CHAPTER 6

Discussions and Conclusion
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At the end we epitomise the results obtained in the present thesis. A brief review of the defects of the Standard Model (SM) of elementary particle physics is presented in chapter 1. Many different extensions of the SM have been proposed to overcome these defects. $Z'$ boson could appear in several well-motivated extensions of the SM [1–8]. It is an electrically neutral spin-1 gauge particle. Theoretically it is predicted that $Z'$ boson exists in grand unified theories (GUTs), left-right symmetric models, Little Higgs models, superstring theories and theories with large extra dimensions but experimentally they are not observed so far. If discovered they would represent irrefutable proof of new physics, most likely that SM gauge group is to be extended.

We have discussed some models with extra $Z'$ gauge boson, $Z'$ searches at the LHC and at the Future Linear Colliders (FLC) briefly. A brief introduction to $B$ meson decays is also presented. The two $B$-factories, BABAR and BELLE, have produced $\sim 10^9 B$ mesons and have explored various facets of the decays of $B^*$ and $B_d$ mesons. The Tevatron experiments CDF and DØ have already provided a large number of data on the $B_s$ decays. Although almost all the $B$ decay measurements till now have been consistent with the SM [9–11], recently there have been a number of hints for new physics (NP) beyond the Standard Model (BSM). The experiments at the LHC–ATLAS, CMS and LHCb (a dedicated flavor physics experiment) will collect enough data to explore the flavor sector soon. The $B$ meson decays [12–16] provide information about the flavor structure of the SM, the origin of CP violation, the dynamics of hadronic decays, and to search for any signals of new physics beyond the SM. From the various experiments like the Tevatron, the LHC, the FLC etc; the discovery of $Z'$ boson is not ruled out, it is therefore interesting to study its effect on $B$ meson decays to reveal new physics beyond the Standard Model.

In chapter 2, we have discussed the effect of both $Z$ and $Z'$-mediated flavor-changing neutral currents (FCNCs) on the $\Lambda_b \rightarrow \Lambda \ell^+\ell^-$ ($\ell = \mu, \tau$) rare decay. We have found the branching ratios are $B\left(\Lambda_b \rightarrow \Lambda\mu^+\mu^{-}\right)_{Z, Z'} = \left( 46.52 \pm 0.01 \right) \times 10^{-6}$, $B\left(\Lambda_b \rightarrow \Lambda\tau^+\tau^{-}\right)_{Z, Z'} = \left( 2.03 \pm 0.12 \right) \times 10^{-6}$ for $M_{Z'} = 130$ GeV, and $B\left(\Lambda_b \rightarrow \Lambda\mu^+\mu^{-}\right)_{Z, Z'} = \left( 21.23 \pm 0.11 \right) \times 10^{-6}$, $B\left(\Lambda_b \rightarrow \Lambda\tau^+\tau^{-}\right)_{Z, Z'} = \left( 0.93 \pm 0.03 \right) \times 10^{-6}$.
$0.02 \times 10^{-6}$ for $M_{Z'} = 1000$ GeV. Whereas the values of the branching ratios in the SM [18] are $B\left(\Lambda_{b} \rightarrow \Lambda \mu^+ \mu^-\right) = 4.55 \times 10^{-6}$ and $B\left(\Lambda_{b} \rightarrow \Lambda \tau^+ \tau^-\right) = 0.17 \times 10^{-6}$. Our estimated branching ratios are reasonably enhanced from its SM value due to the effect of both Z and $Z'$-mediated FCNCs, and give the possibility of new physics beyond the SM. The contribution of $Z'$ boson depends upon the precise value of $M_{Z'}$. Recently [19,20], it is shown that $Z'$ boson gives considerable contribution to the decay width of $\Lambda_{b} \rightarrow \Lambda \ell^+ \ell^-$. Zero position of the forward-backward asymmetry is shifted to the left compared to the SM result. It is also observed that the lepton polarization effects in $\Lambda_{b} \rightarrow \Lambda \ell^+ \ell^-$ decay are sensitive to the $Z'$ contribution. The LHCb is expected to give us more insight on the flavor structure of new physics through precise measurements of rates and CP asymmetries in rare decays. The experimental observation of the $\Lambda_{b} \rightarrow \Lambda \ell^+ \ell^-$ rare decay would provide precision tests of the SM in the crucial and as yet untested FCNC sector of B decays.

In chapter 3, we have discussed the effect of $Z'$-mediated flavor-changing neutral current on the $B \rightarrow \pi \pi$ decays. The branching ratios of these decays can be enhanced remarkably in the non-universal $Z'$ model. Our [21] estimated branching ratios $B\left(B^0 \rightarrow \pi^0 \pi^0\right)$ are enhanced significantly from their SM value. For $g'/g = 1$, the branching ratios $B\left(B^0 \rightarrow \pi^0 \pi^0\right)$ are very close to the recently observed experimental values and for higher values of $g'/g$ branching ratios are more. Our calculated branching ratios $B\left(B^0 \rightarrow \pi^+ \pi^-\right)$ and $B\left(B^+ \rightarrow \pi^+ \pi^-\right)$ are also enhanced from the SM value as well as the recently observed experimental values. These enhancements of branching ratios from their SM value give the possibility of new physics. Furthermore, future observations of these decays would help us to constrain the mass of $Z'$ boson within the model.

In chapter 4, we have considered $B_s^0 - \overline{B_s^0}$ and $B_d^0 - \overline{B_d^0}$ mass differences taking the effect of both Z- and $Z'$-mediated FCNCs in the $B_q^0 - \overline{B_q^0}$ mixing ($q = d, s$). We [22] observe that the experimental value of $\Delta M_{B_s} = 17.77 \pm 0.10 \text{ (stat)} \pm 0.07 \text{ (syst) ps}^{-1}$ [23] is consistent with the mass of $Z'$ boson in the range 989 GeV – 1665 GeV. Similarly, we observe that the experimental value of
\( \Delta M_{B_d} = (0.507 \pm 0.005 \text{ ps}^{-1}) \) [9] is consistent with the mass of \( Z' \) boson in the range 1352 - 1824 GeV. If one tries with any other values of \( Z' \) boson mass, there is a discrepancy in the values of \( \Delta M_{B_d} \) and \( \Delta M_{B_s} \).

In chapter 5, we have evaluated \( B_s^0 - \overline{B_s^0} \) and \( B_d^0 - \overline{B_d^0} \) decay width differences in \( Z' \) model. Depending on the precise value of \( M_{Z'} \), the \( Z' \)-mediated FCNCs gives considerable contributions to \( B_q^0 - \overline{B_q^0} \) mixing. Our estimated \( B_q^0 - \overline{B_q^0} \) decay width differences [24] \( \Delta \Gamma_s = (0.100 \pm 0.008) - (0.105 \pm 0.007) \text{ ps}^{-1} \) and \( \Delta \Gamma_d = (45.20 \pm 0.20) \times 10^{-4} - (46.35 \pm 0.50) \times 10^{-4} \text{ ps}^{-1} \) are enhanced relative to the SM prediction. Lower the mass of \( Z' \) boson, more is the deviation from the SM. Hence, the \( B_q^0 - \overline{B_q^0} \) mixing could provide signals for new physics beyond the SM.

More interestingly, our predicted \( \Delta \Gamma_s \) values are very close to the recent measurement done by the LHCb collaboration [25] \( \Delta \Gamma_s = 0.106 \pm 0.011 \text{ (stat)} \pm 0.007 \text{ (syst) ps}^{-1} \).

Recently [26,27], it is shown that sizable \( \Delta \Gamma_s \) affects the extraction of \( B_s^0 \rightarrow \mu^+ \mu^- \) branching ratio and constraints the new physics parameter space. It is also found that \( \Delta \Gamma_s \) provide a new observable, the effective \( B_q^0 \rightarrow \mu^+ \mu^- \) lifetime \( \tau_{\mu^+ \mu^-} \), which offers a clean probe for new physics searches. Recently [28], it is claimed that the deviation in the value of \( \Delta \Gamma_d \) from the SM prediction would contribute to the like-sign dimuon charge asymmetry measured by the D0 collaboration [29–31].

The theoretical framework for studying \( Z' \) production at hadron colliders has been developed almost three decades ago [32]. At the Tevatron, searches for additional neutral gauge bosons have been performed in a variety of processes during last twenty years [33]. For the sequential standard model \( Z' \) (\( Z'_{\text{SSM}} \)), a lower mass limit of 1023 GeV and 1071 GeV are obtained by D0 collaboration [34] and CDF collaboration [35] respectively. From the electroweak precision data analysis, the lower limits on the \( Z' \) mass are given in the range 1.1–1.4 TeV at 95 % CL [36]. From the recent CMS collaboration analyses [37] the mass limits for the sequential standard model \( Z' \) and the superstring inspired \( Z'_{\nu} \) are about 2590 GeV and 2260 GeV respectively at 95% CL. The LHC has the potential of discovering the \( Z' \) up to
$M_{Z'} = 4.5 \text{ TeV}$ with 100 fb$^{-1}$ data at centre of mass energy $\sqrt{s} = 14 \text{ TeV}$ [38]. These limits on $Z'$ boson mass favours higher energy ($\geq 1 \text{ TeV}$) collisions for direct observation of the signal. It is also possible that the $Z'$ bosons can be much heavy or weak enough to escape beyond the discovery reach expected at the LHC. In this case, only the indirect signatures of $Z'$ exchanges may occur at the high energy colliders [39]. Recently [40], it has been shown that one can probe a $Z'$ boson with a mass in the TeV scale at the LHC in a supersymmetric model where the gauge group is extended by an additional $U(1)_{B-L}$ factor. More interestingly, our estimation [22] of mass of $Z'$ boson lies in the range of $1352 - 1665 \text{ GeV}$. Our result is satisfied the limits $1.3 \text{ TeV} \leq M_{Z'} \leq 3.1 \text{ TeV}$ [41,42]. Recently, Chiang et al. [43] have studied the effects of $Z'$ boson on leptonic decays of Higgs and weak boson in the mass range $10 \text{ GeV} \leq M_{Z'} \leq 3 \text{ TeV}$. Our predicted mass of $Z'$ boson also lies within this range.

One expects that future experiments in B meson decays will lead us to a better understanding of flavor physics in the SM, and perhaps even give an indirect signal for physics beyond the SM [44,45]. As theorists we can not do full justice to experimental endeavours. Yet we try to communicate our conviction that physics is so wonderfully exciting exactly because it is science where theory and experiment play an interactive role. Our analysis is consistent with the experimental predictions at various laboratories and the physics beyond the Standard Model will show up after the discovery of the $Z'$ boson. We hope that the LHCb experiment at the LHC and/or the upcoming Super B-factories will provide a signal of the $Z'$ boson and can constrain its mass. Hence, the current and future exciting experimental situation will stimulate novel activities in this direction. We have no doubt that an exciting future is ahead of us!
References


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