

New Physics

Beyond Flavour Dogmas

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Work done in collaboration with

F. Botella, M. Nebot and M.N. Rebelo

and earlier work with L. Lavoura, W. Grimus

• Neutral currents have played a crucial rôle in the construction of the SM and its experimental tests.

• The discovery of Neutral weak currents was the first great success of the SM

• An important feature of Flavour-Changing-Neutral Currents (FCNC)

They are forbidden at tree level, both in the SM and in most of its extensions

• EPS prize to Gargamelle collaboration in 2009

• EPS prize to GIM in 2011.

At loop level FCNC are generated and have played a crucial role in testing the SM and in putting bounds on New Physics beyond the SM: $K^0-\bar{K}^0$, $D^0-\bar{D}^0$, $B_d^0-\bar{B}_d^0$, $B_s^0-\bar{B}_s^0$
 rare kaon decays, rare b-meson decays
 CP violation

SM contributes to these processes at loop level
 ↓

New Physics has a chance to give significant contributions

The need to suppress FCNC led to 4

Two dogmas:

- No Z -mediated FCNC at tree level
- No FCNC in the scalar sector, at tree level.

Glashow and Weinberg (PRD 1977)

E. A. Paschos (PRD 1977)

derived necessary and sufficient conditions

(i) All quarks of fixed charge and helicity must transform according to the same irreducible representation of $SU(2)$ and correspond to the same eigenvalue of T_3

(ii) All quarks should receive their contributions to the quark mass matrix from a single neutral scalar
Vev

Can one violate these two dogmas in reasonable extensions of the SM? Yes!

"Reasonable" means that FCNC should be naturally suppressed, without fine-tuning.

In the gauge sector, the Dogma can be violated through the introduction of a $Q = 1/3$ and/or $Q = 2/3$ vector-like quark.

Naturally small violations of 3×3 unitarity of V_{CKM}

Z-mediated, Naturally suppressed FCNC at tree level

Example: Addition of one $Q = -1/3$ vector.

Like quark to the SM:

$D_L, D_R \rightarrow$ singlets under $SU(2)_L$

Charged currents:

$$(\bar{u} \quad \bar{c} \quad \bar{t})_L \gamma^\mu \begin{bmatrix} V_{ud} & V_{us} & V_{ub} & V_{uD} \\ V_{cd} & V_{cs} & V_{cb} & V_{cD} \\ V_{td} & V_{ts} & V_{tb} & V_{tD} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \\ D \end{bmatrix} W_\mu + h.c.$$

Non orthogonality of columns of V leads to terms like:

$$g/\cos\theta_W Z_{bd} \bar{b}_L \gamma_\mu d_L Z^\mu$$

$$Z_{bd} = V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^*$$

$Z_{bd} \rightarrow$ suppressed
by $(m/M)^2$

m - mass of standard quarks
 M - mass of D-quark

Some Comments

- Nothing "strange" in having deviations from 3×3 unitarity in V_{CKM} . The PMNS matrix in the leptonic sector, in the context of Type-I seesaw is not 3×3 unitary!

For model independent analysis: S. Antusch, M. Bilen Garola et al
(JHEP)

- Vector-like quarks provide the simplest model with Spontaneous CP violation, which generates a complex V_{CKM} , in agreement with experiment.

- Provide a framework to have a Common Origin of all CP violations!

- Potential Solution of the Strong CP Problem, without Axions

Some details of a Minimal Model 71

Add to the SM:

$D_L, D_R \rightarrow$ isosinglet $Q = -1/3$ quark

$S \rightarrow$ complex $SU(2) \times U(1)$ singlet

Introduce a Z_2 symmetry under which all SM fields transform trivially, but D_L, D_R, S are odd.

$$M_d = \begin{bmatrix} m_d & & & \\ & \dots & & \\ & & M_D & \\ & & & \dots \\ & & & & M \end{bmatrix}$$

CP invariance at Lagrangian level

$$\langle S \rangle = V_e^{i\alpha}$$

$$\bar{D}_L d_{Rj} (f_j S + f_j^* S^*) \rightarrow M_D = \begin{bmatrix} f_j V_e^{i\alpha} + f_j^1 V_e^{-i\alpha} \end{bmatrix}$$

E Effective 3×3 matrix for $Q = -1/3$ quarks ^{7"}

$$m_{\text{eff}}^+ m_{\text{eff}}^+ = m_d m_d^+ - \frac{m_d M_D M_D m_d^+}{(M_D M_D^+ + M^2)}$$

Both terms of the same order of magnitude!

The presence of the 2nd term can generate a complex V_{CKM} : All CP violation can arise

from: $\alpha = \arg \langle S \rangle$

potential solution

$$\bar{\Theta} \equiv \Theta_{QCD} + \Theta_{QFD} = 0 \rightarrow$$

of the String CP problem

Analogy to solution proposed by R. N. Mohapatra, G. Senjanovic, R. N. Mohapatra, G. Senjanovic

Another Remark:

There was another **Dogma** in Particle Physics

"Neutrinos are Strictly Massless in the SM and in $SU(5)$ " !!

We all know what happened to this **Dogma**.

There is some similarity between vector-like quarks and ν_R .

$$\left. \begin{array}{l} \nu_R^T C \nu_R \\ \bar{D}_L M D_R \end{array} \right\}$$

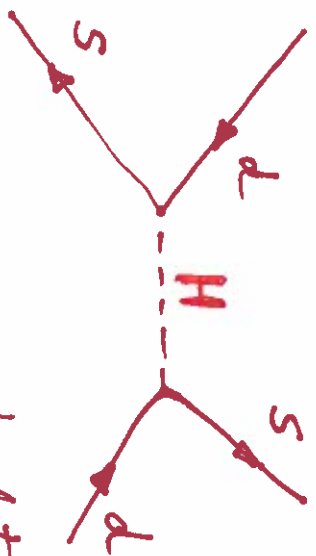
Both terms are

$SU(2) \times U(1)$ invariant

Scalar Sector

Can one have scalar-mediated FCNC at tree level, but somehow suppressed by "small V_{CKM} elements"?

Most dangerous couplings:



$$K_L - K_S \text{ mass difference} \Rightarrow m_H \geq 1 \text{ TeV}$$

$$\text{CP violation} (\epsilon_K) \Rightarrow m_H \geq 30 \text{ TeV}$$

The possibility that FCNC could be suppressed by small V_{CKM} elements was considered by various authors

L. Hall, S. Weinberg

A. Antaramian, L. Hall, A. Rasin

Yoshikawa, S. D. Rindani

Interesting, but ad-hoc assumptions, not based on an exact (or softly broken) symmetry of the Lagrangian

Question: Can one have a multi-scalar extension of the SM, where as a result of a symmetry of the Lagrangian, there are FCNC at tree level, but all couplings are controlled by V_{CKM} , without any other flavour parameters? Answer: Yes!!

- First we show that this looks like an Impossible Mission
- Then we show that there are Models which fulfil the above condition but the number of models is severely restricted!

G.C.B., W. Grimus, L. Lavoura, Phys. Lett. (1995)

F. Botella, G.C.B., M.N. Rebelo, Physics Lett. B (2010)

F. Botella, G.C.B., M.N. Rebelo, M. Nebot

- What is the motivation for considering multi-scalar models with FCNC? It is likely that a theory of flavour will involve various **scalar doublets**.

- It is desirable that a correct theory of flavour predicts new phenomena, making some testable predictions.

A possible prediction could be the existence of non-vanishing but naturally suppressed scalar-mediated FCNC

- Nature may, **once more**, surprise us:

Recent "surprises" with **flavour**:

- A heavy top
- Large leptonic mixing

We need **surprises** in the **Scalar Sector!!**

The requirement of rephasing invariance

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Let us consider a **FCNC** transition connecting a quark d_j to another quark d_k . The transition could be mediated by a scalar or by a vector boson:

$$\mathcal{L}_{\text{scalar}} = \bar{d}_j \Gamma_{jk}^S d_R \quad S ; \quad \mathcal{L}_{\text{vector}} = \bar{d}_j \Gamma_{jk}^V \gamma_\mu d_k \quad V_\mu$$

Γ^S, Γ^V may arise at **tree level** or in higher orders.

Assume that d_j denotes quark mass eigenstates.

Under rephasing of quark fields:

$$d_j \rightarrow d'_j = \exp(-i\beta_j) d_j$$

Γ^S, Γ^V have to transform in such a way that the above interactions remain invariant. This implies that under rephasing

$$\Gamma_{jk} \rightarrow \Gamma'_{jk} = \exp[i(\beta_k - \beta_j)] \Gamma_{jk}$$

If we require that the **flavour dependence** of Γ_{jk} be **completely controlled** by V_{CKM} , this severely restricts the functional dependence of Γ_{jk} on V_{CKM} . The simplest forms allowed by **rephasing invariance** are:

$$\Gamma_{jk} = \sum_{\alpha} c_{\alpha} V_{\alpha j} V_{\alpha k}^*$$

where c_{α} are coefficients which are invariant under rephasing. Note that the form of $\sum_{bd} Z_{bd}$, found previously, satisfies this requirement **(as it had to !!)** with $c_{\alpha} = 1$ for all c_{α} .

$$\sum_{bd} Z_{bd} = V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^*$$

The case of Two scalar doublets models

Yukawa Interactions

$$\mathcal{L}_Y = -\bar{Q}_L^i \Gamma_1 \phi_1 d_R^i - \bar{Q}_L^i \Gamma_2 \phi_2 d_R^i - \bar{Q}_L^i \Delta_1 \tilde{\phi}_1 u_R^i - \bar{Q}_L^i \Delta_2 \tilde{\phi}_2 u_R^i + \text{h.c.}$$

$Q_L^i \rightarrow$ left-handed doublets ; d_R^i, u_R^i right-handed singlet

So this is a two-scalar doublet model of type III

Quark mass matrices :

$$M_d = \frac{1}{\sqrt{2}} (v_1 \Gamma_1 + v_2 e^{i\alpha} \Gamma_2) ; M_u = \frac{1}{\sqrt{2}} (v_1 \Delta_1 + v_2 e^{-i\alpha} \Delta_2)$$

Diagonalized by :

$$U_{dL}^\dagger M_d U_{dR} = D_d \equiv \text{diag.} (m_d, m_s, m_b)$$

$$U_{uL}^\dagger M_u U_{uR} = D_u \equiv \text{diag.} (m_u, m_c, m_t)$$

Expand Φ_j :
$$\Phi_j = e^{i\alpha_j} \begin{bmatrix} \phi_j^+ \\ \frac{1}{\sqrt{2}} (\nu_{j+P} + i\eta_j) \end{bmatrix} \quad j=1,2$$

It is convenient to define new fields G^+, G^0, H^\pm, H^0, R :

$$\begin{bmatrix} G^+ \\ H^+ \end{bmatrix} = O \begin{bmatrix} \phi_1^+ \\ \phi_2^+ \end{bmatrix}; \quad \begin{bmatrix} G^0 \\ I \end{bmatrix} = O \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix}; \quad \begin{bmatrix} H^0 \\ R \end{bmatrix} = O \begin{bmatrix} \nu_1 \\ \nu_2 \end{bmatrix}$$

where: $O = \frac{1}{v} \begin{bmatrix} \nu_1 & \nu_2 \\ \nu_2 & -\nu_1 \end{bmatrix}; \quad v = \sqrt{\nu_1^2 + \nu_2^2} = (\sqrt{2} G_F)^{-1/2} \approx 246 \text{ GeV}$

- $G^+, G^0 \rightarrow$ Goldstone bosons
- $H^0, R, I \rightarrow$ neutral scalars
- $H^\pm \rightarrow$ charged scalar

It is convenient to write the Yukawa coupling in terms of quark mass eigenstates and the new fields H^\pm, H^0, R, I

$$\begin{aligned} \mathcal{L}_Y = & \frac{\sqrt{2}}{v} H^\dagger \bar{u} \left[V_{ud} \gamma_R + N_u^\dagger V \gamma_L \right] d_L + \text{h.c.} - \frac{H^0}{v} \left[\bar{u} D_\mu u + \bar{d} D_\mu d \right] - \\ & - \frac{R}{v} \left[\bar{u} (N_u \gamma_R + N_u^\dagger \gamma_L) u + \bar{d} (N_d \gamma_R + N_d^\dagger \gamma_L) d \right] + \\ & + i \frac{F}{v} \left[\bar{u} (N_u \gamma_R - N_u^\dagger \gamma_L) u - \bar{d} (N_d \gamma_R - N_d^\dagger \gamma_L) d \right] \end{aligned}$$

$u, d \rightarrow$ *quark mass eigenstates* ; $\gamma_L = \frac{1}{2}(1 - \gamma_5)$; $\gamma_R = \frac{1}{2}(1 + \gamma_5)$

The matrices N_d, N_u are given by :

$$N_d = \frac{1}{\sqrt{2}} U_{dL}^\dagger \left[v_2 \Gamma_1 - v_1 e^{i\alpha} \Gamma_2 \right] U_{dR} ; \quad N_u = \frac{1}{\sqrt{2}} U_{uL}^\dagger \left[v_2 \Delta_1 - v_1 e^{-i\alpha} \Delta_2 \right] U_{uR}$$

Flavour-Changing Neutral couplings are controlled by the matrices N_d, N_u . For generic 2 scalar doublet models N_d, N_u are arbitrary!

It is convenient to write N_d in the following way :

$$N_d = \underbrace{\frac{\sqrt{2}}{\sqrt{1}} D_L - \frac{\sqrt{2}}{\sqrt{2}}}_{\text{Convenient Flavour}} \underbrace{\left(\frac{\sqrt{2}}{\sqrt{1}} + \frac{\sqrt{1}}{\sqrt{2}} \right)}_{\text{leads to FCNC}} U_{dL}^\dagger e^{i\alpha} U_{dR}$$

From the above expression for N_d , one concludes that there are **Two Major Obstacles** which one has to **surmount** in order for N_d to be entirely controlled by V_{CKM} , with no free parameters:

(i) It is U_{dL} rather than the combination $U_{dL}^\dagger U_{dL} \equiv V_{CKM}$ which appears in N_d

(ii) How to get rid of the dependence on U_{dR} ?

The first difficulty can be solved by means of a flavour symmetry constraining U_{dL} to have mixing only among two generations, for example:

$$U_{dL} = \begin{bmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & 1 \end{bmatrix}; \text{ In this case:}$$

$$V_{CKM} = \begin{bmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \times & \times & \times \\ \times & \times & \times \\ U_{d31} & U_{d32} & U_{d33} \end{bmatrix} = \begin{bmatrix} \times & \times & \times \\ \times & \times & \times \\ U_{d31} & U_{d32} & U_{d33} \end{bmatrix}$$

So one has:

$$(V_{CKM})_{3j} = (U_{dL})_{3j}$$

In order to surmount difficulty (i) one has to further require that the flavour dependence of N_d on U_{dL} is only on the 3rd row of U_{dL} .

How to surmount obstacle (ix), i.e. how to avoid the dependence on U_{LR} ? Let us assume that Γ_2 is such that:

$$\Gamma_2 \propto P M_d \quad \text{where } P \text{ is a fixed matrix.}$$

In this case:

$$U_{dL}^+ \Gamma_2 U_{dR} \propto U_{dL}^+ P M_d U_{dR} = U_{dL}^+ P \underbrace{U_{dL} U_{dL}^+}_{D_d} M_d U_{dR} = U_{dL}^+ P U_{dL} D_d$$

The flavor structure of Γ_1, Γ_2 should be such that a fixed matrix P exists satisfying:

$$\Gamma_2 \propto P M_d$$

One way of achieving this is by having:

$$P \Gamma_2 = k \Gamma_2 \quad ; \quad P \Gamma_1 = 0$$

Recall that

$$M_d = \frac{1}{\sqrt{2}} (\nu_1 \Gamma_1 + \nu_2 e^{ix} \Gamma_2)$$

It has been shown (B, GIMM and LAWURA \equiv BGL) that it is possible to find a **flavour symmetry** of the

Lagrangian such that it leads to a structure for Γ, Δ which imply **FCNC** at tree level, with strength completely **controlled by V_{CKM}** . BGL have imposed the following symmetry on the Lagrangian:

$$q) Q_{Lj}^{\circ} \rightarrow \exp(i\alpha) Q_{Lj}^{\circ}; U_{Rj}^{\circ} \rightarrow \exp(i2\alpha) U_{Rj}^{\circ}; \phi_2 \rightarrow \exp(i\alpha) \phi_2$$

where $\alpha \neq 0, \pi$, with all other quark fields transforming trivially under the symmetry.

- The index j can be $j = 1, 2, 3$

Alternatively, one can choose the symmetry:

$$b) Q_{Lj}^{\circ} \rightarrow \exp(i\alpha) Q_{Lj}^{\circ}; d_{Rj}^{\circ} \rightarrow \exp(i2\alpha) d_{Rj}^{\circ}; \phi_2 \rightarrow (-i\alpha) \phi_2$$

Altogether δ BGL models in the quark sector

Let us choose $j=3$:

$$Q_{L3}^i \rightarrow \exp(i\alpha) Q_{L3}^i ; U_{R3} \rightarrow \exp(i2\alpha) U_3^i ; \phi_2 \rightarrow \exp(i\alpha) \phi_2$$

In this case the Yukawa matrices Γ_1, Γ_2 have the structure

$$\Gamma_1 = \begin{bmatrix} \times & \times & \times \\ \times & \times & \times \\ 0 & 0 & 0 \end{bmatrix} ; \Gamma_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \times & \times & \times \end{bmatrix} ; A_1 = \begin{bmatrix} \times & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & 0 \end{bmatrix} ; A_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \times \end{bmatrix}$$

And $PM_d = \frac{\sqrt{2}}{\sqrt{2}} e^{i\alpha} \Gamma_2$; with $P = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

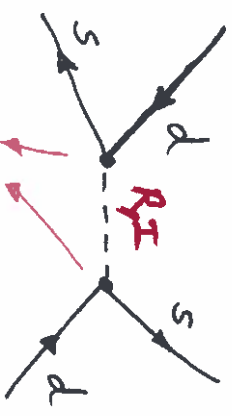
$$(N_d)_{ij} = \frac{\sqrt{2}}{\sqrt{1}} (D_d)_{ij} - \left(\frac{\sqrt{2}}{\sqrt{1}} + \frac{\sqrt{1}}{\sqrt{2}} \right) (V_{CKM})_{i3}^* (V_{CKM})_{3j} (D_d)_{ij}$$

$$(N_u) = -\frac{\sqrt{1}}{\sqrt{2}} \text{diag.} (0, 0, m_t) + \frac{\sqrt{2}}{\sqrt{1}} \text{diag.} (m_u, m_c, 0)$$

In this example, the Higgs mediated FCNC are suppressed by the 3rd row of V_{CKM} . Furthermore, there are FCNC only in the down sector!

An important feature of the Model which we have described :

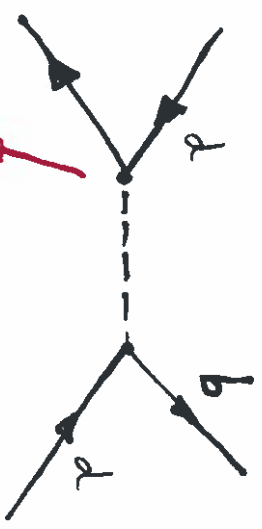
Strong and Natural Suppression of the "most dangerous penguins"



$V_{cd} V_{cs}^* \sim \lambda^5 \Rightarrow$ altogether λ^{10} suppression !!

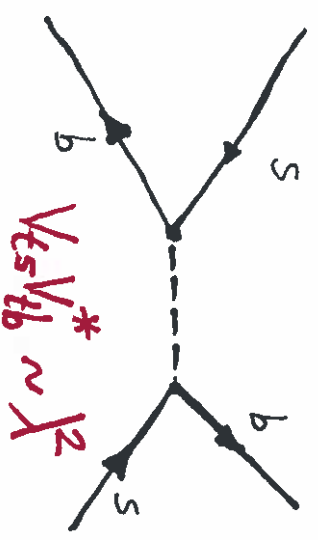
$\Delta S = 2$ penguins are strongly suppressed

"light" Higgs are allowed



$V_{td} V_{tb}^* \sim \lambda^3$

\rightarrow may contribute significantly to $B_d - \bar{B}_d$ mixing



$V_{ts} V_{tb}^* \sim \lambda^2$

\rightarrow contribution to $B_s - \bar{B}_s$ mixing

An important Question:

Are there any other models, based on different abelian symmetries, leading also to **FCCNC** at tree-level but **completely controlled** by V_{CKM} , without any further parameters? "Intuitive" answer: **Yes**. **Correct answer**: **No!!**

Pedro Ferreira and João Silva (Phys. Rev. D 83 (2011)) have classified all possible implementations of an Abelian symmetry in two-scalar doublet models, imposing the request of having non-vanishing quark masses and not block-diagonal V_{CKM} . "Answer": **BGL are unique?!!!**

This is a truly amazing result. We (BGL) did not use any systematic study, just used "intuition" and we were also **Lucky!**

So far, we have considered models which, due to the presence of a family symmetry, lead to FCNC, completely controlled by V_{CKM}

Question:

Can one make a "minimal-flavour-type" expansion of N_d, N_u ?

It is clear that a necessary condition for N_d^0, N_u^0 to be of the "MFV type" is that they should be functions of M_d, m_u and no other flavour dependent couplings

The terms entering in the expansion of N_d^0, N_u^0 should have the right transformation properties under weak-basis (WB) transformations

Under a WB transformation, defined by:

$$Q_L^0 \rightarrow W_L Q_L \quad ; \quad d_R^0 \rightarrow W_R^d d_R^0 \quad ; \quad u_R^0 \rightarrow W_R^u u_R^0$$

The quark mass matrices M_d, M_u transform as:

$$M_d \rightarrow W_L^{\dagger} M_d W_R^d \quad ; \quad M_u \rightarrow W_L^{\dagger} M_u W_R^u$$

The matrices $U_{dL}, U_{dR}, U_{uL}, U_{uR}$ transform as

$$U_{dL} \rightarrow W_L^{\dagger} U_{dL} \quad ; \quad U_{uL} \rightarrow W_L^{\dagger} U_{uL}$$

$$U_{dR} \rightarrow W_R^{d\dagger} U_{dR} \quad ; \quad U_{uR} \rightarrow W_R^{u\dagger} U_{uR}$$

While the Hermitian matrices $H_{d,u} \equiv M_{d,u} M_{d,u}^{\dagger}$ transform as:

$$H_d \rightarrow W_L^{\dagger} H_d W_L \quad ; \quad H_u \rightarrow W_L^{\dagger} H_u W_L$$

It is convenient to write H_d , H_u in terms of projection operators

(E. Botta, M. Nebot, O. Vives)

$$H_d = \sum_i m_{d_i}^2 P_i^{dL}, \text{ where } P_i^{dL} = U_{dL} P_i U_{dL}^\dagger, \text{ with } (P_i)_{jk} = \delta_{ij} \delta_{ik}$$

Obviously, under a WB transformation, N_d^0 , N_u^0 should transform as M_d , M_u . A MFV expansion for N_d^0 , N_u^0 with proper transformation properties is:

$$N_d^0 = \lambda, M_d + \lambda_{2i} U_{dL} P_i U_{dL}^\dagger M_d + \lambda_{3i} U_{uL} P_i U_{uL}^\dagger M_d + \dots$$

$$N_u^0 = \tau, M_u + \tau_{2i} U_{uL} P_i U_{uL}^\dagger M_u + \tau_{3i} U_{dL} P_i U_{dL}^\dagger M_u + \dots$$

In the mass eigenstate basis:

$$N_d^0 = \lambda, D_d + \lambda_{2i} P_i D_d + \lambda_{3i} V_{cKM}^\dagger P_i V_{cKM} D_d + \dots$$

With analogous expression for N_u^0 .

The BGL example considered before corresponds to the following truncation of our MUV expansion:

$$N_{\alpha}^0 = \frac{\nu_2}{\nu_1} M_{\alpha} - \left(\frac{\nu_2}{\nu_1} + \frac{\nu_1}{\nu_2} \right) U_{\alpha L} P_{\beta} U_{\alpha}^{\dagger} M_{\alpha}$$

$$N_{\alpha}^0 = \frac{\nu_2}{\nu_1} M_{\alpha} - \left(\frac{\nu_2}{\nu_1} + \frac{\nu_1}{\nu_2} \right) U_{\alpha L} P_{\beta} U_{\alpha}^{\dagger} M_{\alpha}$$

Note that the "truncation" corresponds to an exact symmetry of the Lagrangian.

Important point: Of the six BGL-type models only one is compatible with the MUV principle.

See: **A. Buras, M. Careacci, S. Gori, G. Isidori**
(1005.5318v1)

Extension to the Leptonic Sector

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BGL models can be extended to the Leptonic Sector.

Consider implementation in the seesaw framework:

$$\mathcal{L}_{+mass} = - \bar{L}_L^{\circ} \Pi_1 \Phi_1 \chi_R^{\circ} - \bar{L}_L^{\circ} \Pi_2 \Phi_2 \chi_R^{\circ} - \bar{L}_L^{\circ} \Sigma \tilde{\phi}_2 \nu_R^{\circ} - \bar{L}_L^{\circ} \Sigma_2 \tilde{\phi}_2 \nu_R^{\circ} + \frac{1}{2} \nu_R^{\circ T} C^{-1} M_R \nu_R^{\circ} + h.c.$$

M_R → right-handed Majorana mass matrix.

Impose the following Z_4 symmetry on the Lagrangian:

$$L_{L3}^{\circ} \rightarrow \exp(i\alpha) L_{L3}^{\circ} ; \nu_{R3}^{\circ} \rightarrow \exp(i2\alpha) \nu_{R3}^{\circ} ; \phi_2 \rightarrow e^{i\alpha} \Phi_2$$

$\alpha = \pi/2$ → choice dictated by the request of having a non-vanishing $\det M_R$

Structure of Leptonic mass matrices:

$$\pi_1 = \begin{bmatrix} x & x & x \\ x & x & x \\ 0 & 0 & 0 \end{bmatrix} ; \pi_2 = \begin{bmatrix} 0 & 0 & 0 \\ x & 0 & 0 \\ x & x & x \end{bmatrix}$$

$$\Sigma_1 = \begin{bmatrix} x & x & 0 \\ x & x & 0 \\ 0 & 0 & 0 \end{bmatrix} ; \Sigma_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & x \end{bmatrix} ; M_R = \begin{bmatrix} x & x & 0 \\ x & x & 0 \\ 0 & 0 & x \end{bmatrix}$$

The non-vanishing of this entire
requires Z_4 !



Conclusions

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- We live in the LHC ERA. At this stage "Nobody knows" what is the detailed mechanism of electroweak symmetry breaking, chosen by **Nature**.
- Multi-Scalar models may play an important rôle in solving the Flavour puzzle. For that, it may be necessary to violate the Dogma of **N.F.C.** in the Scalar Sector. A theory of flavour may have its own mechanism for the suppression of FCNC in the Scalar Sector
- LHC may bring some surprises in the Scalar Sector for example "Non-Standard Higgs", hopefully giving us new hints to find a solution to the **Flavour Puzzle**