The Iso-singlet Down Quark Model and CP Violation Experiments

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Snowmass 2001
Updated August 27, 2001

1 Introduction

- To decide whether the B Factory is significantly testing the standard CKM model of CP violation, and to determine the "reach" of the B factory in ruling out "new physics" models, we need several alternate but full physical models for comparison.
- The flavor changing neutral current (FCNC) model resulting from extra weak iso-singlet down quarks, as in E_6 with one for each generation, introduces new phases, and has not been ruled out by present experiments.
- In this talk, the predictions are constrained by new experiments with the full inclusion of SM amplitudes.
- The constraints are updated for $\sin 2\beta$ **measurements, new** x_s **bounds, new BNL results on** $K^+ \to \pi^+ \nu \bar{\nu}$**, and for** ϵ'/ϵ.
- Analysis before latest updates: D. Silverman, Phys. Rev. D **58**, 095006 (1998), hep-ph/9806489.
- Previous collaborators: Myron Bander, Michael Shin, Yossi Nir, Woon-Seng Choong, Tony Yao. Current analysis with Donovan Hawkins.

2 Iso-singlet Down Quark Mixing

The initial quarks of definite weak isospin in E_6, for each generation are: the left handed iso-doublet (u^0_{iL}, d^0_{iL}), their right handed iso-singlets u^0_{iR} and d^0_{iR}, and the yet to be found iso-singlet pair D^0_{iL} and D^0_{iR}.

We can take the initial up quark matrix to be the mass eigenstates, so $u^0_i = u_i$, giving $V^u = I_{3\times 3}$. The down quarks (d^0_i, D^0_i) corresponding to the same generations as u_i mix to form mass eigenstates (d_i, D_i) via the matrix $V^d(6\times 6)$. The weak interaction charged current matrix is then $U = V^{u\dagger} \times V^d$, the 3×6 matrix that is the upper three rows of V^d. The lower three rows of V^d are the three linear combinations of (d_i, D_i) that are the iso-singlet D^0_i which cannot couple to up quarks by the weak interactions.

We truncate the V^d matrix to the 4×4 matrix using only the D quark that mixes most, giving the Four Down Quark Model (FDQM). The D mixture now has weak charged currents to u, c, and t quarks with amplitudes $s_{14}e^{-i\delta_{14}}$, $s_{24}e^{-i\delta_{24}}$, and s_{34}, respectively, which is the fourth column. The fourth row gives the linear combination that is the initial iso-singlet D^0_4.

Leading Terms in the 4×4 Down Quark Mixing Matrix With 6 Angles and 3 Phases.

$$V = \begin{array}{c} \\ u \\ c \\ t \\ 4 \end{array} \begin{array}{c} \begin{array}{cccc} \quad d \quad & \quad s \quad & \quad b \quad & \quad D \quad \end{array} \\ \begin{pmatrix} c_{12}c_{34} & s_{12}c_{34} & s_{13}e^{-i\delta_{13}} & s_{14}e^{-i\delta_{14}} \\ -s_{12} & 1 & s_{23} & s_{24}e^{-i\delta_{24}} \\ (s_{12}s_{23} - s_{13}e^{i\delta_{13}}) & -s_{23} & 1 & s_{34} \\ V_{4d} & V_{4s} & V_{4b} & V_{44} \end{pmatrix} \end{array}$$

$$\begin{aligned} V^*_{4d} &= -s_{14}e^{-i\delta_{14}} + s_{24}e^{-i\delta_{24}}s_{12} - s_{34}(s_{12}s_{23} - s_{13}e^{-i\delta_{13}}), \\ V^*_{4s} &= -s_{24}e^{-i\delta_{24}} - s_{14}e^{-i\delta_{14}}s_{12} + s_{34}(s_{23} + s_{12}s_{13}e^{-i\delta_{13}}), \\ V^*_{4b} &= -s_{34} - s_{24}e^{-i\delta_{24}}s_{23} - s_{14}e^{-i\delta_{14}}s_{13}e^{i\delta_{13}}. \end{aligned}$$

3 FCNC in Z^0 Couplings From Extra Iso-singlet Down Quarks

FCNC Amplitudes The FCNC are given by the mixings V_{4i} to form the iso-singlet down quark by

$$-U_{ij} \equiv V_{4i}^* V_{4j} \quad \text{for} \quad i \neq j.$$

The FCNC couplings of the down quarks to the Z are then given by:

$$\mathcal{L}^Z_{FCNC} = -\frac{e}{2\sin\theta_W \cos\theta_W} U_{ij} \bar{d}_{iL} \gamma^\mu d_{jL} Z_\mu.$$

There will be constraints on three FCNC amplitudes:

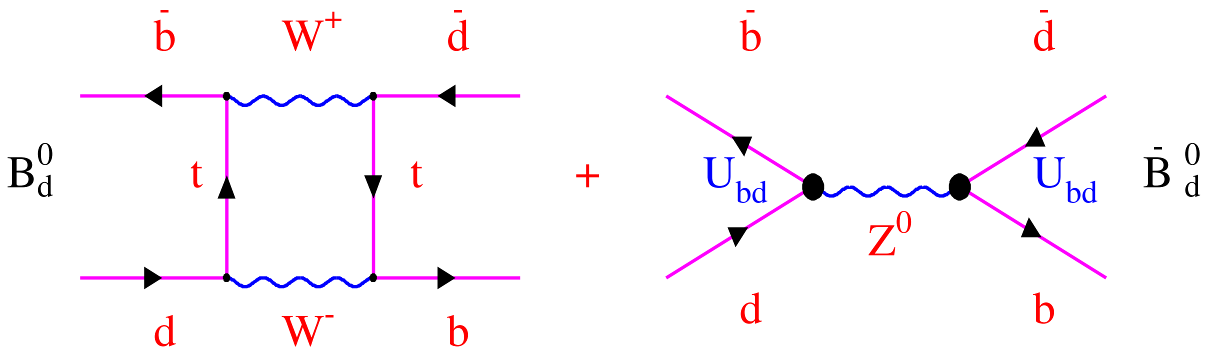
$$\begin{aligned} -U_{ds} &= V_{4d}^* V_{4s} \\ -U_{sb} &= V_{4s}^* V_{4b} \\ -U_{bd} &= V_{4b}^* V_{4d} \end{aligned}$$

Diagonal Neutral Current Decrease The diagonal neutral current couplings are reduced in strength by the amplitudes into the FCNC, becoming

$$\mathcal{L}^Z_{NC} = -\frac{e}{2\sin\theta_W \cos\theta_W} \sum_i (1 - |V_{4i}|^2) \bar{d}_{iL} \gamma^\mu d_{iL} Z_\mu.$$

4 $B_d - \bar{B}_d$ Mixing

The FCNC give rise to a second order FCNC tree level meson mixing diagram using Z^0 exchange.



$$x_d = \frac{2G_F}{3\sqrt{2}} B_B f_B^2 m_B \eta_B \tau_B \left| U_{std-db}^2 + (U_{db})^2 \right|$$

where $x_d = \Delta m_{B_d}/\Gamma_{B_d} = \tau_{B_d} \Delta m_{B_d} = \tau_{B_d} 2|M_{12}|$.

$$\begin{aligned} x_d &= 0.73 \pm 0.05, \\ \sqrt{B_B} f_B &= 0.230 \pm 0.035 \text{ GeV}. \end{aligned}$$

To leading order in s_{34}, $s_{24}e^{-i\delta_{24}}$, and $s_{14}e^{-i\delta_{14}}$ we have:

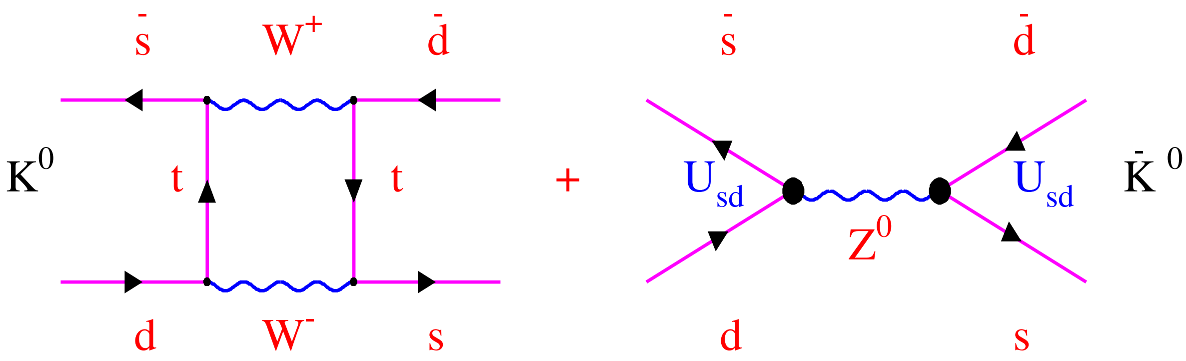
$$U_{db} = s_{34}(s_{14}e^{-i\delta_{14}} + s_{34}V_{td}^* - s_{24}e^{-i\delta_{24}} s_{12}).$$

The dominant term will turn out to be the s_{14} term with the δ_{14} phase, and the other terms are only a 5% correction.

We define the standard model amplitude for $B_d - \bar{B}_d$ mixing from x_d normalized so that it adds directly to U_{db}^2

$$U_{std-db}^2 \equiv \frac{\alpha}{4\pi \sin^2\theta_W} y_t f_2(y_t) (V_{td}^* V_{tb})^2.$$

5 Bounds on FCNC CP Violation in $|\epsilon|$



$$M_{12} =< K^0|H|\bar{K}^0 >$$

$$1 - 2\epsilon = \sqrt{\frac{M_{12}^*}{M_{12}}} \approx 1 - i\mathrm{Im}(M_{12})$$

$$|\epsilon| = 2.27 \times 10^{-3}$$

$$|\epsilon| = \frac{G_F f_K^2 B_K m_K}{12\Delta m_K} \left|\mathrm{Im}(U^2_{std-ds}) + \mathrm{Im}(U^2_{ds})\right|.$$

where

$$U^2_{std-ds} \equiv \frac{\alpha}{4\pi \sin^2\theta_W}(\eta_2 y_t f_2(y_t)(V^*_{td}V_{ts})^2 + \ldots)$$

$$\begin{aligned} |\mathrm{Im}[(U_{ds})^2]| &\leq 9.2 \times 10^{-10} \\ |\mathrm{Re}(U_{ds})\mathrm{Im}(U_{ds})| &\leq 4.6 \times 10^{-10} \end{aligned}$$

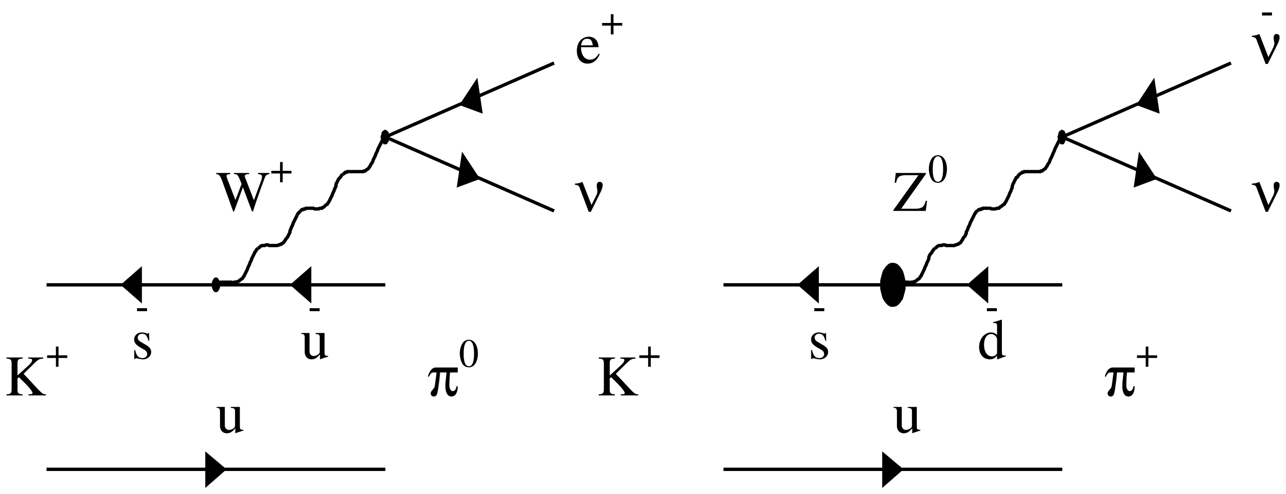
6 Bounds From $K^+ \to \pi^+ \nu\bar{\nu}$

BNL E-787 with one event, giving a branching ratio

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = 1.5^{+3.4}_{-1.2} \times 10^{-10},$$

is now in the standard model range of $(0.6 - 1.5) \times 10^{-10}$. Because of this, we have now added in the SM contribution with the extra down quark FCNC.

The diagram on the right shows how the FCNC can contribute to this process. Diagrams for $s \to d + Z^0$ also exist in the standard model using penguins.



To cancel out the hadronic interactions, this is scaled to a ratio

$$\frac{\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu})}{\mathrm{BR}(K^+ \to \pi^0 e^+ \nu)} = \frac{1}{2}\frac{|U_{ds}|^2}{|V_{us}|^2}.$$

This gives a contribution to $\chi^2 = 2 < n >= 0.84 \times 10^9 \; |U_{ds}|^2$.

At 90% CL, where $\chi^2 = (1.64)^2$, this gives

$$|U_{ds}|^2 \leq 3.2 \times 10^{-9},$$

comparable to the limits from ϵ.

7 Bound From $Z^0 \to b\bar{b}$

Weak isovector part of $Z^0 \to b\bar{b}$ reduced by $(1 - |V_{4b}|^2)$

$$
\begin{aligned}
V^b &= -\frac{1}{2}(1 - |V_{4b}|^2) + \frac{2}{3}\sin^2\theta_W + \frac{1}{3}\rho_t, \\
A^b &= -\frac{1}{2}(1 - |V_{4b}|^2) + \frac{1}{3}\rho_t \\
C_{QCD} &= 3(1.0385) \\
\Gamma^{std}(Z^0 \to b\bar{b}) &= \frac{C_{QCD} G_F m_Z^3}{6\sqrt{2}\pi}\left[(V^b)^2 + (A^b)^2\right]
\end{aligned}
$$

where $\rho_t = 0.0094$ for $m_t = 174$ GeV. Present data and theory:

$$
\begin{aligned}
R_b^{\text{exp}} &= 0.21642 \pm 0.00073 \\
R_b^{\text{theory}} &= 0.2158 \pm 0.0003
\end{aligned}
$$

Note that the $|V_{4b}|$ effect is to decrease R_b, while the experiment is about 1σ above the theory.

$$
\frac{\Gamma_{b\bar{b}}^{std+FCNC}}{\Gamma_{b\bar{b}}^{std}} = (1 - 2.29|V_{4b}|^2),
$$

$$
\chi^2 = \left(\frac{0.2164 - 0.2158(1 - 2.29|V_{4b}|^2)}{0.00073}\right)^2,
$$

$$
\chi^2 = (0.82 + 0.68 \times 10^3 |V_{4b}|^2)^2.
$$

Taking the 90% CL limit at $\chi^2 = (1.64)^2$, gives

$$
|V_{4b}| \approx |s_{34}| \leq 0.035.
$$

8 CKM, FCNC, and B Factory Experiments

- CKM Experiments (8) Commonly Used for Standard Model

V_{us}	
$\lvert V_{cb}\rvert = 0.0404 \pm 0.0016$	
$\lvert V_{ub}/V_{cb}\rvert = 0.101 \pm 0.016$	
x_d	U_{db}
$\lvert\epsilon\rvert$	$\mathrm{Im}(U_{ds}^2)$
x_s bound	U_{sb}
$\sin(2\beta) = 0.79 \pm 0.19$	U_{db}^2

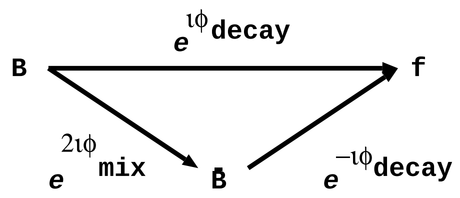
- Added Experiments (7) for the Four Down Quark Model

V_{ud}, V_{cd}	
$K_L \to \mu\mu$	$\mathrm{Re}(U_{ds})$
$B \to \mu\mu X_s$	$\lvert U_{sb}\rvert$
$Z^0 \to b\bar{b}\ (R_b)$	$\lvert V_{4b}\rvert$
$K^+ \to \pi^+\nu\bar{\nu}$	$\lvert U_{ds}\rvert$
$\mathrm{Re}(\epsilon'/\epsilon) = 17.3 \pm 2.4$	$\mathrm{Im}(U_{ds})$

- B Factory Projected Experiment (1)

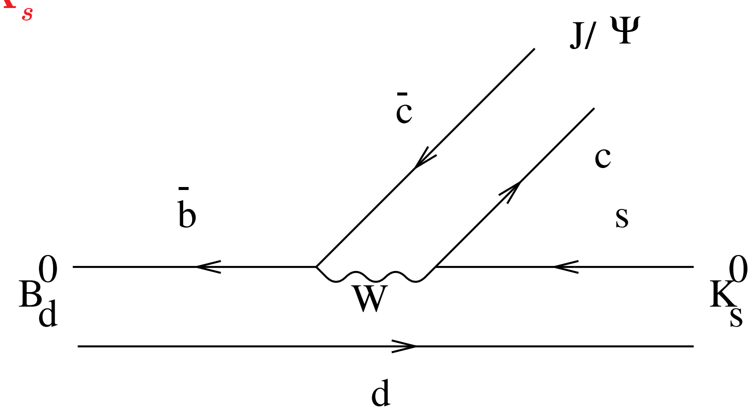
$\sin(2\alpha)$	U_{db}^2

9 CP Violating Asymmetries at the B Factory



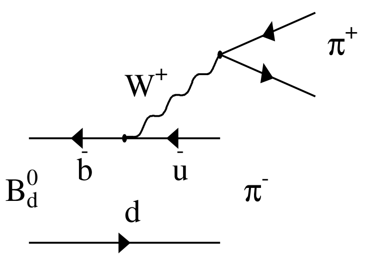
- sin (2α) and sin (2β) are now defined as the measured B factory asymmetries, but they do not correspond to unitarity triangle or quadrangle angles in the four down quark model.

- $B_d^0 \rightarrow J/\Psi K_s^0$



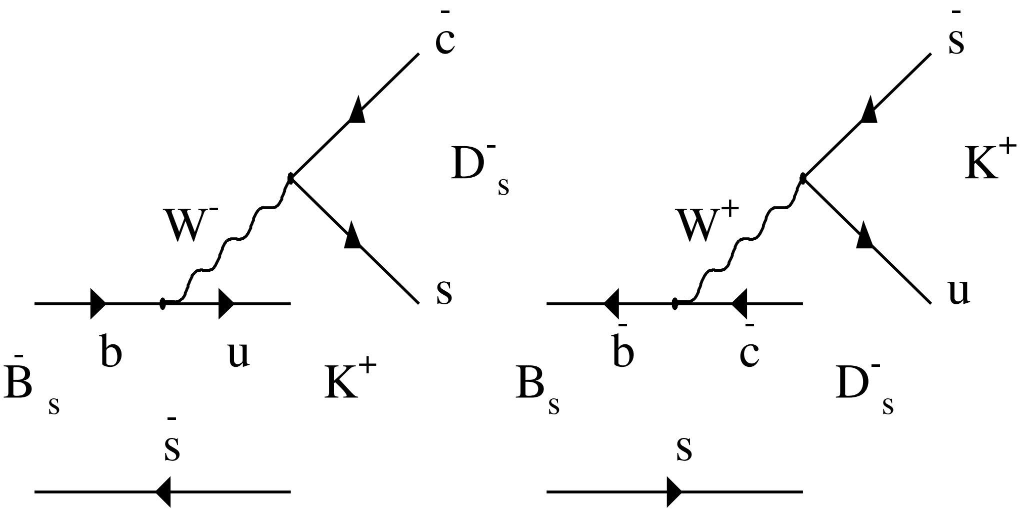
$$\sin(2\beta) \equiv A_{B_d^0 \rightarrow \Psi K_s^0} = \mathrm{Im}\left[\frac{(U_{std-db}^2 + U_{db}^2)}{|U_{std-db}^2 + U_{db}^2|}\frac{(V_{cb}^* V_{cs})}{(V_{cb}^* V_{cs})^*}\right]$$

- $B_d^0 \rightarrow \pi^+\pi^-$



$$\sin(2\alpha) \equiv -A_{B_d^0 \rightarrow \pi^+\pi^-} = -\mathrm{Im}\left[\frac{(U_{std-db}^2 + U_{db}^2)}{|U_{std-db}^2 + U_{db}^2|}\frac{(V_{ub}^* V_{ud})}{(V_{ub}^* V_{ud})^*}\right]$$

10 CP Violation and $\sin(\gamma)$ in $\bar{b} \to \bar{u} + c + \bar{s}$



The B_s oscillation amplitude is almost real, allowing phases from decay amplitudes to be measured alone. The phase is

$$\phi_{qf} = -(2\phi(B_q \to \bar{B}_q) + \phi(\bar{B}_q \to f) - \phi(B_q \to f))$$

Two of the four processes, out of those for B_s and $\bar{B}_s$ decays into final states f and $\bar{f}$, must be measured together. The largest branching ratios for $\sin(\gamma)$ processes is in

$$B_s,\ \bar{B}_s \to D_s^{\pm}\ K^{\mp}$$

where the $BR \approx 2 \times 10^{-4}$

Here, the $\bar{B}_s$ decay to the final state involves V_{ub}^*, but the conjugate process for B_s does not involve $b \to u$ and is thus almost real. Since
$V_{ub} = s_{13}e^{-i\gamma}$, and B_s mixing is almost real, the final asymmetry which is the imaginary part, only involves $\sin(\gamma)$, not $\sin(2\gamma)$.

In the four down quark model

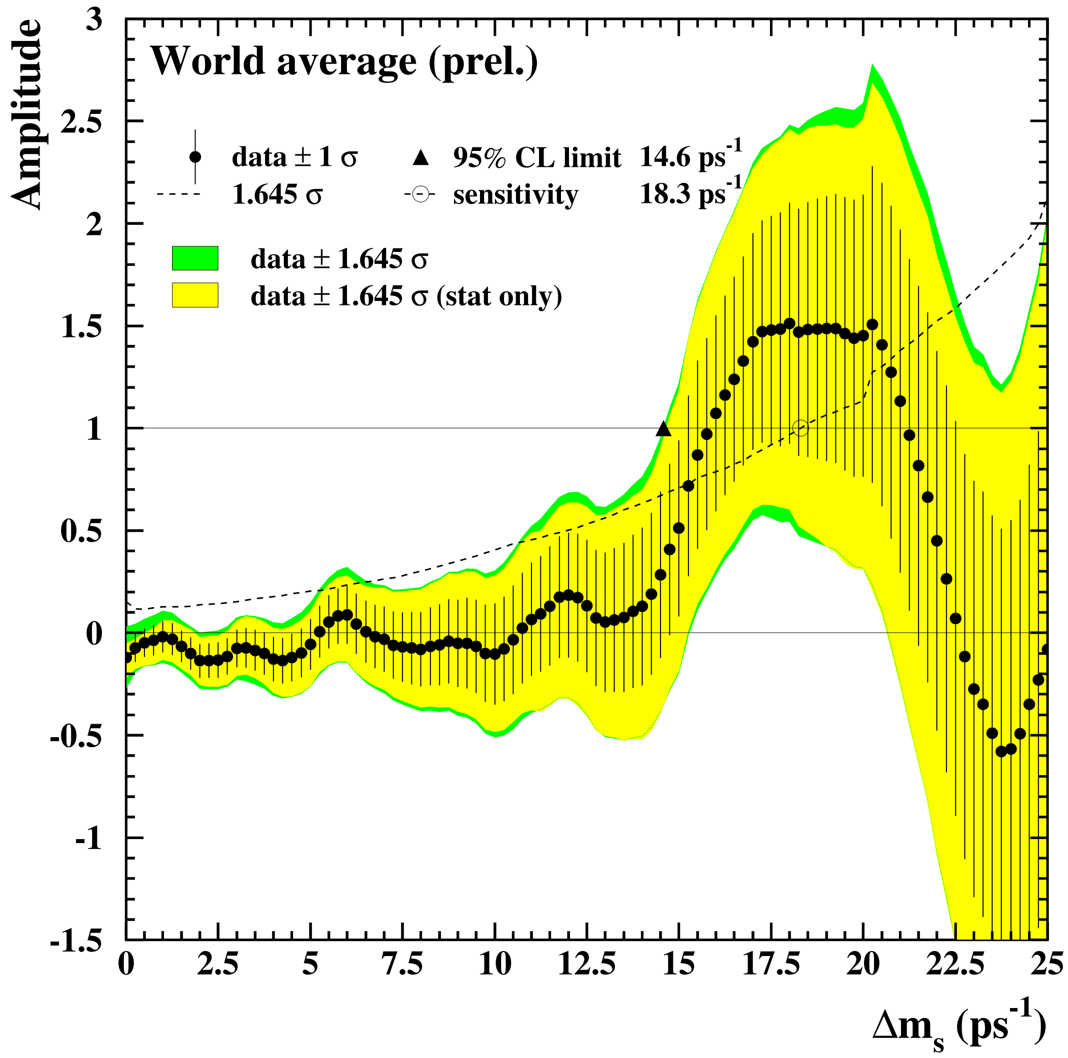
$$\sin(\gamma) = \mathrm{Im}\left(\frac{(U_{std-bs}^2 + U_{bs}^2)}{|U_{std-bs}^2 + U_{bs}^2|}\frac{(V_{ub}^* V_{cs})}{|V_{ub} V_{cs}|}\right).$$

11 The "Frequency" of B_s Oscillations, x_s

Here we exclude the theoretical uncertainty on $B_{B_s} f_{B_s}^2$, and take the ratio of x_s to x_d, which is better calculated, and in which we have also included the FCNC with Z^0 exchange

$$x_s = \frac{\Delta m_s}{\Gamma_{B_s}} = 1.35\ x_d \frac{|U_{std-bs}^2 + U_{bs}^2|}{|U_{std-db}^2 + U_{db}^2|}$$

We now include the amplitude method analysis of LEP with SLD to assign a $\Delta\chi^2$ for each Δm_s calculated in the parameter grid. The world compiled data is shown in the figure below, where a value of 1 would be the detection of the correct Δm_s.



12 The B_s Decay Asymmetry, $\sin(2\phi_s)$

In the standard model, B_s mixing involves $(V_{ts}^* V_{tb})^2$ which is almost exactly real. Thus almost no CP violating phase develops in the most likely B_s decays involving the real amplitude for $\bar{b} \to \bar{c} + c + \bar{s}$. This occurs in the decays $B_s \to J/\Psi\phi$, $B_s \to D_s^+ D_s^-$, and $B_s \to J/\Psi K_S$. In the SM the angle ϕ_s is the small angle in the $b-s$ unitarity triangle, whose non-zero value indicates CP violation.

In the four down quark model, the CP violating decay asymmetry is

$$\sin(2\phi_s) = \mathrm{Im}\left(\frac{(U_{std-bs}^2 + U_{bs}^2)}{|U_{std-bs}^2 + U_{bs}^2|}\frac{(V_{cb}^* V_{cs})}{(V_{cb} V_{cs}^*)}\right).$$

Because of the additional flavor changing term, the angle given by the above asymmetry will not be an angle in the four down quark model.

13 Comprehensive Maximum Likelihood Analysis: Experiments and Degrees of Freedom

Standard Model Alone

4 parameters (3 angles, 1 phase)

- 8 common experiments - 4 parameters $\rightarrow$ 4 degrees of freedom

Standard Model With Comparison Experiments

4 parameters (3 angles, 1 phase)

- 8 common experiments + 3 extra for comparison - 4 parameters $\rightarrow$ 7 degrees of freedom

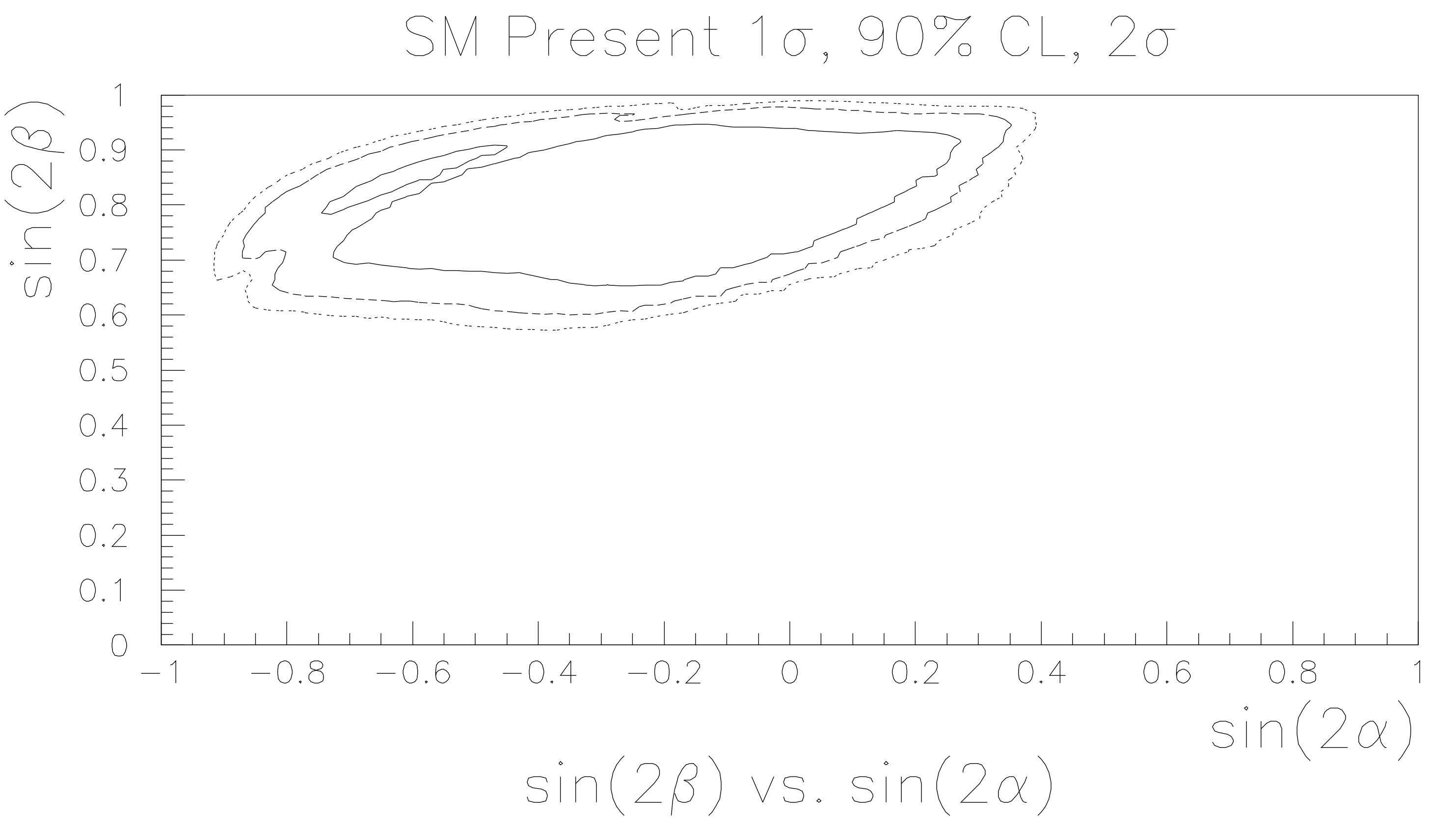
Four Down Quark Model

9 parameters (6 angles, 3 phases)

- 15 present experiments - 9 parameters $\rightarrow$ 6 degrees of freedom
- $\sin 2\alpha$ at B factory, add 1 expt. $\rightarrow$ 7 degrees of freedom

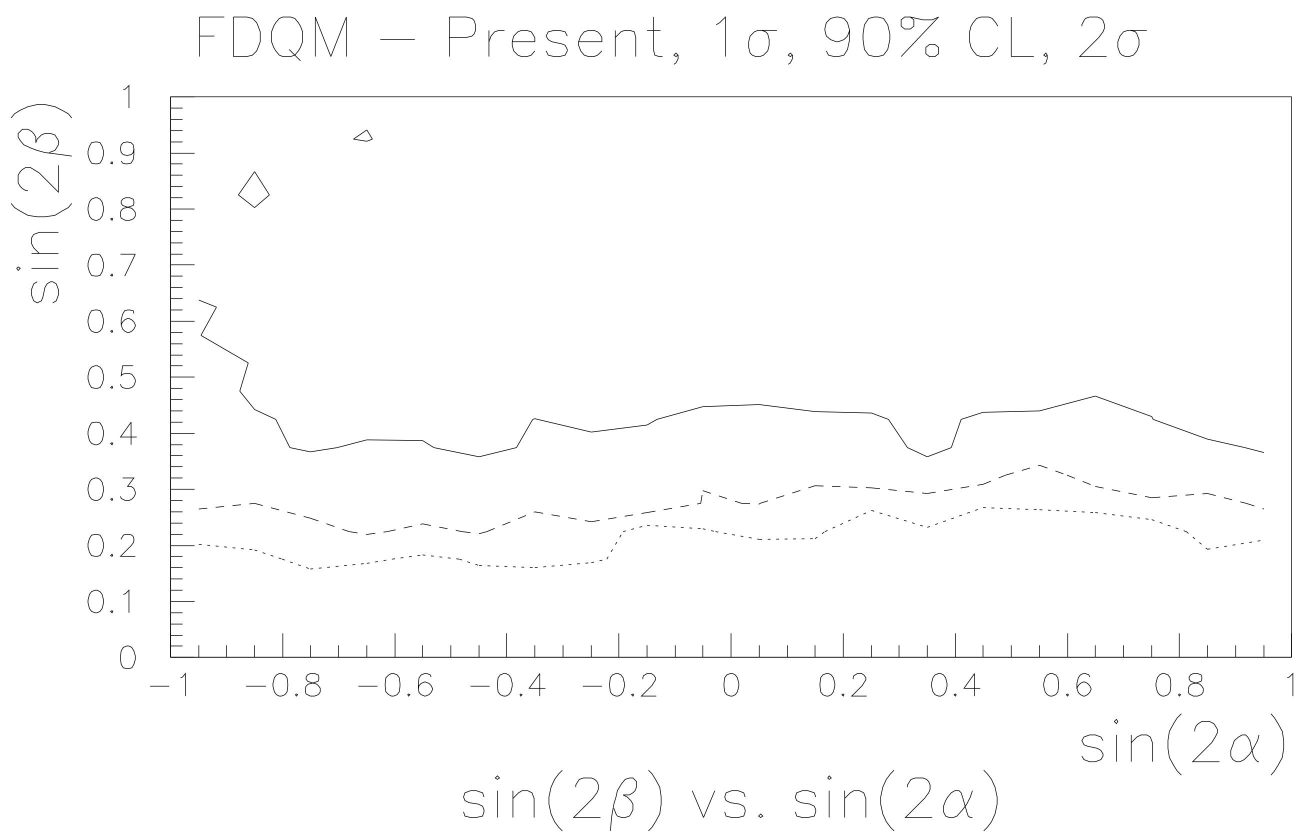
14 Standard Model Alone $(\sin(2\alpha), \sin(2\beta))$ Plot - Present Constraints

- Present Data: $\sin(2\beta) = 0.79 \pm 0.19$.
- $\sin(2\beta)$ range from 0.56 to 1.0 at 2-σ, centered around experimental average of 0.79.
- $\sin(2\alpha)$ range at 2-σ is -0.95 to +0.4.



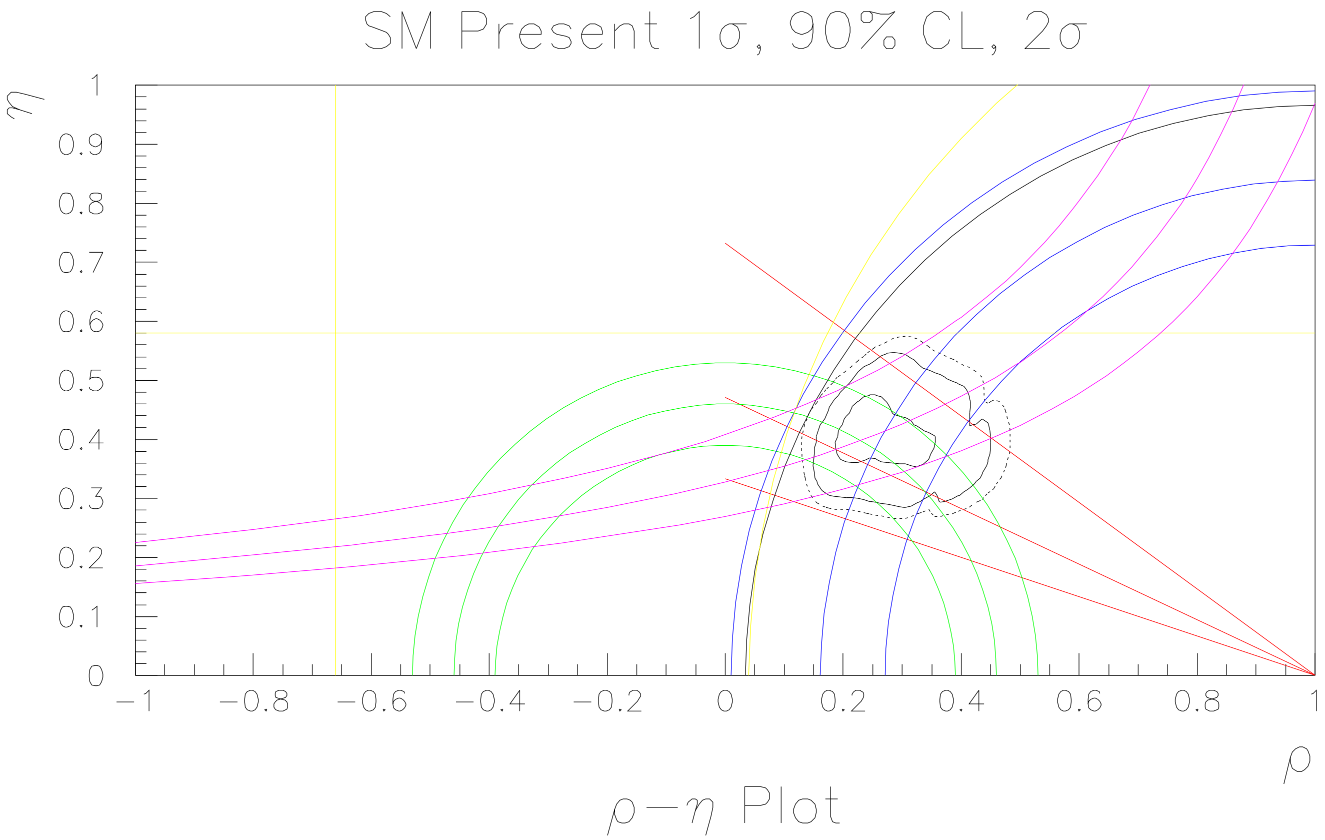
15 Four Down Quark Model $(\sin(2\alpha), \sin(2\beta))$ Plots - Present Limits

- Almost the entire region $\sin(2\beta) > 0.2$ is allowed at 2-σ.
- All of $\sin(2\alpha)$ is allowed.



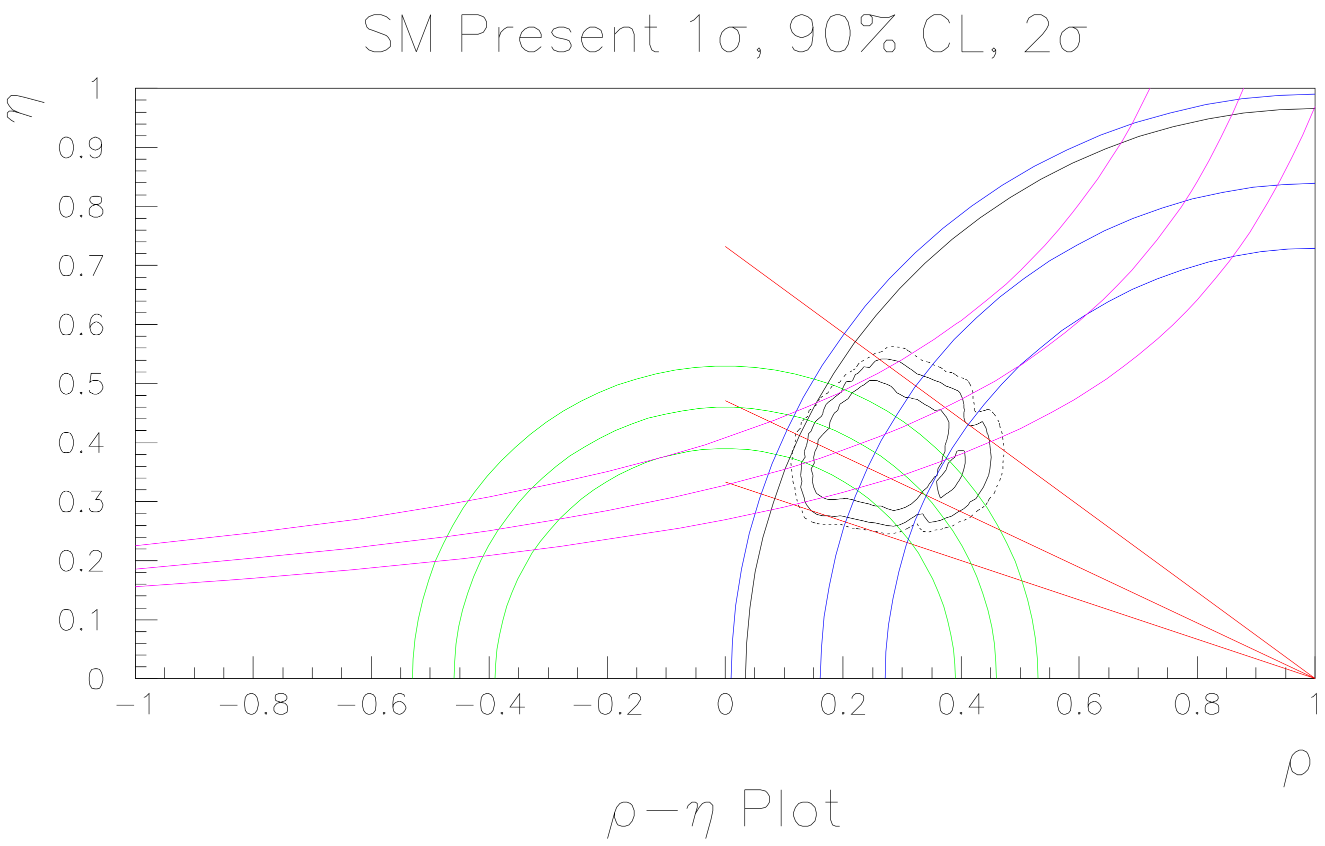
16 Standard Model with Comparison Experiments (ρ, η) Plot

- Contours are 1-σ, 90% CL, and 2-σ.
- Loose contours for SM are in yellow for ϵ'/ϵ (horizontal), $K_L \to \mu\mu$ (vertical), and $K^+ \to \pi^+ \nu \bar{\nu}$ (arc of circle).
- The Δm_s 90% circular arc is in black.



17 Standard Model Alone (ρ, η) Plot

- Contours are 1-σ, 90% CL, and 2-σ.
- The Δm_s 90% circular arc is in black.
- The green circles are center and 1-σ for $|V_{ub}|$.
- The purple hyperbolas are for ϵ.
- The blue circles are for x_d in $B_d - \bar{B}_d$ mixing.
- The red lines are for $\sin(2\beta)$.



18 Four Down Quark Model: (ρ, η) Plots

➤ Here, the plotted ρ and η are taken as the coordinates of V_{ub}^*

$$\rho + i\eta = V_{ub}^*/|V_{cd}V_{cb}|$$

➤ The plots are extended to negative $\eta = \mathrm{Im}(V_{ub}^*/|V_{cd}V_{cb}|)$.

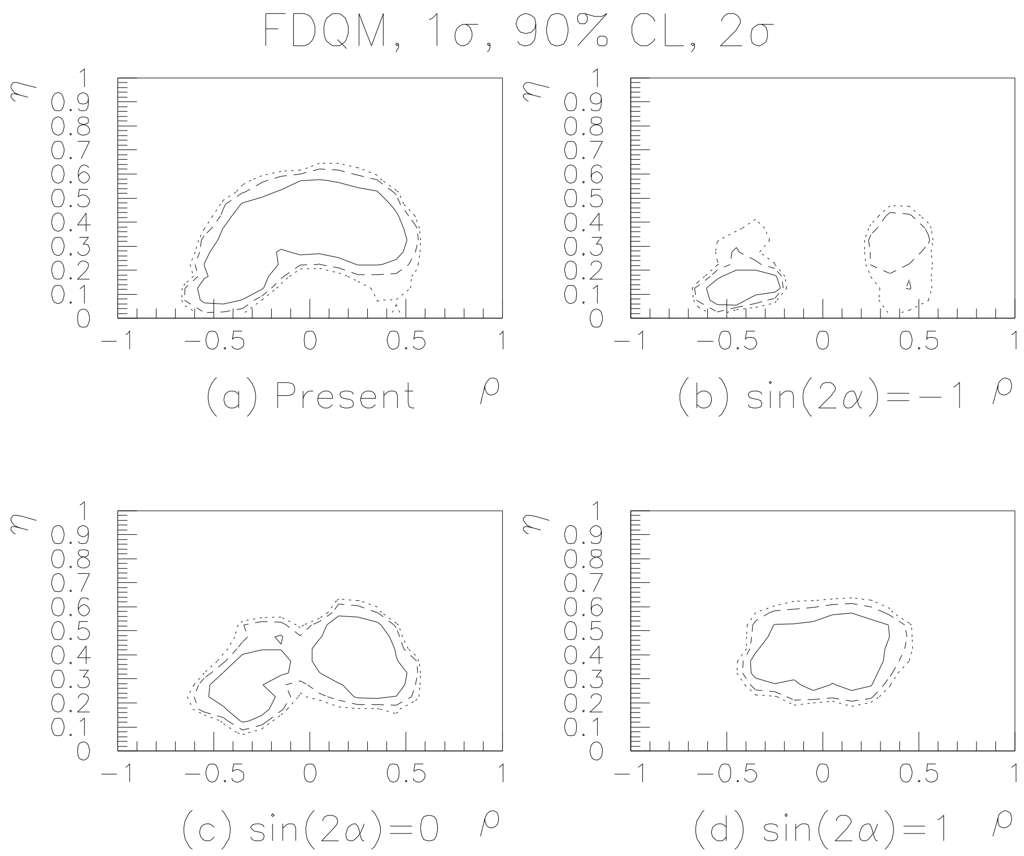
➤ There is now a unitarity quadrangle

$$V_{ub}^*V_{ud} + V_{cb}^*V_{cd} + V_{tb}^*V_{td} + V_{4b}^*V_{4d} = 0$$

where the last term has limits $|U_{bd}/V_{cb}^*V_{cd}| \le 0.1$.

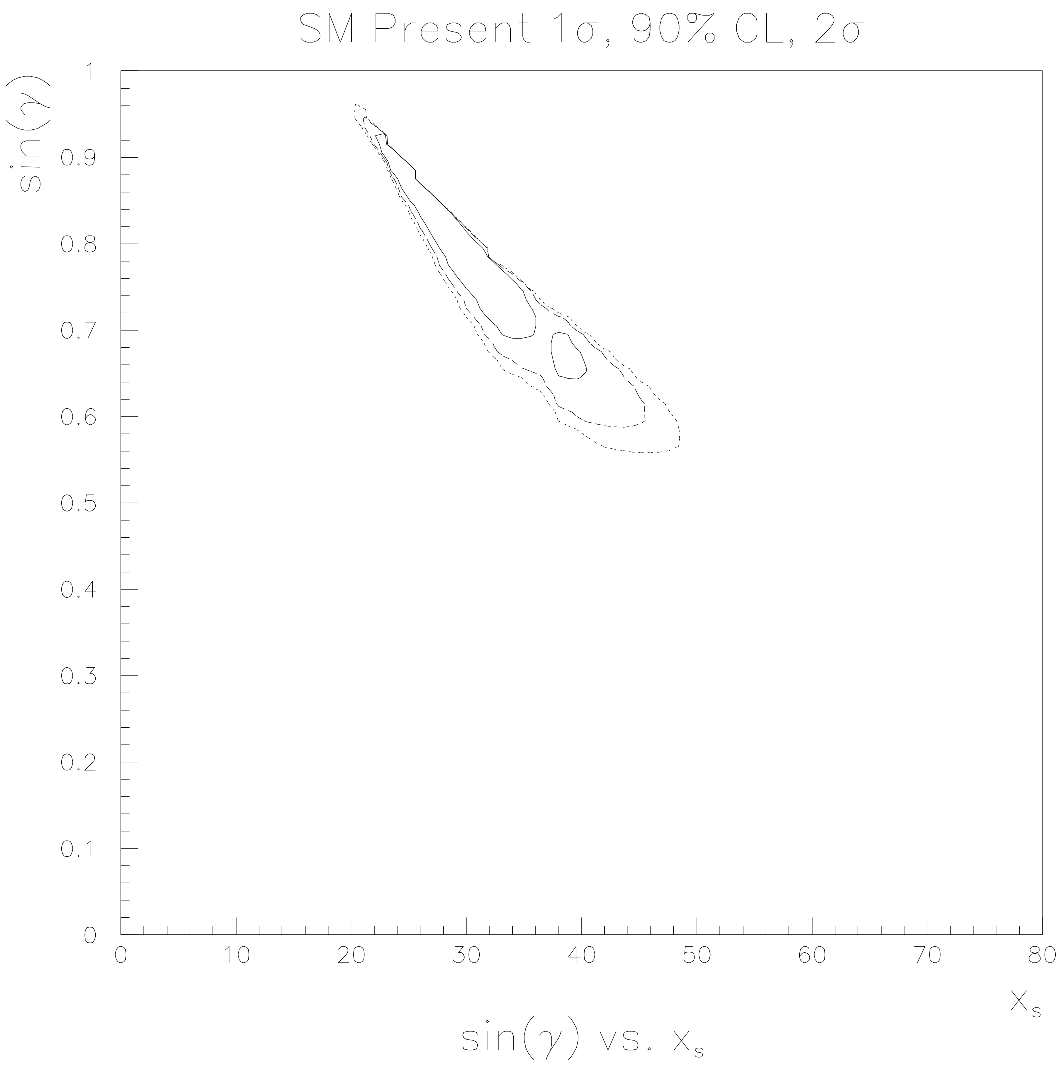
➤ The half circles in $\delta = \delta_{13}$ ($V_{ub}^* = s_{13}e^{i\delta_{13}}$) are due to δ_{14} or δ_{24} being some of the source of the observed CP violation in ϵ, so that δ_{13} is less constrained.

➤ The regions no longer go into the full (ρ, η) plane due to the new $\sin(2\beta)$ measurements.



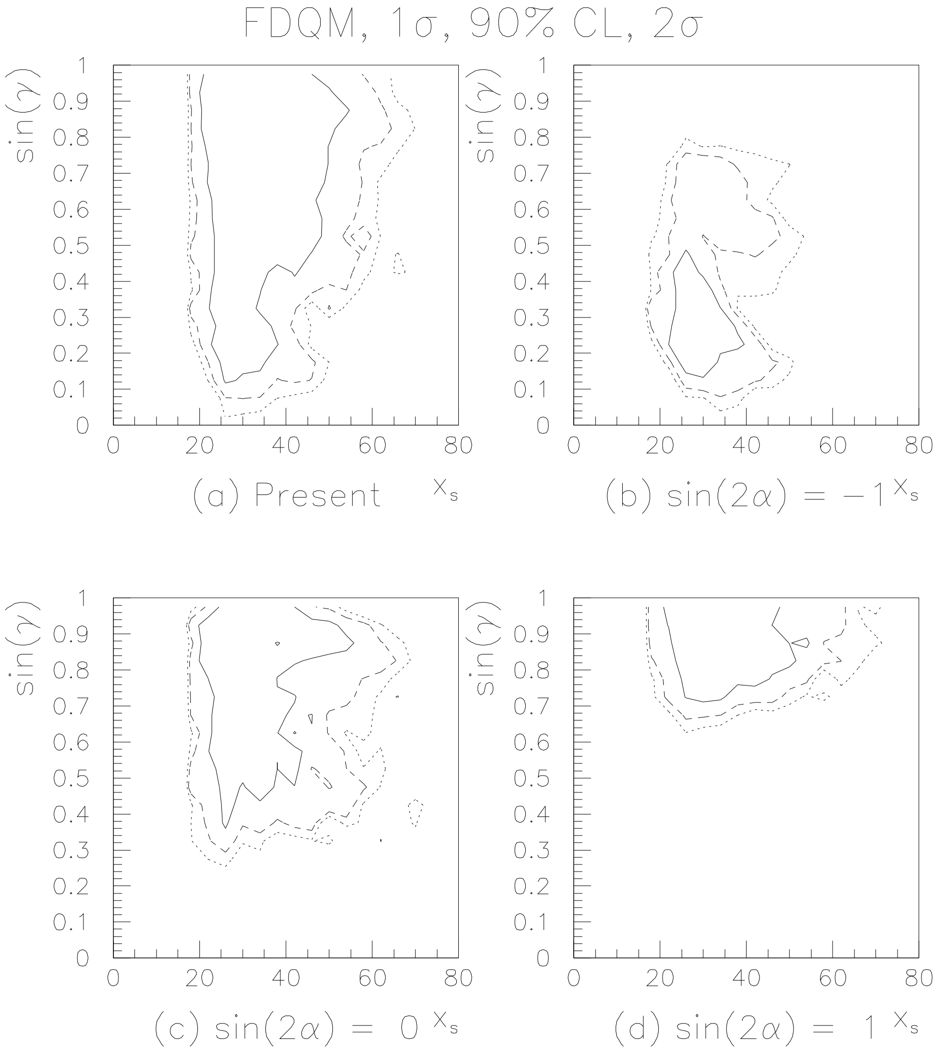
19 Standard Model Alone ($x_s, \sin(\gamma)$) Plots

- Present Data: $0.55 \le \sin(\gamma) \le 0.95$, $\quad 20 \le x_s \le 54$ at 2-σ.
- x_s measurement can strongly constrain $\sin(\gamma)$.



20 Four Down Quark Model $(x_s, \sin(\gamma))$ Plots

- Extended $\sin(\gamma)$ range including to $-1 \leq \sin(\gamma) \leq 1$ not much needed as η is now positive or zero.
- A larger $\sin(\gamma)$ range is allowed than in the standard model.
- The x_s allowed region is 15 to 70 at 2-σ, larger than in the standard model.



21 B_s Decay Asymmetry from B_s Mixing, $\sin(2\phi_s)$

➤ ϕ_s is the small angle in the $b-s$ unitarity triangle given by

$$V_{cb}^* V_{cs} + V_{tb}^* V_{ts} + V_{ub}^* V_{us} = 0.$$

➤ In Wolfenstein terms this is

$$(A\lambda^2) \times 1 + 1 \times (-A\lambda^2) + (A\lambda^3(\rho + i\eta)) \times \lambda = 0.$$

➤ Then, $\sin(\phi_s) = A\lambda^4\eta / A\lambda^2 = \lambda^2\eta$.

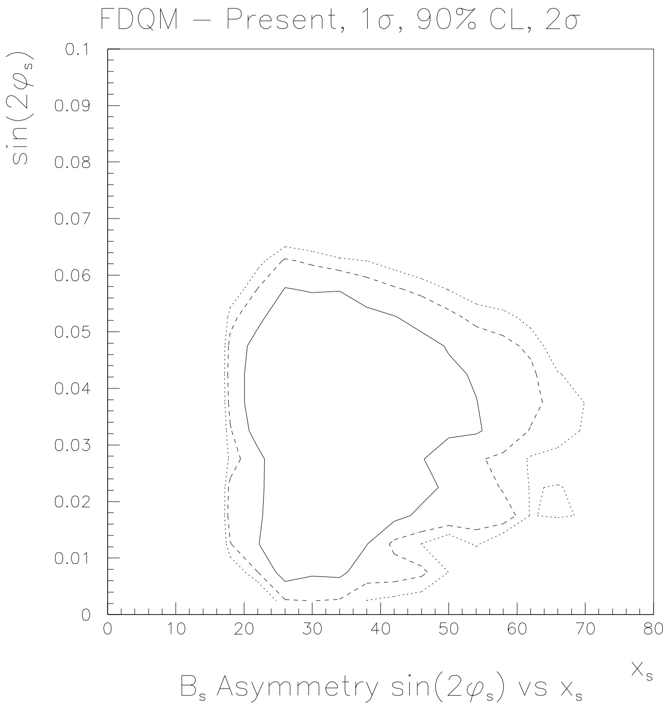
➤ This is almost zero in the Standard Model where $\sin(2\phi_s) = 2\lambda^2\eta = 0.10\eta$, or at 2σ

$$0.030 \leq \sin(2\phi_s) \leq 0.060.$$

➤ In the four down quark model, $0 \leq \sin(2\phi_s) \leq 0.065$ at 2σ.

➤ Here the range continues down to zero since η can go down to zero.

➤ Hence, a low value of $\sin(2\phi_s)$ would signify a deviation from the SM. However, the low η would show up much sooner in the $\rho-\eta$ plot which is being measured now.



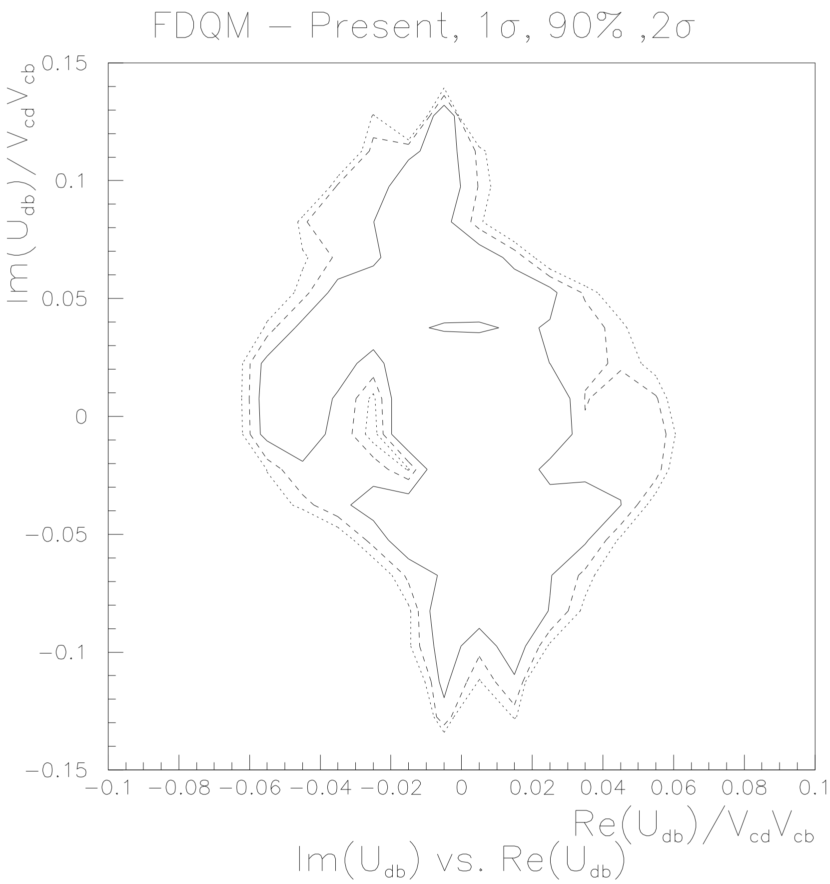
22 Fourth Side of the Unitary Quadrangle U_{bd}

- Unitarity of the $b-d$ columns has four terms, which may be written as

$$V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} - U_{bd} = 0, \tag{1}$$

since $-U_{bd} = V_{4b}^{*}V_{4d}$. (We use $U_{db} = U_{bd}^{*}$).

- As the unitarity triangle is scaled by $|V_{cb}^{*}V_{cd}|$ to make a unit base, the complex plot of U_{bd} is also so scaled.
- The length of the $U_{bd}/|V_{cb}^{*}V_{cd}|$ side is thus of the order of 0.1, compared to the unit base in the (ρ, η) plot, prefering possibly a more vertical direction.
- The accuracy of angles and sides of the unitarity triangle must and should reach this accuracy for a good test of the SM.

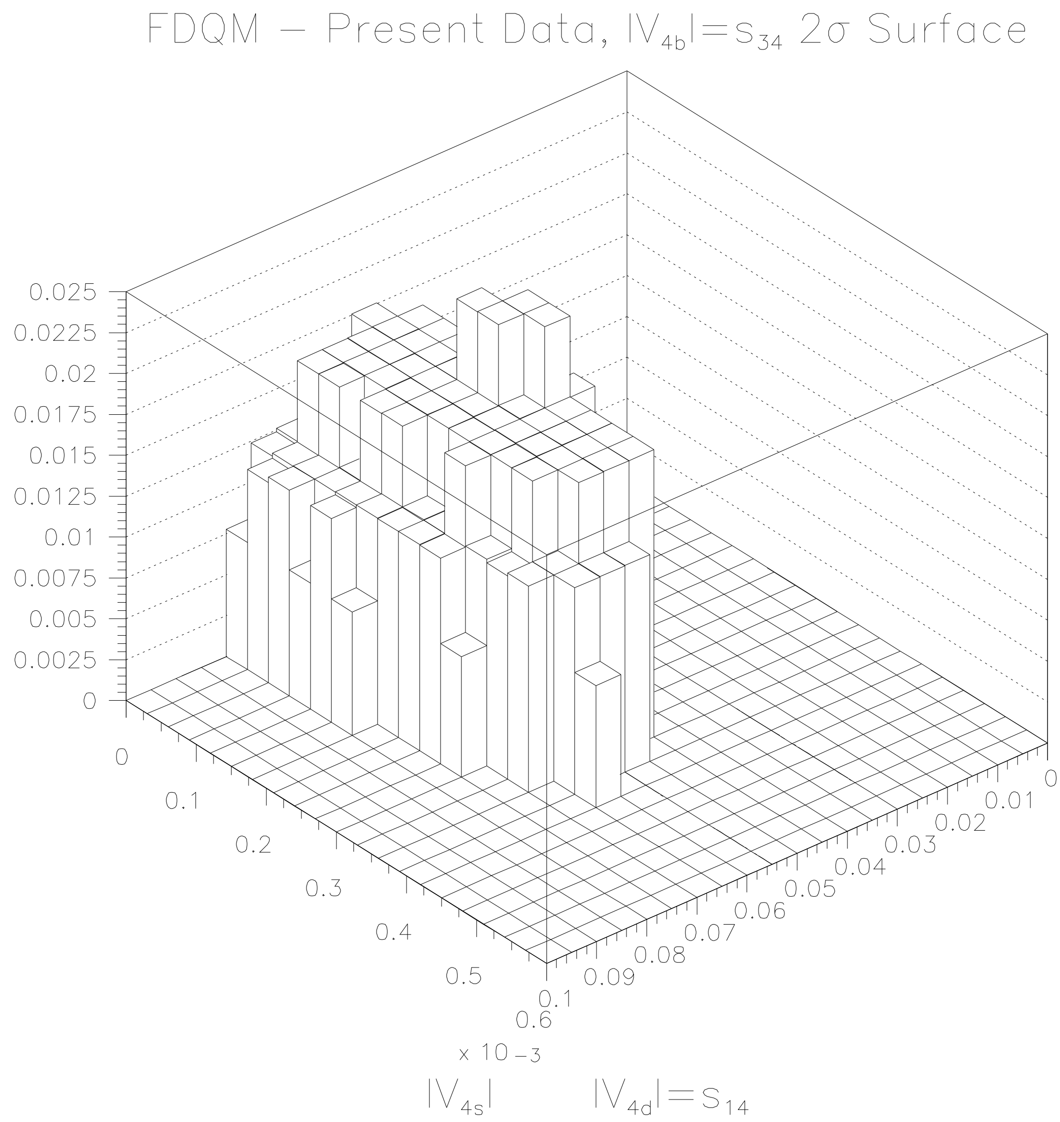


23 Size of the Mixing Matrix Elements and Mixing Angles

- To 5% accuracy, $V_{4d} = -s_{14}e^{i\delta_{14}}$, and its magnitude ranges from 0.04 to 0.08 at 2σ (see next slide).
- To 10% accuracy, $V_{4b} = -s_{34}$, and its magnitude ranges up to 0.023 at 2σ.
- V_{4s} is bounded by 0.0004, and requires a fine cancellation in $-s_{24}e^{i\delta_{24}} - s_{12}s_{14}e^{i\delta_{14}}$, such that $s_{24} \approx s_{12}s_{14}$ and $\delta_{24} = \delta_{14} + \pi$ to get the cancelling minus sign.
- This means that there is effectively only one new phase, which we may consider as δ_{14}.
- From the cancellation, s_{24} ranges from 0.009 to 0.017 at 2σ.
- The cancellation is to about 1/20 of the value of s_{24}.
- The third term in V_{4s}, $s_{34}(s_{23} + s_{12}s_{13}e^{i\delta_{13}})$ then contributes the same order, ≤ 0.0009.
- The cancellation does not mean fine tuning since one could have parametrized V_{4s} by s_{24} instead. However, the incredibly small size of $|V_{4s}| \leq \lambda^5$ could be considered a fine tuning itself.
- In Wolfenstein terms, $|V_{4d}| = s_{14} \approx \lambda^2$, $s_{24} \approx s_{12}s_{14} \approx \lambda^3$, $|V_{4b}| = s_{34} < \lambda^2/2$, but $|V_{4s}| \leq \lambda^5$. The sequence violates the heirarchical expectation from the 3×3 CKM matrix.
- In the double FCNC Z^0 exchange amplitude in $B_d - \bar{B}_d$ mixing, via

  $$U_{db} = -V_{4d}^* V_{4b} = s_{14}e^{-i\delta_{14}}s_{34},$$

  it is only the δ_{14} phase in $(U_{db})^2 \approx e^{-2i\delta_{14}}$ that can add to the SM box diagram term with its phase $e^{2i\beta}$.


FDQM – Present Data, $|V_{4b}|=s_{34}$ 2σ Surface
0.025
0.0225
0.02
0.0175
0.015
0.0125
0.01
0.0075
0.005
0.0025
0
0
0.1
0.2
0.3
0.4
0.5
0.6
x 10 −3
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
$|V_{4s}|$
$|V_{4d}|=s_{14}$

24 Conclusions for Iso-singlet Down Quark Models

- FCNC can contribute significantly to $B_d - \bar{B}_d$ mixing and to $B_s - \bar{B}_s$ mixing, and give new phases.
- Almost all $\sin(2\beta) > 0$ and $\sin(2\alpha)$ are allowed.
- There are **larger allowed regions** in the (ρ, η) and in the $(x_s, \sin(\gamma))$ plots from new physics with new phases after the B factory results.
- This will **require the additional experiments of x_s and $\sin(\gamma)$**, first to isolate a region, and then to rule in or out a new physics model.
- In new physics models, the SM phase **δ can be smaller or arbitrary**, with the other phases causing the presently observed CP violation.
- The present range for x_s is from 20 to 54 at 2-σ in this SM analysis, and from 15 to 70 at 2-σ in the four down quark model.
- The **$\sin(\gamma)$** range is from 0.55 to 0.95 at 2-σ in the SM analysis, and **from 0 to 1** in the four down quark model.
- The **unitarity triangle** has to be measured to an accuracy of 0.1 to test the SM.
- Each E_6 generation also contains an iso-singlet neutrino, which may provide a connection between the quark and lepton searches for new physics.
- The **mass** of the lightest singlet down quark in E_6 could be roughly related to the mixing angle by

  $$\theta_{34}^2 \simeq m_b/m_D, \quad |V_{4b}| \simeq \theta_{34} \leq 0.02$$

  (from combined fits), giving

  $$m_D \geq 2500 \times m_b = 11 \text{ TeV}.$$

  Using the single R_b 90% CL limit of $|\theta_{34}| \leq 0.035$, which is not as good, gives $m_D \geq 4$ TeV. The previous analysis (1998) gave a limit of 1.2 TeV.
- This talk is on the web at http://www.physics.uci.edu/~silverma/snow.ps.