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Muon anomalous magnetic moment in a supersymmetric $U(1)'$ model

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Abstract

We study the muon anomalous magnetic moment $a_\mu = (g_\mu - 2)/2$ in a supersymmetric $U(1)'$ model. The neutralino sector has extra components from the superpartners of the $U(1)'$ gauge boson and the extra Higgs singlets that break the $U(1)'$ symmetry. The theoretical maximum bound on the lightest neutralino mass is much smaller than that of the Minimal Supersymmetric Standard Model (MSSM) because of the mixing pattern of the extra components. In a $U(1)'$ model where the $U(1)'$ symmetry is broken by a secluded sector (the S-model), $\tan\beta$ is required to be $\lesssim 3$ to have realistic electroweak symmetry breaking. These facts suggest that the a_μ prediction may be meaningfully different from that of the MSSM. We evaluate and compare the muon anomalous magnetic moment in this model and the MSSM and discuss the constraints on $\tan\beta$ and relevant soft breaking terms. There are regions of the parameter space that can explain the experimental deviation of a_μ from the Standard Model calculation and yield an acceptable cold dark matter relic density without conflict with collider experimental constraints.

1. Introduction

The anomalous magnetic moment of the muon $a_\mu = (g-2)_\mu/2$ is one of the most precisely measured physical quantities. Its current value from the Brookhaven National Laboratory E821 experiment is [1,2]

$$a_\mu(\mathrm{exp}) = (11\,659\,208 \pm 6) \times 10^{-10}, \tag{1}$$

which is a 2.4σ deviation from the Standard Model (SM) prediction

$$\Delta a_\mu \equiv a_\mu(\mathrm{exp}) - a_\mu(\mathrm{SM}) = (23.9 \pm 10.0) \times 10^{-10}, \tag{2}$$

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when the hadronic vacuum polarization information is taken directly from the annihilation of e^+e^- to hadrons [3] measured at CMD-2 [4]. The uncertainties involved in Eq. (2) are 7.2×10^{-10} from the leading-order hadronic contribution [5], 3.5×10^{-10} from the hadronic light-by-light scattering [6], and 6×10^{-10} from the a_μ experiment. The indirect hadronic information from the hadronic τ decay gives a higher SM value that does not indicate a significant discrepancy with the SM (only a 0.9σ deviation).[1] Recently released KLOE data [8] show an overall agreement with the CMD-2 data [4], confirming that there is a discrepancy between the hadronic contributions from the e^+e^- data and the τ data obtained from ALEPH, CLEO and OPAL [9].

New physics is expected to exist at the TeV-scale to resolve various theoretical problems, including Higgs mass stabilization, and new physics could give a significant contribution to a_μ to explain the above deviation [10]. There have been extensive studies of a_μ in supersymmetric (SUSY) models [11], which show that supersymmetry can naturally explain the deviation of Eq. (2).

The a_μ data constrains the SUSY parameters, including the sign of μ [12] and upper limits on relevant scalar and fermion superpartner masses [13]. In the minimal supergravity model (mSUGRA) or the Minimal Supersymmetric Standard Model (MSSM), the dominant additional contribution to a_μ comes from the first-order radiative corrections of the chargino–sneutrino and the neutralino–smuon loops; it is

$$\Delta a_\mu(\mathrm{SUSY}) \sim 13 \times 10^{-10} \frac{\tan\beta\,\mathrm{sign}(\mu)}{(M_{\mathrm{SUSY}}/100\ \mathrm{GeV})^2} \tag{3}$$

in the limit that all the supersymmetric masses are degenerate at M_{SUSY} [14]. The 2-loop corrections involve sfermion subloops or chargino/neutralino subloops and are at about the few percent level, although full calculations are not yet complete [15]. The discrepancy in Eq. (2) shows that a supersymmetry solution can be found if $\mathrm{sign}(\mu) > 0$ and $M_{\mathrm{SUSY}} \lesssim 700$ GeV for $\tan\beta \lesssim 50$, in the limit that supersymmetric masses are degenerate. The deviation of a_μ similarly gives constraints on the parameters of other new physics models including the mass of a second generation leptoquark [16], the mass of the heavy photon in the little Higgs model [17] and the compactification scale of an extra dimension [18].

Given that a_μ has been a powerful tool for constraining the new physics models, due to the accuracy of its measurement and the SM evaluation, it is interesting to pursue what a_μ can tell about recently emerging models. The recent idea of split supersymmetry assumes large masses (e.g., 10^{10} GeV) for scalar superpartners (sleptons, squarks) while keeping fermionic superpartners (gauginos, higgsinos) at the TeV-scale [19]. The large masses of the smuon and sneutrino would make the chargino–sneutrino and neutralino–smuon loop contributions to a_μ negligible; the split supersymmetry model would be rejected if the deviation of a_μ is in fact real.

Another interesting TeV-scale new physics model is the supersymmetric $U(1)'$ model [20,21]. It has a structure similar to the MSSM but has an extra $U(1)$ gauge symmetry ($U(1)'$), which is spontaneously broken at the TeV-scale by one or multiple Higgs singlets. This model can provide natural solutions to some of the difficulties the MSSM faces, including the explanation of the electroweak scale of the μ parameter (μ-problem [22]) and the lack[2] of a sufficiently strong first-order phase transition for electroweak baryogenesis (EWBG) [24]. The Next-to-Minimal Supersymmetric Standard Model (NMSSM) [25] can also resolve the μ-problem but its discrete $\mathbf{Z}_3$ symmetry invokes a cosmological domain wall problem [26]; a variant which avoids this problem is discussed in Refs. [27,28].

Besides the bottom-up reasons to introduce an additional $U(1)$ symmetry to supplement the MSSM, many new physics models, including grand unified theories (GUTs), extra dimensions [29], superstrings [30], little Higgs [31], dynamical symmetry breaking [32] and Stueckelberg mechanism models [33] predict extra $U(1)$ symmetries or

[1] For a recent review of the various SM predictions and the a_μ discrepancies, see Ref. [7].

[2] The required strong first-order phase transition for EWBG is allowed in the MSSM only if the light Higgs mass is only slightly above the LEP experimental bound and the light stop mass is smaller than the top mass [23].