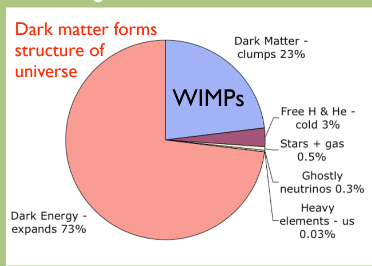
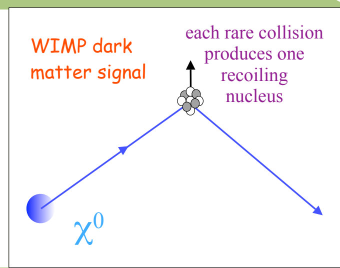
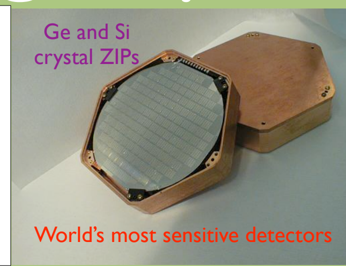
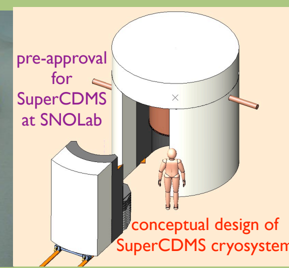
SuperCDMS 25 kg Experiment







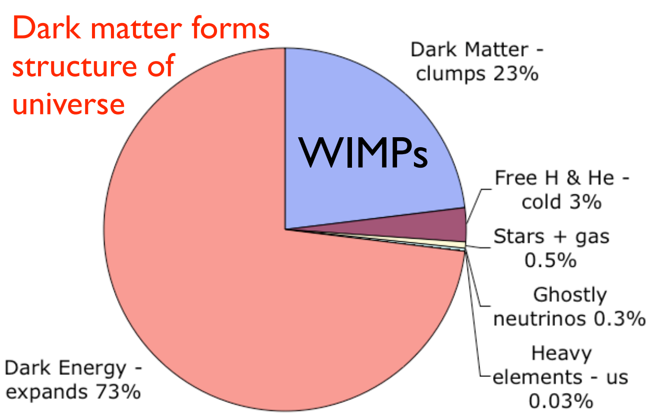


September 25, 2005

SuperCDMS 25 kg experiment can discover neutralino dark matter

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 any known particle. Deciphering the nature of this dark matter would be of fundamental importance to cosmology, astrophysics, and high-energy particle physics. A leading theory called supersymmetry tells us that dark matter is made of neutralino WIMPs (Weakly Interacting Massive Particles) that were produced moments after the Big Bang. If neutralinos are the dark matter, then their presence in our Milky Way may be detected from rare recoils of atomic nuclei in laboratory detectors. The technology for detecting WIMPs has been demonstrated by our Cryogenic Dark Matter Search (CDMS-II) experiment. A larger SuperCDMS experiment, with 25 kg of target mass, has a good chance to discover neutralino dark matter and may provide better measurements than the LHC and the future ILC for some neutralino properties.

WIMP Dark Matter: Cosmology and Supersymmetry

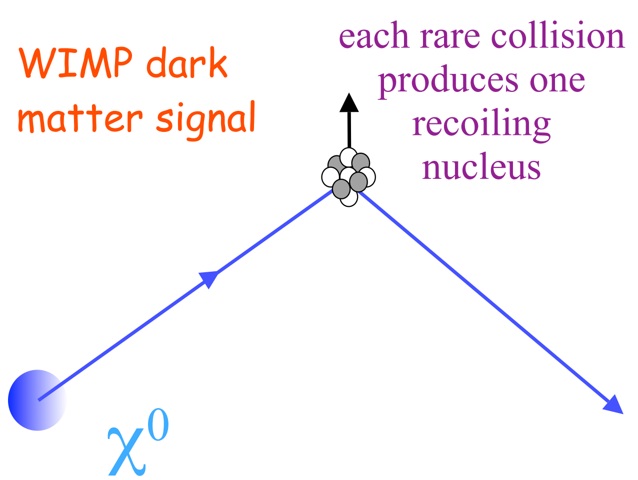


Over the last decade, a variety of cosmological observations, from the primordial abundance of light elements, to the study of large scale structure, to the observations of high redshift supernovae, to the detailed mapping of anisotropy of the cosmic microwave background, have led to a coherent model of cosmology. In this very successful model, the universe is made of 4% baryons which constitute ordinary atomic matter, 23% nonbaryonic dark matter and 73% dark energy. 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. These Big Bang relic particles are particularly interesting because 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 (likely the neutralino) 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.

Direct Detection of Dark Matter

If neutralino 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 laboratory target (see figure below). 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.

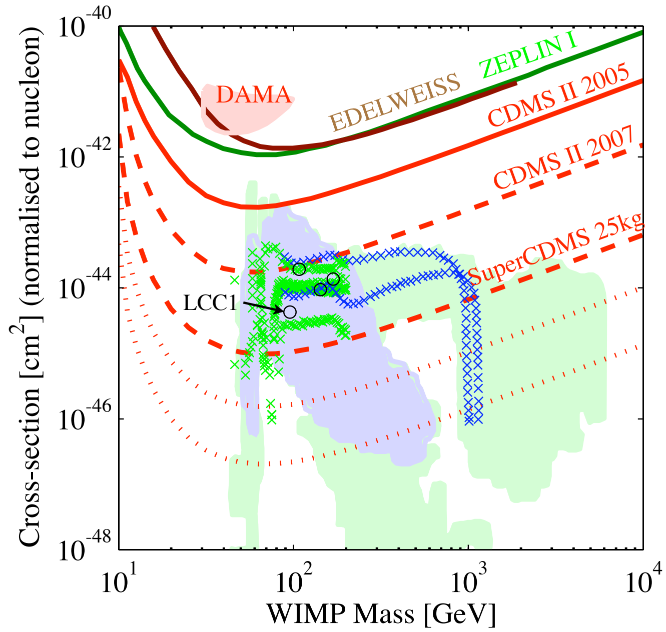


In most quantitative models (such as supersymmetry) scalar interactions dominate, and the quantum number that adds in the coherent scattering matrix element is very close to the atomic number of the nucleus. This process is also referred to in our field as ``spin-independent'' scattering. Together with a standard galactic halo model, this WIMP-nucleus scattering prescription allows a cross-section upper limit to be calculated from a scattering-rate upper limit. In addition, it is possible in restricted regions of parameter space, in particular for a spin-$^1/_2$ 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.

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; ``Neutrinos and Beyond,'' chaired by B.~Barish) and from HEPAP (``The Quantum Universe,'' chaired by P.~Drell) 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 suite will include research and development needs for specific experiments, associated technology needs, physical specifications, and preliminary cost estimates''.

CDMS-II Experiment leads world

The next figure plots the mass of the neutralino versus the scattering cross-section of that particle with nucleons, and shows that the direct-detection experiments, in particular CDMS II, and at less sensitivity EDELWEISS, ZEPLIN I and CRESST-II, are beginning to significantly constrain the WIMP-nucleon scattering cross section. Our recent result from CDMS~II provides the most sensitive WIMP-neutron scattering limits, more sensitive by a factor of ten than the next best experiments. This result rules out spin-independent scattering and 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 show that there is presently no compelling evidence that any experiment to date has detected dark matter.



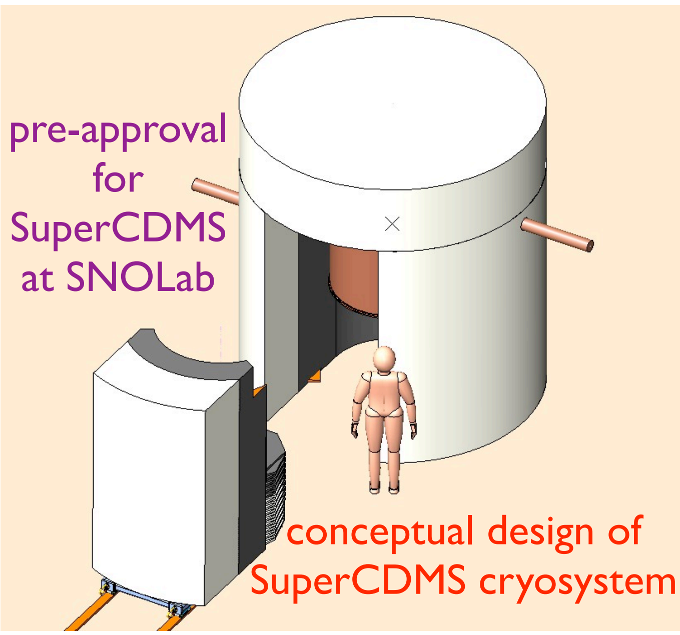
The CDMS-II experiment at Soudan (2600 feet underground) has demonstrated the detector technology necessary to see such dark matter recoils. These results have been published in *Physical Review Letters* **93**, 211301 (2004) [also astro-ph/0405033], with a detailed description in astro-ph/0507190 (accepted for publication in *Physical Review* **D**). Two new papers have just been submitted to *Physical Review Letters*, one reporting the best spin-independent limit [astro-ph/0509259] and the second one the best neutron spin-dependent limit [astro-ph/0509269]. With our unique germanium and silicon ZIP (Z-dependent Ionization and Phonon) detectors, shown in the next figure, we have demonstrated the superb background-rejection power of electron-vs-nuclear recoil discrimination and the additional advantages of obtaining the information provided by the athermal phonons caused from a scattering event. This additional prompt phonon information is the main reason we are leading our European competitors (EDELWEISS and CRESST-II), who use slower phonon mediated methods.

We are in the process of cooling down nineteen Ge ZIP (4.5 kg) and eleven Si ZIP (1.1 kg) detectors at Soudan to complete the final stage of the CDMS-II experiment. Our final sensitivity, shown in the limit plot above, is expected to be a factor of ten better than our current limit and is shown as the upper dashed line labeled CDMS-II 2007. This factor of ten will allow us to explore additional supersymmetric models which contain excellent dark matter candidates. In the next year or two, the CDMS-II experiment may discover WIMP dark matter. If it does, we need to build larger-mass experiments to study the signal. If only better limits are set, we still need to build larger-mass experiments to explore more of the region allowed by supersymmetry.

SuperCDMS 25 kg experiment

We believe that the CDMS detector technology is the fastest way to continue to improve the sensitivity for direct detection of WIMPs. A SuperCDMS experiment, with 25 kg of instrumented target mass, could discover neutralino dark matter down to the lower dashed line labeled SuperCDMS-A in the limit plot. CDMS has demonstrated technology for discriminating WIMPs from laboratory backgrounds with unsurpassed sensitivity to the WIMP-nucleon scattering cross section, and we believe it is now the strongest candidate for continuing the direct detection dark matter search over the next three years.

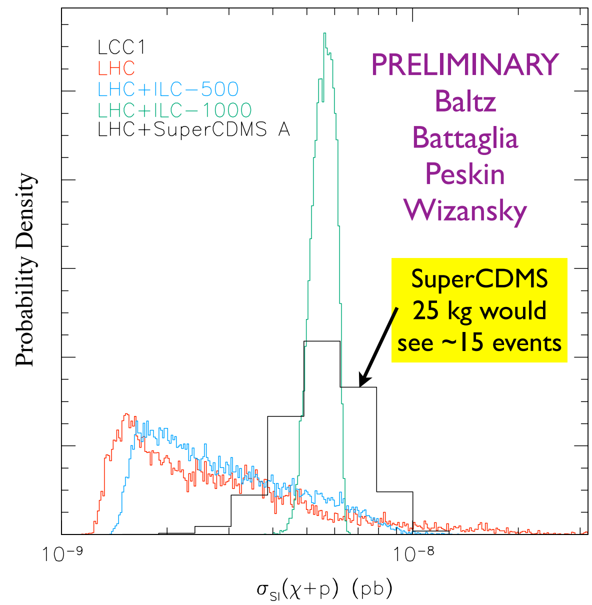
To achieve the lower cosmic ray backgrounds needed for a larger mass experiment, we have proposed performing the experiment within SNOLab, the recently funded Canadian deep underground science laboratory (6800 feet underground). The Program Advisory Board at SNOLab has approved our proposal contingent on SuperCDMS support from the DOE and NSF. If funded, we could begin to set up the installation in early 2007.



The figure above shows conceptual design work on the SuperCDMS apparatus, including the cryogenic system and the lead and polyethylene shields.

Past this next three year period, we see a clear path forward to extend our SuperCDMS sensitivity by factor of 100 or more . Such a larger mass (150 kg or more) experiment will compete with other technologies such as liquid xenon or bubble chambers, which will have had time to demonstrate their sensitivity, which, as we have seen, is often limited by the edge effects or radioactive contamination. In addition, given the importance of the science, it is wise to support more than one large-mass technology in keeping with the OSTP report, which refers to a suite of experiments.

Complementary to LHC and ILC



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 a future ILC. As shown in the figure above, there are supersymmetry models (e.g., LCC1 from the Linear Collider Cosmology study) in which SuperCDMS would measure particle physics parameters, such as the WIMP-nucleon cross-section, better than the LHC or even the combined LHC and ILC.

In summary, CDMS-II is now leading the field and by carrying out the SuperCDMS 25 kg experiment, we will be able to stay at the frontier of the WIMP search and explore a central region of parameter space, in a way that is complementary to the LHC. If a WIMP is discovered by direct detection, accelerator experiments are needed to completely understand its properties, and conversely, if accelerators discover supersymmetery direct detection experiments are needed to show that the neutralino is in fact the dark matter.