On possible lower bounds for the direct detection rate of SUSY Dark Matter

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Abstract

One can expect accessible lower bounds for dark matter detection rate due to restrictions on masses of the SUSY-partners. To explore this correlation one needs a new-generation large-mass detector. The absolute lower bound for detection rate can naturally be due to spin-dependent interaction. Aimed at detecting dark matter with sensitivity higher than $10^{-5}$ event/day/kg an experiment should have a non-zero-spin target. Perhaps, the best is to create a GENIUS-like detector with both $^{73}$Ge (high spin) and $^{76}$Ge nuclei.

A new generation of high-sensitivity dark matter detectors, in particular aimed at searching for neutralinos, lightest SUSY particles (LSP), has been proposed (see for example, proposals GENIUS [1], GENIUS-TF [2], CRESST [3] and CDMS [4]). The question naturally arises of how small the expected event rate, $R$, of the LSP can be, provided the LSP is a cold dark matter particle (or so-called WIMP). The upper and lower bounds for the neutralino-nucleon cross section were considered in various SUSY models [5]–[8]. The main goal of this paper is to attract extra attention to possible lower bounds for $R$, which is to be measured directly.

To this end the exploration of the MSSM parameter space is performed at the weak scale (without any unification assumptions). The MSSM parameter space is determined by entries of the mass matrices of neutralinos, charginos, Higgs bosons, sleptons and squarks. Available restrictions from cosmology ($0.1 < \Omega_{\chi} h^2 < 0.3$), rare FCNC $b \to s\gamma$ decay ($1.0 \times 10^{-4} < B(b \to s\gamma) < 4.2 \times 10^{-4}$), accelerator SUSY searches, etc were taken into account [7, 8].

Scatter plots with individual cross sections of spin-dependent and spin-independent (scalar) interactions of LSP with the proton and the neutron are given in Fig. 1 as functions of the LSP mass. The different behavior of these cross sections with the mass of the LSP can be seen from the plots. There is a lower bound for the spin-dependent cross section. Due to the absence of a clear lower bound for the scalar cross section of the WIMP-neutron interaction, one can expect that the lower bound for the rate can be established by the spin-dependent interaction, which in contrast to the scalar interaction is associated with an about 3-order-of-magnitude larger WIMP-nucleon cross sections.

The existence of the absolute lower bound for the event rate (thick curve in Fig. 2) and the variation of the bound with the MSSM parameters and masses of the SUSY particles [8] allow one to consider prospects to searching for dark matter under special assumptions about restricted values for the MSSM parameters and masses.

Figure 2 gives different lower bounds for $R$ obtained with extra limitations on SUSY-particle masses [7]. A restriction for the single (light) squark mass to be quite small ($M_{sq} < 230$ GeV) as well as another assumption that all sfermion masses do not exceed 300–400 GeV, put upper limits on the mass of the LSP and therefore do not
Figure 1: Cross sections of spin-dependent and spin-independent interactions of WIMPs with the proton and the neutron.

permit $R$ to drop very deeply with increasing LSP mass. Furthermore, in both cases the lower bound for the rate is established for all allowed masses of the LSP at a level of $10^{-3}$ events/kg/day. This value is considered as an optimistic sensitivity expectation for future high-accuracy detectors of dark matter, such as GENIUS [1]. One can see that the mass of the light neutral CP-even Higgs boson $M_{H^0}$ has unfortunately a very poor restrictive potential. The situation looks most promising when one limits the mass of the charged Higgs boson. If it happened, for instance, that either the SUSY spectrum is indeed light or $M_{H^+} < 200$ GeV, in both cases at least the GENIUS experiment should detect a dark matter signal.

Therefore the prospects could be very promising if from collider searches one would restrict $M_{H^+}$ at a level of about 200 GeV. The observation, due to its importance for dark matter detection, could serve as a source for extra efforts in searching for the charged Higgs boson with colliders. Otherwise, non-observation of any dark matter signal with very sensitive dark matter detectors would exclude, for example, a SUSY spectrum with masses lighter than 300–400 GeV, charginos with masses smaller than 250 GeV (Fig. 2), the charged Higgs boson with $M_{H^+} < 200$ GeV, etc.
Figure 2: Different lower bounds for the total event rate in $^{73}$Ge. Here $M_{\text{sq}}$, $M_{H^+}$, $M_0$ denote masses of the squark, the charged Higgs boson and the light neutral CP-even Higgs boson respectively. Heavy chargino mass is denoted as $M_{\text{charginos}}$. The thick curve corresponds to the absolute lower bound. "Light spectrum" denotes the lower bound for the rate, obtained when all sfermion masses are lighter than $300–400$ GeV. The dotted line represents the expected sensitivity for the direct dark matter detection with GENIUS [1].

It was claimed that nuclear spin is not important for detection of dark matter particles, provided the detection sensitivity does not exceed $0.01$ event/day/kg, which was considered unattainable in 1994 [9]. Now, with new-generation detectors, the situation changes and targets with spin-non-zero nuclei should again be taken into account.

For any mass of the LSP one can find very large and very small values for the spin-dependent to spin-independent cross section (or rate) ratio. The spin-independent (scalar) contribution obviously dominates in the domain of large expected rates (Fig. 3) in the spin-non-zero germanium detector ($R > 0.1$ event/day/kg). But as soon as the total rate drops down to $R < 0.01$ event/day/kg or, equivalently, the scalar neutralino-proton cross section becomes smaller than $10^{-9}$–$10^{-10}$ pb, the spin-dependent interaction may produce a rather non-negligible contribution to the total event rate. Moreover, if the scalar cross section further decreases ($\sigma < 10^{-12}$ pb), it becomes obvious that the spin contribution alone saturates the total rate and protects it from decreasing below $R \approx 10^{-6}$–$10^{-7}$ event/day/kg [4]. With only a spinless detector one can miss a signal caused by spin-dependent interaction. Aimed at detecting dark matter with sensitivity higher than $10^{-5}$ event/day/kg an experiment should have a spin-non-zero target. Indeed, while the scalar cross sections governed mostly by Higgs exchange can be rather small, the spin cross section cannot be arbitrary small, because the mass of the $Z$ boson, which gives the dominant contribution, is well defined, provided one ignores any possible fine-tuning cancellations [4].

Therefore, if an experiment with sensitivity $10^{-5}$–$10^{-6}$ event/day/kg fails to detect a dark matter signal, an experiment with higher sensitivity should have a spin-non-
Figure 3: Ratio of the spin-dependent event rate to the spin-independent event rate in the $^{73}$Ge isotope (spin = $9/2$) as a function of the total (spin-dependent plus spin-independent) event rate (left) and the scalar cross section of the neutralino-proton interaction (right). The solid vertical lines give the expected sensitivity of GENIUS [1]. In the region above the horizontal line the spin contribution dominates.

zero target and will be able to detect dark matter particles only due to the spin neutralino-quark interaction. In this situation, it seems the best to create a huge GENIUS-like detector with both $^{73}$Ge (high spin) and $^{76}$Ge (spinless) isotopes.

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