Abstract

Flavor physics is the study of quark "flavors" and their interactions involving change of one type of flavor to another type of flavor. It is known that, historically, the study of flavor physics has played a key role in the development of the Standard Model (SM) of particle physics. The recent discovery of the last missing piece, the Higgs boson, in the first run of the Large Hadron Collider (LHC) marks the completion of the SM. The SM has been exceptionally successful in explaining the experimental data collected so far. However, there are many experimental measurements which point towards the existence of physics beyond the SM. Therefore, it is natural to consider SM as the low-energy limit of a more general theory above the electroweak scale. The next important task is then to look for hints of the physics beyond the SM. In this endeavour, the study of flavor physics continues to be an integral part of the searches at the intensity frontier. The study of flavor physics offers unique possibilities to study the weak interactions operating at the fundamental level governing the decays in conjunction with the strong forces responsible for keeping the constituents bound in various colorless hadronic states. In recent years, due to dedicated efforts by the Belle, BaBar, CDF, and LHCb experiments, a great theoretical understanding of the flavor dynamics of the SM has been achieved, and severe constraints on the new physics parameters have been imposed. The rare and flavor changing neutral current processes of b quark have been quite instrumental and valuable probes of new physics, thanks to their suppressed nature in the SM and high sensitivity to the new physics effects.

In this context, the exclusive semileptonic decay $B \to K^* \ell^+ \ell^-$ governed by the quark-level transition $b \to s \ell^+ \ell^-$ is one of the most interesting candidates, which has received great attention, experimentally as well as theoretically. The analysis of the angular distribution of its four-body final state gives access to a large number of experimentally accessible observables as a function of invariant mass squared of the dilepton system (q^2). Interestingly, the LHCb collaboration has found deviations from the SM predictions in the measurement of angular observables of $B \to K^* \mu^+ \mu^-$. These measurements are reported in bins of q^2.

Particularly, the discrepancy in one of the angular observables, P_5', in two of low q^2 bins is quite intriguing. However, in order to be certain that the reported deviations are hints of new physics or artifacts of underestimated theoretical uncertainties, it is necessary to measure the observables which are as insensitive to hadronic effects as possible with more precision. In this thesis, we study some of these "theoretically cleaner" observables which are independent of hadronic form factors within the heavy quark effective framework. We show that zero crossing points of observables P_5', P_4', and of a new observable, $O_T^{\mathrm{L,R}}$, are independent of form factors, and are functions of short-distance Wilson coefficients in the considered limit. The zero crossing of $O_T^{\mathrm{L,R}}$ in the standard model coincides with the zero crossing of the forward-backward asymmetry (A_{FB}) of the lepton pair. But in the presence of new physics contributions they show different behaviors. Moreover, we show that there exist relations between the zeros of P_5', P_4', $O_T^{\mathrm{L,R}}$, and the zero of A_{FB}, which are also independent of hadronic uncertainties. We point out that precise measurements of these zeros in the near future would provide a crucial test of the standard model and would be useful in distinguishing between different possible new physics contributions to the Wilson coefficients. If the experimental observations are in fact due to NP in $b \to s\ell\ell$, then similar effects must also be seen in other $b \to s\ell\ell$ transitions involving different hadronic states. This fact sets the tone for our next work in which we study the semileptonic baryonic $b \to s$ decay, $\Lambda_b \to \Lambda\ell^+\ell^-$. We construct new angular observables and asymmetries; all of which have zero crossing points in the large q^2 region. The zeros of proposed observables in the heavy quark and large q^2 limit are again functions of Wilson coefficients only, and therefore have less sensitivity to hadronic effects. We discuss the potential of the decay $\Lambda_b \to \Lambda\ell^+\ell^-$ in probing the new physics effects in $b \to s\ell^+\ell^-$ along with the decays $B \to K^{(*)}\ell^+\ell^-$.

In the second part of the thesis, we present the explanation of some of the experimentally observed anomalies in the flavor sector within the framework of left-right symmetric gauge theories motivated by one of the low-energy subgroups of E_6 naturally accommodating leptoquarks. First, we explain the enhanced decay rates of $B \to D^{(*)}\tau\nu$ in E_6 motivated Alternative Left-Right Symmetric

Model. We discuss the constraints from the flavor sector on the couplings involved in explaining the experimental data. We further consider the framework of E_6 motivated Neutral Left-Right Symmetric Model, and give simultaneous explanation for B decay anomalies in $B \to D^{(*)}\tau\nu$ and $\bar{B} \to \bar{K}\ell^+\ell^-$ together with the anomalous magnetic moment of the muon, consistent with the constraints from other flavor data.

In the last part of the thesis, we carry out a detailed study of the effects of new physics originating from a scalar leptoquark model on the kaon sector. It is known that kaon decays provide some of the most stringent constraints on various extensions of the SM. We consider a simple extension of the SM by a scalar leptoquark of charge $-1/3$ with $(\mathrm{SU(3)_C}, \mathrm{SU(2)_L})$ quantum numbers $(3, 1)$, which is able to account for the deviations observed in B decays. The leptoquark we consider is a TeV-scale particle and within the reach of the LHC. We use the existing experimental data on the several kaon processes including $K^0 - \bar{K}^0$ mixing, rare decays $K^+ \to \pi^+\nu\bar{\nu}$, $K_L \to \pi\nu\bar{\nu}$, the short-distance part of $K_L \to \mu^+\mu^-$, and lepton-flavor-violating decay $K_L \to \mu^\pm e^\mp$ to obtain useful constraints on the model.

Keywords: flavor physics, rare decays, semileptonic B decays, Kaon decays, baryonic b decay, effective field theory, Wilson coefficients, beyond the Standard Model, leptoquarks.