New Physics Models and CP Violation Experiments

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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, has been very effective in causing new effects, but not being ruled out by present experiments.
- In this talk, the predictions are extended to the full range of angular experimental results.
- The constraints are updated for new x_s bounds, and for new data on R_b, the D0 bound on $K \to \mu\mu X$, and the BNL bound on $K^+ \to \pi^+\nu\bar{\nu}$.
- With Herng Tony Yao we also analyze the Left-Right Symmetric Model (LRSM).
- Most recent published version: D. Silverman, Int. Journal of Modern Physics A11, 2253 (1996), hep-ph/9504387.
- Previous collaborators: Myron Bander, Michael Shin, Yossi Nir, Woon-Seng Choong, Tony Yao.

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

Mixing Angles in the 4×4 Mixing Matrix Have 6 Angles and 3 Phases.

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

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

FCNC Amplitudes The FCNC are given by the mixings to the fourth 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:

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

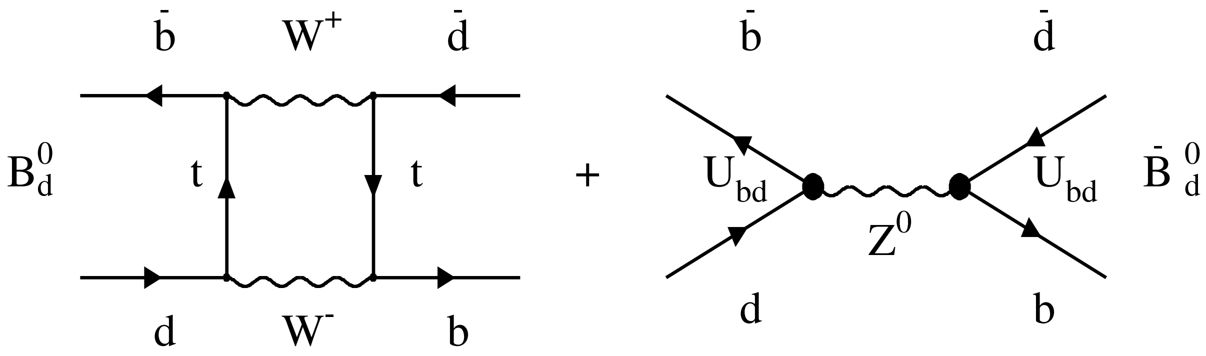
There will be constraints on three FCNC amplitudes:

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

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

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

3 $B_d - \bar{B}_d$ Mixing



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

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

$$\begin{aligned} x_d &= 0.73 \pm 0.05, \\ \sqrt{B_B} f_B &= 0.200 \pm 0.040 \text{ GeV}. \end{aligned}$$

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

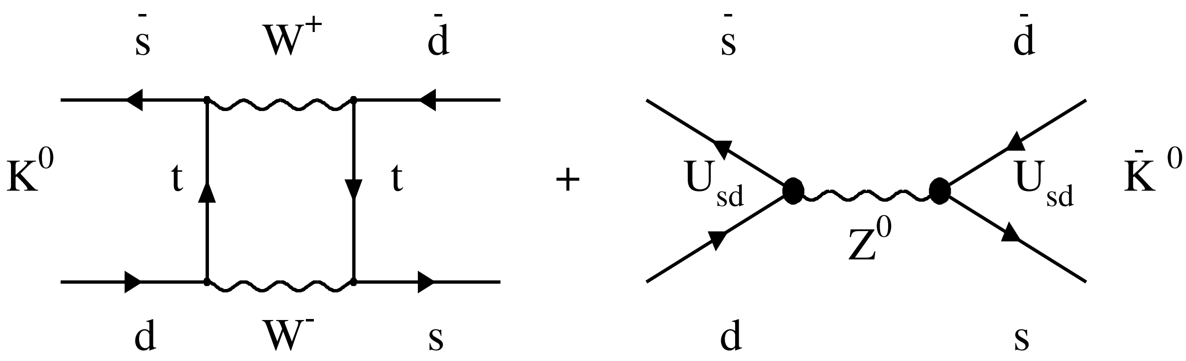
$$U_{db} = -s_{34}(s_{34}V^*_{td} + s_{14}e^{-i\delta_{14}} - s_{24}e^{-i\delta_{24}}s_{12}).$$

The first term has the phase δ_{13} as in the standard model, but the other two phases can also account for CP violation.

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

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

4 Bounds on FCNC $\boldsymbol{CP}$ Violation in $|\epsilon|$



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

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

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

$$|\epsilon| = \frac{G_F f_K^2 B_K m_K}{12\Delta m_K}\left[\frac{\alpha}{4\pi\sin^2\theta_W}\mathrm{Im}(-\tilde{E}^*) + \mathrm{Im}(U_{ds}^2)\right].$$

$$\mathrm{Im}(-\tilde{E}^*) = \mathrm{Im}(\eta_2 y_t f_2(y_t)(V_{td}^* V_{ts})^2)$$

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

5 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:

$$\begin{aligned}
R_b^{\mathrm{Aleph(FiveTag)}} &= 0.2158 \pm 0.0014 \\
R_b^{\mathrm{expt.avg.}} &= 0.2178 \pm 0.0011 \\
R_b^{\mathrm{theory}} &= 0.2156 \\
\text{Difference} &= 0.0022 \pm 0.0011
\end{aligned}$$

The conservative approach is again to interpret the discrepancy by increasing the errors on the experiment to equal the deviation, or use the improved Aleph analysis. Either method changes the old 2.4% error to the new 1.0% error.

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

$$\chi^2 = (\frac{2.29|V_{4b}|^2}{0.010})^2.$$

6 CKM, FCNC, and B Factory Experiments

- **CKM Experiments (9) for Standard Model - Present Data**
  - **Charged Current (5):**
    V_{ud}, V_{us}, V_{cd}, and

$$\begin{aligned} |V_{cb}| &= 0.039 \pm 0.004 \\ |V_{ub}/V_{cb}| &= 0.080 \pm 0.016 \end{aligned}$$

  - **Neutral Current (4):**

x_d	U_{db}
$\lvert\epsilon\rvert$	$\mathrm{Im}(U_{ds}^2)$
$K_L \to \mu\mu$	$\mathrm{Re}(U_{ds})$
x_s bound	U_{sb}

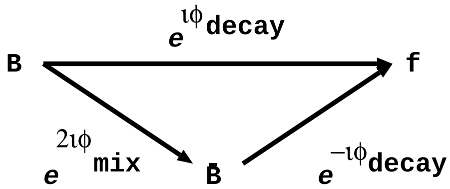
- **Exclusively FCNC Experiments for Four Down Quark Model (4)**

$B \to \mu\mu X$	UA1 and D0	$\lvert U_{db}\rvert$, $\lvert U_{sb}\rvert$
$Z^0 \to b\bar{b}$		$\lvert V_{4b}\rvert$
$K^+ \to \pi^+\nu\bar{\nu}$		$\lvert U_{ds}\rvert$

- ***B* Factory Projected Experiments (2)**

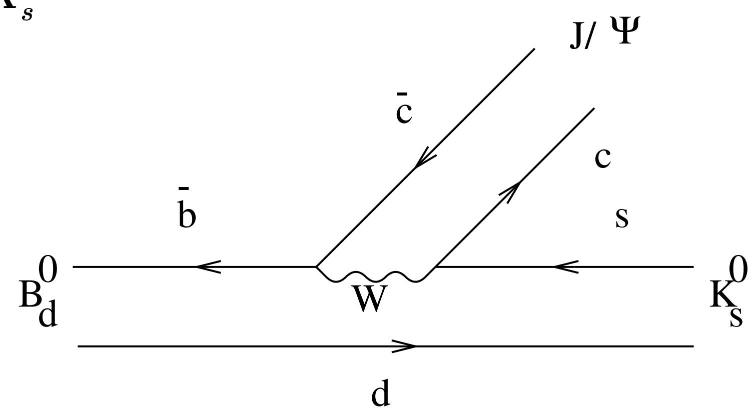
$\sin(2\beta)$	U_{db}^2
$\sin(2\alpha)$	U_{db}^2

7 CP Violating Asymmetries at the B Factory



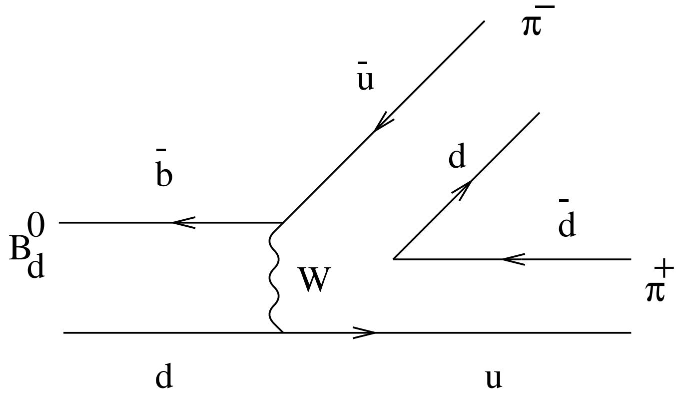
- $\sin(2\alpha)$ and $\sin(2\beta)$ are now defined as the measured B factory asymmetries, but do not correspond to unitarity triangle or quadrangle angles in the four down quark model.

- $\boldsymbol{B_d^0 \to J/\Psi K_s^0}$



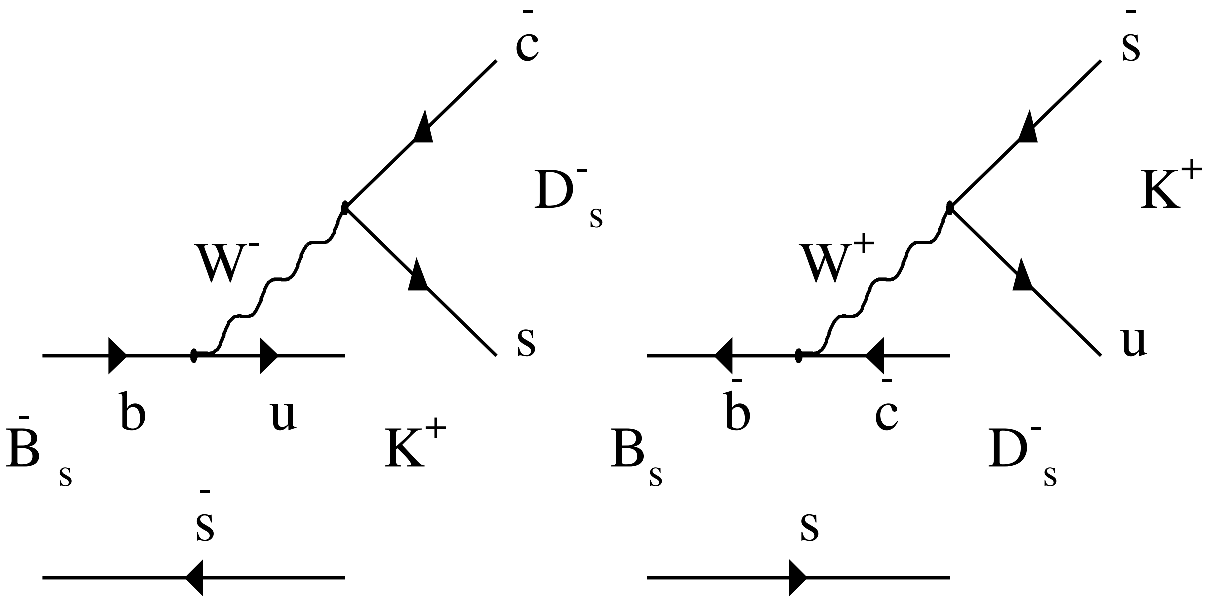
$$\sin(2\beta) \equiv A_{B_d^0 \to \Psi K_s^0} = \mathrm{Im}\left[\frac{(U^2_{std-db} + U^2_{db})}{|U^2_{std-db} + U^2_{db}|}\frac{(V^*_{cb}V_{cs})}{(V^*_{cb}V_{cs})^*}\right]$$

- $\boldsymbol{B_d^0 \to \pi^+\pi^-}$



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

8 $\boldsymbol{CP}$ 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

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

Since this imaginary part can be both positive and negative, we now include the full range $-1 \leq \sin(\gamma) \leq 1$ motivated by Wolfenstein's approach of finding the full range of predictions, rather than perturbations around the SM result.

9 The "Frequency" of B_s Oscillations, x_s

Here we exclude the theoretical uncertainty on $B_{B_s} f^2_{B_s}$, 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

$$x_s = 1.35\ x_d \frac{|U^2_{std-bs} + U^2_{bs}|}{|U^2_{std-db} + U^2_{db}|}$$

We now include the amplitude method analysis of LEP to assign a $\Delta\chi^2$ for each x_s calculated in the parameter grid.

10 The B_s Decay Asymmetry, A_{B_s}

In the standard model, B_s mixing involves $(V^*_{ts} V_{tb})^2$ which is almost exactly real. Thus 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 $B_s \to \Psi\phi$, $B_s \to D^+_s D^-_s$, and $B_s \to \Psi K_S$.

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

$$A_{B_s} = \mathrm{Im}\left(\frac{(U^2_{std-bs} + U^2_{bs})}{|U^2_{std-bs} + U^2_{bs}|} \frac{(V^*_{cb} V_{cs})}{(V_{cb} V^*_{cs})} \right).$$

Since this is an imaginary part of an $e^{i\Phi}$, we again include the full range $-1 \leq A_{B_s} \leq 1$.

11 Comprehensive Maximum Likelihood Analysis: Experiments and Degrees of Freedom

Standard Model

4 parameters (3 angles, 1 phase)

- 9 present experiments $\rightarrow$ 5 degrees of freedom
- B factory, add 2 expts. $\rightarrow$ 7 degrees of freedom

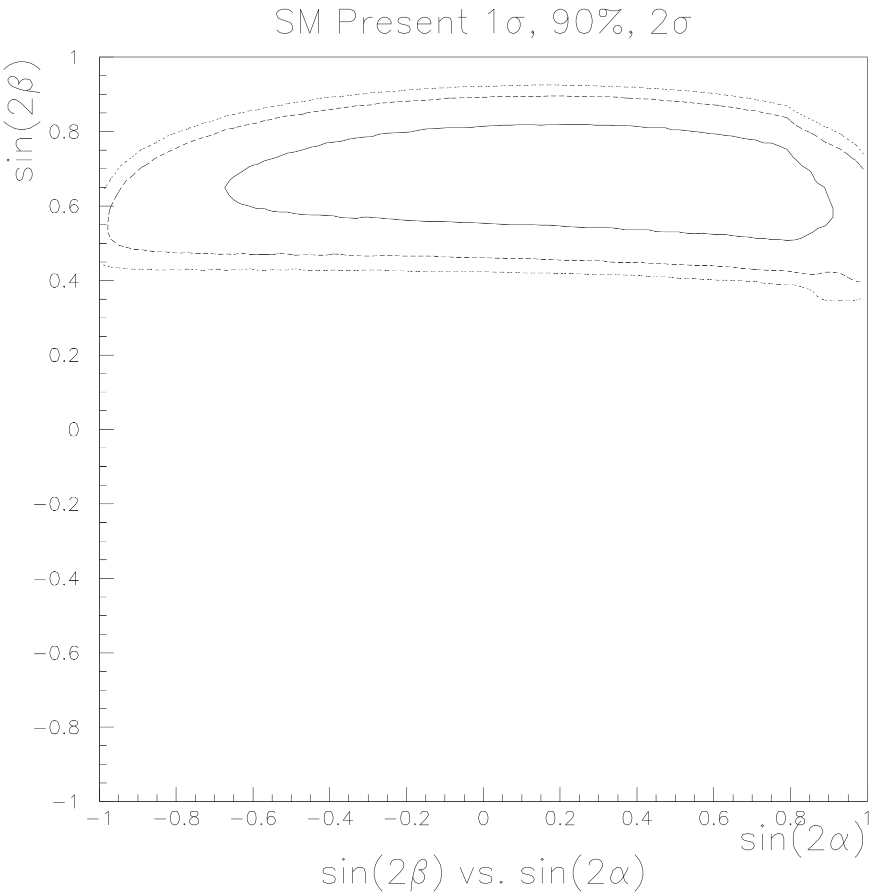
Four Down Quark Model

9 parameters (6 angles, 3 phases)

- 13 present experiments $\rightarrow$ 4 degrees of freedom
- B factory, add 2 expts. $\rightarrow$ 6 degrees of freedom

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

- Present Data: $\sin(2\beta) \approx 0.65 \pm 0.15$.
- $\sin(2\alpha)$ unconstrained but not likely to be -1 or $+1$.



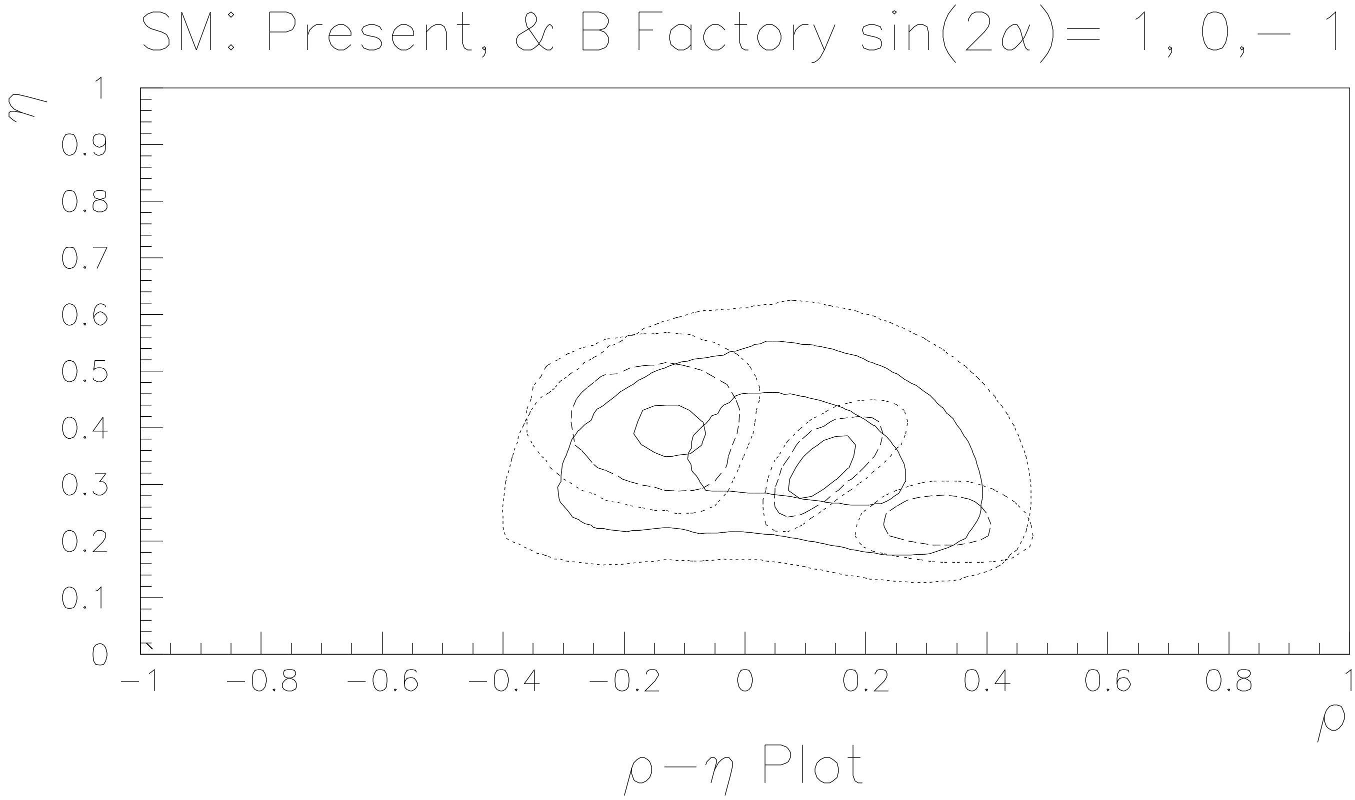
13 Four Down Quark Model $(\sin(2\alpha), \sin(2\beta))$ Plots - Present Limits

➤ The entire plane is allowed at 1-σ.

➤ Even a rough, early measurement of $\sin(2\beta)$ might give a surprising result.

14 Standard Model (ρ, η) Plot (broad), with Projected B-Factory Cases (small)

- Contours are 1-σ (solid), 2-σ (dashed), and 3-σ (dotted).
- Cases of B factory results at $\sin(2\alpha) = 1, \quad 0, \quad -1$ are shown from left to right, respectively.



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

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

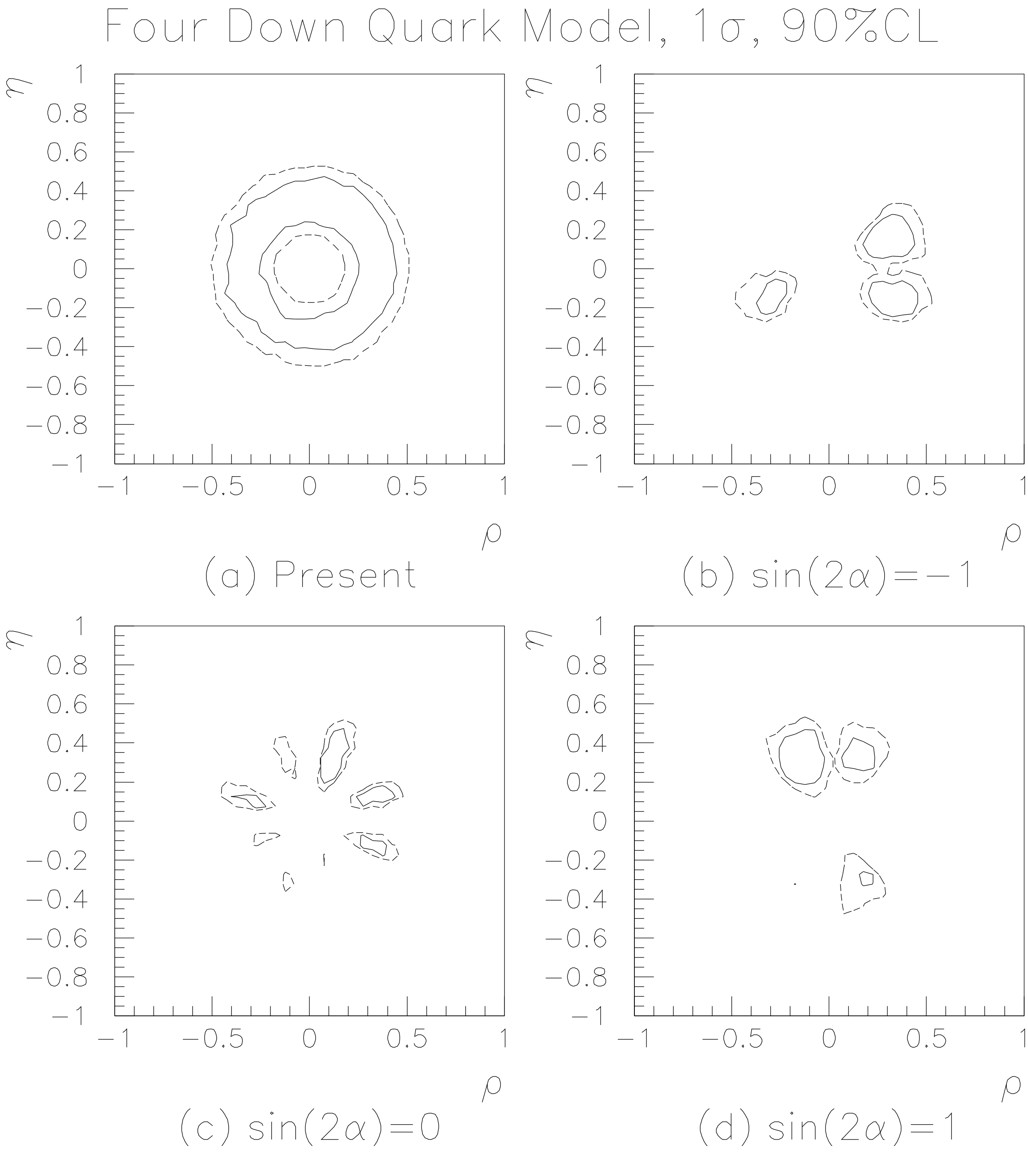
$$\rho + i\eta = V_{ub}^*/|V_{cd}V_{cb}|$$

- The plots are extended to negative $\eta = \mathrm{Im}(V_{ub}^*/|V_{cd}V_{cb}|)$.
- There is now a unitarity quadrangle

$$V_{ub}^*V_{us} + V_{cb}^*V_{cs} + V_{tb}^*V_{ts} + V_{4b}^*V_{4s} = 0$$

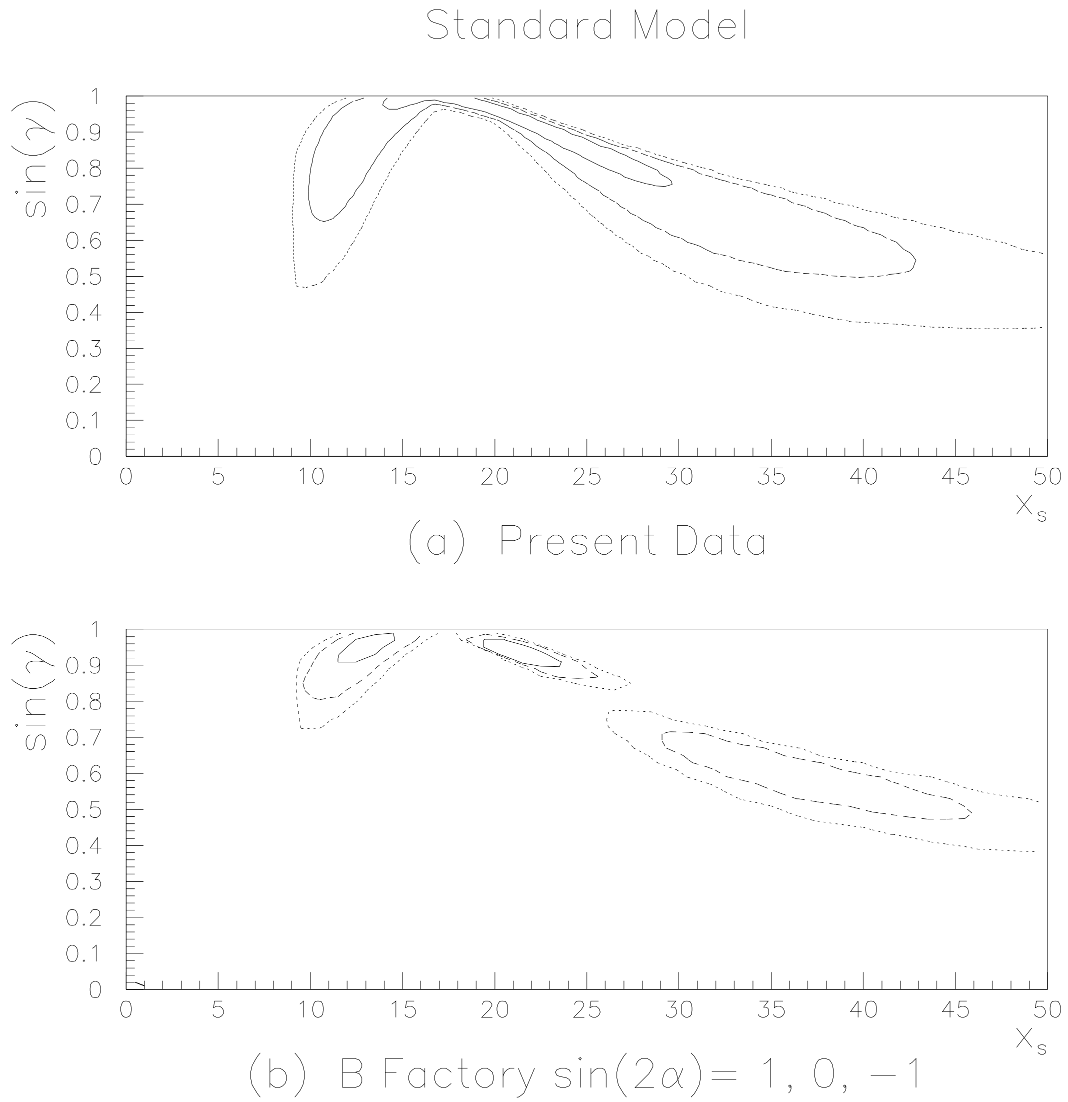
  where the last term is $-U_{bs}$.

- The circles in $\delta = \delta_{13}$ ($V_{ub}^* = s_{13}e^{i\delta_{13}}$) are due to δ_{14} or δ_{24} being the source of the observed CP violation in ϵ, so that δ_{13} is unconstrained.
- Due to the newest data on the x_s bound, on R_b, and on $K^+ \to \pi^+\nu\bar{\nu}$, the multiple regions are decreasing somewhat, especially for the $\sin(2\alpha) = 0$ case.
- The multiple regions, however, are now extended to the full (ρ, η) plane.


Four Down Quark Model, 1σ, 90%CL
η
ρ
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−0.5
0.5
(a) Present
(b) sin(2α)=−1
(c) sin(2α)=0
(d) sin(2α)=1

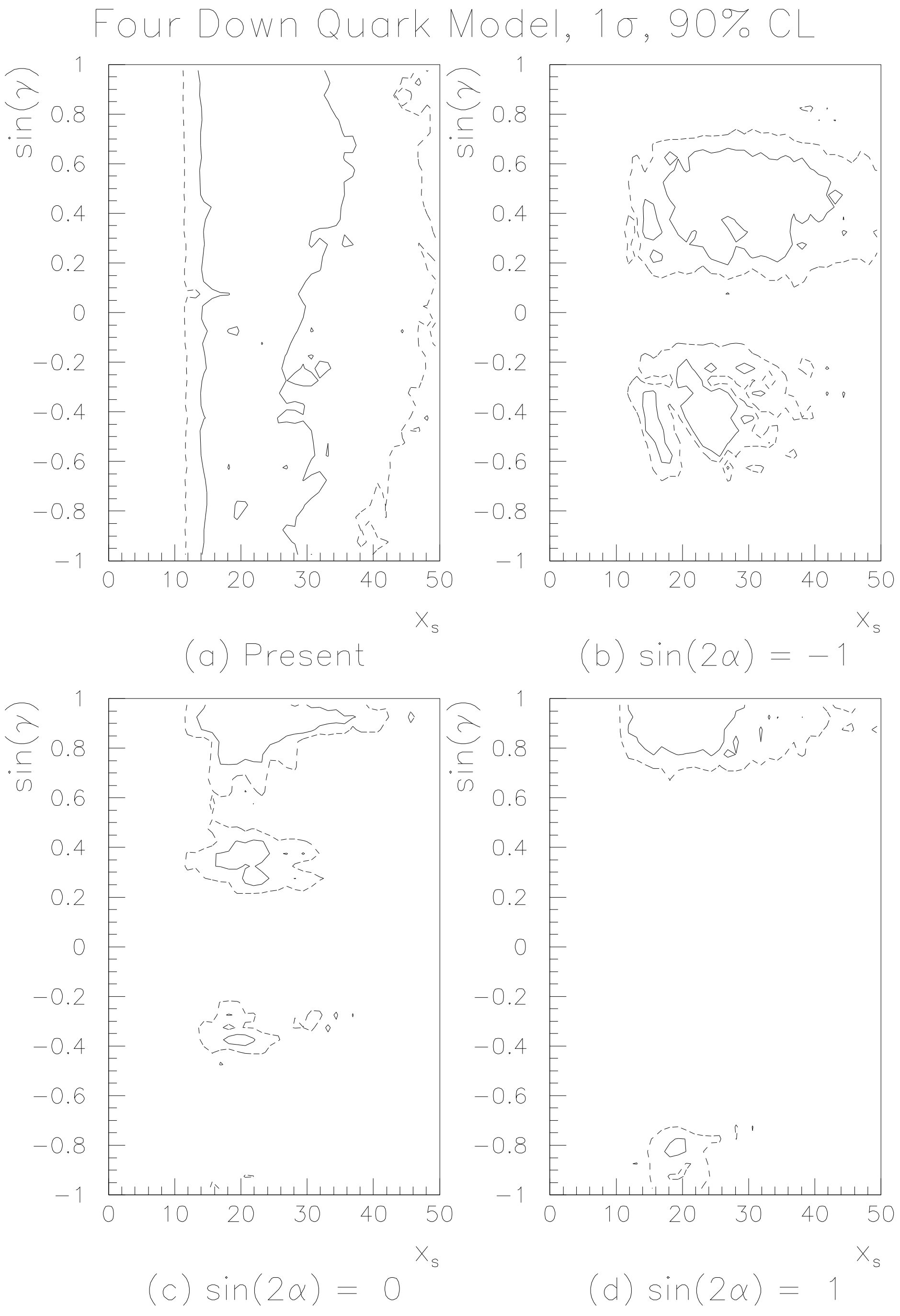
16 Standard Model $(x_s, \sin(\gamma))$ Plots

- Present Data: $0.75 \leq \sin(\gamma) \leq 1, \quad 14 \leq x_s \leq 29$ at 1-σ.
- x_s measurement can strongly constrain $\sin(2\alpha)$.



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

- ➤ Extended $\sin(\gamma)$ range to $-1 \leq \sin(\gamma) \leq 1$ for completeness.
- ➤ All $\sin(\gamma)$ is allowed at 1-σ, as opposed to the limited standard model range.
- ➤ The x_s allowed region is 14 to 39 at 1-σ, larger than in the standard model.

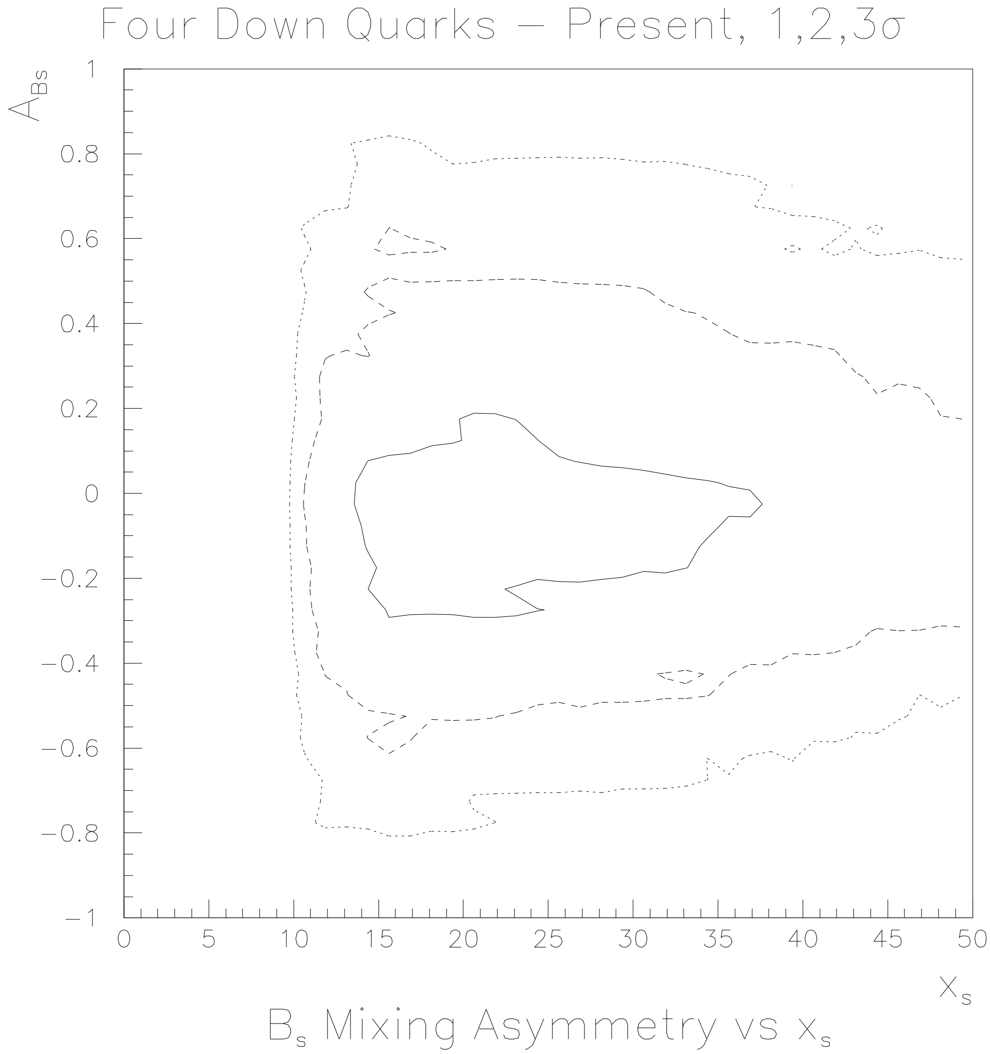


18 B_s Decay Asymmetry from B_s Mixing, A_{B_s}

➤ This is almost zero in the Standard Model, i.e. ≤ 0.025.

➤ $A_{B_s} = \mathrm{Im}(e^{i\Phi})$ is extended here to negative values, and appears roughly symmetric about 0.

➤ $-0.30 \leq A_{B_s} \leq 0.20$ at 1-σ is possibly detectable in the four down quark model.



19 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.
- Since all $\sin(2\beta)$ and $\sin(2\alpha)$ are allowed, even an **early measurement** of $\sin(2\beta)$ will be significant and may be surprising.
- There are **multiple 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 $\boldsymbol{x_s}$ and $\boldsymbol{\sin(\gamma)}$**, first to isolate a region, and then to rule in or out a new physics model.
- In new physics models, the SM phase **$\boldsymbol{\delta}$ can be smaller or arbitrary**, with the other phases causing the presently observed CP violation.
- The present range for x_s is from 14 to 29 at 1-σ in the SM, and from 14 to 39 at 1-σ in the four down quark model.
- The $\sin(\gamma)$ range is from 0.75 to 1.0 in the SM, and **unrestricted at 1-$\boldsymbol{\sigma}$** in the four down quark model.
- The **$\boldsymbol{B_s}$ $\boldsymbol{CP}$ violating decay asymmetry** is almost null in the SM, but could be as large in magnitude as **0.3** at 1-σ in the four down quark model.
- The **mass** of the lightest singlet down quark in E_6 could be roughly related to the mixing angle by

$$
\begin{aligned}
\theta_{34}^2 &\simeq m_b/m_D, \quad |V_{4b}| \simeq \theta_{34} \leq 0.06, \quad \text{giving} \\
m_D &\geq 250 \times m_b = 1.2 \text{ TeV}.
\end{aligned}
$$

Left Right Symmetric Model Analysis

Dennis Silverman and Herng Tony Yao

20 Fine-tuning cases in $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

$SU(2)_R$ has two heavy charged $W_R^{\pm}$ and a Z_0'.

The charged weak current is

$$
\begin{aligned}
L &= \frac{g}{\sqrt{2}}(\bar{u}_L\gamma_\mu d_L + \bar{\nu}_L\gamma_\mu e_L)W_L^+ \\
&+\frac{g}{\sqrt{2}}(\bar{u}_R\gamma_\mu d_R + \bar{\nu}_R\gamma_\mu e_R)W_R^+ + g^2\kappa\kappa' W_L^- W_R^+ + \text{H.C.}
\end{aligned}
$$

The left- and right- handed quark mixing matrices are V^L and V^R.

$$
V^L = \begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}
$$

Langacker has made a detailed analysis on W_R mass limits, and concludes that the lower limit of the W_R mass can be reduced by taking either of the following forms of V^R

$$
V_I^R = \begin{bmatrix} e^{i\omega} & 0 & 0 \\ 0 & ce^{i\xi} & se^{i\sigma} \\ 0 & se^{i\phi} & ce^{i\chi} \end{bmatrix} \text{ (caseI)}, \quad V_{II}^R = \begin{bmatrix} 0 & e^{i\omega} & 0 \\ ce^{i\xi} & 0 & se^{i\sigma} \\ se^{i\phi} & 0 & ce^{i\chi} \end{bmatrix} \text{ (caseII)}.
$$

Here $s = \sin\theta$ and $c = \cos\theta$ $(0 \le \theta \le 90^\circ)$, and the unitarity condition is

$$
\xi - \sigma = \phi - \chi + \pi.
$$

21 CP Violation in K Mesons in the LRSM

$$\epsilon_K \approx \mathrm{Im} < K^0|H(\Delta S = 2)|\bar{K}^0 > /\sqrt{2}\Delta m_K$$

where $H(\Delta S = 2)$ is the Hamiltonian from the box diagrams mediated by two W_L, two W_R, or a W_L-W_R pair.

The H^{LL} contribution is

$$\epsilon_K = \frac{G_F^2 f_K^2 B_K m_K m_W^2}{12\sqrt{2}\pi^2 \Delta m_K}[\eta_{cc} S(x_c) I_{cc} + \eta_{tt} S(x_t) I_{tt} + 2\eta_{ct} S(x_c, x_t) I_{ct}]$$

The two W_R part H^{RR} gives no contribution due to the factors I_{ij} vanishing for both cases of V^R.

The H^{LR} contribution is

$$\begin{aligned} H^{LR} &= \frac{2G_F^2}{\pi^2} m_{W_L}^2 \beta \sum_{i,j=u,c,t} \lambda_i^{LR} \lambda_j^{RL} (\bar{d}_R s_L)(\bar{d}_L s_R) \frac{\sqrt{x_i x_j}}{4} \\ & [(4\eta_{ij}^{(1)} + \eta_{ij}^{(2)} x_i x_j \beta) I_1(x_i, x_j, \beta) - (\eta_{ij}^{(3)} + \eta_{ij}^{(4)} \beta) I_2(x_i, x_j, \beta)], \end{aligned}$$

where $\lambda_i^{LR} = V_{id}^{L*} V_{is}^R$, and $\beta = (m_{W_L}/m_{W_R})^2$.

The contribution to ϵ_K from H^{LR} only comes from the surviving terms on $\lambda_i^{LR} \lambda j^{RL}$.

The contribution to ϵ_K from H^{LR} only comes from the surviving terms on $\lambda_i^{LR}\lambda j^{RL}$:

$$\begin{array}{lll} \text{Case I} & (\text{cu pair}): & \lambda^2 c \sin(\omega - \xi) \\ & (\text{tu pair}): & A\lambda^4[(1-\rho)\sin(\phi-\omega) + \eta\cos(\phi-\omega)]. \end{array}$$

$$\begin{array}{lll} \text{Case II} & (\text{uc pair}): & (1-\lambda^2/2)^2 c \sin(\omega - \xi) \\ & (\text{ut pair}): & As\lambda^2(1-\lambda^2/2)\sin(\omega-\phi). \end{array}$$

Fine-tuning:

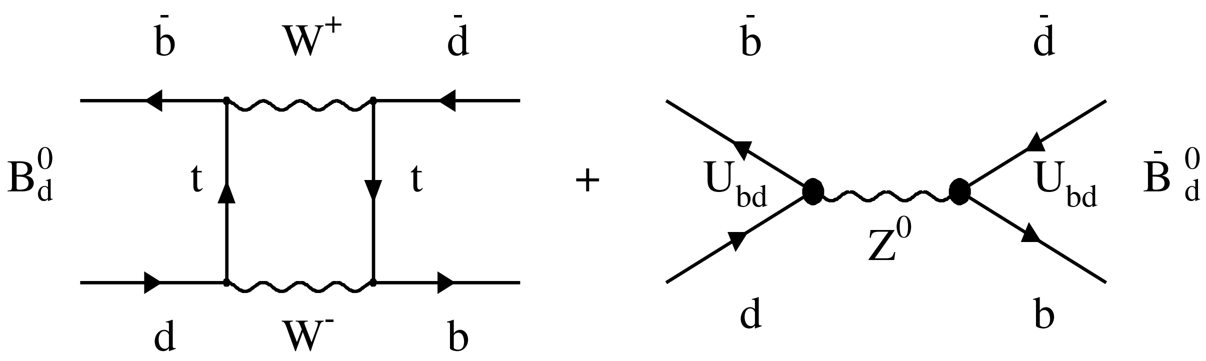
Due to the smallness of $\epsilon_K = (2.28 \pm 0.02) \times 10^{-3}$, one adjusts the parameters in V^R so that no contribution to ϵ_K will come from H^{LR}.

$$\begin{array}{lcc} \text{Case I} & \sin(\omega-\xi) = 0, & \tan(\omega-\phi) = \dfrac{\eta}{(1-\rho)}. \\ \text{Case II} & c = 0, & \sin(\omega-\phi) = 0. \end{array}$$

Case I: Three new parameters in V_I^R: θ (where $s = \sin\theta$), ω, and σ.

Case II: Two new parameters in V_{II}^R: ω and σ.

22 $B^0 - \bar{B}^0$ Mixing



$$M_{12} = M_{12}^{LL} + M_{12}^{RR} + M_{12}^{LR},$$

corresponding to the contributions from box diagrams in which two W_L, two W_R and a W_L-W_R pair are exchanged.

$$\begin{aligned} M_{12}^{RR} &= \frac{G_F^2}{12\pi^2} m_B m_{W_L}^2 (f_B^2 B_B) \eta_{tt} S(x_t) \beta^2 (V_{tq}^{R*} V_{tb}^R)^2. \\ &= 0 \ \text{ in } B_d; \qquad \neq 0 \text{ in } B_s. \end{aligned}$$

$$\begin{aligned} M_{12}^{LR} &= \frac{G_F^2}{2\pi^2} m_B (f_B^2 B_B) (\frac{m_B}{m_b})^2 m_{W_L}^2 \beta \sum_{i,j=u,c,t} \lambda_i^{LR} \lambda_j^{RL} \frac{\sqrt{x_i x_j}}{4} \\ & [(4\eta_{ij}^{(1)} + \eta_{ij}^{(2)} x_i x_j \beta) I_1(x_i, x_j, \beta) - (\eta_{ij}^{(3)} + \eta_{ij}^{(4)} \beta) I_2(x_i, x_j, \beta)], \end{aligned}$$

where $\lambda_i^{LR} = V_{iq}^{L*} V_{ib}^R$ and $\lambda_i^{RL} = V_{iq}^{R*} V_{ib}^L$.

Dominant terms are those of the quark mass factors $\sqrt{x_i x_j}$

$$(t,t) = 11.9, \ \ (t,c) = 4.6 \times 10^{-2}, \ \ \text{the rest} \ < \ 10^{-3}$$
$$(c,t) = 5.0 \times 10^{-2}, \ \ (u,t) = 0.8 \times 10^{-2}$$

23 Numerical Results for $B_d - \bar{B}_d$ Mixing

Case	Comparison with SM	W_R effect
I	$M_{12}^{LR} \ll M_{12}^{LL}$	No
II	$M_{12}^{LR} \sim M_{12}^{LL}$ $(m_{W_R} =$ 5 TeV)	Yes
	$M_{12}^{LR} \leq 10^{-2} M_{12}^{LL}$ $(m_{W_R} =$ 10 TeV)	No

24 Numerical Results for $B_s - \bar{B}_s$ Mixing

Case	Comparison with SM	W_R effect
I	$M_{12}^{LR} \sim M_{12}^{LL}$ $(m_{W_R} = 5$ TeV)	Yes
	$M_{12}^{LR} \ll M_{12}^{LL}$ $(m_{W_R} = 10$ TeV)	No
II	$M_{12}^{LR} \ll M_{12}^{LL}$	No

25 χ^2 Plots for (ρ, η), $(\sin(2\alpha), \sin(2\beta))$, and $(x_s, \sin(\gamma))$ in the LRSM

- **CKM Experiments (5) for SM - Present Data**
  - **Charged Current:** (λ fixed)

$$
\begin{aligned}
|V_{cb}| &= 0.039 \pm 0.004 \\
|V_{ub}/V_{cb}| &= 0.080 \pm 0.016 \quad \text{(CLEO II)}
\end{aligned}
$$

  - **Neutral Current:**

    x_d

    $|\epsilon|$

    x_s bounds

- ***B* Factory Experiments (2):**

  $\sin(2\beta)$

  $\sin(2\alpha)$

- **Left Right Symmetric Model:** (for various choices of W_R)

  With B factory experiments included, we have 5 + 2 = 7 experiments.

  Case I: 6 parameters (3 angles and 3 phases), or 1 degree of freedom

  Case II: 5 parameters (2 angles and 3 phases), or 2 degrees of freedom.

Experimental results predicted with M_{12} including the LRSM

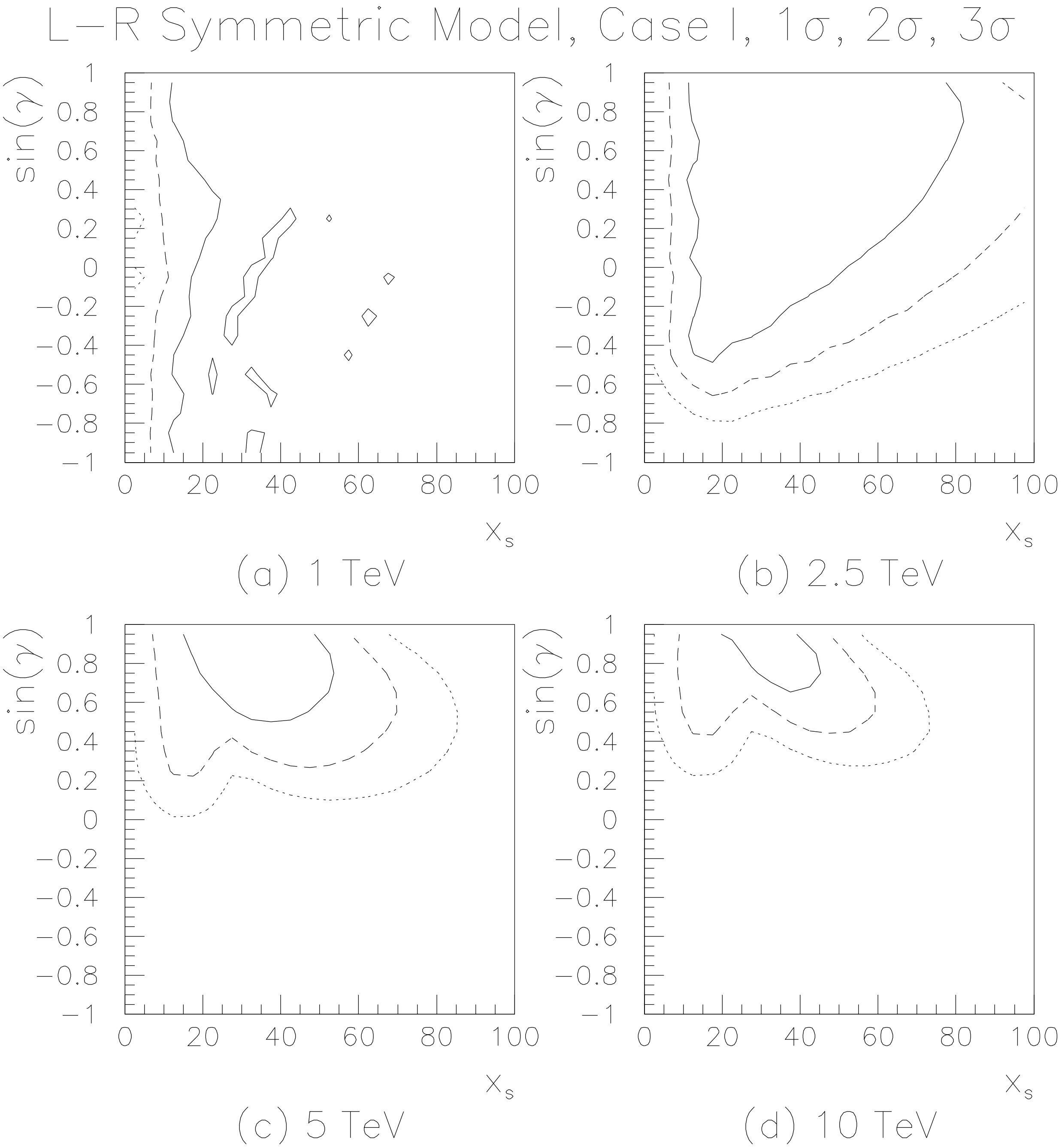
$$
\sin(2\beta) \equiv \mathrm{Im}\left(\frac{M_{12}^*}{|M_{12}|}\frac{V_{cb}^*V_{cs}}{V_{cb}V_{cs}^*}\right), \qquad \sin(2\alpha) \equiv \mathrm{Im}\left(\frac{M_{12}^*}{|M_{12}|}\frac{V_{ub}^*V_{ud}}{V_{ub}V_{ud}^*}\right)
$$

$$
\sin(\gamma) \equiv \mathrm{Im}\left(\frac{M_{12}^{B_s}}{|M_{12}^{B_s}|}\frac{V_{ub}^*V_{cs}}{|V_{ub}V_{cs}|}\right), \qquad x_s = 1.35 x_d \frac{|M_{12}^{B_s}|}{|M_{12}^{B}|}.
$$

26 LRSM $(x_s, \sin(\gamma))$ Plots for Case I

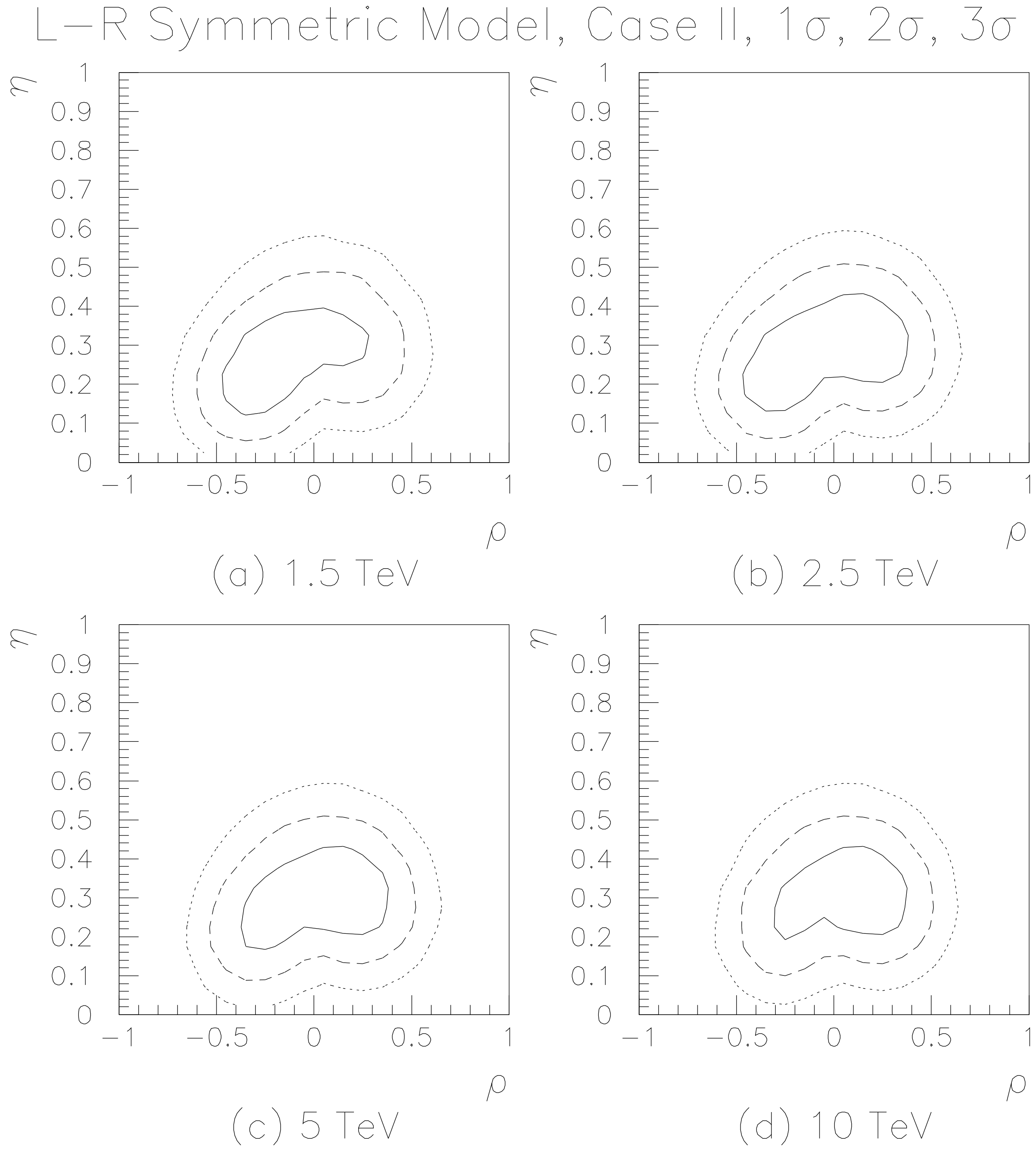
➤ The entire $\sin(\gamma)$ range is allowed for the smaller W_R values.

➤ Larger x_s values are allowed for intermediate W_R values.



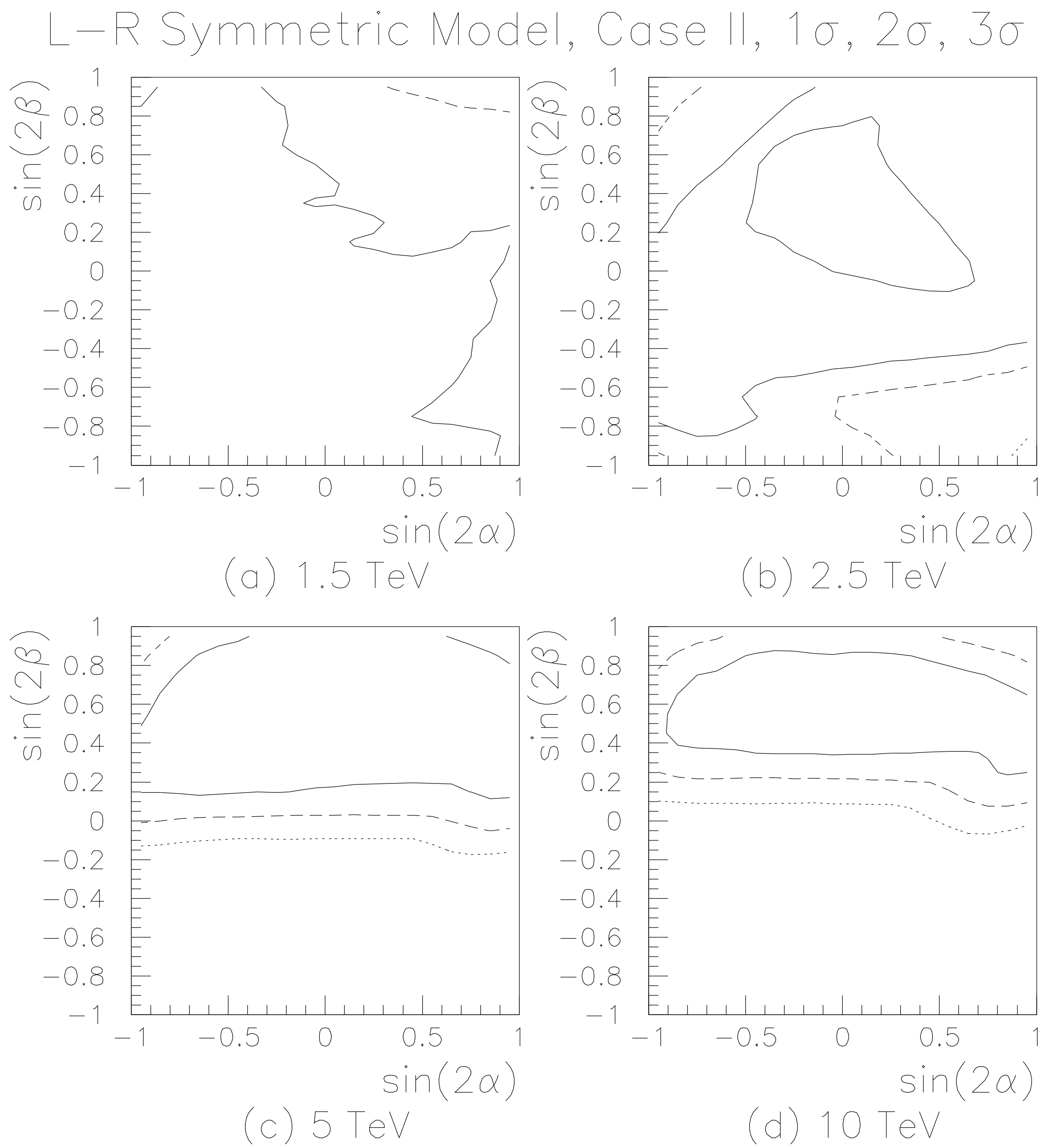
27 LRSM (ρ, η) Plots for Case II

➤ For m_{W_R} there are different or larger regions than in the SM.



28 LRSM $(\sin(2\alpha), \sin(2\beta))$ Plots for Case II

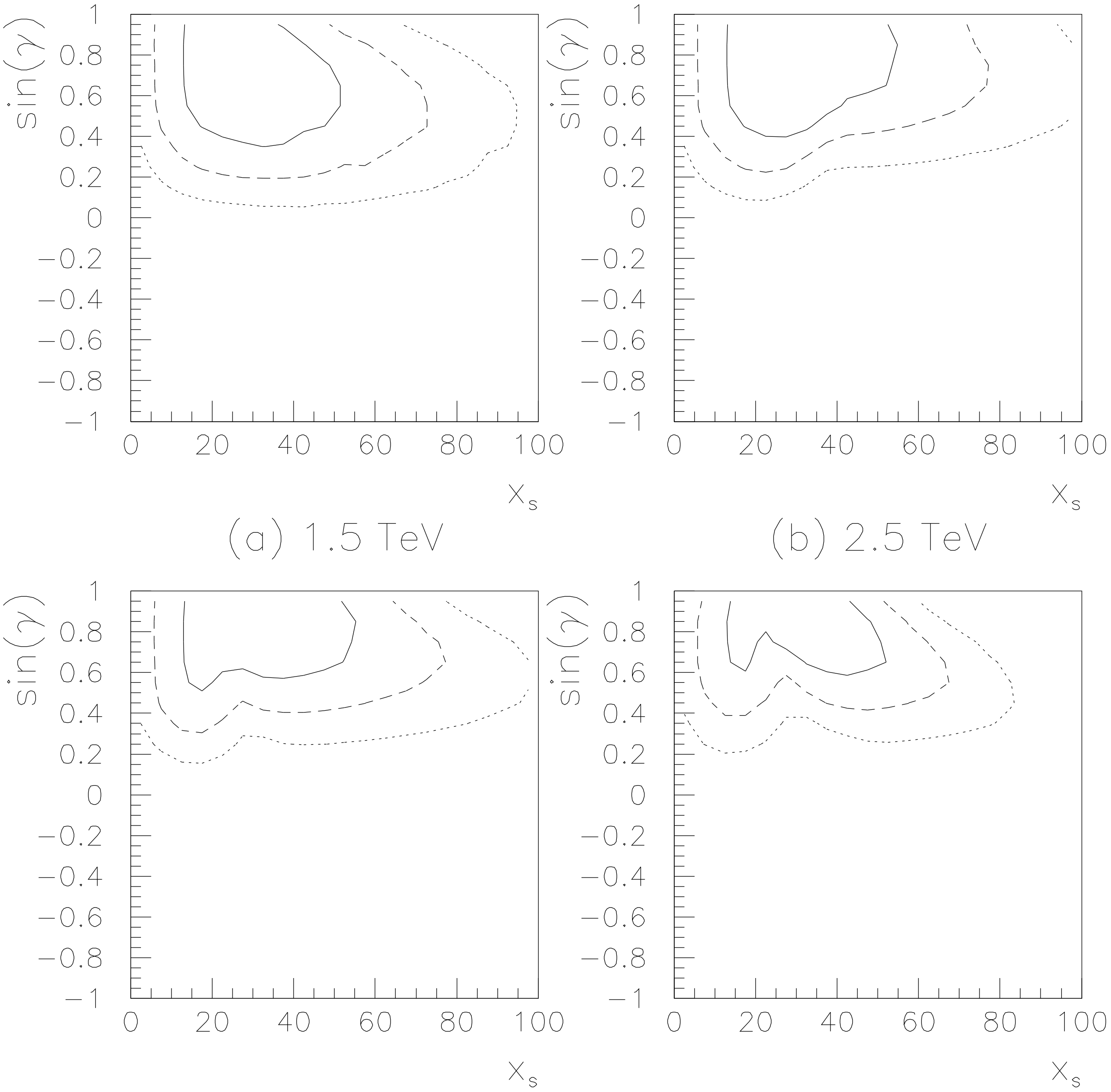
➤ Different preferred 1-σ regions exist between $m_{W_R} = 1.5$ TeV and $M_{W_R} \geq 10$ TeV which is the SM region.



29 LRSM $(x_s, \sin(\gamma))$ Plots for Case II

➤ Lower $\sin(\gamma)$ is allowed than in the SM for $m_{W_R} \leq 2.5$ TeV.

L−R Symmetric Model, Case II, 1σ, 2σ, 3σ

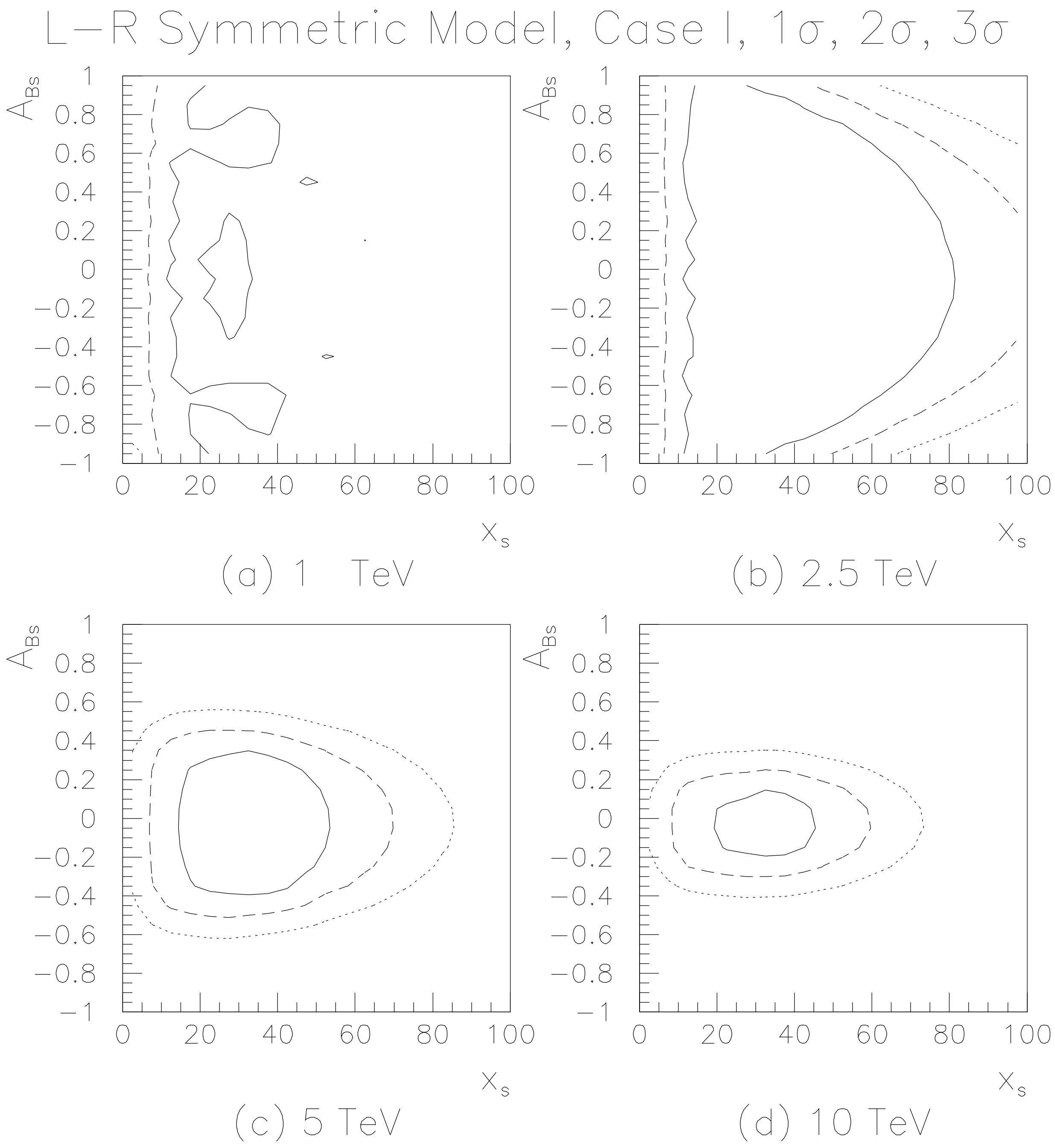


(a) 1.5 TeV (b) 2.5 TeV

(c) 5 TeV (d) 10 TeV

30 LRSM (x_s, A_{B_s}) Plots for Case I

➤ Whereas A_{B_s} is almost null in the SM, in the LRSM for $M_{W_R} \simeq 1$ TeV, this could saturate at $|A_{B_s}| \leq 1$. Even at larger $M_{W_R} \simeq 1$ TeV, this could be as large as 0.4.



31 Conclusions for LRSM

- The LRSM can contribute significantly to $B_d - \bar{B}_d$ mixing (from case II) and to $B_s - \bar{B}_s$ mixing (from case I), and give new phases.
- W_R shows its effects in (ρ, η), in $(\sin(2\alpha), \sin(2\beta))$, and in $(x_s, \sin(\gamma))$ in case II, and in $(x_s, \sin(\gamma))$ in case I, both for $W_R \leq 5$ TeV.
- $\sin(2\beta) \simeq 0.65 \pm 0.15$, and $\sin(2\alpha)$ are only partly constrained in the SM. In the LRSM, all $\sin(2\beta)$ is allowed for $m_{W_R} \leq 2.5$ TeV.
- The present range for x_s is from 14 to 29 at 1-σ in the SM. The range in the LRSM is both lower and greater than that in the SM by about a factor of two, combining the two cases.
- The $\sin(\gamma)$ range is from 0.8 to 1.0 in the SM, and is largely unrestricted for case I in the LRSM for $m_{W_R} < 2.5$ TeV.
- The values for A_{B_s} could be very large and detectable in the LRSM.
- If the results from the B factory, x_s and $\sin(\gamma)$ are consistent with the SM, the LRSM bound will increase from about $m_{W_R} \geq 1.5$TeV to $m_{W_R} \geq 5$ TeV.