# Supersymmetric Dark Matter Detection at Post-LEP Benchmark Points


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We review the prospects for discovering supersymmetric dark matter in a recently proposed set of post-LEP supersymmetric benchmark scenarios. We consider direct detection through spin-independent nuclear scattering, as well as indirect detection through relic annihilations to neutrinos, photons, and positrons. We find that several of the benchmark scenarios offer good prospects for direct detection through spin-independent nuclear scattering, as well as indirect detection through muons produced by neutrinos from relic annihilations in the Sun, and photons from annihilations in the galactic center.


A set of benchmark supersymmetric model parameter choices was recently proposed [1] with the idea of exploring the possible phenomenological signatures in different classes of experiments in a systematic way. The proposed 13 benchmark points (labelled A-M) were chosen by first implementing the constraints on the parameter space of the minimal supersymmetric standard model with universal input soft supersymmetry-breaking parameters that are imposed [2] by previous experiments, and by requiring the calculated supersymmetric relic density to fall within the range $0.1 < \Omega_\chi h^2 < 0.3$ preferred by astrophysics and cosmology. Four general regions of cosmologically allowed parameter space were identified: a 'bulk' region at relatively low $m_0$ and $m_{1/2}$ (points B, C, G, I, and L), a 'focus-point' region [3, 4] at relatively large $m_0$ (E and F), a coannihilation 'tail' extending out to relatively large $m_{1/2}$ [5, 6] (A, D, H, and J), and a possible 'funnel' between the focus-point and coannihilation regions due to rapid annihilation via direct-channel Higgs boson poles [7, 8] (K and M).

Here we ask whether the supersymmetric dark matter candidate, the lightest neutralino, can be observed in experiments that are underway or in preparation. These include direct searches [9] for the elastic scattering of astrophysical cold dark matter particles on target nuclei, and indirect searches [10] for particles produced by the annihilations of supersymmetric relic particles inside the Sun or Earth, in the galactic center, or in the galactic halo.

It was found previously [1] that, in $g_\mu - 2$-friendly scenarios, supersymmetry was relatively easy to discover and study at future colliders such as the LHC and a linear collider with $E_{CM} = 1$ TeV, which would be able to observe rather complementary subsets of superparticles. However, some of the other points might escape detection, except via observations of the lightest neutral Higgs boson. The most difficult points were typically those in the focus-point region, at the tip of the coannihilation tail, or along the rapid-annihilation funnels, with points F, H, and M being particularly elusive.

In this report, we summarize our results [11] on the prospects for the direct and indirect detection of astrophysical dark matter for each of these benchmark points, taking into account the sensitivities of present and planned detectors.

In Fig. 1, we present the spin-independent cross-section for neutralino-proton scattering for each benchmark point using two different codes: `Neutdriver` [15] and `SSARD` [16]. (Experiments sensitive to spin-dependent scattering have inferior reach [11].) We find reasonable agreement, with the largest differences arising for points D and K, where the cross-section is abnormally small due to cancellations [17]. For any given $\tan\beta$, the cancellations occur only for a specific limited range in the neutralino mass.


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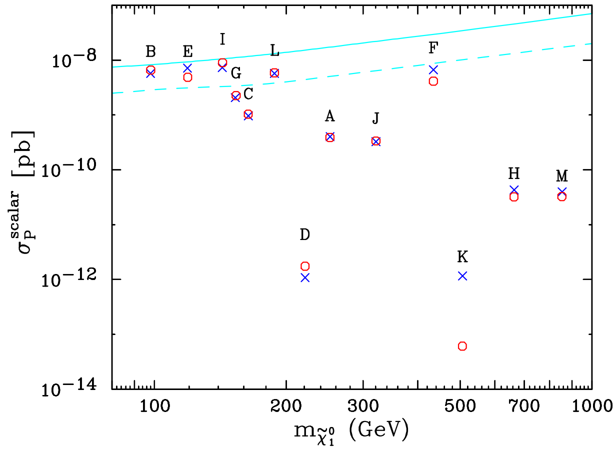


FIG. 1: *Elastic cross sections for spin-independent neutralino-proton scattering. The predictions of* `SSARD` *(blue crosses) and* `Neutdriver` *(red circles) are compared. Projected sensitivities for CDMS II [12] and CRESST [13] (solid) and GENIUS [14] (dashed) are also shown.*

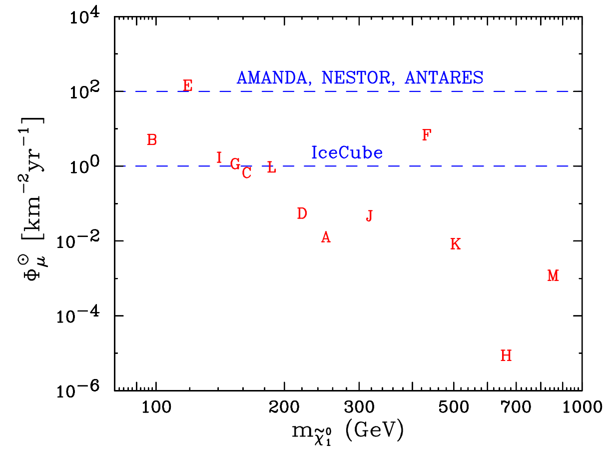


FIG. 2: *Muon fluxes from neutrinos originating from relic annihilations inside the Sun. Approximate sensitivities of near future neutrino telescopes ($\Phi_\mu = 10^2$ km$^{-2}$ yr$^{-1}$ for AMANDA II [19], NESTOR [20], and ANTARES [21], and $\Phi_\mu = 1$ km$^{-2}$ yr$^{-1}$ for IceCube [22]) are also indicated.*

Unfortunately, points D and K fall exactly into this category.

Fig. 1 also shows the projected sensitivities for CDMS II [12], CRESST [13], and GENIUS [14]. Comparing the benchmark model predictions with the projected sensitivities, we see that models I, B, E, L, G, F, and C offer the best detection prospects. In particular, the first four of these models would apparently be detectable with the proposed GENIUS detector.

Indirect dark matter signals arise from enhanced pair annihilation rates of dark matter particles trapped in the gravitational wells at the centers of astrophysical bodies. While most annihilation products are quickly absorbed, neutrinos may propagate for long distances and be detected near the Earth's surface through their charged-current conversion to muons. High-energy muons produced by neutrinos from the centers of the Sun and Earth are therefore prominent signals for indirect dark matter detection [10, 18].

Muon fluxes for each of the benchmark points are given in Fig. 2, using `Neutdriver` with a fixed constant local density $\rho_0 = 0.3$ GeV/cm$^3$ and neutralino velocity dispersion $\bar{v} = 270$ km/s. For the points considered, rates from the Sun are far more promising than rates from the Earth. For the Sun, muon fluxes are for the most part anti-correlated with neutralino mass [11], with two strong exceptions: the focus point models E and F have anomalously large fluxes. In these cases, the dark matter's Higgsino content, though still small, is significant, leading to annihilations to gauge boson pairs, hard neutrinos, and enhanced detection rates.

The potential of current and planned neutrino telescopes has been reviewed in [10]. The exact reach depends on the salient features of a particular detector, *e.g.*, physical dimensions, muon energy threshold, etc., and the expected characteristics of the signal, *e.g.*, angular dispersion, energy spectrum and source (Sun or Earth). Two sensitivities, which are roughly indicative of the potential of upcoming neutrino telescope experiments, are given in Fig. 2. For focus point model E, where the neutralino is both light and significantly different from pure Bino-like, detection in the near future at AMANDA II [19], NESTOR [20], and ANTARES [21] is possible. Point F may be within reach of IceCube [22], as the neutralino's significant Higgsino component compensates for its large mass. For point B, and possibly also points I, G, C, and L, the neutralino is nearly pure Bino, but is sufficiently light that detection at IceCube may also be possible.

Muon energy thresholds specific to individual detectors have not been included. For AMANDA II and, especially, IceCube, these thresholds may be large, significantly suppressing the muon signal in models with $m_\chi$ less than about 4 to 6 $E_\mu^{\rm th}$ [23, 24]. Note also that, for certain neutralino masses and properties, a population of dark matter particles in solar system orbits may boost the rates presented here by up to two orders of magnitude [25]. We have conservatively neglected this possible enhancement.

As with the centers of the Sun and Earth, the center of the galaxy may attract a significant overabundance of relic dark matter particles [26]. Relic pair annihilation at the galactic center will then produce an excess of photons, which may be observed in gamma ray detectors. While monoenergetic signals from $\chi\chi \to \gamma\gamma$ and $\chi\chi \to \gamma Z$ would be spectacular [27], they are loop-suppressed and unobservable for these benchmark points. We therefore consider continuum photon signals here.

We have computed the integrated photon flux $\Phi_\gamma(E_{\rm th})$ in the direction of the galactic center following the procedure of [10]. Our results for each of the

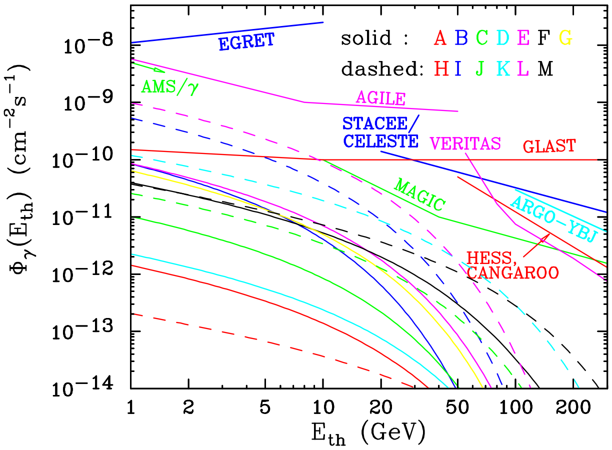


FIG. 3: *The integrated photon flux $\Phi_\gamma(E_{\rm th})$ as a function of photon energy threshold $E_{\rm th}$ for photons produced by relic annihilations in the galactic center. A moderate halo parameter $\bar{J} = 500$ is assumed [27]. Point source flux sensitivities for various gamma ray detectors are also shown.*

benchmark points are presented in Fig. 3. Estimates for point source flux sensitivities of several gamma ray detectors, both current and planned, are also shown. The space-based detectors EGRET, AMS/$\gamma$ and GLAST can detect soft photons, but are limited in flux sensitivity by their small effective areas. Ground-based telescopes, such as MAGIC, HESS, CANGAROO and VERITAS, are much larger and so sensitive to lower fluxes, but are limited by higher energy thresholds. These sensitivities are not strictly valid for observations of the galactic center. Nevertheless, they provide rough guidelines for what sensitivities may be expected in coming years. For a discussion of these estimates, their derivation, and references to the original literature, see [10].

Fig. 3 shows that space-based detectors offer good prospects for detecting a photon signal, while ground-based telescopes have a relatively limited reach. GLAST appears to be particularly promising, with points I and L giving observable signals. Recall, however, that all predicted fluxes scale linearly with $\bar{J}$. For isothermal halo density profiles, the fluxes may be reduced by two orders of magnitude. On the other hand, for particularly cuspy halo models, such as those in [28], all fluxes may be enhanced by two orders of magnitude, leading to detectable signals in GLAST for almost all points, and at MAGIC for the majority of benchmark points.

Relic neutralino annihilations in the galactic halo [29] may also be detected through positron excesses in space-based and balloon experiments [30, 31]. To estimate the observability of a positron excess, we followed the procedure advocated in [10]. For each benchmark spectrum, we first find the positron energy $E_{\rm opt}$ at which the positron signal to background ratio $S/B$ is maximized. For detection, we then require that $S/B$ at $E_{\rm opt}$ be above some value. The sensitivities of a variety of experiments have been estimated in [10]. Among these experiments, the most promising is AMS [32], the anti-matter detector to be placed on the International Space Station. AMS will detect unprecedented numbers of positrons in a wide energy range. We estimate that a 1% excess in an fairly narrow energy bin, as is characteristic of the neutralino signal, will be statistically significant. Unfortunately, our study [11] showed that for all benchmark points the expected positron signals are below the AMS sensitivity. However, one should be aware that as with the photon signal, positron rates are sensitive to the halo model assumed; for clumpy halos [33], the rate may be enhanced by orders of magnitude [31].

In conclusion, we have provided indicative estimates of the dark matter detection rates that could be expected for the benchmark supersymmetric scenarios proposed in [1]. We emphasize that, in addition to the supersymmetric model dependences of these calculations, there are important astrophysical uncertainties. These include the overall halo density, the possibility that it may be enhanced in the solar system, its cuspiness near the galactic center, and its clumpiness elsewhere. For these reasons, our conclusions about the relative ease with which different models may be detected using the same signature may be more reliable than the absolute strengths of different signatures. Nevertheless, our estimates do indicate that there may be good prospects for astrophysical detection of quite a large number of the benchmark scenarios [11].

In particular, four benchmark points (I, B, E and L) may be detected through spin-independent elastic scattering of relic particles using the projected GENIUS [14] detector, with models G, F and C not far from the likely threshold of detectability. The indirect detection of muons generated by high-energy neutrinos due to annihilations inside the Sun should be most easily detectable with the proposed IceCube [22] detector in models E, F and B, followed by models I, G, L and C, which are near the boundary of sensititvity. The best prospects for detecting photons from annihilations in the galactic center (for models L and I) are offered by the GLAST satellite, with its relatively low threshold. However, there may also be prospects for ground-based experiments such as MAGIC if the halo is cuspier at the galactic center than we have assumed.

It was previously noted [1] that the more $g_\mu - 2$-friendly models (I, L, B, G, C and J) offered good prospects for detecting several supersymmetric particles at the LHC and/or a 1 TeV linear $e^+e^-$ collider. Most of these models also exhibit good prospects for dark matter detection, with the exception of model J. Among the less $g_\mu - 2$-friendly models, we note that the focus points E and F offer good astrophysical prospects, demonstrating the complementarity of collider and astrophysics searches. This is particularly interesting in the case of focus-point model F, which is very challenging for colliders.

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[1] M. Battaglia *et al.*, *Proposed post-LEP benchmarks for supersymmetry*, arXiv:hep-ph/0106204.
[2] J. Ellis, T. Falk, G. Ganis and K. A. Olive, Phys. Rev. **D62** (2000) 075010 [arXiv:hep-ph/0004169].
[3] J. L. Feng and T. Moroi, Phys. Rev. D **61**, 095004 (2000) [arXiv:hep-ph/9907319]; J. L. Feng, K. T. Matchev and T. Moroi, Phys. Rev. Lett. **84**, 2322 (2000) [arXiv:hep-ph/9908309]; Phys. Rev. D **61**, 075005 (2000) [arXiv:hep-ph/9909334]; J. L. Feng and K. T. Matchev, Phys. Rev. D **63**, 095003 (2001) [arXiv:hep-ph/0011356].
[4] J. L. Feng, K. T. Matchev and F. Wilczek, Phys. Lett. B **482**, 388 (2000) [arXiv:hep-ph/0004043].
[5] J. Ellis, T. Falk and K. A. Olive, Phys. Lett. **B444**, 367 (1998) [arXiv:hep-ph/9810360]; J. Ellis, T. Falk, K. A. Olive and M. Srednicki, Astropart. Phys. **13** (2000) 181 [arXiv:hep-ph/9905481].
[6] M. E. Gómez, G. Lazarides and C. Pallis, Phys. Rev. **D61**, 123512 (2000) [arXiv:hep-ph/9907261] and Phys. Lett. **B487**, 313 (2000) [arXiv:hep-ph/0004028]; R. Arnowitt, B. Dutta and Y. Santoso, Nucl. Phys. B **606**, 59 (2001) [arXiv:hep-ph/0102181].
[7] J. Ellis, T. Falk, G. Ganis, K. A. Olive and M. Srednicki, Phys. Lett. B **510** (2001) 236 [arXiv:hep-ph/0102098].
[8] A. B. Lahanas and V. C. Spanos, arXiv:hep-ph/0106345.
[9] See, *e.g.*, A. Bottino, F. Donato, N. Fornengo and S. Scopel, Phys. Rev. D **63**, 125003 (2001) [arXiv:hep-ph/0010203]; M. Drees, Y. G. Kim, T. Kobayashi and M. M. Nojiri, Phys. Rev. D **63**, 115009 (2001) [arXiv:hep-ph/0011359]; M. E. Gomez and J. D. Vergados, Phys. Lett. B **512**, 252 (2001) [arXiv:hep-ph/0012020]; A. B. Lahanas, D. V. Nanopoulos and V. C. Spanos, Phys. Lett. B **518**, 94 (2001) [arXiv:hep-ph/0107151].
[10] J. L. Feng, K. T. Matchev and F. Wilczek, Phys. Rev. D **63**, 045024 (2001) [arXiv:astro-ph/0008115].
[11] J. R. Ellis, J. L. Feng, A. Ferstl, K. T. Matchev and K. A. Olive, arXiv:astro-ph/0110225.
[12] CDMS Collaboration, R. W. Schnee *et al.*, Phys. Rept. **307**, 283 (1998).
[13] CRESST Collaboration, M. Bravin *et al.*, Astropart. Phys. **12**, 107 (1999) [arXiv:hep-ex/9904005].
[14] H. V. Klapdor-Kleingrothaus, arXiv:hep-ph/0104028.
[15] G. Jungman, M. Kamionkowski and K. Griest, Phys. Rept. **267**, 195 (1996) [arXiv:hep-ph/9506380]; `http://t8web.lanl.gov/people/jungman`.
[16] Information about this code is available from K. A. Olive: it contains important contributions from T. Falk, G. Ganis, J. McDonald, K. A. Olive and M. Srednicki.
[17] J. Ellis, A. Ferstl and K. A. Olive, Phys. Lett. B **481**, 304 (2000) [arXiv:hep-ph/0001005]; J. Ellis, A. Ferstl and K. A. Olive, arXiv:hep-ph/0111064.
[18] J. Silk, K. Olive and M. Srednicki, Phys. Rev. Lett. **55**, 257 (1985); K. Freese, Phys. Lett. **B167**, 295 (1986); L. M. Krauss, M. Srednicki and F. Wilczek, Phys. Rev. **D33**, 2079 (1986); L. Bergström, J. Edsjö and P. Gondolo, Phys. Rev. **D58**, 103519 (1998) [arXiv:hep-ph/9806293]; A. Bottino, F. Donato, N. Fornengo and S. Scopel, Astropart. Phys. **10**, 203 (1999) [arXiv:hep-ph/9809239]; A. Corsetti and P. Nath, Int. J. Mod. Phys. A **15**, 905 (2000) [arXiv:hep-ph/9904497].
[19] AMANDA Collaboration, C. Spiering *et al.*, talk given at the 8th International Workshop on Neutrino Telescopes, Venice, Italy, 23-26 February 1999, arXiv:astro-ph/9906205.
[20] NESTOR Collaboration, L. K. Resvanis *et al.*, talk given at the 8th International Workshop on Neutrino Telescopes, Venice, Italy, 23-26 February 1999.
[21] ANTARES Collaboration, J. R. Hubbard *et al.*, HE.6.3.03 and ANTARES Collaboration, L. Moscoso *et al.*, HE.6.3.04 in *Proceedings of the 26th International Cosmic Ray Conference (ICRC 99)*, Salt Lake City, Utah, 17-25 August 1999.
[22] M. Leuthold, *Prepared for International Workshop on Simulations and Analysis Methods for Large Neutrino Telescopes, Zeuthen, Germany, 6-9 Jul 1998.*
[23] L. Bergström, J. Edsjö and M. Kamionkowski, Astropart. Phys. **7**, 147 (1997) [arXiv:astro-ph/9702037].
[24] V. Barger, F. Halzen, D. Hooper and C. Kao, arXiv:hep-ph/0105182.
[25] T. Damour and L. M. Krauss, Phys. Rev. Lett. **81**, 5726 (1998) [arXiv:astro-ph/9806165]; L. Bergström, T. Damour, J. Edsjö, L. M. Krauss and P. Ullio, JHEP **9908**, 010 (1999) [arXiv:hep-ph/9905446].
[26] M. Urban, A. Bouquet, B. Degrange, P. Fleury, J. Kaplan, A. L. Melchior and E. Pare, Phys. Lett. **B293**, 149 (1992) [arXiv:hep-ph/9208255]; V. S. Berezinsky, A. V. Gurevich and K. P. Zybin, Phys. Lett. **B294**, 221 (1992); V. Berezinsky, A. Bottino and G. Mignola, Phys. Lett. **B325**, 136 (1994) [arXiv:hep-ph/9402215].
[27] L. Bergström, P. Ullio and J. H. Buckley, Astropart. Phys. **9**, 137 (1998) [arXiv:astro-ph/9712318].
[28] J. F. Navarro, C. S. Frenk and S. D. White, Astrophys. J. **462**, 563 (1996) [arXiv:astro-ph/9508025].
[29] J. Silk and M. Srednicki, Phys. Rev. Lett. **53**, 624 (1984).
[30] A. J. Tylka, Phys. Rev. Lett. **63**, 840 (1989); M. S. Turner and F. Wilczek, Phys. Rev. **D42**, 1001 (1990); M. Kamionkowski and M. S. Turner, Phys. Rev. **D43**, 1774 (1991).
[31] I. V. Moskalenko and A. W. Strong, Phys. Rev. **D60**, 063003 (1999) [arXiv:astro-ph/9905283].
[32] AMS Collaboration, S. Ahlen *et al.*, Nucl. Instrum. Meth. A **350**, 351 (1994); A. Barrau [AMS Collaboration], arXiv:astro-ph/0103493.
[33] J. Silk and A. Stebbins, Astrophys. J. **411**, 439 (1993).