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Collider signals of gravitino dark matter in bilinearly broken R-parity

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Abstract: In models with gauge mediated supersymmetry breaking the gravitino is the lightest supersymmetric particle. If R-parity is violated the gravitino decays, but with a half-live far exceeding the age of the universe and thus is, in principle, a candidate for the dark matter. We consider the decays of the next-to-lightest supersymmetric particle, assumed to be the neutralino. We show that in models where the breaking of R-parity is bilinear, the condition that R-parity violation explains correctly the measured neutrino masses fixes the branching ratio of the decay $\tilde{\chi}^0_1 \to \tilde{G}\gamma$ in the range $10^{-3} - 10^{-2}$, if the gravitino mass is in the range required to solve the dark matter problem, i.e. of the order (few) 100 eV. This scenario is therefore directly testable at the next generation of colliders.

Keywords: Supersymmetry Phenomenology, Neutrino Physics.

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Contents

1. Introduction

Models of gauge mediated supersymmetry breaking (GMSB) generically predict that the lightest supersymmetric particle (LSP) is the gravitino [1]. Such a light gravitino, in principle, is a candidate for the non-baryonic dark matter of the universe [2]. The smallness of the gravitino couplings, however, make such a scenario extremely difficult to test. Direct detection of gravitino dark matter in scattering experiments or indirectly via decays/annihilation to gamma rays is hopeless [3] and consequently gravitino dark matter has received rather scarce attention.

The purpose of the present letter is to show that in models with bilinear breaking of R-parity the branching ratio of the decay of the neutralino into a gravitino and a photon is fixed by data on neutrino masses up to a factor of $m_{3/2}^{-2}$, if the neutralino is the next-to lightest supersymmetric particle (NLSP). A measurement of this branching ratio thus implies a "measurement" of the gravitino mass, $m_{3/2}$. Approximate knowledge of $m_{3/2}$ in turn can be used to constrain the conjecture that the gravitino is the (major component of the) dark matter in the universe.

On the one hand, supersymmetric models with R-parity violation can explain [4]–[7] current data on neutrino masses and mixings [8] without invoking any GUT-scale physics. On the other hand, in supersymmetric models with R-parity violation the LSP decays. For all superpartners of standard model particles these decays proceed at rates that even the most tiny amount of R-parity violation rules out MSSM particles as dark matter. A light gravitino, however, couples so weakly to standard model particles that its half-live far exceeds the age of the universe even for R-parity violating couplings as large as $\mathcal{O}(1)$ [9, 10], see also section 2. Thus, contrary to popular believe, supersymmetry holds the promise to solve the dark matter problem even if R-parity is violated.

If gravitinos were in thermal equilibrium in the early universe (and assuming that there is no non-standard physics between gravitino decoupling and the time of nucleosynthesis, see below), the contribution of gravitinos to the matter content of the universe can be estimated to be [2]

$$\Omega_{3/2}h^2 \simeq 0.11 \left(\frac{m_{3/2}}{100\,\mathrm{eV}}\right)\left(\frac{100}{g_*}\right). \tag{1.1}$$

Here, $\Omega_{3/2}$ is the density of gravitinos in units of the critical density, h is the Hubble parameter in units of 100 km s^{-1} Mpc^{-1} and g_* is the effective number of degrees of freedom at the time of gravitino decoupling. Depending on the so-far unknown supersymmetric particle spectrum one expects $g_* \simeq 90 - 140$ [11]. Current data give the matter density of the universe [12] as $\Omega_M h^2 \simeq 0.134 \pm 0.006$, from which $\Omega_B h^2 \simeq 0.023 \pm 0.001$ is in the form of baryons.

Particle dark matter (DM) is usually classified according to its free-streaming length [13] as either "hot", "warm" or "cold" DM. There is a general consensus that hot DM is ruled out [3, 12, 13]. Cold DM is usually considered the best choice [3, 13] to fit large-scale structure data. However, on galactic and sub-galactic scales pure cold DM seems to produce too much power, see for example [14, 15] and references therein.[1] To resolve the deficits of cold DM, some groups considered warm DM variants, claiming that WDM does actually provide a better fit [15, 17]. However, constraints on the free streaming length (and thus the mass) of WDM particles can be derived from data of the Lyman-α forest [18], and a lower limit of $m_{WDM} \geq 0.55\,\mathrm{keV}$ for *thermal* relics is quoted in [19].

The lower limit on the mass of WDM particles given in [19] seems to be in conflict with the conjecture that gravitinos are the dark matter, see eq. (1.1). However, in the derivation of the gravitino density [2] it is assumed that the universe has a "standard" thermal history. Producing additional entropy after the time of gravitino decoupling would dilute the density of gravitinos,[2] compared to the estimate eq. (1.1), two variations of this idea are discussed in [20, 21]. Both [20] and [21] assume that entropy is produced by the "late" decay of messenger particles. [3] Baltz and Murayama [20] argue that the lightest messenger particle might decay through an intermediate heavy particle with mass $m_X \simeq 10^{12}\,\mathrm{GeV}$, which leads to a messenger decay width sufficiently small to dilute the gravitino density by a factor of $(5 - 8)$. Fujii and Yanagida, on the other hand, claim that adding a constant messenger number violating term to the superpotential, messenger widths of the "correct" order of magnitude are naturally obtained [21].

Given this discussion, we think it is fair to say that gravitinos with a mass in the range of $\mathcal{O}(0.1)$-$\mathcal{O}(1)\,\mathrm{keV}$ are interesting dark matter candidates. Constraining the gravitino mass to be much smaller than given by eq. (1.1) would rule out gravitinos as DM.

[1] For a different point of view, see for example [16].

[2] The other logical possibility, i.e. to raise g_* to values of the order of $g_* \simeq (600-700)$ by the introduction of a sea of new particles, does not seem very economical.

[3] It has been speculated that messenger particles themselves might provide the dark matter, see for example [22, 23]. However, messengers tend to overclose the universe unless the mass of the lightest messenger is rather low, of the order of $m_{LMP} \simeq \mathcal{O}(1)\,\mathrm{TeV}$.

NLSP decays in R-parity violating variants of GMSB have been considered previously [24]. For the case of bilinear R-parity breaking the authors of [24] point out that a bound on $|\vec{\Lambda}|/\sqrt{\det \mathcal{M}_{\tilde{\chi}^0}}$ of (very roughly) the order $\mathcal{O}(10^{-6})$ for $\sqrt{F} = 10^6\,\mathrm{GeV}$ can be obtained from the requirement $\Gamma(\tilde{\chi}^0_1 \to \tilde{G}\gamma) \geq \sum \Gamma(\tilde{\chi}^0_1 \to R\!\!\!/_p)$. Fits [4] to current neutrino data [8] require similar, although somewhat larger, values for bilinear R-parity violating parameters, see next section. In our numerical calculation we thus find $\Gamma(\tilde{\chi}^0_1 \to \tilde{G}\gamma)/\sum \Gamma(\tilde{\chi}^0_1 \to R\!\!\!/_p) < 1$, unless the gravitino mass is much smaller than indicated in eq. (1.1).

The remainder of this paper is organized as follows. In the next section 2 we present some approximate formulas for the decay of the neutralino NLSP. These estimates serve to understand the results of the numerical analysis, presented next. We then close with a short summary.

2. Semi-analytical estimates

In this section we give some (semi-) analytical formulas for the decay of a neutralino NLSP. This will facilitate the understanding of our numerical results presented below. In GMSB with R-parity violation, a neutralino NLSP can either decay into a gravitino and a photon or via R-parity violating interactions directly to standard model particles.

We take into account only bilinear R-parity violating (BRpV) terms, namely,

$$\begin{aligned} W &= W_{\mathrm{MSSM}} + \epsilon_i \widehat{L}_i \widehat{H}_u\,, \\ V_{\mathrm{soft}} &= V_{\mathrm{soft}}^{\mathrm{MSSM}} + B_i \epsilon_i \tilde{L}_i H_u\,. \end{aligned} \tag{2.1}$$

Eq. (2.1) can be considered as a minimal model of R-parity violation. The new terms in V_{soft} induce vacuum expectation values for the scalar neutrinos v_i. One can either treat B_i or v_i as free parameters of the model, since they are connected by the tadpole equations.

In models with bilinear breaking of R-parity, one neutrino mass is generated at tree-level, while the other neutrino masses are due to 1-loop corrections [4]. The decay width of the NLSP to standard model particles is related to the neutrino masses, thus we first discuss some approximate formulas for the calculation of neutrino masses in BRpV models.

The tree-level contribution of BRpV to neutrino masses is given as

$$m_\nu^{\mathrm{tree}} = \frac{m_{\tilde{\gamma}}}{4 \det \mathcal{M}_{\tilde{\chi}^0}} |\vec{\Lambda}|^2\,. \tag{2.2}$$

Here, $m_{\tilde{\gamma}}$ is the "photino mass" $m_{\tilde{\gamma}} = g^2 M_1 + g'^2 M_2$, $\det \mathcal{M}_{\tilde{\chi}^0}$ is the determinant of the (4×4) MSSM neutralino mass matrix and $\vec{\Lambda}$ is the so-called alignment vector, $\Lambda_i = \epsilon_i v_d + v_i \mu$.

The dominant 1-loop corrections to the neutrino mass matrix are usually due to bottom/sbottom and tau/stau loops and are, very roughly, of order [4]

$$m_\nu^{\mathrm{1lp}} \simeq \frac{1}{16\pi^2} \left(3h_b^2 \sin(2\theta_{\tilde{b}}) m_b \Delta B_0^{\tilde{b}_2 \tilde{b}_1} + h_\tau^2 \sin(2\theta_{\tilde{\tau}}) m_\tau \Delta B_0^{\tilde{\tau}_2 \tilde{\tau}_1} \right) \frac{(\tilde{\epsilon}_1^2 + \tilde{\epsilon}_2^2)}{\mu^2}\,. \tag{2.3}$$

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Here, h_b (h_τ) are the bottom (τ) Yukawa coupling, $\theta_{\tilde{b}}$ ($\theta_{\tilde{\tau}}$) is the mixing angle in the sbottom (stau) sector, ΔB_0^{ab} is the difference of two Passarino-Veltman B_0-functions, essentially $\Delta B_0^{ab} \simeq \ln(m_a^2/m_b^2)$ for sfermion masses much larger than the corresponding fermion masses. And, finally $\tilde{\epsilon}$ are the superpotential parameters $\vec{\epsilon}$ rotated to the basis where the tree-level neutrino mass matrix is diagonal.

Eqs. (2.2) and (2.3) produce a hierarchical neutrino spectrum. We will assume that the tree-level contribution is larger than the 1-loop correction. Thus, we identify $m_\nu^{\rm tree} \simeq \sqrt{\Delta m^2_{Atm}} \simeq 0.04 - 0.06\,{\rm eV}$ and $m_\nu^{\rm 1lp} \simeq \sqrt{\Delta m^2_\odot} \simeq 0.009\,{\rm eV}$. For any given choice of R-parity conserving SUSY parameters then $|\vec{\Lambda}|/\sqrt{\det \mathcal{M}_{\tilde{\chi}^0}}$ and $|\vec{\epsilon}|/\mu$ are approximately fixed by neutrino masses. Typical values are [4]: $|\vec{\Lambda}|/\sqrt{\det\mathcal{M}_{\tilde{\chi}^0}} \sim$ (few) 10^{-6} and $|\vec{\epsilon}|/\mu \sim$ (few) 10^{-4}.

The neutralino will decay to three SM fermion final states or, if kinematically allowed, into gauge bosons and leptons, $W^\pm l^\mp$ and $Z^0\nu$. [4] To estimate the most important decay widths, we will make use of the approximate neutralino couplings in first order expansion in small $R\!\!\!/_p$parameters as given in [25].

Consider first the decay to gauge bosons. In GMSB scenarios the lightest neutralino is usually bino dominated [1]. Binos couple to gauge bosons proportional to Λ_i. With couplings from [25] and eq. (2.2) we estimate

$$\Gamma\left(\tilde{\chi}^0_1 \to \sum_i W^\pm l^\mp\right) \sim \frac{g^2 g'^2 M_2 m_{\tilde{\chi}^0_1}}{(16\pi M_1 m_\gamma)} f\left(\frac{m_W^2}{m^2_{\tilde{\chi}^0_1}}\right) m_\nu^{\rm Tree}\,. \tag{2.4}$$

Here, $f(x)$ is a phase space factor, given by $f(x) = \frac{1}{2x} - \frac{3x}{2} + x^2$. A similar expression holds for $\Gamma(\tilde{\chi}^0_1 \to \sum_i Z^0\nu_i)$ with an additional prefactor of $1/(4c_W^2)$. Assuming $M_1 \simeq M_2/2$ and $|\mu|/M_1 \simeq 4$, as is typical for GMSB models, results very roughly in $\Gamma \simeq 2 \times 10^{-4}\frac{m_\nu}{0.05\,{\rm eV}} f(m_W^2/m^2_{\tilde{\chi}^0_1})\,{\rm eV}$.

Neutralino decays to three fermions can also be mediated by scalar quark and scalar lepton exchange. With approximate scalar lepton couplings from [26] we estimate that the decay $\Gamma(\tilde{\chi}^0_1 \to \nu\tau^\pm l^\mp)$ is very roughly of order

$$\Gamma\left(\tilde{\chi}^0_1 \to \nu\tau^\pm l^\mp\right) \sim \frac{g'^2 h_\tau^2}{512\pi^3}\left(\frac{\vec{\epsilon}}{\mu}\right)^2 \left(\frac{m_{\tilde{\chi}^0_1}}{m_{\tilde{\tau}}}\right)^4 g\left(\frac{m^2_{\tilde{\chi}^0_1}}{m^2_{\tilde{\tau}}}\right) m_{\tilde{\chi}^0_1}\,. \tag{2.5}$$

Here,

$$g(y) = \frac{12}{y^2}\left(-\frac{5}{2} + \frac{3}{y} + \left(-1 + \frac{1}{y}\right)\left(-1 + \frac{3}{y}\right)\ln(1-y)\right) \tag{2.6}$$

and we have normalized $g(y)$ conveniently such that $g(0) \to 1$, thus $g(y)$ varies between $[1,6]$. Note, that $\Gamma(\tilde{\chi}^0_1 \to \nu\tau^\pm l^\mp)$ goes to zero proportional to the fourth power of $m_{\tilde{\chi}^0_1}/m_{\tilde{\tau}}$. Since in GMSB the (right) scalar tau is never very much heavier than the neutralino, contrary to squarks and other scalar leptons, eq. (2.5) usually dominates over other Feynman graphs with scalar exchange.

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[4]The decay to a light Higgs plus neutrinos, $h^0\nu$, is also possible. However, for generic GMSB parameter choices it is less important.

Eq. (2.5) can take a wide range of values. Just to give a flavour of its typical size, for $\frac{|\vec{\epsilon}|}{\mu} \sim 3 \times 10^{-4}$, $\tan\beta = 10$, and $m_{\tilde{\chi}^0_1} = 100\,\mathrm{GeV}$ and $m_{\tilde{\tau}} = 120\,\mathrm{GeV}$ one finds $\Gamma(\tilde{\chi}^0_1 \to \nu\tau^\pm l^\mp) \sim 3 \times 10^{-3}\,\mathrm{eV}$. We have checked numerically, see next section, that the decays described by eqs. (2.4) and (2.5) are usually the most important RpV decay channels in GMSB.

The decay width of a neutralino NLSP to gravitino-photon is given by [1]

$$\begin{aligned} \Gamma\left(\tilde{\chi}^0_1 \to \tilde{G}\gamma\right) &= \frac{\kappa_\gamma^2 m^5_{\tilde{\chi}^0_1}}{48\pi m^2_{3/2} M^2_{Pl}} \\ &\simeq 1.2 \times 10^{-6} \kappa_\gamma^2 \left(\frac{m_{\tilde{\chi}^0_1}}{100\,\mathrm{GeV}}\right)^5 \left(\frac{100\,\mathrm{eV}}{m_{3/2}}\right)^2 \mathrm{eV}\,. \end{aligned} \tag{2.7}$$

Here,[5] $\kappa_\gamma = |\cos\theta_W N_{11} + \sin\theta_W N_{12}|$. Neutralinos can also decay into $\tilde{\chi}^0_1 \to \tilde{G} Z^0$ and $\tilde{\chi}^0_1 \to \tilde{G} h^0$ and we include those channels in our numerical calculation. However, these final states are usually less important than $\tilde{\chi}^0_1 \to \tilde{G}\gamma$ and also do not give a promising signal. We will therefore not discuss them in further details.

From eqs. (2.4), (2.5) and (2.7) we can very roughly estimate a branching ratio of $Br(\tilde{\chi}^0_1 \to \tilde{G}\gamma) \sim 10^{-(2-3)}$ for $m_{3/2}$ of $\mathcal{O}(100)\,\mathrm{eV}$. This is the main result of the current paper. We will back up this estimate with a numerically exact calculation in the next section.

We note for comparison that if R-parity is conserved, eq. (2.7) gives a typical decay length of $c\tau \sim 20(\frac{m_{3/2}}{}\mathrm{keV})^2$ m, for a neutralino mass of $m_{\tilde{\chi}^0_1} \simeq 100\,\mathrm{GeV}$. According to [27] the ATLAS detector at LHC should be able to measure even such a "large" decay length rather well given sufficient luminosity ($100 fb^{-1}$).

Finally, we have checked that the gravitino itself lives long enough to be a dark matter candidate. Following [10] the decay width of $\tilde{G} \to \nu\gamma$ can be calculated from the photino content of the neutrino as

$$\Gamma(\tilde{G} \to \sum_i \nu_i\gamma) \simeq \frac{1}{32\pi} |U_{\gamma\nu}|^2 \frac{m^3_{3/2}}{M^2_{Pl}}\,. \tag{2.8}$$

Here, $|U_{\gamma\nu}|^2 = \sum_{i=1}^3 |\cos\theta_W N_{i1} + \sin\theta_W N_{i2}|^2$. The coupling matrices N_{i1} and N_{i2} can be calculated perturbatively [4] and are approximately fixed from the neutrino masses. For $M_1 = 100\,\mathrm{GeV}$ and $m_{3/2} = 100\,\mathrm{eV}$, we find $|U_{\gamma\nu}|^2 \sim 3.5 \times 10^{-14} \frac{m_\nu}{0.05\,\mathrm{eV}}$. This corresponds to a half-life of the order of 10^{31} Hubble times.

3. Numerical results

We stress that none of the approximations discussed above were used in our numerical analysis. Numerical results presented below have been obtained as follows. We generated supersymmetric particle spectra using the package SPheno [28]. GMSB is characterized by two mass scales, the scale of supersymmetry breaking F and the messenger mass M_M.

[5] In MSSM notation. In the notation of [4]: $N_{1j} \to N_{4j}$

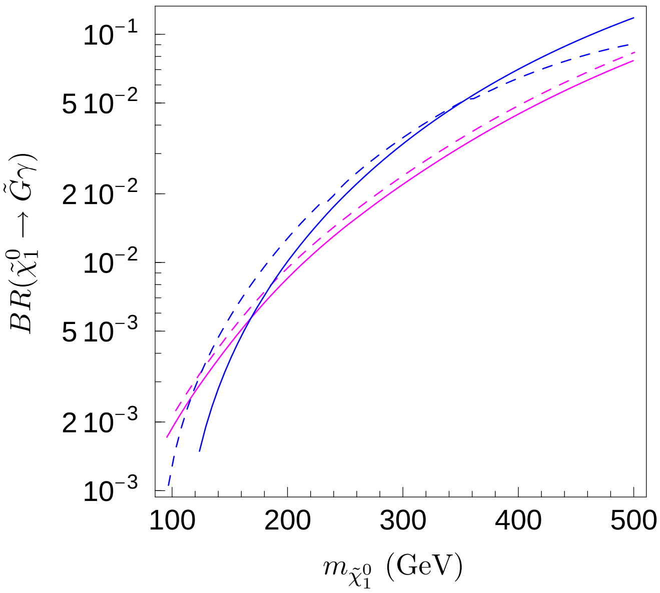

Figure 1: $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ as function of the lightest neutralino mass, $m_{\tilde{\chi}_1^0}$ (GeV). Full lines are for $\mu > 0$, dashed lines $\mu < 0$. Light (on colour printers magenta): $\tan\beta = 10$, Dark (blue): $\tan\beta = 35$.

Since F is related to the gravitino mass via [1]

$$m_{3/2} = \frac{F}{k\sqrt{3}M_P} \tag{3.1}$$

we trade F for the gravitino mass and vary $\Lambda^{GMSB} = F/M_M$ independently. For details see [1]. For definiteness we take $k = 1/20$. We have checked that our results depend only very weakly on the exact value of k as long as $k < 1$. In addition, we have $\tan\beta$, the sign of μ and the number of messengers, n_5, as free parameters. We use only $n_5 = 1, 2$ because for larger values of n_5 the neutralino is rarely the NLSP, since scalar masses scale as $m_{\tilde{\tau}}/m_{\tilde{\chi}_1^0} \sim 1/\sqrt{n_5}$.

We check the generated spectra for a number of phenomenological limits [12]: $m_{\tilde{\chi}_1^+} \geq 105\,\text{GeV}$, $m_{\tilde{\mu}} \geq 95\,\text{GeV}$ and $m_{\tilde{\tau}} \geq 82\,\text{GeV}$. Lower limits on the mass of the lightest neutralino in GMSB have been published by all LEP collaborations [29], bounds are between $92 - 100\,\text{GeV}$ depending on the details of the analysis. However, we have found that the most important constraint for us is the lower limit on the mass of the lightest Higgs [30], which essentially cuts out all points with $m_{\tilde{\chi}_1^0} \lesssim 100\,\text{GeV}$ from our scans.

R-parity violation is then included into SPheno [28] as described for neutrino masses in [4] and for neutralino decays in [25]. Special care is taken to diagonalize the neutrino-neutralino mass matrix at 1-loop order to give neutrino masses and mixings compatible with the values indicated by atmospheric and solar neutrino experiments [8]. For each set of GMSB parameters, $m_{3/2}$, Λ^{GMSB}, $\tan\beta$, $sgn(\mu)$ and n_5, this results in a restricted range of Λ_i and ϵ_i, as discussed above, from which then the RpV neutralino decays are calculated. From the discussion in the previous section one expects that the errors in our calculated branching ratios scale proportional to the errors in the neutrino masses and

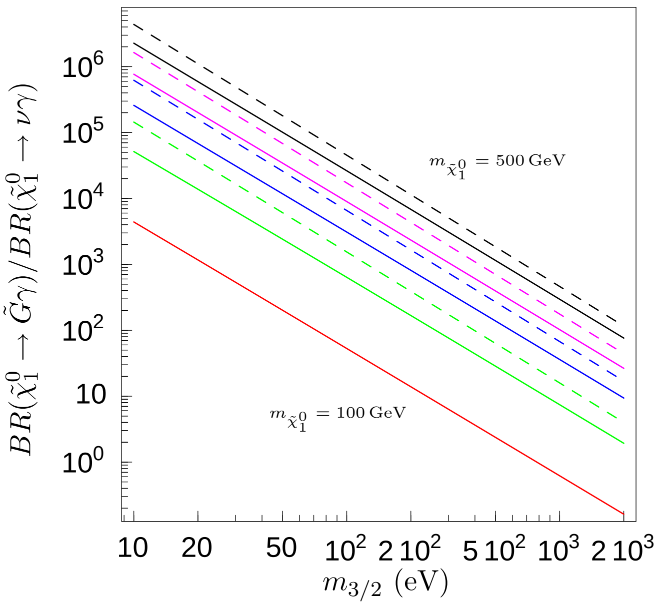

Figure 2: Ratio $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)/BR(\tilde{\chi}_1^0 \to \nu\gamma)$ as function of $m_{3/2}$ eV. Full lines are for $\tan\beta = 10$, dashed lines for $\tan\beta = 35$. The plots shows the case $n_5 = 1$, for $n_5 = 2$ the ratio is typically a factor (2-3) smaller. The different lines are for (from bottom to top) $m_{\tilde{\chi}_1^0} = 100 - 500\,\text{GeV}$ in steps of 100 GeV.

we have checked numerically that this assertion is correct. Results discussed below use neutrino masses near the best fit points for solar and atmospheric physics [8]. Finally, for the calculation of the branching ratio into gravitino plus photon eq. (2.7) is used.

Our numerical results show that the dominant final states are usually either $\tau^\pm l^\mp \nu$ or $W^\pm l^\mp$ (and $Z^0\nu$). Gauge boson final states become more important the larger $m_{\tilde{\tau}} - m_{\tilde{\chi}_1^0}$, as discussed above, and for larger $m_{\tilde{\chi}_1^0}$. We find that for $m_{\tilde{\chi}_1^0} \geq 150\,\text{GeV}$ the final state $h^0\nu$ can reach a branching ratio of the order of $5 - 15$ %. All other final states usually have branching ratios which are smaller. Especially, we find that the final state $b\bar{b}\nu$ is less important than in an mSugra scenario [25]. This can be understood as being due to the smaller ratio of $m_{\tilde{\tau}_1}/m_{\tilde{b}_1}$ in GMSB compared to mSugra. With typical total widths in the range of roughly $\mathcal{O}(10^{-4}) - \mathcal{O}(10^{-2})$ eV, we expect that the neutralino decays with a displaced vertex.

In figure 1 we show the branching ratio $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ as a function of NLSP mass for $n_5 = 1$, two values of $\tan\beta$, both signs of μ and for a fixed value of $m_{3/2} = 0.1\,\text{keV}$. The branching ratio rises strongly with increasing neutralino mass, as expected from eq. (2.7). The plot also shows that the dependence on $\tan\beta$ is rather weak, changing $\tan\beta$ from 10 to 35 induces a change in the branching ratio up to a factor of ~ 2. It is also obvious that the sign of μ is not decisive. Choosing $n_5 = 2$ reduces the branching ratio by typically a factor of ~ 3 compared to the results shown.

The experimental signal for the final state $\tilde{G}\gamma$ is $\not{E}\ \gamma$. In R-parity violating models the neutralino has another decay mode which gives the same experimental signal, namely $\tilde{\chi}_1^0 \to \nu\gamma$. In BRpV this occurs at 1-loop order. To estimate this background we have

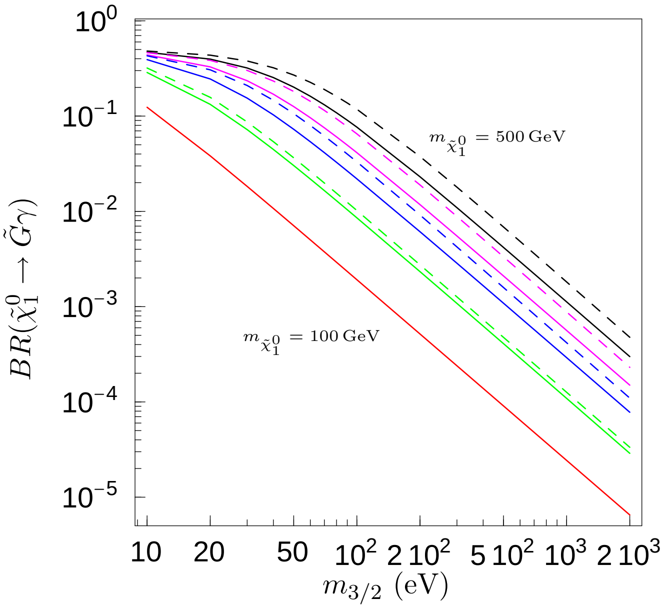

Figure 3: Ratio $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ as function of the gravitino mass, $m_{3/2}$ (eV). Full lines are for $\tan\beta = 10$, dashed lines $\tan\beta = 35$. Lines from bottom to top are for different values of $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_1^0} = 100 - 500\,\mathrm{GeV}$ in steps of $100\,\mathrm{GeV}$. $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ is larger than 10^{-4} for values of $m_{3/2}$ between $0.5 - 2.0\,\mathrm{keV}$, depending on the neutralino mass.

done a calculation of $BR(\tilde{\chi}_1^0 \to \nu\gamma)$. Figure 2 shows $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)/BR(\tilde{\chi}_1^0 \to \nu\gamma)$ as a function of the gravitino mass, for two different choices of $\tan\beta$ and for $n_5 = 1$ for various different values of $m_{\tilde{\chi}_1^0}$. The ratio depends strongly on the neutralino and gravitino masses, for $m_{3/2} \leq 500\,\mathrm{eV}$ it is always larger than 1. For neutralino masses greater than about $m_{\tilde{\chi}_1^0} \simeq 150\,\mathrm{GeV}$ $\nu\gamma$ never seems to be a serious problem up to gravitino masses $m_{3/2} = 2\,\mathrm{keV}$.

Finally, figure 3 shows our main result. Here we plot $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ as a function of the gravitino mass for different values of $m_{\tilde{\chi}_1^0}$, two values of $\tan\beta$ and $n_5 = 1$. $n_5 = 2$ leads to branching ratios approximately a factor of up to 3 smaller. Depending on the neutralino mass, $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ is larger than 10^{-4} for values of $m_{3/2} \simeq 0.5\,\mathrm{keV}$ up to $m_{3/2} \simeq 2\,\mathrm{keV}$. At the LHC one expects to produce very roughly of the order of $\mathcal{O}(10^5)$ - $\mathcal{O}(10^7)$ events from supersymmetry, depending mainly on squark and gluino masses. Thus we think that sufficient statistics to measure branching ratios as small as 10^{-4} should be possible. We conclude therefore, that for cosmologically interesting ranges for the gravitino mass measurably large branching ratios $BR(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ should exist.

4. Conclusions

We have discussed decay properties of the lightest neutralino in models with gauge mediated supersymmetry breaking in which the neutrino masses and mixings are explained by bilinear R-parity violation. Once the BRpV parameters are approximately fixed with information from the neutrino sector, the branching ratio into gravitino plus photon is fixed to be in the range $10^{-(2-3)}$ for a gravitino mass of the order of (few) $100\,\mathrm{eV}$. The branching ratio decreases with increasing gravitino mass. In the scenario discussed one can therefore test whether the gravitino gives a significant contribution to the dark matter of the universe by a "simple" counting experiment.

Can one do better? - Concerning the gravitino mass, the answer is yes. A measurement of the decay length of the neutralino would fix the total neutralino decay width, independent of our assumptions about neutrino masses. Knowing the width and the mass of the neutralino fixes the gravitino mass from the measurement of $Br(\tilde{\chi}_1^0 \to \tilde{G}\gamma)$ in a much tighter range than what we have been able to do. However, one has to admit that even knowing the gravitino mass rather well, one can not calculate $\Omega_{3/2}$ reliably from $m_{3/2}$ without making specific assumptions on the thermal history of the universe. In this sense, gravitino DM can be ruled out by the measurement we have discussed, but never "experimentally confirmed".

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