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(g-2)$_l$ in the general flavour conserving 2HDM

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In two Higgs doublets models (2HDM) we revise the conditions that Yukawa matrices must obey to guaranty the absence of flavour changing Yukawa couplings. The study of the evolution of these conditions under the one-loop renormalization group reveals that such general flavour conserving (gFC) structures, *in the leptonic* sector, are fully stable. This suggest to analyse two different types of 2HDM: those that are gFC in the leptonic sector and type I or type II in the quark sector. These models introduce in a minimal way lepton flavour universality (LFU) violation at the same time that decouple, for example, the muon and electron sectors. We apply those models to understand simultaneously the electron and muon (g-2) anomalies. We find two types of solutions compatible with all experimental constraints from LEP and LHC, from LFU, from flavour and electroweak physics and compatible with the theoretical constraints in the scalar sector. The solutions need the Z_2 symmetry of the Higgs potential to be softly broken. There is a solution where both (g-2) anomalies are understood by two loop graphs with $\tan\beta{\sim}1$, and all the scalars in the $1-2\,TeV$ range. This solution appears in both models. There is another solution, with relevant one and two loop contributions, with scalars bellow $1\,TeV$, and large $\tan\beta$, the second scalar Higgs has a mass in the range $0.2-0.4\,TeV$ and the charged and pseudoscalar bosons are degenerate and heavier than the new scalar. This solution just appears in the model that in the quark sector is type I.

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1.Introduction

It is well-known that general two Higgs doublet models (2HDM) [1] introduce new flavour structures in the couplings to the new scalars, including flavour changing neutral currents (FCNC). Therefore, 2HDM can introduce, in more restricted cases, flavour diagonal fermion structures different from the fermion mass matrices. In particular, in those type of model, it is very easy to introduce lepton flavour universality violation (LFUV). In this contribution we will first revise the general Flavour Conserving (gFC) 2HDM [2], that is, the structure of the general models without FCNC neither in the quark nor in the lepton sectors, but with otherwise arbitrary new couplings. Later on we will concentrate in models where the relevant feature is the presence of LFUV. It is in this context that we will present a preliminary study about the possibility of these models to have a simultaneous explanation of the electron and muon (g-2) anomalies [3].

2.The flavour sector of the 2HDM

The flavour structures of the 2HDM we are interested in, appear in the Yukawa coupling

$$\begin{gathered} L_Y = -\overline{Q_L}(\Gamma_1\Phi_1 + \Gamma_2\Phi_2)d_R - \overline{Q_L}\left(\Delta_1\widetilde{\Phi}_1 + \Delta_2\widetilde{\Phi}_2\right)u_R \\ -\overline{L_L}(\Pi_1\Phi_1 + \Pi_2\Phi_2)l_R + h.c. \end{gathered} \tag{1}$$

where the components of the two scalar doublets are

$$\Phi_j = e^{i\theta_j}\begin{pmatrix} \varphi_j^+ \\ \dfrac{\left(v_j + \rho_j + i\eta_j\right)}{\sqrt{2}} \end{pmatrix} \tag{2}$$

This Yukawa sector in the Higgs basis [4], with - $v^2 = v_1^2 + v_2^2, c_\beta = v_1/v_2, s_\beta = v_1/v_2$, -

$$\begin{pmatrix} e^{-i\theta_1}\Phi_1 \\ e^{-i\theta_2}\Phi_2 \end{pmatrix} = \begin{pmatrix} c_\beta & s_\beta \\ s_\beta & -c_\beta \end{pmatrix}\begin{pmatrix} \mathrm{H}_1 \\ \mathrm{H}_2 \end{pmatrix} \tag{3}$$

can be written as

$$\begin{gathered} L_Y = -\frac{\sqrt{2}}{v}\overline{Q_L}\left(M_d^0\mathrm{H}_1 + N_d^0\mathrm{H}_2\right)d_R - \frac{\sqrt{2}}{v}\overline{Q_L}\left(M_u^0\widetilde{\mathrm{H}}_1 + N_u^0\widetilde{\mathrm{H}}_2\right)u_R \\ -\frac{\sqrt{2}}{v}\overline{L_L}\left(M_l^0\mathrm{H}_1 + N_l^0\mathrm{H}_2\right)l_R + h.c. \end{gathered} \tag{4}$$

where by definition $\langle H_1\rangle^T = (0 \quad v/\sqrt{2}), \langle H_2\rangle^T = (0 \quad 0)$. Once M_f^0 get diagonalized by rotating the right and left handed fermion fields independently, one gets the diagonal mass matrices $M_{d,u,l}$ and the correspondingly new couplings $N_{d,u,l}$, in general with flavour off diagonal terms –of course it is the clash of the rotation of the left handed up and down quarks fields that generates the Cabibbo Kobayashi Maskawa (CKM) charged currents matrix- . It is clear from eq.(4), substituting M_f^0, N_f^0 by M_f, N_f that H_1 has the same couplings than the Standard Model (SM) Higgs and that H_2 couples to fermions with matrices N_f, therefore introducing FCNC: in general one cannot diagonalize simultaneously M_f and N_f.

3.General Flavour Conservation

The conditions to have simultaneous diagonalization of N_d^0, N_u^0, N_l^0 and the corresponding mass matrices M_d^0, M_u^0, M_l^0 were described long ago [5-8]. In the most general 2HDM, the necessary and sufficient conditions obeyed by the quark and lepton Yukawa coupling matrices $\Gamma_\alpha, \Delta_\alpha$ and Π_α in order to have gFC are that each of the following sets be abelian:

$$\left\{\Gamma_\alpha\Gamma_\beta^\dagger\right\};\left\{\Gamma_\alpha^\dagger\Gamma_\beta\right\};\ \alpha,\beta=1,2$$
$$\left\{\Delta_\alpha\Delta_\beta^\dagger\right\};\left\{\Delta_\alpha^\dagger\Delta_\beta\right\};\ \alpha,\beta=1,2 \qquad (5)$$
$$\left\{\Pi_\alpha\Pi_\beta^\dagger\right\};\left\{\Pi_\alpha^\dagger\Pi_\beta\right\};\ \alpha,\beta=1,2$$

therefore, to have a diagonal structure for the matrices N_d, N_u and N_l (to have gFC):

$$N_d=\begin{pmatrix} n_d & 0 & 0\\ 0 & n_s & 0\\ 0 & 0 & n_b\end{pmatrix}\quad N_u=\begin{pmatrix} n_u & 0 & 0\\ 0 & n_c & 0\\ 0 & 0 & n_t\end{pmatrix}\quad N_l=\begin{pmatrix} n_e & 0 & 0\\ 0 & n_\mu & 0\\ 0 & 0 & n_\tau\end{pmatrix} \quad (6)$$

the conditions to be fulfilled are

$$\left[\Gamma_\alpha\Gamma_\beta^\dagger,\Gamma_\gamma\Gamma_\delta^\dagger\right]=0\,;\left[\Gamma_\alpha^\dagger\Gamma_\beta,\Gamma_\gamma^\dagger\Gamma_\delta\right]=0$$
$$\left[\Delta_\alpha\Delta_\beta^\dagger,\Delta_\gamma\Delta_\delta^\dagger\right]=0\,;\left[\Delta_\alpha^\dagger\Delta_\beta,\Delta_\gamma^\dagger\Delta_\delta\right]=0 \qquad (7)$$
$$\left[\Pi_\alpha\Pi_\beta^\dagger,\Pi_\gamma\Pi_\delta^\dagger\right]=0\,;\left[\Pi_\alpha^\dagger\Pi_\beta,\Pi_\gamma^\dagger\Pi_\delta\right]=0$$

The best known particular solutions that implement the structure in eq. (6) are based on the Z_2 symmetry leading to Natural Flavour Conservation (NFC) of Glashow and Weinberg [9]. These solutions correspond to what is known today as 2HDM types I, II, X and Y [1]. Other solutions based on symmetries has been envisage on the basis of broken gauge $U(1)$ symmetries, like in references [10-11]. Still there are approaches not based on symmetries that fulfil eq. (7) like is the case of the so called Aligned 2HDM (A2HDM) [12]. Other approaches contain those proposals that do not impose conditions (7) but impose the suppression of the FCNC either by some popular ansatz, like in the case of the Cheng-Sher ansatz [13] or even by imposing this suppression with symmetries, like is the case of the Branco Grimus Lavoura (BGL) 2HDM and its generalizations [14-18]. An incomplete part of the long list of relevant contributions to the subject can be found here [19-27].

Because there are interesting solutions of the type (6) not protected by symmetries, for example the A2HDM, it is interesting to analyse the stability of these solutions under one loop renormalization group evolution (RGE) with the objective of discovering other suitable solutions.

4.Stability of gFC under RGE

The one-loop evolution of the Yukawa couplings under the renormalization group [28-30] is (with $D=16\pi^2\mu(d/d\mu)$ and μ the energy scale)

$$D\Gamma_k=a_d\Gamma_k+\sum_{l=1}^{2}\left(T_{k,l}^d\Gamma_l-2\Delta_l\Delta_k^\dagger\Gamma_l+\Gamma_k\Gamma_l^\dagger\Gamma_l+\frac{1}{2}\Delta_l\Delta_l^\dagger\Gamma_k+\frac{1}{2}\Gamma_l\Gamma_l^\dagger\Gamma_k\right) \qquad (8)$$

$$D\Delta_k=a_u\Delta_k+\sum_{l=1}^{2}\left(T_{k,l}^u\Delta_l-2\Gamma_l\Gamma_k^\dagger\Delta_l+\Delta_k\Delta_l^\dagger\Delta_l+\frac{1}{2}\Gamma_l\Gamma_l^\dagger\Delta_k+\frac{1}{2}\Delta_l\Delta_l^\dagger\Delta_k\right) \qquad (9)$$

$$D\Pi_k=a_l\Pi_k+\sum_{l=1}^{2}\left(T_{k,l}^l\Pi_l+\Pi_k\Pi_l^\dagger\Pi_l+\frac{1}{2}\Pi_l\Pi_l^\dagger\Pi_k\right) \qquad (10)$$

$$T_{k,l}^l=T_{k,l}^d=T_{k,l}^{u*}=3Tr\left(\Gamma_k\Gamma_l^\dagger+\Delta_k^\dagger\Delta_l\right)+Tr\left(\Pi_k\Pi_l^\dagger\right) \qquad (11)$$

where $a_{u,d,l}$ are numbers that depend on the gauge coupling constants and here are not relevant [28-30]. The structure of equations (6) will be maintained at one loop, provided we have

$$D\left[\Gamma_\alpha\Gamma_\beta^\dagger,\Gamma_\gamma\Gamma_\delta^\dagger\right]=0\,;D\left[\Gamma_\alpha^\dagger\Gamma_\beta,\Gamma_\gamma^\dagger\Gamma_\delta\right]=0$$
$$D\left[\Delta_\alpha\Delta_\beta^\dagger,\Delta_\gamma\Delta_\delta^\dagger\right]=0\,;D\left[\Delta_\alpha^\dagger\Delta_\beta,\Delta_\gamma^\dagger\Delta_\delta\right]=0 \qquad (12)$$
$$D\left[\Pi_\alpha\Pi_\beta^\dagger,\Pi_\gamma\Pi_\delta^\dagger\right]=0\,;D\left[\Pi_\alpha^\dagger\Pi_\beta,\Pi_\gamma^\dagger\Pi_\delta\right]=0$$

These are the stability conditions to preserve gFC at one loop. These equations in the quark sector can be written in terms of a set of equations depending on the CKM matrix, on all the up and down quark masses and all the new complex parameters n_d, n_s, n_b, n_u, n_c, and n_t [2]. And as it is well-know the equations have not solution for arbitrary n_q parameters. The equations in the lepton sector are much more simple because we have not introduce neutrino masses. In the charged lepton sector all the parameters present in the last equation (12) are the charged lepton masses and n_e, n_μ, and n_τ.

In order to learn about the nature of the solutions to eq. (12) it is very interesting to start with a restricted class of solutions that fulfil gFC but are not stable under RGE. If we then impose stability under RGE we will be restricting the solutions to some set that should contain, if any, those solutions implemented by the use of some symmetry and belongs to the initial class. This is the case if we analyse the A2HDM defined by the equations:

$$\Gamma_2=d\cdot\Gamma_1 \quad \Delta_2=u\cdot\Delta_1 \quad \Pi_2=e\cdot\Pi_1 \qquad (13)$$

once it is imposed the stability conditions in eqs. (12) and the generation of an arbitrary CKM matrix, one gets the following results:

- In the quark sector: $(u^*-d)(1+ud)=0$ is a solution of eqs. (12) in the framework (13). The two solutions of this equation correspond to 2HDM type I or II in the quark sector. If additionally it is imposes the no running of d, u and e, the resulting models are the 2HDM type I,II,X and Y [30,31].
- Another type of solution in the quark sector correspond to equation
$$\Delta_1\Delta_1^\dagger\Gamma_1=\lambda_\Gamma\Gamma_1 \text{ and } \Gamma_1\Gamma_1^\dagger\Delta_1=\lambda_\Delta\Delta_1 \qquad (14)$$
this equation, in fact, is not a solution because it does not generate a general CKM. If to this second "solution" one impose Yukawa structures which are, in leading order, in agreement with the observed pattern of quark masses and mixing [31] the result is the democratic mass solution giving rise to an additional quark alignment among the up and the down sectors
$$\Gamma_1=c_d\begin{pmatrix}1&1&1\\1&1&1\\1&1&1\end{pmatrix} \quad \Delta_1=c_u\begin{pmatrix}1&1&1\\1&1&1\\1&1&1\end{pmatrix} \qquad (15)$$
- In the leptonic sector, still in the A2HDM, a not so known result is that $\Pi_2=e\cdot\Pi_1$ is stable under one loop RGE [31,32]. The absence of right-handed neutrinos and the corresponding Yukawa coupling prevents any misalignment in the charged lepton sector. This results suggests to perform fits with 2HDM type I or II in the quark sector but aligned in the leptonic one.

Inspired by this last result we analyzed in reference [2], if general Flavour Conservation (gFC) in the leptonic sector is stable under one loop RGE. The result, now outside the A2HDM framework is that *gFC in the leptonic sector is one loop stable under RGE*. This important result promotes to the category of interesting models 2HDM type I or II in the quark sector and gFC in the leptonic one. In the second part of this contribution we will prove the ability of these models to confront the electron and muon $(g-2)$ anomalies.

It has to be pointed out that eqs. (12) in the quark sector present some Cabibbo like solutions [2]. These solutions do not reproduce a general CKM but instead only a mixing matrix with just one mixing angle. This kind of solutions, given the hierarchy in the CKM matrix, can be interesting as a starting paradigm, like is the case of the democratic mass matrix [2,31].

5.Phenomenology of the gFC 2HDM

The effects of the new physics sector represented by the parameters n_f are probed by the production and decay of the discovered 125 GeV Higgs h. Assuming no CP violation in the Higgs potential, in general the physical Higgs bosons will be a mixture of H_1^0 and H_2^0

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} s_{\beta\alpha} & c_{\beta\alpha} \\ -c_{\beta\alpha} & s_{\beta\alpha} \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix} \quad (16)$$

where we have introduced the standard mixing angle among the two real pieces of the neutral components of the doublets in the Higgs basis as it is traditional [4]. H_1^0 couple to masses and H_2^0 couples to n_f, so it is clear that h production and decay data will constraint n_f provided $s_{\beta\alpha} = \sin\theta_{\beta\alpha} \neq 1$ and $c_{\beta\alpha} = \cos\theta_{\beta\alpha} \neq 0$. The first results of this analysis were presented in [2] and are shown in figure (1)

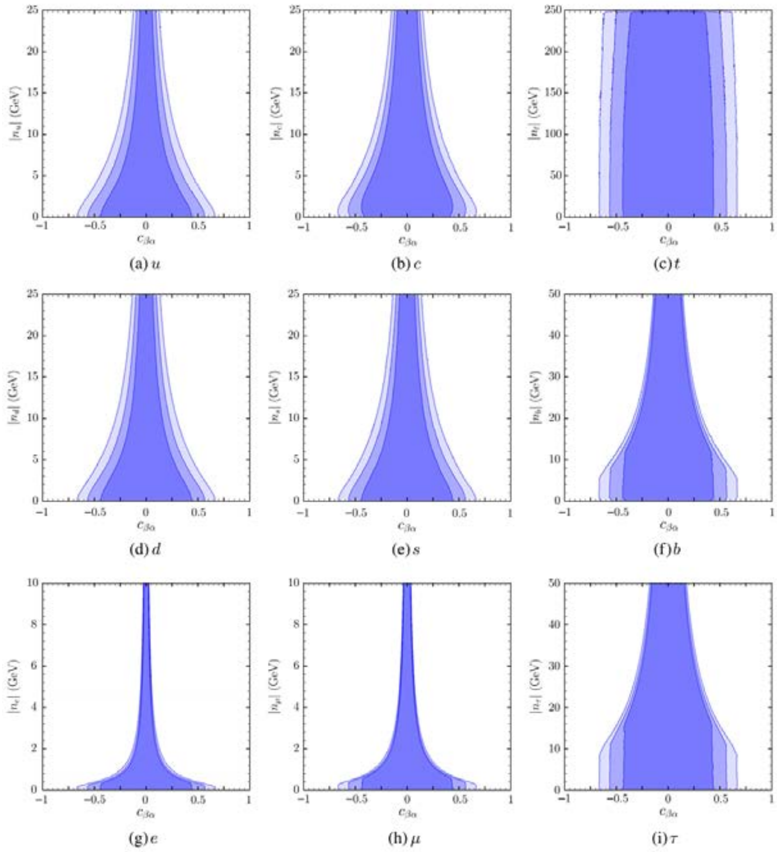

FIG. 1. $|n_f|$ vs $c_{\beta\alpha}$ for the fermion f; darker to lighter regions correspond to 68%, 95%, and 99% C.L.

Instead of the traditional plots where $\tan\beta = v_2/v_1$ is represented versus $c_{\beta\alpha}$ in this case we have the new couplings $|n_f|$ versus $c_{\beta\alpha}$. From figure (1) one realizes that Higgs related measurements are extremely constraining in the electron and muon channel if we depart from the alignment limit $c_{\beta\alpha} \neq 0$. It has to be stressed, for example, that figure (1g), obtained from LHC constraints is much more restrictive than the bounds coming from the electron electric dipole moments (EDM). Comparisons with type I, II, X and Y can be found in reference [2]

6.Two anomalies

It is known that after an improved determination of the fine structure constant[33] it has merged a new $a_l = (g-2)_l$ anomaly for the electron[3,34], a discrepancy among the experimental value and the SM prediction $\delta a_e^{exp} = a_e^{exp} - a_e^{SM}$ given by

$$\delta a_e^{exp} \sim -(8.7 \pm 3.6) \cdot 10^{-13} \qquad (17)$$

A more well-known and long standing anomaly appears in the muon $(g-2)_\mu$ of opposite sign to the electron one

$$\delta a_\mu^{exp} \sim (2.7 \pm 0.9) \cdot 10^{-9} \qquad (18)$$

In general, it is this difference of sign that tend to eliminate several New Physics solutions that has been used for δa_μ^{exp}. In particular, many popular models where the anomaly scales with the lepton mass square[35] tends to generate a larger δa_e with a wrong sign. Some authors[36] argue that if the origin of both anomalies is Beyond the Standard Model, the corresponding BSM must incorporate some sort of effective decoupling between μ and e, and that is precisely what the 2HDM with gFC in the leptonic sector offers us: the introduction of the arbitrary couplings n_e and n_μ.

7.I-*gl*FC and II-*gl*FC two Higgs doublet models for $(g-2)_l$

The models we are going to confront to the two $(g-2)_l$ anomalies are defined in the fermion mass basis and in the Higgs basis by

$$\begin{aligned} L_Y = &-\frac{\sqrt{2}}{v}\overline{Q_L}(M_d \mathrm{H}_1 + N_d \mathrm{H}_2) d_R - \frac{\sqrt{2}}{v}\overline{Q_L}\left(M_u \widetilde{\mathrm{H}}_1 + N_u \widetilde{\mathrm{H}}_2\right) u_R \\ &-\frac{\sqrt{2}}{v}\overline{L_L}(M_l \mathrm{H}_1 + N_l \mathrm{H}_2) l_R + h.c. \end{aligned} \qquad (19)$$

where M_f are the diagonal mass matrices. The model that in the quark sector is type I and in the leptonic sector is gFC we name as I-*gl*FC; from type I and *general lepton* Flavour Conserving. The new couplings are therefore

$$N_d = \cot\beta \cdot M_d \quad N_u = \cot\beta \cdot M_u \quad N_l = \begin{pmatrix} n_e & 0 & 0 \\ 0 & n_\mu & 0 \\ 0 & 0 & n_\tau \end{pmatrix} \quad (20)$$

The second model we will consider is type II in the quarks sector and gFC in the lepton sector and we name as II-*gl*FC. In this case the new physics couplings are

$$N_d = -\tan\beta \cdot M_d \quad N_u = \cot\beta \cdot M_u \quad N_l = \begin{pmatrix} n_e & 0 & 0 \\ 0 & n_\mu & 0 \\ 0 & 0 & n_\tau \end{pmatrix} \quad (21)$$

The complete model - in the quark type I or II framework- has a Z_2 symmetric Higgs potential, with or without a soft breaking term, that is of the form

$$\begin{aligned} V = &\mu_{11}^2 \Phi_1^\dagger \Phi_1 + \mu_{22}^2 \Phi_2^\dagger \Phi_2 - m_{12}^2\left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1\right) \\ &+ \left[\lambda_5\left(\Phi_1^\dagger \Phi_2\right)^2 + h.c.\right] + 2\lambda_3\left(\Phi_1^\dagger \Phi_1\right)\left(\Phi_2^\dagger \Phi_2\right) \\ &2\lambda_4\left(\Phi_1^\dagger \Phi_2\right)\left(\Phi_2^\dagger \Phi_1\right) + \lambda_1\left(\Phi_1^\dagger \Phi_1\right)^2 + \lambda_2\left(\Phi_2^\dagger \Phi_2\right)^2 \end{aligned} \qquad (22)$$

We will adopt this potential paying special attention to two cases, when $m_{12}^2 \neq 0$ and when $m_{12}^2 = 0$, with or without a soft breaking term of the Z_2 symmetry. In the CP conserving limit in the Higgs potential the neutral physical scalars fields are named by h (the 125 GeV) and H and defined in terms of the real neutral components of H_1 and H_2 in equation (16). Named as the pseudoscalar A, we introduce the imaginary part of the neutral component of H_2, its charged component corresponds to the charged Higgs field $H^\pm$.

8.One and two loops contributions to $(g-2)_l$

It is convenient to define the electron and muon $(g-2)_l$ anomalies δa_l in the following way

$$\delta a_l = K_l \Delta_l$$
$$K_l = \frac{1}{8\pi^2}\left(\frac{m_l}{v}\right)^2 = \frac{1}{8\pi^2}\left(\frac{2m_l}{2M_W}\right)^2 \qquad (23)$$

Therefore, to explain the anomalies with new physics, we need to implement the following order of magnitude central values

$$\Delta_e \sim -16 \quad \Delta_\mu \sim 1 \qquad (24)$$

In the 2HDM here considered, it is well-known that both one and two loop (Barr-Zee) contributions can be dominant. So we present here both contributions in the very reasonable alignment limit where $h = H_1^0$. Also if $n_l = n_l^R + i n_l^I$, we will assume that the imaginary parts vanish: $n_l^I = 0$.

The one loop contribution comes from diagrams in figure (2)

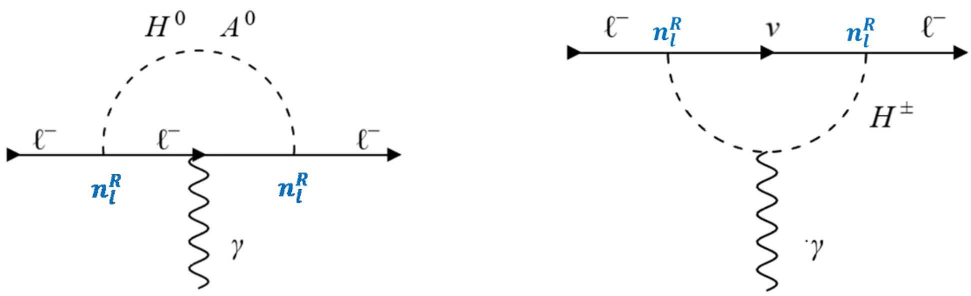

FIG. 2. One loop diagrams contributing to δa_l. The new neutral scalars to the left, the charged scalar contribution to the right.

In the limit of small $(m_l/M_S)^2$ with $S = H, A, H^\pm$ we have [37]

$$\Delta_l^{1-loop} = \left(n_l^R\right)^2 \left(\frac{h_{lH}}{M_H^2} - \frac{h_{lA} - \frac{2}{3}}{M_A^2} - \frac{1}{6M_{H^\pm}^2}\right) \qquad (25)$$
$$h_{lS} = -\frac{7}{6} - 2ln\left(\frac{m_l}{M_S}\right)$$

All our scalars will be in the range $M_S \in (0.2, 2)\ TeV$. For this range we have correspondingly

$$h_{eS} \in (24.6, 29.2) \quad h_{\mu S} \in (13.9, 18.5) \qquad (26)$$

what means that the dominant contributions come from the logarithmically enhanced diagrams with H and A. Because the sign $\Delta_e \sim -16$, the electron anomaly could be obtained from the A contribution but with the requirement $n_e^R \sim M_A$, that will break easily perturbation theory in the Yukawa sector. Consequently, it is not expected to generate the electron anomaly at one loop. By the contrary, one can get $\Delta_\mu \sim 1$ from the H graph and with the more reasonable requirement $n_\mu^R \sim 1/4 M_H$, what could be done with a light $H, M_H \sim 200\, GeV$ and a much more heavy A, to avoid cancellations.

Within the same approximations the two loops contribution is dominated by the Barr-Zee diagrams of figure (3)

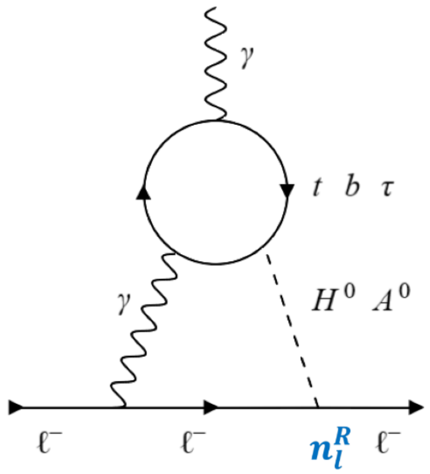

FIG. 3. Two loops dominant diagrams contributing to δa_l. Shown only the leading fermion loop contributions.

The leading contributions for the 2HDM I-*gl*FC and II-*gl*FC are given respectively by [38-41]

$$\Delta_l^{2-loop} = -\left(\frac{2\alpha}{\pi}\right)\left(\frac{n_l^R}{m_l}\right) F^{I,II}(\beta, t, b, \tau, H, A) \qquad (27)$$

$$F^I = \frac{\cot\beta}{3}\left[4(f_{tH} + g_{tA}) + (f_{bH} - g_{bA})\right] + \left(\frac{n_\tau^R}{m_\tau}\right)(f_{\tau H} - g_{\tau A}) \qquad (28)$$

$$F^{II} = \frac{\cot\beta}{3}\left[4(f_{tH} + g_{tA}) - \tan^2\beta\,(f_{bH} - g_{bA})\right] + \left(\frac{n_\tau^R}{m_\tau}\right)(f_{\tau H} - g_{\tau A}) \qquad (29)$$

where we have used the notation $f_{fS} = f\left(m_f^2/M_S^2\right)$ and $g_{fS} = g\left(m_f^2/M_S^2\right)$ and the relevant properties of these functions can be seen in figure (4).

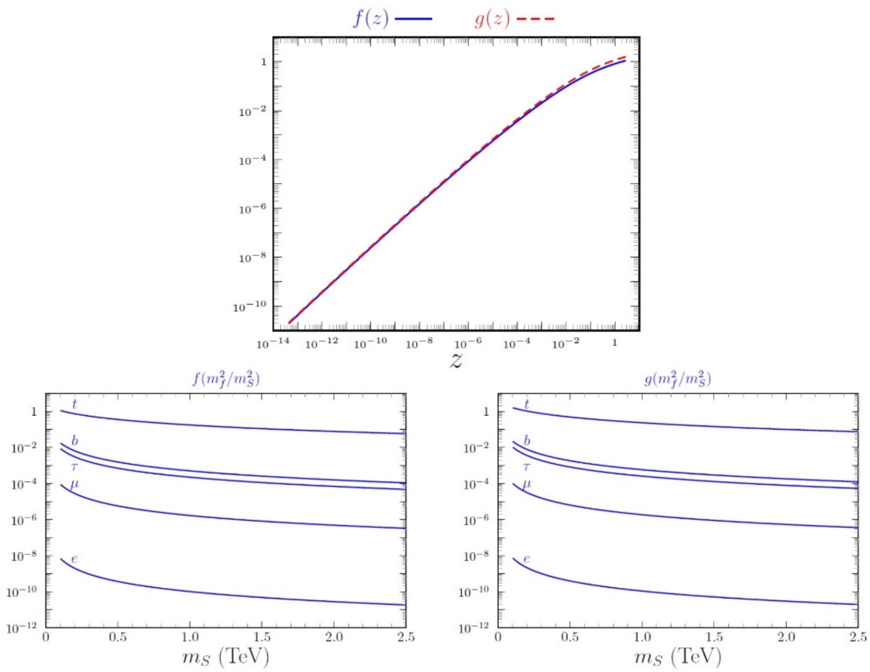

FIG. 4. The two loop function $f(z)$ and $g(z)$, and its values for different fermions.

From the curves in figure (4) it is clear that the function $f(z)$ and $f(z)$ takes similar values and that always, for the same scalar masses, the dominant contribution is coming from the top quark loop. By looking back to eq. (27-29) it is clear that the functions $F^{I,II}$ are independent from the lepton we are considering. Therefore, in a scenario where both anomalies, for the electron and the muon, are generated by the two loop contributions we arrive to the very important scaling law

$$\delta a_e = \frac{m_e n_e^R}{m_\mu n_\mu^R} \delta a_\mu \qquad (30)$$

It is precisely the linear dependence on n_l^R and its corresponding sign that makes possible in an easy way to reverse the signs of both anomalies. In a typical situation: $\tan\beta \sim 1$, $M_A \sim M_H$, in the $1-2\,TeV$ range, we get from the top contribution that δa_e can be reproduced with n_e^R in the range $n_e^R \sim (3-7)GeV$, and $n_\mu^R \sim -(45-105)\,GeV$. This two loop solution should verify eq. (30) that translates into

$$n_\mu^R = -\left(15.11^{+15.11}_{-7.56}\right) n_e^R \qquad (31)$$

From all the previous considerations we can add that for the muon anomaly we can expect some relevant contribution in regions of the parameter space with large $\tan\beta$ and n_e^R together with light M_H and heavier M_A.

9.General constraints

The full set of constraints we have imposed are the following:

- Scalar sector: boundness, perturbative unitarity and oblique parameters.
- Production times decay signal strengths of the $125\,GeV$ Higgs-like scalar h and other properties. Because we need $n_e^R \gg m_e$ and $n_\mu^R \gg m_\mu$, we get important constraints on the mixing among h and H: in fact we are near to the alignment limit.

- The constraints related to Lepton Flavour Universality (LFU): $l \to l' \nu_l \bar{\nu}_{l'}$, $\pi^- \to \mu^- \bar{\nu}_\mu$, $\pi^- \to e^- \bar{\nu}_e$, $K^- \to \mu^- \bar{\nu}_\mu$, $K^- \to e^- \bar{\nu}_e$, $\tau^- \to \pi^- \bar{\nu}_\tau$, $\tau^- \to K^- \bar{\nu}_\tau$.
- Flavour constraints: the charged Higgs contribution to meson mixing and to $b \to s\gamma$.
- Constraints on $e^+e^- \to l^+l^-$ from LEP up to 200 GeV.
- The $(g-2)$ for the electron and muon. In general we have impose $|n_l| < 100\ GeV$.
- LHC searches of dilepton resonances.

10.Results

First we present our preliminary results in the case we introduce the soft breaking term of the Z_2 symmetry in the Higgs potential of equation (22). Note that with large electron and muon couplings to the new scalars LHC dilepton searches become very important. So we present separate results of our fit including or not these LHC dilepton constraints. The most important results, confirming our initial expectations are represented in figure (5)

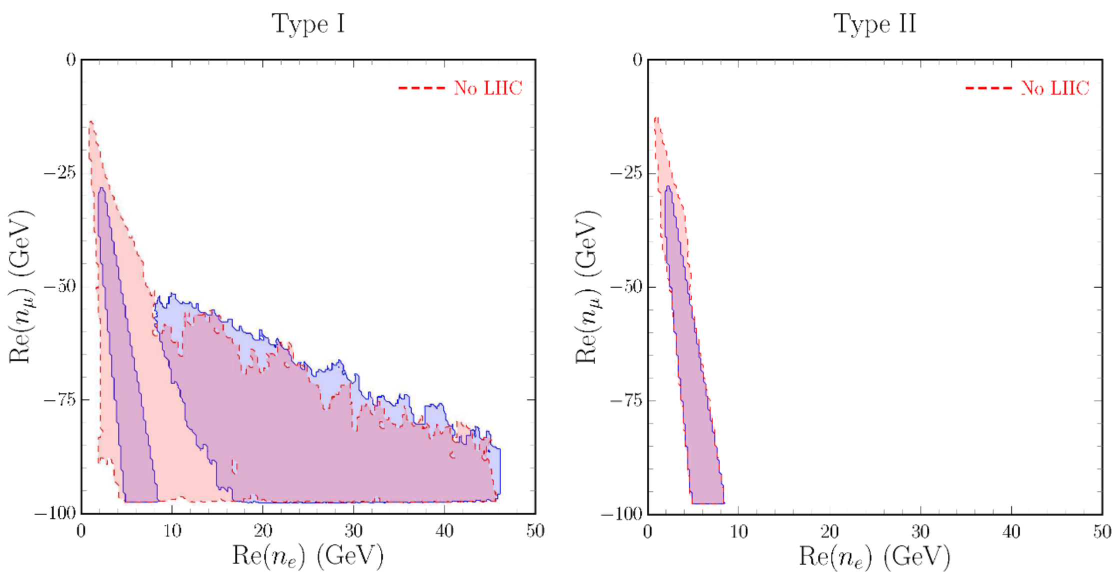

FIG. 5. n_μ^R versus n_e^R in the I-*gl*FC (left) and II-*gl*FC (right) models . In the red regions the LHC dilepton searches are not included, in the blue regions these LHC data are included. The plotted graphics correspond to 3 sigma regions.

In model II-*gl*FC -to the right of figure (5)- we find the two loops dominated region corresponding to eq. (31). In all the graphics the complete analysis is in blue and in red without including LHC dilepton searches. All regions are 3 sigmas. In the I-*gl*FC case we get the same two loop region and another with larger n_e^R, such that n_μ^R could not verify equation (31), therefore in this second region the muon anomaly must be dominated by the one loop contribution. These conclusions are improved by the following figures

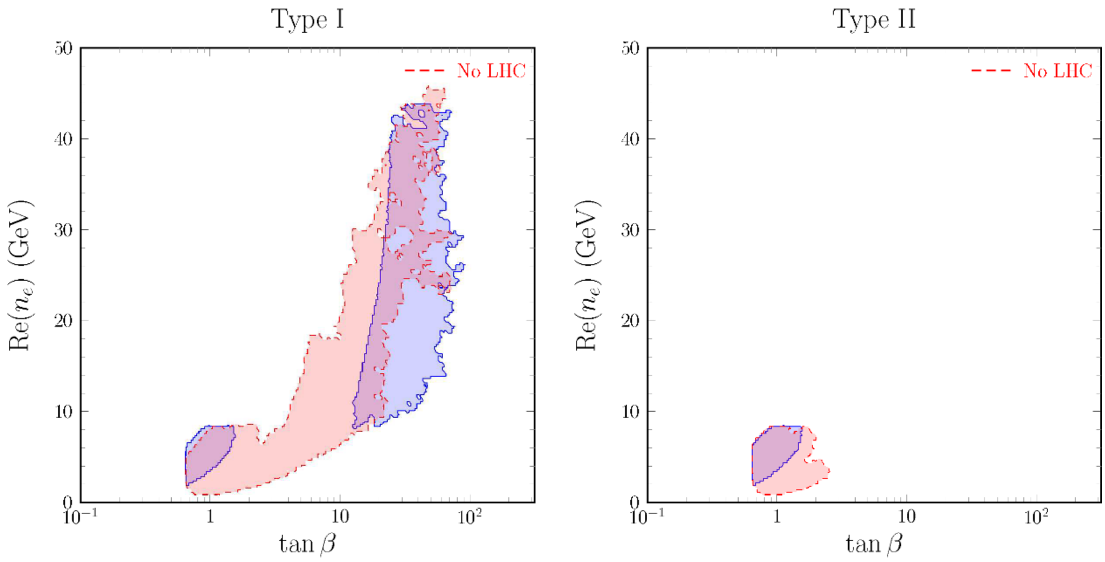

FIG. 6. n_e^R versus $\tan\beta$

Looking to model II-*gl*FC in figure 6 we can see that the two loop solutions corresponds to $\tan\beta\sim 1$ as expected. The second solution (larger n_e^R) in model I-*gl*FC correspond to large $\tan\beta$, that consistently with eq. (28) means that the two loop contribution is $\cot\beta$ suppressed in such a way that the one loop contribution to δa_μ become relevant.

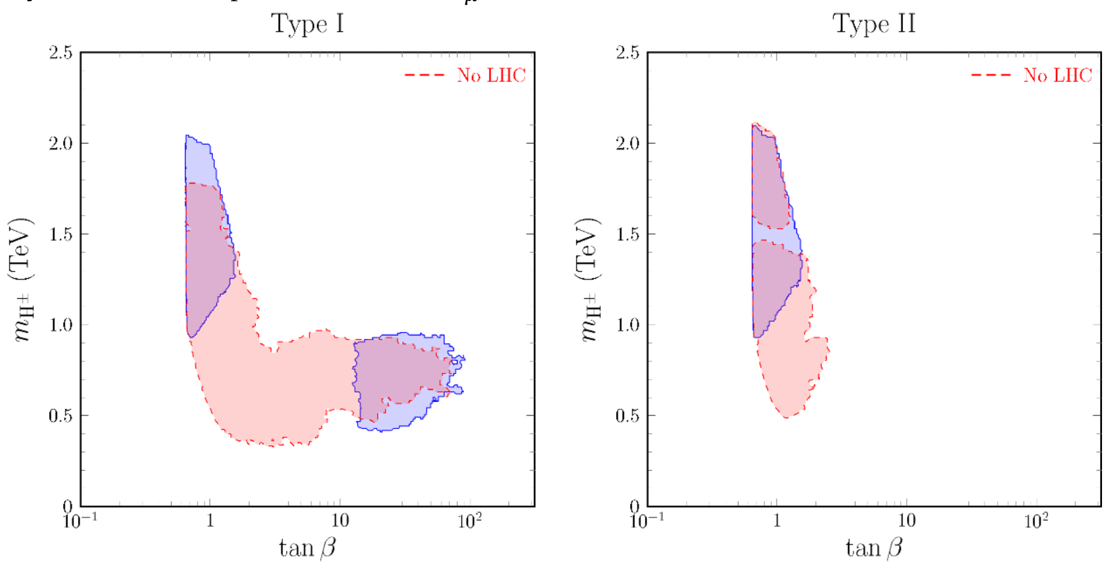

FIG. 7. $M_{H^\pm}$ versus $\tan\beta$

Figure (7) confirms that the $\tan\beta\sim 1$ solutions correspond to the charged Higgs in the $1-2\ TeV$ region, and the large $\tan\beta$ solution correspond to light $M_{H^\pm}$. Figure (8) allows to extend to all the neutral scalars, the previous properties connected with the charged one. In particular we conclude that the $\tan\beta\sim 1$ solution corresponds to heavy $M_{H^\pm}, M_A$ and M_H in the $1-2\ TeV$ range, and the large $\tan\beta$ solution corresponds to light $M_{H^\pm}\sim M_A$ in the range $0.4-0.9\ TeV$ and M_H much lighter in the range $0.2-0.4\ TeV$. In this solution open and important decay channels are $A\to HZ$ and $H^\pm \to HW^\pm$.

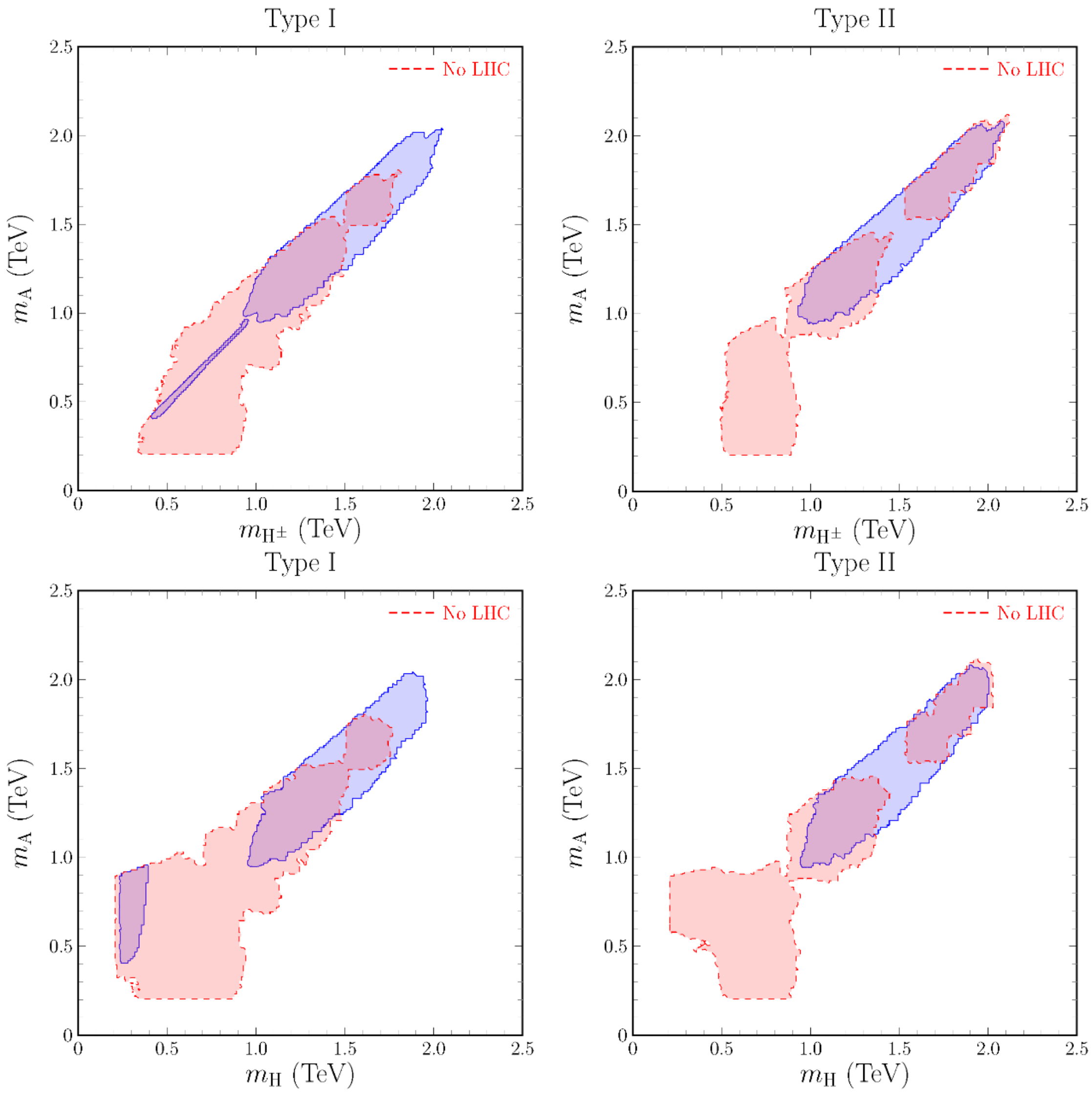

FIG. 8. M_A versus $M_{H^\pm}$ and M_A versus M_H

In the large $\tan\beta$ solution the two loop top and bottom contributions are $\cot\beta$ suppressed and the tau loop can contribute. It turns out that in fact it helps in some region of the parameter space as can be seen in figure (9). In particular, we see in this parameter region that n_τ^R must be positive and in some region forced to be in the large part around 100 GeV.

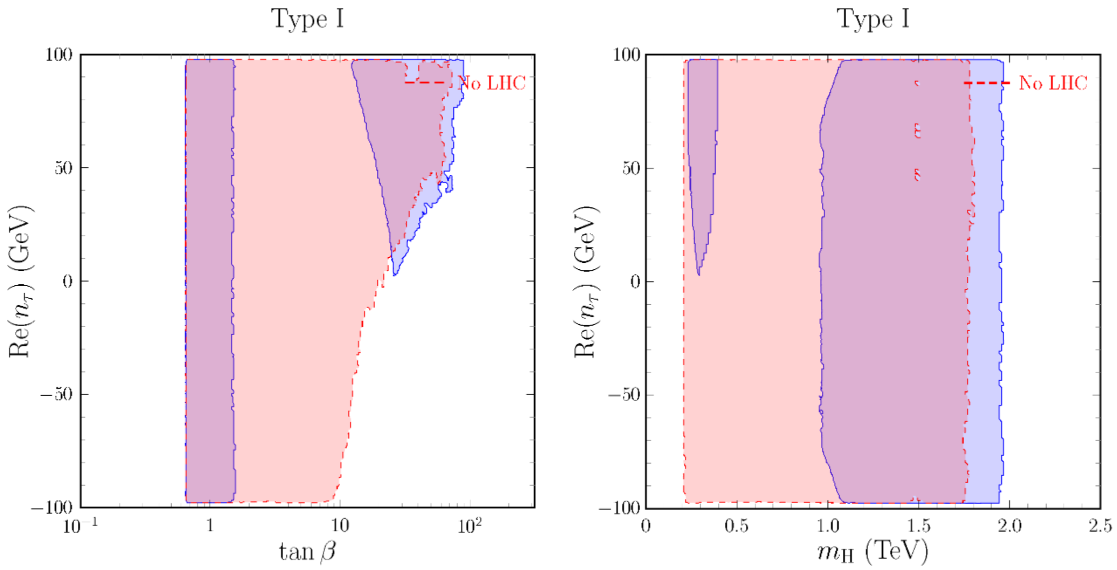

FIG. 9. n_τ^R versus $\tan\beta$ and versus M_H

A final and important comment concerns the analysis in the full symmetric case when there is not soft breaking term of the Z_2 symmetric potential. In this case it is well-known that the absence of the m_{12}^2 term does not allow neither large $\tan\beta$ neither heavy scalars. Consequently, once we include dilepton resonance searches in the analysis we do not find any solution in the Z_2 symmetric case.

11.Conclusions

The lepton sector of 2HDM –without right handed neutrinos- preserve at one loop a general flavor conserving structure: lepton diagonal Yukawa coupling remain diagonal under RGE. This fact suggests to introduce the models 2HDM I-*gl*FC and II-*gl*FC, defined respectively as type I and II in the quark sector and general flavour conserving in the lepton sector. These models introduce LFUV and offer a new and simple possibility to explain simultaneously the electron and muon $(g-2)$ anomalies.

In both models there is a quite similar solution whose major preliminary features are the following: i) both anomalies are explained by the Barr-Zee two loop graphs with the linear scaling $\delta a_l \propto m_l n_l^R$, ii) the parameter space corresponds to $\tan\beta \sim 1$, $M_{H^\pm} \sim M_A \sim M_H$ in the interval $1-2\ TeV$, with $n_\mu^R \sim -15 n_e^R$ and $n_e^R \in (2,8)\ GeV$.

Just in the II-*gl*FC 2HDM there is a second solution with the following characteristics: i) the electron anomaly is explained by the two loop contribution, but the muon one gets very large contribution from the one loop graphs, ii) the lighter scalar corresponds to $M_H \in (0.2, 0.4)\ TeV$, $M_{H^\pm} \sim M_A \in (0.4, 0.9)\ TeV$ and $\tan\beta \in (10, 100)$, iii) Important dominant decay channels are $A \to HZ$ and $H^\pm \to HW^\pm$.

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