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SuperCDMS Development Project

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Proposal to DOE and NSF

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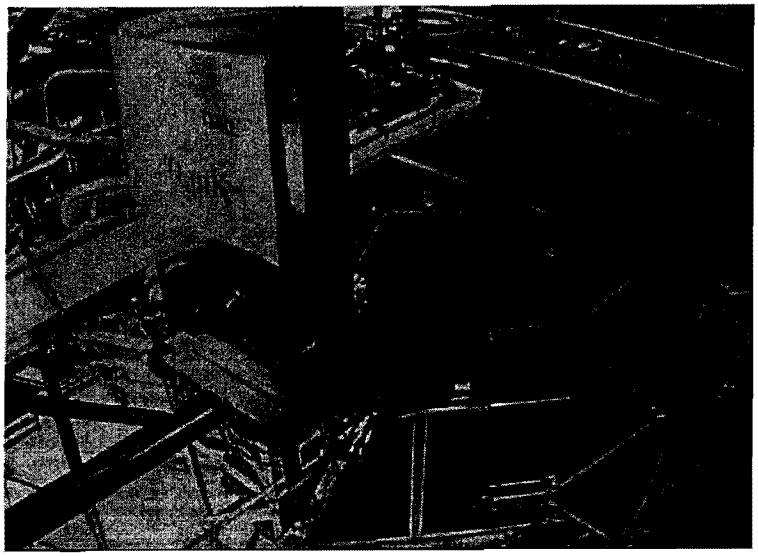

CDMS at Soudan - World-best WIMP sensitivity

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SuperCDMS Development Project

SuperCDMS Collaboration:

Brown University, California Institute of Technology, Case Western Reserve University, Fermi National Accelerator Laboratory, Lawrence Berkeley National Laboratory, National Institute of Standards and Technology - Boulder, Santa Clara University, Stanford University, University of California at Berkeley, University of California at Santa Barbara, University of Colorado at Denver and Health Sciences Center, University of Florida, and University of Minnesota.

Observations of galaxies, superclusters, distant supernovae and the cosmic microwave background radiation, tell us that ~85% of the matter in the universe is not made of ordinary particles. Deciphering the nature of this dark matter would be of fundamental importance to cosmology, astrophysics, high-energy particle physics and our understanding of gravity. A leading hypothesis is that it is comprised of Weakly Interacting Massive Particles, or WIMPs, that were produced moments after the Big Bang. If WIMPs are the dark matter, then their presence in our Milky Way may be detectable via scattering from atomic nuclei in a terrestrial detector.

The Cryogenic Dark Matter Search (CDMS) Collaboration, supported jointly by NSF and DOE, has pioneered the use of low temperature phonon-mediated detectors to distinguish the rare scattering of WIMPs on nuclei from prominent radioactive backgrounds. With this powerful technology, operating deep underground in the Soudan mine in Minnesota, we are the most sensitive WIMP search in the world and our reach is projected to grow by another factor of 20 over the next year.

This document introduces the "SuperCDMS" project, a phased experimental program which builds on the success of the CDMS II project and extends the direct-detection reach for WIMP dark matter by an additional two orders of magnitude over the next decade. To take full advantage of the larger, cleaner detectors we develop for this project, we reduce the cosmogenic neutron level by moving to SNOLab starting in 2009. The increase in sensitivity greatly expands our discovery potential and complements the study of supersymmetry at the Large Hadron Collider.

This proposal to NSF and DOE covers the 4-year development phase of this exciting program, from April 2005 to March 2009. This SuperCDMS Development Project will combine the technical preparation for the SNOLab experiment with continued running of CDMS detectors at our Soudan facility together with six new SuperCDMS detectors. Our technical development will include the fabrication of detectors which are 2.5 times more massive than the CDMS II detectors with improved rejection capability and decreased surface backgrounds. We will also develop more efficient detector production methods and design the necessary cryogenic, electronic and data acquisition systems. This work will lay the foundation for SuperCDMS Phase A and SuperCDMS Phase B, experiments at SNOLab deploying 25-kg and 150-kg of Ge target masses, and running in 2009-2011 and 2012-2014, respectively. The SuperCDMS Development Project deliverables include the Conceptual and Technical Design Reports for these two phases. basis for their eventual approval.

The SuperCDMS Development Project expands the CDMS collaboration to thirteen institutions, with more expected as SNOLab plans mature. The proposed management plan has evolved from the experience of CDMS II. Blas Cabrera will be the spokesperson, Dan Akerib, the co-spokesperson, and Dan Bauer the project manager. The Collaboration Board will be chaired by Bernard Sadoulet.

This Development Project will have broader impact than these scientific results. The technical development will push the envelope of phonon-mediated detectors, which have increasing applications. The project will strongly contribute to the training of undergraduate and graduate students and of postdoctoral researchers, using techniques at the leading edge of measurement technologies. In addition, the SuperCDMS collaboration will expand its public outreach program at Soudan and transfer its experience to SNOLab. We will also continue our involvement in K-12 education, with a focus on collaboration with middle and high school teachers.

SuperCDMS Development Project

1 Introduction

This proposal both (1) presents the case for SuperCDMS — a phased experimental program that will improve sensitivity for direct detection of weakly-interacting massive particles (WIMPs) by more than a factor of 100 beyond the reach of current experiments; and (2) requests funding for the SuperCDMS Development Project — a program of modest detector development and background reduction that will enable these large gains in sensitivity, and also allow continued operation of the CDMS II detectors along with new SuperCDMS prototypes to complete the science reach available at the Soudan Underground Laboratory.

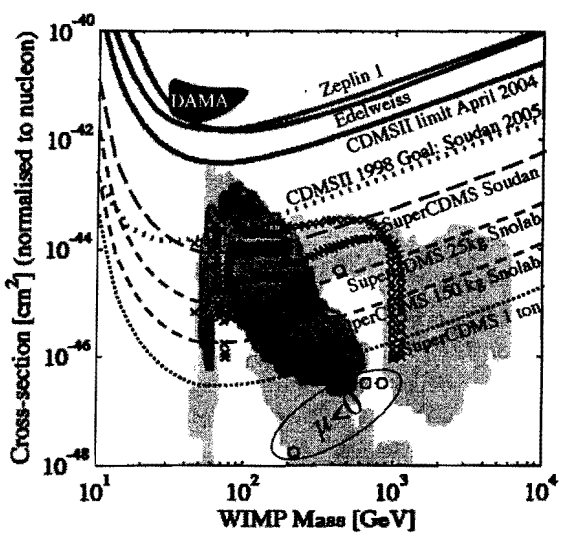

Figure 1: Overview of SuperCDMS science reach showing the current CDMS world-best limit, and the phased SuperCDMS program in steps eventually up to one ton of Ge mass. The blue [1] and green [2] crosses are split-supersymmetry models, the red circles are the constrained MSSM [3] and the blue and green shaded regions are mSUGRA [4] models, all with with WMAP constraints on the relic density. The blue shaded region also imposes a 1-σ constraint from the muon $g-2$ measurement. (See Section 2).

Experiment	Cross-section sensitivity
CDMS II spr. 2004	4×10^{-43} cm^2
CDMS II final (end 2005)	3×10^{-44} cm^2
SuperCDMS Development Project (mid-2008)	1×10^{-44} cm^2
SuperCDMS Phase A (25 kg) (end of 2011)	2×10^{-45} cm^2
SuperCDMS Phase B (150 kg) (mid-2015)	3×10^{-46} cm^2

Table 1: WIMP-nucleon scattering cross-section goals for the SuperCDMS program (see Fig. 1). These are for a WIMP mass of 60 GeV/c^2 and are listed with expected end dates.

Section 2 describes the current landscape for WIMP dark matter, focusing on supersymmetric models. As shown in Fig. 1 and summarized in Table 1, the SuperCDMS program is complementary to explorations of supersymmetry (and other physics beyond the Standard Model) at the Large Hadron Collider (LHC), currently under construction at CERN. Section 3 presents results from the current CDMS II experiment at the Soudan mine. CDMS II has the world's best sensitivity (by a factor of 4) and expects to gain another factor of 10-15 in the next 15 months as the CDMS II project is completed.

Section 4 reviews our strategy for the phased program and how a two-pronged attack of detector development and background reductions will enable this strategy. Section 5 presents the specific modest detector development we plan to undertake to enable the SuperCDMS program, and Section 6 presents our plan for reducing levels of background particle interactions (arising from photons, electrons, and neutrons) to reach the desired sensitivity goals.

Section 7 outlines the specific deliverables of the SuperCDMS Development Project: conceptual and technical design reports for the Phase A and Phase B experiments, as well as sensitivity gains from additional running at Soudan of existing and new detectors.

Section 8 describes the management plan and institutional responsibilities for the SuperCDMS Development Project, and Section 9 presents a

summary of the budget for the project, including related R&D "base" programs.

Section 10 describes these separate base-program proposals in more detail and how their long-term goals relate to the Development Project and subsequent phases. Section 11 reviews the impacts of CDMS II on the broader community and how these will be expanded and enriched by the SuperCDMS program.

2 WIMP Dark Matter: Cosmology and Supersymmetry

Over the last decade, a variety of cosmological observations, from the primordial abundance of light elements, to the study of large scale structure, to the observations of high redshift supernovae, to the detailed mapping of anisotropy of the cosmic microwave background, have led to the construction of a concordance model of cosmology. In this very successful model, the universe is made of ~4% baryons which constitute the ordinary matter, ~23% nonbaryonic dark matter and ~73% dark energy[5]. Understanding the nature of dark matter and dark energy are the most important challenges to cosmology. The solution to these two problems very likely involves particle physics at a deep level: for instance, the dark matter could be an experimental signature of supersymmetry, and the dark energy a measure of the effective gravitation of vacuum energy.

Weakly Interactive Massive Particles (WIMPs) represent a generic class of candidates for this dark matter [6, 7]. These Big Bang relic particles are particularly interesting because of the convergence of independent arguments from cosmology and particle physics. WIMPs would have been in thermal equilibrium with quarks and leptons in the hot early universe and decoupled when they were nonrelativistic. Purely cosmological considerations lead to the conclusion that WIMPs should interact with a cross section similar to that of the Weak Interaction. Separate indications are that new physics appears to be needed at the W and Z scale in order to solve the famous "hierarchy problem." Precision electroweak data constrain the Higgs mass to be in the 120-170 GeV/c^2 range in spite of the radiative corrections that tend to drive it to higher values. These corrections tend to be cancelled in supersymmetry, which naturally predicts that the lightest supersymmetric partner (LSP) is stable and interacts at roughly the Weak-Interaction rate, allowing it to decouple from ordinary matter in the early universe with a relic density comparable to the dark matter density. If WIMPs are indeed the dark matter, their density in the galactic halo may allow them to be detected via elastic scattering from atomic nuclei in a suitable terrestrial target. However, the energy deposition and the rates are low, requiring that this type of experiment be located deep underground to protect it from cosmic rays.

In addition to solving a fundamental cosmological problem, such astrophysical searches attempt to probe new physics at the electroweak scale and thus complement the search for supersymmetry at accelerators. A number of recent reports from the National Research Council ("Connecting Quarks with the Cosmos," chaired by M. Turner [8]; "Neutrinos and Beyond," chaired by B. Barish [9]) and HEPAP ("The Quantum Universe," chaired by P. Drell [10]) have pointed out the high priority of this enterprise. In reviewing some of these findings, the OSTP Interagency Working Group's "Physics of the Universe" report directed that in the area of dark matter "NSF and DOE will work together to identify a core suite of physics experiments. This will include research and development needs for specific experiments, associated technology needs, physical specifications, and preliminary cost estimates" [11]. CDMS has demonstrated technology for discriminating WIMPs from cosmogenic and radioactive backgrounds with unsurpassed sensitivity to the WIMP-nucleon scattering cross section, and we believe it is one of the strongest candidates for inclusion in such a program. Indeed, we see a clear path forward to extend our sensitivity by factor of 100–1000.

2.1 Experimental Limits on WIMPs

The direct-detection experiments, in particular CDMS II [12], EDELWEISS [13], and ZEPLIN I [14], are beginning to significantly constrain the WIMP-nucleon scattering cross section. In particular, it is increasingly difficult to reconcile the DAMA claim of a WIMP signal based on annual modulation [15].

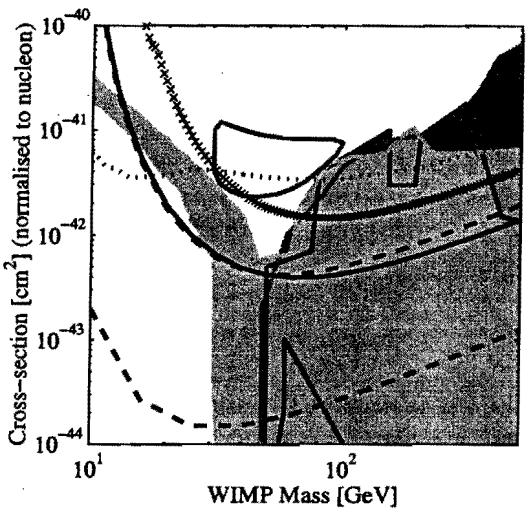

Figure 2: New limit on the WIMP-nucleon scalar cross section from CDMS II at Soudan [12] with no candidate events in 52.6 raw Ge kg-d (solid curve). Parameter space above the curve is excluded at the 90% C.L. These limits constrain supersymmetry models, for example [16] (cyan), [17] (cyan), and [18] (yellow). The DAMA (1-4) 3σ signal region [15] is shown as a closed contour. The projected reach of CDMS II is shown as blue dashes. Also shown are limits from CDMS at the Stanford Underground Facility [19] (dots), the EDELWEISS Experiment [13] ($\times$'s), and the second, nonblind analysis of CDMS II at Soudan with 1 nuclear-recoil candidate event (upper dashes).

In most quantitative models (such as supersymmetry) scalar interactions dominate, and the quantum number that adds in the coherent scattering matrix element is very close to the atomic number of the nucleus. This process is also referred to in our field as "spin-independent" scattering. Together with a standard galactic halo model, this WIMP-nucleus scattering perscription allows a cross-section upper limit to be calculated from a scattering-rate upper limit [20]. Figure 2 shows the present experimental situation. As shown by Copi and Krauss [21], it is difficult to find a halo model which reconciles DAMA with the other experiments.

In addition, it is possible in restricted regions of parameter space, in particular for a spin-$\frac{1}{2}$ WIMP that is its own antiparticle, that the additive quantum number in the scattering matrix is the spin. This case is known as "spin-dependent" scattering. The preliminary result from CDMS II shown in Fig. 3 is based on the simplified framework proposed in [23] and provides the most sensitive WIMP-neutron scattering limits. As shown in [24], this rules out spin-dependent scattering on the unpaired neutron in the nuclei as an explanation for the DAMA modulation result for a standard halo model. Global analyses of direct and indirect detection experiments are becoming more sophisticated [23, 25], with the result that there is presently no compelling evidence that any experiment to date has detected dark matter.

2.2 Constraints on Minimal Supersymmetry

CDMS II is starting to constrain some supersymmetry models, as shown in Fig. 1. In the most general minimal supersymmetric model, there are unfortunately a large number of parameters and theorists usually attempt to reduce their number by imposing additional "natural" assumptions. There are three broad philosophies: (1) constrain the parameters primarily by data to allow observations to guide the theory (e.g. [16, 17]), (2) constrain the parameters through theoretical input to obtain maximum predictive power, and, more recently, (3) "split supersymmetry" which decreases the effective number of parameters by allowing the scalars to be very massive (at the price of fine-tuning). Figure 1 shows the regions of mass and cross section for WIMPs from these models.

Unconstrained models (e.g., [16, 17]) only make minimal unification assumptions and constrain the parameters from accelerator experi-

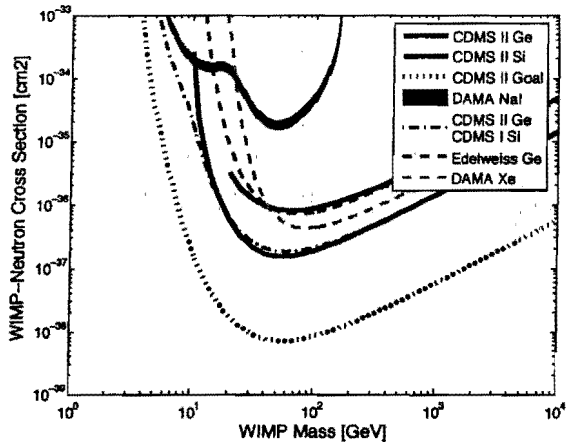

Figure 3: CDMS II preliminary spin-dependent limits from unpaired neutrons. The solid blue line gives the ^{73}Ge limit. The purple line, the ^{29}Si limit. The blue dashes combine Ge data obtained at Soudan with Silicon data obtained at Stanford. We exclude the DAMA claim (filled red region), as computed in [24]. For comparison, we have added the limits from the DAMA Xe [22] and EDELWEISS Ge [13] experiments. We also show the sensitivity reach for the CDMS II goal (dotted blue).

ments and the WIMP relic density. Bottino et al. [18] may represent the most extreme form of such a model, in which unification assumptions are abandoned in an apparent attempt to accommodate the DAMA result. As shown in Fig. 2, CDMS II has begun to put constraints on these scenarios.

Theoretically-constrained models, which serve as a useful benchmark for LHC searches, also provide an example of the complementarity of WIMP and accelerator experiments. For example, consider the Constrained Minimal Supersymmetry Model [26] or the Minimal Supergravity Model (mSUGRA) [4], which impose unification of the SUSY parameters. Some of the regions of parameter space, such as the "focus point" region, which tend to large scalar masses, are inaccessible at the LHC but could be easily seen in SuperCDMS at a WIMP-nucleon cross section of 10^{-44} cm^2. On the other hand, in the "co-annihilation" region, the LHC has a good chance of seeing the 5 Higgs particles, as well as gaugino decays into identifiable squarks and neutralinos. However, the WIMP-nucleon cross section could be anywhere in the range 10^{-46}–10^{-44} cm^2, which requires a ton-scale SuperCDMS detector for a full exploration.

Recent work developing the idea of "split supersymmetry" [27, 1, 2] has led to renewed interest in the WIMP-nucleon cross-section range of 10^{-45}–10^{-44} cm^2, making a staged improvement in sensitivity attractive, as illustrated in Fig. 1. Motivated by the large number of vacua in string theory and the difficulty of accounting for the apparent small value of the cosmological constant, some theorists have discarded the usual concept of "naturalness." Rather, the apparent randomness of physical constants are fine-tuned through the selection of universes that can sustain the formation of structure and the appearance of observers. While these "anthropic" arguments are often criticized due to their perceived lack of predictability, Arkani-Hamed and Dimopoulous, among others, have shown that they could have testable consequences [27, 1].

In their split-supersymmetry model, they propose to break supersymmetry at the unification scale instead of the electroweak scale. In this case, the scalar particles are no longer prevented from going to high masses, while the fermions can stay light if the bare Lagrangian has chiral symmetry. The anthropic argument is applied to fine-tune the Higgs mass to account for the dark matter — otherwise galaxies (and observers) would not have formed. Because the scalar quarks are too heavy to contribute, the effective number of parameters is small and the scattering rate is governed by Higgs exchange. The resulting cross sections are in the range 10^{-45}–10^{-44} cm^2 (the dark blue and dark green crosses in Fig. 1), and accessible to SuperCDMS.

This approach couples the problems of dark matter and dark energy in a very interesting way, and illustrates once again the complementarity of SuperCDMS and the LHC. For instance, in the specific model we just described, the LHC will detect only one Higgs, the neutralino (if it is light enough), and a long-lived gluino [28]. Meanwhile, SuperCDMS would check that indeed the neutralino constitutes the dark mat-

ter in the universe, providing the justification of the split-supersymmetry scheme, and fixing the remaining parameters of the model. According to Arkani-Hamed and Dimopoulos, the long life of the gluino would then be a signature for fine tuning and a strong indication that indeed dark matter and dark energy are the result of the selection of the universe in which we live!

Finally, in the recent years, there has been much excitement about compact extra dimensions of order 1 $TeV^{-}1$ as an alternative explanation of the hierarchy problem. In a broad class of such models, the lightest Kaluza Klein excitation is stable and could be the dark matter [29], with a mass of order 1 TeV/c^2. Remarkably, the elastic scattering cross section covers the range from 10^{-46} to 10^{-42} cm^2 per nucleon, which is accessible by the combination of CDMS II and SuperCDMS.

2.3 Conclusion: SuperCDMS has very high scientific priority

Whatever confidence one wants to give specific theoretical considerations, the foregoing discussion clearly indicates the high scientific priority of increasing the ultimate reach of CDMS. While CDMS II will continue to advance in the coming year into the low-mass supersymmetric region, SuperCDMS will explore the most favored supersymmetric models in a complementary way to the LHC and on a similar time scale. As shown above, the combination of LHC and WIMP-nucleus elastic-scaterring experiments would check the consistency of the model and provide powerful constraints on the parameters. More generally, the low mass of the Higgs inferred from electroweak measurements point to a WIMP-nucleon cross section on the order of 10^{-45}–10^{-44} cm^2.

We should not neglect the possibility that CDMS II will discover WIMPs in the coming year or two, in which case it would be even more important to scale up in mass to confirm such a signal and acquire more statistics. Conversely, should supersymmetry be discovered at the Tevatron or LHC, SuperCDMS will check whether it is responsible for dark matter — again, the larger-mass technology that we propose will be needed.

We believe that the CDMS technology is the fastest way to cover this lower cross section range. We have already demonstrated the background-rejection power of electron-vs-nuclear recoil discrimination and the advantages of obtaining the additional information provided by collecting the athermal phonons caused by a scattering event. This additional phonon information is part of why we are leading our European competitors, who use slower phonon mediated methods: EDELWEISS and CRESST II. The xenon technology also looks like a promising way to positively identify the nuclear recoils on a per event basis. The xenon groups are progressing, but still need to reach key demonstration milestones of scintillation-light and ionization yields as a function of the electric field for nuclear recoils at low threshold. While liquid xenon may scale straightforwardly to large target masses, there are still technical challenges, such as trapped scintillation light from internal reflection and sufficient position resolution to limit the edge effects (the equivalent of our surface events) and, like all dark matter experiments, control of the radioactive background in a complex environment. Given the importance of the science, we believe it wise to support more than one large-mass technology to provide necessary cross checks on systematic effects. Indeed, this approach is in keeping with the OSTP report, which refers to a suite of experiments [11].

In summary, CDMS is leading the field and by carrying out the Development Project proposed here, together with the related proposals on long-term R&D, we will be able to stay at the frontier of the WIMP search and explore a crucial region of parameter space, in a way that is complementary to the LHC.

3 The CDMS II Project

The CDMS II experiment has been carefully constructed over several years in the Soudan Underground Laboratory (2000 mwe) and has now operated successfully for more than a year. The

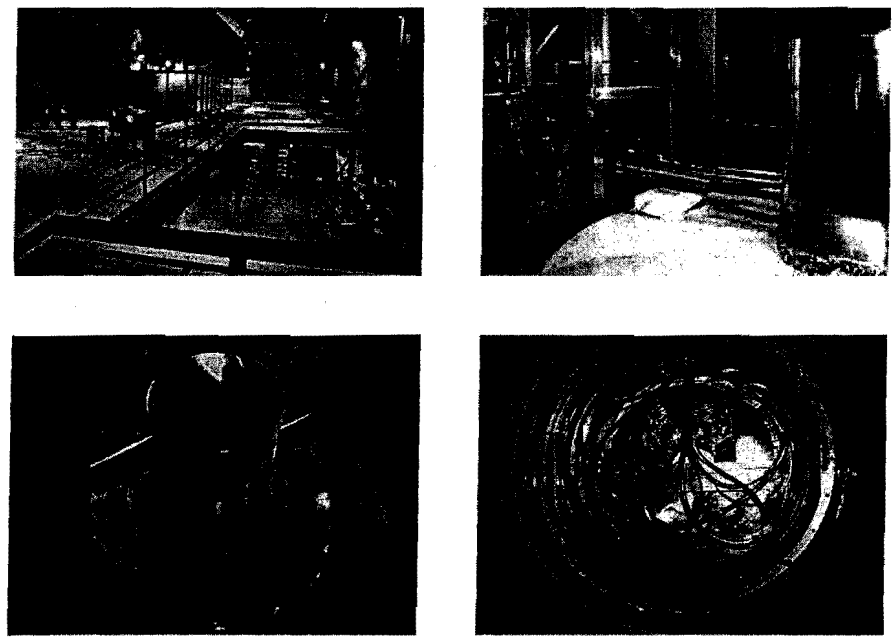

Figure 4: The CDMS II infrastructure at Soudan. Clockwise from upper left: the upper-half of the class-10,000 cleanroom which houses the experiment seen from the mezzanine level; the cryogenics system, with the dilution refrigerator and detector cold volume (icebox) connected via the cold stem; Towers 1 & 2 installed in the inner can of the icebox; a partial assembly of the shielding layers in the cleanroom.

first data run has already resulted in a publication with the best limits in the world on the detection of WIMPs [12]. CDMS II represents a significant investment for the collaboration and the funding agencies. In this section, we briefly describe the Soudan setup, the current results, and our expectations of major gains in sensitivity by the end of the CDMS II project.

3.1 CDMS II in the Soudan Mine

Figure 4 shows elements of the CDMS facility in the Soudan mine. The experiment is housed within an rf-shielded, class-10,000 cleanroom, with an auxiliary clean preparation area (anteroom), a room for electronics and data acquisition, and an area for cryogenic systems.

The experimental apparatus is hermetically surrounded by active shielding, consisting of two-inch-thick plastic scintillator panels. Inside of this "veto" is a 200-cm-tall by 200-cm-diameter hollow cylindrical polyethylene shield with a 50-cm-thick top, bottom and wall, which moderates neutrons from surrounding materials. Inside of that is a 130-cm-tall by 130-cm-diameter hollow Pb shield with 25-cm walls, which stops gamma rays produced by radioactivity in the rock. Farther inside is a second 10-cm-thick polyethylene shield, which moderates neutrons that penetrate the Pb. Finally, at the center is the Icebox, a cryogenic chamber mapped to the thermal layers of the dilution refrigerator via a nested set of copper stems, (or cold stem). There is space in the base temperature chamber for seven six-detector "towers" arranged in a hexagonal pattern.

The detector signals are brought out through another set of nested copper stems to a vacuum bulkhead and from there to front end electronics. After amplification, the signals pass to a second stage of electronics which filters them and form the trigger. They are then sampled by commercial (VME) waveform digitizers and recorded by a modern data acquisition system, which logs both veto and detector data to DLT tape. Real-time online analysis of a fraction of the data in-

sures quality. An offline-analysis facility local to Soudan further examines some of the data. Bulk processing is accomplished at Stanford and Fermilab computer clusters.

The dilution refrigerator is operated using a sophisticated cryogen control system for liquid helium and liquid nitrogen which can be fully monitored and controlled from the outside of the mine. Although we have 24/7 emergency access to the mine, this system has minimized the number of times we have had to use the emergency access.

Figure 5: ZIP detectors mounted in copper housings.

Figure 5 shows a mounted ZIP detector. Each Ge detector currently has a mass of 250 g and each Si detector a mass of 100 g. The CDMS ZIP (Z-dependent Ionization and Phonon) detector technology, using simultaneous athermal phonons and ionization measurement has demonstrated outstanding rejection of gamma and beta backgrounds. These background particles scatter off electrons in the detectors, while WIMPs (and neutrons) scatter off nuclei. The ZIP detectors allow discrimination between electron and nuclear recoils through two effects. First, recoiling electrons are more ionizing than recoiling nuclei, resulting in a higher ratio of ionization to phonon signal, called "ionization yield." Figure 6 shows the discrimination based on ionization yield. Second, the athermal phonon signals due to nuclear recoils have longer rise times and occur later than those due to electron recoils, as is shown in Fig. 7. For recoils

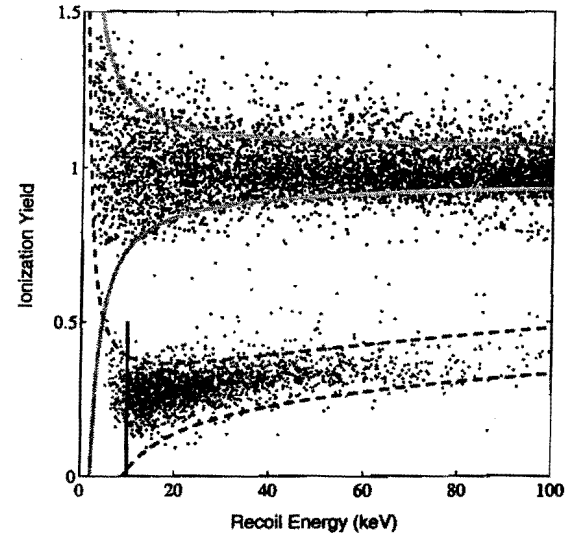

Figure 6: Ionization yield versus recoil energy for calibration data with a ^{252}Cf gamma and neutron source for detectors Z2, Z3 and Z5 in Tower 1 showing the $\pm 2\sigma$ gamma band (solid curves) and the $\pm 2\sigma$ nuclear-recoil band (dashed curves) for Z5, the detector with the worst noise of these three. Events with ionization yield < 0.75 (green) are shown only if they pass the phonon-timing cuts. The vertical line is the 10 keV analysis threshold for these three detectors.

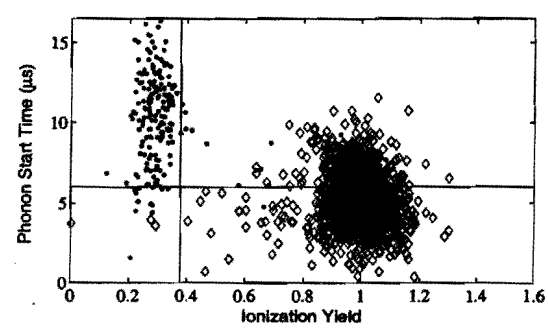

Figure 7: Phonon start time versus ionization yield for ^{133}Ba gamma-calibration events (diamonds) and ^{252}Cf neutron-calibration events (dots) in the energy range 20–40 keV in detector Z5 in Tower 1. Lines indicate typical timing and ionization-yield cuts, resulting in high efficiency for nuclear recoils and a low rate of misidentified electron-recoil events.

within a few μm of a detector's surface (primarily from low-energy electrons), the charge collection is less complete, making discrimination based on ionization yield less effective. Many of these events can be rejected by phonon timing cuts because they have even faster phonon signals than those from bulk electron recoils.

3.2 CDMS II Results

The CDMS II project includes the fabrication, testing and operaton of five towers of detectors, each with six ZIP detectors. Towers 1 & 2 were installed at Soudan in March 2003, and the detectors were cooled to a base operating temperature below 50 mK by June 2003. In the fall of 2003 we began the operation of Tower 1, and in 2004 we operated both Towers 1 & 2.

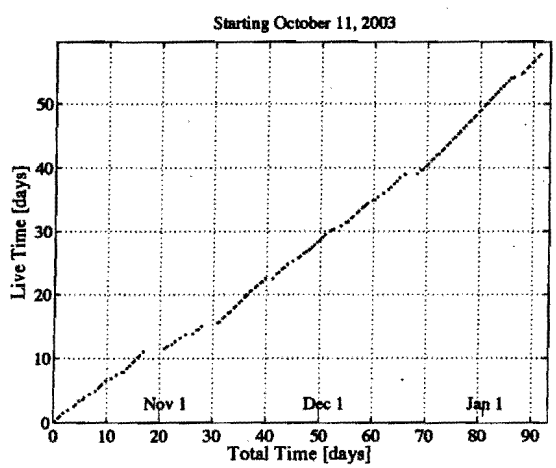

Figure 8: Accumulated exposure in live days for Tower 1 run at Soudan in fall of 2003.

Tower 1 at Soudan

The first WIMP-search data at Soudan was taken between October 11, 2003 and January 11, 2004. We obtained 52.6 live days with the four Ge and two Si ZIP detectors of Tower 1. Figure 8 shows the accumulation of live days over the three months and represents 62% efficiency over the entire period, and 75% over the last six weeks.

Energy calibrations were performed repeatedly during the run using a ^{133}Ba gamma source with distinctive lines at 356 keV and 384 keV. The agreement between data and Monte Carlo simulations and the observation of the 10.4 keV Ga line from neutron activation of Ge indicated that the energy calibration was accurate and stable to within a few percent. To guarantee stability of operation and effective neutralization of the crystals during the WIMP search runs, the region outside the nuclear-recoil band of the WIMP-search data was continuously monitored.

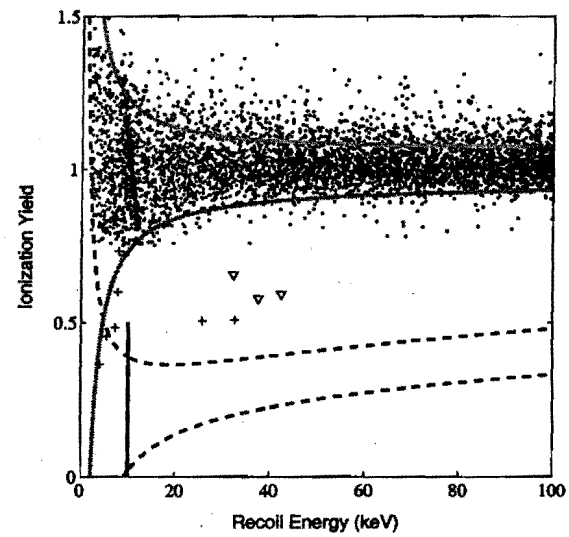

Figure 9: Ionization yield versus recoil energy for WIMP-search data from Z2 (triangle), Z3, and Z5 (+) in Tower 1, using the same yield-dependent cuts and showing the same curves as in Fig. 6. Above an ionization yield of 0.75, the events from all three detectors are drawn as identical points to show the 10.4 keV Ga line from neutron activation of Ge.

We performed a blind analysis, in which the nuclear-recoil region for the WIMP-search data was not inspected until all cuts and analysis thresholds were defined using *in situ* gamma and neutron calibrations. A combination of ionization-yield and phonon-timing cuts rejected virtually all calibration electron recoils while accepting most of the nuclear recoils (see Fig. 7). The ^{133}Ba gamma calibrations produce mostly bulk events, but also a distribution of low-yield surface events primarily from electrons ejected from neighboring material onto the ZIP detectors. These surface events allow us to determine

the effectiveness of phonon-timing cuts for surface events such as those due to surface beta contamination. Based on ^{133}Ba calibration sets and including systematic errors, we expected 0.4 ± 0.3 electron-recoil events in Z1[1] to be misidentified as nuclear recoils and a total of 0.3 ± 0.2 electron-recoil events to be misidentified in the other Ge detectors. Monte Carlo simulations predicted 0.05 ± 0.02 neutrons (some unvetoed) produced from muon interactions outside the shielding, including uncertainties on neutron production.

This blind analysis of the first Soudan CDMS II WIMP-search data set revealed no nuclear-recoil events in 52.6 kg-d raw exposure in our Ge detectors. Figure 9 displays the ionization yield of WIMP-search events in Z2, Z3, and Z5 that passed the same cuts applied to calibration data in Fig. 6. As shown in Fig. 2, these data together with corresponding data for Z1 set an upper limit on the WIMP-nucleon cross-section of 4×10^{-43} cm^2 at the 90% C.L. at a WIMP mass of 60 GeV for (spin-independent) coherent scalar interactions and a standard WIMP halo. At 60 GeV, this limit is eight times lower than our previous results and four times lower than that of EDELWEISS [13]. A report on these results has been accepted for publication in *Physical Review Letters* [12] and a detailed *Physical Review* paper is in preparation.

3.3 CDMS II Completion

Following the successful Tower 1 run, we commissioned Tower 2 and took data with both towers from March 24, 2004 to August 8, 2004, gaining an additional raw Ge exposure of $\sim$ 75 kg-days. In addition to the factor of 3 improvement in sensitivity to be expected from the combined data set, this will give confirmation that our neutron estimates are correct and provide valuable data on beta and gamma backgrounds in an independent set of detectors. We expect to publish results on these data by the end of 2004.

We warmed up the experiment starting August 8, 2004 (after nearly a year at 50 mK!)

[1]Of 4 Ge ZIPs, Z1 has worse resolution than Z2, Z3 and Z5 due to a large T_c gradient in its phonon sensors.

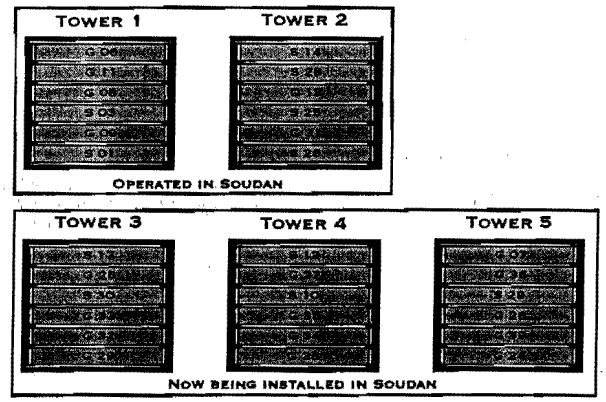

Figure 10: Towers 1 & 2 have been operating in Soudan, Towers 3 & 4 are complete and Tower 5 will be ready in October 2004.

and are currently installing several necessary upgrades. Chief among these are the three new detector towers, the flex circuits to read them out, and a cryo-cooler to mitigate their additional heat loads and reduce helium consumption. Figure 10 shows the five-tower arrangement for this installation. A commissioning period of three months should be sufficient to cool the system and bring the new detectors into operation.

Based on our projected exposure of about 1200 kg-d for the CDMS II experiment through the end of its funding period, December 31, 2005, we expect to extend our sensitivity for a WIMP-nucleon cross section down to a 90%-C.L. upper limit of $\sim 3 \times 10^{-44}$ cm^2 and a 99%-C.L. detection at $\sim 6 \times 10^{-44}$ cm^2.

4 SuperCDMS Strategy

Based on the success of the CDMS II project, we propose an ambitious program that will extend sensitivity to WIMP-nucleon scattering by more than a factor of 100 over the present generation of experiments and by a factor of 1000 over currently published limits. Figure 11 shows our proposed timeline starting with the SuperCDMS Development Project which will plan and propose a 25 kg Ge experiment (Phase A), then a 150 kg Ge experiment (Phase B), and eventually lead to a ton scale experiment. In this section, we

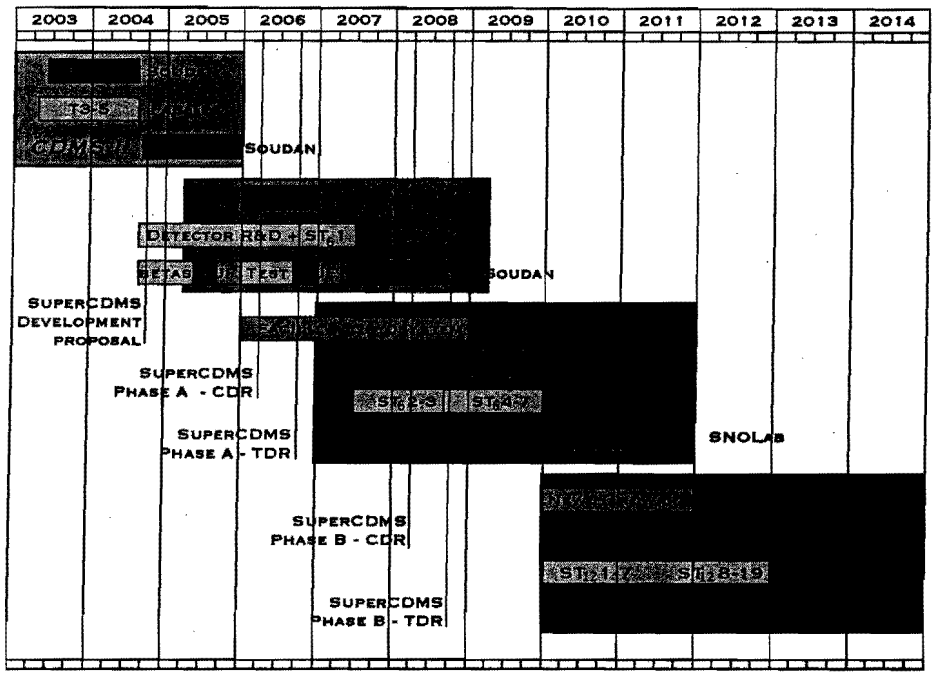

Figure 11: Schedule timelines for CDMS II, SuperCDMS Development and Phases A and B.

outline the strategy by which we expect to make these large gains, specifically explaining how we minimize risk with our phased program.

The fundamental aspect of our risk-reduction strategy is that at the time we propose a given experimental phase, we will have demonstrated the improvement factors needed for that phase. Thus, the SuperCDMS Phase A (25 kg) and Phase B (150 kg) become, in essence, construction and execution projects. In parallel, each phase includes the development for the next phase, so schedule and budget risks are reduced.

4.1 A Zero-Background Experiment

In the absence of backgrounds, the search sensitivity of a detector array is directly proportional to the mass × exposure time (MT). In a mode where subtraction of an estimated background becomes necessary, the sensitivity improvement becomes proportional to $\sqrt{MT}$. Ultimately, the subtraction becomes limited by the systematics of calibrating the detector response to the background and no further improvement in sensitivity is possible. Thus, it is desirable to operate the experiment in "zero-background" mode to obtain the proposed large sensitivity gains.

In order to obtain zero-background operation and significantly increase exposure, we must achieve:

- Improvements in background rejection through technology and analysis advances.
- Reductions in raw rates of electromagnetic and neutron backgrounds, including beta-contamination on or near the detectors themselves.
- Improved detector production and testing rates so that the proposed mass × exposure time be achieved within the proposed time and budget.

Table 2 summarizes our target improvement factors for each of these areas for both Phase A (25 kg of Ge) and Phase B (150 kg of Ge). The first three rows are relative to the detector performance in our recent results [12], which correspond to a misidentified beta rate of 1×10^{-2}

Improve	Phase A	Phase B	combined
Detector rejection	×5	×2	×10
Analysis discrimination	×4	×2	×8
Background reduction	×5	×2	×10
Total Improvement	= ×100	= ×8	= ×800
Production rate per kg	×5	×10	= ×50

Table 2: Target improvement factors to achieve Phase A and Phase B sensitivities.

evts/kg/d (see Section 6). The last row is relative to the detector-production rate of one month per detector to produce the 30 CDMS II detectors. We discuss each of these factors below in more detail, and in the following two sections (Section 5 & Section 6). Overall, these are conservative improvement estimates and as we have seen in our previous development efforts, some areas prove easier and provide larger factors while others prove more difficult. The conservative estimates together with the broad approach reduce the risk and give us confidence that we will succeed.

4.2 Targets and Plans for Phase A

As indicated in Fig. 11, the SuperCDMS Development Project is the first step in this managed-risk program. The SuperCDMS Phase A Conceptual Design Report (CDR-A) is due in the Spring 2006 and the SuperCDMS Phase A Technical Design Report (TDR-A) is due in the Fall 2006. In order to propose the 25-kg Phase A experiment with the TDR-A, we need to demonstrate:

- a factor of ×5 improvement in detector background rejection from the larger volume to surface ratio (×2.5) together with improved hydrogen passivated electrode design (×2).
- a factor of ×4 improvement in background rejection from improved analysis techniques that better utilize the full information available from the ZIP detectors.
- a factor of ×5 reduction in surface contamination of detectors by beta-emitting isotopes.
- a factor of ×5 increased rate for detector fabrication and testing from the larger mass per detector (×2.5 for 2.5-cm–thick) together with a streamlining of the fabrication, mounting and testing methods (×2).

We will demonstrate these improvement factors with (1) a run at SUF (the Stanford Underground Facility) used as a low background test facility in the fall of 2005 with three or more 1-cm thick advanced ZIP detectors, to demonstrate improved surface contamination rejection, and (2) a run at SUF used as a beta screening facility in early 2006 to demonstrate reduction of detector surface contamination. The CDR-A will define the production protocol for the first "SuperTower" (ST_6 1) with six new detectors that will satisfy the improvement targets defined above for Phase A.

In addition, we will develop (1) the initial plan for a SNOLab facility for SuperCDMS, which will provide the reduced neutron background required for continued zero-background operation, (2) an expanded collaboration capable of taking on the larger Phase A project, and (3) a contingency plan for reducing neutron backgrounds at Soudan in case the new SNOLab facility is not completed on schedule.

Accomplishing these items will allow us to complete the TDR-A report in the fall of 2006, which will detail the plans to build six more SuperTowers (ST_6 2-7). The funding for the production of these SuperTowers will need to start in the spring of 2007 in order to follow on from the production of ST_6 1 in the Development Project. This TDR-A will propose the Phase A 25-kg experiment with a cross-section reach of 2×10^{-45} cm^2, a factor of 15 better than the expected final result of CDMS II (see Fig. 1).

4.3 Targets and Plans for Phase B

The SuperCDMS Phase B Conceptual Design Report (CDR-B) is due in spring 2008 and the SuperCDMS Phase B Technical Design Report

(TDR-A) is due in the fall 2008. Continued development work during the latter half of the SuperCDMS Development Project will demonstrate the additional advances required for the Phase B (150-kg) experiment, including:

- a factor of ×2 improvement in detector background rejection, from phonon sensor readouts placed symmetrically on both detector faces, and interleaved charge and phonon channels providing surface event rejection using charge and phonons.
- a factor of ×2 improvement in background rejection from improved analysis techniques that better utilize the full information available from the ZIP detectors.
- a factor of ×2 reduction in surface contamination of detectors by beta-emitting isotopes.
- a factor of ×10 increased rate for detector fabrication and testing, from industrializing detector production together with further streamlining of the fabrication, mounting and testing methods.

We will demonstrate these improvement factors with (1) the run at Soudan of the first SuperTower (ST_6 1) of six 2.5-cm-thick advanced SuperZIP detectors, to demonstrate improved surface contamination rejection and reduced contamination, (2) mass production of detectors with National Laboratories and commercial partners, and (3) detector packaging changes to increase the number of detectors per "SuperTower" assembly from six (ST_6) to twelve (ST_{12}) for Phase B.

Demonstration of these points will make it possible for us to complete the CDR-B in April 2008 and to propose with the TDR-B in October 2008 the Phase B 150-kg experiment with cross-section reach of 3×10^{-46} cm^2, a factor of 100 better than the expected final result of CDMS II and a factor of ~8 better sensitivity than the Phase A experiment (see Fig. 1).

4.4 Facilities, Base Programs, Future

Plans for SUF and Soudan

After 2006 and as detailed in Section 6, the utility of SUF as beta-screening facility is limited given the anticipated contamination goals for Phase B. However, its continued use for beta screening may be warranted in the latter part of the Development Project or early part of Phase A, and is reserved as a potential contingency. Longer term, we envision that with the SUF refurbished during the Development Phase, and able to run a maximum of 18 ZIPs (2.5-cm thick), its role will evolve during Phase A and Phase B into one of batch testing partially assembled SuperTowers for subsequent deployment to SNOLab. In a similar fashion, after the SNOLab facility has begun science runs during Phase A, Soudan can also be used for batch testing 18 SuperZIPs per run for deployment to SNOLab.

Base Programs

In parallel with the clearly delineated goals of the SuperCDMS Development Project, at a modest level, we will pursue development of longer term technological advances via existing and proposed "base" programs at NSF and DOE. These additional developments are not required for the SuperCDMS phased program, since we will demonstrate the baseline technology for Phases A and B within the Development Project resources. However, as new results from our base programs become available in time to positively impact Phase A (or Phase B), the technology improvements will be incorporated into TDR-A (or TDR-B). Each detector deployment cycle will include prototypes of the next generation technology, to gain experience and refine procedures.

Beyond SuperCDMS Phase B

Finally, we discuss briefly a possible path for constructing a post-Phase B experiment with 1000 kg of Ge detector mass. Beyond the Phase B deployment, we would double the number of detectors in each SuperTower module to 24 detectors each (ST_{24}), and outsource the manufacture of 73 of these SuperTowers for a 1-ton deployment. We emphasize that approval of

the SuperCDMS Development Project in no way assumes support for such a future 1000 kg experiment. Instead, we describe this path because the muon-induced background at SNOLab would allow a zero-background 1000 kg experiment, and because we believe that the ZIP detector technology can scale to the ton mass. We will work to turn that vision into reality as we accomplish each of the earlier phases.

5 Detector Development

The SuperCDMS detector development work will focus on the Development Project baseline cryogenic detector technology, which will consist of 7.6-cm-diameter 2.5-cm-thick 0.64-kilogram-mass Ge targets with ionization and athermal phonon sensors. The proposed design is based on the present very successful CDMS ZIP detectors, which consist of 1-cm thick Ge (Si) substrates of 250 (100) grams. As demonstrated in CDMS II, the ZIP detectors possess high rejection capabilites against gamma-induced background events. However, in order to achieve our long-term WIMP sensitivity goals we will require a succession of modest improvements, both in the detectors' capability to discriminate against surface beta events and in a reduction in the beta-emitting surface contaminants. (Quantification and projections on these issues have been outlined in Section 4 and are discussed further in Section 6.) Furthermore, the rapid deployment of a larger number of detectors in the SuperCDMS Phases will require streamlining in the detector fabrication and testing programs. As shown schematically in Fig. 12, a number of detector development sub-tasks will feed into the development project baseline to enable the detector goals of Phases A & B to be met. Some of the sub-tasks pertain to detector fabrication, and others to their electronic readout. In order to understand the linkages between the sub-tasks and the project baseline, we will first describe the present detector technology as successfully deployed in CDMS II.

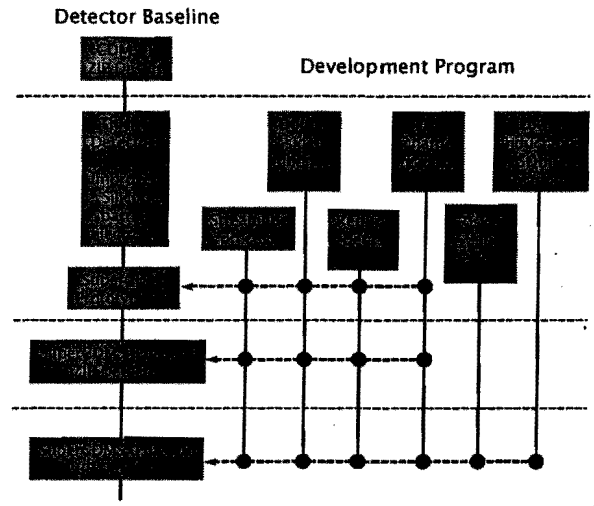

Figure 12: Schematic for the detector development path showing baseline design largely based on existing ZIP detector made thicker (left column). Detector research and development advances are shown in the right columns and will be inserted into baseline design as they are shown to meet specifications.

5.1 Present ZIP detectors

The present CDMS II ZIP (Z-dependent Ionization and Phonon) detectors are crystals of Ge or Si, polished into discs 76 mm in diameter and 1 cm thick. A picture of a packaged ZIP is shown in Fig. 5.

A ZIP detector has metallized grids on both faces to function as the ionization electrodes for the charge readout, and photolithographically patterned phonon sensors on one face to perform the phonon energy measurement. The electrodes are patterned to define both an inner fiducial volume and an outer guard ring in which events are likely to be due to naturally occurring radioactivity and are discarded. The readout of the two ionization channels is presently performed using FETs mounted to a 4 K temperature stage and self-biased up to 130 K. The phonon sensors utilize W Transition Edge Sensors (TESs) connected to Al athermal phonon "collection" fins. For the sensors to operate, the crystal must be cooled to below 50 mK, and the superconducting transition temperature (T_c) of the W TES

must be 80 ± 10 mK across the whole detector. There are 1036 individual phonon sensors occupying each quadrant of the detector face. They are all connected in parallel by superconducting Al bias rails and are in turn connected by superconducting wiring to the input of a dc-SQUID (Superconducting Quantum Interference Device) array amplifier connected to a 600 mK temperature stage. There are thus four phonon channels per ZIP detector. The phonon signal bandwidth is sufficiently high that the relative timing delay between these four phonon signals, and the intrinsic shape of the signals, can be used to reconstruct the recoil event location in the crystal to within a few millimeters. A stack of six 1-cm-thick ZIP detectors are assembled together to form a 'Tower.'

The ZIP detectors are manufactured on the Stanford Campus at the Stanford Nanofabrication Facility (SNF) housed in the Center for Integrated Systems (CIS). The fabrication process is a modified two-layer CMOS process for both sides of the detectors. A number of machines at CIS were modified in the past to allow our 1-cm-thick substrates to be processed. Typically it takes four people three weeks to fabricate a batch of four ZIPs. During the course of CDMS II a number of factors were found to affect detector yield, less than half of which could be identified during the course of fabrication. Thus the CDMS II project had significant resources devoted to the post-fabrication detector inspection, packaging, repairs and testing programs.

At room temperature the Ge substrates are too conductive to completely establish the electrical integrity of the detectors. Thus during the course of CDMS II we introduced at Stanford a liquid-nitrogen testing step into the packaging process. This step is fairly rapid in turn-around and caught $\sim$ 25 % of all the electrical failure issues. To screen the detectors against the majority of failure modes requires going below 1 K, the superconducting transition temperature of Al, which we carried out at the the UCB or Case dilution refrigerator test facilities.

Once detectors had been proven to have electrical integrity, further cryogenic characterization would ascertain the W T_c distribution of the TESs. Invariably the W T_c would be slightly too high or nonuniform for the detector to be of immediate use, so a process was developed whereby the W T_c distribution would be mapped, and then the detectors would be subjected to ion-implantation with ^{56}Fe ions to "compensate" the W T_c to a lower, more acceptable T_c range. After the implantation, we would again test the detectors cryogenically, although towards the end of CDMS II fabrication we have found that this procedural step is no longer necessary since the ion-implantation is invariably successful.

5.2 Detector Analysis Improvements

In the CDMS II analysis of pulse shapes we have made great strides in improving discrimination by utilizing more of the information provided by our fast phonon technology. This progress has used the information from large calibration sets with gamma and neutron sources at SUF and Soudan. In addition, we carried out measurements at the test facilities using gamma and beta sources to thoroughly characterize the ionization dead layers and the inherent asymmetry in the phonon response to betas on the phonon- and charge-sensor faces of the devices.

Here, we propose to extend these studies by implementing accurate Monte Carlo models of our detectors. As our analysis techniques continue to advance, it is clear that there is more information in the athermal phonon signals than is presently being utilized. We are making inroads in both identifying event location information and event type. Until recently, we emphasized the use of the phonon-pulse risetime which is faster for surface events than for events in the bulk. As mentioned earlier, we have recently shown that the use of other timing parameters improved the overall surface-event discrimination from 97% to 99.75% above 15 keV, while maintaining the same nuclear recoil acceptance. This progress indicates that further gains are possible and we intend to take full advantage of them by developing a location dependent pulse-shape model. We believe that using such a model will significantly improve the surface-event rejection (see Table 2).

5.3 Detector Mass Scaling

The major thrust in detector development, depicted as the "baseline" detector development task in Fig. 12, will be in scaling up the detector thickness from 1 cm to 2.5 cm. This requires new fabrication equipment and modifications to some of our present equipment. With the production of the five towers for the CDMS II project now completed, the development baseline program will start in the last quarter of 2004 with funding from a DOE supplement to Stanford University. We anticipate a year-long development program in scaling up the present detector thickness, with the early 2.5 cm thick prototypes available for characterization at the test facilities in late 2005 and their performance demonstrated in time for the proposed CDR-A and TDR-A.

The most critical issue in scaling up the present detector thickness is the exposures required during the photolithographic patterning of the phonon sensors. We have in place plans to migrate from our present Ultratech 1000 stepper, which can accommodate a maximum substrate thickness of 10 mm, to an EV-align contact mask aligner which we will modify to accommodate a range of thicknesses from 13 mm up to 25 mm. Further modifications (and expense) will allow a maximum of 32 mm in the future. Moving to a contact mask aligner will unfortunately result in a degradation of pattern resolution. The present ZIP detector TESs are 1 μm wide, whereas the target goal for the EV-align ZIP phonon sensor design needs to be relaxed to 2 μm. The anticipated slight loss in phonon sensor performance will probably be more than compensated for in the short term by the target mass for the WIMP search being more than doubled for each new detector. During the second year of the SuperCDMS Development program, we propose to explore the option of whole-field 1 μm photolithography using a relatively new nonoptical photolithography technology trademarked "Nanoprint." The modifications for thick substrates will be nearly identical to the EV-align (both machines in the SNF are manufactured by the same vendor with near duplication of parts). The major expense will be the masks themselves: they are micro-grooved mechanical plates, rather that chrome-patterned glass plates.

Other modifications to our present ZIP production process for thicker substrates include the application of photoresist. We are presently cooperating closely with a vendor who appears to be able to modify a photoresist spinner that can satisfy our requirements. For the plasma-etching of amorphous Si on such thick substrates several equipment options and specialized staff exist within the SNF.

The Balzers sputterer will also require mechanical modifications for the thicker substrates. The modifications required may not be compatible with the continued use of the rf-etch process, thus we are also considering the purchase of a Kaufmann ion-source for the Balzers. The present RF-etch process may in itself be a source of unwanted variabilities in detector production yield and performance, thus exploring its substitution is further warranted.

Under an approved SuperCDMS Phase A program, we would also fabricate, package and test, a large number of Ge ionization-only detectors, which will be incorporated into the present detector towers and act as an active veto and shield around, above and below them. We estimate that these detectors cost a factor of five less to fabricate and test than the full ZIP detectors with their complement of W-TES phonon sensors. Experience from the CDMS I experiment showed us that the Ge detector material itself has the cleanest surfaces within the detector housings. Adding veto ionization-only detectors would allow all of the ZIP detectors (including the top and bottom in each SuperTower) to be included in the fiducial detector mass.

In 2008 our Phase B proposal will describe our plans to increase the overall production rate by another factor of ten (see Table 2) and to double the number of detectors in future SuperTower modules from 6 to 12 detectors each (ST_{12}). The first seven SuperTowers (ST_6 1-7) will continue science operations at the new deep site until they can be upgraded/consolidated to ST_{12}, and rapidly redeployed at the beginning of 2012 along-with 16 new ST_{12} SuperTowers, giving a total active target mass of $\sim$ 145 kg for

Phase B.

5.4 Detector Performance Improvements

In order to achieve the scientific objectives of SuperCDMS, we need to improve the detector rejection of surface events, by optimization of both the charge collection and the athermal phonon sensors.

Let us first note that the increase of the thickness of our detectors by a factor 2.5 will decrease the surface to volume ratio by this factor. However, the voltage that we can apply across the drift gap is limited by the requirement that the Luke-Neganov production of phonons by the drifting carriers not dominate the phonon production from the initial interaction. The few measurements that we have made so far indicate only a weak dependence of the surface electron rejection on the drift field and applied voltage. We are therefore optimistic that we can take full advantage of this factor.

The remaining topics in this section describe the approaches (introduced in Section 4) that will improve the present ZIP detector discrimination ability against surface-beta events.

Hydrogenated Amorphous Silicon

First, it is likely that we can improve the performance of our contacts by optimizing the deposition of the amorphous silicon. This layer provides a higher effective gap material which prevents back diffusion of carriers to the wrong electrode (producing a suppressed charge signal).

The low loss of ionization yield in the NTD-based BLIP in CDMS I utilized an electrode structure which included an amorphous Si layer that had been deposited in an argon atmosphere containing 17% hydrogen. The ZIP detectors of CDMS II also used amorphous Si layers, but they were fabricated in SNF where the option of depositing the amorphous Si layer in an argon-hydrogen atmosphere was not possible. With the recent relocation of the Balzers, we are now in a position to implement a hydrogen gas feedline into the Balzers and fabricate new ZIP detectors with an electrode structure that more closely matches the earlier generation of BLIP detectors. A relatively short fabrication and testing program will allow us to optimize the percentage of hydrogen present during the amorphous Si layer depositions, and hence the blocking effectiveness of the electrodes against surface-event charge back-diffusion. This improvement, which depends on the motion of the charge carriers, is expected to be independent of other improvements made through optimization of the phonon signals. Thus, this development work will be given high priority in the Development baseline shown in Fig. 12 and will be one of the first tasks undertaken in the SuperCDMS Development Project.

Optimize Guard Electrode Geometry

Another short-term program that will feed into the development baseline prior to the SuperCDMS TDR-A involves optimizing the boundary between the inner and outer charge electrodes. A small increase in the size of the outer guard-ring will result in a slightly smaller fiducial volume. But, as indicated in Section 5.2, this small penalty may be more than adequately compensated for by the enhanced beta-rejection from phonon signal analyses, which ubiquitously exhibit smaller variations, and hence more powerful discrimination ability, for the central region of the detectors. In addition, a wider outer guard-ring may also be beneficial if the dominant sources of radioactive contaminants are not on the detector surface but on surrounding materials. Further analysis of data from Soudan and development of detector response modelling codes are underway to feed into this design process.

Improve Phonon Sensor Area Coverage

A longer-term concept is our desire to enhance the information content of the athermal phonon signals. In Section 4 we alluded to our past successes and high expectations of beta-rejection from athermal phonon pulse-shape analysis. Here, we will briefly describe possible ways to read out the phonon signal even faster from the detector substrate, and consequently acquire even more effective beta-rejection from the pulse analysis. The present ZIP detectors' phonon sensors only cover effec-

tively 20% of one surface of detector substrate. The maximum surface area coverage permissible in the present phonon sensor design is constrained by our existing design of the single-stage SQUID array readout used for our ZIP detectors. In Section 5.5 we will discuss new phonon-readout schemes that will remove this constraint.

Double-Sided Phonon Sensor Designs

Another, potentially more dramatic, improvement in phonon read-out would occur if *both* sides of the disc-like detectors were instrumented with phonon sensors. This double sided readout is likely to significantly improve the phonon timing information by detecting the leading phonons on both faces of the detector. This design will symmetrize the detector response, and allow a direct determination of the three dimensional position of each event. We estimate a timing resolution of 0.5 μs at 10 keV giving us a resolution of 1.5 mm in three dimensions. Moreover, a double sided phonon readout will allow us to increase the linearity of our transverse position measurements. One side would read the x-coordinate with two complementary phonon sensor patterns designed to produce pulse height variations proportional to the x-coordinate, while the opposite detector face would measure the y-coordinate in a similar way. This information would allow a precise position correction for the energy estimate and for the fiducial volume cut.

We intend to study two methods of implementation of this scheme. One keeps the same drift field configuration used in the existing ZIP detectors. The problem is then to voltage bias the phonon sensors without increasing the capacitance of the electrode on which the ionization measurement is made. Unless we can keep the biasing circuitry capacitance to a few picofarads, the ionization accuracy will be degraded. The best approach appears to use a small DC power supply, fed through a transformer at 20MHz (see the read-out section below). This method would require the modification of the electronics cards on the 4K stage, as discussed further in Section 5.5.

Interleaved Phonon and Charge Design

An alternative scheme is to interleave the ionization electrodes and the phonon collectors on both detector faces. As shown schematically in Fig. 13, on one face the ionization electrodes are at positive voltage (upper large dots) and connected to one amplifier while on the other face they are at negative voltage (large lower dots) and connected to a second amplifier. The phonons sensors (small dots) remain at ground on both faces. In this arrangement, the electric field close to the surfaces is roughly parallel to the detector face and a surface interaction will generate a signal in the near-side charge amplifier only. Bulk events experience a field which is perpendicular to the faces and the electrons and holes from an event will generate equal signals in two charge amplifiers, one on each of the faces. In addition to identifying surface events from the phonon timing information present for both types of double-side phonon sensor designs, the interleaved design provides an independent separation of the surface from the bulk through the charge measurements, and should therefore give excellent surface-event rejection.

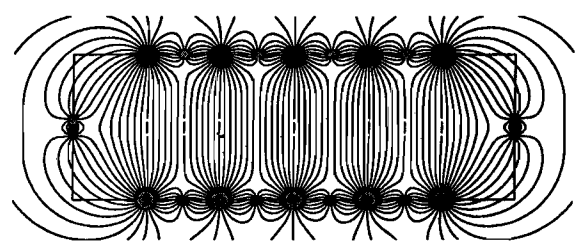

Figure 13: Interleaved phonon (upper and lower small dots) and charge channels(upper and lower large dots) on both sides of iZIP design. There is also a ground ring around the side. This configuration rejects all surface events which are only seen in one charge channel versus bulk events seen equally in both charge channels.

Another advantage of this iZIP (interleaved ZIP) scheme is that the phonon sensors on both sides of the crystal remain at ground for the ionization measurement, hence the biasing electronics remains unchanged from the present ZIP implementation. In addition, if the surface identification works at the outer edges of the detector, we do not need the outer guard electrode,

and the readout of the two ionization channels and their associates electronics also remains unchanged from the the present ZIP implementation of CDMS II.

Preliminary electrostatic simulations are extremely encouraging and suggest that that the optimal pitch for the alternating grid bias lines and phonon sensors is of order 1 mm, with events occurring within the top 0.5 mm of the crystal effectively swept out and identified as surface events. One caution is that there are small regions of low electric field at saddle points in the crystal. We will check that these do not result in significant degradation in charge collection, and even if there is some degradation, that those events may be rejected through phonon signal shape or timing.

Testing Double-Sided Designs

Because of the additional rejection power of these two schemes, we intend to test them as soon as possible. We already possess the capabilities to fabricate such detectors, but the present yield for such a device needs to be improved. Our previous trials have given us early feedback on some process improvements required and our overall fabrication and testing streamlining program will naturally support this additional goal (see below). We intend to produce the first prototypes of both types of double-sided phonon detectors.

For the interleaved ZIP scheme, we have already demonstrated that it is possible to hold the required voltage across a gap of 1 mm (the inner to outer electrode gap in the existing ZIPs), as needed for operation of an interleaved ZIP. The first full-mask photolithographic design for the "iZIP" detector has recently been completed and the first 1 cm thick iZIPs will be fabricated in the fall of 2004 at Stanford and tested in the Berkeley or Case test facilities.

Note that this double-sided phonon rejection is not necessary for Phase A and is not part of our baseline for 25 kg. However, should we demonstrate the power of one of these schemes early enough, it would be incorporated into the TDR-A, with the appropriate modification of the cold electronics. The background level needed for Phase B likely requires the improvement of the detector rejection by a factor of 2.5 compared to Phase A. These double-sided phonon schemes are likely to be the critical technology that will allow this improvement.

5.5 Detector Readout Development

In addition to the improvements in the detector design and fabrication consistent with our present CDMS II-style signal readout schemes, we have also identified a number of developments in our field pertaining to new signal readout schemes that also offer the potential of superior detector rejection of unwanted backgrounds and/or simplification in detector operation/fabrication.

Improvements to Ionization Readout

Our current threshold is entirely determined by our ionization resolution which both limits our energy threshold and more importantly the effectiveness of our rejection of surface electrons at low energy. We currently have a resolution which is twice the theoretical value, in large part because there appears to be a sizeable parasitic capacitance due either to our cold hardware or low drain-source bias that we use to limit the power dissipation of our FETs. It will be a high priority to identify the source of this problem and study simple methods to reduce the power dissipation of the FETs. For instance, at the price of introducing modest turn-ratio transformers (e.g., 1:10), it would be possible to reduce in the same proportion the power dissipation while maintaining the signal to noise. We will also investigate the possibility of building a CMOS integrated circuit operating on the 100 K stage of the new cryogenic system, which would eliminate the power dissipation on the 4 K stage and provide much higher bandwidth. It could have a JFET front end but we will also investigate the performance of MOSFETs. The higher bandwidth would make possible the measurement of the ionization current pulse width (500-1000 ns for 2.5 cm drift), which would give another indication of the depth of the primary interaction.

SQUID Charge Readout

Schemes which use SQUID amplifiers to read out the charge channels would be extremely beneficial and could be placed on the 50 mK stage. This design would not only eliminate the need for tensioned signal wires going inside vacuum coax from 50 mK to 4 K, but also decrease radically the power dissipated on the 4 K stage, an important consideration for the number of channels needed for Phase B and beyond.

The readout scheme which looks most attractive in the short term is the measurement of the ionization current with a SQUID. To have enough sensitivity, we have to use a high turn-ratio superconducting transformer (1:2000) coupled to a two-stage SQUID. Our first designs indicate that the challenges of controlling stray capacitance and internal resonance for such a large transformer are manageable and that performance similar to our current JFET can be achieved. Further optimization could bring additional gain. An additional advantage of this approach is that it uses the same type of amplifier as the phonon sensors, thus simplifying the overall electronics systems.

Shown schematically in Fig. 14 is the design of the first-generation SQUID charge amplifiers. An event deposits charge in our Ge semiconductor crystal, represented by the capacitance C_{Ge}. This charge is read out through the resonant circuit formed by a blocking capacitor C_{block}, a damping resistor R_D, and inductor formed by the primary coil L_{pr} of a lithographic superconducting transformer. The damping resistor is chosen to critically damp the resonance so that the charge flows through the primary of the transformer in a non-oscillating pulse. The dc signal is blocked, so that over a longer timescale the dc charge signal drains off the detector crystal through the bias line.

The primary of the superconducting transformer is a lithographically patterned Nb thin film coil on a silicon substrate that is wound as a gradiometer with 1,000 turns on each side. The total inductance of the primary is calculated to be about 10 mH. In order to damp intracoil resonances, each turn of the coil contains a small series resistor of normal metal (palladium-gold alloy). In order to minimize capacitive coupling, the secondary of the transformer and the SQUID are placed on a second chip spaced a short distance (100 μum) away from the primary chip. The signal coupled into the SQUID is further amplified by a second-stage series-array SQUID before room-temperature amplification. The circuit is operated in a flux-locked loop through feedback to the first-stage SQUID.

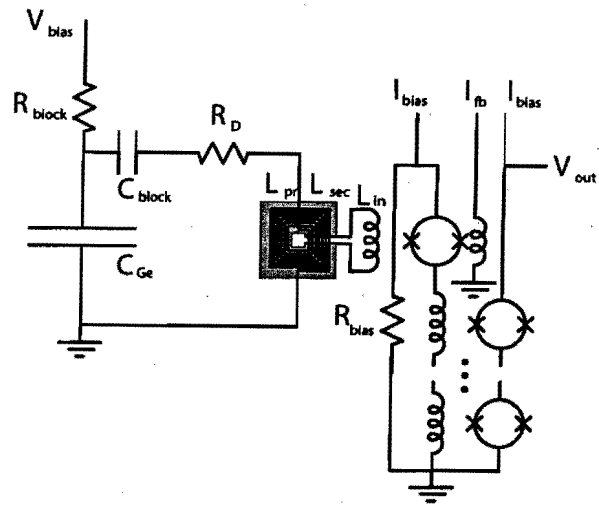

Figure 14: A schematic circuit showing a first-generation design of a SQUID-based charge amplifier.

During the SuperCDMS Development phase, we will investigate the use of these SQUID amplifiers to read out charge channels. We have already developed initial designs that are very promising. We will fabricate transformer-coupled SQUID amplifiers optimized for charge detection and test them with a small detector. If, as expected, the results are competitive or superior to the existing FET channels, we will study the possibility of integrating SQUID charge amplifiers into SuperCDMS. As shown in Fig. 12, a number of years of development are ahead of us on this task and we do not expect to fully replace the FETs by deployment of this readout technology for SuperCDMS until Phase B.

Double-Sided Phonon Readout

As explained in the section above on double-sided phonon readout, we will be investigating two schemes (1) a "floating" phonon biasing

scheme maintaining our current field geometry which will improve our depth phonon estimate, and (2) an interleaved ionization and phonon scheme which also improves the depth phonon estimate and provides direct rejection of surface events from the charge signal.

In scheme (1) we need to provide a voltage of up to 1 μV for the TESs, without adding more that a few picofarads to the capacitance of the ionization electrode and dumping too much power on the 50 mK stage. The best option is a high frequency (20 MHz) AC power supply feeding a small transformer. A diode and LC filter on the secondary will produce the appropriate bias. The voltage applied could be regulated at low bandwidth by monitoring the current through the readout SQUIDs, while maintaining at high bandwidth the pure voltage bias needed for the TES. If successful, this development effort would feed into Phase B as shown in Fig. 12.

In scheme (2) the iZIP concept does not require modification of the cold hardware, if the surface rejection performs well around the sides of the detector so that an outer charge guard ring is not needed. If successful, this development effort can feed into Phase A unless a third charge channel is needed, in which case it could feed into Phase B (see Fig. 12).

Lower-Inductance SQUID Readout

Presently in CDMS II the TESs of each phonon sensor are in series with the input coil to a SQUID array of 100 elements. A voltage is applied across the combined TES/input coil pair, and the SQUID array output measures the current through the TES. The SQUID array must have sufficient TES current sensitivity to resolve phonon events, resulting in a requirement for many turns on the input coil for flux amplification. However, the combined inductance of the 100 SQUID input coils with the operating dynamic resistance of the TES sets a limit on bandwidth due to the time constant given by the ratio of the input inductance of the SQUID array to the dynamic resistance of the TES, $L_{in}(\text{array})/R_{dyn}(\text{TES})$. In order for the phonon sensor readout to have sufficient bandwidth (~100 kHz) and to be stable from electrothermal oscillations, we need the dynamic resistance of the phonon sensor $R_{dyn} > 0.1\,\Omega$.

As we have seen above, a number of the proposed advances of our phonon sensor technology would benefit from a decrease of L_{in}/R_{dyn}. These include the increase of the coverage of the phonon sensors which would require connecting more TES in parallel, the widening of the W TES to ease the fabrication and improve the yield, and the use of manganese-doped aluminum (Al(Mn)) which has intrinsically lower resistivity (see Section 5.7). Moreover the phonon rejection would likely benefit from increased speed.

Two different approaches are possible. One is to decrease the apparent input inductance through feedback. One version of this method replaces our current magnetic feedback through a feedback coil by a resistive feedback to the input of the SQUID, decreasing the effective inductance by the gain of the feedback loop. The advantage of this scheme is that it requires no modification of the warm electronics and only a minor rewiring on the cold electronics stage. UCB and LBNL will investigate the viability of this scheme in the first year of this project.

A second approach is to use a single SQUID front end, so that the input inductance is physically smaller. This scheme requires a two-stage SQUID configuration. A voltage-biased single SQUID is used as the initial sensor of TES current. The current from the single SQUID is amplified by a second-stage SQUID array which would be similar to the single-stage array that is used in the present CDMS II system. A two-stage system has greater current sensitivity at the first-stage input which will provide greater signal to noise, giving us additional design flexibility for our TES and biasing schemes. The cold electronics hardware and the room temperature electronics would share similarities to that discussed above for the SQUID charge readout scheme. The two-stage SQUID system also has the advantage of less stringent design and fabrication requirements on the SQUID array. With a first-stage preamplifier SQUID, less gain is required in the SQUID array; the fewer turns on the input coil will result in greater reliability in the SQUID fabrication and operation.

The design of such two-stage SQUIDs is quite mature, since NIST and UCDHSC have built and operated two-stage systems for many years. The development work required for SuperCDMS is to optimize the current resolution, bandwidth, and placement of the voltage-biasing resistors for power dissipation. To ensure a sufficient production rate of both the single SQUIDs and SQUID array chips an automated screening procedure will be required at UCDHSC to maintain sufficient production of both individual SQUIDs and SQUID arrays. In the SuperCDMS Development Phase, we will modify present CDMS II front-end boards and cold electronics to allow the testing of such SQUID amplifiers and will test their performance on existing detectors. The adoption of this technology for deployment at the SuperCDMS deep sites for a WIMP-search requires revisions to the present cold-hardware and room temperature electronics, and would thus would feed into Phase B (see Fig. 12).

5.6 Detector Surface Contamination

During the course of CDMS II, we implemented a sample surface characterization program where various witness sample wafers generated during the course of the ZIP production were analyzed for surface contamination. More details on this program and the beta-rate observed in the Soudan data can be found in the Backgrounds section of this Proposal under Section 6.4, along with our assessment of the present beta situation and its possible impact beyond CDMS II on our SuperCDMS sensitivity goals.

As indicated in Table 2 of Section 4, we seek a factor of five reduction in the beta-contamination of the proposed SuperCDMS Phase A ZIP detectors. And another factor of two reduction from Phase A to Phase B. Thus, as shown in Fig. 12, one of the sub-tasks that will continue to feed into the detector development baseline throughout the SuperCDMS program is the continued reduction of beta contamination.

Our plans for beta-source contamination reduction for both Phase A and Phase B are discussed elsewhere, in Section 6.6. In the short term we will maintain our present program of monitoring for surface contamination by generating further witness samples and explicitly exploring certain process procedures for indications of radio-isotope contamination. We will continue the close coordination that presently exists in the Collaboration between the detector fabrication site at Stanford, and characterization facilities available in the local area (coordinated by SCU) and those available at Case and U. Minn.

Looking ahead, an understanding of surface-science will become increasingly important. For instance, it is possible that in order to achieve the beta-contamination goals of SuperCDMS Phase B, the sequestering of natural carbon or potassium on the surface of the detectors will need to be understood in greater detail and alternative substrate preparation recipes explored. Naturally, any new methods must be compatible with ionization electrode performance.

5.7 Fabrication Streamlining

Another important goal of the detector development program mentioned in Section 4 that will feed into the detector development baseline throughout the SuperCDMS program (see Fig. 12) is the streamlining of the production process. In the SuperCDMS Development Phase proposed here we will take advantage of what we have learned already in building CDMS II. For instance the apparatus (a Balzers DC sputterer) that we use for sputtering our critical tungsten films has recently been relocated outside of the SNF to our Varian Laboratory building and is now directly under our control. We are considering introducing a mechanical planetary system into the Balzers to improve the W film uniformity. Other improvements in detector fabrication and testing yield are expected from proposed changes in the photolithography: both a change in the method of UV exposure, and recipe changes to the metal-etching processes. For longer-term and further fabrication research efforts, base-program support will be sought in related proposals that will be directed at increasing yield with an over-arching goal of eliminating individual cryogenic testing of all detectors in the fabrication stage. As indicated in Table 2 we

seek a factor of five improvement in overall production and testing rate in order to accomplish the future SuperCDMS Phase A project goal; and another factor of ten improvement for the follow-on SuperCDMS Phase B project.

Achieving uniform T_c in the W thin-film comprising the TES is essential for detector operation. One of the most significant issues that affected our detector yield, was the the lack of uniformity in our W film deposition. Significant resources were required to perform cryogenic testing to determine T_c across the surface of the detector. We pioneered a method to adjust T_c after the initial W deposition through the selective implantation of iron ions [30, 31, 32]. This method has been successfully utilized throughout the detector fabrication and testing program of the CDMS II experiment. However, this approach is too time-consuming and costly to be applied to a ton-scale cryogenic experiment. Therefore, we propose to study tungsten film properties (crystalline phase, resistivity, film thickness, crystallite size and sputtering conditions) with the key goal of establishing room-temperature diagnostic tests that would allow us to reveal superconducting properties of the grown films, most importantly, T_c and its gradient.

The sensitivity of tungsten to processing conditions has, in addition, motivated work by B. Young at SCU to develop alternative films that may be more reproducibly processed. Work on manganese-doped aluminum films indicate that the critical temperature can be tuned down to the necessary 100 mK range required for our transition edge sensors [33]. The resistivity and heat capacity of the Al(Mn) material have been measured and fabrication of an actual X-ray micro-calorimeter detector has been accomplished at NIST [34]. Thin-film aluminium is well-studied, understood, and has reliable superconducting properties. Thus the use of Al as the starting TES material holds the promise of making a ton-scale experiment feasible. Within the SuperCDMS Development Project we will start the exploration of the T_c uniformity and repeatability of Al(Mn) TES fabrication, with the goal of demonstrating a more straightforward fabrication and testing route for future ZIP-style detectors. If the work continues to look promising in allowing a substantial improvement in the streamlining of the overall ZIP detector production then we will propose further development work with the goal to fabricate an actual ZIP detector in the SuperCDMS Phase A TDR. Full-scale adoption of Al(Mn) TESs for all further ZIP fabrication would be decided under the SuperCDMS Phase B TDR process, as indicated in Fig. 12, which would require a low input inductance SQUID-amplifier readout for the phonon sensors as discussed earlier in Section 5.5.

6 Backgrounds

In concert with the detector background rejection and mass scalability improvements discussed in the previous section, reductions in raw rates of background particles are needed to achieve the SuperCDMS sensitivity goals. This section describes (1) the background levels measured in the CDMS II experiment, (2) the resulting rates of misidentified background particles, (3) the background reductions needed to meet the sensitivity goals, (4) a plan for obtaining those reductions, and (5) a methodology for demonstrating the reductions prior to running of full experiment.

We remind the reader of the sensitivity goals for SuperCDMS outlined in Table 1, convert them to detector event rates (15-45 keV deposited energy), and indicate the background rates required to operate in "zero-background" mode (about a factor of four lower than the sensitivity goals):

- Phase A: 2×10^{-45} cm^2 $\rightarrow$ 4×10^{-4}/kg/day; zero-background $\rightarrow$ 1×10^{-4}/kg/day
- Phase B: 3×10^{-46} cm^2 $\rightarrow$ 5×10^{-5}/kg/day; zero-background $\rightarrow$ 1.2×10^{-5}/kg/day

6.1 Electromagnetic Backgrounds

The term "electromagnetic backgrounds" is used to refer to photons and electrons. Electromagnetic backgrounds divide into two subgroups, "bulk" and "surface" backgrounds, owing to the

fact that the ZIP detectors possess a thin surface "dead layer" in which ionization-yield-based rejection is poor compared to that for bulk events. Events falling within the first 35 μm suffer some ionization-yield suppression and events in the first 1 μm lose so much ionization as to be misidentified as nuclear recoils. Phonon-timing-based rejection provides rejection of 97% of surface events, but the overall rejection of such events remains poorer than for bulk events.

Bulk electromagnetic backgrounds consist primarily of high-energy photons, as well as electrons emitted from radioisotopes in the bulk of the detectors. The photon component is determined by bulk contamination levels in the apparatus and shield and by radon penetration into the shield. Because the electron component is usually negligible in comparison to the photon component, bulk events are generically referred to as "photons." They are identified empirically as events with ionization yield ≈ 1 as expected for bulk electron recoils.

Surface electromagnetic backgrounds include (1) "photon-induced" photons or electrons that interact in the dead layer and (2) electrons (and possibly low-energy X-rays) emitted by radioactive contaminants on detector or nearby surfaces. The photon-induced component scales directly with the continuum photon rate and detector surface area/volume ratio. Surface contamination depends on the detailed fabrication and handling history of the detectors. Surface events are generically referred to as "electrons." Surface events are identified empirically as all events with ionization yield below the "bulk" event band and above the nuclear-recoil band.

The rates of bulk and surface electromagnetic background events for Towers 1 and 2 are shown in Table 3.

Detector rejection for bulk electromagnetic backgrounds is extremely good. Rejection of events where a photon ejects an electron from the detector surface is similarly excellent, except for a negligible fraction of such events induced in the first μm of the surface. On the other hand, "electron" events from surface radioactive contaminants have a very shallow interaction depth profile and thus suffer far worse misidentification. About 0.6% of the surface single electrons in Table 3 survive to the nuclear-recoil signal region, contributing the dominant Soudan background of 1×10^{-2}/kg/day.

event type	Ge	Si
Bulk total [/kg/day]	115.2 ±1.6	501.9 ±4.6
Bulk singles [/kg/day]	30.2 ±0.8	194.5 ±2.3
Surface total [/day]	1.57 ±0.09	1.53 ±0.09
Surface singles [/day]	0.41 ±0.05	0.51 ±0.06

Table 3: Average bulk and surface electromagnetic background rates in Tower 1 and Tower 2 at Soudan, 15-45 keV deposited energy, inner detectors.

6.2 Photon Backgrounds at Soudan

Bulk electromagnetic interaction rates in the Ge detectors are approximately 3.8/keV/kg/day at Soudan, or 115/kg/day integrated 15-45 keV. For comparison, rates at the CDMS Stanford Underground Facility (SUF) apparatus (at 16 mwe) were less than half this value, only 1.8/keV/kg/day. The current rates are not yet cause for concern for the WIMP search and are, *a priori*, consistent with the lack of an ancient lead shield inside the Soudan cryostat.

However, the Soudan cryostat and shielding materials had lower measured U/Th/K levels than those used at SUF. We have simulated the contributions to the background from the U/Th/K content of the Cu cans, of the inner and outer polyethylene shields, and from ^{210}Pb in the inner lead shield, with the simulations normalized by high purity Ge (HPGe) spectrometer screening results. The sum of these normalized contributions yields a photon background smaller by about a factor of 4 than the observed background.

A likely additional source of photons are radon decays outside the currently purged volume. The measured radon levels in the Soudan laboratory in the CDMS experimental room show a mean of about 500 Bq/m^3, with large seasonal variations.

During early running at Soudan, photon rates were a factor of 4-6 higher than shown in Table 3 and the ^{214}Bi radon daughter line at 609 keV was clearly identified in the Ge detectors.

To reduce radon gas in the space directly surrounding the icebox, we are purging this volume with air stored long enough to allow its radon to decay ($T_{1/2}$ = 3.2 days). However, the purge system in use when the data presented in Table 3 were taken did not penetrate the full volume, so significant radon buildup was possible outside the purged volume. Monte Carlo simulations show that about 35 Bq/m^3 of radon gas outside the purged volume is sufficient to explain most of the remaining photon background. In preparation for the final CDMS II 2005 run, the purge system has been improved greatly.

6.3 Photon Backgrounds for SuperCDMS

We expect that sufficient radon abatement and an internal ancient lead shield would reduce the photon background to well under 1/keV/kg/day. However, to be conservative, we take 2/keV/kg/day as the prediction for SuperCDMS. This photon background level, when combined with detector background rejection advances for SuperCDMS, yields a misidentified event rate of 3.7×10^{-6}/kg/day, well below the goals for SuperCDMS Phases A and B and approaching the level required for a 1000-kg experiment.

Rejection of photon-related backgrounds in the CDMS II experiment has been measured and simulated. Measurements are done by exposing the entire apparatus to high-energy photon sources via penetrations of the lead shield. Simulations are performed using GEANT4, including tracking of low-energy electrons created by photon interactions and conversion of interaction depth to ionization yield via the a yield vs. depth profile measured by exposure of a detector to a ^{109}Cd electron source.

The simulations indicate that of all photon-related events (15-45 keV), 0.31% are single-scatter surface events and 1.8% of those (or 0.005% of all photon-related events) suffer enough ionization-yield suppression to be misidentified as nuclear recoils. Thus, we have 99.995% rejection based on number of scatters and ionization yield alone. The single-scatter fraction is confirmed by photon-exposure calibration runs and by a comparison of pre/post-radon-purge rates. The overall misidentification is confirmed by seeing 1 single-scatter misidentified event in 25,000 photon-exposure events. The phonon-timing cut rejects low-yield events with 97% success, so the current overall rejection of photon-induced events is 99.9999%. (The cuts have 70% exposure efficiency for nuclear recoils).

As reported in Section 4 and explained further in this section, we expect to gain factors of 2.5, 2, and 4 in background rejection from increasing the detector thickness (1 cm to 2.5 cm), improved ionization-yield-based rejection from H-α-Si electrodes, and improved phonon-timing rejection from more sophisticated analysis. Thus, we project the SuperCDMS Phase A detectors will have 99.999995% rejection photon-related backgrounds.

A 2/keV/kg/day photon background thus results in a rate of 3.7×10^{-6}/kg/day misidentified photon-related events in the 15-45 keV energy range. This rate is smaller even than the Phase B zero-background goal of 1.2×10^{-5}/kg/day, so the photon background goals are well in hand. A 1000-kg experiment with 6 times more stringent background goals than Phase B would require relatively modest further reductions (factor of 2), which can be expected from improved detector background rejection and reduced photon background from self-shielding.

Our success so far with photon backgrounds has rested on careful choice of construction materials and screening for photon emission using HPGe spectrometers. Such measures will continue to be used in SuperCDMS. A NSF Major Research Infrastructure proposal will be submitted by in late 2004/early 2005 to fund an upgrade to the current photon-screening facility at Soudan (the "SOLO" detector) with a new HPGe spectrometer. A prospective Soudan Low-Background Counting Facility (LBCF) would provide a natural site for such screening activities well into the future, perhaps with better

sensitivity afforded by a water-tank shield. SuperCDMS would pay user fees to use this facility.

We have also begun to explore alternative screening methods such as accelerator- and inductively-coupled-plasma mass-spectrometry (AMS, ICP-MS). These methods have come into heavy use in other fields over the last decade and can in many cases provide better sensitivity to the underlying isotopes than conventional photon screening, and at a fraction of the cost and time. Commercial and academic facilities are available on a per-use fee basis. Extensive details are provided in Section 6.5.

6.4 Beta Backgrounds at Soudan

The dominant background at Soudan consists of electrons from radioactive contamination on the detector surfaces, which we refer to as "betas," reflecting the likelihood that most of these events arise from beta decay. We include internal-conversion and Auger electrons as betas, and perhaps some soft x-rays as well.

The total rate of surface electrons in the energy range 15-45 keV is $\sim$ 1.6/detector/day, of which 0.31/detector/day are beta "singles," having a hit in one ZIP detector alone. The largest portion of betas appears to arise from ^{210}Pb deposited by airborne radon, but the conclusion is tentative and awaits confirmation from further analyses. A significant component may not be identified yet. In this section, we detail our efforts to identify the contaminants.

With a half-life $T_{1/2} = 22.3$ years, ^{210}Pb is implanted into surfaces by a decay chain intiated by airborne ^{222}Rn, which itself evolves from ^{238}U. A total of 63 keV is available in the transitions from ^{210}Pb to the ^{210}Bi ground state, which liberates nearly one internal-conversion electron per decay with energy near 40 keV. The ^{210}Bi daughter with half-life $T_{1/2} = 5.01$ days undergoes β^- decay to ^{210}Po with 1.2 MeV endpoint, but the β-electron energy distribution is non-standard, and peaks at the lowest energies. The ^{210}Po then decays with a half-life $T_{1/2} = 138$ days to the stable ^{206}Pb isotope, emitting an α particle with an energy of 5.3 MeV.

Our detectors are exposed to radon during fabrication, mounting and testing. We have measured the ambient radon levels at all the locations where detectors travel and have taken precautions to store them in evacuated vessels or in cabinets purged with nitrogen gas for most of the time. The observed rate of α particles in our detectors is $\sim$ 0.4/detector/day and suggests a similar contribution to the total rate of beta events. Further simulation work is in progress to determine what precise fraction of these events result in single-scatter events in the 15-45 keV range.

Another beta-emitting candidate is ^{40}K, produced in the atmosphere by cosmic-ray interactions. Natural potassium may be deposited through human contact. The lack of a visible 1460 keV photopeak or its Compton edge in the Soudan data sets an upper limit of 15 betas/day per ZIP over the full energy range up to the 1.4 MeV endpoint, which corresponds to a limit on the ^{40}K contribution to the total rate of betas of about 0.15 betas/day per ZIP in the 15-45 keV energy region.

Stricter limits on the amount of ^{40}K were set using materials-science surface-analysis techniques. Assays of test wafers produced at intermediate and final stages of processing were performed at campus facilities at Case and Minnesota using Secondary-Ion Mass Spectroscopy, Auger spectroscopy, RBS, and PIXE. We found that Rutherford backscattering (RBS) combined with particle-induced X-ray emission (PIXE) techniques, done simultaneously for each test wafer, provided the most sensitive normalized test for the presence of light elements such as potassium. RBS is capable of measuring the depth profile of elements and PIXE resolves ambiguities. Our preliminary upper limit on natural K is $1 - 2 \times 10^{14}$ atoms/cm^2; confusion with Ar makes interpretation of the tests challenging. Further studies are in progress to determine whether this upper limit holds generically for witness wafers at all stages of fabrication.

This contamination level would yield a beta rate of about 1–2/detector/day over all energies. Simulations indicate that about 8% of these betas produce energy depositions in the 15–45 keV range and 15% of those (1.4% overall) are sin-

gle scatters, resulting in 0.02–0.04 single scatters/detector/day, a negligible contribution.

Our work with the above technique has convinced us we can detect buried and surface K layers as small as $1-2\times10^{13}$ atoms/cm^2 when there is no confusion with Ar. Such confusion can be avoid by replacing the Ar atmosphere used during metal deposition with He or Kr.

A third possibility is ^{14}C, also produced by cosmic-ray induced reactions. Natural carbon could be introduced during processing, and traces of carbon are easily measurable by surface analysis methods. Auger and RBS both indicate that there are 2-3 monolayers of C present on the ZIP surfaces, consistent with exposure to air. Depth profiles with RBS at the carbon nuclear resonance show that there is no buried carbon at this level. This yields 0.3 betas/day per ZIP with a 156 keV endpoint. The contribution to the single-scatter rate in the 15-45 keV range is thus likely small, no more than 15%.

Overall, then, while we have quantitative estimates or limits for contamination by many possible emitters, we do not have a full accounting. We summarize our current knowledge in Table 6.4.

source	origin	rate (#/day)	% of singles
^{210}Pb	airborne radon	< 0.4 all	$< 100\%$
^{14}C	natural carbon	< 0.05 all	$< 15\%$
^{40}K	natural potassium	$< 0.02 - 0.04$ singles	$< 15\%$

Table 4: Surface-event contributions estimated as indicated in the text. Although photons induce about 25% of the surface singles, they induce less than 1% of the events misidentified as nuclear recoils.

6.5 Screening Program to Identify Beta Contaminants

A reliable identification of beta contaminants is not yet in hand. ^{210}Pb may account for a significant portion and further investigation of ^{40}K via surface analysis is warranted. But, given the lack of certainty, we propose an energetic program of materials screening to determine the origins of these contaminations.

^{210}Pb is a decay daughter of ^{222}Rn and arises in the ^{238}U decay chain. In spite of serious new efforts during production and testing of Tower 2 to mitigate radon exposure, there is no significant difference in the rate of beta events between Tower 1 and Tower 2. Presumably, radon contamination is occuring at a step in the detector production process that is unexpected, or perhaps there is exposure to a compound that is contaminated with ^{238}U. During 2005 we will undertake a a systematic testing program of substances that come in contact with our ZIP detectors. ICP-MS routinely provides sensitivity to ^{238}U at the 100 part-per-trillion (ppt) level, sufficient for our needs. Commercial and academic laboratories are available for this work at reasonable costs.

To progress toward identifying untested contaminants, we have assembled a list of 79 beta-emitting and electron-capture isotopes and performed a preliminary analysis of the possible contribution of these isotopes to our background of surface electrons. Contamination by these isotopes can be potentially determined by mass spectrometry, γ detection, α detection, or of course by detecting the electron itself.

With a commonly achieved ICP-MS sensitivity of 1 ppb, 17 beta-emitting isotopes could be detected. A better ICP-MS sensitivity of 1 ppt, which has been achieved for some isotopes, could allow detection of 20 additional isotopes. We will work with ICP-MS labs to test for these 37 isotopes on the detectors and in substances used during fabrication. As results from ICP-MS are obtained, we will follow up where necessary with PIXE and RBS studies, which localize contaminants spatially. Funds are requested to pay user fees for these screening services.

Forty-three isotopes may be detected by low-level γ-counting, including 25 that cannot be detected by ICP-MS or α-counting. γ detection is advantageous for screening certain materials where high sensitivity can be achieved by using a large mass of sample. As mentioned with regard to photon backgrounds, an upgrade of the

SOLO facility at Soudan, combined with a lower-background environment provided as part of the Soudan LBCF, will provide sensitive γ screening. We will utilize the Soudan γ-screening facilities to complement our use of ICP-MS.

A small number of isotopes, 12, can be detected by their emission of α's. Although few in number, a crucial candidate, ^{210}Pb, is among these isotopes. We have already operated a small Si(Li) detector for α detection, but we believe that detector has a background level that is higher than desired for detecting α's at the small flux now required. We propose to establish an α screening facility at the Soudan lab capable of detecting α's of a flux $< 5 \times 10^{-4}/\text{cm}^2/\text{d}$.

Finally, there are 12 to 21 isotopes, depending on ICP-MS sensitivity, that cannot be screened in any manner except by their emission of beta electrons. To detect these isotopes, we propose to develop a chamber capable of directly detecting betas emitted from surfaces. This chamber will also serve as a very low-background α screener. The development strategy for this chamber is described in Section 6.6.

6.6 Beta Backgrounds in SuperCDMS

As discussed in Section 6.4, the observed surface event rate arising from beta emitters is about 0.31 singles/detector/day (15-45 keV). At the current 99.4% rejection of betas by ionization yield and phonon timing (at 70% efficiency), this leads to a misidentified event rate of 1.1×10^{-2}/kg/day. Reductions in this rate are necessary to meet the SuperCDMS sensitivity goals. In this section, we present our plan for reducing contaminant levels and validating those improvements.

For later reference, the quoted 99.4% rejection breaks down as follows. The combination of ^{109}Cd calibration and WIMP-search data and simulations indicates that the ionization-yield-based rejection is about 80% for such events because of their shallow depth. The phonon-timing based rejection is 97% at 70% cut efficiency,

Beta Reduction for SuperCDMS Phase A

To operate the Phase A (25-kg) experiment in zero-background mode, the expected misidentified beta rate must be below 1×10^{-4}/kg/day 15-45 keV, a factor of 100 below the current rate of 1.1×10^{-2}/kg/day.

As outlined in Table 2 of Section 4 we expect a factor of 20 increase in beta rejection to be obtained from detector improvements (further discussed in Section 5), leaving a desired goal of a factor of 5 to be found in reduction in surface contamination. The single-scatter electron event rate would be 0.024/detector/day. In the 800 kg-d and 13000 kg-d exposures of these new SuperCDMS detectors expected during the Development Project and Phase A, respectively, we would expect to see 0.06 and 1 misidentified event, sufficiently low to be statistically close to "zero-background" mode (see Fig. 16 in Section 7.2).

Obtaining this factor of 5 reduction may be challenging given the current lack of conclusive identification of the beta-emitting isotope(s). The exhaustive screening program outlined in the previous section has already been started and should provide enough information to identify the offending contaminants.

Verification of the rate reduction will be via direct counting of beta particles by and on detectors operated in the SUF cryostat. We will run a tower of six 1-cm-thick, H-α-Si-electrode, cleaner detectors (with 2 ionization-only vetoes) to demonstrate a rate of no higher than 0.06 single-scatters/detector/day from surface contamination, a factor of 5 below current rates. By considering double-scatter events to overcome the photon-induced background, we expect to see 43 beta events in a 60-day (45-kg–day) run with a background of 7 photon-induced surface events. The shallowness of the SUF site does not limit beta-screening sensitivity because the events to be detected lie predominantly in the "electron" band of ionization yield; the neutron background at SUF is negligible for "electron" ionization-yield values.

The timeline for the above work is as follows. Contamination abatement and testing using surface analysis, mass spectrometry, and α counting will be done in the months following submission of this proposal using existing funds, with the goal of demonstrating indirectly the reductions

needed to meet the Phase A 25-kg sensitivity goal by Spring 2005. This work will be performed by groups at Stanford, Minnesota, Case, UCSB, and Caltech. At that point, with the beginning of SuperCDMS Development Project funding, a set of CDMS II-style ZIP detectors will be fabricated using these new methods (Q2 2005), checked at one of the current test facilities (Q3 2005), and run in the SUF apparatus (Q4 2005 - Q1 2006). (During Q1-Q3 2005, the SUF facility will be brought back online by Caltech using funds from a supplementary request submitted concurrently with this proposal.) The SUF run will provide full validation of the beta contamination reduction in time for the Phase A proposal submission in Fall 2006. This work will be performed by the groups at Stanford (detector fab), Case and/or UCB (detector testing), and Caltech (SUF preparation and running).

Beta Reduction for SuperCDMS Phase B

Again, referring to Table 2 in Section 4, if we assumed no further improvements in the detector beta rejection, then an additional factor of 6-8 in beta-contamination reduction would be required to reduce the background to 1.7×10^{-5}/kg/day for the 150 kg phase. In the 80,000 kg-day exposure expected for the Phase B 150-kg experiment, this rate would yield 1 misidentified beta. More realistically, Table 2 indicates only a factor of two reduction in contamination would be required in Phase B along with further detector development giving a detector rejection ability a factor of 2-5 higher than in Phase A.

However, to minimize our overall risk to achieve the sensitivity goals of SuperCDMS the remaining discussion will detail our longer-term beta screening plans. In particular we do not yet know what low-level contaminants will have to be removed to reach the Phase B goal.

Some beta-emitting isotopes are not accessible via the screening methods outlined earlier in Section 6.5. Also, once we have identified and removed all plausible candidates, we must directly measure or set limits on beta emission from detector surfaces in order to explicitly demonstrate that the background goals have been met. Direct counting of beta particles from large numbers of witness samples is a feasible method by which to detect unscreened isotopes and to demonstrate rate goals. (Use of SUF becomes impractical at such low rates due to the need to fabricate and test large numbers of detectors to obtain detectable numbers of events.) A sufficiently large screening chamber (or multiple chambers) can observe beta emission from a large surface area, of order 1 square meter, which is equivalent to 100 detectors. Witness samples can be run through the same fabrication and handling process as full detectors at a fraction of the manpower and cost. Rates can be measured quickly and feedback provided in a timely fashion.

However, such a large-area, low-background beta- (and alpha-) screening device does not exist. As part of the SuperCDMS Development Project, we plan to develop such a detector. We are beginning by prototyping two different technologies. The first is a neon-gas multi-wire proportional chamber, the second a cloud chamber read out by digital video. Both are optimized for identification and meausurement of sub-200 keV electrons. With appropriate construction materials, the limiting background in these detectors is ejection of electrons from the sample surface by Compton-scattering photons. In an environment that would yield a 1/kg/keV/d photon rate in Ge, the rate of such events is about $0.3/\mathrm{m}^2/\mathrm{keV}/\mathrm{day}$.

To determine the event rate in such a screener, we work backward from the rate goal. Assuming 20% single scatters and 99.925% beta rejection, the total 15-45 keV beta rate corresponding to the aforementioned 150-kg rate goal of 1.7×10^{-5}/kg/day is 0.06/kg/day. This rate counts *all* beta events: singles and multiples, and events both misidentified as nuclear recoils and those identified as surface events by ionization yield. The fraction of beta events below 100 keV that are identified as bulk electron recoils is negligible. The 0.06/kg/day rate converts to $12/\mathrm{m}^2/\mathrm{day}$ (0-200 keV) for a beta screener.

The Compton-scatter background mentioned above would yield $60/\mathrm{m}^2/\mathrm{day}$ (0-200 keV) in a 1/kg/keV/d (in Ge) shielded environment. To detect at 2σ confidence level the 150-kg goal rate of $12/\mathrm{m}^2/\mathrm{day}$ using 1 m^2 of sample area would

take 7 days of running, including the time needed to measure the Compton electron and chamber background (using bare wafers). It should be emphasized that, during the feedback period, when beta contamination is higher and we are trying to identify isotopes, screening runs can be shorter.

The counting times are thus short enough to provide the necessary feedback. Under the realistic assumption that detector phonon-timing and charge-channel based rejection will improve by a further factor f, the required rate limits become a factor of f less stringent. This allows counting times to be a factor of f^2 shorter or a screener background to be a factor of f^2 higher.

We note that, for a 1000-kg experiment, the contamination beta rate would have to be reduced by another factor of 6 to $2/\mathrm{m}^2/\mathrm{day}$ (in accordance with the factor of 6 mass increase). Detecting such a rate in a beta-screener would require a reduction in photon background to 0.1 /kg/keV/d and a run of 22 days to detect at 2σ. Note, however, that shorter counting times will be sufficient when rates are still above the goal.

A beta screener is not just useful for detecting betas, but makes an excellent alpha-particle counter as well. This ability provides another handle on many of the isotopes that could give rise to a beta background. Also, we can use the beta screener to check in detail our simulations of surface events. A contaminated detector could be run in a test facility to measure the observed spectrum of beta events in energy, yield, and phonon timing, and then the same detector could be placed in a beta screener.

It is expected that such a screener would be located at the Soudan Low-Background Counting Facility, which would provide most of the necessary shielding and a large muon veto at no cost to SuperCDMS. Should the Soudan LBCF not be available, a small shield and veto dedicated to the screener could instead be constructed. We have made a preliminary estimate for the cost of this shield in the budget for this proposal, but identified it as "supplemental" funding, to be requested as needed.

Beta-screener development is already underway. Our goal is to demonstrate a prototype screener by Q1 2006, choose a technology to pursue, MWPC or cloud chamber, and begin construction of a full-size screener by Q3 2006. In order to allow speedy development, prototype screener development will be done using funds in hand at the various institutions involved. We request project funds (from the SuperCDMS Development and Phase A projects) for the construction and operation of the full-size screener and associated shielding and data-acquisition system due to its significant cost and central importance to the SuperCDMS program. Estimates for screener construction and data acquisition are based on a previous costing of a full-size MWPC; we expect a full-size cloud chamber would be similar in cost.

The screener will be operated as part of the SuperCDMS Development Project to provide feedback on abatement methods, with the goal of demonstrating the 150-kg background goal by Q3 2008 when the Phase B project is to be proposed. It must be emphasized that such a screener will not impact Phase A, but its development must be started now in order for it to demonstrate the necessary backgrounds for the 150-kg phase, and beyond to the one ton scale.

6.7 Neutron Backgrounds

A neutron of kinetic energy approximately 2 MeV can cause a Ge recoil that is indistinguishable from a recoil caused by a WIMP. A principal motivation for deploying WIMP searches at deep underground sites is the reduction of ambient cosmic-ray-induced neutron flux. Neutron background at Soudan arises from environmental radioactivity, primarily from processes in the Uranium/Thorium (U/Th) decay chain, and from particle cascades induced by muons that penetrate to Soudan's depth of approximately 2000 mwe. Neutrons from either process can originate in the material immediately surrounding the ZIP detectors ("internal") or from the relatively distant rock in the mine ("external"). Indeed, the radioactivity in the rock necessitates the massive CDMS II shielding consisting of 49 cm-thick polyethylene to degrade the energy of neutrons from external radioactivity, and

of 23 cm of lead to stop gammas from the same source. The polyethylene suppresses the rate of nuclear recoils due to neutrons from external radioactivity to insignificance. Selection of clean materials for the inner shield and icebox keeps the background from internal contaminations of U/Th small.

The concentration of shielding material near the ZIPs forms a target in which penetrating particles initiate showers of particles, including neutrons. We estimate the rate of Ge nuclear recoils (in the 15-45 keV region) from neutrons in muon-induced showers in the shielding to be 18×10^{-3} /kg/day, or 90 times the target total background rate for Phase A, with an uncertainty of a factor of 2. Currently, we suppress this background with a hermetic, active, plastic scintillator veto system that surrounds the Soudan ZIP detectors. The Soudan veto system tags the incoming muon that initates showers in the shielding, with efficiency well in excess of 99%, reducing this background to insignificance. As of yet, our exposure has been too small to see the first veto-coincident Ge nuclear recoil. The complete CDMS II project should constrain the rate of this background with a fractional statistical error of 25%.

The dominant source of neutrons that cause nuclear recoils in Ge, and are anticoincident with the veto, come from showers produced by the $\sim$ 220 GeV muons that penetrate to and interact in the rock that surrounds the CDMS II experimental hall. This muon-induced neutron background was estimated independently using two Monte Carlo techniques (GEANT4 and FLUKA) and checked for consistency. These simulations indicate that associated shower particles produce signals in our existing veto for $60 \pm 10\%$ of events containing neutrons. This implies a rate for the veto-anticoincident neutron-induced recoils from showers in the rock at Soudan of 3×10^{-4} /kg/day; small contributions from radioactivity raise the estimated total rate of background neutron-induced recoils to 4×10^{-4} /kg/day, with an uncertainty of a factor of 2.

This background rate is sufficiently low that neutron background should be unimportant for the exposures currently planned at Soudan during this Development Project. We would need to reduce this rate by a factor of 4 in order to meet the zero background target of Phase A of SuperCDMS, if it were to be operated at Soudan. That is the principal motivation for moving to SNOLab, where the dominant neutron backgrounds are suppressed compared to Soudan by over two orders of magnitude. Circumstances may lead us to continue operations at Soudan, and so we have made a preliminary evaluation, as a contingency, of upgrades to our neutron shielding that might reduce neutron background to a level beneath the Phase A target.

One method to improve neutron rejection is to veto on the accompanying charged particles which enter the cavern, but do not intersect the veto. This umbrella veto could be realized by installing the old Soudan2 proportional tubes on the roof of our cavern. The tubes have recently been removed from the floor of the cavern to make way for the Low Background Counting Facility. They have been leak-tested and they have working preamps and DAQ. We estimate that this technique would result in a neutron background as small as 2×10^{-4} /kg/day.

Another method of neutron rejection would rely on the detection of the neutrons themselves. Studies done five years ago for the CDMS II proposal, as well recent studies by the UKDMC [35], indicate that up to one order of magnitude suppression of neutron-induced Ge recoils can be achieved by an internal veto, just outside the Icebox. A schematic of an internal veto is shown in Fig. 15. The main role of the inner veto is to detect dangerous neutrons in the MeV energy range, via the recoil protons, with threshold of order 100 keV.

An inner veto could be achieved using scintillator, read out by fibers and either Avalanche PhotoDiodes (APD's) or photomultiplier tubes. The scintillator would detect many of the neutrons, but also gammas from the capture of neutrons.

Our current simulations indicate that upgraded veto systems at Soudan could extend background-free running there to as much as 5000 kg-d. We propose to continue to refine our simulations of these systems. We include in this

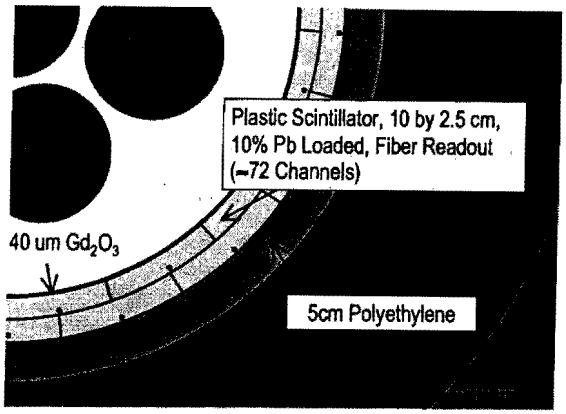

Figure 15: Possible Soudan Inner Veto. A double layer of plastic scintillator, read out by waveshifting fiber, would replace the inner 5 cm of the existing polyethylene shielding. Recoils of protons in the scintillator allow detection of MeV neutrons. A layer of Gd_2O_3 would capture slow neutrons, and emit about 8 MeV in several photons, which would be detected in both the ZIP detectors and the scintillator. Only the "barrel" portion surrounding the ZIP detectors is shown; other, probably unsegmented "endcap" portions would go above and below the ZIP detectors.

proposal an estimate of the supplemental funding request which would be needed to produce both the umbrella and inner vetoes at Soudan. A lead time of about 1 year would be required to produce such vetoes, if they are needed.

7 SuperCDMS Development Project Deliverables

7.1 Design Report Deliverables

The Development Project will deliver a cycle of reports and proposals (see Fig. 11) for the next phases of the experiment: a Conceptual Design Report (CDR-A) in April 2006, and Technical Design Report (TDR-A) in October 2006, for the 25-kg SuperCDMS Phase A experiment, which will have a reach of approximately 2×10^{-45} cm^2 in WIMP-nucleon scattering cross section at 60 GeV WIMP mass; and a CDR-B in April 2008, and TDR-B in October 2008, for the 150-kg SuperCDMS Phase B experiment, with a reach of approximately 3×10^{-46} cm^2 at 60 GeV WIMP mass. The CDRs are intended for review by SAGENAP and to make our plans available to the wider community; the TDRs are intended as specific project proposals to fund and execute the specific phases of the program. In the end, SuperCDMS Phase B will be 100 times more sensitive than the expected final result of the CDMS II project (3×10^{-44} cm^2 at 60 GeV) and 1000 times more sensitive than the current CDMS II limit (4×10^{-43} cm^2 at 60 GeV).

Under the DOE Critical Decision process, we are requesting that this proposal be designated the CD0 report for SuperCDMS. The SuperCDMS Development Project will deliver four major reports over the four year period. The first is the Conceptual Design Report for Phase A (CDR-A), which is intended to fulfill the CD1 approval process. As we develop the CDR-A, we will actively seek additional collaborating institutions. These will include Canadian institutions with expertise in the low background and shielding at the SNO underground laboratory and in cryogenic instrumentation, and a much larger role from national labs, particularly, Fermilab for the cryosystems installation, LBNL for electronics and SLAC for large scale detector production. We are also exploring DAQ and computer-farm contributions from the national laboratories. For the CDR-A preparation, we will set up expert working groups (1) for advanced detectors with improved surface electron rejection; (2) for techniques to reduce beta contamination; (3) for designing and constructing the larger cryosystem; (4) for cold and warm electronics and DAQ systems; and (5) for industrializing and streamlining the production of large numbers of advanced detectors for the later stages of SuperCDMS. The CDR-A is timed for presentation before SAGENAP in the spring of 2006.

To start early the design and construction of the new cryosystem in SNOLab, we are preparing a Major Research Infrastructure (MRI) proposal to the NSF. This proposal is due in January 2005, and will allow a one-year head start on the longest lead-time item in our SuperCDMS Phase A construction project. If successful, funds would be available by the end of 2006.

The Technical Design Report for SuperCDMS Phase A (TDR-A) is planned for the fall of 2006

in time for the NSF annual cycle. This TDR-A will detail the construction project for the 25 kg of Ge experiment which we call Phase A. The studies from the working groups will feed into this proposal. We will complete a full cost analysis with risk assessement, contingency and work breakdown structure appendices. This TDR-A will serve as the CD2/3 report under the DOE approval structure.

Two years later, during 2008, we will deliver two more reports for the 150 kg Ge experiment designated as SuperCDMS Phase B. The CDR-B for Phase B will be prepared in time for approval before SAGENAP at the spring meeting in 2008. Under the DOE approval process, this CDR-B would become the CD1 for SuperCDMS Phase B. Following the same pattern as for Phase A, we would submit the TDR-B for Phase B in time for annual NSF cycle in the Fall of 2008. As before, this TDR-B would constitute the CD2/3 report requesting approval for SuperCDMS Phase B under the DOE system.

7.2 Scientific Reach of the SuperCDMS Development Project

At the same time as we develop the detailed plan to gain a factor 100 in sensitivity, it is important to continue the scientific gains, even though the CDMS II project ends on December 31, 2005. The scientific reach of the five CDMS II towers will not have saturated by that time. As discussed in Section 6.7, the neutrons are not expected to be a problem. Moreover we expect significant improvement in our analysis methods for rejecting backgrounds. Even with the existing detectors we will increase the scientific reach. Finally the Soudan infrastructure is ideal for testing prototypes of the detectors that we are designing for Phase A at SNOLab.

Therefore, within this SuperCDMS Development project, we propose to operate at Soudan the existing CDMS-II detectors (without modification) and starting mid 2007 a SuperCDMS tower of six thick detectors (designated as ST_6 1 in Fig. 11). This will give us a sensitivity reach of 1×10^{-44} cm^2 for a WIMP mass of 60 GeV/c^2, about a factor of 40 better than our current limit and a factor of 3 better than the CDMS-II goal. For example, if the WIMP-nucleon cross section is at the current 90% CL limit of 2×10^{-43} cm^2, then the number of WIMP events in this data set will be 60 ± 8.

In Figure 16 we show the progression of scientific reach from our current position with the first data from Tower 1, through the end of running at Soudan and the SuperCDMS Phases A and B at SNOLab. The dash-dot straight line corresponds to the linear improvement in sensitivity for a zero background experiment. The curved lines show the effect of backgrounds which are subtracted after careful identification, and the rectangles are the projected reach at the end of each phase.

It is interesting to note that the factor 3 improvement in WIMP sensitivity at the end of the Development Project is obtained with a combination of 3000 kg days from CDMS II Towers 1-5 (where the background is substantial), and 1000 kg days obtained with our first SuperTower which should be free of background. In spite of the large difference in exposure, they contribute about equally to the final result.

Background Source	Not Shielded	Not Vetoed	Not Rejected
Soudan Phase (5 kg)			
Total Gamma's	n/a	234,000	0.17
Total Beta's	n/a	1,427	8.4
Neut., muons in shield	31	0.03	0.03
Neut., muons in rock	1.2	0.68	0.68
Total Neutrons	32.2	0.71	0.71
SNOLab Phase A (25 kg)			
Total Gamma's	n/a	785,000	0.08
Total Beta's	n/a	687	1.03
Neut., muons in shield	0.28	0.0003	0.0003
Neut., muons in rock	0.01	0.006	0.006
Total Neutrons	0.29	0.007	0.007

Table 5: Background events expected during the initial phases of SuperCDMS

This figure also illustrates our SuperCDMS "background-free" strategy where even at the end of their projected exposures, the Phase A and B detectors are expected to have less than 2 background events. As a consequence, the upper limits predicted after subtraction of the background are closer to the background-free line

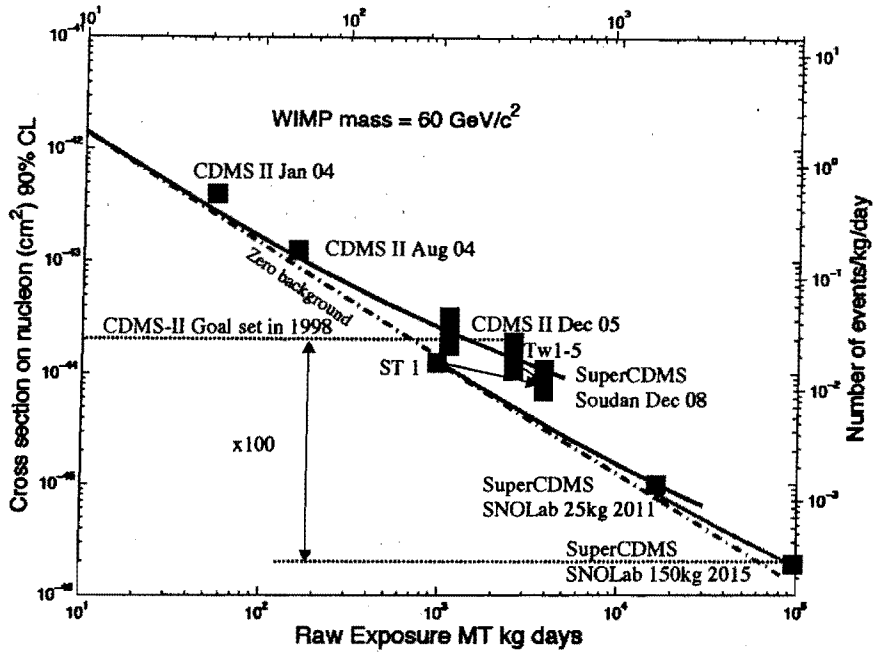

Figure 16: Limiting sensitivity (cm^2) as a function of exposure (kg-d) for CDMS II goals and SuperCDMS goals. These estimates use background subtraction and 10 keV thresholds, whereas in Table 1 we use more conservative estimates that do not subtract the one or two background events expected in Phase A and B.

than is the case for CDMS II. The small background level results in much smaller systematics, as shown in Table 5, which summarizes the total number of background events (in the 15-45 keV range) expected in germanium detectors during the Soudan running and Phase A of SuperCDMS at SNOlab. In the table, "Not Shielded" means the component that penetrates the shielding and interacts in the detectors. "Not Vetoed" refers to the subset of these that are anticoincident with a > 99.9% efficient muon veto. "Not Rejected" refers to the subset of events that are misidentified by the detectors as nuclear recoils. All other sources of backgrounds are expected to be smaller.

To summarize, the continuing scientific output of the existing CDMS II towers at Soudan along with one new SuperTower, to be added in mid 2007, is an important deliverable of the SuperCDMS Development Project. It will allow us to probe further into possible supersymmetry models, significantly increase our discovery potential and contribute to the demonstration of the technologies and methods to be implemented in the next phases of SuperCDMS. Throughout the SuperCDMS Development Project we maintain the best discovery potential of any experiment in the world for finding WIMPs. The detector and analysis experience gained in this phase build the foundations for Phase A starting in 2009 at SNOlab and will keep SuperCDMS at the frontier of the field.

8 Management

The SuperCDMS Development Project will be carried out by the CDMS collaboration, consisting of university and national laboratory groups listed below. Funding and oversight will be provided by the National Science Foundation Physics and Astronomy Divisions, by the Department of Energy through its High Energy Physics University Program and through Fermi National Accelerator Laboratory. This section summarizes the project management, based on

years of experience with the CDMS II project.

8.1 Organization

The SuperCDMS organization chart is shown in Fig. 17. The management team consists of the spokespersons, project manager, and chairperson of the collaboration board. The spokespersons are responsible for the scientific success of the experiment while the project manager is responsible for the technical, budgetary, and scheduling aspects of the experiment. The collaboration board consists of senior members of the collaboration and provides advice to the management via the chairperson. Systems, subsystems and working groups are responsible for coordinating the work of the experiment, under direction of the project manager. An external advisory board provides advice on scientific and technical matters from physicists who are not part of the experiment.

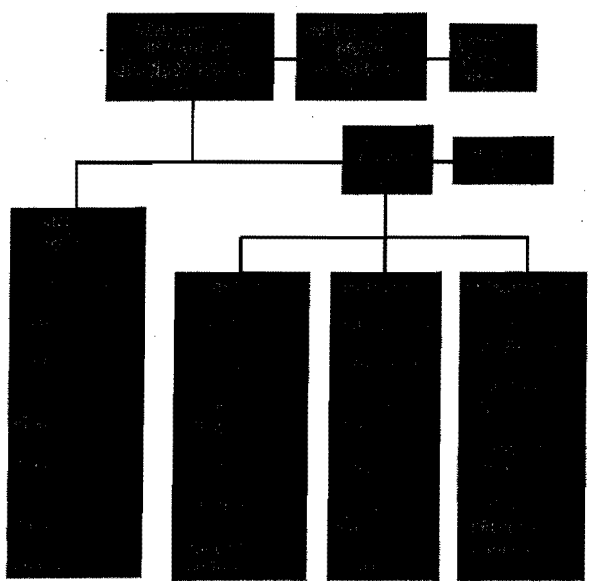

Figure 17: SuperCDMS organization chart

Spokespersons The spokespersons develop the scientific strategies and scope of the experiment. They are the primary source of information to the outside world concerning the scientific progress of SuperCDMS. They appoint the project manager, with the concurrence of the collaboration board and the funding agencies. In addition, the spokespersons oversee the education and outreach activities of the collaboration and are responsible for calling and organizing collaboration meetings.

The spokespersons work closely with the project manager on the technical and management aspects of the project, and with the chairperson of the collaboration board on issues involving the health and welfare of the collaboration. Weekly meetings of this management team are a vital tool to coordinate these activities.

The spokespersons are appointed by the collaboration board with the concurrence of the funding agencies and the laboratory directors. The present Spokesperson of the SuperCDMS experiment is Blas Cabrera and the Co-Spokesperson is Dan Akerib.

Project Manager The project manager is responsible for the technical and operations aspects of the experiment and the management of the schedule and budget for the project. As such, he or she must develop and maintain the project management plan, negotiate and update the Memoranda of Understanding (MOU) between all of the collaborating institutions, and manage all the construction, installation, and related operational activities. The project manager administers both human and financial resources available to the project as determined by the MOUs. He or she develops and tracks the schedule for the project, ensuring that milestones are met, and the budget for the project, as outlined by the financial plan and Work Breakdown Structure (WBS). Finally, it is also the responsibility of the project manager to provide quarterly reports summarizing the progress of the project to the spokespersons, collaboration board, external advisory board and to the funding agencies.

The project manager is appointed by the spokespersons with the concurrence of the collaboration board and funding agencies. The current SuperCDMS Project Manager is Dan Bauer.

Collaboration Board The collaboration board includes all of the senior members of the collaboration. The principal investigator from each in-

stitution will be the voting member representing that institution on the board, and all decisions of the Board will be made by majority vote of those representatives. The chairperson of the board is elected by the voting membership.

The collaboration board provides a forum to discuss scientific and technical progress of the CDMS experiment, the role of each institutional group, and the progress of students. Project execution and managerial issues are also matters for the consideration of the board.

Specific responsibilities of the collaboration board include the appointment of the spokespersons and concurrence on the appointment of the project manager. Furthermore, the board must appoint an External Advisory Board (EAB) to monitor and review the execution of the experiment.

Chairperson of Collaboration Board The chairperson of the collaboration board shall call, organize, and conduct the meetings of the board. Meetings should occur on at least a monthly basis with agendas announced in advance. For confidential matters, meetings can be restricted to the voting members at the discretion of the chairperson or by vote of the board. If the voting member cannot be present for a meeting, it is his/her responsibility to appoint an alternate and inform the chairperson. The chairperson will be responsible for making sure that written reports are distributed to the board and to the funding agencies.

The present Chairperson of the Collaboration Board is Bernard Sadoulet.

External Advisory Board An external advisory board made up of no less than three members with expertise in scientific, technical, and managerial matters shall be appointed by the collaboration board. The external advisory board will meet at least once per year to review the scientific and technical goals and achievements of the experiment. In addition, project execution will also be examined and evaluated by the EAB. Specifically, the EAB will review any schedule, cost, or scope variance that has to be reported to the funding agencies. Furthermore, the EAB will also be charged with reviewing the performance of the Project Management team.

Meetings of the EAB will be called and organized by the chairperson of the collaboration board. Reports, including the recommendations of the panel, will be submitted to the collaboration board and will also be made available to the funding agencies. The current members of the EAB are: Dan McCammon (U. Wisconsin), Natalie Roe (Lawrence Berkeley National Lab), Gary Sanders (Caltech), Tony Tyson (U.C. Davis) and Rocky Kolb (Fermilab).

Change Control Board The Change Control Board (CCB) shall review all changes in cost or schedule which exceed the thresholds tabulated below. The chairperson of the CCB is the project manager, and the board also includes the spokespersons and principal investigators from each collaborating institution.

The CDMS project manager is responsible for calling meetings of the CCB. Meeting intervals are expected to be determined by the number of change requests and the urgency of the requests. Once the CCB has examined the request for change, a recommendation for appropriate actions is made to the project manager. Recommendations are made by a majority vote of the CCB and will be recorded in the quarterly reports made by the project manager.

Technical Board The technical board will be chaired by the project manager and will include the spokespersons and system managers. The primary responsibility of the board will be to examine the status of all systems and address issues which cross system boundaries. Meetings will be called at the discretion of the project manager and minutes will be made available to the collaboration board. Subsystem managers and working group organizers may be invited to meetings when needed.

Systems, Subsystems and Working Groups The SuperCDMS organization includes systems, subsystems and working groups. Systems are the main focal points of the project and constitute the WBS level 1 structure. Subsystems have specific and ongoing responsibilities for construction and maintenance of equipment and/or software as detailed at WBS level 2.

Working groups focus on project and scientific tasks which often cross system boundaries and do not map directly to the WBS.

Systems for the SuperCDMS Development Project include: Soudan, Detectors and Backgrounds, reflecting the focus on continued running while improving both detectors and backgrounds. In addition, there is a SNOLab Design System, focused on the design work needed to produce Conceptual and Technical Design Reports leading to the full SuperCDMS proposal. Finally, there is also the management system, encompassing all of the items in this section of the proposal.

System managers work with the project manager to ensure that the work within their system is following the project schedule and budget, and that subsystems and working groups are coordinated and communicating effectively. This team must also work together as the technical board to manage issues which cross system boundaries. System managers are appointed by the project manager, with concurrence from the spokespersons and collaboration board.

Subsystems have WBS level 2 responsibilities within systems. They focus on specific hardware or software aspects of the experiment (e.g. Soudan operations, data acquisition, shield/veto, etc.). Subsystem managers are charged with keeping the work of their subsystem moving forward along the schedule and budget defined by the project manager and system manager for their subsystem. They are also responsible for documentation of their subsystems and chairing meetings of people working within their subsystem. Subsystem managers are appointed by the system managers, with concurrence from the project manager.

Working groups are aimed at specific topics (e.g. Monte Carlo, analysis, etc.) which cross system boundaries and are not directly tied to the WBS structure. These groups can be formed by either the spokespersons or project manager, to address science or technical issues. Each group will have a coordinator who chairs meetings and ensures communication within the group and to the management.

The complete list of subsystems, and initial list of working groups, will be detailed in conjunction with the development of a full WBS structure, Project Management Plan, and Financial Plan once the proposal reaches the stage of a cost and management review.

8.2 Work Breakdown Structure

All work required for the successful completion of the SuperCDMS Development Project will be organized into a Work Breakdown Structure (WBS). The WBS will contain a complete definition of the scope of the project and forms the basis for planning, execution, and control of the project. Specifically, the WBS will provides the framework for cost estimation, project scheduling, and performance measurement.

The SuperCDMS Development Project WBS is organized with Systems as Level 1 and Subsystems at Level 2. Level 3 refers to the principal tasks for a specific subsystem, and Level 4 provides the detailed breakdown of those tasks. Although Fig. 17 gives a conceptual idea of the structure, a detailed WBS will be provided at the cost and management review stage.

8.3 Schedule

In order to facilitate management of the project, the project manager will maintain a comprehensive schedule of work to track the progress of the SuperCDMS Development Project. The schedule is organized by WBS categories and contains a set of milestones to allow the funding agencies to monitor our progress. Fig. 11 gives a conceptual schedule, which will be developed in full at the cost and management review.

8.4 Institutional Responsibilities

Table 6 lists the levels of staffing for each institution. The first section shows the existing efforts on CDMS II prior to completing detector fabrication in mid-2004. The next two sections show the proposed level of effort on the SuperCDMS Development Project and the related R&D programs in 2006 after the transitional overlap with CDMS II. Not shown is the overlapping ramp

Table 6: **Institutional Participation in CDMS Related Research**

Institution	CDMS II during 2004					SuperCDMS during 2006					R & D during 2006				
	F	S	T	P	G	F	S	T	P	G	F	S	T	P	G
Brown	0.3				2.0	0.2				0.5					
Caltech						0.3			1.0	0.5					0.5
Case	2.0		1.0	2.0	3.0	1.5		0.5	2.0	2.0	0.5		0.5	1.0	1.0
Fermilab		2.0	2.0	1.0			2.0	2.0	1.0		1.0	1.0			
LBNL								1.0							
NIST Boulder												0.2	0.3		
Santa Clara	1.0					0.7					0.3				
Stanford	0.7	1.0	3.0	1.0	3.0	0.5	0.7	3.0	0.7	2.0	0.3	0.3	1.0	0.3	1.0
UC Berkeley	1.0	0.1	1.5	2.6	3.0	0	1.0	1.5	1.0	2.0	1.0			1.0	2.0
UCSB	0.5		1.0	2.0	2.0	0.3		1.0	1.0	1.0	0.3		0.5	1.0	1.0
UCDHSC									0.5		0.5		0.5	0.5	
U Florida	0.5			1.0	1.0	1.0		0.5	2.0	1.5	0.3				0.5
U Minnesota	0.5			1.0	1.0	0.3			0.7	1.5	0.3		1	0.3	1.0
Total	6.2	3.5	9.0	10.0	15.0	5.3	3.3	9.2	10.0	11.5	3.5	1.5	3.0	3.0	5.0

F - Faculty; S - Senior Research; T - Technical; P - Postdocs; G - Grad Students

down of CDMS-II and ramp up of SuperCDMS in this transition.

Brown University, R. Gaitskell

The Brown Group will continue involvement in operations and analysis for the CDMS to SuperCDMS program at Soudan during 2005 and 2006. Two senior graduate students will continue maintaining the CDMS offline event analysis software, and will continue to run Monte Carlo studies of the low energy electromagnetic backgrounds in the CDMS experiment. Over this time, the Brown group will continue to operate low background Ge detectors at Soudan (SOLO), which are used for screening materials for the CDMS experiment, to better understand the sources of gamma backgrounds. The involvement of the Brown group in CDMS will end when the current graduate students have finished their theses towards the end of 2006. They will provide documentation and aid the training of research staff for SuperCDMS.

Caltech, S. Golwala

The Caltech group will focus on ensuring that electromagnetic backgrounds – photons and electrons – can be reduced so that the experiment can reach its desired sensitivity. Specifically, the Caltech group will take responsibility for refurbishing the SUF cryogenic facility to demonstrate that cleaner detectors meet the Phase A background goal. This activity will naturally lead to use of SUF for batch detector testing during Phases A and beyond. In addition, the group will contribute to the development, construction, and operation of beta-screening devices that will be necessary to demonstrate the beta background goals needed for Phase B. Finally, the group will focus its analysis and testing efforts on characterizing the beta particle response of the detectors, with characterization runs at test facilities and analysis efforts on calibration and WIMP-search data that measure beta rejection.

Case Western Reserve Univ., D. Akerib

The Case group will continue to work in the areas of cryogenic detectors, experiment operations, Monte Carlo simulations of backgrounds, data analysis, and surface contamination assessment. Cryogenic detector work will focus on the design and production testing of the baseline inch-thick detectors, and on design studies for improved detectors. The test facility at Case will also be used to study these larger detectors with calibration sources. These data sets will be used to model and optimize the analysis for identifying surface events. Members of the Case team will deploy and operate detectors at Soudan, and participate in the operation of the experiment. Monte Carlo simulations will focus

on the fast neutron background with three specific aims: to simulate the neutron background in the WIMP search data, to test ideas for modest improvement of the neutron veto at Soudan, and to improve our knowledge of fast neutrons for the SNOLab era. We will contribute to the cryogenic modeling of the cryostat (coupled with the MRI proposal) and to new designs for cold-hardware that allow design simplifications and improve reliability.

In the R&D base program, the group will contribute to the design, modelling and testing of new phonon sensors on full-size detectors; to the SQUID-based readout of the charge channels; and to studies that will allow high-production rates with reduced cryogenic testing. We will also continue the ongoing work of identifying beta contamination through surface probes and will begin the development of a low-background gas wire-chamber to be used for beta screening.

Fermilab, D. Bauer

The Fermilab CDMS group will continue the responsibility for project management during the SuperCDMS project. For the Soudan phase, they will maintain the cryogenics, warm electronics, Soudan infrastructure and data acquisition pieces developed at Fermilab. They will also continue to play a leading role in operations, and assume a larger role in the data processing work. Finally, they will ramp up contributions to data analysis with a recent postdoc hire.

The Fermilab group efforts for the SNOLab phase of SuperCDMS will concentrate initially on cryogenics and background measurements. They will play the leading role in development of the new cryogenics system for SNOLab. This will involve design and construction of a new icebox and the stems which connect to a new dilution refrigerator and carry the detector signals to warm electronics. Their contribution to backgrounds will initially focus on making measurements of alpha backgrounds on materials at Soudan and deploying a neutron counter in the Low Background Counting Facility being developed there. They will also assist with design and selection of materials for the shielding and veto system to be deployed at SNOLab. Finally, in collaboration with other groups, Fermilab may participate in the R&D effort to develop a new electronics readout chain. Addition of another staff scientist to the group would allow a substantial expansion of these efforts.

NIST Boulder, K. Irwin

The NIST group will share responsibility with UCDHSC for R&D of a low-impedance charge readout preamplifier. The preamplifier will incoroporate a gradiometer transformer and SQUID sensor. The NIST team will contribute 75% of the total effort required for this R&D project. In addition, the NIST group will be entirely responsible for fabrication of all SQUID sensors (input, arrays, charge preamp) and associated components (superconducting transformers, etc.). The NIST group wil also contribute to electronics development and integration.

Santa Clara University, B. Young

The proposed effort of the SCU team in the Development Phase of SuperCDMS will focus on detector optimization and characterization. In particular, the work will emphasize $^{56}Fe^{+}$ implantation of advanced tungsten-based detectors used in first-generation SuperCDMS detectors; an investigation of the Al(Mn) TES technology for large detector arrays for the next generation ZIPs; materials science analysis of contamination data with collaborators at Case and UMN; T_c testing of SuperCDMS films in the small dilution refrigerator at Stanford; technical support of the Stanford-based detector fabrication team; co-leadership in the commissioning of an Oxford AST dilution refrigerator for use as a test bed of new SuperCDMS detector technologies; and contribute to the SQUID–based readout scheme for SuperCDMS detector charge channels with UCDHSC and NIST. In addition, the P.I. will participate in Soudan operations, and, as needed, will travel to the new deep-site lab to assist in preparation of the cryogenics system.

Stanford University, B. Cabrera

For the SuperCDMS Development Project, the Stanford group is responsible for detector fabrication and mounting facilities on campus and will work closely with UCB, Santa Clara,

Case and Florida on detector testing and characterization. The Senior Research Scientist at Stanford oversees the Detector System collaboration wide. Stanford works closely with UCB, Santa Clara, NIST, Denver and Case on detectors at least one inch thick, on detector designs with improved surface electron rejection, on SQUID-based readout for charge, and on developing an Al(Mn) TES technology for improved yield.

Stanford will work closely with the Caltech group in support of SUF (Stanford Underground Facility) runs. These will measure the beta contamination which produces surface electron events. Stanford with UCSB runs computing facilities at SUF for SuperCDMS for offline analysis and for Monte Carlo work. The group, in close coordination with Caltech, Case, Florida and UCSB, also participates in analysis particularly for understanding background levels, and for improving the detector rejection through an improved understanding of detector physics and developing a detector Monte Carlo.

The DOE base program at Stanford is supported through a block grant which includes dark matter and neutrino programs. The scientific staff on SuperCDMS will be mostly supported under the base program. There is also a modest seed program to develop more advanced detectors for the later stages of SuperCDMS.

SLAC and KIPAC: With the birth of the Kavli Institute for Particle Astrophysics and Cosmology, a collaborative venture between the Physics Department at Stanford and SLAC, we have proposed that SLAC join SuperCDMS under the auspices of KIPAC and lead the effort to industrialization detector production - needed to reach the ton scale mass. Discussions are ongoing.

UC Berkeley, B. Sadoulet

For the SuperCDMS Development Project, UCB will be responsible for detector testing and characterization in close connection with Stanford, Santa Clara, Case and Florida and will explore in particular the improvement of ionization measurement (e.g. with improved amorphous silicon layers) and double-sided phonon measurements. In addition, for SuperCDMS, UCB will lead the design and fabrication of cold electronics and hardware (in collaboration with Case) and collaborate with Stanford, NIST, Denver and LBNL in the exploration of cryogenic amplifiers and methods of decreasing the electric power dumped at 4 K, while speeding up the electronics and multiplexing. The group will continue its involvement with data analysis with emphasis on understanding detector rejection capabilities, statistical methods, and control of systematics. This development program will be enhanced by the long term R&D proposed for the UCB base program extending our athermal phonon technique (Al(Mn) with Santa Clara, kinetic inductance in collaboration with Caltech) and improvement of ionization measurements (in particular with single electron transistors). These technologies may have significant impact for the 150 kg stage and are critical for 1 ton extrapolation.

Berkeley Lab (LBNL), P. Denes

In the SuperCDMS Development Project, LBNL will collaborate with UC Berkeley, Stanford, NIST and Denver on the development of 4K and 100K electronics for the 150kg SCDMS phase. Of particular interest, is the LBNL capability of producing 4K MOSFET and designing 100K CMOS integrated electronics. One of the intriguing possibilities is to considerably increase the speed of our electronics with integrated feedback electronics on the 77K/100K stage of the cryostat system. By tightening feedback loops in this way, we could improve the rejection of surface electrons through the detailed analysis of phonon rise-time and phonon-ionization delay. Combined with improved ionization cold electronics, we could get an independent measurement of the longitudinal position of the event, providing an additional tool for surface rejection. Speeding up the electronic speed will also open the possibility of AC multiplexing, an alternate method to time base multiplexing developed at NIST. Once the basic demonstrations are in hand, LBNL will collaborate with UC Berkeley and Fermilab in the design of the warm electronics.

UC Santa Barbara, H. Nelson

The UCSB group will continue to lead efforts concerning the active veto and passive shielding for CDMS II at Soudan, and will continue to analyze the data from the active shield in order to measure hadron-induced showers in CDMS II. This effort involves close collaboration with Case and Minnesota on simulations, and may lead to the design and implementation of new active elements to suppress neutrons. The UCSB group will continue to coordinate the high-level DAQ software for Soudan, and will continue to analyze the data from the Soudan deployment of the experiment. The UCSB group will continue to maintain the trigger electronics at Soudan, and will make preliminary designs, with Minnesota and Fermilab, for the expanded DAQ system at SNOLab.

The UCSB engineering staff will make preliminary designs of passive shielding for SuperCDMS at SNOLab, and will contribute to mechanical aspects of the cryogenic design for SNOLab.

With local funding, UCSB has designed and operated a simple cloud chamber as a prototype for surface beta screening, and will continue the design and construction of a second cloud chamber for evaluation as a beta screener. Should either beta screening device prove viable, they will participate in the design and construction of the shielding for the screener, which is a major part of the screening endeavor.

UCSB will continue to study and devise methods to screen the seventy or so isotopes that could be contributing to our beta background.

Univ. of Colorado at Denver and Health Sciences Center (UCDHSC), M. Huber

Through base funding, members of the UCDHSC group will be responsible for design and evaluation of a second-generation, two-stage SQUID preamplifier for the phonon channels. This second-generation preamplifier will most likely be required for the next generation of TES technology. In the event that a single-stage SQUID series array amplifier is used in SuperCDMS, the UCDHSC group will be responsible for the redesign of these devices, as well. In addition, the UCDHSC group will share responsibility with NIST for R&D of a low-impedance charge readout preamplifier. The preamplifier will incorporate a gradiometer transformer and SQUID sensor. The UCDHSC team will contribute 25% of the total effort required for this R&D effort, mostly related to evaluation of the device at NIST as well as installation and integration of this device at the test facilities for evaluation with detectors. The UCDHSC team will also actively disseminate knowledge and expertise related to SQUID operation to other collaboration groups.

Through project funding, the UCDHSC group will be responsible for screening all SQUIDs for this project, those used at both test facilities and at the underground site. In addition, the P.I. and postdoctoral associate will participate in Soudan operations at the level required by SuperCDMS collaboration policy.

University of Florida, L. Baudis

The University of Florida group will play a leading role in studying and minimizing the backgrounds of the SuperCDMS experiment. They will improve the tracking of the exposure to Radon of the detectors and the background predictions from this component by dedicated measurements. They will track the exposure of the detectors to cosmic rays and calculate the resulting cosmogenic activation of the Ge and the shielding materials in close proximity to the detectors. They will also predict the cosmogenic background at Soudan/SNOLab caused by muon-capture and inelastic muon reactions. They will simulate the electromagnetic backgrounds of the SuperTowers using the GEANT4 code and establish a full background model for the experiment, and will thus be strongly involved in data analysis with a dedicated cluster of X-servers at UF. The group will also be involved in the operation of the experiment at Soudan and SNOLab. Another contribution will be screening of SuperCDMS materials for their U/Th/K content with a new 100% efficient HPGe spectrometer to be deployed at the Low Background Counting Facility.

With the recent hire of a new faculty member, the UF group will also construct a cryo-

genic detector test facility with the goal of having it available in time for detector R&D for the SuperCDMS detectors as well as for screening and testing of detectors and SuperTowers prior to their installation at the deep sites. Detector calibrations with various radioactive sources will complement the background studies at UF.

University of Minnesota, P. Cushman

The University of Minnesota will continue to play a substantial role in the daily maintenance and operations at the Soudan mine with a research associate who spends half time on site. Their role in the data acquisition has emphasized commissioning, online monitoring and the fast data readout and formatting, and plan to continue in this role in close collaboration with FNAL. They will also work on developing a faster and more portable ROOT-based DAQ and analysis package to replace the current Matlab system. They have been active in the analysis effort and developed the Geant4 Monte Carlo for the Soudan geometry. They will continue to maintain a GEANT4 effort with emphasis on cosmogenic neutrons, and they will explore ways to improve neutron veto efficiency at Soudan in collaboration with UCSB and Fermilab.

Using the Characterization Facility on campus, the group will continue to perform Auger and ion beam analysis (RBS and PIXE) in order to determine the nature of the surface beta contamination and to screen the next generation of detectors for ^{14}C and ^{40}K. Alpha's can also be used to screen for the presence of ^{210}Pb, and they will develop screening capability for alpha's and beta's at Soudan. This will involve operating existing counters, as well as a beta screener in conjunction with a more general low background counting facility at Soudan.

The group will explore ways to support detector fabrication and mounting with a bonding and packaging station at Minneapolis for SQUIDs and detectors, utilizing the Nanofabrication Facility clean rooms and inspection probe stations in order to increase throughput and the capacity of SuperCDMS to deal with repair issues.

9 Budgets

The Project Manager is charged with the responsibility for developing and maintaining the budget for the project. He or she is aided by the Chief Budget Officer in the project office at Fermilab, the NSF budget officer at UC Berkeley, and budget officers at each of the collaborating institutions. A financial plan will be developed in coordination with the funding agencies and progress on the plan will be tracked in the quarterly reports. Spending authorization, cost accounting, contingency allocation, and the change control process are described below.

9.1 Project Offices

The SuperCDMS Development Project office is located at Fermilab. It consists of the Project Manager, currently Dan Bauer, and the Chief Budget Officer, currently Maxine Hronek. All of the project funds are managed and tracked from this office. However, NSF funding for the project is awarded to UC Berkeley, with subawards to Case, UCDHSC, and SCU. The budget officer at UC Berkeley, currently Caryl Esteves, is responsible for annual reports to the NSF concerning this award, which supplement the quarterly reports produced by the project office.

Each of the collaborating institutions will designate a budget officer, whose task is to track project expenses at their institution and report these on a monthly basis to the Project Office. Good communication between the these budget officers and the Project office is vital to tracking the overall project budget.

9.2 Budget Systems

This section describes the tools which will be used to track and manage the project budgets. These tools are based on 5 years experience with the CDMS II project.

Financial Plan Subsequent to the cost and management review of the project, the Project Manager and the funding agencies and Laboratories will draft a financial plan for the project. This plan will be used by the funding agencies

and the Laboratories for the allocation of Project funds to the CDMS collaborating institutions and the laboratory groups. NSF annual reports and project quarterly reports will summarize the status of the Project spending and contingency usage compared with the financial plan.

Spending Authorization Project funds will be allocated at the beginning of each project year to each of the collaborating institutions based on the financial plan described in the previous section. Authorization for spending is granted by the Project Manager and can be made as a block grant of authorization or item by item as deemed necessary.

Cost Accounting A project accounting system will be created and maintained by the Project Manager and the Chief Budget Officer, in consultation with the budget officers at each of the collaborating institutions. Updates to this system will be made monthly by the Chief Budget Officer, and summaries produced in the quarterly reports to the agencies. Equipment spending for each subtask will be reviewed monthly by the Project Manager, in consultation with the individual System and Subsystem Managers.

Contingency The Project Contingency will be defined in the financial plan developed with the agencies. Contingency will be held by the Project Manager, and all use of contingency must be approved by him or her. Contingency usage will be reported in the quarterly reports.

Sum of Cost3 (w/contingency)	Yr				
Agcy	1	2	3	4	Grand Total
DOE Lab Base	1,731,063	1,782,995	1,584,078	1,628,910	6,727,047
DOE Lab Project	847,463	936,510	967,757	999,503	3,751,233
DOE University Base	1,515,864	1,858,865	1,849,599	1,910,850	7,135,178
DOE University Project	2,052,326	1,724,902	1,196,783	818,211	5,792,222
NSF Base	608,158	820,140	877,700	904,090	3,210,088
NSF Project	1,662,919	1,961,895	2,035,633	1,622,884	7,283,331
Grand Total	8,417,792	9,085,307	8,511,551	7,884,449	33,899,099

Figure 18: SuperCDMS Development Project Budget and Base Program Budgets of collaborating institutions by Funding Agency and Project Year

Change Control When any significant changes occur in the cost, schedule, or scope of the project, the change control process will be initiated. A change in scope, or a schedule change which would extend the length of the project require approval of the Collaboration Board and the funding agencies. The Project Manager will bring significant schedule changes that do not extend the project before the Collaboration Board for approval. Smaller schedule changes can be made at the discretion of the Project Manager.

While all cost changes will be reported in the quarterly reports, the level of approval rises with the size of the change. The Project Manager can approve cost changes below the level of $10K. Between $10K and $100K, the Project Manager must seek approval from the Change Control Board. Above $100K, the funding agencies must also give prior approval.

Sum of Cost3 (w/contingency)	Agency			
Inst	DOE Laboratory	DOE University	NSF	Grand Total
Brown		132,646		132,646
Caltech		1,106,449		1,106,449
CWRU			3,261,975	3,261,975
FNAL	9,772,941			9,772,941
LBNL	705,339			705,339
NIST		765,605		765,605
SCU			594,143	594,143
SU		4,806,903		4,806,903
UCB			5,674,572	5,674,572
UCSB		2,003,265		2,003,265
UF		1,689,368		1,689,368
UM		2,423,164		2,423,164
UCDHSC			962,729	962,729
Grand Total	10,478,280	12,927,400	10,493,420	33,899,099

Sum of Cost3 (w/contingency)	fund		
Agency	Base	Project	Grand Total
DOE Laboratory	6,727,047	3,751,233	10,478,280
DOE University	7,135,178	5,792,222	12,927,400
NSF	3,210,088	7,283,331	10,493,420
Grand Total	17,072,313	16,826,786	33,899,099

Figure 19: Top: SuperCDMS Development Project Budget and Base Program Budgets by Institution and Funding Agency. Bottom: SuperCDMS Development Project and Base Program Budget Totals.

9.3 Project budget tables

The following tables provide a summary of the SuperCDMS Development Project and base program cost estimates. Figure 18 shows the profile by project year and funding source, while Fig. 20 gives the breakdown by System (WBS

level 1) and expenditure type. Figure 19 summarizes the costs by institution and funding agency (top panel), and the project and base programs that are described in the following section (bottom panel). Note that all costs include inflation (3%/year) and contingency. Contingency is applied at the following levels: 0% for personnel, 10% for equipment, 20% for S&E and travel. More detailed tables will be produced at the full WBS level for a project funding review.

There are only a few large (more than $50K) equipment purchases in the budget, since this is a development project not a construction project. These include a new dilution refrigerator for the test facility at UC Berkeley ($215K) and Ge blanks for new detector construction at Stanford ($74K). There are also several large items, totaling $527K, which are listed as "supplemental," meaning that they are not included in the budget totals but would be requested if needed. These are associated with the two possible neutron vetoes which could be implemented at Soudan, and shielding for a full-scale beta screener.

10 Related Proposals

10.1 NSF and DOE Base Programs

In parallel with the SuperCDMS Development Project, and as summarized in Section 8.4, all university groups are requesting support for DOE and NSF base programs. The NSF base funding requests are from the detector teams at UC Berkeley, Case, Santa Clara, and Denver. On the DOE side, continuing base support has been requested for Stanford, UCSB, Minnesota, Fermilab and Brown, and new requests will be submitted from Caltech and Florida. These will support many of the scientific personnel for a wide range of Soudan operations and SuperCDMS development as well as modest R&D efforts.

10.2 SNObox and Cryosystem (NSF MRI proposal)

The Canadian government has now funded a new experiment infrastructure at SNOLab, in Ontario, Canada, the world's deepest underground laboratory. In response, the SNOLab management has solicited letters of interest from experimental groups who would like space in the new laboratory. The appendices of this proposal include a positive response to our Letter of Interest by SNOLab's Experiment Advisory Committee.

We intend to submit a multi-institution proposal to NSF's Major Research Infrastructure (MRI) program in January 2005 to fund the construction of the new SuperCDMS infrastructure at SNOLab. This funding would allow the development and purchase of a new dilution refrigerator and materials for a new detector cryostat - the longest lead-time items for SuperCDMS. The MRI would be submitted by UC Berkeley and supported by Stanford, UCSB and Case. Fermilab would supply the design and engineering manpower, and coordinate the cryogenic and mechanical expertise from all of these groups. The design would be complete by the end of 2006 and installation at SNOLab could begin in 2007. Our funding strategy and timeline calls for establishing by the end of 2008 a working system at SNOLab, which will be ready for the first round of new detectors funded by this proposal.

10.3 Low Background Counting (NSF MRI proposal)

To meet the SuperCDMS goals, we must greatly improve our screening facilities for gamma and alpha-emitting contaminants. Since this is a common need in the low-background community, it makes sense to do this in the context of a low-background counting facility (LBCF) at Soudan. We will submit a proposal for an NSF MRI that would cover development of the instrumentation for this background screening. The proposal will be submitted by the University of Minnesota, in conjunction with the University of Florida. DOE supplemental funding would be requested at University of Minnesota and Fermilab to prepare the facility at Soudan for these screening efforts. Work has already begun at Soudan with supplemental funds from DOE, and additional funding in 2005 would allow the full LBCF to be online by 2007.

Sum of Cost3 (w/contingency)	fund	categ									
	Base				Base Total	Project				Project Total	Grand Total
System	Eqpt	Personnel	S&E	Travel		Eqpt	Personnel	S&E	Travel		
Backgrounds	5,090	2,521,429	108,487	47,276	2,682,282	64,876	536,008	325,134	279,568	1,205,586	3,887,867
Detectors	66,722	3,358,216	697,296	98,451	4,220,685	849,903	3,936,973	1,436,518	40,084	6,263,478	10,484,163
Management		1,908,698			1,908,698	6,145	1,328,121	283,260	211,508	1,829,034	3,737,732
Snolab Design		2,337,146			2,337,146	0	538,346	157,917		696,262	3,033,408
Soudan		5,450,586	10,096	462,821	5,923,503	27,852	1,514,741	2,746,063	2,543,769	6,832,426	12,755,929
Grand Total	71,812	15,576,075	815,879	608,548	17,072,313	948,776	7,854,189	4,948,892	3,074,929	16,826,786	33,899,099

Figure 20: SuperCDMS Development Project Budget and Base Program Budgets of collaborating institutions by System and Type of Expenditure

11 Broader impacts

There is no doubt that unraveling the nature of dark matter or shedding light on supersymmetry will have broad scientific impact in astrophysics, particle physics and the theory of gravity. Even a negative result will severely limit theoretical possibilities. CDMS has developed new technologies which have transferred well to other scientific fields. It is anticipated that the technological advances proposed by SuperCDMS will also have a strong impact. In the process of producing exciting new physics, CDMS has provided an excellent education in a broad range of scientific and technical areas for the graduate students and postgraduates involved, as well as a large number of undergraduates who have been able to participate in CDMS through REU programs, private grants, and base program funds. Due to the keen public interest in this field, we have been able to promote science in the larger public arena and forge collaborations with teachers which result in practical educational advantages for students in grades K-12. We discuss each of these areas in turn, reviewing the accomplishments of CDMS II and outlining our plans for the SuperCDMS Development Project

11.1 Technical Development

Building on a rapidly developing field of low temperature detectors, CDMS has returned the favor by contributing important novel technologies: massive phonon-mediated detectors, the simultaneous measurement of ionization and phonon signals as a background rejection tool, the detection of athermal phonons through the coupling of superconducting films with superconducting transition edge sensors (TES), extreme electrothermal feedback in voltage-biased TES and the large-scale use of SQUID array technology.

Not only have these contributions kept CDMS at the leading edge of the dark matter field and directly influenced other WIMP search experiments, such as EDELWEISS and CRESST II, but they have also had a substantial impact on other scientific programs. Voltage-biased TESs, for example, will form the basis of large-scale bolometer arrays for Cosmic Microwave Background (APEX, South Pole Telescope), submillimeter astronomy (SCUBA-2), optical single photon spectroscopy (Stanford) and large-scale arrays of high resolution X ray calorimeters (NIST). These last detectors have also been adapted to surface analysis for electron microscopy with a number of industrial applications. The high sensitivity of TESs may have interesting applications in quantum coherence and quantum computing.

The SuperCDMS program and the long term R&D in the associated base programs will continue on this trajectory, giving our team the opportunity to assimilate new advances such as superconducting film technology, VLSI transformers, SQUID arrays, Single Electron Transistors, low temperature integrated electronics, surface contamination analysis and ultra-low background techniques. These programs will maintain our position at the forefront of new technologies and increase the reach of our science.

11.2 Undergraduate, Graduate and Postgraduate Education

CDMS provides excellent education opportunities for our graduate students and postdocs. Its multidisciplinary character at the border between particle physics, cosmology and condensed matter provides our students with opportunities for advancement in many fields. Our students are also trained in ultra sensitive measurement techniques and statistical analysis. In the last year alone, four PhDs have been granted, based on CDMS work. Among the former students and postdocs of CDMS, four are now tenured faculty (Akerib, Young, Shutt, Lee), four are assistant professors (Gaitskell, Golwala, Baudis, Saab) and two have permanent positions at NIST (Irwin, Nam). During the last four years, while building CDMS II, we have still managed to keep up a significant publication rate with two *Physical Review Letters*, one *Physical Review* rapid communication, one *Physical Review* and numerous papers at conferences [36].

Undergraduates can find work suited to their talents in small self-contained analysis jobs, test facilities at the various institutions, and summer jobs at the Soudan Mine. Typically 12 undergraduate students (3 Berkeley, 3 Case, 1 Stanford, 1 Santa Barbara, 1 Santa Clara and 5 Minnesota) per year are involved in CDMS and are exposed to frontier research.

CDMS is also striving for diversity in its rank: Two of our former students who are now professors are female. We currently have three women and one Hispanic graduate students, one female postdoc and three of the 14 voting members of the SuperCDMS collaboration board are women. Maintaining a friendly and supportive atmosphere within the collaboration is also one of our explicit goals, implemented in part by yearly collaboration-wide retreats.

11.3 K-12 Education

All of the participating universities have ongoing programs for science enrichment with their local public schools. Their education component is explicitly detailed in the NSF base proposal from the individual institutions, but we can mention a few examples here. UCB students and postdocs contributed to the curriculum of a summer school in an underserved local school district in 2002 and 2003. Bernard Sadoulet and Elizabeth Arscott have also been deeply involved in a collaboration between Berkeley and four school districts in the Bay Area to prepare a targeted Math and Science Partnership proposal to the NSF. They are also participating in the coming year in the organization of a "Physics teaching" seminar combining scientists from UC Berkeley and teachers from local high schools to engage scientists from the university and educators from the district in long-term "teaching learning communities". At Case, Dan Akerib's group initiated a project to develop science exhibits in cooperation with Cleveland's Great Lakes Science Center (GLSC) and a local high school teacher. In the future, they will attempt to further develop these exhibits for use in the public program surface exhibits at Soudan and SNOLab. The partnership that the Case group developed with this teacher continues to this day in the form of class visits and guidance on student projects. Sunil Golwala's group at Caltech has recently become involved in the Caltech Classroom Connection, a program to link researchers at Caltech with math and science teachers in the Pasadena Unified School District. Caltech researchers help with curriculum development, in-class activities, and provide role models to encourage students to think about careers in science and technology. At Santa Clara University, Betty Young's undergraduate students have been teaching physics and giving demonstrations to elementary school students in the San Jose area. Priscilla Cushman at Minnesota is the PI for their QuarkNet chapter, established three years ago to create opportunities for high school teachers to do research in High Energy Physics and create related teaching materials. The group is also involved in evaluation of middle school science kits through the "Science Works" program. All of these programs will continue in the development phase of SuperCDMS with special emphasis on underground science and particle astrophysics as appropriate.

CDMS and MINOS partnered in an organized

effort over the last two summers to produce age-appropriate curricula and education packets for primary and secondary school students visiting the Soudan Mine. The majority of this work has been done by middle and high school teachers through the NSF-funded RET program, the DOE-funded QuarkNet program, and Minnesota state funds, organized by several professors and the staff at the Soudan Underground Lab. These packets contain enrichment material: a CD with movies and weblinks, and projects to be done in the classroom before visiting. A dedicated website can be used by all grades to explore the physics further via exercises and informational links. This involvement with area teachers has been a welcome addition to summer work at the mine, providing an enriching experience for the CDMS graduate students, who have made many valuable contributions to the educational material, as well as getting the teachers involved in frontier research.

11.4 Public Outreach

The Soudan Underground Laboratory provides an outstanding opportunity for public outreach because of its location within a state park. The Minnesota Department of Natural Resources (DNR), which owns the mine, operates historic mine tours throughout the summer and by special arrangement in the off-season. For the last two years, MINOS and CDMS have helped to provide science tours to more than 6,000 visitors a year. CDMS has fully participated in all aspects of this outreach by creating underground and surface displays to explain our experiment, attending question and answer sessions with the park guides, contributing to the brochure design and production (more than 10,000 of the brochures were handed out during the last tourist season), taking active part in the yearly spring open house days, and assisting in the ongoing construction of a public website. A kiosk on the surface now includes a touch screen virtual tour of the lab and its physics. CDMS also installed a scintillating fiber tracking detector in the kiosk which displays cosmic rays in real time. In collaboration with CDMS and MINOS scientists, the Fermilab visual media department has taken additional footage for a revised Soudan video, which now includes CDMS along with the earlier MINOS footage. The video is shown at the beginning of each public tour at Soudan and can be used as a general publicity aid.

Because of the success of Soudan, we plan to continue our investment in this outreach by scientific assesment of our impact and better coordination of education and outreach. One identified need is an on-site person who can properly organize the outreach and act as an interface between the DNR and the experiments. Current needs include a maintained webpage with ongoing projects and meeting minutes collected in one place, scientific guidance on the educational material, following through with the suggested improvements as well as maintenence and repair of the exhibits, maintaining contact with area teachers and pursuing new contacts, organizing open houses and community outreach in the local community. We have included $30k/year in the proposal for such a physicist coordinator. The MINOS experiment through Stanford (NSF) continues to provide similar funding for outreach, some of which can also be used to supplement the outreach coordinator. Assessment studies and coordination with other outreach programs such as the K-12 initiatives at Berkeley will be managed by Elizabeth Arscott, included as additional 0.25 FTE in the SuperCDMS budget.

Based on our Soudan experience, we feel we can contribute in a similar way to the SNOLab. Northern Ontario supports a nearby science museum called Science North which has showcased underground science with a 30-minute film about SNOLab. A SuperCDMS public outreach program will combine local exhibits at the new SNOLab campus with contributions to more general underground science education at Science North. By expanding the network of science teachers we have previously established into local schools and colleges near Sudbury, we can hope to establish a solid public outreach program very quickly.

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SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

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September 14, 2004

To: Professor Dan Akerib
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Re: Response to your Letter-of-Interest in staging the CDMS/Cryo-Array experiment at SNOLAB.

Dear Dan,

Thank you very much for submitting your Letter-of-Interest (LOI) in staging the CDMS/Cryo-Array experiment at SNOLAB. LOI's and eventual proposals to stage experiments at SNOLAB are reviewed by an Experiment Advisory Committee (EAC). Chaired by Professor Barry Barish, the charge of the EAC is to provide advice and recommendations to the SNOLAB Director and to the scientific community interested in staging experiments at this new facility. The EAC consists of five experimentalists and two theorists and is representative of an international scientific community:

Baha Balantekin ... Madison University, Wisconsin, USA
Cliff Burgess ... McGill University, Quebec, Canada
Takaaki Kajita ... ICRR, Tokyo, Japan
John Martin ... University of Toronto, Ontario, Canada
Ken Ragan ... McGill University, Quebec, Canada
Kate Scholberg ... Duke University, North Carolina, USA
Dave Wark ... Imperial College, London, England

Members of the EAC have been appointed by the Director for SNOLAB Development, Professor David Sinclair. Andrew Hime serves on the EAC in an *ex officio* capacity as secretary for the EAC in his role as Associate Director for SNOLAB Development and Chair of the Scientific Executive Committee (SEC).

The EAC has reviewed your LOI and endorses it highly as a project appropriate for SNOLAB based upon its exceptional scientific merit, the technical accomplishments achieved to date by the CDMS collaboration, and the well defined program to proceed towards the Cryo-Array project. The response from the EAC is captured below amongst the seven guidelines provided in our original request for LOI's. We ask that you respond to the various queries at your earliest convenience. Please provide this response in electronic form to ahime@lanl.gov. This correspondence does not require a re-submission of your LOI but a direct response to the queries outlined below. A process is presently being defined to call for full proposals to stage experiments at SNOLAB. An intermediate process is required to tune the infrastructure requirements of SNOLAB based upon the input of the scientific community and to consider the mid to long-term road-map that will optimize our ability to meet the scientific goals common to the field and to identify an initial suite of experiments for SNOLAB.

Significant progress has been made on both the underground and surface developments of the project. We still anticipate that some new space will be available in about 1 year and that the complete facility will be ready in 2007. The surface building foundations have been completed and steel erection is underway. This is very close to the original plan so we remain confident that the completion date of May 2005 will be met. With these developments in progress, it is important that you continue to interact with SNOLAB to ensure that specific details of your project's infrastructure can be met and implemented. In parallel with the EAC review of your LOI, a subset of the SEC has studied the infrastructure needs of your experiment. Specific queries regarding your

infrastructure needs are discussed in section 2 below. The accompanying figure provides a possible layout for your experiment. Please take the liberty to work with this layout at your own convenience and provide feedback.

We look forward to continue working with you and are eager to help in any way we can to make your experiment a success. In the meantime, please feel free to use this letter in any way you see fit in approaching the funding agencies and deliberating with your colleagues to establish a successful program at SNOLAB.

Sincerely,

Barry C. Barish

Barry Barish
Chair SNOLAB Experiment Advisory Committee

Hime

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Associate Director SNOLAB Development

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Director's Office

April 15, 2004

Dr. Blas Cabrera
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Dr. Dan Bauer
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Dear Blas and Dan,

Thank you for your submission, presentations, and discussion at the recent meeting of the Fermilab Physics Advisory Committee (PAC). The Committee had the following comments on the Cryogenic Dark Matter Search experiment:

The Committee was pleased by the CDMS-II collaboration's completion of two towers in Soudan and the successful start of data-taking. The Committee was also very impressed by the first science produced from the Soudan operation, which already excludes a very interesting region of the Dark Matter parameter space, and is the current world-best limit. The Committee fully supports the science of a seven-tower CDMS-III that will make the most out of the investment already made. The Committee encourages the collaboration to aggressively try to increase the analysis role of the Fermilab group.

I am also impressed by the first results from the Tower 1 running at the Soudan Laboratory. The absence of background events is especially encouraging. The design sensitivity for CDMS-II appears within reach, and the chance for a discovery in the next two years is real. This makes your proposed extension of CDMS III very exciting, and it should also help in the efforts to attract talented people to the collaboration and to the Fermilab group. We look forward to publication of the new results.

Sincerely,

Michael Witherell

cc: K. Stanfield
H. Montgomery
S. Holmes, J. Appel