Dig in. Preliminary excavation has begun at Homestake, funded by South Dakota.

CREDIT: BILL HARLAN/SANFORD UNDERGROUND LABORATORY

Scientific Gold Mine Or Dicey Money Pit?

Scientists say a proposed underground laboratory in South Dakota could be a world beater. But they must persuade the National Science Foundation to pay for the massive project

MINERS ONCE HAULED GOLD OUT OF THE Homestake mine in the Black Hills of South Dakota. Now particle physicists hope to find scientific treasures there. They want to convert the mine into the Deep Underground Science and Engineering Laboratory (DUSEL), the largest underground lab in the world. In it they would seek the elusive "dark matter" whose gravity binds the galaxies, a type of radioactivity that would blur the line between matter and antimatter, and protons falling apart as predicted by some particle theories.

Advocates say the $875 million project is too good an opportunity to pass up. "We're investing in a suite of experiments, and three, four, or five of them could be discovery experiments that will change the textbooks," says Kevin Lesko, a physicist at Lawrence Berkeley National Laboratory in California, who leads the DUSEL design team. But DUSEL is not a typical project for the U.S. National Science Foundation (NSF), which historically builds scientific instruments such as telescopes. Instead, DUSEL is mostly an infrastructure project to provide lab space for a host of experiments in a variety of disciplines. Moreover, the biggest experiment in it would be a gargantuan particle detector funded primarily by the Department of Energy (DOE), not NSF. Operations such as pumping water out of the mine also cost $1 million a month.

The project must win approval from the National Science Board (NSB), which sets policy for NSF, and observers say that board members will want good answers to three important questions before they sign off on the project. How would DUSEL stack up against other underground labs around the world? How will NSF and DOE coordinate efforts to ensure the project stays on track? And will DUSEL yield enough science to justify the investment? "The NSF science projects have to be enough in the forefront to make it a good sell," says Barry Barish, a physicist at the California Institute of Technology in Pasadena and a consultant to the board. "The more it looks like it's just a big hole in the ground for a DOE experiment, the less sellable it is."

The project is entering a crucial period. The preliminary design should be completed by year's end. Meanwhile, the National Academies' National Research Council has begun a study of the three main questions and should provide input to NSF by the spring. Based on the preliminary design, NSB could vote on the project as early as August. "The question is, how much of this list of issues will be settled by next summer?" Barish says.

The lowdown on labs low down

When it comes to underground labs, "the deeper the better, the bigger the better, there is no doubt," says Franz von Feilitzsch, a physicist at the Technical University of Munich in Germany. Deep under ground, scientists can escape the hail of ordinary particles from space called cosmic rays to search for more exotic things. Big labs provide room for the huge detectors needed to spot very rare phenomena.

At a lab like DUSEL, four physics studies would anchor the research program. One would search for the dark matter that cosmologists say makes up 85% of all matter. Physicists are already trying to glimpse dark-matter particles smacking into nuclei in detectors weighing tens of kilograms in various underground labs around the world. They're spurred by a concept called "supersymmetry," which predicts that every known particle has a massive "superpartner." The lightest superpartner would be a prime candidate for dark matter. Fully testing the idea may require a detector weighing a metric ton.

Physicists would also search for a type of radioactivity called "neutrinoless double beta decay" that would blur the distinction between matter and antimatter. Many a nucleus can change identity through beta decay, when a neutron in it turns into a proton and spits out an electron and an elusive antineutrino. Others change by absorbing a neutrino instead of emitting an antineutrino. In neutrinoless double beta decay, two neutrons in a nucleus such as germanium-76 or tellurium-130 would change into protons while ejecting only two electrons. That can happen only if the neutrino is its own antiparticle—so the antineutrino emitted by one neutron can absorb the other neutron because it's also an antineutrino.

The biggest experiment in DUSEL would be a detector weighing between 100,000 and 200,000 tons that would snare neutrinos fired through Earth from a distant particle accelerator. Using such setups, physicists in the United States, Europe, and Japan are already studying

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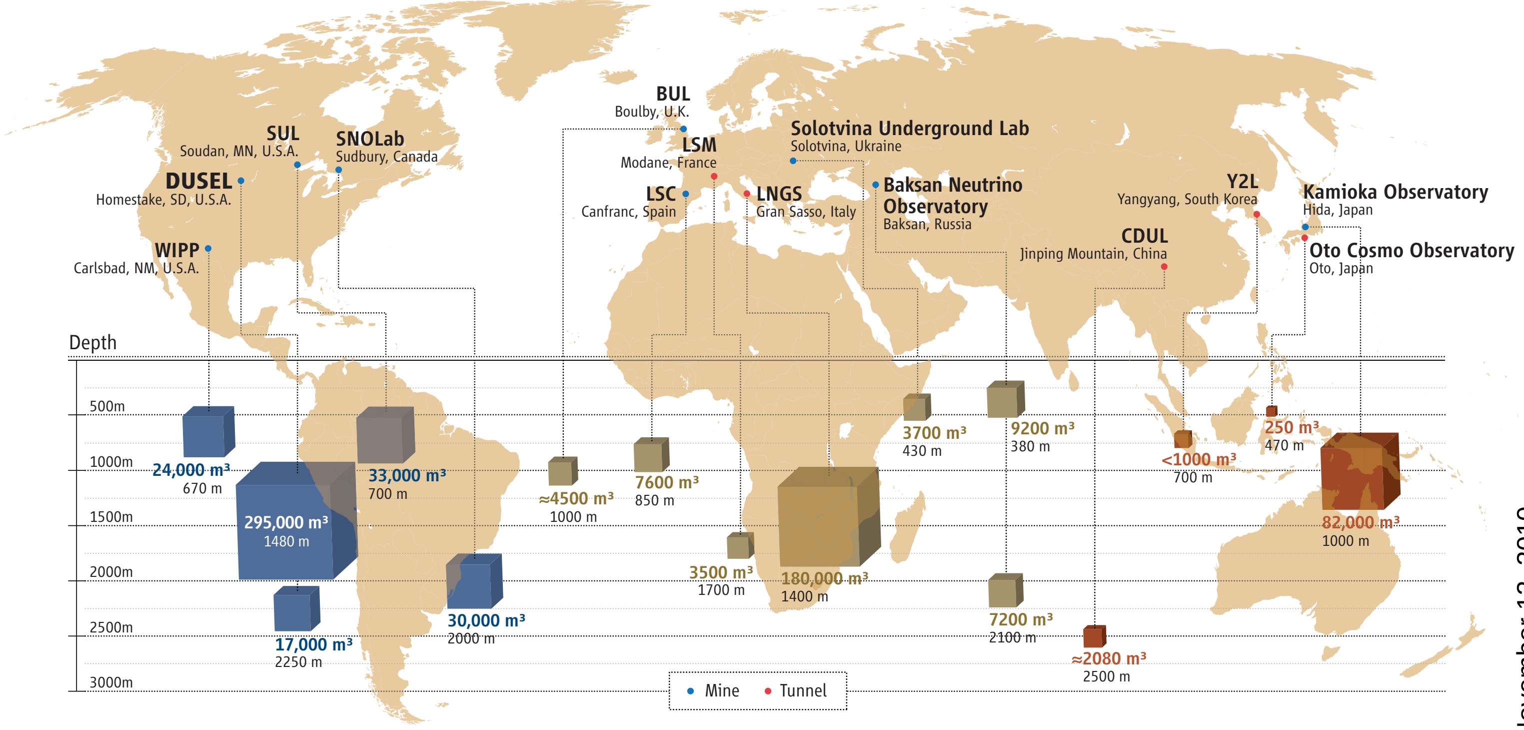


how the three types of neutrinos—electron, muon, and tau—change into one another as they whiz along. The Long-Baseline Neutrino Experiment (LBNE) would go further and look for an asymmetry between the behavior of neutrinos and antineutrinos, called charge-parity (CP) violation, that might explain why the universe contains so much more matter than antimatter. LBNE would cost between $660 million and $940 million.

In addition to detecting neutrinos from the sun or from supernovae, such a huge detector could also search for proton decay, the fourth key experiment. Theorists have developed "grand unified theories" that roll together the three forces that dominate particle interactions: electromagnetism, the strong force that binds the nucleus, and the weak force that causes beta decay. Those theories predict that the otherwise eternal proton should decay, albeit on a time scale so immensely long that physicists would have to study hundreds of thousands of tons of matter in a detector to spot a few decays.

DUSEL would also house experiments in microbiology, geoscience, and engineering. For example, Derek Elsworth, a geophysicist at Pennsylvania State University, University Park, has proposed heating a 10-meter-wide cubic volume of rock to see how heat affects stresses, chemistry, and fluid flow in it. The data could aid in, among other things, designing geothermal reservoirs. "You have these processes going on 2 or 3 kilometers down in geothermal structures, but you can never see them," Elsworth says. With DUSEL, "you're right there."

CREDIT: M. TWOMBLY/SCIENCE

Leapfrogging the competitors

All of this would occur at Homestake, the deepest mine in North America. Starting in 2014, workers would carve out two labs with a total volume of 72,000 cubic meters at a depth of 1480 meters, and a third smaller lab 2255 meters down. On the upper level they would dig at least one 50-meter-tall, 260,000-cubic-meter cavity for the LBNE detector to field neutrinos beamed from Fermi National Accelerator Laboratory (Fermilab) 1300 kilometers away in Batavia, Illinois. Construction would take about 5 years, but some experiments could move in before work is completed.

A dozen mines and tunnels around the world already house underground labs (see map). None has enjoyed more success than the Kamioka Observatory in central Japan. In 1998, physicists there used the 22,500-ton Super-Kamiokande detector to prove that muon neutrinos generated in the air change type in flight. (Fewer survived the long trip through Earth than the short trip from above, proving that some changed en route.) This year they began shooting neutrinos at the detector from a lab 295 kilometers away in Tokai to measure a key parameter describing such "neutrino oscillations," a number called θ_{13}.

Italy's Gran Sasso National Laboratory is currently the largest underground lab. Lying next to a highway tunnel under the Apennine Mountains in central Italy and boasting a volume of 180,000 cubic meters, it houses, among others, two detectors to field neutrinos from the European particle physics laboratory, CERN, near Geneva, Switzerland. SNOLab in Sudbury, Canada, is the deepest

The hole story. DUSEL would provide more lab space than any other facility in the world and would be among the deepest. Volume estimates are approximate.

big lab, with a depth of 2073 meters. Physicists there showed in 2001 that electron neutrinos from the sun also change type in transit.

But even though they have large labs, physicists in Europe and Asia say DUSEL would propel the United States to the lead in underground science. "Japan is doing really well, but I am worried that the U.S. will pull ahead of us," says Masayuki Nakahata of the University of Tokyo. In fact, overseas researchers are planning bigger labs that resemble DUSEL. But they have not yet found sites for them.

In Europe, physicists hope to build a lab with a neutrino detector weighing as much as 440,000 tons to receive a beam from CERN. They are studying seven possible sites, ranging from Canfranc, Spain, to Pyhäsalmi, Finland, says Andre Rubbia of the Swiss Federal Institute of Technology Zurich. In Japan, physicists want to build a huge lab either 20 kilometers south of Kamioka or on the island of Okinoshima, 658 kilometers west of Tokai. The site decision may have to wait 2 or 3 years for measurements of θ_{13}, says Takashi Kobayashi of Japan's accelerator lab KEK in Tsukuba. That's because CP violation can exist among neutrinos only if θ_{13} is not zero.

Experiments in existing labs could discover dark matter or neutrinoless double beta decay before those planned for DUSEL. But that would only spur more experiments requiring more lab space, physicists say.

Some say that relatively shallow Kamioka and Gran Sasso may soon be inadequate for newer experiments requiring even lower background radiation. Munich's von Feilitzsch works on a detector called Borexino in Gran Sasso that detects low-energy neutrinos from the sun. "For this physics, Gran Sasso is not deep enough," he says. "It's done its job."

Worries closer to home

Although DUSEL may have non-U.S. researchers looking over their shoulders, U.S. scientists are afraid that cost considerations may force designers to pare down their plans in ways that would dull the lab's competitive edge. In particular, they worry that the lab's lower 2250-meter level, which is currently flooded, will be smaller than they want and may not be available right away. A 2007 "conceptual design report" envisioned three halls at that lower level with a total volume of 4500 cubic meters; current plans call for a single hall of 1700 cubic meters.

Those changes could cause some scientists to make do with existing facilities. "It's possible that by the time DUSEL is built the people who need easy access will have gone to Gran Sasso and the people who need to go deep will have gone to SNOLab and there will be no customers," says Giorgio Gratta, a physicist at Stanford University in Palo Alto, California, who is working on neutrinoless double beta decay.

Others say that the changes simply reflect a determination to build only what's necessary. Design-team leader Lesko notes that when the conceptual design report was written in 2007, designers had received no specific proposals for experiments to go into DUSEL. Now, they have more than a dozen to which they're tailoring their plans.

At the same time, some scientists fret over the balance between spending on infrastructure and funding for experiments. When Homestake was selected in 2007 over seven other potential sites, NSF officials estimated it would cost $500 million, with half of the money going to key experiments other than LBNE. That pot of money would make DUSEL the obvious place to propose a dark-matter experiment, says Blas Cabrera, a physicist at Stanford.

However, the balance between infrastructure and science has shifted, so that grant money now accounts for $175 million of the $875 million total. In part, retrofitting the old mine has proved more expensive than originally estimated. Also, Lesko says, the original cost breakdown did not include the $123 million NSF would now contribute to LBNE, to which DOE gave the initial nod earlier this year.

Nevertheless, NSF officials say that anything less than a broad science program and four key experiments would be hard to sell to the science board. "If it turned out that only one of these experiments could be done within the cost envelope, then obviously [getting approval] would be difficult," says Edward Seidel, who leads NSF's mathematical and physical sciences directorate.

Observers say concern over the balance of science and infrastructure may have led to a glitch in the president's 2011 budget request for NSF that threatened DUSEL. NSF initially asked for $38 million for DUSEL design work, but the White House Office of Management and Budget (OMB) cut that amount in half. NSF and OMB officials now seem to have agreed to support the project until NSB can evaluate it, although parties to the negotiations declined to discuss the details.

The 2011 budget is still pending before Congress, but Lesko says the design team has submitted a proposal to NSF to fund the "scope of work" to be completed in 2011. NSB consultant Barish says he's "absolutely sure" the board will approve the additional money.

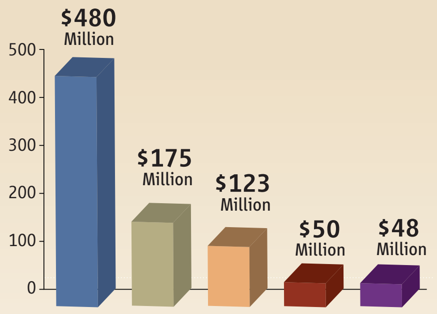
Some researchers also worry about the partnership between NSF and DOE. DOE's interest in DUSEL should bolster the project, especially as LBNE anchors DOE's plans for Fermilab's future. But the two agencies have a mixed record on joint projects. One glaring failure, scientists say, was a pair of NSF experiments known as Rare Symmetry Violating Processes (RSVP) that in 2000 was approved to run at DOE's Brookhaven National Laboratory in Upton, New York. Uncertainties over whether DOE would run an accelerator long enough to complete the experiments or make NSF pay for more time led NSF to cancel the project in 2005. Researchers say the agencies didn't discuss the problem until after RSVP was approved.

To avoid such snags with DUSEL, officials from DOE and NSF are hammering out an arrangement in which one agency would take the lead for an experiment but the other would also contribute. For example, DOE would lead on neutrinoless double beta decay, and NSF would spearhead dark-matter searches. The approach would give both agencies a stake in every experiment. "It's like any marriage," says Fermilab's Robert Tschirhart. "If you have a common goal, you'll work it out."

Of course, most marriages begin with a wedding. And DUSEL scientists are hoping that it won't be too long until the science board responds to their proposal with "I do."

–ADRIAN CHO

DISSECTING DUSEL's COST



Infrastructure: excavating cavities, renovating lifts, running power lines, etc.

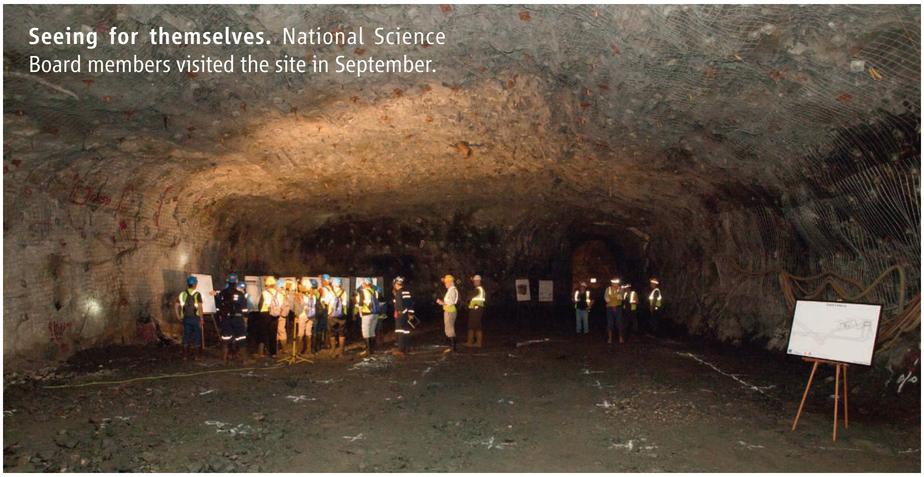
Experiments: funds to be competitively awarded

Neutrino detector: NSF share; DOE to contribute $537 million to $817 million

Surface campus: aboveground buildings for preparing experiments

Project office: office buildings for managing project

Price list. Funding for experiments, including a huge neutrino detector, accounts for 34% of DUSEL's cost.



Seeing for themselves. National Science Board members visited the site in September.

CREDITS (TOP TO BOTTOM): KEVIN LESKO (SOURCE); BILL HARLAN/SANFORD UNDERGROUND LABORATORY

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