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The SuperCDMS proposal for dark matter detection

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Abstract

Presently the CDMS-II collaboration's Weakly Interacting Massive Particle (WIMP) search at the Soudan Underground Laboratory sets the most stringent exclusion limits of any WIMP cold dark matter direct-detection experiment. To extend our reach further, to WIMP-nucleon cross-sections in the range $10^{-46} - 10^{-44}\,\mathrm{cm}^2$, we propose SuperCDMS, which would take advantage of a very deep site. One promising site is the recently approved SNOLab facility in Canada. In this paper we will present our overall program and focus on phase A of SuperCDMS.

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1. Introduction

The CDMS II experiment at Soudan [1–3] has demonstrated unsurpassed sensitivity to the WIMP-nucleon scattering cross-section (see Fig. 1). Thus, the technological approach used in CDMS II is a strong contender for an even more sensitive WIMP-search that will place the properties of the astrophysically motivated WIMP particle in the realm of recent developments in supersymmetry [4–8] that naturally contain a stable lightest supersymmetric particle (LSP) with the desired WIMP properties.

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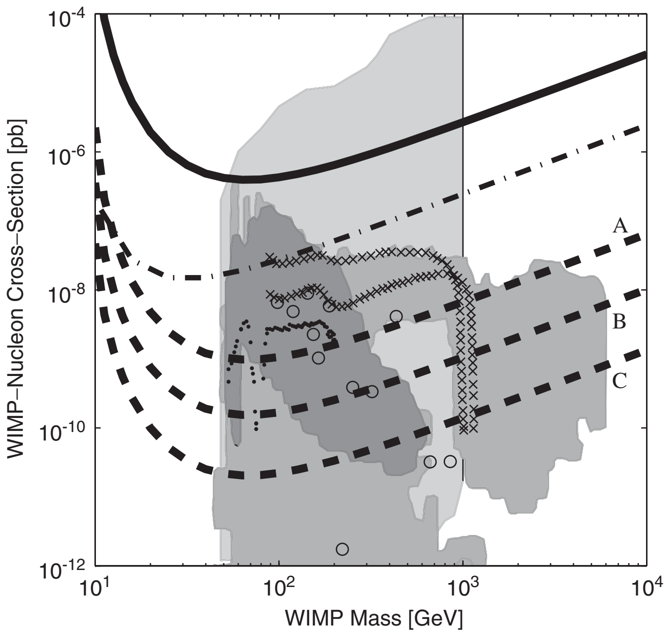

Fig. 1. Proposed science-reach for the SuperCDMS program. The CDMS II WIMP-exclusion limit from the first data-run at Soudan (Run 118) is shown as the solid curve [1]. The ultimate sensitivity at the 2090 m.w.e. depth of Soudan expected at the end of the CDMS II program is indicated by the dot–dashed curve. The lightest gray region is the theoretical region of interest from a scan of MSSM parameter space [4]. SuperCDMS will probe nearly all recently-proposed split-supersymmetry models (×'s [5] and dots [6]) and much of the mSUGRA region [7] (medium gray), including most post-LEP benchmark points (circles) [8] and nearly all the subset (dark gray) consistent with a supersymmetric interpretation of muon $g-2$ measurement.

The SuperCDMS program proposed last year to the US National Science Foundation (NSF) and Department of Energy (DOE) includes a scaling up of the CDMS detector technology in several phases [9]. The projected sensitivities to scalar WIMP interactions on the Ge targets for each phase are indicated in Fig. 1.

For each phase of SuperCDMS, not only does the target exposure need to increase but also, to maintain maximum improvement in sensitivity as a function of exposure time, we desire a *zero background* experiment for each phase. For instance, scaling from the present Soudan results gives a background event rate goal for Phase A of 1×10^{-4}/kg/day, integrated over 15–45 keV, the nuclear recoil energy range of interest.

2. SuperCDMS Phase A

The SuperCDMS Phase A proposed is 27 kg of Ge comprised of 7 towers, each containing 6 ZIP [10] detectors similar to those used in CDMS II. The detectors would be scaled up in substrate thickness from the 10 mm used in CDMS II to 25 mm for Phase A.

The dominant source of background events in the present CDMS II ZIP detectors are surface electron events due to surface beta-source contamination. The results of [1] suggest that a total reduction by a factor of 100 is required (per unit target mass) for surface electron events in the energy range of interest, 15–45 keV. In order to accomplish this goal we are targeting a factor of two improvement in the ZIP detector surface rejection capability by optimizing the hydrogenation of the amorphous Si electrodes used for the ionization signal measurement. An additional effective factor of 2.5 improvement in surface event rate reduction also follows from increasing the detector thickness from 10 to 25 mm. A further factor of four is anticipated from improved analysis of the athermal phonon signal pulse-shapes compared to that reported last year in Ref. [1]. Recent impressive progress has already been made [2,3,11].

A final factor of five improvement is targeted in the source of beta contamination itself. Preliminary surface analysis studies suggest that K-40 and C-14 presently comprise less than 20% of the CDMS II ZIP detector surface contamination and are thus not a source of concern for Phase A. Instead, Pb-210 plate-out from radon exposure during detector production is the most likely source of contamination. During the construction of the 5 towers of CDMS II the radon plate-out protocols were improved. Thus, as further data from the latter CDMS II detector towers at Soudan becomes available and we will be able to determine the success of our later Rn suppression efforts. In addition, we propose surface screening programs for gammas, betas and alphas; and surface analysis techniques such as inductively-coupled plasma mass spectroscopy (ICP-MS) to identify other possible, more exotic, sources of surface beta contamination.

3. Present activities

SuperCDMS Phase A could be performed using the present icebox at Soudan, but we would not have background-free operation: the neutron background due to muons at the present 2090 m.w.e. depth Soudan site, with the present CDMS II apparatus shielding, is anticipated to be 1×10^{-4}/kg/day, integrated over 15–45 keV. Thus, a new cryogenic facility is proposed, at a deeper site, which can also accommodate the subsequent SuperCDMS phases.

Early conceptual studies on a new cryogenic facility, and associated shielding requirements, have been initiated at Fermilab that could satisfy the Phase A, B & C requirements.

Equipment upgrades at the Stanford Nanofabrication Facility are on-going to allow the processing of 25 mm thick substrates, with the first UV photolithographic exposures successfully accomplished. In addition, new detector concepts with enhanced surface rejection capability that show early promise for the later, even more stringent background goals, of the later phases of SuperCDMS are undergoing research and development.

Last year the Canadian government approved the SNOLab facility at the Sudbury mine for occupancy as early as 2007. The ~6000 m.w.e. overburden at this site satisfies the neutron background for even the 1.1 ton Phase C of SuperCDMS. The SuperCDMS proposal has generated strong interest at SNOLab and further discussions are in progress. Recently, the NSF has down-selected the DUSEL (Deep Underground Science and Engineering Laboratory) project to two possible sites for further study: the Henderson mine near Denver, and the Homestake mine in South Dakota.

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