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Pattern of New Physics in the angular analysis of $B_s \to D_s^* (\to D_s \gamma, D_s \pi) \tau \nu$ decays

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Decoding the exact Lorentz structure of possible new physics in various B decays involving $b \to c\, l\, \nu$ charged current and $b \to s\, l\, l$ neutral current transition is very crucial. There still exists a long standing discrepancy in the combined measurements of the ratio of branching ratio $R_{D^{(*)}}$ in $B \to D^{(*)}\, l\, \nu$ decays which stands 3σ away from the standard model expectations. In addition, the lepton polarization fraction and longitudinal polarization fraction of D^* meson in $B \to D^*\, \tau\, \nu$ decays also witness considerable deviations from SM expectations. In this context, we perform a detailed angular analysis of $B_s \to D_s^* (\to D_s \gamma, D_s \pi)\, l\, \nu$ decays in a model independent effective field theory formalism. Under the SU(3) favor symmetry both $B \to D^*$ and $B_s \to D_s^*$ decays exhibit similar properties and hence this decay channel can, in principle provide complementary information regarding the anomalies present in $B \to D^*\, l\, \nu$ decays. We give predictions of various physical observables in standard model and in the presence of various new physics couplings.

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1. Introduction

The $b \to cl\nu$ charged current decays induced by the exchange of W boson at tree level are not loop suppressed compared to the flavor changing neutral current transition. The experimental measurements of various flavor ratios in $B \to D^{(*)}l\nu$ and $B_c \to J/\psi l\nu$ decays show significant deviation from the Standard Model (SM) expectations. The various flavor ratios such as R_D, R_{D^*} and $R_{J/\psi}$ are 1.4σ, 2.5σ and 1.7σ away from the SM prediction respectively. Similarly, $P_\tau^{D^*}$ and $F_L^{D^*}$ in $B \to D^*l\nu$ decay deviate at $1.5-1.6\sigma$ away from the SM expectations. In the present context, we perform a detailed angular analysis of $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\tau\nu$ decays in a model independent way. The study of $B_s \to D_s^*\, l\, \nu$ decay mode is of great interest in the present experiments because of several reasons. First, under the SU(3) flavor symmetry both $B \to D^*\, l\, \nu$ and $B_s \to D_s^*\, l\, \nu$ should show similar properties. Second, $B \to D^*\, l\, \nu$ and $B_s \to D_s^*\, l\, \nu$ decay modes undergo similar $b \to c$ quark level transitions and in principle it can provide complementary information regarding the anomalies present in B decays. Here, we give predictions of various physical observables within the SM and in the presence of several New Physics (NP) couplings.

2. Theoretical framework

The most common effective Hamiltonian of $b \to c\, l\, \nu$ transition can be expressed as [1, 2]

$$\mathcal{L}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}}\,V_{cb}\Bigg\{(1+g_{V_L})\,\bar{l}_L\,\gamma_\mu\,\nu_L\,\bar{c}_L\,\gamma^\mu\,b_L + g_{V_R}\,\bar{l}_L\,\gamma_\mu\,\nu_L\,\bar{c}_R\,\gamma^\mu\,b_R$$
$$+ g_{S_L}\,\bar{l}_R\,\nu_L\,\bar{c}_R\,b_L + g_{S_R}\,\bar{l}_R\,\nu_L\,\bar{c}_L\,b_R + g_{T_L}\,\bar{l}_R\,\sigma_{\mu\nu}\,\nu_L\,\bar{c}_R\,\sigma^{\mu\nu}\,b_L\Bigg\} + \text{h.c.}\,, \qquad (1)$$

Here $g_{V_{L,R}}$, $g_{S_{L,R}}$, and g_{T_L} NP couplings are associated with left handed neutrinos. Similarly G_F and V_{cb} represents the Fermi coupling constant and CKM matrix element respectively. We obtain the four body decay distribution for both γ and π decay channel from the effective Lagrangian. Using the four body differential decay distribution of $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\tau\nu$, one can easily calculate the various q^2 and $\cos\theta$ dependent observable for both γ and π decay channels. For our analysis we use the recent Lattice QCD form factor results [3]. The relevant formulas and the omitted details are available in the ref [6].

3. Results and Discussions

In SM, the branching ratio (BR) of γ channel is found to be $O(10^{-2})$, whereas for π channel it is obtained to be $O(10^{-3})$. The observables such as BR, A_3, A_4 and A_7 are different for both γ and π decay channel. The angular observable A_3, A_4 and A_7 for π channel are two times that of the γ channel. For both γ and π channel, the angular observable A_7 is absent in SM.

Similarly, we discuss the effect of NP under $2D$ NP scenarios as mentioned in Table 1, where the best fit results are both real and complex, the fit values are obtained at $\mu = 1$TeV scale and we run them upto the renormalization scale $\mu = m_b$ [4, 5].

In Table 2, we report the central values and the corresponding 1σ standard deviation of various physical observables for both γ and π channels in the presence of $2D$ NP couplings. In the presence

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$(g_{V_L}, g_{S_L} = -4g_{T_L})$	(g_{S_R}, g_{S_L}) (Set A)	(g_{S_R}, g_{S_L}) (Set B)	(g_{V_L}, g_{S_R})	$(g_{S_L} = 4g_{T_L})$
$(0.10, -0.04)$	$(0.21, -0.15)$	$(-0.26, -0.61)$	$(0.08, -0.01)$	$(-0.06 \pm i\,0.31)$

Table 1: Best fit values of NP couplings [4, 5].

of $(g_{V_L}, g_{S_L} = -4g_{T_L})$ NP coupling, the BR is more pronounced in comparison to rest of the NP couplings in both γ and π decay channel. Similarly the $R_{D_s^*}$ is significantly deviated from the SM in the presence of all 2D NP couplings. The C_F^τ and F_L are found to be deviated more in the presence of (g_{S_R}, g_{S_L}) (set A or Set B) NP couplings in both γ and π channel. Also, the angular observable A_7 is non zero only in the presence of complex $(g_{S_L} = 4g_{T_L})$ NP couplings for both γ and π channel. One can refer to [6] for all the omitted details.

Observables	$B_s \to D_s^*(\to D_s\gamma, D_s\pi)\,\tau\,\nu$ mode					
	SM	$(g_{V_L}, g_{S_L} = -4g_{T_L})$	(g_{S_R}, g_{S_L})(Set A)	(g_{S_R}, g_{S_L})(Set B)	(g_{V_L}, g_{S_R})	$g_{S_L} = 4g_{T_L}$
$[BR \times 10^{-2}]_\gamma$	1.1954 ± 0.0372	1.4049 ± 0.0437	1.2984 ± 0.0404	1.2963 ± 0.0404	1.3918 ± 0.0433	1.3696 ± 0.0426
$[A_{FB}^\tau]_{\gamma/\pi}$	-0.0896 ± 0.0020	-0.0936 ± 0.0021	-0.0302 ± 0.0021	-0.0311 ± 0.0021	-0.0912 ± 0.0020	-0.0328 ± 0.0017
$[F_L]_{\gamma/\pi}$	0.4482 ± 0.0015	0.4537 ± 0.0015	0.4920 ± 0.0015	0.4912 ± 0.0015	0.4472 ± 0.0015	0.4438 ± 0.0015
$[A_3]_{\gamma/\pi}$	0.0081 ± 0.0001	0.0083 ± 0.0001	0.0075 ± 0.0001	0.0075 ± 0.0001	0.0081 ± 0.0001	0.0066 ± 0.0001
$[A_4]_\gamma$	-0.0442 ± 0.0001	-0.0454 ± 0.0001	-0.0407 ± 0.0001	-0.0407 ± 0.0001	-0.0443 ± 0.0001	-0.0359 ± 0.0001
$[C_F^\tau]_{\gamma/\pi}$	-0.0550 ± 0.0014	-0.0567 ± 0.0014	-0.0506 ± 0.0013	-0.0507 ± 0.0013	-0.0551 ± 0.0014	-0.0559 ± 0.0011
$[A_7 \times 10^{-2}]_\gamma$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0086 ± 0.0001
$R_{D_s^*}$	0.2430 ± 0.0015	0.2856 ± 0.0018	0.2639 ± 0.0018	0.2635 ± 0.0018	0.2829 ± 0.0018	0.2784 ± 0.0018
$[BR \times 10^{-3}]_\pi$	0.7415 ± 0.0231	0.8715 ± 0.0271	0.8054 ± 0.0251	0.8041 ± 0.0251	0.8634 ± 0.0269	0.8496 ± 0.0264
$[A_3]_\pi$	-0.0162 ± 0.0001	-0.0167 ± 0.0001	-0.0149 ± 0.0001	-0.0150 ± 0.0001	-0.0162 ± 0.0001	-0.0132 ± 0.0001
$[A_4]_\pi$	0.0883 ± 0.0001	0.0909 ± 0.0002	0.0813 ± 0.0002	0.0815 ± 0.0002	0.0885 ± 0.0001	0.0719 ± 0.0001
$[A_7 \times 10^{-2}]_\pi$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0172 ± 0.0001

Table 2: Best fits of various physical observable in $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\,\tau\,\nu$ decay within SM and in the presence of 2D NP scenarios.

In fig 1, we show the various q^2 and $\cos\theta$ dependent observables of $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\tau\nu$ within the SM and in the presence of the 2D NP couplings. We represent each physical observable in three row, in the first rows we show those observables whose behaviour is similar in π and γ channel. In the second and third row, we display the observables in a pair, within each pair the left figure is for γ channel and the right figure is for π channel. Our observations are as follows

- The zero crossing of $A_{FB}^\tau(q^2)$ in SM is observed at $q^2 = 5.25 \pm 0.10\ GeV^2$, whether in the presence of (g_{S_R}, g_{S_L}) (Set A or Set B) and $(g_{S_L} = 4g_{T_L})$ NP couplings the SM zero crossing is observed at $q^2 = 6.28\ GeV^2$ and $q^2 = 6.16\ GeV^2$ respectively. Hence it lies more than 8σ away from the SM.

- The $F_L(q^2)$ and $C_F^\tau(q^2)$ show maximum deviation in the presence of (g_{S_R}, g_{S_L}) (Set A or Set B) NP couplings. Similarly $R_{D_s^*}$ is deviated more in the presence of $(g_{V_L}, g_{S_L} = -4g_{T_L})$, (g_{V_L}, g_{S_R}) and $(g_{S_L} = 4g_{T_L})$ NP coupling.

- The $DBR(q^2)$ is observed to be deviated more in the appearance of $(g_{V_L}, g_{S_L} = -4g_{T_L})$ NP coupling and it is clearly distinguishable from the SM expectations in both γ and π channel.

- The angular observable $A_3(q^2)$ and $A_4(q^2)$ is deviated more once we switch on the $(g_{S_L} = 4g_{T_L})$ NP coupling for both γ and π channel.

- The non-zero q^2 distribution of A_7 is obtained in the presence of the complex $(g_{S_L} = 4g_{T_L})$ NP coupling for both γ and π decay channel.

- Due to the $(g_{S_R},\, g_{S_L})$ (Set A or Set B) NP coupling, $F_L(\cos\theta_{D_s})$ is deviated from SM at $\cos\theta_{D_s} = 0$ for the γ channel, whereas in π channel it deviated from SM at $\cos\theta_{D_s} = \pm 1$.

- The SM zero crossing of $A_{FB}^{\tau}(\cos\theta_{D_s})$ is obtained at $\cos\theta_{D_s} = \pm 0.456 \pm 0.018$ for the γ channel and at $\cos\theta_{D_s} = \pm 0.626 \pm 0.007$ for the π channel. However, in the presence of $(g_{S_R},\, g_{S_L})$ (Set A or Set B) and $(g_{S_L} = 4g_{T_L})$ NP couplings, the zero crossing point is shifted to $\cos\theta_{D_s} = \pm 0.601$ and $\cos\theta_{D_s} = \pm 0.563$ for the γ and π channel respectively. Hence it lies more than 8σ away from the SM expectations in both γ and π decay channels.

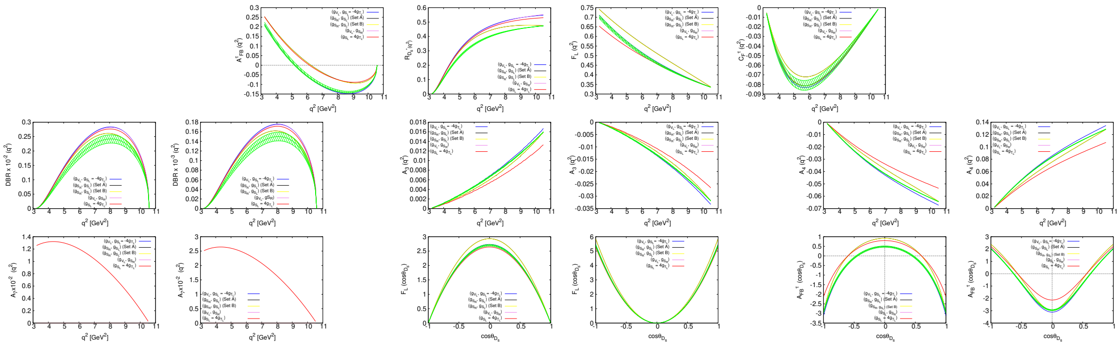

Figure 1: The q^2 and $\cos\theta$ of dependency various observables within the SM (green) and in the presence of $(g_{V_L}, g_{S_L} = -4g_{T_L})$ (blue), (g_{S_R}, g_{S_L})(Set A) (black), (g_{S_R}, g_{S_L})(Set B) (yellow) , (g_{V_L}, g_{S_R}) (violet) and $(g_{S_L} = 4g_{T_L})$ (red) coupling for $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\tau\nu$ decay.

4. Conclusions

Motivated from the current anomalies in $b \to c\,l\,\nu$ sector, we perform a detailed angular analysis of $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\,\tau\,\nu$ decays using the recent lattice QCD form factors. The angular observable $A_{FB}^{\tau}(q^2)$ and $A_{FB}^{\tau}(\cos\theta_{D_s})$ are found to be very interesting as the zero crossing points lie 8σ away from the SM. The future experimental results pertaining to $B_s \to D_s^*(\to D_s\gamma, D_s\pi)\,\tau\,\nu$ decay can be used to distinguish between various NP scenarios.

References

[1] T. Bhattacharya, V. Cirigliano, S. D. Cohen, A. Filipuzzi, M. Gonzalez-Alonso, M. L. Graesser, R. Gupta and H. W. Lin, Phys. Rev. D **85**, 054512 (2012)

[2] V. Cirigliano, J. Jenkins and M. Gonzalez-Alonso, Nucl. Phys. B **830**, 95 (2010)

[3] J. Harrison [arXiv:2105.11433 [hep-lat]].

[4] M. Blanke, A. Crivellin, S. de Boer, T. Kitahara, M. Moscati, U. Nierste and I. Nišandžić, Phys. Rev. D **99** (2019) no.7, 075006

[5] M. Blanke, A. Crivellin, T. Kitahara, M. Moscati, U. Nierste and I. Nišandžić, Phys. Rev. D **100** (2019) no.3, 035035

[6] N. Das and R. Dutta, [arXiv:2110.05526 [hep-ph]].