm\pm}}^2 < 1{,}2 \times 10^{-4}$
muon $g-2$	$< 4{,}0 \times 10^{-9}$	$\sum_{k=e,\mu,\tau} \lvert h_{\mu k}\rvert^2/M_{H^{\pm\pm}}^2 < 1{,}7 \times 10^{-5}$
muonic oscillation	$< 8{,}2 \times 10^{-11}$	$\lvert h_{ee}^\dagger h_{\mu\mu}\rvert^2/M_{H^{\pm\pm}}^2 < 1{,}2 \times 10^{-7}$
$ee \to ee$ (LEP)	$\Lambda_{\rm eff} > 5{,}2$ TeV	$\lvert h_{ee}\rvert^2/M_{H^{\pm\pm}}^2 < 1{,}2 \times 10^{-7}$
$ee \to \mu\mu$ (LEP)	$\Lambda_{\rm eff} > 7{,}0$ TeV	$\lvert h_{\mu\mu}\rvert^2/M_{H^{\pm\pm}}^2 < 6{,}4 \times 10^{-8}$

- For $v_\Delta = 3$ GeV, $h_{mm} \simeq 0{,}1$ ($m = e, \mu$), and considering the limits from $\ell\ell \to \ell\ell$ ($\ell = e, \mu$) $\Rightarrow m_{H^{\pm\pm}} \gtrsim 395$ GeV. We obtain:

$$\begin{aligned} BR(\Sigma^- \to pee)_{HTM} &= 1{,}1 \times 10^{-30}, \\ BR(\Sigma^- \to pe\mu)_{HTM} &= 1{,}3 \times 10^{-39}, \\ BR(\Sigma^- \to p\mu\mu)_{HTM} &= 1{,}0 \times 10^{-31}. \end{aligned} \tag{15}$$

- Trabajo actual:

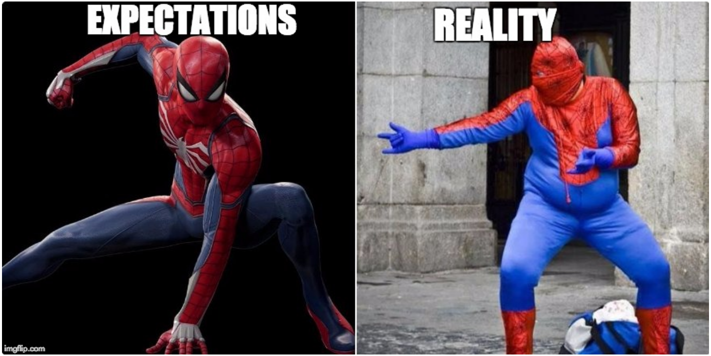
  - Codirección de tesis con Gabriel López de doctorado de Diego Portillo Sánchez. $\tau^- \to \eta\pi^-\nu_\tau$ induced by radiative corrections:



  - *Resonant Majorana effects in $\Delta L = 2$ hyperon decays* ($\Sigma^- \to n\pi^+e^-e^-$, $\Xi^- \to \Lambda\pi^+e^-e^-$) en colaboración con Gabriel López y Genaro Toledo.

  $*$ $H_2 \to H_1\gamma\gamma$ *in two Higgs doublet model* en colaboración con M. Arroyo Ureña y Pablo Roig.

Perspectivas y trabajo futuro



• Lograr mantenerme en el juego • Abierto a nuevas colaboraciones • Seguir explotando la experiencia adquirida en el cálculo de correcciones radiativas y el estudio de procesos raros • Eventualmente explorar nuevos territorios: neutrino and scalar portal, helicity amplitudes, etc.

Happy beerday!

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