

## SUSY in the light of the new “MUON G-2” Result

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The recently published result from the Fermilab “MUON G-2” experiment has confirmed the persistent  $3 - 4 \sigma$  discrepancy between the experimental result from BNL for the anomalous magnetic moment of the muon,  $(g-2)_\mu$ , and its Standard Model (SM) prediction. The combination of the two measurements yields a deviation of  $4.2 \sigma$  from the SM value. Here, we review the parameter space of the electroweak (EW) sector of the Minimal Supersymmetric Standard Model (MSSM), that can accommodate the anomaly while being in full agreement with other experimental data, particularly the direct searches for EW particles at the LHC and dark matter (DM) relic density and direct detection constraints. We find that the combined constraints set an upper limit of  $\sim 600$  GeV for the LSP and NLSP masses establishing clear targets for the future collider searches.

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## 1. Introduction

The sustained deviation of 3-4  $\sigma$  in the anomalous magnetic moment of muon,  $(g - 2)_\mu$ , between the theoretical prediction of the SM [1] (see Ref. [2] for a full list of references) and the experimental observation by the Brookhaven National Laboratory (BNL) [3] has long been hinting towards the existence of some new physics scenario. The new result from the Fermilab “MUON G-2” collaboration [4] which was announced recently [5], is within 0.8  $\sigma$  in agreement with the older BNL result on  $(g - 2)_\mu$ . The combination of the two results yields a new deviation from the SM prediction of

$$\Delta a_\mu^{\text{new}} = (25.1 \pm 5.9) \times 10^{-10}, \quad (1)$$

corresponding to a discrepancy of 4.2  $\sigma$ . The deviation in Eq. (1) can easily be explained in the realm of the Minimal Supersymmetric Standard Model (MSSM) [6] with electroweak (EW) supersymmetric (SUSY) particle masses around a few hundred GeV. In these proceedings, following Refs. [2, 7], we present an analysis of the parameter space of MSSM that can accommodate the  $(g - 2)_\mu$  result while simultaneously being in agreement with the latest direct search constraints from the LHC as well as the constraints from dark matter (DM) relic density and direct detection (DD). We assume that the lightest SUSY particle (LSP), given by the lightest neutralino,  $\tilde{\chi}_1^0$ , makes up the full DM content of the universe <sup>1</sup>. We include the latest LHC searches via recasting in CheckMATE [9–11]. We find that the combined data helps to narrow down the allowed parameter region, providing clear targets for possible future colliders.

## 2. The EW sector of MSSM

We give a very brief description of the EW sector of MSSM, consisting of charginos, neutralinos and sleptons. The masses and mixings of the charginos and neutralinos are determined by  $U(1)_Y$  and  $SU(2)_L$  gaugino masses  $M_1$  and  $M_2$ , the Higgs mixing parameter  $\mu$  and the ratio of the two vacuum expectation values (vevs) of the two Higgs doublets of MSSM,  $\tan \beta = v_2/v_1$ , all taken to be real. This results in four neutralinos and two charginos with the mass ordering  $m_{\tilde{\chi}_1^0} < m_{\tilde{\chi}_2^0} < m_{\tilde{\chi}_3^0} < m_{\tilde{\chi}_4^0}$  and  $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\chi}_2^\pm}$ . Considering the size and sign of the anomaly, we focus on positive values of  $M_1$ ,  $M_2$  and  $\mu$  [7]. For the sleptons, we choose common soft SUSY-breaking parameters for all three generations,  $m_{\tilde{l}_L}$  and  $m_{\tilde{l}_R}$ . We take the trilinear coupling to be zero for all the three generations of leptons ( $l = e, \mu, \tau$ ). In general we follow the convention that  $\tilde{l}_1$  ( $\tilde{l}_2$ ) has the large “left-handed” (“right-handed”) component. The symbols are equal for all three generations,  $m_{\tilde{l}_1}$  and  $m_{\tilde{l}_2}$ , but we also refer to scalar muons directly,  $m_{\tilde{\mu}_1}$  and  $m_{\tilde{\mu}_2}$ .

Following the stronger experimental limits from the LHC [12, 13], we assume that the colored sector of the MSSM is decoupled from the EW sector. We also assume that the stop masses in the TeV range provide radiative corrections necessary to bring the light  $C\mathcal{P}$ -even Higgs boson mass in the experimentally observed region,  $M_h \sim 125$  GeV [14, 15].  $M_A$  has also been set to be above the TeV scale.

<sup>1</sup> In Ref. [8] we updated the analysis using the DM relic density only as an upper bound.

### 3. Relevant constraints

The most important constraint that we consider comes from the  $(g-2)_\mu$  result. We use Eq. (1) as a cut at the  $\pm 2\sigma$  level. We note that the main contribution to  $(g-2)_\mu$  in MSSM at the one-loop level comes from diagrams involving  $\tilde{\chi}_1^\pm - \tilde{\nu}$  and  $\tilde{\chi}_1^0 - \tilde{\mu}$  loops. In our analysis the MSSM contribution to  $(g-2)_\mu$  at two loop order is calculated using GM2Calc [16], implementing two-loop corrections from [17–19] (see also [20, 21]).

Various other constraints that are taken into account comprises the following. All points are checked to possess a stable and correct EW vacuum, e.g. avoiding charge and color breaking minima, using the public code Evade [22, 23]. All relevant EW SUSY searches from the LHC are taken into account, mostly via CheckMATE [9–11], where many analyses had to be implemented newly [7]. For dark matter relic density we use the latest result from Planck [24]:  $\Omega_{\text{CDM}} h^2 = 0.120 \pm 0.001$ . We employ the constraint on the spin-independent DM scattering cross-section  $\sigma_p^{\text{SI}}$  from XENON1T [25].

### 4. Parameter scan

The scan regions that cover the parameter space under consideration are as given below. A more complete coverage of the MSSM parameter space can be found in Refs. [2, 7, 8].

#### (A) bino/wino DM with $\tilde{\chi}_1^\pm$ -coannihilation

$$\begin{aligned} 100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV}, \quad M_1 \leq M_2 \leq 1.1M_1, \\ 1.1M_1 \leq \mu \leq 10M_1, \quad 5 \leq \tan\beta \leq 60, \\ 100 \text{ GeV} \leq m_{\tilde{l}_L} \leq 1 \text{ TeV}, \quad m_{\tilde{l}_R} = m_{\tilde{l}_L}. \end{aligned} \quad (2)$$

#### (B) bino DM with $\tilde{l}^\pm$ -coannihilation: Case-R (SU(2) singlet)

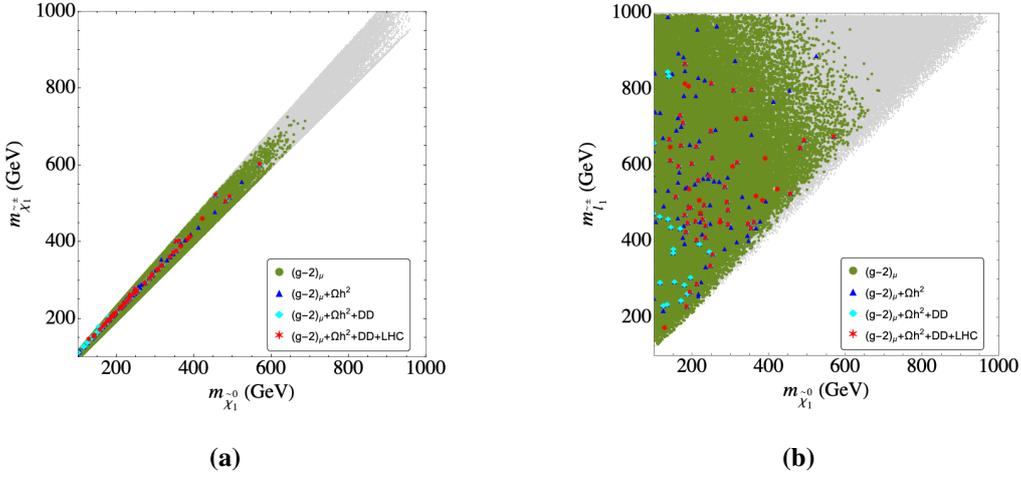
$$\begin{aligned} 100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV}, \quad M_1 \leq M_2 \leq 10M_1, \\ 1.1M_1 \leq \mu \leq 10M_1, \quad 5 \leq \tan\beta \leq 60, \\ M_1 \text{ GeV} \leq m_{\tilde{l}_R} \leq 1.2M_1, \quad M_1 \leq m_{\tilde{l}_L} \leq 10M_1. \end{aligned} \quad (3)$$

In all the scans we choose flat priors of the parameter space and generate  $O(10^7)$  points. A detailed account of our numerical set up and analysis flow can be found in Ref. [7].

### 5. Results

In this section we review some of the results for the scenarios defined above [2, 7]. We denote the points surviving certain constraints with different colors. In grey (round) we show all of our scan points. In green (round), blue (triangle), cyan (diamond) and red (star) we show points that additionally pass the  $(g-2)_\mu$ , correct relic density, DD and the LHC constraints respectively. We start with the results in the  $\tilde{\chi}_1^\pm$ -coannihilation scenario in Fig. 1. In the  $m_{\tilde{\chi}_1^0} - m_{\tilde{\chi}_1^\pm}$  plane, shown in the left plot, by definition of  $\tilde{\chi}_1^\pm$ -coannihilation the points are clustered along the diagonal of

the plane. One observes a clear upper limit on the (green) points allowed by the new  $(g-2)_\mu$  result of about 700 GeV. Applying the CDM constraints reduce the upper limit further to about 600 GeV. Applying the LHC constraints, corresponding to the “surviving” red points (stars), does not yield a further reduction from above, but cuts always only points in the lower mass range. Thus, the experimental data set an upper as well as a lower bound, yielding a clear search target for the upcoming LHC runs as well as for future electron-positron colliders. The distribution of the lighter slepton mass (where it should be kept in mind that we have chosen the same masses for all three generations) is presented in the  $m_{\tilde{\chi}_1^0}-m_{\tilde{l}_1}$  plane, shown in the right plot of Fig. 1. The LHC constraints which are most important in this scenario comes from slepton pair production leading to two leptons and missing energy in the final state [26] and compressed spectra searches [27].

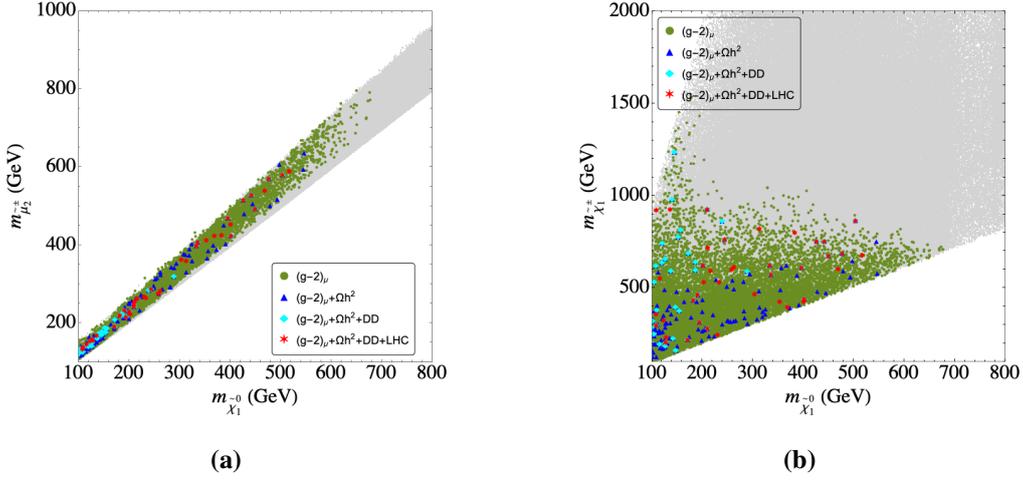


**Figure 1:** The results of our parameter scan for the bino/wino  $\tilde{\chi}_1^\pm$ -coannihilation scenario in the  $m_{\tilde{\chi}_1^0}-m_{\tilde{\chi}_1^\pm}$  plane (left) and  $m_{\tilde{\chi}_1^0}-m_{\tilde{l}_1}$  plane (right). For the color coding: see text.

We now turn to the scenario of  $\tilde{l}^\pm$ -coannihilation Case-R, where in the scan we require the “right-handed” sleptons to be close in mass to the LSP. It should be kept in mind that in our notation the “left-handed” (“right-handed”) slepton corresponds to  $\tilde{l}_1$  ( $\tilde{l}_2$ ). We start in Fig. 2 with the  $m_{\tilde{\chi}_1^0}-m_{\tilde{\mu}_2}$  plane in the left plot. By definition of the scenario the points are concentrated along the diagonal. The  $(g-2)_\mu$  bound yields an upper limit on the LSP mass of  $\sim 690$  GeV. The  $(g-2)_\mu$  bound also places an upper limit on  $m_{\tilde{\mu}_2}$  (which is close in mass to the  $\tilde{e}_2$  and  $\tilde{\tau}_2$ ) of  $\sim 800$  GeV. Including the CDM and LHC constraints, these limits reduce to  $\sim 520$  GeV for the LSP, and correspondingly to  $\sim 600$  GeV for  $m_{\tilde{\mu}_2}$  and  $\sim 530$  GeV for  $m_{\tilde{\tau}_2}$ . In the right plot of Fig. 2 we show the results in the  $m_{\tilde{\chi}_1^0}-m_{\tilde{\chi}_1^\pm}$  plane. The upper limits on the chargino mass are reached at  $\sim 900$  GeV, including all the constraints. The most relevant LHC constraints in this scenario comes from  $\tilde{\chi}_1^\pm - \tilde{\chi}_2^0$  pair production leading to three leptons and missing energy in the final state [28], direct slepton pair production searches [26] and compressed spectra searches [27].

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**Figure 2:** The results of our parameter scan for the  $\tilde{l}^\pm$ -coannihilation case-R scenario in the  $m_{\tilde{\chi}_1^0}$ - $m_{\tilde{\mu}_2}$  plane (left) and  $m_{\tilde{\chi}_1^0}$ - $m_{\tilde{\chi}_1^\pm}$  plane (right). For the color coding: see text.

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