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ANTIMATTER SEARCHES AS PROBES OF SUSY DARK MATTER

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Abstract

We investigate the discrimination perspectives for neutralino dark matter at future antimatter search experiments. Theoretically well motivated benchmark scenarios are introduced, with the purpose of comparing projected experimental search strategies, and in order to show in which cases antimatter searches could be of particular relevance. We resort to *visibility ratios* (*i.e.* signal-to-sensitivity ratios) which allow a comparison among different neutralino dark matter detection techniques. We also introduce a novel quantity, I_ϕ, defined as an integral of the squared expected exotic signal over the background, which allows to estimate the future reach of antimatter search experiments independently of the experimental apparatus. We point out that antiprotons, positrons and antideuterons searches constitute a primary neutralino dark matter search strategy for a class of large annihilation rates models, which will be largely probed at upcoming experiments, like PAMELA and AMS-02.

1 Introduction

The Dark Matter (DM) problem, *i.e.* the observation that the majority of the matter content of the Universe is made of some kind of non-luminous and non-baryonic gravitationally interacting substance, stands as one of the greatest challenge in astroparticle physics. As now, many particle candidates have been proposed to solve the DM puzzle, and an extensive experimental program has been deployed with the purpose of detecting and understanding this elusive not less than seemingly inevasible component of the Universe. One of the best theoretically motivated candidates is the *lightest supersymmetric particle*, LSP, of the minimal supersymmetric extension of the Standard Model (MSSM), which turns out to be an ideal DM claimant, provided it is the lightest neutralino (as it is the case in large parameter space regions of many SUSY breaking scenarios).

Complementarity between direct detection and indirect detection methods has been repeatedly stressed [1]. However, the question regarding how competitive a given detection technique is compared to the others, can be addressed only resorting to particular particle physics frameworks, and making definite assumptions about the features of the Milky Way DM Halo.

In the present paper we address the issue of confronting a set of leading DM search strategies, focusing in particular on antimatter searches [2]. Pair annihilation is the mechanism which sets the thermal relic abundance of neutralinos; although the density of neutralinos in DM halos today is much smaller than in the early Universe environment, there is still a finite probability for WIMPs in the Galactic halo to annihilate in pairs. In these annihilations the same amount of matter and antimatter is produced; while the matter component is likely to be very subdominant compared to standard astrophysical sources, there seems to be no standard primary source of antimatter, with the bulk of the (scarce) antimatter component in cosmic rays which is likely to be of secondary origin, i.e. generated in the interaction of primary cosmic rays (mainly protons) with the interstellar medium (mainly hydrogen and helium). The goal is then to identify, through their peculiar spectral features, the WIMP-induced antimatter fluxes, or at least to exclude those DM candidates which would overproduce antimatter compared to the relatively low background term.

We will first outline our particle physics setup, in sec. 2, defining a set of benchmark neutralino models which we claim to be of particular relevance at antimatter searches; then, in sec. 3, we provide the details of our calculation of the antimatter fluxes. Finally, sec. 4 is devoted to the question of the future discrimination sensitivity at antimatter search facilities, and summarizes the comparison of the latter with different direct and indirect detection techniques. We draw our conclusions in sec. 5.

Model	$M_{1/2}$, $m_{3/2}$, M_3	$\tan\beta$	sgn(μ)	Defining Condition
Funnel	$700 \div 1450$	55	> 0	$2\, m_\chi \simeq m_A$
AMSB	$23 \div 231$	50	> 0	$m_0 = 1500$ GeV
NUGM	$879 \div 1096$	50	> 0	$M_1/M_3 = 10$, $M_2/M_3 = 2$, $\widetilde{H} = 99.8\%$

Table 1: The defining parameters for three SUSY models under consideration (see [2] for details).

2 Large Annihilation Rates Benchmark Models

From the point of view of indirect detection experiments, the most favorable situation in the particle physics setup occurs when neutralinos feature large pair annihilation rate $\langle\sigma_{\rm ann} v\rangle$. Since the thermal relic abundance of neutralinos in a standard cosmological setup forces $\langle\sigma_{\rm ann} v\rangle \simeq 3 \cdot 10^{-27}{\rm cm}^3{\rm s}^{-1}/\Omega_{\rm CDM}h^2$, resorting to models with a large annihilation rate translates into assuming that either non-thermal mechanisms of neutralino production, or cosmological enhancement processes are operative [3]. We focus here on three benchmark neutralino scenarios, respectively featuring bino, wino and higgsino like LSP's (see Tab. 1). The models present remarkable purity in their dominant gauge-eigenstate component, in all cases larger than 98%, and the values for $\langle\sigma_{\rm ann} v\rangle$ lie, at a sample neutralino mass of 300 GeV, between 10^{-24} and 10^{-25} ${\rm cm}^3{\rm s}^{-1}$.

3 Computing Antimatter Yields

We discuss here the case of neutralino-induced antiproton, positron and antideuteron cosmic ray fluxes. The stable antimatter species generated by neutralino annihilations are simulated using the Monte Carlo code `Pythia` [4] 6.154, and we take the conservative cored Burkert profile as the reference DM halo model [5]. Concerning the propagation of charged cosmic rays through the Galactic magnetic fields, we consider an effective two-dimensional diffusion model in the steady state approximation where the diffusion coefficient D takes the form of a broken power law in rigidity, R,

$$\begin{aligned} D = D_0\,(R/R_0)^{0.6} \qquad & \text{if} \quad R \geq R_0 \\ D = D_0 \qquad & \text{if} \quad R < R_0\,. \end{aligned} \tag{1}$$

We take eq. (1) with $D_0 = 2.5 \times 10^{28}$ cm^2 s^{-1} and $R_0 = 4$ GV, in a cylindrical diffusion region of radius equal to 30 kpc and half height equal to 4 kpc, plus a galactic wind term (see [2] for details). Finally, to sketch solar modulation effects we implement the one parameter model based on the analytical force-field approximation [7] taking for simplicity the parameter `smod` to be charge-independent.

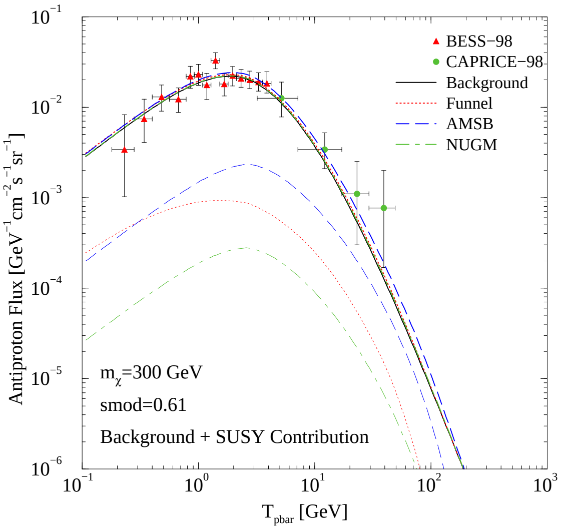

Figure 1: The solar modulated antiproton flux, as a function of the antiprotons kinetic energy $T_{\rm pbar}$ [2].

Fig. 1 shows the spectral features, after solar modulation for a given step along the solar activity cycle, of primary antiprotons and of the background, comparing the total expected signals to the data taken during the corresponding modulation phase. The figure refers to a common neutralino mass of 300 GeV. As regards the secondary antimatter fluxes, which play here the role of backgrounds, our estimates are produced running the `Galprop` [6] code in the configuration for propagation parameters we have adopted for the signals. We remark that we find, for both antiprotons and positrons, that the computed backgrounds provide by themselves excellent fits of the data: we obtain, for background only, a reduced χ^2 equal to 0.82 for antiprotons and to 0.95 for positrons. Excessive exotic signals may be therefore statistically ruled out [2].

4 Discrimination of SUSY DM Through Antimatter

New generation space-based experiments for antimatter searches PAMELA and AMS [8] will tremendously enhance the resolution and accuracy of positron and antiproton spectra measurements, as compared to existing balloon borne results. With the purpose of assessing discrimination capabilities of future experimental facilities, we will sketch here the possibility of disentangling an exotic component out of a standard secondary background. To this extent, we introduce a novel quantity, I_ϕ, to compare the case of a pure background

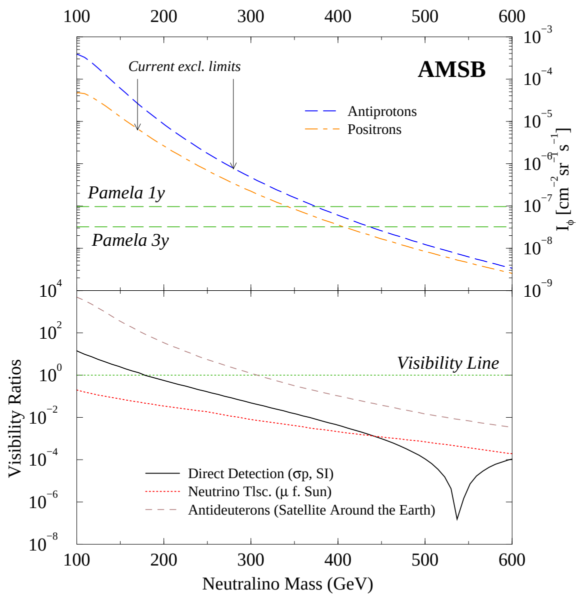

Figure 2: The comparison of future sensitivities for various detection techniques in the **AMSB** model.

measurement to that of the occurrence of a signal. It can be shown [2] that a signal with flux ϕ_s can be discriminated from a background flux ϕ_b at a payload with geometrical factor A and time of data acquisition T, at 95% C.L., if

$$I_\phi \equiv \int_{E_{\rm min}}^{E_{\rm max}} \frac{\phi_s^2}{\phi_b} {\rm d}E > \frac{(\chi^2)^{95\%}_{n_{\rm b}}}{A \cdot T}, \tag{2}$$

where $(\chi^2)^{95\%}_{n_{\rm b}}$ corresponds to $n_{\rm b}$ degrees of freedom, namely the number of energy bins of the data. We focus, for definiteness, on the case of the PAMELA detector, with an effective area of 24.5 cm^{2}sr, an exposure time of 3 years, and resorting to a trial energy binning as sketched in ref. [8]. This corresponds to a critical $I_\phi \simeq 3.2 \cdot 10^{-8}{\rm cm}^{-2}{\rm sr}^{-1}{\rm s}^{-1}$.

As regards antideuterons, the background is expected to be totally negligible in the low energy regime, and we refer here to the proposed gaseous antiparticle spectrometer (GAPS) [9], looking for antideuterons in the energy interval 0.1-0.4 GeV per nucleon, with an estimated sensitivity level of $2.6 \times 10^{-9}{\rm m}^{-2}{\rm sr}^{-1}{\rm GeV}^{-1}{\rm s}^{-1}$.

Fig. 2 compares future detection perspectives in the **AMSB** benchmark model [2]. Direct and indirect detection techniques rates are given in terms of signal to sensitivity ratios (*Visibility Ratios*). Remarkably, the most promising detection strategies, as emerging from the upper panel of the figure, reside in antiproton searches, but both positron and antideuteron searches look more promising than direct detection. We point out that our conclusions could have been even stronger had we resorted to a cuspy halo profile [2].

5 Conclusions

We considered antimatter yields in three benchmark scenarios with large annihilation rates, respectively featuring a bino, wino and a higgsino-like lightest neutralino. We introduced a new parameter I_ϕ which allows, given a SUSY model, to reliably assess its visibility at given future experiments. The comparison of future experimental DM search strategies shows that antimatter searches may be highly competitive with respect to both direct detection and neutrino telescopes. In some cases, such as for antiprotons in a wino DM scenario, antimatter searches may be *the only viable DM detection technique*. In the context of SUSY models with large annihilation cross sections, and in view of the imminent launch of space-based dedicated experiments, antimatter searches are therefore to be considered as a highly promising path towards the detection of DM.

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