Model Independent analysis of $\bar{B}^* \to Pl\bar{\nu}_l$ decay processes

Atasi Ray, Rukmani Mohanta

University of Hyderabad

XXIII DAE-BRNS High Energy Physics Symposium 2018

December 14, 2018

Outline

1. Motivation
2. $B^* \to Pl\bar{\nu}_l$ decay processes
3. Constraints on new couplings
    1. $b \to ul\bar{\nu}_l$ decay processes.
    2. $b \to cl\bar{\nu}_l$ decay processes
4. Effect of NP in various parameters of $B^* \to D^0 l\bar{\nu}_l$ and $B^* \to \pi^0 l\bar{\nu}_l$ decay process
5. Conclusion

Motivation

- Recently several anomalies has observed in the rare semileptonic B decays driven by $b \to (c/s)$ quark level transitions.

Table: List of measured lepton non-universality parameters.

LNU parameters	Experimental value	SM prediction	Deviation
$R_K\|_{q^2\in[1,6]\ \mathrm{GeV}^2}$	$0.745^{+0.090}_{-0.074} \pm 0.036$	1.003 ± 0.0001	2.6σ
$R_{K^*}\|_{q^2\in[0.045,1.1]\ \mathrm{GeV}^2}$	$0.66^{+0.11}_{-0.07} \pm 0.03$	0.92 ± 0.02	2.2σ
$R_{K^*}\|_{q^2\in[1.1,6]\ \mathrm{GeV}^2}$	$0.69^{+0.11}_{-0.07} \pm 0.05$	1.00 ± 0.01	2.4σ
R_D	$0.391 \pm 0.041 \pm 0.028$	0.300 ± 0.008	1.9σ
R_{D^*}	$0.316 \pm 0.016 \pm 0.010$	0.252 ± 0.003	3.3σ
$R_{J/\psi}$	$0.71 \pm 0.17 \pm 0.184$	0.289 ± 0.01	2σ

- In this context we wish to scrutinize the possibility of observing LNU parameters and other asymmetries in various rare semileptonic decay process mediated by $b \to (c, u)$ quark level transitions.

Effective Lagrangian

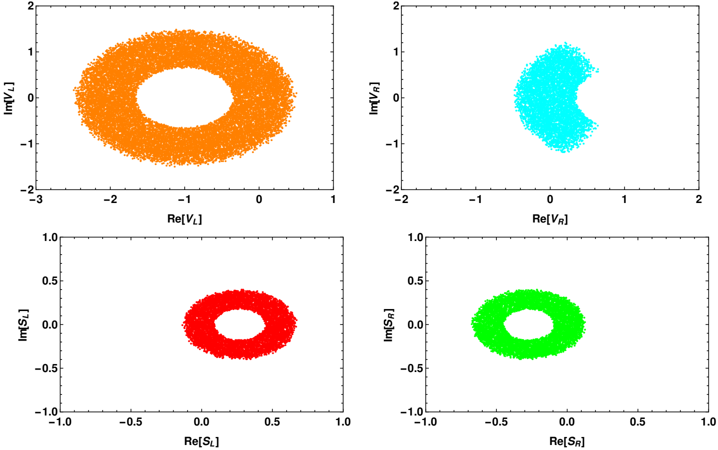
The most effective Lagrangian for $\bar{B}^* \to Pl\bar{\nu}_l$ decay process mediated by $b \to q'$ quark level transition can be expressed in presence of new physics (NP) as,

$$\begin{aligned}\mathcal{L}_{eff} &= -2\sqrt{2}G_F \sum V_{q'b}[(1+V_L)\bar{q}'_L\gamma^\mu b_L \bar{l}_L\gamma_\mu\nu_L \\ &+V_R\bar{q}'_R\gamma^\mu b_R\bar{l}_L\gamma_\mu\nu_L + S_L\bar{q}'_R b_L\bar{l}_R\nu_l \\ &+S_R\bar{q}'_R b_L\bar{l}_R\nu_L + T_L\bar{q}'_R\sigma^{\mu\nu}b_L\bar{l}_R\sigma_{\mu\nu}\nu_L] + h.c.\end{aligned}$$

Where,

- P is a pseudo-scalar meson, G_F is the Fermi constant and $V_{q'b}$ are the CKM matrix elements.
- $(q,l)_{L,R} = \frac{1\pm\gamma_5}{2}(q,l)$, where $\frac{1\pm\gamma_5}{2}$ are the projection operators.
- $V_{L,R}$ and $S_{L,R}$ are the new Wilson coefficients. In SM $V_{L,R} = S_{L,R} = 0$

Constraints on $b \to ul\bar{\nu}_l$ decay process



Constraints on V_L, V_R, S_L, S_R new coefficients associated with $b \to u\tau\bar{\nu}_\tau$ transitions, obtained from $\mathrm{Br}(\mathrm{B}_\mathrm{u}^+ \to \tau^+\nu_\tau)$, $\mathrm{Br}(\mathrm{B} \to \pi\tau\bar{\nu}_\tau)$, R_π^l observables.

Constraint on $b \to cl\bar{\nu}_l$ decay process

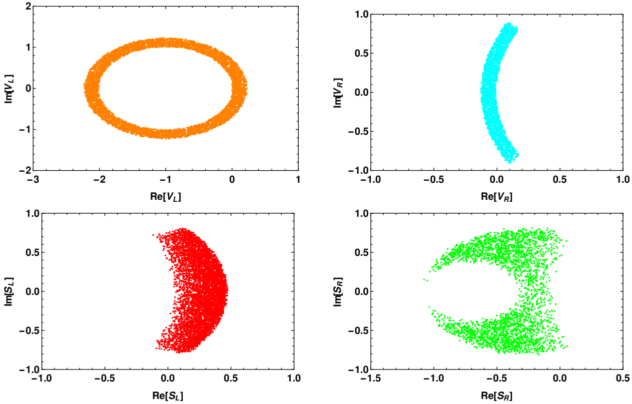


Figure: Constraints on V_L, V_R, S_L, S_R new coefficients associated with $b \to c\tau\bar{\nu}_\tau$ transitions, obtained from $\mathrm{Br}(\mathrm{B}_\mathrm{c}^+ \to \tau^+\nu_\tau)$, $R_{D^{(*)}}$ and $R_{J/\psi}$ observables.

Constraint on new couplings

Table: Allowed ranges of the new coefficients.

Decay Processes	New coefficients	Min. value	Max. Value
$b \to u\tau\bar{\nu}_\tau$	$(\mathrm{Re}[V_L], \mathrm{Im}[V_L])$	$(-2.489, -1.5)$	$(0.504, 1.48)$
	$(\mathrm{Re}[V_R], \mathrm{Im}[V_R])$	$(-0.478, -1.185)$	$(0.645, 1.198)$
	$(\mathrm{Re}[S_L], \mathrm{Im}[S_L])$	$(-0.136, -0.396)$	$(0.672, 0.398)$
	$(\mathrm{Re}[S_R], \mathrm{Im}[S_R])$	$(-0.6743, -0.398)$	$(0.1265, 0.398)$
$b \to c\tau\bar{\nu}_\tau$	$(\mathrm{Re}[V_L], \mathrm{Im}[V_L])$	$(-2.224, -1.228)$	$(0.225, 1.225)$
	$(\mathrm{Re}[V_R], \mathrm{Im}[V_R])$	$(-0.129, -0.906)$	$(0.173, 0.89)$
	$(\mathrm{Re}[S_L], \mathrm{Im}[S_L])$	$(-0.116, -0.788)$	$(0.474, 0.8)$
	$(\mathrm{Re}[S_R], \mathrm{Im}[S_R])$	$(-1.076, -0.809)$	$(0.06, 0.807)$

$\bar{B}^* \to Pl\bar{\nu}_l$ decay processes

The differential decay rate with particular leptonic helicity states ($\lambda = \pm\frac{1}{2}$) can be written as,

$$\frac{d^2\Gamma[\lambda_l = -\frac{1}{2}]}{dq^2 d\cos\theta} = \frac{G_F^2 V_{q'b}^2 p}{256\pi^3 m_{B^*}^2}\frac{1}{3}q^2(1-\frac{m_l^2}{q^2})^2\Big[|1+V_L|^2[(1-\cos\theta)^2 H_{-+}^2 + (1+\cos\theta)^2 H_{+-}^2 + 2\sin^2\theta H_{00}^2 + |V_R|^2[(1-cos\theta)^2 H_{+-}^2 + (1+\cos\theta)^2 H_{-+}^2 + 2\sin^2\theta H_{00}^2] - 4\mathcal{R}e[(1+V_L)V_R^*][(1+\cos\theta)^2 H_{+-}H_{-+} + \sin^2\theta H_{00}^2]\Big]$$

$$\frac{d^2\Gamma[\lambda_l = \frac{1}{2}]}{dq^2 d\cos\theta} = \frac{G_F^2 V_{q'b}^2 p}{256\pi^3 m_{B^*}^2}\frac{1}{3}q^2(1-\frac{m_l^2}{q^2})^2 \times \Big[(|1+V_L|^2 + |V_R|^2) \left[\sin^2\theta(H_{-+}^2 + H_{+-}^2) + 2(H_{0t} - \cos\theta H_{00})^2\right] - 4\mathcal{R}e\left[(|1+V_L|V_R^*)\right]\left[\sin^2\theta H_{-+}H_{+-} + (H_{0t} - \cos\theta H_{00})^2\right] + 4\mathcal{R}e[(1+V_L-V_R)(S_L^* - S_R^*)]\frac{\sqrt{q^2}}{m_l}[H'_{0t}(H_{0t} - \cos\theta H_{00})] \left[\sin^2\theta(H_{-+}^2 + H_{+-}^2) + 2(H_{0t} - \cos\theta H_{00})^2\right] - 4\mathcal{R}e\left[(|1+V_L|V_R^*)\right]\left[\sin^2\theta H_{-+}H+- + (H_{0t} - \cos\theta H_{00})^2\right]$$

$\bar{B}^* \to Pl\bar{\nu}_l$ decay processes

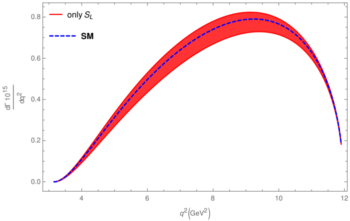
- The differential decay rate can be written explicitly as,

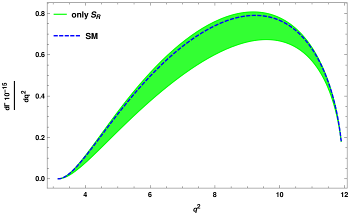
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 V_{q'b}|^2|p|^2}{96\pi^3 m_{B*}^2}\frac{1}{3}q^2(1-\frac{m_l^2}{q^2})^2[(|1+V_L|^2+|V_R|^2)$$
$$[H_{-+}^2+H_{+-}^2+H_{00}^2)(1+\frac{m_l^2}{2q^2})+\frac{3m_l^2}{2q^2}H_{0t}^2]$$
$$-2\mathcal{R}e[(1+V_L)V_R^*][(2H_{-+}H_{+-}+H_{00}^2)(1+\frac{2m_l^2}{2q^2})+\frac{3m_l^2}{2q^2}H_{0t}^2]$$
$$+3\mathcal{R}e[(1+V_L-V_R)(S_L^*-S_R^*)H_{0t}'H_{0t}\frac{m_l}{\sqrt{q^2}}+\frac{3}{2}|S_L-S_R|^2H_{0t}']$$

Where, $H_{(+-,-+,00,0t)}$ are the helicity amplitudes which are the functions of form factors.

- The Lepton non-universality parameter is defined as, $R_P^*(q^2) = \frac{d\Gamma(B^*\to P\tau^-\bar{\nu_\tau})/dq^2}{d\Gamma(B^*\to Pl'^-\bar{\nu_{l'}})/dq^2}$
- Lepton spin asymmetry parameter: $A_\lambda^P(q^2) = \frac{d\Gamma[\lambda_l=-1/2]/dq^2-d\Gamma[\lambda_l=1/2]/dq^2}{d\Gamma[\lambda_l=-1/2]/dq^2+d\Gamma[\lambda_l=1/2]/dq^2}$

$\bar{B}^* \to D^0 l \bar{\nu}_l$ decay process



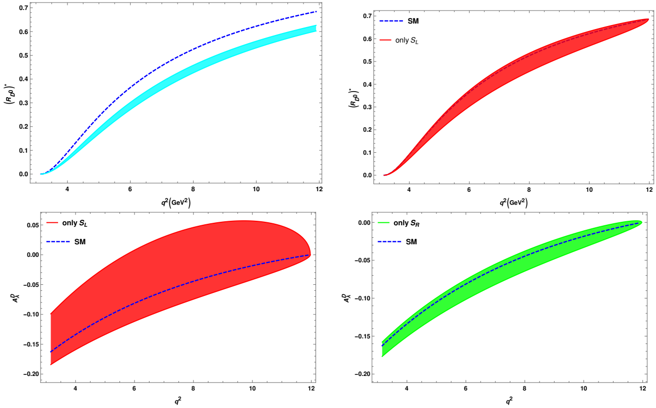


The differential decay rates in presence of various new coefficients are,

- In presence of V_L only: $2.0608 \times 10^{-14} \to 2.05402 \times 10^{-14}$
- In presence of V_R only: $1.91578 \times 10^{-14} \to 1.95402 \times 10^{-14}$
- In presence of S_R only: $3.44565 \times 10^{-15} \to 4.77632 \times 10^{-15}$

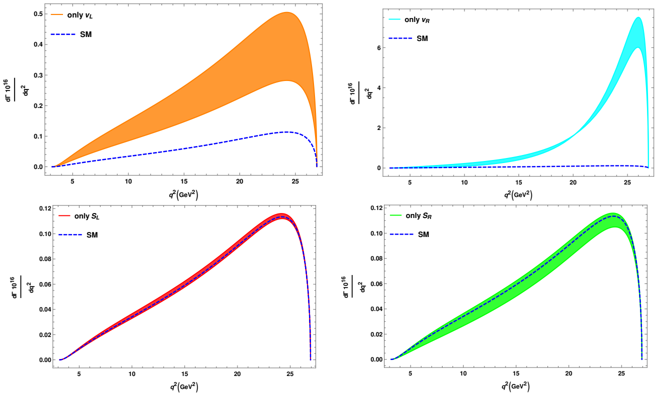
These values shows significant variation from the corresponding SM value, 4.61326×10^{-15}

$\bar{B}^* \to D^0 l \bar{\nu}_l$ decay process



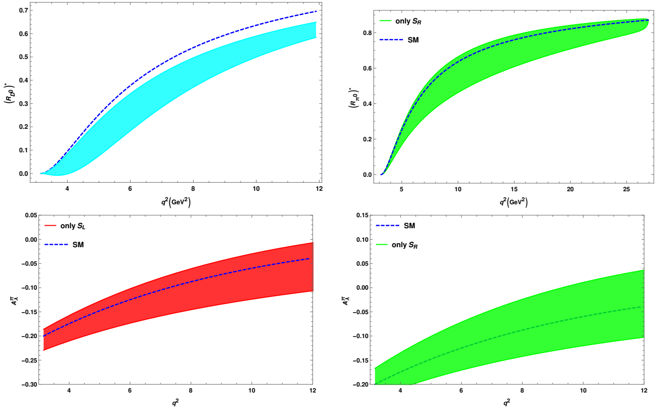
q^2 variation of R_D^* in presence of V_R coefficient only (top-left panel), S_L coefficient only (top-right panel) and q^2 variation of A_λ^D in presence of S_L coefficient only(bottom-left panel), S_R coefficient only(bottom-right panel).

$\bar{B}^* \to \pi^0 l \bar{\nu}_l$ decay process



q^2 variation of Branching ratio in presence of V_L coefficient only(top-left panel), V_R coefficient only(top-right panel), S_L coefficient only(bottom-left panel), S_R coefficient only(bottom-right panel).

$\bar{B}^* \to \pi^0 l \bar{\nu}_l$ decay process



q^2 variation of $R^*_{\pi^0}$ in presence of V_R coefficient only(top-left panel),S_R coefficient only(top-right panel), q^2 variation of A^π_λ in presence of S_L coefficient only(bottom-left panel), S_R coefficient only(bottom-right panel).

Conclusion

- We have studied $\bar{B}^* \to Pl\bar{\nu}_l$ decay process in a model independent way.
- We considered the new couplings to be complex. Considering one coefficient at a time the allowed parameter space of the new coefficients was obtained.
- In presence of individual complex Wilson coefficient we have studied their effects on various parameters associated with $\bar{B}^* \to Pl\bar{\nu}_l$ decay processes.
- We have shown the q^2 variation of Branching ratio, LNU parameter and Lepton spin asymmetry in presence of NP.

Thank You!!