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The absolute maximum and detailed phenomenology of the muon magnetic moment in the 2HDM

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We present the muon magnetic moment $g-2$ in the flavour-aligned 2HDM evaluated by employing the recent result of full two-loop computation and making comprehensive use of experimental constraints from Higgs and flavour physics and characterize the parameter regions possible to explain the current 3σ deviation. We particularly focus on the light CP-odd neutral Higgs boson A and present the maximum possible Yukawa couplings to leptons and quarks of a light A allowed by the LHC and B–physics results, which can enhance $a_\mu^{\rm 2HDM}$ in this mass region. As a result we find an overall maximum of 45×10^{10} for $a_\mu^{\rm 2HDM}$ in the parameter region $20 < M_A < 100$ GeV.

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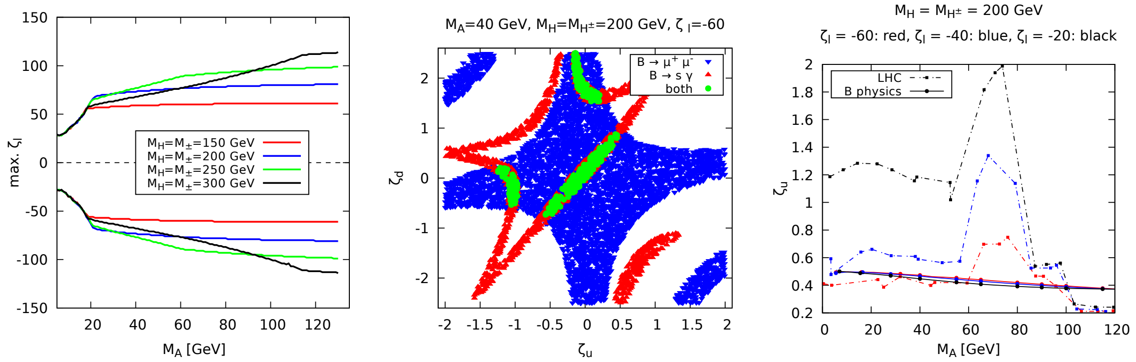


(a) (b) (c)

Figure 1

1. Introduction

The present proceedings are a review of the detailed numerical analysis of the muon magnetic moment $g-2$ in the two-Higgs doublet model (2HDM) in Ref. [1], which is obtained by using the complete two-loop correction results in Ref. [2].

The discrepancy in the muon magnetic moment $g-2$ between the experimental measurement [3] and the Standard Model (SM) predictions evaluated from the most recent studies [4–6] amounts to

$$a_\mu^{\text{Exp.}} - a_\mu^{\text{SM}} = (28.1 \pm 6.3^{\text{Exp.}} \pm 3.6^{\text{Th}}) \times 10^{-10}. \tag{1.1}$$

A substantial increase in the accuracy is expected in the further measurements at Fermilab and J-PARC. This persisting 3–4σ deviation motivates new physics (NP) scenarios beyond the SM. Typically the NP contributions to the muon $g-2$ is suppressed by heavy NP masses $\sim (m_\mu^2/M_{\text{NP}}^2)$. Therefore, a NP scenario with a very high M_{NP} scale is inappropriate to explain the discrepancy in Eq. 1.1.

The 2HDM is a minimal extension to the SM and includes four physical Higgs masses M_h, M_H, M_A and $M_{H^\pm}$. The two neutral CP-even Higgs mass eigenstates h and H are combined states of the two scalar doublets with mixing angle $\sin(\beta-\alpha)$. When $\sin(\beta-\alpha)=1$ the SM-limit is reached and hence, h becomes an SM-like Higgs boson h_{SM}. The 2HDM muon $g-2$ contribution a_μ^{2HDM} is obtained from the additional Higgs bosons: A, H, $H^\pm$. Z_2 symmetry permits four different Yukawa coupling scenarios: the usual type I, II, X and Y. In the more general flavour-aligned 2HDM (A2HDM) [7] the Yukawa couplings are proportional to the Yukawa parameters $\zeta_{l,u,d}$.

Here we concentrate on three questions : (a) What are the constraints on the 2HDM parameters relevant for a_μ? (b) What are the parameter regions to explain the current deviation in a_μ? (c) What is the overall maximum possible value of a_μ in the 2HDM?

2. The 2HDM contributions and constraints on the parameters

As the one-loop contributions are suppressed by higher order of muon mass $\sim \mathscr{O}(m_\mu^4)$ through the Yukawa couplings the leading contributions to a_μ^{2HDM} come from the Barr-Zee type two-loop diagrams, where the muon line is coupled with one gauge boson and one Higgs boson with either fermions or bosons in the Barr-Zee loop. The leading fermion loop corrections are from the Barr-Zee τ– or t–loop corrections. The following semi-numerical expressions for the leading fermionic two-loop and bosonic two-loop contributions are useful approximations to estimate the contributions for light M_A:

$$a_\mu^{\tau-\text{loop, 2HDM}} \simeq \left(\frac{\zeta_l}{100}\right)^2 \left\{\frac{8+4\hat{x}_{M_A}^2+2\ln(\hat{x}_{M_A})}{\hat{x}_{M_A}^2}\right\}, \tag{2.1}$$

$$a_\mu^{t-\text{loop, 2HDM}} \simeq \left(\frac{-\zeta_l\zeta_u}{100}\right) \left\{54-14\ln(\hat{x}_{M_A})-15\ln(\hat{x}_{M_H})\right\}, \tag{2.2}$$

$$|a_\mu^{B\,\text{2HDM}}| \simeq \rho|C_{HH^+H^-}/\text{GeV}||\zeta_l| \times 10^{-15}, \tag{2.3}$$

where $\rho = 6,3,2,1$ for $M_H = M_{H^\pm} = 150,200,250,300\,\text{GeV}$ respectively.

The τ–loop correction is enhanced by ζ_l^2 and the t–loop correction by $\zeta_l\zeta_u$. Thus the 2HDM fermion loop contribution $a_\mu^{F\,\text{2HDM}}$ depends on the Yukawa parameters ζ_l and ζ_u as well as the Higgs boson masses. The t–loop correction becomes positive when we set the signs of ζ_l and ζ_u opposite to each other. In the numerical analysis we set ζ_l negative and ζ_u positive. Eq. 2.3 shows that the bosonic contributions are enhanced by the triple Higgs coupling constant $C_{HH^+H^-}$ and are proportional to ζ_l. From Eqs. 2.1– 2.3 we find that ζ_l, ζ_u and M_A are the determining parameters for a_μ^{2HDM}.

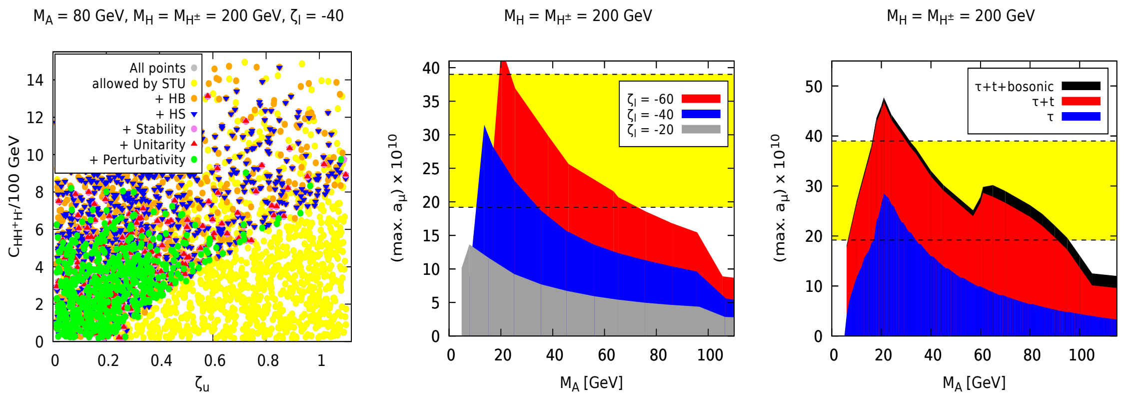
It is necessary to investigate the allowed ζ_l and ζ_u for given Higg boson mass points to analyse a_μ^{2HDM}. ζ_l is constrained by τ–decay, leptonic Z–decay and $ee \to \tau\tau A$ searches at LEP. Theses experiments set upper bounds on ζ_l. As the decay rates in the 2HDM are enhanced by ζ_l, large ζ_l leads to disagreement with experimental observations. Fig. 1a shows the upper bounds on ζ_l for different Higgs boson mass values. For $20 < M_A < 120\,\text{GeV}$ and $150 < M_H(= M_{H^\pm}) < 300\,\text{GeV}$ we obtain $|\zeta_l| < 60$.

ζ_u gains constraints from B–decay channels ($b \to s\gamma$ and $B_s \to \mu\mu$) as well as from the LHC Higgs searches ($gg \to A \to \tau\tau$ or $gg \to H \to \tau\tau$). Fig. 1b shows the allowed ζ_u and ζ_d regions by B–decays. The green space indicates the parameter range allowed by both decay modes. It shows that ζ_u is more restricted compared to ζ_d. ζ_u is also constrained by LHC Higgs searches. Large ζ_u produces abundant intermediate Higgs H and consequently results in excessive τ final states. Fig. 1c shows ζ_u upper bounds allowed by B–decays and LHC. Depending on the Higgs boson masses and ζ_l, the upper bounds on ζ_u are determined by B–physics or by LHC results. The overall combined upper bound of ζ_u lies between 0.3 and 0.6.

The LHC upper limit on ζ_u is also related to the triple Higgs coupling constant C_{HAA}. Large C_{HAA} which is strongly correlated with $C_{HH^+H^-}$ enhances the decay process $H \to AA$. Thus the final τ states are regulated by either ζ_u or $C_{HH^+H^-}$. Fig. 2a shows the proportional relation between $C_{HH^+H^-}$ and the possible maximum of ζ_u. It also shows the upper limit of $C_{HH^+H^-}$, which is constrained by theoretical and electro-weak constraints. The upper limit of $C_{HH^+H^-}$ determines the maximum of the bosonic contributions $a_\mu^{B\,\text{2HDM}}$ along with ζ_l.

3. The overall maximum of the muon $g-2$ and conclusion

Figs. 2b and 2c show the possible range of a_μ^{2HDM} for different ζ_l and $M_H = M_{H^\pm}$. The yellow



(a) (b) (c)

Figure 2

band indicates the current discrepancy in the muon $g-2$ in Eq. 1.1. The plot in Fig. 2b shows $a_\mu^{\rm 2HDM}$ for different ζ_l. For fixed M_A and ζ_l the maximum of ζ_u obtained in Fig. 1c is adopted. We need $|\zeta_l| > 30$ to explain the discrepancy as we cannot find any M_A points to lie in the yellow band for $\zeta_l = -20$ (the gray region). Fig. 2c shows the overall maximum of $a_\mu^{\rm 2HDM}$ in the 2HDM. The allowed maxima of ζ_l and ζ_u for given Higgs masses are used to evaluate the possible maximum of $a_\mu^{\rm 2HDM}$. The blue space is only from the τ–loop, the red space from adding the t–loop. The black space indicates the bosonic corrections. We observe that the maximum of $a_\mu^{\rm 2HDM}$ reaches up to $\sim 45\times 10^{-10}$ around $M_A = 20\,$GeV and that it is possible to explain the discrepancy at low mass scales $20 < M_A < 100\,$GeV in the 2HDM in contrast to the Minimal Supersymmetric SM (MSSM), where the typical scales are $M_{\rm NP} \sim 500\,$GeV or $M_{\rm NP} \sim 1\,$TeV for the scenario with $\tan\beta \to \infty$ [8]. This result further motivates searches of low scale pseudoscalar Higgs bosons at the LHC.

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