Chapter 1

Introduction

Violation of the charge-parity symmetry (CP violation) was first discovered in the neutral kaon system by Cronin and Fitch in 1964 [1]. For an explanation, in 1973, Makoto Kobayashi and Toshihide Maskawa developed a theory, the KM model [2]. There, they conclude that one or more irreducible complex phases remain in the quark-mixing matrix (called Cabbibo-Kobayashi-Maskawa matrix, or CKM matrix) in the weak charged current when six or more quarks exist; and these complex phases violate the CP symmetry in the framework of the Standard Model. The KM model, which was presented at a time when only the u, d and s quarks were known to exist, was remarkable because it required the existence of six quarks. The subsequent discoveries of the c, b and t quarks, and the compatibility of the model with the CP violation observed in the neutral K meson system led to the incorporation of the KM mechanism into the Standard Model.

While the results in the K^0 system are well consistent with the KM model, the complications introduced by the strong interaction effects make it nearly impossible to ascertain whether the complex CKM phase is the sole source of the observed asymmetries. For many years the phenomenon is seen in only K meson. Is something peculiar about this system? Further progress in our understanding of CP violation requires observation of the phenomenon outside the K system. The magnitude and the phase of the CKM matrix are not experimentally well measured. Therefore, it is of great importance for the particle physics to make the measurements that have been done more precisely and also to measure a variety of other parameters in other particle systems in order to further test the current models.

In 1980, Carter, Bigi and Sanda pointed out that the sizable CP violation could be observed in the B meson decays within the framework of the Standard Model [3]. The B meson is a bound state of a $\bar{b}$ quark and a light quark. While the binding is provided by the strong interaction, B^0 mesons can only decay by the weak interaction. Since the top quark mass is large, B mesons are the only attainable mesons containing quarks of the third generation. Independent observations of CP violation in B decays are important tests of the Standard Model.

1.1 The Standard Model

The Standard Model (SM) is a framework to describe the matter consisting of the elementary particles, leptons and quarks, and their interactions, the strong, electromagnetic, and weak forces (gravitation hasn't been included effectively in the theory yet).

The leptons family consists of electrons (e), muons (μ), tau leptons (τ), as well as their associated neutrinos ν_e, ν_μ and ν_τ, which can be classified into three generations as follows,

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}, \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}, \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}.$$

Electrons, muons and tau leptons have the same negative electric charge $-e$, and suffer both electromagnetic and weak interactions; while the neutrinos possess zero electric charge and experience only weak interactions.

The quarks family consists of up (u), down (d), strange (s), charm (c), bottom (b), and top (t), which are classified into three distinct generations as leptons,

$$\begin{pmatrix} u \\ d \end{pmatrix}, \quad \begin{pmatrix} c \\ s \end{pmatrix}, \quad \begin{pmatrix} t \\ b \end{pmatrix}.$$

All quarks have fractional electric charge, $+\frac{2}{3}e$ for u, c, and t, and $-\frac{1}{3}e$ for d, s, and b. Quarks and antiquarks experience strong, electromagnetic, and weak interactions.

Each of the three forces is mediated by one or more carrier particles. For the electromagnetic force, which causes like-charged particles to repel and oppositely-charged particles to attract, the carrier is the photon; for the strong force that holds the quarks together to form hadrons, the carrier is the gluon; for the weak interaction that is responsible for the decay of massive quarks and leptons into lighter ones, the W^+, W^- and Z^0 are the mediators.

1.2 CP Violation

CP symmetry refers to the fact that processes in nature occur precisely in the same manner if all particles were converted to their antimatter counterparts using the CP transformation. To be more explicit, the C (charge conjugation) operation reverses all additive quantum numbers such as electric charge, hypercharge, strangeness, etc., while the P (parity) transformation inverts the coordinate system and the orientation of all objects in it: $x \to -x$, $y \to -y$, $z \to -z$. P reverses the relationship between the intrinsic angular momentum (spin) of a particle and the direction of its velocity; since under a P transformation, the velocity direction is reversed but the spin direction is not. So under a CP transformation, a negative helicity proton becomes a positive helicity antiproton. It was believed for a number of years that CP invariance is valid for all interactions until CP violation (CPV) was found in the weak interaction of the K^0 system.

Mesons K^0 and their charge conjugate $\bar{K}^0$ mesons can decay into the $\pi\pi$ final state. K^0 and $\bar{K}^0$ are particles with negative intrinsic parity,

$$CP|K^0\rangle = -|\bar{K}^0\rangle, \quad CP|\bar{K}^0\rangle = -|K^0\rangle.$$

The following linear combinations of $|K^0\rangle$ and $|\bar{K}^0\rangle$ are two independent CP eigenstates.

$$|K_1\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle + |\bar{K}^0\rangle), \quad CP = -1, \tag{1.1}$$

$$|K_2\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle - |\bar{K}^0\rangle), \quad CP = 1. \tag{1.2}$$

Since the $\pi\pi$ state has the CP eigenvalue of $+1$, it is only the K_2 state that can decay to $\pi\pi$ if the CP symmetry is strictly conserved,

$$K_2 \to \pi\pi,$$

$$K_1 \not\to \pi\pi.$$

Due to the phase space difference, the lifetime for the CP odd state K_1 is expected to be much longer than that for the CP even K_2. Thus, it is customary to refer them as K_L and K_S respectively. The measurements for their lifetime are $\tau(K_L) = 5.15 \times 10^{-8}\,\text{s}$ and $\tau(K_S) = 0.89 \times 10^{-10}\,\text{s}$.

However in 1964, Christenson, Cronin, Fitch and Turlay discovered that [1],

$$\mathcal{B}(K_L^0 \to \pi^+\pi^-) = (2.0 \pm 0.4) \times 10^{-3}.$$

This unexpected and important result means that the $|K_L^0\rangle$ is not a pure CP eigenstate, instead, the K_L state contains a small admixture of a CP even component in addition to its dominant CP odd part,

$$|K_L\rangle = \frac{1}{\sqrt{1 + |\bar{\epsilon}|^2}}(|K_1\rangle + \bar{\epsilon}|K_2\rangle). \tag{1.3}$$

With CPT invariance, the K_S state in turn contains a CP odd component,

$$|K_S\rangle = \frac{1}{\sqrt{1+|\bar{\epsilon}|^2}}(|K_2\rangle + \bar{\epsilon}|K_1\rangle), \tag{1.4}$$

where ϵ is the complex impurity parameter.

1.3 The KM Model

In 1973, Kobayashi and Maskawa proposed that CP violation in the K^0 system can be explained within the Standard Model only if there are at least six quark flavors [2], twice the number of quark flavors known at that time. The source of the CP violation is the complex phases of the unitary matrix V that represents the quark mixing.

In this model, the weak eigenstates are considered as linear combinations of the mass eigenstates. The mass eigenstates of quarks are denoted by d, s, b; the weak eigenstates of quarks are denoted by d', s' and b'. The relation between weak eigenstates and mass eigenstates is expressed via a 3×3 complex unitary matrix V, which is called the Cabbibo-Kobayashi-Maskawa (CKM) matrix,

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V \begin{pmatrix} d \\ s \\ b \end{pmatrix}, \quad V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}, \quad VV^\dagger = 1,$$

where the elements V_{ij} represent the coupling constant of the weak current of quark i and j.

A general $n \times n$ complex matrix contains $2n^2$ real parameters. Unitarity implies $\sum_j V_{ij}V^*_{jk} = \delta_{ik}$, yielding n constraints for $i = k$ and $n^2 - n$ for $i \neq k$. Since the overall phase is irrelevant, the phases of the quark fields can be rotated freely, $2n-1$ relative phases can be removed from V. A general orthogonal $n \times n$ matrix is constructed from $\frac{1}{2}n(n-1)$ quantities describing the independent angles. Therefore the number of parameters remaining for the irremovable complex phases in V is $N_{phases} = \frac{1}{2}(n-1)(n-2)$. To produce an irreducible phase, at least 3 generations are needed [4].

The charged weak interactions can be written as the space-integral of the Lagrangian density [5]

$$L_{int}(t) = \int d^3x \left(\mathcal{L}_{qW}(x) + \mathcal{L}^\dagger_{qW}(x)\right), \tag{1.5}$$

where the Lagrangian density $\mathcal{L}_{qW}(x)$, is given by

$$\mathcal{L}_{qW}(x) = \frac{g}{\sqrt{8}} \sum_{i,j=1,3} V_{ij}\bar{U}_i(x)\gamma_\mu(1-\gamma_5)D_j(x)W_\mu(x), \tag{1.6}$$

$$\mathcal{L}^{\dagger}_{qW}(x) = \frac{g}{\sqrt{8}} \sum_{i,j=1,3} V^*_{ij} \left(\bar{U}_i(x)\gamma_\mu(1-\gamma_5) D_j(x) W_\mu(x)\right)^{\dagger}, \tag{1.7}$$

where U_i and D_i are the up-type and down-type quark fields,

$$U_i(x) \equiv \begin{pmatrix} u(x) \\ c(x) \\ t(x) \end{pmatrix}, \quad D_j(x) \equiv \begin{pmatrix} d(x) \\ s(x) \\ b(x) \end{pmatrix}.$$

Since the CP transformation exchanges particle q and its antiparticle $\bar{q}$, flips momentum p, and keeps the spin unchanged,

$$(CP)\bar{U}_i(CP)^{\dagger} = e^{-i\theta_{U_i}} U_i,$$
$$(CP)D_i(CP)^{\dagger} = e^{i\theta_{D_i}} \bar{D}_i,$$

where θ_{U_i} and θ_{D_i} are arbitrary phases.

A CP transformation on the Lagrangian density ($\mathcal{L}$) gives (by setting the irrelevant phase of W, η_W, to be unity)

$$(CP)\mathcal{L}_{qW}(CP)^{\dagger} = \frac{g}{\sqrt{8}} \sum_{i,j=1,3} e^{-i\theta_{U_i}} e^{i\theta_{D_i}} V_{ij} \left(\bar{U}_i(x)\gamma_\mu(1-\gamma_5) D_j(x) W_\mu(x)\right)^{\dagger}. \tag{1.8}$$

Thus if one can choose the phase such that

$$e^{i(\theta_{D_i}-\theta_{U_i})} V_{ij} = V^*_{ij},$$

then we have $(CP)\mathcal{L}_{qW}(CP)^{\dagger} = \mathcal{L}^{\dagger}_{qW}$, and the two terms in Equation 1.5 swaps keeping the interaction Lagrangian invariant under CP transformation. The condition above is equivalent to being able to rotate quark phases to make all V_{ij} real. Therefore, the irremovable phase in the CKM matrix allows possible CP violation.

The nontrivial phases are typically assigned to the furthest off-diagonal elements V_{ub} and V_{td}. The strengths of the couplings decrease as one moves from the diagonal. A popular approximation is the Wolfenstein parameterization [6]

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix} + \mathcal{O}(\lambda^4),$$

where A, ρ and η are real numbers with order of unity, λ is set using the Cabbibo angle (θ_c) as

$$\lambda = \sin\theta_c \approx 0.22.$$

The λ and A are relatively well determined from the measurements of the K decay for the $|V_{us}|$, and the $b \to cl\nu$ decays for the $|V_{cb}|$ respectively, while the other two parameters are less known.

A geometric representation can greatly facilitate an intuitive understanding. The unitarity of the CKM matrix leads to the following relations,

$$\sum_{i=1}^{i=3} V_{ij}V_{ik}^* = 0 = \sum_{i=1}^{i=3} V_{ji}V_{ki}^*; \quad j,k = 1,2,3, \quad j \neq k,$$

so that,

$$V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0 \tag{1.9}$$

$$V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^* = 0 \tag{1.10}$$

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0 \tag{1.11}$$

$$V_{cd}V_{td}^* + V_{cs}V_{ts}^* + V_{cb}V_{tb}^* = 0 \tag{1.12}$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \tag{1.13}$$

$$V_{ud}V_{td}^* + V_{us}V_{ts}^* + V_{ub}V_{tb}^* = 0. \tag{1.14}$$

Since each term in the above equations is complex, in a complex plane each equation can form a closed triangle, characterized through their dependence on λ. Figures. 1.1 (a) to (f) show the triangles constructed from Equations 1.9 to 1.14. A size of the triangle side is the magnitude of product of the CKM-matrix elements that can be measured as decay rate. An angle corresponds to a complex phase that can cause asymmetry of the amplitudes between quark and anti-quark transitions. Thus, a measurement of a non-zero angle is equivalent to the observation of the CP violation.

Figure 1.1 (a) and (b) show the triangle related to the strange and charm decays. The triangle is extremely squashed, since two sides are order of $\mathcal{O}(\lambda)$ and one side is order of $\mathcal{O}(\lambda^5)$. There the effective weak phases are obviously tiny. Figures 1.1 (c) and (d) have two sides with order of $\mathcal{O}(\lambda^2)$, and one side with order $\mathcal{O}(\lambda^4)$. Figures 1.1 (e) and (f) show the angles are equally large, and the sizes of all sides are the same order of $\mathcal{O}(\lambda^3)$. The triangle in (e) relates to B meson decays; that in (f) relates to the top quark decays.

Thus, although CP violation is small in the kaon system, it can be large in systems containing b quarks.

Further, if dividing both sides of Equation 1.13 by the middle term, we obtain

$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + 1 + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0.$$

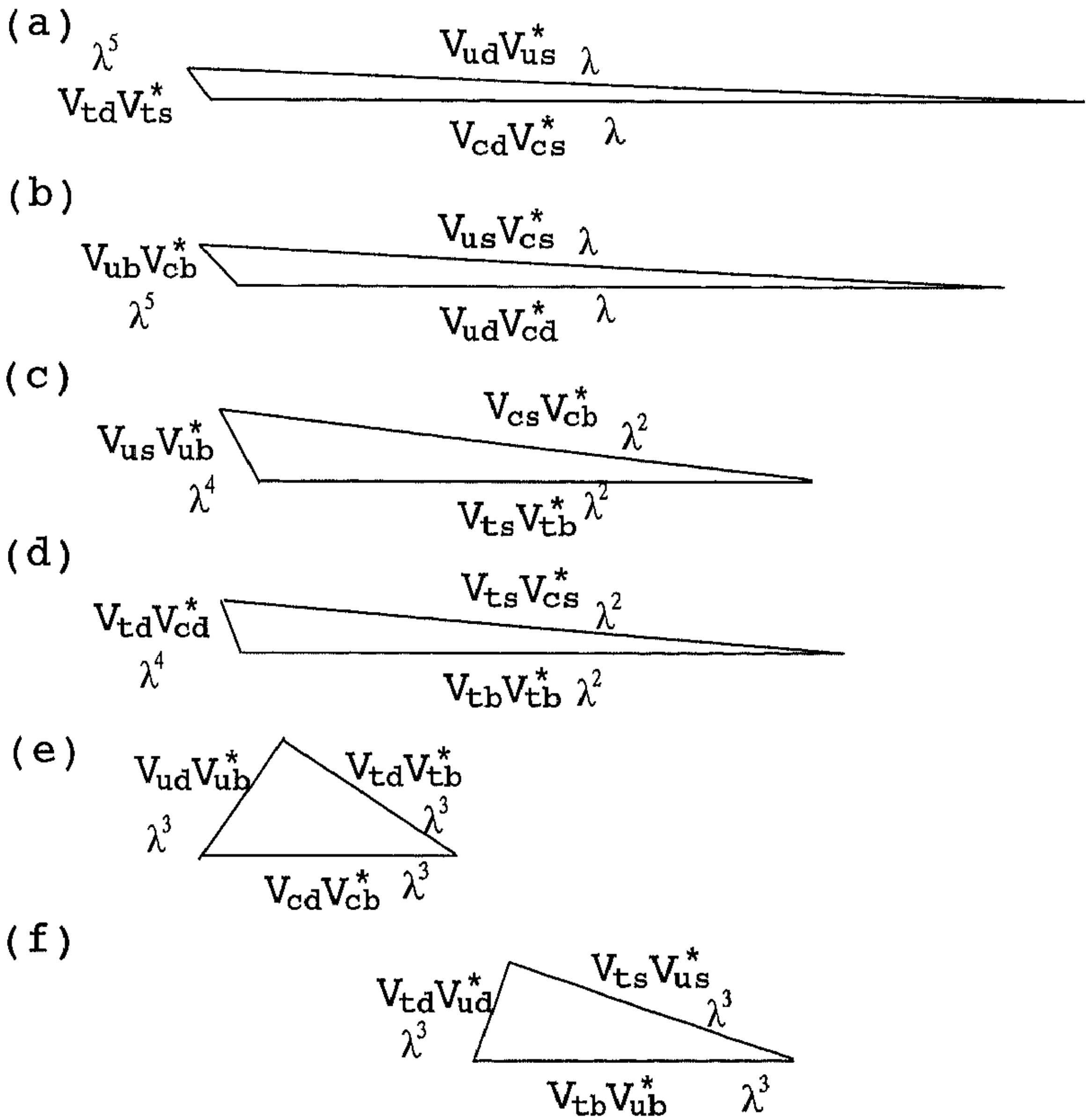

Figure 1.1: Triangles constructed by Equations 1.9 to 1.14. (a) corresponding to CP violation in K decays. (e) relates to the B decays.

Figure 1.2 shows the corresponding unitarity triangle, with a single point in the plane specified by the coordinates $(\tilde{\rho}, \tilde{\eta})$,

$$\tilde{\rho} \equiv (1 - \frac{\lambda^2}{2})\rho, \quad \tilde{\eta} \equiv (1 - \frac{\lambda^2}{2})\eta.$$

The three angles ϕ_1, ϕ_2, and ϕ_3 are also known as β, α, and γ, respectively. They are

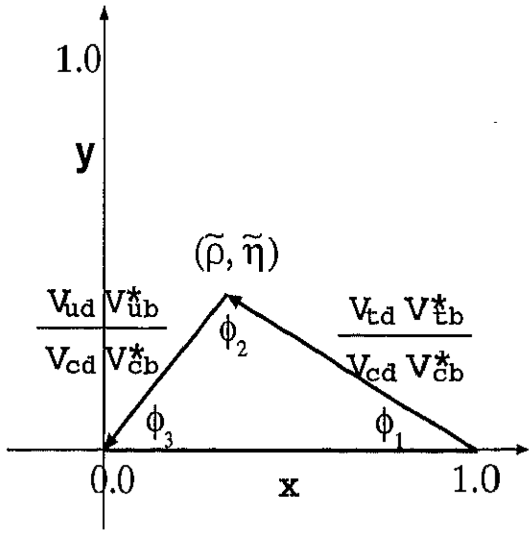

Figure 1.2: The unitarity triangle

defined as [7]

$$\phi_1 = \pi - arg\left(\frac{-V_{tb}^* V_{td}}{-V_{cb}^* V_{cd}}\right), \quad \phi_2 \equiv arg\left(\frac{V_{tb}^* V_{td}}{-V_{ub}^* V_{ud}}\right), \quad \phi_3 \equiv arg\left(\frac{V_{ub}^* V_{ud}}{-V_{cb}^* V_{cd}}\right) \qquad (1.15)$$

1.4 Direct CP Violation in Charmless VV Decays

A significant CP-violating asymmetry in decays of neutral B mesons to final states containing charmonium, has been observed by BaBar [8] and Belle [9] as measurements of non-zero ϕ_1 angle. In this case, the asymmetry is due to the presence of the complex phase V_{td} in the $B^0 - \bar{B}^0$ mixing, and it is called indirect CP violation. CP violation can also occur in the decay process, which is called direct CP violation (DCPV) [10]. Charmless B decay is an ideal field to search for DCPV phenomena because of the possible involvement of penguin (P) and tree (T) amplitude of comparable magnitude.

Two-body charmless B decays where the final state consists of two pseudoscalar mesons (PP) or a pseudoscalar meson and a vector meson (PV) have been studied in detail [11], while the measurement on charmless vector-vector (VV) decays is rather limited, only the $B \to \phi K^*$ decay channels have been previously observed [12]. In this dissertation, we will discuss the charmless vector-vector decay $B^+ \to \rho^+\rho^0$. Since charged B meson cannot mix, a measurement of a CP violating observable in the decay would be a clear sign for direct CP violation, which arises when amplitude for a decay and its CP conjugate process have different magnitudes.

The most straightforward DCPV observable is the rate asymmetry [13, 14] between a decay channel and its charge conjugate channel. One may also search for DCPV in other observables even there is no rate asymmetry. For $B \to VV$ decays, the azimuthal angular correlation [15] is such an example. In the following sections, we give a detailed discussion on the partial rate asymmetries, and discuss the angular correlation of the $B \to VV$ mode briefly.

1.4.1 Partial Rate Asymmetries

The rate asymmetries occur even for spinless final state and require both weak and strong phase differences in interfering amplitude. The rate asymmetries can be expressed as

$$\frac{|\bar{A}_{\bar{f}}|}{|A_f|} \neq 1,$$

where

$$A_f \equiv \langle f|B\rangle, \quad \bar{A}_{\bar{f}} \equiv \langle \bar{f}|\bar{B}\rangle.$$

For any final state f, the quantity $\bar{A}_{\bar{f}}/A_f$ is independent of phase conventions.

There are two types of phases that may appear in $\bar{A}_{\bar{f}}$ and A_f: CP violating weak phase and CP conserving strong phase.

Complex parameters in any Lagrangian term that contributes to amplitude will appear in complex conjugate form in the CP conjugate amplitude. Thus their phases appear in $\bar{A}_{\bar{f}}$ and A_f with opposite signs. In the SM, these phases occur only in the CKM matrix, called weak phases. The weak phase of any single term is convention dependent. However, the difference between the weak phases in two different terms is convention independent; the initial and final states are the same for every term, and thus any phase rotation of the fields that appear in these states will affect all terms in the same way.

The second type of phase can appear in scattering or decay amplitudes even when the Lagrangian is real. Such phases do not violate CP, since they appear in A_f and $\bar{A}_{\bar{f}}$ with the same signs. Their origin is the possible contribution from intermediate on-shell states in the decay process, that is an absorptive part of an amplitude that has contributions from coupled channels. Usually the dominant rescattering is due to strong interactions, hence called "strong phases". Only the relative strong phases of different terms in a scattering amplitude have physical content, and overall phase rotation of the entire amplitude has no physical consequences.

If several amplitudes contribute to $B \to f$, the amplitude A_f and the CP conjugate amplitude $\bar{A}_{\bar{f}}$ are given by

$$A_f = \sum_i |A_i| e^{i\delta_i + \phi_i}, \quad \bar{A}_{\bar{f}} = \sum_i |A_i| e^{i\delta_i - \phi_i},$$

where $|A_i|$ is magnitude, $e^{i\phi_i}$ denotes weak phase, and $e^{i\delta_i}$ denotes strong phase. The convention-independent quantity is then,

$$\left| \frac{\bar{A}_{\bar{f}}}{A_f} \right| = \left| \frac{\sum\limits_i |A_i| e^{i\delta_i - \phi_i}}{\sum\limits_i |A_i| e^{i\delta_i + \phi_i}} \right|.$$

When CP is conserved, the weak phases ϕ_i are all equal. Therefore, one sees that

$$|\bar{A}_{\bar{f}}/A_f| \neq 1 \Longrightarrow \text{CP violation}.$$

If there is only one mechanism involved, the weak phases do not appear in decay amplitude, then we can not determine information about the complex phase. Suppose, there are two mechanisms involved in the decay, then the decay amplitudes A_f and $\bar{A}_{\bar{f}}$ are:

$$|A_f|^2 = |A_1|^2 + |A_2|^2 + 2|A_1||A_2| \cos(\Delta\delta + \Delta\phi),$$

$$|\bar{A}_{\bar{f}}|^2 = |A_1|^2 + |A_2|^2 + 2|A_1||A_2| \cos(\Delta\delta - \Delta\phi),$$

where $\Delta\delta = \delta_1 - \delta_2$, $\Delta\phi = \phi_1 - \phi_2$. Then

$$|\bar{A}_{\bar{f}}|^2 - |A_f|^2 = 4|A_1||A_2| \sin(\Delta\delta) \sin(\Delta\phi).$$

Therefore, a complex phase in the CKM matrix can lead to a difference in the interference terms of CP conjugate decays; it is needed that the two amplitudes must have different weak phases and different strong phases. We define the partial rate asymmetry as,

$$\mathcal{A}_{CP} = \frac{|\bar{A}_{\bar{f}}|^2 - |A_f|^2}{|\bar{A}_{\bar{f}}|^2 + |A_f|^2} = \frac{2|A_1||A_2| \sin(\Delta\delta) \sin(\Delta\phi)}{|A_1|^2 + |A_2|^2 + 2|A_1||A_2| \cos(\Delta\delta) \cos(\Delta\phi)}.$$

In addition, if one amplitude dominates, $|A_1| \gg |A_2|$, then

$$\mathcal{A}_{CP} \approx 2\frac{|A_2|}{|A_1|} \sin(\Delta\delta) \sin(\Delta\phi) \ll 1,$$

showing the need for the two amplitudes of comparable strength.

Therefore, an observable partial rate asymmetry requires (1) more than one mechanisms (2) having different weak phases (3) and different strong phases (4)and comparable strength.

1.4.2 Azimuthal Angular Correlations

In addition to possible partial-rate asymmetries, CP violation may be accessed in charmless $B \to VV$ decays via azimuthal angular correlations between the two vector particles. The advantage of this method is that the CP violating terms occur even when there are no strong phase difference between the interfering weak amplitudes. On the other hand, these coefficients in the azimuthal correlation can be non-zero even in the absence of the CP violation. By measuring these coefficients in charge conjugate $B^{\pm}$ decays one has the possibility to disentangle the effects of strong and weak phase. This feature makes $B \to VV$ decays especially interesting. A detailed description is given in Appendix A.

1.5 $B \to \rho\rho$ Decay

For the vector-vector decay $B \to \rho\rho$ mode, there are three possible decay channels, $B^0 \to \rho^0\rho^0$, $B^+ \to \rho^+\rho^0$ and $B^0 \to \rho^+\rho^-$, all of which are expected to have small branching fractions. The branching fraction for $B^+ \to \rho^0\rho^+$ is predicted to be $\mathcal{O}(10^{-5})$ [15, 16].

Because the $\rho^+\rho^0$ final state must have total isospin $I = 2$, gluonic penguin processes that change isospin by $\Delta I = 1/2$ are prohibited unless the isospin symmetries are violated. Thus, in the SM, the amplitude of the $B^+ \to \rho^+\rho^0$ decay only has a tree and an electroweak penguin (EWP) contribution. Figure 1.3 shows the tree and EWP diagrams for $B^+ \to \rho^+\rho^0$, and Fig. 1.4 shows the prohibited gluonic penguin diagrams. Since the relative weak phase between tree and EWP terms is ϕ_2, the second internal angle of the unitary triangle, a significant EWP could result in an observable direct CP violation [17, 18]. If the presence of gluonic penguin through the isospin breaking is significant, it also can result in an observable direct CP violation. Therefore, observation of non-zero CP asymmetry in $B^{\mp} \to \rho^{\mp}\rho^0$ will be an indication that either a significant EWP is present or an isospin breaking gluonic penguin is present in the decay. In either case, this opens a new and exciting window of new physics. Moreover, in most isospin studies, the assumption that EWPs do not play a large role is required, since the EWPs have the isospin properties of the tree but the weak phase of the penguin so it cannot be cleanly separated from the tree without additional information. The level of its influence can be specifically checked in the decay $B^{\pm} \to \rho^{\pm}\rho^{0}$.

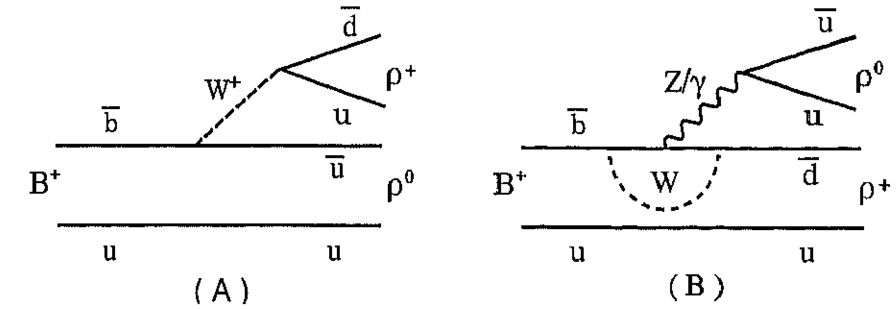

Figure 1.3: The tree (A) and EWP (B) diagrams

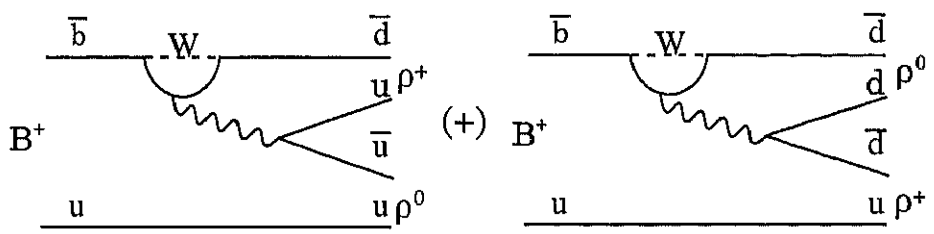

Figure 1.4: The prohibited gluonic penguin diagrams.

This dissertation is organized as follows. In chapter 2, we describe the experimental apparatus, including the KEKB accelerator and the Belle detector. In chapter 3, we discuss the reconstruction of candidate $B^{+} \to \rho^{+}\rho^{0}$ decays and signal extraction. An analysis of helicity-angle distribution is described in chapter 4. A partial rate asymmetry is discussed in chapter 5. At last, in chapter 6, we summarize the results and make a further discussion.