Estimation of mass of Z' boson from $B_S \to \tau^+\tau^-$ decay

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Introduction

In recent years, $B_S \to \tau^+\tau^-$ rare decay has attracted a lot of attention since it is very sensitive to the structure of standard model (SM) and provides important constraints on models of new physics (NP). These decays are highly suppressed in the SM. However, they can be significantly enhanced in many scenarios beyond the SM. Here, considering the effect of both Z and Z'-mediated flavor-changing neutral currents (FCNCs) on the $B_S \to \tau^+\tau^-$ decay we calculate its branching ratio. Z' bosons are known to exist naturally in well-motivated extensions of the SM [1]. Since the Z' boson has not yet been discovered, its exact mass is unknown. Here, using the experimental value of branching ratio we estimate the mass of Z' boson.

Theoretical model

In the SM, $B_s \to \ell^+\ell^-$ ($\ell = \tau$) decay involves $b \to s$ transitions. The effective Hamiltonian [2] describing the process is

$$H_{eff}^{SM} = \frac{G_F\,\alpha}{\sqrt{2}\,\pi}\lambda_t \Big[C_9^{eff}\left(\bar{s}\,\gamma^\mu P_L b\right)\left(\bar{\ell}\,\gamma^\mu\,\ell\right) + C_{10}\left(\bar{s}\,\gamma^\mu P_L b\right)\left(\bar{\ell}\,\gamma^\mu\gamma_5\,\ell\right) - \frac{2\,C_7\,m_b}{p^2}\left(\bar{s}\,p\,\gamma^\mu P_R\,b\right)\left(\bar{\ell}\,\gamma^\mu\gamma_5\,\ell\right)\Big], \quad (1)$$

where G_F is the Fermi coupling constant, $\lambda_t = V_{tb}V_{ts}^*$, $P_{R,L} = \frac{1}{2}\left(1 \pm \gamma_5\right)$, $p = p_+ + p_-$ the sum of the momenta of the ℓ^+ and ℓ^-, and C_7, C_9^{eff} and C_{10} are Wilson coefficients evaluated at the b quark mass scale.

In extended quark sector model [3], besides the three standard generations of the quarks, there is an $SU(2)_L$ singlet of charge $-1/3$. This model allows for Z-mediated FCNCs. Considering the contribution of Z-mediated FCNC to $B_s \to \ell^+\ell^-$ ($\ell = \tau$) decay, the effective Hamiltonian [2] will be:

$$H_{eff}(Z) = \frac{G_F}{\sqrt{2}}U_{sb}\left[\bar{s}\gamma^\mu(1-\gamma_5)b\right]\left[\bar{\ell}\left(C_V^\ell\,\gamma_\mu - C_A^\ell\,\gamma_\mu\gamma_5\right)\ell\right] \quad (2)$$

where C_V^ℓ and C_A^ℓ are the vector and axial vector $Z\ell^+\ell^-$ couplings.

The same idea can be applied for a Z' boson. The new contributions from Z' boson have similar effect as from the Z boson. Therefore, considering the effect of Z' boson, we can write the general effective Hamiltonian that contributes to the decay as,

$$H_{eff}(Z') = \frac{G_F}{\sqrt{2}}U_{sb}\left[\bar{s}\gamma^\mu(1-\gamma_5)b\right]\left[\bar{\ell}\left(C_V^\ell\,\gamma_\mu - C_A^\ell\,\gamma_\mu\gamma_5\right)\ell\right]\left(\frac{g'}{g}\frac{M_Z}{M_{Z'}}\right)^2 \quad (3)$$

where $g = e/\left(\sin\theta_W\cos\theta_W\right)$ and g' is the gauge coupling associated with the $U(1)'$ group. The net effective Hamiltonian can be written as $H_{eff} = H_{eff}(Z) + H_{eff}(Z')$ and the corresponding branching ratio is [4]:

$$B\left(B_S \to \ell^+\ell^-\right)_{Z+Z'} = \frac{G_F^2\,\tau_{B_S}}{4\pi}\left|U_{sb}\right|^2 f_{B_S}^2\, m_{B_S}\, m_\ell^2\left|C_A^\ell\right|^2\sqrt{1-\frac{4m_\ell^2}{m_{B_S}^2}}\left[1+\left(\frac{g'}{g}\frac{M_Z}{M_{Z'}}\right)^2\right]^2 \quad (4)$$

Results and Discussions

This decay has not been fully observed experimentally yet due to the low efficiency for detecting τ's. However, the LHCb collaboration has allowed this branching ratio up to 3.5 % . We estimate the mass of Z' boson using this experimental value $B\left(B_s \to \tau^+\tau^-\right) \le 3.5\times10^{-2}$ [5,6]. For this purpose we use all the recent data from PDG 2014 [7] in equation (4), M_Z =91.1876GeV, $m_\tau = 1776.82 \pm 0.16$ MeV, $m_{B_s} = 5.3667 \pm 0.00024$ GeV , τ_{B_s} = $(1.497 \pm 0.015)\times 10^{-12} s$, decay constant $f_{B_s} = 0.24$ GeV, M_Z = 91.1876 GeV, $G_F = 1.16639\times10^{-5}\ GeV^{-2}$, $\sin^2\theta_W = 0.23$ and $\left|U_{sb}\right| \cong 10^{-3}$. We observe that the value of branching ratio in Z' model is consistent with our estimated value of $M_{Z'} \ge 12$ GeV. The existence of light Z' boson could have important implications in dark matter (DM) phenomenology. Recently [8] it is shown that the genesis of DM is possible with a light Z' boson. They have studied the genesis of DM by a Z' portal for a spectrum of Z' mass in the range 1 GeV – 1 TeV. In [9] it is depicted that the strong first order electroweak phase transition (EWPT) can be realized in the light of Z' boson region, $M_{Z'} < 220$ GeV. Furthermore, it is claimed that in our model [10] for a light Z' boson $M_{Z'} \sim 16$ GeV, the D0 result for the same-sign dimuon charge asymmetry can be produced.

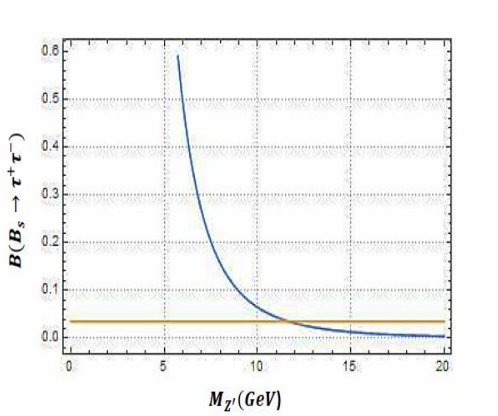

Fig-1: Blue line represents the variation of $B\left(B_s \to \tau^+\tau^-\right)$ with $M_{Z'}$ and yellow line represents its experimental upper limit [5,6].

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