Welcome to the Soudan Underground Laboratory

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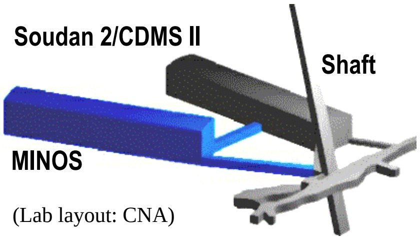
Soudan Underground Mine State Park, Soudan, Minnesota


(Headframe: J. Meier)

Welcome to the Soudan Underground Laboratory, operated by the University of Minnesota in partnership with the Fermi National Accelerator Laboratory, the Minnesota Department of Natural Resources, and the CDMS II and MINOS Collaborations. This unique facility is located almost a half-mile underground, and is designed to explore fundamental questions about the structure of our universe. Not all have answers—at least not yet—but we hope this guide and your hosts can help explain how we go about asking such questions, and why we think they are important. Enjoy your visit!



(Lab layout: CNA)

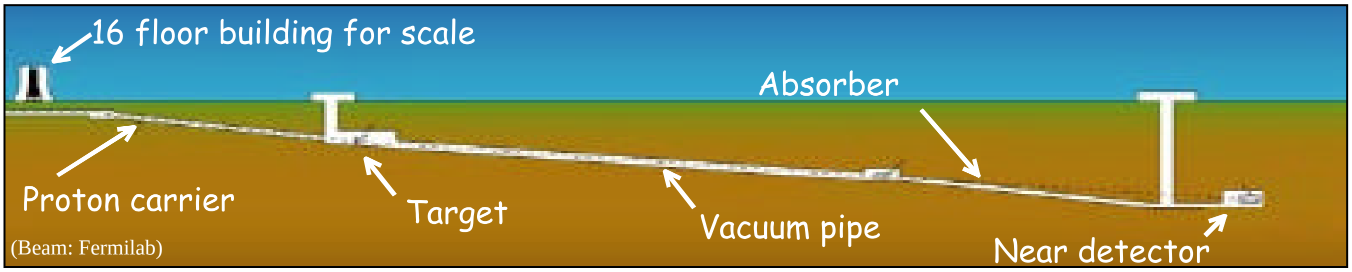
The Soudan Underground Laboratory is a general-purpose science facility, which provides the deep underground environment required by a variety of sensitive experiments. The Lab currently hosts two large projects: MINOS, which investigates elusive and poorly understood particles called neutrinos; and CDMS II, a "dark-matter" experiment which may help explain how galaxies are formed. Both were built for basic research—exploring how the universe works—but similar efforts have spawned practical (if unforeseen) byproducts, including the world-wide web and even advanced medical imaging techniques.

What is a neutrino? A neutrino is a tiny particle similar to an electron but without its electric charge. Neutrinos are produced by natural radioactive decay and inside the sun and other stars. They don't interact very often with normal matter, but MINOS can still teach us how they behave, and how important they are to the rest of the universe.

What is "dark matter"? Actually, no one really knows! What we *do* know (from astronomical observations) is that there is a lot of dark matter around—perhaps 90% or more of the material in the universe. We can't see it, but we know it's there from the gravitational force it exerts. Neutrinos may make up part of the dark matter, but another possibility is very heavy (so-far undiscovered) particles nicknamed "WIMPs" (Weakly-Interacting Massive Particles). CDMS II searches for WIMPs that may have been produced shortly after the "Big Bang," the cataclysmic explosion that formed the universe some 15 billion years ago.

Why is the Laboratory so far underground? MINOS and CDMS II are extremely sensitive instruments searching for particles that (at best) are very seldom seen. At ground level, naturally occurring "cosmic rays" strike the surface of the earth so often they could completely mask the rare effects these experiments seek. The half-mile or so of earth above the Lab blocks almost all these cosmic rays, providing a much "quieter" research environment.

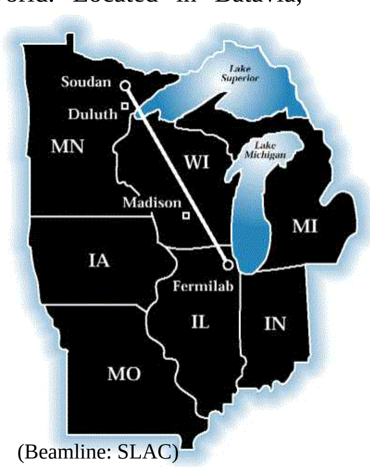
How big is the Laboratory? The MINOS cavern is 82 meters (270') long, 15 meters (50') wide, and 13 meters (40') high. The Soudan 2/CDMS II cavern is similar in shape but only 70 meters (230') long. The surrounding rock formation is not iron ore but actually Ely Greenstone, about 2.7 billion years old. Nearly 100,000 tons of it was excavated to build the lab—all hoisted to the surface, six tons at a time. Some was used beneath the parking area west of the Engine House, while the rest can be seen piled southeast of the headframe.



(Beam: Fermilab)

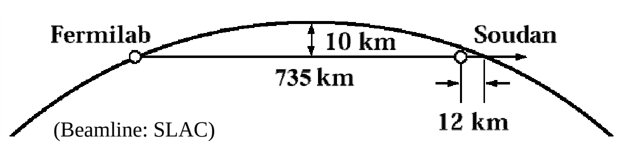
Where do neutrinos come from? Most are made naturally, by cosmic rays and the sun, but MINOS looks primarily for neutrinos from the Fermi National Accelerator Laboratory (Fermilab). There, the "Main Injector" accelerator can direct an intense beam of protons onto a special graphite target, where they produce new particles called "pions." The pions are pointed toward Soudan along a 675-meter (2,200') vacuum pipe (top illustration), where they decay to make neutrinos. Other particles are also created, but they are stopped at the end of the pipe by a 10-meter (33') thick steel "absorber" and 240 meters (800') of solid rock. Because neutrinos don't interact very much, virtually all simply pass straight through the absorber and rock, as well the 735 km (455 miles!) of earth between Fermilab and Soudan.

What and where is Fermilab? Fermilab was established in 1970 to house the highest-energy particle accelerator ("atom smasher") in the world. Located in Batavia, Illinois (40 miles west of Chicago), it is operated by a consortium of more than ninety major universities who guide its mission to probe the fundamental nature of matter and energy. In addition to MINOS, Fermilab directs a major effort to discover the "Higgs." Perhaps the last missing piece in the particle physics puzzle, the Higgs is a key to the secret of why some particles have mass, while others do not.



(Beamline: SLAC)

How big is MINOS? The MINOS "Far Detector" at Soudan consists of two identical "super-modules." Each is an octagon (a neutrino stop sign!) 8 meters (26') across, and 15 meters (48') long. Together they will weigh more than 6,000 tons (about the same as a medium-sized destroyer). The MINOS "Near Detector" at Fermilab is similar but smaller, about 1,000 tons. The Near Detector samples the beam at its source, providing a comparison for Far Detector results at Soudan.



(Beamline: SLAC)

What is MINOS made of? The MINOS detector consists of alternating planes of 1" steel and plastic scintillator strips. These give off light when charged particles pass through them. An electric current through the middle of the detector magnetizes the steel, helping identify these particles and measure their energy.


(First MINOS detector plane, July 2001: J. Nelson)

How does the detector "see" neutrinos? Most of the time, in fact, it doesn't! Neutrinos interact only very weakly with ordinary matter, which is why they don't need a tunnel to get from Fermilab to Soudan. The number of neutrinos in the beam is *very* large, however, so about once every two hours one is unlucky enough to actually hit something as it passes through the detector. Even then we don't see the neutrino itself, but only the charged particles ejected from its interaction.

How does it all work? When charged particles travel through the detector they create light in the plastic scintillator. This is collected by special optical fibers, which also change the color to green. The light travels down the fiber to the edge of the detector, where it passes to another fiber, and then to sensitive devices called photomultipliers. These convert the light to electrical signals, from which the original tracks can be reconstructed using sophisticated computer analysis.

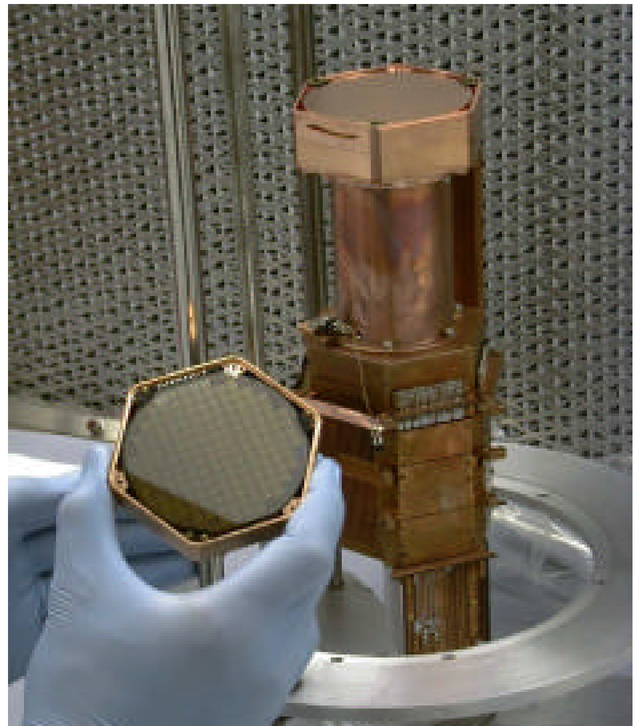
What will MINOS tell us about neutrinos? Neutrinos come in at least three different types: one paired with the electron, another with its heavier cousin the "muon," and the last with the even heavier "tau." Quantum mechanics, the physics of particles, tells us that mass allows neutrinos to spontaneously change from one type to another and back again (that is, to "oscillate"). MINOS is designed to search for these oscillations. Because neutrinos were long thought to be massless and independent, a positive signal would be tremendously important. Any masses are already known to be quite small, however, so the beam must travel a long way (from Fermilab to Soudan) to give MINOS a chance to see anything. Nevertheless previous experiments, studying naturally-occurring neutrinos in Italy, Japan, and right next door in the original Soudan 2 cavern, indicate that neutrino oscillations may well occur, and have told MINOS how to look for them.

How do you tell the neutrinos apart? Neutrino type can be determined from the particles they produce. Electron-type neutrinos tend to make electrons, which create short "shower-like" patterns in the detector. Muon-type neutrinos make muons, which exhibit long straight "tracks." The tau-type is difficult to observe directly, but could be seen *statistically* as "too many of the wrong sort" of events. The beam contains primarily one type of neutrino (muon-type). If neutrinos have no mass it should look essentially the same here at Soudan as it did when it left Fermilab. Any significant difference between the "Near" and "Far" Detectors is the signature of neutrino oscillations and thus neutrino mass.

Why are neutrinos important? Neutrino mass and neutrino oscillations could add considerably to our knowledge of the fundamental interactions that govern the universe. From the "Big Bang" some 15 billion years ago to the present, and at all scales from the sub-atomic to the astrophysical and cosmological, these interactions determine the fate of our universe. There are so many neutrinos that even a small mass could make them an important park of the "dark matter"—not all of it, or even most of it, but significant relative to the "normal" matter that stars and planets (and people) are made of.

What does MINOS *mean*? MINOS is the Main Injector Neutrino Oscillation Search: "Main Injector" for the Fermilab accelerator, and "Oscillation Search" for the theory that links neutrino mass to oscillations. In Greek mythology Minos was the son of Zeus and Europa, King of Crete, and builder of the labyrinth.

What's Next Door? The other cavern is the original Soudan 2 Laboratory. The Soudan 2 detector is about the same size as the MINOS Near Detector (1,000 tons) and is also built primarily of steel, but employs a different (gas-based) detector technology. Soudan 2 was built to test the ultimate stability of matter by looking for "proton decay," and operated between 1989 and 2001. While proton decay has not yet been observed, Soudan 2 contributed to the initial evidence for neutrino oscillations on which MINOS is based.


(CDMS II detector: CDMS II)

What's CDMS II? The Soudan 2 cavern also houses the Cryogenic Dark Matter Search (CDMS II). This experiment looks for the "main component" of dark matter, which may be in the form of WIMPs (Weakly Interacting Massive Particles). In contrast to neutrinos, which are light, fast, and plentiful, WIMPs would be heavy, slow, and less common, and could be even more difficult to detect.

How does CDMS II work? The CDMS II detectors are hockey puck-sized disks of silicon and germanium. A special cryogenic apparatus cools them to less than a *hundredth* of a degree above absolute zero (–460° F, the coldest place in Minnesota!). A WIMP passing through would deposit only a tiny amount of energy in the detector, but it should be enough to raise its temperature very slightly. The detector signals are carefully recorded and analyzed by computers to distinguish "true" WIMP signals from random "noise." Despite being under a half mile of rock, scientists also use intricate shielding, carefully selected materials, and a special clean room to further reduce unwanted signals.

How was all this equipment brought underground? Much like the proverbial ship in a bottle. Everything you see in the Lab came down the same narrow mine shaft that brought you underground. The hoist can handle equipment 1.3 m by 2 m by 10 m long (a little over 4' by 6' by 33'), weighing up to six tons. Each item in the laboratory was carefully designed to fit within these limits. During excavation of the cavern a full-sized front-end loader was brought underground in pieces, assembled, used for a year, and brought back out again.

How are the detector planes put together? Eight sheets of 0.5" steel are needed for each 1" thick octagon. They are "plug" welded in the open area directly below the Visitors' Gallery, where the scintillator modules are also attached and tested. The crane uses a special fixture called a strongback to lift the assembled plane to vertical, and to its proper location in the detector.

How long did it take to build the Laboratory? The "Soudan 1" experiment began in 1981, using an existing cavern on the 23rd level of the mine. The Soudan 2 Detector Lab was completed 1986, and MINOS Far Detector excavation began in 1999. The ceiling, walls, and floor were completed in 2000, with outfitting—steel supports, electrical, communications, and other systems—finished in July 2001. The first MINOS Far Detector plane was installed at the end the same month. The CDMS II enclosures were completed in spring 2002.

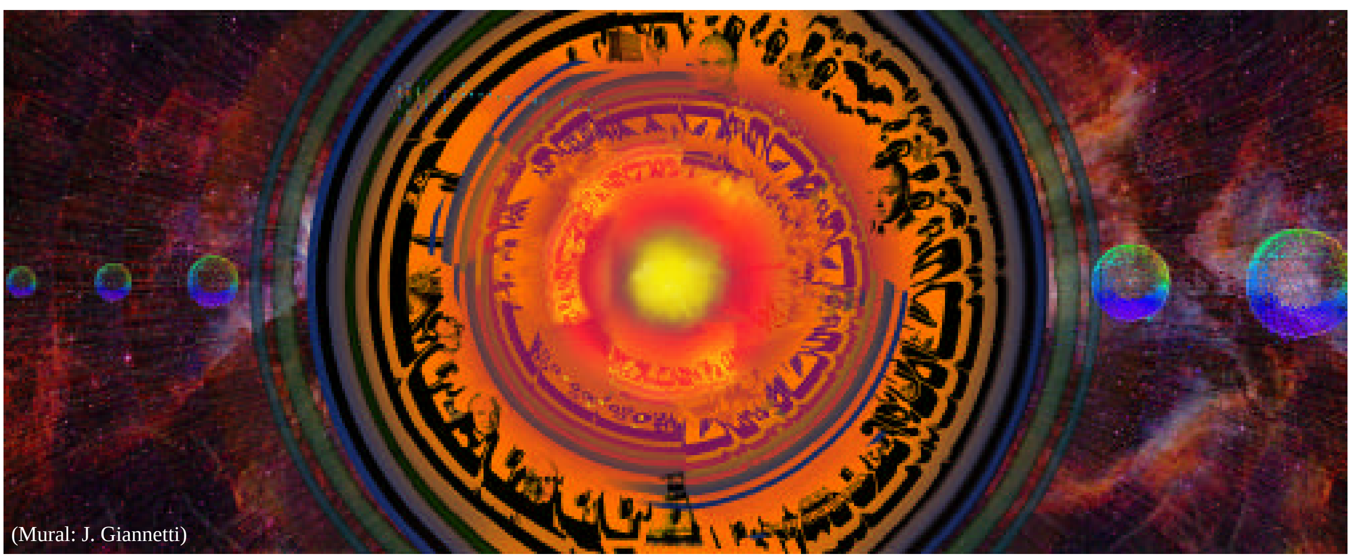
How much do the projects cost? The overall cost of MINOS over a period of several years is about $174 million, most spent on neutrino production facilities at Fermilab. The MINOS Far Detector cost is about $32 million. The cavern was approximately $7 million to excavate plus a similar amount for steel supports and other outfitting. CDMS II will cost about $16 million.

Who funds the projects? The U.S. Department of Energy provides primary MINOS support, with additional major contributions from the science funding agency of the United Kingdom, the National Science Foundation, the State of Minnesota, Research Corporation, and the member institutions. CDMS II is funded by the National Science Foundation and the Department of Energy.

How is the Laboratory related to the State Park? U.S. Steel donated the Soudan site to the people of Minnesota in 1962. The Department of Natural Resources has administered it as a State Park since then, operating and maintaining the hoist, pumps, and electrical and other systems, and escorting approximately 40,000 visitors each year underground to the last working areas of the mine. The University of Minnesota leases the Soudan Underground Laboratory from the State, and operates it under contract with the Department of Energy.

Are there other labs like this? During the past fifty years more than a dozen underground mines and tunnels have been used for physics experiments. Major active underground laboratories include Homestake (Lead, SD) Creighton (Sudbury, Canada), Boulby (northeastern England), Gran Sasso (Italy), Frejus (between Italy and France), Baksan (Russia), Kamioka (Japan), and Soudan.

MINOS institutions (March 2002): Argonne National Laboratory, University of Athens, Brookhaven National Laboratory, California Institute of Technology, Cambridge University, College de France, Fermi National Accelerator Laboratory, Harvard University, Illinois Institute of Technology, Indiana University, Institute for Theoretical and Experimental Physics (Moscow), Lebedev Institute (Moscow), Lawrence Livermore National Laboratory, University College (London), Macalester College, University of Minnesota (Duluth), University of Minnesota (Twin Cities), Northwestern University, Oxford University, University of Pittsburgh, Institute for High Energy Physics (Protvino, Russia), Rutherford Appleton Laboratory, University of South Carolina, Stanford University, University of Sussex, Texas A&M University, University of Texas (Austin), Tufts University, Western Washington University, University of Wisconsin (Madison). **CDMS II institutions** (March 2002): Brown University, Case Western Reserve, Fermi National Accelerator Laboratory, Lawrence Berkeley National Laboratory, University of Minnesota (Twin Cities), National Institute of Standards and Technology, Princeton University, Santa Clara University, Stanford University, University of California (Berkeley), University of California (Santa Barbara), University of Colorado (Denver).



(Mural: J. Giannetti)

Science and art provide complementary insight into the universe of natural phenomena. The mural was created by Joseph Giannetti in order to convey one artist's impression of neutrino physics and the Soudan Mine, and includes images of people important to the development of both physics and the mining industry. Mr. Giannetti designed the mural with computer graphics, projecting his image onto a 25' by 60' rectangle prepared with 25 gallons of white primer by Laboratory staff. Mr. Giannetti and his assistants completed the installation from a movable "window washing" platform, applying approximately 50 gallons of color paint over several months' time.