Prospects for detecting supersymmetric dark matter at Post-LEP benchmark points

J. Ellis\textsuperscript{1}, J. L. Feng\textsuperscript{2,3}, A. Ferstl\textsuperscript{4}, K.T. Matchev\textsuperscript{1}, K.A. Olive\textsuperscript{5}

\textsuperscript{1} TH Division, CERN, 1211 Geneva 23, Switzerland
\textsuperscript{2} Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
\textsuperscript{3} Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA
\textsuperscript{4} Department of Physics, Winona State University, Winona, MN 55987, USA
\textsuperscript{5} Theoretical Physics Institute, School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA

Abstract. A new set of supersymmetric benchmark scenarios has recently been proposed in the context of the constrained MSSM (CMSSM) with universal soft supersymmetry-breaking masses, taking into account the constraints from LEP, $b \rightarrow s \gamma$ and $g_\mu - 2$. These points have previously been used to discuss the physics reaches of different accelerators. In this paper, we discuss the prospects for discovering supersymmetric dark matter in these scenarios. We consider direct detection through spin-independent and spin-dependent 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 via spin-independent nuclear scattering and indirect detection via muons produced by neutrinos from relic annihilations inside the Sun, and some models offer good prospects for detecting photons from relic annihilations in the galactic centre.

1 Introduction

After the closure of LEP, at the start of Run II of the Tevatron Collider, with the LHC experimental programme being prepared, and linear $e^+e^-$ collider projects under active discussion, now is an appropriate time to review the available experimental constraints on supersymmetry and assess the prospects for its discovery. In parallel with present and future accelerator projects, many non-accelerator experiments that may contribute to the search for supersymmetry are underway or in preparation. These include direct searches for the elastic scattering of astrophysical cold dark matter particles on target nuclei, and indirect searches for particles produced by the annihilations of supersymmetric relic particles inside the Sun or Earth, in the galactic centre or in the galactic halo.

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 benchmark points were chosen by first implementing the constraints on the CMSSM parameter space [2] imposed by previous experiments, such as the searches for sparticle [3] and Higgs bosons at LEP [4] and elsewhere, the measured rate for $b \rightarrow s \gamma$ decay [5], and (optionally) the value of $g_\mu - 2$ recently reported by the BNL E821 experiment [6]. The CMSSM parameter space was also constrained 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 allowed parameter space were identified: a ‘bulk’ region at relatively low $m_0$ and $m_{1/2}$, a ‘focus point’ region [7,8] at relatively large $m_0$, a coannihilation ‘tail’ extending out to relatively large $m_{1/2}$ [9,10], and a possible ‘funnel’ between the focus point and coannihilation regions due to rapid annihilation via direct-channel Higgs boson poles [11,12].

The benchmark points were chosen not to provide an unbiased statistical sample of the CMSSM parameter space, which is in any case difficult to define in the absence of any unbiased \textit{a priori} measure, but rather to select representative examples of different possibilities that cannot yet be logically excluded. Note that while these scenarios are confined to the context of supergravity, they span a large range of dark matter properties. While other supersymmetry-breaking schemes lead to a variety of collider signals, with respect to dark matter, they often predict vanishing or highly suppressed thermal relic densities for the most natural candidate, the neutralino. These alternative scenarios therefore typically have no viable dark matter candidates, at least without additional structure and an accompanying loss of predictability.

Of the 13 benchmark points, B, C, G, I, and L lie within the ‘bulk’ region; E and F are in the focus point region; A, D, H, and J are strung out along the coannihila-
lution tail; and K and M are chosen at (relatively) large \(m_{1/2}\) and \(m_0\), in the rapid annihilation funnel regions. All but one of the proposed points yield a value of \(g_\mu - 2\) within two standard deviations of the value reported by BNL E821, but we did not impose this as an absolute requirement. Figure 1 provides an overview of the locations of the benchmark points in the \((m_0, m_{1/2})\) and \((|\mu|, M_1)\) planes. We see that the proposed scenarios mainly have \(m_{1/2} > m_0\), except for the two focus point models E and F. These also have larger values of \(M_1/|\mu|\), and therefore more Higgsino-like lightest supersymmetric particles (LSPs). Table 1 displays many properties of the proposed scenarios, including the LSP mass, its gaugino composition, its cosmological relic density, and rates for the many astrophysical signatures to be discussed in subsequent sections of this paper.

It was found previously [1] that in many 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 CMSSM particles. However, some of the other points might escape detection, except via observations of the lightest neutral Higgs boson of the CMSSM. 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 paper, we report on the prospects for the direct and indirect detection of astrophysical dark matter for each of these benchmark points. We present cross sections for the elastic scattering of supersymmetric relic particles off both protons and neutrons via both spin-independent and spin-dependent matrix elements, the rates for observing muons induced by the collisions in rock of energetic neutrinos produced by relic annihilations inside the Sun and Earth, the rates for photons produced by annihilations in the galactic centre, and the rates for positrons produced by the annihilations of relic particles in the galactic halo. In all cases, we take into account the sensitivities of present and planned detectors in estimating the observability of signals from relic particles. We emphasize that all our results necessarily depend on the halo model used: this is particularly true for the photon signal from the galactic centre. This model-dependence enters when comparing the power of various experimental probes. However, for any given signature, our conclusions concerning the relative ease with which different models can be seen should be quite reliable.