Rare decay of B_s^0 and B^0 mesons into dimuon ($\mu^+\mu^-$) using relativistic formalism

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Introduction

Decays that are highly suppressed in the standard model are excellent places to search for effects of new physics. The rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ are discovered from the CMS (Compact Muon Solenoid) and LHCb (Large Hadron Collider beauty) collaborations very recently [1–4]. The decay of B_s^0 and B^0 mesons to two muons is forbidden at the elementary level because the Z_0 cannot couple directly to quarks of different flavours and there are no direct flavour changing neutral currents (FCNC). However, this decay occurs through higher order transitions such as those shown in Fig. 1. These are highly suppressed because each additional interaction vertex reduces their probability of occurring significantly. They are also helicity and CKM suppressed. Consequently, the branching fraction for the $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decay is expected to be very small compared to the dominant b antiquark to c antiquark transitions.

Theoretical Framework

The effective weak interaction Lagrangian relevant for $B_q \to \ell^+\ell^-$ ($\ell = \mu$) reads [5–7]

$$\mathcal{L}_{eff} = V_{tb}^* V_{tq} C_{10}[(\bar{b}\gamma_\alpha\gamma_5\ q)(\bar{\ell}\gamma^\alpha\gamma_5\ell)] + \mathcal{L}_{QCD\times QED} + H.c. \quad (1)$$

The decay width for rare decays of B_s^0 and B^0 mesons is given by

$$\Gamma_{(B_q^0\to\ell^+\ell^-)} = \frac{G_F^2}{\pi}\frac{\alpha^2 f_{B_q}^2 m_\ell^2}{(4\pi sin^2\Theta_W)^2}\, m_{B_q} \sqrt{1-4\frac{m_\ell^2}{m_{B_q}^2}}|V_{tb}^* V_{tq}|^2|C_{10}|^2 \quad (2)$$

The branching ratio for $B_q^0 \to \ell^+\ell^-$ is

$$BR = \Gamma_{(B_q^0\to\ell^+\ell^-)} \times \tau_{B_q} \quad (3)$$

G_F is the fermi coupling constant, f_{B_q} is the corresponding decay constant and C_{10} is the Wilson coefficient.

In the relativistic quark model, the decay constant can be expressed through the meson wave function in the momentum space [8, 9]

$$f_P = \left(\frac{3|I_p|^2}{2\pi^2 M_p\ J_p}\right)^{\frac{1}{2}} \quad (4)$$

Here M_p is mass of the pseudoscalar meson and I_p and J_p are defined as

$$I_p = \int_0^\infty dp\ p^2 A(p)[G_{q1}(p)G_{q2}^*(-p)]^{\frac{1}{2}} \quad (5)$$

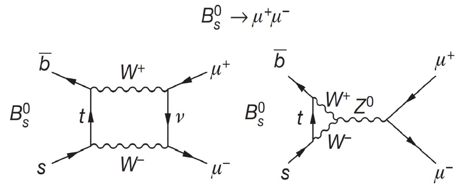

FIG. 1: Higher-order flavour changing neutral current processes for the $B_s^0 \to \mu^+\mu^-$ decay allowed in the SM

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$$J_p = \int_0^\infty dp\ p^2 [G_{q1}(p) G^*_{q2}(-p)] \qquad (6)$$

respectively. Where,

$$A(p) = \frac{(E_{p1} + m_{q1})(E_{p2} + m_{q2}) - p^2}{[E_{p1}\ E_{p2}(E_{p1} + m_{q1})(E_{p2} + m_{q2})]^{\frac{1}{2}}} \qquad (7)$$

and $E_{p_i} = \sqrt{{k_i}^2 + m_{q_i}^2}$.

For the present study, the constituent quarks inside a meson are independently confined by an average potential of the form [10, 11]

$$V(r) = \frac{1}{2}(1 + \gamma_0)(\lambda r^\nu + V_0) \qquad (8)$$

To a first approximation, the confining part of the interaction is believed to provide the zeroth-order quark dynamics inside the meson core through the quark Lagrangian density

$$\mathcal{L}_q^0(x) = \bar{\psi}_q(x) \left[\frac{i}{2} \gamma^\mu \overleftrightarrow{\partial_\mu} - V(r) - m_q \right] \psi_q(x). \qquad (9)$$

The normalized quark wave functions $\psi(\vec{r})$ obtained from eqn. (9) satisfies the Dirac equation given by

$$[\gamma^0 E_q - \vec{\gamma}.\vec{P} - m_q - V(r)]\psi_q(\vec{r}) = 0. \qquad (10)$$

By numerically solving the two component (positive and negative energy) solution of Dirac eqn., we obtained binding energy and the radial solution [11]. The parameters are fixed from the spectroscopic study of B and B_s mesons. The optimized quark mass parameters m_b, $m_{u,d}$ and m_s are 4.67 GeV, 0.003 GeV and 0.1 GeV respectively.

The calculated pseudoscalar decay constant (f_{B_q}) for B_s and B mesons are 240.21 MeV and 188.56 MeV respectively. The computed decay widths (Γ) and branching ration (BR) are listed in Table I and compared with the recent experimental as well as other theoretical predictions.

TABLE I: The Rare leptonic decay widths and Branching Ratio (Br) of B_s and B mesons.

Decay Process		$B_s^0 \to \mu^+\mu^-$	$B^0 \to \mu^+\mu^-$
Γ (keV)	Present	1.583 $\times 10^{-15}$	4.406 $\times 10^{-17}$
BR	Present	3.58×10^{-9}	1.018×10^{-10}
	CMS[2]	$3.0^{+1.0}_{-0.9} \times 10^{-9}$	$< 1.1 \times 10^{-9}$
	LHCb[3]	$3.2^{+1.5}_{-1.2} \times 10^{-9}$	$< 9.4 \times 10^{-10}$
	LHCb[4]	$2.9^{+1.1}_{-1.0} \times 10^{-9}$	$< 7.4 \times 10^{-10}$
	EFT[7]	$(3.65 \pm 0.23) \times 10^{-9}$	$(1.06 \pm 0.09) \times 10^{-10}$

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