New Physics upper bound on $B(B_s \to l^+ l^-)$

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CONTENTS

- **New Physics bounds on $B(B_s \to l^+ l^-)$, $l = e, \mu$. [A.K.Alok and S.U. Sankar, Phys. Lett. B 620(2005)61]**
- **New Physics bounds on $B(B_s \to l^+ l^- \gamma)$, $l = e, \mu$. [hep-ph/0603262]**
- **Summary**

- **The same $b \to s l^+ l^-$ Four Fermi interaction is responsible for both leptonic decay $B_s \to l^+ l^-$ and semi-leptonic decays $B \to (K^*, K) l^+ l^-$.**

- **Recently, the semi-leptonic decays $B \to (K^*, K) l^+ l^-$ have been observed at BaBar and Belle.**

$$B_{exp}(B \to K^* l^+ l^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2) \times 10^{-7}$$

$$B_{exp}(B \to K l^+ l^-) = (4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1) \times 10^{-7}$$ **(Belle)**

- **These branching ratios are very close to the values predicted by the SM. Hence we considered the impact of these measurements on predictions for $B_s \to l^+ l^-$.**

- **SM predictions for these modes are** $B(B_s \to e^+e^-) < (7.58 \pm 3.50) \times 10^{-14}$ **and** $B(B_s \to \mu^+\mu^-) < (3.2 \pm 1.5) \times 10^{-9}$.

- **50% uncertainty in these predictions is due to 12% uncertainty in the decay constant** f_{B_s} **and 10% uncertainty in** V_{ts}**.**

- $B_s \to l^+l^-$ **has been studied in various models, both with and without natural flavor conservation, before. In both these kinds of models it was shown that** $B_s \to \mu^+\mu^-$ **can have a branching ratio** $\geq 10^{-8}$**.**

- **Present experimental limits are** $B(B_s \to e^+e^-) < 5.4 \times 10^{-5}$ (L3) and $B(B_s \to \mu^+\mu^-) < 5 \times 10^{-7}$ (D0).

- **The effective new physics Lagrangian for $b \to s l^+ l^-$ can be written as**

$$L_{eff} = L_{VA} + L_{SP} + L_T$$

where L_{VA} : Vector & Axial vector, L_{SP} : Scalar & Pseudoscalar

and L_T : Tensor.

- $\langle 0 \, |\bar{s}\sigma^{\mu\nu} b| \, B(p_B)\rangle = 0 \quad \Rightarrow L_T$ **doesn't contribute to $B_s \to l^+ l^-$.**

So we will not consider tensor terms any more.

- **We will consider L_{VA} and L_{SP} one at a time.**

- $L_{VA} = \frac{G_F}{\sqrt{2}} \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right) \bar{s}\gamma^\mu (g_V + g_A\gamma_5) b \; \bar{l}\gamma_\mu (g'_V + g'_A\gamma_5) l$
- g_V, g_A, g'_V & g'_A **are effective couplings due to new physics.**
- $\Gamma_{VA}(B_S \to l^+ l^-) = \frac{G_F^2 f_{B_s}^2}{8\pi} \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 (g_A g'_A)^2 m_{B_S} m_l^2$
- **To get bounds on** $(g_A g'_A)^2$**, we look at semi-leptonic decays.**

- **We first consider $B \to K^* l^+ l^-$.**

$$\Gamma_{NP}(B \to K^* l^+ l^-) = \frac{1}{2}\,\frac{G_F^2 m_B^5}{192\pi^3}\left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 (g_V'^2 + g_A'^2) I_{VA}$$

where $I_{VA} = g_V^2 V^2 I_1 + g_A^2 A_1^2 I_2$

- I_1 **and** I_2 **are integrals over** q^2 **from** $q^2_{min} = (2m_l)^2$ **to** $q^2_{max} = (m_B - m_{K^*})^2$**.**

- $\Gamma_{NP}(B \to K^* l^+ l^-)$ **depends on both vector and axial vector couplings. To get a handle on vector couplings we look at** $B \to K l^+ l^-$**.**

- $\Gamma_{NP}(B \to K l^+ l^-) = g_V^2 (g_V'^2 + g_A'^2) \left(\frac{G_F^2 m_B^5}{192\pi^3}\right) \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 \left[\frac{f^+(0)}{2}\right]^2$

- **We are trying to see what is the maximum value of $(g_A g_A^{'})^2$, consistent with semi-leptonic data.**

- **To get this, we make the approximation**

$$\Gamma_{exp}^{semi-lep} = \Gamma_{NP}^{semi-lep}$$

- $g_V^2(g_V'^2 + g_A'^2) = \frac{B_{exp}(B \to K l^+ l^-)}{3.45[f^+(0)]^2} \times 10^4$

- $g_A^2(g_V'^2 + g_A'^2) = \frac{B_{exp}(B \to K^* l^+ l^-) \times 10^4 - 1.58\, V^2\, g_V^2 (g_V'^2 + g_A'^2)}{8.94\, A_1^2}$

- **Adding all errors in quadrature we get**

$$g_A^2(g_V'^2 + g_A'^2) = (6.76 \pm^{4.04}_{3.48}) \times 10^{-3}$$

- **The maximum values for $B(B_S \to l^+ l^-)$ are**

$$B(B_s \to e^+ e^-) < 6.71 \times 10^{-14}$$

$$B(B_s \to \mu^+ \mu^-) < 2.87 \times 10^{-9}$$ **at** 1σ.

and

$$B(B_s \to e^+ e^-) < 1.2 \times 10^{-13}$$

$$B(B_s \to \mu^+ \mu^-) < 5.1 \times 10^{-9}$$ **at** 3σ.

- **These bounds are similar to SM predictions.**

- **Should not be surprising because**

$$\Gamma = (c.c)^2 \, [f.f.]^2 \, Phase \; Space$$

In semi-leptonic case $\Gamma_{exp} \simeq \Gamma_{SM}$**. Then we assumed** $\Gamma_{NP} = \Gamma_{exp}$ **which implies** $(c.c.)_{NP} \simeq (c.c.)_{SM}$ **and hence** $\Gamma_{NP}^{B_S \to l^+ l^-} \simeq \Gamma_{SM}^{B_S \to l^+ l^-}$**.**

- **A more stringent upper bound is obtained if we equate the new physics branching ratio to the difference between the experimental value and the SM prediction.**

- **Given the measured values of branching ratios of** $B \to (K^*, K) l^+ l^-$ **by Belle and Babar, *new physics cannot boost*** $B_s \to l^+ l^-$ ***above SM value if it is of the form vector/axial-vector*.**

- **Let us turn now to L_{SP} with scalar and pseudoscalar couplings.**

$$L_{SP} = \frac{G_F}{\sqrt{2}} \left(\frac{\alpha}{4\pi \sin^2\theta_W} \right) \bar{s}(g_S + g_P\gamma_5)b \, \bar{l}(g_S^{'} + g_P^{'}\gamma_5)l$$

- $B_{SP}(B_s \to l^+l^-) = \frac{0.17\, f_{B_S}^2\, g_P^2 (g_S^{'2} + g_P^{'2})}{(m_b + m_s)^2}$

- **To get a bound on $g_P^2(g_S^{'2} + g_P^{'2})$ we need to consider only $B \to K^* l^+ l^-$.**

- $\Gamma_{NP}(B \to K^* l^+ l^-) = g_P^2 (g_S'^2 + g_P'^2) \left(\frac{G_F^2 m_B^5}{256\pi^3}\right) \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 A_0^2 \left(\frac{m_B}{m_b - m_s}\right)^2 I_{SP}$

- $g_P^2 (g_S'^2 + g_P'^2) = \frac{(m_b - m_s)^2 \, B_{exp}(B \to K^* l^+ l^-) \times 10^3}{2.16 \, A_0^2}$

- **Substituting this in** $(B_s \to l^+ l^-)$ **rate we get**

$$B(B_s \to \mu^+ \mu^-) = (2 \pm 1) \times 10^{-5}$$

(Larger than present upper bound !)

- **If new physics effective Lagrangian is of the scalar/pseudoscalar form, then the present measurements of semi-leptonic rates DO NOT provide any useful constarint on $B_s \to l^+ l^-$.**

- ***If experiments at Tevatron or LHCb find that $B(B_s \to l^+ l^-) > 10^{-8}$, then we can immediately conclude that the new physics responsible for it is of scalar/pseudoscalar type.***

- **Recently we repeated the exercise for $B_s \to l^+ l^- \gamma$.**

- **We are interested on how the current data on $b \longrightarrow s$ transitions, due to effective interactions $b \longrightarrow s l^+ l^-$ and $b \longrightarrow s\gamma$, constrain the new physics contribution to $B_s \rightarrow l^+ l^- \gamma$.**

- **Unlike in the case of $B_s \rightarrow l^+ l^-$, if new physics is in the form scalar/pseudoscalar, then it makes no contribution to $B_s \rightarrow l^+ l^- \gamma$ as**

$$\langle \gamma \left| \bar{s} b \right| B_S \rangle = 0 = \langle \gamma \left| \bar{s} \gamma_5 b \right| B_S \rangle$$

- **A legitimate question to ask at this stage is : Is it possible to have an order of magnitude or more enhancement of $B_s \rightarrow l^+ l^- \gamma$ for any type of new physics operator?**

- **We found that if new physics is in the form of vector/axial-vector operators then the present data on** $B \to (K^*, K) l^+ l^-$ **doesn't allow a large boost for** $B(B_s \to l^+ l^- \gamma)$**.**

- **If 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 SM 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*** $B(B_s \to l^+ l^- \gamma)$***.***

SUMMARY

- The quark level interaction $b \to s l^+ l^-$ 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 $B_s \to l^+ l^- \gamma$.

- If $B(B_s \to l^+ l^-) \geq 10^{-8}$ then the new physics operators responsible for this have to be of the form scalar/pseudoscalar. Such operators have no effect on $B_s \to l^+ l^- \gamma$.

- Current data on $B \to (K^*, K) l^+ l^-$ and $B \to K^* \gamma$ do not allow any kind of New Physics to give rise to a *large* enhancement of $B(B_s \to l^+ l^- \gamma)$.