SUSY Phenomenology—From the Early Universe to the LHC Era

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If supersymmetry exists around the TeV scale, it affects not only experiments at the LHC but also searches for rare processes, astroparticle physics and cosmology. The goal of the project was to combine information from all these sources in order to learn as much as possible about processes in the early universe and about physics at very high energies that are inaccessible to colliders. Examples include the impact of relatively late decaying particles on big bang nucleosynthesis, supersymmetry breaking and the origin of the observed flavor structures.

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) [1–3]. The observed abundances of primordial light elements therefore either require a gravitino mass $m_{3/2} \gg 1\,\mathrm{TeV}$ or a reheating temperature after inflation $T_\mathrm{R} \lesssim 10^6\,\mathrm{GeV}$ [4]. The former constraint implies a quite unnatural mass spectrum in most scenarios of SUSY breaking, whereas the latter one prevents thermal leptogenesis [5] without fine-tuning [6]. This motivates scenarios where the gravitino is the LSP and thus stable [7]. For SUSY at the TeV scale and $T_\mathrm{R} \sim 10^9\,\mathrm{GeV}$, 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 [8, 9]. 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 [10]. Charged NLSPs are further constrained since they form bound states with nuclei, which alters BBN reaction rates [11]. Consequently, the gravitino problem is present also in gravitino LSP scenarios but significantly alleviated.

Given the nature of the constraints from late decays, there are three logical possibilities to tackle the problem. First, we can minimize the impact of decays by choosing an NLSP whose decay products interact only weakly; the classical example is the sneutrino, which is mostly harmless for BBN [12] but also difficult to probe at the LHC [13, 14]. Second, we can minimize the density of decaying particles by either choosing regions in parameter space with enhanced annihilation or by modifying the thermal history of the universe. Third, we can minimize the lifetime of the NLSP in order to let it decay before decisive BBN processes set in, either by making it quite heavy or by opening new decay channels.

With a gravitino LSP, 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, family symmetries, or a high overall superparticle mass scale. Vice versa, measurements of rare processes where flavor or CP is violated, are a promising way to probe SUSY and other new physics scenarios.

2 Gravitino LSP scenarios at the LHC

For gravitino masses in the cosmologically motivated mass range, the NLSP is effectively stable on timescales relevant for collider experiments. Leaving aside BBN constraints for the time being, this is especially interesting for an electrically charged NLSP like the stau because it leaves a spectacular signature at LHC experiments, charged tracks leaving the detector and no missing transverse energy. Searches for heavy stable charged particles (HSCP) at the LHC test this possibility.

Considering the production of staus via the Drell–Yan process $p\bar{p} \to \gamma, Z \to \tilde{\tau}^+\tilde{\tau}^-$, which depends only on the stau mass and mixing angle, the luminosity required for discovering or excluding a stau NLSP in an HSCP search at the LHC can be determined as a function of its mass alone. The main experimental limitation is the discrimination of metastable staus from muons by measuring the particle velocity, which is usually smaller for staus due to their heavy mass. Employing a conservative but realistic estimate for the background rejection factor due to the velocity discrimination, which was based on discussions with experimentalists from project B2 of the SFB, and a careful statistical treatment using Poisson statistics, which is appropriate due to the small number of events, the LHC reach for stau NLSPs from Drell–Yan production was determined in [15]. For example, with a luminosity of $300\,\mathrm{fb}^{-1}$ and a center-of-mass energy of $14\,\mathrm{TeV}$, the LHC can discover such staus with masses up to roughly $750\,\mathrm{GeV}$. The results were later largely confirmed by ATLAS and CMS [16, 17], which however were able to exclude higher masses since the experimental performance exceeded the conservative assumptions in the theoretical analysis.

The limits from Drell–Yan production are the most model-independent and conservative ones possible because they depend only on the properties of the stau itself. If other superparticles are not much heavier, their production and subsequent decay to staus will extend the mass reach of HSCP searches, in particular for the initial production of squarks or gluinos via the strong interaction. Of course, this increases the number of free parameters. In order to enable an analysis without assumptions about a model for SUSY breaking despite this obstacle, a

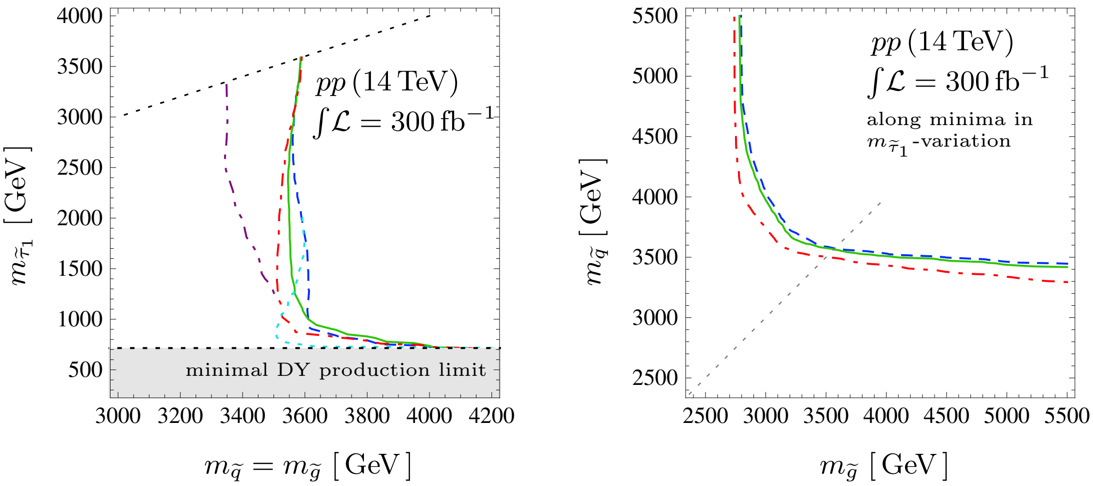

Figure 1: Projected LHC sensitivity (95% CL_s exclusion and approximate 5σ discovery reach) for the simplified models with a metastable stau NLSP in the case of a common squark mass $m_{\tilde{q}}$. In the right panel the curves represent the minima in the sensitivity with respect to the variation of $m_{\tilde{\tau}_1}$. Reprinted figures with permission from Ref. [18]. Copyright (2012) by the American Physical Society.

simplified model approach was proposed in [18]. A total of six simplified models were introduced, covering the possibilities of mass-degenerate squarks and a light stop, and in each case three limiting cases for the masses of the intermediate superparticles in the decay chain from the originally produced squark or gluino to the stau, capturing the phenomenology of any realistic spectrum within the long-lived stau scenario. Each model contains the three free parameters $m_{\tilde{\tau}_1}$, $m_{\tilde{g}}$ and either the common squark mass $m_{\tilde{q}}$ or $m_{\tilde{t}_1}$. As an example, Fig. 1 shows the potential of Run 3 of the LHC for the case of a common squark mass.

The simplified model approach turned out to work even better than in searches for SUSY with a neutralino LSP, although the number of relevant parameters is larger at first sight. It is possible to cover the whole parameter space with a small number of selection criteria that yield both a high signal efficiency and a very good background rejection, enabling a model-independent analysis. The direct Drell–Yan contribution to stau production prevents a loss of sensitivity for a large mass difference between the stau and the colored superparticles, in which case both staus in a cascade event are typically too fast to be identified. As a consequence, there are no regions in parameter space where the scenario can hide from detection, so the exclusion bounds expected if the LHC does not find a signal are in fact more robust than in the neutralino LSP case.

3 Supersymmetry in the early universe

The effect of stau decays on primordial element abundances is less severe than that of neutralino decays due to the smaller hadronic branching ratio. However, due to their electric charge they form bound states with light nuclei, which leads to a drastic change of some BBN reaction rates

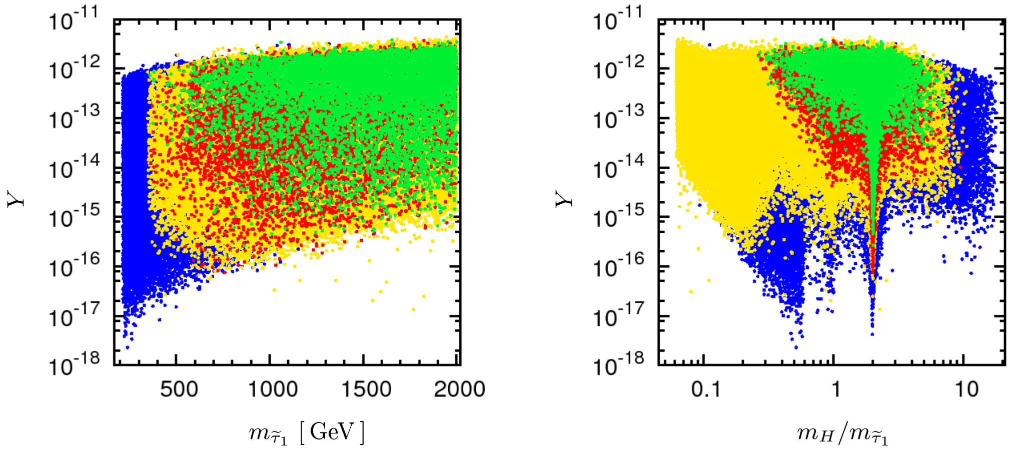

Figure 2: Stau yields in a 17-parameter pMSSM scan as a function of the stau mass (left) and the ratio $m_H/m_{\tilde{\tau}_1}$ (right). The green points pass all the constraints. The blue points are excluded by LHC searches for long-lived particles. The yellow points are rejected by HiggsBounds [25], are inconsistent with the measured W mass, or violate flavor physics constraints. At the red points, charge- or color-breaking minima may occur in the scalar potential. Readers of the black and white version can identify colors by noting that in the left panel the sequence of dominating colors from left to right is blue-yellow-red-green. Figures taken from Ref. [24].

resulting in an overproduction of ^{6}Li [11]. Consequently, a viable stau NLSP has to have either a lifetime smaller than about 10^3 sec or a very small yield $Y \equiv n/s \lesssim 10^{-15}$ [19, 20], where n is the stau number density just before its decay and s is the entropy density.

Generically, the production of staus by thermal freeze-out in the early universe yields $Y \sim 10^{-13}$ for a mass around 100 GeV [21]. Thus, BBN requires an exceptional suppression of the yield for long-lived staus. This is indeed possible, for example, for particular values of the stau mass parameters that lead to an enhanced stau-Higgs coupling and thereby to a strongly enhanced stau annihilation cross section [22, 23]. More generally, the parameter space of the MSSM can be classified according to the stau yield [24]: a bulk region with generic abundance, an electroweakino co-annihilation region with a reduction by up to two orders of magnitude, gluino and squark co-annihilation regions with a yield reduction by around one order of magnitude, as well as Higgs final state, Higgs resonant and third-generation squark co-annihilation regions with a reduction by up to four orders of magnitude.

Performing a scan in the phenomenological MSSM (pMSSM) with 17 free parameters, these regions were constrained by all available experimental and theoretical limits [24]. A careful inclusion of the HSCP searches at Run 1 of the LHC was emphasized, refining and extending the methods developed in [15, 18]. For instance, the production of staus via decays of initially produced neutralinos and charginos as well as via intermediate Higgs particles ($pp \to h, H \to \tilde{\tau}_1\tilde{\tau}_1$) was included. Further relevant constraints stem from Higgs measurements (mass, rates, searches for heavy Higgses), searches for metastable particles different from the stau, the W mass, flavor observables, and charge- or color-breaking minima in the scalar potential. The impact of these constraints on the stau relic abundance is shown in Fig. 2. We see that suppressed abundances are still viable. The smallest values require enhanced stau-Higgs couplings and stau annihila-

No.	Requirement	Comment
i	$T_\phi^{\rm dec} < T_{\rm NLSP}^{\rm fo}$	to have effect on $\Omega_{\rm NLSP}$
ii	$T_\phi^{\rm dec} > T_{\rm BBN}$	not to spoil BBN
iii	$\frac{\rho_\phi}{\rho_{\rm rad}}(T_\phi^{\rm dec}) > 1$	$\mathcal{O}(10) < \Delta < 10^4$
iv	$\frac{\rho_\phi}{\rho_{\rm rad}}(T_{\rm NLSP}^{\rm fo}) < 1$	for standard NLSP freeze-out
v	$\mathrm{BR}(\phi \to \mathrm{NLSP} + \ldots) \simeq 0$	from NLSP decay problem
vi	$\mathrm{BR}(\phi \to \mathrm{gravitino} + \ldots) \simeq 0$	from overproduction ($\Omega_{3/2}^{\rm tp} \simeq \Omega_{\rm DM}$)
vii	e.g., $\tau_{3/2} \gg t_0$	compatibility with gravitino dark matter
viii	ii) and v)–vii)	for by-products; no new problems

Table 1: Requirements for a viable scenario of entropy production by decays of a long-lived particle ϕ that dilutes the NLSP density. Reprinted table with permission from Ref. [28]. Copyright (2010) by the American Physical Society.

tion via the exchange of a heavy Higgs H^0 in resonance, as demonstrated by the narrow region of green points at $m_H \simeq 2\,m_{\widetilde{\tau}_1}$ in the right panel of the figure. The lowest viable stau yield is about 2×10^{-16}. The very tip of this peak is excluded by HSCP searches, to a large extent due to the resonant production of staus via the heavy Higgs.

Extending the scan parameters by the gravitino mass, the reheating temperature can be calculated from the observed dark matter density [26]. Points with $T_{\rm R} > 10^9$ GeV are allowed in the Higgs resonant region where $m_H \simeq 2\,m_{\widetilde{\tau}_1}$. Consequently, the gravitino problem can be solved and thermal leptogenesis can occur within the R-parity-conserving MSSM. In the corresponding parameter space points, the staus produced at the LHC tend to be very slow. Their discovery would hence be facilitated by an extended buffering of the tracker data in the detectors [18].

Generic stau or neutralino NLSP yields can be made compatible with BBN by modifying the thermal history of the early universe compared to the standard scenario. If a long-lived particle ϕ dominates the energy density for a short period between the NLSP's freeze-out at temperature $T_{\rm NLSP}^{\rm fo}$ and BBN, its decays at $T_\phi^{\rm dec}$ increase the entropy by a factor Δ, which can dilute the NLSP density below the upper limit from BBN [27]. However, the baryon asymmetry is diluted as well, which has to be compensated by a larger heavy neutrino mass M_1 and a correspondingly higher reheating temperature in thermal leptogenesis. As washout processes reduce the efficiency of leptogenesis for very large M_1, this mass cannot be increased arbitrarily. Consequently, entropy generation is limited from above. The upper bound was estimated as $\Delta \lesssim 10^4$ [28], but it could possibly be larger by up to an order of magnitude [29]. As a consequence, constraints on the NLSP remain, which were studied in detail for the neutralino in [28].

An overview of the criteria that the entropy-producing particle has to satisfy [28] is given in Tab. 1. Although they are satisfied quite generically in any scenario with long-lived particles, it is non-trivial to find a candidate that satisfies all criteria in a natural way. For example, the axion supermultiplet contains the saxion as a weakly coupled, massive scalar field. The version of the scenario where thermal saxion production dominates is very predictive but not able to generate a sufficient amount of entropy. Besides, the axino causes severe problems. Decoupling saxion production and decay by assuming production in coherent oscillations, which is generically expected anyway, these difficulties can be overcome, enabling a scenario with a completely consistent cosmology. The biggest price to pay from the point of view of naturalness is a saxion mass around 10 GeV, which is somewhat lighter than generically expected.

Late decays can also quite naturally produce dark radiation, i.e., relativistic particles different from photons and Standard Model neutrinos, which contribute to the effective number of neutrino species N_{eff}. Together with indications for a larger N_{eff} than expected in the Standard Model [30–32],[1] this motivated the first systematic study of particle decay as the origin of dark radiation [35]. In the simplest scenario, a non-relativistic "mother" particle decays into two "daughters". The lighter daughter acts as dark radiation. Depending on how close in mass the heavier daughter is to the mother, it can contribute to dark radiation as well, but it could also form the dark matter or a component thereof in principle. It turned out that the heavier daughter acts as hot dark matter if the amount of dark radiation is non-negligible; consequently, it can form a subdominant component of the dark matter at most. However, this leaves the interesting possibility that the heavier daughter could mimic the effect of non-vanishing neutrino masses in cosmological observations, which could explain a contradiction with laboratory experiments if that should arise in the future.

If the mother has two possibilities to decay, either into a pair of light daughters or into a pair of heavy daughters, the relative branching fraction between these decay modes is an additional free parameter that allows for new possibilities. In the most interesting case, the lighter daughter again forms the dark radiation. The heavier daughter can now form all of the observed dark matter. What is more, its free-streaming length can be adjusted such that the missing satellite problem of structure formation [36, 37] is solved.

The scenario is predictive because the amount of dark radiation determines the energy density of the mother at the time of decay. It is therefore possible to determine bounds on the involved branching ratios and mass hierarchies as functions of the lifetime of the long-lived particle, employing constraints from BBN, the cosmic microwave background and structure formation. As an example, Fig. 3 shows limits on the branching fraction of the decaying particle into photons and electron-positron pairs, which could arise from off-shell or loop-induced processes. Note that the thinner lines in the figure ("strongest bounds") correspond to a very large dark radiation density that is now ruled out.

A particular realization of the scenario is a model with mixed axion and axino dark matter [42]. The axino has a mass below a keV and is the LSP, while the gravitino with a mass of order 100 GeV is the NLSP. In this case the superpartners of the Standard Model particles decay into axino and photon before BBN, which realizes the third possibility of avoiding BBN problems mentioned in the introduction (although strictly speaking now the particle whose decays could be problematic is the next-to-NLSP). The gravitino decays after BBN but before the creation of the cosmic microwave background into axino and axion, which do not affect the light element abundances due to their weak couplings. However, these particles are created as dark radiation and thus contribute to N_{eff} [43]. The increase of this quantity is of order one for expected (natural) masses and a reheating temperature around 10^{10} GeV. This makes the model more easily testable but also leads to a new upper bound on the reheating temperature four orders of magnitude stronger than the one derived in [42].

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[1] These indications were not confirmed by the Planck satellite, but a sizable amount of dark radiation remains allowed [33]. There are even hints that late decays to dark radiation are preferred by current cosmological data [34].

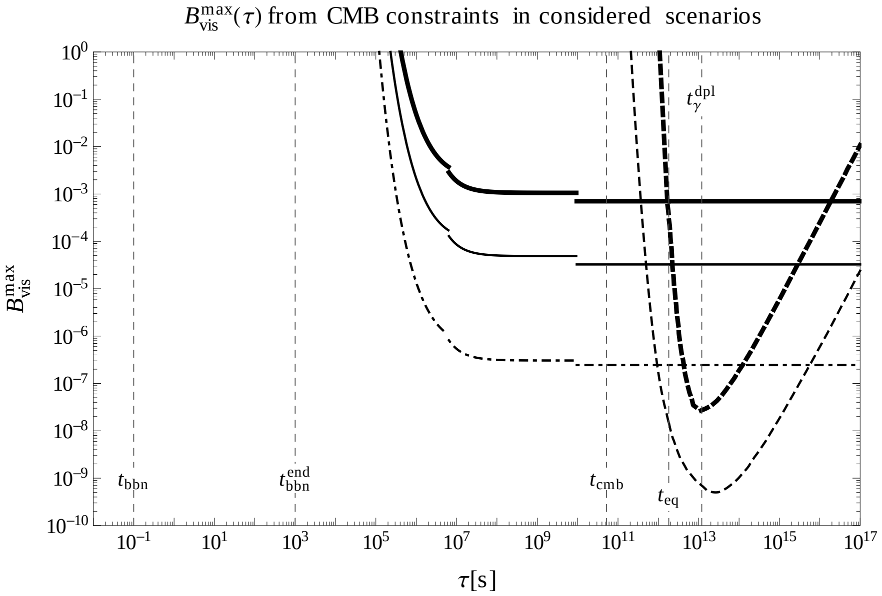

Figure 3: Upper bounds from the cosmic microwave background on the branching ratio of a decaying particle as a function of its lifetime τ in the scenario of particle decay as the origin of dark radiation. Thick and thin solid curves represent the weakest and the strongest bounds, respectively, on the branching ratio into photons that can be derived from CMB spectral distortions [38, 39]. The dash-dotted curve indicates the discovery reach of the proposed PIXIE experiment [40] if $\Delta N_{\mathrm{eff}} = 1$. Thick and thin dashed curves represent weakest and strongest bounds on the branching ratio into electrons, positrons and photons, which were obtained from the ionization history of the universe [41]. Figure reprinted from Ref. [35]. © 2013 IOP Publishing Ltd and Sissa Medialab srl.

Another way to reduce the lifetime of potentially dangerous particles is introducing a small violation of R parity. This causes the NLSP to decay mainly into Standard Model particles before BBN and thus satisfies the constraints [44]. The cosmological bounds on the axion multiplet in this scenario were determined in [45]. We systematically considered different axion models and NLSP candidates and compared the standard scenario with R parity conservation to the one with R parity violation as well as a setup with both R parity violation and late-time entropy production. The faster NLSP decay turned out to be the most important effect of R parity violation. It allows the axino, whose decays produce NLSPs, to decay shortly before BBN, relaxing the stringent lower bound on its mass in the standard scenario. Also decays of the saxion are allowed to produce NLSPs at any time before BBN, and its mass is virtually unconstrained. Consequently, generically expected spectra are allowed where both saxion and axino mass are of the same order of magnitude as the other superparticle masses. It is thus fair to conclude that R parity violation not only solves the gravitino problem but also makes it easier to solve the strong CP problem via the Peccei–Quinn mechanism [46].

Finally, applying the formalism of late-decaying particles to decays before BBN, it was shown that moduli from string theory compactifications could leave traces in the gravitational wave background [47].

4 FCNCs, CP violation and the fermionic flavor structure

Extensions of the Standard Model typically contain new sources of flavor and CP violation. Therefore, they are testable and constrained not only by direct searches for new particles at colliders but also by indirect searches for flavor-changing neutral currents (FCNCs) and CP violation.

A CP- and T-violating triple spin correlation in muon to electron conversion in nuclei is generally of order one in left-right symmetric theories, offering hope of observing CP violation in this lepton-flavor-violating (LFV) process [48]. Such a measurement might even enable a determination of the Majorana phases in the lepton mixing matrix in case neutrinos are Majorana particles.

Indirect new physics searches, in particular employing the mass differences of neutral kaons and B mesons as well as CP violation in these systems, also yield the most important constraints on the scale of left-right symmetry restoration in the minimal left-right symmetric model. A combined analysis [49] yielded $M_{W_\mathrm{R}} \gtrsim 3.5\,\mathrm{TeV}$ and $M_{W_\mathrm{R}} \gtrsim 2.5\,\mathrm{TeV}$, respectively, where the two limits correspond to two ways of defining the parity symmetry. The signatures at the LHC were studied as well, in particular same-sign dileptons from the decay of the heavy right-handed neutrino, demonstrating the complementarity between direct and indirect searches. Even in the minimal case, it is possible to observe both the charged and the neutral gauge boson at the LHC, if their masses are sufficiently close to the lower limits.

Lepton flavor violation can also be used to probe models with light fermionic $\mathrm{SU}(2)_\mathrm{L}$ triplets that are motivated by a minimal extension of the SU(5) grand unified theory [50]. The most relevant constraint comes from a search for the transition of a muon to an electron inside a gold nucleus. In the minimal case of a single triplet, the constraints on muonic transitions are precise enough to forbid an observation of a transition in the tau sector, at least in the foreseeable future. In non-minimal cases with several triplets, this restriction disappears. The follow-up work [51] examined leptogenesis in the model, including a more complete treatment of flavor effects.

In the case of SUSY, the non-observation of larger flavor and CP violation than predicted in the Standard Model is a long-standing problem. A very interesting approach are non-Abelian family symmetries introduced in order to understand the observed fermion masses and mixings. They can also restrict the soft SUSY breaking parameters to conserve flavor and CP [52, 53]. The breaking of a family symmetry leads to suppressed flavor- and CP-violating soft parameters, which are in principle calculable. In this way, one could not only solve the SUSY flavor problem but also obtain an additional experimental test of models with family symmetries. Unfortunately, it turned out that the predictivity for the SUSY breaking parameters is in fact more limited than previously assumed [54]. The reason is that the predictions depend on unknown details of the messenger sector, which is needed to generate couplings between the Standard Model fermions and the flavons breaking the family symmetry. Depending on the model, it can be possible to improve the predictivity by a change of the messenger sector.

A different route to suppress FCNCs and CP violation in supersymmetric models was followed in [55]. The study considered a scenario derived from string theory, the G_2-MSSM [56], where only the gauginos have masses below a TeV while the other superparticles are heavier than about 20 TeV. The trilinear scalar couplings are large as well and in general not proportional to the Yukawa couplings. Analyzing the flavor- und CP-violating observables, the largest sensitivity to new physics was found in the neutral kaon system. While the change of the kaon mass difference is very small, a sizable contribution to the CP-violating parameter ϵ_K

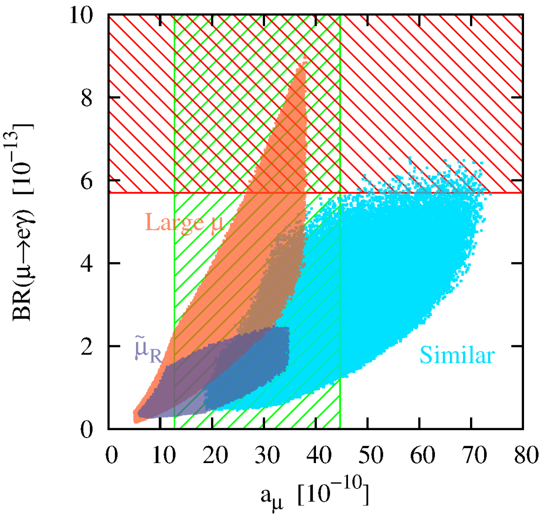

Figure 4: Supersymmetric contribution to the anomalous magnetic moment of the muon, $a_\mu = (g-2)_\mu/2$, versus $\mathrm{BR}(\mu \to e\gamma)$ for similar SUSY masses, large μ and heavy left-handed sleptons (dark region labeled "$\tilde{\mu}_\mathrm{R}$"), respectively. In each case, $\delta_\mathrm{LL} = \delta_\mathrm{RR} = 2 \times 10^{-5}$ and $\tan\beta = 50$. The vertical hatched band corresponds to the experimentally favored 2σ range for a_μ, while the horizontal band marks the region excluded by MEG [61]. Figure taken from Ref. [62].

is possible, which turned out to depend sensitively on the choice of trilinear couplings. Thus, heavy scalars alone do not guarantee the absence of flavor and CP problems. Nevertheless, parts of the parameter space of the G_2-MSSM are compatible with the observed value of ϵ_K, thanks largely to the theoretical uncertainty of the Standard Model prediction.

Subsequently, [57] improved the calculation of flavor- and CP-violating observables in scenarios where the gauginos have masses around a TeV while either all sfermions or only those of the first and second generation are much heavier. The latter option, known as natural SUSY, is also motivated by the relatively heavy observed Higgs mass and the SUSY discovery problem [58]. The results are thus useful not only for constructing models like the G_2-MSSM or family symmetries but also for constraining supersymmetric scenarios that currently are receiving a lot of attention. We analyzed the flavor- und CP-violating observables in the neutral kaon system, taking into account QCD corrections at the next-to-leading order. Working in the mass insertion approximation, we derived limits on the heavy squark masses and on the flavor-violating parameters that govern the mixing between the first and second squark generation.

If the deviation of the measured value of the muon's anomalous magnetic moment $(g-2)_\mu$ from the Standard Model prediction is due to SUSY, this may enable predictions for the LFV decay $\mu \to e\gamma$, since the Feynman diagrams leading to both processes in supersymmetric models are closely related. In short, the value of $(g-2)_\mu$ sets the scale of superpartner masses that enters into the branching ratio for $\mu \to e\gamma$. Thus, the only unknowns in the latter process are the actual LFV parameters δ_LL and δ_RR. They can then be constrained using the experimental upper limit and determined after a discovery of the decay in the future. However, a clear correlation between the two processes requires that a single Feynman diagram dominate both processes [59, 60].

If this is not the case, the correlation is weakened by significant cancellations between diagrams in large parts of the parameter space. However, the order of magnitude of $\mathrm{BR}(\mu \to e\gamma)$ for a fixed flavor-violating parameter can often be predicted [62]. Consider for example the region labeled "Similar" in Fig. 4, which was obtained by randomly varying the seven relevant SUSY mass parameters between 300 GeV and 600 GeV while fixing $\delta_{\mathrm{LL}} = \delta_{\mathrm{RR}} = 2 \times 10^{-5}$ such that the experimental limit $\mathrm{BR}(\mu \to e\gamma) < 5.7 \times 10^{-13}$ [61] is satisfied. We can see that for a fixed SUSY contribution to $(g-2)_\mu$, the branching ratio varies by a factor of 10 at most. This allows to determine a limit $\delta_{\mathrm{LL}} \lesssim 2 \times 10^{-5}$ below which $\mathrm{BR}(\mu \to e\gamma)$ is guaranteed to satisfy the experimental bound if the relevant SUSY masses vary by up to 30 % around a mass scale M chosen such that we obtain the best-fit value of $(g-2)_\mu$ for all masses equal to M.

A strong correlation between the two observables is realized, for example, in the case of neutralino-$\tilde{\mu}_{\mathrm{R}}$ dominance, which occurs for very heavy left-handed sleptons and $M_1, m_{\tilde{\ell}_{\mathrm{R}}} < M_2, |\mu|$ [62]. This is illustrated by the dark region labeled "$\tilde{\mu}_{\mathrm{R}}$" in Fig. 4. A special case occurs for large values of μ and $\tan\beta$, which do cause a single Feynman diagram to dominate and a significant correlation, as evidenced by the "Large μ" region in the figure. However, in this case LFV is not governed by δ_{LL} or δ_{RR} but by a different combination of parameters. In such regions with characteristic mass hierarchies and strong correlations, the experimental limit on $\mathrm{BR}(\mu \to e\gamma)$ can yield severe constraints on LFV parameters that cannot be evaded by raising the overall SUSY mass scale, since it is fixed by the measured value of $(g-2)_\mu$.

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