Gaugino Mediation with Large Trilinears

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Gaugino mediation is an attractive supersymmetry breaking scheme naturally avoiding flavor problems by suppressing the soft sfermion masses at a high-energy scale. We consider an extension of the original model which yields non-vanishing trilinear scalar couplings. This increases the viable parameter space predicting a sufficiently large Higgs mass. Assuming the gravitino to be the lightest superparticle, we consider additional constraints from direct searches at the LHC, finding allowed points with a neutralino, sneutrino or stau next-to-lightest superparticle.

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1. Introduction

While low-energy supersymmetry (SUSY) remains the most elegant solution of the hierarchy problem, it is being pressured on a number of fronts. In addition to the classical problems like the flavor and gravitino problem, the lack of a signal for superparticles at the LHC becomes an increasingly severe issue, which might be dubbed the SUSY discovery problem. This may imply that SUSY is not realized in nature after all. However, it may also imply that the realization of SUSY chosen by nature has somewhat unusual features that limit the effectiveness of the LHC searches.

One such feature is the nature of the lightest SUSY particle (LSP). If it is the neutralino, as is usually assumed, the gravitino is unstable. Due to its extremely weak interactions, it has a relatively long lifetime of up to several years. In this case, the energetic decay products created by gravitino decays in the early universe destroy nuclei produced by Big Bang Nucleosynthesis (BBN) [1, 2, 3]. The observed abundances of primordial light elements therefore either require a gravitino mass $m_{3/2} \gg 1\,\text{TeV}$ or a reheating temperature after inflation $T_\text{R} \lesssim 10^6\,\text{GeV}$ [4]. The former constraint implies a quite unnatural mass spectrum in most scenarios of SUSY breaking, whereas the latter one prevents thermal leptogenesis without fine-tuning [5]. This motivates scenarios where the gravitino is the LSP and thus stable. For SUSY at the TeV scale and $T_\text{R} \sim 10^9\,\text{GeV}$, thermal production shortly after inflation yields a gravitino density that is consistent with the observed dark matter density, if the gravitino has a mass of some tens of GeV [6, 7]. Thus, a relatively heavy gravitino LSP is a viable cold dark matter candidate. In this case the next-to-LSP (NLSP) becomes long-lived in the absence of R-parity violation, as the only superparticle it can decay into is the gravitino with its superweak interactions. So even in this scenario we have to worry about the effect of late decays on BBN. For NLSP masses below a TeV, this rules out neutralinos, charginos and gluinos as NLSPs, but a slepton or stop NLSP can be allowed. Charged NLSPs are further constrained since they form bound states with nuclei, which alters BBN reaction rates [8]. Consequently, the gravitino problem is present also in gravitino LSP scenarios but significantly alleviated. In addition, the LHC phenomenology is determined by the properties of the NLSP and quite different from the standard neutralino LSP case, which may alleviate the discovery problem.

The appearance of unacceptably large flavor and CP violation in a generic SUSY scenario is a problem that can be tackled by the mechanism mediating SUSY breaking from the hidden to the visible sector. Here we will consider the example of gaugino mediation [9, 10]. It employs a setup with extra spacetime dimensions to prevent direct couplings between the sfermions and the field breaking SUSY, which suppresses the soft sfermion masses at a high-energy scale and thus avoids flavor problems. It also allows a gravitino LSP with a mass in the range needed to alleviate the gravitino problem [11] and a slepton NLSP [12]. Alternatively, the lightest neutralino could be the LSP and dark matter particle, at the price of a heavy gravitino to satisfy BBN constraints.

In the realization that was proposed originally, gaugino mediation also yields suppressed trilinear scalar couplings, which is unfortunate since the measured Higgs mass [13] then requires a unified gaugino mass of $m_{1/2} \gtrsim 3\,\text{TeV}$ and thus very heavy superparticles [14]. However, a simple extension of the model produces non-vanishing trilinears and thus allows for a lighter superparticle spectrum [15, 16]. In the following, we will explore the phenomenology of this extended scenario, summarizing the results of [16].

2. Trilinear-Augmented Gaugino Mediation

2.1 General Setup

The setup of gaugino mediation [9, 10] is illustrated in fig. 1. There are D spacetime dimensions, $D-4$ of which are compact with volume V_{D-4}. This volume determines the compactification scale $M_c \equiv (1/V_{D-4})^{\frac{1}{D-4}}$, which we will assume to equal the unification scale of about 10^{16} GeV. The D-dimensional bulk contains two 4-dimensional branes. The MSSM matter fields are localized on one of them (MSSM brane), while the SUSY-breaking sector is localized on a different brane (hidden brane). For our purposes it is sufficient to consider a single chiral superfield S of the hidden sector, which is a Standard Model (SM) singlet and develops an F-term vacuum expectation value (VEV) $\langle F_S \rangle$ that breaks SUSY.
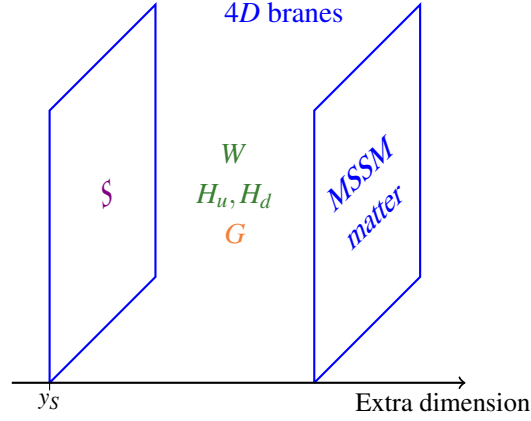

Figure 1: Geometrical setup of gaugino-mediated SUSY breaking (S: SUSY-breaking field, W: gauge supermultiplets, G: gravity supermultiplet).

The gauge fields, the graviton and the gravitino are placed in the bulk. Therefore, gauginos and the gravitino can couple to the SUSY-breaking field localized on the hidden brane and obtain soft masses proportional to $\langle F_S \rangle$. In contrast, the SM fermions and their superpartners are constrained to the MSSM brane. Consequently, the sfermions' couplings to S and the corresponding soft masses are strongly suppressed. This avoids contributions to flavor violation from the scalar soft mass matrices and thus solves a part of the SUSY flavor problem. The remaining part of the problem, potential flavor violation from trilinear scalar couplings, will be addressed below.

In the version of gaugino mediation proposed in [9], also the Higgs superfields are localized on the MSSM brane and thus do not obtain soft masses, whereas the version of [10] features bulk Higgses and non-vanishing Higgs-S couplings. We will consider the latter setup in the following.

2.2 Trilinear Couplings

The most general D-dimensional Lagrangian coupling bulk Higgses to the SUSY-breaking field is

$$\mathscr{L}_{HS} = \frac{\delta^{(D-4)}(y - y_S)}{M^{D-4}} \left[\frac{S}{M} \left(a\hat{H}_u^\dagger \hat{H}_d^\dagger + b_u \hat{H}_u^\dagger \hat{H}_u + b_d \hat{H}_d^\dagger \hat{H}_d \right) + \text{h.c.} + \right.$$
$$\left. + \frac{S^\dagger S}{M^2} \left(c_u \hat{H}_u^\dagger \hat{H}_u + c_d \hat{H}_d^\dagger \hat{H}_d + (d\hat{H}_u \hat{H}_d + \text{h.c.}) \right) \right]_D + \dots, \quad (2.1)$$

where y_S is the position of the hidden brane in the extra dimensions and hats denote bulk fields with canonically normalized kinetic terms in D dimensions. The dots refer to terms containing additional powers of S, which do not lead to qualitatively new results but at most to corrections suppressed by powers of M, the scale up to which the theory is valid. Finally, a, $b_{u,d}$, $c_{u,d}$ and d are dimensionless couplings.

Importantly, the original gaugino mediation models [9, 10] did not include the terms with couplings b_u and b_d. It is precisely these terms that give rise to trilinear couplings [15]. In order to show this, let us integrate over the extra dimensions to arrive at the effective 4-dimensional Lagrangian valid below M_c,

$$\mathcal{L}_{4D} \supset \left[H_u^\dagger H_u + H_d^\dagger H_d \right]_D + \rho \left[\frac{S}{M} \left(a H_u^\dagger H_d^\dagger + b_u H_u^\dagger H_u + b_d H_d^\dagger H_d \right) + \text{h.c.} + \right.$$
$$\left. + \frac{S^\dagger S}{M^2} \left(c_u H_u^\dagger H_u + c_d H_d^\dagger H_d + (d H_u H_d + \text{h.c.}) \right) \right]_D , \quad (2.2)$$

where we have denoted the canonically normalized zero modes of the Higgses by $H_{u,d}$ and included their kinetic terms. The canonical normalization of the bulk fields has yielded a volume factor

$$\rho \equiv \frac{1}{V_{D-4} M^{D-4}} \equiv \left(\frac{M_c}{M} \right)^{D-4} \quad (2.3)$$

in front of the bulk-brane interaction terms. The terms proportional to b_u and b_d can be removed by the field redefinitions[1]

$$H_{u,d} \equiv H'_{u,d} \left(1 - \rho b_{u,d} \frac{S}{M} \right), \quad (2.4)$$

which changes the Lagrangian (2.2) to

$$\mathcal{L}_{4D} \supset \left[H_u'^\dagger H_u' + H_d'^\dagger H_d' \right]_D + \rho \left[\frac{S}{M} \left(a H_u'^\dagger H_d'^\dagger \right) + \text{h.c.} + \right.$$
$$\left. + \frac{S^\dagger S}{M^2} \left(c_u' H_u'^\dagger H_u' + c_d' H_d'^\dagger H_d' + (d' H_u' H_d' + \text{h.c.}) \right) \right]_D \quad (2.5)$$

(again omitting irrelevant higher-order terms), where

$$c_{u,d}' = c_{u,d} - \rho |b_{u,d}|^2 \quad , \quad d' = d - \rho a^* (b_u + b_d). \quad (2.6)$$

Thus, we obtain a contribution to the μ-term, soft Higgs masses and $B\mu$ proportional to $\langle F_S \rangle$. Gaugino masses are generated by a term in the gauge kinetic function that we do not show here [9, 10]. In the part of the Lagrangian stemming from the superpotential $W_{\text{MSSM}} = \bar{u} y_u Q H_u - \bar{d} y_d Q H_d - \bar{e} y_e L H_d + \mu H_u H_d$, the field redefinitions (2.4) yield

$$\mathcal{L}_{4D} \supset \left[\bar{u} y_u Q H_u' - \bar{d} y_d Q H_d' - \bar{e} y_e L H_d' - \rho b_u \frac{S}{M} \bar{u} y_u Q H_u' + \rho b_d \frac{S}{M} \bar{d} y_d Q H_d' + \rho b_d \frac{S}{M} \bar{e} y_e L H_d' \right]_F$$
$$\supset -\rho b_u \frac{\langle F_S \rangle}{M} \tilde{u}_R^* y_u \tilde{Q}_L H_u' + \rho b_d \frac{\langle F_S \rangle}{M} \tilde{d}_R^* y_d \tilde{Q}_L H_d' + \rho b_d \frac{\langle F_S \rangle}{M} \tilde{e}_R^* y_e \tilde{L}_L H_d' \quad (2.7)$$

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[1]The factor ρ in eq. (2.4) is missing in [16].

3

and thus trilinear scalar couplings

$$a_u = A_{u0} y_u \quad , \quad a_d = A_{d0} y_d \quad , \quad a_e = A_{d0} y_e \tag{2.8}$$

with

$$A_{u0} = \left(\frac{M_c}{M}\right)^{D-4} \frac{\langle F_S \rangle}{M} b_u \quad , \quad A_{d0} = \left(\frac{M_c}{M}\right)^{D-4} \frac{\langle F_S \rangle}{M} b_d \,. \tag{2.9}$$

This result can also be derived from the general expressions for soft SUSY-breaking terms in the supergravity formalism, see *e.g.* [17], and by integrating out the Higgs auxiliary fields [16]. As the trilinear and Yukawa matrices are proportional to each other, they are simultaneously diagonalized when changing to the super-CKM basis. Consequently, the trilinears do not cause additional flavor violation compared to the SM and the second part of the SUSY flavor problem is solved, too. Interestingly, the proportionality factors A_{u0} for the up-type squarks and A_{d0} for the down-type squarks and charged sleptons can be different.

3. Phenomenology

Let us now discuss the superparticle spectrum and the lightest Higgs mass, as computed by SPHENO 3.3.8 [18, 19] and FEYNHIGGS 2.12.2 [20, 21, 22, 23, 24, 25], respectively, that can be obtained in trilinear-augmented gaugino mediation. From the above considerations it follows that the free parameters are the gaugino masses, the Higgs soft masses $m_{H_u}^2$ and $m_{H_d}^2$, the trilinear couplings A_{u0} and A_{d0}, as well as $B\mu$ and $\tan\beta$ at the compactification scale. The soft sfermion masses are negligibly small at M_c. Here we assume a unified gauge theory above the compactification scale, resulting in a unified gaugino mass $m_{1/2}$. In addition, we restrict ourselves to the simplest case regarding the trilinears, $A_{u0} = A_{d0} \equiv A_0$. In this way we arrive at a restricted realization of the NUHM2 scenario [26] with $m_0 = 0$. Finally, we choose $\mu > 0$, $A_0 \leq 0$ and $m_{H_{u,d}}^2 \geq 0$.

3.1 Higgs Mass

The observed value of the Higgs mass, $m_h = 125.09\,\text{GeV}$ [13], is a challenge for SUSY model building, since it requires significant corrections to the tree-level prediction $m_h < m_Z$. The dominant one-loop correction,

$$\Delta m_h^2 \propto m_t^2 \left[\log \frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2} \left(1 - \frac{X_t^2}{12 M_S^2} \right) \right], \tag{3.1}$$

depends on the overall superparticle mass scale $M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ and the stop trilinear via $X_t = A_t - \mu \cot\beta$. As a small value of M_S facilitates a discovery of SUSY, a large (absolute) value of the trilinear coupling is desirable. Consequently, generating large trilinears in gaugino mediation is crucial for the observability of the scenario.

As the theoretical uncertainty of Higgs mass calculations in the MSSM is around $2\,\text{GeV}$ [24, 27], we consider parameter space points with $123\,\text{GeV} \leq m_h \leq 127\,\text{GeV}$ to be allowed in our numerical analysis. For each point we studied, the Higgs mass computed by FEYNHIGGS 2.12.2 is typically about $3\,\text{GeV}$ smaller than the one found by SPHENO 3.3.8. However, a good agreement between the results of FEYNHIGGS and SPHENO 4 has been reported [28]. Besides, we observed a downward shift of the computed Higgs mass by about $1\,\text{GeV}$ when switching from

FEYNHIGGS 2.11 to version 2.12, which was mainly caused by a more accurate calculation of electroweak corrections to the $\overline{\text{MS}}$ top mass [25]. As a result, it seems likely that the superpartner mass scale required to reach the observed Higgs mass had been underestimated in studies using older versions of the codes.

3.2 NLSP Candidates

The superparticle mass spectrum is determined by the aforementioned input parameters at the compactification scale and the renormalization group running to low energy. The overall SUSY *mass scale* is determined by the unified gaugino mass $m_{1/2}$. To a good approximation, a change of this parameter results in a common rescaling of all superparticle masses. The *mass ordering* depends on the other free parameters, among which the soft Higgs mass $m_{H_d}^2$ and the trilinear coupling A_0 are the most important. Assuming a gravitino LSP, the lightest of the MSSM superparticles is the NLSP. For $m_{H_d}^2 = 0$, this particle is always the (predominantly right-handed) lighter stau. For non-trivial values of $m_{H_d}^2$ and A_0, the NLSP can also be a neutralino or a tau sneutrino, as illustrated in fig. 2. For non-zero A_0, it is even possible to obtain a stau NLSP that is a maximal mixture between $\widetilde{\tau}_R$ and $\widetilde{\tau}_R$. This happens, for example, for the points on the long-dashed line in the right panel of the figure.
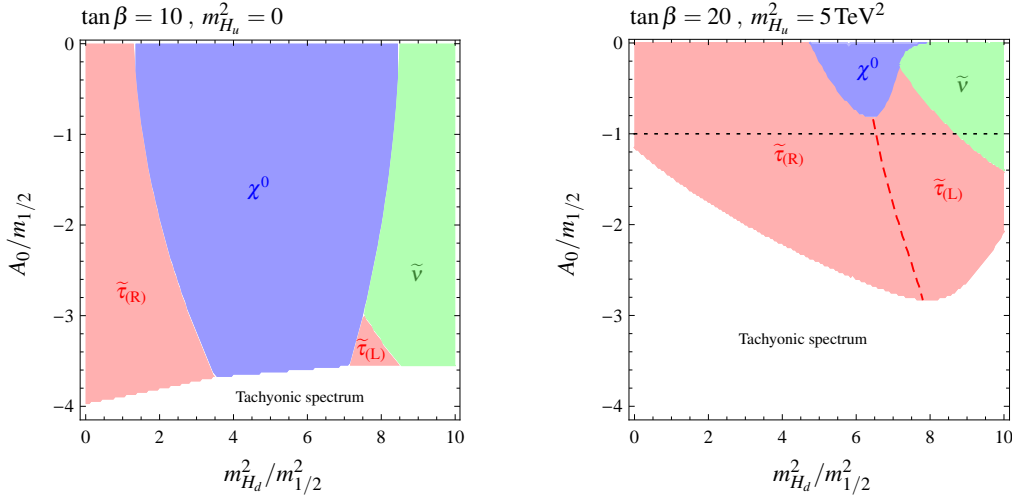

Figure 2: Nature of the NLSP as a function of the down-type soft Higgs mass and the trilinear scalar coupling for two different choices of $\tan\beta$ and $m_{H_u}^2$. In both panels, $m_{1/2} = 2\,\text{TeV}$, but the figures look almost the same for different values of this parameter. In the white regions at the bottom, a soft mass squared becomes negative. The red-dashed curve in the right panel indicates a maximally mixed stau NLSP, i.e., $\sin^2\theta_{\widetilde{\tau}} = 1/2$. Figures taken from [16].

3.3 LHC Constraints

As the gravitino cannot be lighter than about $10\,\text{GeV}$ in gaugino mediation [11], the NLSP is effectively stable on timescales relevant for collider experiments. In the stau NLSP case, the scenario is therefore tested by searches for heavy stable charged particles (HSCP) at the LHC. Performing a Monte Carlo simulation of the expected signal with MADGRAPH5_AMC@NLO [29] (event generation) and PYTHIA 6 [30] (total cross section, decay, showering, hadronization), we
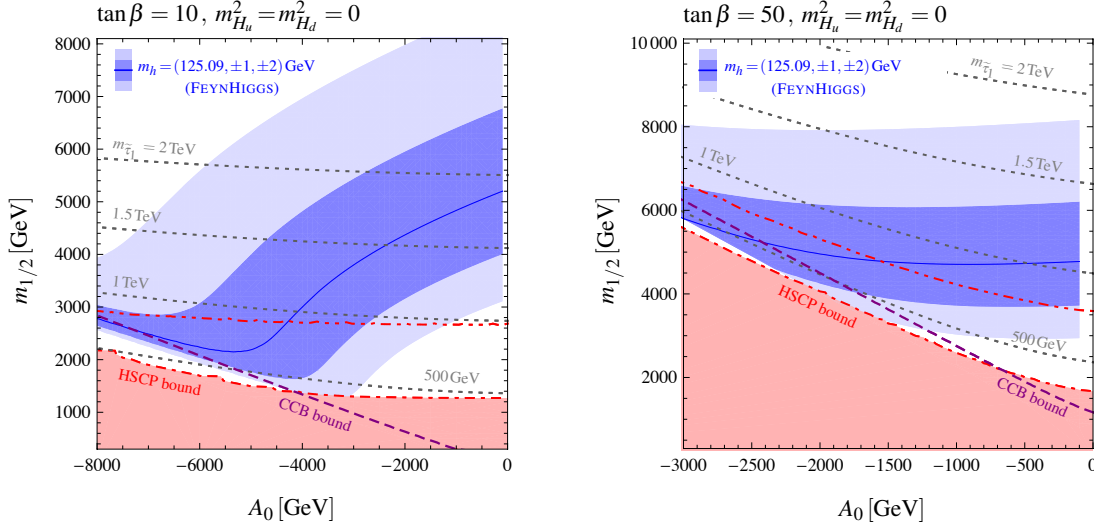
Figure 3: Constraints on the A_0–$m_{1/2}$ plane of gaugino mediation with a stau NLSP and $\tan\beta = 10$ (left) or $\tan\beta = 50$ (right). The grey dotted curves show the contours of a constant lighter stau mass $m_{\tilde{\tau}_1}$. The solid contours and blue-shaded bands show where the Higgs mass is precisely 125.09 GeV and where it deviates from this value by at most 1 GeV and 2 GeV, respectively. The red-shaded regions are excluded by searches for heavy stable charged particles (HSCP) at the 8 TeV LHC. For $\tan\beta = 50$ and $A_0 \lesssim -2.3$ TeV the HSCP limit extends into a region with a tachyonic spectrum, where it is only an extrapolation. The dot-dot-dashed curves denote projections for 13 TeV and 300 fb^{-1}. The purple dashed lines indicate constraints from charge- and color-breaking minima in the scalar potential. Figures taken from [16].

applied a CMS search with an integrated luminosity of 18.8 fb^{-1} at the 8 TeV run of the LHC [31] to constrain the parameter space.

We also considered the latest available 13 TeV results, a preliminary CMS analysis using 12.9 fb^{-1} [32]. As fewer details of the analysis are provided than for the run-1 search, a reinterpretation of the results is more difficult. Nevertheless, we obtained a meaningful estimate of the exclusion bound, which is slightly more stringent than the 8 TeV limit. Finally, we estimated the discovery reach with 300 fb^{-1}.

The results are shown in fig. 3 in the A_0–$m_{1/2}$ plane for vanishing soft Higgs masses at the compactification scale and two different values of $\tan\beta$. In both cases we have a stau NLSP in the entire considered parameter plane. The HSCP search by CMS [31] at $\sqrt{s} = 8$ TeV excludes the red-shaded regions below the dot-dashed lines at 95% CL. The figure includes contours of constant stau mass to give an impression of the physical mass spectrum. Stau masses below about 400 GeV are excluded. For $\tan\beta = 10$, this translates into a lower limit on $m_{1/2}$ between 1 and 2 TeV; for large $\tan\beta$, this bound becomes significantly stronger. We do not show the preliminary run-2 limit to reduce clutter, but we include the estimated sensitivity for 300 fb^{-1} at 13 TeV as dot-dot-dashed curves.

Figure 3 also shows the contours on which $m_h = 125.09$ GeV (blue solid lines) as well as the bands where the Higgs mass deviates from this value by at most 1 GeV and 2 GeV, respectively (darker and lighter shaded regions). We see that the existing HSCP limit barely touches the

-2 GeV band, leaving most of the parameter space with an acceptable Higgs mass unchallenged. The projected sensitivity curves indicate that future LHC runs will probe a larger portion of this parameter space. In particular, stau masses up to almost 1 TeV can be tested.

In addition to collider searches, the emergence of charge- and color-breaking (CCB) minima in the scalar potential for large trilinears constrains the parameter space. We applied the "traditional" condition for the stop trilinear coupling [33, 34],

$$A_t^2 < 3\left(m_{H_u}^2 + \mu^2 + m_{Q_3}^2 + m_{\bar{u}_3}^2\right),\qquad(3.2)$$

the analogous bound on the stau trilinear and the upper limit on the product $\mu\tan\beta$ valid for large $\tan\beta$ [35]. These bounds are superimposed in fig. 3, where we show the most constraining one in each case as a purple dashed line. For large negative A_0, they extend into the part of the parameter space compatible with the observed Higgs mass and are slightly stronger than the 8 TeV HSCP bounds. Note, however, that these CCB constraints are not entirely reliable [36, 37] and can therefore only serve as indicators of regions that *might* be excluded.

In the parameter space regions with a neutralino or sneutrino NLSP, the scenario is probed by standard missing energy searches at the LHC. Again utilizing MADGRAPH5_AMC@NLO and PYTHIA 6 for a Monte Carlo simulation, we added CHECKMATE 1 [38] to test the signal against all 8 TeV ATLAS searches implemented in this tool. These searches considered final states with a significant amount of missing transverse energy in addition to jets or leptons. We found that even for the lightest superparticle spectra with $m_h > 123$ GeV, the signal lies below the exclusion limits by at least an order of magnitude. Consequently, the LHC will most likely not be able to discover SUSY if gaugino mediation with a neutral NLSP is realized in nature.

4. Conclusions

We have verified that with a slight generalization of the original scenario, gaugino-mediated SUSY breaking allows for large trilinear scalar couplings, which help to lower the superparticle mass scale required to reach the observed Higgs mass. As the trilinears are proportional to Yukawa coupling matrices, no new sources of flavor violation arise. Thus, the solution of the SUSY flavor problem in the model is not endangered.

If the gravitino is the lightest superparticle and forms the dark matter, the cosmological gravitino problem is alleviated. In this case, the next-to-lightest superparticle can be a neutralino or a slepton. The observed Higgs mass is reached for $400\,\text{GeV} \lesssim m_{\text{NLSP}} \lesssim 1.4\,\text{TeV}$. As a consequence, a neutralino or sneutrino NLSP is most likely too heavy for a discovery at the LHC, while a stau NLSP is long-lived and potentially accessible in searches for heavy stable charged particles.

References

[1] I. V. Falomkin et al., *Low-energy anti-p He-4 annihilation and problems of the modern cosmology, GUT and SUSY models*, *Nuovo Cim.* **A79** (1984) 193–204.

[2] M. Y. Khlopov and A. D. Linde, *Is it easy to save the gravitino?*, *Phys. Lett.* **B138** (1984) 265–268.

[3] J. R. Ellis, J. E. Kim and D. V. Nanopoulos, *Cosmological gravitino regeneration and decay*, *Phys. Lett.* **B145** (1984) 181.

[4] M. Kawasaki, K. Kohri, T. Moroi and Y. Takaesu, *Revisiting Big-Bang Nucleosynthesis Constraints on Long-Lived Decaying Particles*, *Phys. Rev.* **D97** (2018) 023502, [1709.01211].

[5] W. Buchmüller, P. Di Bari and M. Plümacher, *Cosmic microwave background, matter-antimatter asymmetry and neutrino masses*, *Nucl. Phys.* **B643** (2002) 367–390, [hep-ph/0205349].

[6] M. Bolz, A. Brandenburg and W. Buchmüller, *Thermal production of gravitinos*, *Nucl. Phys.* **B606** (2001) 518–544, [hep-ph/0012052].

[7] J. Pradler and F. D. Steffen, *Thermal gravitino production and collider tests of leptogenesis*, *Phys. Rev.* **D75** (2007) 023509, [hep-ph/0608344].

[8] M. Pospelov, *Particle physics catalysis of thermal Big Bang Nucleosynthesis*, *Phys. Rev. Lett.* **98** (2007) 231301, [hep-ph/0605215].

[9] D. E. Kaplan, G. D. Kribs and M. Schmaltz, *Supersymmetry breaking through transparent extra dimensions*, *Phys. Rev.* **D62** (2000) 035010, [hep-ph/9911293].

[10] Z. Chacko, M. A. Luty, A. E. Nelson and E. Ponton, *Gaugino mediated supersymmetry breaking*, *JHEP* **01** (2000) 003, [hep-ph/9911323].

[11] W. Buchmüller, K. Hamaguchi and J. Kersten, *The gravitino in gaugino mediation*, *Phys. Lett.* **B632** (2006) 366–370, [hep-ph/0506105].

[12] W. Buchmüller, J. Kersten and K. Schmidt-Hoberg, *Squarks and sleptons between branes and bulk*, *JHEP* **02** (2006) 069, [hep-ph/0512152].

[13] ATLAS, CMS collaboration, G. Aad et al., *Combined Measurement of the Higgs Boson Mass in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS Experiments*, *Phys. Rev. Lett.* **114** (2015) 191803, [1503.07589].

[14] R. Kitano, R. Motono and M. Nagai, *MSSM without free parameters*, *Phys. Rev.* **D94** (2016) 115016, [1605.08227].

[15] F. Brümmer, S. Kraml and S. Kulkarni, *Anatomy of maximal stop mixing in the MSSM*, *JHEP* **08** (2012) 089, [1204.5977].

[16] J. Heisig, J. Kersten, N. Murphy and I. Strümke, *Trilinear-Augmented Gaugino Mediation*, *JHEP* **05** (2017) 003, [1701.02313].

[17] A. Brignole, L. E. Ibáñez and C. Muñoz, *Soft supersymmetry breaking terms from supergravity and superstring models*, *Adv. Ser. Direct. High Energy Phys.* **21** (2010) 244–268, [hep-ph/9707209].

[18] W. Porod, *SPheno, a program for calculating supersymmetric spectra, SUSY particle decays and SUSY particle production at e^+e^- colliders*, *Comput. Phys. Commun.* **153** (2003) 275–315, [hep-ph/0301101].

[19] W. Porod and F. Staub, *SPheno 3.1: Extensions including flavour, CP-phases and models beyond the MSSM*, *Comput. Phys. Commun.* **183** (2012) 2458–2469, [1104.1573].

[20] S. Heinemeyer, W. Hollik and G. Weiglein, *The Masses of the neutral CP-even Higgs bosons in the MSSM: Accurate analysis at the two loop level*, *Eur. Phys. J.* **C9** (1999) 343–366, [hep-ph/9812472].

[21] S. Heinemeyer, W. Hollik and G. Weiglein, *FeynHiggs: A Program for the calculation of the masses of the neutral CP even Higgs bosons in the MSSM*, *Comput. Phys. Commun.* **124** (2000) 76–89, [hep-ph/9812320].

[22] G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich and G. Weiglein, *Towards high precision predictions for the MSSM Higgs sector*, *Eur. Phys. J.* **C28** (2003) 133–143, [hep-ph/0212020].

[23] M. Frank, T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, *The Higgs Boson Masses and Mixings of the Complex MSSM in the Feynman-Diagrammatic Approach*, *JHEP* **02** (2007) 047, [hep-ph/0611326].

[24] T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, *High-Precision Predictions for the Light CP -Even Higgs Boson Mass of the Minimal Supersymmetric Standard Model*, *Phys. Rev. Lett.* **112** (2014) 141801, [1312.4937].

[25] H. Bahl and W. Hollik, *Precise prediction for the light MSSM Higgs boson mass combining effective field theory and fixed-order calculations*, *Eur. Phys. J.* **C76** (2016) 499, [1608.01880].

[26] J. R. Ellis, K. A. Olive and Y. Santoso, *The MSSM parameter space with nonuniversal Higgs masses*, *Phys. Lett.* **B539** (2002) 107–118, [hep-ph/0204192].

[27] S. Borowka, T. Hahn, S. Heinemeyer, G. Heinrich and W. Hollik, *Momentum-dependent two-loop QCD corrections to the neutral Higgs-boson masses in the MSSM*, *Eur. Phys. J.* **C74** (2014) 2994, [1404.7074].

[28] F. Staub and W. Porod, *Improved predictions for intermediate and heavy Supersymmetry in the MSSM and beyond*, *Eur. Phys. J.* **C77** (2017) 338, [1703.03267].

[29] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, *JHEP* **07** (2014) 079, [1405.0301].

[30] T. Sjöstrand, S. Mrenna and P. Skands, *PYTHIA 6.4 Physics and Manual*, *JHEP* **05** (2006) 026, [hep-ph/0603175].

[31] CMS collaboration, V. Khachatryan et al., *Constraints on the pMSSM, AMSB Model and on Other Models from the Search for Long-Lived Charged Particles in Proton-Proton Collisions at $\sqrt{s} = 8\,TeV$*, *Eur. Phys. J.* **C75** (2015) 325, [1502.02522].

[32] CMS collaboration, V. Khachatryan et al., *Search for heavy stable charged particles with* $12.9\,\text{fb}^{-1}$ *of 2016 data*, CMS-PAS-EXO-16-036.

[33] J. P. Derendinger and C. A. Savoy, *Quantum Effects and SU(2) x U(1) Breaking in Supergravity Gauge Theories*, *Nucl. Phys.* **B237** (1984) 307–328.

[34] J. A. Casas, A. Lleyda and C. Muñoz, *Strong constraints on the parameter space of the MSSM from charge and color breaking minima*, *Nucl. Phys.* **B471** (1996) 3–58, [hep-ph/9507294].

[35] T. Kitahara and T. Yoshinaga, *Stau with Large Mass Difference and Enhancement of the Higgs to Diphoton Decay Rate in the MSSM*, *JHEP* **05** (2013) 035, [1303.0461].

[36] J. E. Camargo-Molina, B. O'Leary, W. Porod and F. Staub, *Stability of the CMSSM against sfermion VEVs*, *JHEP* **12** (2013) 103, [1309.7212].

9

[37] D. Chowdhury, R. M. Godbole, K. A. Mohan and S. K. Vempati, *Charge and Color Breaking Constraints in MSSM after the Higgs Discovery at LHC*, *JHEP* **02** (2014) 110, [`1310.1932`].

[38] M. Drees, H. Dreiner, D. Schmeier, J. Tattersall and J. S. Kim, *CheckMATE: Confronting your Favourite New Physics Model with LHC Data*, *Comput. Phys. Commun.* **187** (2015) 227–265, [`1312.2591`].

PoS(CORFU2017)079