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Lepton $g - 2$ anomalies in general flavour conserving two Higgs doublets models

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The potential discrepancies between the anomalous magnetic moments of the electron and the muon and their Standard Model expectations are addressed in the context of a class of Two Higgs doublets models with tree level neutral flavour conservation. These "anomalies" can be explained in two regimes, either scalar masses > 1.3 TeV and similar vacuum expectation values of the scalar doublets, or scalar masses < 1 TeV and a strong hierarchy of vacuum expectation values. The electron anomaly is explained through two loops contributions in both regimes; the muon anomaly is explained through two loops contributions for large scalar masses, and through one loop contributions in the second regime with scalar masses < 1 TeV.

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1. Introduction

We address the possibility to explain two "anomalies" in the anomalous magnetic moments $a_\ell = \frac{g_\ell}{2} - 1$ of μ and e (g_ℓ are the gyromagnetic ratios) in the context of a particular class of Two Higgs doublets models which do not have tree level flavour changing scalar couplings. For a_μ, the *Muon* $g-2$ collaboration [1–3] reports

$$\delta a_\mu^{\text{Exp}} \equiv a_\mu^{\text{Exp}} - a_\mu^{\text{SM}} = +(2.5 \pm 0.6) \times 10^{-9}, \tag{1}$$

where a_μ^{Exp} is the measurement and a_μ^{SM} is the corresponding Standard Model (SM) expectation [4] (although part of the discrepancy might be attributed to hadronic effects [5], we assume that it is due to physics beyond the SM). Concerning a_e, precise determinations [6] together with the extraction of the fine structure constant α from ^{133}Cs recoil measurements [7] give

$$\delta a_e^{\text{Exp}} \equiv a_e^{\text{Exp}} - a_e^{\text{SM}} = -(8.7 \pm 3.6) \times 10^{-13}. \tag{2}$$

^{87}Rb recoil measurements give rise to a different δa_e^{Exp}, but we do not address that possibility here.

In the following, we briefly present the model in section 2. The new contributions to a_ℓ are visited in section 3. The analysis and some selected results are discussed in section 4. For further details on different aspects of this work we refer to [8] and [9].

2. Model

We consider a Two Higgs doublets model with a Z_2 symmetric scalar potential, with the symmetry softly broken by a ($\mu_{12}^2\Phi_1^\dagger\Phi_2$+H.c.) term with $\mu_{12}^2 \neq 0$, necessary to accommodate scalar masses larger than 1 TeV [10]. The Yukawa couplings for fermion mass eigenstates and scalar doublets in the Higgs basis are

$$\begin{aligned}\mathscr{L}_{\text{Y}} = -\frac{\sqrt{2}}{v}\bar{Q}_L\left(H_1\text{M}_d + H_2\text{N}_d\right)d_R - \frac{\sqrt{2}}{v}\bar{Q}_L\left(\tilde{H}_1\text{M}_u + \tilde{H}_2\text{N}_u\right)u_R \\ -\frac{\sqrt{2}}{v}\bar{L}_L\left(H_1\text{M}_\ell + H_2\text{N}_\ell\right)\ell_R + \text{H.c.}\end{aligned} \tag{3}$$

with (real, positive) diagonal M_f (we consider massless neutrinos).

We consider two different models, I-gℓFC and II-gℓFC; model I-gℓFC is defined by

$$\text{N}_u = t_\beta^{-1}\text{M}_u, \quad \text{N}_d = t_\beta^{-1}\text{M}_d, \quad \text{N}_\ell = \text{diag}(n_e, n_\mu, n_\tau). \tag{4}$$

The couplings N_u, N_d in eq. (4) are the same as in 2HDMs of types I or X.

Model II-gℓFC is defined by

$$\text{N}_u = t_\beta^{-1}\text{M}_u, \quad \text{N}_d = -t_\beta\text{M}_d, \quad \text{N}_\ell = \text{diag}(n_e, n_\mu, n_\tau). \tag{5}$$

The couplings N_u, N_d in eq. (5) are the same as in 2HDMs of types II or Y.

In both models N_ℓ is diagonal, arbitrary and stable at one loop level under RGE (it remains diagonal). The effective decoupling among the new e and μ couplings required to explain

the $g-2$ anomalies is obtained with the independence of n_e and n_μ.
As a final simplifying assumption, we will consider that (i) there is no CP violation in the scalar sector (there is a pseudoscalar A and two scalars h and H, and there are no $\mathrm{h}-\mathrm{A}$ and $\mathrm{H}-\mathrm{A}$ mixings), and (ii) the new Yukawa couplings are real, $\mathrm{Im}\,(n_\ell)=0$.

3. New contributions to δa_ℓ

In this context, the full theoretical prediction of a_ℓ is

$$a_\ell^{\mathrm{Th}} = a_\ell^{\mathrm{SM}} + \delta a_\ell, \tag{6}$$

where a_ℓ^{SM} is the Standard Model contribution and δa_ℓ corresponds to the new corrections due to the model. In order to solve the discrepancies, the aim is to obtain

$$\delta a_e \simeq \delta a_e^{\mathrm{Exp}}, \qquad \delta a_\mu \simeq \delta a_\mu^{\mathrm{Exp}} \tag{7}$$

within models I-gℓFC and II-gℓFC. We rewrite

$$\delta a_\ell = K_\ell\,\Delta_\ell, \qquad K_\ell = \frac{1}{8\pi^2}\left(\frac{m_\ell}{v}\right)^2 = \frac{1}{8\pi^2}\left(\frac{g m_\ell}{2M_W}\right)^2, \tag{8}$$

where K_ℓ collect typical factors arising in one loop contributions; we have

$$K_e \simeq 5.5\times 10^{-14}, \qquad K_\mu \simeq 2.3\times 10^{-9}, \tag{9}$$

and thus eq. (7) corresponds to

$$\Delta_e \simeq -16, \qquad \Delta_\mu \simeq 1\,. \tag{10}$$

There are relevant new contributions at one loop, proportional to $|n_\ell|^2$, and at two loops (Barr-Zee type contributions) proportional to $\mathrm{Re}\,(n_\ell)$. A detailed analysis of these contributions (see [8, 11]), considering the values in eq. (10) necessary to reproduce the anomalies, shows that one can identify two different regimes in which the model might accommodate the anomalies.

- For values of $t_\beta \simeq 1$ and masses of the scalars larger than 1.3 TeV, both anomalies are reproduced through the two loops contributions. Since these two loops contributions have a dominanting term with a top quark in the closed fermion loop, there is an approximate relation among the lepton couplings $\mathrm{Re}\,(n_\mu) \sim -16\mathrm{Re}\,(n_e)$.

- For values of $t_\beta \gg 1$ and masses of the scalars below 1 TeV, δa_e is still obtained via the two loops contributions, but δa_μ can now be obtained through the one loop contributions with virtual H.

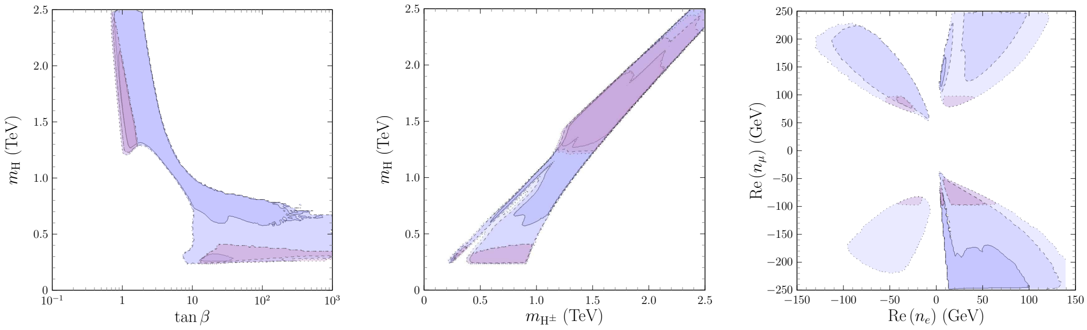
4. Analysis and results

In order to explore properly how the model can explain both δa_ℓ anomalies, a numerical analysis of its parameter space is conducted. The results shown in the following are obtained in this manner (for details, see [8, 11]). It is important to recall that besides the anomalies of interest, the model has to respect the following relevant constraints (which are incorporated into the numerical analysis).

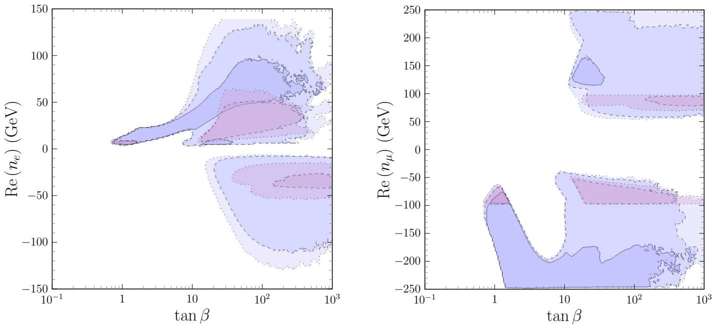
- In the scalar sector, the potential has to be bounded from below, perturbativity and perturbative unitarity of $2 \to 2$ high energy scattering are respected, and agreement with electroweak precision data is imposed through the oblique parameters S, T.
- In the fermion sector, perturbative Yukawa couplings are imposed by requiring $|n_\ell| \leq n_0$ with either $n_0 = 95$ GeV or $n_0 = 245$ GeV.
- Higgs signal strengths: agreement with production × decay signal strengths of the usual channels is imposed, and considering that we have large lepton couplings we also include $\mathrm{h} \to \mu^+\mu^-, e^+e^-$ information.
- $\mathrm{H}^\pm$ mediated contributions typically affect SM charged current processes, and thus we impose agreement with lepton flavour universality measurements (in purely leptonic decays $\ell_j \to \ell_k \nu \bar{\nu}$ and in decays with light pseudoscalar mesons $K, \pi \to e\nu, \mu\nu$ and $\tau \to K\nu, \pi\nu$) and with $b \to s\gamma$ and B_q^0–$\bar{B}_q^0$ mixing measurements.
- Agreement with $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$ data from LEP: measured cross sections up to $\sqrt{s} = 208$ GeV essentially impose $m_{\mathrm{H}}, m_{\mathrm{A}} > 208$ GeV.
- Agreement with LHC (negative) searches concerning dilepton resonances ($\sigma(pp \to S)_{[\mathrm{ggF}]} \times \mathrm{Br}\,(S \to \ell^+\ell^-)$, $S = \mathrm{H}, \mathrm{A}$ and $\ell = \mu, \tau$) and searches of charged scalars ($\sigma(pp \to \mathrm{H}^\pm tb) \times \mathrm{Br}\,(\mathrm{H}^\pm \to f)$, $f = \tau\nu, tb$).

The following plots show allowed regions for model I-gℓFC where the previous constraints are satisfied and the lepton δa_ℓ anomalies are satisfactorily reproduced. For model II-gℓFC, the different t_β dependence of the quark couplings in the previous observables eliminates the low mass solutions. The plots show results for to the two different assumptions concerning the perturbativity constraint on Yukawa couplings: blue regions correspond to $n_0 = 245$ GeV while magenta regions correspond to $n_0 = 95$ GeV. Furthermore, darker shading of the region reflects better agreement with the constraints (see [8, 11] for details).

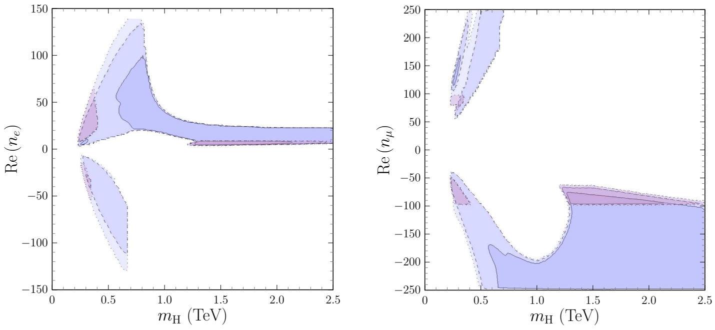
Figures 1a and 1b illustrate the existence of roughly two regimes in which the anomalies can be reproduced, (i) scalar masses > 1.3 TeV and $t_\beta \simeq 1$, or (ii) scalar masses < 1 TeV and $t_\beta \gg 1$. For $t_\beta \simeq 1$, the lepton couplings follow $\mathrm{Re}\,(n_\mu) \sim -16\mathrm{Re}\,(n_e)$ with $\mathrm{Re}\,(n_e)$ values in the range $[10; 16]$ GeV. For $t_\beta \gg 1$, a richer pattern of correlations of $\mathrm{Re}\,(n_\mu)$ and $\mathrm{Re}\,(n_e)$ emerges. It is also important to notice that for the tighter perturbativity assumption, the two regimes are clearly separated, there are no allowed regions with $m_{\mathrm{H}} \in [0.4; 1.2]$ TeV and $t_\beta \in [2; 10]$. As figures 1e and 1g, this gap between the two regimes is bridged through $\mathrm{Re}\,(n_\mu) < -100$ GeV.



(a) m_{H} vs t_β. **(b)** m_{H} vs $m_{\mathrm{H}^\pm}$. **(c)** $\mathrm{Re}\,(n_\mu)$ vs $\mathrm{Re}\,(n_e)$.



(d) $\mathrm{Re}\,(n_e)$ vs t_β. **(e)** $\mathrm{Re}\,(n_\mu)$ vs t_β.



(f) $\mathrm{Re}\,(n_e)$ vs m_{H}. **(g)** $\mathrm{Re}\,(n_\mu)$ vs m_{H}.

Figure 1: Illustrative plots of allowed regions involving the new leptons couplings n_e, n_μ, masses of the new scalars and t_β.

Conclusions

In this contribution we have illustrated how the potential discrepancies concerning the anomalous magnetic moments of the electron and the muon can be addressed in the context of a class of Two Higgs doublets models with tree level neutral flavour conservation. Two models within this class are considered, models I-gℓFC and II-gℓFC. The "anomalies" can be reproduced either with scalar masses > 1.3 TeV and $t_\beta \simeq 1$, or scalar masses < 1 TeV and $t_\beta \gg 1$; this second possibility is not available for model II-gℓFC. The electron anomaly is always obtained via two loops contributions. The muon anomaly, on the contrary, is obtained through two loops contributions for large scalar masses, and through one loop contributions for scalar masses < 1 TeV.

References

[1] Muon g-2 collaboration, *Final report of the Muon E821 anomalous magnetic moment measurement at BNL*, *Phys. Rev. D* **73** (2006) 072003 [`hep-ex/0602035`].

[2] Muon $g-2$ collaboration, *Measurement of the positive muon anomalous magnetic moment to 0.46 ppm*, *Phys. Rev. Lett.* **126** (2021) 141801 [`2104.03281`].

[3] Muon $g-2$ collaboration, *Measurement of the anomalous precession frequency of the muon in the Fermilab muon $g-2$ experiment*, *Phys. Rev. D* **103** (2021) 072002 [`2104.03247`].

[4] T. Aoyama et al., *The anomalous magnetic moment of the muon in the Standard Model*, *Phys. Rept.* **887** (2020) 1 [`2006.04822`].

[5] S. Borsanyi et al., *Leading hadronic contribution to the muon magnetic moment from lattice QCD*, *Nature* **593** (2021) 51 [`2002.12347`].

[6] D. Hanneke, S. Fogwell and G. Gabrielse, *New measurement of the electron magnetic moment and the fine structure constant*, *Phys. Rev. Lett.* **100** (2008) 120801 [`0801.1134`].

[7] R.H. Parker, C. Yu, W. Zhong, B. Estey and H. Müller, *Measurement of the fine-structure constant as a test of the standard model*, *Science* **360** (2018) 191 [`1812.04130`].

[8] F.J. Botella, F. Cornet-Gomez and M. Nebot, *Electron and muon $g-2$ anomalies in general flavour conserving two Higgs doublets models*, *Phys. Rev. D* **102** (2020) 035023 [`2006.01934`].

[9] F.J. Botella, F. Cornet-Gomez and M. Nebot, *Flavor conservation in two-Higgs-doublet models*, *Phys. Rev. D* **98** (2018) 035046 [`1803.08521`].

[10] M. Nebot, *Bounded masses in two Higgs doublets models, spontaneous CP violation and Z_2 symmetry*, *Phys. Rev. D* **102** (2020) 115002 [`1911.02266`].

[11] F.J. Botella, F. Cornet-Gomez, C. Miro and M. Nebot, *Muon and electron $g-2$ anomalies in a flavor conserving 2HDM with an oblique view on the CDF M_W value.* [`2205.01115`].