PROCEEDINGS OF SCIENCE

Electron and muon $(g - 2)$ in the 2HDM

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Recent precise determination of the electron anomalous magnetic moment (AMM) adds to the longstanding tension of the muon AMM and together strongly point towards physics beyond the Standard Model (BSM). Here we present a solution to both anomalies via a light scalar that emerges from a second Higgs doublet and resides in the $O(10)$-MeV to $O(1)$-GeV mass range. A scalar of this type is subject to a number of various experimental constraints, however, as we show, it can remain sufficiently light by evading all experimental bounds and has the great potential to be discovered in the near-future low-energy experiments. In addition to the light scalar, our theory predicts the existence of a nearly degenerate charged scalar and a pseudoscalar, which have masses of the order of the electroweak scale. This scenario can be tested at the LHC by looking at the novel process $pp \to H^{\pm}H^{\pm}jj \to l^{\pm}l^{\pm}jj + \not{E}_T$ via same-sign pair production of charged Higgs bosons. This talk is based on results presented in hep-ph 2003.03386 [1].

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The measurements of anomalous magnetic moment of the leptons and its deviation with the theoretically calculated value in the Standard Model (SM) point towards new physics. In the muon sector, this discrepancy is about 4.2σ, which corresponds to a deviation [2–4]

$$\Delta a_\mu = (2.51 \pm 0.59) \times 10^{-9}. \tag{1}$$

On the other hand, the recently measured fine-structure constant α using Caesium atoms [5] has resulted in a $\sim 2.4\sigma$ discrepancy between the experimental and the theoretical prediction of the electron anomalous magnetic moment, which corresponds to a deviation

$$\Delta a_e = -(8.7 \pm 3.6) \times 10^{-13}. \tag{2}$$

It is important to note that the deviation in the electron anomalous magnetic moment is opposite in sign to that of muon. Moreover, the magnitude of Δa_μ is larger than the naive lepton mass-scaling m_e^2/m_μ^2. Due to these reasons, resolving these two anomalies concomitantly is a challenging task.

In the literature, various mechanisms have been proposed to address these two anomalies simultaneously, e.g., by introducing lepto-quarks [6, 7], in models with gauge-extension [8], by introducing new scalar states and fermionic states [9–12], etc. Here we discuss a minimal setup in which without extending the gauge sector of the SM or without introducing any exotic fermions or lepto-quarks, one could resolve these two anomalies simultaneously. The key ingredient of this mechanism is a light CP-even scalar, which has a non-negligible coupling with the charged leptons. A light scalar of similar type has been studied in the context of muon anomalous magnetic moment [13, 14]. In contrast to these attempts, in our setup, a two-loop Barr-Zee diagram could explain Δa_e, whereas a one-loop contribution could resolve the deviation in Δa_μ. The corresponding contributions to Δa_ℓ are shown in Fig. 1. A scalar of this type is subject to a number of various experimental constraints, however, as we recently showed in Ref. [1], it can remain sufficiently light by evading all experimental bounds. Results of our analysis are summarized in Fig. 2.

Figure 1: One-loop (left) and two-loop (right) contributions to lepton anomalous magnetic moments arising from beyond-SM neutral scalars.

The minimal UV-complete model that could accommodate such a light scalar is the well-motivated two Higgs-doublet-model (2HDM). In this theory, in addition to the SM Higgs h, there exist one CP-even scalar H, one CP-odd scalar A, and a charged scalar H^+. The full one-loop and

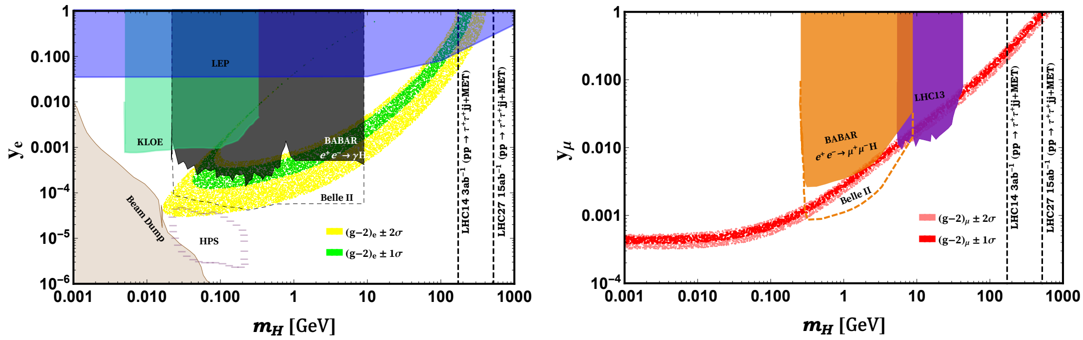

Figure 2: The parameter space in Yukawa coupling (y_l, whrere l= e or μ) vs mass (m_H) plane consistent with both the electron and muon anomalous magnetic moments. The green (red) and yellow (pink) regions represent the experimental 1σ and 2σ bands for the electron (muon) anomalous magnetic moment Δa_e (Δa_μ). The color shaded regions with solid boundary denote the excluded parameter space by current experiments. The projected sensitivities for the signal $pp \to H^\pm H^\pm jj \to \tau^\pm\tau^\pm jj+ \not{E}_T$ at the LHC for centre of mass energy 14 TeV with integrated luminosity $\mathcal{L}$ = 3 ab^{-1} and also for the centre of mass energy 27 TeV with integrated luminosity $\mathcal{L}$ = 15 ab^{-1} are shown by black dashed vertical lines.

two-loop contributions to Δa_ℓ are given by [15]:

$$\Delta a_{1,\ell}^{H^+} = \frac{Q_{H^+}\left(Y_\ell^{H^+}\right)^2}{4\pi^2}\int_0^1 dx \frac{x^2(x-1)}{x^2+x(z_{H^+}^2-1)}, \tag{3}$$

$$\Delta a_{1,\ell}^{\phi^0} = \frac{-1}{8\pi^2}\sum_f \sum_{\phi^0=}^{H,A} Q_f \left|Y_\ell^{\phi^0}\right|^2 \int_0^1 dx \frac{x^2(1-x\pm z_f)}{x^2+x(z_f^2-1)+z_{\phi^0}^2(1-x)}, \tag{4}$$

$$z_{H^+} = \frac{m_{H^+}}{m_\ell}, z_f = \frac{m_f}{m_\ell}, z_{\phi^0} = \frac{m_{\phi^0}}{m_\ell}, \tag{5}$$

$$\Delta a_{2,\ell}^{\phi^0} = \frac{\alpha}{8\pi^3} m_\ell Y_\ell^{\phi^0} \sum_f \sum_{\phi^0=}^{H,A} \frac{N_f^c Q_f^2 Y_f^{\phi^0}}{m_f} F_{\phi^0}\left[\frac{m_f^2}{m_{\phi^0}^2}\right], \tag{6}$$

$$F_{\phi^0}\left[z_{\phi^0}\right] = z_{\phi^0}\int_0^1 dx \frac{w_{\phi^0}}{x(1-x)-z_{\phi^0}} \ln\frac{x(1-x)}{z_{\phi^0}}, \tag{7}$$

$$w_H = 2x(1-x)-1, \quad w_A = 1. \tag{8}$$

In the above equation, + and − corresponds to the cases $\phi^0 = H$ and $\phi^0 = A$, respectively. Here the Y_ℓ is the Yukawa matrix, which is defined as follows

$$-\mathcal{L}_Y \supset \left[Y_{\ell,ij}^{H^0} H^0 + i\, Y_{\ell,ij}^{A^0} A^0\right] \bar{\ell}_{Li}\ell_{Rj} + Y_{\ell,ij}^{H^+}\bar{\nu}_{Li}\ell_{Rj}H^+\sqrt{2} + h.c., \tag{9}$$

with $Y_\ell^{H^0} = Y_\ell^{A^0} = Y_\ell^{H^+} = Y_\ell$. We assume a diagonal texture for this Yukawa matrix and take them to be real.

Since the contributions to the lepton anomalous magnetic moments from the CP-odd scalar and the charged scalar is in the opposite direction compare to that of the contribution from the

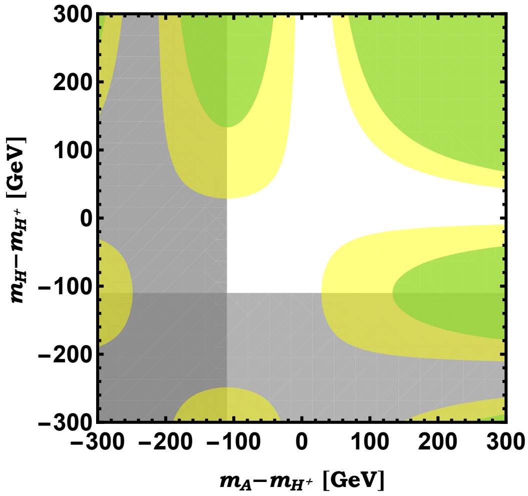

Figure 3: Scalar mass splittings allowed by the T parameter constraint in the 2HDM. The yellow and green shaded regions represent the 1σ and 2σ exclusion regions from the T parameter constraint [16]. The horizontal and vertical grey shaded regions indicate the positivity criteria for $m_H > 0$ and $m_A > 0$, respectively. Here, we set $m_{H^\pm} = 110$ GeV.

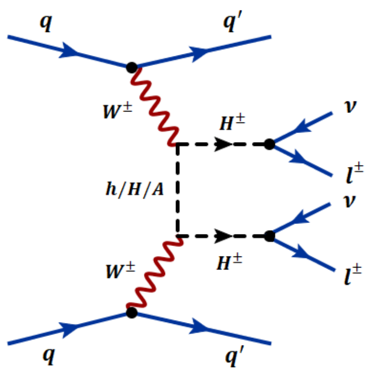

Figure 4: Representative Feynman diagram for the signal $pp \to \tau^+\tau^+ jj + \not{E}_T$ at the LHC.

CP-even scalar, we are interested in the scenario with a mass hierarchy of the form: $m_H^2 \ll m_{H^+}^2, m_A^2$. However, such a choice of mass hierarchy is constrained from the electroweak precision measurements. Recently, we showed in Ref. [1] that for the case where $m_{H^+} \approx m_A \gg m_H$, the constraints from the electroweak precision measurements can be evaded. Results of our analysis are shown in Fig. 3.

Now we discuss the testability of the proposed scenario in the upcoming experiments. As we discussed earlier, explanations of the experimental data of $\Delta a_{e,\mu}$ solely depend on the existence of a light CP-even scalar. This scenario can be tested at the LHC by looking at the novel process $pp \to H^\pm H^\pm jj \to \tau^\pm\tau^\pm jj + \not{E}_T$, and the corresponding representative Feynman diagram is presented in Fig. 4. It is interesting to note that if the mass splitting between the CP-even and CP-odd neutral scalars is turned off, then the amplitude for this process will be exactly zero. Correspondingly, our scenario will fail to explain the lepton anomalous magnetic moments, since a large mass splitting is essential to properly incorporate $\Delta a_{e,\mu}$ data as discussed above. Hence, observed deviations in the lepton anomalous magnetic moments are directly correlated with the signal $pp \to \tau^\pm\tau^\pm jj + \not{E}_T$ in our set-up. Due to this complementarity, this particular explanation of the electron and the muon $g-2$ within the 2HDM can be tested by this novel same sign charge lepton process. This same-sign charged lepton signature via vector-boson fusion process at the LHC has been studied extensively in Ref. [17], although in a different context. We recast this analysis for our case and obtain the projected sensitivity for the signal $pp \to H^\pm H^\pm jj \to \tau^\pm\tau^\pm jj + \not{E}_T$ at the LHC . These projected sensitivities are shown in Fig. 2 by black dashed lines.

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PoS(EPS-HEP2021)696