

# The lepton flavor universality violation in $\Upsilon$ and B meson decays and the $W'$ -triplet boson model

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## 1. Introduction: LFUV and W'-model

We can test the **Lepton Flavor Universality** (LFU), by studying semi-leptonic or leptonic decays, such as the  $b \rightarrow cl\bar{\nu}$  and  $b\bar{b} \rightarrow l\bar{l}$  processes.

Hints of **LFU-Violation** in the measurements of the ratio of semileptonic  $B$  meson decays [1]:

$$R(M) = \frac{Br(B \rightarrow M\tau\bar{\nu}_\tau)}{Br(B \rightarrow Ml\bar{\nu}_l)},$$

where,

$$l = e, \mu$$

$$M = D, D^*(\bar{q}c)$$

Different experimental facilities observed an excess of the a  $\tau$ -lepton on  $b \rightarrow cl\bar{\nu}$  processes.

[1] A. Greljo, G. Isidori, and D. Marzocca, *On the breaking of lepton flavor universality in B decays*, J. High Energy Phys. 07 (2015) [arXiv:1506.01705]

[2] D. A. Faroughy, A. Greljo, and J. F. Kamenik, *Confronting lepton flavor universality violation in B decays with high-pT tau lepton searches at LHC*, Phys. Lett. B 764, 126 (2017). [arXiv:1609.07138]

So, we choose an **extension** of the SM that is a color-neutral real  $SU(2)_L$  triplet of massive **vectors**  $W'$  and  $Z'$  that coupled predominantly to **left-handed fermions** from the third generation.

The **Lagrangian** that describes the interactions between fermions and the new vector bosons, in the interaction basis, is [2]:

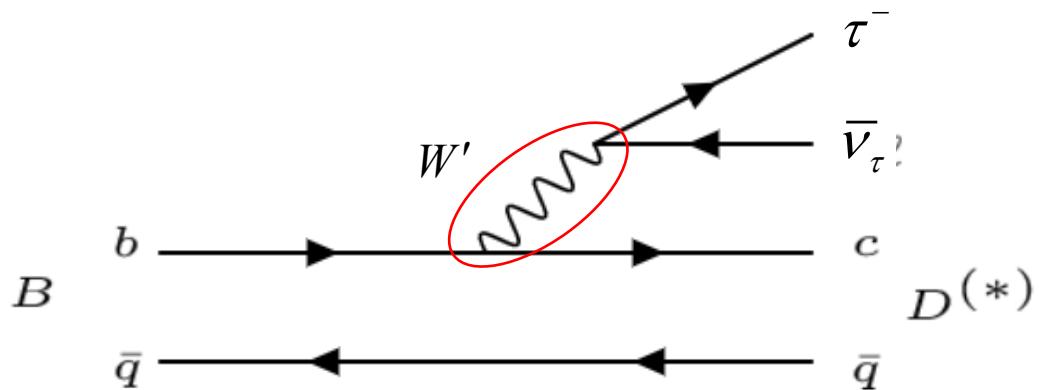
$$\mathcal{L}_{W'+Z'} = \textcolor{red}{g_b} \bar{Q}_3 \frac{\sigma_a}{2} \gamma^\mu W_\mu^a Q_3 + \textcolor{blue}{g_\tau} \bar{L}_3 \frac{\sigma_a}{2} \gamma^\mu W_\mu^a L_3$$

The mass of the new bosons has been taken as  $M_{W'}=M_{Z'}=1\text{TeV}$ .

## 2. W' Bosons Model: Charged and Neutral Decays

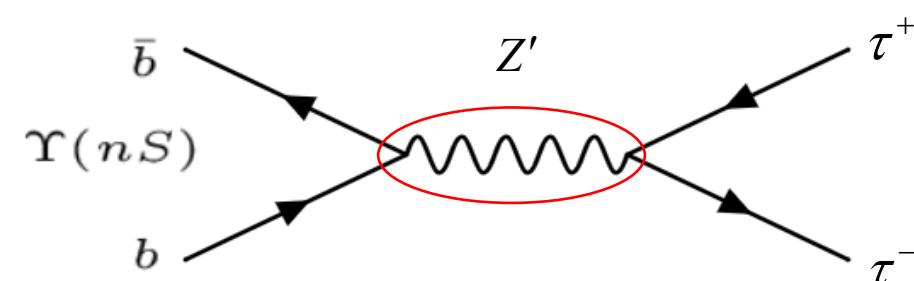
**Charged Current:** Semileptonic decay [1]

$$B^- \rightarrow D^0 \tau^- \bar{\nu}_\tau, \quad b \rightarrow c \ell \bar{\nu}_\ell, \quad \ell = e, \mu, \tau$$



**Neutral Current:** Leptonic decay [1]

$$\Upsilon(nS) \rightarrow \tau^- \tau^+, \quad b \bar{b} \rightarrow \ell \bar{\ell}, \quad \ell = e, \mu, \tau$$



$$\mathcal{L}_{CC} = -\frac{g_b g_\tau}{2M_{W'}^2} V_{cb} (\bar{c} \gamma^\mu P_L b) (\bar{\tau} \gamma^\mu P_L \nu_\tau) + H.c.$$

$$\mathcal{L}_{NC} = -\frac{g_b g_\tau}{4M_{W'}^2} V_{cb} (\bar{b} \gamma_\mu P_L b) (\bar{\tau} \gamma^\mu P_L \tau)$$

[1] A. Greljo, G. Isidori, and D. Marzocca, *On the breaking of lepton flavor universality in B decays*, J. High Energy Phys. 07 (2015) [arXiv:1506.01705]

### 3. $R(M)$ Anomalies: Observables

$b \rightarrow c\ell \bar{\nu}_\ell$

Observable	Experimental measure	SM Prediction	References
$R(D^*)$	$0.295 \pm 0.011 \pm 0.008$	$0.258 \pm 0.005$	2019[1]
$R(D)$	$0.340 \pm 0.027 \pm 0.013$	$0.299 \pm 0.003$	2019[1]
$R(J/\psi)$	$0.71 \pm 0.17 \pm 0.18$	$0.283 \pm 0.048$	2018[2], 2018[3]
$R(X_c)$	$0.223 \pm 0.030$	$0.216 \pm 0.003$	2019[4]
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$	$-0.497 \pm 0.013$	2017[5], 2013[6]
$F_L(D^*)$	$0.60 \pm 0.08 \pm 0.04$	$0.216 \pm 0.003$	2019[7], 2017[8]
$\text{BR}(B_c \rightarrow \tau\nu)$	$\lesssim 10\%$		2017[9]

$b\bar{b} \rightarrow \ell\bar{\ell}$

Observable	Experimental measure	SM Prediction	References
$R(\Upsilon(1S))$	$1.005 \pm 0.013 \pm 0.022$	$0.9924 \pm 10^{-5}$	2010 [10,11]
$R(\Upsilon(2S))$	$1.04 \pm 0.04 \pm 0.05$	$0.9940 \pm 10^{-5}$	2007 [12,11]
$R(\Upsilon(3S))$	$1.05 \pm 0.08 \pm 0.05$	$0.9948 \pm 10^{-5}$	2007 [12,11]
$R(\Upsilon(3S))$ 2020	$0.966 \pm 0.008 \pm 0.014$	same	2020 [13]
$R(\Upsilon(3S))$ comb	$0.968 \pm 0.016$	same	

[1-13] List of references can be found in the slide number 7.

$$C_{VLL}^{bc\tau\nu} = \frac{\sqrt{2}}{4G_F} \frac{g_b g_\tau}{M_W^2}.$$

$$C_{VLL}^{bb\tau\tau} = \frac{g_b g_\tau}{4M_W^2}.$$

## 4. Phenomenological Study: Chi-squared Analysis

Setting  $M_W = M_Z = 1 \text{ TeV}$ , and using:

$$\text{pull}_{\text{SM}} = \sqrt{\chi_{\text{SM}}^2 - \chi_{\min}^2}$$

Best Fit Points,  $\chi_{\min}^2/N_{dof}$ , p-value and  $\text{Pull}_{\text{SM}}$ :

Dataset	$g_b$	$g_\tau$	$\chi_{\min}^2/N_{dof}$	p-value [%]	$\text{Pull}_{\text{SM}}$
$b \rightarrow c\tau\nu$	2.99	1.54	1.04	39.0	3.72
$b \rightarrow c\tau\nu + R(\gamma)2010$	3.05	1.52	0.79	61.3	3.75
$b \rightarrow c\tau\nu + R(\gamma)2020$	3.27	1.39	1.20	29.3	3.68
$b \rightarrow c\tau\nu + R(\gamma)\text{combined}$	3.05	1.52	1.11	35.3	3.68

**Dataset 1:**  $b \rightarrow c\tau\nu$ :

$R(D) + R(D^*) + R(J/\psi) + R(X_c) + P_\tau(D^*) + F_L(D^*) + \text{BR}(B_c \rightarrow \tau\nu)$ ,  $N_{dof}=5$

**Dataset 2:**  $b \rightarrow c\tau\nu + R(\gamma)2010$  :

$R(D) + R(D^*) + R(J/\psi) + R(X_c) + P_\tau(D^*) + F_L(D^*) + \text{BR}(B_c \rightarrow \tau\nu) + R(\gamma(1S)) + R(\gamma(2S)) + R(\gamma(3S))$  2010,  $N_{dof}=8$

**Dataset 3:**  $b \rightarrow c\tau\nu + R(\gamma)2020$  :

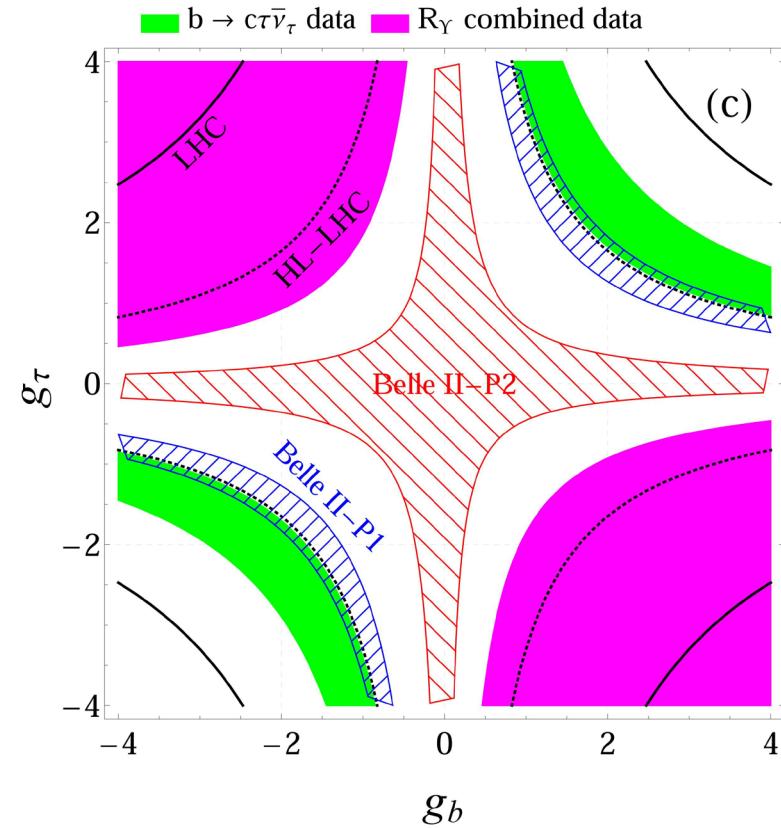
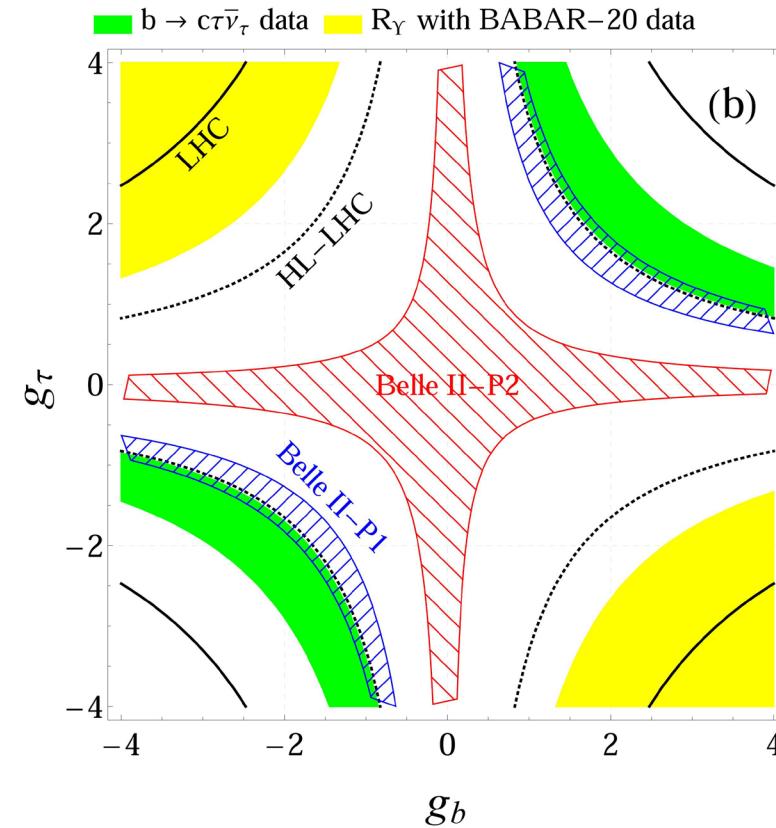
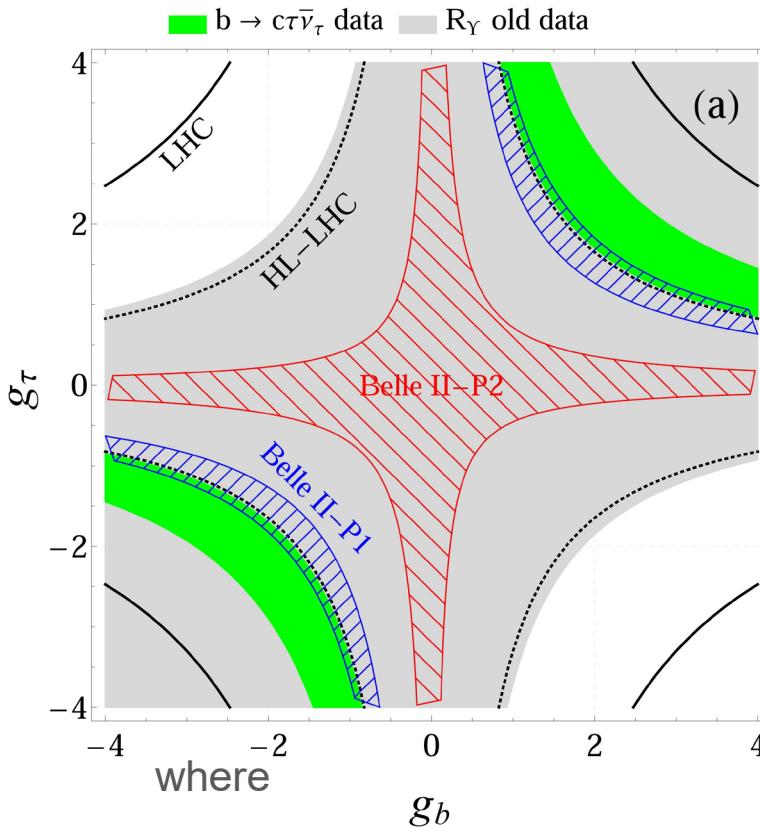
$R(D) + R(D^*) + R(J/\psi) + R(X_c) + P_\tau(D^*) + F_L(D^*) + \text{BR}(B_c \rightarrow \tau\nu) + R(\gamma(1S)) + R(\gamma(2S)) + R(\gamma(3S))$  2020,  $N_{dof}=8$

**Dataset 4:**  $b \rightarrow c\tau\nu + R(\gamma)\text{combined}$  :

$R(D) + R(D^*) + R(J/\psi) + R(X_c) + P_\tau(D^*) + F_L(D^*) + \text{BR}(B_c \rightarrow \tau\nu) + R(\gamma(1S)) + R(\gamma(2S)) + R(\gamma(3S))$  2010 +  $R(\gamma(3S))$  2020,  $N_{dof}=9$

## 5. Phenomenological Study: Parameter Space

We show our results, using  $1\sigma$  allowed parameter space, Belle-II future prospects [1] and LHC bounds [2]:



[1] (Belle-II Collaboration) E. Kou *et al.*, *The Belle II physics book*, Prog. Theor. Exp. Phys. 2019, 123C01 (2019); Erratum, Prog. Theor. Exp. Phys. 2020, 029201 (2020).

[arXiv:1808.10567]

[2] D. Marzocca, U. Min, and M. Son, *Bottom-flavored mono-tau tails at the LHC*, J. High Energy Phys. 12 (2020) 035. [arXiv:2008.07541]

## 6. Products

PHYSICAL REVIEW D 103, 073003 (2021)

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### Extra gauge bosons and lepton flavor universality violation in $\Upsilon$ and $B$ meson decays

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Citing articles:

Testing lepton flavor universality in  $\Upsilon(4S)$  decays

Sébastien Descotes-Genon, Martín Novoa-Brunet, Svjetlana Fajfer, and Jernej F. Kamenik  
Phys. Rev. D **103** 113009 (2021)

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- [6] M. Tanaka and R. Watanabe, *New physics in the weak interaction of  $B \rightarrow D^{(*)}\tau\nu$* , Phys. Rev. D 87, 034028 (2013) [arXiv:1212.1878]
- [7] (Belle Collaboration) A. Abdesselam *et al.*, *Measurement of the  $D^*$  polarization in the decay  $B \rightarrow D^*\tau\nu$* , (2019) [arXiv:1903.03102]
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