WEINBERG MODEL OF CP VIOLATION

— RULING IT OUT

BRUCE H J MCKELLAR

DARWIN CHANG

XIAO GANG HE

ICHEP 2000
Osaka

WEINBERG PROPOSED A 3 HIGGS MODEL OF CP VIOLATION IN 1976

ADVANTAGES:

- NATURAL SUPRESSION OF FCNC
- CP IS SPONTANEOUSLY BROKEN.

MANY HAVE CLAIMED THAT IT IS RULED OUT BY

- ϵ AND/ OR
- ϵ'/ϵ AND/ OR
- d_n AND/ OR
- $b \to s\gamma$

$\boxed{\text{THE MAJOR MESSAGE:}}$

UNCERTAINTIES IN THE CALCULATION OF THE RELEVANT MATRIX ELEMENTS MEAN THAT THE WEINBERG MODEL IS IN TROUBLE ONLY FROM ϵ'/ϵ AND $b \to s\gamma$ TOGETHER.

THE BASIC CHARGED HIGGS - FERMION COUPLING IS

$$\mathcal{L} = 2^{3/4} G_F^{1/2}\, \bar{U}\Big[V_{KM} M_D (\alpha_1 H_1^+ + \alpha_2 H_2^+) R + M_U V_{KM} (\beta_1 H_1^+ + \beta_2 H_2^+) L \Big] D + h.c.$$

$$\begin{matrix} R \\ L \end{matrix} = \tfrac{1}{2}(1 \pm \gamma_5) \quad \text{etc}$$

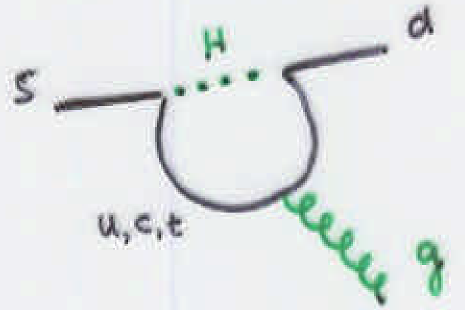
THE KM MATRIX ELEMENTS ARE TAKEN AS REAL

$$\mathrm{Im}(\alpha_1 \beta_1^*) = -\mathrm{Im}(\alpha_2 \beta_2^*) \neq 0$$

introduces CP Violation

[α_i, β_i come from diagonalisation of the Charged Higgs Mass Matrix.

Basic CPV coupling is [for $\Delta S = 1$]



$$\sim \; i g_s \tilde{f} m_s \bar{s} \sigma_{\mu\nu} \lambda^a G_a^{\mu\nu} (1-\gamma_5) d$$

$$\tilde{f} = \frac{G_F}{\sqrt{2}} \frac{1}{16\pi^2} \sum_{i=u,c,t} V_{is} V_{id} \, \mathrm{Im}(\alpha_1^* \beta_1) \left[F_3\left(\frac{m_i^2}{m_{H_1}^2}\right) - F_3\left(\frac{m_i^2}{m_{H_2}^2}\right) \right] \eta_{QCD}$$

$$F_3(x) = \frac{1}{2} \frac{x}{(1-x)^3} \left[-\frac{3}{2} + 2x - \frac{1}{2} x^2 - \ln x \right]$$

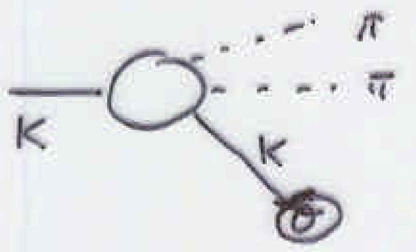
η_{QCD} is a QCD correction $\left(\frac{\alpha_s(m_H)}{\alpha_s(\mu)} \right)^{\frac{14}{33-2n_f}}$

The key operator is

$$\mathcal{O} = g_s m_s \bar{s} \sigma_{\mu\nu} \lambda^a G^{\mu\nu}_a (1-\gamma_5) d$$

For ϵ' we need $\langle (\pi\pi)_0 | \mathcal{O} | K \rangle$

AND $\langle 0 | \mathcal{O} | K \rangle$ as



AND

contribute and cancel to leading order.

For ϵ we need

$\boxed{\epsilon'/\epsilon}$

At order p^4 in χPT

$$\langle (\pi\pi)_0 | O | K \rangle = -11 \sqrt{\frac{3}{2}} \frac{m_s}{m_s + m_d} \frac{f_K^2}{f_\pi^3} m_K^2 m_\pi^2 B_0$$

$0.5 < B_0 < 2$

— There are still large uncertainties

ϵ'/ϵ then implies

$0.35 \lesssim \tilde{f} \lesssim 3.6$ in units $10^{-10}\,GeV^{-2}$.

$\boxed{\epsilon}$

Long distance dominates ϵ.

A variety of uncertain input

$g_s(m_K)$

m_s — 0.3 - 0.5 GeV

$\eta - \eta'$ mixing

SU(3) and U(3) breaking } enter a parameter x

uncertain by factor 5 ___

and uncertain in sign!

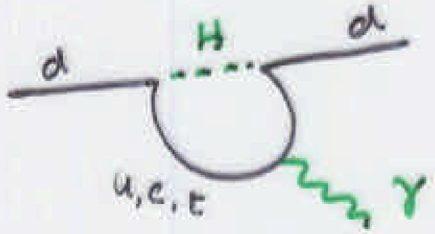
also uncertain by factor ~ 3

$0.17 \lesssim \tilde{f} \le 2.6$

$\tilde{f} \sim -0.17$

} units $10^{-10}\,\text{GeV}^{-2}$

$\boxed{d_n}$



Different loop but relate back to

$\tilde{f}$ [depends on KM matrix elements]

d-dominates and

$d_n \propto m_d$.

But what is m_d.

take current masses and

constituent masses

to illustrate. — see graph.

NB Neutral Higgs
ignored but can
contribute!

$\boxed{b \to s\gamma}$

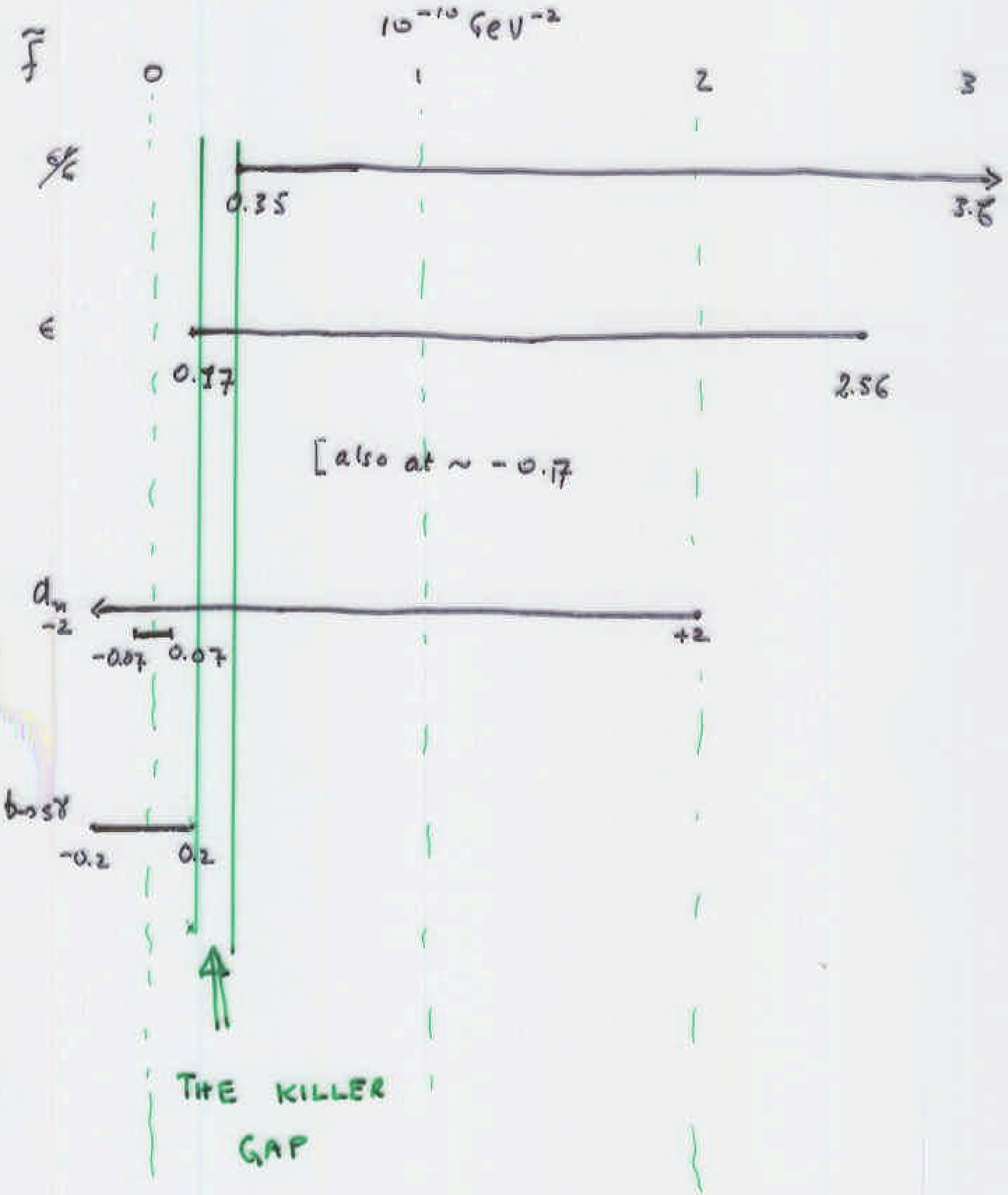
Again relate to $\tilde{f}$ in calculable way

Also a CP conserving contribution

$B(b \to s\gamma) \lesssim 4.5 \times 10^{-4}$

$$\Rightarrow \quad |\tilde{f}| < 0.2 \times 10^{-10}\ \mathrm{GeV}^{-2}$$

FITTING IT TOGETHER.



A WAY OUT?

ALLOW CPV in KM Matrix AND in $\mathrm{Im}(\alpha_1 \beta_1^*)$

ϵ'/ϵ is KM — supress $\mathrm{Im}(\alpha_1 \beta_1^*)$

OK with $b \to s\gamma$ [redacted]

An additional nail

$$\sin 2\phi_B = 0.91 \pm 0.25$$ Before this meeting

in Weinberg model, with $\mathrm{Im}(\alpha_1 \beta_1^*)$ constrained by $b \to s\gamma$

$$\sin 2\phi_B < 0.05$$

ruled out at 2 sd, but not at 3 sd.