Delving Υ and ψ leptonic decays with an extra gauge boson

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Abstract

- We observed that lepton flavour universality can be examined through the ratio of leptonic $\Upsilon = \Upsilon(ns)(n = 1, 2, 3)$ and ψ quarkonia decays.
- In BABAR, the neutral current transitions $b\bar{b} \to \tau\bar{\tau}$ reported that leptonic decay ratio $R_{\Upsilon}(3s) = Br(\Upsilon(3s) \to \tau\bar{\tau})/Br(\Upsilon(3s) \to \mu\bar{\mu})$ is showing an agreement with the SM at 1.8σ level, where the ratio $R(J/\psi)$ expose discrepancies with resembling SM estimations.
- We perform an analysis by using a clarify model with an extra massive gauge boson W' that catenate substantially to left handed leptons of the third generation.

Introduction

- A general W' boson exchange leads to additional tree level effective interactions to the $b \to c\tau\bar{\nu}_\tau$ transition.
- The total low energy effective Lagrangian is

$$\mathcal{L}_{eff}(b \to c\tau\bar{\nu}_\tau)_{SM+W'} = \frac{4G_F}{\sqrt{2}} V_{cb} \left[(1 + C_V^{LL})(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\tau) + C_V^{RL}(\bar{c}\gamma_\mu P_R b)(\bar{\tau}\gamma_\mu P_L \nu_\tau) + C_V^{LR}(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma_\mu P_R \nu_\tau) + C_V^{RR}(\bar{c}\gamma_\mu P_R b)(\bar{\tau}\gamma_\mu P_R \nu_\tau)\right] \quad (1)$$

- C_V^{LL}, C_V^{LR}, C_V^{RL}andC_V^{RR} are the wilson coefficients, depends on the choices of chiral charges, associated with the NP operators.

$$C_V^{LL} = \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon^L_{cb}\epsilon^L_{\tau\nu}}{M^2_{W'}} \qquad C_V^{RR} = \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon^R_{cb}\epsilon^R_{\tau\nu}}{M^2_{W'}} \quad (2)$$

$$C_V^{LR} = \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon^L_{cb}\epsilon^R_{\tau\nu}}{M^2_{W'}} \qquad C_V^{RL} = \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon^R_{cb}\epsilon^L_{\tau\nu}}{M^2_{W'}}$$

- We will pay attention to the wilson coefficients and the W' boson mass which can provide an explanation for the $b \to c\tau\bar{\nu}$ anomalies.

Phenomenological Analysis

- χ^2 function is given by the sum of the squared pulls i.e $\chi^2 = \sum_i pull_i^2$.
- $pull_i = (\mathcal{O}^i{}_{exp} - \mathcal{O}^i{}_{th})/\sqrt{\sigma^{i2}{}_{exp} - \sigma_{th}{}^{i2}}$ where $\sigma^i{}_{exp,th}$ corresponds to the experimental and theoretical error.
- It is possible to obtain several models by turning on some of the couplings, while the remaining ones are set equal to zero.
- In order to adjust the experimental anomalies, any model must contain a charm-bottom interaction term in the quark sector and the corresponding $\tau - \nu_\tau$ interaction term in the lepton sector, i.e it is necessary to have at least two nonzero couplings in the Lagrangian.

Table

Parameters on	R(D)	$R(D^*)$	$R(J/\psi)$	$P_\tau(D^*)$	$F_L(D^*)$	$\chi^2{}_{min}$
$(\epsilon^L_{cb}, \epsilon^L_{\tau\nu})$	-0.045	0.031	1.53	0.22	1.47	5.48
$(\epsilon^L_{cb}, \epsilon^R_{\tau\nu})$	-0.046	0.027	1.53	-0.013	1.46	5.43
$(\epsilon^R_{cb}, \epsilon^L_{\tau\nu})$	2.57	0.46	1.56	0.19	1.52	12.27
$(\epsilon^R_{cb}, \epsilon^R_{\tau\nu})$	-0.047	0.027	1.53	-0.013	1.46	5.43

Table 1: Turning on the parameters we analysis the χ^2 fitting, for a gauge boson mass $M_W{}'$=1 Tev

- In order to check whether it is possible to adjust the deviations of the standard model predictions in these models, we carried out a χ^2 analysis with the five experimental observables mentioned above.
- All the models have an acceptable value for $\chi^2{}_min/dof \sim 1$ except the model with RH coupling to quarks and LH coupling to leptons.

LL Scenario ($C_V^{LL} \neq 0$)

- W' that couples only to LH quark and LH lepton currents.

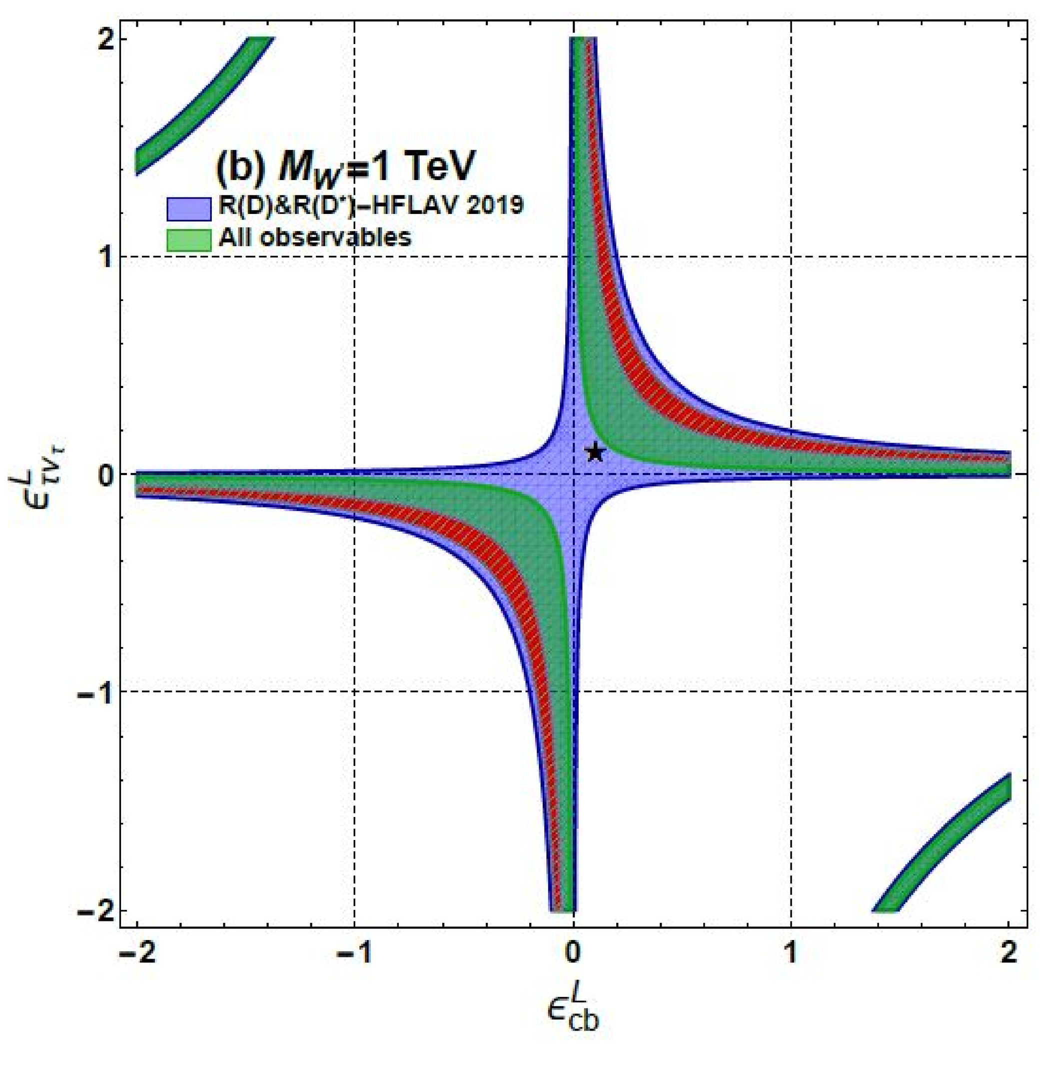

Fig. 1: Allowed parameter space in the $(\epsilon^L_{cb}, \epsilon^L_{\tau\nu})$ plane for $M_{W'} = 1\,Tev$.

- The purple region is obtained by considering only $R(D^*)$ from HFLAV-2019 average, while the green one is showing the constraints for all the observables of $b \to c\tau\bar{\nu}$ taking into account.

RR Scenario ($C_V^{RR} \neq 0$)

- W' that couples only to RH quark and RH lepton currents involving a RH sterile neutrino.

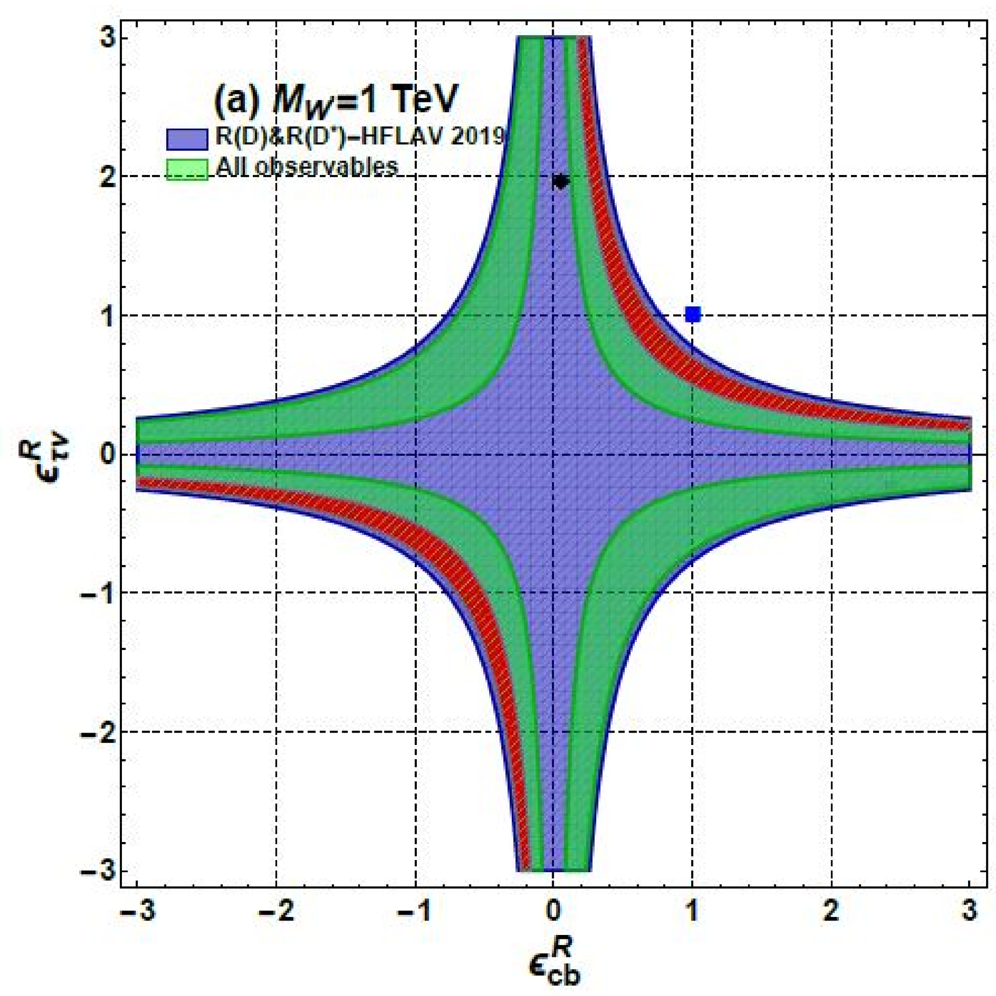

Fig. 2: Allowed parameter space in the $(\epsilon^R_{cb}, \epsilon^R_{\tau\nu})$ plane for $M_{W'} = 1\,Tev$.

- The purple region is obtained by considering only $R(D^*)$ from HFLAV-2019 average, while the green one is showing the constraints for all the observables of $b \to c\tau\bar{\nu}$ taking into account. The red red region is obtained from GMR analysis.

LR and RL Scenarios

- where the quark and lepton currents with different chiralities projection couple to the W' boson i.e $C_V^{LR} \neq 0$ and $C_V^{RL} \neq 0$.

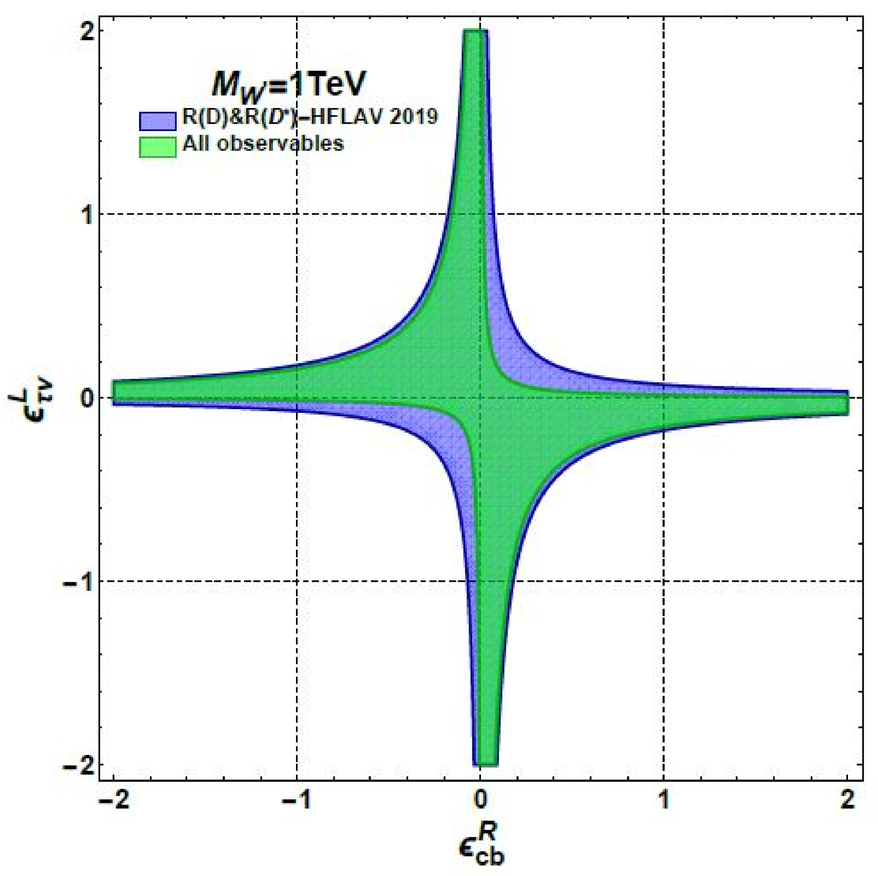

Fig. 3: Allowed parameter space in the $(\epsilon^R_{cb}, \epsilon^L_{\tau\nu})$ plane for $M_{W'} = 1\,Tev$.

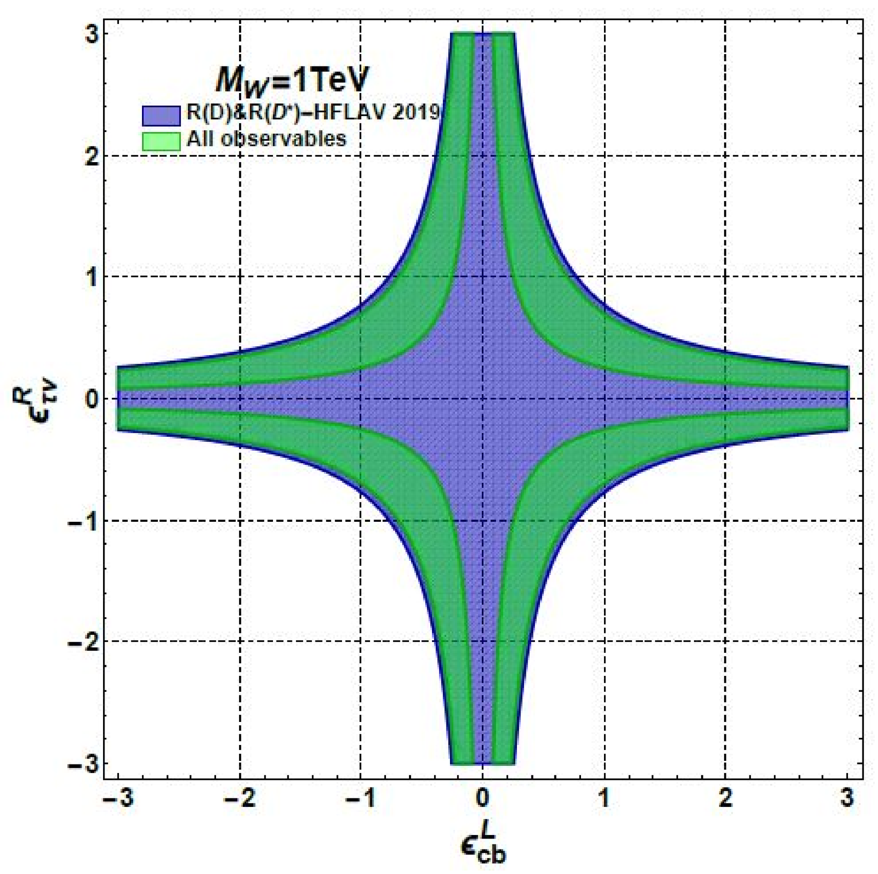

Fig. 4: Allowed parameter space in the $(\epsilon^L_{cb}, \epsilon^R_{\tau\nu})$ plane for $M_{W'} = 1\,Tev$.

Conclusion

- The anomalies $R(D^*)$ related to the charged current transition $b \to c\tau\bar{\nu}$ with in a W' boson scenario.
- Effective Lagrangian given in terms of the flavour dependent couplings $\epsilon^{L,R}_{cb}, \epsilon^{L,R}_{\tau\nu}$ yields to a tree level effective contribution generated by a W' boson.
- we performed a χ^2 analysis by considering the cases of two non zero couplings which later show the best candidate to adjust the experimental charged current B anomalies.
- Taking into account two different datasets $R(D^*)$ and all $b \to c\tau\bar{\nu}$ observables we determined the regions for allowed parameter space which is favoured by those observables and our results showed that it would be interesting to study a particular NP model.