Impact of nonleptonic $\bar{B}_{d,s}$ decay modes on $\bar{B}_{d,s} \to \bar{V}\ell^+\ell^-$ processes

Manas K. Mohapatra[1], Suchismita Sahoo[2] and Anjan K. Giri[1]

[1] Indian Institute of Technology, Hyderabad, India
[2] Physical Research Laboratory, Ahmedabad, India

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Outline

Anomalies in B sector

- $B \to \pi K$ puzzle
- 3σ deviation in the decay rate and P_5' angular observable of $\bar{B} \to \bar{K}^* l^+ l^-$ decay modes.
- Discrepancy of 3.3σ in the decay rate of $B_s \to \phi\mu^+\mu^-$ process in the high recoil limit.
- Observation of the violation of lepton universality in B decays.

LNU parameters	Expt. Results	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

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Effective Hamiltonian (Nonleptonic)

- The SM effective Hamiltonian describing the decay mode $b \to sq\bar{q}$ transition is given as

$$H_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{ub} V_{us}^* (C_1 \mathcal{O}_1 + C_2 \mathcal{O}_2) - V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i \mathcal{O}_i \,. \qquad (1)$$

- The effective Hamiltonian in the Z' model is

$$H_{\rm eff}^{Z'} = \frac{-2G_F}{\sqrt{2}} V_{tb} V_{tq}^* \left(\frac{g' M_Z}{g_1 M_Z'}\right)^2 \left[\frac{-B_{sb}^L B_{qq}^L}{V_{tb} V_{tq}^*} (\bar{s}b)_{V-A} (\bar{q}q)_{V-A} - \frac{B_{sb}^L B_{qq}^R}{V_{tb} V_{tq}^*} (\bar{s}b)_{V-A} (\bar{q}q)_{V+A}\right] + h.c \qquad (2)$$

- This will contribute additional Wilson coefficients to SM as

$$C_9^{Z'} = -2 \left(\frac{g' M_Z}{g_1 M_{Z'}}\right)^2 \frac{B_{sb}^L (B_{qq}^L + B_{qq}^R)}{V_{tb} V_{ts}^*},$$
$$C_{10}^{Z'} = 2 \left(\frac{g' M_Z}{g_1 M_{Z'}}\right)^2 \frac{B_{sb}^L (B_{qq}^L - B_{qq}^R)}{V_{tb} V_{ts}^*} \qquad (3)$$

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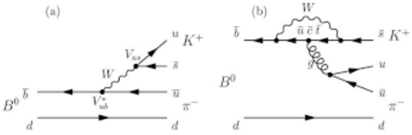
Constraint on new couplings

We constrain the new couplings from the branching ratios of following nonleptonic decay modes

- $\bar{B}_d \to \pi K$
- $\bar{B}_d \to K\rho$
- $\bar{B}_s \to \eta'\eta'$
- $\bar{B}_s \to \phi\phi$
- $\bar{B}_s \to K^{0^*}\bar{K}^{0^*}$

$\bar{B}_d \to \pi^+ K^-$

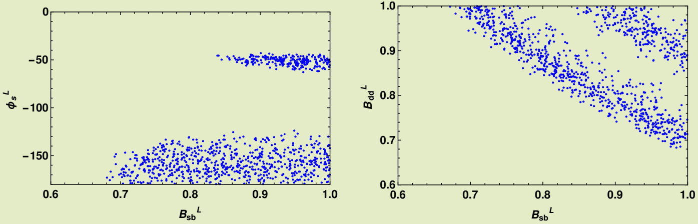


- The amplitude of $\bar{B}_d \to \pi^+ K^-$ decay is given as

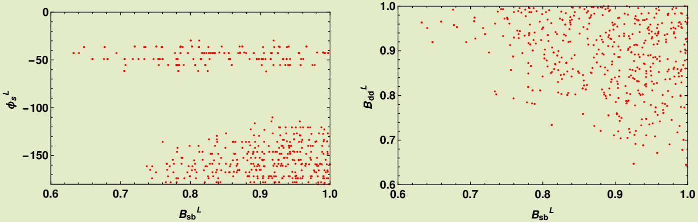
$$\mathcal{M} \;=\; \frac{G_F}{\sqrt{2}}\Big[V_{ub}V_{us}^* a_1 - V_{tb}V_{ts}^*\{a_4 + a_{10} + 2(a_6+a_8)\frac{m_{K^-}^2}{(m_b-m_u)(m_u+m_s)}\}\Big] X^{(\bar{B}_d^0\pi^+, K^-)}$$

$$- V_{tb}V_{ts}^*\Big[a_4 - \frac{a_{10}}{2} + (2a_6 - a_8)\frac{m_{\bar{B}_d^0}^2}{(m_b+m_d)(m_s-m_d)}\Big] X^{(\bar{B}_d^0,\pi^+ K^-)} \qquad (4)$$

Case A : $B^R_{qq} = 0$



Case B : $B^R_{qq} = B^L_{qq}$



$B_s - \bar{B}_s$ mixing

- The effective hamiltonian in SM

$$H_{\text{eff}} = \frac{G_F^2}{16\pi^2} M_W^2 (V_{tb} V_{ts}^*)^2 C_{LL}(\mu) O^{LL} + h.c \tag{5}$$

- The mixing amplitude, corrected up to NLO in QCD

$$M_{12}^{\text{SM}} = \frac{G_F^2}{12\pi^2} M_W^2 \, (V_{tb} V_{ts})^2 \, (\hat{B}_{B_s} f_{B_s}^2) M_{B_s} \eta_B S_0(X_t) [\alpha_s(\mu_b)]^{-\frac{\gamma_Q^0}{2\beta_0}} \left[1 + \frac{\alpha_s(\mu_b)}{4\pi}\right] J_5 \tag{6}$$

- The effective hamiltonian in non universal Z' model is

$$H_{\text{eff}}^{Z'} = \frac{G_F}{\sqrt{2}} (\frac{g' M_Z}{g_1 M_{Z'}} B_{sb}^L)^2 O^{LL}(m_b) \tag{7}$$

- The mixing amplitude due to additional Z' gauge boson,

$$M_{12}^{Z'} = \frac{G_F}{\sqrt{2}} |\rho_s^L|^2 \exp^{2I\phi_s^L} \frac{8}{3} (\hat{B}_{B_s} f_{B_s}^2) [\frac{\alpha_s(\mu_W)}{\alpha_s(\mu_b)}]^{\frac{-\gamma_Q^{(0)}}{2\beta_0}}][1 + \frac{\alpha(\mu_b) - \alpha(\mu_W)}{4\pi} J_5] \tag{8}$$

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Effective Hamiltonian (Semileptonic)

- The effective Hamiltonian responsible for $b \to sll$ decay modes is given by

$$H_{\rm eff} = \frac{-G_F}{\sqrt{2}} \lambda_t \left[C_1 \mathcal{O}_1^c + C_2 \mathcal{O}_2^c + \sum_{i=1}^{10} C_i \mathcal{O}_i \right] \quad (9)$$

- In the Z' model, the effective Hamiltonian is

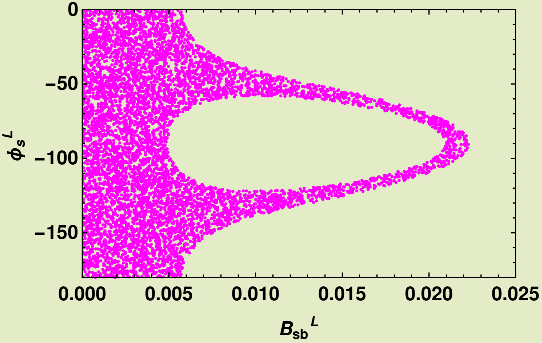
$$H_{\rm eff}^{Z'} = \frac{-2G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left(\frac{g' M_Z}{g_1 M_{Z'}} \right)^2 \left[\frac{-B_{sb}^L B_{\ell\ell}^L}{V_{tb} V_{tq}^*} (\bar{s}b)_{V-A} (\bar{\ell}\ell)_{V-A} - \frac{B_{sb}^L B_{\ell\ell}^R}{V_{tb} V_{tq}^*} (\bar{s}b)_{V-A} (\bar{\ell}\ell)_{V+A} \right] + h.c \quad (10)$$

- This will contribute new Wilson coefficients

$$C_9^{Z'} = -2 \left(\frac{g' M_Z}{g_1 M_{Z'}} \right)^2 \frac{B_{sb}^L \left(B_{\ell\ell}^L + B_{\ell\ell}^R \right)}{V_{tb} V_{ts}^*},$$

$$C_{10}^{Z'} = 2 \left(\frac{g' M_Z}{g_1 M_{Z'}} \right)^2 \frac{B_{sb}^L \left(B_{\ell\ell}^L - B_{\ell\ell}^R \right)}{V_{tb} V_{ts}^*} \quad (11)$$

Constraint from All discussed processes



Effects on $\bar{B}_{(s)} \to K^*(\phi)\mu^+\mu^-$ processes

The differential decay distribution of $\bar{B} \to \bar{K}^* l^+ l^-$ process is given by

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} J\left(q^2, \theta_l, \theta_{K^*}, \phi\right), \qquad (12)$$

where

$$\begin{aligned} J\left(q^2, \theta_l, \theta_{K^*}, \phi\right) &= J_1^s \sin^2\theta_{K^*} + J_1^c \cos^2\theta_{K^*} + \left(J_2^s \sin^2\theta_{K^*} + J_2^c \cos^2\theta_{K^*}\right)\cos 2\theta_l \\ &+ J_3 \sin^2\theta_{K^*} \sin^2\theta_l \cos 2\phi + J_4 \sin 2\theta_{K^*} \sin 2\theta_l \cos\phi + J_5 \sin 2\theta_{K^*} \sin\theta_l \cos\phi \\ &+ (J_6^s \sin^2\theta_{K^*} + J_6^c \cos^2\theta_{K^*}) \cos\theta_l + J_7 \sin 2\theta_{K^*} \sin\theta_l \sin\phi \\ &+ J_8 \sin 2\theta_{K^*} \sin 2\theta_l \sin\phi + J_9 \sin^2\theta_{K^*} \sin^2\theta_l \sin 2\phi\,, \qquad (13) \end{aligned}$$

Anomalies

- Zero crossing of forward backward asymmetry
- polarization asymmetry
- form factor independent observables, $(P_{1,..,6,8}, P'_{4,5,6,8})$

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Observables

- Forward backward asymmetry

$$A_{FB}\left(q^2\right) = \left[\int_{-1}^{0} d\cos\theta_l \frac{d^2\Gamma}{dq^2 d\cos\theta_l} - \int_{0}^{1} d\cos\theta_l \frac{d^2\Gamma}{dq^2 d\cos\theta_l}\right] \Big/ \frac{d\Gamma}{dq^2}$$
$$= -\frac{3}{8}\frac{J_6}{d\Gamma/dq^2}\,. \qquad (14)$$

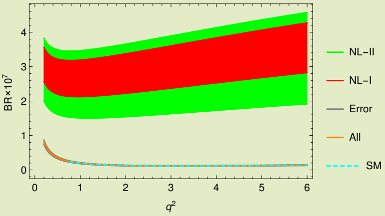
- Polarization asymmetry

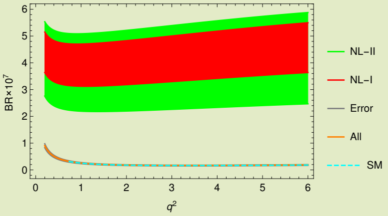
$$F_L\left(q^2\right) = \frac{3J_1^c - J_2^c}{4d\Gamma/dq^2}\,, \qquad F_T\left(q^2\right) = 1 - F_L(q^2)\,. \qquad (15)$$

- Form factor independent observables

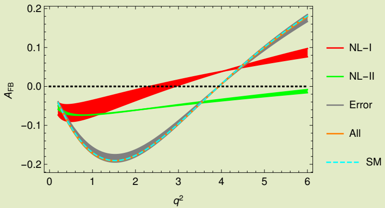
$$P_1\left(q^2\right) = \frac{J_3}{2J_2^s}\,, \qquad P_2\left(q^2\right) = \beta_l\frac{J_6^s}{8J_2^s}\,, \qquad P_3\left(q^2\right) = -\frac{J_9}{4J_2^s}\,.$$
$$P_4' \equiv P_4\sqrt{1-P_1}\,, \quad P_5' \equiv P_5\sqrt{1+P_1}\,, \quad P_{6,8}' \equiv P_{6,8}\sqrt{1-P_1}\,. \qquad (16)$$

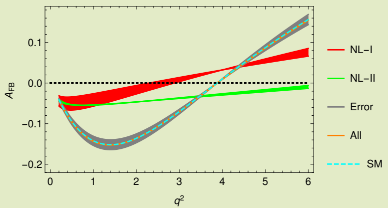
Branching Ratio



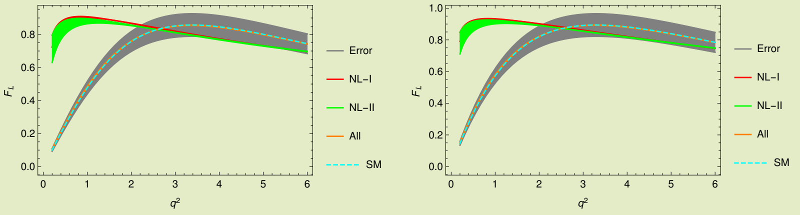


Forward-backward asymmetry

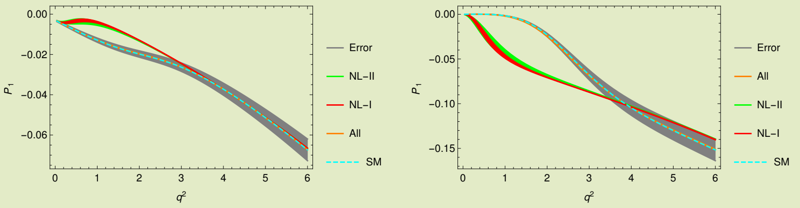




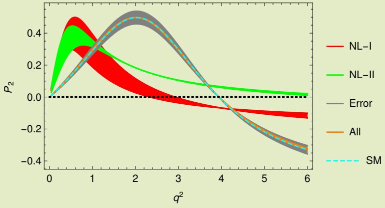
Longitudinal polarization asymmetry



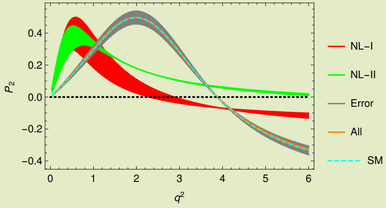
P_1



P_2

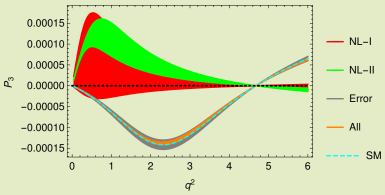


P2
q2
NL−I
NL−II
Error
All
SM

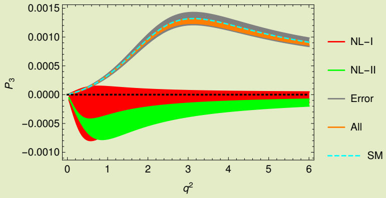


P2
q2
NL−I
NL−II
Error
All
SM

P_3

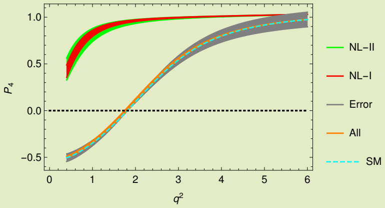


P3
q2
NL−I
NL−II
Error
All
SM

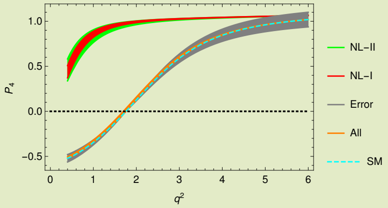


P3
q2
NL−I
NL−II
Error
All
SM

P_4'

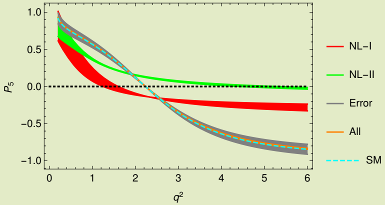


1.0
0.5
0.0
−0.5
P_4
0
1
2
3
4
5
6
q^2
NL−II
NL−I
Error
All
SM

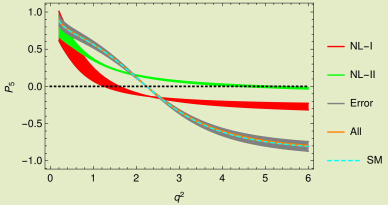


1.0
0.5
0.0
−0.5
P_4
0
1
2
3
4
5
6
q^2
NL−II
NL−I
Error
All
SM

P_5'

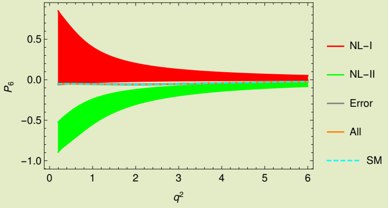


1.0
0.5
0.0
−0.5
−1.0
P_5
0
1
2
3
4
5
6
q^2
NL−I
NL−II
Error
All
SM

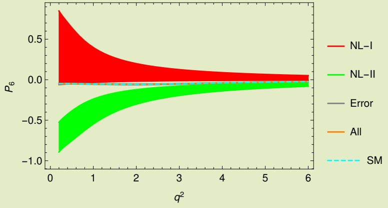


1.0
0.5
0.0
−0.5
−1.0
P_5
0
1
2
3
4
5
6
q^2
NL−I
NL−II
Error
All
SM

P_6'

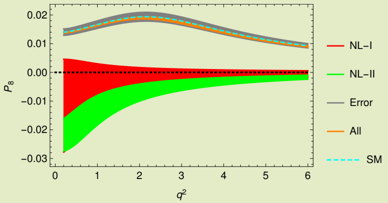


P_6
q^2
NL–I
NL–II
Error
All
SM

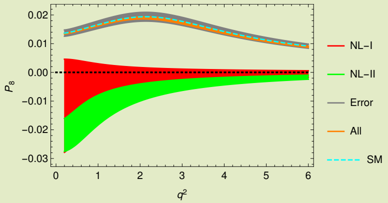


P_6
q^2
NL–I
NL–II
Error
All
SM

P_8'



P_8
q^2
NL–I
NL–II
Error
All
SM



P_8
q^2
NL–I
NL–II
Error
All
SM

Conclusion and summary

- Studied the anomalies in B sector, then we constrain on new couplings from non leptonic decay modes.
- We have also studied mixing as well as semi leptonic decay modes then enveloped constraints including non leptonic decay modes as well.
- Have shown the effect of the above on $\bar{B}_{(s)} \to K^*(\phi)\mu^+\mu^-$ processes.

Backup slides

TABLE – 1

Decay processes	Theoretical value	Experimental value
$\bar{B}_d \to \pi^- K^+$	6.37×10^{-6}	$(1.96 \pm .05) \times 10^{-5}$)
$\bar{B}_d \to \pi^0 K^0$	8.33×10^{-7}	$(9.9 \pm .5) \times 10^{-6}$
$\bar{B}_d \to \rho^0 K^0$	9.65×10^{-7}	$(4.7 \pm .6) \times 10^{-6}$
$\bar{B}_d \to \rho^- K^+$	9.2×10^{-7}	$(7 \pm .9) \times 10^{-6}$
$\bar{B}_s \to \eta' \eta'$	1.73×10^{-5}	$(3.3 \pm .7) \times 10^{-5}$
$\bar{B}_s \to K^{0^*} \bar{K}^{0*}$	3.54×10^{-6}	$(1.11 \pm .27) \times 10^{-5}$
$\bar{B}_s \to \phi\phi$	7.47×10^{-6}	$(1.87 \pm .15) \times 10^{-5}$

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