Implications of new physics in semileptonic $b \to c\tau\bar{\nu}$ transitions

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Introduction

- Several hints of lepton non-universality have been observed in the charged-current ($b \to cl\bar{\nu}_l$) transitions of semileptonic B meson decays.
- We examine the semileptonic decays involving $b \to c\tau\bar{\nu}$ quark level transitions by considering the most general effective Lagrangian in the presence of new physics.
- we scrutinize $\Lambda_b \to \Lambda_c\tau\bar{\nu}_\tau$, $B_c^+ \to \eta_c\tau^+\nu_\tau$, and $B \to D^{**}\tau\bar{\nu}_\tau$ (where $D^{**} = \{D_0^*, D_1^*, D_1, D_2^*\}$ are the four lightest excited charm mesons) processes, in the presence of new physics.
- We perform a global fit to different sets of new coefficients, making use of the measurements on R_D, R_{D^*}, $R_{J/\psi}$, $P_\tau^{D^*}$ and the upper limit on Br($B_c^+ \to \tau^+\nu_\tau$).
- We then inspect the effect of constrained new couplings on the branching ratios, forward-backward asymmetry parameters, lepton non-universality ratios (LNU), lepton and hadron polarization asymmetries of these decay modes.

Theoretical Framework

Effective hamiltonian associated with the quark level transition $b \to c l \bar{\nu}_l$:

$$H_{eff} = 2\sqrt{2} G_F V_{cb} \left[O_{V_L} + \frac{\sqrt{2}}{4 G_F V_{cb}} \frac{1}{\Lambda^2} \left\{ \sum_i \left(C_i O_i + C_i^{'} O_i^{'} + C_i^{''} O_i^{''} \right) \right\} \right] \quad (1)$$

- Here O_{V_L} is the SM operator, O_i, $O_i^{'}$ and $O_i^{''}$ are four-fermion operators. The constants C_i, $C_i^{'}$ and $C_i^{''}$ are the respective Wilson coefficients of the NP operators in which NP effects are encoded.

Observables

Forward-backward asymmetry parameter :

$$A_{FB}(q^2) = \left(\int_{-1}^{0} d\cos\theta_l \, \frac{d^2\Gamma}{dq^2 d\cos\theta_l} - \int_{0}^{1} d\cos\theta_l \, \frac{d^2\Gamma}{dq^2 d\cos\theta_l} \right) \Big/ \frac{d\Gamma}{dq^2} \tag{2}$$

Longitudinal hadron and lepton polarization asymmetry parameter :

$$P_L^h(q^2) = \frac{\mathrm{d}\Gamma^{\lambda_2=1/2}/\mathrm{d}q^2 - \mathrm{d}\Gamma^{\lambda_2=-1/2}/\mathrm{d}q^2}{\mathrm{d}\Gamma/\mathrm{d}q^2} \tag{3}$$

$$P_L^\tau(q^2) = \frac{\mathrm{d}\Gamma^{\lambda_\tau=1/2}/\mathrm{d}q^2 - \mathrm{d}\Gamma^{\lambda_\tau=-1/2}/\mathrm{d}q^2}{\mathrm{d}\Gamma/\mathrm{d}q^2} \tag{4}$$

Lepton non-universality parameter:

$$R_{\Lambda_c} = \frac{\mathrm{Br}(\Lambda_b \to \Lambda_c \tau^- \bar{\nu}_\tau)}{\mathrm{Br}(\Lambda_b \to \Lambda_c \, l^- \bar{\nu}_l)}, \quad l = e, \mu. \tag{5}$$

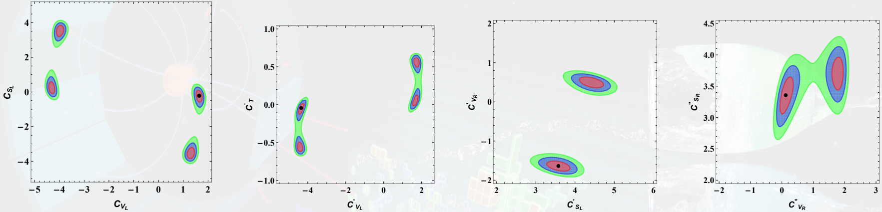
Constraints on New couplings

- We consider either one NP operator or a combination of two similar operators (for example $[O_{V_L}, O_{V_R}]$, $[O_{S_L}, O_{S_R}]$, $[O^{'}_{V_L}, O^{'}_{V_R}]$ and $[O^{''}_{S_L}, O^{''}_{S_R}]$) at a time while making the fit to the experimental observables.
- The corresponding χ^2 is defined as

$$\chi^2(C^i_{\rm eff}) = \sum \frac{(\mathcal{O}^{\rm th}(C^i_{\rm eff}) - \mathcal{O}^{\rm Expt})^2}{(\Delta\mathcal{O}^{\rm Expt})^2 + (\Delta\mathcal{O}^{\rm SM})^2}\,. \tag{6}$$

- The expressions for various $C^i_{\rm eff}$, as linear combinations of C_i, $C^{'}_i$ and $C^{''}_i$, are defined below

$$\begin{aligned}
C^{S_L}_{\rm eff} &= -\alpha\left(6C^{'}_T + 6C^{''}_T - C_{S_L} + 0.5C^{'}_{S_L} + 0.5C^{''}_{S_L}\right)\\
C^{S_R}_{\rm eff} &= -\alpha\left(2C^{'}_{V_R} + 2C^{''}_{V_R} - C_{S_R}\right)\\
C^{V_L}_{\rm eff} &= \alpha\left(C_{V_L} + 0.5C^{''}_{S_R} + C^{'}_{V_L}\right)\\
C^{V_R}_{\rm eff} &= -\alpha\left(C^{''}_{V_L} - C_{V_R} + 0.5C^{'}_{S_R}\right)\\
C^{T}_{\rm eff} &= \alpha\left(C_T + 0.5C^{'}_T - 0.5C^{''}_T - 0.125C^{'}_{S_L} + 0.125C^{''}_{S_L}\right).
\end{aligned} \tag{7}$$



- some of constraints on various combination of new coefficients obtained from χ^2 fitting. Here red, blue and green colours represent the 1σ, 2σ and 3σ contours and the black dots represent the best-fit values.
- In this analysis, we fit the following combinations of new Wilson coefficients, which are classified as

Case I : Presence of only one new coefficient at a time.

Case II : Presence of various combinations of two new coefficients at a time.

A: C_i & C_j B: $C_i^{'}$ & $C_j^{'}$ C: $C_i^{''}$ & $C_j^{''}$

Cases	NP Coefficient(s)	Best fit value(s)	$\chi^2_{\rm min}/{\rm d.o.f}$	*pull*
Case I	C_{V_L}	-2.839	0.56	3.54
	C_T	-0.069	1.50	2.96
	C'_{V_L}	-2.839	0.56	3.54
	C''_{S_L}	-0.584	0.57	3.53
	C''_{S_R}	-5.678	0.56	3.54
Case II A	(C_{V_L}, C_{S_L})	$(1.642, -0.219)$	1.48	3.216
	(C_{V_R}, C_{S_R})	$(-1.142, -2.537)$	1.09	3.39
	(C_{S_L}, C_{V_R})	$(-2.644, -0.962)$	1.10	3.40
B	(C'_{V_L}, C'_{S_L})	$(-1.969, -5.626)$	0.71	3.56
	(C'_{V_L}, C'_{S_R})	$(-4.223, -0.207)$	0.90	3.47
	(C'_{V_L}, C'_T)	$(-4.342, -0.044)$	0.96	3.45
	(C'_{V_L}, C'_{V_R})	$(-4.512, -1.794)$	1.06	3.41
	(C'_{S_L}, C'_{V_R})	$(3.580, -1.642)$	0.77	3.53
	(C'_{S_L}, C'_T)	$(2.726, -0.479)$	0.74	3.54
	(C'_{V_R}, C'_{S_R})	$(1.270, 2.272)$	0.51	3.64
C	(C''_{V_L}, C''_{V_R})	$(1.142, 1.268)$	1.09	3.40
	(C''_{V_L}, C''_{S_L})	$(0.397, -3.584)$	1.21	3.34
	(C''_{V_R}, C''_{S_R})	$(0.129, 3.35)$	1.12	3.20

Table: Best fit values of new WCs for all possible cases. We also show the pull values using *pull* = $\sqrt{\chi^2_{SM} - \chi^2_{min}}$. Here we list solutions with $\chi^2_{\rm min}/{\rm d.o.f} \lesssim 1.5$.

$$\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$$

$\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$

- The double differential decay rate is

$$\frac{d\Gamma}{dq^2} = N\left(1-\frac{m_l^2}{q^2}\right)^2\left[A_1+\frac{m_l^2}{q^2}A_2+2A_3+\frac{1}{4}A_4+\frac{4m_l}{\sqrt{q^2}}(A_5+A_6)+A_7\right] \quad (8)$$

Where $N = \frac{G_F^2|V_{cb}|^2 q^2\sqrt{\lambda}}{2^{10}\pi^3 M_{\Lambda_b}^3}$ and the mathematical expressions for $\sum_i A_i's$ are depend upon the helicity amplitudes in terms of different form factors and the new physics couplings.

CASE I

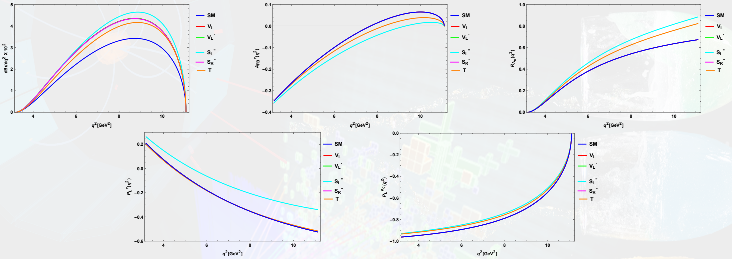


Figure: The branching ratio (top-left), forward-backward asymmetry (top-right), R_{Λ_c} (middle-left), tau (middle-right) and Λ_c (bottom) longitudinal polarization asymmetry of $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ for case I.

Observables	SM	C_{V_L}	C'_{V_L}	C''_{S_L}	C''_{S_R}	C_T
Br$(\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau)$	0.0480 ± 0.04	0.0610 ± 0.02	0.0610 ± 0.02	0.0586 ± 0.05	0.0609 ± 0.02	0.0545 ± 0.06
Br$(\Lambda_b \to \Lambda_c \mu \bar{\nu}_\tau)$	0.4158 ± 0.62	0.0528 ± 0.29	0.0528 ± 0.29	0.0448 ± 0.38	0.0528 ± 0.29	0.0434 ± 0.22
$A_{FB}^{\Lambda_c}$	0.09 ± 0.006	0.09 ± 0.003	0.09 ± 0.003	0.12 ± 0.027	0.09 ± 0.087	0.102 ± 0.032
R_{Λ_c}	1.156 ± 0.03	1.156 ± 0.04	1.156 ± 0.04	1.306 ± 0.02	1.156 ± 0.03	1.256 ± 0.02
$P_L^{\Lambda_c}$	-0.796 ± 0.02	-0.796 ± 0.08	-0.796 ± 0.08	-0.752 ± 0.06	-0.796 ± 0.06	-0.765 ± 0.09
P_L^{τ}	-0.207 ± 0.01	-0.207 ± 0.32	-0.207 ± 0.32	-0.086 ± 0.08	-0.207 ± 0.03	-0.209 ± 0.05

CASE IIA

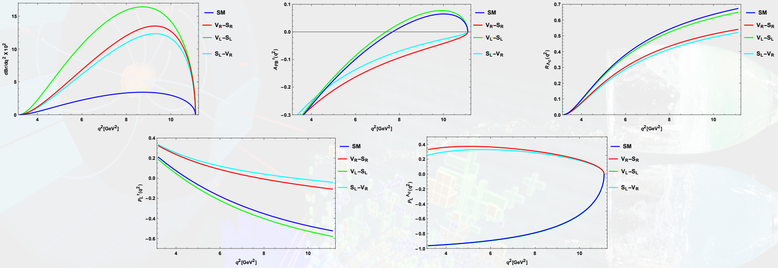


Figure: The branching ratio (top-left), forward-backward asymmetry (top-right), R_{Λ_c} (middle-left), tau (middle-right) and Λ_c (bottom) longitudinal polarization asymmetry of $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ for case IIA.

Observables	SM	(C_{V_R}, C_{S_R})	(C_{V_L}, C_{S_L})	(C_{S_L}, C_{V_R})
Br$(\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau)$	0.0480 ± 0.04	0.121 ± 0.29	0.233 ± 0.45	0.517 ± 0.87
Br$(\Lambda_b \to \Lambda_c \mu \bar{\nu}_\tau)$	0.4158 ± 0.62	0.175 ± 0.32	0.206 ± 0.48	0.637 ± 0.61
$A_{FB}^{\Lambda_c}$	0.09 ± 0.006	0.135 ± 0.06	0.078 ± 0.08	0.152 ± 0.06
R_{Λ_c}	1.156 ± 0.03	0.689 ± 0.08	1.130 ± 0.04	0.811 ± 0.08
$P_L^{\Lambda_c}$	-0.796 ± 0.02	0.292 ± 0.56	-0.797 ± 0.08	0.099 ± 0.05
P_L^{τ}	-0.207 ± 0.02	0.049 ± 0.26	-0.248 ± 0.03	-0.286 ± 0.08

CASE IIB

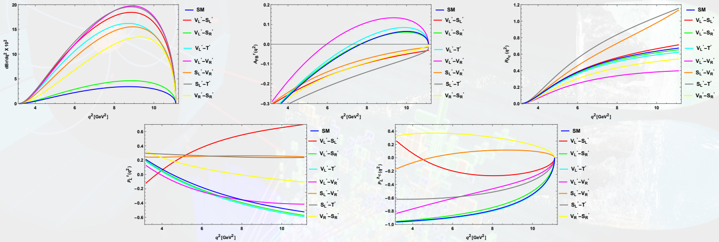


Figure: The branching ratio (top-left), forward-backward asymmetry (top-right), R_{Λ_c} (middle-left), tau (middle-right) and Λ_c (bottom) longitudinal polarization asymmetry of $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ for case IIB, where the plot legends represent diffrent combinations of the new primed coefficients.

Observables	SM	(C'_{V_L}, C'_{S_L})	(C'_{V_L}, C'_{S_R})	(C'_{V_L}, C'_T)	(C'_{V_L}, C'_{V_R})	(C'_{S_L}, C'_{V_R})	(C'_{S_L}, C'_T)	(C'_{V_R}, C'_{S_R})
Br$(\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau)$	0.0480 ± 0.04	0.2917 ± 0.10	0.0620 ± 0.02	0.234 ± 0.18	0.256 ± 0.11	0.165 ± 0.13	0.276 ± 0.25	0.120 ± 0.17
Br$(\Lambda_b \to \Lambda_c \mu \bar{\nu}_\tau)$	0.4158 ± 0.62	0.221 ± 0.13	0.056 ± 0.12	0.210 ± 0.19	0.363 ± 0.34	0.128 ± 0.13	0.159 ± 0.16	0.175 ± 0.13
$A_{FB}^{\Lambda_c}$	0.09 ± 0.006	0.151 ± 0.019	0.083 ± 0.007	0.075 ± 0.004	0.001 ± 0.005	0.104 ± 0.048	0.191 ± 0.019	0.134 ± 0.011
R_{Λ_c}	1.156 ± 0.03	1.318 ± 0.04	1.095 ± 0.02	1.110 ± 0.07	0.712 ± 0.03	1.292 ± 0.02	1.730 ± 0.01	0.688 ± 0.08
$P_L^{\Lambda_c}$	-0.796 ± 0.02	-0.163 ± 0.03	-0.761 ± 0.08	-0.804 ± 0.03	-0.536 ± 0.09	-0.420 ± 0.04	-0.508 ± 0.06	0.291 ± 0.11
P_L^τ	-0.207 ± 0.01	0.445 ± 0.13	-0.247 ± 0.02	-0.256 ± 0.06	-0.240 ± 0.02	-0.342 ± 0.01	0.257 ± 0.11	0.050 ± 0.03

CASE IIC

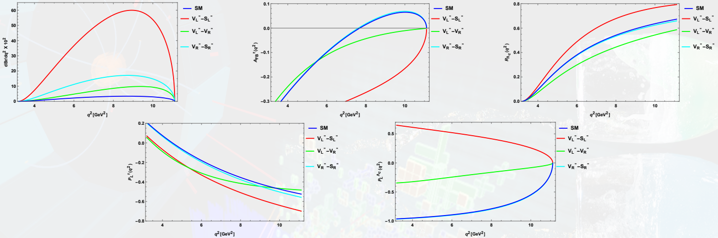
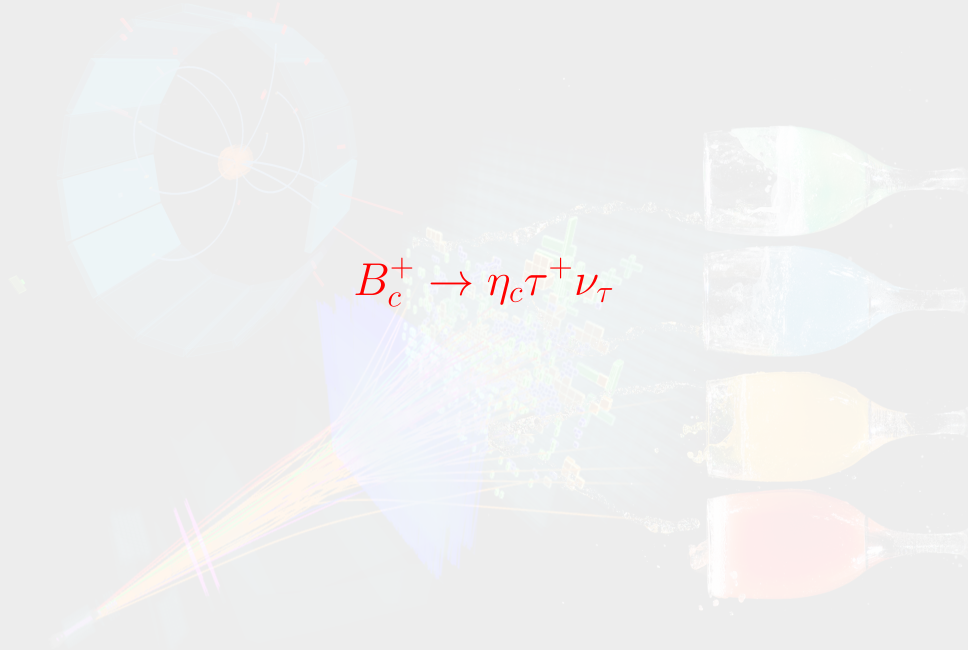


Figure: The branching ratio (top-left), forward-backward asymmetry (top-right), R_{Λ_c} (middle-left), tau (middle-right) and Λ_c (bottom) longitudinal polarization asymmetry of $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ for case IIC.

Observables	SM	(C''_{V_L}, C''_{S_L})	(C''_{V_L}, C''_{V_R})	(C''_{V_R}, C''_{S_R})
Br($\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$)	0.0480 ± 0.04	0.702 ± 0.65	0.092 ± 0.02	0.242 ± 0.29
Br($\Lambda_b \to \Lambda_c \mu \bar{\nu}_\tau$)	0.4158 ± 0.62	0.557 ± 0.74	0.123 ± 0.12	0.211 ± 0.15
$A_{FB}^{\Lambda_c}$	0.09 ± 0.006	0.290 ± 0.026	0.093 ± 0.009	0.087 ± 0.002
R_{Λ_c}	1.156 ± 0.03	1.260 ± 0.04	0.750 ± 0.01	1.147 ± 0.07
$P_L^{\Lambda_c}$	-0.796 ± 0.02	0.445 ± 0.03	-0.190 ± 0.08	-0.803 ± 0.03
P_L^{τ}	-0.207 ± 0.01	-0.381 ± 0.07	-0.331 ± 0.05	-0.224 ± 0.03

conclusion

- In $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ decay channel, we observed that in case I due to the degeneracy of C_{V_L}, C'_{V_L} and C''_{S_R} they provide the same results and show no deviation from the SM for every angular observable.
- For other coefficients, branching ratio, forward-backward asymmetry and LNU parameter give appreciable deviation. In case IIA, all the couplings are showing significant deviation whereas for other observable (C_{V_L}, C_{S_L}) shows very negligible deviation.
- In case IIB, all the seven constraints are revealing an outstanding discrepancies from SM for branching fraction, but for all other observable (C'_{V_L}, C'_{S_R}) and (C'_{V_L}, C'_T) show some marginal deviations.
- In case IIC, we can sense that (C''_{V_L}, C''_{S_L}) shows the maximum deviation for all the observable. Except branching ratio (C''_{V_R}, C''_{S_R}) shows no deviation from SM predictions.



$$B_c^+ \to \eta_c \tau^+ \nu_\tau$$

$B_c^+ \to \eta_c \tau^+ \nu_\tau$

- Including all the new physics operators, the differential decay rate of $B_c^+ \to \eta_c l^+ \nu_l$ processes, where η_c is the pseudo-scalar mesons, with respect to q^2 is given by

$$\frac{d\Gamma(B_c^+ \to \eta_c l^+ \bar{\nu}_l)}{dq^2} = \frac{|V_{cb}|^2 G_F^2}{192\pi^3 M_B^3} q^2 \sqrt{\lambda(q^2)} \left(1 - \frac{m_l^2}{q^2}\right)^2 \tag{9}$$
$$\left\{ \left|1 + C_{V_L}^{\rm eff} + C_{V_R}^{\rm eff}\right|^2 \left[\left(1 + \frac{m_l^2}{2q^2}\right) H_0^2 + \frac{3}{2}\frac{m_l^2}{q^2} H_t^2\right] \right.$$
$$+ \frac{3}{2}\left|C_{S_L}^{\rm eff} + C_{S_R}^{\rm eff}\right|^2 H_S^2 + 8\left|C_T^{\rm eff}\right|^2 \left(1 + \frac{2m_l^2}{q^2}\right) H_T^2$$
$$+3{\rm Re}\left[(1 + C_{V_L}^{\rm eff} + C_{V_R}^{\rm eff})(C_{S_L}^{\rm eff\,*} + C_{S_R}^{\rm eff\,*})\right] \frac{m_l}{\sqrt{q^2}} H_S H_t$$
$$\left. -12{\rm Re}\left[\left(1 + C_{V_L}^{\rm eff} + C_{V_R}^{\rm eff}\right) C_T^{\rm eff\,*}\right] \frac{m_l}{\sqrt{q^2}} H_T H_0 \right\}$$

where $\lambda_\eta = \lambda(M_{B_c}^2, M_\eta^2, q^2)$, M_{B_c} (M_η) is the mass of the B_c (η) meson, m_l is the charged lepton mass and $H_{0,t,S,T}$ are the helicity amplitudes which include the form factors $(F_{0,1,T})$.

CASE I

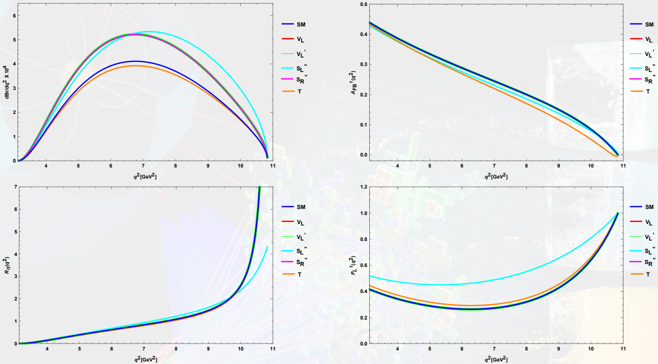


Figure: The branching ratio (left top), forward-backward asymmetry (right top), R_{η_c} (left bottom) and tau longitudinal polarization asymmetry (right bottom) of $B_c^+ \to \eta_c \tau^+ \nu_\tau$ for case I.

Observables	SM	C_{V_L}	C'_{V_L}	C''_{S_L}	C''_{S_R}	C_T
Br$(B_c^+ \to \eta_c \tau^+ \nu_\tau)$	0.0020 ± 0.124	0.0026 ± 0.112	0.0026 ± 0.112	0.0028 ± 0.101	0.0026 ± 0.112	0.0019 ± 0.127
Br$(B_c^+ \to \eta_c \mu^+ \nu_\mu)$	0.0072 ± 0.23	0.0092 ± 0.32	0.0092 ± 0.32	0.0078 ± 0.29	0.0092 ± 0.32	0.0071 ± 0.23
A_{FB}^{η}	1.850 ± 0.028	1.850 ± 0.021	1.850 ± 0.021	1.765 ± 0.024	1.850 ± 0.021	1.678 ± 0.027
R_η	0.284 ± 0.02	0.284 ± 0.01	0.284 ± 0.01	0.353 ± 0.06	0.284 ± 0.01	0.275 ± 0.06
P_L^τ	0.342 ± 0.09	0.342 ± 0.06	0.342 ± 0.06	0.554 ± 0.02	0.342 ± 0.06	0.371 ± 0.04

CASE IIA

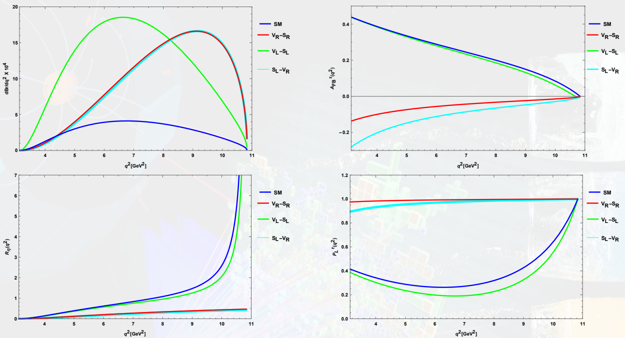


Figure: The branching ratio (top-left), forward-backward asymmetry (top-right), R_{η_c} (bottom-left) and tau longitudinal polarization asymmetry (bottom-right) of $B_c^+ \to \eta_c \tau^+ \nu_\tau$ for case IIA.

Observables	SM	(C_{V_R}, C_{S_R})	(C_{V_L}, C_{S_L})	(C_{S_L}, C_{V_R})
Br$(B_c^+ \to \eta_c \tau^+ \nu_\tau)$	0.0020 ± 0.124	0.0072 ± 0.067	0.0091 ± 0.195	0.0071 ± 0.108
Br$(B_c^+ \to \eta_c \mu^+ \nu_\mu)$	0.0072 ± 0.23	0.0309 ± 0.81	0.0359 ± 0.24	0.0336 ± 0.12
A_{FB}^{η}	1.850 ± 0.028	-0.394 ± 0.016	1.761 ± 0.034	-0.791 ± 0.023
R_η	0.284 ± 0.02	0.234 ± 0.08	0.255 ± 0.03	0.213 ± 0.05
P_L^{τ}	0.342 ± 0.09	0.996 ± 0.02	0.262 ± 0.08	0.985 ± 0.02

CASE IIB

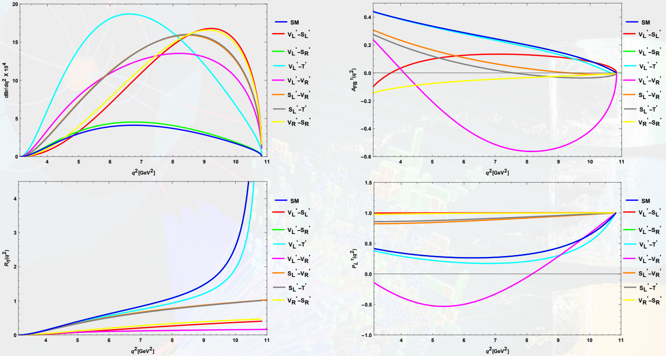


Figure: The branching ratio (top left), forward-backward asymmetry (top right), R_{η_c} (bottom left) and tau longitudinal polarization asymmetry (bottom right) of $B_c^+ \to \eta_c \tau^+ \nu_\tau$ for case IIB.

Observables	SM	(C'_{V_L}, C'_{S_L})	(C'_{V_L}, C'_{S_R})	(C'_{V_L}, C'_T)	(C'_{V_L}, C'_{V_R})	(C'_{S_L}, C'_{V_R})	(C'_{S_L}, C'_T)	(C'_{V_R}, C'_{S_R})
Br$(B_c^+ \to \eta_c \tau^+ \nu_\tau)$	0.0020 ± 0.124	0.0070 ± 0.110	0.0090 ± 0.341	0.0092 ± 0.119	0.0073 ± 0.106	0.0080 ± 0.109	0.0080 ± 0.120	0.0072 ± 0.190
Br$(B_c^+ \to \eta_c \mu^+ \nu_\mu)$	0.0072 ± 0.23	0.0391 ± 0.19	0.0316 ± 0.22	0.0367 ± 0.29	0.095 ± 0.11	0.0196 ± 0.39	0.0196 ± 0.29	0.0301 ± 0.21
A_{FB}^{η}	1.850 ± 0.028	0.698 ± 0.011	1.850 ± 0.019	1.761 ± 0.028	-2.570 ± 0.021	0.707 ± 0.080	0.410 ± 0.012	-0.407 ± 0.039
R_η	0.284 ± 0.02	0.179 ± 0.02	0.284 ± 0.08	0.250 ± 0.06	0.076 ± 0.04	0.415 ± 0.01	0.408 ± 0.05	0.234 ± 0.07
P_L^{τ}	0.342 ± 0.09	0.999 ± 0.03	0.342 ± 0.07	0.242 ± 0.04	-0.052 ± 0.07	0.910 ± 0.08	0.929 ± 0.01	0.995 ± 0.01

CASE IIC

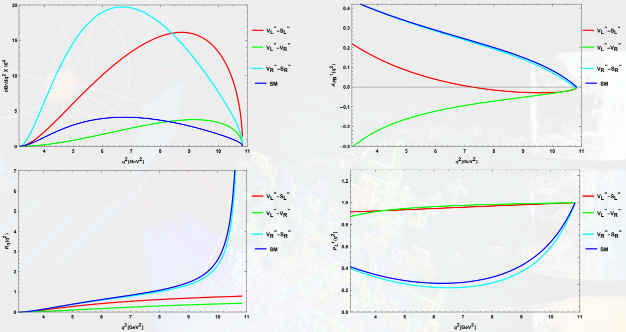


Figure: The branching ratio (top left), forward-backward asymmetry (top right), R_{η_c} (bottom left) and tau longitudinal polarization asymmetry (bottom right) of $B_c^+ \to \eta_c \tau^+ \nu_\tau$ IIC.

Observables	SM	(C''_{V_L}, C''_{S_L})	(C''_{V_L}, C''_{V_R})	(C''_{V_R}, C''_{S_R})
Br$(B_c^+ \to \eta_c \tau^+ \nu_\tau)$	0.0020 ± 0.124	0.0016 ± 0.106	0.0078 ± 0.111	0.0098 ± 0.091
Br$(B_c^+ \to \eta_c \mu^+ \nu_\mu)$	0.0072 ± 0.23	0.0077 ± 0.124	0.0202 ± 0.129	0.0367 ± 0.192
A^η_{FB}	1.850 ± 0.028	0.282 ± 0.061	-0.864 ± 0.012	1.803 ± 0.061
R_η	0.284 ± 0.02	0.209 ± 0.06	0.385 ± 0.09	0.267 ± 0.05
P^τ_L	0.342 ± 0.09	0.967 ± 0.07	0.982 ± 0.01	0.297 ± 0.05

Conclusion

- For $B_c^+ \to \eta_c \tau^+ \nu_\tau$, we observed that in case I C''_{S_L} gives the maximum deviation where as C_T shows a marginal deviation from SM prediction. Other constraints except C''_{S_L} and C_T show no deviation in other angular observable.
- From case IIA we can derive that all the couplings show some significant deviation in case of branching fraction. For forward-backward asymmetry (C_{V_L}, C_{S_L}) display an outstanding deviation and it gives idea about the zero crossing point. In case of LNU parameter (C_{V_L}, C_{S_L}) shows slight deviation but all the other coupling show some standard deviation. In lepton polarization asymmetry (C_{V_L}, C_{S_L}) gives an unique deviation compared to other couplings.
- In case IIB, the deviation coming from (C'_{V_L}, C'_{S_R}) is very negligible. But all other couplings show outstanding discrepancies from the SM prediction for all the angular observable.
- From case IIC, we conclude that (C''_{V_R}, C''_{S_R}) and (C''_{V_L}, C''_{S_L}) show a good deviation in branching ratio, forward-backward and lepton polarization asymmetry. But in LNU parameter (C''_{V_R}, C''_{S_R}) gives very negligible divergence.

$$B \to D^{**}\tau\bar{\nu}_\tau$$
$$D^{**} = (D_0^*, D_1^*, D_1, D_2^*)$$

$B \to D_0^* \ell \bar{\nu}$

For the double differential rates in the SM for the $s_l^\pi = \frac{1}{2}^+$ states $B \to D_0^* \ell \bar{\nu}$, we find

$$\frac{d\Gamma_{D_0^*}}{d\cos\theta dw} = 3\Gamma_0\, r^3 (1 - 2rw + r^2 - \rho_\ell)^2 \sqrt{w^2 - 1} \tag{10}$$

$$\Big\{ \sin^2\theta \, \frac{(w^2-1)[g_+(1+r) - g_-(1-r)]^2 + \rho_\ell [g_-^2 (w-1) + g_+^2 (w+1)]}{(1 - 2rw + r^2)^2}$$

$$+ (1 + \cos^2\theta)\, \rho_\ell \, \frac{[g_-^2 (w-1) + g_+^2 (w+1)](w - 2r + r^2 w) - 2 g_- g_+ (1 - r^2)(w^2 - 1)}{(1 - 2rw + r^2)^3}$$

$$- 2\cos\theta\, \rho_\ell \sqrt{w^2 - 1}\, \frac{[g_+(1+r) - g_-(1-r)]\,[(w-1) g_-(1+r) - (w+1) g_+(1-r)]}{(1 - 2rw + r^2)^3} \Big\}$$

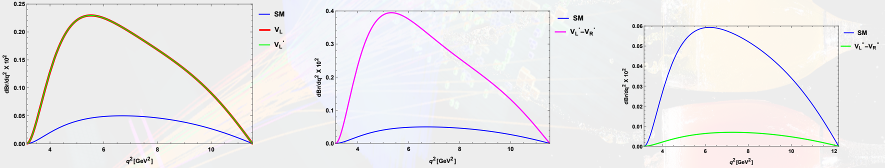


Figure: The branching ratio for case I (left), case IIB (middle) and case IIC (right) of $B \to {D_0}^* \tau \bar{\nu}_\tau$ decay.

$B \to D_1^* \ell \bar{\nu}$

For the double differential rates in the SM for the $s_l^\pi = \frac{1}{2}^+$ state $B \to D_1^* \ell \bar{\nu}$, we find

$$\frac{d\Gamma_{D_1^*}}{d\cos\theta\, dw} = 3\Gamma_0\, r^3 (1 - 2rw + r^2 - \rho_\ell)^2 \sqrt{w^2 - 1} \Bigg\{ \sin^2\theta \left[\frac{[g_{V_1}(w - r) + (g_{V_3} + r g_{V_2})(w^2 - 1)]^2}{(1 - 2rw + r^2)^2} + \right. \tag{11}$$
$$\left. \rho_\ell \frac{g_{V_1}^2 + (w^2 - 1)(2g_A^2 + g_{V_2}^2 + g_{V_3}^2 + 2g_{V_1}g_{V_2} + 2w g_{V_2} g_{V_3})}{2(1 - 2rw + r^2)^2} \right] + (1 + \cos^2\theta) \left[\frac{g_{V_1}^2 + g_A^2 (w^2 - 1)}{1 - 2rw + r^2} + \right.$$
$$\rho_\ell \frac{[g_{V_1}^2 + (w^2 - 1) g_{V_3}^2](2w^2 - 1 + r^2 - 2rw)}{2(1 - 2rw + r^2)^3} + \rho_\ell (w^2 - 1) \frac{2g_{V_1}g_{V_2}(1 - r^2) + 4 g_{V_1} g_{V_3}(w - r)}{2(1 - 2rw + r^2)^3} +$$
$$\left. \rho_\ell (w^2 - 1) \frac{g_{V_2}^2 (1 - 2rw - r^2 + 2r^2 w^2) + 2 g_{V_2} g_{V_3} (w - 2r + r^2 w)}{2(1 - 2rw + r^2)^3} \right] - 2\cos\theta \sqrt{w^2 - 1}$$
$$\left[\frac{2 g_A g_{V_1}}{1 - 2rw + r^2} - \rho_\ell \frac{[g_{V_1}(w - r) + (g_{V_3} + r g_{V_2})(w^2 - 1)]}{(1 - 2rw + r^2)^3} \frac{[g_{V_1} + g_{V_2}(1 - rw) + g_{V_3}(w - r)]}{(1 - 2rw + r^2)^3} \right] \Bigg\}$$

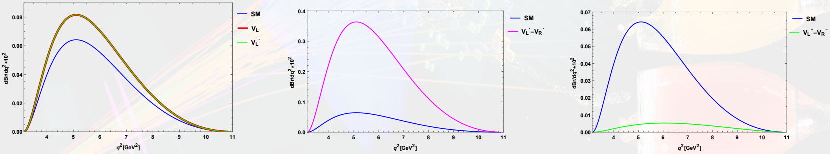


Figure: The branching ratio for case I (left), case IIB (middle) and case IIC (right) of $B \to {D_1}^* \tau \bar{\nu}_\tau$ decay.

$B \to D_1 \tau \bar{\nu}_\tau$

For the double differential rates in the SM for the $s_l^\pi = \frac{3}{2}^+$ states, we obtain

$$\frac{d\Gamma_{D_1}}{d\cos\theta dw} = 3\Gamma_0\, r^3 \sqrt{w^2-1}\,(1-2rw+r^2-\rho_\ell)^2 \Bigg\{ \sin^2\theta \Bigg[\frac{[f_{V_1}(w-r)+(f_{V_3}+rf_{V_2})(w^2-1)]^2}{(1-2rw+r^2)^2} + \rho_\ell \frac{f_{V_1}^2 + (2f_A^2 + f_{V_2}^2 + f_{V_3}^2 + 2f_{V_1}f_{V_2} + 2wf_{V_2}f_{V_3})(w^2-1)}{2(1-2rw+r^2)^2} \Bigg] + (1+\cos^2\theta) \Bigg[\frac{f_{V_1}^2 + f_A^2(w^2-1)}{1-2rw+r^2} + \rho_\ell(w^2-1) \frac{2f_{V_1}f_{V_2}(1-r^2) + 4f_{V_1}f_{V_3}(w-r) + f_{V_2}^2(1-2rw-r^2+2r^2w^2) + 2f_{V_2}f_{V_3}(w-2r+r^2w)}{2(1-2rw+r^2)^3} + \rho_\ell \frac{[f_{V_1}^2 + (w^2-1)f_{V_3}^2](2w^2-1+r^2-2rw)}{2(1-2rw+r^2)^3} \Bigg] - 2\cos\theta\sqrt{w^2-1} \Bigg[\frac{2f_A f_{V_1}}{1-2rw+r^2} - \rho_\ell \frac{[f_{V_1}(w-r)+(f_{V_3}+rf_{V_2})(w^2-1)][f_{V_1}+f_{V_2}(1-rw)+f_{V_3}(w-r)]}{(1-2rw+r^2)^3} \Bigg] \Bigg\} \quad (12)$$

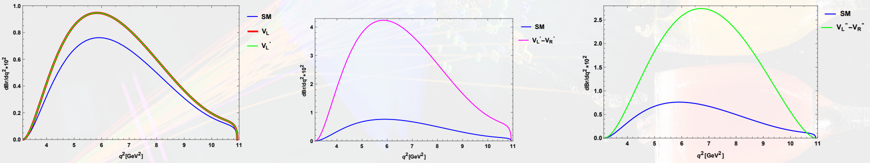


Figure: The branching ratio for case I (left), case IIB (middle) and case IIC (right) of $B \to D_1 \tau \bar{\nu}_\tau$ decay.

$B \to D_2^* \tau \bar{\nu}_\tau$

For the double differential rates in the SM for the $s_l^\pi = \frac{3}{2}^+$ states we obtain

$$\frac{d\Gamma_{D_2^*}}{d\cos\theta\, dw} = \Gamma_0\, r^3 (1+r^2-\rho_\ell-2rw)^2(w^2-1)^{3/2}\Big\{\sin^2\theta\Big[\frac{2[(w-r)k_{A_1}+(w^2-1)(k_{A_3}+rk_{A_2})]^2}{(1-2rw+r^2)^2} + \rho_\ell\frac{3k_{A_1}^2+(w^2-1)(3k_V^2+2k_{A_2}^2+2k_{A_3}^2+4k_{A_1}k_{A_2}+4wk_{A_2}k_{A_3})}{2(1-2rw+r^2)^2}\Big] + (1+\cos^2\theta)\Big[\frac{3}{2}\frac{k_{A_1}^2+k_V^2(w^2-1)}{1-2rw+r^2} + \rho_\ell\frac{[k_{A_1}^2+(w^2-1)k_{A_3}^2](2w^2-1+r^2-2rw)}{(1-2rw+r^2)^3} + \rho_\ell(w^2-1)\frac{2k_{A_1}k_{A_2}(1-r^2)+4k_{A_1}k_{A_3}(w-r)+k_{A_2}^2(1-2rw-r^2+2r^2w^2)+2k_{A_2}k_{A_3}(w-2r+r^2w)}{(1-2rw+r^2)^3}\Big] - 2\cos\theta\sqrt{w^2-1}\Big[\frac{3k_V k_{A_1}}{1-2rw+r^2} - 2\rho_\ell\frac{[k_{A_1}(w-r)+(k_{A_3}+rk_{A_2})(w^2-1)][k_{A_1}+k_{A_2}(1-rw)+k_{A_3}(w-r)]}{(1-2rw+r^2)^3}\Big]\Big\} \quad (13)$$

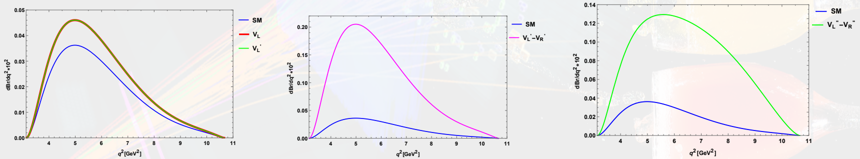


Figure: The branching ratio for case I (left), case IIB (middle) and case IIC (right) of $B \to D_2^* \tau \bar{\nu}_\tau$ decay.

Results and Conclusion

	SM	Case I	Case I	Case IIB	Case IIC
Observables	Values for SM	Values for C_{V_L}	Values for C'_{V_L}	Values for (C'_{V_L}, C'_{V_R})	Values for (C''_{V_L}, C''_{V_R})
Br($B \to D_0^* \tau\bar{\nu}$)	0.0027 ± 0.02	0.0119 ± 0.01	0.0119 ± 0.01	0.0194 ± 0.02	0.00041 ± 0.05
Br($B \to D_1^* \tau\bar{\nu}$)	0.0022 ± 0.05	0.0028 ± 0.07	0.0028 ± 0.07	0.0126 ± 0.05	0.00023 ± 0.08
Br($B \to D_1 \tau\bar{\nu}$)	0.0343 ± 0.04	0.0423 ± 0.06	0.0423 ± 0.06	0.1900 ± 0.04	0.1212 ± 0.08
Br($B \to D_2^* \tau\bar{\nu}$)	0.0012 ± 0.08	0.0016 ± 0.05	0.0016 ± 0.05	0.0072 ± 0.03	0.0060 ± 0.06

Table: Calculated values of branching ratio of $B \to \{D_0^*, D_1^*, D_1, D_2^*\}\tau\bar{\nu}$ process in the SM and in the presence of new complex Wilson coefficients.

- In $B \to D^{**}\tau\bar{\nu}_\tau$ decay channels we manifest that all the vector couplings show extreme deviation as compared to other decay modes.

Conclusion

- Using the best-fit values of the total of 18 constraints extracting from the fitting, we evaluated the branching ratios, forward-backward asymmetries, lepton non-universality parameter, lepton and hadron polarization asymmetries of $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$, $B_c^+ \to \eta_c \tau^+ \nu_\tau$, and $B \to D^{**} \tau \bar{\nu}_\tau$in the full q^2 (in GeV^2) limit.
- We have investigated the sensitivity of the new couplings towards the different angular observables of $b \to c \tau \bar{\nu}_\tau$ transition, where we have taken into consideration two different cases. First case includes the presence of only one new coefficient whereas second case consists of two new coefficients at a time, i.e., unprimed, primed and double primed respectively.
- Coming to an end we can say that we investigated the branching fraction and angular observable of the above decay processes for one and two coefficients at a time for full q^2 range. From these above data we have remarked the sensitivity of new couplings on angular observable which will furnish a clear proposal on the fabric of new physics.

THANK YOU.