Explore Physics Beyond the Standard Model with GLAST

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Abstract. We give an overview of the possibility of GLAST to explore theories beyond the Standard Model of particle physics. Among the wide taxonomy we will focus in particular on low scale supersymmetry and theories with extra space-time dimensions. These theories give a suitable dark matter candidate whose interactions and composition can be studied using a gamma ray probe. We show the possibility of GLAST to disentangle such exotic signals from a standard production background.

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INTRODUCTION

Dark matter still remains one of the main unsolved problem in physics. The common accepted paradigm is the existence of an exotic weakly interacting massive particle (WIMP). Such a particle has to be found in some extension of the Standard Model (SM) of particle physics. Supersymmetry and extra space-time dimensions are commonly used ingredients for a consistent theory beyond the SM. One the most studied framework is the MSSM, the minimal supersymmetric extension of the SM. In the MSSM the lightest supersymmetric particle (LSP) is usually a neutralino, which is a good candidate for cold dark matter (for a recent review see [1]). The pattern of the soft supersymmetry breaking terms and the presence of extra space-time dimensions greatly affects the composition and the strength of the dominant interactions of the neutralino. Hence it is crucial to study the neutralino phenomenology in different scenarios. The GLAST experiment will have a great chance to shed light on the nature of dark matter, for example through the analysis of the continuum $\gamma$-ray flux supposed to come from pair WIMP annihilations.

EXPLORING THE CMSSM WITH GLAST

One of the most studied supersymmetric scenario is the constrained MSSM (CMSSM) in which the soft supersymmetry breaking terms are supposed to derive from a high energy supergravity theory with a common scalar mass $m_0$ and a common gaugino mass $m_{1/2}$ at the GUT scale. In this framework the neutralino is the LSP in most of the parameter space. It can be studied through indirect detection of $\gamma$-rays from pair annihilation. The expected $\gamma$-ray continuum flux at a given photon energy $E$ from a direction that form an angle $\psi$ is given by

$$\phi_\chi(E, \psi) = \frac{\sigma v}{4\pi} \sum_i \frac{dN_i}{dE} B_f \int_{\text{l.o.s.}} dl(\psi) \frac{\rho(l)^2}{2 m_\chi^3}.$$  

(1)

It depends on the particle physics model assumed through the neutralino mass $m_\chi$, the total annihilation cross section $\sigma v$ and through the sum of all the photon yield $dN_i/dE$ per each annihilation channel weighted by the corresponding branching ratio $B_f$. The flux (1) also depends on the WIMP density in the galactic halo $\rho(l)$. The integral has to be performed along the line of sight (l.o.s.). The WIMP density profiles $\rho(l)$ are in general extremely cuspy towards the galactic center (GC) that hence is a good place where to look for an exotic signal. In our analysis we take into account the Navarro, Frenck and White (NFW) profile [2] and the Moore profile [3]. The usual parametrization for a dark matter halo density is

$$\rho(r) = \frac{\rho_0}{(r/R)^\gamma [1 + (r/R)^\alpha]^\beta - \gamma/\alpha}.$$  

(2)
FIGURE 1. GLAST reach in the CMSSM parameter space

The NFW profile behaves like $r^{-1}$ towards the GC while the Moore profile goes as $r^{-1.5}$. In general one expects also contributions coming from standard astrophysical sources. In many diffuse continuum $\gamma$-ray production models [4] in our galaxy, the dominant astrophysical contribution comes from $\pi^0 \rightarrow 2\gamma$. This has to be considered the "standard" background. We performed a statistical analysis, based on the usual $\chi^2$ test, in order to determine what are the models that can be disentangled against the background by GLAST at a given significance [5]. We have taken into account only the statistical errors, i.e. $\sigma = \sqrt{N_b}$ where $N_b$ is the number of background photons in each energy bin.

Doing a detailed scan of the CMSSM parameter space defined by $m_0$, $m_{1/2}$, $\tan\beta$, $A_0$ and sign($\mu$) one can find the regions that are detectable by GLAST. Besides the previously explained parameters $m_0$, $m_{1/2}$, $\tan\beta$ denotes the ratio of the vacuum expectation values of the two neutral components of the SU(2) Higgs doublet, $A_0$ is the proportionality factor between the supersymmetry breaking trilinear couplings and the Yukawa couplings while $\mu$ is determined (up to a sign) by imposing the Electro-Weak Symmetry Breaking (EWSB) conditions at the weak scale.

The result, at a $3\sigma$ confidence level, for $\tan\beta = 55$ case is shown in fig. 1. We assumed a total exposure of $3.7 \times 10^{10}$ cm$^2$ s, an angular resolution (at 10 GeV) of $\sim 3 \times 10^{-5}$ sr and 4 years of data taking [6].

Blue solid lines represent the GLAST reach for a NWF and Moore profile while dashed lines represent the neutralino isomass contours (expressed in GeV). Gray shaded regions are parameter space regions excluded by either theoretical or experimental (accelerator) constraints. The upper left region is excluded because the lightest stau is the LSP, the lower left region is excluded due the accelerator bounds on the Higgs boson masses, $b \rightarrow s\gamma$, slepton and squark masses, etc., while the right lower region is excluded because there is no electroweak symmetry breaking. The WMAP compatible region (with relic density $0.09 \leq \Omega h^2 \leq 0.13$) is the red one while in the green region the neutralino is a subdominant dark matter component (with $\Omega h^2 \leq 0.09$).

EXTRA DIMENSIONS AND GLAST

In recent times many scenarios involving extra space-time dimensions with or even without supersymmetry received great attention. It is very interesting to see if GLAST is able to detect signals in this context. We consider a very wide scenario involving extra dimensions and low energy supersymmetry [7].

In this framework there are three additional parameters, namely the typical size of extra dimensions $\mu_0 = R^{-1}$, their number $\delta$ and the number $\eta$ of fermion generations that are allowed to have extra Kaluza-Klein (KK) states. The most
striking feature in this class of models is the presence of power-law corrections to all the couplings and masses of the MSSM [8]. This implies that one can have a grand unification scale (GUT) scale as low as few TeV. From the point of view of indirect detection the case \( \eta > 0 \) in which some fermion generation have KK tower is disfavored. Thus in the following we concentrate on the minimal case \( \eta = 0 \). Moreover the number of extra dimensions \( \delta \) does not seem to be crucial for the neutralino phenomenology [7]. In almost all the parameter space the neutralino is still the LSP. One of the main result is that, unlike the standard CMSSM case, the neutralino is no longer bino-like but it tends to be a very pure higgsino. In general this result holds for not too high compactification scale \( \mu_0 \ll 100 \) TeV while going towards higher scale the neutralino tends to be a bino.

We show the 3\( \sigma \) GLAST reach (along the line sketched in the previous section) for \( \mu_0 = 10 \) TeV, \( \delta = 2 \) and \( \eta = 0 \) and for a low value of tan\( \beta \).

The plot assumptions and the explanation of the different regions are the same as in fig. 1. In this scenario a NFW profile is not enough for GLAST to be able to explore the cosmologically favored region in which the neutralino has a mass greater than 200 GeV. In order to do that a Moore profile is needed. This corresponds to an enhancement factor of about one order of magnitude in the continuum flux. It has to be remarked that assuming some non standard cosmological evolution the green region could become a WMAP compatible region. This is due to a non thermal enhancement of the relic density (see for example [9]). These kind of scenarios are particularly motivated in scenarios with extra dimensions. In fig. 3 we show the case with \( \mu_0 = 10^5 \) TeV and with only one extra dimensions \( \delta = 1 \). All the KK particles are quite heavy in this case but the effects on the low energy theory, through one loop processes, are still sizable.

In this scenario the GLAST reach for a NFW profile is still below the WMAP allowed region but for a Moore profile GLAST will be able to probe almost all the cosmologically favored region.

CONCLUSIONS

We have shown that, assuming a NFW profile, GLAST will be able to probe a huge part of the WMAP allowed zone of the CMSSM parameter space especially in the high tan\( \beta \) case. In the scenario involving extra dimensions, with quite low compactification scale \( \mu_0 \ll 10 \) TeV, GLAST will still be able to probe some part of the cosmologically favored region of the parameter space either in the case of more cuspy Moore profile or in the case of an enhancement of the
neutralino relic density in a non standard cosmological scenario. In the case of higher compactification scale $\mu_0 \gtrsim 10^5$ TeV GLAST will be able to cover almost all the WMAP region.

REFERENCES

1. G. Bertone, D. Hooper and J. Silk, Phys. Rept. 405 (2005) 279
2. J. F. Navarro, C. S. Frenk and S. D. White, Astrophys. J. 462 (1996) 563
3. B. Moore, T. Quinn, F. Governato, J. Stadel and G. Lake, Mon. Not. Roy. Astron. Soc. 310 (1999) 1147
4. F. W. Stecker, Astrophys. J. 212 (1977) 60.
5. A. Cesarini, F. Fucito, A. Lionetto, A. Morselli and P. Ullio, Astropart. Phys. 21 (2004) 267
6. http://www-glast.slac.stanford.edu/software/1S/glast_lat_performance.htm
7. F. Fucito, A. Lionetto and M. Prisco, JCAP 0606 (2006) 002
8. K. R. Dienes, E. Dudas and T. Gherghetta, Nucl. Phys. B 537 (1999) 47
9. T. Moroi and L. Randall, Nucl. Phys. B 570 (2000) 455