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Updating of 2HDM-III employing a four-zero texture in the Yukawa matrices and phenomenology of the charged Higgs

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Outline

- Brief introduction of 2HDM-III, employing four zero texture in the Yukawa matrices.
- As this version of 2HDM-III could contain the other versions of 2HDM.
- Flavor contraints at low energy processes.
- Phenomenology of charged Higgs could be quite different.
- Some interesting decays channels of H+:

H+ → cs, cb, ts, W gamma, W Z

Versions of the 2HDM

Type I: one Higgs doublet provides masses to all quarks (up- and down-type quarks) (~SM).

Type II: one Higgs doublet provides masses for up-type quarks and the other for down-type quarks (~MSSM).

Type III: the two doublets provide masses for up and down type quarks, as well as charged leptons.

We could consider this model as a generic description of physics at a higher scale (i. e. Radiative corrections of the MSSM Higgs sector* or from extradimension**).

*J. L. Díaz-Cruz, R. Noriega-Papaqui and A. Rosado, Phys. Rev. D 71, 015014 (2005).

**A. Aranda, J.L. Díaz-Cruz, J. Hernández-Sánchez, R. Noriega-Papaqui, Phys. Lett. B 658, 57 (2007).

$$\mathcal{L}_{\text{yukawa}}^{\text{THDM}} = -\sum_{f=u,d,\ell}\left(\frac{m_f}{v}\xi_h^f\overline{f}fh + \frac{m_f}{v}\xi_H^f\overline{f}fH - i\frac{m_f}{v}\xi_A^f\overline{f}\gamma_5 fA\right)$$
$$-\left\{\frac{\sqrt{2}V_{ud}}{v}\overline{u}\left(m_u\xi_A^u\mathrm{P}_L + m_d\xi_A^d\mathrm{P}_R\right)d\,H^+ + \frac{\sqrt{2}m_\ell\xi_A^\ell}{v}\overline{\nu_L}\ell_R H^+ + \text{H.c.}\right\},$$

	ξ_h^u	ξ_h^d	ξ_h^ℓ	ξ_H^u	ξ_H^d	ξ_H^ℓ	ξ_A^u	ξ_A^d	ξ_A^ℓ
Type-I	c_α/s_β	c_α/s_β	c_α/s_β	s_α/s_β	s_α/s_β	s_α/s_β	$\cot\beta$	$-\cot\beta$	$-\cot\beta$
Type-II	c_α/s_β	$-s_\alpha/c_\beta$	$-s_\alpha/c_\beta$	s_α/s_β	c_α/c_β	c_α/c_β	$\cot\beta$	$\tan\beta$	$\tan\beta$
Type-X	c_α/s_β	c_α/s_β	$-s_\alpha/c_\beta$	s_α/s_β	s_α/s_β	c_α/c_β	$\cot\beta$	$-\cot\beta$	$\tan\beta$
Type-Y	c_α/s_β	$-s_\alpha/c_\beta$	c_α/s_β	s_α/s_β	c_α/c_β	s_α/s_β	$\cot\beta$	$\tan\beta$	$-\cot\beta$

TABLE II: The mixing factors in Yukawa interactions in Eq. (6)

Mayumi Aoki, Shinya Kanemura, Koji Tsumura, Kei Yagyu. Phys.Rev. D80 (2009) 015017

Absence of (tree-level) FCNCs

→ constraints on Higgs couplings

In SM FCNC automatically absent as same operation diagonalising the mass matrix automatically diagonalises the Higgs-fermion couplings.

- There are three ways:
- (1) Discrete symmetries. This choice is based on the Glashow–Weinberg's theorem concerning FCNC's in models with several Higgs doublets.
  (MSSM: Y=-1 (+1) doublet copules to donw (up)-type fermion, as required by SUSY)
- (2) Radiative suppression. When a given set of Yukawa matrices are present at tree-level, but the other ones arise only as a radiative effect: i.e. the 2HDM-II, it is transformed into 2HDM-III through loops-effects of sfermions and gauginos.
- (3) Flavor symmetries. Suppression of FCNC effects can also be achieved when a certain form of the Yukawa matrices that reproduce the observed fermion masses and mixing angles is implemented in the model, i.e. THDM-III. (Yukawa textures)

J.L. Diaz-Cruz, R Noriega-Papaqui, A. Rosado. Phys. Rev. D69,095002 (2004)

Seesaw mechanism in MSSM

Flavor Violation among the Sleptons. In the leptonic sector, we begin with a Lagrangian:

$$-\mathcal{L} = \overline{E}_R Y_E L_L H_d + \overline{\nu}_R Y_\nu L_L + \frac{1}{2}\nu_R^\top M_R \nu_R \tag{1}$$

$$\begin{aligned}\frac{d}{d\log Q}(m^2_{\tilde{L}})_{ij} \quad = \quad & \left(\frac{d}{d\log Q}(m^2_{\tilde{L}})_{ij}\right)_{\mathrm{MSSM}} \\ & + \frac{1}{16\pi^2}\left[m^2_{\tilde{L}} Y_\nu^\dagger Y_\nu + Y_\nu^\dagger Y_\nu m^2_{\tilde{L}} + 2(Y_\nu^\dagger m^2_{\tilde{\nu}_R} Y_\nu + m^2_{H_u} Y_\nu^\dagger Y_\nu + A_\nu^\dagger A_\nu)\right]_{ij}\end{aligned} \tag{2}$$

$$\left(\Delta m^2_{\tilde{L}}\right)_{ij} \simeq -\frac{\log(M/M_R)}{16\pi^2}\left(6m_0^2(Y_\nu^\dagger Y_\nu)_{ij} + 2\left(A_\nu^\dagger A_\nu\right)_{ij}\right) \tag{3}$$

where m_0 is a common scalar mass evaluated at the scale $Q = M$, and $i \neq j$. If we further assume that the A-terms are proportional to Yukawa matrices, then:

$$\left(\Delta m^2_{\tilde{L}}\right)_{ij} \simeq \xi\left(Y_\nu^\dagger Y_\nu\right)_{ij} \tag{4}$$

K.S. Babu, C. Kolda, Phys. Rev. Lett. 89,241802 (2002).

2. Effective Lagrangians and branching ratios for LFV processes. We now present the calculational details we use in arriving at the approximate results of the previous Section and the numerical results to be presented in the next Section. We consider the R-parity conserving superpotential:

$$W = \boxed{\begin{array}{l} U_i^c (Y_u)_{ij} Q_j H_2 - D_i^c (Y_d)_{ij} Q_j H_1 + \\ N_i^c (Y_\nu)_{ij} L_j H_2 - E_i^c (Y_e)_{ij} L_j H_1 + \end{array}} \frac{1}{2} {N^c}_i (M_N)_{ij} N_j^c + \mu H_2 H_1 \,, \tag{8}$$

where the indices i, j run over three generations and M_N is the heavy singlet-neutrino mass matrix. We work in a basis where $(Y_d)_{ij}$, $(Y_e)_{ij}$ and $(M_N)_{ij}$ are real and diagonal. At the one-loop level, this leads to the effective Lagrangian [3, 5, 8, 14].

$$\begin{aligned} -\mathcal{L}^{eff} \;=\; & \bar{d}_R^i Y_{di} \left[\delta_{ij} H_1^0 + (\epsilon_0 \delta_{ij} + \epsilon_Y (Y_u^\dagger Y_u)_{ij}) \, H_2^{0*} \right] d_L^j + h.c. + \\ & \bar{l}_R^i Y_{ei} \left[\delta_{ij} H_1^0 + (\epsilon_1 \delta_{ij} + \epsilon_2 E_{ij}) \, H_2^{0*} \right] l_L^j + h.c. \,, \end{aligned} \tag{9}$$

A. Dedes, J.R. Ellis, M. Raidal, Phys. Lett. B549, 159 (2002)

Yukawa sector in 2HDM type III

$$\mathcal{L}_Y = Y_1^u \bar{Q}_L \Phi_1 u_R + Y_2^u \bar{Q}_L \Phi_2 u_R + Y_1^d \bar{Q}_L \Phi_1 d_R + Y_2^d \bar{Q}_L \Phi_2 d_R \,,$$

$Y_1^u = Y_1^d = 0$ or $Y_2^u = Y_2^d = 0$ $\longrightarrow$ 2HDM-I

$Y_1^u = Y_2^d = 0$ or $Y_2^u = Y_1^d = 0$ $\longrightarrow$ 2HDM-II (MSSM)

Yukawa sector of the 2HDM-III is similar to effective lagrangian of the MSSM with a seesaw mechanism.

This lagrangian contains loop effects of sfermions and gauginos.

2HDM type III could be a generic description of physics at higher scale (of order TeV o maybe higher)

Yukawa textures

The structure of quarks mass matrices (quark flavor mixing) is unknown.

A theory more fundamental than SM could determine:
6 quark masses, 3 flavor mixing angles, one CP-violating phase.

Phenomenologically, it has introduced a common approach:
simple textures of quarks mass matrices (called Yukawa textures).

The Yukawa textures are consistents with the relations between quarks masses and flavor mixing parameters.

Yukawa textures could come of a theory more fundamental and it could be a flavor symmetry.

H. Fritzsch, Z. Z. Xing, Prog.Part. Nucl. Phys. 45 (2000) 1.
H. Fritzsch, Z. Z. Xing, Phys. Lett. 555 (2003)63.

2HDM-III + Yukawa texture contain the following information:

It could come from a more fundamental theory (susy models with seesaw mechanism).

+

Yukawa texture is the flavor symmetry of the model and do not require of the discrete flavor symmetry.

+

The Higgs potential must be expressed in the most general form.

T. P. Cheng, M. Sher, Phys. Rev. D33,11 (1987)
J.L. Diaz-Cruz, R Noriega-Papaqui, A. Rosado. Phys. Rev. D69,095002 (2004)

Yukawa texture chosen

After SSB (Spontaneous Symmetry Breaking), one can derive the fermion mass matrices from eq. (1), namely

$$M_f = \frac{1}{\sqrt{2}}(v_1 Y_1^f + v_2 Y_2^f), \qquad f = u, d, l, \tag{2}$$

We will assume that both Yukawa matrices Y_1^f and Y_2^f have the four-texture form and Hermitic [22, 26]. Following this convention, the fermions masses matrices have the same form, which are written as:

$$M_f = \begin{pmatrix} 0 & C_f & 0 \\ C_f^* & \tilde{B}_f & B_f \\ 0 & B_f^* & A_f \end{pmatrix}. \tag{3}$$

when $\tilde{B}_q \to 0$ one recovers the six-texture form. We also consider the hierarchy: $\mid A_q \mid \gg \mid \tilde{B}_q \mid, \mid B_q \mid, \mid C_q \mid$, which is supported by the observed fermion masses in the SM.

The mass matrix is diagonalized through the bi-unitary matrices $V_{L,R}$, though each Yukawa matrices are not diagonalized by this transformation. The diagonalization is performed in the following way

$$\boxed{\bar{M}_f = V_{fL}^\dagger M_f V_{fR}.} \tag{4}$$

$$\bar{M}_f = \frac{1}{\sqrt{2}}(v_1\tilde{Y}_1^f + v_2\tilde{Y}_2^f) \tag{6}$$

where $\tilde{Y}_i^f = V_{fL}^\dagger Y_i^f V_{fR}$. In order to compare the new physics comes from Yukawa texture with some traditional 2HDM (in particular with 2HDM-II), in previous works [22, 23, 28–30], we have implemented the following redefinition ((a) like-2HDM-II):

$$\begin{aligned}
\tilde{Y}_1^d &= \frac{\sqrt{2}}{v\cos\beta}\bar{M}_d - \tan\beta\tilde{Y}_2^d \\
\tilde{Y}_2^u &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_u - \cot\beta\tilde{Y}_1^u \\
\tilde{Y}_1^\ell &= \tilde{Y}_1^d(d \to \ell)
\end{aligned} \tag{7}$$

(b) like-2HDM-I

$$
\begin{aligned}
\tilde{Y}_2^d &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_d - \cot\beta\tilde{Y}_1^d \\
\tilde{Y}_2^u &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_u - \cot\beta\tilde{Y}_1^u \\
\tilde{Y}_2^\ell &= \tilde{Y}_2^d(d\to\ell)
\end{aligned}
$$

(c) like-2HDM-X

$$
\begin{aligned}
\tilde{Y}_2^d &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_d - \cot\beta\tilde{Y}_1^d \\
\tilde{Y}_2^u &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_u - \cot\beta\tilde{Y}_1^u \\
\tilde{Y}_1^\ell &= \tilde{Y}_1^d(d\to\ell)
\end{aligned}
$$

(d) like-2HDM-Y

$$
\begin{aligned}
\tilde{Y}_1^d &= \frac{\sqrt{2}}{v\cos\beta}\bar{M}_d - \tan\beta\tilde{Y}_2^d \\
\tilde{Y}_2^u &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_u - \cot\beta\tilde{Y}_1^u \\
\tilde{Y}_2^\ell &= \tilde{Y}_2^d(d\to\ell)
\end{aligned}
$$

Then the rotated form $\tilde{Y}_2^l$ has the general form,

$$\begin{aligned}\tilde{Y}_2^l &= O^T P Y_2^l P^\dagger O \\ &= \begin{pmatrix} \tilde{Y}_{211}^l & \tilde{Y}_{212}^l & \tilde{Y}_{213}^l \\ \tilde{Y}_{221}^l & \tilde{Y}_{222}^l & \tilde{Y}_{223}^l \\ \tilde{Y}_{231}^l & \tilde{Y}_{232}^l & \tilde{Y}_{233}^l \end{pmatrix}.\end{aligned}$$

$$\begin{aligned}(\tilde{Y}_2)_{22}^l &= \eta[C_2^* e^{i\Phi_C} + C_2 e^{-i\Phi_C}]\frac{(A-\lambda_2)}{m_3-\lambda_2}\sqrt{\frac{m_1 m_3}{A m_2}} + \tilde{B}_2\frac{A-\lambda_2}{m_3-\lambda_2} \\ &\quad + A_2\frac{A-\lambda_2}{m_3-\lambda_2} - [B_2^* e^{i\Phi_B} + B_2 e^{-i\Phi_B}]\sqrt{\frac{(A-\lambda_2)(m_3-A)}{m_3-\lambda_2}}\end{aligned}$$

$$
\begin{aligned}
\left(\tilde{Y}_2^l\right)_{11} &= (\tilde{b}_2 - 2c_2)\, m_1/v \\
\left(\tilde{Y}_2^l\right)_{12} &= (c_2 - \tilde{b}_2)\, \sqrt{m_1 m_2}/v \\
\left(\tilde{Y}_2^l\right)_{13} &= (a_2 - b_2)\, \sqrt{m_1 m_2}/v \\
\left(\tilde{Y}_2^l\right)_{22} &= \tilde{b}_2\, m_2/v \\
\left(\tilde{Y}_2^l\right)_{23} &= (b_2 - a_2)\, m_2/v \\
\left(\tilde{Y}_2^l\right)_{33} &= a_2\, m_3/v
\end{aligned}
$$

Then we introduce the matrix $\tilde{\chi}$ as follows:

$$
\begin{aligned}
(\tilde{Y}_2^l)_{ij} &= \frac{\sqrt{m_i m_j}}{v}\tilde{\chi}_{ij} \\
&= \frac{\sqrt{m_i m_j}}{v}\chi_{ij} e^{\vartheta_{ij}},
\end{aligned}
$$

which differs from the usual Cheng-Sher ansatz not only because of the appearance of the complex phases, but also in the form of the real parts $\chi_{ij} = |\tilde{\chi}_{ij}|$.

$$\widetilde{\chi}_{11} = [\widetilde{b}_2 - (c_2^* e^{i\Phi_C} + c_2 e^{-i\Phi_C})]\eta$$
$$+ [a_2 + \widetilde{b}_2 - (b_2^* e^{i\Phi_B} + b_2 e^{-i\Phi_B})]\beta,$$

$$\widetilde{\chi}_{12} = (c_2 e^{-i\Phi_C} - \widetilde{b}_2)$$
$$- \eta[a_2 + \widetilde{b}_2 - (b_2^* e^{i\Phi_B} + b_2 e^{-i\Phi_B})]\beta,$$

$$\widetilde{\chi}_{13} = (a_2 - b_2 e^{-i\Phi_B})\eta\sqrt{\beta},$$

$$\widetilde{\chi}_{22} = \widetilde{b}_2\eta + [a_2 + \widetilde{b}_2 - (b_2^* e^{i\Phi_B} + b_2 e^{-i\Phi_B})]\beta,$$

$$\widetilde{\chi}_{23} = (b_2 e^{-i\Phi_B} - a_2)\sqrt{\beta},$$

$$\widetilde{\chi}_{33} = a_2 .$$

Recently we are doing a X^2-fit with CKM and we have found Xij O(1).

F.F. González-Canales, O. Félix-Beltrán, J. Hernández-Sánchez, S. Moretti, R. Noriega, A. Rosado, work in progress.

Another form to get the versions of 2HDM

- Partial Aligment 2HDM:
- J. Hernández-Sánchez, L. López-Lozano, R. Noriega-Papaqui. A. Rosado, PRD85, 071301(R) (2012)

$$\boxed{\tilde{Y}_2^f = \frac{1}{v}\tilde{A}_L^f \bar{M}_f \tilde{A}_R^f,}$$

where $\tilde{A}_{L,R}^f = U_{L,R}^{f\dagger} A_{L,R}^f U_{L,R}^f$, $\bar{M}_f = \mathrm{Diag}[m_{f1}, m_{f2}, m_{f3}]$, and $U_{L,R}^f$ are the matrices that diagonalize the mass matrix M_f. So, the contribution to fermion-fermion-Higgs bosons couplings is given by

$$(\tilde{Y}_2^f)_{ij} = \frac{1}{v}(m_{f1}(\tilde{A}_L^f)_{i1}(\tilde{A}_R^f)_{1j} + m_{f2}(\tilde{A}_L^f)_{i2}(\tilde{A}_R^f)_{2j} + m_{f3}(\tilde{A}_L^f)_{i3}(\tilde{A}_R^f)_{3j}). \leq \sqrt{m_{fi}m_{fj}}|\tilde{\chi}_{ij}^f|.$$

TABLE I. Matrices that reproduce several versions of the Yukawa interactions for the 2HDM in terms of $SU_F(3)$ generators. The $C's$ parameters are complex coefficients and they are proportional to the parameters $\tilde{\chi}^f_{ij}$ defined in Eq. (6).

	A^u_L	A^u_R	A^d_L	A^d_R
I	$\sqrt{\frac{3m_W}{v}}\lambda_0$	$\sqrt{\frac{3m_W}{v}}\lambda_0$	$\sqrt{\frac{3m_W}{v}}\lambda_0$	$\sqrt{\frac{3m_W}{v}}\lambda_0$
II	$\sqrt{\frac{3m_W}{v}}\lambda_0$	$\sqrt{\frac{3m_W}{v}}\lambda_0$	$0_{3\times3}$	$0_{3\times3}$
III-IV	$\sum_{a=0,3,8} C^u_a \lambda_a$	$(\sum_{a=0,3,8} \tilde{C}^u_a \lambda_a)^\dagger$	$\sum_{a=0,3,8} C^d_a \lambda_a$	$(\sum_{a=0,3,8} \tilde{C}^d_a \lambda_a)^\dagger$
A2HDM	$C^u_0 \lambda_0$	$\tilde{C}^{u*}_0 \lambda_0$	$C^d_0 \lambda_0$	$\tilde{C}^{d*}_0 \lambda_0$

$$\mathcal{L}^{\bar{f}_i f_j H^+} = -\left\{ \frac{\sqrt{2}}{v} \overline{u}_i \left(m_{d_j} X_{ij} P_R + m_{u_i} Y_{ij} P_L \right) d_j \, H^+ + \frac{\sqrt{2} m_{\ell_j}}{v} Z_{ij} \overline{\nu_L} \ell_R H^+ + H.c. \right\}$$

$$X_{ij} = \sum_{l=1}^{3} (V_{\rm CKM})_{il} \left[X \frac{m_{d_l}}{m_{d_j}} \delta_{lj} - \frac{f(X)}{\sqrt{2}} \sqrt{\frac{m_{d_l}}{m_{d_j}}} \tilde{\chi}^d_{lj} \right],$$

Non-diagonal model (See the talk of Jie Lu)

$$Y_{ij} = \sum_{l=1}^{3} \left[Y \delta_{il} - \frac{f(Y)}{\sqrt{2}} \sqrt{\frac{m_{u_l}}{m_{u_i}}} \tilde{\chi}^u_{il} \right] (V_{\rm CKM})_{lj}.$$

$$Z^{\ell}_{ij} = \left[Z \frac{m_{\ell_i}}{m_{\ell_j}} \delta_{ij} - \frac{f(Z)}{\sqrt{2}} \sqrt{\frac{m_{\ell_i}}{m_{\ell_j}}} \tilde{\chi}^{\ell}_{ij} \right],$$

2HDM-III	X	Y	Z
like-2HDM-I	$-\cot\beta$	$\cot\beta$	$-\cot\beta$
like-2HDM-II	$\tan\beta$	$\cot\beta$	$\tan\beta$
like-2HDM-X	$-\cot\beta$	$\cot\beta$	$\tan\beta$
like-2HDM-Y	$\tan\beta$	$\cot\beta$	$-\cot\beta$

$$\left(g^{f_u i f_d j H^+}_{2HDM-III} = g^{f_u i f_d j H^+}_{2HDM-any} + \Delta g^{f_u i f_d j H^+} \right)$$

A. Akeroyd, J. Hernandez-Sanchez, S. Moretti, R. Noriega- Papaqui, A. Rosado, work in progress

For light charged Higgs

$$\Gamma(H^{\pm} \to u_i d_j) = \frac{3G_F m_{H^{\pm}}(m_{d_j}^2 |X_{ij}|^2 + m_{u_i}^2 |Y_{ij}|^2)}{4\pi\sqrt{2}}$$

; the case $Y >>, X, Z$ the channel decay $H^{+} \to c\bar{b}$

$$m_c Y_{cb} = m_c Y_{23} = V_{cb} m_c \left(Y - \frac{f(Y)}{\sqrt{2}} \chi_{22}^u \right) - V_{tb} \frac{f(Y)}{\sqrt{2}} \sqrt{m_t m_c} \chi_{23}^u$$

$(H^{\pm} \to cs)$

$$m_c Y_{cs} = m_c Y_{22} = V_{cs} m_c \left(Y - \frac{f(Y)}{\sqrt{2}} \chi_{22}^u \right) - V_{ts} \frac{f(Y)}{\sqrt{2}} \sqrt{m_t m_c} \chi_{23}^u$$

$$\frac{\mathrm{BR}(H^{\pm} \to cb)}{\mathrm{BR}(H^{\pm} \to cs)} = R_{sb} \sim \frac{|V_{tb}|^2}{|V_{ts}|^2}$$

For light charged Higgs

Other case is when $X >>, Y, Z$, we get the dominants terms $m_b X_{23}$, $m_s X_{22}$:

$$m_b X_{cb} = m_b X_{23} = V_{cb} m_b \left(X - \frac{f(X)}{\sqrt{2}} \chi^d_{33} \right) - V_{cs} \frac{f(X)}{\sqrt{2}} \sqrt{m_b m_s} \chi^d_{23}$$

$$m_s X_{cs} = m_s X_{22} = V_{cs} m_s \left(X - \frac{f(X)}{\sqrt{2}} \chi^d_{22} \right) - V_{ts} \frac{f(X)}{\sqrt{2}} \sqrt{m_b m_s} \chi^d_{23}$$

If $\chi = O(1)$ and positive then $\left(X - \frac{f(X)}{\sqrt{2}} \chi^d_{33} \right)$ is small and $R_{sb} \sim \frac{|V_{cs}|^2}{|V_{cb}|^2}$,

Other situation is when, $\chi = O(1)$ and negative, then $R_{sb} \sim \frac{m_b^2 |V_{cb}|^2}{m_s^2 |V_{cb}|^2}$;

A.G. Akeroyd, S. Moretti and J. Hernández-Sánchez, PRD85:115002 (2012)

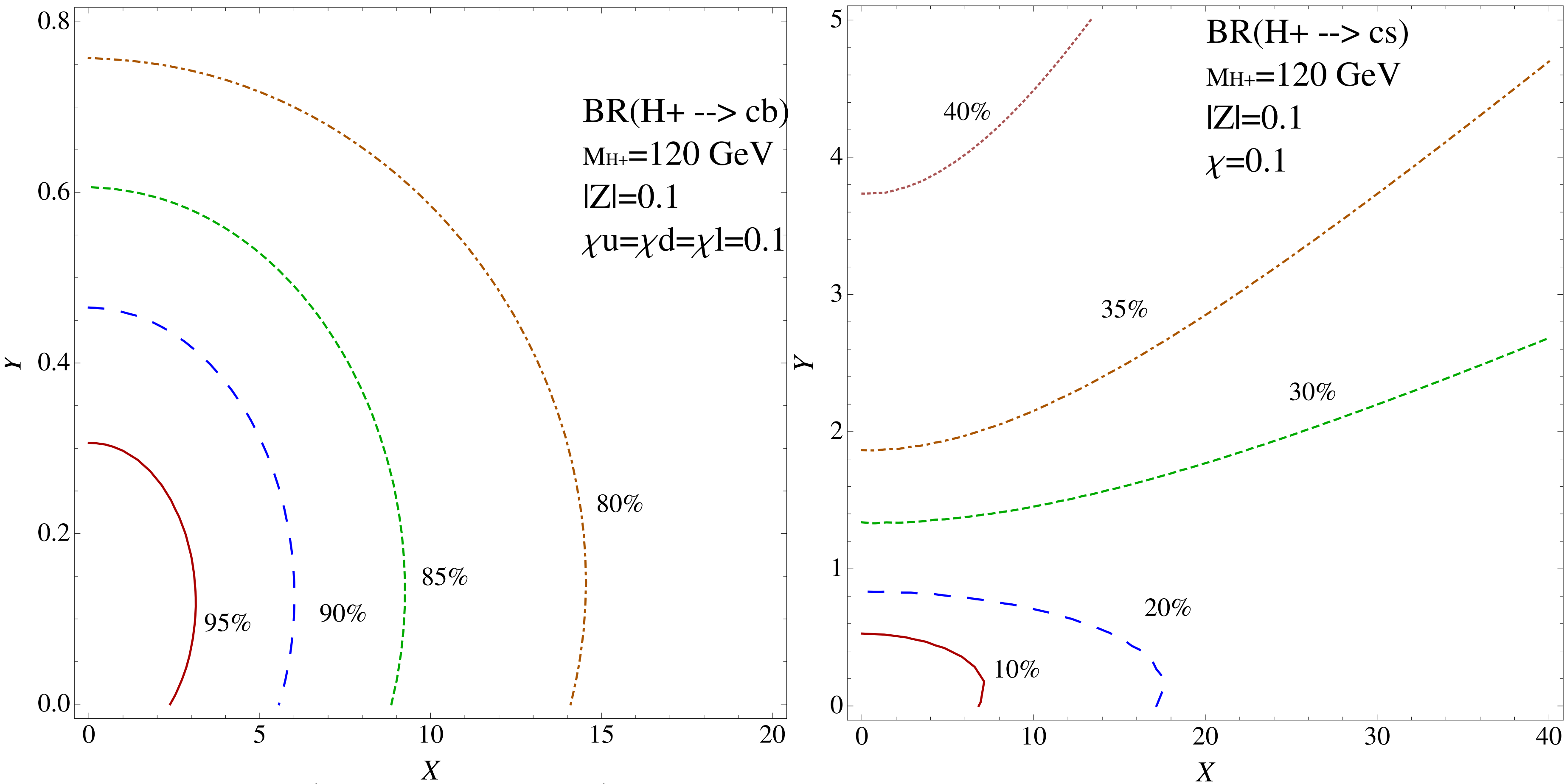


FIG. 1: $BR(H^{\pm} \to cb)$ and $BR(H^{\pm} \to cs)$, $Z = 0.1$, $X >> Y$, $\leq mH^{+} \leq 120$ GeV and $\chi = 0.1$

Others phenomenological consequences

- If we combine:

- The effects of texture in the coupling.
- The general Higgs potential.
-

It's possible to enhacement processes at one-loop-level, e.g.

- H,h→ $\gamma\gamma$
- H^+→ W^+ γ, W^+ Z

J. Hernández-Sánchez, C. G. Honoratp, M.A. Pérez, J.J. Toscano, PRD85:015020 (2012).

J.E. Barradas, F. Cazares-Bush, A. Cordero-Cid, O. Félix-Beltrán, J. Hernández-Sanchez, R. Noriega-Papaqui, J.Phys. G37 (2010) 115008

Some constraints of processes to below energy

$\mu - e$ *universality in* τ *decays*

$$\frac{BR(\tau \to \mu\bar{\nu}_\mu\nu_\tau)}{BR(\tau \to e\bar{\nu}_e\nu_\tau)}\,\frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)} \simeq 1 + \frac{R^2}{4} - 0.25R.$$

$$R = \frac{m_\tau m_\mu}{M_{H^+}^2}\, Z_{33}\, Z_{22} \;=\; \frac{m_\tau m_\mu}{M_{H^+}^2}\left[Z - \frac{f(Z)}{\sqrt{2}}\chi_{33}^l\right]\left[Z - \frac{f(Z)}{\sqrt{2}}\chi_{22}^l\right].$$

$$\frac{|Z_{22}Z_{33}|}{m_{H^\pm}^2} \leq 0.16\ GeV^{-1}$$

We use the analysis of Pich and Tuzon, JHEP11(2010)003

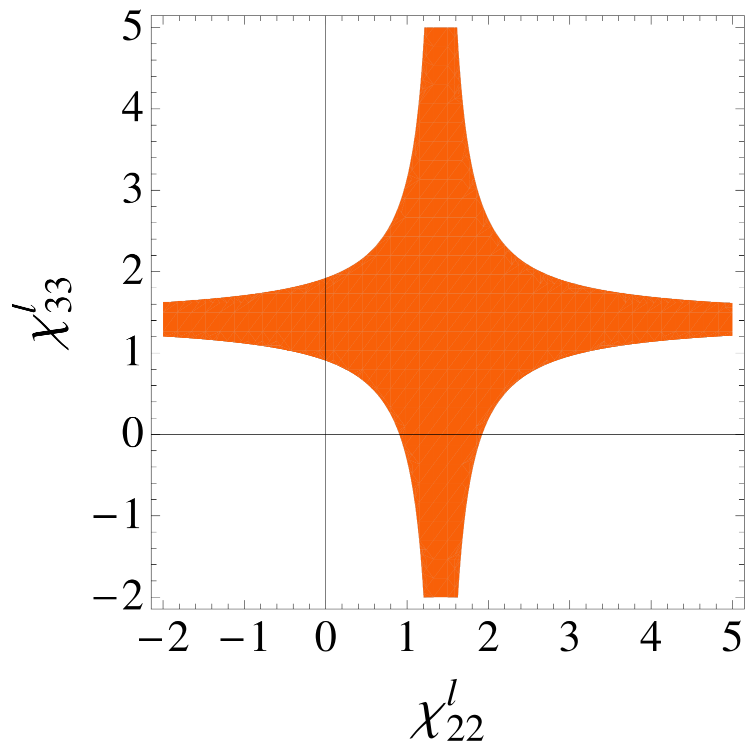
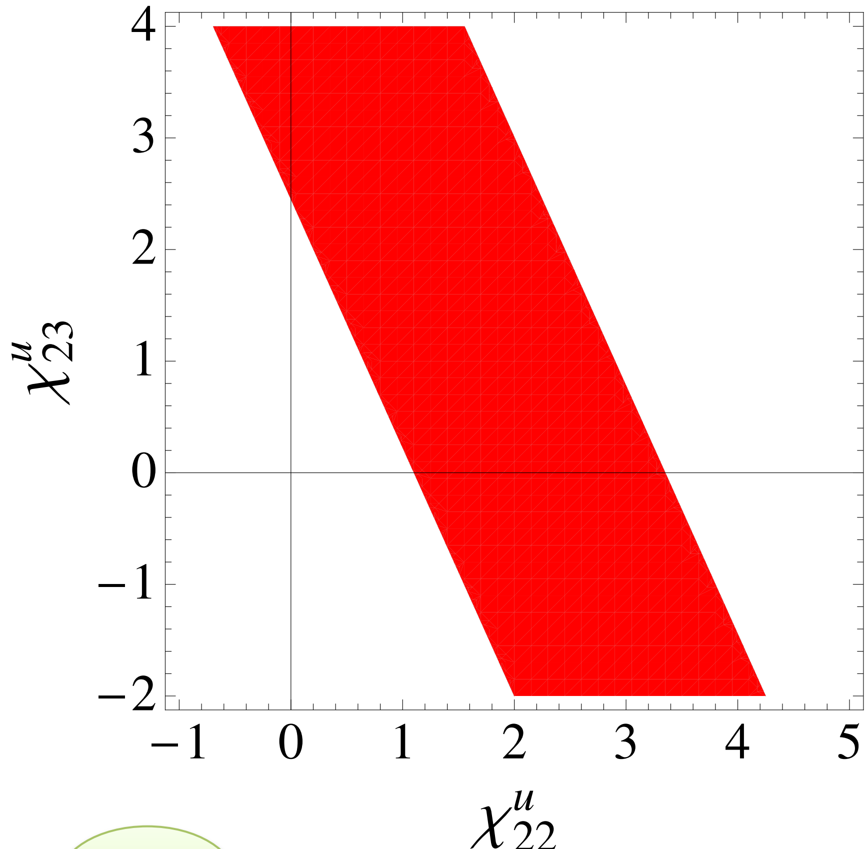


FIG. 2: Allowed region for χ_{22}^ℓ and χ_{33}^ℓ from $\mu-e$ universality in τ decays, Ztakes values of 0.5 to 80, and 100 GeV $\leq mH^+ \leq$ 150 GeV

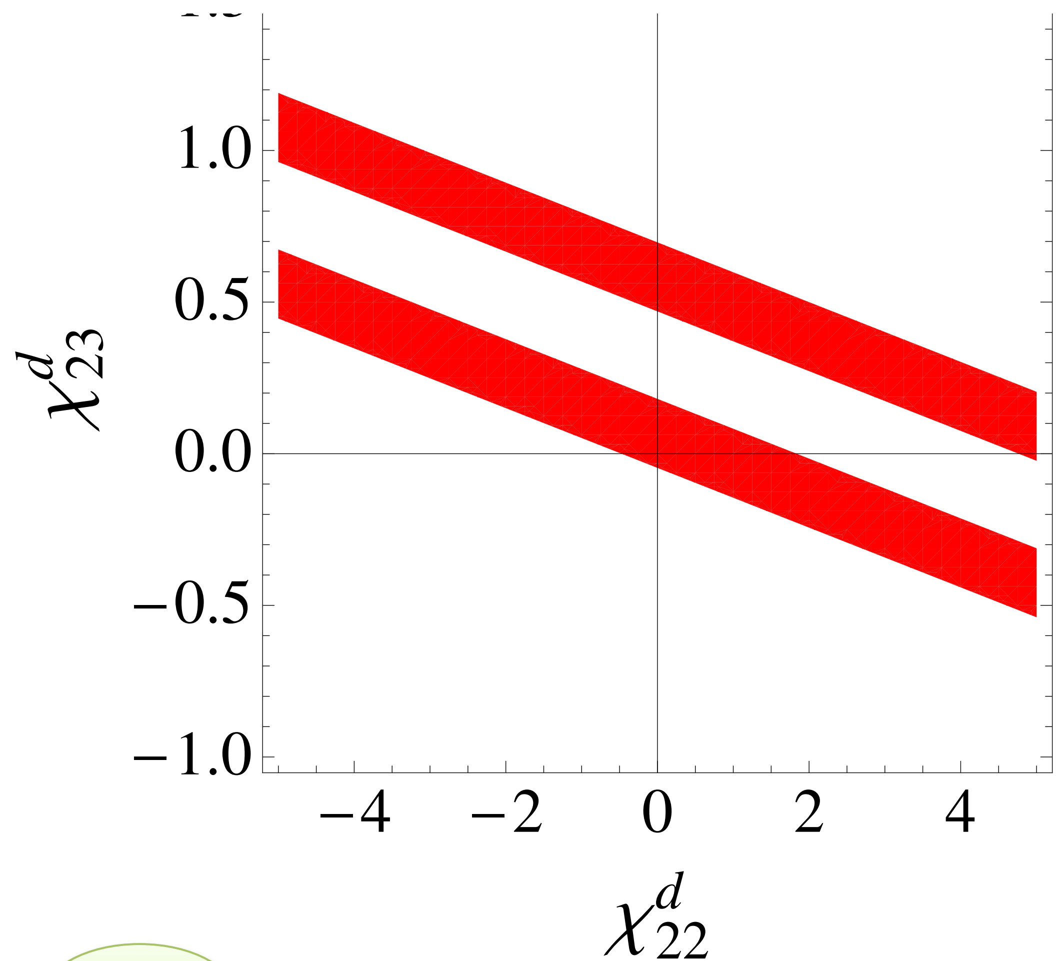
We consider $D \to \mu\nu$, $B \to \tau\nu$, $D_s \to \mu\nu, \tau\nu$

$$\frac{B(M \to \ell\nu)}{B(M \to \ell\nu)_{SM}} = |1 - \Delta_{ij}|^2$$

$$\Delta_{ij} = \left(\frac{m_M}{m_{H^\pm}}\right)^2 Z\left(\frac{Y_{ij} m_{u_i} + X_{ij} m_{d_j}}{m_{u_i} + m_{d_j}}\right)$$



from $R_{D\to\mu\nu}$, Z takes values of 0.5 to 80 and $Z >> Y$, We use the analysis of Pich and Tuzon, JHEP11(2010)003



from $R_{B\to\tau\nu}$, Z takes values of 0.5 to 80 and $Z, X >> Y$,

J. L. DÍAZ-CRUZ *et al.* PHYSICAL REVIEW D 79, 095025 (2009)

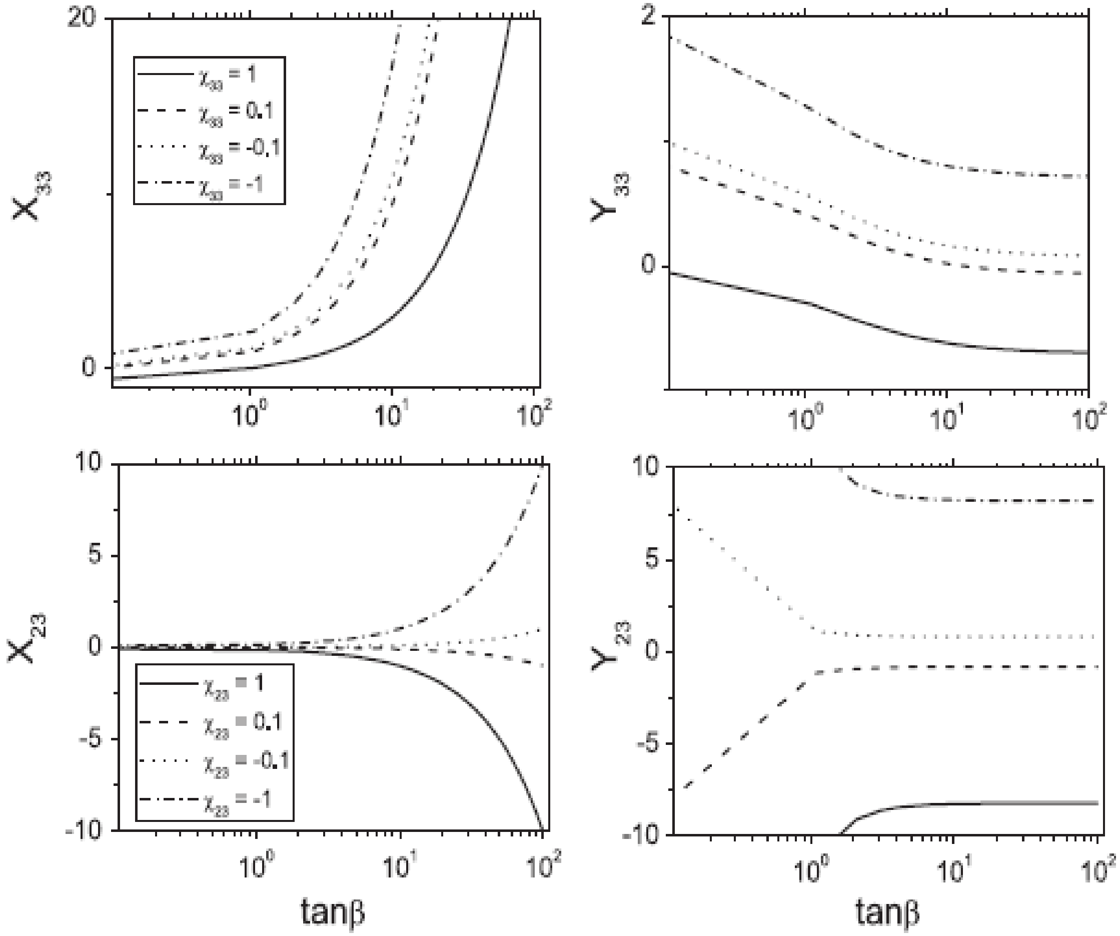


FIG. 1. The figure shows X_{33}, Y_{33}, X_{23}, and Y_{23} vs $\tan\beta$, taking $\tilde{\chi}^{u,d}_{3,3} = 1$ (solid line), $\tilde{\chi}^{u,d}_{3,3} = 0.1$ (dashed line), $\tilde{\chi}^{u,d}_{3,3} = -0.1$ (dotted line), and $\tilde{\chi}^{u,d}_{3,3} = -1$ (dashed-dotted line).

Based on the analysis of $B \to X_s\gamma$ [36, 37], it is claimed that $X \leq 20$ and $Y \leq 1.7$

Phenomenology of H+

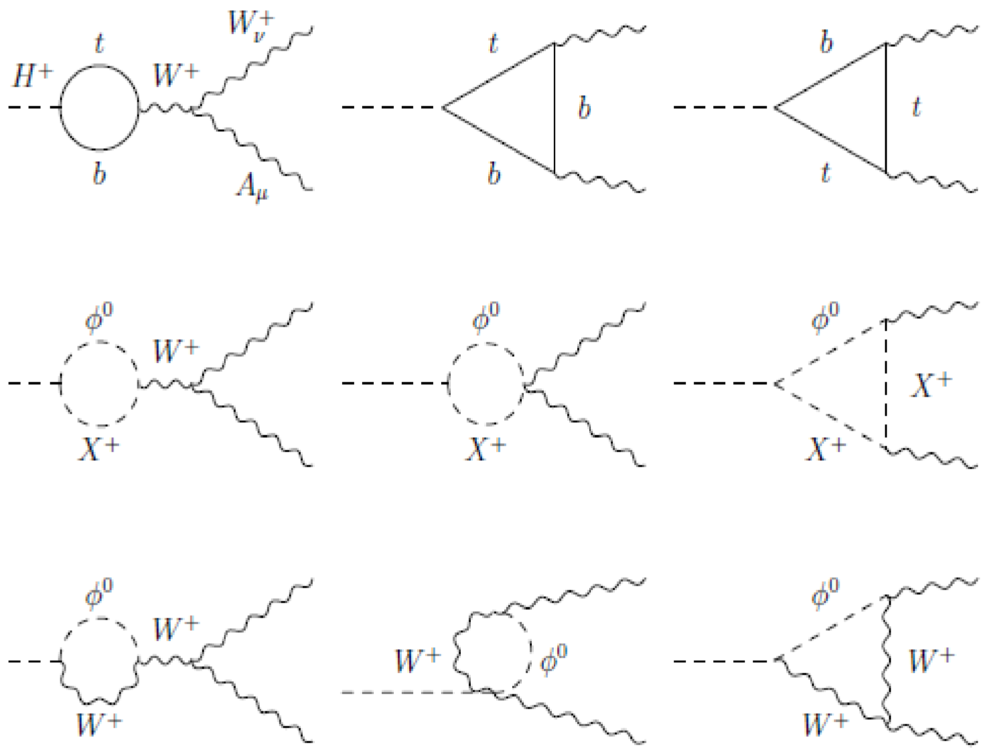
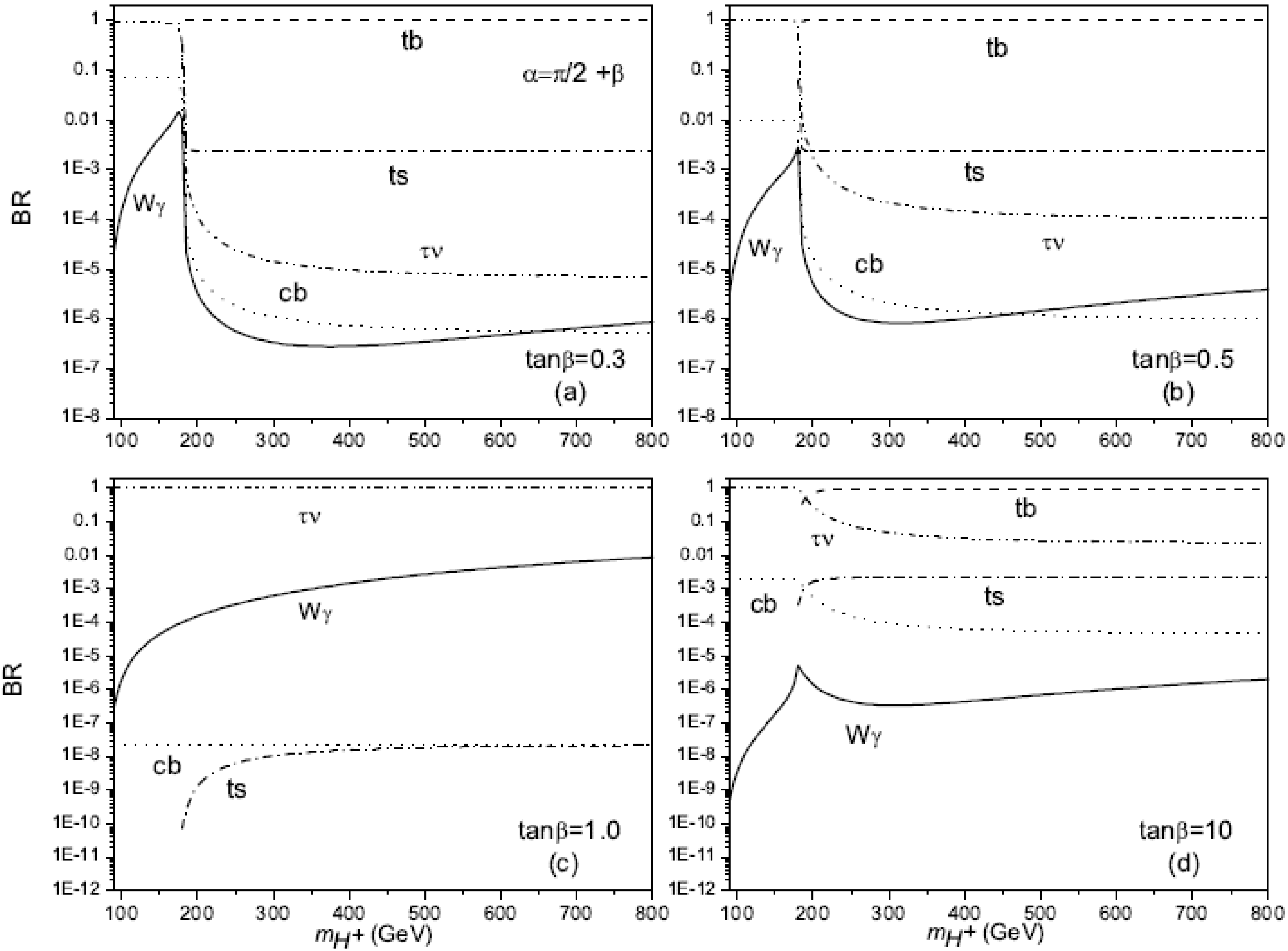


Figure 1. Feynman diagrams contributing to the $H^+ \to W^+\gamma$ decay in the nonlinear R_ξ-gauge. ϕ^0 stands for h^0 and H^0, and X^+ for H^+ and G_W^+.

Scenario with χ=1, but α=π/2+β



C. s-channel production of charged Higgs boson

Large flavor mixing coupling $H^{\pm}\bar{q}q'$ enables the possibility of studying the production of charged Higgs boson via the partonic s-channel production mechanism, $c\bar{b}, \bar{c}b \to H^{\pm}$. This mechanism was discussed first by He and Yuan

$$\sigma(h_1 h_2(c\bar{b}) \to H^+ X) \frac{\pi}{12s}\left(|C_L|^2 + |C_R|^2\right) I_{c,\bar{b}}^{h_1,h_2}$$

where

$$I_{c,\bar{b}}^{h_1,h_2} = \int_{\tau}^{1} dx \left[f_c^{h_1}(x,\tilde{Q}^2) f_{\bar{b}}^{h_2}(\tau/x,\tilde{Q}^2) + f_{\bar{b}}^{h_1}(x,\tilde{Q}^2) f_c^{h_2}(\tau/x,\tilde{Q}^2)\right]/x$$

and $\tau = m_{H^{\pm}}^2/s$. The parton distribution functions (PDFs) $f_q^{h_i}(x,\tilde{Q}^2)$ describe the quark q content of the hadron i at a scale interaction of $\tilde{Q}^2$. In other words, the PDFs $f_q^h(x,\tilde{Q}^2)$ give the probabilities to find a quark q inside a hadron with the fraction x of the hadron momentum, in a scattering process with momentum transfer square $\tilde{Q}^2$, in this case we will take $\tilde{Q}^2 = m_{H^+}^2$.

H. J. He and C.P. Yuan , Phys. Rev. Lett. 83, 28 (1999)

TABLE II: Summary of LHC event rates for some parameter combinations within Scenarios A, B, C, D with for an integrated luminosity of 10^5 pb^{-1}, for several different signatures, through the channel $c\bar{b} \to H^+ +$ c.c.

$(\tilde{\chi}^u_{ij}, \tilde{\chi}^d_{ij})$	$\tan\beta$	m_{H^+} in GeV	$\sigma(pp \to H^+ + X)$ in pb	Relevant BRs	Nr. Events
(1,1)	15	400	1.14×10^{-1}	$\mathrm{BR}(H^+ \to t\bar{b}) \approx 3.2 \times 10^{-1}$	3648
				$\mathrm{BR}(H^+ \to \tau^+ \nu^0_\tau) \approx 2.1 \times 10^{-3}$	24
				$\mathrm{BR}(H^+ \to W^+ h^0) \approx 6.3 \times 10^{-1}$	7182
				$\mathrm{BR}\left(H_2^+ \to W^+ A^0\right) \approx 1.7 \times 10^{-2}$	194
(1,1)	70	400	1.25×10^{-1}	$\mathrm{BR}(H^+ \to t\bar{b}) \approx 3.5 \times 10^{-1}$	4375
				$\mathrm{BR}(H^+ \to c\bar{b}) \approx 1.4 \times 10^{-2}$	175
				$\mathrm{BR}(H^+ \to \tau^+ \nu_\tau) \approx 2.5 \times 10^{-1}$	3125
				$\mathrm{BR}(H^+ \to W^+ h^0) \approx 3.6 \times 10^{-1}$	4500
(0.1,1)	1	600	3.41×10^{-4}	$\mathrm{BR}(H^+ \to t\bar{b}) \approx 3 \times 10^{-1}$	10
				$\mathrm{BR}(H^+ \to t\bar{s}) \approx 9.1 \times 10^{-4}$	0
				$\mathrm{BR}(H^+ \to W^+ h^0) \approx 3.6 \times 10^{-1}$	12
				$\mathrm{BR}(H^+ \to W^+ A^0) \approx 3.2 \times 10^{-1}$	11

Table 1. Summary of LHC event rates for some parameter combinations within Scenario B ($\tilde{\chi}_{ij}^{u,d} = 1$) with an integrated luminosity of 10^5 pb^{-1}, for the signal $H^+ \to W^+\gamma$, through the channel $c\bar{b} \to H^+$ + c.c.

α	$\tan\beta$	m_{H^+} in GeV	$\sigma(pp \to H^+ + X)$ in pb	$BR(H^+ \to W^+\gamma)$	N_S	$\frac{N_S}{\sqrt{N_B}}$
$\pi/2$	0.3	200	2.1×10^2	2×10^{-6}	42	2.02
$\pi/2+\beta$	0.5	300	4.5×10	9×10^{-7}	4	0.223
$\pi/2$	1	200	4.5	1.4×10^{-4}	63	3.03
$\pi/2+\beta$	1	300	0.89	7×10^{-4}	62	3.46
$\pi/2$	10	200	2.5	2×10^{-6}	0	0
$\pi/2$	10	300	5.2×10^{-1}	1.5×10^{-7}	0	0

Table 2. Summary of LHC event rates for some parameter combinations within Scenarios B ($\tilde{\chi}_{ij}^{u,d} = 1$) with an integrated luminosity of 10^5 pb^{-1}, for $H^+ \to W^+\gamma$ signature, through the channel $q\bar{q}, gg \to \bar{t}bH^+$ + c.c.

α	$\tan\beta$	m_{H^+} in GeV	$\sigma(pp \to H^+\bar{t}b)$ in pb	BR$(H^+ \to W^+\gamma)$	N_S	$\frac{N_S}{\sqrt{N_B}}$
$\pi/2$	0.3	200	25.8	2×10^{-6}	5	0.62
$\pi/2 + \beta$	0.5	300	5	9×10^{-7}	0	0
$\pi/2$	1	200	2.3	1.4×10^{-4}	32	3.98
$\pi/2 + \beta$	1	300	1.79	7×10^{-4}	125	18.04
$\pi/2$	10	200	2.4	2×10^{-6}	0	0
$\pi/2$	10	300	0.68	1.5×10^{-7}	0	0

Conclusions

- 2HDM-III with a four-zero texture in the Yukawa matrices could contain the versions of 2HDM.
- The terms off-diagonal matrices Xij could be O(1) and cannot omitted, including some important constraints of processes to low energy.
- H+ → cb could be relevant.
- H+ → W+ gamma could enhance.
- Production H+ could be quite different to the results of the others versions of 2HDM.