4
Probing new physics through branching ratio of $B_s^* \to \mu^+\mu^-$ decay

4.1 Introduction

As discussed in Chapter 2, there are several observables in the decays of B mesons, in particular decays induced by the quark level transition $b \to s l^+ l^-$ ($l = e,\, \mu$), which do agree with the predictions of the SM and can be considered as indications of new physics which one needs to explore. The R_K and R_{K^*} measurements can be explained by assuming new physics in $b \to s e^+ e^-$ and/or $b \to s \mu^+\mu^-$. However, the anomalous measurements of some of the angular observables in $B \to K^* \mu^+\mu^-$ as well as the branching ratio of $B_s \to \phi \mu^+\mu^-$ can be attributed to new physics in $b \to s\mu^+\mu^-$ only. Hence it is quite natural to account for all of these anomalies by assuming new physics only in $b \to s\mu^+\mu^-$ transition.

In [197, 198], new physics in $b \to s\mu^+\mu^-$ decays were analysed in a model independent way by making use of an effective Hamiltonian with all possible Lorentz structures. It was found that any large effects in $b \to s\mu^+\mu^-$ sector, in particular decays like $B \to K^*\mu^+\mu^-$ and $B_s \to \phi\mu^+\mu^-$, can mainly be due to new physics vector (V) and axial-vector operators (A). Scalar (S) and pseudoscalar (P) operators are insignificant for these decays. This fact is corroborated by several global fits using model independent analysis. These fits suggest various new physics solutions to explain anomalies in the $b \to s\mu^+\mu^-$ decay and they are mainly in the form of V and A operators. These new physics operators could affect other observables related to $b \to s\mu^+\mu^-$ transitions as well. In order to discriminate between various solutions and pin down the type of new physics responsible for all anomalies in the decays included by $b \to s\mu^+\mu^-$ transition, one should look for alternative observables. Also, it would be desirable to have an access to observables which are theoretically clean.

The purely leptonic decay of B_s^* meson is one such decay channel [199]. Its sensitivity to new physics is quite complementary to that of $B_s \to \mu^+\mu^-$ as $Br(B_s^* \to \mu^+\mu^-)$ is sensitive to different combinations of Wilson coefficients e.g. $Br(B_s \to \mu^+\mu^-)$ is sensitive to only the axial-vector operator O_{10} whereas the $Br(B_s^* \to \mu^+\mu^-)$ is sensitive to the operators C_7, C_9 and C_{10}. Also, as B_s^* meson is a vector meson, $Br(B_s^* \to \mu^+\mu^-)$ is not chirally suppressed. This property helps to reduce the effect of short lifetime of B_s^* meson. Further, this decay is theoretically very clean as the amplitude depends only upon decay constants which are accurately determined in the lattice QCD and the invariant mass of the process, $q^2 = m^2_{B_s^*} = 28\ \text{GeV}^2$, is well above the charmonium states. This enables the application of an operator-product expansion for the nonlocal contributions through the quark-hadron duality. Therefore the branching ratio of $B_s^* \to \mu^+\mu^-$ can be accurately predicted in the SM provided the B_s^* decay width is well known. However, at present, this width is neither measured experimentally not accurately determined theoretically [199, 200]. Therefore the B_s^* decay width is the only hindrance in the clean determination of the branching ratio. In future, this situation can improve owing to lattice QCD calculations. Using $\Gamma \sim 0.1$ KeV, the branching fraction for this process is predicted to be $\sim 10^{-11}$ [199]. This can be within reach of next run of LHC.

These properties of $B_s^* \to \mu^+\mu^-$ decay make it a golden decay channel to probe new physics in

$b \to s\mu^+\mu^-$ sector. The impact of $B_s^* \to \mu^+\mu^-$ on $B_s \to \mu^+\mu^-$ was studied in [201]. In [202] this decay is investigated in scalar leptoquark and family non-universal $Z^{'}$ models. It was shown that the scalar leptoquark model can provide significant enhancement in the branching ratio of $B_s^* \to \mu^+\mu^-$ whereas in $Z^{'}$ model, large enhancement is not possible.

In this chapter we perform a model independent analysis of $B_s^* \to \mu^+\mu^-$ decay by considering new physics in the form of V, A, S and P operators. We find that S and P operators do not contribute to the branching ratio of $B_s^* \to \mu^+\mu^-$. We then perform a global fit to all relevant $b \to s\mu^+\mu^-$ data assuming new physics in the form of V/A operators and identify various new physics solutions. For each of these solutions, we obtain predictions for branching ratio of $B_s^* \to \mu^+\mu^-$.

The organisation of this chapter is as follows. In the next section, we calculate the branching ratio of $B_s^* \to l^+l^-$ decay in the SM as well as in new physics. In Sec. 4.3, we discuss the methodology adopted in the fit to $b \to s\mu^+\mu^-$ data. In Sec. 4.4, we present fit results along with predictions of $Br(B_s^* \to \mu^+\mu^-)$ for various new physics scenarios. The conclusions of the analysis is presented in Sec. 4.5.

4.2 $B_s^* \to l^+l^-$ decay

The B_s^*, is a vector meson, with the same quark content as the B_s meson and can be used as a complementary probe to study semileptonic B decays. In this section we sketch the calculation, in brief, by using the effective Hamiltonian for the process $B_s^* \to l^+l^-$ in the SM and obtain the decay rate. We then explore new physics contributions to this process in a model-independent way by adding V, A, S and P operators to the SM effective Hamiltonian and calculate the decay rate.

4.2.1 $B_s^* \to l^+l^-$ decay in the SM

The effective Hamiltonian for the quark level transition $b \to sl^+l^-$ within the SM is given by

$$\begin{aligned}\mathcal{H}_{SM} = &-\frac{4G_F}{\sqrt{2}\pi}V_{ts}^*V_{tb}\bigg[\sum_{i=1}^{6}C_i(\mu)O_i(\mu) + C_7\frac{e}{16\pi^2}[\bar{s}\sigma_{\mu\nu}(m_sP_L + m_bP_R)b]F^{\mu\nu} \\ &+ C_9\frac{\alpha_{em}}{4\pi}(\bar{s}\gamma^\mu P_Lb)(\bar{l}\gamma_\mu l) + C_{10}\frac{\alpha_{em}}{4\pi}(\bar{s}\gamma^\mu P_Lb)(\bar{l}\gamma_\mu\gamma_5 l)\bigg],\end{aligned} \tag{4.1}$$

where G_F is the Fermi constant, V_{ij} are elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and $P_{L,R} = (1 \mp \gamma^5)/2$. The short-distance structure of the $b \to s$ transition is contained in the SM Wilson Coefficients C_i's of the respective operators O_i's where $O_{9,10}$ are the semi-leptonic operators and O_7 is the electric dipole operator. The effect of the operators O_i, $i = 1-6, 8$ can be included in the effective Wilson Coefficients by redefining $C_7(\mu) \to C_7^{eff}(\mu, q^2)$ and $C_9(\mu) \to C_9^{eff}(\mu, q^2)$.

The amplitude for the decay $B_s^* \to l^+l^-$ is given by

$$\mathcal{M}_{SM} = \left\langle l^+l^- \middle| \mathcal{H}_{SM} \middle| B_s^*(p_{B_s^*}, \epsilon) \right\rangle .$$

The matrix elements of the operators $O_{7,9,10}$ can be related to the decay constant, $f_{B_s^*}$ of B_s^* meson as follows [199]

$$\begin{aligned}\left\langle 0 \middle| \bar{s}\gamma^\mu b \middle| B_s^*(p_{B_s^*}, \epsilon) \right\rangle &= f_{B_s^*} m_{B_s^*} \epsilon^\mu, \\ \left\langle 0 \middle| \bar{s}\sigma^{\mu\nu} b \middle| B_s^*(p_{B_s^*}, \epsilon) \right\rangle &= -if_{B_s^*}^T (p_{B_s^*}^\mu \epsilon^\nu - \epsilon^\mu p_{B_s^*}^\nu), \\ \left\langle 0 \middle| \bar{s}\gamma^\mu\gamma_5 b \middle| B_s^*(p_{B_s^*}, \epsilon) \right\rangle &= 0,\end{aligned} \tag{4.2}$$

where ϵ_μ is the polarization vector of the B_s^* meson. In the heavy quark limit, these are related to the decay constant of B_s ($\langle 0|\bar{s}\gamma^\mu\gamma_5 b|B_s(p)\rangle = -if_{B_s}p^\mu$) as

$$f_{B_s^*} = f_{B_s}\left[1 - \frac{2\alpha_s}{3\pi}\right],$$
$$f_{B_s^*}^T = f_{B_s}\left[1 + \frac{2\alpha_s}{3\pi}(\log(\frac{m_b}{\mu})) - 1\right]. \tag{4.3}$$

We use the relations in the heavy quark limit, $f_{B_s^*}/f_{B_s} = f_{B_s^*}^T/f_{B_s}$ = 0.953 as given in [199], which hold up to $\mathcal{O}(\alpha_s)$. The SM amplitude for $B_s^* \to l^+l^-$ is then given by,

$$\mathcal{M}_{SM} = -\frac{\alpha G_F}{2\sqrt{2}\pi} f_{B_s} V_{ts}^* V_{tb} m_{B_s^*} \epsilon^\mu \left[(C_9^{eff} + \frac{2m_b f_{B_s^*}^T}{m_{B_s^*} f_{B_s^*}} C_7^{eff})(\bar{l}\gamma_\mu l) + C_{10}(\bar{l}\gamma_\mu\gamma_5 l)\right]. \tag{4.4}$$

After neglecting $\mathcal{O}(m_l^2/m_{B_s^*}^2)$ contributions, the SM decay rate is given by [199]

$$\Gamma_{SM} = \frac{\alpha_{em}^2 G_F^2 f_{B_s^*}^2 m_{B_s^*}^3}{96\pi^3} |V_{ts}V_{tb}^*|^2 \sqrt{1 - \frac{4m_l^2}{m_{B_s^*}^2}} \left[\left(1 + \frac{2m_l^2}{m_{B_s^*}^2}\right)\left|C_9^{eff} + \frac{2m_b f_{B_s^*}^T}{m_{B_s^*} f_{B_s^*}} C_7^{eff}\right|^2 + \left(1 - \frac{4m_l^2}{m_{B_s^*}^2}\right)|C_{10}|^2\right]. \tag{4.5}$$

The decay rate shows explicit dependence on the Wilson Coefficients C_7^{eff} and C_9^{eff} unlike the purely leptonic decay of pseudoscalar meson B_s.

Using the values of the SM Wilson Coefficients up to NNLL accuracy as given in [203] along with $\alpha_{em} = 1/127.94$, $f_{B_s^*} = 0.2284 \pm 0.037$ GeV[199], $m_{B_s^*} = 5415.4 \pm 2.25$ MeV, the SM decay rate is obtained to be

$$\Gamma(B_s^* \to \mu^+\mu^-)|_{SM} = 1.14 \pm 0.04 \times 10^{-18}\ \text{GeV}. \tag{4.6}$$

To compute the branching ratio of $B_s^* \to \mu^+\mu^-$, we need to know the total decay width of B_s^* meson which is yet not known precisely from theoretical calculations or measurements. In order to get an estimate on the branching ratio, it is assumed that the total decay width of B_s^*, $\Gamma_{B_s^*}^{tot}$ is comparable to the dominant decay process $B_s^* \to B_s\gamma$. From current experimental data and recent lattice QCD results, the decay width of $B_s^* \to B_s\gamma$ is found to be $\Gamma(B_s^* \to B_s\gamma) = 0.10 \pm 0.05$ KeV [199]. Using this, the branching ratio of $B_s^* \to \mu^+\mu^-$ in the SM is given by

$$\begin{aligned} Br(B_s^* \to \mu^+\mu^-)|_{SM} &= \frac{\Gamma(B_s^* \to \mu^+\mu^-)|_{SM}}{\Gamma_{B_s^*}^{tot}} \\ &= \frac{\Gamma(B_s^* \to \mu^+\mu^-)|_{SM}}{\Gamma(B_s^* \to B_s\gamma)} \times \frac{\Gamma(B_s^* \to B_s\gamma)}{\Gamma_{B_s^*}^{tot}}. \\ Br(B_s^* \to \mu^+\mu^-)|_{SM} &= (1.14 \pm 0.57)\left(\frac{0.10 \pm 0.05}{\Gamma_{B_s^*}^{tot}}\right) \times 10^{-11}. \end{aligned}$$

It is thus evident that the SM branching ratio of $B_s^* \to \mu^+\mu^-$ is roughly two orders of magnitude smaller than that of $B_s \to \mu^+\mu^-$.

4.2.2 Branching ratio of $B_s^* \to l^+l^-$ with new physics contributions

To study new physics effects in $B_s^* \to l^+l^-$ decay, we consider the addition of V, A, S and P operators to the SM effective Hamiltonian of $b \to sl^+l^-$ given in Eq. (4.1) . The effective Hamiltonian in the presence of these new physics operators is gives by

$$\mathcal{H}^{eff}(b \to sl^+l^-) = \mathcal{H}_{SM} + \mathcal{H}_{VA} + \mathcal{H}_{SP}, \tag{4.7}$$

where $\mathcal{H}_{VA}$ and $\mathcal{H}_{SP}$ are as

$$\mathcal{H}_{VA} = \frac{\alpha G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} \Big[C_9^{NP} (\bar{s}\gamma^\mu P_L b)(\bar{l}\gamma_\mu l) + C_{10}^{NP} (\bar{s}\gamma^\mu P_L b)(\bar{l}\gamma_\mu \gamma_5 l) + C_9^{\prime NP} (\bar{s}\gamma^\mu P_R b)(\bar{l}\gamma_\mu l) + C_{10}^{\prime NP} (\bar{s}\gamma^\mu P_R b)(\bar{l}\gamma_\mu \gamma_5 l) \Big], \quad (4.8)$$

$$\mathcal{H}_{SP} = \frac{\alpha G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} \Big[R_S (\bar{s} P_L b)(\bar{l} l) + R_P (\bar{s} P_L b)(\bar{l}\gamma_5 l) + R_S^{\prime} (\bar{s} P_R b)(\bar{l} l) + R_P^{\prime} (\bar{s} P_R b)(\bar{l}\gamma_5 l) \Big], \quad (4.9)$$

where $C_9^{NP}, C_{10}^{NP}, C_9^{\prime NP}, C_{10}^{\prime NP}, R_S, R_P, R_S^{\prime}, R_P^{\prime}$ are new physics couplings. In presence of NP, there can be additional contributions to the SM NP operators already present in SM. For example, if we have a NP model with $Z^{\prime}$ contributing to $b \to s\mu^+\mu^-$ decay at the tree level as shown in Fig. 4.1 then, in general, it would modify the SM Wilson coefficients C_9 and C_{10}. However if we have a scalar particle (χ) inducing $b \to s\mu^+\mu^-$ decay, it would generate O_S and O_P operators represented in $\mathcal{H}_{SP}$.

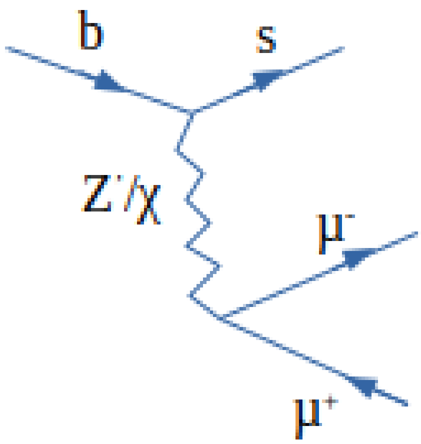

Figure 4.1: Feynman diagram illustrating NP contributions to $b \to s\mu^+\mu^-$ transition.

We first compute the decay rate by considering new physics in the form of S and P operators. From the structure of the these operators, it can be seen that the matrix elements which appear in the calculation of the amplitude are $\langle 0|\bar{s}b|B_s^*\rangle$ and $\langle 0|\bar{s}\gamma^5 b|B_s^*\rangle$. Using the first and third relations defined in Eq. (4.2), one can show that,

$$\langle 0|\bar{s}b|B_s^*\rangle = 0, \quad (4.10)$$

$$\langle 0|\bar{s}\gamma^5 b|B_s^*\rangle = 0. \quad (4.11)$$

Hence the branching ratio of $B_s^* \to l^+l^-$ is not affected by new physics in the form of S and P operators.

We now examine the contribution from V and A operators. Note that the matrix elements accompanying C_9^{NP}, and $C_9^{\prime NP}$ in the Hamiltonian for V and A contributions have the same Lorentz structure as the SM one for C_9 while the matrix elements accompanying C_{10}^{NP} , and $C_{10}^{\prime NP}$ are the same as the SM ones for C_{10}. The only difference being that unlike SM, new physics has right-handed chiral operator as well. Using the relationship between the matrix elements and decay constants defined in Eq. (4.2), the decay rate including new physics VA contribution is obtained to be,

$$\Gamma(B_s^* \to l^+l^-) = \frac{G_F^2\alpha^2}{96\pi^3}|V_{tb}V_{ts}^*|^2 f_{B_s^*}^2 m_{B_s^*}^2 \sqrt{m_{B_s^*}^2 - 4m_l^2}\Bigg[\Bigg|C_9^{eff}(m_{B_s^*}^2) + 2\frac{m_b f_{B_s^*}^T}{m_{B_s^*} f_{B_s^*}} C_7^{eff}(m_{B_s^*}^2) + C_9^{NP} + C_9^{\prime NP}\Bigg|^2 + \Bigg|C_{10} + C_{10}^{NP} + C_{10}^{\prime NP}\Bigg|^2\Bigg]. \quad (4.12)$$

Now we obtain constraints on new physics Wilson coefficients contributing to the branching ratio of $B_s^* \to \mu^+\mu^-$.

4.3 Methodology

As new physics in the form of S and P operators do not contribute to the branching ratio of $B_s^* \to \mu^+\mu^-$, we consider new physics only in the form of V and A operators. We consider various possible combinations of these new physics operators and obtain constraints on their coefficients by doing a global fit to all CP conserving observables in the $b \to s\mu^+\mu^-$ sector. Most of these observables probe the kinematical distribution in $B \to K^*\mu^+\mu^-$ and $B_s^0 \to \phi\mu^+\mu^-$. The observables used in the fit are:

1. The branching ratio of $B_s \to \mu^+\mu^-$ which is $(2.9 \pm 0.7) \times 10^{-9}$ [166, 167].

2. The measurements of R_K [42] and R_{K^*} [47].

3. The differential branching ratio of $B^0 \to K^0\mu^+\mu^-$. The measured values in various q^2 bins are given in Table A.1 of Appendix A.

4. The differential branching ratio of $B^+ \to K^+\mu^+\mu^-$. The experimentally measured values are given in Table A.2 of Appendix A.

5. The angular observables in different q^2 bins in the decay $B^0 \to K^{*0}\mu^+\mu^-$. The measured values are listed in Table A.3 of Appendix A.

6. The differential branching ratio of $B^+ \to K^{*+}\mu^+\mu^-$. The measurements are listed in Table A.4 of Appendix A.

7. The measurements of the angular observables and the differential branching ratio of $B_s^0 \to \phi\mu^+\mu^-$. The experimental measurements are given respectively in Tables A.5 and A.6 of Appendix A.

8. The experimental measurements for the differential branching ratio of $B \to X_s\mu^+\mu^-$. These measurements are listed in Table A.7 of Appendix A.

A χ^2 fit is done by using CERN minimization code MINUIT [204, 205]. The χ^2 function is constructed as

$$\chi^2(C_i) = (O_{th}(C_i) - O_{exp})^T \mathcal{C}^{-1}(O_{th}(C_i) - O_{exp}). \quad (4.13)$$

The χ^2 function is minimized to get the best fit points and the theoretical predictions, O_{th}(Ci) are calculated using flavio [206]. O_{exp} are the experimental measurements of the observables used in the fit. We obtained the total covariance matrix $\mathcal{C}$ by adding the individual theoretical and experimental covariance matrices.

We consider all possible combinations of new physics operators and obtain $\Delta\chi^2$ between the new physics best-fit points and SM best fit point. The fit results are presented Table 4.1. We want to see if any new physics scenario can provide large enhancement in the branching ratio of $B_s^* \to \mu^+\mu^-$ above its SM value.

Scenario	New physics couplings	$\Delta\chi^2$	Branching Ratio
$C_i = 0(SM)$	-	0	$(1.23 \pm 0.48) \times 10^{-11}$
C_9^{NP}	-1.24 $\pm$ 0.18	43.27	$(0.95 \pm 0.48) \times 10^{-11}$
C_{10}^{NP}	0.91 $\pm$ 0.19	29.47	$(1.01 \pm 0.51) \times 10^{-11}$
$C_9^{'}$	0.13 $\pm$ 0.16	0.66	$(1.30 \pm 0.65) \times 10^{-11}$
$C_{10}^{'}$	-0.11 $\pm$ 0.13	0.68	$(1.29 \pm 0.65) \times 10^{-11}$
$C_9^{NP} = C_{10}^{NP}$	0.01 $\pm$ 0.18	0.001	$(1.26 \pm 0.64) \times 10^{-11}$
$C_9^{NP} = -C_{10}^{NP}$	-0.65 $\pm$ 0.11	43.04	$(0.89 \pm 0.45) \times 10^{-11}$
$C_9^{'} = C_{10}^{'}$	-0.04 $\pm$ 0.17	0.06	$(1.26 \pm 0.64) \times 10^{-11}$
$C_9^{'} = -C_{10}^{'}$	0.07 $\pm$ 0.08	0.81	$(1.30 \pm 0.65) \times 10^{-11}$
$[C_9^{NP}, C_{10}^{NP}]$	[-1.10,0.33]	47.33	$(0.88 \pm 0.44) \times 10^{-11}$
$[C_9^{'}, C_{10}^{'}]$	[0.08,-0.07]	0.81	$(1.31 \pm 0.66) \times 10^{-11}$
$[C_9^{NP} = C_{10}^{NP}, C_9^{'} = C_{10}^{'}]$	[-0.02,-0.02]	0.07	$(0.97 \pm 0.49) \times 10^{-11}$
$[C_9^{NP} = -C_{10}^{NP}, C_9^{'} = -C_{10}^{'}]$	[-0.67,0.16]	46.27	$(1.00 \pm 0.52) \times 10^{-11}$
$[C_9^{NP}, C_{10}^{NP}, C_9^{'}, C_{10}^{'}]$	[-1.31,0.26,0.34,-0.25]	56.04	$(1.00 \pm 0.52) \times 10^{-11}$

Table 4.1: Calculation of the branching ratios of $B_s^* \to \mu^+\mu^-$ for various new physics scenarios. Here $\Delta\chi^2 = \chi^2_{SM} - \chi^2_{bf}$ and χ^2_{bf} is the χ^2 at the best fit points. We provide 1σ range of the new physics couplings for the one parameter fits and the central values for multiple parameter fits.

4.4 Results and Discussions

The fit results for various new physics scenarios, along with the corresponding predictions for the branching ratio of $B_s^* \to \mu^+\mu^-$, are presented in Table 4.1. As $\Delta\chi^2$ is defined as $\chi^2_{SM} - \chi^2_{bf}$, an extremely low value of $\Delta\chi^2$ means that χ^2_{SM} and χ^2_{bf} or χ^2_{NP} are almost the same. Therefore it implies that in such a case, the given NP scenario cannot provide an improvement over the SM and hence is disfavoured. This implies that the NP Lorentz structure for which $\Delta\chi^2$ is extremely low will not be able to explain the observed discrepancies. Thus by observing $\Delta\chi^2$, one can predict the best possible Lorentz structure of NP.

Global fits suggest that a large negative C_9^{NP} contribution can provide a good fit to the data, i.e., having a large χ^2. A large negative value of C_9^{NP} on the one hand allows large deviations in $P_5^{'}$ with respect to the SM and on the other hand drives $R_{K^{(*)}}$ to a value lower than their SM predictions of $\sim$1, in agreement with the experimental measurements. Another good fit scenario is $C_9^{NP} = -C_{10}^{NP}$. This corresponds to an operator with only left-handed leptons and is predicted by various new physics models. A positive value of C_{10}^{NP} can also improve the fit however the improvement is moderate. The effect of individual chirality flipped operators are almost insignificant i.e., they hardly improve the fit.

From Table 4.1, it can be seen that the new physics scenarios which provide a good fit to the data, suppress the branching ratio of $B_s^* \to \mu^+\mu^-$ as compared to its SM value. In order to understand this, let us first consider a good-fit scenario $C_9^{NP} < 0$. From Eq. (4.12), it can be seen that the branching ratio, in the presence of the new physics operator O_9^{NP}, depends upon $|C_9^{eff} + C_9^{NP}|^2$. Now as $C_9^{eff} \sim 4.2$ in the SM, a large negative value of C_9^{NP} will decrease the effective Wilson coefficient $|C_9^{eff} + C_9^{NP}|^2$ and hence will result in the suppression of the branching ratio of $B_s^* \to \mu^+\mu^-$. Another scenario which provides a good fit is $C_9^{NP} = -C_{10}^{NP}$. In this scenario the effective Wilson coefficient $|C_9^{eff} + C_9^{NP}|^2$ becomes less than the SM value thereby lowering the branching ratio. In addition to this, a positive value of C_{10}^{NP}, in this scenario, reduces the value of the effective Wilson coefficient $|C_9^{eff} + C_9^{NP}|^2$, as in the SM the value of C_{10} is negative. Therefore in this NP scenario, the effect of both C_9^{NP} and C_{10}^{NP} is to suppress the branching ratio of $B_s^* \to \mu^+\mu^-$ in comparison to the SM.

Other scenarios which provide a good fit to the data, similarly have $C_9^{NP} < 0$ and $C_{10}^{NP} > 0$. These scenarios, in addition have small positive and negative values of $C_9^{'}$ and $C_{10}^{'}$ respectively. This in principle could lead to some enhancement in the branching ratio. However the allowed values of $C_9^{'}$ and $C_{10}^{'}$ are very small as compared to the values of C_9^{NP} and C_{10}^{NP}, so the effect of the latter dominates leading to suppression in the branching ratio.

The remaining scenarios have χ^2 small and hence they do not provide a good fit to the data. These scenarios cannot induce significant deviation in the branching ratio from the SM value. This is because the new physics Wilson coefficients for these scenarios are very small as compared to the SM and hence they cannot lead to a significant enhancement or suppression of the branching ratio.

Thus none of the new physics scenarios can provide large enhancement in the branching ratio of $B_s^* \to \mu^+\mu^-$ above its SM value. In scenarios where a good fit to the data is obtained, $Br(B_s^* \to \mu^+\mu^-)$ is seen to be suppressed as compared to the SM value. Hence, most likely, the future measurements are expected to observe $B_s^* \to \mu^+\mu^-$ decay with a branching ratio less than its SM prediction.

4.5 Conclusions

The new physics sensitivity of $B_s^* \to \mu^+\mu^-$ decay is quite complementary to that of $B_s \to \mu^+\mu^-$ decay as it is sensitive to different combinations of Wilson coefficients. More importantly, this decay is theoretically very clean. The decay rate can be accurately predicted in the SM provided the B_s^* decay width is well known. In this chapter, we perform a model independent analysis of new physics in $B_s^* \to \mu^+\mu^-$ decay with an intend to identify the Lorentz structure of new physics which can provide large enhancement in the branching ration of $B_s^* \to \mu^+\mu^+$ above its SM value. For this, we consider new physics in the form of V , A, S and P operators. We show that the S and P operators do not contribute to $Br(B_s^* \to \mu^+\mu^-)$. We then perform a global fit to all relevant $b \to s\mu^+\mu^-$ data for different combinations of new physics V and A operators. For each of these scenarios, we predict $Br(B_s^* \to \mu^+\mu^-)$. We find that none of these scenarios can significantly enhance $Br(B_s^* \to \mu^+\mu^-)$. All new physics operators which provide a good fit to the present $b \to s\mu^+\mu^-$ data indicate suppression in $Br(B_s^* \to \mu^+\mu^-)$ in comparison to its SM prediction.