HEPP-CPV-project

John Ronayne (), Kevin Maguire (10318135), Sinead Hales(), Dudley Grant (10275291)
(Dated: November 14, 2013)

I. INTRODUCTION

Short intro here

II. $\hat{P}$, $\hat{C}$ AND $\hat{C}\hat{P}\hat{T}$

III. CP VIOLATION

CP violation was first observed in the mixing of neutral K-mesons by Christenson, Cronin, Fitch and Turlay in 1964 [1]. They observed the $\hat{C}\hat{P} = -1$ state K_L^0 decaying to 2 pions, a state with $\hat{C}\hat{P} = 1$. Although the fraction of K_L^0 decays violating $\hat{C}\hat{P}$ in this way is tiny, the discovery was significant.

IV. $\hat{C}\hat{P}$V IN KAON SYSTEM

A. Neutral Kaon Mixing

As mentioned $\hat{C}\hat{P}$V was first observed in the neutral kaon system. Direct and indirect $\hat{C}\hat{P}$V have been observed but it is found that the process is entirely dominated by the indirect method [Zeng, need better reference]. Essential to these mechanisms is the mixin g between the neutral Kaon and its anti-particle, corresponding to the states $|K^0\rangle$ and $|\bar{K}^0\rangle$. These have quark compositions of $d\bar{s}$ and $s\bar{d}$, respectively.

In interactions involving the strong or EM force, the quantum number strangeness, which tells us the number of strange quarks in a particle, must be conserved. For the weak force it is found that, like parity, this symmetry is not conserved. Due to this many processes forbidden for the strong and EM interactions are allowed through the weak force. This violation is what makes mixing possible. Mixing is the decay of a particle into its anti-particle and can only take place when a particle is its own anti-particle, or if the particles differ by a quantum number which is not conserved by some interaction. This is the case in neutral Kaon mixing, also know as Kaon oscillations. The neutral Kaon and its anti-particle have opposite strangeness but can decay into each other through the strangeness violating weak force. See Fig.(add in feynman digram of M+S pg 289)

Analogous to the mixing of mass eigenstate quarks to different quark flavours, it is found that the neutral Kaon flavour eigenstates do not correspond to eigenstates of the $\hat{C}\hat{P}$ operator. To show this we first operate on the Kaon states with the $\hat{C}$ operator. We first assume that there is no $\hat{C}\hat{P}$V, then neglecting phase throughout we obtain:

$$
\begin{aligned}
\hat{C}\,|K^0(d\bar{s})\rangle &= (1)(-1)\,|\bar{K}^0(s\bar{d})\rangle = -\,|\bar{K}^0(s\bar{d})\rangle \\
\hat{C}\,|\bar{K}^0(s\bar{d})\rangle &= (1)(-1)\,|K^0(d\bar{s})\rangle = -\,|K^0(d\bar{s})\rangle
\end{aligned}
$$

Where we have used the convention that $\hat{C}(q) = 1$ and $\hat{C}(\bar{q}) = -1$. Also, the action of the $\hat{P}$ is given by:

$$
\begin{aligned}
\hat{P}\,|K^0(d\bar{s})\rangle &= \hat{P}(d)\hat{P}(\bar{s})(-1)^l\,|K^0(d\bar{s})\rangle = (1)(-1)(-1)^0\,|K^0(d\bar{s})\rangle = -\,|K^0(d\bar{s})\rangle \\
\hat{P}\,|\bar{K}^0(s\bar{d})\rangle &= \hat{P}(s)\hat{P}(\bar{d})(-1)^l\,|\bar{K}^0(s\bar{d})\rangle = (1)(-1)(-1)^0\,|\bar{K}^0(s\bar{d})\rangle = -\,|\bar{K}^0(s\bar{d})\rangle
\end{aligned}
$$

Where we have used the convention $\hat{P}(fermion) = 1$ and $\hat{P}(anti-fermion) = -1$ as well as $l = 0$ because the Kaon is the lowest energy combination of these quarks and itself has a J^P pf 0^-. Now we are in a position to determine the eigenstates of $\hat{C}\hat{P}$:

$$\hat{C}\hat{P}\,|K^0\rangle = |\bar{K}^0\rangle$$
$$\hat{C}\hat{P}\,|\bar{K}^0\rangle = |K^0\rangle$$

So we can see that any eigenfunction of the $\hat{C}\hat{P}$ operator will be a linear combination of the two Kaon states:

$$|K_1^0\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle + |\bar{K}^0\rangle) \tag{1}$$
$$|K_2^0\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle - |\bar{K}^0\rangle) \tag{2}$$

Where 1 and 2 are the usual labels given to these states. Now we investigate the action of $\hat{C}\hat{P}$ on these linear combinations

$$\hat{C}\hat{P}\,|K_1^0\rangle = \frac{1}{2}(\hat{C}\hat{P}\,|K^0\rangle + \hat{C}\hat{P}\,|\bar{K}^0\rangle) = \frac{1}{2}(|\bar{K}^0\rangle + |K^0\rangle) = |K_1^0\rangle$$
$$\hat{C}\hat{P}\,|K_2^0\rangle = \frac{1}{2}(\hat{C}\hat{P}\,|K^0\rangle - \hat{C}\hat{P}\,|\bar{K}^0\rangle) = \frac{1}{2}(|\bar{K}^0\rangle - |K^0\rangle) = -\,|K_2^0\rangle$$

In experiment, two Kaon states are observed, a short lived state denoted by $|K_S^0\rangle$ and a relatively long lived state, $|K_L^0\rangle$. The lifetimes of these particles are $8.954 \pm 0.004 \times 10^{11}$ s and $5.116 \pm 0.021 \times 10^{8}$ s [2]. We make the natural assumption that these are the $\hat{C}\hat{P}$ eigenstates just derived. We make the identifications $|K_S^0\rangle = |K_1^0\rangle$ and $|K_L^0\rangle = |K_2^0\rangle$ and see what this predicts. If $\hat{C}\hat{P}$ is conserved then all the decays of the $|K_S^0\rangle$ $(CP = 1)$ state must be to final products with $CP = 1$, and similarly, the decays of $|K_L^0\rangle$ $(CP = -1)$ must be to final products with $CP = -1$. The observed decays for these states are as follows [3, pg. 292]:

$$K_S^0 \to \pi^0\pi^0(B = 0.31), \quad K_S^0 \to \pi^+\pi^-(B = 0.69)$$
$$K_L^0 \to \pi^0\pi^0\pi^0(B = 0.20), \quad K_L^0 \to \pi^+\pi^-\pi^0(B = 0.13)$$

The reason for the difference in lifetimes of these two Kaon states is that the mass of the K_L^0 is not much bigger than the mass of three pions, thus it is relatively unlikey for it to undergo decay, compared to the K_S^0 which must only create energy to make two pions. We now determine the CP of these final states. This is easy for the two pion final states. We find:

$$P(\pi^0\pi^0) = (-1)(-1)(-1)^{l=0} = +1 \qquad \Rightarrow P = 1 \tag{3}$$
$$C(\pi^0\pi^0) = 1 \qquad \Rightarrow C = 1 \tag{4}$$
$$P(\pi^+\pi^-) = (-1)(-1)(-1)^{l=0} = +1 \qquad \Rightarrow P = 1 \tag{5}$$
$$C(\pi^+\pi^-) = (-1)^{l=0} \qquad \Rightarrow C = 1 \tag{6}$$

Thus $\hat{C}\hat{P}\,|\pi\pi\rangle = 1$. Now for the three pion final state we must take account of the second orbital angular momentum introduced by the third pion. The general formula for such a system is $\hat{P}(ABC) = \hat{P}(A)\hat{P}(B)\hat{P}(C)(-1)^{\mathbf{L}_{AB}}(-1)^{\mathbf{L}_{(AB)C}}$ where $\mathbf{L}_{AB}$ is the orbital angular momentum of the first two pions and $\mathbf{L}_{(AB)C}$ is the orbital angular momentum of the third pion with respect to the mutual centre of mass of the first two pions. The J^P of the Kaon is 0^-, thus the overall orbital angular momentum must be zero: $\mathbf{L} = \mathbf{L}_{AB} + \mathbf{L}_{(AB)C} = 0$. As this is angular momentum addition and $\mathbf{L}$ can only take positive values, we conclude that $L_{AB} = L_{(AB)C}$ so $L_{AB} + L_{(AB)C} = 2L$, which is an even number:

$$P(\pi^0\pi^0\pi^0) = (-1)(-1)(-1)(-1)^{2L=even} = -1 \qquad \Rightarrow P = -1$$
$$C(\pi^0\pi^0\pi^0) = (1)(1)(1) = 1 \qquad \Rightarrow C = +1$$
$$CP(\pi^0\pi^0\pi^0) = -\,1$$

For the $|\pi^+\pi^-\pi^0\rangle$ final state the parity is also -1, but the charge conjugation picks up an extra factor of $(-1)^l$ as in Eqn.(6). So if we take the centre of mass of pions A and B to be the centre of mass between the π^+ and π^- we obtain:

$$\begin{aligned} C(\pi^+\pi^-\pi^0) =& C(\pi^0)(-1)^{L_{AB}} = 1 \qquad\qquad \Rightarrow C = +1 \\ CP(\pi^0\pi^0\pi^0) =& -1 \end{aligned}$$

Where $L_{AB} = 0$ is an experimentally determined quantity [Verify: "Measurement of the $1H(\gamma, \pi^0)$ cross section near threshold. II. Pion angular distributions" - J. C. Bergstrom, R. Igarashi, and J. M. Vogt , Phys. Rev. C 55, 20162023 (1997)]. Thus as long as K^0_L deacy to final states with three pions or other $CP = -1$ states and K^0_S only decay to two pion final states or other $CP = 1$ states, then CP is conserved.

This was thought to be the case until in 1964 when Christenson et al discovered the decay mode $K^0_L(CP = -1) \rightarrow \pi^+\pi^-(CP = 1)$ with a branching ratio of $(2.3 \pm 0.3) \times 10^{-3}$, thus discovering CP violation for the first time [1]. The experiment exploits the difference in lifetimes between K^0_S and K^0_L. A 30GeV proton beam is incident on a metal target which creates a secondary beam of many different particles. The centre of mass energy for such an arrangement is 787 MeV, which is more than enough energy to produce a neutral Kaon having about a 497 MeV rest mass. The secondary beam is passed through a magnetic field to remove any charged particles and through a 4 cm thick block of lead to remove photons. At this point the beam contains both K^0_S and K^0_L. The detecting aparatus is placed 18 m away from the metal target, so by the time the beam reaches it, all of the K^0_S have decayed and only K^0_L remain. The beam is further collimated and then undergoes collisions in a helium filled bag. Two arms containing a series of detectors are mounted symmetrically around the helium bag, so they both make the same angle with the horizontal. These arms consist of a spark chamber and magnet to determine the momentum and direction of an incident particle. Water Cherenkov and scintillation detectos act as a trigger by only recording events with two oppositely charged particles and a velocity of 0.75 c to eliminate background, see Fig.(1). The aim of the experiment is to measure the angular distribution of produced particles. The results of the experiment are shown in Fig.(2) where N is the number of counts and θ is the angle between the net momentum of the detected particles and the initial beam direction. These measurements were taken in various mass ranges, two are shown. If $K^0_L \rightarrow \pi^+\pi^-$ is observed, the detected particles will have opposite signs, their invariant mass will match that of $K^0_L(497)$ and their net momentum will be in the same direction as the incident beam, hence the measured angle will be zero. We see from the results that a peak occurs at an angle of 0° in the correct mass range. This is clear evidence of the CP violating decay $K^0_L \rightarrow \pi^+\pi^-$.

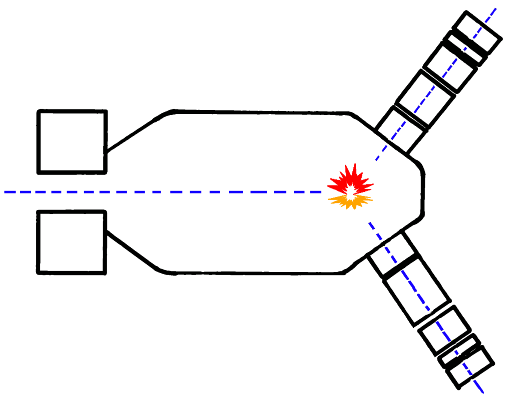

FIG. 1: *Apparatus used in the Christenson et al experiment [4]*

The results of the Christensen et al experiment implies, that the weak eigenstates $|K^0_S\rangle$ and $|K^0_L\rangle$ are not aligned with the true CP eigenstates $|K^0_1\rangle$ and $|K^0_2\rangle$. As in Eqn.(**??**) we write:

$$|K^0_S\rangle = a\,|K^0_1\rangle + b\,|K^0_2\rangle \tag{7}$$

$$|K^0_L\rangle = a\,|K^0_1\rangle - b\,|K^0_2\rangle \tag{8}$$

Where a and b are complex numbers. We can determine the degree to which the states are not aligned using the CP violation decay amplitudes and corresponding CP conserving amplitudes [5]:

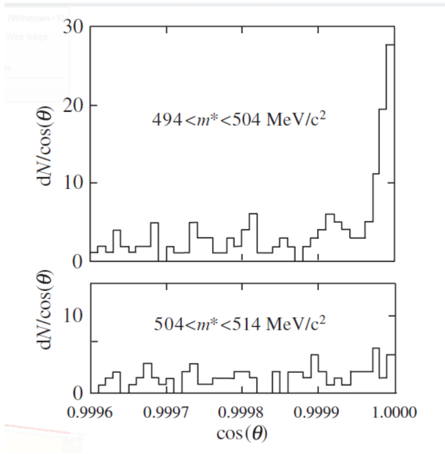

FIG. 2: *Results of the Christenson et al experiment [1]*

$$\eta_{+-} := \frac{A(K_L^0 \to \pi^+\pi^-)}{A(K_S^0 \to \pi^+\pi^-)} = \epsilon + \epsilon'$$
$$\eta_{00} := \frac{A(K_L^0 \to \pi^0\pi^0)}{A(K_S^0 \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

The two complex parameters ϵ and ϵ' determine the amount of indirect and direct CPV, respectively. The indirect CPV is due to the CP conserving decay of the $K_1^0(CP = 1)$ component of the $K_L^0(CP = -1)$ to $CP = 1$ final states, this is possible because of Kaon oscillations. The direct CPV is due to the CP violating decay of the $K_2^0(CP = -1)$ component of the $K_L^0(CP = -1)$ to $CP = 1$ final states, this is possible due to interference between different decay methods with the same final state, as in Fig.(3).

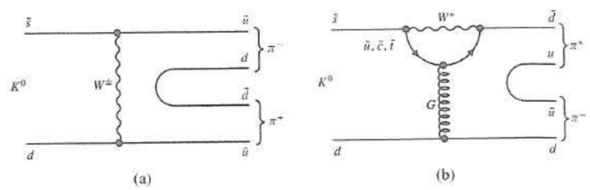

FIG. 3: *Two possible decay modes for $K^0 \to \pi^+\pi^-$. (a) Tree diagram for decay by exchanging W boson (b) Penguin diagram for decay via quark states [6]*

However it is found that the direct CPV contribution is much smaller in this case. The indirect CPV almost completely dominates as can be seen from the similarity of the experimental values for $|\eta_{+-}|$ and $|\eta_{00}|$ [2]:

$$|\eta_{00}| = 0.002220 \pm 0.000011 \qquad |\eta_{+-}| = 0.002232 \pm 0.000011$$

If these values were significantly different it would suggest the amount of direct CPV would be comparable to the amount of indirect CPV, this of course is not the case. An experimentally determined value which illustrates this is the real part of the ratio of ϵ' to *epsilon* [2]:

$$\mathbb{R}(\frac{\epsilon'}{\epsilon}) = \big(1 - |\frac{\eta_{00}}{\eta_{+-}}|\big)/3 = 0.00166 \pm 0.00023$$

We can also determine $|\epsilon|$ using:

$$|\epsilon| = (2|\eta_{+-}| + |\eta_{00}|)/3 = 0.002228 \pm 0.000011$$

If we ignore the direct CPV contributions we can write Eqn.(7) and (8) in terms of ϵ:

$$|K_L^0\rangle = \frac{1}{(1+|\epsilon|^2)^{1/2}}\left[\epsilon\,|K_1^0\rangle + |K_2^0\rangle\right. \tag{9}$$

$$|K_S^0\rangle = \frac{1}{(1+|\epsilon|^2)^{1/2}}\left[\,|K_1^0\rangle - \epsilon\,|K_2^0\rangle\right. \tag{10}$$

Thus we have a linear combination which shows the non-zero amplitude for a state with definite CP to osciallate and decay into final states with the opposite CP.

B. Semi-leptonic decays

Decays of neutral Kaons to products containing leptons can be used to verify Eqn.(9) and (10) as well as finding the asymmetry in the Kaon oscillation $K^0 \leftrightarrow \bar{K}^0$. First we must discuss the selection rules that play an important role in these decays.

The $\Delta S = \Delta Q$ selection rule is an empirical rule backed up by some theoretical approximations. This rules states that in decays involving strangeness(S) and leptons, the change in the charge(Q) of the hadrons must be the same as the change in strangeness which must have a value of ± 1. We first look at semi-leptonic decays of the charged Σ baryon. Two semi-leptonic decays of this baryon are:

$$\Sigma^-(dds) \rightarrow n(udd) + e^- + \bar{\nu}_e \tag{11}$$

$$\Sigma^+(uus) \rightarrow n(udd) + e^+ + \nu_e \tag{12}$$

The feynmann diagram for decay (11) can be drawn as in Fig.(pg232 M+S[use jaxo or others know how feynmann latex??]), while decay (12) requires a diagram such as Fig.(Two W decay). It is clear that the diagram for Σ^- is quite likely as it contains the Cabbibo favoured quark coupling V_{ud} while the digram for Σ^+ is very unlikely. In fact, the decay (12) must always contain at least two W bosons, as there are two quark flavour changes in the decay. For this reason it is highly suppressed and has a braching ratio of $< (5 \times 10^{-6})$, which is consitent with it not existing in nature [2]. In comparrison the decay (11) has a branching ratio of $(1.017 \pm 0.034) \times 10^{-3}$. As there is no selection rule forbidding this decay, the $\Delta S = \Delta Q$ rule was introduced to identify these types of decays. The change in strangeness and hadron charge for these decays can be found in Table.(I).

TABLE I: $\Delta S = \Delta Q$ *selection rule table for the decays (11) and (12)*

Shown decay of	ΔS	ΔQ	$\Delta S = \Delta Q$
Σ^-	+1	+1	yes
Σ^+	+1	-1	no

Where ΔA as the difference between the final and initial states of A such that $\Delta A = A_{final} - A_{initial}$. Also remember that the definition of strangeness assigns the strange quark a value of -1 and the anti-strange quark a value of $+1$. Thus we see that the decay (12) violates the $\Delta S = \Delta Q$ selection rule. Similarly, a decay with $\Delta S = \pm 2$ will contain two W bosons and as a result will be very suppressed. In conclusion, $\Delta S = \Delta Q = \pm 1$ for an allowed process.

This can now apply this rule to semi-leptonic decays of Kaons of the form $K \rightarrow \pi l \nu_l$. There are four Kaon decays that have this form:

$$K^0(d\bar{s}) \rightarrow \pi^- l^+ \nu_l \tag{13}$$

$$\bar{K}^0(s\bar{d}) \rightarrow \pi^+ l^- \bar{\nu}_l \tag{14}$$

$$K^0(d\bar{s}) \rightarrow \pi^+ l^- \bar{\nu}_l \tag{15}$$

$$\bar{K}^0(s\bar{d}) \rightarrow \pi^- l^+ \nu_l \tag{16}$$

TABLE II: $\Delta S = \Delta Q$ *selection rule table for the decays (13) - (16)*

Shown decay of	ΔS	ΔQ	$\Delta S = \Delta Q$
(13)	-1	-1	yes
(14)	+1	+1	yes
(15)	-1	+1	no
(16)	+1	-1	no

A similar table as before can no be constructed. See Table.(II), where the number shown refers to the equations above Thus it is clear that the only possible semi-leptonic decays of this form for K^0 and $\bar{K}^0$ are (13) and (14). As there is only one way for these processes to occur we determine that there can be no direct CP violation in the semi-leptonic decays of Kaons as there is no interference between processes, because there is only one [7, pg. 10]. So it is clear that the amplitudes of the $\Delta S = \Delta Q$ violating decays are:

$$A(K^0 \to \pi^+ l^- \bar{\nu}_l) = A(\bar{K}^0 \to \pi^- l^+ \nu_l) = 0$$

It is possible now to write these amplitudes in terms of K_S^0 and K_L^0. Using Eqn.(1),(2),(9) and (10) we obtain[7, pg. 11]:

$$A(K_S^0 \to \pi^+ l^- \bar{\nu}_l) = -A(K_L^0 \to \pi^+ l^- \bar{\nu}_l) = \frac{1-\epsilon}{\sqrt{2}} A(\bar{K}^0 \to \pi^+ l^- \bar{\nu}_l)$$
$$A(K_S^0 \to \pi^- l^+ \nu_l) = A(K_L^0 \to \pi^- l^+ \nu_l) = \frac{1+\epsilon}{\sqrt{2}} A(K^0 \to \pi^- l^+ \nu_l)$$

Where terms of order $|\epsilon|^2$ have been neglected. The quantities δ_L, S can now be defined, which show the tendency for the oscillations $K^0 \leftrightarrow \bar{K}^0$ to favour the matter particle state. Thus making a very small contribution to the matter anti-matter assymmetry.

$$\delta_L, S = \frac{A(K_{L,S}^0 \to \pi^- l^+ \nu_l) - A(K_{L,S}^0 \to \pi^+ l^- \bar{\nu}_l)}{A(K_{L,S}^0 \to \pi^- l^+ \nu_l) + A(K_{L,S}^0 \to \pi^+ l^- \bar{\nu}_l)} := 2\mathbb{R}(\epsilon)$$

The experimental value for this quantity is $\delta_L = (3.27 \pm 0.12) \times 10^3$. Which clearly indicates a small tendency to favour the matter particle in oscillations. This can also be illustrated graphically by measuring the relative number(N) of K^0 and $\bar{K}^0$ particles over time in a beam consisting initially of K^0. See Fig.(4)

C. Testing CPT conservation through Strangenss Oscillation

The CPT theorem links conservation of CPT with Lorentz invarience. Thus to preserve the fundamental Lorentz symmetry we desperately hope CPT is conserved. Here is presented some evidence that this is indeed the case. The theorem requires particles and their anti-particles to have the same masses and lifetimes. It has been stated previously that the K_L^0 and K_S^0 particles have very different lifetimes, but thankfully these are not a particle anti-particle pair. From earlier it is clear that K^0 and $\bar{K}^0$ are such a pair. Thus we aim to test CPT conservation by measuring their mass difference.

CKM

Decay between Generations: The weak force allows the change of flavour of say an up quark to a down quark. A deeper connection in the standard model can be made when we relate this to the electron and electron neutrinos that may also transition. It was originally noted by Nicola Cabibbo that the strengths of these process were remarkably similar to within 4% This discrepancy however bore some real consequences. It was the assumption of the charmed and 3rd generation of quarks by Kobayshi and Maskawas that noted this 4% uncertainty had some real significance and this 4% difference didn't simply disappear with more accurate readings. The ability of the Weak force to decay

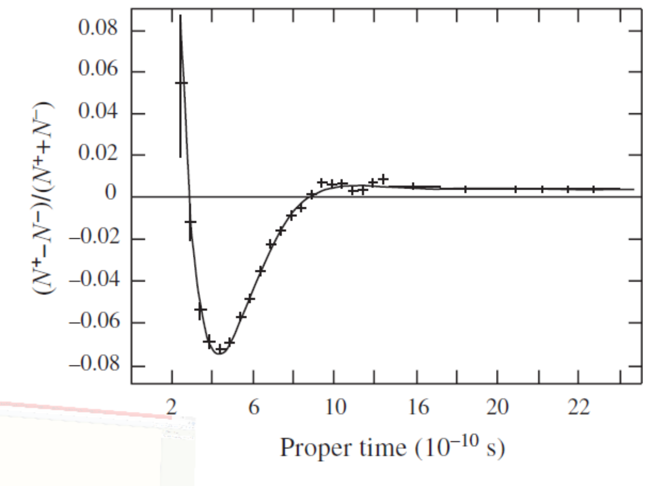

FIG. 4: *Meaurements of observed Kaon semi-leptonic decays from a beam initially consisting of K^0 mesons which shows the oscillation between the states K^0 and $\bar{K}^0$ as well as the small asymmetry, favouring the matter particle [8]*

between the generations explained this reduction in the strength of the decay amplitude. This has some rather interesting features, namely we can make use of Pythagorass theorem to determine a unique angle between each decay path, known as the Cabibbo angle. If two generations were the full story we would be left with figure [1.a].

///figure[1.a]//

Only one thousandth of the 4% deviation here is accountable from the 3rd generation but for the moment lets look a bit more into the first two.When we get to it these subtle effects arising from the 3rd generation is where are theory upon CP violation developed from. From figure [a] we note that the transition within a generation $u \rightarrow d$ is calculated as $cos\theta$ and across the generation as $sin\theta$ which actually corresponds to $u \rightarrow s$. If we were naive enough to presume only two generations of matter existed we would construct an amplitude matrix of the corresponding transitions based on this, as we will demonstrate now. Note that, for the moment, anti-particles have amplitudes that are the same as their matter counterparts.[4]

$$\begin{pmatrix} A_u d & A_u s \\ A_c d & A_c s \end{pmatrix} = \begin{pmatrix} cos\theta_c & sin\theta_c \\ -sin\theta_c & cos\theta_c \end{pmatrix}$$

From our diagram we see that the $\theta_c \sim 12\circ$ experimentally this is measured $\theta_c = 13.1\circ$ [?].The impact of this was that the decay rate of many hadronic particles could be calculated akin to lepton decays with the additional factor of $cos\theta_c$or $sin\theta_c$ in the matrix element. At a quick glance of the Weak Lagrangian [insert fancy lagrangian WL] we see the interaction term is a key element in the vertexes of our Feynman diagram describing the interactions. An element of this the γ signifies axial vector coupling with properties which contribute to CPV [ref].

[insert fancy feynman digram and amplitudes]Figure 2.a and 2.b

To progress onto a mechanism for mixing 3 generations of quarks we must look further into what sets the Weak interacting quarks apart from the quarks we associate with electromagnetic and strong interactions. To begin let us look at an example of the kaon decay into two muons.

[more fancy fyneman diagrams]Figure 3.a3.b

So for a decay scheme as the Kaon in [3.a] , we find a virtual up quark transmitted between the down and s. This is what would be know as a second order diagram as the direct decay to a W boson is forbidden.

When the amplitdes are found the branching ratio between that and the $K^+ \rightarrow \mu\nu$ is calculated to be, $K^0 \rightarrow \mu\mu/K^+ \rightarrow \mu\nu = 10^-8$. However experimentally this value is found to be too high. What could also be possible is the diagram in [3.b] where our virtual quark is now charm. When we account for these two process we find that in [3.a] the amplitude is proportional to $sin\theta_c cos\theta_c$ and in [3.b] the amplitude is proportional to $-sin\theta_c cos\theta_c$ on account of A_{cd} in our simple matrix above. In 1970, what is called the (Glashow, Iliopoulos and Maiani) GIM mechanism was responsible for a solution,it proposed that throuh the interference with another order diagram there would be a near cancellation. The remaining value come from the difference in mass between the up and charmed quark. Using the experimental Amplitudes this allowed calculation provide a clear prediction for the mass of the charmed quark of about $1.5Gev$ which was discovered in 1974.

Cabibbos theory of mixing together with the GIM mechanism allows us to look at quarks from a different perspective.