New Physics search with $B_s^0 \to l^+ l^-$ in Z' model

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Need of New Physics in $B_s^0 \to l^+ l^-$

❖ Rare leptonic $B_s^0 \to l^+ l^-$ $(l = e, \mu, \tau)$ decays are highly suppressed in the Standard Model (SM). The branching ratio of $B_s^0 \to \mu^+\mu^-$ is measured experimentally but the branching ratio values for e and τ channels are not be measured till now (only the upper limits are predicted).

❖ The experimental value of the branching ratio for $B_s^0 \to \mu^+\mu^-$ is set as $(3.0 \pm 0.6) \times 10^{-9}$[1].

Experimental upper limit [1]:
$\mathcal{B}(B_s \to e^+e^-) < 2.8 \times 10^{-7}$

Experimental upper limit:[1]
$\mathcal{B}(B_s \to \tau^+\tau^-) < 6.8 \times 10^{-3}$

1. M. Tanabashi et al. (Particle Data Group), *Phys. Rev. D* **98**, 030001 (2018).

Theoretical Framework

- The SM effective Hamiltonian for rare $b \to s l^+ l^-$ decay at μ scale is given by [2, 3],

$$H_{eff}^{SM} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1}^{8} C_i(\mu) Q_i + C_{9V}(\mu) Q_{9V} + C_{10A}(\mu) Q_{10A}\right] + h.c \quad \text{..........(1)}$$

- This Hamiltonian is modified with the approximations for the non-universal Z' couplings. Here we include $s\bar{b}Z'$ coupling as B_{sb}^L and the right handed and the left handed $\bar{\mu}\mu Z'$ couplings as $B_{\mu\mu}^R$ and $B_{\mu\mu}^L$ respectively.

As Q_9 and Q_{10} are the electro-weak operators, so the modification in Z' model is done on the Wilson co-efficients C_9 and C_{10} as [2], $C_{9V}^{Z'} = -2\frac{B_{sb}^L}{V_{tb}V_{ts}^*}\left(B_{\mu\mu}^L + B_{\mu\mu}^R\right)$, $C_{10A}^{Z'} = 2\frac{B_{sb}^L}{V_{tb}V_{ts}^*}\left(B_{\mu\mu}^L - B_{\mu\mu}^R\right)$.

- The branching ratio expression for $B_s^0 \to \mu^+\mu^-$ in Z' model becomes as,

$$\mathcal{B}(B_s \to \mu^+\mu^-) = \tau_{B_s} \frac{G_F^2}{4\pi} f_{B_s}^2 m_\mu^2 m_{B_s} \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} |V_{tb}V_{ts}^*|^2 \times \left|\frac{\alpha}{2\pi \sin^2\theta_W} Y(x_t) - 2\frac{B_{sb}^L(B_{\mu\mu}^L - B_{\mu\mu}^R)}{V_{tb}V_{ts}^*}\right|^2 \quad \text{.........(2)}$$

2. G. Buchalla, A. J. Buras and M. E. Lautenbacher, *Rev. Mod. Phys.* 68, 1125 (1996).
3. Q. Chang, X. Li and Y. Yang, Family Non-universal Z' effects on $\bar{B}_q - B_q$ mixing, $B \to X_s\mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ Decays, *JHEP* 02, 082 (2010).

Z' couplings from $B_q - \overline{B_q}$ mixing

❖ Here we are interested to find the constraints of the flavour-changing Z' couplings [3] from the mass difference of B_q mass eigenstates and this signalizes the $B_q - \overline{B_q}$ mixing event. This mass difference physically interpret the strength of the $B_q - \overline{B_q}$ mixing.

❖ The standard model value and the experimental value are given in Table 1 [1]. The ratio of the mass differences $\Delta M_q^{exp}/\Delta M_q^{SM}$ is varied in Fig. 1 and we have obtained the values of NP couplings which are recorded in Table 2.

Table. 1

ΔM_s^{SM}	20.12
ΔM_s^{exp}	17.757

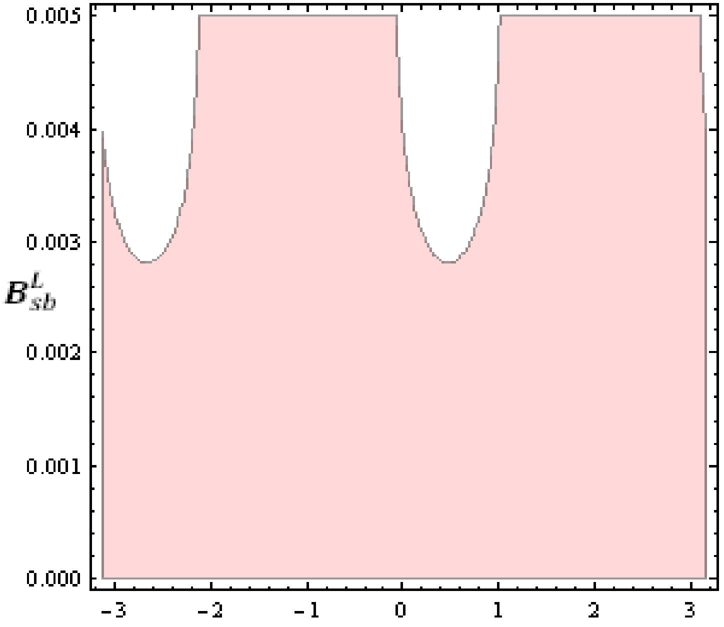

Fig. 1

Table. 2

	B_{sb}^L	φ_s^L
From $B_s - \overline{B_s}$ mixing	2.8×10^{-3}	$34°$

Numerical Analysis for $B_s \to \mu^+\mu^-$ channel

❖ **To get the leptonic couplings we have used the statistical method of χ^2 fitting [4] with some specific constraints . Here χ^2 can be defined as,**

$$\chi^2 = \sum_i \frac{\left(f_i^{th} - f_i^{exp}\right)^2}{(\Delta f_i)^2} \quad \ldots(3)$$

❑ **In this fitting we have used the experimental results given below [1]-**

Mode	Branching value
$\mathrm{Br}(B_s \to \mu^+\mu^-)$	$(3.0 \pm 0.6) \times 10^{-9}$
$\mathrm{Br}^{\mathrm{low}}(B \to X_s\mu^+\mu^-)$	$(16.0 \pm 5.0) \times 10^{-7}$
$\mathrm{Br}^{\mathrm{high}}(B \to X_s\mu^+\mu^-)$	$(4.4 \pm 1.2) \times 10^{-7}$
$\mathrm{Br}(B \to X_s\mu^+\mu^-)$	$(43 \pm 12.5) \times 10^{-7}$

4. R. Andrae, T. Schulze-Hartung, P. Melchior, “Dos and don’ts of reduced chi squared”, [astro-ph.IM/1012.3754].

❖ Minimising the χ^2 expression in our software we have obtained the best fit values in Table 2 and the fitted results are plotted in Fig. 2.

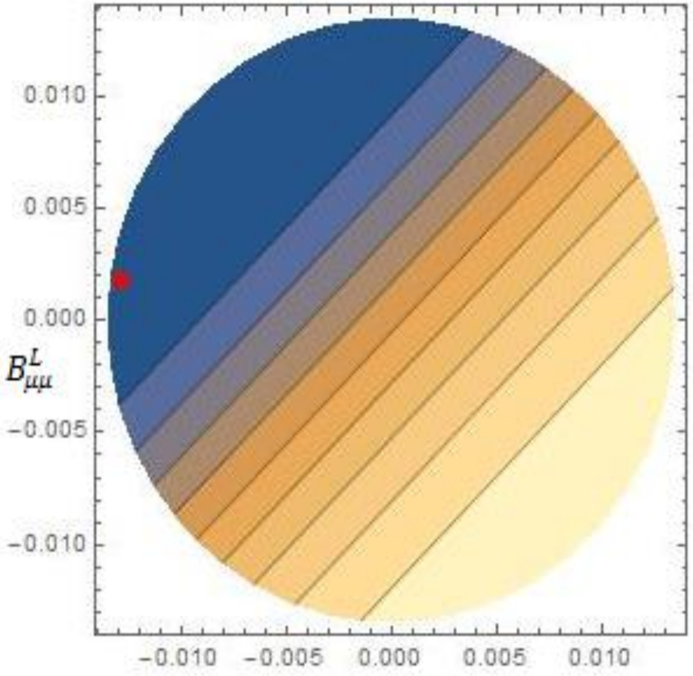

Fig. 2

Table. 3

$\chi^2_{min} = 0.235/2$, p-value = 0.889	
Parameter	**Best-fit value**
$B^L_{\mu\mu}$	$(-1.28 \pm 2.24) \times 10^{-2}$
$B^R_{\mu\mu}$	$(1.8 \pm 0.2) \times 10^{-2}$

❑ The branching ratio value in Z' model is calculated as 3.01×10^{-9}. The value is enhanced from the SM (1.17×10^{-9}) and is in agreement with the experimental result $((3.0 \pm 0.6) \times 10^{-9})$.

Numerical Analysis for $B_s \to e^+e^-$ channel

❖ As we can say that this fitting is very useful for $B_s \to \mu^+\mu^-$ and it can predict the branching ratio value correctly, we have used the same procedure for the electronic channel also.

Here we inspect the Z' couplings with leptons separately for electronic channel which may provide some NP stuffs.

❖ In this fitting we have used the experimental results given below [1]-

Mode	Branching value
$\mathrm{Br^{low}}(\mathrm{B} \to \mathrm{X_s e^+ e^-})$	$(1.64 \pm 0.11) \times 10^{-6}$
$\mathrm{Br^{high}}(\mathrm{B} \to \mathrm{X_s e^+ e^-})$	$(0.21 \pm 0.07) \times 10^{-6}$
$\mathrm{Br}(\mathrm{B} \to \mathrm{K e^+ e^-})$	$(1.6 \pm 0.1) \times 10^{-7}$

❖ After minimisation the best fit values are recorded in Table 4 and the fitted results are plotted in Fig. 3.

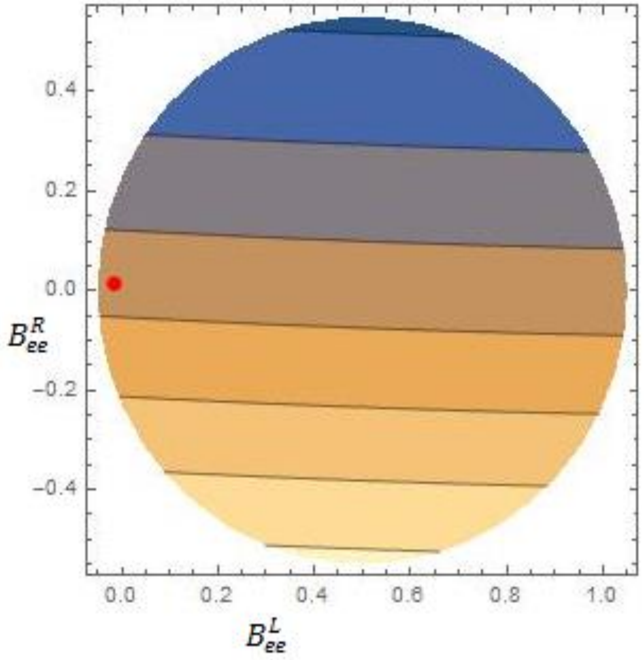

Fig. 3

Table. 4

$\chi^2_{\min} = 1.29/1$, p-value = 0.267	
Parameter	**Best-fit value**
B_{ee}^L	$(-1.42 \pm 1.24) \times 10^{-2}$
B_{ee}^R	$(1.32 \pm 0.07) \times 10^{-2}$

- **The branching ratio value in Z' model is calculated as 1.25×10^{-13}. Here also we see that the branching ratio is enhanced than the SM (2.65×10^{-14}) and lied within the experimental upper limit $(< 2.8 \times 10^{-7}$ (90% C.L.)).**

Results and Discussions

- ❖ **We investigated the non-universal leptonic couplings in Z' model for μ and e channels in accordance with the data of LHCb experiments.**

- ❖ **In both the channels the predicted branching ratio values are increased from their SM values.**

In the fitting for μ channel the p-value is 88.9% and the result is in accordance with the experimental value also.

⬇

Following the same procedure we calculated the NP couplings for electronic channel and the obtained p-value is 26.7%. And the calculated branching ratio is within the experimental upper limit.

- ❖ **These couplings may help the high energy physicists to explore various anomalies in B meson sector as a new benchmark of NP contribution through the exchange of Z' boson.**

Thank you