$\not{CP}$ in MODELS with LR symmetry, non-comutative geometry and 2 HDMs.

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REPORT ON 3 DIFFERENT ABSTRACTS

1) Possible Effects of Noncommutative Geometry on Weak $\not{CP}$ and Unitarity Triangle.
   ABS# 118, Z. Z. Xing hep-ph/0204255

2) Two-Higgs-Doublet Models with $\not{CP}$
   ABS #957; I. GINZBURG, M. KRAWCZYK & P. OSLAND
   hep-ph/0101208, hep-ph/0101229

3. UBIQUITOUS $\not{CP}$ in a TOP INSPIRED LEFT-RIGHT MODEL hep-ph/0205082
   A.S in collab. with K. Kiers, G.-H Wu, J. KOLB & J. Lee.

POSSIBLE EFFECTS OF NONCOMMUTATIVE GEOMETRY ON WEAK CP VIOLATION AND UNITARITY TRIANGLES

Zhe Chang & Zhi-zhong Xing (IHEP, Beijing)

hep-ph/0204255 (To appear in Phys. Rev. D)

$\boxed{1}$ New CP Violation from Noncommutative Geometry:

$$\boxed{[x^\mu \overset{*}{,} x^\nu] = i\theta^{\mu\nu} \neq 0}$$

At Low Energies, the CKM Matrix V Gets Modified and the New Effective Flavor Mixing Matrix $\overline{V}$ Is Momentum-dependent (Hinchliffe & Kersting 01, Wess et al 02):

$$\overline{V} = V - \frac{i}{2}\begin{pmatrix} V_{ud}x_{ud} & V_{us}x_{us} & V_{ub}x_{ub} \\ V_{cd}x_{cd} & V_{cs}x_{cs} & V_{cb}x_{cb} \\ V_{td}x_{td} & V_{ts}x_{ts} & V_{tb}x_{tb} \end{pmatrix}$$

with $x_{\alpha k} \equiv p^\mu_\alpha \theta_{\mu\nu} q^\nu_k$ for $\alpha = u, c, t$ and $k = d, s, b$. $\overline{V}$ Is Not Unitary! To Measure CP Violation, Define

$$\mathcal{J}^{ij}_{\alpha\beta} \equiv \mathrm{Im}\left(\overline{V}_{\alpha i}\overline{V}_{\beta j}\overline{V}^*_{\alpha j}\overline{V}^*_{\beta i}\right) = \mathcal{J}\sum_{\gamma,k}\left(\epsilon_{\alpha\beta\gamma}\epsilon_{ijk}\right) + \mathcal{R}^{ij}_{\alpha\beta}\xi^{ij}_{\alpha\beta}$$

$\mathcal{J}$: Jarlskog Parameter in the SM; $\mathcal{R}^{ij}_{\alpha\beta} \equiv \mathrm{Re}(V_{\alpha i}V_{\beta j}V^*_{\alpha j}V^*_{\beta i})$; $\xi^{ij}_{\alpha\beta} \equiv (x_{\alpha j} + x_{\beta i} - x_{\alpha i} - x_{\beta j})/2$. In Particular,

$$\mathcal{J}^{ds}_{uc} \approx A^2\lambda^6\eta - \lambda^2\xi^{ds}_{uc}\,, \quad \mathcal{J}^{sb}_{ct} \approx A^2\lambda^6\eta - A^2\lambda^4\xi^{sb}_{ct}$$

Thus Noncommutative CP-violating Effects May be Comparable with or Dominant over the SM One, If ξ^{ds}_{uc} Is of $\mathcal{O}(\lambda^4)$ or Larger in $\mathcal{J}^{ds}_{uc}$; And if ξ^{sb}_{ct} Is of $\mathcal{O}(\lambda^2)$ or Larger in $\mathcal{J}^{sb}_{ct}$.

$\boxed{2}$ Take $D^\pm_s \to K^\pm K_S$ for Example. Direct CP Violation Arises from Interference between Cabibbo-allowed and Doubly Cabibbo-suppressed Channels. And K^0-$\bar{K}^0$ Mixing Leads to Additional CP-violating Effects of Magnitude $2\mathrm{Re}\epsilon_K \approx 3.3 \times 10^{-3}$ (Lipkin & Xing 99). When Noncommutative Geometry is Taken into Account, We Obtain the Momentum-dependent CP-violating Asymmetry 3

$$\mathcal{A}_s \equiv \frac{|A(D_s^- \to K^- K_S)|^2 - |A(D_s^+ \to K^+ K_S)|^2}{|A(D_s^- \to K^- K_S)|^2 + |A(D_s^+ \to K^+ K_S)|^2}$$
$$\approx 2\mathrm{Re}\epsilon_K - 2\overline{\mathcal{J}}^{ds}_{uc} R_s \sin\delta_s$$

δ_s: Strong Phase Difference; $R_s \approx 1 + a_2/a_1 \approx -1.2$ in Factorization Approximation. If $\delta_s \sim \mathcal{O}(1)$ and $\xi^{ds}_{uc} \sim \mathcal{O}(\lambda^2)$ Or $\overline{\mathcal{J}}^{ds}_{uc} \sim \mathcal{O}(\lambda^4)$) Held, Significant Deviation of $\mathcal{A}_s$ from $2\mathrm{Re}\epsilon_K$ Would Appear – Signal of Noncommutative Geometry!

$\boxed{3}$ In the Complex Plane, Vector $\overline{V}^*_{\alpha i}\overline{V}_{\beta i}$ Can Be Obtained from Rotating Vector $V^*_{\alpha i}V_{\beta i}$ Anticlockwise to A Small Angle $(x_{\alpha i} - x_{\beta i})/2$. Hence $\overline{V}^*_{ub}\overline{V}_{ud}$, $\overline{V}^*_{cb}\overline{V}_{cd}$ And $\overline{V}^*_{tb}\overline{V}_{td}$ Do NOT Form A Close Triangle (See Figure 1). But

$$\overline{\alpha} = \alpha + \xi^{db}_{tu}, \quad \overline{\beta} = \beta + \xi^{db}_{ct}, \quad \overline{\gamma} = \gamma + \xi^{db}_{uc}$$

Still Satisfy $\overline{\alpha} + \overline{\beta} + \overline{\gamma} = \alpha + \beta + \gamma = \pi$, Due to $\xi^{db}_{tu} + \xi^{db}_{ct} + \xi^{db}_{uc} = 0$.

Besides α, β And γ, CP Violation in Weak B-meson Decays Is Associated with

$$\overline{\gamma}' \equiv \arg\left(-\frac{\overline{V}^*_{ub}\overline{V}_{tb}}{\overline{V}^*_{us}\overline{V}_{ts}}\right), \quad \overline{\delta} \equiv \arg\left(-\frac{\overline{V}^*_{tb}\overline{V}_{ts}}{\overline{V}^*_{cb}\overline{V}_{cs}}\right), \quad \overline{\varpi} \equiv \arg\left(-\frac{\overline{V}^*_{us}\overline{V}_{ud}}{\overline{V}^*_{cs}\overline{V}_{cd}}\right)$$

with $\overline{\delta} + \overline{\varpi} = \overline{\gamma} - \overline{\gamma}'$. In Table 1, We List Some Typical Channels of B_d And B_s Mesons And Their CP-violating Asymmetries.

$\boxed{4}$ B-meson Factories Would Test Low-energy Effects of Noncommutative Geometry on CP Violation.

Further Progress in the Noncommutative Gauge Field Theory Will Allow Us to Study the Phenomenology of Noncommutative Geometry on A More Solid Ground.

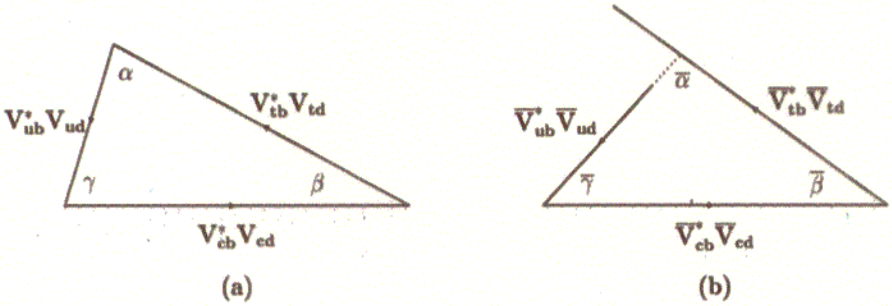


Figure 1: **The CKM Unitarity Triangle in the SM (a) And Its Deformed Counterpart in the Noncommutative SM(b).**

Table 1: **CP Violation in B^0 Decays in the Noncommutative SM.**

Class	Sub-process	Decay mode	CP asymmetry
1d	$\bar{b} \to \bar{c}c\bar{s}$	$B^0_d \to J/\psi K_S$	$+\sin 2(\overline{\beta} + \overline{\omega})$
2d	$\bar{b} \to \bar{c}c\bar{d}$	$B^0_d \to D^+D^-$	$-\sin 2\overline{\beta}$
3d	$\bar{b} \to \bar{u}u\bar{d}$	$B^0_d \to \pi^+\pi^-$	$+\sin 2\overline{\alpha}$
4d	$\bar{b} \to \bar{s}s\bar{s}$	$B^0_d \to \phi K_S$	$-\sin 2(\overline{\alpha} + \overline{\gamma}')$
1s	$\bar{b} \to \bar{c}c\bar{s}$	$B^0_s \to D^+_s D^-_s$	$+\sin 2\overline{\delta}$
2s	$\bar{b} \to \bar{c}c\bar{d}$	$B^0_s \to J/\psi K_S$	$-\sin 2(\overline{\gamma} - \overline{\gamma}')$
3s	$\bar{b} \to \bar{u}u\bar{d}$	$B^0_s \to \rho K_S$	$+\sin 2\overline{\gamma}'$
4s	$\bar{b} \to \bar{s}s\bar{s}$	$B^0_s \to \eta'\eta'$	0

2HDM models with CP violation

I. Ginzburg, M. Krawczyk, P. Osland

hep-ph/0101208, hep-ph/0101229

2HDM Potential: quartic and quadratic terms separated:

$$\begin{aligned} V = & \tfrac{1}{2}\lambda_1(\phi_1^\dagger\phi_1)^2 + \tfrac{1}{2}\lambda_2(\phi_2^\dagger\phi_2)^2 \\ & + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) \\ & + \tfrac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right] \\ & + \left\{\left[\lambda_6(\phi_1^\dagger\phi_1) + \lambda_7(\phi_2^\dagger\phi_2)\right](\phi_1^\dagger\phi_2) + \text{h.c.}\right\} \\ & - \left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\} \end{aligned}$$

soft violation of Z_2 symmetry

NO (ϕ_1, ϕ_2) mixing if Z_2 symmetry satisfied:
$\phi_1 \to -\phi_1,\ \phi_2 \to \phi_2$ (or vice versa) $\Rightarrow \lambda_6 = \lambda_7 = m_{12}^2 = 0$

14 parameters: $\lambda_1, \lambda_2, \lambda_3, \lambda_4,\ \lambda_5, \lambda_6, \lambda_7,\ m_{11}^2,\ m_{22}^2,\ \mathrm{Re}\, m_{12}^2,\ \mathrm{Im}\, m_{12}^2$

Hard violation of Z_2 symmetry: quartic terms with $\lambda_6,\ \lambda_7$

How to get small CP and FCNC effects?

(6)

Soft CP violation

With $\lambda_6 = \lambda_7 = 0$: minimum (vacuum) at:

$$\phi_1 = \begin{bmatrix} 0 \\ \frac{1}{\sqrt{2}} v_1 \end{bmatrix}, \quad \phi_2 = \begin{bmatrix} 0 \\ \frac{1}{\sqrt{2}} v_2 e^{i\xi} \end{bmatrix}, \qquad \begin{array}{l} m_{12}^2 = [\frac{\mu^2}{v^2} + i\,\mathrm{Im}(\lambda_5 e^{2i\xi})] v_1 v_2 e^{-i\xi} \\ \mathrm{Im}(m_{12}^2 e^{i\xi}) = \mathrm{Im}(\lambda_5 e^{2i\xi}) v_1 v_2 \equiv 4\delta\, v_1 v_2 \end{array}$$

Naive conclusion: phase ξ violates CP

However (eg. Branco), phase ξ can be removed by suitable redefinitions of phases of Higgs fields ϕ_i, λ_5, m_{12}^2 and fermion fields

With $\boxed{\delta \neq 0} \Rightarrow$ CP violation

All three neutral Higgs states mix:

h_1, h_2, h_3

$$\mathcal{M}^2 = v^2 \begin{pmatrix} \mathcal{M}_{11}^2 & \mathcal{M}_{12}^2 & \bullet \\ \mathcal{M}_{21}^2 & \mathcal{M}_{22}^2 & \bullet \\ \bullet & \bullet & \mathcal{M}_{33}^2 \end{pmatrix} \quad \bullet \Leftarrow \delta$$

7

For $\boxed{\delta \to 0}$ $\Rightarrow$ CP cons. w/ Higgs sector: h, H, A and $H^{\pm}$ (α, β, μ^2)

LARGE ~~ge~~ $M_A^2 = \frac{1}{2}\mu^2 - \mathrm{Re}\,\lambda_5 v^2$ from $\begin{cases} (i) & \text{large } \mu^2\text{, decoupling a la Haber} \\ (ii) & \text{small } \mu^2\text{, "large" } |\lambda_5| \end{cases}$ OR

Consider CP cons. Model II — d-mass $\leftrightarrow \phi_1$, u-mass $\leftrightarrow \phi_2$ $\Rightarrow$ Yukawa couplings

SM-LIKE SCENARIO: light h (or H), properties like H_{SM} — small μ!

$$g_i = g_i^{SM}, \quad i = W, Z, d, u$$

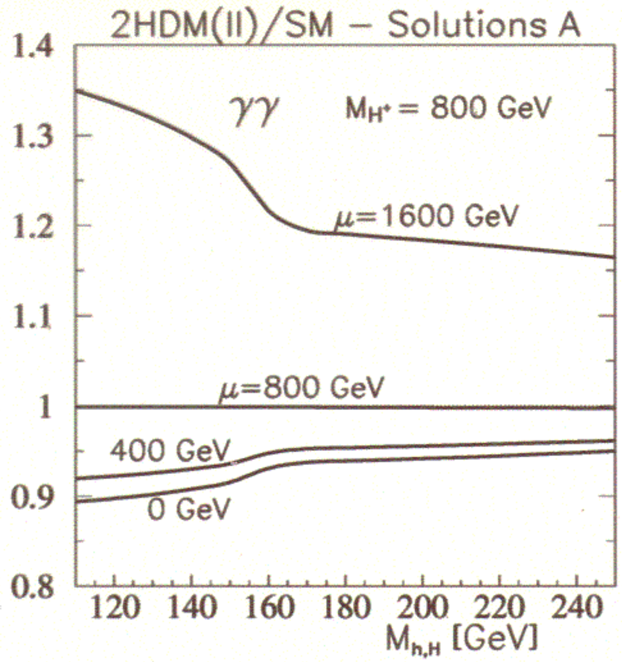
Other Higgs bosons heavy, $\mathcal{O}(1\ \mathrm{TeV})$

However, loop-induced coupling like $h \to \gamma\gamma$ may differ from SM prediction

if $\mu^2 \sim M_{H_\pm}^2$, no effect in $\Gamma_{\gamma\gamma}$

if $\mu^2 < M_{H_\pm}^2$ several % difference

Form of the 2HDM potential (large or small μ) can be tested!



UBIQUITOUS ~~CP~~ in a TOP INSPIRED LR Model

↓ CP everywhere i.e. Yukawa's as well as VEV's

ALTHOUGH STARTING POINT is very general
The model exhibits:

- SURPRISING SIMPLICITY ... MANY of the new DOF in the RH sector have SIMPLE relations to their LH counterparts.

- OBSERVED ~~CP~~ in ϵ_K, $B \to \psi_{K_S} K_S$ of CKM-Paradigm Seem to be all due to (β_{23}) ie Complex Yukawa

- However V_R^{CKM} in couplings of 3rd family ~~CP~~ phase due complex VEV appears (α_K')

- Should have important consequences for BSM LAB searches as well as baryogenesis.

BRIEF Recapitulate.

SM: $SU(2) \times U(1)$

e.g. for 1st family: $\begin{pmatrix} u \\ d \end{pmatrix}_L$ $\underbrace{u_R, d_R}$ singlets

$\begin{pmatrix} \nu \\ e \end{pmatrix}_L$ e_R

ASY treatment of L-R is somewhat of an "eye sore".

LRSM: $SU(2)_L \times SU(2)_R \times U(1)$ PATI, SALAM, MOHAPATRA, SENJANOVIC, RIZZO, FRITZSCH & MINKOWSKI ! ! !

e.g. for 1st Family: $\begin{pmatrix} u \\ d \end{pmatrix}_L$, $\begin{pmatrix} u \\ d \end{pmatrix}_R$

$\begin{pmatrix} \nu \\ e \end{pmatrix}_L$, $\begin{pmatrix} \nu \\ e \end{pmatrix}_R$

symmetric treatment of L & R; parity violation is spontaneous. $m_{W_R} \gg m_{W_L}$ via VEV

AESHETICALLY BETTER.

HOWEVR, '80-81 BEALL, BANDER + A.S.

$\Delta m_K \Rightarrow M_{W_R} \gtrsim 1.7$ TeV

SUCH A LARGE MASS SCALE [esp. by the standards of early 80's) made LRSM SOMEWHAT UNATTRACTIVE

SEVERAL REASONS NOW that in a "grounds-up approach" LRSM NEEDS Re-examination.

I. ν's HAVE MASS!!

HAD WEINBERG KNOWN ν's are massive, it is a safe bet that $SU(2)_L \times U(1)$ MODEL WOULD NOT HAVE BEEN HIS CHOICE.

LRSM $SU(2)_L \times SU(2)_R \times U(1)$ WOULD BE A MUCH MORE SUITABLE CHOICE AS MASSIVE ν's OCCUR MUCH MORE READILY .... IN A MORE SYMMETRICAL MODEL

II. 2 TEV ORSO IS NO LONGER THAT IMPOSING IN THIS pre-LHC / precision B-physics era.

III NOT ONLY LARGE m_{top} CAN BE ACCOMODATED VERY NATURALLY IT ENDOWS THE LRSM A STRIKING SIMPLICITY

(a) THE OBSERVED hierarchy IN MASSES & mixing ANGLES occurs readily.

(b) MANY of the XTRA DOF relevant to LRSM OBEY SIMPLE RELATIONS to their ~~key~~ counterpart in SM so they are already known and the model has a lot fewer unknown parameters & ∴ less freedom.

IV In this era of precise test of CKM-paradigm of CP via B Physics it is very important to have in hand a simple (well motivated) extension of SM with 1 and only 1 extra CP phase to explore & confront the upcoming wealth of data.

Much of PAST Effort IN L-R MODELS tackled SPECIAL CASES.

1) (QUASI) MANIFEST LRS... CP in YUKAWA COUPLINGS ONLY ... DESHPANDE, GUNION, KAYSER, OLNESS '91

$$V_{R\,ij}^{CKM} = \pm V_{L\,ij}^{CKM}$$

2) (PSEUDO) MANIFEST LRS... CP in $\langle\Phi\rangle$ NOT in YUKAWA...... CP SPONTANEOUS & ∴ attractive ... BUT $(\sin 2\beta)^{eff} \lesssim 0.1$

SEE BALL &, Frere, MATIAS '00 $\sin 2\beta^{expt} = .79 \pm .08$

(3) TO EVADE BBS BOUND ON M_{W_R} & LANGACKER & SARKAR CHOSE:

$$V_{R(A)}^{CKM} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c & \pm s \\ 0 & s & \mp c \end{pmatrix}, \quad V_{R(B)}^{CKM} = \begin{pmatrix} 0 & 1 & 0 \\ c & 0 & \pm s \\ s & 0 & \mp c \end{pmatrix}$$

(4) WE STUDY A GENERAL CASE ALLOWING COMPLEX YUKAWA'S AND COMPLEX V's .... BUT ADOPT "TOP - INSPIRED" hierarchy of VEV.

SEARCH "EXACT" SOLN VIA NUMERICAL

FIND ALL 3 SPECIAL CASES DISFAVORED.

Features of our LRSM. $G = SU(2)_L \times SU(2)_R \times U(1)$

Use a bidoublet Higgs $\Phi \sim (2, \bar{2}, 0)$

+ 2 Triplets $\Delta_L \sim (3,1,2)$, $\Delta_R \sim (1,3,2)$

$$\Phi = \begin{pmatrix} \phi_1^0 & \phi_2^+ \\ \phi_1^- & \phi_2^0 \end{pmatrix}, \quad \Delta_{L,R} = \begin{pmatrix} \Delta_{L,R}^+/\sqrt{2} & \Delta_{L,R}^{++} \\ \Delta_{L,R}^0 & -\Delta_{L,R}^+/\sqrt{2} \end{pmatrix}$$

$$-\mathcal{L}_Y = \bar{\psi}'_{iL} \left(F_{ij} \Phi + G_{ij} \tilde{\Phi} \right) \psi'_{jR} + h.c.$$

F & G 3x3 Hermitian

$$\psi'_{iL,R} = \begin{pmatrix} u'_{iL,R} \\ d'_{i,L,R} \end{pmatrix}$$

$$M_u = KF + K'^* G$$

$$M_d = K'F + K^* G$$

In terms of mass e.s. $g_L = g_R \equiv g$

$$\mathcal{L}_{CC} = -\frac{g}{\sqrt{2}} \bar{u}_L V_L^{CKM} \gamma_\mu d_L V_R^{CKM} - \frac{g}{\sqrt{2}} \bar{u}_R V_R \gamma_\mu d_R W_R^{\mu +} + h.c.$$

QUARK MASS MATRICES

- QUARK MASSES COME FROM YUKAWA couplings to bidoublet Higgs

$$\Phi = \begin{pmatrix} \phi_1^0 & \phi_2^+ \\ \phi_1^- & \phi_2^0 \end{pmatrix}; \qquad \langle\Phi\rangle = \begin{pmatrix} K & 0 \\ 0 & K' \end{pmatrix}$$

- TWO CONSTRAINTS ON BIDOUBLET Higgs VEV's:

LANGACKER & SARKAR $\quad |K|^2 + |K'|^2 \simeq 2\dfrac{m_W^2}{g^2} \simeq (174.1\ \text{GeV})^2$

Ecker et al; Frere et al $\quad \left|\dfrac{K'}{K}\right| = \dfrac{m_b}{m_t} \quad$ ("TOP-INSPIRED")

- MAGNITUDES of K and K' are fixed

$$|K| \sim m_t \quad \& \quad |K'| \sim m_b$$

- ONE NON-REMOVABLE ~~phase~~ ~~ph~~ phase AMONG ~~among~~ K & K'

~~$\alpha \equiv$ Arg(K')~~

$$\alpha_{K'} \equiv \text{Arg}(K')$$

" THE SPONTANEOUS PHASE"

SIMPLIFICATION OF QUARK MASS MATRICES

$$M_u = KF + K'^{*}G$$
$$M_d = K'F + K^{*}G$$

F & G are 3×3 Hermitian, K' is complex

SIMULTANEOUS UNITARY ROTATION OF F & G IS PHYSICALLY UNOBSERVABLE

USE THIS ROTATION TO: ~~DIAGONALIZE~~

- DIAGONALIZE F
- ELIMINATE 2 PHASES IN G

GENERL RESULT

$$F = \begin{pmatrix} f_{11} & 0 & 0 \\ 0 & f_{22} & 0 \\ 0 & 0 & f_{33} \end{pmatrix}; \quad G = \begin{pmatrix} g_{11} & g_{12} & g_{13} \\ g_{12} & g_{22} & g_{23}e^{i\beta_{23}} \\ g_{13} & g_{23}e^{-i\beta_{23}} & g_{33} \end{pmatrix}$$

$\Rightarrow$ 11 Free Parameters.

THIS INCLUDES 2 CP-odd PHASES

$$\alpha_{K'} \equiv \mathrm{Arg}(K') \;\&\; \beta_{23}$$

$\not{C}\not{P}$ in HIGGS VEV & Yukawas

- CKM matrices

  V_L^{CKM} CONTAINS 1 PHASE ("δ_L")

  V_R^{CKM} " 6 PHASES

  HOWEVR, all 7 are functions of the 2 basic phases: α_K' & β_{23}

- NUMERICAL SOLUTION of the MODEL

  9 "Level I" Constraints: 6 m_q's & 3 LH angles $\theta_{12}, \theta_{13}, \theta_{23}$

  \+

  5 "LEVEL II" Constraints: ϵ_K, Δm_K, $\sin 2\beta_{CKM}^{eff}$, Δm_{Bd}, Δm_{Bs}

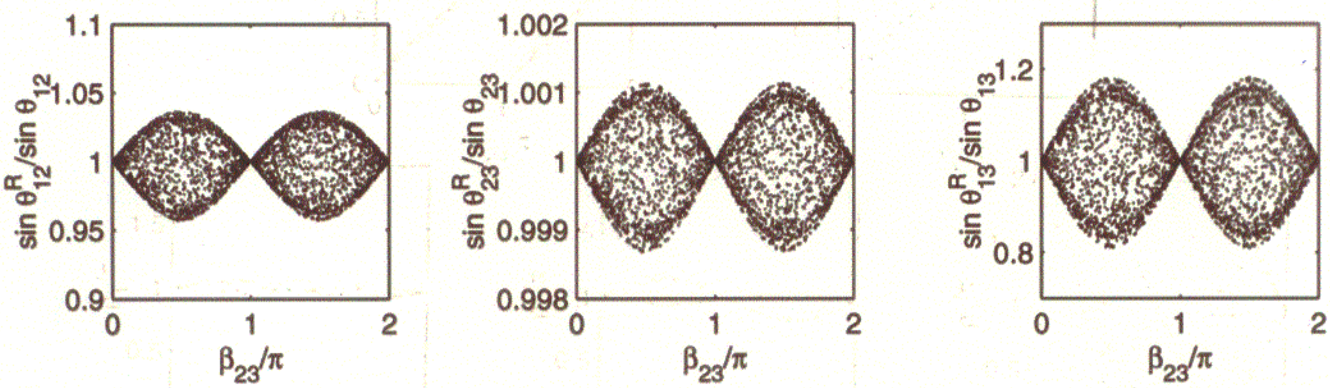
SEARCH 11 DIM [$f_{11}, f_{22}, f_{33}, g_{11}, g_{22}, g_{33}, g_{12}, g_{13}, g_{23}$, α_K', β_{23}] space for solutions.

FOR EACH Set Can:

- calculate quark masses
- " V_L^{CKM}, V_R^{CKM}
- (possibly) combine with M_H & ~~$M_{..}$~~ M_{W_R} — FChanging

$\Rightarrow$ Calculate "Level II" quantities

Level I prediction for RH/LH rotation angles



- Ratios of right and left-handed rotation angles
- surprising simplicity: $\theta^R_{ij} \simeq \theta^L_{ij}$
- numerical observation:

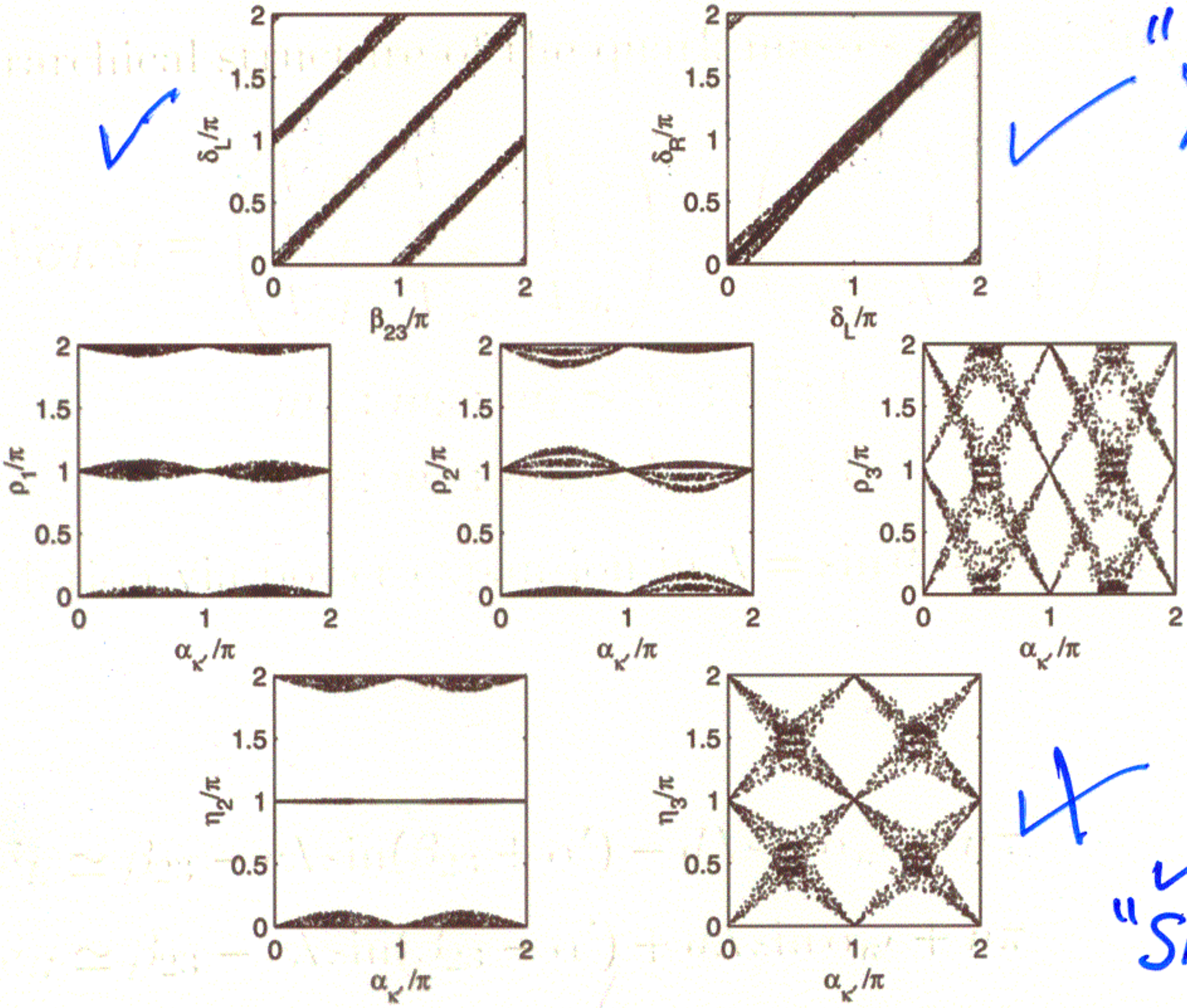
$$\theta^R_{12} = \theta^L_{12} \times (1 + \overbrace{\mathcal{O}(4\%)}^{\lambda^2})$$

$$\theta^R_{23} = \theta^L_{23} \times (1 + \overbrace{\mathcal{O}(0.1\%)}^{\lambda^3})$$

$$\theta^R_{13} = \theta^L_{13} \times (1 + \underbrace{\mathcal{O}(20\%)}_{\lambda})$$

$\boxed{\lambda \sim \theta_c \sim 0.22}$

Level I prediction for 7 phases in LH/RH CKMs



"YUKAWA"

"SPONTANEOUS"

- LH and RH CKM phases vs $\alpha_{\kappa'}$ or β_{23}
- $\delta_L \simeq \beta_{23} \pm \pi \pm 0.25$ rad
- $\delta_R \approx \delta_L \pm 0.50$ rad as a marriage between manifest LRSM ($\delta_R = \delta_L$) and pseudo-manifest LRSM ($\delta_R = -\delta_L$, $|\delta_L - n\pi| \leq 0.25$)

Analytic solution for the CKM phases

- hierarchical structure of the quark masses and mixing

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim \begin{pmatrix} 1 & \lambda & \lambda^4 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

$$m_u : m_c : m_t \sim \lambda^8 : \lambda^4 : 1$$

$$m_d : m_s : m_b \sim \lambda^4 : \lambda^2 : 1$$

solution via power expansion in $\lambda = \sin\theta_c = 0.22$

- Phase relations

$$\delta_L \simeq \beta_{23} - c\lambda \sin(\beta_{23} + \alpha') - d\lambda \sin\alpha_{\kappa'} + n\pi$$

$$\delta_R \simeq \beta_{23} - c\lambda \sin(\beta_{23} - \alpha') + d\lambda \sin\alpha_{\kappa'} + n\pi$$

where $c, d = \mathcal{O}(1)$ and $n = 0, 1$

$\Rightarrow$ Yukawa phase dominant
VEV phase Cabibbo-suppressed

- $\delta_R = \delta_L + 2c\lambda \cos\beta_{23} \sin\alpha' + 2d\lambda \sin\alpha_{\kappa'} + \mathcal{O}(\lambda^2)$

$\Rightarrow$ $\delta_R = \delta_L + \mathcal{O}(\lambda)$

- (quasi)manifest limit ($\alpha_{\kappa'} = 0, \pi$):

$$\delta_R = \delta_L \simeq \begin{cases} \beta_{23} - c\lambda \sin\beta_{23} + n\pi & (\alpha' = 0) \\ \beta_{23} + c\lambda \sin\beta_{23} + n\pi & (\alpha' = \pi) \end{cases}$$

- pseudo-manifest limit (or SB-LR): $\beta_{23} = 0, \pi$

$$\delta_R = -\delta_L \simeq \begin{cases} c\lambda \sin\alpha' + d\lambda \sin\alpha_{\kappa'} + n\pi \\ -c\lambda \sin\alpha' + d\lambda \sin\alpha_{\kappa'} + (n+1)\pi \end{cases}$$

i.e. $|\delta_{L,R} - n\pi| \leq \mathcal{O}(\lambda)$

$\Rightarrow$ CKM phases Cabibbo-suppressed in SB-LR!

- Angle relations:

$$\theta_{12}^R = \theta_{12}^L \times (1 + \mathcal{O}(\lambda^2))$$

$$\theta_{23}^R = \theta_{23}^L \times (1 + \mathcal{O}(\lambda^5))$$

$$\theta_{13}^R = \theta_{13}^L \times (1 + \mathcal{O}(\lambda))$$

The 7 Phases in a Top-inspired LR General Model.

V_L^{CKM} = "Standard" form (PDG) with KM phase δ_L

$V_L^{CKM}(\theta_{12}^L, \theta_{23}^L, \theta_{13}^L, \delta_L)$ $\quad \{\delta_L \simeq \gamma \simeq \arg[-V_{ub}^*]\}$

$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_L} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_L} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_L} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_L} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_L} & c_{23}c_{13} \end{pmatrix}$$

$$V_R^{CKM} = \mathcal{R}\, V_L^{CKM}(\theta_{12}^R, \theta_{23}^R, \theta_{13}^R, \delta_R)\, \tilde{\mathcal{R}}^{+}$$

$$\mathcal{R} = \mathrm{diag}(e^{i\rho_1}, e^{i\rho_2}, e^{i\rho_3}); \quad \tilde{\mathcal{R}} = \mathrm{diag}(1, e^{i\eta_2}, e^{i\eta_3})$$

LEVEL I CONSTRAINTS GIVE:

$$\theta_{ij}^R \simeq \theta_{ij}^L \;; \quad \delta_R \simeq \delta_L \simeq \beta_{23}$$ YUKAWA PHASE

ρ_1, ρ_2, η_2 are $0, \pi$.

$\rho_3, \eta_3 = f(\alpha_{K'})$ ⇒ ① SHOULD AFFECT 3rd family Physics.

HIGGS PHASE

② ρ_3, η_3 LIKELY TO BE IMPT for BARYOGENESIS.

TAKING CUE from CORNWALL, GRIGORIEV & KUSENKO hep-ph/0106127

SUMMARY ... LRSM

- Given now that $m_\nu \neq 0$, LR model ~~should~~ deserve serious study in a grounds-up approach

- DESPITE A VERY GENERAL IMPLEMENTATION, with a heavy top, model exhibits surprising simplicity.

$$\theta^R_{ij} \simeq \theta^L_{ij} \quad ; \quad \delta_R \simeq \delta_L \simeq \beta_{23}$$

complex Yukawa

- BUT V_R^{CKM} in couplings of 3rd family show ~~CP~~ due to the complex VEV ($\alpha\kappa'$)

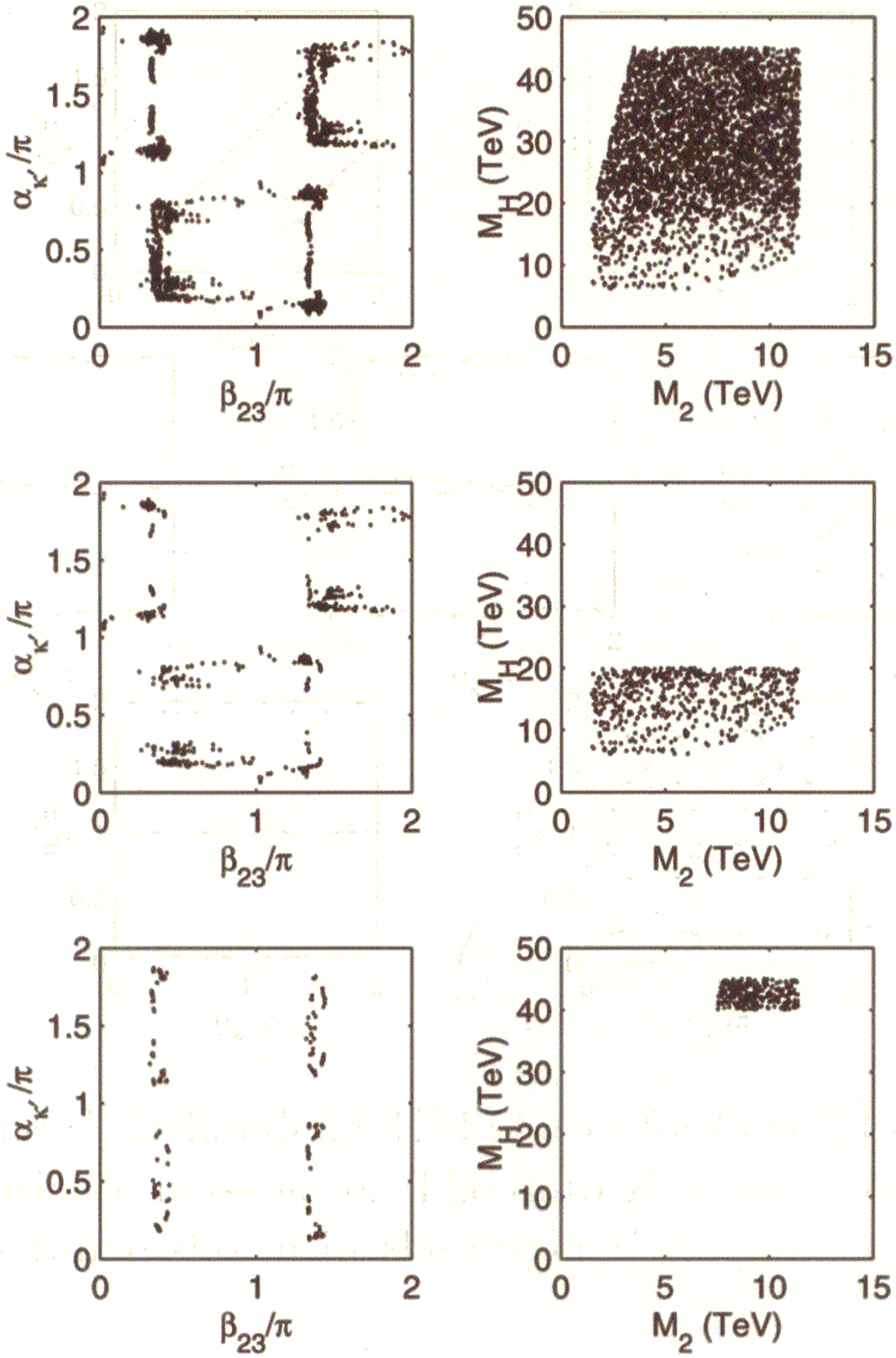
impt. for baryogenesis

- EXPT CONSTRAINTS SEEM TO REQUIRE

$$m_{W_R} \gtrsim 2\,\text{TeV}, \quad m_{H(\text{FCNH})} \gtrsim 7\,\text{TeV}$$

[i.e. VIABLE SOLNS. SATISFYING LEVEL I + II CONSTRNTS EXIST subject to these bounds]

Level II solutions: varying M_2, M_H



- The middle and lower plots are subsets of upper plots.