29th International Cosmic Ray Conference Pune (2005) **9**, 255-258

Impact of A_0 on the mSUGRA parameter space and consequences for Dark Matter Searches

Luisa Sabrina Stark[a], Petra Häfliger[a,b], Adrian Biland[a] and Felicitas Pauss[a]
(a) Institute for Particle Physics, ETH Zurich, CH-8093 Zurich, Switzerland
(b) Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
Presenter: Adrian Biland (biland@particle.phys.ethz.ch) swi-biland-A-abs1-he23-oral

In mSUGRA models the lightest supersymmetric particle (assumed to be the lightest neutralino) provides an excellent cold dark matter (CDM) candidate. Using the deduced limit on the CDM relic density $\Omega_{CDM}h^2$ from WMAP data, the supersymmetric parameter space is significantly reduced. However, recent calculations have demonstrated that this parameter space exhibits an important dependence on the trilinear scalar coupling A_0, assumed to be zero in earlier calculations.
This A_0 parameter also influences the predicted γ-ray flux expected from neutralino-pair annihilation like e.g. in the galactic center and thus impacts on the possible detection of CDM using Cherenkov telescopes.

1. Introduction

The Standard Model (SM) of particle physics describes experimental data with an impressive accuracy. Nevertheless, the SM encounters several theoretical problems, which cannot be solved without introducing new physics. The supersymmetric (SUSY) extension of the SM appears to have the necessary features for a valuable theory beyond the SM. These features include its role in understanding the fundamental distinction between bosons and fermions, the problem of hierarchy and unification. In addition, in the mSUGRA framework of SUSY, the lightest neutralino (χ) – a neutral, stable, massive and weakly interacting particle – is an excellent cold dark matter (CDM) candidate.

The SUSY parameter space in mSUGRA scenarios is usually studied in terms of the common scalar mass m_0, the common gaugino mass $m_{1/2}$, $\tan\beta$ (the ratio of the Higgs expectation values) and the sign of the Higgsino mass parameter μ. However, the fifth free parameter, the common trilinear scalar coupling A_0 was usually set to zero. In recent studies, the impact of non-zero A_0 values on the mSUGRA parameter space was recognized [1]. The soft SUSY breaking part of the Lagrangian provides additional contributions to the couplings of Higgs bosons to sfermions. However, as they are proportional to the mass of the corresponding SM fermion, they are only relevant for the third generation. These new couplings affect the masses of the SUSY particles (sparticles) through renormalization group evolutions and through mixing effects.

The inclusion of cosmological experimental data reduces significantly the mSUGRA parameter space. The satellite born WMAP experiment measured the abundance of CDM in the universe to be $0.094 < \Omega_{CDM}\, h^2 < 0.129$ (at 2σ C.L.) [2]. The relic density of the CDM particles, $\Omega_{CDM}h^2$, is connected to the neutralino annihilation cross section by the Lee-Weinberg equation. A variation of A_0 affects the effective cross section and therefore also the relic density through the dependence of the SUSY particle masses on these trilinear scalar couplings at the electroweak scale. Thus, the allowed SUSY parameter space also depends on the assumed A_0 values. Furthermore, the number of photons produced per neutralino annihilation, as well as the photon energy, depend on the annihilation products and exhibit a strong mSUGRA parameter dependence.

2. The mSUGRA Parameter Space

Assuming CDM to consist exclusively of the lightest neutralino, the cosmological bounds on the neutralino relic density $\Omega_\chi h^2$ imply constraints on the mSUGRA parameter space, which however also depend on A_0, as illustrated in Fig. 1. Under the assumption of $A_0 = 0$ and fixed tanβ values, only narrow lines in the $m_0 - m_{1/2}$ plane (left plot in Fig. 1) are left over as allowed regions after including WMAP data [3]. The right plot of Fig.1 illustrates the effect of varying A_0 within ± 4TeV [4]. In contrast to the left plot, where only a line survived the WMAP constraints for each chosen tanβ value, extended regions in the mSUGRA parameter space are allowed for the same tanβ value, if A_0 is varied. For example, for tanβ = 10, mSUGRA parameter regions up to $m_0 \sim 350$ GeV and large negative A_0 values are within the WMAP constraints, while for $A_0 = 0$ only regions up to $m_0 \sim 200$ GeV are allowed. A similar behavior can be observed for larger tanβ values [4].

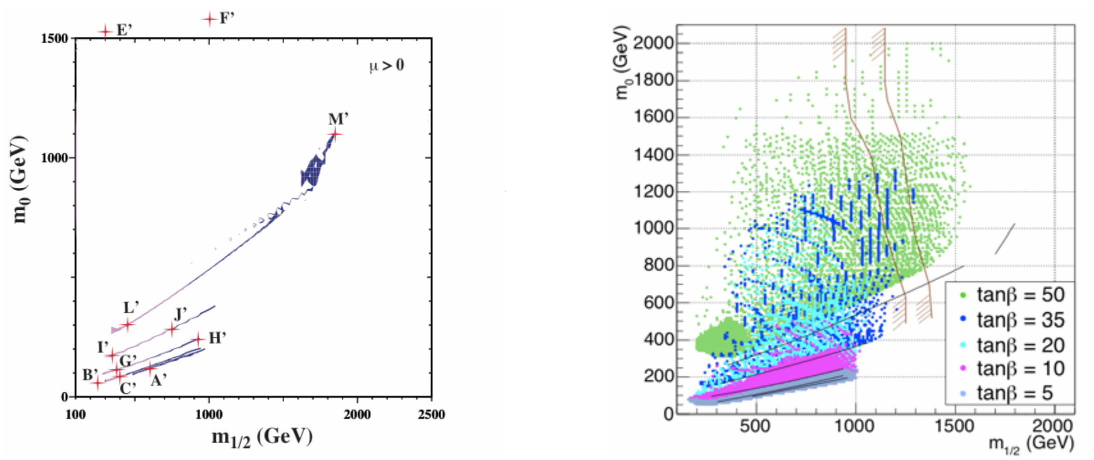

Figure 1. Allowed parameter space for m_0 and $m_{1/2} \leq 2$ TeV, tanβ = 5, 10, 20, 35, 50 and μ > 0 after imposing the WMAP constraints on $\Omega_\chi h^2$. In the left plot a vanishing trilinear scalar coupling A_0 is assumed, while A_0 was left free between ± 4 TeV in the right plot. The brown lines in the right plot indicate the LHC discovery reach for an integrated luminosity of 100 fb^{-1} and 300 fb^{-1} respectively.

3. γ-Ray Flux from CDM annihilation

The expected γ-ray flux is a function of the SUSY parameters and the halo properties of the observed target:

$$\Phi_\gamma(\Psi) = \underbrace{\frac{N_\gamma < \sigma v >}{4\pi M_\chi^2}}_{\text{fSUSY}} \cdot \underbrace{\frac{1}{2}\int_{los} \rho^2(l) dl(\Psi)}_{\text{J}(\Psi)} .$$

The factor derived from particle physics is called fSUSY and includes the information about the number of photons produced per annihilation N_γ, the thermal average of the annihilation cross section times the velocity < συ > and the neutralino mass M_χ. The cosmological characteristics of the source enter in the calculation of the so called J(Ψ)–factor, which is the integral over the line of sight (*los*) of the CDM density distribution (ρ^2). Ψ is the angle between the direction of the target and that of observation.

The properties of the SUSY model determine the fSUSY factor. Three different parameter regions in the $m_0 - m_{1/2}$ plane exist (Fig. 2a): The bulk region at low m_0 , $m_{1/2}$ values, the focus point region at low $m_{1/2}$ values and the region for very high m_0 values. mSUGRA models with m_0 values in the multi TeV region correspond to large fSUSY factors (Fig. 2b). Thus, these models provide higher γ-ray fluxes, but they are unfavored in particle physics. In the following only the upper bound on the CDM relic density provided by WMAP is respected, as the total amount of CDM may not consist exclusively of neutralinos.

The fSUSY factor is detector dependent, since the energy threshold of the telescope affects the measured photon yield per annihilation. The number of photons produced per neutralino annihilation can be parameterized as a function of the energy threshold and the neutralino mass [5]. This parameterization (black line in Fig. 2c) reproduces reasonably well the number of photons produced in the different fragmentation processes (denoted as N_γ^{cc}, etc) and in channels including gauge and Higgs bosons (N_γ^{WW}, etc). However, neutralinos may also annihilate producing a lepton pair (e.g. yellow line in Fig. 2c for ττ production). For these processes the parameterization is not a good approximation. For models with m_0 smaller than 2 TeV the annihilation into two tau leptons produces the largest amount of detectable photons, whereas for larger m_0 values, most of the photons originate from W, Z and top pair productions (Fig. 3). Thus the parameterization of the photon yield N_γ shown in Fig. 2c is not appropriate for the low m_0 region.

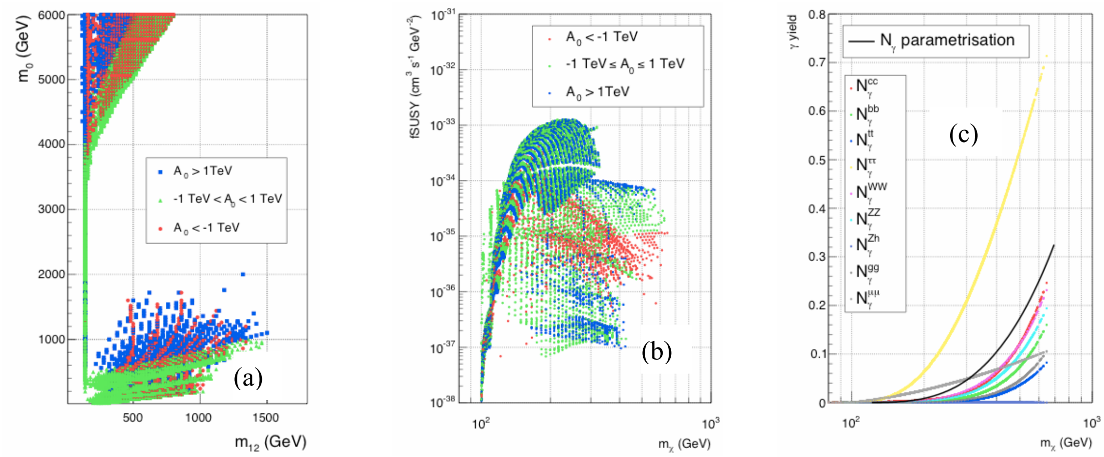

Figure 2. (a) Allowed mSUGRA models in the $m_0 - m_{1/2}$ plane for different A_0 regions (all other parameters like in Fig. 1). (b) The corresponding fSUSY factor and (c) the γ-yield per annihilation as a function of the neutralino mass, assuming an γ-energy threshold of 100 GeV. N_γ^{ij} represents the γ-yield for different annihilation products.

Since the energy dependence of the neutralino CDM flux does not depend on the cosmological J(Ψ) factor, the form of the annihilation spectra is already defined by the fSUSY factor (Fig. 4). The spectra of models with a small neutralino mass show a strong A_0 dependence for small values of tanβ.

4. Conclusions

The lightest neutralino in the MSSM is an excellent CDM candidate. Within the mSUGRA framework neutralino annihilation cross sections can be calculated. However, the predicted number of photons produced per annihilation as well as their energy spectrum depends strongly on the chosen parameters. Particular care must be taken to also include a possible non-zero trilinear scalar coupling A_0, resulting in an extended area of the allowed SUSY parameter space, after taking WMAP constraints into account. This also influences the discovery potential for CDM using space-born or ground-based instruments for photon detection.

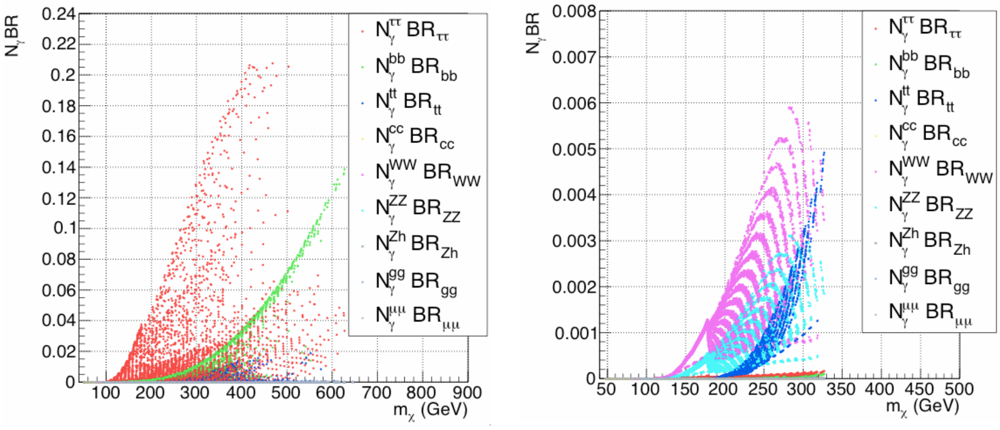

Figure 3. Photon yield multiplied by the branching ration for models with low m_0 values (left plot) and high m_0 values (right plot) with an assumed energy threshold of 100 GeV.

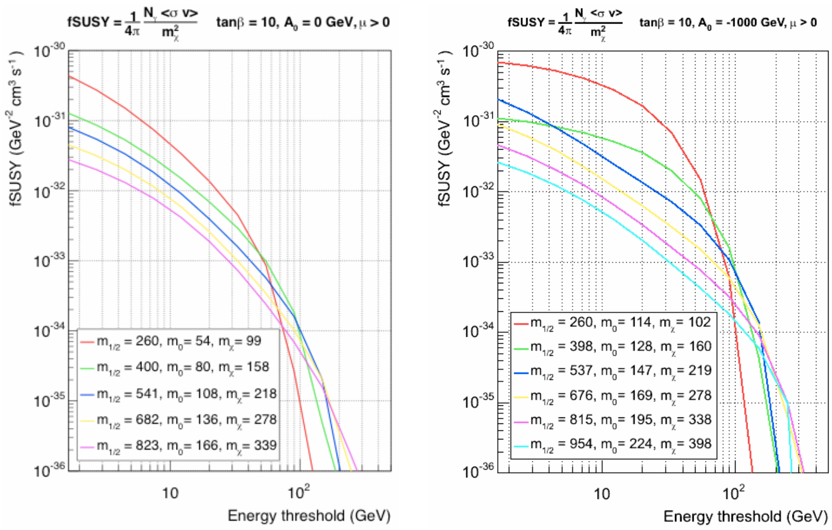

Figure 4. Annihilation spectra as a function of the γ energy threshold for different mSUGRA models assuming $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$ GeV (left plot) and $A_0 = -1000$ GeV (right plot). The masses are given in units of GeV.

References

[1] V. Bertin, E. Nezri and J. Orloff, *Eur.Phys.J.* **C26** (2002) 111;
J.R. Ellis, S. Heinemeyer, K.A. Olive and G. Weiglein, *JHEP* **0502** (2005) 013.

[2] C. Bennett et al., *Astrophys. J. Suppl.* **148** (2003) 1;
D.N. Spergel et al. [WMAP Collaboration], *Astrophys.J.Suppl.* **148** (2003) 175.

[3] J.R. Ellis, K.A. Olive, Y. Santoso, V.C. Spanos, *Phys. Lett.* **B565** (2003) 176.

[4] L.S. Stark, P. Häfliger, A. Biland and F. Pauss, arXiv:hep-ph/0502197, accepted for JHEP

[5] A. Tasitiomi and A.V. Olinto, arXiv:astro-ph/0206040.