Study of New Physics in Leptonic B-Decays

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Chapter 1

Introduction

Particle physics is the study of what everything is made of ? Particle Physicists study the fundamental particles that make up all of matter and how they interact with each other. Everything around us is made up of these fundamental building blocks of nature. So, what are these building blocks ? In the early 1900's, it was believed that atoms were fundamental, they were thought to be the smallest part of nature and were not made up of anything smaller. Soon there after, experiments were done to see if this truly was the case. It was discovered that atoms were not fundamental at all, but were made up of two components: a positively charged nucleus surrounded by a cloud of negatively charged electrons.

Then the nucleus was probed to see if it was fundamental, but it too was discovered to be made up of something smaller; positive protons and neutral neutrons bound together with the cloud of electrons still surrounding it.

Now that these protons and neutrons were found, it was time to see if they were fundamental. It was discovered that they were made up of smaller particles called "quarks", which today are believed to be truly fundamental, along with electrons. There are two families of fundamental particles the quarks and the leptons. There are six sorts of quarks and six sorts of leptons. Together they make up a theory called the Standard Model. Most matter on earth is made from a combination of two quarks, called the up and the down quarks and a lepton called the electron. The up and down quarks form protons and neutrons inside the nucleus of the atom and the electrons orbit the nucleus to complete the whole atom. The rest of the twelve fundamental particles are more commonly found in high energy environments, for example in particle accelerator collisions or right at the start of the universe just after the Big Bang[1].

The elementary particles are split up into two families, namely the quarks and the leptons. Both of these families consist of six particles, split into three generations, with the first generation being the lightest and the third the heaviest. Furthermore, there are four different forces carrying particles which lead to the interactions between particles. To be more precise, the fundamental interaction are widely believed to be described by quantum field theory theories possessing local gauge symmetry.

In the last half century, many particles and features of their interactions have been discovered. Out of the confusing and terrifying proliferation of hundreds of particles, a coherent picture gradually emerged known as the Standard Model. The Standard Model is a theoretical picture that describes how the different elementary particles are organized and how they interact with each other along with the different forces. This model has been stable for two decades and explains everything (so far) believing that nature contrives on enormous complexity of structure and dynamics from just a dozen elementary particles (six leptons, six quarks and their antimatter counterparts) and three of the forces; electromagnetism, weak and strong nuclear forces (gravitation has not been included in the theory yet)[2]. In the sub atomic realm, these interactions between particles can produce changes in energy, momentum and even transitions between particles. An interaction can also affect a particle in isolation, in a spontaneous decay process. Combined with special relativity, this theory is so far consistent with virtually all physics down to the scales probed by particle accelerators, roughly 10^{-16}cm and also passes a variety of indirect tests that probe even shorter distances.

In spite of its impressive successes, the Standard Model is believed to be not complete. For a really final theory it is too arbitrary especially considering the large number of parameters in the Lagrangian. Examples for such parameters, that are largely different from what one naively expects them to be, are the weak scale compared with the Planck scale or the small value of the strong CP-violation parameter. Questions like: Why are there three particle generations ?, Why is the gauge structure with the assignment of charges as it is?, or What is the origin of the mass spectrum ? Demand an answer by a really fundamental theory, but the Standard Model gives no replies. Furthermore, the union of gravity with quantum theory yields a nonrenormalizable quantum field theory, indicating that New Physics should show up at very high energies.

The ideas of grand unification, extra dimensions, or supersymmetry were put forward to find a more complete theory, But applying these ideas has not yet led to theories that are substantially simpler or less arbitrary than the Standard Model. To date, string theory[3], the relativistic quantum theory of one-dimensional objects, is a promising and so far the only, candidate for such a "Theory of Everything".

Remarkbly, the field of particle physics is completely different today from it was before the 1970's; Quarks and leptons are fundamental objects of which matter is composed. They interact via gauge bosons. The force that significantly effect them are the unified electroweek force, whose gauge bosons are photon and the $W^{\pm}$ and Z^o bosons and the strong force, whose mediator are gluons. The strong force is called quantum choromodynamics(QCD)[4].

We have organized the subsequent pages as follws: In chapter 2, a brief reviw of the Standard Model and Higgs mechanism is given, after this the discussion is about the unsolved mysteries beyond the Standard Model which leads to New Physics.

In chapter 3, we discussed the new and Beauty physics. We first gave the introduction of $B-Physics$, after this how the $B-mesons$ decay and their types of decays. Secondly we have discuss the Effective Lagrangian with his general consideration by means of effective theory. At the end of this chapter, we have given the motivation for new physics and new physics scenarios.

Chapter 4 contain the main subject of this work: In the start the Decay kinamatics which will be used has been discussed. We want to find the upper bound on the branching ratios of $B_S \to l^+l^-$. For this, we consider the most effective Lagrangian for $B_S \to l^+l^-$ in new physics. For finding the values of new physics coupling constants, we consider two related semileptonic decay process, $B \to K^*l^+l^-$ and $B \to Kl^+l^-$. Fisrt we consider the vector/axial couplings and find out the values of couplings constants and find the upper bound on branching ratios for $B_S \to l^+l^-$. Again we consider the scalar/pseudoscalar couplings and find the branching ratios on $B_S \to l^+l^-$. At the end of this dissertation we have conclude that new physics is only of scalar/pseudoscalar type couplings.

Chapter 2

The Standard Model

2.1 Introduction to Particle Physics

All known particle physics phenomena are extremely well described within the Santard Model (SM) of elementary particles and their fundamental interactions. The SM provides a very elegant theoretical framework and it has succesfully passed very precise tests which at present are at the 0.1% level. We understand by elementary particles the point like constituents of matter with no known substructure up to the present limits of $10^{-18} - 10^{-19}m$. These are of two types of the basic building blocks of matter konwn as matter particles and the force particles which mediates the interaction between particles. The first ones are fermions of spin $s = 1/2$ and are classified into leptons and quarks.

There are six types of leptons in three pairs: i.e electron - neutrino, muon - neutrino and tau - neutrino (these three neutrino's are different from each other). The electron, muon and tau each carry a negative charge, where as the three neutrinos carry no charge. Leptons, unlike quarks exist by themselves and like all particles have a corresponding antiparticles.

	Flavour	Mass $\frac{GeV}{C^2}$	Charge(e)
ν_e	electron neutrino	$< 7 \times 10^{-9}$	0
e^-	electron	0.000511	-1
ν_μ	muon neutrino	< 0.0003	0
μ^-	muon(mu − minus)	0.106	-1
ν_τ	tau neutrino	< 0.03	0
τ^-	tau(tau − minus)	1.7771	-1

Table 2.1: Leptons

As the chart indicates the tau and muon are much heavier than the electron. Furthermore, they are not found in everyday matter. This is because they decay very quickly, usually into lighterleptons[5]. There are a couple of rules that govern the decay of leptons.

	Flavour	Mass $\frac{GeV}{C^2}$	Charge(e)
u	up	0.004	$\frac{+2}{3}$
d	down	0.08	$\frac{-1}{3}$
c	charm	1.5	$\frac{+2}{3}$
s	strang	0.15	$\frac{-1}{3}$
t	top	176	$\frac{+2}{3}$
b	bottom	4.7	$\frac{-1}{3}$

Table 2.2: Quarks

The quarks have an additional quantum number, the color, which is of three types, generally denoted as qi, where $i = 1, 2, 3$. We know that color is not seen in Nature and therefore the elementary quarks must be confined into the experimentally observed matter particles, the hadrons. These colorless composite particles are classified into baryons and mesons. The baryons are fermions made of three quarks, qqq, as for instance the proton, $p \sim uud$ and the neutron $n \sim ddu$. The mesons are bosons made up of one quark and one antiquark as for instance the pions, $\pi^+ \sim u\bar{d}$ and $\pi^- \sim \bar{d}u$.

$Force$	$Mediator$	$Ch\arg e$	$Mass$
$Strong$	$gluon$	0	0
$Electromagnetic$	$Photon$	0	0
$Weak\ (Ch\arg ed)$	$W\pm$	± 1	$81,800$
$Weak\ (neutral)$	Z^o	0	$92,600$

Table 2.3: Mediators

The second kind of elementary particles are the intermediate interaction particles. Leaving apart the gravitational interactions, all the relevant interactions in Particle Physics are known to be mediated by the exchange of an elementary particle that is a boson with $spin\ s = 1$. The photon is the exchanged particle in the electromagnetic interactions, the eight gluons g_α, where $\alpha = 1, ...8$ mediate the strong interactions among quarks and the three weak bosons, $W\pm$, Z are the corresponding intermediate bosons of the weak interactions[6].

2.2 Guage Theories: The Governing Laws of The Standard Model

One of the most profound insights in theoretical physics is that interactions are dictated by symmetry principles. Therefore in determining the dynamical structure of SM, *symmetry* is advertized as its foundation stone. A theory based on the symmetry involving the invariance of a physical system under various shifts in the values of force charges is a *gauge theory*. The present belief is that all particle interactions may be dictated by so-called *local guage symmetries*. This is intimately connected with the idea that the conserved physical quantities (such as electric charge, color, etc) are conserved also in local regions of space and not just globally.

A gauge theory involves two kinds of particles, those which carry "charge" and those which "mediate" interactions between currents by coupling directly to charge. In the former class are the fundamental fermions and non-abelian gauge bosons, whereas the latter consists only of gauge bosons, both abelian and non-abelian. The physical nature of charge depends on the specific theory. Three such kinds of charge called *color weak isospin* and *weak hypercharge* appear in the Standard Model.

The dynamics of interacting fermions are defined by a Lagrangian density. The Standard Model Lagrangian $\mathcal{L}_{SM}$ embodies our knowledge of the strong and electromagnetic interactions. It contains as fundamental degrees of freedom the spin 1/2 quarks and leptons, spin-1 gauge bosons and spin- 0 Higgs fields. The Lagrangian exhibits invariance under $SU(3)_C$ gauge transformations for the strong interactions and under $SU(2)_L \otimes U(1)_Y$ guage transformation for electromagnetic interactions. So, we can say that in the standard model each Lagrangian density is generated by requiring local guage invariance. Physically this means that transformations of the form

$$\psi\left(\vec{x},t\right) \longrightarrow e^{iH(\vec{x},t)}\psi\left(\vec{x},t\right) \tag{2.1}$$

will not alter the physically observeable effects. The quantity $H\left(\vec{x},t\right)$ is referred to as the guage and may be any $n \otimes n$ Hermitian matrix.

The theory of the electromagnetic interaction, quantum electrodynamics(QED), is constructed by applying the principle of local guage invariance to the free Dirac Lagrangian. In this case the gauge H is just a real number and the corresponding operator $U = e^{iH}$ belongs to the abelian group $U(1)_Y$. To construct a locally invariant Lagrangian, it is necessary to introduce a vector field A_μ. This field contains the guage freedom necessary to absorb changes in the Lagrangian produced by a local guage tansformation. The desired symmetry is achieved only if the vector field is long-ranged and massless. The resulting QED interaction Lagrangian can be written:

$$\mathcal{L}_{QED} = \left(e\bar{\psi}\gamma^\mu\psi\right)A_\mu \tag{2.2}$$

where e is the electric charge, γ are the Dirac matrices related to the spin of the fermions and the quantity in parentheses is the fermion current. The resulting field equations are precisely those predicted by classical electrodynamics. Here the fermions are quanta of the Dirac fields $\bar{\psi}$ and photons are quanta of the electrodynamic fie A_μ.

The theory of strong interactions, quantum chromodynamics (QCD) arises from the special unitary symmetry (a non-Abelian group) $SU(3)_C$. The procedure for constructing the QCD Lagrangian is completely analogous to the procedure used in QED. In this case, however, the guage H is a $3\otimes3$ matrix and the corresponding operator U is a unitary matrix with determinant equal to 1. The three dimensions correspond to the three color "charges" of quarks: red, green and blue. The interaction Lagrangian describing the "color" force between a quark q_α of color α and quark q_β of color β is given by

$$\mathcal{L}_{QCD} = g_3 \sum \bar{q}_\alpha \gamma^\mu \lambda^\delta_{\alpha\beta}\, q_\beta G^\delta_\mu, \tag{2.3}$$

where G is the chromoelectric field, g_3 is the coupling strength, and γ and λ are the Dirac and Gell-Mann matrices related to the spin of the quarks and color of the gluons respectively. The chromoelectric field produces changes in the quark colors and the color difference is carried away by the gluons. The gluon involved in the coupling of q_α and q_β will carry away colors α and β. From three colors, eight independent gluon combinations can be constructed. Because gluons carry color, they may srongly interact with each other. There is good evidence that this complicated set of interactions is responsible for *quark confinement,* the phenomenon that prevents quarks from existing in isolation. In addition, the dynamics of the chromoelectric field are known to produce an "antiscreening effect" called *asymptotic freedom* which leads to a progressively weaker force between quarks as they approach one another (or equivalently as the momentum involved in an interaction increases). This allows us to compute colour interactions using perturbative techniques and turns QCD into a quantitative calculational scheme. In the words of Yuri Dokshitzer: "QCD, the marvellous theory of the strong interactions has a split personality. It embodies hard and soft physics, both being hard subjects, the softer ones being the hardest[6, 7].

The electromagnetic and the weak interactions have been integrated into a single guage theory based on a $SU(2)_L\otimes U(1)_Y$ symmetry. In the electroweak theory the interaction Lagrangian for the first family or "generation" of fermion is:

$$\begin{aligned}\mathcal{L}_{EW} &= f = l, q \sum g_1 \left(\bar{f}\gamma^\mu f\right) A^\mu \\ &+ \frac{g_2}{\cos\theta_W} f = l, q \sum \left[\bar{f}_L \gamma^\mu f_L \left(T^3_f - Q_f \sin^2\theta_W\right) + \bar{f}_R \gamma^\mu f_R \left(-Q_f \sin^2\theta_W\right)\right] Z_\mu \\ &+ \frac{g_2}{\sqrt{2}} \left[\left(\bar{u}_L \gamma^\mu d_L + \bar{v}_{eL}\gamma^\mu e_L\right) W^+_\mu + \text{ h.c.}\right],\end{aligned} \tag{2.4}$$

where f and $\bar{f}$ are the fields of fermions, A is the field of the photon and Z and W are the fields of the two weak guage bosons; g_1 is the electric coupling strength (or electric charge), g_2 is the weak coupling strength and T_f^3 is the third component of the weak isospin of the interacting fermions. The subscripts L and R denote the chirality or handedness of the fermions. For massless fermions, the chirality is equal to the helicity, which is positive (negative) if the fermion spin is directed toward (away from) its direction of motion. The Weinberg or weak mixing angle, θ_W is a measure of a relative strength of the electromagnetic coupling and weak coupling strength. In electroweak interactions, the neutral currents involve left and right-handed fermions, while charge currents involve *only* left-handed fermions. An important consequence of the left-handed charged current is parity violation, the hallmark of the weak interaction.

The most important and immediate goal in our quest to understand nature at the macroscopic level is the determination of the mechanism by which elementary particles acquire masses. One very attractive approach is the extention of the spontaneous symmetry breaking to create massive vector bosons in a guage invariant theory.

2.2.1 The Higgs Mechanism: Proposed Solution to the Mystry of Mass Generation

The electroweak theory as described above is known to be flawed. The guage symmetry $SU(2)_L \times U(1)_Y$ is invarient only if the fermions and bosons are massless. To treat the situation, it is assumed that the underlying guage symmetry is *spontaneously* broken. The symmetry breaking mechanism must not only generate the fermion and boson masses but also lead to a renormalizable theory. In the Salam Weinberg-(SW) model, this is accomplished by introducing a scalar isospin doublet complex Higgs fields[8], $\phi = \phi \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$,expanding the Higgs fields around an asymmetrical ground state (i.e. with non vanishing vacuum expectation value) and demanding local guage invariance. Three of the four scalar degrees of freedom of the Higgs field give masses to the W and Z bosons. The remaining manifests itself in a massive neutral spin zero boson, the physical Higgs boson. It is the only particle of the Standard Model which lacks direct experimental detection. The current lower limit on its mass is 114.1 GeV at the 95% confidence level. From electroweak precision data there is much evidence for a light Higgs.

But as soon as such a light Higgs is found, this gives birth to the *hierarchy problem.* A scalar (Higgs) mass is not protected by gauge or chiral symmetries so we expect $m_H \approx \Lambda \approx 10^{16}$ GeV if we do not want to fine-tune the bare Higgs mass against the mass aquired from quantum effects.

Fermion masses in SW model are generated via a Yukawa interaction $\bar{\psi}(x)\phi(x)\psi(x)$ with the Higgs field. The terms representing the fermion-Higgs interaction in the Lagrangian are not necessarily diagonal in fermion generations. Since fermion-Higgs interaction must be expressed in terms of mass eigenstates. The weak eigenstates giving currents diagonal in generations are not the same as the mass eigenstates. Hence the intergenerational mixing between fermions can occur.

To express the fermion-Higgs interaction in terms of mass eigenstates, the mass matrix is diagonalized using a pair of unitary transformations (one for each quark charge) relating the physical and weak quark bases. The product of unitary matrices that accomplishes this task and which appears in the charge-current interaction Lagrangian is known as the *mixing matrix.* For neutral currents the mass matrix stays diagonal and mixing does not occur.

The mixing matrix is unitary by construction and therefore contains n^2 parameters. However, an arbitrary choice of phases for the quark fields can be used to eliminate $2n$ parameters. An overall phase can be chosen to render one of these operations ineffective, so we can remove a total of $2n-1$ phases. of the n^2-2n+1 parameters, it can be shown that $\frac{1}{2}n\,(n-1)$ are real parameters and $\frac{1}{2}\,(n-1)\,(n-2)$ are imaginary parameters.

For two generations ($n=2$), the mixing matrix contains one real parameter: the Cabibbo angle θ_C. The resulting charge current (CC) part of the Lagrangian is:

$$\mathcal{L}_{CC} = W_+^\mu\,(\bar{u}_L\bar{c}_L)\,\gamma_\mu \begin{pmatrix} \cos\theta_C & \sin\theta_C \\ -\sin\theta_C & \cos\theta_C \end{pmatrix} \begin{pmatrix} d_L \\ s_L \end{pmatrix} + h.c., \tag{2.5}$$

where all coupling constants are real. The well-known GIM mechanism uses the notion of "Cabibbo-rotated" quark states to explain the suppression of flavor-changing neutral currents and justify the existence of the charm quark.

For three generations ($n=3$), the resulting charge current part of the Lagrangian is:

$$\mathcal{L}_{CC} = W_{+}^{\mu} \left(\bar{u}_L \bar{c}_L \bar{t}_L\right) \gamma_\mu \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix} + h.c. \tag{2.6}$$

Like fermion masses, the matrix elements of above mixing matrix for three generations are fundamental input parameters and must be determined experimentally. For three generations the matrix contains four independent quantities: three real parameters (or angles) and one imaginary parameter (a complex phase) as discussed below.

2.3 Cabibbo-Kobayashi-Maskawa (CKM) Matrix

The weak interaction is the only one in which a quark can change into another type (flavor) of quark or a lepton into another type of lepton. In this transformation a quark is allowed only to change charge by a unit amount e. Because quarks can change flavor by weak interactions, only the lightest quarks and leptons are included in the stable matter of the world around us all heavier ones decay to one or another of the lighter ones. If we look at all the ways in which one quark can change into another quark with a charge change of e, that's just all quarks with charge $+\frac{2}{3}e$ (u, c or t) paired with quarks with charge $-\frac{1}{3}e$ (d, s, or b), that's nine possible pairings. Each of these pairings has its own weak charge associated with it, which is related to a physical constant which we call a "coupling constant" which contains real or imaginary parts it is **complex.** The set of coupling constants can be represented by a **matrix** with 3 rows and 3 columns.

d	s	b	
V_{ud}	V_{us}	V_{ub}	u
V_{cd}	V_{cs}	V_{cb}	c
V_{td}	V_{ts}	V_{tb}	t

It has a name - the **Cabibbo-Kobayashi-Maskawa (CKM) matrix.** In contrast with electric charge, which seems to come in a well-defined universal unit, each of these nine coupling constants is different. The triumph of the Standard Model is that it predicts a set of relationships between the nine elements of the CKM matrix and it predicts that they include properties that result in CP violation. The inclusion of a complex phase in the CKM matrix is believed to be responsible for CP violation in charged-current interactions. If we look at enough decays that involve the different matrix elements, we can see whether the relationships are true. One important test of the the standard model is obtained by experimentally verifying the unitary of the CKM matrix. The unitarity condition can be expressed as

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \tag{2.7}$$

Experimentally, cross-generational mixing is known to be small, the diagonal elements V_{ud}, V_{cs}, V_{tb} are close to unity and the off-diagonol elements are much smaller in magnitude[9]. That is weak interactions nearly respect the quark generations but not completely.

As an example the rate for the process $B \to \pi\ell\nu$, which involves a $b \to u$ transition, is suppressed by a factor $|V_{ub}|^2$ and is therefore rarely observed. In this dissertation, discussed is the B-meson decays through $b \to s$ transition.

As for the theoretical aspects, the SM is a quantum field theory that is based on the gauge symmetry $SU(3)_C\times$ $SU(2)_L \times U(1)_Y$. This gauge group includes the symmetry group of the strong interactions, $SU(3)_C$ and the symmetry group of the electroweak interactions, $SU(2)_L \times U(1)$. The group symmetry of the electromagnetic interactions, $U(1)em$ appears inthe SM as a subgroup of $SU(2)_L\times$ $U(1)_Y$ and it is in this sense that the weak and electromagnetic interactions are said to be unified.

2.3.1 Gauge Sector of Standard Model

The gauge sector of the SM is composed of eight gluons which are the gauge bosons of $SU(3)_C$ and the $W\pm$ and Z particles which are the four gauge bosons of $SU(2)_L\times$ $U(1)_Y$. The main physical properties of these intermediate gauge bosons are as follows. The gluons are massless, electrically neutral and carry color quantum number. There are eight gluons since they come in eight different colors. The consequence of the gluons being colorful is that they interact not just with the quarks but also with themselves. The weak bosons, $W\pm$ and Z are massive particles and also selfinteracting. The $W\pm$ are charged with $Q = \pm 1$ respectively and the Z is electrically neutral. The photon is massless, chargeless and non-selfinteracting.

Concerning the range of the various interactions, it is well known the infinite range of the electromagnetic interactions as it corresponds to an interaction mediated by a massless gauge boson, the short range of the weak interaction of about $10^{-16}cm$ correspondingly to the exchange of a massive gauge particle with a mass of the order of $MV\tilde{~}100GeV$ and finally, the strong interactions whose range apparently should be infinite, as it corresponds to the exchange of a massless gluon but it is finite due to the extra physical property of confinement. In fact the short range of the strong interactions of about $10^{-13}cm$ corresponds to the typical size of the lightest hadrons.

As for the strength of the three interactions, the electromagnetic interactions are governed by the size of the electromagnetic coupling constant e or equivalently $\alpha = \frac{e^2}{4\pi}$ which at low energies is given by the fine structure constant, a $(Q = me) = \frac{1}{137}$. The weak interactions at energies much lower than the exchanged gauge boson mass, M_V, have an effective (weak) strength given by the dimensionful Fermi constant $G_F = 1.167\times\ 10^{-5}GeV^{-2}$ strong interaction as indicated by its name has more stronger strength compare to other interactions. This strength is governed by the size of the strong copling constant g_S or equivalently $\alpha_S = \frac{g_S^2}{4\pi}$ and is varies from large values to low energies, $\alpha_S(Q = mhadron)\tilde{~}1$ up to the vanishing asymptotic limit $\alpha_S(Q \to \infty) \to 0$. This last limit indicates that the quarks behave as free particles when they are observed at infinitely large energies or, equivalently inflinitely short distances and this is known as asymptotic freedom. Finally, regarding the present status of the matter particle content of the SM the situation is property of QCD summarized as follows.

2.3.2 Fermionic Sector

The fermionic sector of quarks and leptons are organized in three families with identical properties except for mass. The particle content in each family is

$$1^{st}\text{ family: } \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L, \ e_R^-, \ \begin{pmatrix} u \\ d \end{pmatrix}_L, \ u_R, \ d_R,$$

$$2^{nd} \text{ family: } \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L, \mu_R^-, \begin{pmatrix} c \\ s \end{pmatrix}_L, c_R, s_R,$$

$$3^{rd} \text{ family: } \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L, \tau_R^-, \begin{pmatrix} t \\ b \end{pmatrix}_L, t_R, b_R,$$

and their corresponding antiparticles. The left-handed and right-handed fields are defined by means of the chirality operator γ_5 as usual.

$$e_L^- = \frac{1}{2}(1-\gamma_5)e^-; \frac{1}{2}(1+\gamma_5)e^-,$$

and they transform as doublets and singlets of SU(2)L respectively.

2.3.3 Scalar Sector

The scalar sector of the SM is not experimentaly confirmed yet. The fact that the weak gauge bosons are massive particles, $M_W^\pm$, $M_Z \# 0$, indicates that $SU(2)_L \times U(1)_Y$ is NOT a symmetry of the vacuum. In contrast, the photon being massless reflects that U(1)em is a good symmetry of the vacuum. Therefore, the Spontaneous Symmetry Breaking pattern in the SM must b

$$SU(3)_C \times SU(2)_L \times U(1)_Y \rightarrow SU(3)_C \times U(1)em.$$

The above pattern is implemented in the SM by means of the so-called, Higgs Mechanism which provides the proper masses to the $W\pm$ and Z gauge bosons and to the fermions and leaves as a consequence the prediction of a new particle, the Higgs boson particle. This must be scalar and electrically neutral[10].

2.4 Unsolved Mysteries Beyond The Standard Model

The Standard Model answers many of the questions about the structure and stability of matter with its six types of quarks, six types of leptons and four forces. But the Standard Model is not complete; there are still many unanswered questions.

Why do we observe matter and almost no antimatter if we believe there is a symmetry between the two in the universe?

What is this "dark matter" that we can't see that has visible gravitational effects in the cosmos?

Why can't the Standard Model predict a particle's mass?

Are quarks and leptons actually fundamental, or made up of even more fundamental particles?

Why are there exactly three generations of quarks and leptons?

How does gravity fit into all of this?

The two important defects in standard model are

1. The model contains 19 free parameters, such as particle masses, which must be determined experimentally (plus another 10 for neutrino masses). These parameters cannot be independently calculated.

2. The model does not describe the gravitational interaction.

Since the completion of the Standard Model, many efforts have been made to address these problems.

In addition, there are cosmological reasons why the Standard Model is believed to be incomplete. In the Standard Model, matter and antimatter are related by the CPT symmetry, which suggests that there should be equal amounts of matter and antimatter after the Big Bang. While the preponderance of matter in the universe can be explained by saying that the universe just started out this way, this explanation strikes most physicists as inelegant. Furthermore, the Standard Model provides no mechanism to generate the cosmic inflation that is believed to have occurred at the beginning of the universe.

The Higgs boson, which is predicted by the Standard Model, has not been observed as of 2006 (though some phenomena were observed in the last days of the LEP collider that could be related to the Higgs). One of the reasons for building the LHC is that the increase in energy is expected to make the Higgs observable.

The first experimental deviation from the Standard Model (as proposed in the 1970's) came in 1998, when Super-Kamiokande published results indicating neutrino oscillation. Under the Standard Model, a massless neutrino cannot oscillate, so this observation implied the existence of non-zero neutrino masses. It was therefore necessary to revise the Standard Model to allow neutrinos to have mass; this may be simply achieved by adding 10 more free parameters beyond the initial 19.

A further extension of the Standard Model can be found in the theory of supersymmetry, which proposes a massive supersymmetric "partner" for every particle in the conventional Standard Model. Supersymmetric particles have been suggested as a candidate for explaining dark matter. Although supersymmetric particles have not been observed experimentally to date, the theory is one of the most popular avenues of research in theoretical particle physics.

While the Standard Model provides a very good description of phenomena observed by experiments, it is still an incomplete theory. The problem is that the Standard Model cannot explain why some particles exist as they do. For example, even though physicists knew the masses of all the quarks except for top quark for many years, they were simply unable to accurately predict the top quark's mass without experimental evidence because the Standard Model lacks any explanation for a possible pattern for particle masses[11].

2.4.1 Does this mean that the Standard Model is wrong?

No - but we need to go beyond the Standard Model in the same way that Einstein's Theory of Relativity extended Newton's laws of mechanics. Sir Isaac Newton's laws of mechanics are not wrong but his theory only works as long as velocity is much smaller than the speed of light. Einstein expanded Newtonian physics with his Theory of Relativity, which allows for the possibility of very high velocities. We will need to extend the Standard Model with something totally new in order to thoroughly explain mass, gravity and other phenomenas.

Chapter 3

New and Beauty Physics

3.1 Introduction to B-Physics

In particle physics, a meson is a strongly interacting boson. It is a hadron with integral spin. In the Standard Model, mesons are composite (non-elementary) particles composed of an even number of quarks and antiquarks. The quark and anti quark are bound together mainly by the strong force and they orbit each other much as the earth and the moon each other. Because they must obey the laws of quantum mechanics. The quark can orbit each other in few specific ways and each orbit corrospond to different meson with different mass. The lightest meson containing a given quark combination is known as "pseodoscalar" state.

A $B - meson$ consists of a b-antiquark(called $b - bar$) and either a $u - or\ d-$quark (these are two lightest quarks) and is pseudoscalar state. Its antiparticle, called the B antimeson or "$B - bar$" meson, is made up of a b-quark and a u- or d-antiquark ($u - bar\ or\ d - bar$). Usually we lump the B and $B-$bar mesons together and just call them "$B - meson$" unless the discussion requires them to be distinguished from each other.

The $B - meson$ is a relatively heavy particle, having a mass of $5.28 GeV/c^2$, which is more than five times the mass of proton. This is because b-quark contains almost that massive[12].

3.1.1 How the B-mesons Decay?

If the quarks that comprise the $B - meson$ are elementary, then how can they break up into even smaller particles? Technically, they don't. The weak interaction allows quarks to be transformed into other quarks. When a particle decay, it must obey the laws of physics, which include certain conservation rules. For example, energy must be conserved, the total energy of all decay products must be equal to the total energy of the original particle. Electric charge must also be conserved, the sum of electric charges on all decay products must be equal to the electric charge of the original particle and so on. In general, this means a particle decays into two or more particles whose total mass is less than that of the original particle. In addition, each interaction has its own set of conservation rules, so how a particle decays depends on what it can do and still obey the rules. It might be able to do more than one combination of things.

The $B-meson$ would be stable if the b-quark and companion antiquark didn't have weak charge. Because the B-meson is heavier than many other mesons, there are many ways in which it can decay. All of these ways involve the $b-quark$ transforming itself into another quark, which could be a t, c, or u quark. If it's a t, the t must then be transformed again, to a quark that's lighter than b, because t is more massive than b and couldn't be there in the end and still obey the laws. Sometimes the companion antiquark also gets transformed. In any case, many of these transformations can be detected experimentally, and we can measure the weak charge associated with them[13].

3.1.2 B-meson decays in a new way

An international team of physicists has observed $B-mesons$ decaying into pairs of baryon and antibaryon for the first time using the Belle detector at the KEK laboratory in Japan. This result distinguishes between the different models for $B-meson$ decay that currently exist .

$B-mesons$ are particles that consist of a "bottom" quark or antiquark plus another lighter quark or antiquark. $B-mesons$ have been observed decaying into various combinations of baryons, particles that contain three quarks and other mesons before, but never into two baryons. The Belle collaboration has now observed $B-mesons$ decaying into an antiproton and a lambda baryon, Λ_c^+. This particle contains an up, down and a charmed quark.

There are three currently accepted models for the decay of $B-mesons$ into a Λ_c^+ and an antiproton: the diquark, QCD sum rule and pole models. The predictions of the models differ by an order of magnitude and the Belle experiment is able to distinguish between them.

An elementary particle can decay into a certain number of lighter particles. Most particles exhibit several different decay modes, leading to the production of a specific set of particles. The fraction of the time a particle decays via a specific mode is known as the "branching" fraction. The researchers measured this fraction for the decay of the $B - meson$ into an antiproton and a Λ_c^+.

The team found a value of approximately 2.19×10^{-5} for the two-body decay of the $B - meson$. This fraction is about an order of magnitude smaller than a three body decay, which suggests that the "pole model" is correct[14].

3.2 Types of Decays

The rich phenomenology of weak decays has always been a source of information about the nature of elementary particle interactions. A long time ago, β-decay and μ-decay experiments revealed the effective flavor changing interactions at low momentum transfer. Today, weak decays of hadrons containing heavy quarks are employed for tests of the Standard Model and measurements of its parameters. In particular, they offer the most direct way to determine the weak mixing angles, to test the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and to explore the physics of CP violation. Hopefully, this will provide some hints about New Physics beyond the Standard Model. On the other hand, hadronic weak decays also serve as a probe of that part of strong-interaction phenomenology which is least understood: the confinement of quarks and gluons inside hadrons.

The structure of weak interactions in the Standard Model is rather simple. Flavor changing decays are mediated by coupling of the charged current J^μ_{CC} to the $W - boson$ field:

$$L_{CC} = -\frac{g}{\sqrt{2}} J^\mu_{CC} W^+_\mu + h.c., \tag{3.1}$$

where

$$J^\mu_{CC} = (\bar{\upsilon}_e, \bar{\upsilon}_\mu, \bar{\upsilon}_t) \begin{pmatrix} e_L \\ \mu_L \\ t_L \end{pmatrix} + (\bar{u}_L, \bar{c}_L, \bar{t}_L)\gamma^\mu V_{CKM} \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix}, \tag{3.2}$$

contains left-handed lepton and quark fields and

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}, \tag{3.3}$$

is the CKM matrix. At low energies, the charged-current interaction gives rise to local four-fermion couplings of the form

$$L_{eff} = -2\sqrt{2} G_F J^{\mu}_{CC} J_{CC,\mu}, \tag{3.4}$$

where

$$G_F = \frac{g^2}{\sqrt[4]{2} M_W^2} = 1.16639(2) GeV^{-2}, \tag{3.5}$$

is Fermi constant.

According to the structure of the charged-current interaction, weak decays of hadrons can be divided into three classes: leptonic decays, in which the quarks of the decaying hadron annihilate each other and only leptons appear in the final state; semi-leptonic decays, in which both leptons and hadrons appear in the final state; and non-leptonic decays, in which the final state consists of hadrons only. Representative examples of these three types of decays are shown in Fig.(3.1). The simple quark-line graphs shown in this figure are a gross over simplification. However, in the real world, quarks are confined inside hadrons, bound by the exchange of soft gluons.

The simplicity of the weak interactions is over shadowed by the complexity of the strong interactions. A complicated interplay between the weak and strong forces characterizes the phenomenology of hadronic weak decays. As an example, a more realistic picture of a non-leptonic decay is shown in Fig.3.2

Fig(3.2), More realistic representation of a non-leptonic decay. The complexity of strong-interaction effects increases with the number of quarks appearing in the final state. Bound-state

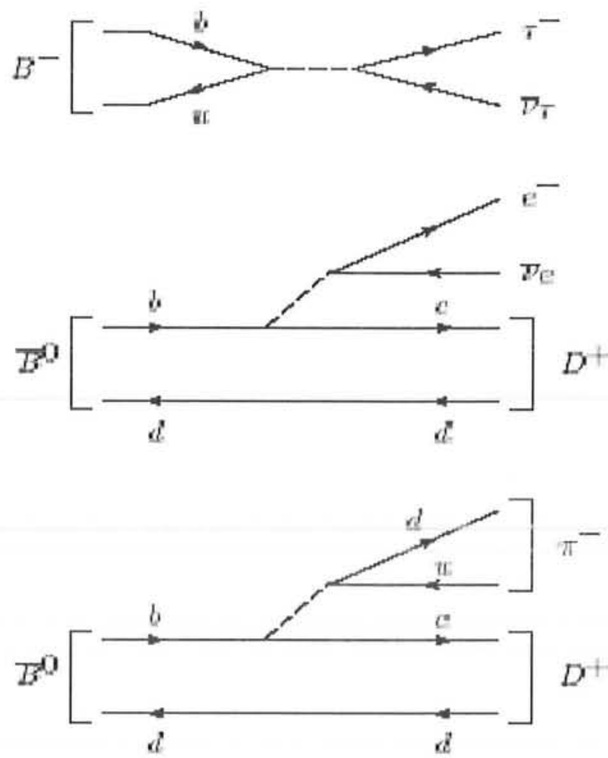

Figure 3-1: Examples of leptonic($B^- \to \tau\bar{\upsilon}_\tau$), semileptonic($\bar{B}^o \to D^+\bar{e}\ \bar{\upsilon}_e$)

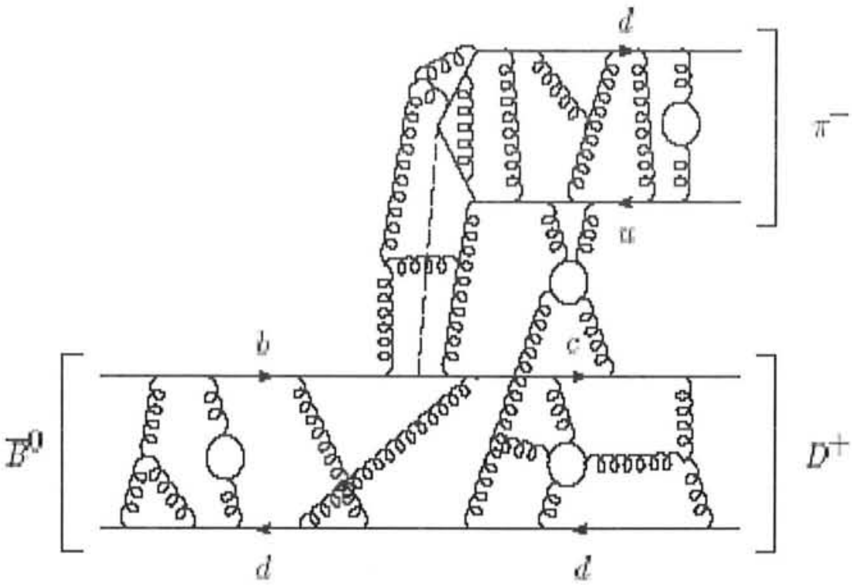

Figure 3-2: More realistic representation of non-leptonic decays

effects in leptonic decays can be lumped into a single parameter (a decay constant), while those in semi-leptonic decays are described by invariant form factors depending on the momentum transfer q2 between the hadrons. Approximate symmetries of the strong interactions help us to constrain the properties of these form factors. Non-leptonic weak decays, on the other hand, are much more complicated to deal with theoretically. Only very recently reliable tools have been developed that allow us to control the complex *QCD* dynamics in many two-body B decays using a heavy-quark expansion.

Over the last decade, a lot of information on heavy-quark decays has been collected in experiments at e^+ e^- storage rings operating at the (γ4s) resonance and more recently at high-energy e^+ $e^-$and hadron colliders. This has led to a rather detailed knowledge of the flavor sector of the Standard Model and many of the parameters associated with it. In the years ahead the B factories at *SLAC*, *KEK*, *Cornell* and *DESY* will continue to provide a wealth of new results, focusing primarily on studies of *CP violation* and rare decays.

The experimental progress in heavy-flavor physics has been accompanied by a significant progress in theory, which was related to the discovery of heavy- quark symmetry.The development of the heavy-quark effective theory and more generally the establishment of various kinds of heavy-quark expansions. The excitement about these developments rests upon the fact that they allow model-independent predictions in an area in which progress in theory often meant nothing more than the construction of a new model, which could be used to estimate some strong-interaction hadronic matrix elements[15].

3.3 Effective Field Theory

In physics effective field theory is an approximate theory that contains the appropriate degrees of freedom to describe the physical phenomena occuring at the choosen length scale, but ignores the substructure and the degrees of freedom at the shorter distance (or, equivalently, highers energies).

Nowadays, effective field theories are discussed in the context of the renormalization group (RG) where the process of integrating out short distance degrees of freedom is made systematic. Although this method is not sufficiently concrete to allow the actual construction of effective field theories the gross understanding of their usefulness becomes clear through an RG anaysis. This method also lends credence to the main technique of constructing effective field theories, i.e. through the analysis of symmetries. If there is a single mass scale M in the microscopic theory, then the effective field theory can be seen as an expansion in 1/M. This technique is useful for scattering or other processes where the maximum momentum scale k satisfies the condition k/M<<1. Since effective field theories are not valid at small length scales, they need not be renormalizable.

The most well-known example of an effective field theory is the Fermi theory of beta decay. This was developed during the early study of weak decays of nuclei when only the hadrons and leptons undergoing weak decay were known. The typical reactions studied were

$$n \rightarrow p + \bar{e} + \bar{\nu}_e$$

$$\bar{\mu} \longrightarrow \bar{e} + \bar{\nu}_e + \nu_\mu$$

This theory posited a pointlike interaction between the four fermions involved in these reactions.

The theory had great phenomenological success and was eventually understood to arise from the gauge theory of electroweak interactions, which forms a part of the standard model of particle physics. In this more fundamental theory, the interactions are mediated by a flavour-changing gauge boson which are the $W^{\pm}$. The immense success of the Fermi theory was due to the fact that the W has mass of about 80 GeV, whereas the early experiments were all done at an energy scale of less than 10 MeV. Such a separation of scales, by over 3 orders of magnitude, has not been met in any other situation as yet.

3.4 Effective Lagrangian

The purpose of effective lagrangian method is to represent in a simple way the dynamical content of a theory in the low energy limit, where the effects of the heavy particles can be incorporated into a few constants. The plane of attack is to write out the most general lagrangian consistent with the symmstries of the theory. At sufficiently low energies only one, or perhapes a few of the lagrangians are relavent and it is straight forward to read off the prediction of the theory. The effective lagrangians are used in all aspects of the Standard Model and beyond, from QED to superstrings. Perhaps the best setting for learning about them is that of chiral symmetry.

3.4.1 Effective Lagrangians:General Considerations

In the absence of a specific model of new physics effective Lagrangian techniques are extremely useful. An effective Lagrangian parameterizes in a Model independent way, the low energy effects of the new physics to be found at high energies. It is only necessary to specify the particle content and symmetries of low energy theory. Although Effective lagrangian contains an infinite number of terms they are organized in powers of $\frac{1}{\Lambda}$, where Λ is the scale of new physics. Thus, at energies which are smaller than Λ only first few terms of effective lagrangian are important.

The Fermi theory of weak interaction perhaps the best known example of the efefctive Lagrangian within the Standard Model. The charged current interaction between the two fermions is described by the exchange of $W - bosn$ is given as.

$$\frac{g^2}{8}\bar{\Psi}\gamma_\mu(1-\gamma_5)\Psi\frac{1}{q^2-m_w^2}\bar{\Psi}\gamma_\mu(1-\gamma_5)\Psi, \tag{3.6}$$

where q^2 is the momentum transfer(energy scale) of the ineteraction. We can expand the W-propagator in the powers of $\frac{q^2}{m_w^2}$ i.e. is

$$\frac{1}{q^2-m_w^2} = -\frac{1}{m_w^2}[1+\frac{q^2}{m_w^2}+ ....]. \tag{3.7}$$

The interaction in equation Eq(3.6) can thus be written as the sum of an infinite number of terms. However, we note that, for enegies well below the W mass, only the first term is important. This simply the 4-fermion interaction of the Fermi theory.

$$-\frac{G_F}{\sqrt{2}}\bar{\Psi}\gamma_\mu(1-\gamma_5)\Psi\bar{\Psi}\gamma_\mu(1-\gamma_5)\Psi, \tag{3.8}$$

where $\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_w^2}$. In other words, Fermi theory is the effective theory produced when one integrates out, the heavy degrees of freedom(in this case W boson). It is valid at energy scale much less than the scale of heavy physics ($q^2 << m_w^2$).

Note that, as q^2 approaches to m_w^2, one can no longer turncate after the lowest order term in $\frac{q^2}{m_w^2}$. This is the evidence that effective lagrangian is breaking[16, 17].

3.5 Motivation for New Physics

The Standard Model of elementary particles has been very successful in explaining a wide variety of existing experimental data. It covers a range of phenomena from low energy (less than a GeV) physics, such as kaon decays, to high energy (a few hundred GeV) processes involving real weak gauge bosons (W *and* Z) and top quarks. There is, therefore a little doubt that the present Standard Model is a theory to describe the physics below the energy scale of several hundred GeV, which has been explored so far.

However, the Standard Model is not satisfactory as the theory of elementary particles beyond the TeV energy scale. First of all, it does not explain the characteristic pattern of the mass spectrum of quarks and leptons. The second generation quarks and leptons are several orders of magnitude heavier than the corresponding first generation particles and the third generation is even heavier by another order of magnitude. The quark flavor mixing matrix the $-CKM$ matrix also has a striking hierarchical structure, i.e. the diagonal terms are close to unity and $1 \gg \theta_{12} \gg \theta_{23} \gg \theta_{13}$, where θ_{ij} denotes a mixing angle between the $i-th$ and $j-th$ generation. The recent observation of neutrino oscillations implies that there is also a rich flavor structure in the lepton sector. All of these masses and mixings are free parameters in the Standard Model, but ideally they should be explained by higher scale theories.

The particles in the Standard Model acquire masses from the Higgs mechanism. The Higgs potential itself is described by a scalar field theory, which contains a quadratic mass divergence. This means that a Higgs mass of order $100GeV$ is realized only after a huge cancellation between the bare Higgs mass squared μ_o^2 and the quadratically divergent mass renormalization, both of which are quantities of order Λ^2 where Λ is the cutoff scale. If Λ is of the order of the Planck scale, then a cancellation of more than 30 orders of magnitude is required. This is often called the hierarchy problem. Therefore it would be highly unnatural if the Standard Model were the theory valid at a very high energy scale, such as the Planck scale. Instead, the Standard Model should be considered as an effective theory of some more fundamental theory, which most likely lies in the TeV energy region.

$CP-violation$ is needed in order to produce the observed baryon number (or matter-antimatter) asymmetry in the universe. In the Standard Model, the complex phase of the CKM matrix provides the only source of the $CP-violation$, but models of baryogenesis suggest that it is quantitatively insufficient. This is another motivation to consider new physics models.

3.5.1 New physics scenarios

Several scenarios have been proposed for the physics beyond the Standard Model. They introduce new particles, dynamics, symmetries or even extra-dimensions at the TeV energy scale. In the supersymmetry ($SUSY$) scenarios, one introduces a new symmetry between bosons and fermions and a number of new particles that form supersymmetric pairs with the existing Standard Model particles. The quadratic divergence of the Higgs mass term then cancels out among superpartners. Technicolor-type scenarios assume new strong dynamics (like QCD) at the TeV scale and the Higgs field is realized as a composite state of more fundamental particles. The large extra space time dimension models cure the problem by extending the number of space time dimensions beyond four. In Little Higgs models the Higgs is a pseudo-Nambu-Goldstone boson and thus naturally light.

Flavor Changing Neutral Current (FCNC) processes, such as $B^0 - \bar{B}^0$ mixing and the $b \to s\gamma$ transition, provide strong constraints on new physics models. If there is no suppression mechanism for $FCNC$ processes, such as the GIM mechanism in the Standard Model, the new physics contribution can easily become too large to be consistent with the experimental data. In fact, if one introduces a $FCNC$ interaction as a higher dimensional operator to represent some new physics interaction, the associated energy scale is typically of order $10^3 TeV$, which is much higher than the expected scale of the new physics ($\tilde{} TeV$). Therefore, one has to introduce some flavor structure in new physics models[18].

Chapter 4

New physics upper bound on the branching ratio of $B_S \to l^+l^-$

In this chapter, we consider the most general four fermion effective Lagrangian for $b \to sl^+l^-$ transition due to new physics. We derive upper bounds on branching ratios for $B_S \to e^+e^-$ and $B_S \to \mu^+\mu^-$ by demanding that the predictions of this new physics Lagrangian for $B \to K^*l^+l^-$ and $B \to Kl^+l^-$ should be consistent with current experimental values.

The most effective Lagrangian for $b \to sl^+l^-$ transitions due to new physics can be written as

$$L_{eff} = L_{VA}+L_{SP}+L_T, \tag{4.1}$$

where, L_{VA} contain vector and axial-vctor couplings, L_{SP} contain scalar and pseudo-scalar cuoplings and L_T contains tensor couplings. L_T does not contribute to $B_S \to l^+l^-$ because

$$\langle 0 \left| \overline{s}\sigma^{\mu\nu} \right| B_S(P_{Bs})\rangle = 0,$$

hence we will drop it from further consideration.

Here,

$$\sigma^{\mu\nu} = \frac{i}{2}(\gamma^{\mu}\gamma^{\nu} - \gamma^{\nu}\gamma^{\mu}). \tag{4.2}$$

Befor the consideration of different couplings the discussion about the decay kinematics is necessary.

4.1 Decay Kinematics

For the study of the decays $B \to K^* l^+ l^-$, $B \to K l^+ l^-$, we inroduce here the decay kinamatics. $P = (E_B, P_B)$, $K^* = (E_{K^*}, P_{K^*})$, $K = (E_K, P_K)$, $P_1 = (E_l, P_l)$, $P_2 = (E_2, P_{l^-})$ are the four momentas of B-mesons, Kaons and charged leptons respectively.

The equations for the energy and momentum conservation are given as

$$E_B = E_{K^*} + E_1 + E$$

$$P_B = P_{K^*} + P_1 + P_2$$

The masses of the particles in the decays are,

$$M_B = 5.82 \ GeV,$$

$$M_{K^*} = 0.89 GeV,$$

$$M_K = 0.494 \ GeV,$$

and

$$m_l = \left\{ \begin{array}{c} 0.51 \ MeV \ (l = e) \\ 105.67 \ MeV \ (l = \mu) \end{array} \right\}. \tag{4.3}$$

Defining the Kinamatical variables x and y (in the $B-meson$ rest frame) as

$$x = 2\frac{P_B.P_K}{M_B^2} = 2\frac{E_K}{M_B}, \tag{4.4}$$

$$y = 2\frac{P_B.P_2}{M_B^2} = 2\frac{E_2}{M_B}, \tag{4.5}$$

The energies E_{K^*}, E_K and E_2 are two of the three quantities directly measureable in the decay. The third observable is the angle θ_{K^*l} between the K^*-*meson* and one of the lepton momenta. In the $B-meson$ rest frame these three quantities are related as

$$\cos\theta_{K^*l} = \frac{y(x-2)+2(1-x+r^2)}{y\sqrt{x^2-4r^2}}, \tag{4.6}$$

where

$$r^2 = \frac{M_K^2}{M_B^2} = 0.1529,$$

$$r_l^2 = \frac{m_l^2}{M_B^2} = \left\{ \begin{array}{ll} 9.329\times10^{-9} & (l=e) \\ 4.005\times10^{-4} & (l=\mu) \end{array} \right\}. \tag{4.7}$$

In above we have neglected the ratio between the mass of lepton and $B-meson$. The ranges of variables are easily established as

$$1-\frac{1}{2}x-\frac{1}{2}\sqrt{x^2-4r^2} \leq y \leq 1-\frac{1}{2}x+\frac{1}{2}\sqrt{x^2-4r^2} \tag{4.8}$$

$$2r \leq x \leq 1+r^2. \tag{4.9}$$

By using the energy-momentum conservation laws, in the $B-meson$ rest frame, it is useful to express the scalar products as follow:

$$P_1.P_2 = \frac{1}{2}M_B^2(1 + r^2 - x - 2r_l^2) \tag{4.10}$$

$$P_{k^*}.P_1 = \frac{1}{2}M_B^2(1 - r^2 - y) \tag{4.11}$$

$$P_2.P_{k^*} = \frac{1}{2}M_B^2(x + y - 1 - r^2)$$

and also

$$P_B.P_{k^*} = \frac{1}{2}M_B^2 x \tag{4.12}$$

$$P_B.P_2 = \frac{1}{2}M_B^2 y$$

$$P_B.P_1 = \frac{1}{2}M_B^2(2 - x - y). \tag{4.13}$$

Now we consider the different couplings[19].

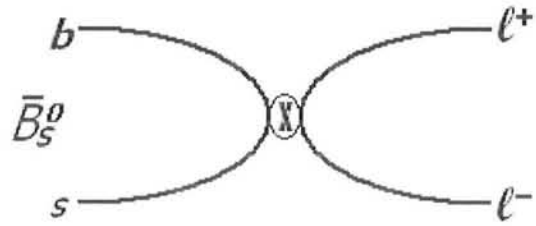

Figure 4-1: $B_s \rightarrow l^+l^-$

4.2 Vector and Axial-Vector Couplings

First we will consider that the new physics Lagrangian contains only vector and axial vector couplings. We parametrize it as

$$L_{VA}(b \rightarrow sl^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\bar{s}(g_V + g_A\gamma_5)\gamma_\mu b\bar{l}(\acute{g}_V + \acute{g}_A\gamma_5)\gamma_\mu l. \quad (4.14)$$

Here the constants g and $\acute{g}$ are the effective coupling constant which characterize the new physics.

From the above equation, we write the matrix elements for $B_S \rightarrow l^+l^-$

$$M(B_S \rightarrow l^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})(g_A\acute{g}_A)\left\langle 0\left|\bar{s}\gamma_5\gamma_\mu b\right|B_S\right\rangle\left\langle l^+l^-\left|\bar{l}\gamma_5\gamma^\mu l\right|0\right\rangle. \quad (4.15)$$

Only the axial-vector parts contributes for both hadronic and leptonic parts of the matrix elements

$$g_V\left\langle 0\left|\bar{s}\gamma_\mu b\right|B_S(P_{Bs})\right\rangle = 0$$

Substituting

$$\left\langle 0\left|\bar{s}\gamma_5\gamma_\mu b\right|B_S(P_{Bs})\right\rangle = -if_{Bs}P_{B\mu}.$$

in the above equation, we have

$$M(B_S \to l^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_W^2})(g_A \acute{g}_A)(-if_{Bs}P_{B\mu})\overline{U}(p_l)\gamma_5\gamma^\mu V(p_{\bar{l}}). \tag{4.16}$$

where f_{Bs} is a decay constant.

By making the use of Dirac equation, we have

$$M(B_S \to l^+l^-) = -2im_l f_{Bs}(g_A \acute{g}_A)\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\overline{U}(p_l)\gamma_5 V(p_{\bar{l}}). \tag{4.17}$$

and its complex conjugate is

$$M^+(B_S \to l^+l^-) = -2im_l f_{Bs}(g_A \acute{g}_A)\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\overline{V}(p_{\bar{l}})\gamma_5 U(P_l). \tag{4.18}$$

$$\begin{aligned} |M|^2 &= M^+ M \qquad (4.19)\\ &= (-2im_l f_{Bs}(g_A \acute{g}_A)\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_W^2})\overline{V}(p_{\bar{l}})\gamma_5 U(P_l)) \times (-2im_l f_{Bs}(g_A \acute{g}_A)\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_W^2})\overline{U}(p_l)\gamma_5 V(p_{\bar{l}})). \end{aligned}$$

Hence, the sum over spin of the lepton and integrating over lepton momenta

$$\Gamma_{NP}(B_S \longrightarrow l^+l^-) = \frac{G_F^2 f_{BS}^2}{8\pi}(\frac{\alpha}{4\pi s_w^2})^2(g_A \acute{g}_A)^2 m_{Bs} m_l^2 \tag{4.20}$$

4.2.1 Determination of coupling constants

Thus decay rate depends upon the value of $(g_A \acute{g}_A)^2$. To estimate the value of $(g_A \acute{g}_A)^2$, We consider the related semi leptonic decays $B \longrightarrow K^* l^+ l^-$ and $B \longrightarrow K l^+ l^-$, which also recieve the contribution from the effective Lagrangian Eq(4.14). In deriving the equation Eq(4.20), we dropped the terms proportional to $\frac{m_l^2}{m_B^2}$, as their contribution is negligible in the decay rate. We will make the same approximation in calculating the decay width of semi leptonic modes also.

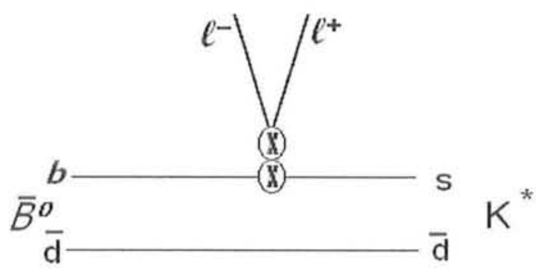

Figure 4-2: $B \to K^* l^+ l^-$

For

$$\bar{B}^0 \to K^* l^+ l^-$$

At quark level [see fig 4.2]

$$(b\bar{d}) \longrightarrow (s\bar{d}) l^+ l^-$$

For this semi leptonic operators are

$$Q_A = (\bar{s}b)_{V-A} (\bar{l}l)_A$$

$$Q_V = (\bar{s}b)_{V-A} (\bar{l}l)_V$$

The matrix elements are

$$\begin{aligned}
M(\bar{B}^o &\rightarrow K^* l^+ l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\{\langle K^*(P_{K^*})\left|\bar{s}(g_V - g_A\gamma_5)\gamma_\mu b\right| B(P_B)\rangle \acute{g}_A\gamma_\mu V(p_{\bar{l}}) + \qquad (4.21)\\
&\langle K^*(P_{K^*})\left|\bar{s}(g_V - g_A\gamma_5)\gamma_\mu b\right| B(P_B)\rangle \bar{U}\acute{g}_V\gamma_\mu V(p_{\bar{l}})\}.\\
M(\bar{B}^o &\rightarrow K^* l^+ l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\langle K^*(P_{K^*})\left|\bar{s}(g_V + g_A\gamma_5)\gamma_\mu b\right| B(P_B)\rangle (\bar{U}(P_l)(\acute{g}_V + \acute{g}_A\gamma_5)\gamma_\mu V(p_{\bar{l}})).
\end{aligned}$$

where the hadronics matrix elements are defind as.

$$\begin{aligned}
\langle K^*(P_{K^*})\left|\bar{s}\gamma_\mu b\right| B(P_B)\rangle &= i\epsilon_{\mu\gamma\lambda\sigma}\varepsilon^\nu(p_{K^*})(P_B + P_{K^*})^\lambda(P_B - P_{K^*})^\sigma V(q^2). \qquad (4.22)\\
\langle K^*(P_{K^*})\left|\bar{s}\gamma_5\gamma_\mu b\right| B(P_B)\rangle &= \varepsilon_\mu(p_{K^*})(m_B^2 - m_{K^*}^2)A_1(q^2) - (\varepsilon.q)(P_B + P_{K^*})_\mu A_2(q^2).
\end{aligned}$$

where

$$q = P_l + P_{\bar{l}}$$

In the above eqations, a term proportional to q_μ is dropped because its contribution to the decay rate is proportional to m_l^2/m_B^2. It is assumed that the q^2 dependence of these form factors is well approximated by a pole fit[20, 21, 22].

$$\begin{aligned}
V(q^2) &= \frac{V}{(m_B + m_{K^*})(1 - q^2/m_B^2)}.\\
A_i(q^2) &= \frac{A_i}{(m_B + m_{K^*})(1 - q^2/m_B^2)}.
\end{aligned}$$

so the matrix elements becomes

$$M(\bar{B}^o \to K^* l^+ l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_W^2}) \tag{4.23}$$

$$\left(\frac{\begin{array}{c}\{i\epsilon_{\mu\gamma\lambda\sigma}\varepsilon^\nu(p_{K^*})(P_B + P_{K^*})^\lambda(P_B - P_{K^*})^\sigma V(q^2)\}g_V - \\ \{\varepsilon_\mu(p_{K^*})(m_B^2 - m_{K^*}^2)A_1(q^2) - (\varepsilon.q)(P_B + P_{K^*})_\mu A_2(q^2)\}g_A\end{array}}{(m_B + m_{K^*})(1 - q^2/m_B^2)} \right)$$

$$\times(\bar{U}(P_l)(\acute{g}_V + \acute{g}_A\gamma_5)\gamma_\mu V(p_{\bar{l}})).$$

so that

$$|M|^2 = \frac{G_F^2}{2}(\frac{\alpha}{4\pi s_w^2})^2 \times \tag{4.24}$$

$$\left(\frac{\begin{array}{c}[\{i\epsilon_{\mu\gamma\lambda\sigma}\varepsilon^\nu(p_{K^*})(P_B + P_{K^*})^\lambda(P_B - P_{K^*})^\sigma V(q^2)\}g_V + \\ \{\varepsilon_\mu(p_{K^*})(m_B^2 - m_{K^*}^2)A_1(q^2) - (\varepsilon.q)(P_B + P_{K^*})_\mu A_2(q^2)\}g_A]^\dagger \\ \times \quad \{i\epsilon_{\mu\gamma\lambda\sigma}\varepsilon^\nu(p_{K^*})(P_B + P_{K^*})^\lambda(P_B - P_{K^*})^\sigma V(q^2)\}g_V + \\ \{\varepsilon_\mu(p_{K^*})(m_B^2 - m_{K^*}^2)A_1(q^2) - (\varepsilon.q)(P_B + P_{K^*})_\mu A_2(q^2)\}g_A\end{array}}{(m_B + m_{K^*})^2(1 - q^2/m_B^2)^2} \right) \tag{4.25}$$

$$\times(\overline{V}(P_{\bar{l}})\gamma_\mu(\acute{g}_V - \acute{g}_A\gamma_5)\overline{U}(P_l) \times (\bar{U}(P_l)(\acute{g}_V + \acute{g}_A\gamma_5)\gamma_\mu V(p_{\bar{l}})).$$

The decay rate is

$$\Gamma_{NP}(\bar{B}^0 \to K^* l^+ l^-) = 3.24 \times 10^{-16}\{1.345(\acute{g}_V^2 + \acute{g}_A^2)A_1^2 g_A^2 + .2316 g_V^2(\acute{g}_V^2 + \acute{g}_A^2)\}.$$

$$A_1 \approx A_2$$

From the Eq(4.25), We see that $(g_A\acute{g}_A)^2$ can be measured rate $\Gamma(\bar{B}^0 \to K^* l^+ l^-)$, provide

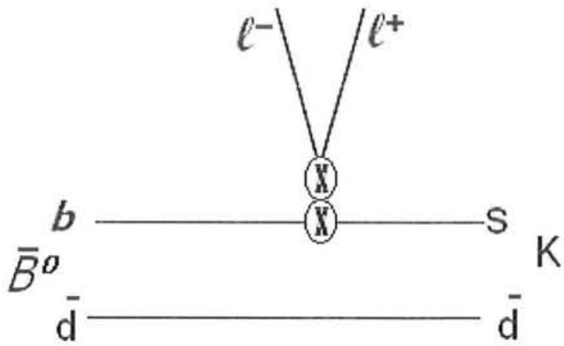

Figure 4-3: $B \rightarrow Kl^+l^-$

the value of $(\acute{g}_V^2 + \acute{g}_A^2)g_V^2$ is known.

For this, we consider the decay of $\bar{B}^o \rightarrow Kl^+l^-$. The matrix element in this case is [3]

$$M(B- > Kl^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_W^2})\left\langle K(P_K)\right|\bar{s}\; g_V\gamma_\mu b\left|B_S(P_B)\right\rangle \bar{U}(P_l)(\acute{g}_V + \acute{g}_A\gamma_5)\gamma_\mu V(P_l). \tag{4.26}$$

where

$$\left\langle K(p_K)\right|\bar{s}\gamma_\mu b\left|B(p_B)\right\rangle = (P_B + P_K)_\mu \; f_{KB}^+(q^2).$$

The q^2 dependence of the form factor, again is apporoximated by a single pole with mass $\approx m_B$.

$$f_{KB}^+(q^2) = \frac{f^+(0)}{(1 - \frac{q^2}{m_B^2})}. \tag{4.27}$$

so the matrix element becomes

$$M(B \to Kl^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})(P_B + P_K)_\mu f_{KB}^+(q^2)\bar{U}(P_l)(\acute{g}_V + \acute{g}_A\gamma_5)\gamma_\mu V(P_l).$$

and its complex conjugate is

$$M^\dagger(B \to Kl^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})(P_B + P_K)_\mu f_{KB}^+(q^2)\bar{U}(P_l)(\acute{g}_V - \acute{g}_A\gamma_5)\gamma_\mu V(P_l).$$

The decay rate is given by

$$\Gamma_{NP}(\bar{B}^o \to Kl^+l^-) = 1.6213 \times 10^{-16} g_V^2(\acute{g}_V^2 + \acute{g}_A^2)[f^+(0)]^2. \tag{4.28}$$

We assume that the maximum value of this decay rate is measured experimetal value i.e.

$$\Gamma \exp = \Gamma_{NP}$$

$$\Gamma_{NP}(\bar{B}^o \to K^*l^+l^-) = B_r(\bar{B}^o \to K^*l^+l^-) \times 4.50513347 \times 10^{-13}.$$

from Eq(4.25)

$$g_A^2(\acute{g}_V^2 + \acute{g}_A^2) = \frac{B_r(\bar{B}^o \to K^*l^+l^-) \times (1.38 \times 10^3) - V^2 g_V^2(\acute{g}_V^2 + \acute{g}_A^2) \times (0.231617)}{A_1^2 \times 1.345}. \tag{4.29}$$

Now from Eq(4.28), we get

$$g_V^2(\acute{g}_V^2 + \acute{g}_A^2) = \frac{B_r(\bar{B}^o \to Kl^+l^-)}{(3.45) \times [f^+(0)]^2} \times 10^4. \tag{4.30}$$

In our calculations, we take the form factors to be[23, 24]

$$f^{+}(0) = 0.319^{+0.052}_{-0.041}.$$

$$V = 0.45^{+0.091}_{-0.058}.$$

$$A_1 = 0.337^{+0.048}_{-0.043}.$$

$$fBs = 240 \pm 30 * 10^{-3} GeV$$

$$G_F = 1.166 * 10^{-5} GeV^{-2}$$

and the experimental value of $B_r(B \to (K\ , K^*)\ l^+l^-$ given in [?, ?] as

$$B \to Kl^+l^- = 4.8^{+1.0}_{-0.9} \times 10^{-7}.$$

$$B \to K^*l^+l^- = 11.5^{+2.6}_{-2.4} \times 10^{-7}.$$

$$g_A^2(\acute{g}_V^2 + \acute{g}_A^2) = (6.245^{+4.04}_{-3.48}) \times 10^{-3}. \quad (4.31)$$

$$g_V^2(\acute{g}_V^2 + \acute{g}_A^2) = (1.31027^{+0.53}_{-0.44}) \times 10^{-2}. \quad (4.32)$$

Thus the maximum value of $(g_A \acute{g}_A)^2$ can have is

$$(g_A \acute{g}_A)^2 = (6.245^{+4.04}_{-3.48}) \times 10^{-3}. \tag{4.33}$$

4.2.2 Branching Ratio and Upper Bounds

Substituting the $f_{BS} = 240 \pm 30 MeV$ [12] and maximum value for $(g_A \acute{g}_A)^2$ from Eq(4.32), we get the branching ratio for $B_S \to l^+ l^-$ due to L_{VA}

$$\Gamma_{NP}(B_S \to l^+ l^-) = \frac{G_F^2 f_{BS}^2}{8\pi} (\frac{\alpha}{4\pi s_w^2})^2 (g_A \acute{g}_A)^2 m_{Bs} m_l^2. \tag{4.34}$$

$$\begin{aligned} B(B_S &\to e^+ e^-) = 4.02^{+2.65}_{-2.34} \times 10^{-14}. \\ B(B_S &\to \mu^+ \mu^-) = 1.64^{+1.13}_{-1.00} \times 10^{-9}. \end{aligned} \tag{4.35}$$

Therefore the upper bounds on the branching ratios are

$$\begin{aligned} B(B_S &\to e^+ e^-) < 6.67 \times 10^{-14}. \\ B(B_S &\to \mu^+ \mu^-) < 2.77 \times 10^{-9}. \end{aligned} \tag{4.36}$$

The decays rates are close to the Standard Model predictions(SM). The answer for this is quiet simple, the decay rate for exclusive semileptonic process can be written as

$$\Gamma = (c.c)^2 (f.f)^2 phase\ space$$

Where $(c.c)$ is the coupling constant and $f.f$ is the form factor. The measured rates for the exclusive semi-leptonic decays are close to SM prediction and we assume that the new physics predictions for these processes are equal to their corrosponding experimental values. Also, the same set of form factors are used in both SM and in new physics calculation. Thus the assumption that the new physics predictions for semi-leptonic branching are equal to their experimental values (which in turn are equal to their SM predictions) implies that the coupling of new physics are very close to the coupling of SM. Therefore, new physics whose effective lagrangian for $b \to sl^+l^-$ consists of only vector and axial vector currents, cannot boost the rate of $B_S \to l^+l^-$ due to present experimental constraints coming from decays[25, 26, 27].

$$\begin{aligned} B &\to Kl^+l^- \\ B &\to K^*l^+l^- \end{aligned}$$

4.3 Scalar and Pseudo-scalar Couplings

Now, we consider the new physics effective Lagrangian to consist of scalar-pseudoscalar couplings.

$$L_{SP}(b \to sl^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\bar{s}(g_S + g_P\gamma_5)b\bar{l}(\acute{g}_S + \acute{g}_P\gamma_5)l. \tag{4.37}$$

The matrix element for $B_S \to l^+l^-$ is given as

$$\begin{aligned} M(\bar{B}_S^o &\to l^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\left\langle l^+l^- \left|current\right| B_S\right\rangle. \\ M(\bar{B}_S^o &\to l^+l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})\left\langle 0\left|\bar{s}(g_S + g_P\gamma_5)b\right| B_S(P_{Bs})\right\rangle \left\langle l^+l^- \left|\bar{l}(\acute{g}_S + \acute{g}_P\gamma_5)l\right| 0\right\rangle. \end{aligned}$$

$$\therefore \left\langle 0\left|\bar{s}b\right| B_S(P_{Bs})\right\rangle = 0$$

$$\left\langle 0\left|\bar{s}\gamma_5 b\right| B_S(P_{Bs})\right\rangle = \frac{-if_{Bs}m_{Bs}^2}{mb + m_s}$$

Where mb and m_s are the masses of bottom and strange quarks respectively.

then the matrix element becomes

$$M(\bar{B}^o_S \to l^+l^-) = -ig_P\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\Pi s^2_W})\frac{f_{Bs}m^2_{Bs}}{mb+m_s}(\acute{g}_S\overline{U}(p_l)V(p_{\bar{l}}) + \acute{g}_P\overline{U}(p_l)\gamma_5V(p_{\bar{l}})) \quad (4.38)$$

$$M^+(\bar{B}^o_S \to l^+l^-) = ig_P\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s^2_w})\frac{f_{Bs}m^2_{Bs}}{mb+m_s}(\acute{g}_S\bar{V}(p_{\bar{l}})U(p_l) - \acute{g}_PU(p_l)\bar{V}(p_{\bar{l}})\gamma_5U(p_l)) \quad (4.39)$$

and then

$$\begin{aligned}
|M|^2 &= M^+M \\
|M|^2 &= g^2_P\frac{G^2_F}{2}(\frac{\alpha}{4\pi s^2_w})^2\frac{f^2_{Bs}m^4_{Bs}}{(mb+m_s)^2}\times \\
&[(\acute{g}_S\bar{V}(p_{\bar{l}})U(p_l) - \acute{g}_PU(p_l)\bar{V}(p_{\bar{l}})\gamma_5U(p_l) \times (\acute{g}_S\bar{V}(p_{\bar{l}})U(p_l) - \acute{g}_PU(p_l)\bar{V}(p_{\bar{l}})\gamma_5U(p_l).
\end{aligned}$$

Here we see that there is no helicity supression i.e. the rates of decays $B_S \to e^+e^-$ and $B_S \to \mu^+\mu^-$ will be same provide $\acute{g}_S$ and $\acute{g}_P$ for both electrons and muons are the same[20].

Hence,taking the sum over the spin of the lepton and integrating over lepton momenta, the calculation of the decay width gives

$$\Gamma_{NP}(B_S \to l^+l^-) = \frac{G^2_F f^2_{BS}}{16\pi}(\frac{\alpha}{4\pi s^2_w})^2\frac{f^2_{Bs}m^5_{Bs}}{(mb+m_s)^2}g^2_P(\acute{g}^2_S + \acute{g}^2_P). \quad (4.40)$$

where G_F is fermi coupling constant.

The total decay width is given as

$$\Gamma = 4.5013347 \times 10^{-13}GeV$$

Branching ratio = decay rate/total decay width

$$Br(\bar{B}^o_S \to l^+l^-) = 0.17\frac{f^2_{BS}g^2_P(\acute{g}^2_S + \acute{g}^2_P)}{(mb+m_s)^2}. \quad (4.41)$$

To estimate the value of $g_P^2(\acute{g}_S^2+\acute{g}_P^2)$, We again consider the related decay $\bar{B}^o \to K^* l^+ l^-$.Its matrix element due L_{SP} is given by

$$M(\bar{B}^o \to K^* l^+ l^-) = \frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2}) \left\langle K^* \left| \bar{s}(g_S + g_P\gamma_5)b \right| B_S(P_{Bs}) \right\rangle \left\langle l^+ l^- \left| \bar{l}(\acute{g}_S + \acute{g}_P\gamma_5)l \right| 0 \right\rangle .$$

$$\left\langle K^* \left| \bar{s}b \right| B_S(P_{Bs}) \right\rangle = 0$$

The pseudoscalar hadronic matrix element is give [citation 15]

$$\left\langle K^* \left| \bar{s}\gamma_5 b \right| B_S(P_{Bs}) \right\rangle = -i(\frac{2m_K^*}{(mb-m_s)})A_o(q^2)(q.\epsilon).$$

The q^2 dependence of the form factor is described by a pole fit

$$A_o(q^2) = \frac{A_o(0)}{(1-q^2/m_B^2)}.$$

Then the matrix element becomes

$$M(\bar{B}^o \to K^* l^+ l^-) = -ig_P\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})(\frac{2m_K^*}{(mb-m_s)})A_o(q^2)(q.\epsilon)(\acute{g}_S\overline{U}(p_l)V(p_{\bar{l}}) + \acute{g}_P\overline{U}(p_l)\gamma_5 V(p_{\bar{l}})). \tag{4.42}$$

The complex conjugate is

$$M^+(\bar{B}^o \to K^* l^+ l^-) = ig_P\frac{G_F}{\sqrt{2}}(\frac{\alpha}{4\pi s_w^2})(\frac{2m_K^*}{(mb-m_s)})(A_o(q^2)(q^*.\epsilon^*)(\acute{g}_S\overline{U}(p_l)V(p_{\bar{l}}) - \acute{g}_P\overline{U}(p_l)\gamma_5 V(p_{\bar{l}}).$$

$$|M|^2 = M^+ M$$

$$|M|^2 = g_P^2\frac{G_F^2}{2}(\frac{\alpha}{4s_W^2})^2(\frac{2m_{K^*}}{(mb-m_s)})^2[A_o(q^2]^2 \times$$
$$\{(q^*.\epsilon^*)(\acute{g}_S\overline{U}(p_l)V(p_{\bar{l}}) - \acute{g}_P\overline{U}(p_l)\gamma_5V(p_{\bar{l}}) \times (q.\epsilon)(\acute{g}_S\overline{U}(p_l)V(p_{\bar{l}}) + \acute{g}_P\overline{U}(p_l)\gamma_5V(p_{\bar{l}})\}.$$

The full calculation gives us

$$\Gamma_{NP}(\bar{B}^o \to K^*l^+l^-) = 23.624g_p^2(\acute{g}_s^2 + \acute{g}_p^2) \tag{4.43}$$

as

$$\Gamma_{NP}(\bar{B}^o \to K^*l^+l^-) = Br_{EXP}(\bar{B}^o \to K^*l^+l^-)$$

$$g_P^2(\acute{g}_S^2 + \acute{g}_P^2) = \frac{(mb-m_s)^2B_{EXP}(\bar{B}^o \to K^*l^+l^-)}{2.34[A_o(0)]^2}. \tag{4.44}$$

Taking the values of

$$A_o(0) = 0.471^{+0.127}_{-0.059}[11].$$
$$B_{EXP}(\bar{B}^o \to K^*l^+l^-) = 1.17 \times 10^{-6}.$$

4.3.1 Branching Ratio and uper Bounds

by putting the values of $A_o(0)$ and $B_{EXP}(\bar{B}^o \to K^*l^+l^-)$, we get

$$g_P^2(\acute{g}_S^2 + \acute{g}_P^2) = 4.60^{+2.41}_{-1.41} \times 10^{-2}. \tag{4.45}$$

substituting the value of $g_P^2(\acute{g}_S^2 + \acute{g}_P^2)$ in below equation

$$Br(\bar{B}_S^o \to l^+l^-) = 0.17\frac{f_{BS}^2g_P^2(\acute{g}_S^2 + \acute{g}_P^2)}{(mb+m_s)^2}. \tag{4.46}$$

$$Br(\bar{B}_S^o \to l^+l^-) = 0.17\frac{f_{BS}^2 g_P^2(\acute{g}_S^2 + \acute{g}_P^2).}{(mb + m_s)^2} \tag{4.47}$$

$$Br(\bar{B}_S^o \to l^+l^-) = 2.10^{+1.38}_{-0.93} \times 10^{-5}. \tag{4.48}$$

The upper bound on $B(B_S \to \mu^+\mu^-)$ from the above equation is much higher than the present experimental bound . Thus we see that the measured values of $B(B_S \to (K\ , K^*)\ l^+l^-$ do not provide any useful constraint on L_{SP} contribution to $B(B_S \to \mu^+\mu^-)$[28, 29, 30]. The significance of this result is that if a future experiment, such as LHC [16] observers $B(B_S \to \mu^+\mu^-) \geqslant 10^{-8}$, one can confidently assert that the new physics giving rise to this a large branching ratio must necessarily be scalar/pseudoscalar type.

4.4 Conclusion

The rare decays of $B - mesons$ involving flavour changing neutral interaction (FCNI) $b \to s$ has been a topic of great interest for long. Not only will it subject the Standard Model to accurate test but will also put strong constraints on the several models beyond the SM. In the SM, FCNI occur only one or more loops. We concider the most general effective lagrangian for the flavour changing neutral process $b \to sl^+l^-$, arising due to new physics. We showed that the present experimental values of $B_r(\ B \to (K\ , K^*)\ l^+l^-)$ set strong bounds on $B_r(B_S \to l^+l^-)$, if the effective Lagrangian is product of vectors/axial-vectors. Given that the above semi-leptonic decay rates of $B - mesons$ are compare able to their SM predicted values, we showed that the rate of purely leptonic decays of B_S cannot be much above the their SM predicted value, If the effective lagrangian for $b \to sl^+l^-$ is product of scalar/pseudoscalars then present experimental values of B ($B \to (K\ , K^*)\ l^+l^-$) do not lead to any useful bound on $B_r(B_S \to l^+l^-)$. This leads us to very importent conclusion that, if a future experiment observes $B_S \to l^+l^-$ with a branching ratio greater than 10^{-8}, then the new physics responsible for this decay must of be scalar/pseudoscalar type.

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