Charged current $b \to c\tau\nu$ anomalies in a general W' scenario

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COMPHEP

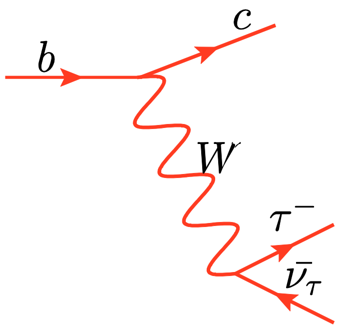
OUTLINE

- LFU
- General W' scenario
- Phenomenological analysis
- Scenarios
- Conclusions

Overview

LFU

$$b \to c\tau\bar{\nu}$$

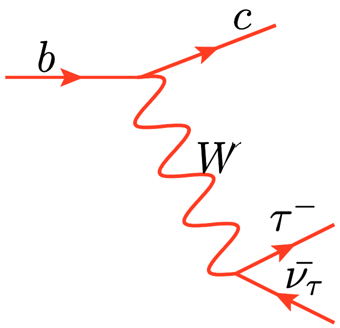


$$A \sim \frac{g_2}{M_w^2} V_{cb}$$

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

Overview

LFU → $b \to c\tau\bar{\nu}$



$$A \sim \frac{g_2}{M_W^2} V_{cb}$$

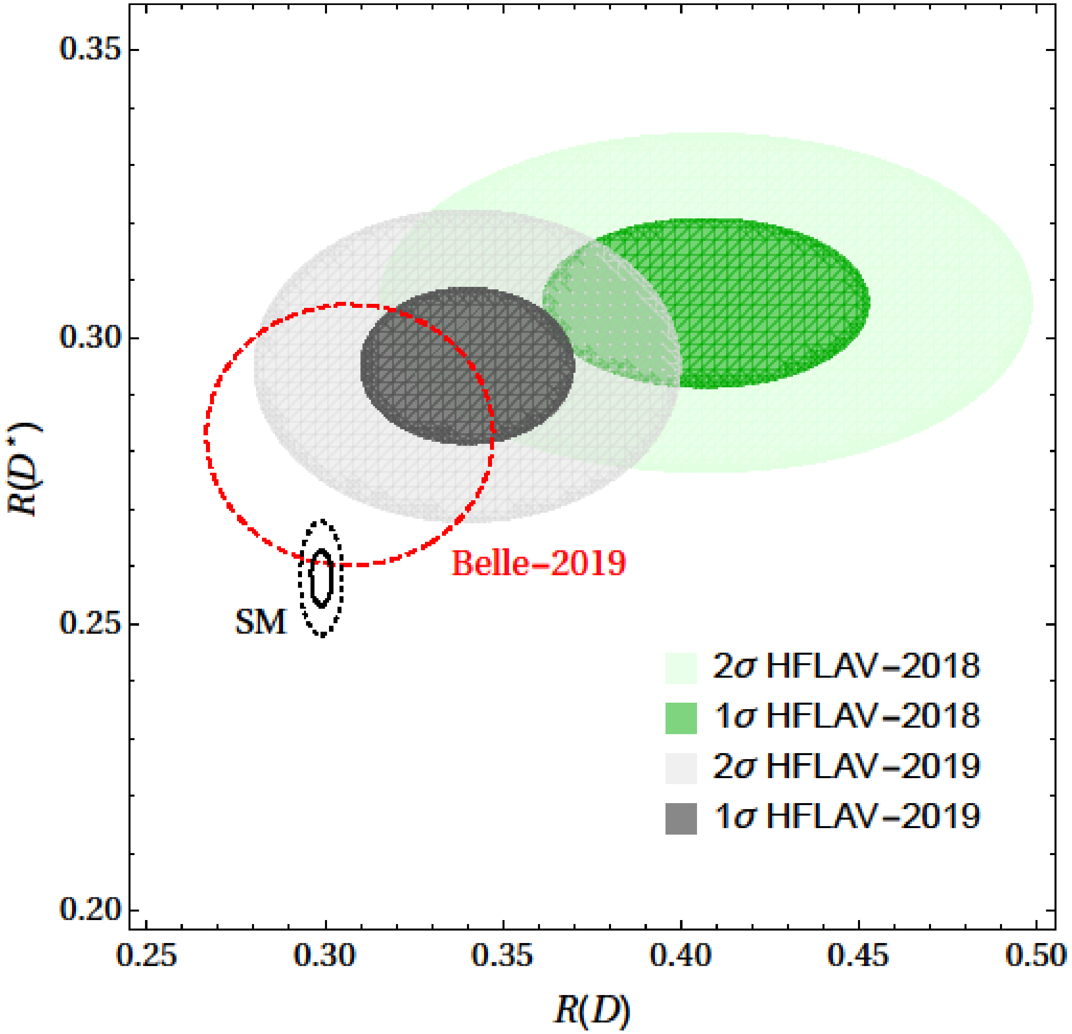
Before Moriond 2019
$R(D)$ & $R(D^*)$ 3.8σ

At Moriond 2019
$R(D)$ & $R(D^*)$ 3.1σ

Observable	Expt. measurement	SM prediction
$R(D)$	$0.307 \pm 0.037 \pm 0.016$ Belle-2019 [22]	0.299 ± 0.003 [15,16]
	$0.340 \pm 0.027 \pm 0.013$ HFLAV [15]	
$R(D^*)$	$0.283 \pm 0.018 \pm 0.014$ Belle-2019 [22]	0.258 ± 0.005 [15,16]
	$0.295 \pm 0.011 \pm 0.008$ HFLAV [15]	
$R(J/\psi)$	$0.71 \pm 0.17 \pm 0.18$ [23]	0.283 ± 0.048 [24]
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$ [10,11]	-0.497 ± 0.013 [25]
$F_L(D^*)$	$0.60 \pm 0.08 \pm 0.035$ [26]	0.46 ± 0.04 [27]
$R(X_c)$	0.223 ± 0.030 [28]	0.216 ± 0.003 [28]

Overview

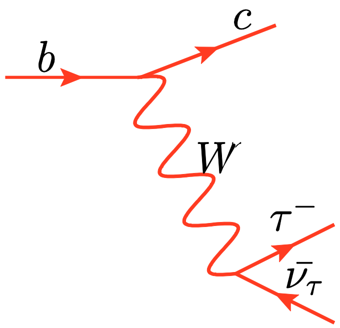
The tension has been reduced with the new result presented by Belle Collaboration



Overview

LFU

$$b \to c\tau\bar{\nu}$$



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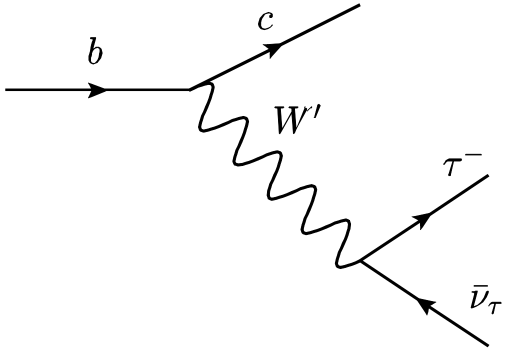
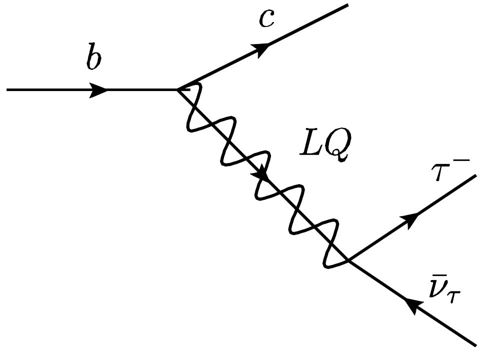
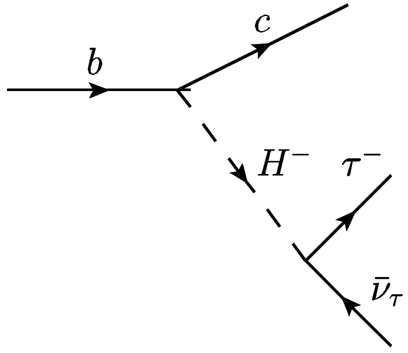
NP contribution



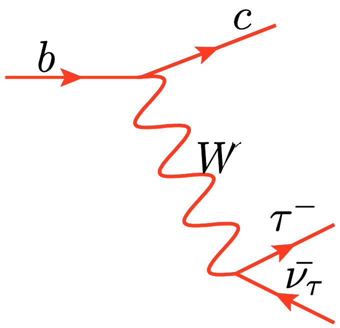




Overview

LFU

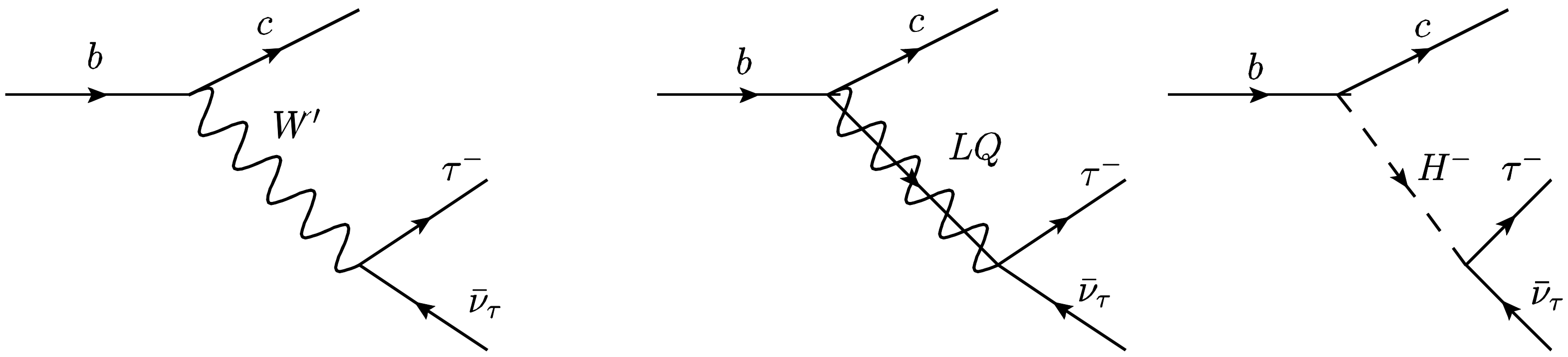
$b \to c\tau\bar{\nu}$



$A \sim \frac{g_2}{M_W^2} V_{cb}$

NP contribution

PRL118.081802



$B_c \to \tau\,\bar{\nu}$

General W' scenario

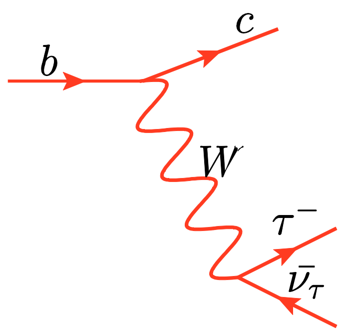
SM

$$-\mathcal{L}_{\rm eff}(b \to c\tau\bar{\nu}_\tau)_{\rm SM} = \frac{4G_F}{\sqrt{2}} V_{cb}(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau)$$

NP

$$\mathcal{L}_{\rm eff}^{W'} = \frac{W'_\mu}{\sqrt{2}}\left[\bar{u}_i(\epsilon^L_{u_i d_j} P_L + \epsilon^R_{u_i d_j} P_R)\gamma^\mu d_j + \bar{\ell}_i(\epsilon^L_{\ell_i \nu_j} P_L + \epsilon^R_{\ell_i \nu_j} P_R)\gamma^\mu \nu_j\right] + \text{h.c.}$$

General W' scenario



SM

$$-\mathcal{L}_{\rm eff}(b \to c\tau\bar{\nu}_\tau)_{\rm SM} = \frac{4G_F}{\sqrt{2}} V_{cb} (\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau)$$

NP

$$\mathcal{L}_{\rm eff}^{W'} = \frac{W'_\mu}{\sqrt{2}} \left[\bar{u}_i (\epsilon^L_{u_i d_j} P_L + \epsilon^R_{u_i d_j} P_R)\gamma^\mu d_j + \bar{\ell}_i (\epsilon^L_{\ell_i \nu_j} P_L + \epsilon^R_{\ell_i \nu_j} P_R)\gamma^\mu \nu_j \right] + {\rm h.c.}$$

SM + NP

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

General W' scenario

SM + NP

$$-\mathcal{L}_{\rm eff}(b \to c\tau\bar{\nu}_\tau)_{\rm SM+W'} = \frac{4G_F}{\sqrt{2}} V_{cb}\Big[(1 + C_V^{LL})(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau) + C_V^{RL}(\bar{c}\gamma_\mu P_R b)(\bar{\tau}\gamma^\mu P_L \nu_\tau)$$

$$+ C_V^{LR}(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_R \nu_\tau) + C_V^{RR}(\bar{c}\gamma_\mu P_R b)(\bar{\tau}\gamma^\mu P_R \nu_\tau)\Big]$$

$$C_V^{LL} \equiv \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon_{cb}^L \epsilon_{\tau\nu_\tau}^L}{M_{W'}^2},$$

$$C_V^{RL} \equiv \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon_{cb}^R \epsilon_{\tau\nu_\tau}^L}{M_{W'}^2},$$

$$C_V^{LR} \equiv \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon_{cb}^L \epsilon_{\tau\nu_\tau}^R}{M_{W'}^2},$$

$$C_V^{RR} \equiv \frac{\sqrt{2}}{4G_F V_{cb}} \frac{\epsilon_{cb}^R \epsilon_{\tau\nu_\tau}^R}{M_{W'}^2}$$

← Wilson Coefficients

General W' scenario

$$R(D) = R(D)_{\rm SM}\Big(\big|1 + C_V^{LL} + C_V^{RL}\big|^2 + \big|C_V^{LR} + C_V^{RR}\big|^2\Big),$$

$$R(D^*) = R(D^*)_{\rm SM}\Big(|1 + C_V^{LL}|^2 + |C_V^{RL}|^2 + |C_V^{LR}|^2 + |C_V^{RR}|^2 - 1.81\ {\rm Re}\big[(1 + C_V^{LL})C_V^{RL*} + (C_V^{RR})C_V^{LR*}\big]\Big)$$

$$R(J/\psi) = R(J/\psi)_{\rm SM}\Big(|1 + C_V^{LL}|^2 + |C_V^{RL}|^2 + |C_V^{LR}|^2 + |C_V^{RR}|^2 - 1.92\ {\rm Re}\big[(1 + C_V^{LL})C_V^{RL*} + (C_V^{RR})C_V^{LR*}\big]\Big)$$

$$F_L(D^*) = F_L(D^*)_{\rm SM}\ r_{D^*}^{-1}\Big(\big|1 + C_V^{LL} - C_V^{RL}\big|^2 + \big|C_V^{RR} - C_V^{LR}\big|^2\Big)$$

$$P_\tau(D^*) = P_\tau(D^*)_{\rm SM}\ r_{D^*}^{-1}\Big(|1 + C_V^{LL}|^2 + |C_V^{RL}|^2 - |C_V^{RR}|^2 - |C_V^{LR}|^2 - 1.77\ {\rm Re}\big[(1 + C_V^{LL})C_V^{RL*} - (C_V^{RR})C_V^{LR*}\big]\Big)$$

$$R(X_c) = R(X_c)_{\rm SM}\Big(1 + 1.147\ \Big[\big|C_V^{LL}\big|^2 + \big|C_V^{RR}\big|^2 + 2{\rm Re}(C_V^{LL}) + \big|C_V^{LR}\big|^2 + \big|C_V^{RL}\big|^2\Big]\ - 0.714\ {\rm Re}\big[(1 + C_V^{LL})C_V^{RL*} + (C_V^{RR})C_V^{LR*}\big]\Big)$$

$$r_{D^*} = R(D^*)/R(D^*)_{\rm SM}$$

$${\rm BR}(B_c^- \to \tau^-\bar{\nu}_\tau) = {\rm BR}(B_c^- \to \tau^-\bar{\nu}_\tau)_{\rm SM}\ \Big(\big|1 + C_V^{LL} - C_V^{RL}\big|^2 + |C_V^{RR} - C_V^{LR}|^2\Big)$$

Phenomenological Analysis

Observable	Expt. measurement	SM prediction
$R(D)$	$0.307 \pm 0.037 \pm 0.016$ Belle-2019 [22]	0.299 ± 0.003 [15,16]
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$$\chi^2 = \sum_i \mathrm{pull}_i^2$$

$$\mathrm{pull}_i = \frac{\mathcal{O}^i_{\mathrm{exp}} - \mathcal{O}^i_{\mathrm{th}}}{\sqrt{\sigma^{i2}_{\mathrm{exp}} + \sigma^{i2}_{\mathrm{th}}}}$$

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SM Pulls

$R(D)$	$R(D^*)$	$R(J/\psi)$	$P_\tau(D^*)$	$F_L(D^*)$	$R(X_c)$
1.36	2.55	1.69	0.21	1.46	0.23

Phenomenological Analysis

$M_{W'} = 1\, TeV$

	Parameters on	Pull$_i$								Best-fit point			
		$R(D)$	$R(D^*)$	$R(J/\psi)$	$P_\tau(D^*)$	$F_L(D^*)$	$R(X_c)$	$\mathrm{BR}(B_c \to \tau\bar{\nu})$	$\chi^2_{\min}$	ϵ^L_{cb}	ϵ^R_{cb}	$\epsilon^L_{\tau\nu}$	$\epsilon^R_{\tau\nu}$
2P	$(\epsilon^L_{cb}, \epsilon^L_{\tau\nu})$	−0.045	0.032	1.53	0.21	1.46	−0.93	−0.27	5.49	−0.345	⋯	−0.276	⋯
	$(\epsilon^L_{cb}, \epsilon^R_{\tau\nu})$	−0.047	0.027	1.53	−0.013	1.46	−0.94	−0.27	5.44	0.584	⋯	⋯	0.897
	$(\epsilon^R_{cb}, \epsilon^L_{\tau\nu})$	2.57	0.46	1.55	0.19	1.52	−0.059	−0.26	12.28	⋯	−0.322	0.271	⋯
	$(\epsilon^R_{cb}, \epsilon^R_{\tau\nu})$	−0.047	0.027	1.53	−0.013	1.46	−0.121	−0.27	5.44	⋯	0.584	⋯	0.897
3P	$(\epsilon^L_{cb}, \epsilon^R_{cb}, \epsilon^L_{\tau\nu})$	0.31	−0.20	1.52	0.22	1.41	−0.91	−0.27	5.34	0.272	−0.051	0.326	⋯
	$(\epsilon^R_{cb}, \epsilon^L_{\tau\nu}, \epsilon^R_{\tau\nu})$	0.31	−0.21	1.52	0.011	1.41	−0.91	−0.27	5.29	⋯	0.466	−0.038	1.082
	$(\epsilon^L_{cb}, \epsilon^L_{\tau\nu}, \epsilon^R_{\tau\nu})$	−0.048	0.027	1.53	-7.4×10^{-7}	1.46	−0.94	−0.27	5.44	0.666	⋯	0.008	0.764
4P	$(\epsilon^L_{cb}, \epsilon^R_{cb}, \epsilon^L_{\tau\nu}, \epsilon^R_{\tau\nu})$	0.31	−0.21	1.52	-4.1×10^{-6}	1.41	−0.91	−0.27	5.29	1.016	−0.105	0.009	−0.469

$$\chi^2 = \sum_i \mathrm{pull}_i^2$$

$$\mathrm{pull}_i = \frac{\mathcal{O}^i_{\exp} - \mathcal{O}^i_{\mathrm{th}}}{\sqrt{\sigma^{i2}_{\exp} + \sigma^{i2}_{\mathrm{th}}}}$$

dof = 7-p

$$\frac{\chi^2}{\mathrm{dof}} = 1 \ \to 2P \qquad \frac{\chi^2}{\mathrm{dof}} = 1.4 \ \to 3P$$

$$\frac{\chi^2}{\mathrm{dof}} = 1.8 \ \to 4P$$

Phenomenological Analysis

$$M_{W'} = 1\ TeV$$

	Parameters on	Pull$_i$							$\chi^2_{\min}$	Best-fit point			
		$R(D)$	$R(D^*)$	$R(J/\psi)$	$P_\tau(D^*)$	$F_L(D^*)$	$R(X_c)$	$\mathrm{BR}(B_c \to \tau\bar{\nu})$		ϵ^L_{cb}	ϵ^R_{cb}	$\epsilon^L_{\tau\nu}$	$\epsilon^R_{\tau\nu}$
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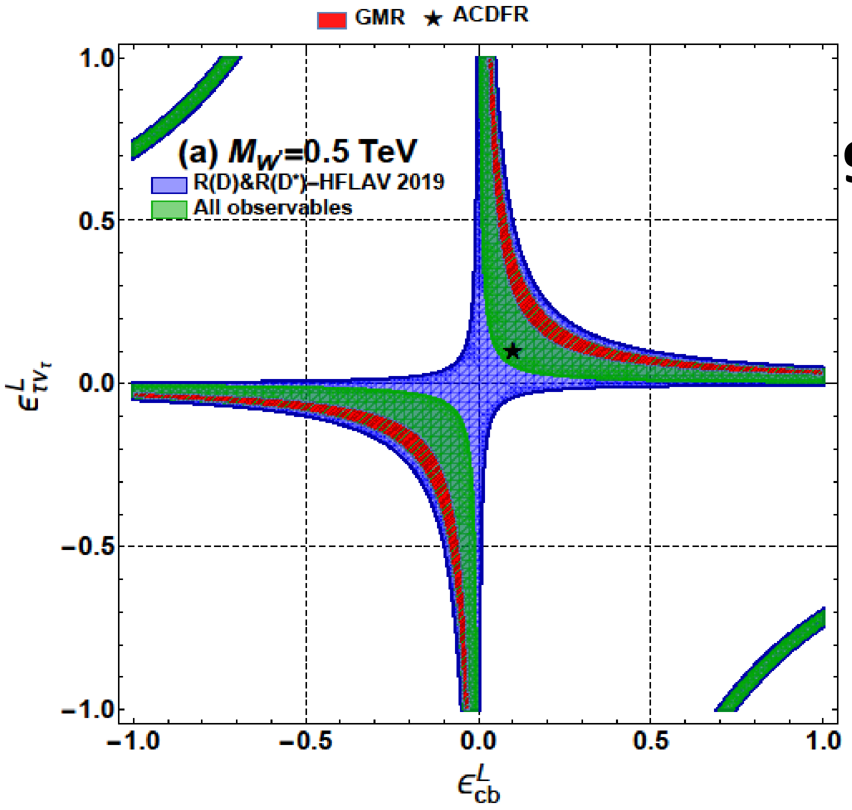
$$\chi^2_{R(D)\text{-}R(D^*)} = \frac{\mathrm{pull}(D) + \mathrm{pull}(D^*)^2 - 2\rho\ \mathrm{pull}(D)\mathrm{pull}(D^*)}{\sqrt{1-\rho^2}}$$

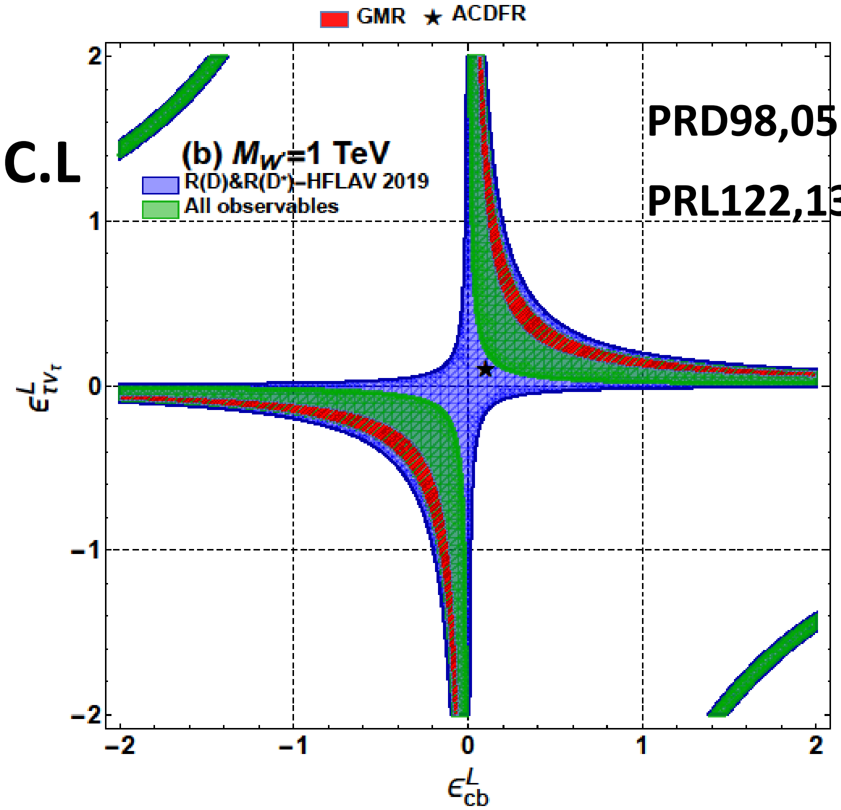
$$\rho = -0.203$$

Scenarios

$$(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau) \rightarrow C_{LL}^V \neq 0$$



95% C.L



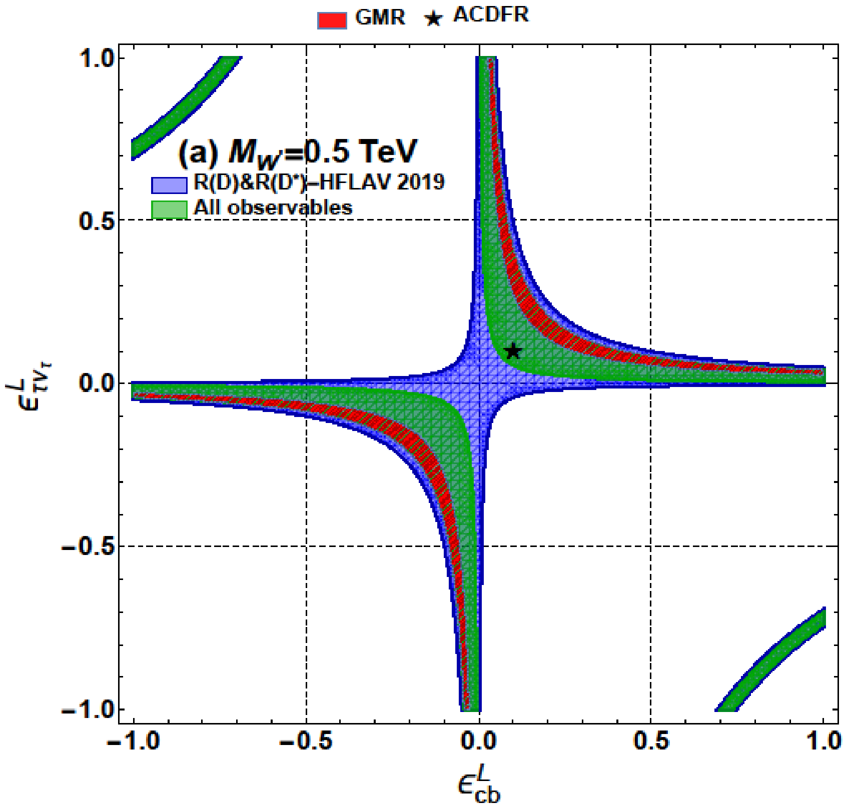
PRD98,055016(2018)

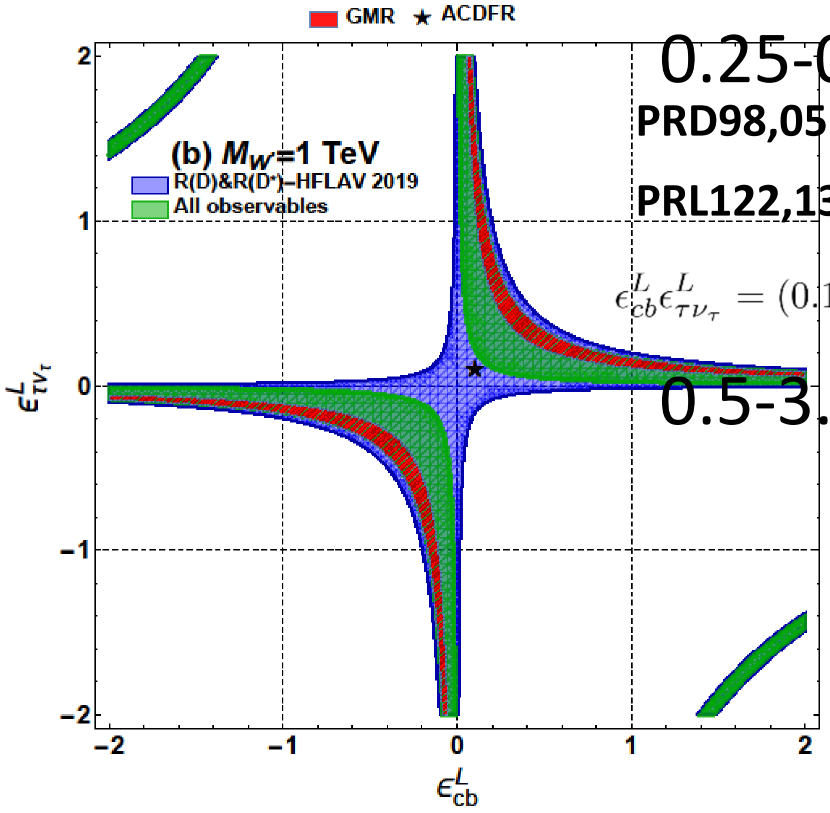
PRL122,131803(2019)

$$\mathrm{BR}(B_c^- \rightarrow \tau^- \bar{\nu}_\tau) < 10\%$$

Scenarios

$$(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau) \to C_{LL}^V \neq 0$$





0.25-0.75 TeV

PRD98,055016(2018)

PRL122,131803(2019)

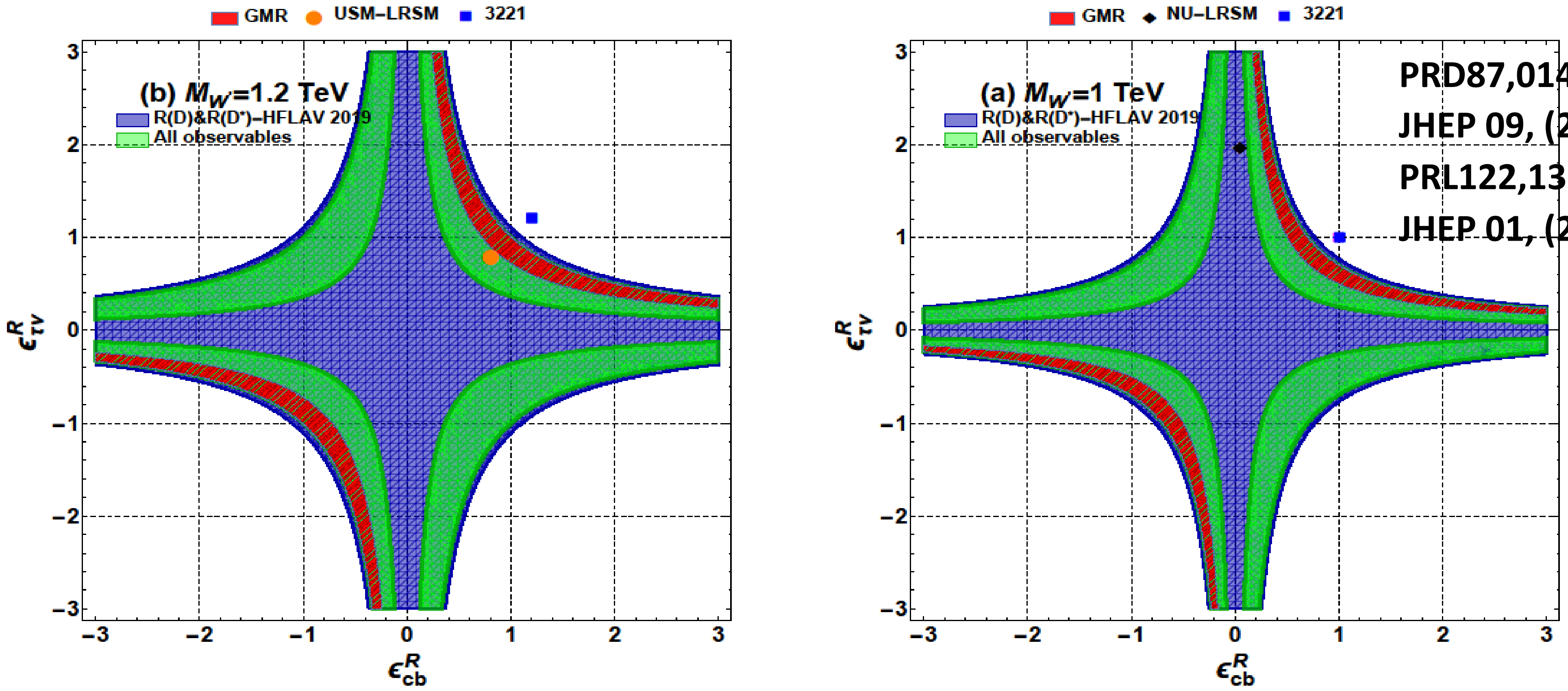
$$\epsilon^L_{cb}\epsilon^L_{\tau\nu_\tau} = (0.14 \pm 0.03)\left(\frac{M_{W'}}{\text{TeV}}\right)^2$$

0.5-3.5 TeV

$$\text{BR}(B_c^- \to \tau^- \bar{\nu}_\tau) < 10\%$$

Scenarios

$$C_{RR}^{V} \neq 0$$

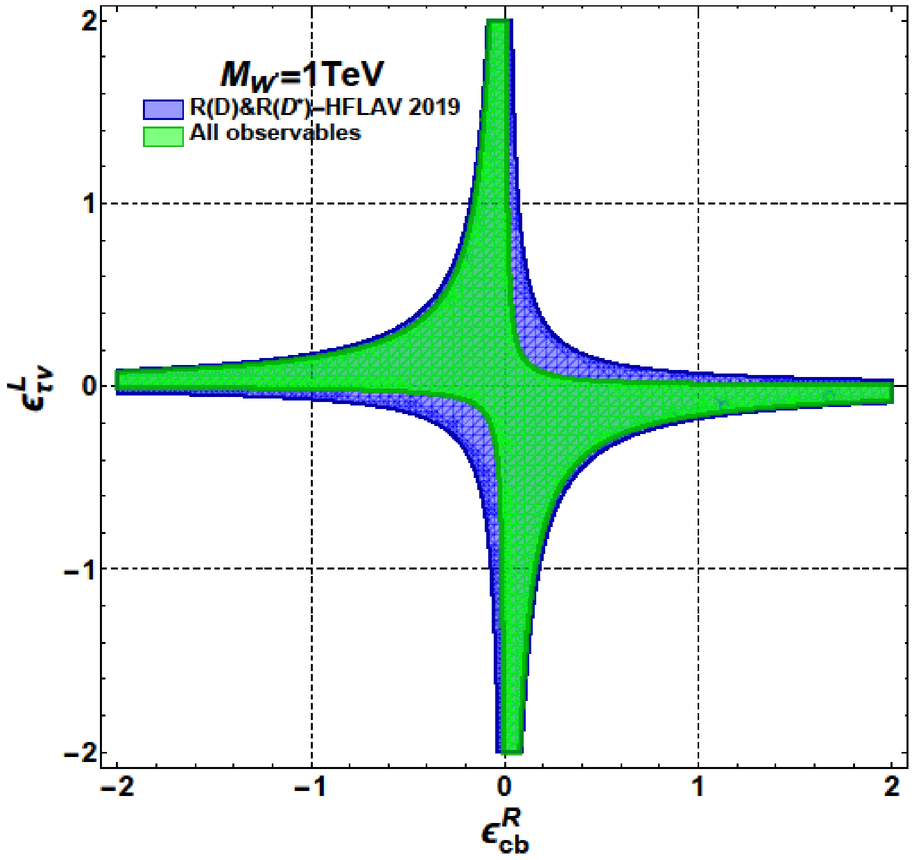


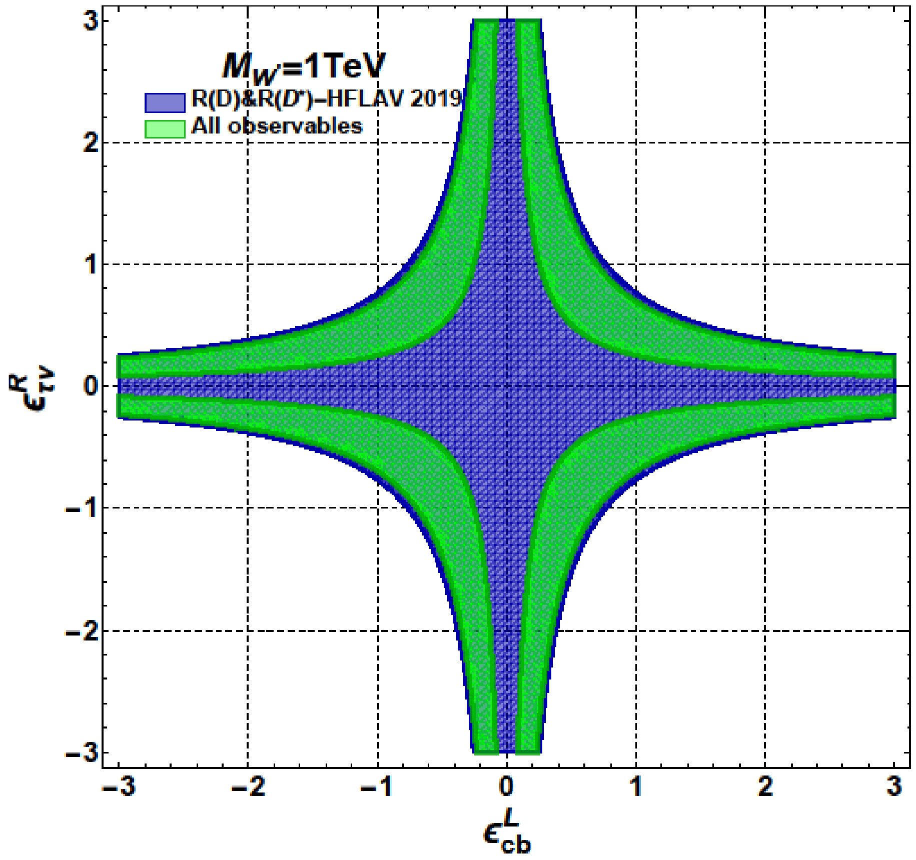
PRD87,014014(2013)
JHEP 09, (2018) 010
PRL122,131803(2019)
JHEP 01, (2019) 168

$$\mathrm{BR}(B_c^- \to \tau^- \bar{\nu}_\tau) < 10\%$$

Scenarios

$$C^V_{LR} \neq 0 \neq C^V_{RL}$$





$$\mathrm{BR}(B_c^- \to \tau^- \bar{\nu}_\tau) < 10\%$$

Conclulsion

- We considered the available experimental information on all of the charged transition $b \to c\tau\bar{\nu}$ observables.
- We found that the 2P models represent the best candidate to adjust the experimental charged current B anomalies.
- We determined the regions in parameter space favored by these observables for differents values of W' mass.
- We obtained that part of the allowed parametric space is consistent with the mono-tau signature $pp \to \tau_h X + \mathrm{MET}$ at LHC.
- We found which of these benchmark models are favored or disfavored by the new data.

Thank you