Muon g-2, DM relic density and LHC results in nonuniversal gaugino mass models

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Introduction to $(g-2)_\mu$

- The magnetic moment of a particle with mass m and charge e is

$$\mu = g\left(\frac{e}{2m}\right)\vec{S}$$

- In QFT the muon-photon vertex function has the form

$$\begin{aligned}\bar{u}(p')\Gamma_{\mu\bar{\mu}A^\rho}(p,-p',q)u(p) =& e\,\bar{u}(p')\left[\gamma_\rho F_V(q^2)\right.\\ &\left.+(p+p')_\rho F_M(q^2)+\ldots\right]u(p)\end{aligned}$$

- This leads to a term

$$\frac{i\,e}{2m_\mu}[1-2m_\mu F_M(0)]\sigma_{\rho\nu}q^\nu$$

- The gyromagnetic ratio g is then given by $g = 2[1-2m_\mu F_M(0)]$ and hence $a_\mu = -2m_\mu F_M(0)$.
- The anomalous magnetic moment therefore arises at one-loop and gets contribution from higer orders in perturbation theory, defined as $a = \dfrac{g-2}{2}$

Introduction to $(g-2)_\mu$

- Loop contributions from heavy particles of mass M are suppressed by $\frac{m^2}{M^2}$
- Hence anomalous magnetic moment of muon is $\frac{m_\mu^2}{m_e^2} \approx 40000$ times more sensitive to higher order/new physics contributions than electron.
- Thus $(g-2)_\mu$ provides a test for not only for SM interactions but also possible new physics at EW scale

Introduction to $(g-2)_\mu$

- Experimentally measured value of a_μ has a precision of 0.54 ppm

$$a_\mu^{exp} = 11659208.9(6.3) \times 10^{-10}$$

Muon G-2 collaboration, PRD(2006)

- SM prediction of $(g-2)_\mu$ = QED+Hadronic+Weak
- Weak contribution is smallest $\sim 15.4 \times 10^{-10}$ (*Perris et al, JHEP(2002)*)
- Main source of uncertainty in SM contributions comes from the hadronic sector
- Current uncertainty in $a_\mu^{had} \sim 4 - 5 \times 10^{-10}$
- Latest result for SM prediction for a_μ is

$$a_\mu^{SM} = 11659182.8(4.9) \times 10^{-10}$$

Hagiwara et al, J. Phys. G (2011)

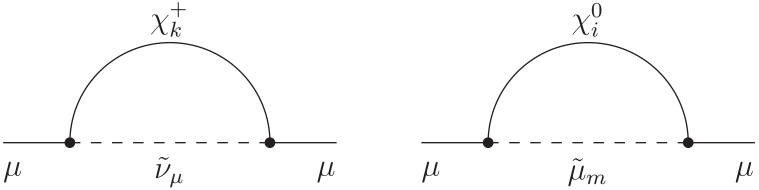
- This leads to a discrepancy of 3.3σ between expt. and SM prediction

$$\Delta a_\mu = 26.1 \pm 8.0 \times 10^{-10}$$

SUSY contribution to $(g-2)_\mu$

Stockinger, J. Phys. G(2007)

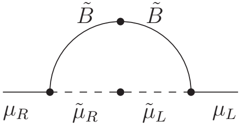
- SUSY provides a natural framework for new physics contributions to $(g-2)_\mu$ which could alleviate the discrepancy between SM and experiment
- In MSSM, at one loop level, the dominant contribution comes from the following loop diagrams



- For light neutralino and chargino $\sim$ 100 GeV, SUSY contribution to $(g-2)_\mu$ is significant and can relax the discrepancy between SM and experiment

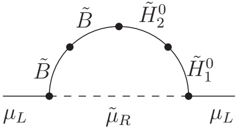
- One-loop (neutralino) diagram in terms of gauge eigenstates

(N1)



$$\propto \quad m_\mu^2 \tan\beta \, \mu \, M_1 \, F(M_1, m_{\tilde{\mu}_{L,R}})$$

(N2)



$$\propto \quad m_\mu^2 \tan\beta \, \mu \, M_1 \, F(\mu, M_1, m_{\tilde{\mu}_R})$$

SUSY contribution to $(g-2)_\mu$

- The enhancement due to large $\tan\beta$ is due to the fact that the muon Yukawa coupling in the MSSM is larger than that in SM by a factor of $1/\cos\beta$ which is $\approx \tan\beta$ for large $\tan\beta$
- The μ-parameter which governs the mixing between the two higgs doublets in MSSM can also enhance the SUSY contribution to $(g-2)\mu$
- The $\tilde{H}_1 - \tilde{H}_2$ transition introduces the μ-parameter in the expression for a_μ
- In diagram (N1) the contribution increases linearly with μ but for (N2) it is suppressed for large μ by the μ dependent loop function F

Non-universal Gaugino Masses in SU(5) GUT

Mohanty, Rao and Roy, JHEP(2013)

- The bulk annihilation region provides a natural solution to the DM problem
- However LHC sets stringent lower limits on the bino LSP mass as well as sfermion masses in CMSSM through its measurement of the neutral Higgs boson which rules out the bulk annihilation region
- To evade the LHC constraint while accessing the bulk region one has to give up the universality of gaugino masses at GUT scale and assume that the GUT scale bino mass is significantly smaller than the gluino mass
- A heavy gluino at GUT scale ensures that the Higgs mass value from LHC is satisfied while the low GUT scale bino mass makes the bulk region accessible
- One can construct such a model for nonuniversal gaugino masses by assuming that the latter get contributions from SUSY breaking superfields belonging to non-singlet representations of the GUT group

Non-universal Gaugino Masses in SU(5) GUT

- We assume that SUSY is broken by a combination of two superfields belonging to singlet and non-singlet representations of SU(5)
- The chiral superfield responsible for SUSY breaking can belong to any of the irreducible representations of the symmetric product

$$(24 \times 24)_{sym} = 1 + 24 + 75 + 200$$

- The GUT scale gaugino masses are given by

$$M^G_{1,2,3} = C^1_{1,2,3} m^1_{1/2} + C^I_{1,2,3} m^I_{1/2} \quad \& \quad I = 24, 75 \text{ or } 200$$

- The input parameters for this theory are m_0, M^G_1, M^G_3, $\tan\beta$ and A_0
- The bulk region corresponds to

$$M^G_1 = 150 - 250 \text{ GeV} \; ; \quad m_0 = 50 - 80 \text{ GeV}$$

- We take $M^G_3 \geq 600$ GeV to avoid the gluino bound from LHC

Muon $g-2$

- The muon anomalous magnetic moment or $g-2$ as measured by the BNL experiment shows an excess over the SM prediction

$$\Delta a_\mu = (28.7 \pm 8.0) \times 10^{-10}$$

Davier et al, EPJ C(2011)

- The observation of Higgs boson of mass 125 GeV by ATLAS and CMS has pushed m_0 and $m_{1/2}$ in CMSSM upto the TeV scale, thus making the CMSSM contribution to muon $g-2$ much too small to explain the above excess
- Also direct SUSY search results from 5 fb^{-1} LHC data and $B_s \to \mu^+\mu^-$ results from ATLAS, CDF, CMS and LHCb along with direct detection results from XENON100 exclude the low mass part of resonant annihilation region, focus point region and stau co-annihilation region in both CMSSM and NUHM
- This suggests an incompatibility between the SUSY explanations of the observed muon $g-2$ result and the DM relic density with the observed 125 GeV Higgs boson at the LHC

Muon $g-2$ results

$m_0 = 80$ GeV, $\tan\beta = 10$, $A_t = A_b = -2.1$ TeV

Particle	$M_1^G = 200$			
	$M_3^G = 600$	$M_3^G = 700$	$M_3^G = 800$	$M_3^G = 900$
$\tilde{\chi}_1^0$ (bino)	80.7	80.3	80.0	79.5
$\tilde{e}_R, \tilde{\mu}_R$	118	117	117	117
$\tilde{e}_L, \tilde{\mu}_L$	368	421	474	527
M_2	435	506	577	648
$\tilde{g}$	1354	1561	1766	1969
$\tilde{\tau}_1$	94.8	95.3	94.8	93.5
h	122	123	123	124
a_μ (Δa_μ)	2.04×10^{-9} (1.04σ)	1.66×10^{-9} (1.51σ)	1.39×10^{-9} (1.85σ)	1.17×10^{-9} (2.12σ)

Muon $g-2$ results

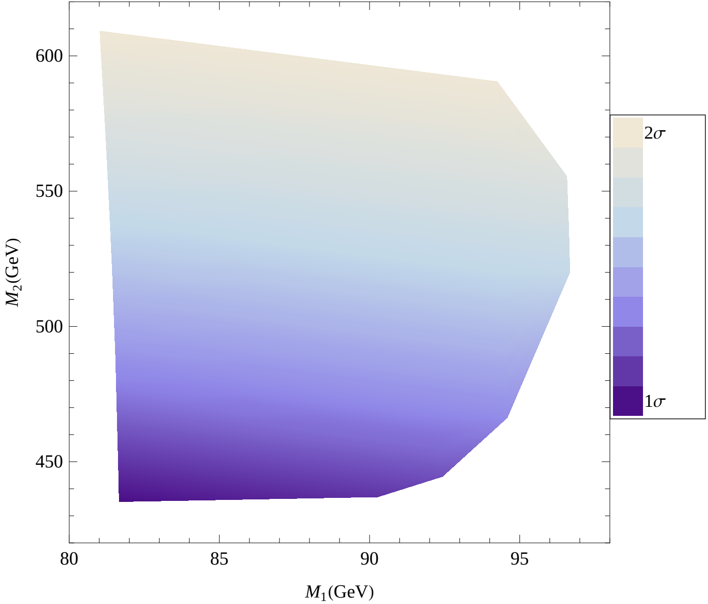
$m_0 = 103$ GeV, $\tan\beta = 15$, $A_t = A_b = -1.4$ TeV

Particle	$M_1^G = 200$			
	$M_3^G = 600$	$M_3^G = 700$	$M_3^G = 800$	$M_3^G = 900$
$\tilde{\chi}_1^0$ (bino)	80.2	79.9	79.6	79.1
$\tilde{e}_R, \tilde{\mu}_R$	134	133	133	132
$\tilde{e}_L, \tilde{\mu}_L$	373	425	477	530
M_2	435	506	577	648
$\tilde{g}$	1354	1561	1766	1969
$\tilde{\tau}_1$	97.4	96.2	93.6	89.8
h	122	122	122	123
a_μ (Δa_μ)	2.28×10^{-9} (0.75σ)	1.89×10^{-9} (1.24σ)	1.59×10^{-9} (1.61σ)	1.37×10^{-9} (1.89σ)

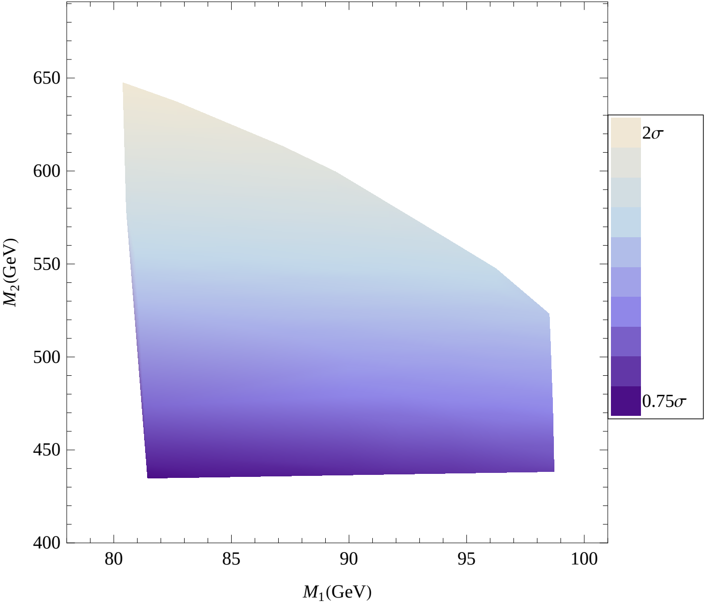
Muon $g-2$ results

Particle	$M_1^G = 200$, $M_2^G = 575$ and $M_3^G = 1200$		
	$m_0 = 100$ $\tan\beta = 10$	$m_0 = 138$ $\tan\beta = 15$	$m_0 = 175$ $\tan\beta = 20$
$\tilde{\chi}_1^0$ (bino)	76.6	76.9	77.0
$\tilde{e}_R, \tilde{\mu}_R$	128	159	192
$\tilde{e}_L, \tilde{\mu}_L$	367	379	394
M_2	442	442	442
$\tilde{g}$	2580	2580	2581
$\tilde{\tau}_1$	93	95.6	99.8
h	123	123	122
a_μ (Δa_μ)	2.47×10^{-9} (0.51σ)	2.67×10^{-9} (0.26σ)	2.62×10^{-9} (0.32σ)

Muon $g-2$ results



Muon $g-2$ results



Conclusions

- $(g-2)_\mu$ value as measured by experiment at BNL and its prediction from SM have a discrepancy of 3.3σ which points to BSM physics
- SUSY could solve the $(g-2)_\mu$ problem through additional loop contributions to $(g-2)_\mu$
- SUSY contributions to muon $(g-2)$ enhanced by light neutralino and smuon masses, large $\tan\beta$ and μ-parameter
- The bulk annihilation region of dark matter relic density can be achieved without fine-tuning in models with nonuniversal gaugino masses arising from combination of two SUSY breaking fields belonging to singlet and non-singlet representations of the GUT group SU(5)
- Nonuniversal SU(5) GUT models studied here provide the appropriate mass spectrum required to achieve the right SUSY contribution which can alleviate the $(g-2)_\mu$ problem

Conclusions

- Using the same nonuniversal gaugino mass model one can reconcile the observed muon $g-2$ and the DM relic density with the Higgs boson mass of 125 GeV as measured at the LHC which are otherwise incompatible in CMSSM and NUHM