EL SABOR DE LA FÍSICA

Taller en celebración del 60 aniversario de Gabriel López Castro

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OUTLINE

1. Recapitulación de Trabajo
   - Why Study Lepton Number Violating (LNV) Processes
   - Searches of $\Delta L = 2$ processes
   - Trabajos de Doctorado
2. Trabajo Actual
   - Test of LFU in $b \to c\tau\bar{\nu}_\tau$ decays
   - Test of LFU in leptonic Υ meson decays
   - Test of LFU in $b \to s\mu^+\mu^-$ decays
   - Nuestra contribución
   - Atomki anomaly (Berillium anomaly)
3. Visión de futuro en el campo

1. Recapitulación de Trabajo

Why Study Lepton Number Violating (LNV) Processes ?

- Establish nature of the neutrinos

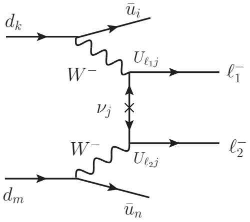
¿ **Dirac** $(\nu \neq \nu^c)$ o **Majorana** $(\nu = \nu^c)$?

$$-\mathcal{L}_Y = \underbrace{\bar{\mathsf{L}}_L Y_\nu \tilde{H} N_R}_{\textbf{Dirac Term}} + \underbrace{\bar{N}_R^c M_R N_R/2}_{\textbf{Majorana Term}} + h.c.$$

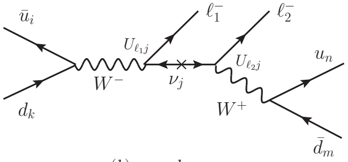
- Mechanism of neutrino masses generation
- Leptogenesis (Explain baryonic asymmetry of the Universe)

It is important to study all possible channels that may be sensitive to the effects of **LNV ($\Delta L = 2$) Processes**

Lepton-number-violating ($\Delta L = 2$) processes



$(a)\ canal - t$



$(b)\ canal - s$

- Light Majorana neutrinos

$$\langle m_\nu \rangle_{\ell_1 \ell_2} = \sum_j U_{\ell_1 j} U_{\ell_2 j}\, m_{\nu_j}$$

- Heavy Majorana neutrinos

$$\langle m_N^{-1} \rangle_{\ell_1 \ell_2} = \sum_k V_{\ell_1 k} V_{\ell_2 k} / m_{N_k}$$

- **Intermediate Majorana neutrinos (on-shell)**

$$\sim \sum_k V_{\ell_1 k} V_{\ell_2 k}\, m_{N_k} / \Gamma_{N_k}$$

Ranges of sterile neutrino masses

	N mass	ν masses	eV ν anomalies	BAU	DM	M_H stability	direct search	experiment
GUT see–saw	10^{10-16} GeV	YES	NO	YES	NO	NO	NO	–
EWSB	10^{2-3} GeV	YES	NO	YES	NO	YES	YES	LHC
ν MSM	keV – GeV	YES	NO	YES	YES	YES	YES	a'la CHARM
ν scale	eV	YES	YES	NO	NO	YES	YES	a'la LSND

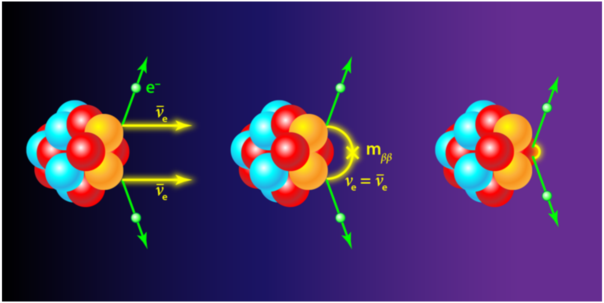
[Drewes, arXiv:1303.6912]

[de Gouvêa, arXiv:0706.1732]

Different mass scales are technically possible and worth exploring !

Neutrinoless double-β ($0\nu\beta\beta$) decay: ${}^{A}_{Z}X \to {}_{Z+2}^{\;\;A}Y + 2e^{-}$

The $0\nu\beta\beta$ nuclear decay is considered as the most attractive and sensitive way to prove that neutrinos are their own antiparticles (or not), i.e., elucidate if neutrinos are Majorana particles (or Dirac ones) .



Furry, Phys. Rev. 56, 1184 (1939).

Neutrinoless double-β ($0\nu\beta\beta$) decay: ${}^{A}_{Z}X \to {}_{Z+2}^{\;\;A}Y + 2e^-$

Isotope	Experiment	$T^{0\nu}_{1/2} >$ [years]	$\langle m_{\beta\beta}\rangle <$ [eV]
^{76}Ge	Heidelberg-Moscow (HdM)	$= 1.9 \times 10^{25}$	0.32
	GERDA Phase II	8×10^{25}	(0.12 - 0.26)
	MAJORANA	1.9×10^{25}	(0.24 - 0.52)
^{136}Xe	EXO-200	1.8×10^{25}	(0.14 - 0.38)
	KamLAND-Zen (KLZ)	1.9×10^{25}	(0.12 - 0.25)
^{130}Te	CUORE	1.5×10^{25}	(0.11 - 0.52)

Drawbacks:

- Very difficult to calculate due to the nature of many bodies of nuclear physics.
- Calculations by different models (methods) do not agree very well: Quasi-particle Random Phase Approximation (QRPA), Interacting Boson Model (IBM), Nuclear Shell Model (NSM), ...
- It would test the LNV ee sector.

Trabajo de Doctorado

PHYSICAL REVIEW D **84,** 096011 (2011)

Lepton number violation in top quark and neutral *B* meson decays

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Lepton number violation can be induced by Majorana neutrinos in four-body decays of the neutral B meson and the top quark. We study the effects of Majorana neutrinos in these $|\Delta L| = 2$ decays in a scenario where a single heavy neutrino can enhance the amplitude via the resonant mechanism. Using current bounds on heavy neutrino mixings, the most optimistic branching ratios turn out to be at the level of 10^{-6} for $\bar{B}^0 \to D^+ e^- e^- \pi^+$ and $t \to b l^+ l^+ W^-$ decays. Searches for these lepton number violation decays at future facilities can provide complementary constraints on masses and mixings of Majorana neutrinos.

DOI: 10.1103/PhysRevD.84.096011 PACS numbers: 11.30.Fs, 13.20.He, 14.60.Pq, 14.60.St

Trabajo de Doctorado

PHYSICAL REVIEW D **85,** 076006 (2012)

Lepton-number-violating four-body tau lepton decays

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(Received 21 February 2012; published 5 April 2012)

We study the four-body $\tau^{\pm} \to \nu_{\tau} l^{\pm} l^{\pm} X^{\mp}$ decays where $l = e$ or μ and $X = \pi, K, \rho$, and K^* mesons. These decay processes violate the total lepton number ($|\Delta L| = 2$) and can be induced by the exchange of Majorana neutrinos. We consider a scenario where these decays are dominated by the exchange of only one heavy neutrino, which produces an enhancement of the decay amplitude via the resonant mechanism. Searches for these novel decay channels with branching fractions sensitivities of $O(10^{-7})$ can provide constraints on the parameter space of the Majorana neutrinos, which are stronger than the ones obtained from $\Delta L = 2$ decays of charged pseudoscalar mesons.

DOI: 10.1103/PhysRevD.85.076006 PACS numbers: 11.30.Fs, 13.35.Dx, 14.60.Pq, 14.60.St

Trabajo de Doctorado

PHYSICAL REVIEW D **87,** 056005 (2013)

Lepton-number-violating decays of heavy flavors induced by doubly-charged Higgs boson

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(Received 12 December 2012; published 12 March 2013)

We study lepton-number-violating (LNV) decays of heavy flavors (τ lepton and top quark) induced by a doubly-charged Higgs boson in the Higgs triplet model. It is found that the branching fractions of LNV $\tau^- \to \ell^+ M_1^- M_2^-$ decays are highly suppressed compared with the current experimental limits. On the other hand, for LNV top-quark decays, the most optimistic branching ratios for $t \to b\ell^+\ell^+W^-$ turn out to be at the level of $\sim 10^{-7} - 10^{-8}$. The observation of these rare top-quark decays would be a clear signal of LNV processes, and their nonobservation would allow us to constrain the parameters of the Higgs triplet model.

DOI: 10.1103/PhysRevD.87.056005 PACS numbers: 11.30.Fs, 14.80.Fd, 13.35.Dx, 14.65.Ha

Trabajo de Doctorado

PHYSICAL REVIEW D **87,** 077901 (2013)

Bounding resonant Majorana neutrinos from four-body *B* and *D* decays

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(Received 6 February 2013; published 23 April 2013)

Searches of lepton-number violation in different processes are very useful to constrain the parameter space of Majorana neutrinos. Here we use available upper bounds on the branching fractions of $B^- \to D^0\pi^+\mu^-\mu^-$ and $D^0 \to (\pi^-\pi^-/K^-\pi^-)\mu^-\mu^-$ decays to derive constraints on the mass and mixings of Majorana neutrinos by assuming they are produced resonantly in these four-body decays. While the excluded region obtained from B^- decays are competitive with existing limits from three-body D^- and B^- decays, it is shown that experimental improvements on D^0 decays offer a good potential to provide similar results.

DOI: 10.1103/PhysRevD.87.077901 PACS numbers: 11.30.Fs, 13.20.Fc, 13.20.He, 14.60.St

Trabajo de Doctorado

PHYSICAL REVIEW D **89,** 093014 (2014)

Lepton pair emission in the top quark decay $t \to bW^+\ell^-\ell^+$

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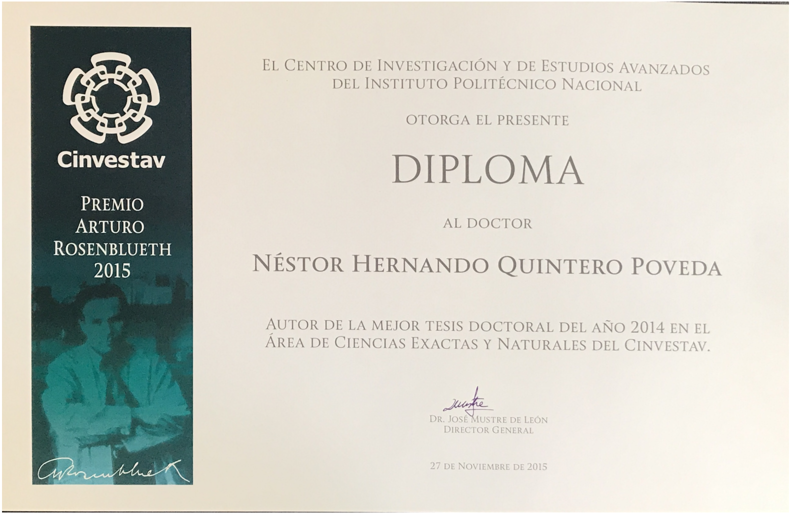
The heaviness of the top quark makes its two-body Cabibbo-favored decay mode $t \to bW^+$ to be dominant, at such a level that hardly any other decay mode reaches a detectable branching ratio within the Standard Model. Here we study the decay $t \to bW^+\ell^-\ell^+$ ($\ell = e, \mu, \tau$), which diverges for massless leptons, and it can reach a branching ratio $\sim\mathcal{O}(10^{-5} \sim 10^{-6})$ for reasonable values of the low energy cut in the lepton pair invariant mass. This rate surpasses almost any other rare decays such as $t \to cX$ ($X = \gamma, Z, g, H, W^+W^-$), and thus offers the possibility of being detectable. Furthermore, the estimate of this channel is relevant because it can mimic the signal arising from the lepton number violating decay $t \to bW^-\ell^+\ell^+$, when the W boson decays into lepton channels.

DOI: 10.1103/PhysRevD.89.093014 PACS numbers: 12.15.Ji, 14.60.-z, 14.65.Ha, 13.40.Ks

Trabajo de Doctorado



Después del Doctorado...

PHYSICAL REVIEW D **93,** 094026 (2016)

Sensitivity to Majorana neutrinos in $\Delta L = 2$ decays of B_c meson at LHCb

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The possible existence of Majorana neutrinos can be tested through the study of processes where the total lepton number L is violated by two units ($\Delta L = 2$). In this work, the production of an on-shell Majorana neutrino with a mass around ~0.2 GeV to a few GeV is studied in $\Delta L = 2$ decays of the B_c meson. We focus on the same-sign di-muon channels: three-body $B_c^- \to \pi^+\mu^-\mu^-$ and four-body $B_c^- \to J/\psi\pi^+\mu^-\mu^-$ and their experimental sensitivity at the LHCb. In both channels, we find that sensitivities on the branching fraction of the order $\lesssim 10^{-7}(10^{-8})$ might be accessible at the LHC run 2 (future LHC run 3), allowing us to set additional and complementary constraints on the parameter space associated with the mass and mixings of the Majorana neutrino. In particular, bounds can be obtained on the mixing $|V_{\mu N}|^2 \sim \mathcal{O}(10^{-5}\text{–}10^{-4})$ that are similar or better that the ones obtained from heavy meson $\Delta L = 2$ decays: $D_{(s)}^- \to \pi^+\mu^-\mu^-$ and $B^- \to \pi^+\mu^-\mu^-(D^0\pi^+\mu^-\mu^-)$.

DOI: 10.1103/PhysRevD.93.094026

Después del Doctorado...

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Constraints on lepton number violating short-range interactions from $|\Delta L| = 2$ processes

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A R T I C L E   I N F O

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A B S T R A C T

In this work we study the short-range contributions that induce effective lepton number violating (LNV) interactions. We obtain a full set of constraints on the effective short-range couplings from a large variety of low-energy $|\Delta L| = 2$ processes of pseudoscalar mesons K, D, D_s, B, and τ-lepton. These constraints provide complementary and additional information to the one obtained from the neutrinoless double-β ($0\nu\beta\beta$) decay. As expected, the bounds on electron–electron short-range couplings are the only ones that are strongly constrained by the $0\nu\beta\beta$ decay. Although weaker, LNV effective couplings with different flavors are not accessible to $0\nu\beta\beta$ decay and these can be probe by the $|\Delta L| = 2$ processes in consideration.

Después del Doctorado...

PHYSICAL REVIEW D **96**, 015039 (2017)

Exploring GeV-scale Majorana neutrinos in lepton-number-violating Λ_b^0 baryon decays

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In this work, the lepton-number-violating processes in $|\Delta L| = 2$ decays of Λ_b^0 baryon, $\Lambda_b^0 \to p\pi^+\mu^-\mu^-$ and $\Lambda_b^0 \to \Lambda_c^+\pi^+\mu^-\mu^-$, are investigated for the first time, via an intermediate on-shell Majorana neutrino N with a mass in the GeV scale. We explore the experimental sensitivity of these dimuon channels at the LHCb and CMS experiments, in which heavy neutrino lifetimes in the accessible ranges of $\tau_N = [1, 100, 1000]$ ps are considered. For a integrated luminosity collected of 10 and 50 fb^{-1} at the LHCb and 30, 300, and 3000 fb^{-1} at the CMS, we found significant sensitivity on branching fractions of the order $\mathrm{BR}(\Lambda_b^0 \to p\pi^+\mu^-\mu^-) \lesssim \mathcal{O}(10^{-9}\text{–}10^{-8})$ and $\mathrm{BR}(\Lambda_b^0 \to \Lambda_c^+\pi^+\mu^-\mu^-) \lesssim \mathcal{O}(10^{-8}\text{–}10^{-7})$. Exclusion regions on the parameter space $(m_N, |V_{\mu N}|^2)$ associated with the heavy neutrino are presented and compared with those from $K^- \to \pi^+\mu^-\mu^-$ (NA48/2) and $B^- \to \pi^+\mu^-\mu^-$ (LHCb) as well as by different search strategies such as NA3, CHARMII, NuTeV, Belle, and DELPHI.

DOI: 10.1103/PhysRevD.96.015039

Después del Doctorado...

PHYSICAL REVIEW D **97,** 075018 (2018)

Lepton-number violation in B_s meson decays induced by an on-shell Majorana neutrino

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Lepton-number violation can be induced by the exchange of an on-shell Majorana neutrino N in semileptonic $|\Delta L| = 2$ decays of the B_s meson, $B_s^0 \to P^- \pi^- \mu^+ \mu^+$ with $P = K, D_s$. We investigate the production of such a heavy sterile neutrino through these four-body $\mu^+\mu^+$ channels and explore the sensitivity that can be reached at the LHCb and CMS experiments. For heavy neutrino lifetimes of $\tau_N = [1, 100, 1000]$ ps and integrated luminosities collected of 10 and 50 fb^{-1} at the LHCb and 30, 300, and 3000 fb^{-1} at the CMS, we find a significant sensitivity on branching fractions of the orders $\mathrm{BR}(B_s^0 \to K^- \pi^- \mu^+ \mu^+) \lesssim \mathcal{O}(10^{-9}\text{–}10^{-8})$ and $\mathrm{BR}(B_s^0 \to D_s^- \pi^- \mu^+ \mu^+) \lesssim \mathcal{O}(10^{-8}\text{–}10^{-7})$. In the kinematically allowed mass ranges of $m_N \in [0.25, 4.77]$ GeV and $m_N \in [0.25, 3.29]$ GeV, respectively, we exclude regions on the parameter space $(m_N, |V_{\mu N}|^2)$ associated with the heavy neutrino, which could slightly improve the limits from $B^- \to \pi^+ \mu^- \mu^-$ (LHCb).

DOI: 10.1103/PhysRevD.97.075018

2. Trabajo Actual

Test of LFU in $b \to c\tau\bar{\nu}_\tau$ decays

Tests of **lepton flavor universality (LFU)** in B meson decays ($b \to c\tau\bar{\nu}_\tau$), performed by the BABAR, Belle and LHCb experiments, have shown consistent deviations from the SM predictions.

$$R(D^{(*)}) = \frac{\text{BR}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\text{BR}(B \to D^{(*)}\ell'\bar{\nu}_{\ell'})}, \quad (\ell' = e \text{ or } \mu).$$

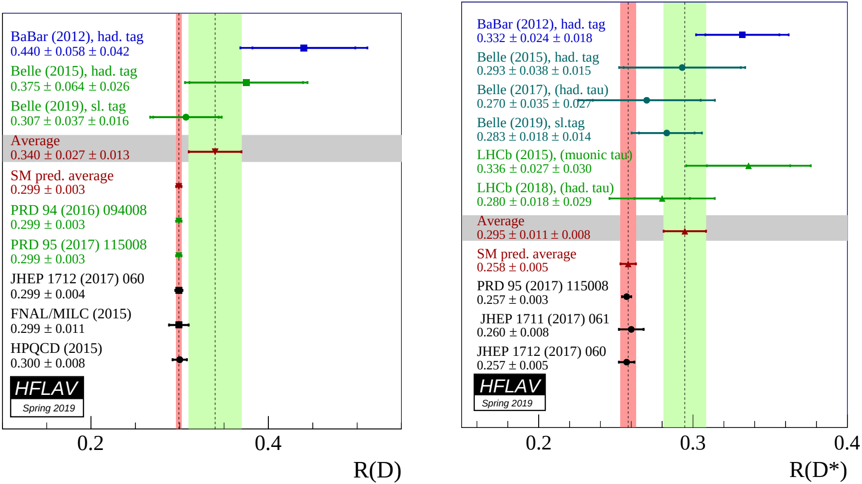
Observable	Measurement	Experiment	SM prediction	Tension
$R(D)$	$0.307 \pm 0.037 \pm 0.016$	Belle-2019	0.299 ± 0.003	0.2σ
	$0.340 \pm 0.027 \pm 0.013$	HFLAV-2019		1.4σ
$R(D^*)$	$0.283 \pm 0.018 \pm 0.014$	Belle-2019	0.258 ± 0.005	1.1σ
	$0.295 \pm 0.011 \pm 0.008$	HFLAV-2019		2.5σ

Experimental status on observables related to the charged transition $b \to c\tau\bar{\nu}_\tau$.

$R(D)$ and $R(D^*)$ anomalies!

Test of LFU in semileptonic B meson decays

Heavy Flavor Averaging Group (HFLAV) - 2019



Test of LFU in semileptonic B meson decays

In addition, the LHCb reported a measurement on $R(J/\psi) = \mathrm{BR}(B_c \to J/\psi\tau\bar{\nu}_\tau)/\mathrm{BR}(B_c \to J/\psi\mu\bar{\nu}_\mu)$, and the polarization observables τ lepton polarization $P_\tau(D^*)$ and. D^* longitudinal polarization $F_L(D^*)$ have been observed by the Belle experiment.

Observable	Measurement	Experiment	SM prediction	Tension
$R(D)$	$0.307 \pm 0.037 \pm 0.016$	Belle-2019	0.299 ± 0.003	0.2σ
	$0.340 \pm 0.027 \pm 0.013$	HFLAV-2019		1.4σ
$R(D^*)$	$0.283 \pm 0.018 \pm 0.014$	Belle-2019	0.258 ± 0.005	1.1σ
	$0.295 \pm 0.011 \pm 0.008$	HFLAV-2019		2.5σ
$R(J/\psi)$	$0.71 \pm 0.17 \pm 0.18$	LHCb-2018	0.283 ± 0.048	2.0σ
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$	Belle-2018	-0.497 ± 0.013	0.2σ
$F_L(D^*)$	$0.60 \pm 0.08 \pm 0.035$	Belle-2019	0.46 ± 0.04	1.6σ
$R(X_c)$	0.223 ± 0.030	PDG	0.216 ± 0.003	0.2σ
$R(\Lambda_c)$	0.242 ± 0.076	LHCb-2022	0.324 ± 0.004	1.2σ
$B_c^- \to \tau^-\bar{\nu}_\tau$	$< 10\,\%$		$(2.16 \pm 0.16)\,\%$	

Experimental status on observables related to the charged transition $b \to c\tau\bar{\nu}_\tau$.

charged-current $b \to c\tau\bar{\nu}_\tau$ anomalies!

Test of LFU in leptonic Υ meson decays

- LFU can also be tested through the ratio of leptonic decays of bottomonium meson $\Upsilon(nS)$ [Aloni, Efrati, Grossman, & Nir, 1702.07356].

$$R_{\Upsilon(nS)} \equiv \frac{\mathrm{BR}(\Upsilon(nS) \to \tau^+\tau^-)}{\mathrm{BR}(\Upsilon(nS) \to \ell^+\ell^-)}, \quad (n = 1, 2, 3)$$

Observable	Measurement	Experiment	SM prediction	Tension
$R_{\Upsilon(1S)}$	$1.005 \pm 0.013 \pm 0.022$	BABAR-2010	0.9924 $\pm\, \mathcal{O}(10^{-5})$	0.5σ
$R_{\Upsilon(2S)}$	$1.04 \pm 0.04 \pm 0.05$	CLEO-2007	0.9940 $\pm\, \mathcal{O}(10^{-5})$	0.8σ
$R_{\Upsilon(3S)}$	$1.05 \pm 0.08 \pm 0.05$	CLEO-2007	0.9948 $\pm\, \mathcal{O}(10^{-5})$	0.6σ
	$0.966 \pm 0.008 \pm 0.014$	BABAR-2020		1.8σ
	0.968 ± 0.016	Average		1.7σ

Experimental status on observables related to the neutral transition $b\bar{b} \to \tau^+\tau^-$.

- New physics scenarios aiming to provide an explanation to the LFU violation anomalies in $b \to c\tau\bar{\nu}_\tau$ decays also induce effects in the neutral-current $b\bar{b} \to \tau^+\tau^-$ transition [Faroughy, Greljo, & Kamenik, 1609.07138; Aloni, Efrati, Grossman, & Nir, 1702.07356].

Test of LFU in $b \to s\mu^+\mu^-$ decays

Experimental measurements related to the neutral-current transition $b \to s\mu^+\mu^-$ show deviations respect with the Standard Model (SM) predictions. The ratio of semileptonic decay channels,

$$R_{K^{(*)}} = \frac{\mathrm{BR}(B \to K^{(*)}\mu^+\mu^-)}{\mathrm{BR}(B \to K^{(*)}e^+e^-)},$$

provides a test of μ/e lepton flavor universality (LFU) in different dilepton mass-squared range q^2.

- The ratio R_K was first reported in 2014 by the LHCb collaboration **[arXiv:1406.6482]**,

  $$R_K^{\mathrm{LHCb-14}} = 0.745^{+0.090}_{-0.074} \pm 0.036, \quad \text{for } q^2 \in [1.0, 6.0]\ \mathrm{GeV}^2,$$

  which deviates from the SM prediction of $R_K^{\mathrm{SM}} \approx 1$ at the level of 2.6σ.

- Recently, the LHCb has released an updated measurement on R_K **[arXiv:2103.11769]**

  $$R_K^{\mathrm{LHCb-21}} = 0.846^{+0.044}_{-0.041}, \quad \text{for } q^2 \in [1.1, 6.0]\ \mathrm{GeV}^2,$$

  which is 3.1σ away from the SM predicition.

$b \to s\mu^+\mu^-$ anomalies!

Test of LFU in $b \to s\mu^+\mu^-$ decays

- In 2017, the flavor ratio R_{K^*} was measured by the LHCb Collaboration in the low and central q^2 bins **[arXiv:1705.05802]**,

$$R_{K^*}^{\rm LHCb-17} = \begin{cases} 0.66^{+0.11}_{-0.07} \pm 0.03, & \text{for } q^2 \in [0.045, 1.1] \ {\rm GeV}^2, \\ 0.69^{+0.11}_{-0.07} \pm 0.05, & \text{for } q^2 \in [1.1, 6.0] \ {\rm GeV}^2, \end{cases}$$

  respectively. These measurements differ from the SM in the two q^2 regions by $\sim 2.3\sigma$ and $\sim 2.5\sigma$, respectively.
- These discrepancies are reinforced by some anomalous observables (such as angular observables and differential branching fraction) related with $B \to K^*\mu^+\mu^-$ and $B_s \to \phi\mu^+\mu^-$ decays

$b \to s\mu^+\mu^-$ **anomalies!**

NP explanations to the B meson anomalies.

Global analyses

- The global analyses of $b \to s\mu^+\mu^-$ data suggest various new physics solutions [Altmannshofer and Straub, 2103.13370; Carvunis et al 2102.13390; Alguero et al 2104.08921; Geng et al 2103.12738].
- Considering one NP operator or two related operators at a time and assuming new physics only in the muon sector, the $\mathcal{O}_9 = (\bar{s}P_L\gamma_\mu b)(\bar{\mu}\gamma^\mu\mu)$ **operator** as well as a combination of $\mathcal{O}_9$ and $\mathcal{O}_9 = (\bar{s}P_L\gamma_\mu b)(\bar{\mu}\gamma^\mu\gamma_5\mu)$ with $C_9 = -C_{10}$ can account for all $b \to s\mu^+\mu^-$ data.
- These model independent solutions can be realized in several NP models.
- NP arising from **LH vector** C_{V_L} associated with the **operator** $(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau)$ is a preferred solution to address the anomalies, providing a **good fit to the data.**

Murgui, Peñuelas, Jung & Pich, 1904.09311; Mandal, Murgui, Peñuelas, & Pich, 2004.06726; Shi *et al*, 1905.08498; Blanke *et al*, 1905.08253; Bhardam & Ghosh, 1904.10432

Nuestra contribución

J. D. Gómez, NQ and E. Rojas, PRD **100**, 093003 (2019) [arXiv:1907.08357 [hep-ph]].

PHYSICAL REVIEW D **100**, 093003 (2019)

Charged current $b \to c\tau\bar{\nu}_\tau$ anomalies in a general W' boson scenario

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Very recent experimental information obtained from the Belle experiment, along with that accumulated by the *BABAR* and LHCb experiments, has shown the existence of anomalies in the ratios $R(D)$ and $R(D^*)$ associated with the charged-current transition $b \to c\tau\bar{\nu}_\tau$. Although the Belle measurements are in agreement with standard model (SM) predictions, the new experimental world averages still exhibit a tension. In addition, the D^* longitudinal polarization $F_L(D^*)$ related with the channel $B \to D^*\tau\bar{\nu}_\tau$ observed by the Belle Collaboration and the ratio $R(J/\psi)$ measured by the LHCb Collaboration also show discrepancies with their corresponding SM estimations. We present a model-independent study based on the most general effective Lagrangian that yields a tree-level effective contribution to the transition $b \to c\tau\bar{\nu}_\tau$ induced by a general W' boson. Instead of considering any specific new physics (NP) realization, we perform an analysis by considering all of the different chiral charges to the charm-bottom and $\tau - \nu_\tau$ interaction terms with a charged W' boson that explain the anomalies. We present a phenomenological study of parameter space allowed by the new experimental $b \to c\tau\bar{\nu}_\tau$ data and with the mono-tau signature $pp \to \tau_h X + \text{MET}$ at the LHC. For comparison, we include some of the W' boson NP realizations that have already been studied in the literature.

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Nuestra contribución

J. Cardozo, J. H. Muñoz, N. Q. and E. Rojas, J. Phys. G **48**, no.3, 035001 (2021) [arXiv:2006.07751 [hep-ph]].

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **48** (2021) 035001 (27pp) — https://doi.org/10.1088/1361-6471/abc865

Analysing the charged scalar boson contribution to the charged-current *B* meson anomalies

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Nuestra contribución

C. H. García-Duque, J. H. Muñoz, NQ and E. Rojas, PRD **103**, 073003 (2021) [arXiv:2103.00344 [hep-ph]]

PHYSICAL REVIEW D **103**, 073003 (2021)

Extra gauge bosons and lepton flavor universality violation in Υ and B meson decays

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Lepton flavor universality can be tested through the ratio of semileptonic B meson decays and leptonic Υ meson decays, with $\Upsilon \equiv \Upsilon(nS)$ $(n = 1, 2, 3)$. For the charged-current transitions $b \to c\tau\bar{\nu}_\tau$, discrepancies between the experiment and the Standard Model (SM) have been observed in recent years by different flavor facilities such as *BABAR*, Belle, and LHCb. While for the neutral-current transitions $b\bar{b} \to \tau\bar{\tau}$, the *BABAR* experiment reported recently a new measurement of leptonic decay ratio $R_{\Upsilon(3S)} = \mathrm{BR}(\Upsilon(3S) \to \tau^+\tau^-)/\mathrm{BR}(\Upsilon(3S) \to \mu^+\mu^-)$, showing an agreement with the SM at the 1.8σ level. In light of this new *BABAR* result and regarding the connection between new physics (NP) interpretations to the charged-current $b \to c\tau\bar{\nu}_\tau$ anomalies and neutral-current $b\bar{b} \to \tau\bar{\tau}$ processes, in this study, we revisit the NP consequences of this measurement within a simplified model with extra massive gauge bosons that coupled predominantly to left-handed leptons of the third generation. We show that the *BABAR* measurement of $R_{\Upsilon(3S)}$ cannot easily be accommodated (within its experimental 1σ range) together with the other $b \to c\tau\bar{\nu}_\tau$ data, hinting toward a new anomalous observable.

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Nuestra contribución

J. M. Cabarcas, J. H. Muñoz, NQ and E. Rojas, 2203.14172 [hep-ph]

Triplet vector boson model explanation to the B meson anomalies: An updated view and perspectives

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The triplet vector boson (TVB) is a simplified new physics model involving massive vector bosons transforming as a weak triplet vector, which it has been proposed as a combined explanation to the anomalous $b \to s\mu^+\mu^-$ and $b \to c\tau\bar{\nu}_\tau$ data (the so-called B meson anomalies). In this work, we carry out an updated view of the TVB model, including the Belle II perspectives. We perform a global fit to explore the allowed parameter space by the most current $b \to s\mu^+\mu^-$ and $b \to c\tau\bar{\nu}_\tau$ data, by considering all relevant low-energy flavor observables. Our results are confronted with the most recent LHC constraints. We also incorporate in our study the first measurement on the ratio $R(\Lambda_c) = \text{BR}(\Lambda_b \to \Lambda_c\tau\bar{\nu}_\tau)/\text{BR}(\Lambda_b \to \Lambda_c\mu\bar{\nu}_\mu)$ very recently obtained by LHCb. In particular, we show that the TVB model can provide an explanation to the B meson anomalies; however, this framework is in strong tension with LHC bounds. In respect to future flavor measurements at Belle II, our results suggest that a small new physics window would be allow to solely explain the $b \to c\tau\bar{\nu}_\tau$ data in agreement with LHC constraints. Furthermore, the implications of our phenomenological analysis of the TVB model to some known flavor parametrizations are also discussed.

U_1 leptoquark model

- The interaction of the $SU(2)_L$ **singlet vector leptoquark** $U_1 \equiv U_1 \sim (\mathbf{3}, \mathbf{1}, 2/3)$ with the SM fermions can written as [Angelescu *et al*, 1808.08179; 2103.12504]

$$\Delta\mathcal{L}_{U_1} = (x_L^{ij}\ \bar{Q}_{iL}\gamma_\mu L_{jL} + x_R^{ij}\ \bar{d}_{iR}\gamma_\mu \ell_{jR})U_1^\mu,$$

  where quark-lepton flavor couplings x_L and x_R are (in general) complex 3×3 matrices,Q_L and L_L are the LH quark and lepton doublets.

- After integrating out the vector leptoquark U_1, the Lagrangian $\Delta\mathcal{L}_{U_1}$ can generate tree-level contributions to **neutral-current** $b \to s\mu^+\mu^-$ and **charged-current** $b \to c\tau^-\bar{\nu}_\tau$ transitions, as well as **LFV decays** ($B^+ \to K^+\mu^\pm\tau^\mp$, $B_s \to \mu^\pm\tau^\mp$, $\tau \to \mu\phi$, $\Upsilon(nS) \to \mu^\pm\tau^\mp$), and **rare B decays** ($B \to K\tau^+\tau^-, B_s \to \tau^+\tau^-$).

- We will consider the flavor structure

$$x_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & x_L^{s\mu} & x_L^{s\tau} \\ 0 & x_L^{b\mu} & x_L^{b\tau} \end{pmatrix}, \quad x_R = 0.$$

  We neglect RH contributions for simplicity. This is the so-called *minimal U_1 model*. [Angelescu *et al*, 1808.08179; 2103.12504].

Atomki anomaly (Berillium anomaly)

PRL **116,** 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

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(Received 7 April 2015; published 26 January 2016)

Electron-positron angular correlations were measured for the isovector magnetic dipole 17.6 MeV ($J^\pi = 1^+$, $T = 1$) state → ground state ($J^\pi = 0^+$, $T = 0$) and the isoscalar magnetic dipole 18.15 MeV ($J^\pi = 1^+$, $T = 0$) state → ground state transitions in ^{8}Be. Significant enhancement relative to the internal pair creation was observed at large angles in the angular correlation for the isoscalar transition with a confidence level of $> 5\sigma$. This observation could possibly be due to nuclear reaction interference effects or might indicate that, in an intermediate step, a neutral isoscalar particle with a mass of $16.70 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})$ MeV$/c^2$ and $J^\pi = 1^+$ was created.

Krasznahorkay and collegues of the Institute of Nuclear Research (Atomki) in Hungary reported the existence of a **new light boson** only 34 times heavier than the electron **[PRL 116, 042501 (2016)]**.

$X17$ boson interpretation to the Atomki anomaly

PRL **117,** 071803 (2016) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2016

Protophobic Fifth-Force Interpretation of the Observed Anomaly in ^{8}Be Nuclear Transitions

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(Received 3 May 2016; published 11 August 2016)

Recently a 6.8σ anomaly has been reported in the opening angle and invariant mass distributions of e^+e^- pairs produced in ^{8}Be nuclear transitions. The data are explained by a 17 MeV vector gauge boson X that is produced in the decay of an excited state to the ground state, $^8\text{Be}^* \to {}^8\text{Be}\,X$, and then decays through $X \to e^+e^-$. The X boson mediates a fifth force with a characteristic range of 12 fm and has millicharged couplings to up and down quarks and electrons, and a proton coupling that is suppressed relative to neutrons. The protophobic X boson may also alleviate the current 3.6σ discrepancy between the predicted and measured values of the muon's anomalous magnetic moment.

[Feng et al, PRL 117, 071803 (2016)]

- The 6.8σ anomaly in excited ^8Be nuclear decays via internal pair creation is fit well by a new particle interpretation.
- A **17 MeV protophobic gauge boson ($X17$)** provides a particle physics explanation of the anomaly consistent with all existing constraints.

$X17$ boson interpretation to the Atomki anomaly

A new anomaly observed in ^{4}He supports the existence of the hypothetical X17 particle

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Energy-sum and angular correlation spectra of e^+e^- pairs produced in the ^{3}H(p,γ)^{4}He nuclear reaction have been studied at E_p=510, 610 and 900 keV proton energies. The main features of the spectra can be understood by taking into account the internal and external pair creations following the direct proton radiative capture by ^{3}H. However, these processes cannot account for the observed peak around 115° in the angular correlation spectra. This anomalous excess of e^+e^- pairs can be described by the creation and subsequent decay of a light particle during the direct capture process. The derived mass of the particle is $m_X c^2$=16.94±0.12($stat$) ± 0.21($syst$) MeV. According to the mass and branching ratio ($B_x = 5.1(13) \times 10^{-6}$), this is likely the same X17 particle, which we recently suggested [Phys. Rev. Lett. 116, 052501 (2016)] for describing the anomaly observed in the decay of ^{8}Be.

[Krasznahorkay et al, 2104.10075 [nucl-ex]]

Lepton pair decays of heavy mesons $H^* \to He^+e^-$

PHYSICAL REVIEW D **103,** 093002 (2021)

Tests of the Atomki anomaly in lepton pair decays of heavy mesons

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The anomalies recently reported in lepton pair transitions of $^8Be^*$ and ^4He nuclei may be attributed to the existence of a feebly interacting light vector boson $X17$. We study the effects of this hypothetic particle in the semileptonic $H^* \to He^+e^-$ decays (H a $Q\bar{q}$ meson) in the framework of the HQET + VMD model. Using current bounds and the universality assumption of the $X17$ boson to quarks, we find that decays of D^{*+} and D_s^{*+} mesons can be importantly enhanced relative to the dominant photon-mediated contributions. Dedicated experimental searches at current heavy meson factories may confirm the existence of this light boson or set stronger bounds of their couplings to ordinary matter.

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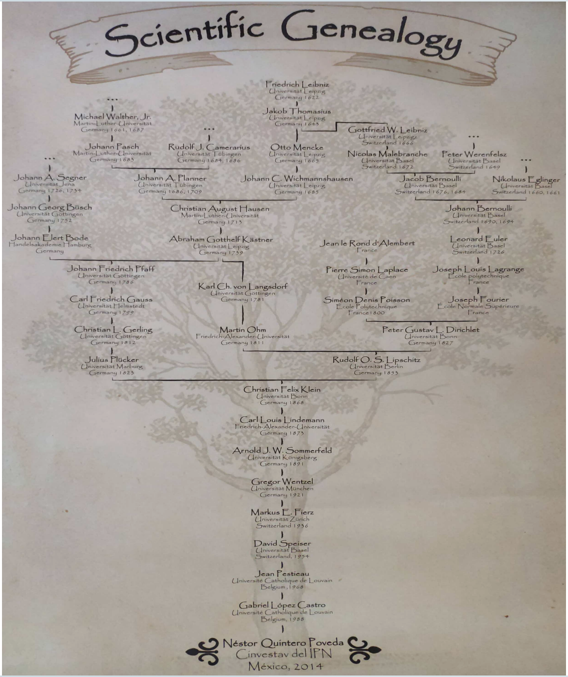
3. Visión de futuro en el campo

Visión de futuro en el campo

- **¿ Dirac o Majorana ?** $\rightarrow$ Observation of $\Delta L = 2$ decays will establish the Majorana nature of neutrinos.
- Dedicated experimental searches at current heavy meson factories (Belle II, LHCb, BESIII) may confirm the existence of this light boson or set stronger bounds of their couplings to quarks.
- Simultaneous explanation of the B meson anomalies ($b \to c\tau\bar{\nu}_\tau$ and $b \to s\mu^+\mu^-$ data).
- Future measurements from Belle II (as well as LHCb) will be a matter of importance.
- **Long live the anomalies !**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GRACIAS !