Imprints of New Physics via $B \to K^{*0}(1430)\ell\nu_\ell$ decay

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Abstract

Branching ratio and Lepton Flavor Non-Universality (LFNU) ratio for $B \to (K^{*0}(1430))\ell\bar{\nu}_\ell$ where $(\ell = \mu, \tau)$ decay has been studied, by probing the NP observables using B decays, in a model independent scenario. For this decay, the form factors derived in the covariant light front quark model are used. To analyze the NP effects, for BR and LFNU ratio, in a model independent scenario, the best fit values as well as 1σ range values of Wilson coefficients has been used. It is found that the above mentioned physical observables shows a significant deviation from the SM predictions for $B \to (K^{*0}(1430))\ell\bar{\nu}_\ell(\ell = \tau, \mu)$ decay. The hope is that either in the current collider experiments or in the future colliders these observables will test the Standard Models parameters, but can also be useful to probe the properties of NP particles.

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Chapter 1

Introduction

The life long curiosity of mankind is to understand the Nature. For this endeavor, since it's inception the mankind is making discoveries and doing experiments to peal off the knowledge layer by layer by observing the order and structure of Nature. One of the key area in that aspect is Particle Physics. Since last century, many important discoveries have been made from understanding the atomic structure By Bohr to discovery of subatomic particles. In 1954, CERN (European Organization For Nuclear Research) was established to provide a collaborative platform for physicists to conduct the research in high-energy particle physics.The fundamental foal of CERN was to study the structure of subatomic particles along with their behavior, leading to significant advancements in our understanding f the fundamental forces and building blocks of the universe. Today, CERN remains one of the world's leading centers for high-energy particle physics, operating the world's largest and most powerful accelerator Large Hadron Collider (LHC). In 1960, Emilio Serge and Owen Chamberlain discovered antiproton at CERN, which confirmed the existence of antimatter. In 1962, researchers at CERN observed W and Z bosons, the force carrying particles responsible for weak nuclear force. In 1967, Steven Weinberg proposed a unified electroweak theory that combined weak nuclear forces and electromagnetic, describing them as different aspects of a single electroweak force and in 1968, Glashow-Salm-Weinberg Electroweak Model proposed a complete theory for the unified elrctroweak force. In 1971, the charm quark was discovered at the SLAC (Stanford Linear Accelerator Center) and Brookhaven National Laboratory, providing further evidence for fundamental particles. In early 1970s, the culmination of these discoveries and theoretical developments led to the proposal and acceptance of the Standard Model as the fundamental theory of particle physics, providing a theoretical framework to describe the behavior of elementary particles and their interactions, except for gravity. Its success in predicting and explaining a wide range of experimental results led to its recognition as one of the most successful and tested model in physics. One of its most important prediction came true in July, 2012, when Higgs boson was discovered by the ATLAS and CMS at CERN's LHC. The Higgs mechanism provides the mechanism for the masses of particles, explaining why some particles are heavy while others are massless. This discovery was a significant achievement for the Standard Model and confirmed its ability to describe the origin of mass for elementary particles [1].

The Standard Model of physics, while highly successful in explaining many fundamental interactions, has several shortcomings and leaves some big questions unanswered [2]:

1. The SM does not explain why there are three generations of particles or why charged leptons and quarks have hierarchical mass structure [3] and are differentiated in an increasing order of mass in three generations. The SM have 19 constants that are fundamental and are to be measured experimentally rather than constrained by the model [4], such as masses of the fundamental particles (quarks and leptons)‘[5, 6].

2. Standard Model does not incorporate the Gravity, one of the weakest among the fundamental forces and therefore generally not considered as far as interaction of fundamental particles, described by the Einstein's General Theory of Relativity. The Gravity, also considered to be fundamentally quantum force, can be described using a theory of Quantum Gravity [7].

3. The matter-antimatter asymmetry observed in the universe is related to the CP violation and, although, there are instances within the Standard Model of CP violation but those effects are too small to rectify the issue [8, 9].

4. The SM only explains the so far observed universe, as in matter, which constitute about 5% of the universe. The Standard model cannot account for the Dark matter and Dark Energy which happens to constitute 26 % and 79 % of the universe, respectively [10].

This is the main reason why physicists are looking for new physics beyond the Standard Model. Many models have been proposed for BSM. But the main focus of this work is on B physics and its decays. B physics focuses on the studying the bottom quark or b quark. B physics BSM is an area of research that seeks to explore potential deviations from the predictions of SM in the behavior B meson which constitute the bottom quark and its anti quark. While the SM has been remarkably successful in explaining a wide range of experimental results , there are several phenomena that it does not fully account for, and B physics experiments offer an oppurunity to probe these potential new physics effects. Some of the aspects of B physics beyond the SM are [11]:

1. CP Violation and Matter- Antimatter Asymmetry: In the SM, CP violation is accommodated using the complex phase in CKM matrix, that describes the quark flavors mixing in weak interactions. While CKM matrix successfully explains the observed CP violation in B mesons decays, it cannot account for the matter antimatter asymmetry in the observed universe. This remains one of the most significant unsolved puzzls in particle physics. For instance, the high precision measurements for $B^0 \rightarrow K^0\pi^0$ decay provides the crucial data points for the NP effects that may provide a complete explanation for the matter-antimatter asymmetry.

2. Rare Decays and Lepton Flavor Universality: The SM predicts that certain rare decays of B mesons, such as $B \rightarrow K\ell\ell$ should occur at specific rates and exhibit LFU, meaning that the rates for different charged leptons should be approximately equal.However, experimental data from LHCb and Belle experiments have hinted at deviations from LFU, particularly in $B \rightarrow K\mu\mu$ decays, suggesting new physics effects.

3. Flavor-Changing Neutral Currents (FCNCs): In the Standard Model , FCNC processes occur at very low rates and are highly suppressed. However, new physics beyond the Standard Mdel cold introduce new particles and interactions that enhance these processes, leading to observable signals in B meson decays and other FCNC phenomena. The $B^0 \rightarrow K^0\nu\nu$ decay is a rare FCNC process that proceeds through a loop diagram involving virtual W and top quarks. However, due to small masses of neutrinos and the significant suppression of FCNC processes in the SM, the BR for this decay is predicted to be exceedingly low, making it highly challenging to detect.While no direct observation of the $B^0 \rightarrow K^0\nu\nu$ decay has been made to date, experiments such as LHCb and Belle have set upper limits on

its branching fraction. These upper limits serve as constraints on NP models that predict an enhanced decay rate.

Chapter 2

Overview of Standard Model

The Standard Model consists of classes of boson, spin 1 force carriers, and fermions, spin half matter particles. The bosons in SM mediate the different forces during particle interaction. The known forces in the observable universe are Electromagnetic, Gravitational, Weak and Strong Nuclear forces. These forces cause particles to interact, that posses the specific property, by coupling the fermion field to the boson field. The particles that possess mass and interact via the gravitational field are yet to be explained by the Standard Model. But, the particles possessing the electric charge interact via electromagnetic force are mediated by photons. $W^{\pm}$ and Z bosons are the mediators for the particles, interacting through weak force, that possess flavor and the particles that possess color charge, are mediated by gluons, interact via strong force [12].

The fermions, on the other hand, are classified further into leptons and quarks. The leptons come in three generations and two separate classes. The class of charged leptons consists of electrons (e^-), muon (μ), and tau (τ) each carrying an electric charge of $-1e^-$, where e^- is a fundamental electric charge. The generations, here, are listed in increasing order of mass. Each of these leptonic particles are associated with neutrino, ν, that constitute the second class. Similarly, quarks are also classified in three generations and two classes which are known as up-type quarks and down-type quarks. Both up-type and down-type quarks are listed in the increasing order of mass in three generations each having a different flavor. The up-type quarks, each carry a charge of $+2/3e^-$, are up (u), charm (c), top(t) quarks and the down-type quark, each carry a charge of $-1/3e^-$, are down (d), strange (s), bottom (b) quarks. These particles, leptons and quarks, constitute all of the matter in the observable universe. The only stable fermions observed in the nature are up and down quarks, the electron and the neutrinos. All the other fermions are observed to be unstable and decay into the respective lighter particles [12].

In 1970s, strong force, was first formalized, which is responsible for binding of protons and neutrons together in the nuclei of an atom. In Standard Model, strong force is known to the binding factor of the quarks in protons and neutrons in an atomic nuclei. In nature, quarks have never been observed by themselves, they only exist as Baryons (3 quarks), such as proton (uud) and neutron (udd), and Mesons($q\bar{q}$), such as B mesons and D mesons.This is due to the color confinement that all existing matter have neutral color charge.

The process involving the radioactive decay of atoms and nuclei known as weak interaction was first observed in 1930s. The weak interaction occurs in three distinct regimes: leptonic, semi-leptonic and non-leptonic. All of these weak interactions are flavor dependent. These interactions are governed through the basic vertices as shown in figure below.

2.1 Guage Symmetries

The three fundamental forces mediating the interaction between the elementary particles, in the Standard Model, are explained using the structure of group upon which the three gauge symmetries are stemmed from

$$SM = SU(3)_c * (SU(2)_L * U(1)_Y)_{EW} \tag{2.1.1}$$

where the EM force and weak nuclear force are unified into a single EW force. Y, known to be assigned as a quantum number corresponding to the $U(1)_Y$ symmetry, is a *weak hypercharge.*

Below the electroweak force energy scale, the guage symmetry is broken, due to the *Higgs Mechanism* [13], by a phenomena known as *spontaneous symmetry breaking* (SSB) to provide a group structure,in its effective form, that includes the EM force and strong nuclear force.

$$SM_{eff} = SU(3)_c * U(1)_{EM} \tag{2.1.2}$$

For the strong nuclear force interaction, the $(SU(3)_c$ remains unbroken, the boson is called *gluon* (g), a massless guage boson. There are eight generators of the unbroken guage group, corresponding to 8 gluons. The strong nuclear force, among all the other fundamental forces, at high energy scale has a very strong coupling, and the interaction between elementary particles through strong force is explained by the theory of QCD, there is a corresponding quantum number called *color*. Color charge have three different types *red, green, blue*. The strong interaction guage boson are known to to be self interacting gluons that means they can interact with each other. The eigen behavior of the strong force indicates that quarks are detected in combined, strongly-bound states known as Hadrons. The highly known types of quarks are called *baryons*, these are composed of a quark triplets. But, the preeminent hadronic type, for this dissertation, are *mesons*, composed of a pair of quark and antiquark. Meson are known to be made up from the b-quark, the heaviest among all of them that made up a meson, are known as B-*mesons*. For instance, B^o and $B^o{}_s$ mesons consists of $\bar{b}$ along with an d- or s- quark to form a pair, respectively. The flavor of quark and antiquark pair for $\bar{B}^o$ and $\bar{B^o}_s$ states is exchanged. Such particles are found to be unstable and have zero spin.

The photon (γ), a massless vector, is the guage boson of the EM interaction. The photon, a particle correlates, to a broken symmetry, to the guage fields of the $(SU(2)_L * U(1)_Y)_{EW}$. This interation of massless vector is explained using theory of QED, that associate quantum number called *electric charge*.

Interaction mediated by the weak guage bosons corresponds, to a broken symmetry, to guage fields of the $(SU(2)_L * U(1)_Y)_{EW}$. Because $W^{\pm}$ are electrically charged, the weak interaction violates flavor. Since $W^{\pm}$ are massive, the weak interaction is weakest among the fundamental forces below the energy scale of the $W^{\pm}$ mass. The quantum number associated with weak interaction is called *weak isospin*. The fundamental weak interaction is known as *chiral* that couples left-handed with the right -handed antiparticle states, which means that the states that are chiral, under weak interaction, remains charged. Which explains why the weak interaction violates *parity* maximally. The Z^0 is electrically neutral whereas $W^{\pm}$ bosons are weakly charged [14].

The last boson, and most famous one, in the Standard Model is a *scalar* boson known as Higgs (H^0), which stems from the Higgs mechanism. Whenever the elementary particles interact with the Higgs field, they gain there corresponding intrinsic mass. Since, EM boson is massless , while the weak bosons are massive, is a direct result of the kinetic term, in the SM Lagrangian, for the Higgs field. The fermionic masses, in the SM, stems from L_{Yukawa} which explains the interaction between the fermions and the Higgs field [12].

2.2 Standard Model Lagrangian

The SM encompasses the fundamental interactions between the particles as the group $SU(3)_c * (SU(2)_L * U(1)_Y)_{EW}$. The Standard Model have fermionic spinor fields, ψ;the EW interaction guage fields, W^1_μ, W^2_μ, W^3_μ and B_μ ; and gluons guage fields , G^α_μ; and the Higgs field, Φ, contains two scalar fields which is an doublet of SU_2 .

The complete form Standard Model Lagrangian stems from theory's guage invariance. It is explained in the form of summation of the fermionic kinetic term, $L_{kinetic}$, a term for guage field, term that includes Higgs field, L_{Higgs}, and the fermionic interaction with the Higgs field term known as Yukawa interaction, L_{Yukawa} [15].

$$L_{SM} = L_{guage} + L_{fermion} + L_{Yukawa} + L_{Higgs} \tag{2.2.1}$$

2.2.1 Guage Fields

The field that arise from the guage symmetries are called gauge field. The guage part carry twelve gauge feilds depending on the guage group dimensions. The right handed neutrino are netral according to three guage groups so they would not be added. The Lagrangian for the guage field:

$$L_{guage} = -\frac{1}{4}G^i_{\mu\nu}G^{\mu\nu} - \frac{1}{4}W^i_{\mu\nu}W^{\mu\nu}_i - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} \tag{2.2.2}$$

where $B_{\mu\nu}, W^i_{\mu\nu}, G^i_{\mu\nu}$ are field stress tensor of electromagnetic, weak and strong forces respectively, which are given as

$$\begin{aligned} U(1)_Y \rightarrow B_{\mu\nu} &= \partial_\mu B_\nu - \partial_\nu B_\mu \\ SU(2)_{weak} \rightarrow W^i_{\mu\nu} &= \partial_\mu W^i_\nu - \partial_\nu W^i_\mu + g^{'}\epsilon^{ijk}W^j_\mu W^k_\nu \\ SU(3)^i_{strong\mu\nu} &= \partial_\mu G^i_\nu - \partial_\nu G^i_\mu + g_s\epsilon^{ijk}G^j_\mu G^k_\nu \end{aligned} \tag{2.2.3}$$

The corresponding covariant derivatives D_μ is

$$\begin{aligned} D_\mu &= \partial_\mu - ig_e Y B_\mu \\ D_\mu &= \partial_\mu - ig^{'}\frac{\sigma^i}{2}W^i_\mu \\ D_\mu &= \partial_\mu - ig_s\frac{\tau^i}{2}G^i_\mu \end{aligned} \tag{2.2.4}$$

where G^i_μ is associated with the $SU(3)_c$ color symmetry group and $i = 1, 2, ..., 8$ shows number of gluons. W^i_μ related to the $SU(2)_{weak}$ weak iso spin here $i = 1, 2, 3$ shows the three guage boson and B_μ is linked with $U(1)_Y$ weak hypercharge. ϵ^{ijk} is the structure constant, g is the coupling constant which runs with energy scales, as $g_e, g^{'} and g_s$ are the coupling constants,respectively, for the EM, weak nuclear force and strong nuclear force. The main difference between the non abelian and abelian strength field tensor is the extra term that leads to the field self interaction in non abelian field strength tensor and implies the asymptotic freedom in QCD.

2.2.2 Fermionic Field

In Standard Model there are three generations for fermions and each generation consist of up-type, down-type quark, charged lepton and their corresponding neutrinos. The fermions are further classified into right-handed singlets fermions and left-handed doublet fermions, with respect to $SU(2)_{weak}$

$$\begin{aligned} L^i_L &= \begin{pmatrix} \nu_{e_L} \\ e_L \end{pmatrix}, \begin{pmatrix} \nu_{\mu_L} \\ \mu_L \end{pmatrix}, \begin{pmatrix} \nu_{\tau_L} \\ \tau_L \end{pmatrix} \\ q^i_L &= \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \begin{pmatrix} c_L \\ s_L \end{pmatrix}, \begin{pmatrix} t_L \\ b_L \end{pmatrix} \end{aligned} \tag{2.2.5}$$

and the singlets are

$$\begin{aligned} e^i_R &= \begin{pmatrix} e_R & \mu_R & \tau_R \end{pmatrix} \\ u^i_R &= \begin{pmatrix} u_R & c_R & t_R \end{pmatrix} \\ d^i_R &= \begin{pmatrix} d_R & s_R & b_R \end{pmatrix} \end{aligned} \tag{2.2.6}$$

In terms of quarks and lepton field, the fermionic part of Lagrangian is

$$L_{fermion} = i\bar{L}^i_L D_L L^i_L + i\bar{q}^i_L D_q q^i_L + i\bar{e}^i_R D_e e^i_R + i\bar{u}^i_R D_u u^i_R + i\bar{d}^i_R D_d d^i_R \tag{2.2.7}$$

The covariant derivative is defined as $D = \gamma D^{\mu}$ and is explicitly acting o the fermion field as

$$\begin{aligned} D^{\mu}_{L_L} &= \partial_{\mu} - ig_e Y_L B^{\mu} - ig^{'}\frac{\sigma^i}{2}W^{i,\mu} \\ D^{\mu}_{q_L} &= \partial_{\mu} - ig_e Y_q B^{\mu} - ig^{'}\frac{\sigma^i}{2}W^{i,\mu} - ig_s\tau^i G^{i,\mu} \\ D^{\mu}_{e_R} &= \partial_{\mu} - ig_e Y_e B^{\mu} \\ D^{\mu}_{a_L} &= \partial_{\mu} - ig_e Y_a B^{\mu} - ig_s\tau^i G^{i,\mu}, a = u, d \end{aligned} \tag{2.2.8}$$

where σ_i represents the Pauli matrices the generator of $SU(2)_{weak}$, Y is weak hypercharge and τ^i, generator of $SU(3)_{strong}$, is associated with Gell Mann matrices as $\tau^i = \frac{\gamma^{'}}{2}$.

In agreement to weak interaction theory, the weak innteraction only subsist on lepton doublet and left quark

$$\begin{aligned} L_{fermion} &= i\begin{pmatrix} \bar{u}_L & \bar{d}_L \end{pmatrix}\gamma_{\mu}(\partial_{\mu} - ig(\frac{\sigma^i}{2})W^i_{\mu})\begin{pmatrix} u_L \\ d_L \end{pmatrix} \\ &= i\bar{u}_L\gamma_{\mu}\partial_{\mu}u_L + i\bar{d}_L\gamma_{\mu}\partial_{\mu}d_L - \frac{1}{2}g\bar{u}_L\gamma_{\mu}W^{-}{}_{\mu}d_L - \frac{1}{2}g\bar{d}_L\gamma_{\mu}W^{+}{}_{\mu}u_L \end{aligned} \tag{2.2.9}$$

The flavor changing of quarks from up-type to down-type and from down-type to up-type takes place with exchange of $W^{\pm}$ guage bosons. this type of interaction is termed as change current.

$$L_{cc} = -\frac{1}{2}g\bar{u}_L\gamma_{\mu}W^{-}{}_{\mu}d_L - \frac{1}{2}g\bar{d}_L\gamma_{\mu}W^{+}{}_{\mu}u_L \tag{2.2.10}$$

2.2.3 Higgs Field Term

The Higgs field of SM Lagrangian is introduced by additional complex scalar fiels in an existing theory which has hypercharge $Y_\phi = \frac{1}{2}$ and $SU(2)_L$ doublet as [16]

$$\phi = \begin{pmatrix} \phi_+ \\ \\ \phi_0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} (\phi_1 + i\phi_2) \\ \\ (\phi_3 + i\phi_4) \end{pmatrix} \tag{2.2.11}$$

The extra term in the SM Lagrangian is

$$L_{Higgs} = (D^\mu \phi)(D_\mu \phi) - V(\phi) \tag{2.2.12}$$

The covariant derivative D_μ and potential $V(\phi)$ is given as

$$\begin{aligned} D_\mu = \partial - \frac{1}{2} i g_e B_\mu - \frac{1}{2} i g^{'} \sigma^i W^i_\mu \\ V(\phi) = m^2 \phi\phi - \lambda(\phi\phi)^2 \end{aligned} \tag{2.2.13}$$

the Higgs field becomes [17]

$$L_{Higgs} = |\partial_\mu - \frac{1}{2} i g_e B_\mu - \frac{1}{2} i g^{'} \sigma^i W^i_\mu|^2 |\phi|^2 - \frac{m^2}{2}|\phi|^2 - \frac{\lambda}{4}|\phi|^2 \tag{2.2.14}$$

2.2.4 Yukawa Field

The Yukawa term of the SM model is

$$\begin{aligned} L_{Yukawa} = Y_f[\bar{\psi}_L \phi \psi_R + \psi_R \bar{\phi} \psi_L] \\ L_{Yukawa} = -(\bar{q}_L \phi) Y_u u_R - (\bar{q}_L \phi) Y_d d_R - (\bar{L}_L \phi) Y_L e_R + h.c. \end{aligned} \tag{2.2.15}$$

where $e_R, u_R and d_R$ are right-handed leptons and rigt-handed up-type and down-type quarks.

$$\begin{aligned} e_R &= p_R e, \\ u_R &= p_R u, \\ d_R &= p_R d \end{aligned} \tag{2.2.16}$$

and the left-handed quarks and leptons, $q_L and L_L$, respectively are

$$q_L = p_L \begin{pmatrix} u_L & d_L \end{pmatrix},$$
$$L_L = p_L \begin{pmatrix} \nu_{e_L} & e_L \end{pmatrix} \tag{2.2.17}$$

where projection operators $p_L and p_R$ are defined as

$$p_L = \frac{(1-\gamma_5)}{2},$$
$$p_R = \frac{(1+\gamma_5)}{2} \tag{2.2.18}$$

The Yukawa coupling for lepton Y_L, up-type, Y_u, and down-type quark, Y_d are 3*3 general complex matrices, the Yukawa term for lagrangian by leaving the Higgs boson mixed around the vacuum expectation value is

$$L_{Yukawa} = -\frac{\nu}{\sqrt{2}}\bar{u_L}Y_u u_R - \frac{\nu}{\sqrt{2}}\bar{d_L}Y_d d_R - \frac{\nu}{\sqrt{2}}\bar{e_L}Y_e e_R + interactions + h.c \tag{2.2.19}$$

If ϕ has non zero vacuum expectation value, the fermions will gain finite mass. In terms of three generations of leptons the lagrangian for Yukawa term will be

$$L_{Yukawa_{lep}} = \begin{pmatrix} \bar{e_R} & \bar{\mu_R} & \bar{\tau} \end{pmatrix} Y_L \phi \begin{pmatrix} \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \\ \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L \\ \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L \end{pmatrix} + h.c \tag{2.2.20}$$

Fermions to Higgs fields cupling and Yukawa coupling for fermions is

$$Y_l = \sqrt{2}(\frac{m_l}{\nu}),$$
$$\frac{Y_l}{\sqrt{2}} = \frac{m_l}{\nu} \tag{2.2.21}$$

For up-type and down-type quarks the Yukawa term takes the form as

$$L_{Yukawa} = Y_u \bar{\psi_R}\phi\psi_L + h.c. \tag{2.2.22}$$

where

$$\phi = -\iota\sigma_2\phi^* = -\frac{1}{\sqrt{2}}\begin{pmatrix} \nu + h \\ 0 \end{pmatrix} \tag{2.2.23}$$

and

$$L_{Yukawa_q} = \begin{pmatrix} \bar{u}_R & \bar{c}_R & \bar{t}_R \end{pmatrix} Y_u(\iota\sigma_2\phi) \begin{pmatrix} \begin{pmatrix} u \\ d \end{pmatrix}_L \\ \begin{pmatrix} c \\ s \end{pmatrix}_L \\ \begin{pmatrix} t \\ b \end{pmatrix}_L \end{pmatrix} + h.c \tag{2.2.24}$$

here $\iota\sigma_2\phi^*$ is SU(2) complex doublet and σ_2 is a pauli matrix. The mixed mass terms are still present, in order to evaluate the proper mass terms, mass eigen sates, the Yukawa matrices are diagonalized by man of unitary matrices as

$$Y_{diagonal_q} = V_L^q Y^q V_R^q, q = u, d \tag{2.2.25}$$

The matrices V must be unitary, the field to eliminate the unitary matrices are defined as

$$\begin{aligned} d_{L_i} &= V_L^d d_L^{'}, d_{R_i} = V_R^d d_R^{'} \\ u_{L_i} &= V_L^u u_L^{'}, _{L_i} = V_L^u u_R^{'} \end{aligned} \tag{2.2.26}$$

These transformations convert the quark fields to the basis of mass eigenstates.

2.3 Flavor Changing Charged Currents

In flavor changing charged current (FCCC) process, both types of quarks flavors, up-type and down-type quarks, and both type of leptons flavors, charged lepton and their corresponding neutrinos are involved. For instance, in muon (μ) decay through a decay channel $\mu \to e\bar{\nu_e}\nu_\mu$, $K^- \to \mu\bar{\nu_\mu}$ (which at quark level, to $s\bar{u} \to \mu\nu_\mu$ and $B \to \psi K$

($b \to c\bar{c}s$). These process are mediated, within the Standard Model, by W-bosons propagators and they are known to happen in the form of tree level.

The charged current interactions, that are connected by W boson, among the left-handed isospin doublet interaction eigenstates are

$$L_{cc}^{q_L} = \frac{g}{\sqrt{2}}\bar{u}_L\gamma_\mu W^-{}_\mu d_L + \frac{g}{\sqrt{2}}\bar{d}_L\gamma_\mu W^+{}_\mu u_L$$
$$L_{cc}^{q_L} = \frac{g}{\sqrt{2}}\bar{u}'_L(V_L^u V_L^d)\gamma_\mu W^-{}_\mu d'_L + \frac{g}{\sqrt{2}}\bar{d}'_L(V_L^d V_L^u)\gamma_\mu W^+{}_\mu u'_L \tag{2.3.1}$$

where the mixing matrix called as CKM, V_{CKM}, matrix and will be explained int he next chapter.

Chapter 3

Imprints of NP via B Physics

3.1 CKM Matrix

Among the SM interactions, the W boso mediated interactions are the only ones that are not diagonal. Consequently, all flavor changing processes depend on the CKM parameters. The fact that there are only four independent CKM parameters, while the number of measured flavor changing processes is much larger, allows for compelling tests of the CKM mechanism for flavor changing processes [18].

3.1.1 Parametrization of CKM Matrix

The Cabibbo Kobayashi-Maskawa (CKM) matrix explains the strength of coupling between the fermions or more specifically quarks. The CKM matrix is 3*3 unitary matrix. The CKM matrix, in the Standard Model, stems from the L_{Yukawa} after spontaneous symmetry breaking. The weak quark eigenstates formed of consistent combination of distinct mass eigenstates. Therefore, Cabibbo Kobayashi-Maskawa matrix is

$$Q_d^{'} = V_{CKM} Q_d$$

$$\begin{pmatrix} d^{'} \\ s\prime \\ b\prime \end{pmatrix} = \begin{pmatrix} V_{ub} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \tag{3.1.1}$$

where matrix elements,$V_{i,j}$, explains the strength of coupling using transformations between the quarks mass eigenstates by $|V_{i,j}|$.

3.1.2 Standard Parametrization

As V is unitary and is dependent on four independent physical parameters is explained by choosing a paricular parametrization. Standard choice for this parametrization is [19]

$$V_{CKM} = \begin{pmatrix} c_{12}c_{13} & s_{12}s_{13} & s_{13}\exp -\iota\delta \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}\exp\iota\delta & c_{12}s_{23} - s_{12}s_{23}s_{23}\exp\iota\delta & s_{23}c_{13} \\ s_{12}c_{23} - c_{12}s_{23}s_{13}\exp\iota\delta & -s_{23}c_{12} - s_{12}c_{23}s_{13}\exp\iota\delta & c_{23}c_{13} \end{pmatrix} \tag{3.1.2}$$

where $c_{ij} = \cos\theta_{ij} and s_{ij} = \sin\theta_{ij}$. The $\theta_{ij}^{'}s$ are the three real mixing parameters while δ is the Kobayashi-Maskawa phase. The experimental central values of four parameters are given by

$$s_{12} = 0.225, s_{23} = 0.042, s_{13} = 0.0037, \delta = 74 \tag{3.1.3}$$

Since $s_{13} << s_{23} << s_{12} << 1$, it is helpful to choose an approximate expression where this hierarchy is manifested.

3.1.3 Wolfenstein Parametrization

Wolfenstein Parametrization [20] explains why there is a coupling strength hierarchy among quarks categorized in three different generations which is built in Cabibbo Kobayashi-Maskawa matrix. It is explained by the four parameters of order unity λ, A, ρ, η for each matrix element.

$$V_{CKM} = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - \iota\eta) \\ -\lambda & 1 - \frac{\lambda[2]}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - \iota\eta) & -A\lambda^2 & 1 \end{pmatrix} + \lambda^4 \tag{3.1.4}$$

where $\lambda \approx |V_{us}| \approx |V_{cd}| \approx 0.22$ [21]. This parameterisation explains why CKM matrix is closely diagonal, and why element's magnitude decrease when we move further away they are from the diagonal.

3.2 Effective Field Theory

The FCCC decays dynamics is explained in terms of an EFT which separates the interactions at very distinct energy scales. The examining of system at any specific energy scale, necessitates to compartmentalize the effective parameters to examine a system at that specific scale. Key thing is to choose most relevant variables that describe the physics thoroughly at that scale, and in the case when the system is associated with very distinct energy scales. Therefore, for such systems the low-energy contribution can be explained independently of the contributions of high-energy ones, using an OPE [22].

The mechanism is applicable for theory of weak interaction, because energy of interaction is significantly larger than the m_b at $\Lambda_{QCD} \sim 0.2\frac{GeV}{c^2}$ [21]. Anther way to factorize this lies in effective theory of heavy quarks [23] at the m_b, where contributions at high- and low-energy levels are distincted as $m_b \sim 4\frac{GeV}{c^2}$ which is significantly deviated from Λ_{QCD} scale [24].

H_{eff}, can be formalised, using an OPE by categorizing the contributions that stems from distinct energy scales. The H_{eff} is expressed, by integrating out the high energy terms, in terms of appropriate low-energy terms and at the same time also encode quantum corrections, the high-energy scales effects . The Fermi theory of interactions [25], can be expressed as generalized view of weak interaction, which means high energy contributions are treated as point-like. For β-decay, interaction at high energy scale for W^+ propagator can be replaced with four-point interaction vertex explained through local current operator, either vector oerator or axial vector operator, integrating out high-energy interaction terms. By generalizing the phenomenology, H_{eff} can be defined as

$$H_{eff} = \frac{G_F}{\sqrt{2}}\Sigma_j V^j_{CKM} C^{(')}_j(\mu)\mu^{(')}_j \tag{3.2.1}$$

where μ is a renormalisation scale of energy, chosen arbitrarily, differentiating out low energy and high energy interaction terms, G_F is the Fermi coupling constant, V^j_{CKM} shows matrix elements for Cabibbo Kobayashi-Maskawa matrix, O_j being local quark operators determines low-energy terms and C_j known as known as Wilson coefficients, these are coupling constants.

After the internal loop contributions to Feynman diagrams are being integrated out coming from $W\pm$, Z, top quark, H_0, C_j depends on these particles masses. C_j are computed in the independent model, and for the theory of weak interaction at high energy scale, are computed through perturbation theory [26]. Local quark operators are calculated using perturbation theory, rather require different tools such as light cone QCD sum rule [27, 28].

In case of any specific decay, Wilson coefficients weighing out the local quark operators connects final and initial states, so transition amplitude in form of H_{eff} is defined as

$$M(i \to f) \equiv \langle f|H_{eff}|i\rangle = \frac{G_F}{\sqrt{2}}\Sigma_j V^j_{CKM} C^{(')}_j \langle f|O^{(')}_j|i\rangle \tag{3.2.2}$$

In this thesis, FCCC transitions having quark level transition $b \to u\ell\nu$ is being researched on. The H_{eff}, in the general form, for the tree level transition of $b \to q\ell\nu$ is

$$H_{eff}(b \to q\ell\nu) = \frac{G_F\alpha}{\sqrt{2}\pi} V^*_{tq} V_{tb}(\Sigma_j C^j O_j + C^{'}_j O_j) \tag{3.2.3}$$

where α is known as fine-structure constant and $V_{tq} and V_{tb}$ are CKM matrix elements. Local quark operators O_j can be written as

$$\begin{aligned}
O_7 = \frac{m_b}{e}(\bar{q}\sigma_{\mu\nu}P_R u)F^{\mu\nu}, O^{'}_7 = \frac{m_b}{e}(\bar{q}\sigma_{\mu\nu}P_L b)F^{\mu\nu} \\
O_9 = (\bar{q}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell), O^{'}_9 = (\bar{q}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell) \\
O_{10} = (\bar{q}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell), O^{'}_{10} = (\bar{q}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \\
O_S = m_b(_R b)(\bar{\ell}\ell), O^{'}_S = m_b(_L b)(\bar{\ell}\ell) \\
O_P = m_b(_R b)(\bar{\ell}\gamma_5 \ell), O^{'}_P = m_b(_L b)(\bar{\ell}\gamma_5 \ell)
\end{aligned} \tag{3.2.4}$$

where $F_{\mu\nu}$ is stress field tensor and the operators , in primed form, depicts the contributions for currents of right handed quarks.

Chapter 4

The Exclusive Semileptonic $B \to (K^{*0}(1430))\tau\bar{\nu}_\tau$ Decay

The exclusive semileptonic decay $B \to (K^{*0}(1430))\tau\bar{\nu}_\tau$ is governed at the quark level by $b \to u\ell\nu_\ell$ transition. This quark level transition is a tree level decay as shown in

The effective field theory provides the best framework for both the inclusive and exclusive decays. Using the standard OPE (operator product expansion) method helps a separation of B meson decay amplitude in two parts, first known as Wilson coefficients which describe the short distance physics and second one known as operator matrix elements, in this case six four fermion operators, which explains the long distance contributions of the decay. The effective Hamiltonian in terms of weak interactions can be written as

$$H_{eff} = \frac{4G_F}{\sqrt{2}} V_{ub} \left[(1+V_L)O_{V_L} + V_R O_{V_R} + S_L O_{S_L} + S_R O_{S_R} + T_L O_{T_L}\right] \tag{4.0.1}$$

here $O_{V_L}, O_{V_R}, O_{S_L}, O_{S_R}, O_{T_L}$ are the four fermion operators and are defined as,

$$\begin{aligned}
O_{V_L} &= (\bar{u}_L \gamma^\mu P_L b_L)(\bar{\tau_L} \gamma_\mu P_L \nu_L), & O_{V_R} &= (\bar{u}_L \gamma^\mu P_R b_R)(\bar{\tau_L} \gamma_\mu P_L \nu_L), \\
O_{S_L} &= (\bar{u}_L P_L b_R)(\bar{\tau_R} P_L \nu_L), & O_{S_R} &= (\bar{u}_R P_R b_L)(\bar{\tau_R} P_L \nu_L), \\
O_{T_L} &= (\bar{u}_R \sigma^{\mu\nu} P_L b_L)(\bar{\tau_R} \sigma_{\mu\nu} P_L \nu_L) & &
\end{aligned} \tag{4.0.2}$$

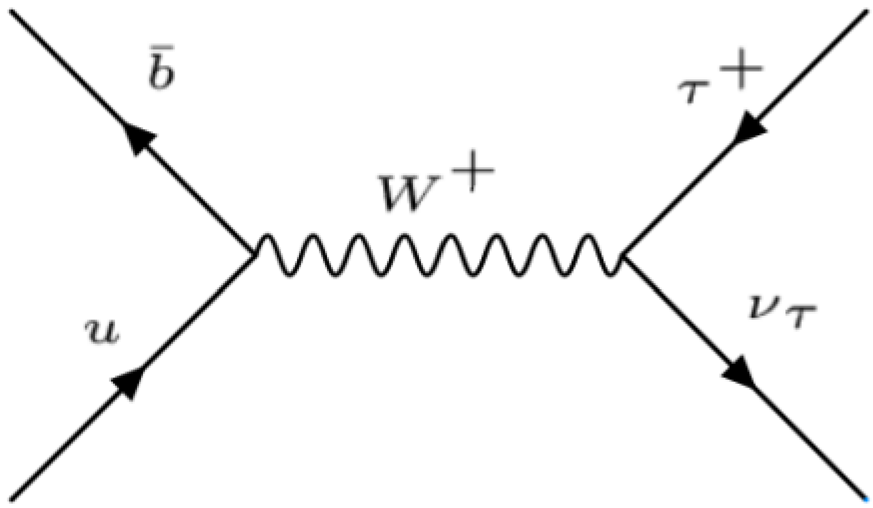

Figure 4.1: quark level transition of $b \to u\tau\nu_\tau$ decay at tree level

where $P_L and P_R$ are defined as

$$\begin{aligned} P_L &= \frac{(1-\gamma_5)}{2}, \\ P_R &= \frac{(1+\gamma 5)}{2} \end{aligned} \tag{4.0.3}$$

and V_L, V_R, S_L, S_R, T_L are corresponding Wilson coefficients. The complete top and W boson mass dependence, after the integration out of the heavy fields, is contained in Wilson coefficients. In case of SM, all of the Wilson coefficients become zero and the effective hamiltonian, for weak interactions, becomes,

$$H_{eff} = \frac{4G_F}{\sqrt{2}} V_{ub} \tag{4.0.4}$$

The G_F is known Fermi coupling constant. The subscripts L and R denotes the left-handed and right-handed components of fermionic field respectively.

The Wilson coefficients, although can be calculated with perturbative methods, enter both inclusive and exclusive processes, the computational approaches to the hadronic matrix elements of the operators differ for both cases. In inclusive process, the QHD (quark hadron duality) is used to derive a well defined heavy mass expansion of the deacy rate in $\frac{\Lambda}{m_b}$ powers. Whereas for exclusive process, the hadronic matrix elements are calculated between meson states, as the quark hadron duality can be relied upon.

The helicity amplitude for the exclusive semileptonic deacy $B \to K^{*0}\ell\bar{\nu}_\ell$ decay and its decay width which is proportinal to the helicity amplitude mod squared are,

$$\mathcal{M} = -\frac{G_F}{\sqrt{2}} V_{ub} \Big[(1+V_L)\langle K^{*0}|\bar{u}\gamma_\mu(1-\gamma_5)b|B\rangle \bar{\ell}\gamma^\mu(1-\gamma^5)\bar{\nu}_\ell + V_R\langle K^{*0}|\bar{u}\gamma_\mu(1+\gamma_5)b|B\rangle \bar{\ell}\gamma^\mu(1-\gamma^5)\bar{\nu}_\ell$$
$$+S_L\langle K^{*0}|\bar{u}(1-\gamma_5)b|B\rangle \bar{\ell}(1-\gamma^5)\bar{\nu}_\ell + S_R\langle K^{*0}|\bar{u}(1+\gamma_5)b|B\rangle \bar{\ell}(1-\gamma^5)\bar{\nu}_\ell$$
$$+T_L\langle K^{*0}|\bar{u}\gamma_\mu\sigma_{\mu\nu}(1-\gamma_5 b|B\rangle)\bar{\ell}\gamma^\mu(1-\gamma_5)\bar{\nu}_\ell \Big] \tag{4.0.5}$$

4.1 Hadronic Matrix Element Parametrization for Semileptonic $B \to K^{*0}\tau\bar{\nu}_\tau$ Decay

The hadronic matrix elements parametrization of exclusive semileptonic $B \to (K^{*0}(1430))\tau\bar{\nu}_\tau$ decay can be written, in terms of Lorentz invariant form factors, as,

$$\langle K_0^*(k)|\bar{u}\gamma_\mu\gamma_5 b|B\rangle = -i\left[(p+k)_\mu f_+(q^2) + q_\mu f_-(q^2)\right] \tag{4.1.1}$$

here the parameters f_+ and f_-, depended on momentum squared, are known as transition form factors. p and k are, respectively, the momenta of intial and final state mesons and q is defined as $q = p - k$. The form factors are parametrized using the light -cone QCD sum rule and are defined as [29]

$$f_\pm(q^2) = \frac{f_\pm(0)}{1 - q^2/m^2_{\text{pole}}} \tag{4.1.2}$$

where the numerical values of$f_{\pm(q[2])}$ and m^2_{pole} are given in [30].

4.2 Helicity Amplitudes formalism in terms of form fcators

The formalism for differential decay rate $\frac{d\Gamma}{dq^2}$ and lepton flavor non-universality ratio R_M for $B_s \to K_0^*\ell\bar{\nu}_\ell$ can be explained by the amplitude for the decays under consideration in terms of helicity amplitudes,

$$\mathcal{M}_k^{\lambda_\ell,\lambda_M} = \delta_{kl}\mathcal{M}_{SM}^{\lambda_\ell,\lambda_M} + \mathcal{M}_{V_1,k}^{\lambda_\ell,\lambda_M} + \mathcal{M}_{V_2,k}^{\lambda_\ell,\lambda_M} + \mathcal{M}_{S_1,k}^{\lambda_\ell,\lambda_M} + \mathcal{M}_{S_2,k}^{\lambda_\ell,\lambda_M} \tag{4.2.1}$$

where λ_ℓ is the helicity of lepton under consideration, $\lambda_M = s$ represents the helicity of $B_s^0 \to K_0^*(1430)\ell\bar{\nu}_\ell$ in the rest frame of B_s^0 meson.

The amplitude can be written in terms of hadronic and leptonic tensors as follows [31]

$$\mathcal{M}_{SM}^{\lambda_\ell,\lambda_M} = \frac{G_F}{\sqrt{2}} V_{ub} \sum_\lambda \eta_\lambda H_{V_1,\lambda}^{\lambda_M} L_{\lambda,\ell}^{\lambda_\ell} \tag{4.2.2}$$

$$\mathcal{M}_{V_i,k}^{\lambda_\ell,\lambda_M} = \frac{G_F}{\sqrt{2}} V_{ub} C_{V_i}^\ell \sum_\lambda \eta_\lambda H_{V_i,\lambda}^{\lambda_M} L_{\lambda,\ell}^{\lambda_\ell} (i=1,2) \tag{4.2.3}$$

$$\mathcal{M}_{S_i,k}^{\lambda_\ell,\lambda_M} = \frac{G_F}{\sqrt{2}} V_{ub} C_{S_i}^\ell H_{S_i}^{\lambda_M} L_k^{\lambda_\ell} (i=1,2) \tag{4.2.4}$$

where $H's$ and $L's$ represents the hadronic and leptonic amplitudes.

The form of hadronic amplitudes, $H_{V_i,\lambda}^{\lambda_M}$,$H_{S_i}^{\lambda_M}$ and $H_{\lambda,\lambda'}^{\lambda_M}$ are given below,

$$H_{V_{1,2},\lambda}^{\lambda_M}(q^2) = \varepsilon_\mu^*(\lambda)\langle M(\lambda_M)|\bar{u}\gamma^\mu(1\mp\gamma_5)b|B\rangle$$

$$H_{S_{1,2},\lambda}^{\lambda_M}(q^2) = \langle M(\lambda_M)|\bar{u}(1\pm\gamma_5)b|B\rangle$$

$$H_{T,\lambda\lambda'}^{\lambda_M}(q^2) = \varepsilon_\mu^*(\lambda)\varepsilon_\nu^*(\lambda')\langle M(\lambda_M)|\bar{u}\sigma^{\mu\nu}(1-\gamma_5)b|B\rangle$$

where λ_M and λ represents mesons and helicitiesof virtual particle using values $\lambda_M = 0, \pm 1$ for scalar and axial vector meson states, and $\lambda = 0, \pm 1, t$ for a virtual particle. The non-zero hadronic tensors for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ is explained explicitly in terms of transition form factors as follows, Helicity amplitude for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay can be defined in terms of form factors as [32],

$$H_{V_1,0}^s = H_{V_2,0}^s = \sqrt{\frac{\lambda_{K_0^*}(q^2)}{q^2}} F_1(q^2) \tag{4.2.5}$$

$$H_{V_1,t}^s = H_{V_2,t}^s = \frac{M_B^2 - M_{K_0^*}^2}{\sqrt{q^2}} F_0(q^2) \tag{4.2.6}$$

$$H_{S_1}^s(q^2) = H_{S_1}^s(q^2) = \frac{M_B^2 - M_{K_0^*}^2}{m_b - m_u} F_0(q^2) \tag{4.2.7}$$

The differential decay rate equation for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ can be written as,

$$d\Gamma_{\lambda_{K_0^*}}^{\lambda_\ell} = \frac{1}{2M_B} \sum_k |\mathcal{M}_k^{\lambda_\ell,\lambda_{K_0^*}}(q^2, \cos\theta_\ell)|^2 d\Phi_3 \tag{4.2.8}$$

where $d\Phi_3$ is a phase space for three body and is defined by the following relation

$$d\Phi_3 = \frac{\sqrt{Q_+Q_-}}{256\pi^3 M_B^2}\left(1 - \frac{m_\ell^2}{q^2}\right) dq^2 d\cos\theta_\ell \tag{4.2.9}$$

and $Q_\pm = (M_B^2 \pm M_{K_0^*}^2) - q^2$.

The differential decay rate for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay, in terms of amplitude in the form of hadronic and leptonic tensors, is [33]

$$\Gamma(B_s^0 \to K_0^*(1430))q^2 = \frac{G_F^2|V_{ub}|^2}{192\pi^2 M_B^3}q^2$$
$$\sqrt{\lambda_{K_0^*(q^2)}}(1-\frac{m_l^2}{q^2})^2 * |1+C_{V_1}+C_{V_2}|^2[(1+\frac{m_l^2}{2q^2})H_{V,0}^{s2}+\frac{3}{2}\frac{m_l^2}{q^2}H_{V,t}^{s2}] \tag{4.2.10}$$
$$+\frac{3}{2}|C_{S_1}+C_{S_2}|^2 H_S^{s2} + 3Re[(1+C_{V_1}+C_{V_2})(C_{S_1}^*+C_{S_2})]\frac{m_l}{\sqrt{q^2}}H_S^s H_{V,t}^s$$

Another observable sensitive to NP is Lepton Flavor Non-Universality (LFNU) ratio and is defined as, [34]

$$R_{K_0^*(1430)} = \frac{\Gamma(B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau))q^2}{\Gamma(B_s^0 \to K_0^*(1430)\mu\bar{\nu}_\mu))q^2} \tag{4.2.11}$$

To analyze NP using physical observables, like BR and LFNU rato, for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay we use fit values of Wilson coeffcents $V_L, V_R, S_L and S_R$. The values of said Wilson coefficient were obtained from the χ^2 fit of the observables R_π^l, BR($B_u^+ \to \tau^+\nu_\tau$) and BR($B^0 \to \pi^+\tau^-\bar{\nu}$) data.

The best fitted values and values for 1σ range of the Wilson coefficients $V_L, V_R, S_L and S_R$ for $b \to u\tau\nu_\tau$ are given the table below.

4.3 Numerical Analysis

Using the best-fitted values and values for 1σ range for vector type V_L, V_R and scalar type $S_L and S_R$ Wilson coefficients given in Table I, the predicted values of BR and LFUV ratio ($R_{K_0^*(1430)}$ for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay. In order to exploit the NP effects, plots of branching ratio, LFUV ratios are presented for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay as a function of square of momentum transfer q_2. Moreover the numerical values of NP observables, BR and LFNU ratio, in framework of SM and, correspondingly, in cases of NP are presented in Tables II and III [35].

4.3.1 V_L coefficient present only

The case in which only vector like coupling V_L is present along with the SM one, while the rest of NP coefficients are set to zero. It is important to mention here that in all the figures, black dashed line represents the SM, red dashed line represents the best fit value and scattered blue line represents the 1σ range.

New Physics Couplings	Best fit Value	1σ Range	Pull
(R_{V_L}, T_{V_L})	(0.915, 1.108)	([1.45, 0.65],[1.02, 1.19])	1.16
(R_{V_R}, T_{V_R})	(0.116, 0)	([0.205, 0.025], [0.41, 0.41])	1.215
(R_{S_L}, T_{S_L})	(-0.024,0)	([0.042, 0.004], [0.092, 0.092])	1.192
(R_{S_R}, T_{S_R})	(0.439, 0.005)	([0.457, 0.421], [0.092, 0.092])	1.192

Table 4.1: Best fitted values and values of 1σ range of the Wilson coefficients for $b \to u\tau\nu_\tau$ decay modes

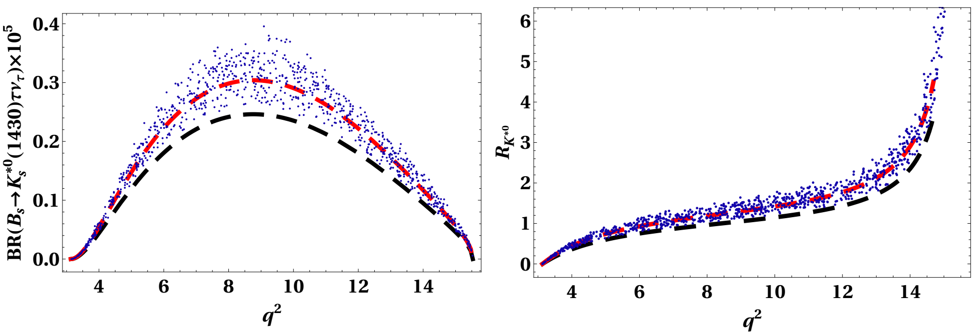

Figure 4.2: Branching ratio and $R_{K_0^*(1430)}$in the SM and the case in which only V_L NP coefficient is present. Black dashed line represents the SM, red dashed line and the scattered blue plot represents the best fit value and 1σ range for NP coupling parameter V_L

Observables	SM Predictions	Values with V$_L$	Values with V$_R$
BR $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$	1.95×10^5	2.41×10^5	2.79×10^5
$R_{K_0(1430)}$	1.257	1.552	1.64

Table 4.2: Differential decay rate and LFUV observables for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ values in the SM framework and when only Wilson coefficients V_L, V_R are present

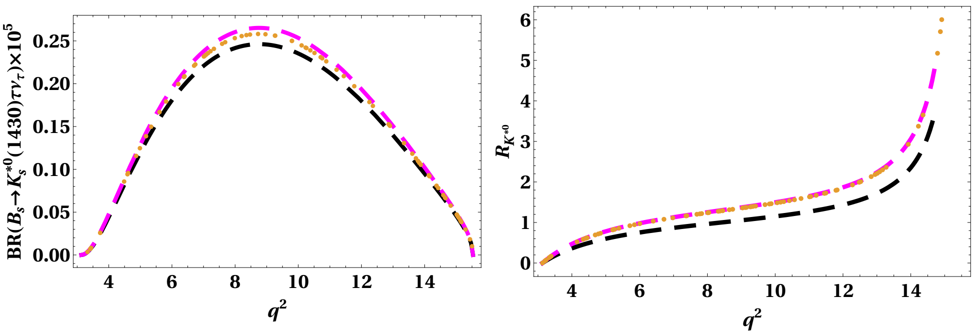

Figure 4.3: Branching ratio and $R_{K_0^*(1430)}$ in the SM and the case in which only V_R NP coefficient is present. Black dashed line represents the SM, pink dashed line and the scattered orange dotted plot represents the best fitted value and 1σ range for NP coupling parameter V_R

4.3.2 V_R coefficient present only

The case in which only vector like coupling V_R is present along with the SM one, while the rest of NP coefficients are set to zero. It is important to mention here that in all the figures, black dashed line represents the SM, pink dashed line represents the best fitted value and scattered orange dotted line represents the 1σ range.

4.3.3 S_L coefficient present only

The case in which only vector like coupling S_L is present along with the SM one, while the rest of NP coefficients are set to zero. It is important to mention here that in all the figures, black dashed line represents the SM, pink dashed line represents the best fit value and scattered orange dotted line represents the 1σ range.

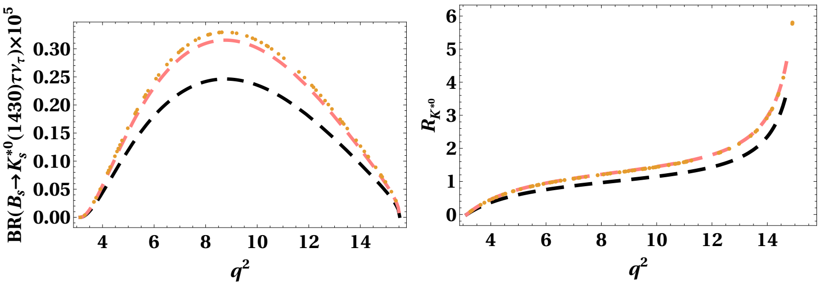

Figure 4.4: Branching ratio and $R_{K_0^*(1430)}$ in the SM and the case in which only S_L NP coefficient is present. Black dashed line represents the SM, pink dashed line and the scattered orange dotted plot represents the best fitted value and 1σ range for NP coupling parameter S_L

Observables	Values with S_L	Values with S_R
BR $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$	1.88×10^5	2.16×10^5
$R_{K_0(1430)}$	0.901	1.196

Table 4.3: Differential decay rate and LFUV observables for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ values in the SM framework and when only Wilson coefficients S_L, S_R are present

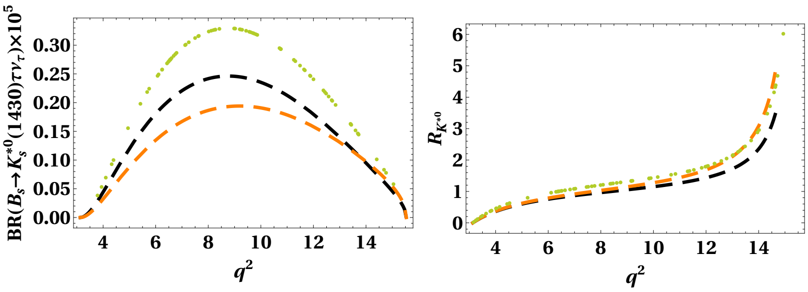

Figure 4.5: Branching ratio and $R_{K_0^*(1430)}$ in the SM and the case in which only S_R NP coefficient is present. Black dashed line represents the SM, orange dashed line and the scattered green dotted plot represents the best fitted value and 1σ range for NP coupling parameter s_R

4.3.4 S_R coefficient present only

The case in which only vector like coupling S_R is present along with the SM one, while the rest of NP coefficients are set to zero. It is important to mention here that in all the figures, black dashed line represents the SM, ornage dashed line represents the best fit value and scattered green dotted line represents the 1σ range.

Chapter 5

Conclusion

The exclusive semileptonic decay of B meson $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ has been investigated extensively both theoretically in SM and experimentally not only to find out the signatures of physics beyond the SM (BSM), but also to test the SM parameters. In this way exclusive semileptonic B meson decays of the kind $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ provides a complementary way to explore the NP beyond the SM. In light of recently observed anomaly R_π^l which involves $b \to u\ell\nu_\ell$ transition, we investigate the above mentioned decay in model independent way. To analyze signatures for NP in model independent scenarios, we consider a vector type and scalar type NP operators along with their Wilson coefficients. Using the best fitted values and values for 1σ range of the Wilson coefficients given in Table-I, we invstigated the BR, lepton flavor non universality ratio for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay. The BR and LFUV observables of the decay mode under study shows significant deviation in presence of Wilson coefficient V_L compared to that of SM predictions. It is also important to mention here that the lepton flavor universalilty violating observable enhances at 1σ value of the Wilson coefficient V_L , however there is no significant deviation being observed in in the presence of V_L both at best fit value and 1σ range. In the presence of Wilson coefficient V_R , a small deviation has been observed in the branching ratio for $B_s^0 \to K_0^*(1430)\tau\bar{\nu}_\tau$ decay, but just like V_L there is an enhancement in the value of $R_{K_0^*}$ around ($q^2 \equiv 15$ GeV_2). When the scalar couplings S_L and S_R are incorporated to test NP , we found for both decays that all observables shows a significant deviation from the SM predictions. Just to summarize, the BR ratios are more sensitive to both vector and scalar type coupling, in order to probe the imprints of NP, as compared to LFUV ratio. Furthermore, we have observed that in the presence of $V_L and S_R$ there is significant deviation in the case of BR as compared to $V_R and S_L$. The hope is that the observation of the $B_s^0 \rightarrow K_0^*(1430)\tau\bar{\nu}_\tau$ decay will hopefully be investigated at LHCb and future collider experiments.

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