Chapter 5

Conclusion And Future Scope

5.1 Conclusion

This thesis incorporates the detailed study about the dynamics of the weak interaction to understand the decays of open flavor mesons. We have focused mainly on semileptonic decays of open flavor mesons. Weak decays are very significant in the study of Standard Model and prediction of various parameters like elements of CKM matrix and in the study of CP violation. Flavor Changing Neutral Current are important object which can hint towards the physics beyond standard model called New Physics. There are many experimental facilities available worldwide along with plenty of Effective Field Theory approaches to study the dynamics of weak decays. We have employed Covariant Confined Quark Model (CCQM) for this study. CCQM has few unique features such as accountability for the complete physical range of momentum transfer and built-in infrared confinement.

We have studied the $B_s \to D_s^{(*)-}$ and $B_s \to K^{(*)-}$ transitions for semileptonic decays in detail. These channels are studied within the standard model framework of covariant confined quark model (CCQM). We have calculated the required transition form factors in the entire physical range of momentum transferred squared and comparison is made with RQM, PQCD, LFQM and QCD sum rule approaches, where our results match well with RQM other than $V(0)$, however the result deviates a bit from PQCD data. Using the form factors, decay rates has been calculated and spreading of the uncertainty is also calculated. For the purpose of comparison with LQCD and LHCb results, normalized decay rates have been calculated for different bin values which shows very good agreement with both LQCD and LHCb result, which in a way also validates the compatibility of CCQM to work with binned q^2 values. Further we have calculated branching fraction for $B_s \to D_s^*$ transition and results are compared with LHCb, LFQM, RQM and PQCD results. Calculated results show an overshoot in comparison with RQM and PQCD data for $\ell = e$ and μ mode. This difference mainly arises due to the difference in values of form factor used in our calculations and RQM calculation. As a probe for Lepton Flavor Universality, the ratio of decay width of τ mode to μ mode for both D_s and D_s^* has been evaluated and which is in very good agreement with LHCb and available lattice results. Ratio of decay width of $B_s \to D$ and $B_s \to D_s^*$ also matches well with LHCb and lattice data for muon channel. Further the calculated result of $R(D_s^*)$ matches well within the uncertainty range given by Belle Collaboration. It is to be noted that the calculated value without uncertainty is lower by 16%. LHCb results are yet not reported for the branching fraction of tau mode for $B_s \to D_s$ transition. We anticipate this result in near future. We have also calculated the form factor and branching fraction for $B_s \to K^*$ transition, where our results are very close to LHCb results and also agree very well with other theoretical approaches like LFQM and LCSR. The average value of forward-backward asymmetry and longitudinal polarization of leptons in the final states for $B_s \to D_s$ and $B_s \to D_s^*$ transitions are computed and forward-backward asymmetry, longitudinal and transverse polarization, convexity parameters for both $B_s \to K$ and $B_s \to K^*$ transition and longitudinal polarization fraction for the final vector meson for $B_s \to K^*$ transition is calculated in entire q^2 range in this study.

We have also carried out the detailed study of rare $b \to d$ decay. The transition form factors are calculated in the entire q^2 range, which are used to obtain branching fraction and other observables. The branching fractions are obtained using both resonant and non resonant contribution while other observables are computed using vector resonant contribution only. For the resonant contribution we have excluded the experimentally vetoed regions. Branching fraction for $\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)$ is on lower side, $\mathcal{B}(B_s^0 \to \bar{K}^*(890)^0\mu^+\mu^-)$ is within the range predicted by LHCb and nonresonant $\mathcal{B}(B^+ \to \rho^+\mu^+\mu^-)$ matches well with the uncertainty predicted by RQM and LCSR approach. The result for nonresonant B^0 decays are in good agreement with LCSR results for almost all the channels. The ratio $\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)$ / $\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$ is a bit lower than the measured value due to the small value of $\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$ in our model. Furthermore, additional observables are calculated in the low and entire q^2 ranges and compared with the pQCD and LCSR approaches. These observables' experimental results have not yet been released. Given that the Upgrade II dataset provides an abundance of data for the transition corresponding to $b \to d$ decays, we anticipate that they could be observed by LHCb and other B factories.

5.2 Future Scope

Since it has been so successful in explaining a broad range of experimental data with energies ranging from less than 1 GeV to a few TeV, the Standard Model (SM) is widely acknowledged as the theory describing elementary particle interactions. Many theories are there to explain the strong and weak interactions in SM, however there are many issues in SM which are still unresolved like the undiscovered source of CP violation in quark sector which can clarify why matter dominates over antimatter in the universe. Therefore testing the SM is of utmost importance in which Charm sector can still play an important role.

Our results of the above study shows that CCQM with uncertainty calculation is fully capable of exploring the dynamics of both exclusive and rare semileptonic decays of meson. Because of the fact that Flavor Changing Neutral Current (FCNC) decays are very important candidates to study the New Physics (NP) beyond Standard Model (SM) because of their large supression, we would further like to explore a rare decay $D_+ \to \pi^+\ell^+\ell^-$ ($\ell = e, \mu$) in detail which corresponds to $c \to u\ell^+\ell^-$ transition. This type of process where D^+ meson decays into two oppositely charged leptons in final state are highly suppressed in SM due to Glashow–Iliopoulos–Maiani (GIM) mechanism and are only allowed through loop and box diagrams and not allowed via tree level diagram. Here the c quark couples to u (up-type) quark which makes it a rare decay and provides excellent opportunity to probe for physics beyond SM. Although the experimental measurement of branching fraction has reached at the sensitivity of 10^{-9} [235–238], as of now there is no experimental evidence obtained for the branching fraction of this decay. Till date not much experimental data is available

Table 5.1: Overview of Branching fraction for the semileptonic decay of baryons

Channels	Experiment	Other Models
$\Lambda_c^+ \to p\bar{K}e^+\bar{\nu}_e$	$(0.88 \pm 0.17 \pm 0.07) \times 10^{-3}$ [239]	- - -
$\Xi_c^+ \to \Xi^0 e^+\bar{\nu}_e$	$2.3 \pm 0.6^{+0.3}_{-0.6}$ [240]	$7.18 \pm 0.9 \pm 0.96 \pm 0.20$ [241]
$\Xi_c^0 \to \Xi^- e^+\bar{\nu}_e$	$(1.31 \pm 0.04 \pm 0.07 \pm 0.38)$ [242],$(2.43 \pm 0.25 \pm 0.35 \pm 0.72)$ [243]	2.38 [244],1.35 [245],7.26 ± 2.54 [246],4.87 ± 1.74 [247], 2.4 ± 0.3 [248], $2.38 \pm 0.3 \pm 0.32 \pm 0.07$ [241]
$\Omega_c^0 \to \Omega^- e^+\nu_e$	$(5.4 \pm 0.2) \times 10^{-3}$ [249]	

for semileptonic decays of baryon, although some theoretical data is available from different groups. The theoretical treatement for calculating decay for the baryons having single heavy quark is somewhat easier than the baryons having two heavy quarks because, for two heavy quarks we can not make the use of the expansion in terms of the inverse heavy quark masses [134]. In spite of the above difficulty, doubly heavy baryon decay opens up one more avenue to calculate CKM matrix element V_{cb} due to the fact that the spin symmetry relation in heavy quark limit is obeyed by transition matrix element of doubly heavy baryons [250]. With very few modifications CCQM can also be adopted to explore baryonic decays, hence next, we would like to focus on the study of semileptonic decays of the baryons. Baryons are hadrons containing three quarks. Tab. 5.1 shows the list of semileptonic decay channels for baryons which are not attemped by CCQM. Here for the channel $\Xi_c^+ \to \Xi^0 e^+\bar{\nu}_e$ we can see that there is a hugh difference between the experimental and theoretical result. Theoretical result is obtained from LQCD calculations. This provides a very good avenue to apply and test CCQM. For the channel $\Omega_c^0 \to \Omega^- e^+\nu_e$, Belle collaboration has provided the branching fraction ratio $\mathcal{B}(\Omega_c^0 \to \Omega^- e^+\nu_e)/\mathcal{B}(\Omega_c^0 \to \Omega^-\pi^+)$ and $\mathcal{B}(\Omega_c^0 \to \Omega^-\mu^+\nu_\mu)/\mathcal{B}(\Omega_c^0 \to \Omega^-\pi^+)$, however value of absolute branching fraction for $\Omega_c^0 \to \Omega^- e^+\nu_e$ has not been provided. Belle collaboration has also provided the ratio of $\mathcal{B}(\Omega_c^0 \to \Omega^- e^+\nu_e)/\mathcal{B}(\Omega_c^0 \to \Omega^-\mu^+\nu_\mu)$ which is consistent with the expectation of Lepton Flavor Universality test [251]. Our main focus will be on $c \to s$ and $c \to d$

transitions because, recently there are two upgrades planned for BESIII experiments, one will increase the beam energy to 2.8 GeV and other will increase the peak luminosity by a factor of 3 for $\sqrt{s} = 4.0 - 5.6$ GeV. This will enable BESIII to produce large amount of data regarding decay of charmed mesons and baryons as well as for the exotic charmonium states. On top of that we would also like to explore hadronic decays of meson as well as the rare baryon decays in future.