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# Munich Cryogenic Detector Development 1995

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At the Technical University of Munich and the Max Planck Institute of Physics we are developing cryogenic detectors for the detection of small deposited energies, for example from the elastic scattering of WIMP dark matter particles, or the absorption of X-rays. Together with the University of Oxford and the Laboratori Nazionali del Gran Sasso we are preparing the CRESST experiment which uses our detectors to search for WIMP dark matter. This preprint contains reports of our work which we have presented at the Sixth International Workshop on Low Temperature Detectors (LTD-6) in Beatenburg/Interlaken, Switzerland, 28 Aug. - 1 Sept. 1995. This work has been supported in part by the "Sonderforschungsbereich 375 für Astroteilchenphysik" and the EU ERBCHRXCT930341 Network on Cryogenic Detectors.

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# Cross section of low mass neutralino dark matter in the Unconstrained Minimal Supersymmetric Standard Model

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## Abstract

Preliminary results are presented of an exploration of the allowed parameter space for the lightest neutralino as the dark matter. The Minimal Supersymmetric Standard Model as the low-energy effective theory is used without further theoretical constraints. Selecting parameter values which are in agreement with present experimental limits and applying the additional requirement that the lightest neutralino be in a cosmologically interesting range gives limits on the neutralino mass, composition, and cross section for elastic scattering on nuclei.

Any weakly interacting massive particle (WIMP) considered as a dark matter candidate is subject to at least two constraints: its relic abundance must be cosmologically interesting, say $0.025 < \Omega h^2 < 1$ and its existence must be in accord with present experimental limits, provided mainly by the LEP experiments. In this paper, we address the question of the most general limits on the lightest neutralino of the Minimal Supersymmetric Standard Model (MSSM) which follow only from these two constraints without any further theoretical assumptions.

The stable neutralino is the lowest mass superposition of neutral gauginos and higgsinos. The neutralino composition is defined by the neutralino mass matrix, which depends on several, in general free, parameters of the model: the gaugino masses $M_1$ and $M_2$, the higgsino mass parameter $\mu$, and $\tan\beta = v_2/v_1$, where $v_1$ and $v_2$ are the vacuum expectation values of the two Higgs particles present in the model. All of these are independent parameters of the low-energy effective lagrangian.

In the present work, the values of these parameters are chosen randomly in the ranges $1 \leq M_2$ [GeV] $\leq 1000$, $0 \leq M_1/M_2 \leq 1$, $-1000 \leq \mu$ [GeV] $\leq 1000$ and $1 \leq \tan\beta \leq 50$. We incorporate the existing experimental limits from accelerator experiments in the parameter space as it is discussed in Ref. [1]. We restrict the analysis to neutralinos lighter than 100 GeV and calculate [2] the relic neutralino abundance in the parameter region allowed by the above constraints. For this we need the masses of the squark $M_{sq}$, slepton $M_{sl}$, and Higgs pseudo scalar $M_A$. We assume equal mass for all squarks and for all sleptons. Since the purpose of this study is to explore the parameter space, we need limits which are model-independent, whereas most experimental limits are based on certain assumptions or values of the parameters. Thus we have chosen to repeat the relic abundance calculation for several different sets of values of $M_{sq}$, $M_{sl}$ and $M_A$: set A (45,45,25-70), set B (100,45,25-70), set C (150,90,25-70) and set D (200,200,200) with the masses in GeV. For sets A-C the masses $M_A$ are randomly chosen in the range 25-70 GeV in the regions of the plane $M_A$-$M_h$ allowed by present LEP data [3]. The lowest values of $M_{sq}$ and $M_{sl}$ are taken as 45 GeV assuming that lower-mass particles are, or will soon be, ruled out in a model-independent way by LEP data. The top quark mass is set to 170 GeV.

For low squark and slepton masses (set B) a cosmological relic abundance $\Omega h^2 < 1$ is obtained for neutralino masses above 2 GeV. Decreasing the squark masses to 45 GeV (set A) gives very similar results for $\Omega h^2$ and the same value of 2 GeV for the lowest neutralinos, which can then be regarded as an absolute lower bound on the neutralino mass in the MSSM. These low mass neutralinos are dominantly gauginos (mostly photino and bino) with a substantial higgsino component coming in above 30 GeV. The lower bound in the neutralino mass rises with $M_{sq}$ and $M_{sl}$ to reach 10 GeV for set D.

Dark matter neutralinos can be directly detected via their elastic scattering on nuclei. The scattering cross section has two components. An effective axial-vector interaction gives a spin-dependent (SD) cross section which is non-zero only for nuclei with net spin. Scalar and vector interactions give spin-independent (SI) cross sections which involve the squares of nuclear neutron and proton numbers. The relative strengths of the two parts of the neutralino interaction on nuclei depends on the neutralino composition. A pure gaugino couples only to squarks and sleptons and has only an SD interaction. The sleptons are not relevant for interactions with nuclei. A pure higgsino couples significantly to nuclei only via the axial-vector part of the $Z$ boson and thus has only an SD interaction. Higgs exchange is an SI interaction, but only a gaugino-higgsino mixture couples to the Higgs. The actual scattering cross section depends on the coefficients that specify the neutralino composition, and on the masses $M_{sq}$, $M_{sl}$ and $M_A$ of the exchanged particles.

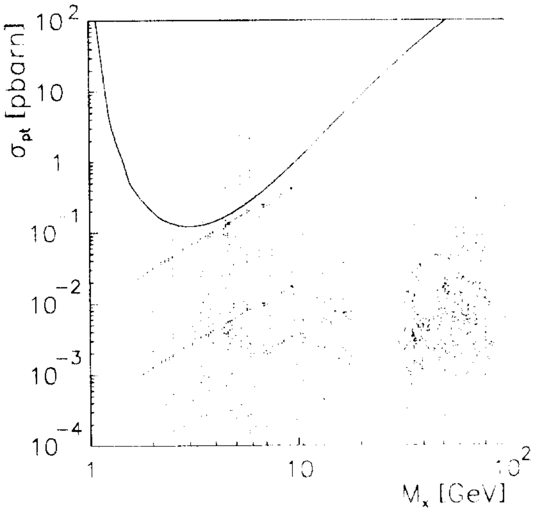

Figure 1: Preliminary neutralino cross section for interactions on $^{27}$Al versus the neutralino mass. The data from sets A–D are combined. The line is a rough estimate of the sensitivity of the first phase of the CRESST experiment consisting of 1 kg sapphire detector with an energy threshold of 0.5 keV. The sensitivity is evaluated for a measurement time of 1 kg-year assuming a flat background of 1 event/kg/keV/day.

To calculate the equivalent point-like cross section $\sigma_{pt}$ we use the expression derived in Ref. [4] for the effective axial-vector and scalar currents. The SD cross section depends on the nuclear model used to evaluate the proton and neutron contributions to the nuclear spin. We use predictions from the Odd Group Model (OGM) [5] where only the nucleon in excess contributes to the SD cross section. On average the OGM gives lower cross sections than the one obtained with detailed nuclear shell model calculations resulting in a factor of 2-3 uncertainty in the evaluation of the SD cross section. The SD cross section also depends on the quark model used to evaluate the quark contributions to the nucleon spin and we use the European Muon Collaboration values [6].

A preliminary calculation of the cross section $\sigma_{pt}$ for the cosmologically relevant neutralinos of data sets A–D is plotted in Fig. 1 versus the neutralino mass for the isotope $^{27}$Al (spin 5/2, 100 % natural abundance). The cross section increases with the neutralino mass mainly due to the dependence of $\sigma_{pt}$ on the reduced mass.

The SD cross section for sets A and B is sometimes even larger than the cross section for a Majorana neutrino; this happens because the squark mass is low and its exchange gives a significant contribution to the cross section. In contrast, the maximum values of the SI cross section are two orders of magnitude below that for Dirac neutrinos. As a result the SD and SI cross sections have the same magnitude. The neutralino SD cross section decreases with increasing squark masses. For each set, the maximum values of the SD cross section correspond to pure photinos which produce the band structure appearing in Fig. 1.

In order to explore the low mass window, the first stage of the CRESST experiment [7] will use a 1 kg sapphire ($Al_2O_3$) cryogenic detector with an energy threshold of 0.5 keV. Fig. 1 shows a rough estimate of the expected sensitivity assuming a flat background of 1 count/keV/kg/day and a measurement time of 1 year. For each dark matter particle mass, the exclusion limit is evaluated by fitting simulated background data with the sum of a flat component for the background and the calculated recoil energy spectrum for $^{27}$Al using an exponential form factor for both SD and SI interactions as proposed in Ref. [5].

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