Minimal Flavour Violation and Multi-Higgs Models

M. N. REBELO

CFTP / IST LISBON

Planck 2010, CERN, Geneva 2 June 2010

Work done in collaboration

F. J. Botella, G. C. Branco, MNR
(IFIC/CSIC, Valencia) (Lisbon)

Phys. Lett. B687 (2010) 194
arXiv: 0911.1753

Further Work in progress

Models with two Higgs doublets

potentially large HFCNC

strict limits on FCNC processes!

solutions: NFC

or

existence of suppression factors in HFCNC

Antaramian, Hall, Rasin (1992)
Hall, Weinberg (1993)
Joshipura, Rindani (1991)

first models of this type with suppresion by small off-diagonal elements of V_{CKM} : BGL models

Branco, Grimus, Lavoura (1996)

More recently, we have generalized BGL models to larger class of models of "Minimal Flavour Violation" type

About Minimal Flavour Violation

Buras, Gambino, Gorbahn, Jager, Silvestrini (2001)
D'Ambrosio, Giudice, Isidori, Strumia (2002)

leptonic sector

Cirigliano, Grinstein, Isidori, Wise (2005)

$G_F = U(3)^5$ largest symmetry of the gauge sector

flavour violation completely determined by Yukawa couplings

Our framework

- multi-Higgs models
- no Natural Flavour Conservation
- obey above condition (one of the defining ingredients of MFV framework)

"Higgs-mediated FCNC's: Natural Flavour Conservation vs. Minimal Flavour Violation"
Buras, Carlucci, Gori, Isidori, arXiv:1005.5310

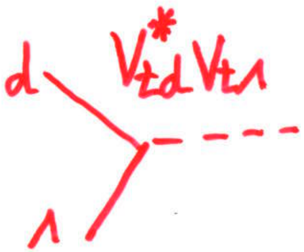
Question: Under what conditions the neutral Higgs couplings are only functions of V_{CKM} ?

Two Higgs doublets, generalization of BGL models
(plenary: G.C. Branco)

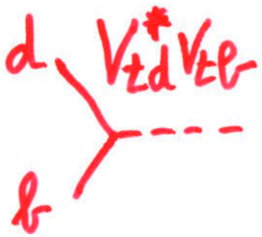
Three Higgs doublets, BGL type

No ad-hoc assumptions!

BGL models, two Higgs doublets
- discrete symmetry
- FCNC at tree level
- HFCN couplings entirely determined CKM elements (together with ratios of v_1 and v_2 and quark masses)



$$(N_d)_{ij} = \frac{v_2}{v_1} (D_d)_{ij} - \left(\frac{v_2}{v_1} + \frac{v_1}{v_2}\right) \overbrace{(V_{CKM}^\dagger)_{i3} (V_{CKM})_{3j}}^{MFV} (D_d)_{jj}$$



$$N_u = -\frac{v_1}{v_2} \, \mathrm{diag}(0, 0, m_t) + \frac{v_2}{v_1} \, \mathrm{diag}(m_u, m_c, 0)$$

Six different models

Models with three Higgs doublets

Yukawa interactions

$$\mathcal{L}_Y = -\bar{Q}_L^0 \Gamma_1 \Phi_1 d_R^0 - \bar{Q}_L^0 \Gamma_2 \Phi_2 d_R^0 - \bar{Q}_L^0 \Gamma_3 \Phi_3 d_R^0 -$$
$$- \bar{Q}_L^0 \Delta_1 \tilde{\Phi}_1 u_R^0 - \bar{Q}_L^0 \Delta_2 \tilde{\Phi}_2 u_R^0 - \bar{Q}_L^0 \Delta_3 \tilde{\Phi}_3 u_R^0 + h.c.$$

$$\tilde{\Phi}_i = -i \tau_2 \Phi_i^*$$

Quark mass matrices

$$M_d = \frac{1}{\sqrt{2}} \left(v_1 e^{i\alpha_1} \Gamma_1 + v_2 e^{i\alpha_2} \Gamma_2 + v_3 e^{i\alpha_3} \Gamma_3 \right)$$

$$M_u = \frac{1}{\sqrt{2}} \left(v_1 e^{-i\alpha_1} \Delta_1 + v_2 e^{-i\alpha_2} \Delta_2 + v_3 e^{-i\alpha_3} \Delta_3 \right)$$

after spontaneous symmetry breakdown

$$\Phi_j = e^{i\alpha_j} \begin{pmatrix} \phi_j^+ \\ \frac{1}{\sqrt{2}} (v_j + \rho_j + i\eta_j) \end{pmatrix}$$

We perform the following transformation

$$\begin{pmatrix} H^0 \\ R \\ R' \end{pmatrix} = O \begin{pmatrix} \rho_1 \\ \rho_2 \\ \rho_3 \end{pmatrix} , \qquad \begin{pmatrix} G^0 \\ I \\ I' \end{pmatrix} = O \begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{pmatrix}$$

$$O = \begin{pmatrix} \frac{v_1}{v} & \frac{v_2}{v} & \frac{v_3}{v} \\ \frac{v_2}{v'} & -\frac{v_1}{v'} & 0 \\ \frac{v_1}{v''} & \frac{v_2}{v''} & \frac{-(v_1^2+v_2^2)/v_3}{v''} \end{pmatrix} , \qquad \begin{aligned} v &= \sqrt{v_1^2+v_2^2+v_3^2} \\ v' &= \sqrt{v_1^2+v_2^2} \\ v'' &= \sqrt{v_1^2+v_2^2+(v_1^2+v_2^2)^2/v_3^2} \end{aligned}$$

O singles out

H^0 with couplings to quarks proportional to mass matrices

G the neutral pseudo-Goldstone boson

$$\mathcal{L}_Y(\text{neutral}) = -\frac{H^0}{v}\left(\bar{d}_L D_d d_R + \bar{u}_L D_u u_R\right) -$$

$$- \bar{d}_L \frac{1}{v'} N_d (R + iI) d_R - \bar{u}_L \frac{1}{v'} N_u (R - iI) u_R -$$

$$- \bar{d}_L \frac{1}{v''} N_d' (R' + iI') d_R - \bar{u}_L \frac{1}{v''} N_u' (R' - iI') u_R + h.c.$$

With

$$N_d = \frac{1}{\sqrt{2}} U_{d_L}^{\dagger} \left(v_2 e^{i\alpha_1} \Gamma_1 - v_1 e^{i\alpha_2} \Gamma_2\right) U_{d_R}$$

$$N_u = \frac{1}{\sqrt{2}} U_{u_L}^{\dagger} \left(v_2 e^{-i\alpha_1} \Delta_1 - v_1 e^{-i\alpha_2} \Delta_2\right) U_{u_R}$$

$$N_d' = \frac{1}{\sqrt{2}} U_{d_L}^{\dagger} \left(v_1 e^{i\alpha_1} \Gamma_1 + v_2 e^{i\alpha_2} \Gamma_2 + x e^{i\alpha_3} \Gamma_3\right) U_{d_R}$$

$$N_u' = \frac{1}{\sqrt{2}} U_{u_L}^{\dagger} \left(v_1 e^{-i\alpha_1} \Delta_1 + v_2 e^{-i\alpha_2} \Delta_2 + x e^{-i\alpha_3} \Delta_3\right) U_{u_R}$$

$$x = -(v_1^2 + v_2^2)/v_3$$

Imposing the following discrete symmetry on the Lagrangian

$$Q^0_{L1} \to \omega\, Q^0_{L1}\ , \quad Q^0_{L2} \to \omega^2 Q^0_{L2}\ , \quad Q^0_{L3} \to \omega^4 Q^0_{L3}$$

$$\Phi_1 \to \omega\, \Phi_1\ , \quad \Phi_2 \to \omega^2 \Phi_2\ , \quad \Phi_3 \to \omega^4 \Phi_3$$

$$u^0_{R_1} \to \omega^2 u^0_{R_1}\ , \quad u^0_{R_2} \to \omega^4 u^0_{R_2}\ , \quad u^0_{R_3} \to \omega^8 u^0_{R_3}$$

$$d^0_{R_f} \to d^0_{R_f} \qquad \text{with } \omega = \exp i\pi/4$$

restricts the Yukawa coupling matrices. Following structure

$$\Gamma_1 = \begin{bmatrix} \times & \times & \times \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} ; \quad \Gamma_2 = \begin{bmatrix} 0 & 0 & 0 \\ \times & \times & \times \\ 0 & 0 & 0 \end{bmatrix} ; \quad \Gamma_3 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \times & \times & \times \end{bmatrix}$$

$$\Delta_1 = \begin{bmatrix} \times & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} ; \quad \Delta_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \times & 0 \\ 0 & 0 & 0 \end{bmatrix} ; \quad \Delta_3 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \times \end{bmatrix}$$

all three Higgs doublets have non-zero Yukawa couplings both in the up and down sectors

In this case there are Higgs mediated FCNC only down sector

$$(N_d)_{ij} = \frac{v_2}{v_1}(D_d)_{ij} - \left(\frac{v_2}{v_1} + \frac{v_1}{v_2}\right)(V_{CKM}^{\dagger})_{i2}(V_{CKM})_{2j}(D)_{jj} -$$

$$- \frac{v_3}{v_1}(V_{CKM}^{\dagger})_{i3}(V_{CKM})_{3j}(D)_{jj}$$

$x = -(v_1^2 + v_2^2)/v_3$

$$(N_d')_{ij} = (D_d)_{jj} - \frac{v_3 - x}{v_3}(V_{CKM}^{\dagger})_{i3}(V_{CKM})_{3j}(D_d)_{jj}$$

N_d includes FCNC terms where the suppression factor in $\Delta S = 2$ transitions is only $(V_{cd}^{*} V_{cs})^2$, which then requires quite heavy neutral Higgs

Conclusions

Multi-Higgs models are very interesting candidates for NP

There are new mechanisms beyond NFC to obtain strong suppression of FCNC as required by experiment

LHC results may bring surprises for the Higgs sector