Signature of new Physics in rare radiative $B_s^0 \to \tau^+\tau^-\gamma$ decay

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Introduction

Rare leptonic B meson decays are theoretically as well as experimentally very clean probes for testing the flavor sector of Standard Model (SM) and possible physics beyond the SM. Among the rare B meson decays, radiative leptonic decays $B_s^0 \to l^+l^-\gamma$ $(l = e, \mu, \tau)$ [1, 2] are of special interest due to their relative cleanliness and their sensitivity to the new physics (NP). These decays can be obtained from $b \to sl^+l^-$ transition directly by attaching a real photon to any charged internal and external fermion lines in it. Several studies [1, 2] are done on these decay modes with models beyond the SM. The non-universal Z' model is one of the extension of SM with an extra gauge boson [3]. In this paper, we investigate $B_s^0 \to \tau^+\tau^-\gamma$ decay in a model in which the flavor changing neutral currents (FCNC) are mediated through non-universal Z' boson which may offer an important base to understand the NP effects. In the next section we discuss the theoretical framework to study $B_s^0 \to \tau^+\tau^-\gamma$ decay in non-universal Z' boson model. Finally in the last section we study the forward backward asymmetry (A_{FB}) for $B_s^0 \to \tau^+\tau^-\gamma$ decay in Z' model and compare our results with SM value.

Theoretical framework

The matrix element for the radiative $B_s^0 \to \tau^+\tau^-\gamma$ decay can be obtained from the quark level $b \to s\tau^+\tau^-$ transition. The short distance contributions to decay $b \to s\tau^+\tau^-$ comes from the box, Z and photon mediated penguins. When a photon is radiated from initial quark lines, the corresponding matrix element gives structure dependent (SD) part [4, 5] and when a photon is radiated from outgoing lepton lines, the corresponding matrix element gives the internal bremsstrahlung (IB) part [5, 6] for the $B_s^0 \to \tau^+\tau^-\gamma$ decay. So, the total matrix element is given as, $\mathcal{M} = \mathcal{M}_{SD} + \mathcal{M}_{IB}$.

And corresponding differential decay width of the $B_s^0 \to \tau^+\tau^-\gamma$ process is given as [5],

$$\frac{d\Gamma}{ds} = \frac{G_F^2\,\alpha^3}{2^{10}\,\pi^4}\,|V_{tb}V_{ts}^*|^2 m_{B_s}^3\,\Delta \qquad (1)$$

and hence, the forward backward asymmetry is given as [5],

$$A_{FB} = \frac{1}{\Delta}\left\{\begin{array}{l} 2m_{B_s}^2\hat{s}(1-\hat{s})^3 v_l^2 Re(A_1^* B_2 + B_1^* A_2) \\ +32 f_{B_s} r_l\,(1-\hat{s})^2\, ln\left(\frac{4r_l}{\hat{s}}\right) Re(C_{10}B_2^*)\end{array}\right\} \qquad (2)$$

where, $\Delta = \frac{4}{3}m_{B_s}^2(1-\hat{s})^2 v^l\big((\hat{s}+2r_l)(|A_1|^2 + |B_1|^2) + (\hat{s}-4r_l)(|A_2|^2+|B_2|^2)\big) - 64\frac{f_{B_s}^2}{m_{B_s}^2}\frac{r_l}{1-\hat{s}}C_{10}^2\left((4r_l - \hat{s}^2 - 1)ln\frac{1-v_l}{1-v_l} + 2\hat{s}\,v_l\right) - 32r_l(1-\hat{s})^2 f_{B_s} Re(C_{10}A_1^*)$ (3)

$A_1 = 2C_7\frac{m_b}{q^2}F_{TV} + C_9\frac{F_V}{m_{B_s}}$, $A_2 = C_{10}\frac{F_V}{m_{B_s}}$

$B_1 = -2C_7\frac{m_b}{q^2}F_{TA} - C_9\frac{F_A}{m_{B_s}}$, $B_2 = -C_{10}\frac{F_A}{m_{B_s}}$

The q^2 (= s) dependence of the form factors are given as $F(E_\gamma) = \beta\frac{f_{B_s}m_{B_s}}{\Delta + E_\gamma}$, where E_γ is the photon energy and $4m_l^2 \le s \le m_{B_s}^2$. The values of the parameters β and Δ are taken from ref. [4]. Here, we study $B_s^0 \to \tau^+\tau^-\gamma$ decay in a non-universal Z' model [3] which is derived from the extension of SM by including an additional $U'(1)$ gauge symmetry to it. In this model the FCNC transitions could be induced at tree level because of the non-diagonal chiral coupling

matrix. Hence, the effect of non-universal Z' boson can be evaluated by replacing the SM Wilson coefficients C_9 and C_{10} as [7]:

$$C_9^{SM+Z'} = C_9^{SM} + \frac{4\pi e^{-i\varphi_{sb}}}{\alpha V_{tb}V_{tb}^*}|B_{sb}|S_{ll} \quad (4)$$

$$C_{10}^{SM+Z'} = C_{10}^{SM} + \frac{4\pi e^{-i\varphi_{sb}}}{\alpha V_{tb}V_{tb}^*}|B_{sb}|D_{ll} \quad (5)$$

In above expression, the S_{ll} and D_{ll} are associated with the couplings of the Z' boson with the left- and right-handed leptons respectively, B_{sb} corresponds to the off-diagonal left handed coupling of quarks with Z' boson, and φ_{sb} corresponds to a new weak phase.

Results and Discussions

In this section, we study the forward backward asymmetry (A_{FB}) for $B_s^0 \to \tau^+\tau^-\gamma$ decay. To examine the implication of non-universal Z' boson on it we need to fix various input parameters. Here, we have considered two scenarios for numerical values of the Z' parameters corresponding to two different fitting values for $B_s - \overline{B_s}$ mixing data from [7] which are listed below. All other parameters' numerical values are taken from PDG [8].

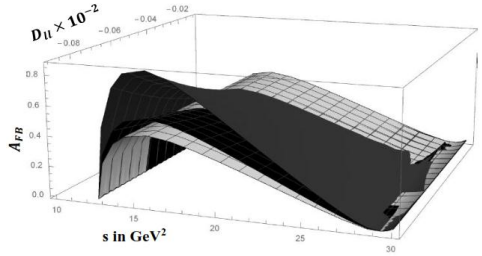

Fig. 1

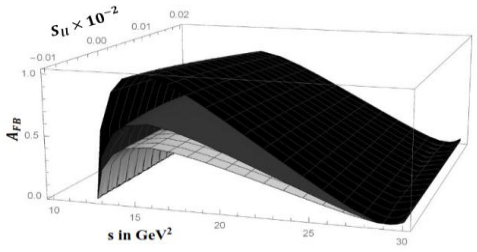

Fig. 2

	$\|B_{sb}\| \times 10^{-3}$	φ_{sb} in degree	$S_{ll} \times 10^{-3}$	$D_{ll} \times 10^{-3}$
S_1	1.31	-65	-2.8±3.9	-6.7±2.6
S_2	2.35	-78	-1.2±1.4	-2.5±0.9

Figure-1 and 2 show the variation of A_{FB} with respect to s as well as D_{ll} and S_{ll} respectively for scenario S_1, S_2 and SM. The black, dark grey, light grey surfaces correspond to S_1, S_2 and SM, respectively. In order to analyse the two scenarios fully, we can say that Fig. 1 represents the situation when NP comes mainly from the modification of C_{10}, whereas Fig. 2 represents the situation when NP comes mainly from the modification of C_9. In both the figures we can see the A_{FB} is increased from its SM value and is proportional to the Z' parameters which give us a clue to physics beyond the SM. Still, more analysis is required in order to fully verify the nature of NP in $B_s^0 \to \tau^+\tau^-\gamma$ decay.

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