Effect of Z' gauge boson on lepton flavor violating $B_s \to \mu\tau$ decay

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Introduction

The standard model (SM) of particle physics is the most ingenious theory till the date with the support of experimental results. Flavor-changing neutral current (FCNC) [1-3] events are rare in SM both in quark and lepton sector. FCNC which involves the third generation quarks and leptons are interesting as they have larger masses for which they become more susceptible as a sensitive probe for new physics (NP) beyond the standard model. In the lepton sector FCNC decays are severely suppressed and the lepton number for each generation is conserved in the SM. Therefore, FCNC effects and lepton flavor violation in this sector are sensible probes of NP. In this paper, we investigate the lepton flavor violating (LFV) $B_s \to \mu\tau$ decay in a model in which the FCNC are mediated through non-universal Z' boson. The Z' boson exists in well-motivated extension of SM by adding an extra U(1)' gauge group. In the next section we discuss $B_s \to \mu\tau$ decay in Z' model. Finally in the last section we calculate the branching ratio and discuss our result.

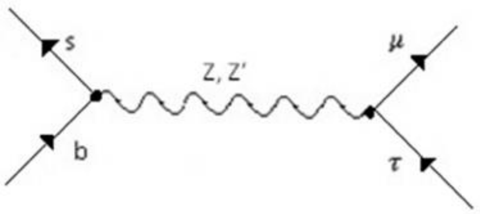

Fig. 1 Feynman diagram for $B_s \to \mu\tau$ decay with Z- and Z′-mediated FCNC.

$B_s \to \mu\tau$ decay in Z' model

Let us consider the decay $B_s \to \mu\tau$ in the presence of Z-mediated FCNC (Fig. 1). Considering the contribution of Z-mediated FCNC to this decay, effective Hamiltonian can be written as [4]

$$H_{eff}(Z) = \frac{G_F}{2\sqrt{2}} U_{bs} U_{\mu\tau} (\bar{s}\gamma^\mu(1-\gamma_5)b) \times (\bar{\mu}\gamma^\mu(1-\gamma_5)\tau), \quad (1)$$

where U_{bs} represents the FCNC coupling of the quark sector. To evaluate the transition amplitude we can use the matrix elements of quark current between the initial B_s meson and vacuum as

$$< 0|\bar{s}\gamma^\mu\gamma_5 b|B_s(p_B) > = if_{B_s} p_B^\mu. \quad (2)$$

Thus we get the transition amplitude as,

$$M(B_s \to \mu\tau) = -\frac{iG_F}{2\sqrt{2}} U_{bs} U_{\mu\tau} m_\tau f_{B_s} [\bar{\mu}(1-\gamma_5)\tau] \quad (3)$$

The corresponding decay width can be written as, $\Gamma(B_s \to \mu\tau)$

$$= \frac{G_F^2}{16\pi} m_\tau^2 m_{B_s} |U_{sb} U_{\mu\tau}|^2 f_{B_s}^2 \left(1 - \frac{m_\tau^2}{m_{B_s}^2}\right)^2 \quad (4)$$

The branching ratio in Z-model is

$$Br_Z(B_s \to \mu\tau) = \frac{G_F^2}{16\pi} m_\tau^2 m_{B_s} |U_{sb} U_{\mu\tau}|^2 \tau_{B_s} f_{B_s}^2 \left(1 - \frac{m_\tau^2}{m_{B_s}^2}\right)^2 \quad (5)$$

Now consider $B_s \to \mu\tau$ decay in Z' model. The new contributions from Z' boson have similar effect as from Z boson [5]. In the presence of Z'-mediated FCNC, the effective Hamiltonian for $B_s \to \mu\tau$ decay can be written as

$$H_{eff}(Z') = \frac{G_F}{2\sqrt{2}} U_{bs} U_{\mu\tau} (\bar{s}\gamma^\mu(1-\gamma_5)b) \times (\bar{\mu}\gamma^\mu(1-\gamma_5)\tau) \left(\frac{g' M_Z}{g M_{Z'}}\right)^2 \quad (6)$$

Then, the net effective Hamiltonian

$$H_{eff}(\text{Total}) = H_{eff}(Z) + H_{eff}(Z') = \frac{G_F}{2\sqrt{2}} U_{bs} U_{\mu\tau} (\bar{s}\gamma^\mu(1-\gamma_5)b) \times (\bar{\mu}\gamma^\mu(1-\gamma_5)\tau) \times \left[1 + \left(\frac{g' M_Z}{g M_{Z'}}\right)^2\right] \quad (7)$$

From this effective Hamiltonian we can calculate the branching ratio as

$$Br(Total) = Br_{Z+Z'} = \frac{G_F^2}{16\pi} m_\tau^2 m_{B_s} |U_{sb} U_{\mu\tau}|^2 \tau_{B_s} f_{B_s}^2 \times \left(1 - \frac{m_\tau^2}{m_{B_s}^2}\right)^2 \left[1 + \left(\frac{g' M_Z}{g M_{Z'}}\right)^2\right]^2 \quad (8)$$

Result and Discussions

We calculate the branching ratio of decay $B_s \rightarrow \mu\tau$ using the data from [4, 6]. The value of $\frac{g'}{g}$ is undetermined [7]. However, generally, one expects that $\frac{g'}{g} \sim 1$ if both U (1) groups have the same origin from some grand unified theory. We consider $\frac{g'}{g} \sim 1$ in our calculation. The Z' boson is not discovered so far, hence its exact mass is unknown. The Z' mass is constrained by direct searches from different accelerators and detectors [8-10] which give model-dependent lower bound around 500 GeV. Sahoo, et. al. [11] estimated the range of Z' boson mass as 1352-1665 GeV. Oda, et al. predicted the upper bound on the mass of Z' boson as 6 TeV, in classically conformal U(1)' extended standard model [12]. Considering the mass of Z' boson within the range 500-6000 GeV, we estimate the branching ratio of the decay and presented in the Table. 1 and Table. 2. Fig. 2 shows the variation of the branching ratio of this decay with the mass of Z' boson. From this plotting we can conclude that lower is the mass of Z' boson, higher is the branching ratio. Our numerical results show that Z' boson gives significant contribution to this LFV $B_s \rightarrow \mu\tau$ decay process.

Table.1. Numerical estimation of branching ratio of $B_s \rightarrow \mu\tau$ in Z' model

Decay Process	$M_{z'}$ in TeV	$Br_{z+z'}$
$B_s \rightarrow \mu\tau$	0.5	2.131×10^{-10}
	1	2.029×10^{-10}
	4	1.997×10^{-10}
	6	1.996×10^{-10}

Table. 2. Comparison of branching ratio between Z and Z' model

Decay Process	Br_z [4]	$Br_{z+z'}$ (Our predicted)
$B_s \rightarrow \mu\tau$	1.9×10^{-10}	$(1.996 - 2.131) \times 10^{-10}$

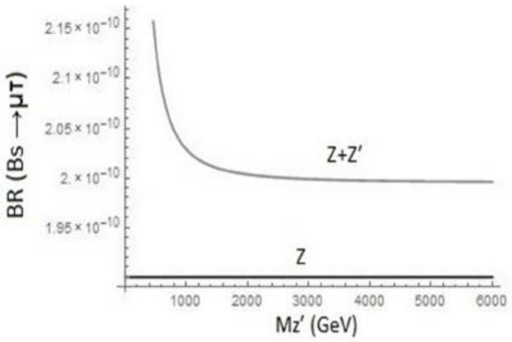

Fig. 2. The variation of branching ratio of $B_s \rightarrow \mu\tau$ with the mass of Z' boson

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