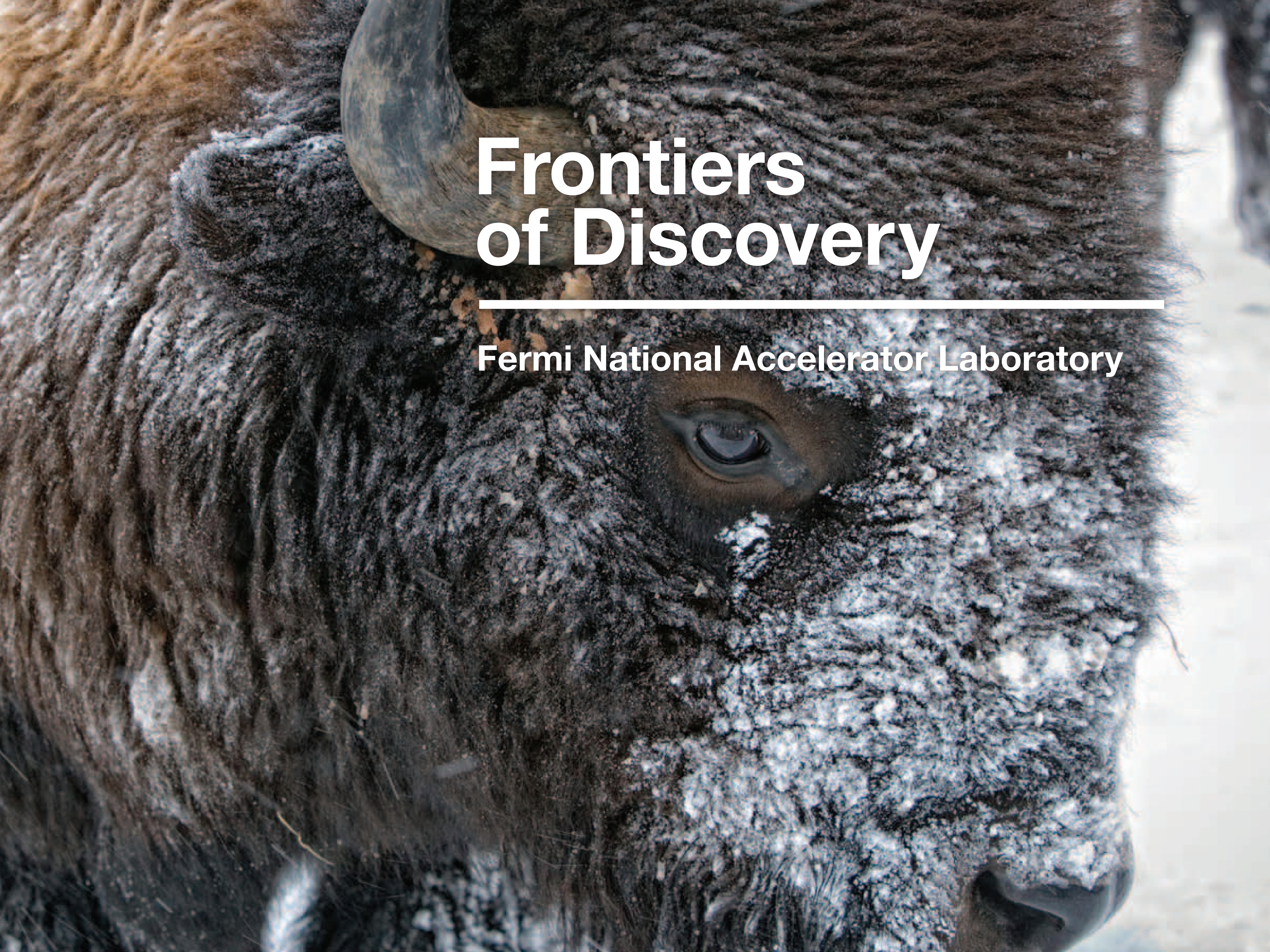

Frontiers of Discovery

Fermi National Accelerator Laboratory

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Robert Wilson, Fermilab's founding director, introduced the first American bison, a bull and four cows, to the Fermilab site in 1969. The bison symbolize the laboratory's historic connection to the great Midwestern prairie and Fermilab's role at the frontiers of research in particle physics.

Frontiers of discovery

What is the nature of the universe? What are matter and energy, space and time? To discover what the universe is made of and how it works is the challenge of particle physics. At the Department of Energy's Fermi National Accelerator Laboratory, thousands of scientists from universities and laboratories across the country and around the world collaborate on experiments at the frontiers of discovery. From their work in the science and technology of particle physics come a profound understanding of the physics of the universe and many practical benefits to society.

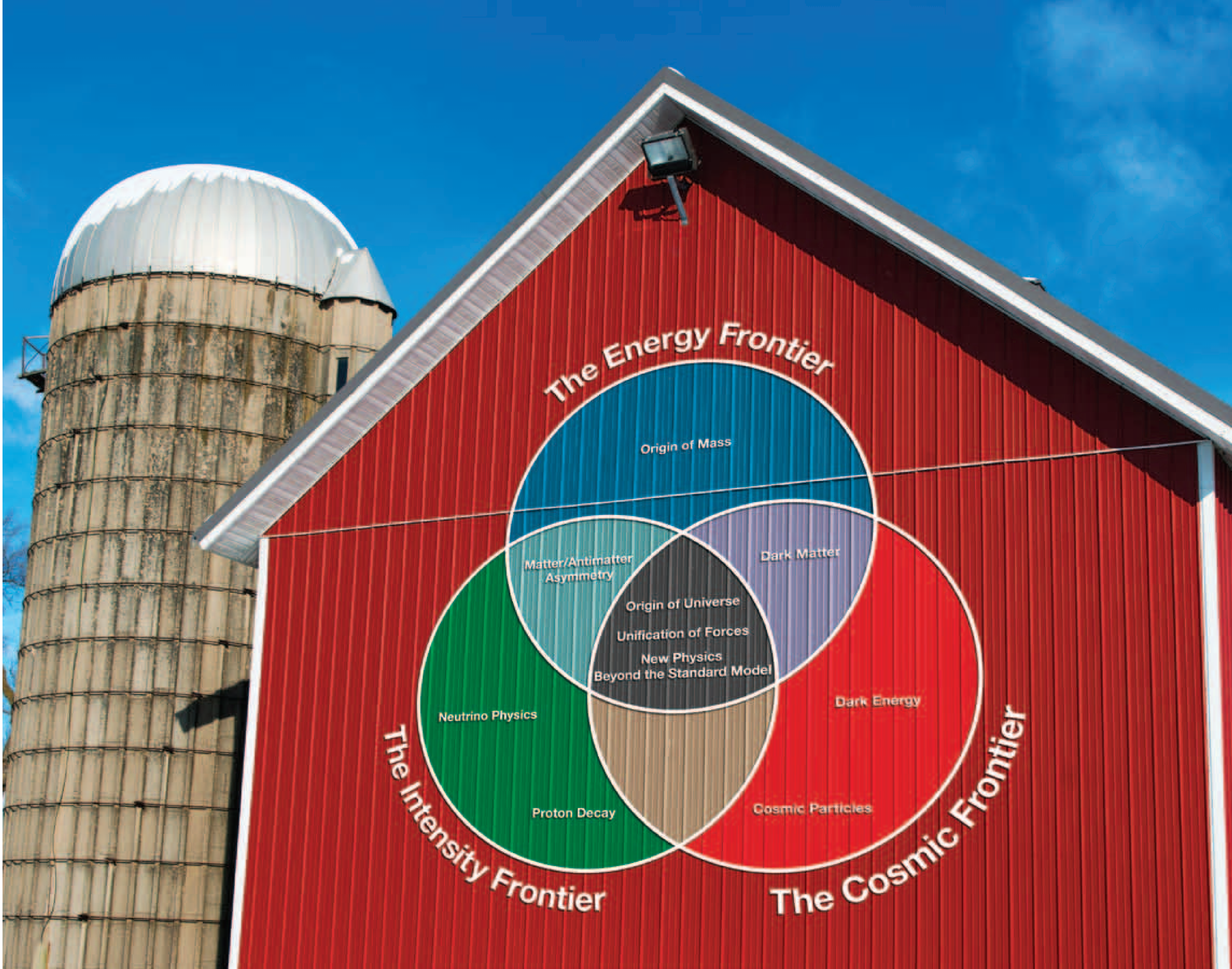
Wilson Hall, inspired by a Gothic cathedral in Beauvais, France, is the focal point for administrative and scientific activity at Fermilab.

Questions for the universe

At Fermilab, current and future particle physics experiments give scientists the capability to address a well-defined set of questions about the basic physical laws that govern the universe. These questions define the path for particle physics in the 21st century.

- Are there undiscovered principles of nature: new symmetries, new physical laws?
- How can we solve the mystery of dark energy?
- Are there extra dimensions of space?
- Do all the forces become one?
- Why are there so many kinds of particles?
- What is dark matter? How can we make it?
- What are neutrinos telling us?
- How did the universe come to be?
- What happened to the antimatter?

Questions from the Quantum Universe *report, DOE/NSF High Energy Physics Advisory Panel*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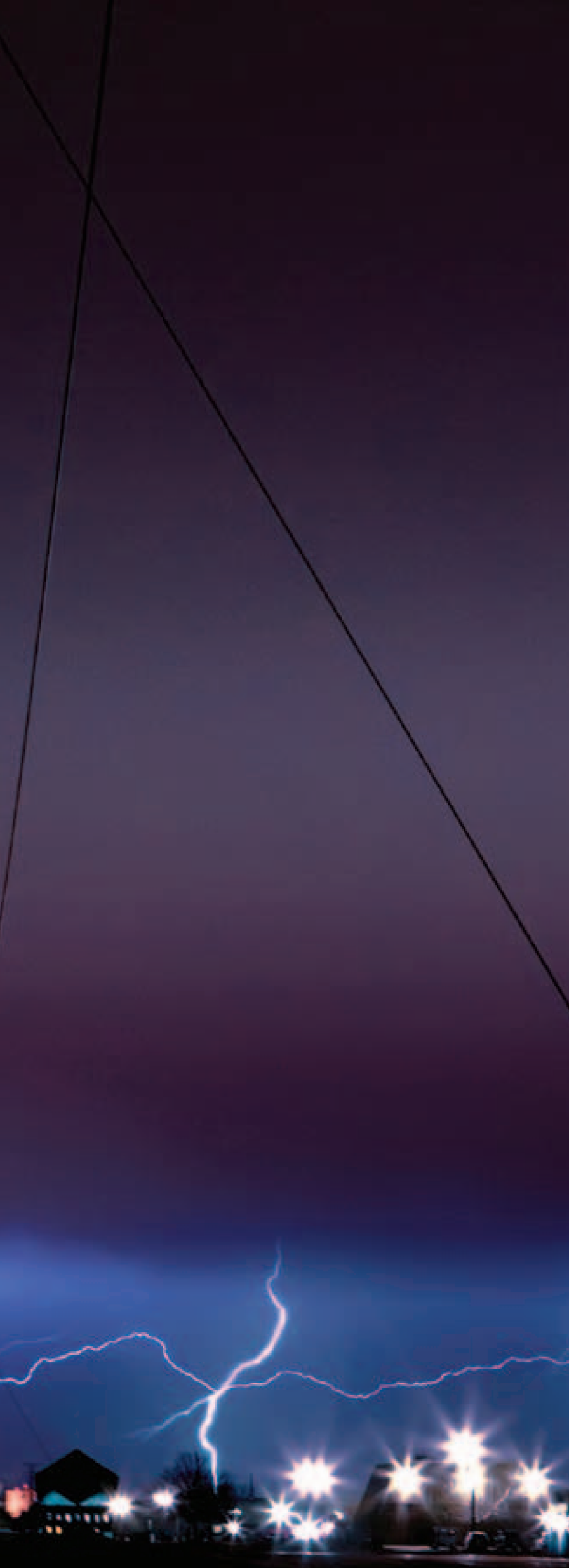
Three frontiers of particle physics

Scientists have identified three frontiers of scientific opportunity for the field of particle physics: the Energy Frontier, the Intensity Frontier and the Cosmic Frontier. Answers to the most challenging questions about the fundamental physics of the universe will come from combining the most powerful insights and discoveries at each of the three frontiers. Fermilab's scientific program pushes forward with world-leading research at all three interrelated frontiers.

A thunderstorm crackles over Fermilab, highlighting power poles resembling the Greek letter “pi,” a Robert Wilson design from the laboratory’s early days. *Photo: Martin Murphy, Fermilab*



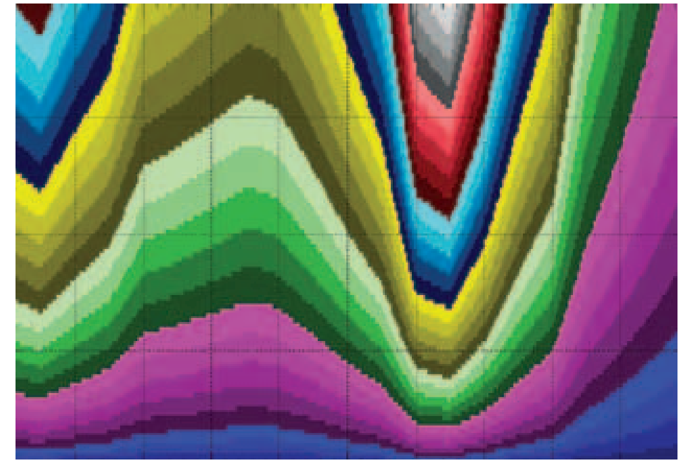
Energy Frontier

Particle accelerators at the Energy Frontier produce high-energy collisions that signal new phenomena, from the origin of mass to the nature of dark matter and extra dimensions of space. Fermilab's Tevatron experiments, CDF and DZero, continue to set new records in a physics program of exciting discoveries and ultra-precise measurements, involving more than 1,000 scientists from 150 institutions in some 30 states and 30 countries. Fermilab is the U.S. host laboratory for the CMS experiment at the Large Hadron Collider at CERN, in Geneva, Switzerland. Some 1,700 U.S. scientists from 87 universities and seven national laboratories carryout research at the LHC, the world's new energy-frontier accelerator.

CDF

Using the Tevatron particle collider, the 600-member CDF collaboration explores the subatomic world to search for the origin of mass, extra dimensions of space, and new particles that could explain the nature of our universe. On average, the collaboration publishes a scientific paper every six days.

Right: Data produced by particle collisions at the CDF experiment helps physicists on the hunt for the elusive Higgs boson. The data provides information on the mass of the Higgs particle.



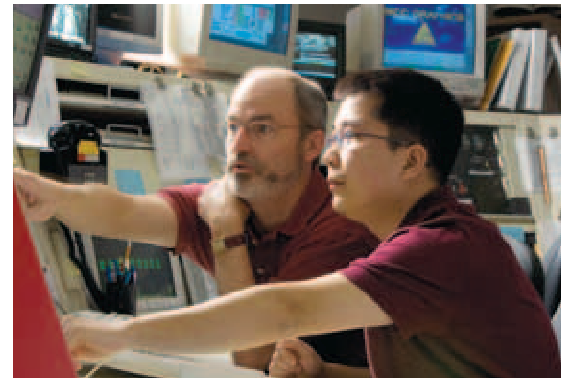
Right: The silicon-based subdetector at the heart of the 6,000-ton CDF experiment takes snapshots of the particles that emerge when protons and antiprotons collide.

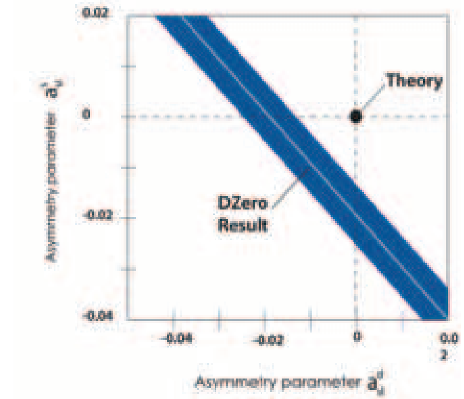
Above: At the control room, members of the CDF collaboration from countries all around the world observe data from particle collisions 24 hours a day, seven days a week.

Above: The energy, momentum, and electric charges of subatomic particles are measured by subdetectors wrapped around DZero's collision area like the layers of an onion.

Below: Physicists monitor data delivered by approximately one million readout channels of the DZero detector. The members of the DZero collaboration count on each others' strengths as they search for the Higgs boson.

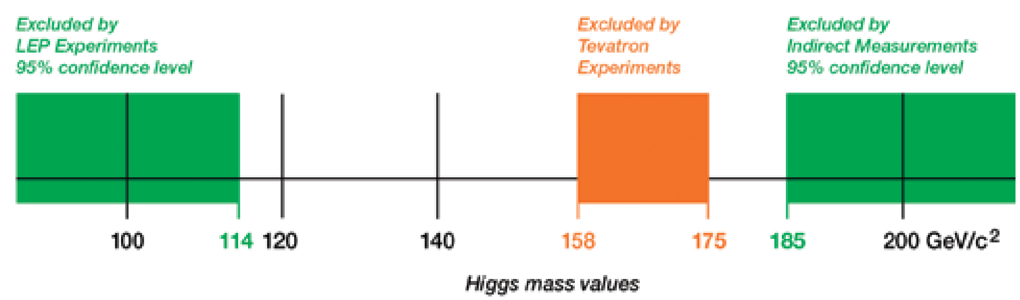
Below, right: DZero data provides an intriguing look at new and unexplained realms of physics. Results from the detector provide clues to the universe's origins.





Search for the Higgs Particle

Status as of July 2010 **95% confidence level**



Above: The experiments at the Tevatron collider have already provided significant contributions to the Higgs boson search.

DZero

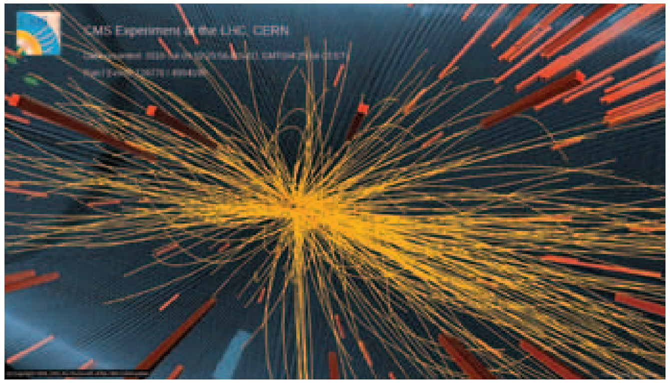
The international DZero collaboration comprises approximately 550 physicists from 90 institutions in 18 countries. Publishing about 50 scientific papers per year, the collaboration pushes the boundaries of knowledge and explores the nature of matter, energy, space and time. Every year, about three dozen students complete Ph.D. theses with new results from DZero data.

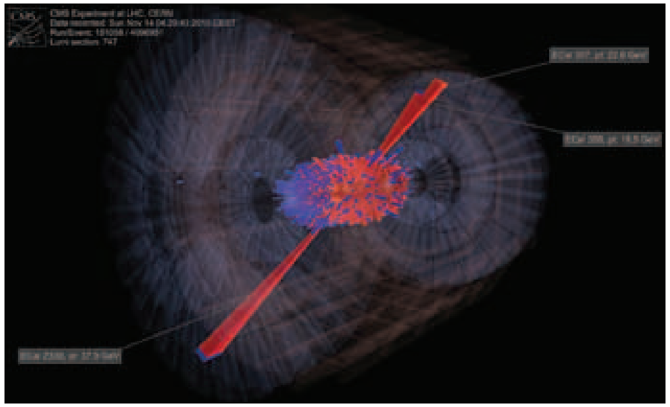
CMS

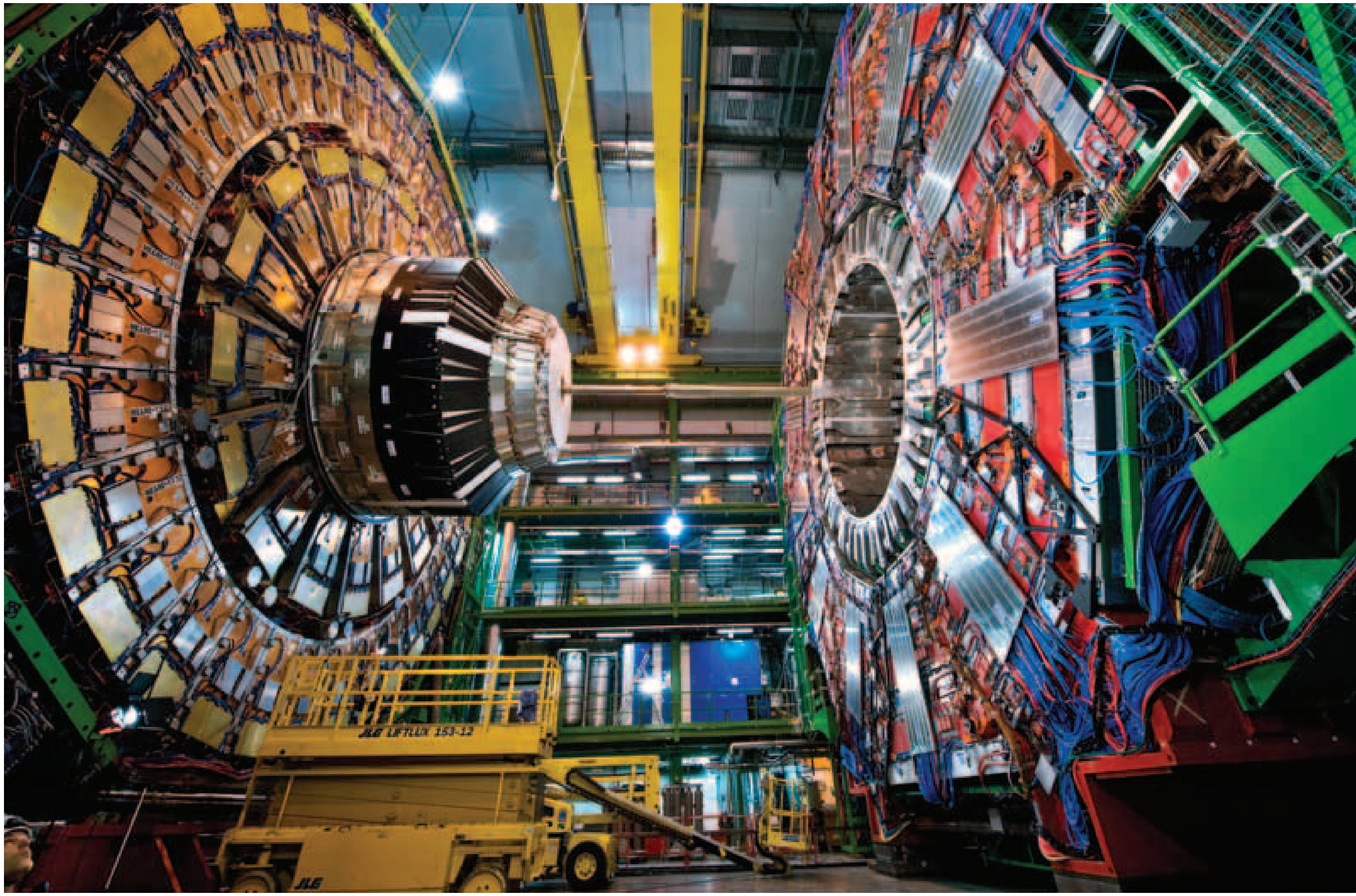
Recording the tiniest components of the universe requires the world's largest scientific instruments. The 13,800-ton CMS experiment is one of four large detectors at the Large Hadron Collider at CERN, the European particle physics laboratory located in Geneva, Switzerland. More than 1,000 U.S. scientists belong to the international CMS collaboration, including about 200 students.

Right: Fermilab physicist Harry Cheung monitors the CMS detector while on shift at the experiment's control room in Cessy, France.

Below: The CMS detector, shown here in its home 330 feet underground, consists of 15 huge slices that can be pushed apart for easy maintenance of electronics and other components.
Photo courtesy of CERN







Top: From March to October of 2010, the CMS detector recorded the results from the world's highest-energy collisions of protons.

Bottom: CMS scientists use collisions of lead nuclei in the Large Hadron Collider to explore the conditions that existed in the universe mere microseconds after the Big Bang.
Images courtesy of CERN

Above: Seven days a week from noon to midnight, U.S. scientists take shifts in the LHC Remote Operations Center at Fermilab.

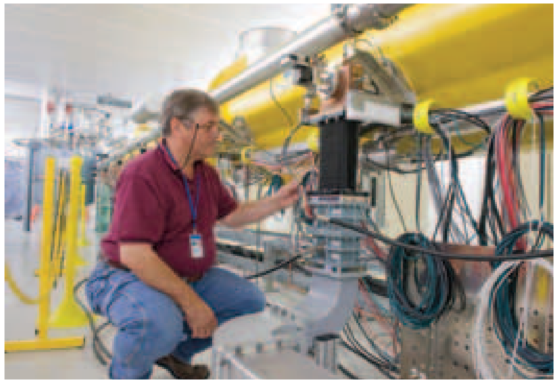
LHC Remote Operations

Fermilab's Remote Operations Center keeps U.S. scientists closely connected to the Large Hadron Collider in Europe. From this state-of-the-art facility, U.S. physicists help operate the CMS experiment and monitor its data acquisition. CMS collaborators from universities across the U.S. come to Fermilab and use the center to work CMS night shifts during daytime hours.

SRF Technology

Superconducting radio-frequency cavities are the technology of choice for the next generation of accelerators. They provide a highly efficient way to accelerate particles. Fermilab is partnering with U.S. industry and other research institutions to develop and build SRF cavities in cost-effective ways. The technology has potential applications in medicine, nuclear energy and materials science.

Below: Many employees worked on the development of Fermilab's Cryomodule 1, which comprises eight superconducting radio-frequency cavities. Researchers will use CM1 to test the SRF cavities.

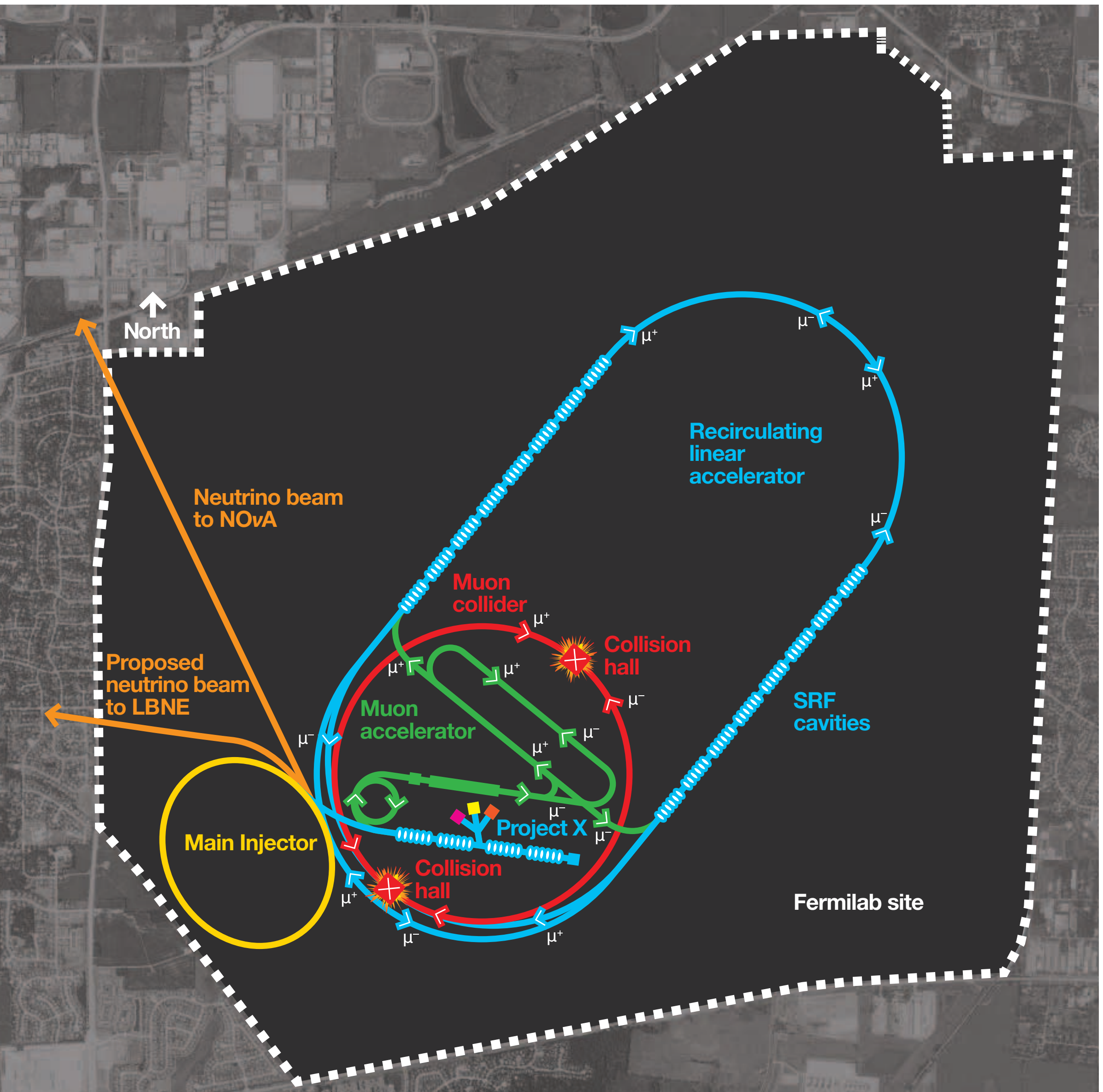


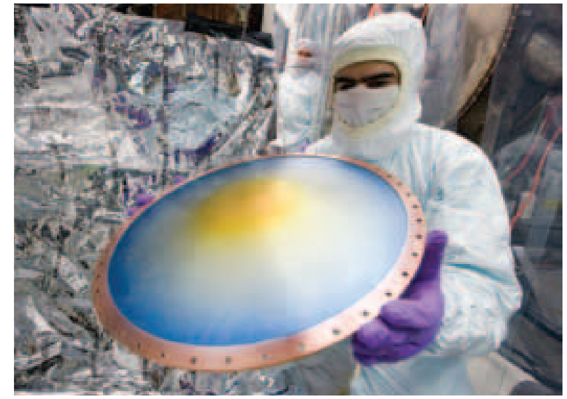
Above: Hundreds of cables coming out of the cryomodule will feed data from the SRF cavities to computers.

Right: With every test on an SRF cavity, scientists gain a better understanding of its behavior. This nine-cell cavity is being put through its paces on a vertical test stand.

Muon Collider

An international collaboration of scientists is advancing plans for a new, innovative type of energy-frontier machine that would accelerate muons, the short-lived cousins of electrons. A muon collider would be much smaller than the Large Hadron Collider and fit on the Fermilab site, yet it would provide access to physics beyond the LHC. Worldwide about 200 scientists are working on the R&D for this machine.





Far left: The proposed muon collider layout. Its collider ring (in red) is only six kilometers in circumference, about one-fourth the length of the Large Hadron Collider ring.

Left: Vacuum chamber parts must be kept immaculately clean. Even the smallest speck of dust will disrupt their successful operation.

Below: A superconducting radio-frequency cavity from the viewpoint of a positron or electron beam. The cavity kicks the beams to higher energies, preparing them for collision.

ILC

The proposed International Linear Collider is a 20-mile-long machine that would accelerate electrons and positrons to world-record energies and smash them together. The ILC would extend the discovery potential of the Large Hadron Collider, the proton-proton collider at the European laboratory CERN. With LHC discoveries pointing the way, the ILC would decode the nature of the new physics territory.


Sunrise over the Fermilab site.

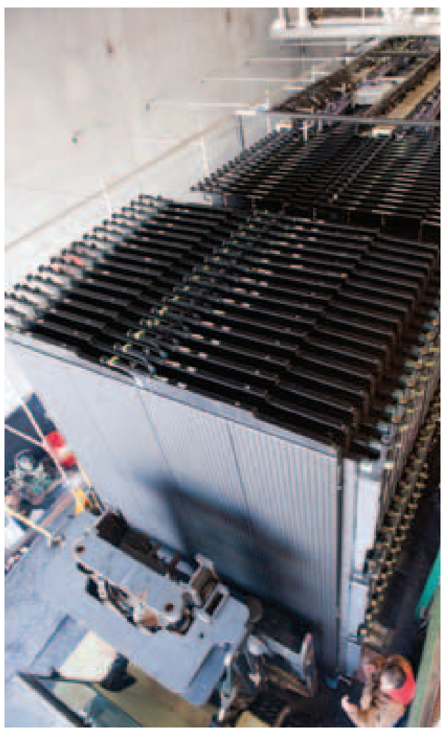
Intensity Frontier

Scientists use intense beams from particle accelerators for intensity-frontier experiments that explore neutrino interactions and ultra-rare processes in nature. Neutrino discoveries are central to understanding key questions of 21st-century physics: How did the universe come to be? What happened to the antimatter? Do all the forces unify? Precise observations of nature's rarest processes open a doorway to realms of ultra-high energies beyond those that any particle accelerator could ever directly achieve, to the region where physicists believe all of nature's forces become one.

NOvA

Scientists suspect that neutrinos played a major role in the evolution of the universe, despite the fact that they account for less than 1 percent of the mass of the universe. The NOvA experiment will shed light on the strange properties of neutrinos, especially the mysterious transition of muon neutrinos into electron neutrinos—a process that most physicists considered science fiction less than 20 years ago.

Left: The NOvA experiment will use a neutrino beam that will travel from Fermilab to northern Minnesota. A building under construction in Ash River, Minn., will house the 15,000-ton NOvA neutrino detector.
Photo: Steve Conley, Burns and McDonnell



Above: NOvA will use liquid scintillator contained in PVC cells to detect neutrino interactions. In December 2010, a prototype detector at Fermilab detected the first tracks of charged particles produced in a neutrino interaction.

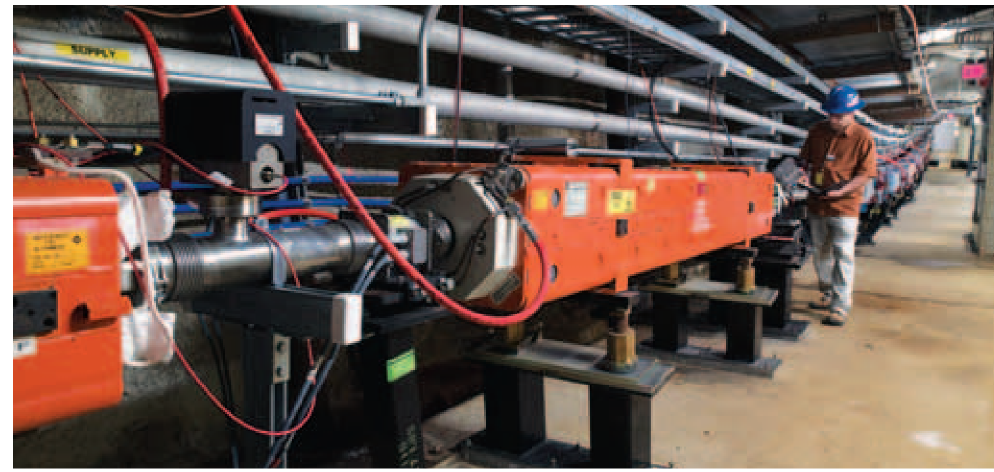
Right: The 220-foot-long NOvA neutrino detector will have PVC structures that are about 50 feet high and 50 feet wide. Engineers have developed a hydraulic platform to pivot the structures from horizontal to vertical position.

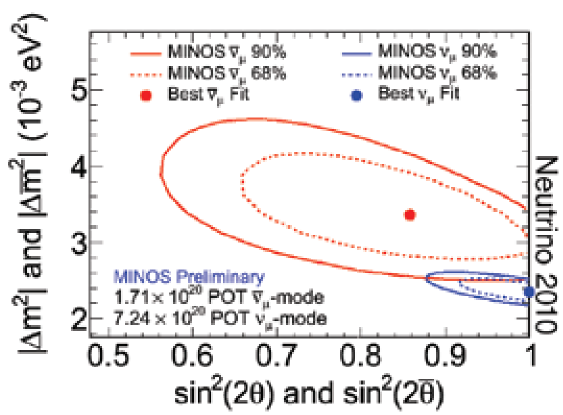
Above: The MINOS near detector, located 350-feet underground on the Fermilab site, checks the purity of a muon neutrino beam as it leaves the Fermilab site.

MINOS

Neutrinos are among the most abundant and least understood particles in the universe. There are three distinct types of neutrinos. Strangely, each type of neutrino can morph into the other types, a process known as neutrino oscillation. The MINOS experiment looks for the oscillation of muon neutrinos as they travel from Fermilab 450 miles through the earth to an underground detector in Soudan, Minn.

Below: At Fermilab, scientists use a 300-kilowatt proton beam to create the world's most intense neutrino beam. Further upgrades will increase the beam power to 700 kilowatts.





Above: The MINOS experiment has made the world's most precise measurement of the difference in mass between different antineutrino types. The result differs from the corresponding neutrino result by approximately 40 percent. If confirmed, this would be the first observation of a fundamental difference between neutrinos and antineutrinos that current theory could not explain. MINOS physicists need more data and analysis to know for certain if the variance is real.

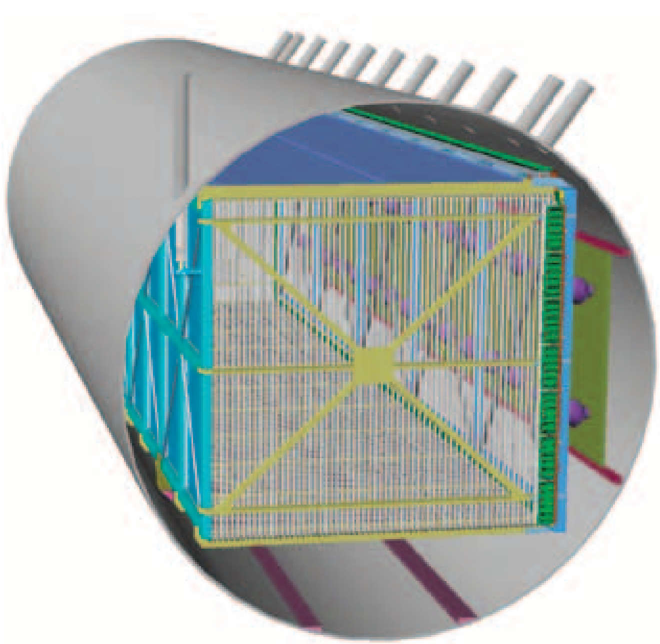
MicroBooNE

Scientists working on the proposed MicroBooNE experiment plan to build the first U.S. experiment based on an innovative neutrino detection technique that uses liquid argon. The experiment has received second-stage approval by the Department of Energy. Physicists hope the project will teach them how to build multi-kiloton, liquid-argon neutrino detectors, a project no other group has attempted.

MiniBooNE

More than 800 tons of mineral oil fill the detector of the MiniBooNE neutrino experiment. Scientists use the detector to search for unexpected neutrino interactions that would contradict the widely accepted theory of neutrino oscillation, such as the decay of neutrinos or the existence of a fourth type of neutrino. Scientists will report their final results after the experiment stops taking data in 2012.

Below: The 100-ton MicroBooNE neutrino detector is a step toward the construction of even larger neutrino detectors that will use liquid-argon technology to observe neutrino interactions.



Right: Georgia Karagiorgi, shown here in the MiniBooNE counting room, is one of 54 scientists working on the MiniBooNE experiment. In 2010, the collaboration announced antineutrino oscillation results that suggest that neutrinos and antineutrinos behave differently.

Left: The 95 members of the MINERvA collaboration, led by cospokespersons Debbie Harris (pictured) and Kevin McFarland, finished the construction of their neutrino detector in March 2010.

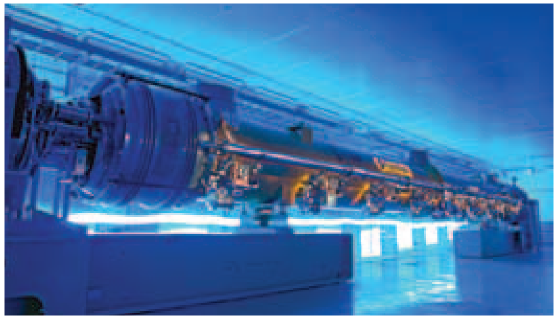
Above: The MINERvA detector is located in an experimental hall 350 feet underground. Scientists can install various targets to investigate how neutrinos interact with different types of nuclei.

MINERvA

To better understand the structure of individual nucleons — a largely uncharted realm — scientists have constructed the MINERvA experiment at Fermilab. A high-intensity neutrino beam, fired point-blank at a 6-ton detector, reveals the reaction of neutrinos with different materials: carbon, iron and lead. The MINERvA results will help fine-tune neutrino oscillation measurements by other experiments.

SRF Test Accelerator

To advance plans for future high-intensity proton accelerators, Fermilab is constructing a superconducting test accelerator with support from the American Recovery and Reinvestment Act. The test facility will be the most advanced R&D center for SRF technology in the United States. Fermilab is working with U.S. industry to boost America's capability in manufacturing SRF cavities.



Left: Composed of eight 9-cell superconducting radio-frequency cavities arranged end to end and nestled in a long tube to keep them cooled to temperatures near absolute zero, the cryo-module at Fermilab is the only one of its kind in the United States.

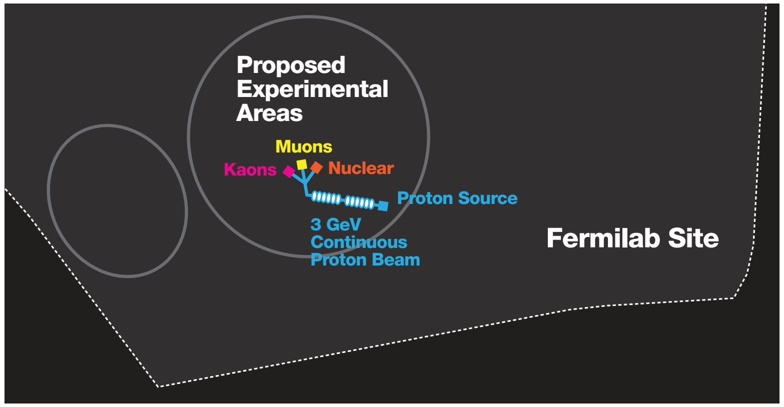
Above: Over the past four years, U.S. industry has delivered 18 superconducting radio-frequency cavities to Fermilab.

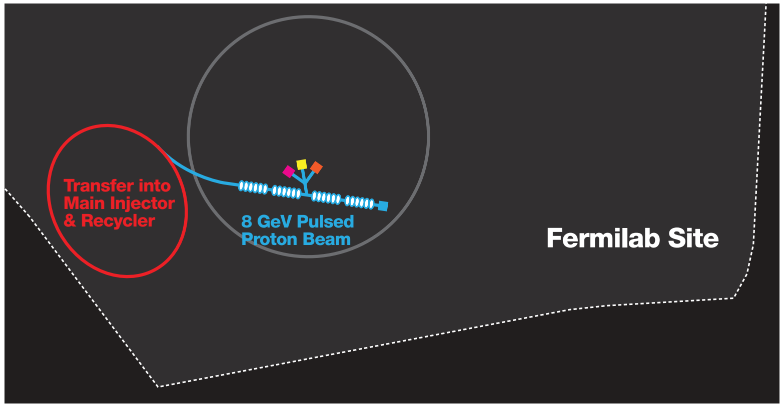
Right: A 202-foot extension to the old New Muon Laboratory will allow Fermilab to build a test accel-erator that uses superconducting radio-frequency cavities, the technology of choice for future particle accelerators.

Above: The proposed Project X would provide the best neutrino, kaon and muon beams. The new facility would use superconducting radio-frequency cavities to accelerate protons for numerous experiments, making it the best in the world for experiments at the Intensity Frontier.

Project X

Fermilab is developing plans for an accelerator that would revolutionize research at the Intensity Frontier: Project X. The high-tech proton accelerator, less than a mile long, would provide high-intensity beams for a range of intensity-frontier experiments. The R&D for Project X would pave the way for a future machine at the Energy Frontier and for many other applications.





Top: A high-intensity, low-energy proton beam would provide particles for kaon, muon and nuclear physics experiments. Project X could also provide the basis for a future muon collider.

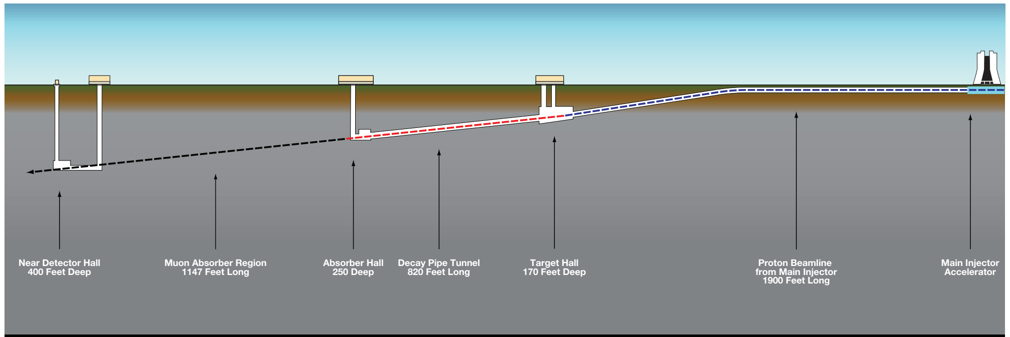
Bottom: Project X could accelerate protons to 8 billion electron volts. These particles would travel to the existing Main Injector accelerator, replacing its less powerful 35-year-old proton source. The Main Injector provides particle beams for Fermilab's neutrino experiments.

LBNE

Physicists wonder whether neutrinos tipped the balance of matter and antimatter that existed after the Big Bang, sparing some matter from annihilation. Experiments have shown that quarks can cause such an effect, but it is too small to explain the makeup of our universe. Scientists now are proposing the LBNE neutrino experiment to find out whether neutrinos are the reason we exist.

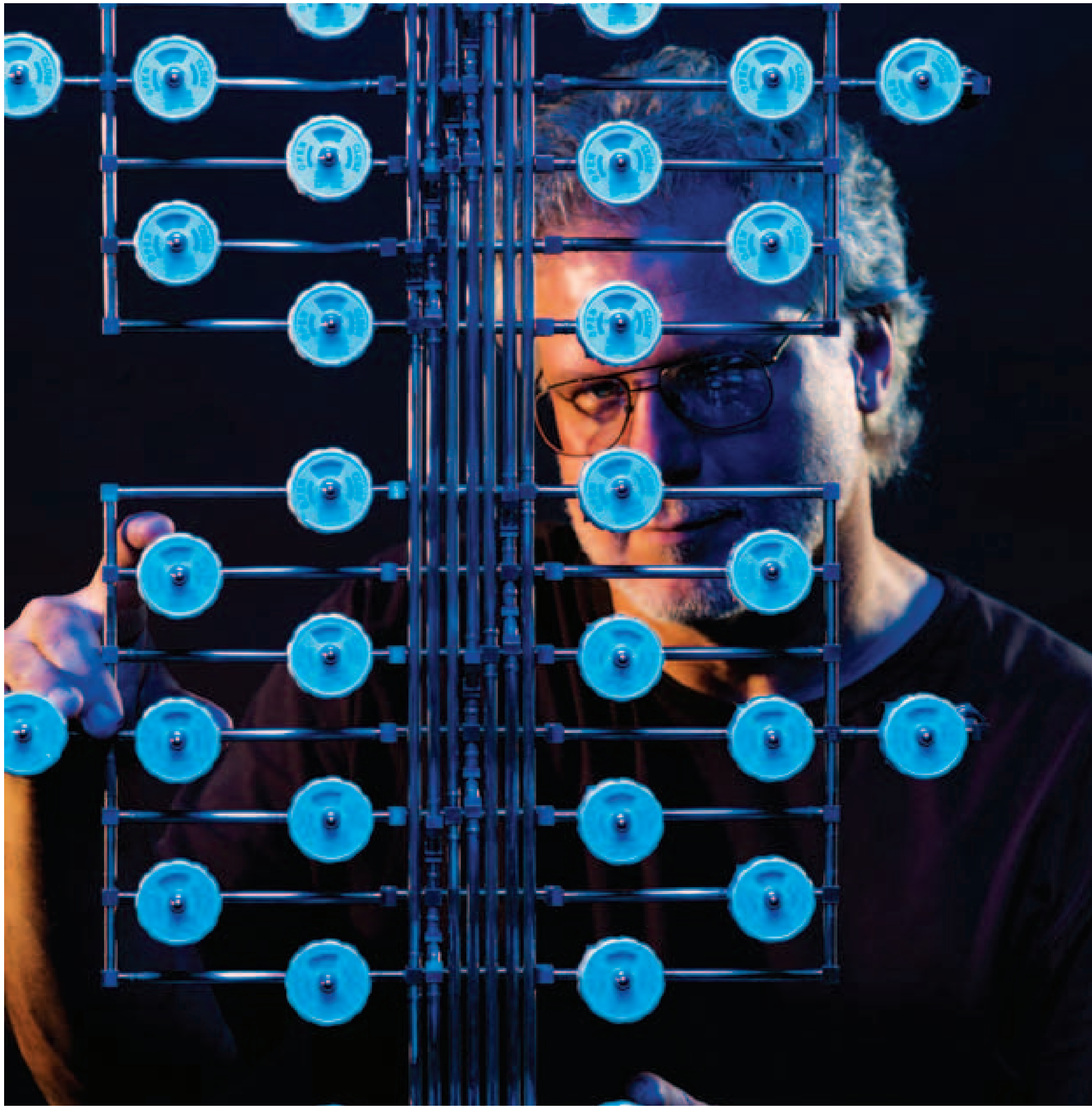
Right: The LBNE collaboration has grown to more than 280 members from 54 institutions. Scientists work together with engineers and project specialists to keep the project moving forward.

Below: Collaborators on the LBNE project work together to create a functional and frugal design. Project control specialists work with scientists to evaluate the performance and cost of LBNE technology.



Long Baseline Neutrino Experiment

Right: Members of the local community are shown where the LBNE tunnels and beamline may be placed. The beam will travel 800 miles through the earth to a mine in South Dakota.



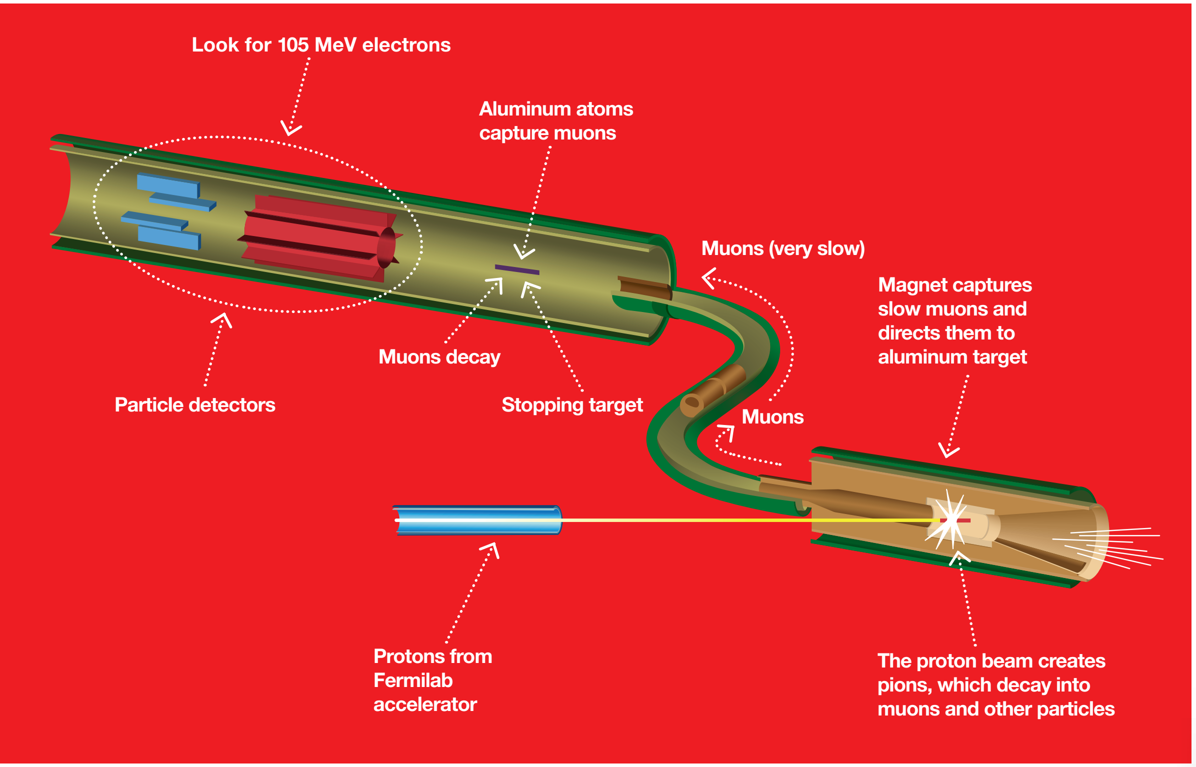
Upper right: A gas manifold used to monitor the purity of Fermilab's liquid argon. Liquid argon is an excellent target material for neutrino and dark-matter experiments.

Liquid Argon

Particle tracks in ultra-pure liquid argon are leading the way to next-generation detectors for neutrino and dark-matter experiments. Research and development at Fermilab focuses on optimizing liquid argon's unique scintillation and ionization properties to create beautiful images of neutrino interactions and clean signals of dark matter.

Mu2e

Scientists plan to use Fermilab's high-intensity particle beams to search for rare subatomic processes, such as the conversion of a muon into its lighter cousin the electron, a process predicted by theory but never yet observed. The proposed Mu2e experiment, which has received first-stage approval, could find indirect evidence for new particles and forces far beyond the reach of the LHC.



Above: The Mu2e particle detector is embedded in a series of magnets that create a low-energy beam of muons and steer it into an aluminum target. Scientists plan to break ground at Fermilab in Batavia, Illinois, in 2013 and begin taking data four years later.

Right: Mu2e is trying to catch a glimpse of an incredibly rare phenomenon: a muon—the electron's fatter cousin—turning into its more slender and well-known relative, the electron.

From left: Jim Miller, Ron Ray and Robert Bernstein think the Mu2e experiment may answer one of the fundamental riddles of particle physics.


More than 95 percent of the universe consists of unknown dark matter and dark energy. Research at the Cosmic Frontier will shed light on this dark side of the universe.

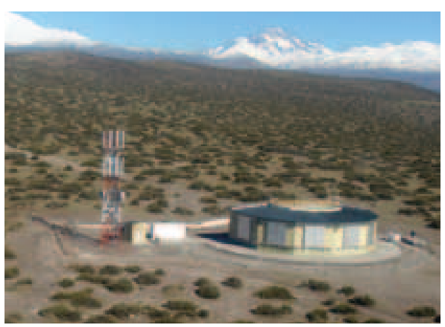
Cosmic Frontier

At the Cosmic Frontier, astrophysicists use the cosmos as a laboratory to investigate the fundamental laws of physics from a perspective that complements experiments at particle accelerators. Thus far, astrophysical observations, including the bending of light known as gravitational lensing and the properties of supernovae, reveal a universe consisting mostly of dark matter and dark energy. A combination of underground experiments and telescopes, both ground- and space-based, will explore these mysterious dark phenomena that constitute 95 percent of the universe.

Pierre Auger

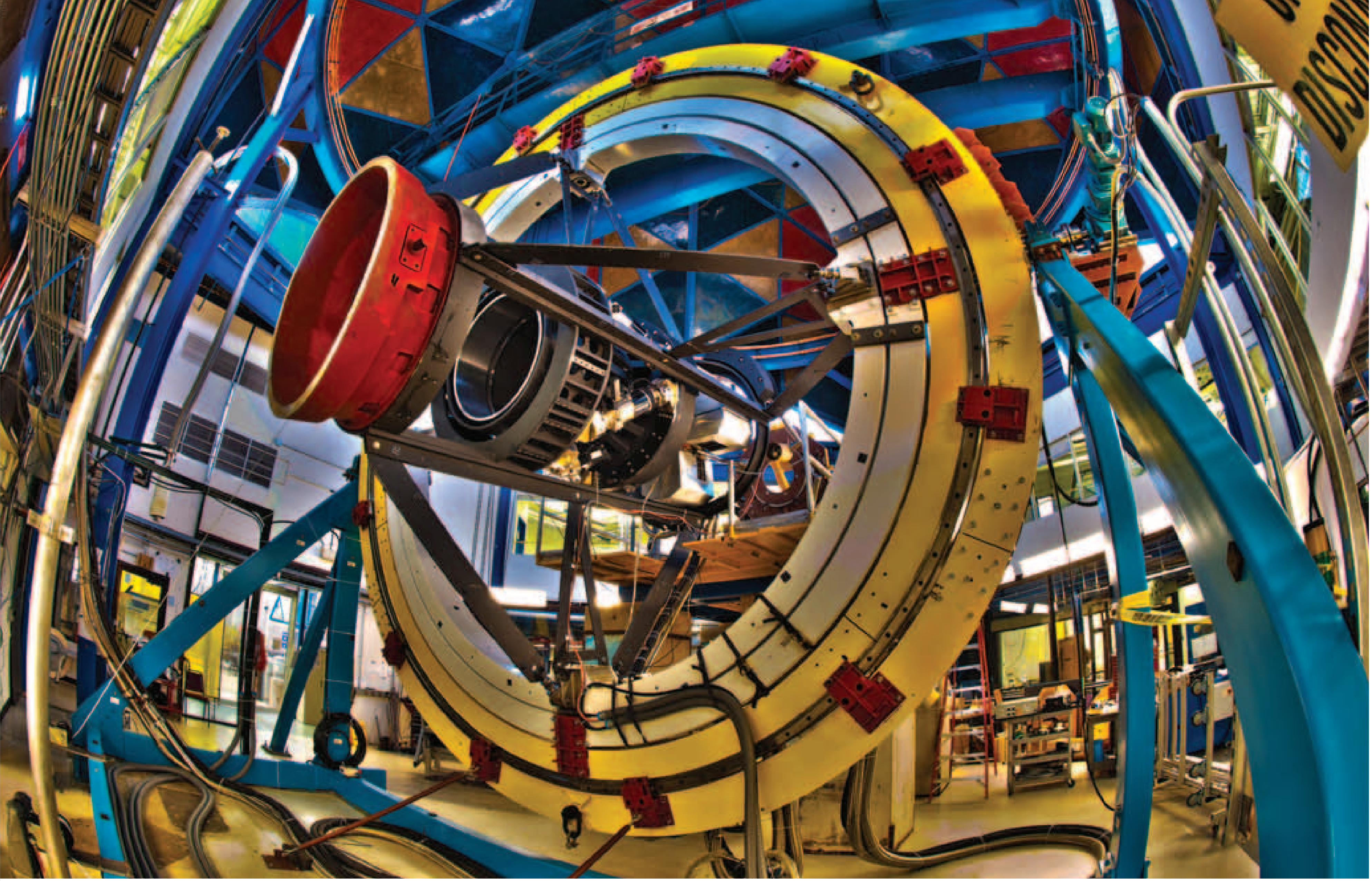
Are supermassive black holes the origin of the most powerful cosmic rays? An international collaboration of scientists at the Pierre Auger Observatory in Argentina may provide the answer. Covering an area three times the size of Los Angeles, the observatory records the particle showers hitting the Earth's surface. Seventeen countries contributed to the observatory's construction.

Below: A fluorescence detector building at dusk with a rainbow on the horizon. Four fluorescence detectors at the observatory house 24 telescopes.
Photos courtesy of Pierre Auger Observatory and Greg Snow, Pierre Auger Observatory



Top: One of 1,600 water tanks used in cosmic-ray detection. Each detector operates on only 20 watts of solar power.

Bottom: Physicists use fluorescence detectors to observe ultraviolet light emitted high in the Earth's atmosphere. A single cosmic ray can create a particle shower covering up to 10 square miles of the observatory.



Above and right: The Dark Energy Camera will observe light from distant galaxies and stars. Its 2.2-degree field of view is so large that a single image will record data from an area of the sky 20 times the size of the moon as seen from Earth.

Dark Energy Survey

Dark energy accounts for 70 percent of all energy and mass in the universe. Yet we know very little about this remarkable phenomenon, which speeds up the expansion of the universe. Fermilab is building a 570-megapixel camera to peer deep into the cosmos. Mounted on a telescope in Chile, it will reveal dark energy by taking photos of galaxies when they were only a few billion years old.

DAMIC

DAMIC breaks new ground in dark-matter research by using charge coupled devices in an underground experiment. The CCDs will allow DAMIC to detect collisions with dark-matter particles that are eight times less energetic than those seen by any other experiment. DAMIC seeks to pinpoint what particles make up dark matter. Without the added gravitational attraction of dark matter, stars and galaxies would never have formed. The expansion of the universe after the Big Bang would have dispersed visible matter too quickly.

Right: Fermilab physicist Juan Estrada (last row, far right) transformed technology used to search for signs of dark energy into the best detector in the world for spotting low-mass dark-matter particles. That work earned him the Presidential Early Career Award for Scientists and Engineers. *Photo courtesy of Juan Estrada*

Right: Fermilab physicist Juan Estrada and high-school student Natalie Harrison, with DAMIC's single-chip detector. DAMIC saved $200,000 by using electronics and CCDs originally developed for the Dark Energy Camera. The heart of an ordinary digital camera uses the same technology, although not of the same quality.

Below: The Cryogenic Dark Matter Search uses 30 super-clean detectors made of crystals of germanium and silicon in an attempt to detect WIMP scatters. The detectors are cooled to temperatures very near absolute zero.

Left: Particle interactions in the crystalline detectors deposit energy as heat and as charges that move in an applied electric field. Special sensors detect these signals, which are then amplified and recorded for later study.

Above: A close-up image of a CDMS detector component in its mount. It uses state-of-the-art thin film and superconducting technology to collect phonon energy from the crystal displaced by a particle interaction.

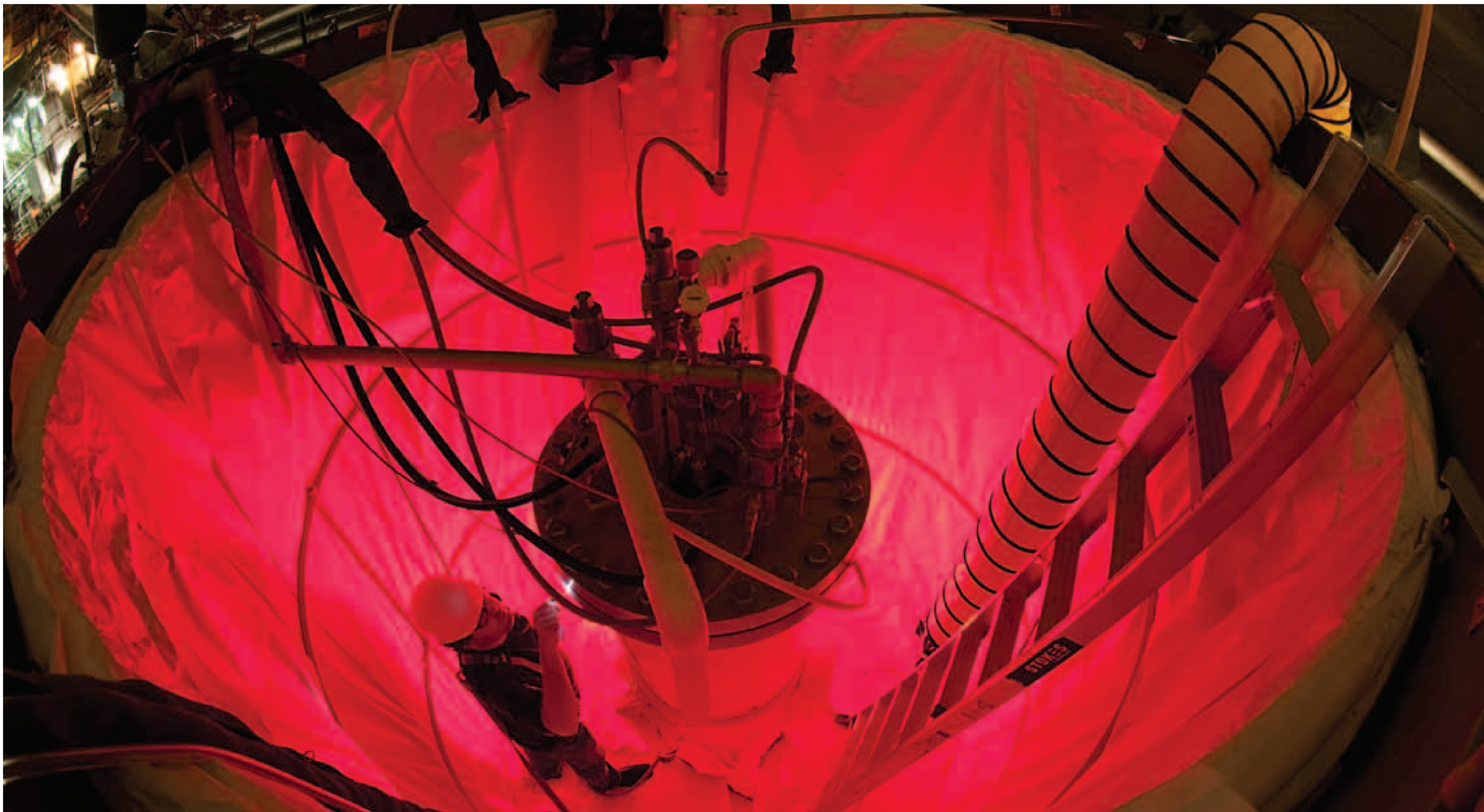
CDMS

Using state-of-the-art cryogenic germanium and silicon detectors, the CDMS collaboration searches for weakly interacting massive particles, or WIMPS, whose discovery could resolve the dark-matter problem, revolutionizing particle physics and cosmology. The CDMS experiment, located a half-mile underground at the Soudan mine in northern Minnesota, has been searching for WIMPs since 2003.

COUPP

The Chicagoland Observatory for Underground Particle Physics, or COUPP, seeks to pinpoint what particles make up dark matter. A quartz jar serves as a bubble chamber and holds a liquid kept just above its normal boiling point, but under enough pressure that it will not boil unless disturbed. When a charged particle zips through the liquid, it triggers boiling along its path, visible as a series of small bubbles. Scientists expect a dark-matter particle to leave a single bubble in a particular area of the jar in contrast to the multi-bubble tracks left by many other particles.

Below: The ability to switch the type of liquid in the detector with minimal effort and cost gives the bubble chamber an advantage over other dark-matter detection devices.



Above: A twin set up of lasers shot through 40-meter-long vacuum cavities encased in metal will seek tiny, rapid fluctuations in the apparent speed of light when compared between different directions. Certain kinds of fluctuations could be due to jitter caused by the limited resolution of spacetime itself, or "holographic noise."

Below: The Holometer could show that the third dimension of space only appears to exist on large scales, but when viewed very close up is really two dimensional, like a hologram.

Holometer

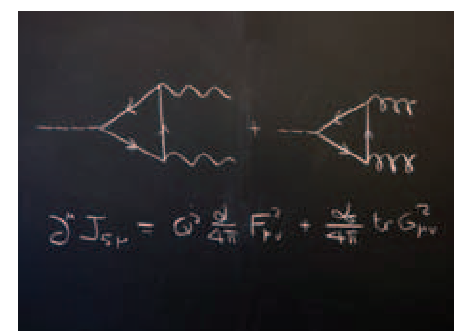
Is the entire universe a hologram? The Holographic Interferometer, or Holometer, could produce experimental access to Planck-scale physics and offer unique insight into the quantum nature of space and time. The Holometer will compare multiple laser beams to measure noise caused by tiny imperfections in the fabric of spacetime at the smallest scales.

Theory and computing

Theorists seek the fundamental symmetries and equations that describe how the universe works. At Fermilab, theoretical physicists work hand in hand with experimenters. Theorists' ideas, calculations and predictions guide the future direction of experiments. Experimental results, in turn, can confirm or rule out theoretical models, or make discoveries that stimulate the development of new theoretical ideas.

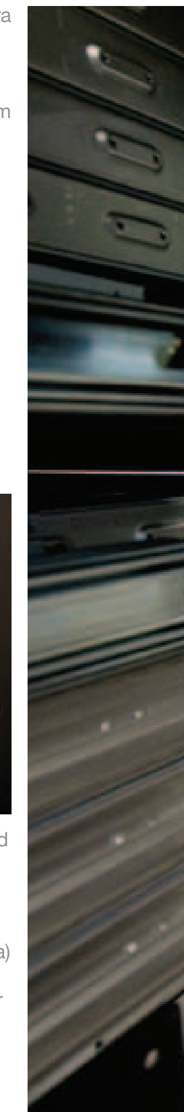
The Computing Division develops and supports innovative, cutting-edge computing solutions for Fermilab science: experiments, data acquisition and controls, accelerator and detector simulations, research and development of physics analysis software. Fermilab runs the world's largest Tier-1 Center for the LHC's Compact Muon Solenoid experiment, providing solutions to tackle the massive data transfer, data archiving and data processing that CMS requires.

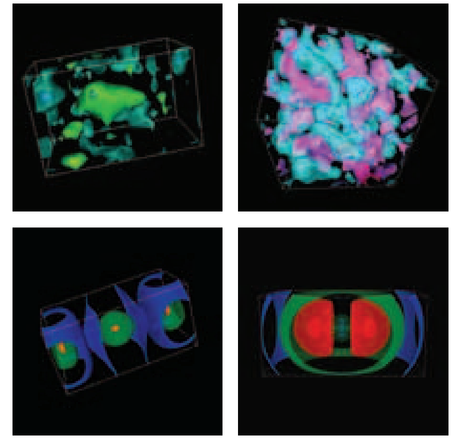
Above right: The Computing Division's Ryan Rivera at the Supercomputing 2010 conference, where he showcased CAPTAN, a Fermilab-designed general-purpose data acquisition and control system with the flexibility to create a unique system for each user and application.
Photo courtesy of Gene Oleynik, Fermilab



Above: Theorists use Feynman diagrams, named for physicist Richard Feynman, as a way of keeping track of the mathematical complexities of particle interactions.

Right: Fermilab's Amitoj Singh (facing the camera) and Jerry Comacho of Koi Computer work on the installation of "Ds," Fermilab's newest cluster devoted to lattice QCD simulations for theoretical physics.





Left: Computer-generated visualizations of simulations of lattice QCD, or quantum chromo-dynamics, an important tool of particle physics theory. *Images courtesy of Massimo di Pierro, DePaul University*

Above: Fermilab scientist Don Holmgren performs maintenance on a GPU, or graphics processing unit, computer. Scientists have begun to exploit GPUs for the ability to do parallel computations with very high efficiency and low power consumption.

Education

Below: Children learn about physics and Fermilab experiments through a show using liquid nitrogen. The show is performed about two dozen times a year at schools, clubs and businesses.

Fermilab's education programs serve students from pre-kindergarten to graduate school. The programs promote a life-long interest in science, raise scientific literacy and encourage young people to consider careers in science.

K-12 students	**FY2009**	**FY2010**
Students participating in activities at Fermilab	18,730	18,742
Students visited in classrooms by Fermilab staff	12,918	16,434
Students participating in other Fermilab activities	10,353*	2,453
Total	**42,001**	**37,629**
Professional development opportunities for teachers	3,418	2,499
Fermilab education Web site hits per year	9 million	11 million
College/university students	**2009**	**2010**
Ph.D.s received working at Fermilab (1,828 total Ph.D.'s received since 1974)	62	47**
Students involved in onsite programs or internships	about 1,000	about 1,000
Universities and laboratories with researchers working with Fermilab	**2009*** **	**2010**
U.S. universities represented	107	108
States represented	34	36
U.S. laboratories represented	6	8
Illinois universities represented	10	10
Illinois laboratories represented	1	1
Foreign universities represented	--	116
Foreign laboratories represented	--	24

*Number includes year-long Science in Chicago event outreach activities.

**Incomplete number because reporting of all Ph.D. recipients can lag behind for one or two years.

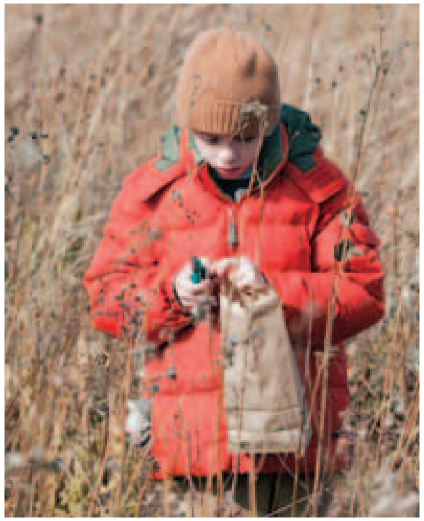
***Data collection system change resulted in incomplete data.

Other educational outreach

- Fermilab operates a free, hands-on science education center, the Lederman Science Center.
- Fermilab staff serve as research mentors to high school students for periods of about a month, either done all at once or spread throughout a year. Students learn about careers in science, engineering and computing.
- Fermilab helped found and continues to partner with SciTech, a hands-on science museum in Aurora.
- Fermilab offers internships for college students studying physics, engineering, computing, ecology and journalism.
- The Saturday Morning Physics Program offers a nine-week course for about 400 local high-school students a year.
- The Ask-A-Scientist program puts local residents in touch with physicists, engineers and computer specialists at an open house on the first Sunday of every month.
- Fermilab has donated native prairie seeds to more than 40 schools since 1993, plus Kane and DuPage county forest preserves.

Left: Students in the TARGET program prepare to launch hot air balloons. The program encourages underrepresented groups to study math and science and consider careers in science and engineering.

Below: The annual prairie seed harvest helps Fermilab in its goal to restore native vegetation to the site. Fermilab has restored more than 1,100 acres of tall-grass prairie.



Above: Science education classes held on weekends and school breaks expose thousands of children a year to math, science, engineering and computing skills and careers.

Far left: Fermilab joined the DOE and other laboratories in presenting science exhibits and shows at the first U.S. Science and Engineering Festival, which was held in Washington, D.C. More than 1 million people attended.

Near left: A yearly Family Outdoor Activity Fair focuses on the laboratory's ecology programs, its pioneer past and how families can incorporate science in outdoor summer fun.

Fermilab connection

2,311 scientists worldwide work with Fermilab. In the U.S., 1,390 scientists from 117 institutions in 36 states rely on Fermilab for their research.

Alabama
University of Alabama
University of South Alabama
Arizona
Embry Riddle Aeronautical University
University of Arizona, Tucson
California
California Institute of Technology, Pasadena
California State University
Lawrence Berkeley National Laboratory, Berkeley
Lawrence Livermore National Laboratory, Livermore
SLAC National Accelerator Laboratory, Palo Alto
Stanford University, Stanford
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of California, Los Angeles
University of California, Riverside
University of California, San Diego
University of California, Santa Barbara
Colorado
University of Colorado, Boulder
Connecticut
Yale University, New Haven
Florida
Florida State University, Tallahassee
University of Florida, Gainesville
Hawaii
University of Hawaii at Manoa
Idaho
Idaho State University, Pocatello

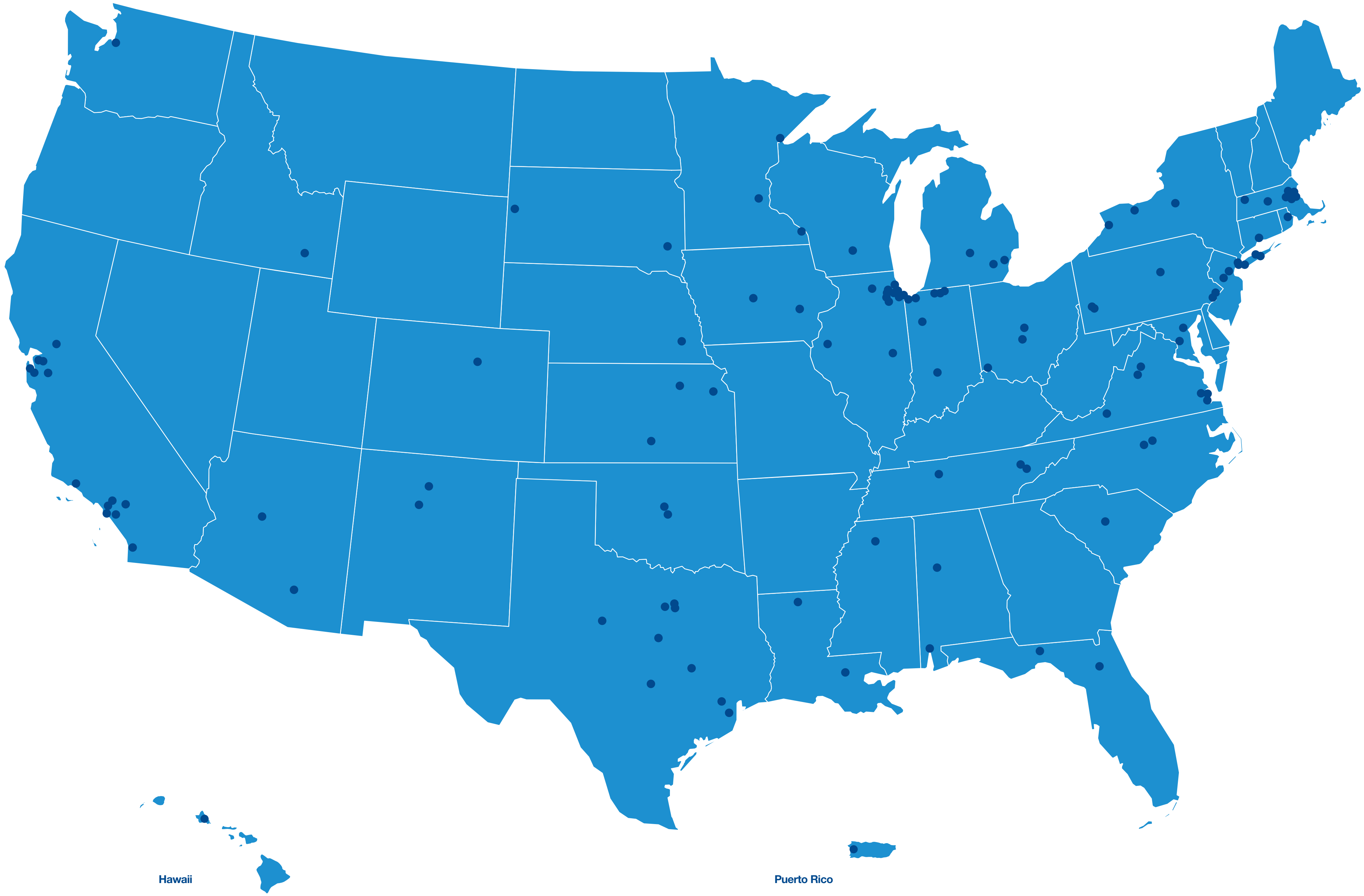
Illinois
Argonne National Laboratory
Benedictine University
Elmhurst College
Enrico Fermi Institute
Illinois Institute of Technology
Illinois Math and Science Academy, Aurora
Muon, Inc.
Northern Illinois University, DeKalb
Northwestern University, Evanston
University of Chicago, Chicago
University of Illinois at Chicago
University of Illinois at Urbana-Champaign
Western Illinois University
Indiana
Holy Cross College, South Bend
Indiana University, Bloomington
Indiana University, South Bend
Purdue University, West Lafayette
Purdue University Calumet, Hammond
University of Notre Dame, South Bend
Valparaiso University
Iowa
Iowa State University, Ames
University of Iowa, Iowa City
Kansas
Kansas State University, Manhattan
University of Kansas, Lawrence
Wichita State University, Wichita
Louisiana
Louisiana State University
Louisiana Tech University, Ruston

Maryland
Johns Hopkins University, Baltimore
University of Maryland, College Park
Massachusetts
Boston University, Boston
Brandeis University, Waltham
Harvard University, Cambridge
Massachusetts College of Liberal Arts, North Adams
Massachusetts Institute of Technology, Cambridge
Northeastern University, Boston
Tufts University, Medford
University of Massachusetts, Amherst
Michigan
Michigan State University, East Lansing
University of Michigan, Ann Arbor
Wayne State University, Detroit
Minnesota
Saint Mary's University of Minnesota
University of Minnesota, Minneapolis
University of Minnesota at Duluth
Mississippi
University of Mississippi, Oxford
Nebraska
University of Nebraska, Lincoln
New Jersey
Princeton University, Princeton
Rutgers State University of New Jersey, Piscataway
New Mexico
Los Alamos National Laboratory
University of New Mexico, Albuquerque

New York
Brookhaven National Laboratory, Upton
Columbia University (Nevis Laboratory), New York
Rockefeller University, New York
State University of New York at Buffalo
State University of New York at Stony Brook
Syracuse University
University of Rochester, Rochester
York College at CUNY, New York
North Carolina
Duke University, Durham
University of North Carolina
Ohio
Ohio State University, Columbus
Otterbein College, Westerville
University of Cincinnati
Oklahoma
Langston University
Oklahoma State University, Oklahoma City
University of Oklahoma, Norman
Pennsylvania
Bucknell University
Carnegie Mellon University, Pittsburgh
Temple University, Philadelphia
University of Pennsylvania, Philadelphia
University of Pittsburgh, Pittsburgh
Puerto Rico
University of Puerto Rico, Mayaguez
Rhode Island
Brown University, Providence
South Carolina
University of South Carolina, Columbia

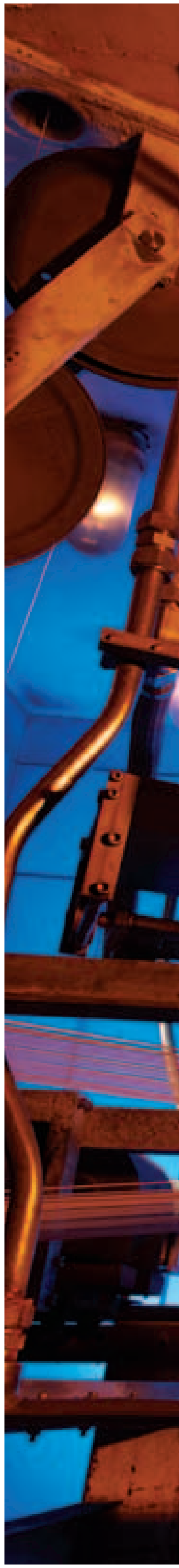
South Dakota
Augustana College, Sioux Falls
Black Hills State University, Spearfish
Tennessee
Oak Ridge National Laboratory, Oak Ridge
Vanderbilt University, Nashville
University of Tennessee, Knoxville
Texas
Abilene Christian University
Baylor University
Rice University, Houston
Southern Methodist University, Dallas
Texas A&M University, College Station
University of Houston, Houston
University of Texas at Arlington
University of Texas at Austin
University of Texas at Dallas
Virginia
College of William and Mary
Hampton University, Hampton
James Madison University
Thomas Jefferson National Accelerator Facility
Virginia Polytechnic Institute and State University
University of Virginia, Charlottesville
Washington
University of Washington, Seattle
Wisconsin
University of Wisconsin, Madison

List as of December 2010


Hawaii
Puerto Rico

Benefits to society

A beam of particles is a very useful tool. A beam of the right particles with the right energy at the right intensity can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, package a Thanksgiving turkey or discover the secrets of the universe.



Above: Created with particle accelerators, hydrogel bandages do not dry and stick to a wound the way gauze does. Instead, they act more like the body's own tissue, creating an ideal environment for wounds to heal.

Right: Electron Beam Technologies in Kankakee, Illinois, uses particle accelerators to treat the coatings for wires and cables found in cars, planes and many other electrical devices.

Left: Electron beam treatment improves the heat resistance of coatings for wire and cable by crosslinking the polymers in the material.

Below: The medical industry uses particle accelerators to sterilize syringes, bandages, surgical tools and other medical gear.

Above: Cereal boxes, juice boxes, salad bags and other items found in the grocery store often feature inks and coatings that have been cured with electron beams.

Milestones

In 2010, Fermilab accelerators set records for beam intensity and number of collisions produced. The superb performance of the accelerator complex and numerous experiments allowed physicists to push the boundaries of the Energy, Intensity and Cosmic Frontiers.

Jan. 2 New MINOS results help rule out a theorized fourth neutrino and strengthen the case against the decay of neutrinos.

Jan. 8 The Long-Baseline Neutrino Experiment receives Critical Decision-0, the first-stage approval by the Department of Energy. The designation establishes DOE's mission need for this experiment.

January The NuMI beamline repeatedly sets records for the numbers of particles delivered to Fermilab's neutrino experiments.

January The HINS collaboration successfully accelerates a proton beam to 2.5 MeV using RFQ technology, laying the groundwork for creating a high-intensity proton source.

January Fermilab tests and ships the first nine-cell, ILC-type cavities made in the United States to Japan for installation in the S1-Global Effort, a prototype of the ILC main linac.

Feb. 8 The CMS collaboration, which includes more than 800 U.S. particle physicists, publishes its first scientific result based on high-energy proton-proton collisions.

Feb. 22 The ArgoNeuT collaboration successfully completes the five-month-long operation of its neutrino test detector, which is based on liquid-argon technology.

February The partnership between Fermilab and Indian institutions achieves a milestone when the first Indian-made 1.3-GHz, single-cell SRF cavity exceeds the particle acceleration specification of 19 MV/m for Project X.

March 2 Construction workers pour the first concrete for the NOvA detector building in Minnesota.

March 15 The MINERvA collaboration installs the last of 120 modules for its neutrino detector.

March 19 The COUPP collaboration announces new spin-dependent WIMP limits obtained from four months of data that were analyzed using alpha discrimination, a new technique to eliminate background events.

April The Tevatron achieves an integrated luminosity of 71.71 inverse picobarns in a single week.

April 16 The Tevatron sets a peak luminosity record of 4×10^{32} cm^{-2} sec^{-1}.

May 14 DZero announces evidence for the violation of matter-antimatter symmetry in the behavior of particles containing bottom quarks. If confirmed, this result could explain the dominance of matter over antimatter in our universe.

May 5 The NuMI beamline has delivered more than 10^{21} protons since its startup in spring of 2005.

May Fermilab's nature conservation efforts lead to the discovery of two rare, native plants on site: blue cohosh and woodland bluegrass.

May A Fermilab team installs and powers up a Fermilab-made beam position monitoring system at KEK's Accelerator Test Facility.

June 14 MINOS scientists announce the world's most precise measurement of the parameters that govern antineutrino oscillations and see a

Fermilab is often called a jewel of the Fox Valley by members of neighboring communities in part because much of its 6,800 acres consists of conserved native prairies, grasslands, wetlands, woods and agricultural fields harboring an abundant amount of wildlife. The laboratory is one of seven National Environmental Research Parks.

hint that neutrinos and antineutrinos might behave differently.

June 14 A new result announced by the MiniBooNE collaboration suggests that antineutrinos might oscillate differently from neutrinos.

July 26 CDF and DZero scientists announce the best constraints yet on the Higgs boson from Tevatron data, excluding the Higgs mass range from 158 to 175 GeV/c^2.

August Fermilab helps organize the first African School of Physics, held in Stellenbosch, South Africa.

September Phase II starts for the construction of a pioneering accelerator test facility, which will host a 460-foot-long accelerator based on superconducting RF technology.

September The Dark Energy Survey collaboration ships the first part of its Dark Energy Camera from Fermilab to Chile for installation on the 4-meter Blanco telescope.

October The COUPP experiment begins searching for dark matter with its 4-kilogram bubble chamber at SNOLAB.

Oct. 28 The CMS collaboration announces its first measurement of top quark production at the Large Hadron Collider.

Nov. 22 Fermilab cools down the first SRF cryomodule at its accelerator test facility to 2 Kelvin.

December The total integrated luminosity delivered during Tevatron Run II reaches 10 inverse femtobarns, the equivalent of 1.5 quadrillion collisions.

December The Proton Source sets a record for the number of protons delivered in a single year, providing more than 6.2 x 10^{20} protons to experiments during 2010.

Dec. 15 The NOvA prototype detector constructed at Fermilab records its first neutrinos.

Fermilab and the frontier

The quintessential symbol of Fermilab is the frontier. The laboratory's founding director, Robert Wilson, born in Frontier, Wyoming in 1914, incorporated the frontier imagery of his western heritage in a site designed for discovery at the frontiers of science. Wilson's introduction of American bison, the restoration of hundreds of acres of native tall-grass prairie, and a frontier spirit of adventure and resourcefulness helped to establish Fermilab's unique character. Today, 21st-century Fermilab carries forward Wilson's vision of a pioneering laboratory dedicated to discovery at the frontiers of particle physics.

Above: Founding Fermilab Director Robert Wilson on horseback in Fermilab's early days.
Photos courtesy of the Fermilab Archives

Above: In October 1969, with founding Fermilab Director Robert Wilson on hand, Fermilab broke ground on its first accelerator.

Left: Buffalo auctions, held at Fermilab until 1990, attracted colorful visitors to the laboratory.

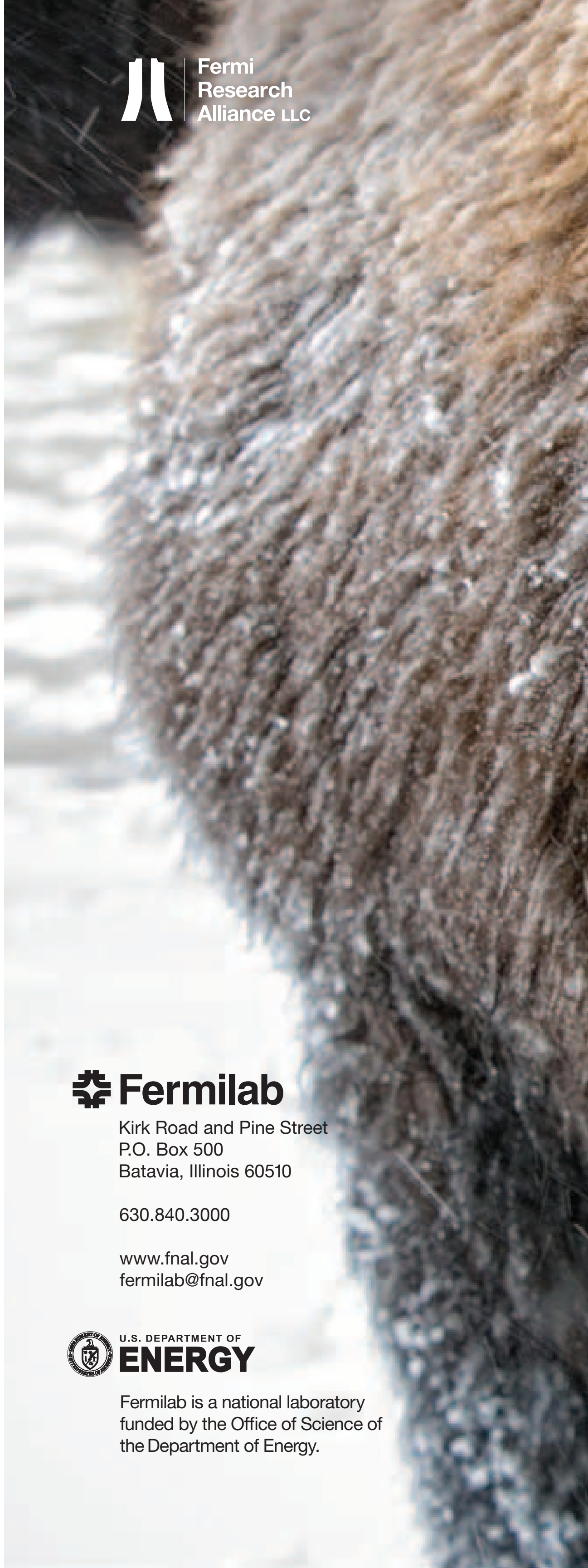
Above: Fermilab Director Pier Oddone and Barbara Oddone gather prairie seeds in Fermilab's annual prairie seed harvest, held every October.

Photos: Fermilab Visual Media Services

Design: Sandbox Studio, Chicago

Artifacts from Fermilab's first users

"In the Woodland period from 2,500 B.C.–500 A.D., visits to the Fermilab site were brief; hunting and gathering nuts and berries were main activities. Afterwards, the Indians would return to their more permanent settlements along the banks of the larger rivers." *From a history of the Fermilab site by Adrienne Kolb, archivist*



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