B meson processes whitin a 2HDM-IIII

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Motivation

Beyond SM, 2HDM-III

New Physics window

B meson process involving NP.

Leptonic Universal Violation

The Leptonic Universality Violation (LUA) is an effect reported experimentally as

$$R_K = \frac{BR(B^+ \to K^+ \mu\bar{\mu})}{BR(B^+ \to K^+ e\bar{e})} \tag{1}$$

$$R_{K^*} = \frac{BR(B^+ \to K^{*+} \mu\bar{\mu})}{BR(B^+ \to K^{*+} e\bar{e})} \tag{2}$$

$$R_{D^*} = \frac{BR(B^0 \to D^* \tau^+ \nu_\tau)}{BR(B^0 \to D^* \mu^+ \nu_\mu)} \tag{3}$$

Process	Exp	Experiment
R_K	$0.745^{+0.090}_{-0.074} \pm 0.036$ $0.846^{+0.044}_{-0.041}$	LHCb 2014 LHCb 2021
R_{K^*}	$\begin{cases} 0.66^{+0.11}_{-0.07} \pm 0.03, \\ 0.69^{+0.11}_{-0.07} \pm 0.05. \end{cases}$, [1]	LHCb 2017
R_{D^*}	$0.291 \pm 0.019 \pm 0.029$	averaged LHCb

[1] upper value for momentum transfered $0.045 < q^2 < 1.1\text{GeV}^2/c^4$, the lower value for $1.1 < q^2 < 6\text{GeV}^2/c^4$

B meson processes using effective Lagrangians.

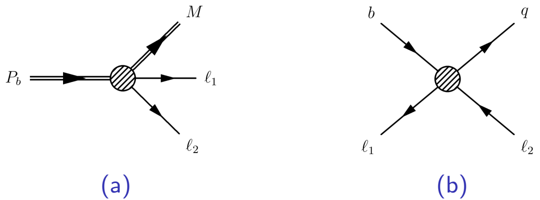

Figure: In the (a) diagram it is shown the semileptonic decay of a pseudoscalar B meson with $P_b = B^0, B^{\pm}, B_s^0$ with $M = \pi, K, K^*$, $\ell_1 = e, \mu$ and $\ell_2 = e, \mu, \nu_\mu, \nu_e$. The observables for the anomalies are given by ratio between the images $BR(P_b \to M\ell_1\ell_2)$. In (b) it is shown the effective coupling for the $b \to q$ transition involving leptons that it is described by Wilson operator, *[Hiller2003]*

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The Lagrangian of the 2HDM-III

The 2HDM-III lagrangian of the Yukawa sector has the form

$$L_Y = \sum_{a,i} Y_a^i \overline{F}_L^i \Phi_a f_R^i + h.c., \tag{4}$$

where F_L denotes the fermion left-handed doublet, f_R is the fermion right-handed singlet, and Φ_a are the Higgs doublets $(a = 1, 2)$. Considering three generations, the coefficient Y_a^i can be expressed as a 3×3 matrix and tagged as Y_a^l, Y_a^u, Y_a^d, for leptons, u and d type quarks.

The Lagrangian of the 2HDM-III

two Yukawas couplings we have

$$\begin{aligned} L_y^q &= \bar{u}_{Li}\left[\frac{v_2}{\sqrt{2}}Y_{2ij}^u + \frac{v_1}{\sqrt{2}}Y_{1ij}^u\right]u_{Rj} + \bar{d}_{Li}\left[\frac{v_2}{\sqrt{2}}Y_{2ij}^d + \frac{v_1}{\sqrt{2}}Y_{1ij}^d\right]d_{Rj} \\ &+\bar{u}_{Li}\left[\phi_2^{0*}Y_{2ij}^u + \phi_1^{0*}Y_{1ij}^u\right]u_{Rj} + \bar{d}_{Li}\left[\phi_2^0 Y_{2ij}^d + \phi_1^0 Y_{1ij}^d\right]d_{Rj} \\ &+\bar{u}_{Li}\left[\phi_2^+ Y_{2ij}^u + \phi_1^+ Y_{1ij}^u\right]u_{Rj} + \bar{d}_{Li}\left[\phi_2^- Y_{2ij}^d + \phi_1^- Y_{1ij}^d\right]d_{Rj} \end{aligned} \quad (5)$$

with

$$M_q = \frac{1}{\sqrt{2}}(v_1 Y_1^q + v_2 Y_2^q) \quad (6)$$

The Lagrangian of the 2HDM-III

In the physical basis M_q is diagonal but not necessary are each of the two Yukawa matrices, we would have

$$\bar{M}_u^{diag} = V_L^u M_u V_R^{u^\dagger} \qquad \bar{M}_d^{diag} = V_L^d M_d V_R^{d^\dagger} \tag{7}$$

So, the CKM matrix given as usual $V_{CKM} = V_L^u V_L^{d\dagger}$, and

$$\tilde{Y}_{1,2}^q = V_L^q Y_{1,2}^q V_R^{q^\dagger} \tag{8}$$

where $q = u, b$. We may write one of the Yukawa matrices in therm of the other as

$$\begin{aligned} \tilde{Y}_1^d &= \frac{\sqrt{2}}{v\cos\beta}\bar{M}_d - \tan\beta\,\tilde{Y}_2^d \\ \tilde{Y}_2^u &= \frac{\sqrt{2}}{v\sin\beta}\bar{M}_u - \cot\beta\,\tilde{Y}_1^u \end{aligned} \tag{9}$$

In scalar mass basis, for pseudoscalars with fermions couplings are given as:

$$\begin{aligned}\mathcal{L}_Y^q &= i\bar{d}_i\left[-\left(\frac{m_{d_i}}{m_W}\right)\tan\beta\delta_{ij}+\frac{\sqrt{2}}{g\ \cos\beta}(\tilde{Y}_2^d)_{ij}\right]\gamma^5 d_j A^0 \\ &\quad +i\bar{u}_i\left[-\left(\frac{m_{u_i}}{m_W}\right)\cot\beta\delta_{ij}+\frac{\sqrt{2}}{g\ \sin\beta}(\tilde{Y}_1^u)_{ij}\right]\gamma^5 u_j A^0\end{aligned} \tag{10}$$

Using the Sheng-Cher Ansatz

$$\begin{aligned}(\tilde{Y}_2^{d,l})_{ij} &= \frac{\sqrt{m_i^{d,l}m_j^{d,l}}}{v}\tilde{\chi}_{ij}^{d,l} \\ (\tilde{Y}_1^u)_{ij} &= \frac{\sqrt{m_i^u m_j^u}}{v}\tilde{\chi}_{ij}^u\end{aligned} \tag{11}$$

The charged scalar Lagrangian of the 2HDM-III

The charged Higgs couplings with fermions, in the interaction basis are given as

$$\begin{aligned} L^{H^\pm}_{Yuk} &= \bar{u}_{Li}\left[\phi_2^+ (Y^d_{2CKM}) + \phi_1^+ (Y^d_{1CKM})\right] d_{Rj} \\ &\quad -\bar{d}_{Li}\left[\phi_2^- (Y^u_{2CKM}) + \phi_1^- (Y^u_{1CKM})\right] u_{Rj} + h.c. \end{aligned} \quad (12)$$

Rotating the quark fields to their physical basis we get the Yukawa matrices in CKM basis as

$$Y^d_{1,2CKM} = V^u_L Y^d_{1,2} V^{d\dagger}_R \quad (13)$$

$$Y^u_{1,2CKM} = V^d_L Y^u_{1,2} V^{u\dagger}_R \quad (14)$$

with the usual Cabibbo-Kobayashi-Maskawa matrix given as $V_{CKM} = V^u_L V^{d\dagger}_L$

The narrow space for NP in B meson processes

Although $B_s^0 \to \mu\bar{\mu}$ is measured. The most stringent bound on NP parameter space comes from B-mixing.

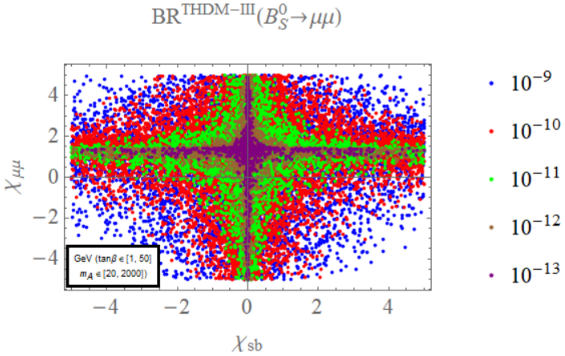

Figure: $BR(B_s \to \mu\mu)$ running aleatory and different the parameters of the yukawa χ_{ll} and χ_{sb} between $[-5, 5]$. Running $\tan\beta$ from 1 to 50, we also consider a range for pseudoscalar masses as $m_A = [20, 2000]$ GeV.

The contribution to $B_q^0 - \bar{B}_q^0$ mixing coming from the interchange of the pseudoscalar contributions in the 2HDM-III.

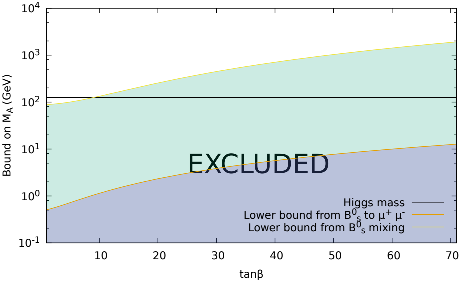

Figure: Lower bounds for pseudoscalar mass in the 2HDM-III for $B_s \to \mu\bar{\mu}$ and $B_s^0 - \bar{B}_s^0$ in the 2HDM-III. for $|\chi_{22}^{\ell}| \sim 1$ for the leptonic sector *[Felix-Beltran2013]*

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B mixing involving NP.

If we do not take into account short distance QCD quantum corrections *[Buras1990]*, contributions to $B_q^0 - \bar{B}_q^0$ mixings from 2HDM-III

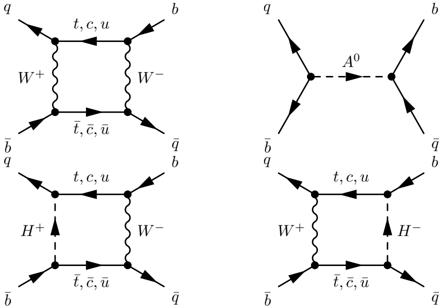

Figure: Diagrams contributing to $B_q^0 - \bar{B}_q^0$ mixing including (a) SM next to leading order, (b) tree level FCNC at the couplings with pseudoscalar and (c)-(d)LO charged scalar contributions. *[Becirevic2001, Huang2004, Urban1997]*

B meson process involving extra scalar and pseudosclar bosons.

The NP contribution to B_s mixing can be taken into account in the form

$$\Delta M_q = \Delta M_q^{\text{SM}} + \Delta M_q^{\text{NP}} \tag{15}$$

where ΔM_q^{NP} have contribution at tree level of the A^0 pseudoscalar and box diagrams with charged scalars the contribution to B_q^0 mixing to Wilson coefficient is given by

$$C_2 = C_2^{\text{SM}} + C_2^{\text{Box}-H^+} + C_2^{A_0} \tag{16}$$

where

$$C_2^{A_0} = \frac{|(\tilde{Y}_2^d)_{bs}|^2}{M_A^2}(1 + \tan^2\beta) \tag{17}$$

Thus the pseudoscalar NP contribution is given by

$$\Delta M_s^{\text{NP}} = |C_2^{A^0}| \frac{M_{B_s}^2 f_{B_s}^2}{[m_b(m_b) + m_s(m_b)]^2} \sigma_S(m_b) \tag{18}$$

The narrow space for NP in B mixing.

In order to find an upper bound on the Yukawa that parameterized NP contributions, we assume that its contribution is smaller than the difference between SM contribution and the experimental measurement of B_s^0 mixing, with the errors summed by quadratures

$$E_{B_s} = \left|\Delta M^{\text{SM}} - \Delta M^{\text{Exp}}\right| - \sqrt{\delta^2(\Delta M^{\text{SM}}) + \delta^2(\Delta M^{\text{Exp}})} \qquad (19)$$

Thus the $|\Delta M_s^{\text{NP}}|$ should be smaller than E_{B_s}. Using the expressions (17) and (18), we obtained an upper bound for $|\tilde{\chi}_{bs}|$ through the NP Yukawa contribution of the model, given by

$$|\tilde{\chi}_{bs}| \leq \left(\frac{2M_A^2}{1+\tan^2\beta}\right) \frac{v(m_b+m_s)^2}{\sqrt{m_b m_s} M_{B_s}^2 f_{B_s}^2} \frac{E_{B_s}}{\sigma_S(m_b)} \qquad (20)$$

Upper bounds for NP in B mixing

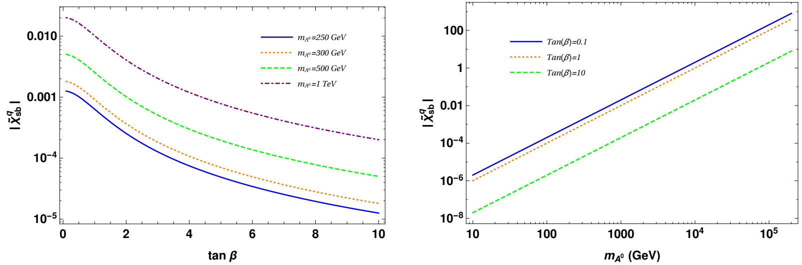

Figure: $B_q^0 - \bar{B}_q^0$ mixing upper bounds windows for NP (a) FV model parameter with respect of $\tan\beta$, (b) FV model parameter with respect of pseudoscalar mass.

B meson semi leptonic decays.

Considering only contribution via A_0 Higgs boson

$$\frac{\Gamma(\bar{b} \longrightarrow \bar{s}\mu\bar{\mu})}{\Gamma(\bar{b} \longrightarrow \bar{s}e\bar{e})} = \frac{M_\mu^2 \eta_{2\mu\mu}}{M_e^2 \eta_{2ee}} \tag{21}$$

where we have for different leptons $\eta_{2ij} = (\tilde{Y}_{2ij}^l)^2$ and for the same lepton

$$\eta_{2kk} = \tan^2\beta - 4\tan\beta F_k(\tilde{Y}_{2kk}^l) + 4F_k^2(\tilde{Y}_{2kk})^2. \tag{22}$$

where $F_k = \frac{c_w}{\sqrt{2}g\cos\beta}(\frac{M_z}{M_k})$

B meson process involving extra scalar and pseudosclar bosons.

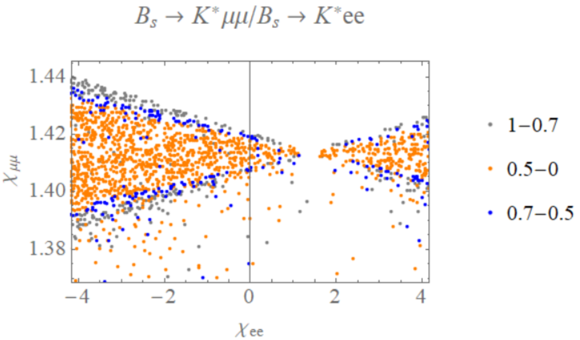

Figure: PRELIMINAR RESULTS. The flavour parameter values for different ranges of R_K^*. We see that the parameter $\chi_{\mu\mu}$ could be bounded.

.. to be continued....

Thanks !

4-zero textures matrices

The assumption that the corresponding Yukawa matrices have the *hermitian 4-zero texture type* (2 zeros for each type of quark) is enough in order to suppress FCNC. The Yukawa matrices have a hierarchy of the form:

$$Y_i^f = \begin{pmatrix} 0 & C_i^f & 0 \\ C_i^{f*} & \tilde{B}_i^f & B_i^f \\ 0 & B_i^{f*} & A_i^f \end{pmatrix}. \qquad \mid A_i^f \mid \gg \mid \tilde{B}_i^f \mid, \mid B_i^f \mid, \mid C_i^f \mid .$$