New physics sensitivity in $\Lambda_b \to (\Lambda^*(\to pK^-), \Lambda(\to p\pi))\,(\mu^+\mu^-,\, \nu\bar{\nu})$ baryonic decays

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Introduction

- Measurements of various LFU observables in $b \to s\,l^+l^-$ decays continue to disagree with the SM.
- The $b \to s\,l^+l^-$ and $b \to s\,\nu\bar{\nu}$ decays are closely related not only in SM but also in BSM.
- In BSM these decays are related via $SU(2)_L$ gauge symmetry which relates neutrinos to the left handed charged leptons.
- The B decays with $\nu\bar{\nu}$ final state are theoretically cleaner as they do not suffer from hadronic uncertainties beyond the form factors such as the non-factorizable corrections and photonic penguin contributions.
- Hence, we explore $\Lambda_b \to (\Lambda^*(\to pK^-), \Lambda(\to p\pi))\mu^+\mu^-$ and $\Lambda_b \to (\Lambda^*(\to pK^-), \Lambda(\to p\pi))\nu\bar{\nu}$ decays under SMEFT framework.

	q^2 bins	Theoretical predictions	Experimental measurements	Deviation
R_K	[1.1, 6.0]	1 ± 0.01	$0.846^{+0.044}_{-0.041}$	$\sim 3.1\sigma$
$R_{K_S^0}$	[1.1, 6.0]	1 ± 0.01	$0.66^{+0.20}_{-0.14}$ (stat) $^{+0.02}_{-0.04}$ (syst)	$\sim 1.4\sigma$
R_{K^*}	[0.045, 1.1]	1 ± 0.01	$0.660^{+0.110}_{-0.070}$ (stat) ± 0.024 (syst)	$\sim 2.2 - 2.5\sigma$
		1 ± 0.01	$0.52^{+0.36}_{-0.26}$ (stat) ± 0.05 (syst)	
	[1.1, 6.0]	1 ± 0.01	$0.685^{+0.113}_{-0.069}$ (stat) ± 0.047 (syst)	
		1 ± 0.01	$0.96^{+0.45}_{-0.29}$ (stat) ± 0.11 (syst)	
$R_{K^{*+}}$	[0.045, 6.0]	1 ± 0.01	$0.70^{+0.18}_{-0.13}$ (stat) $^{+0.03}_{-0.04}$ (syst)	$\sim 1.5\sigma$
P_5'	[4.0, 6.0]	-0.757 ± 0.074	-0.21 ± 0.15	$\sim 3.3\sigma$
	[4.3, 6.0]	$-0.774^{+0.0.061+0.087}_{-0.059-0.093}$	$-0.96^{+0.22}_{-0.21}$ (stat) ± 0.16 (syst)	$\sim 1.0\sigma$
	[4.0, 8.0]	-0.881 ± 0.082	$-0.267^{+0.275}_{-0.269}$ (stat) ± 0.049 (syst)	$\sim 2.1\sigma$
$\mathcal{B}(B_s \to \phi\,\mu^+\mu^-)$	[1.1, 6.0]	$(5.37 \pm 0.66) \times 10^{-8}$	$(2.88 \pm 0.22) \times 10^{-8}$	$\sim 3.6\sigma$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$(3.66 \pm 0.14) \times 10^{-9}$	$(3.09^{+0.46+0.15}_{-0.43-0.11}) \times 10^{-9}$	-
$\mathcal{B}(B^+ \to K^+\nu\nu)$	-	$(4.4 \pm 0.07) \times 10^{-6}$	$< 1.6 \times 10^{-5}$ $< 4.1 \times 10^{-5}$	-
$\mathcal{B}(B^0 \to K^0\nu\nu)$	-	$(4.1 \pm 0.05) \times 10^{-6}$	$< 2.6 \times 10^{-5}$	-
$\mathcal{B}(B^0 \to K^{0*}\nu\nu)$	-	$(9.5 \pm 0.09) \times 10^{-6}$	$< 1.8 \times 10^{-5}$	-
$\mathcal{B}(B^+ \to K^{+*}\nu\nu)$	-	$(10 \pm 1) \times 10^{-6}$	$< 4.0 \times 10^{-5}$	-

Table 1: Current status of $b \to sl^+l^-$

Theory

The effective Hamiltonian for $b \to s\,(l^+l^-, \nu\bar{\nu})$ decays [1],

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2} \sum_i C_i \mathcal{O}_i + h.c., \tag{1}$$

For $i = L, R$, the sum include the operators $\mathcal{O}_{L,R}$ contributing to $b \to s\,\nu\,\bar{\nu}$ decays where,

$$\mathcal{O}_L = (\bar{s}\gamma_\mu P_L b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu), \quad \mathcal{O}_R = (\bar{s}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu). \tag{2}$$

Here, $C_L = C_L^{SM} + C_L^{NP}$ with $C_L^{SM} = -6.38 \pm 0.06$ being the SM Wilson coefficient and $C_R = 0$ in SM. Similarly, for $i = 9, 10$ the sum include the operators $\mathcal{O}_{9,10}^{(\prime)}$ contributing to $b \to s\,l^+l^-$ decays where,

$$\mathcal{O}_L = (\bar{s}\gamma_\mu P_L b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu), \quad \mathcal{O}_R = (\bar{s}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu(1-\gamma_5)\nu). \tag{3}$$

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$$\mathcal{O}_9^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{l}\gamma^\mu l), \quad \mathcal{O}_{10}^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{l}\gamma^\mu\gamma_5 l). \tag{4}$$

Starting from the effective Hamiltonian one can construct the various physical observable for $\Lambda_b \to \Lambda^*(\to pK^-)l^+l^-$ is defined as

$$\frac{d\mathcal{B}}{dq^2} = \frac{1}{3}\Big[K_{1cc} + 2K_{1ss} + 2K_{2cc} + 4K_{2ss} + 2K_{3ss}\Big].$$

$$F_L = 1 - \frac{2(K_{1cc} + 2K_{2cc})}{K_{1cc} + 2(K_{1ss} + K_{2cc} + 2K_{2ss} + K_{3ss})} \tag{5}$$

$$A_{\rm FB}^{\ell} = \frac{3(K_{1c} + 2K_{2c})}{2\big[K_{1cc} + 2(K_{1ss} + K_{2cc} + 2K_{2ss} + K_{3ss})\big]}.$$

- Similarly, for $\Lambda_b \to \Lambda(\to p\pi)l^+l^-$ is defined as

$$\frac{d\mathcal{B}}{dq^2} = 2K_{1ss} + K_{1cc} \qquad F_L = \frac{2K_{1ss} - K_{1cc}}{2K_{1ss} + K_{1cc}} \qquad A_{\rm FB}^{\ell} = \frac{3}{2}\frac{K_{1c}}{2K_{1ss} + K_{1cc}}.$$

For the $\Lambda_b \to (\Lambda(\to p\pi), \Lambda^*(\to pK^-))\nu\bar{\nu}$ we replaced $m_l = 0$ and calculate the different physical observable. We make use of lattice QCD form factor inputs for both channels[2,3]. Here K_i's are the angular coefficient.

Results and Discussions

- The WC $C_{9^{(\prime)},10^{(\prime)}}$ of $b \to s\,\mu^+\mu^-$ and C_L, C_R of $b \to s\,\nu\,\bar{\nu}$ are defined in terms of SMEFT coefficient [1]

$$\begin{aligned}
C_9 &= C_9^{\rm SM} + \tilde{c}_{qe} + \tilde{c}_{ql}^{(1)} + \tilde{c}_{ql}^{(3)} - \zeta\tilde{c}_Z \\
C_{10} &= C_{10}^{\rm SM} + \tilde{c}_{qe} - \tilde{c}_{ql}^{(1)} - \tilde{c}_{ql}^{(3)} + \tilde{c}_Z \\
C_L^{\nu} &= C_L^{\rm SM} + \tilde{c}_{ql}^{(1)} - \tilde{c}_{ql}^{(3)} + \tilde{c}_Z \\
C_9' &= \tilde{c}_{de} + \tilde{c}_{dl} - \zeta\tilde{c}_Z' \\
C_{10}' &= \tilde{c}_{de} - \tilde{c}_{dl} + \tilde{c}_Z' \\
C_R^{\nu} &= \tilde{c}_{dl} + \tilde{c}_Z'
\end{aligned} \tag{6}$$

- NP considered in the left handed WC $C_{9,10}$ and right handed WC $C_{9',10'}$ in $b \to s\,\mu^+\mu^-$.
- We refer to [4] for the SMEFT best fits results. The fits are obtained by fitting the recent $b \to sll$ data.
- We consider two best NP scenarios $(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$ = (-3.824, -4.905) and $(\tilde{c}_Z, \tilde{c}_Z')$ = (4.560, -3.938)

	$\Lambda_b \to \Lambda^*(\to pK^-)\mu^+\mu^-$[16.0 - 16.8]		
Observables	SM	$(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$	$(\tilde{c}_Z, \tilde{c}_Z')$
$BR \times 10^{-9}$	0.645 ± 0.045	0.261 ± 0.017	0.475 ± 0.032
F_L	0.378 ± 0.031	0.414 ± 0.030	0.384 ± 0.030
A_{FB}	-0.048 ± 0.033	0.043 ± 0.004	0.022 ± 0.002
	$\Lambda_b \to \Lambda^*(\to pK^-)\nu\bar{\nu}$		
Observables	SM	$(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$	$(\tilde{c}_Z, \tilde{c}_Z')$
$BR \times 10^{-10}$	(1.037 ± 0.759)	0.305 ± 0.018	0.209 ± 0.012
F_L	0.385 ± 0.033	0.536 ± 0.0275	0.510 ± 0.002
	$\Lambda_b \to \Lambda(\to p\pi)\nu\bar{\nu}$		
Observables	SM	$(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$	$(\tilde{c}_Z, \tilde{c}_Z')$
$BR \times 10^{-6}$	(1.798 ± 0.133)	1.036 ± 0.096	0.651 ± 0.058
F_L	0.472 ± 0.028	0.589 ± 0.039	0.578 ± 0.038

Table 2: $\Lambda_b \to (\Lambda^*(\to pK^-))\mu^+\mu^-$ and $\Lambda_b \to (\Lambda^*(\to pK^-), \Lambda(\to p\pi))\nu\bar{\nu}$ decay within the SM and 2D NP scenario.

	$\Lambda_b \to \Lambda(\to p\pi)\mu^+\mu^-$			
Observables		SM	$(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$	$(\tilde{c}_Z, \tilde{c}_Z')$
$BR \times 10^{-7}$	[0.1 - 6.0]	1.210 ± 0.181	0.995 ± 0.131	0.972 ± 0.146
	[14.2 - 20.83]	4.208 ± 0.263	2.263 ± 0.121	3.005 ± 0.184
F_L	[0.1 - 6.0]	0.759 ± 0.040	0.644 ± 0.050	0.749 ± 0.040
	[14.2 - 20.83]	0.355 ± 0.013	0.383 ± 0.014	0.366 ± 0.014
A_{FB}	[0.1 - 6.0]	-0.040 ± 0.027	0.062 ± 0.026	0.027 ± 0.022
	[14.2 - 20.83]	-0.317 ± 0.012	0.055 ± 0.005	0.017 ± 0.003

Table 3: $\Lambda_b \to (\Lambda(\to p\pi))\mu^+\mu^-$ decay within the SM and 2D NP scenario.

- BR of $\Lambda_b \to \Lambda^*(\to pK^-)\mu^+\mu^-$ and $\Lambda_b \to \Lambda(\to p\pi)\mu^+\mu^-$ is found to be in the $\mathcal{O}(10^{-9})$ and $\mathcal{O}(10^{-7})$.

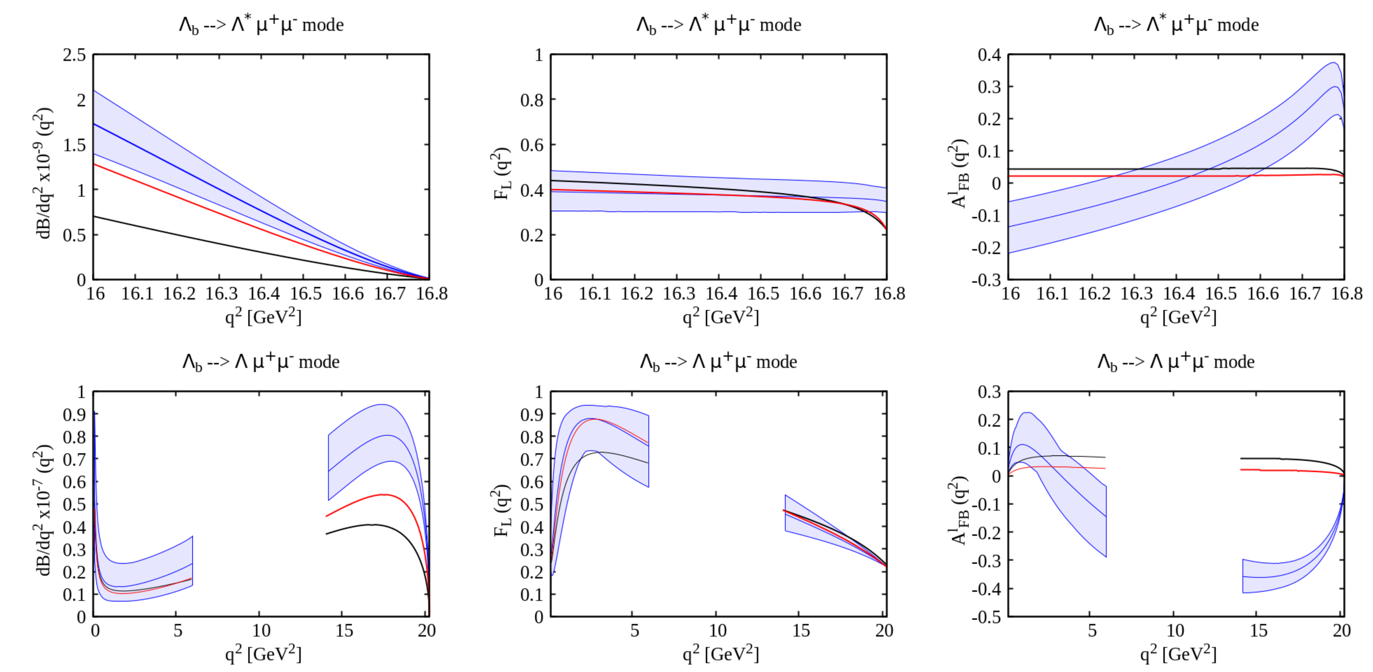

Figure 1: q^2 plots of $\Lambda_b \to (\Lambda(\to p\pi), \Lambda^*(\to pK^-))\mu^+\mu^-$ in SM (blue) and $(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$(black), $(\tilde{c}_Z, \tilde{c}_Z')$(red))

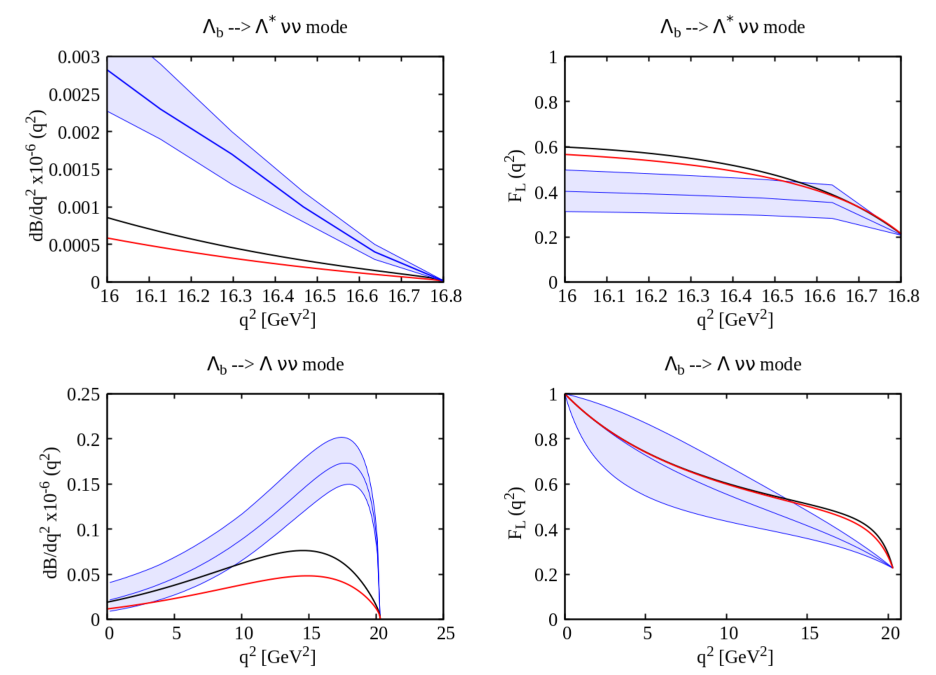

Figure 2: q^2 plots of $\Lambda_b \to (\Lambda(\to p\pi), \Lambda^*(\to pK^-))\nu\bar{\nu}$ within SM (blue) and $(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$(black) , $(\tilde{c}_Z, \tilde{c}_Z')$(red)

- $(\tilde{c}_{ql}^{(3)}, \tilde{c}_Z')$:
  - BR: Deviated $> 5\sigma$ in all four decay mode except in the low region of $\Lambda_b \to \Lambda(\to p\pi)\,\mu^+\mu^-$
  - F_L: No significant deviation except for $\Lambda_b \to \Lambda^*(\to pK^-)\,\nu\bar{\nu}$ with $> 3\sigma$.
  - A_{FB}: Exhibit very different behaviour from SM
- $(\tilde{c}_Z, \tilde{c}_Z')$:
  - BR: is deviated more than 3σ in di-muon channels and $> 5\sigma$ in di-neutrino decay channels except in the low region of $\Lambda_b \to \Lambda(\to p\pi)\,\mu^+\mu^-$.
  - F_L: No significant deviation except for $\Lambda_b \to \Lambda^*(\to pK^-)\,\nu\bar{\nu}$ with $> 3\sigma$
  - A_{FB}: Exhibits very different behaviour than SM

Conclusion

- We see the consequences of latest $b \to s\,\mu^+\mu^-$ experimental data on $\Lambda_b \to (\Lambda^*(\to pK^-), \Lambda(\to p\pi))\,(\mu^+\mu^-,\, \nu\bar{\nu})$ baryonic decays.
- In the ongoing work, we are trying to examine the various 1D and 2D NP hypothesis and also the implications of right handed currents in $b \to sl^+l^-$ and $b \to s\nu\bar{\nu}$ baryonic decays under SMEFT approach.
- Measurements of $\Lambda_b \to (\Lambda^*(\to pK^-), \Lambda(\to p\pi))\,(\mu^+\mu^-,\, \nu\bar{\nu})$ in future may help to identify possible NP in $b \to sl^+l^-$ decays.

References

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