STATUS of the CKM Paradigm

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Work done with DAVID ATWOOD, IOWA STATE UNIV
RELATED WORKS

J. Rosner ---
A. Ali + D. London
Stocchi ---
Martinelli ---
Mele
S. Plaseczynski + M-H Schune
G. Eigen
S. Stone
M. Artuso
R. Forty ---

Here

A. Hoecker
H. Lacker

A. Twod + I.Time Technion WKSHP'94?
1. Theoretical Underpinnings
   - We Hold These Truths
   - More Mundane

2. Inputs and Concerns
   - Experiment
     - Hadronic Parameters

3. Constraints and their Stability

4. Implications for the SM

5. Desperately Seeking Godot

6. Future Directions

7. Conclusions/Outlook
CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

When we apply the renormalizable theory of weak interaction\(^1\) to the hadron system, we have some limitations on the hadron model. It is well known that there exists, in the case of the triplet model, a difficulty of the strangeness changing neutral current and that the quartet model is free from this difficulty. Furthermore, Maki and one of the present authors (T.M.) have shown\(^7\) that, in the latter case, the strong interaction must be chiral $SU(4) \times SU(4)$ invariant as precisely as the conservation of the third component of the iso-spin $I_3$. In addition to these arguments, for the theory to be realistic, CP-violating interactions should be incorporated in a gauge invariant way. This requirement will impose further limitations on the hadron model and the CP-violating interaction itself. The purpose of the present paper is to investigate this problem. In the following, it will be shown that in the case of the above-mentioned quartet model, we cannot make a CP-violating interaction without introducing any other new fields when we require the following conditions: a) The mass of the fourth member of the quartet, which we will call $\xi$, is sufficiently large, b) the model should be consistent with our well-established knowledge of the semi-leptonic processes. After that some possible ways of bringing CP-violation into the theory will be discussed.

We consider the quartet model with a charge assignment of $Q, Q-1, Q-1$
Next we consider a 6-plet model, another interesting model of CP-violation. Suppose that 6-plet with charges \((Q, Q, \bar{Q}, \bar{Q} - 1, Q - 1, \bar{Q} - 1)\) is decomposed into \(SU_{\text{weak}}(2)\) multiplets as \(2 + 2 + 2\) and \(1 + 1 + 1 + 1 + 1 + 1\) for left and right components, respectively. Just as the case of \((A, C)\), we have a similar expression for the charged weak current with a \(3 \times 3\) instead of \(2 \times 2\) unitary matrix in Eq. (5). As was pointed out, in this case we cannot absorb all phases of matrix elements into the phase convention and can take, for example, the following expression:

\[
\begin{pmatrix}
\cos \theta_1 & -\sin \theta_1 \cos \theta_2 & -\sin \theta_1 \sin \theta_2 \\
\sin \theta_1 \cos \theta_2 & \cos \theta_2 \cos \theta_3 & \cos \theta_2 \sin \theta_3 + \sin \theta_2 \cos \theta_3 e^{i \phi} \\
\sin \theta_1 \sin \theta_2 & \cos \theta_1 \cos \theta_3 & \cos \theta_1 \sin \theta_3 + \cos \theta_1 \sin \theta_3 e^{i \phi}
\end{pmatrix}
\]

Then, we have CP-violating effects through the interference among these different current components. An interesting feature of this model is that the CP-violating effects of lowest order appear only in \(\Delta S \neq 0\) non-leptonic processes and in the semi-leptonic decay of neutral strange mesons (we are not concerned with higher states with the new quantum number) and not in the other semi-leptonic, \(\Delta S = 0\) non-leptonic and pure-leptonic processes.

So far we have considered only the straightforward extensions of the original Weinberg's model. However, other schemes of underlying gauge groups and/or scalar fields are possible. Georgi and Glashow's model\(^1\) is one of them. We can easily see that CP-violation is incorporated into their model without introducing any other fields than (many) new fields which they have introduced already.

References

ELEMENTARY INTERACTION

\[ g_2 (\pi e F) V_{\text{CKM}} \left( \frac{s}{\sqrt{2}} \right) W^- \]

\[ \sqrt{\text{ENCAPSULATES ROTATION BET. CHANGE}} \]
\[ \text{CKM CURRENT C.S. & Mass e.s.} \]

\[ V_{\text{CKM}} = \begin{pmatrix}
V_{u d} & V_{u s} & V_{u c} \\
V_{c d} & V_{c s} & V_{c c} \\
V_{d d} & V_{d s} & V_{d c}
\end{pmatrix} \]

Following PDB adopt parameterization of Chan-Huang

\[ V_{\text{CKM}} = \begin{pmatrix}
C_{12} C_{13} & S_{12} C_{13} & S_{13} e^{i \delta} \\
-S_{12} C_{23} - C_{12} S_{23} S_{13} e^{i \delta} & C_{23} + S_{12} S_{23} S_{13} e^{i \delta} & S_{13} e^{i \delta} \\
S_{23} S_{13} - C_{12} C_{23} S_{13} e^{i \delta} & -C_{23} S_{13} - S_{12} C_{23} S_{13} e^{i \delta} & C_{13} C_{23}
\end{pmatrix} \]

\[ S_{12} = |V_{us}| 0.22 ; \quad S_{23} = |V_{cb}| 0.04 ; \quad S_{13} = |V_{ub}| 0.004 \]

\[ \delta \text{ is the Kobayashi-Maskawa Phase} \]

CRUCIAL for CP

Hierarchy of \( \lambda \)s more readily depicted in the Wolfenstein reps.

\[ V_{\text{WOLF}} = \begin{pmatrix}
1 - \frac{\lambda^2}{2} & \lambda & \lambda A^2 (\text{e}^{i \eta}) \\
-\lambda & 1 - \frac{\lambda^2}{2} & -\lambda A^2 \\
A^2 (1 - \text{e}^{i \eta}) & -A^2 & 1
\end{pmatrix} \]

\( \lambda, A, \eta, \eta \)
Following Burns et al. and Schmidtler and Schubert, to avoid \( \lambda \) function (in \( \lambda^4 \)) and to restore unitarity exactly:

\[
S_{12} = \lambda, \quad S_{23} = A^{1/2}, \quad S_{13} = A^{1/2} (\rho - i \eta)
\]

ALSO NOW FOR A GENERALIZATION OF \( \mathcal{U} \Delta \) TO HIGHER ORDER IN \( \lambda \).

Thus \( V_{us} = \lambda + O(\lambda^2) \); \( V_{ub} = A \lambda^3 (\rho - i \eta) \); \( V_{cd} = A \lambda^2 + O(\lambda^3) \)

\[
V_{td} = A \lambda^2 [1 - \rho - i \eta]; \quad \beta = \beta (\rho - i \eta); \quad \eta = \eta (\rho - i \eta)
\]

\( \tan \beta = m_t / \langle \bar{t} t \rangle = \frac{\bar{t} / \rho}{\beta / \rho} \)

\( L \rightarrow H \) UNITARITY:

\[
V_{ud} V_{ule}^{*} + V_{cd} V_{cle}^{*} + V_{td} V_{tbc}^{*} = 0
\]

\( A (\rho, \eta) \)

\[
\sin \alpha = \sin \beta = \frac{2 \eta (1 - \eta)}{[1 - (1 - \rho)^2 + \eta^2]}
\]

\[
\sin \alpha_1 = \sin \alpha_2 = \frac{2 \eta (\eta^2 + \rho^2 - \rho)}{[1 - (1 - \rho)^2 + \eta^2]}
\]

\[
\sin \alpha_3 = \sin \alpha_2 = \frac{2 \eta (\eta^2 + \rho^2)}{[1 - (1 - \rho)^2 + \eta^2]}
\]

**Note**: \( \alpha(\rho, \eta_1, \eta_2) \propto \eta \neq 0 \implies \eta \)

Recall:

\[
V_{td} = |V_{td}| e^{-i \phi_1} = |V_{td}| e^{i \beta}
\]

\[
V_{ub} = |V_{ub}| e^{-i \phi_3} = |V_{ub}| e^{-i \gamma}
\]
$1^\text{st}$ **Exptal + Theo. Input:**

$\mathcal{K}^0 - \bar{\mathcal{K}}^0$ CP:

$$|F_K| = \frac{B_K}{B_{\mathcal{K}}} \cdot \text{ CKM} \cdot \left[ x \chi^2 \frac{A^2}{y^4} \left[ \eta_1 S(x_1) + \eta_2 S(x_2) \right] \right]$$

$C_K = 0.0005 \frac{f_K^2 m_K m_W}{6\pi \alpha' \Delta m_K}$

$x = \frac{m_K^2}{m_W^2}$

$\eta \neq 0$ due $6K$

$\text{II SEMILEPTONIC CHARLESS B-decays i.e. } b \to (u\nu\bar{e})/b \to (c\nu\bar{e})$

$$R_{uc} = \frac{|V_{ub}|^2}{|V_{cb}|^2} = \lambda \frac{(\bar{e}^2 + \bar{\nu}^2)^{1/2}}{(1 - \lambda)}$$

CLEO + LEP $\geq 0.085 \pm 0.033 \pm 0.0125$ "Nominal"

$\text{III } b \to \bar{b}$ Osc

$$\Delta m_d = \frac{|V_{ub}|^2}{|V_{cb}|^2} \cdot \frac{G_F^2}{6\pi^2} \cdot \frac{m_b}{m_d} \cdot \frac{m_c}{m_w} \cdot \chi^2 \left[ S(x_1) + \chi^2 \right]$$

$\text{IV } b \to \bar{b}$ Osc (lim from LEP)

$$\frac{\Delta m_d}{\Delta m_s} = \frac{\eta_1^2}{\eta_2} \cdot \frac{m_b}{m_s} \cdot \chi^2 \cdot \left[ (1 - \eta)^2 + \eta^2 \right]$$

$\varepsilon = \frac{\Delta m_d}{\Delta m_s} \cdot \chi^2 \cdot \left[ (1 - \eta)^2 + \eta^2 \right]$ $\Rightarrow$ SU(3) Breaking Ratio

$\text{(LEP)}$ LEP: $\{ \Delta m_s > 15.0 \text{ ps}\}$ e 95% CL
# Hadronic Parameters from Lattice

<table>
<thead>
<tr>
<th>Qty</th>
<th>Nominal</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_k$</td>
<td>$0.86 \pm 0.06 \pm 0.14$</td>
<td>Coincidentally same as Lellouch et al. 2000, $\downarrow$ QCD; $\uparrow$ SU(3); UNO? $\downarrow$ all small effects. $\downarrow$ JLQCD; CP-PACS; B$+53$ RBCC</td>
</tr>
<tr>
<td>$f_{B_d} / f_{B_s}$</td>
<td>$230 \pm 40$ MeV</td>
<td>Bernard et al. 2000, S. Horiike here, central value $\uparrow$ 0.10 - 0.15, due quench. $\downarrow$ Bernard $1.16 \pm 0.05$ (error)</td>
</tr>
<tr>
<td>$\frac{f_{B_s}}{f_{B_d}}$</td>
<td>$1.16 \pm 0.08$</td>
<td>Concern alternate method B.B.S. PRD 98, also $L+L$. $\frac{\langle B_s \mid (1 - \tau_5) S \rangle \mid B_s \rangle}{\langle B_d \mid (1 - \tau_5) S \rangle \mid B_s \rangle} = \frac{m_{B_s}^2}{m_{B_d}^2} \xi^2$ [Use of $B$ parameter is a historical accident] $\Rightarrow$ tend to lower $\sin \theta_P$</td>
</tr>
</tbody>
</table>

**Will also study more conservative choices**

- $B_k$ $0.90 \pm 0.06 \pm 0.14$
- $f_{B_d} / f_{B_s}$ $217 \pm 40$ MeV
- UNO $\uparrow$ Karp $et al.$
- $B_{dd} \downarrow$ UNO
- Gimenes $et al.$
nominal-Bs

Input Values
Thu Feb 15 17:43:55 CST 2001

<table>
<thead>
<tr>
<th>thing</th>
<th>variable</th>
<th>value</th>
<th>$\text{err}_1$</th>
<th>$\text{err}_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$</td>
<td>vveb</td>
<td>0.04</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}/V_{cb}</td>
<td>$</td>
<td>vruc</td>
<td>0.085</td>
</tr>
<tr>
<td>$\frac{B_{K^0}/B_{K}}$</td>
<td>vbfr</td>
<td>0.23 GeV</td>
<td>0.04</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\xi$</td>
<td>vxi</td>
<td>1.16</td>
<td>0.08</td>
<td>-1.01</td>
</tr>
<tr>
<td>$B_K$</td>
<td>vbk</td>
<td>0.86</td>
<td>0.1523</td>
<td>-1.01</td>
</tr>
<tr>
<td>$M_B(m_s)$</td>
<td>vaunt</td>
<td>167. GeV</td>
<td>3.0</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\lambda (\approx \sin \theta_{BC})$</td>
<td>val</td>
<td>0.2237</td>
<td>0.0018</td>
<td>-1.01</td>
</tr>
<tr>
<td>$x_d$</td>
<td>vxd</td>
<td>0.723</td>
<td>0.032</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\tau_B$</td>
<td>vtaub</td>
<td>1.548</td>
<td>0.032</td>
<td>-1.01</td>
</tr>
<tr>
<td>$c_K(10^{-3})$</td>
<td>vepsk</td>
<td>2.28</td>
<td>0.019</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>vet_1</td>
<td>1.38</td>
<td>0.53</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\eta_2$</td>
<td>vet_2</td>
<td>0.574</td>
<td>0.004</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\eta_3$</td>
<td>vet_3</td>
<td>0.47</td>
<td>0.04</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\eta_8$</td>
<td>vet_b</td>
<td>0.55</td>
<td>0.01</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\Delta m_{B_d}$</td>
<td>vd_mbd</td>
<td>0.467054264 $h \text{ps}^{-1}$</td>
<td>0.0206718346</td>
<td>-1.01</td>
</tr>
<tr>
<td>$\Delta m_{B_s}$-bound</td>
<td>vd_mbd</td>
<td>15. $h \text{ps}^{-1}$</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Notes:

- -1 indicates that this error is not used
- $\text{err}_1$ is a gaussian pdf; $\text{err}_2$ is a square shaped pdf.
- If both are on they are multiplied if $\text{iconv}=0$ and convoluted if $\text{iconv}=1$
- $m_c(m_s) \approx m_{phys} - 9$
- $\Delta m_{B_d}$ is derived from $x_d$
- $\Delta m_{B_s}$ is a bound
Nominal input with \( B_3 \)

\[ \bar{\eta} \approx \frac{0.242 - 0.336}{2.03} = 0.075 \] (95%)

\[ \bar{\xi} \approx \frac{0.207 - 0.316}{0.164 - 0.375} = 0.68/0.75 \% \]
Other Inputs:
- iconv = 1
- blob contour(rat_b) = 0.68 and also: 0.95
- histogram intervals = 0.68; 0.95
- plot elements(dots,curves,blob) = (0, 1, 1)
- iseed = 334567
- iter = 15000
- iswbs = 1, $B_s$ data used
- tag = nominal-Bs
- color = 1
- graph title = Nominal input with B

Statistic

- $\sin(2\beta) = 0.692 \ [0.6032, 0.7776] \ [0.5195, 0.8521]$
- $Br(K_L \rightarrow \pi^0 \nu \bar{\nu}) = 0.2033 \ [0.155, 0.2673] \ [0.118, 0.3463] \ (\times 10^{-10})$
- $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = 0.6589 \ [0.5725, 0.762] \ [0.5024, 0.8754] \ (\times 10^{-10})$
- $\sin(2\alpha) = -0.633 \ [-0.8506, -0.3666] \ [-0.9704, -0.118]$
- $\gamma\omega = 43.3483 \ [36.2922, 50.0473] \ [30., 55.9224]$
- $J_{CP} = 1.23 \ [1.0753, 1.4135] \ [0.9395, 1.6074] \ (\times 10^{-5})$
- $\bar{p} = 0.2584 \ [0.2069, 0.316] \ [0.1638, 0.3733]$
- $\bar{\eta} = 0.2667 \ [0.2422, 0.3358] \ [0.2033, 0.3853]$
- $|V_{td}/V_{ts}| = 0.1784 \ [0.1655, 0.1896] \ [0.1524, 0.1993]$
- $Im(\lambda_t) = 1.1005 \ [0.961, 1.2643] \ [0.8387, 1.4891] \ (\times 10^{-4})$
Nominal input with $B_2$
Nominal input with B
\[
\sin \theta_p = 0.52 - 0.85 \quad (95\%);
\]
\[
\sin \theta = -0.97 - 1.2
\]
\[
30^\circ - 56^\circ
\]
\[
60^\circ - 78^\circ \quad 68\%
\]
\[
85^\circ - 37
\]
\[
36^\circ - 58^\circ
\]
Gauss and Flat

sin 2*beta

0.0  0.2  0.4  0.6  0.8  1.0

0.00 0.25 0.50 0.75 1.00 1.25 1.50

No Bs
Dependence on $b_k$

$\sin 2\beta$ vs $b_k$

**Nominal** $b_K = 0.86 \pm 0.15$
Dependence on \( \text{brf} \equiv \frac{\mathcal{L}}{f_0 \sqrt{B}} \)

\begin{align*}
\sin 2 \beta & \quad \text{vs.} \quad \text{GeV} \\
0.2 & \quad 0.4 & \quad 0.6 & \quad 0.8 & \quad 1.0 \\
0.18 & \quad 0.2 & \quad 0.22 & \quad 0.24 & \quad 0.26 & \quad 0.28 & \quad 0.3 & \quad 0.32
\end{align*}

**Nominal** \( \frac{\mathcal{L}}{f_B \sqrt{B}} = 0.23 \pm 0.04 \)
Dependence on $x_i$ = \[ \frac{f_{ex}}{f_{th}} \]

$\sin 2\beta$

$0.8$

$0.6$

$0.4$

$0.2$

$x_i \equiv \delta$

NOMINAL VALUE: $\delta = 1.16 \pm 0.08$
Dependence on ruc \[ \frac{V_{\text{duc}}}{V_{\text{duc}}} \]

\[ \sin 2 \beta \]

\[ \text{NOMINAL} \quad R_{\text{duc}} = \frac{|V_{\text{duc}}|}{|V_{\text{duc}}|} = 0.085 \pm 0.0136 \]
Dependence on dmbs $\equiv \Delta m_{B{s}}^{\text{bound}}$

$\sin 2\beta$

$dmbs$

NOMINAL $\Delta m_{B{s}} = 0.15 \pm 0.05 \, \text{GeV}$
Dependence on dmbs

$\sin 2\beta$ vs dmbs

The graph shows a series of horizontal lines, indicating a constant variation of $\sin 2\beta$ with respect to dmbs.
$\sin 2\beta (\Phi)$ vs. Inputs

1. Nominal (with $B_s$)  \hspace{1cm} 68\% 
2. Nominal $B_s - No f_{B_0}B$  \hspace{1cm} 95\% 
3. "Wide Vale"  \hspace{1cm} .60 - .78 
\hspace{1cm} .52 - .85 
4. Weaken $B_K$ & $f_{B_0}B$  \hspace{1cm} .61 - .79 
\hspace{1cm} .53 - .86 
5. Nominal - No $B_s$  \hspace{1cm} .62 - .87 
\hspace{1cm} .51 - .97 
6. "MAGIC"  \hspace{1cm} .59 - .77 
\hspace{1cm} .51 - .85 
7. Nominal $B_s$ (Nominal)  \hspace{1cm} .56 - .76 
\hspace{1cm} .41 - .84 
8. CP Conserving Phenomena require $\beta \neq 0$ [\neq 0]! 
\hspace{1cm} \text{CP:} \hspace{1cm} 0.16 - 0.29 [68\%] 
\hspace{1cm} 0.11 - 0.36 [95\%]
3.7 Constraint Due $E_k$ Alone
68\% - 95\% \text{ bounds on } \bar{m} \text{ from B physics} \Rightarrow \bar{m} \neq 0
**Time-Dependent CP Asymmetry in $B^0 \rightarrow \psi K^0$**

\[
\frac{f}{\bar{f}} = \frac{\Gamma(B^0 \rightarrow f) - \Gamma(\bar{B}^0 \rightarrow \bar{f})}{\Gamma(B^0 \rightarrow f) + \Gamma(\bar{B}^0 \rightarrow \bar{f})} = -f_{CP} \sin \alpha \phi_1(\rho) \sin(\Delta m_{Bd} t)
\]

\[f_{CP} = \pm 1\]

**Clean Way to Determine $\sin \alpha \phi_1(\rho)$**

<table>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>$\sin \alpha \phi_1(\rho)$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Belle</strong></td>
<td>$0.58 \pm 0.32 \pm 0.09$</td>
</tr>
<tr>
<td><strong>Babar</strong></td>
<td>$0.34 \pm 0.20 \pm 0.05$</td>
</tr>
<tr>
<td><strong>CDF</strong></td>
<td>$0.79 \pm 0.49$</td>
</tr>
<tr>
<td><strong>Combined</strong></td>
<td>$0.46 \pm 0.17$</td>
</tr>
</tbody>
</table>

**Due to decay of $B^0$ into $K^0$**
Measurements in \( B^{-}\to K^0 \) Confirm the CRM Paradigm
DESPERATELY SEEKING ---

"WHERE HAVE ALL THE BSM CP PHASES GONE?"

CKM gives a qualitative and quantitative good account for $E_k + A_{CP} (B^0 \rightarrow \psi K_0)$

IT IS RATHER DIFFICULT TO MAKE AN EXTENSION OF SM WITH CKM phase = 0 AND give a "Natural" (qualitative & quantitative) account of $E_k + A_{CP} (B^0 \rightarrow \psi K_0)$ + ---

ILLUSTRATION

"TWO Higgs Doublet Model for the Top Quark"

TOP quark is very heavy

* Top is the only quark that couples to the 2nd doublet with a very large VEV.

You can view it LEET incorporating dynamical model such as TOP - COLOR

$H^\pm$ CP new phases $FCNC$ in $t \rightarrow c \rightarrow u$
SEARCHING FOR BSMCP phases in these channels will require PRECISION STUDIES
\[ a \gamma_{K_s} = \sin(2\beta_{\text{CKM}} + \theta) \]

(Model can accommodate \( \epsilon_K \) with \( \delta_{\text{CKM}} = 0 \))

\[ \gamma = 68^\circ \]

\[ \gamma = 0^\circ \left( \epsilon_{\text{CKM}} = 0 \right) \]

\[ \gamma = -45^\circ \]
**Experimental Determination of $f_B$ via $B^+ \rightarrow l^+ \nu l^0 \nu$**

- $f_B = 200 \text{ MeV}$; $\frac{V_{tb}}{V_{cb}} = 0.085$
- $\text{BR}(B \rightarrow ll) \sim 7.5 \times 10^{-5}$
- $\text{BR}(B \rightarrow l\nu l\nu) \sim 3.2 \times 10^{-7}$

**Method**

- QCD; ATWOOD, KORCHEMSKY, PIRJOL, YAN
- Low energy
- Light cone

**Values**

- $\frac{\text{BR}}{\text{BR}(B \rightarrow l\nu l\nu)} \sim 5.2 \times 10^{-6}$
- $\frac{\text{BR}}{\text{BR}(B \rightarrow ll)} \sim 3.7 \times 10^{-6}$
- $\frac{\text{BR}}{\text{BR}(B \rightarrow l\nu l\nu)} \sim 1 \times 10^{-6}$

*Not very clean but $\sim 30\%$ or so gives $f_B$*

- $(\pi^+ \rho + \rho \pi^0) \sim 10^{-5}$
- Characteristic photon spectrum "spin flip"
Nominal input s2b+
1) $B_s \rightarrow \bar{B}_s$ Osc --- ...TEV, BTeV, LHCb --- BEYOND LEP Bound

2) a) Exptally Measure $B^0 \rightarrow \phi + \phi$ (NOT $B^\pm$)

\[ \frac{V_{td}}{|V_{ts}|} = \sqrt{C} \frac{BR(B^0 \rightarrow \phi + \phi)}{BR(B^0 \rightarrow X^0 + Y)} \]

Phase space correction

Atwood, Bloxham

$SU(3)$ breaking FROM THE LATTICE

$M_{\mu} = \langle V(\alpha) \mid J_\mu \mid B(\phi) \rangle$

$J_{\mu} = \bar{q} G^{\mu \nu} q_{\nu} B$

$M_{\mu} = 2 \epsilon_{\mu\nu\rho\sigma} \phi^{(b)} \rho^{(b)} \sigma^{(b)} \tau^{(b)} + \left[ \begin{array}{c} J_{\varepsilon}(\sigma) \\ J_{\xi}(\omega) \end{array} \right] \tau^{(b)} + \eta [ \eta ] \tau^{(b)}$

$R_V = \frac{\Gamma(b \rightarrow V\phi)}{\Gamma(b \rightarrow q\bar{q})} \approx 4 \left( \frac{m_b}{m_c} \right)^3 \left[ 1 - \frac{m_V^2}{m_b^2} \right]^3 T_1(\omega)$

BERNARD, HSIEH + AS
PRL 94
UK@CD, APE

(Propagators cancel shared with other heavy light physics, such Vud form factors)

$\phi^0$ is much EASIER THAN $T_1(\omega)$

$SU(3)$ Breaking "small"

NEEDS PRECISION
3) \[ \text{Real \ via \ } K^+ \rightarrow \pi^+ \pi^- \bar{\nu} \bar{\nu} \text{ Extremely clean} \]

\[ \text{E787 OR } (1.5^{+3.4}_{-1.2}) \times 10^{-10} \]

\[ \text{EXPECTATIONS from our fit: } (0.50 - 0.88) \times 10^{-10} \]

\[ \text{New Effort: AGS E949} \]

\[ \text{FINAL CKM} \]

\[ 10^{-11} \text{ sensitivity} \]

\[ 10^{-12} \]

\[ 11 \]

\[ \text{IMPORTANT for Cross-Checks} \]
CONCLUSIONS/OUTLOOK

- Using $E_K$, $R_{uc}$, $\Delta m_{s}$, $\Delta m_{d}$, in approx. linear. comp. + theory
  $\Rightarrow$ valuable const on the CKM matrix. In particular

- Using $B$-physics (CP-conserving) input $\Rightarrow$ KM phase $\neq 0$
  $0.11 < \epsilon < 0.36 (95\%)$; $0.32 < \text{sin} \beta < 0.86 (95\%)$
  Recall $E_K \neq 0 \Rightarrow$ Requires $\pi > 0.12$

- $E_K$, $R_{uc}$, $\Delta m_{s}/\Delta m_{d}$ inputs + theory + robust $[A_f^bG_b]$ or $B$
  $\Rightarrow$ $0.51 < \text{sin} \beta < 0.85 (95\%)$

- Using $A_L$ with conservative theory input $\Rightarrow$
  $0.51 < \text{sin} \beta < 0.86 (95\%)$

- (CDF + BELLE + BABAR $\Rightarrow$ sin $\beta = 0.46 \pm 0.17$
  $\Rightarrow$ completely compatible with theoretical expectations

- No glaring signs of new CP-odd phase

- Search for BSM CP phase (3) in these channels will require precision studies

- More data, extra effort at $f_0$, $\Lambda_c$, $B$-Osc., $B \to\psi K$

$\Rightarrow$ B-factory experiments spell resounding success of the CKM paradigm