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MSSM parameters space regions allowed by indirect neutralino detection

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ABSTRACT

We show a simple method, based on the standard χ^2 test statistic, to discriminate what supersymmetric models are detectable by indirect searches of neutralino annihilation. We can then put different constraints on the allowed region of the parameters space of the MSSM.

1 Introduction

The neutralino seems to be one of the most promising candidate as a constituent for cold dark matter [1], i.e. non relativistic at the temperature of the freeze out. It appears to be the LSP (Lightest Supersymmetric Particle) in a large portion of the parameters space of the MSSM, that is the minimal supersymmetric extension of the standard model with R-parity conservation

[4]. Indirect detection is possible through the search of neutralino annihilation products that are produced in the galactic halo. The detectable products are the typical constituents of cosmic rays such as antiprotons, positrons and gamma rays [2]. Here we consider mainly the antiprotons production [3]. Cosmic ray induced antiprotons are generated mainly through $pp \rightarrow \bar{p} + X$ collisions of cosmic ray protons with interstellar medium.

2 Theoretical framework

We work in the framework of the Minimal Supersymmetric extension of the Standard Model (MSSM) with the allowed renormalizable soft supersymmetry breaking terms [4]. The phenomenological parameters are reduced to 7 starting from the usual 125 [5]: μ the higgsino mass parameter, M_2 the gaugino mass parameter, m_A the CP-odd Higgs bosons mass, $\tan(\beta) = v_2/v_1$ the higgs bosons vacuum expectation ratio, m_q the scalar mass parameter, A_b and A_t the trilinear coupling in the bottom and top sector respectively.

These parameters are given at the electroweak symmetry breaking scale, i.e. at energy of order of 1 TeV.

The lightest neutralino is defined, as usual, as a linear combination of the gauginos $\widetilde{B}$ and $\widetilde{W}^3$, the superpartners of the $U(1)$ gauge field B and the third component of the $SU(2)$ gauge field W^3 that appears in the standard model, and the neutral higgsinos $\widetilde{H}_1^0$ and $\widetilde{H}_2^0$, that are the superpartners of two of the Higgs bosons doublet neutral components that appears explicitly in the MSSM:

$$\chi = N_{10}\widetilde{B} + N_{20}\widetilde{W}^3 + N_{30}\widetilde{H}_1^0 + N_{40}\widetilde{H}_2^0 \tag{1}$$

We have used the DarkSUSY [6] fortran routines for the differential antiproton flux calculation. We have considered, at tree level, the relevant states for $\bar{p}$ production. These include all the heavier quarks (c, b, and t), gauge bosons and Higgs bosons, and the subsequent hadronization of the states. In input we have used a random generated sampling of the parameters space of the order of 10^5 models. The only constraint used here, in addition to the physical consistency, is that on the neutralino relic density, in order to get rid of this dependence. We have used for the allowed range for the cold dark matter relic abundance:

$$0.1 \leq \Omega_{DM} h^2 \leq 0.3 \tag{2}$$

where Ω_{DM} is the ratio between the dark matter density and the critical density and h is a parameter in the Hubble constant.

3 Supersymmetric detectable models

The problem is to discriminate between different supersymmetric models. The intuitive idea is to "calculate" how far are the two flux curves, the background and the supersymmetric contribution (fig. 1). The first curve, the background curve, is obtained considering only the standard model production and propagation of the $\bar{p}$ [7]. In the background contribution is not present any source of exotic components. The other curve, the supersymmetric contribution, represents the contribution coming from a source of annihilating neutralinos.

To do this job we can use an hypothesis test method. The simplest of this method is the χ^2 test. We use the usual definition of the reduced χ^2 as:

$$\chi_r^2 = \frac{1}{N-1} \sum \frac{(y_i - x_i)^2}{\sigma_i^2} \tag{3}$$

where N is the number of degrees of freedom, i.e. the number of points in which we calculate the fluxes. In order to be able to apply this kind of test we must associate an error to the points of, at least, one of the theoretical flux curves (the standard one or the standard plus susy contribution). A simplifying assumption is to consider only the statistical errors naturally coming from a counting experiment. So, indicating with N_i the number of counts, the associated error is the Poisson one:

$$\sigma_i = \sqrt{N_i} \tag{4}$$

There is a simple relation between flux and number of counts, that depends explicitly by the detector characteristics of the particular experiment we want to consider:

$$N_i = \phi_{\overline{p}} \cdot A \cdot \Delta t \cdot \Delta E_i \tag{5}$$

where $\phi_{\overline{p}}$ is the antiproton flux in units of $GeV^{-1} m^2 sr^{-1} s^{-1}$, A is the effective area of the detector, Δt is the acquisition data time and ΔE_i is the energy bin. With the aim of this formula it's straightforward to calculate the statistical error associated to the flux (fig. 1), that is:

$$\Delta\phi = A \cdot \Delta t \cdot \Delta E_i \cdot \sigma_i \tag{6}$$

Fixing the significance level, we accept, as detectable, all the models, for a given number of degrees of freedom, that satisfy:

$$\chi_r^2 \geq c \tag{7}$$

where c can be obtained from the standard tabulation [8], i.e. integrating the probability distribution function of the χ_r^2.

4 Limits on the parameters space

We can use this machinery in order to single out parameters space regions that generate models with detectable flux. This can be achieved for example, making contour plots of χ_r^2 vs. model parameters. The main problem is to reduce the number of parameters to consider. There are two ways to do this. One is to start *ab initio* with a more constrained models, such as for example the CMSSM, or models with anomaly mediated supersymmetry breaking. This is, by far, the most appealing possibility from a pure theoretical ground, because at he end we wants some theory with less phenomenological parameters as possible. The other is to identify the relevant parameters for a given process, fixing the values of the others. This can be justified if the χ_r^2 weakly depends by some parameters.

When we consider the processes of $\bar{p}$ production (fig. 2), we see that two of the relevant parameters are the neutralino mass M_χ and the gaugino fraction Z_g, that are function, in terms of the fundamental parameters that define the model, of M_2, μ and $tan(\beta)$.

5 Conclusions

The method, described above, allows to understand what kind of models are phenomenologically interesting, considering only indirect detection of neutralino annihilations. This implies that we are able to identify what regions of parameters space can really be probed, and what regions are not yet explorable. We

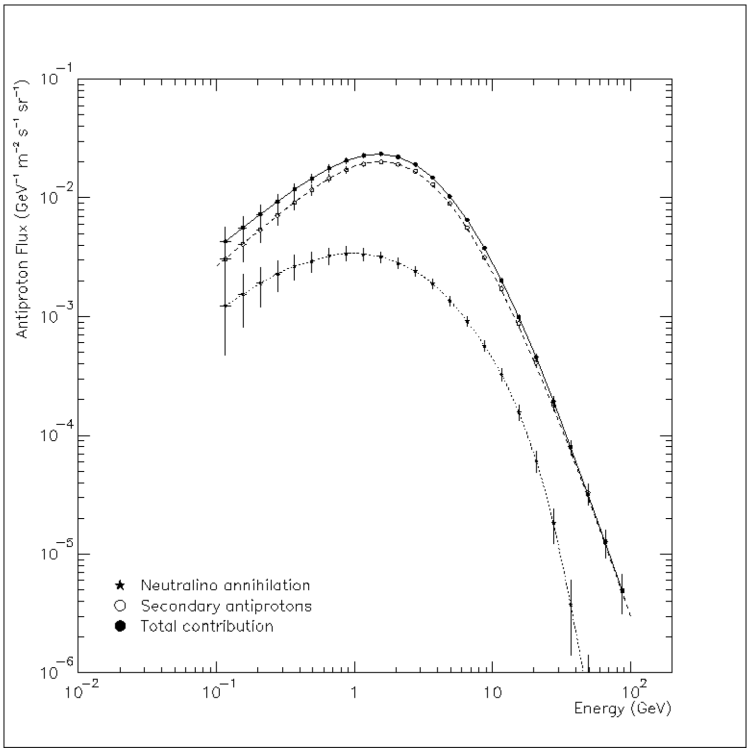

Figure 1: *flux from a particular supersymmetric model.*

can also consider immediate extension for positrons and gamma rays, in order to put more constraints.

One possible development concerns the possibility to apply some other test hypothesis method, such as the generalized likelihood ratio, or even some more sophisticated method such as bayesian and neural networks. It would be interesting to find some algorithmic procedure in order to be able to scan a large portion of the parameters space.

The other possible development concerns the study of theoretical models that involve a less number of parameters, such as the anomaly mediated

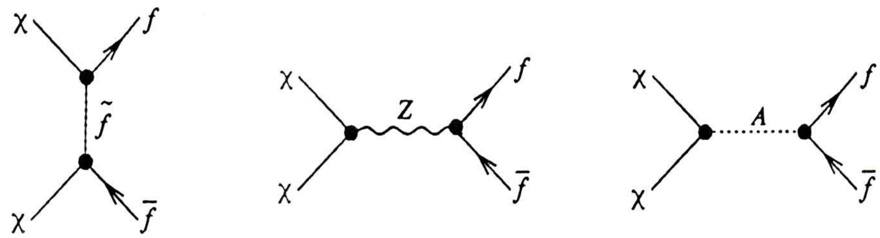

Figure 2: *relevant diagrams or the process* $\chi\chi \rightarrow p\bar{p}$.

supersymmetry breaking models.

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