Chapter 1

INTRODUCTION

The Higgs boson plays an important role in the spontaneous breakdown of the $SU(2) \times U(1)$ symmetry in the Standard Model. But its existence remains elusive. The search for the Higgs particle is therefore one of the central theme in particle physics. The confirmation of the existence of the Higgs particle will definitely be an event that physicists look forward to in the near future.

In the Standard Model, an important characteristic of the Higgs boson is that its coupling to a fermion is proportional to the mass of the fermions. This is a direct consequence of its role in generating masses. Its coupling to a fermion is inversely proportional to the vacuum expectation value. It can be determined by requiring that the electroweak model reproduces the standard beta-decay interaction. Due to the fact that the known quarks with the exception of the top quark have very small masses, their couplings to the Higgs boson are very small. Consequently its coupling to stable matter is very small rendering its production and detection in experiments extremely difficult.

If the Higgs mass is very large, the couplings of the Higgs to itself and to longitudinally polarized gauge bosons become large. By imposing the restriction that these couplings remain weak enough so that perturbation theory is applicable implies that the mass of Higgs is less than 1 TeV [1]. While this is not an absolute bound, it is
an indication of the mass scale at which one can no longer speak of an elementary Higgs particle. But non-pertubative calculations using lattice gauge theory [2] that can be used to compute at arbitrary values of the Higgs mass indicate that the mass of Higgs should be less than 750 GeV. If the Higgs mass were small, then the vacuum (ground) state with the correct value of $M_\nu$ could cease to be the true ground state of the theory [3]. A theoretical constraint can then be obtained from the requirement that this is not the case [4]. Since this constraint may be too restrictive, a much more general constraint is given by [5].

There has been an extensive search for the very light Higgs boson with $m_H \leq 5$ GeV. Nuclear physics experiments [6] have ruled out $m_H < 11.5$ MeV. For larger Higgs masses, the only direct experimental limit derives from the beam dump experiment on $eN \to ee^+e^-N$ [7] which excludes $12$ MeV $\leq m_H \leq 50$ MeV. Experiments on $\pi^+ \to e^+ve^-e^-$ [8] ruled out $10$ MeV $< m_H \leq 100$ MeV. Preliminary results [9] on $K_L^0 \to \pi^0 e^+e^-$ excluded $20$ MeV $< m_H \leq 2m_\mu$ with little sensitivity to theoretical uncertainties. $m_H \leq 55$ MeV is excluded by $K^+ \to \pi^+ +$ nothing and $K^+ \to \pi^+ + \gamma\gamma$ limit [10]. For the kaon decay experiment $K^+ \to \pi^+e^+e^-$ [11], the range of $60$ MeV $< m_H \leq 100$ MeV is excluded.

The Z boson is an especially attractive potential source for Higgs boson because the coupling $ZZH$ is not suppressed. The most important decay mode is $Z \to HZ^*$, $Z^* \to \ell^+\ell^-$ where $Z^*$ is a virtual Z. The search for $Z \to H^0\nu\bar{\nu}$ (acoplanar jets) and $Z \to H^0 + (e^+e^-, \mu^+\mu^-)$ (Lepton pairs in hadronic jets) found that
\( m_H > 58.4 \) GeV [12]. There was a search for \( Z \to H^e + (\nu \bar{\nu}, e^- e^-, \mu^+ \mu^-) \) with \( H^e \) decaying hadronically to \( \tau \bar{\tau} \). Two \( e^+ e^- \) and \( \mu^+ \mu^- \) candidates and one \( \mu^+ \mu^- \) candidate are found consistent with expected background result. Their conclusion was that \( m_H > 57.7 \) GeV [13]. The search for \( Z \to H^\ell + (e^+ e^-, \mu^+ \mu^- , \tau^+ \tau^- , \nu \bar{\nu}) \) with \( H^\ell \to q \bar{q} \) found four \( \ell^+ \ell^- \) candidates, consistent with expected background results and came to the conclusion that \( m_H > 55.7 \) GeV [14].

Both \( B \to KH \) and \( K^+ \to \pi^+ H \) are suppressed in the Standard Model. The suppression arises because the Higgs boson couplings are directly proportional to the mass terms. The physical quark states are actually those for which the mass matrix is diagonal. Neither the mass matrix nor the coupling with the Higgs boson can change a \( b \) quark into an \( s \) quark. However, the process \( b \to s H \) can occur through higher order effects. The \( b \) quark can become \( s \) quark by either the \( t \) or the \( W \), following which the \( t \) and \( W \) combine to form the \( s \) quark. The \( K^+ \to \pi^+ H \) proceeds analogously. Willey and Yu [15] and independently Grzadkowski and Krawczyk [16] calculated the process \( b \to s H \) directly diagramatically and found that the result is in contradiction with the early estimate given by Ellis [17] and has been criticised by Pham and Sutherland [18] who questioned whether counter terms introduced in renormalization might change the results. Bottela and Lim [19] subsequently showed explicitly that the contribution due to the counter terms are exactly zero. Work on this Higgs-penguin processes has also been pursued independently by Grinstein [20] and Wiley [21]. In summary, the decays of \( Ks \) and \( Bs \) give no direct evidence of a Higgs boson. Some impressive limits can be set, but not every region can be excluded.
We shall present a systematic study for Higgs-penguin processes in which one of the quarks undergoes a change of flavour accompanied by the emission of a virtual Higgs particle. We shall also investigate the process of a Higgs particle decaying into a quark-antiquark pair. The motivation behind the study of Higgs-penguin processes is the need to investigate the behaviour of the $\bar{s}dH$ vertex functions using the first approximation whereby the mass of Higgs is neglected. We found that our results are in exact agreement with several other authors [15, 16]. We decided to introduce a new renormalization scheme to produce the necessary counter term for the process of $\bar{s}dH$. Soares and Barroso [22] adopted a different approach by using the Ward-Takahashi identity to obtain the necessary counter term. By taking the mass of Higgs into consideration we have the opportunity to shed more light on the CP-Violating behaviour of the Higgs-penguin processes. This is because there exist real and imaginary parts of the form factors if the mass of Higgs is taken into consideration. The imaginary parts will be the main contributing factor for the Higgs-penguin processes to exhibit CP-violation. We decided to perform our calculations in the 't Hooft-Feynman gauge even though we need to calculate extra Feynman diagrams due to the unphysical Higgs which is characteristic of 't Hooft-Feynman gauge. Expression for the $\bar{q}_i q_j H$ vertices have been calculated earlier in different gauges [15-21].

A brief account of the historical development of the theory of weak interaction and the Standard $SU(2) \times U(1)$ Glashow-Weinberg-Salam model is given in Chapter 2. A list of the Feynman rules in the 't Hooft-Feynman gauge for our calculation is also included in Chapter 2. The result of the calculation of the
unrenormalized $\bar{s}dH$ vertex function is given in Chapter 3. We also include the renormalization scheme needed to remove the divergence in the $\bar{s}dH$ vertex function. Finally we present the renormalized $\bar{s}dH$ vertex function when we impose the on-shell conditions. Here we have neglected the masses of the external quarks and the Higgs boson. We shall then present the result of the $\bar{s}dH$ vertex function without neglecting the mass of the Higgs boson. The result of the numerical integration using Romberg method is given in that section. Chapter 4 contains the application of the result of our calculation to various decay processes. We shall investigate the CP-Violating asymmetries in the decays of the Higgs particle to a quark-antiquark pair in Chapter 5. Finally, in Chapter 6, we shall make the necessary conclusions based on the results of our calculation.