New physics upper bound on the branching ratio of $B_s \to l^+l^-\gamma$.

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We consider the effect of new physics on the branching ratio of $B_s \to l^+l^-\gamma$ where $l = e, \mu$. If the new physics is of the form scalar/pseudoscalar, then it makes *no* contribution to $B_s \to l^+l^-\gamma$, unlike in the case of $B_s \to l^+l^-$, where it can potentially make a very large contribution. If the new physics is in the form of vector/axial-vector operators, then present data on $B \to (K, K^*)l^+l^-$, does not allow a large enhancement for $B(B_s \to l^+l^-\gamma)$. If the new physics is in the form of tensor/pseudotensor operators, then the data on $B \to (K, K^*)l^+l^-$ gives no useful constraint but the data on $B \to K^*\gamma$ does. Here again, a large enhancement of $B(B_s \to l^+l^-\gamma)$, much beyond the Standard Model expectation, is not possible. Hence, we conclude that the present data on $b \to s$ transitions allow a large boost in $B(B_s \to l^+l^-)$ but not in $B(B_s \to l^+l^-\gamma)$.

The quark level transition $b \to sl^+l^-$ can lead to a number of important flavour changing neutral current (FCNC) decays in B mesons. Among them are the semi-leptonic modes $B \to (K, K^*)l^+l^-$, the purely leptonic mode $B_s \to l^+l^-$ and the leptonic radiative mode $B_s \to l^+l^-\gamma$. The relationship between the semi-leptonic and purely leptonic modes was discussed in [1]. It was shown that, if the new physics occurs in the form of vector/axial-vector operators, then present data on semi-leptonic branching ratios [2, 3] constrain the branching ratio for $B_s \to l^+l^-$ to be of the same order of magnitude as that of the Standard Model (SM). On the other hand, if the new physics operators are in the form of scalar/pseudoscalar, then the semi-leptonic branching ratios do not lead to any useful constraint on the rate for the purely leptonic mode. Hence a large enhancement of $B_s \to l^+l^-$ is possible only if the new physics is in the form of scalar/psuedoscalar operators. Tensor/pseudotensor operators do not contribute to $B_s \to l^+l^-$. In this letter, we examine the relation between the rates for effective $b \to s$ transitions and $B_s \to l^+l^-\gamma$.

In the SM, the decay $B_s \to l^+l^-$ has small branching ratio due to helicity suppression. The radiative decay $B_s \to l^+l^-\gamma$ is free from helicity suppression due to emission of a photon in addition to the lepton pair. Thus the branching ratio for this leptonic radiative mode is much higher than that for the purely leptonic mode despite an additional factor of α. Because of this higher rate, this mode will be an important probe of $b \to sl^+l^-$ transitions which will be studied at present and future experiments. The decays $B_s \to l^+l^-\gamma$ have been studied in several papers [4, 5, 6, 7, 8, 9, 10] within the framework of SM. The effective new physics Lagrangian for $b \to sl^+l^-$ transition is the sum of three terms: vector/axialvector, scalar/pseudoscalar and tensor/pseudotensor. The first two terms can arise both via penguin and box diagrams but the last term arises only via the penguin diagram for $b \to s\gamma$, in which the real photon is replaced by a virtual photon coupling to a lepton-antilepton pair. In [5, 6], the effective $b \to sl^+l^-$ interaction was dressed with an on-shell photon in all possible ways. Helicity suppression is operative for the case where the photon is emitted from the final lepton and the resultant amplitude is proportional to the lepton mass and is negligible. For the case where the photon is emitted from the internal lines of the $b \to s$ loop transition, the amplitude is suppressed by factors m_b^2/m_W^2 and is also negligible. The main contribution to the $B_s \to l^+l^-\gamma$ amplitude comes from the diagrams where the final state photon is emitted from either b or s quark in the effective $b \to sl^+l^-$ interaction. With this procedure, the SM prediction for $B\left(B_s \to e^+e^-\gamma\right)$ is calculated, in [5, 6], to be about $(2-7)\times 10^{-9}$, with the rate for $B_s \to \mu^+\mu^-\gamma$ being a little lower.

In ref.[7] a higher value of branching ratio for $B_s \to l^+l^-\gamma$ is predicted within SM. This higher value is due to a different parametrization of the form factors f_V, f_A, f_{TV} and f_{TV}. The parametrization of form factors in [5] is based on QCD sum rules whereas in [6] it is based on light front models. But ref.[7] uses the parametrization based on perturbative QCD methods combined with heavy quark effective theory [11]. In ref.[10], it was argued that there are additional contributions to the $B_s \to l^+l^-\gamma$ amplitude. The most important one comes from the case where the real photon is emitted from the $b \to s$ loop transition and the virtual photon, which pair produces the leptons, is emitted from the initial quarks. Due to this additional amplitude, the SM prediction for $B\left(B_s \to e^+e^-\gamma\right)$ in [10], is about 2×10^{-8}, with the branching ratio for $B_s \to \mu^+\mu^-\gamma$, being a little smaller compared to $B_s \to e^+e^-\gamma$.

In the present calculation, we are interested on how the current data on $b \to s$ transitions, due to the effective interactions $b \to sl^+l^-$ and $b \to s\gamma$, constrain the new physics contribution to the leptonic radiative decays $B_s \to l^+l^-\gamma$.

As mentioned earlier, new physics in the form of scalar/pseudoscalar operators can give a large enhancement to the leptonic decay mode $B_s \to l^+l^-$. The question then follows: What is the effect of these operators on the leptonic radiative modes $B_s \to l^+l^-\gamma$? Unfortunately, scalar/pseudoscalar operators do not contribute to $B_s \to l^+l^-\gamma$. The photon has $J = 1$. Hence the l^+l^- pair also must be in $J = 1$ state so that the angular momentum of the final state can be zero. However, by Wigner-Eckert theorem, the matrix element $\langle l^+l^-(J = 1)|\bar{l}(g_s + g_p\gamma_5)l|0\rangle$ is zero. This result also follows from direct calculation, as we illustrate below.

We parametrize the scalar/pseudoscalar operator for $b \to sl^+l^-$ transition as

$$L_{SP}(b \to sl^+l^-) = \frac{G_F}{\sqrt{2}}\left(\frac{\alpha}{4\pi s_W^2}\right)\bar{s}(g_S + g_P\gamma_5)b\,\bar{l}(g_S^{'} + g_P^{'}\gamma_5)l. \tag{1}$$

The matrix element for $B_s \to l^+l^-\gamma$ is given by

$$M(B \to l^+l^-\gamma) = \frac{G_F}{\sqrt{2}}\left(\frac{\alpha}{4\pi s_W^2}\right)\left[g_S\langle\gamma\,|\bar{s}b|\,B_s(p)\rangle + g_P\langle\gamma\,|\bar{s}\gamma_5 b|\,B_s(p)\rangle\right]\bar{u}(p_l)(g_S^{'} + g_P^{'}\gamma_5)v(p_{\bar{l}}). \tag{2}$$

To calculate the matrix elements of the quark operators in the above equation, we need to first consider the following vector and axial-vector matrix elements [7, 8],

$$\begin{aligned}
\langle\gamma(k)\,|\bar{s}\gamma_\mu b|\,B_s(p)\rangle &= e\epsilon_{\mu\nu\rho\sigma}\epsilon^{*\nu}p^\rho k^\sigma f_V(q^2)/m_{B_s}, \\
\langle\gamma(k)\,|\bar{s}\gamma_\mu\gamma_5 b|\,B_s(p)\rangle &= -ie\left[\epsilon_\mu^*(p\cdot k) - (\epsilon^*\cdot p)k_\mu\right]f_A(q^2)/m_{B_s},
\end{aligned} \tag{3}$$

where $q = p_l + p_{\bar{l}}$. Dotting the above equations with the momentum of B_s meson p^μ, we get the scalar and pseudoscalar matrix elements to be identically zero,

$$\langle\gamma(k)\,|\bar{s}b|\,B_s(p)\rangle = 0 = \langle\gamma(k)\,|\bar{s}\gamma_5 b|\,B_s(p)\rangle. \tag{4}$$

That this amplitude vanishes, was also demonstrated in [12]. So, even if a large enhancement of $B_s \to l^+l^-$ is observed at LHC-b [13] due to new physics operators in scalar/psuedoscalar form, there will be no corresponding enhancement of $B_s \to l^+l^-\gamma$.

A legitimate question to ask at this stage is: Is it possible to have a large enhancement of $B_s \to l^+l^-\gamma$ for any type of new physics operator? Here we consider vector/axial-vector operators and tensor/pseudo-tensor operators one at a time and examine their contribution to $B_s \to l^+l^-\gamma$ given the current experimental results on the $b \to s$ transitions.

First we will assume that the new physics Lagrangian contains only vector and axial-vector couplings. We parametrize it as

$$L_{VA}(b \to sl^+l^-) = \frac{G_F}{\sqrt{2}}\left(\frac{\alpha}{4\pi s_W^2}\right)\bar{s}(g_V + g_A\gamma_5)\gamma_\mu b\,\bar{l}(g_V^{'} + g_A^{'}\gamma_5)\gamma^\mu l, \tag{5}$$

where g and $g^{'}$ are effective couplings which characterise the new physics.

The vector and axial-vector matrix elements are shown in Eq. (3) [7, 8]. The q^2 dependence of the formfactors is parametrized as [8, 10],

$$f_i(q^2) = \beta_i \frac{f_{B_s} m_{B_s}}{\Delta_i + 0.5 m_{B_s}\left(1 - q^2/m_{B_s}^2\right)}, \tag{6}$$

where $i = V, A, TA, TV$ and the parameters β and Δ are given in Table I.

Table I: Parameters for the form factors

Parameter	f_V	f_{TV}	f_A	f_{TA}
$\beta(GeV^{-1})$	0.28	0.30	0.26	0.33
$\Delta(GeV)$	0.04	0.04	0.30	0.30

The calculation of decay rate gives

$$\Gamma_{NP}\left(B_s \to l^+ l^- \gamma\right) = \left(\frac{G_F^2 \alpha^3 m_{B_s}^5 f_{B_s}^2}{3072\pi^4 s_W^4}\right)\left[g_V^2\left(g_V^{'2} + g_A^{'2}\right)\beta_V^2 I_V + g_A^2\left(g_V^{'2} + g_A^{'2}\right)\beta_A^2 I_A\right], \tag{7}$$

where I_i ($i = V, A$) are the integrals over the dilepton invariant mass ($z = q^2/m_{B_s}^2$). They are given by

$$I_i = \int_0^1 dz \, \frac{z(1-z)^3}{\left[(\Delta_i/m_{B_s}) + 0.5(1-z)\right]^2} \tag{8}$$

Here we have neglected the lepton masses in comparison to m_B as we are only considering $l = e, \mu$. We will work under this approximation throughout the paper.

In order to put bounds on $B_{NP}\left(B_s \to l^+ l^- \gamma\right)$ we need to know the values of $g_V^2\left(g_V^{'2} + g_A^{'2}\right)$ and $g_A^2\left(g_V^{'2} + g_A^{'2}\right)$. For this we will have to consider the semi-leptonic decay modes $B \to (K,\, K^*) l^+ l^-$. The values of these quantities were calculated in [1],

$$\begin{aligned} g_V^2(g_V^{'2} + g_A^{'2}) &= (1.36^{+0.53}_{-0.44}) \times 10^{-2} \\ g_A^2(g_V^{'2} + g_A^{'2}) &= (6.76^{+4.04}_{-3.48}) \times 10^{-3}. \end{aligned} \tag{9}$$

These values were calculated under the assumption that $B_{NP}\left[B \to (K,\, K^*) l^+ l^-\right] = B_{Exp}\left[B \to (K,\, K^*) l^+ l^-\right]$ i.e. the experimentally measured semi-leptonic branching ratios are saturated by the new physics couplings. Putting these values in Eq. (7), we get

$$B_{NP}\left(B_s \to l^+ l^- \gamma\right) = 2.06^{+0.84}_{-0.76} \times 10^{-9}. \tag{10}$$

Therefore the upper bounds on the branching ratios are,

$$\begin{aligned} B_{NP}\left(B_s \to l^+l^-\gamma\right) &\leq 2.90 \times 10^{-9} \text{ at } 1\sigma \\ B_{NP}\left(B_s \to l^+l^-\gamma\right) &\leq 4.58 \times 10^{-9} \text{ at } 3\sigma. \end{aligned} \tag{11}$$

These values are of the same order of magnitude as SM prediction. Thus we see that we can't boost $B_{NP}\left(B_s \to l^+l^-\gamma\right)$ above its SM prediction even after assuming that the contribution to the decay rate is totally due to new physics. The fact, that the experimentally measured values of the semileptonic branching ratios $B(B \to (K,\, K^*)l^+l^-)$ are close to their SM predictions, doesn't allow $B_{NP}\left(B_s \to l^+l^-\gamma\right)$ to have a value much different from its SM predictions if the new physics responsible for this decay is of the form vector/axial-vector. A more stringent upper bound is obtained if we equate the new physics branching ratio to be the difference between the experimental value and the SM prediction. In fact, this upper bound is consistent with zero at 1 σ and is $B_{NP}(B_s \to l^+l^-\gamma) \leq 2 \times 10^{-9}$ at 3 σ. Thus we can't boost $B_{NP}\left(B_s \to l^+l^-\gamma\right)$ much above its SM prediction if new physics is of the form vector/axial-vector.

We now consider new physics interaction in the form of tensors/pseudo-tensor operators. We parametrize this Lagrangaian as,

$$L_T(b \to s l^+ l^-) = \frac{G_F}{\sqrt{2}}\left(\frac{\alpha}{4\pi s_W^2}\right)\left(\frac{i m_b}{q^2}\right)\bar{s}\sigma_{\mu\nu}q^\nu(g_{TV} + g_{TA}\gamma_5)b\,\bar{l}\gamma^\mu l. \tag{12}$$

The necessary matrix element for $B_s \to l^+l^-\gamma$ is given by,

$$\begin{aligned} \langle\gamma(k)\left|\bar{s}i\sigma_{\mu\nu}q^\nu b\right|B_s(p)\rangle &= -e\epsilon_{\mu\nu\rho\sigma}\epsilon^{*\nu}p^\rho k^\sigma f_{TV}(q^2), \\ \langle\gamma(k)\left|\bar{s}i\sigma_{\mu\nu}\gamma_5 q^\nu b\right|B_s(p)\rangle &= -ie\left[\epsilon^*_\mu(p\cdot k) - (\epsilon^*\cdot p)k_\mu\right] f_{TA}(q^2). \end{aligned} \tag{13}$$

The q^2 dependence of the formfactors is given in Eq. (6). The calculation of decay rate gives,

$$\Gamma_{NP}\left(B_s \to l^+l^-\gamma\right) = \left(\frac{G_F^2\alpha^3 m_{B_s}^5 f_{B_s}^2}{3072\pi^4 s_W^4}\right)\left[g_{TV}^2\beta_{TV}^2 I_{TV} + g_{TA}^2\beta_{TA}^2 I_{TA}\right], \tag{14}$$

where I_i ($i = TV, TA$) are the integrals over the dilepton invariant mass ($z = q^2/m_{B_s}^2$). They are given by

$$I_i = \int_{(4m_l^2/m_{B_s^2})}^1 dz\,\frac{(1-z)^3}{z\left[(\Delta_i/m_{B_s}) + 0.5(1-z)\right]^2}. \tag{15}$$

Here again we have neglected the lepton masses everywhere except in the lower limit of the integral I_i due to the presence of term $1/z$ in the integrand. Thus we expect larger value for

$\Gamma_{NP}\left(B_s \to e^+e^-\gamma\right)$ in comparison to $\Gamma_{NP}\left(B_s \to \mu^+\mu^-\gamma\right)$ due to presence of term lnz in the expression of decay rate. We need to know the values of g_{TV}^2 and g_{TA}^2 in order to obtain the upper bound on $B_{NP}\left(B_s \to l^+l^-\gamma\right)$. For this we will consider first the semi-leptonic decays $B \to (K,\, K^*)l^+l^-$ and then the radiative decay $B \to K^*\gamma$.

In order to obtain bounds on g_{TV}^2, we will have to consider the process $B \to Kl^+l^-$. The necessary matrix element in this case is [14, 15] ,

$$\langle K(p_k)\left|\bar{s}i\sigma_{\mu\nu}q^\nu b\right| B(p_B)\rangle = \frac{1}{(m_B + m_{K^*})} q^2 (p_B + p_k)_\mu f_T(q^2). \tag{16}$$

In above equation we have dropped a term proportional to q_μ as it will give rise to a term proportional to $(m_l/m_B)^2$ in the decay rate. The q^2 dependence of the formfactor is assumed to be

$$f_T(q^2) = \frac{f_T(0)}{(1 - q^2/m_B^2)}. \tag{17}$$

The calculation of decay rate gives,

$$\Gamma_{NP}(B \to Kl^+l^-) = g_{TV}^2 \left(\frac{G_F^2 m_B^5}{192\pi^3}\right)\left(\frac{\alpha}{4\pi s_W^2}\right)^2 f_T^2(0) I^{BK}, \tag{18}$$

where I_{BK} is the integral over the dilepton invariant mass ($z = q^2/m_{B_s}^2$). This integral is given by

$$I^{BK} = \int_{z_{min}}^{z_{max}} dz\, \frac{\phi(z)^{3/2}}{2(1+k)^2(1-z)^2}, \tag{19}$$

where $\phi(z) = \left(z - 1 - k^2\right)^2 - 4k^2$ with $k = m_K/m_B$ and the limits of integration for z are given by $z_{min} = 4m_l^2/m_B^2$ and $z_{max} = (1-k)^2$.

Here again we make the approximation $\Gamma_{NP} = \Gamma_{Exp}$. Under this approximation we get from Eq. (18),

$$g_{TV}^2 = \frac{B_{Exp}(B \to Kl^+l^-)}{2.35\left[f^+(0)\right]^2} \times 10^4. \tag{20}$$

In order to obtain bounds on g_{TA}^2, we will have to consider the process $B \to K^*l^+l^-$. The necessary matrix elements in this case are [14, 15],

$$\begin{aligned} \langle K^*(p_k)\left|\bar{s}i\sigma_{\mu\nu}q^\nu b\right| B(p_B)\rangle &= iT_1(q^2)\epsilon_{\mu\nu\rho\sigma}\epsilon^{*\nu}(p_B + p_k)^\rho (p_B - p_k)^\sigma, \\ \langle K^*(p_k)\left|\bar{s}i\sigma_{\mu\nu}q^\nu\gamma_5 b\right| B(p_B)\rangle &= T_2(q^2)(m_B^2 - m_{K^*}^2)\epsilon_\mu^* + T_3(q^2)(\epsilon^* \cdot p_B)(p_B + p_{K^*})_\mu. \end{aligned} \tag{21}$$

Here again we have dropped the terms proportional to q_μ. The q^2dependence of the form-factors is assumed to have the from,

$$T_i(q^2) = \frac{T_i(0)}{(1 - q^2/m_B^2)}, \tag{22}$$

where $i = 1, 2, 3$.

The calculation of decay rate gives,

$$\Gamma_{NP}(B \to K^* l^+ l^-) = \left(\frac{G_F^2 m_B^5}{192\pi^3}\right)\left(\frac{\alpha}{4\pi s_W^2}\right)^2 \left[g_{TV}^2 T_1^2(0) I_{TV}^{BK^*} + g_{TA}^2 T_2^2(0) I_{TA}^{BK^*}\right], \tag{23}$$

where $I_i^{BK^*}$ $(i = TV, TA)$ are the integrals over the dilepton invariant mass $(z = q^2/m_{B_s}^2)$. They are given by

$$\begin{aligned} I_{TV}^{BK^*} &= \int_{z_{min}}^{z_{max}} \frac{dz}{z(1-z)^2}\, \phi(z)^{3/2} \\ I_{TA}^{BK^*} &= \int_{z_{min}}^{z_{max}} \frac{dz}{z^2(1-z)^2}\, \phi(z)^{3/2} \left[\frac{(1-k^{*2})^2}{2\phi(z)}\left\{2z + \frac{(1-k^{*2}-z)^2}{4k^{*2}}\right\}\right. \\ &\quad \left. + \frac{1}{8k^{*2}} + \frac{(1-k^{*2})(1-z-k^{*2})}{4k^{*2}}\right] \end{aligned} \tag{24}$$

with $k^* = \frac{m_{K^*}}{m_B}$. Here we assumed $T_2(0) \simeq T_3(0)$. $\phi(z)$ and z_{max} are the same as in the case of $B \to K l^+ l^-$ with k replaced by k^*. For $B \to K^* l^+ l^-$, the experimental branching ratio is given with a lower cut on the di-lepton invariant mass, $m_{l\bar{l}} > 0.14$ GeV, in order to supress background from photon conversions and $\pi^0 \to e^+ e^- \gamma$ [3]. We use this cut as the lower limit of integration for z. In all previous kinematic integrals, z_{min}, the lower limit of intergration for $z = q^2/m_B^2$ is taken to be the theoretical minimum $4m_l^2/m_B^2$. The kinematic integral, $I_{TA}^{BK^*}$ in Eq. (24), contains a $1/z^2$ term which comes from the propagator of virtual photon pair producing a lepton anti-lepton pair. At very small values of z, this term dominates the integral and makes it very large. However, experimentally the lower limit on q^2 is much larger than the theoretical lower limit. Therefore, in calculating the bounds on new physics, the lower limit of q^2 in the theoretical calculation should be the same as the experimental lower limit.

Under the assumption $\Gamma_{NP} = \Gamma_{Exp}$ and using Eq. (23), we get

$$g_{TA}^2 = \frac{B_{Exp}(B \to K^* l^+ l^-) \times 10^3 - 1.37 I_{TV}^{BK^*} T_1^2(0) g_{TV}^2}{1.37 I_{TA}^{BK^*} T_2^2(0)}. \tag{25}$$

In our calulation we take the formfactors to be [16], $f_T(0) = 0.355^{+0.016}_{-0.055}$, $T_1(0) = 0.379^{+0.058}_{-0.045}$, $T_2(0) = 0.379^{+0.058}_{-0.045}$. The experimentally measured values of the branching ratios are [3], $B_{Exp}(B \to K l^+ l^-) = (4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1) \times 10^{-7}$ and $B_{Exp}(B \to K^* l^+ l^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2) \times 10^{-7}$. Adding all errors in quadrature, we get $g_{TV}^2 = 1.63^{+0.39}_{-0.60} \times 10^{-2}$ for $l = e, \mu$. The best fit values for g_{TA}^2 turn out to be negative and very small $(\mathcal{O} \simeq 10^{-6})$. The fact that these come out to be negative means that the semi-leptonic decay rates *can not* be explained purely in terms of tensor/pseudo-tensor operators. Imposing the condition that g_{TV}^2 and g_{TA}^2 should be non-negative, gives us the conditions

$$g_{TA}^2 = 0, \text{ and } g_{TV}^2 = 1.63^{+0.39}_{-0.60} \times 10^{-2} \text{ for } l = e, \mu. \tag{26}$$

The branching ratio for $B_s \to l^+ l^- \gamma$, due to L_T is,

$$B_{NP}\left(B_s \to l^+ l^- \gamma\right) = \left[3.15\, I_{TV} g_{TV}^2 + 3.81\, I_{TA} g_{TA}^2\right] f_{B_s}^2 \times 10^{-6}. \tag{27}$$

Substituting $f_{B_s} = 240 \pm 30$ MeV [17] and the values of g_{TV}^2 and g_{TA}^2 in Eq. (27), we get

$$\begin{aligned} B_{NP}\left(B_s \to e^+ e^- \gamma\right) &= 1.91^{+0.66}_{-0.85} \times 10^{-7} \\ B_{NP}\left(B_s \to \mu^+ \mu^- \gamma\right) &= 6.45^{+2.24}_{-2.86} \times 10^{-8}. \end{aligned} \tag{28}$$

Therefore the upper bounds on the branching ratios are,

$$\begin{aligned} B_{NP}\left(B_s \to e^+ e^- \gamma\right) &\leq 2.57 \times 10^{-7}, \\ B_{NP}\left(B_s \to \mu^+ \mu^- \gamma\right) &\leq 8.69 \times 10^{-8} \end{aligned} \tag{29}$$

at 1σ and

$$\begin{aligned} B_{NP}\left(B_s \to e^+ e^- \gamma\right) &\leq 3.89 \times 10^{-7}, \\ B_{NP}\left(B_s \to \mu^+ \mu^- \gamma\right) &\leq 1.32 \times 10^{-7} \end{aligned} \tag{30}$$

at 3σ. These branching ratios are about 40-50 times greater than the predictions in [4, 6]. Thus the data on semileptonic decays allows an enhancement of one to two orders of magnitude in $B_{NP}\left(B_s \to l^+ l^- \gamma\right)$ if new physics interactions are of type tensor/pseudo-tensor.

Here we note that $b \to s\gamma$ transition also has a tensor operator and we consider the constraint on the tensor/pseudotensor contribution to $B_s \to l^+ l^- \gamma$ from the experimentally measured value of the branching ratio of $B \to K^* \gamma$. For this we consider the quark level interction $b \to s\gamma$. We parametrize new physics effective Lagrangian for $b \to s\gamma$ as

$$L(b \to s\gamma) = \left(\frac{G_F}{\sqrt{2}}\right)\left(\frac{iem_B}{16\pi^2 s_W^2}\right) \overline{s}\sigma_{\mu\nu} q^\nu (g_{TV} + g_{TA}\gamma_5) b\, \epsilon^{(\gamma)\mu}. \tag{31}$$

where $\epsilon^{(\gamma)\mu}$ is the polarization vector of the photon and q^ν is its momentum. Replacing $\epsilon^{(\gamma)\mu}$ by $(e/q^2)\bar{l}\gamma^\mu l$ gives rise to $b \to s l^+ l^-$ tensor/pseudotensor operators. Thus the present experimental limit on $B \to K^*\gamma$ leads to a bound on $B_s \to l^+l^-\gamma$ arising from new physics operators of tensor/pseudotensor form.

The amplitude for $B \to K^*\gamma$ is given by,

$$A(B \to K^*\gamma) = \left(\frac{G_F}{\sqrt{2}}\right)\left(\frac{em_B}{16\pi^2 s_W^2}\right)\epsilon^{(\gamma)\mu}\left\langle K^*(p_k)\left|\bar{s}\sigma_{\mu\nu}q^\nu(g_{TV}+g_{TA}\gamma_5)b\right|B(p)\right\rangle. \quad (32)$$

The necessary matrix elements are given in Eq. (21) with $T_1(0) = T_2(0)$ for real photon emission. The calculation of decay rate gives,

$$\Gamma_{NP}(B \to K^*\gamma) = (g_{TV}^2 + g_{TA}^2)\left(\frac{G_F^2\alpha}{1024\pi^4 s_W^4}\right)m_B^5(1-k^{*2})^3 T_1^2(0). \quad (33)$$

The process $B \to K^*\gamma$ has been observed with a branching ratio [18],

$$B_{Exp}(B \to K^*\gamma) = (3.92 \pm 0.20 \pm 0.24) \times 10^{-5}. \quad (34)$$

Under the assumption $\Gamma_{NP}(B \to K^*\gamma) = \Gamma_{Exp}(B \to K^*\gamma)$, we get

$$g_{TV}^2 + g_{TA}^2 = 1.92^{+0.59}_{-0.48} \times 10^{-4}. \quad (35)$$

Comparing this constraint with those in Eq. (26) we see that the process $B \to K^*\gamma$ puts a much stronger constraint on the g_{TV}^2 in comparison to that from $B \to (K, K^*)l^+l^-$. We substitute the above limit in Eq. (14) along with the approximation $\beta_{TV} \simeq \beta_{TA} = 0.33$ GeV^{-1}. The phase space integrals I_{TV} and I_{TA} are essentially equal to each other. For electrons their value is 64 and for muons their value is 22. Then we get the branching ratios to be

$$\begin{aligned} B_{NP}(B_s \to e^+e^-\gamma) &= 2.71^{+1.10}_{-0.95} \times 10^{-9}, \\ B_{NP}(B_s \to \mu^+\mu^-\gamma) &= 9.18^{+3.64}_{-3.25} \times 10^{-10}. \end{aligned} \quad (36)$$

These values are of the same order as SM predictions. Thus the stronger constraint on tensor/pseudo-tensor couplings coming from the experimentally measured value of $B(B \to K^*\gamma)$ doesn't allow an enhancement of $B_{NP}(B_s \to l^+l^-\gamma)$.

Conclusions. The quark level interaction $b \to sl^+l^-$ is responsible for the three types of decays (a) semi-leptonic $B \to (K, K^*)l^+l^-$, (b) purely leptonic $B_s \to l^+l^-$ and also (c) leptonic radiative $B_s \to l^+l^-\gamma$. It was shown in previously [1] that if the purely leptonic branching ratio $B(B_s \to \mu^+\mu^-) \geq 10^{-8}$ then new physics operators responsible for this have to be of the form scalar/pseudoscalar. Here we have shown that such scalar/pseudoscalar operators have no effect on the leptonic radiative modes $B_s \to l^+l^-\gamma$. Regarding other types of new physics operators, the vector/axial-vector operators *can not* enhance the branching ratios of $B_s \to l^+l^-\gamma$ much beyond their SM values, given the constraints coming from the measured semi-leptonic rates. New physics operators in the form of tensor/pseudo-tensor also *can not* enhance $B_s \to l^+l^-\gamma$ branching ratios given the constraints coming from $B \to K^*\gamma$. **Thus we are led to the conclusion that the present data on $b \to s$ transitions allow a large boost in $B(B_s \to l^+l^-)$ but not in $B(B_s \to l^+l^-\gamma)$.**

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