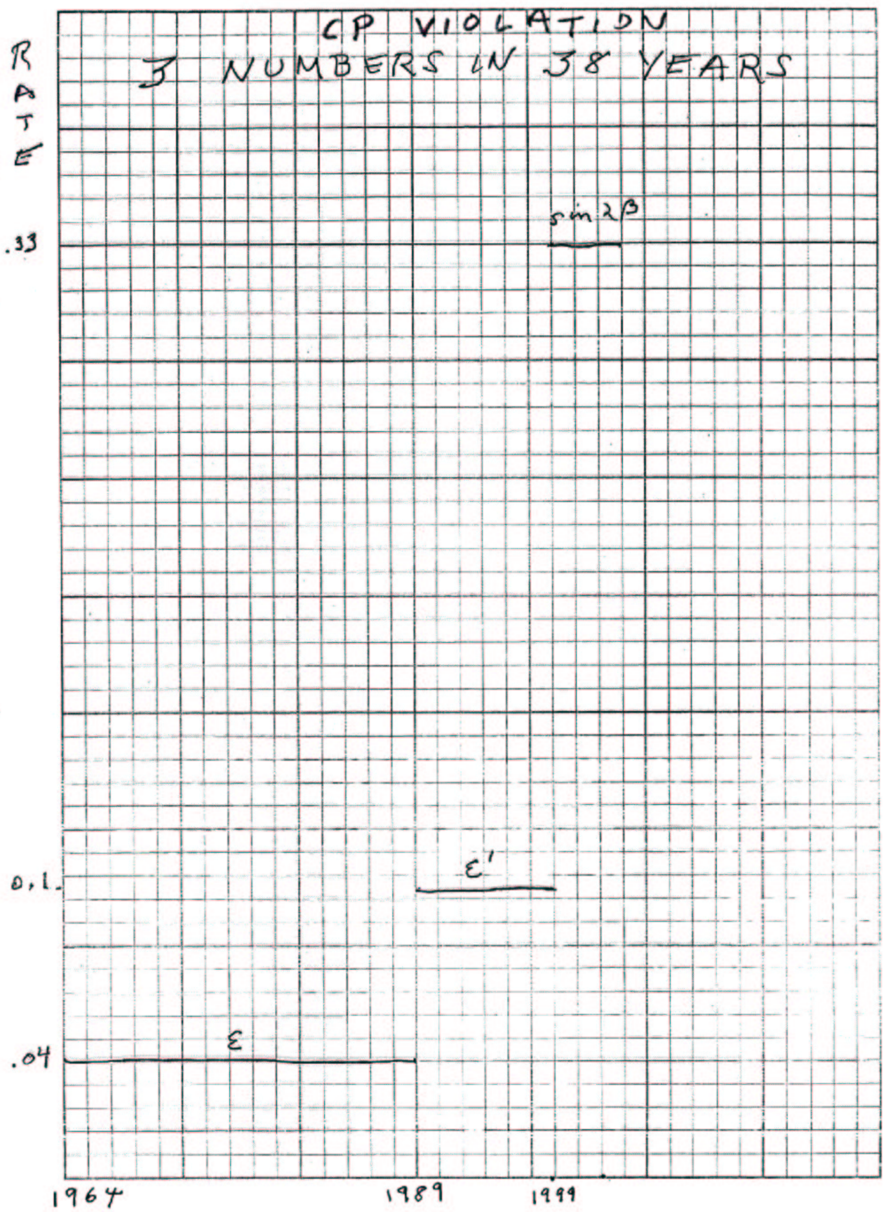


1. 3 numbers – ε, ε′ for K
   $\epsilon_K = 2 \times 10^{-3}$
   $\epsilon_B = \sin 2\beta$

   ε′ for K $= 4 \times 10^{-6}$ →
   Evidence against some SWk

   $\sin 2\beta \sim 0.7$ → Qualitative
   evidence for Stand. Model

2. ϵ'_B is next goal. Now at
   2σ from $S_{\pi\pi}$

3. Experimental Future
   (1) Precision B physics
   To limit or find new physics
   (2) Search for quantities
   like de that vanish in S.M.
   (3) ~~CP~~ in lepton sector from
   ν oscillations

A. The CKM matrix

In the standard electroweak model, the interactions (the quarks with the charged gauge bosons W are given b

$$g\bar{u}_j V_{ji}\gamma_\lambda(1-\gamma_5)d_i W^\lambda + \text{H.c.} \quad (3.$$

Here $u_j=(u,c,t)$ are the up-type quarks and $d_j=(d,s,$ are the down type. V is the unitary CKM (Cabibb Kobayashi-Maskawa) matrix, the 3×3 generalization (the Cabibbo mixing matrix. A convenient parametriz tion of V due to Maiani (1977) is

$$V=\begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} \begin{vmatrix} C_\sigma C_\theta & C_\sigma S_\theta & S_\sigma e^{-i\gamma} \\ -C_\tau S_\theta - C_\theta S_\sigma S_\tau e^{i\gamma} & C_\tau C_\theta - S_\theta S_\sigma S_\tau e^{i\gamma} & C_\sigma S_\tau \\ S_\theta S_\tau - C_\theta C_\tau S_\sigma e^{i\gamma} & -C_\theta S_\tau - C_\tau S_\theta S_\sigma e^{i\gamma} & C_\tau C_\sigma \end{vmatrix}, \quad (3.$$

ere $C_\theta=\cos\theta$ and $S_\theta=\sin\theta$. As originally noted by bayashi and Maskawa (1973), it is possible by defining phase of the quark fields to eliminate all but one of phases in V. Thus all CP violation in this model de- ıds on the phase γ. Experimental data on strange- ticle and B decay rates can determine the magnitudes V_{us}, V_{cb}, and V_{ub}. Given these magnitudes, there is empirical observation (Wolfenstein, 1983) that the xing angles have a hierarchical structure allowing ex- ısion in powers of $\lambda=\sin\theta=0.22$ with

$$\sin\tau = A\lambda^2\,, \quad (3.3a)$$

$$\sin\sigma e^{-i\gamma} = A\lambda^3(\rho - i\eta)\,. \quad (3.3b)$$

The analysis of experimental data from decay rates di cussed in Sec. III.C is summarized by

$$A = \cancel{0.9\pm0.1}\ .83 \pm .07 \quad (3.$$

$$(\rho^2+\eta^2)^{1/2} = \cancel{0.4\pm0.2}\ .4 \pm .15 \quad (3.$$

where the errors are primarily theoretical.

Expanding V in powers of λ to order λ^3, we see th the matrix has the simple form

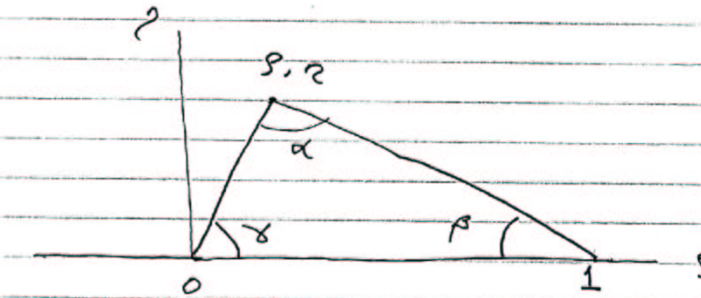
$$V=\begin{vmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{vmatrix}. \quad (3.6)$$

We have chosen a phase convention (that is, a definition of the phases of quark fields) in Eqs. (3.2) and (3.6) such that V is manifestly CP invariant to order λ^2, and CP

The CP-violating part of the $(K^0\text{-}\bar{K}^0)$ mass m be calculated (Ellis *et al.*, 1976) from the seco box diagram (Fig. 2). The result of the calculatio and Lim, 1981; Buras *et al.*, 1984), includin corrections (Gilman and Wise, 1983; Buras *et a* Flynn, 1990), is well represented for $m_t > m_w$ by

$$\epsilon e^{-i\theta} = 3.4\times10^{-3} A^2\eta B\left[1+1.3A^2(1-\rho)\left[\frac{m_t}{m_w}\right.\right.$$

$$V = \begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \to e^{-i\gamma} \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ e^{-i\beta} \leftarrow A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$



CP VIOLATION IN B^0

$$P_a(t) \propto e^{-\Gamma t}\left[1 \pm \alpha_a \eta_a \sin \Delta m t\right]$$

$\eta_a = \pm 1$ Asymmetry parameter $= \alpha_a$

$b \to c\bar{c}s$

$\alpha(\psi K_s) = \sin 2\tilde{\beta}$ ϵ_B

$b \to u\bar{u}d$

$\alpha(\pi^+\pi^-) = \sin 2(\tilde{\beta}+\gamma)$ ϵ'_B

$\tilde{\beta} = \beta$

LONG TERM FRONTIER FOR $\cancel{CP}$

1. SIGNALS of PHYSICS BEYOND S.M.

   New particle effects on
   Boxes (MIXING)
   Loops (PENGUINS)
   Electric Dipole MOMENTS

2. $\cancel{CP}$ in LEPTON PHYSICS
   NEUTRINO MIXING

3. Is $\cancel{CP}$ a SPONTANEOUSLY BROKEN SYMMETRY (θ_{QCD})

4. $\cancel{CP}$ AT A HIGH MASS SCALE TO EXPLAIN BARYON ASYMMETR

Lepton - Quark Symmetry

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

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

1. Three generations
2. $SU(2)_L$ doublets
3. Mass hierarchy e, μ, τ

$SO(10)$ $\quad \underset{\sim}{16}$ of fermions

$$\rightarrow SU(4)_C \times SU(2)_L \times SU(2)_R$$

$SU(3)_C$ $\qquad$ M_R for ν_R

see-saw $m_\nu = m_D M_R^{-1} m_D^T$

m_D = Dirac mass matrix for ν

M_R = Majorana mass matrix for N_R

m_ν defined by 9 numbers

$$U_{PMNS} = \begin{array}{c} e \\ \mu \\ \tau \end{array} \begin{pmatrix} c_\odot & s_\odot & s_{13} e^{-i\delta} \\ -\frac{s_\odot}{\sqrt{2}} & \frac{c_\odot}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ +\frac{s_\odot}{\sqrt{2}} & -\frac{c_\odot}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

$$s_\odot^2 \approx 0.3$$

$$m_\nu^{diag} = \begin{pmatrix} m_3 & & \\ & m_2 e^{i\alpha} & \\ & & m_1 e^{i\beta} \end{pmatrix}$$

$$m_3^2 - m_2^2 \approx 3 \times 10^{-3}\, eV^2$$

$$m_2^2 - m_1^2 \approx 7 \times 10^{-4}\, eV^2$$

Of 9 - 4 are measured

$$\nu_x = (\nu_\mu + \nu_\tau)/\sqrt{2}$$

$$\nu_y = (\nu_\mu - \nu_\tau)/\sqrt{2}$$

$$U_{PMNS} = \begin{pmatrix} c_\odot & s_\odot & s_{13} e^{-i\delta} \\ -s_\odot & c_\odot & \epsilon_{12} \\ \epsilon_{31} & \epsilon_{21} & 1 \end{pmatrix}$$

$$s_\odot \approx .55$$

$$U_{CKM} = \begin{pmatrix} c_\theta & s_\theta & s_\sigma e^{-i\gamma} \\ -s_\theta & c_\theta & s_\tau \\ s_\theta s_\tau - s_\sigma e^{-i\gamma} & -s_\tau & 1 \end{pmatrix}$$

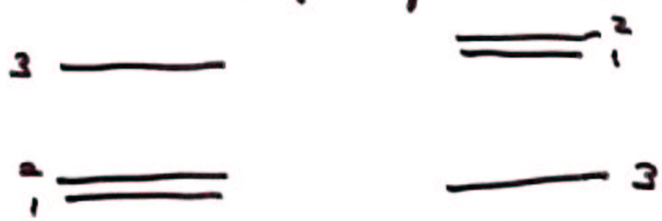
$$s_\theta \approx .22$$

$$s_\sigma e^{-i\gamma} = A\lambda^3 (\rho - i\eta) \approx .003\, e^{-i\gamma}$$

$$s_\tau = A\lambda^2 \approx .04$$

Undetermined

1. Mass scale m_1
2. One mixing angle s_{13}
3. One phase δ in U_{PMS}
4. Discrete ambiguity: sign of Δm^2_{32}



5. Majorana or Dirac?
6. If Majorana: Phases α, β

CP Violation in ν Oscillations

(Detecting the phase δ)

$$P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

1. Rate is proportional to s_{13}^2
2. Difference depends not only on Δm^2_{32}, but also $\underline{\Delta m^2_{21}}$
   Requires long baseline and/or low E
3. In matter the difference is <u>not</u> a direct sign of $\cancel{CP}$.
   Fit data to s_{13} and δ.
4. T violation ("no" matter effect)
   Cf $\nu_\mu \to \nu_e$ with $\nu_e \to \nu_\mu$

CP VIOLATION "PROPOSALS"

$\nu_\mu \to \nu_e$ / $\bar{\nu}_\mu \to \bar{\nu}_e$

1. JHF II → Hyper K

0.7 Gev 300 km
Arafune, Sato Phys Rev D 56, 3093
Y. Itow etal hep-ex/0106019

2. Accelerator Long Baseline

1 Gev, 1200–3000 km
Marciano Phys. Rev D
0.5–7 Gev 2000 km BNL-69395

3. "ν Factory"

20–30 Gev, 3000–7000 km
Freund et al Nuc. Phys B 578, 27
Barger et al hep-ph/0003184
Cervera et al Nuc. Phys B 579, 17

4. Low Energy neutrinos
100 Mev, L = 50 km
Minakata Nunokawa hep-ph 00090

Probing s_{13}^2
($\sin^2 2\theta_{13} = 4 s_{13}^2$)

CHOOZ $s_{13}^2 < .025 - .03$

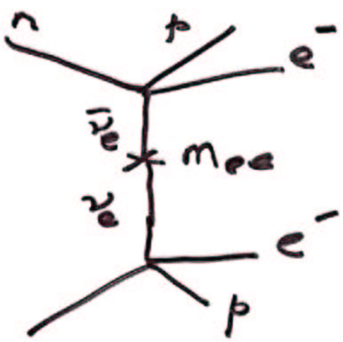
Within 10 years ?

JHF → SUPER K
0.6 Gev, 295 km → .003

Fermilab Off axis beam
"2 Gev" 750 km → .003

CNGS, ICARUS with new beam → .003

Neutrinoless Double Beta Decay



$$m_{ee} = |U_{e1}^2|\, m_1 e^{i\beta} + |U_{e2}^2|\, m_2 e^{i\alpha} + |U_{e3}|^2 m_3$$

Example. $m_{ee} = 0.2$ ev

$m_1 \simeq m_2 \simeq m_3$

$(0.2\text{ ev}) = \cos^2\theta_\odot\, m_1 e^{i\beta} + \sin^2\theta_\odot\, m_2 e^{i\alpha}$

Extremes $e^{i\beta} = e^{i\alpha} = 1$ $\quad m_1 = 0.2$ ev

$e^{i\beta} = +1$ $\quad e^{i\alpha} = -1$ $\quad m_1 = \frac{0.2\text{ ev}}{\cos 2\theta} \simeq 0.5$ ev

If Cosmology → $m_1 < 0.5$ ev

^3H decay → $m_1 > 0.2$ ev

Then ∃ Majorana phase

Conclusions

Future for ν Mass + Oscillation

* 1. Probe value of s_{13}^2

* 2. Search for ββ

1 : If s_{13}^2 is large enough

Find ~~CP~~ phase δ

Hierarchy

2 : If $\langle m_{ee} \rangle$ is large enough

Majorana

Range of m_1

CP phases α, β ??

3. Physics beyond the standard :

ν_s, FCNC

Electric dipole moments of e or n