



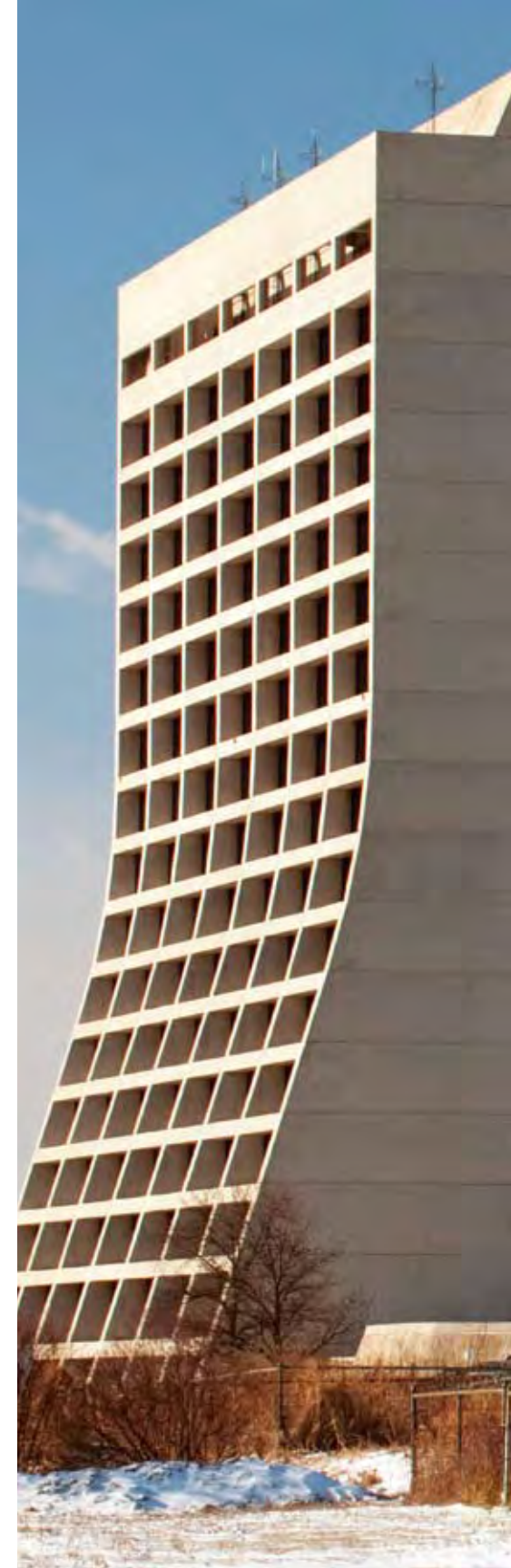
Doorways to Discovery

Fermi National
Accelerator Laboratory



Fermilab's doorways to 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 to open doorways 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.







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





Questions for the Universe

- 1) Are there undiscovered principles of nature?
- 2) How can we solve the mystery of dark matter?
- 3) Are there extra dimensions of space?
- 4) Do all the forces become one?
- 5) Why are there so many kinds of particles?
- 6) What is dark matter? How can we make it in the lab?
- 7) What are neutrinos telling us?
- 8) How did the universe come to be?
- 9) What happened to the antimatter?



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.

Table of contents

Energy Frontier / 6

CDF / 8

DZero / 9

CMS / 10

LHC Remote Operations / 11

SRF Technology / 12

ILC / 12

Muon Collider / 13

Intensity Frontier / 14

MINOS / 16

NuMI / 16

NOvA / 17

MiniBooNE / 18

MINERvA / 18

MicroBooNE / 19

ArgoNeuT / 19

LBNE / 20

Project X / 21

SRF Test Accelerator / 22

Mu2e / 23

Cosmic Frontier / 24

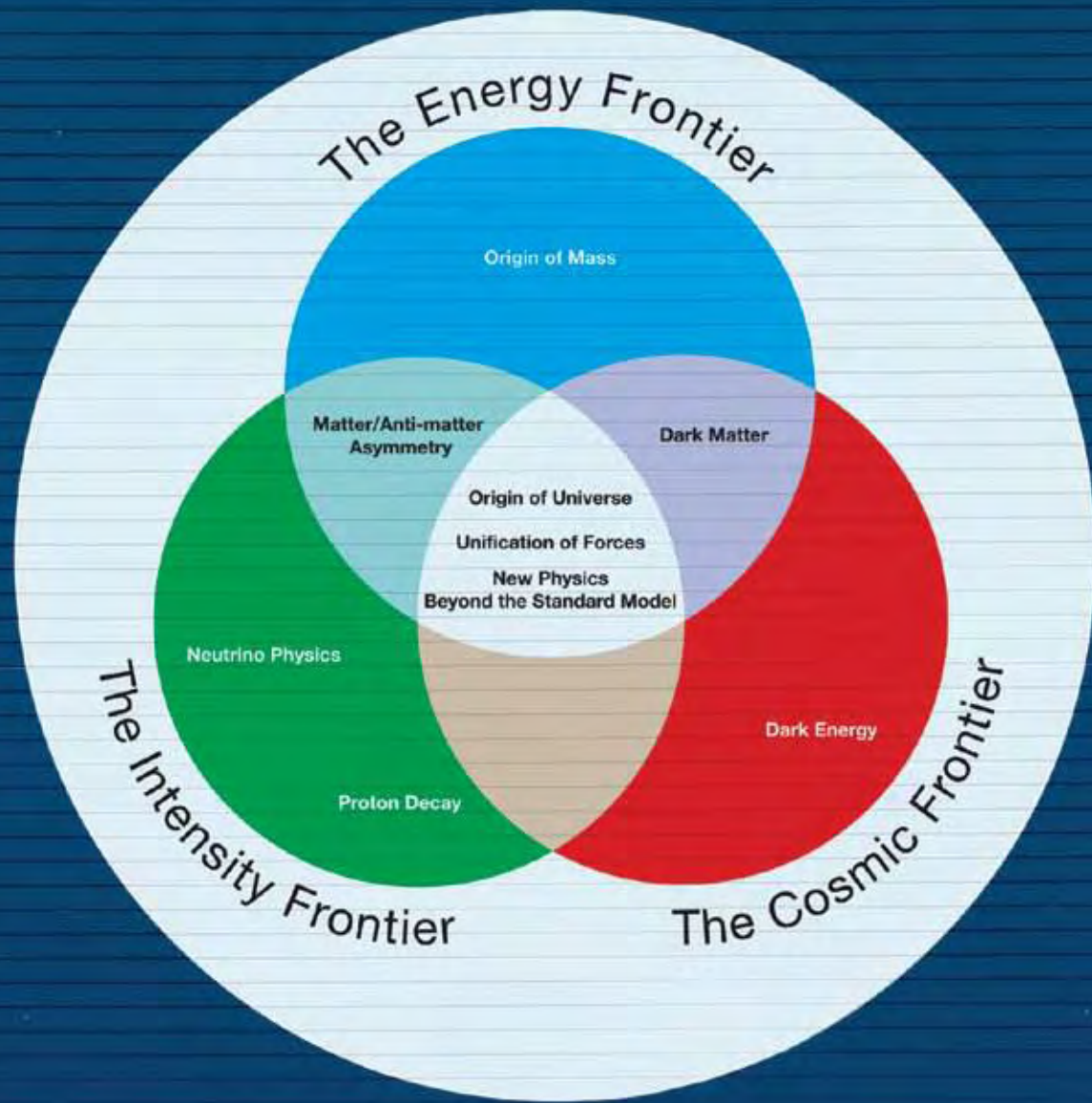
Pierre Auger / 26

Dark Energy Survey / 27

CDMS / 28

COUPP / 29

GammeV / 29





Energy Frontier

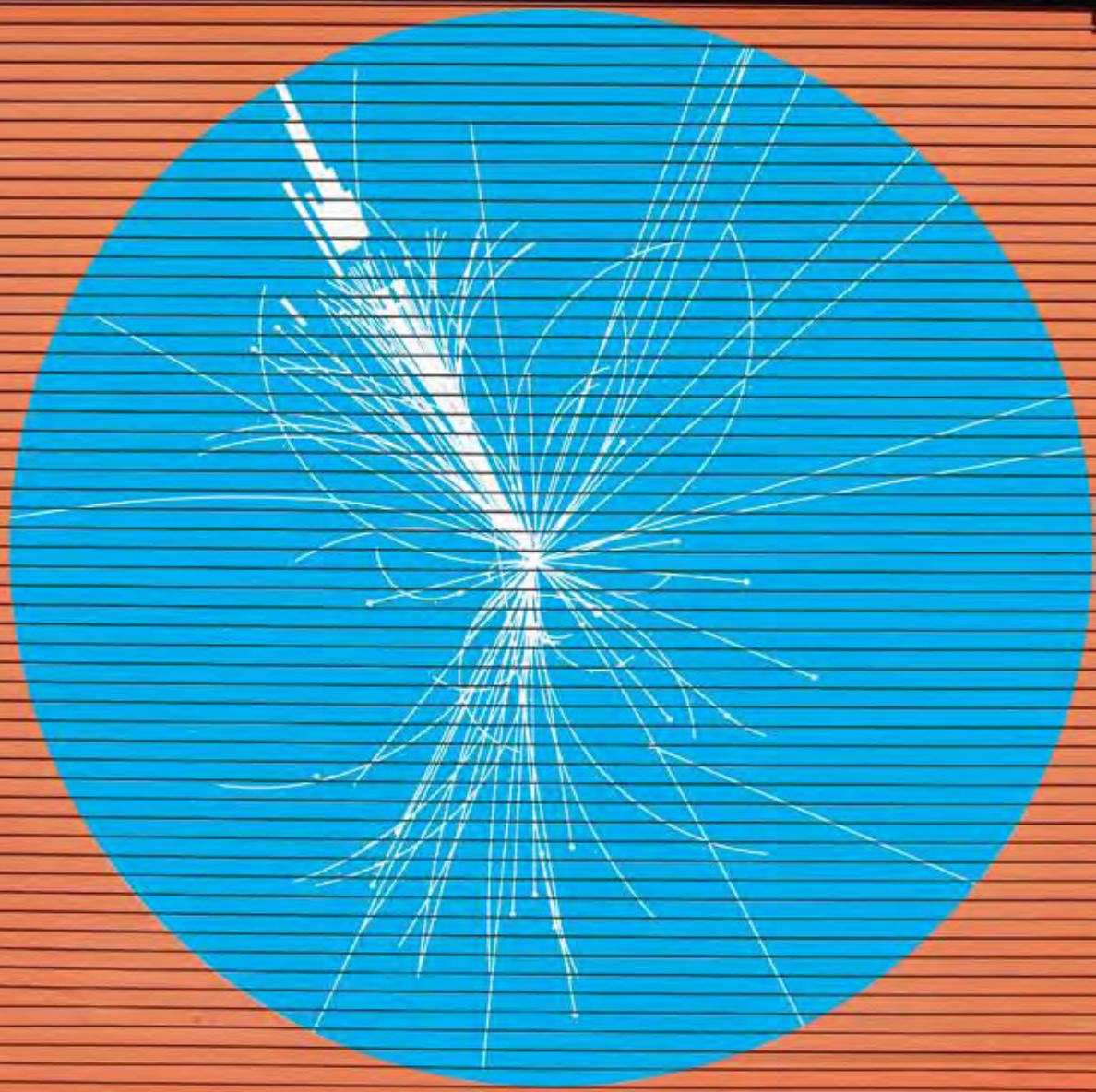
Particle accelerators at the Energy Frontier produce high-energy collisions that signal new phenomena, from the origin of mass to the nature of dark matter and extra dimensions of space. Fermilab's Tevatron experiments, CDF and DZero, continue to set new records in a physics program of exciting discoveries and ultraprecise measurements, involving over 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 carry out research at the LHC, the world's new energy-frontier accelerator.



TSB

**ENERGY FRONTIER
ACCELERATOR DIVISION**

STORAGE AIR
TEMPERATURE 21.3 °C

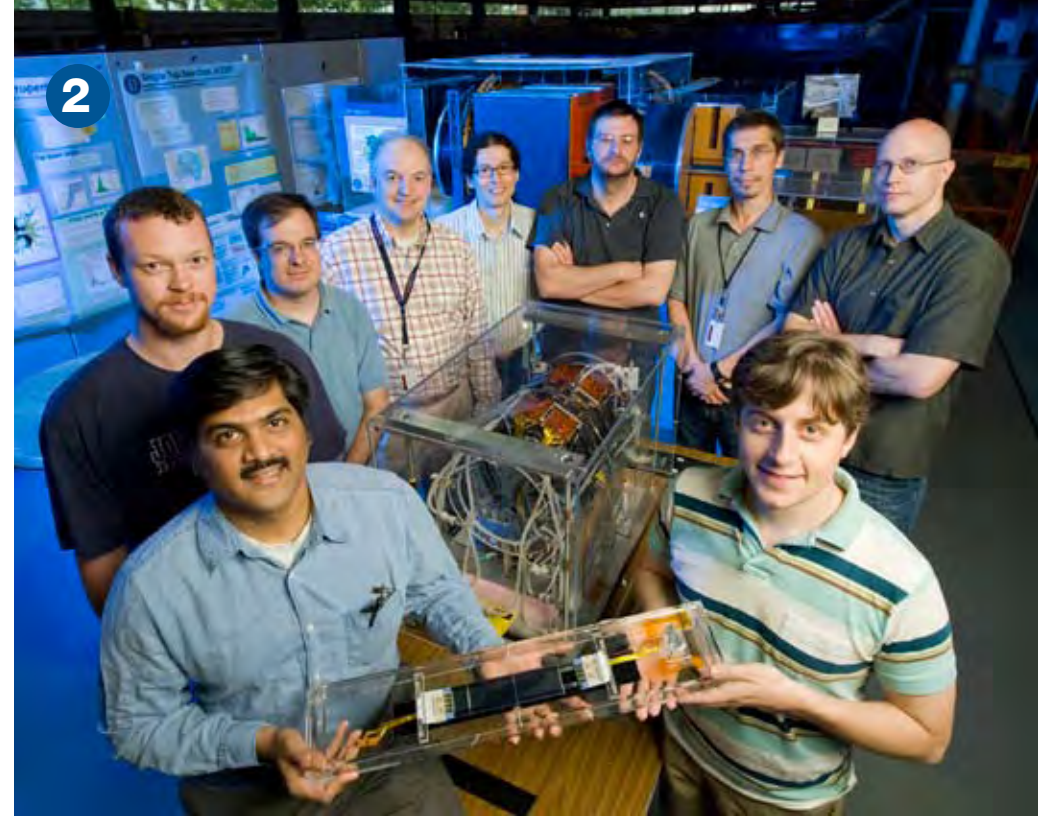


CDF / Using the Tevatron particle collider, the 600-member CDF collaboration explores the subatomic world to search for the origin of mass, extra dimensions of space, and new particles that could explain the nature of our universe. On average, the collaboration publishes a scientific paper every six days. In 2009, two dozen students received Ph.D.s for their research on the CDF experiment.



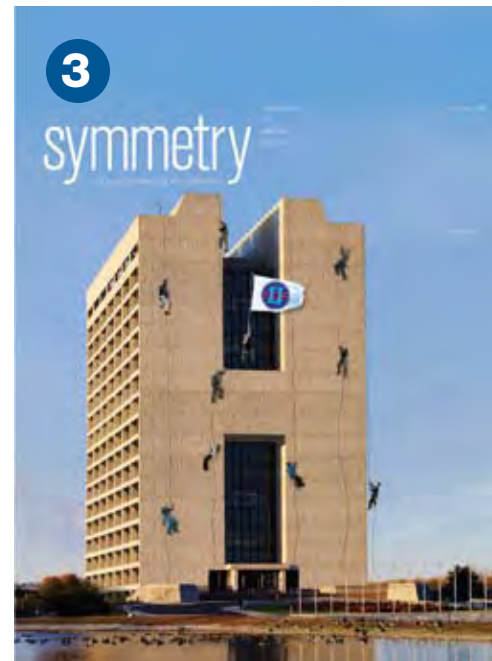
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1 The roughly 6,000-ton CDF detector comprises layers of subdetectors that surround the particle collision area, like layers of an onion.



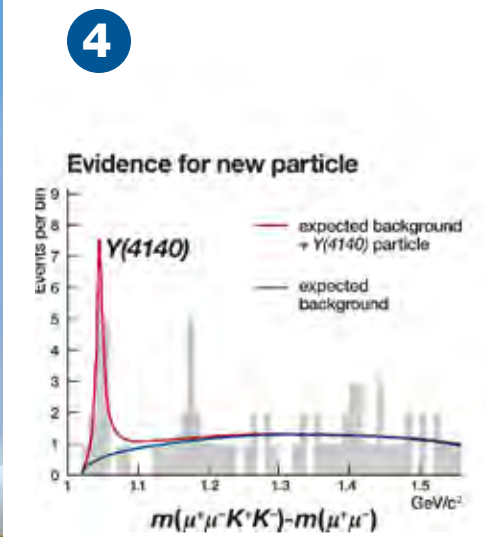
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2 The silicon-based subdetector at the heart of the CDF experiment enables the detector to take snapshots of particles and how they interact.



3

3 In search of the Higgs boson, the Mount Everest of particle physics, CDF physicists have to scale the wall of data generated by millions of collisions per second.



4

4 CDF scientists have found evidence of a new particle, Y(4140), whose characteristics may reveal new ways that quarks can combine to form matter.



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.



5

5

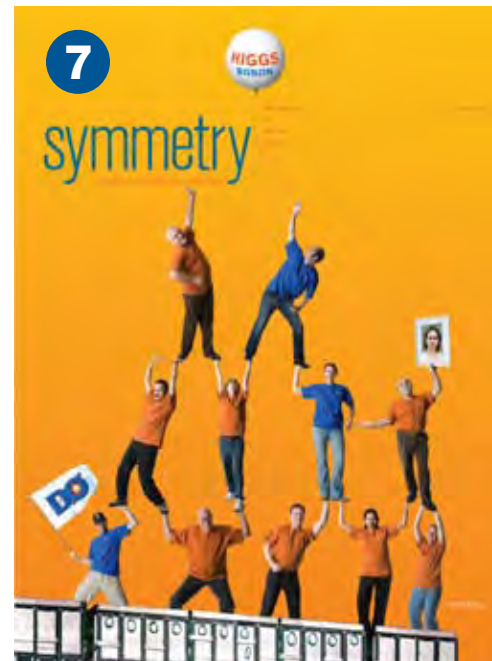
The DZero detector measures the energy, momentum and electric charges of the particles that emerge when a proton and antiproton collide.



6

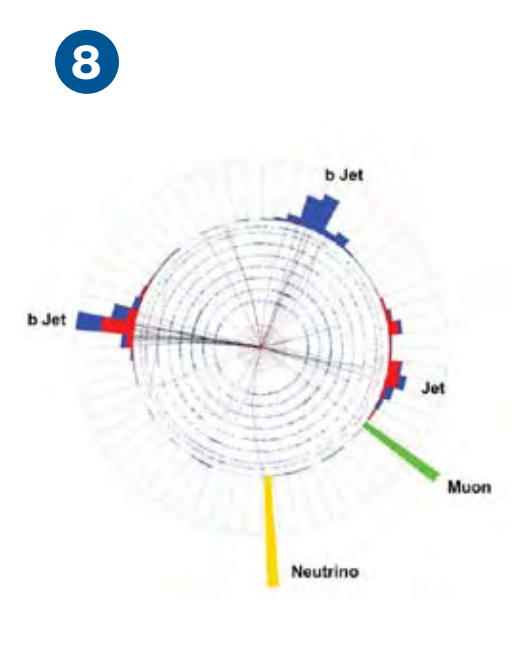
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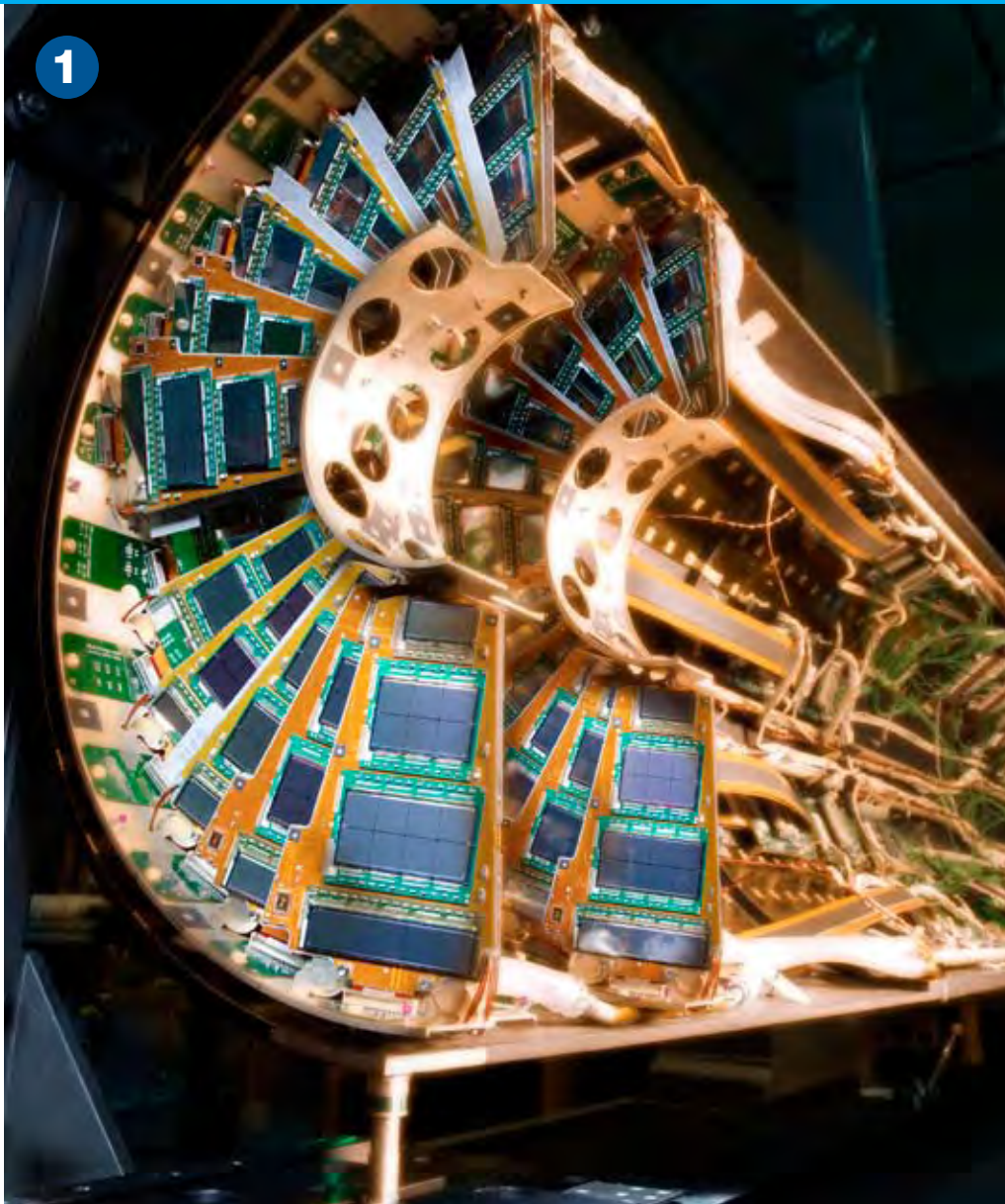
The DZero collaboration has built a strong team of scientists who count on each others' strengths to find the Higgs boson, the origin of mass.



8

This particle event, recorded by the DZero detector, is evidence that the weak nuclear force can generate top quarks in high-energy collisions.

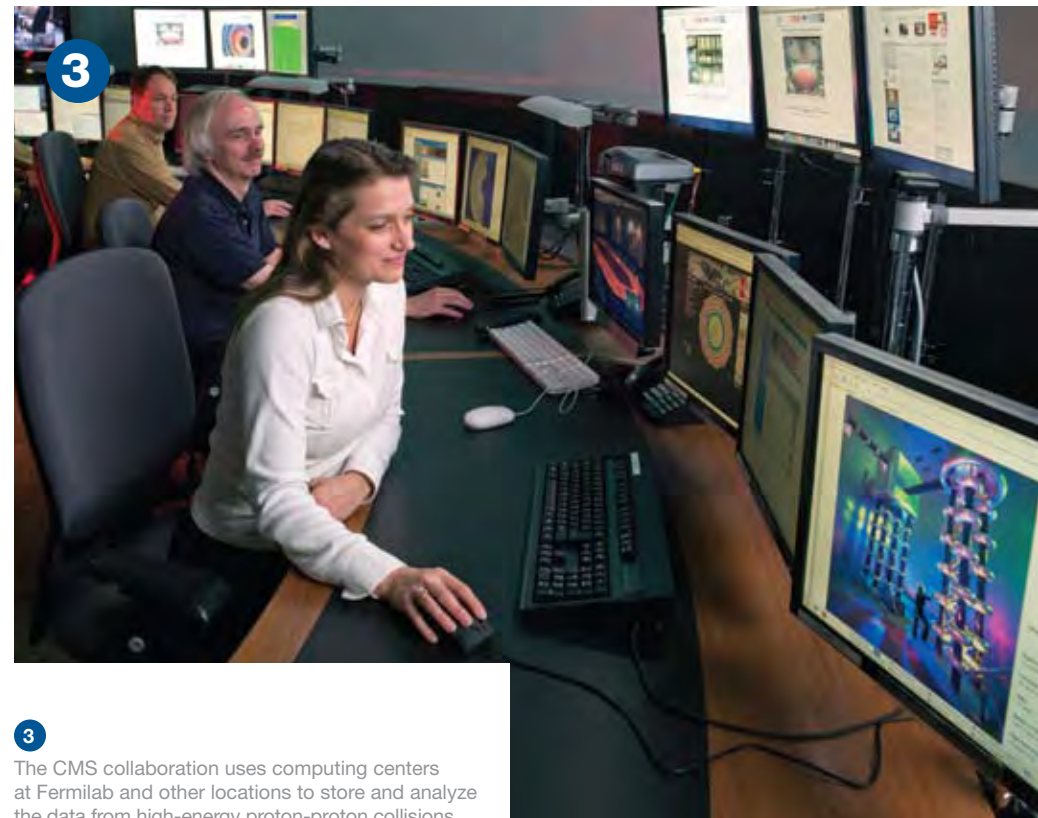
CMS / Recording the tiniest components of the universe requires the world's largest scientific instruments. The 13,800-ton CMS experiment is one of four large detectors at the Large Hadron Collider at CERN, the European particle physics laboratory located in Geneva, Switzerland. More than 1,000 U.S. scientists belong to the international CMS collaboration, including about 600 students.



1 U.S. groups have made major contributions to nearly every aspect of the CMS experiment, including the design and construction of this particle tracker.



Photo: Michael Hoch, Adventure Art



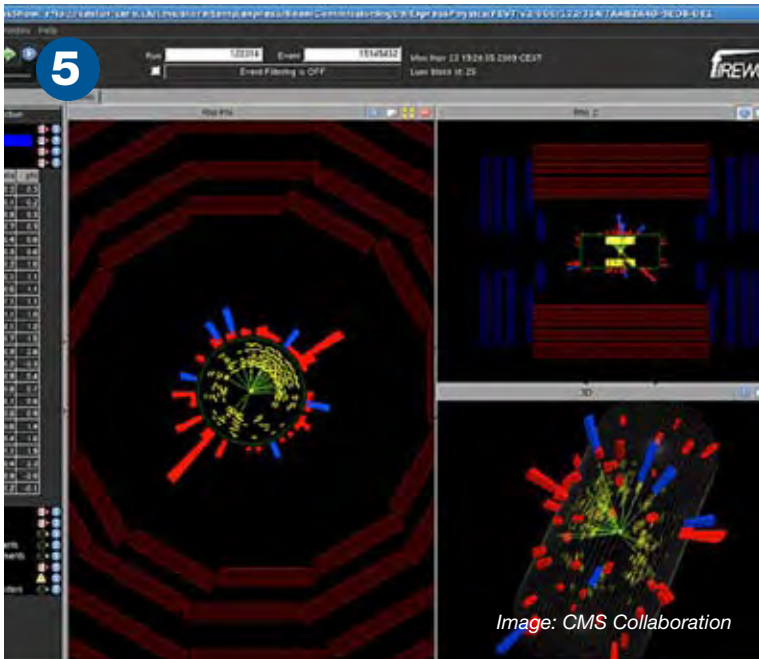
3 The CMS collaboration uses computing centers at Fermilab and other locations to store and analyze the data from high-energy proton-proton collisions.



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 night shifts on CMS during daytime hours.



4



5

Image: CMS Collaboration



6

Photo: CERN

4

Seven days a week from 8:00 a.m. to midnight, U.S. scientists take two eight-hour shifts in the LHC Remote Operations Center at Fermilab.

5

Remote operations allow U.S. scientists to contribute to every milestone at CMS, such as recording the first particle collisions at world-record energy.

6

A round of applause erupted in the CERN Control Centre in Switzerland as beams circulated around the Large Hadron Collider on Nov. 20, 2009.

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.



1



2

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.

1

Fermilab scientists have become experts in SRF technology and are working with U.S. industry to help boost American manufacturing capabilities.

2

Fermilab is collaborating with research laboratories in the U.S., Europe and Japan to build prototype components for future accelerators.

3

Scientists are pursuing new ideas for experiments at the energy frontier. Last fall, about 100 physicists attended a workshop on muon collider physics.

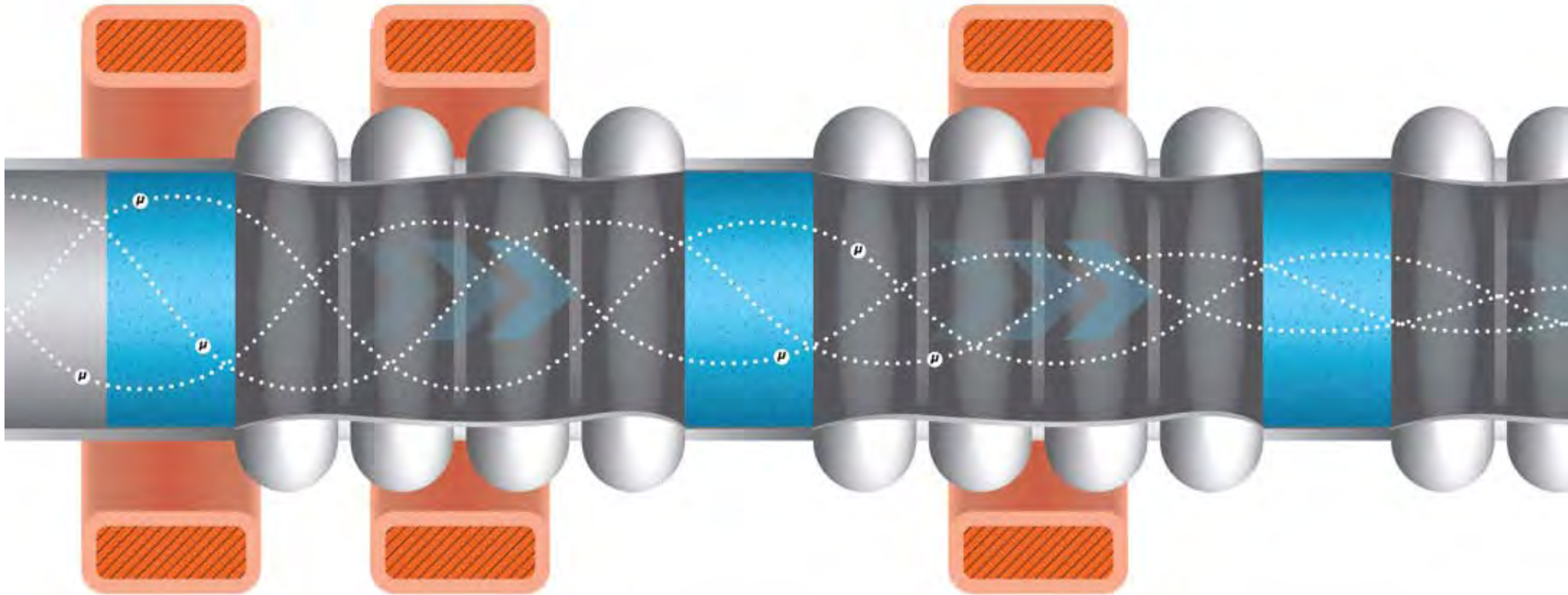


Muon Collider / An internal collaboration of scientists is advancing plans for a new, innovative type of energy-frontier machine that would accelerate muons, the short-lived cousins of electrons. A muon collider would be much smaller than the Large Hadron Collider and fit on the Fermilab site, yet it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

Muon Collider Physics Workshop

Fe
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US

3



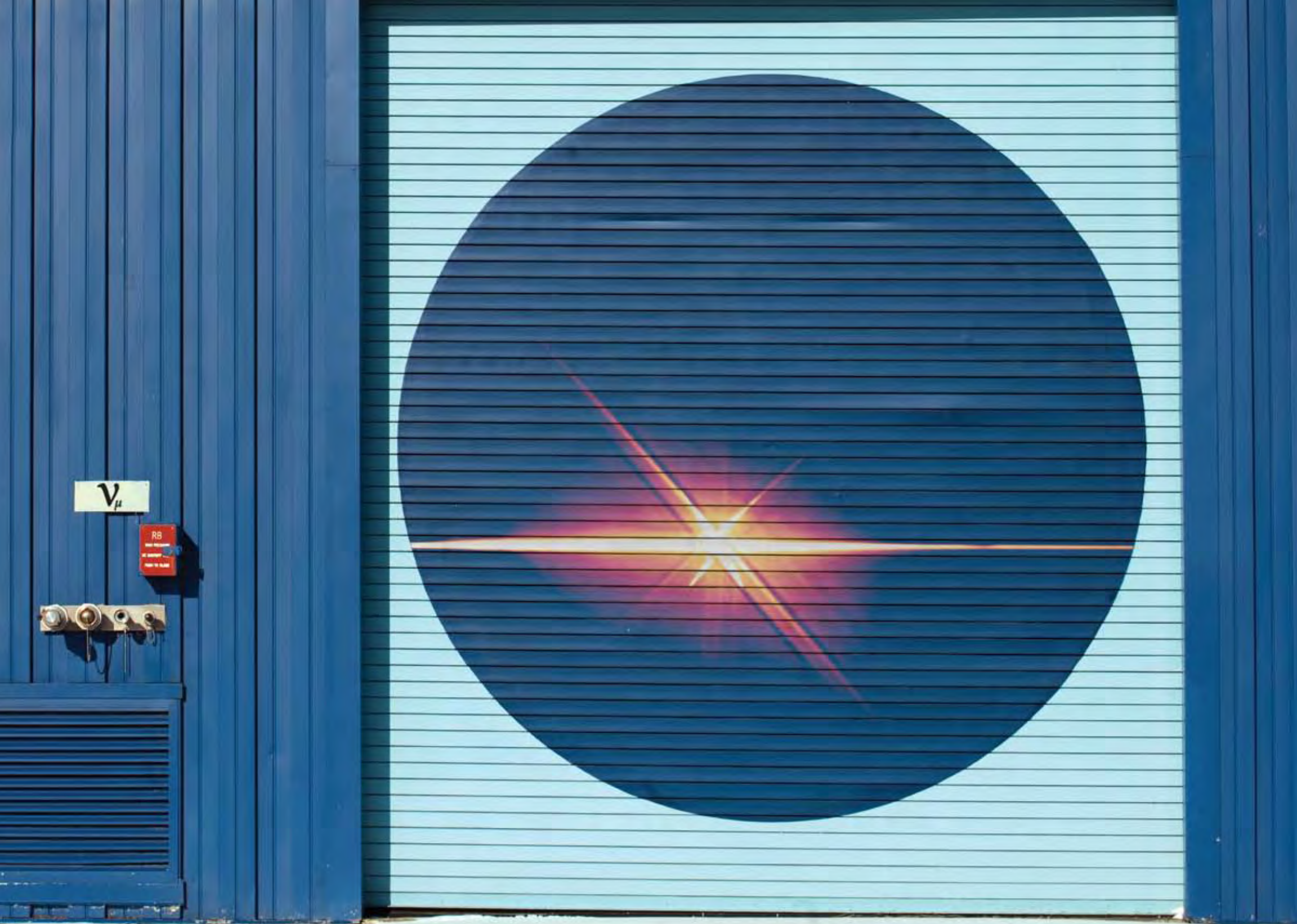
Machine / Detector / Physics



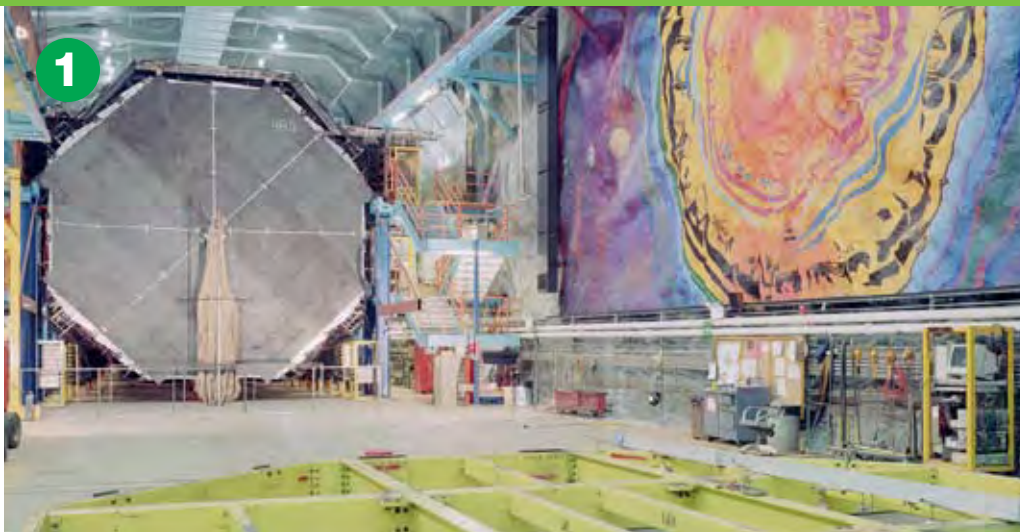
Intensity Frontier

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 anti-matter? 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.

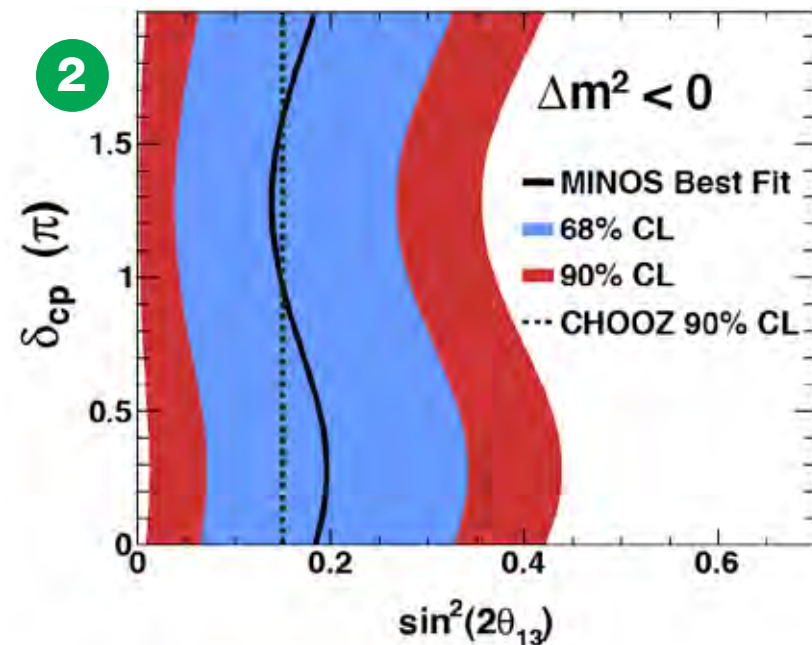




MINOS / Neutrinos are among the most abundant and least understood particles in the universe. There are three distinct types of neutrinos. Strangely, each type of neutrino can morph into the other types, a process known as neutrino oscillation. The MINOS experiment looks for the oscillation of muon neutrinos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



1



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NuMI / The Main Injector accelerator at Fermilab pushes the boundaries of the Intensity Frontier. The machine produces a proton beam with 300 kilowatts of power, a world record, and upgrades already are under way. At the NuMI facility, scientists use the proton beam to make the world's most intense neutrino beam. Future plans include the production of a high-intensity muon beam for the Mu2e experiment.

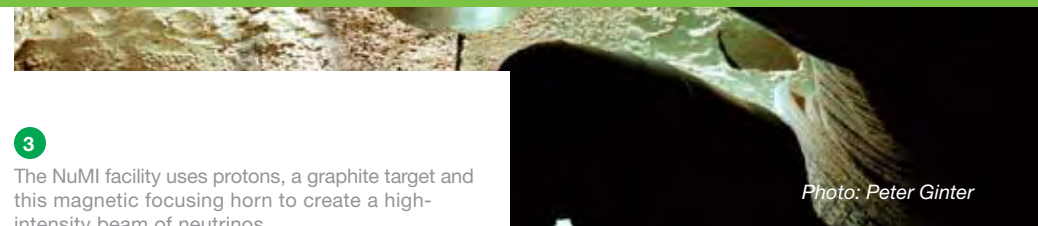


Photo: Peter Ginter

1

Inspired by discoveries in particle physics, artist Joseph Giannetti created the underground mural on the wall next to the MINOS detector in Soudan, Minn.

2

Data from the MINOS experiment constrain the mathematical model that describes the oscillation of muon neutrinos into electron neutrinos.

3

The NuMI facility uses protons, a graphite target and this magnetic focusing horn to create a high-intensity beam of neutrinos.



NOvA / Scientists suspect that neutrinos played a major role in the evolution of the universe, despite the fact that they account for less than one 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.



4

Fermilab Director Pier Oddone and Deputy Director Young-Kee Kim pose at the groundbreaking for the NOvA facility in Minnesota on May 1, 2009.



5



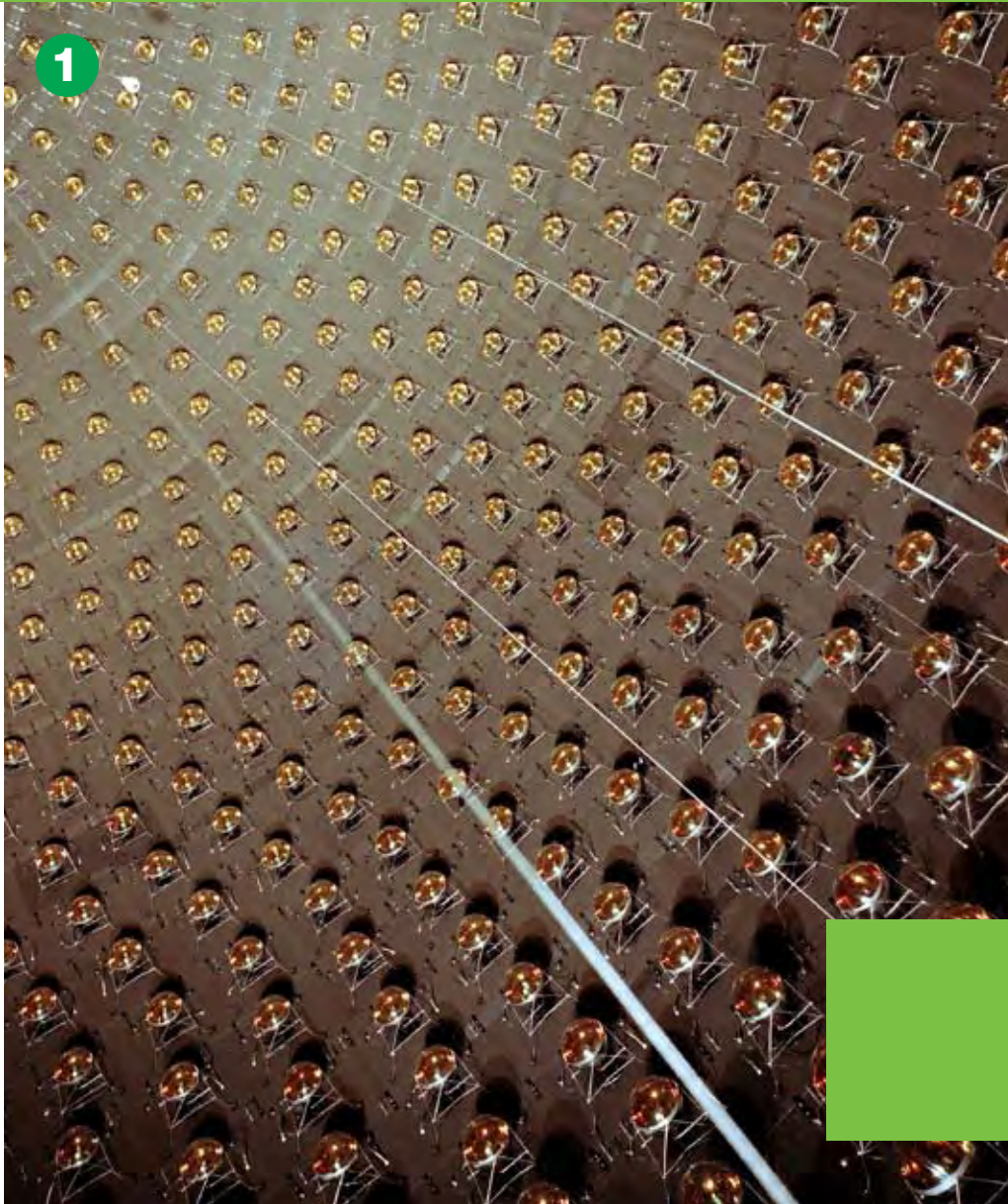
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The NOvA facility will house a 15,000-ton neutrino detector. The project involves about 180 scientists and engineers from 28 institutions.

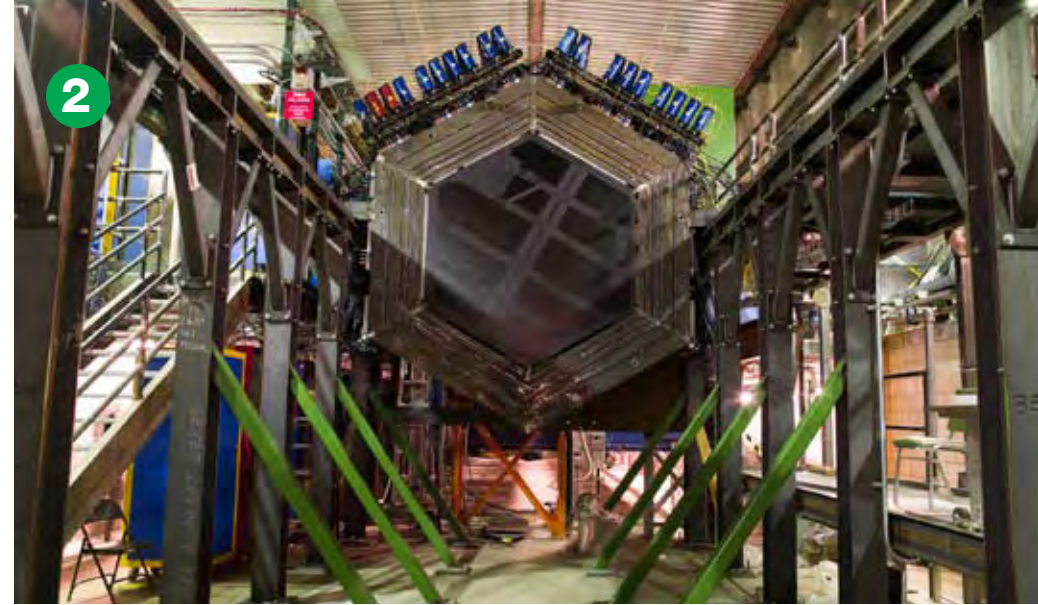


Photo: Dan Traska, Einarson Flying Service

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 2011.



1



2



3

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.

1

The MiniBooNE detector, a spherical steel tank 40 feet in diameter, contains ultrapure mineral oil and is lined with 1,520 photomultiplier tubes.

2

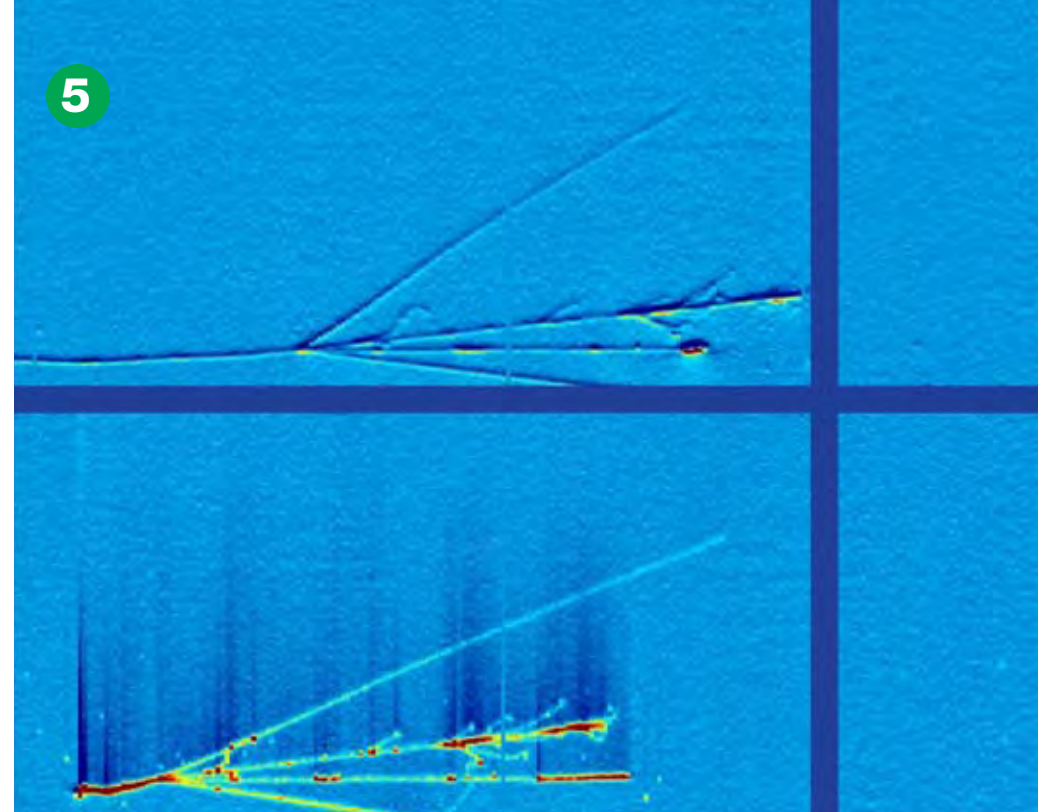
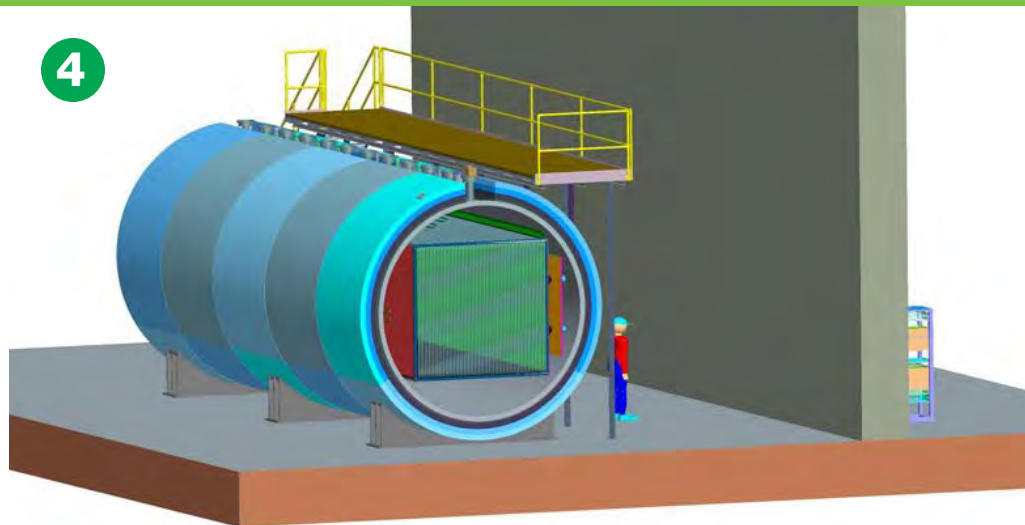
The MINERvA detector is located in an experimental hall 330 feet underground, the same hall that also houses the much larger MINOS near detector.

3

The MINERvA detector caught its first neutrinos in April 2009, while still under construction. Technicians completed the detector in January 2010.



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 first-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.



ArgoNeuT / Liquid-argon neutrino detectors can record neutrino interactions with great efficiency but are challenging to build. To learn more about these detectors, scientists built the ArgoNeuT test detector, nicknamed for Jason and the Argonauts of Greek mythology. Exposed to an intense beam of neutrinos made by an accelerator at Fermilab, the detector recorded thousands of neutrino events.

4

The 100-ton MicroBooNE detector is a step toward the construction of neutrino detectors filled with a few thousand tons of liquid argon.

5

In 2009, neutrinos passing through the ArgoNeuT test detector produced these tracks, the first ever seen in a liquid-argon detector in the U.S.

6

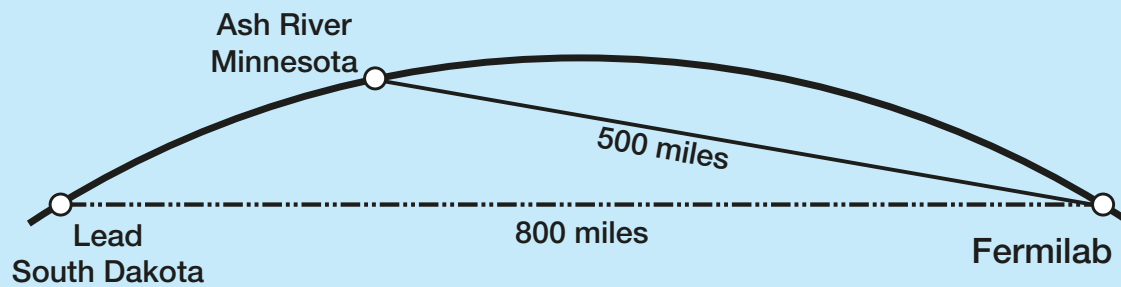
Scientists from Yale University inspect the device that measures the purity of the liquid argon inside the ArgoNeuT test detector.

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.



Long-Baseline Neutrino Experiments

MINOS	Soudan Mine, MN	2340 ft deep
NOvA	Ash River, MN	Surface level
LBNE	Homestake Mine, SD	4850 ft deep



1 The Fermilab accelerator complex could provide the high-intensity neutrino beam necessary for the LBNE experiment.

2 More than 200 scientists from 46 institutions have joined the LBNE collaboration so far, including physicists from India, Italy and Japan.

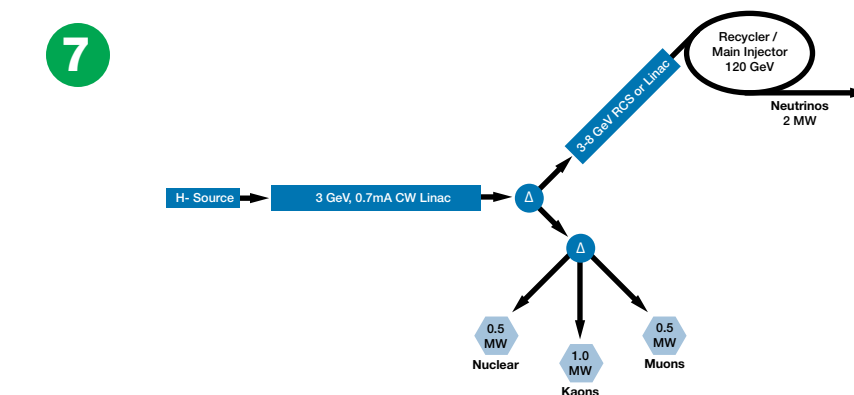
3 Scientists propose to build the LBNE experiment in a mine in South Dakota. LBNE requires a neutrino beam that travels at least 800 miles through the earth.



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.



4 In November, more than 100 physicists gathered at Fermilab to discuss potential experiments that would use Project X, a high-intensity proton source.



6 SRF cavities are made of pure niobium. The cavities save energy by conducting electricity without resistance, making them a highly efficient technology.

7 Project X would provide high-intensity beams of neutrinos, kaons and muons for a wide range of 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.



1

1

Fermilab has begun to install a test accelerator in its SRF test facility. Thanks to ARRA funding, Fermilab can greatly expand the facility.

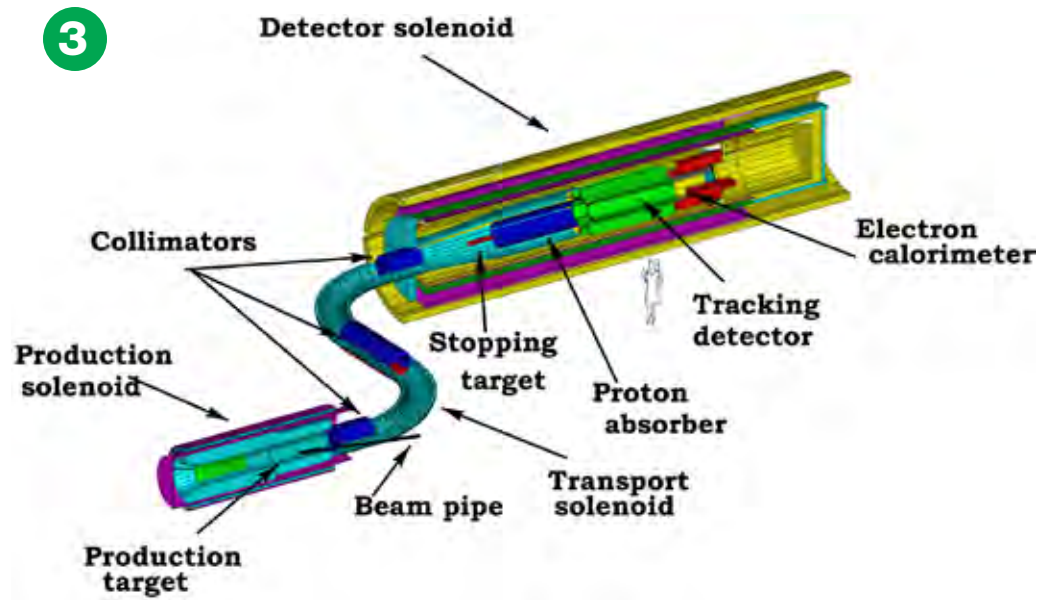
Fermi National Accelerator Laboratory



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, predicted by theory but never yet observed. The Mu2e experiment, which has received first-stage approval, could find indirect evidence for new particles and forces far beyond the reach of the LHC.



2



3



4

2

Scientists from 21 research institutions in the United States, Italy and Russia collaborate on the proposed Mu2e experiment.

3

Mu2e collaborators will push the technological limits of superconducting solenoids and particle trackers to achieve the science goals of the experiment.

4

Scientists have set up a test stand at Fermilab to develop the particle detection technology required for the Mu2e experiment.



Cosmic Frontier

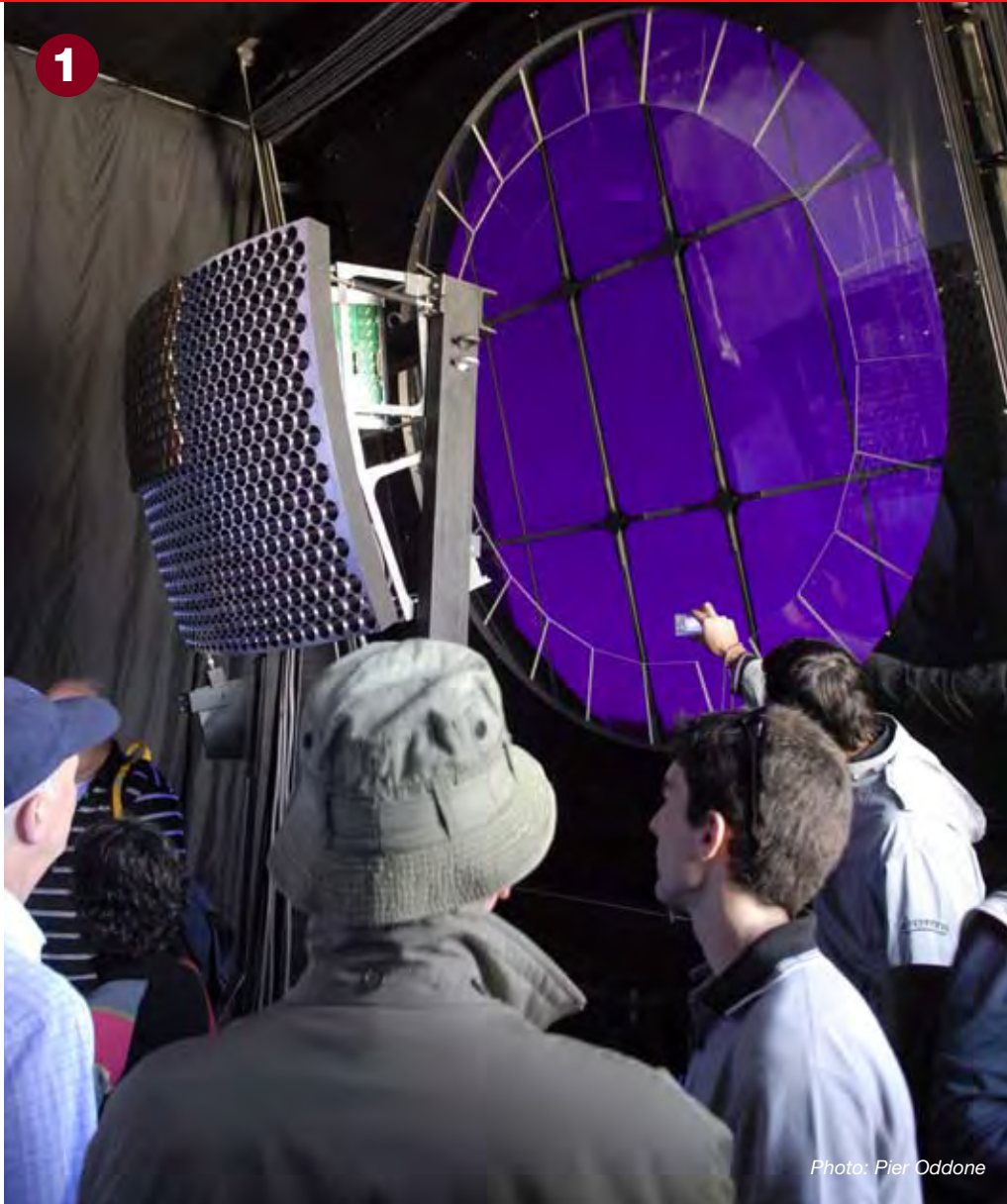
At the Cosmic Frontier, astrophysicists use the cosmos as a laboratory to investigate the fundamental laws of physics from a perspective that complements experiments at particle accelerators. Thus far, astrophysical observations, including the bending of light known as gravitational lensing and the properties 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.



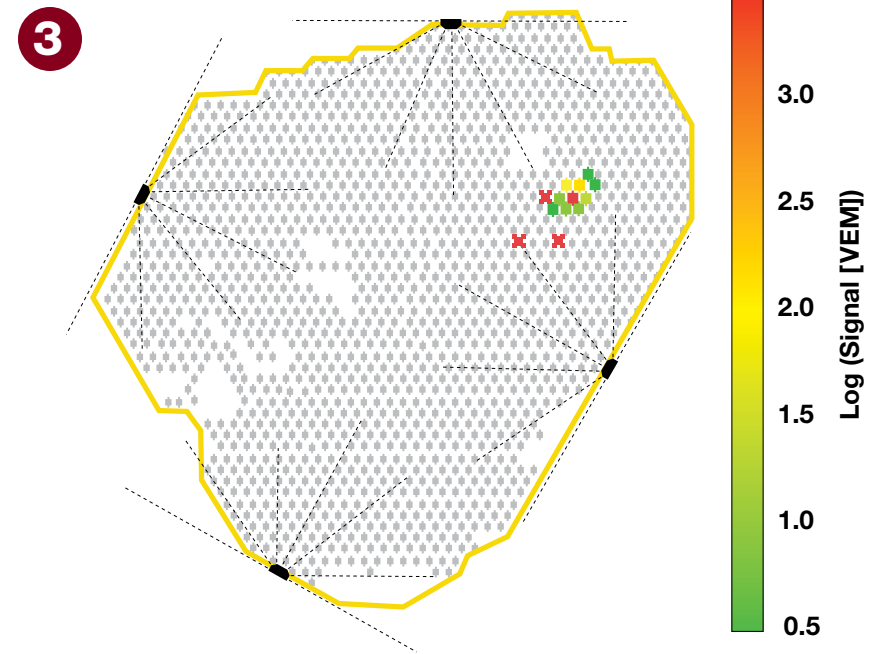


**DARK MATTER
DARK ENERGY**

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.



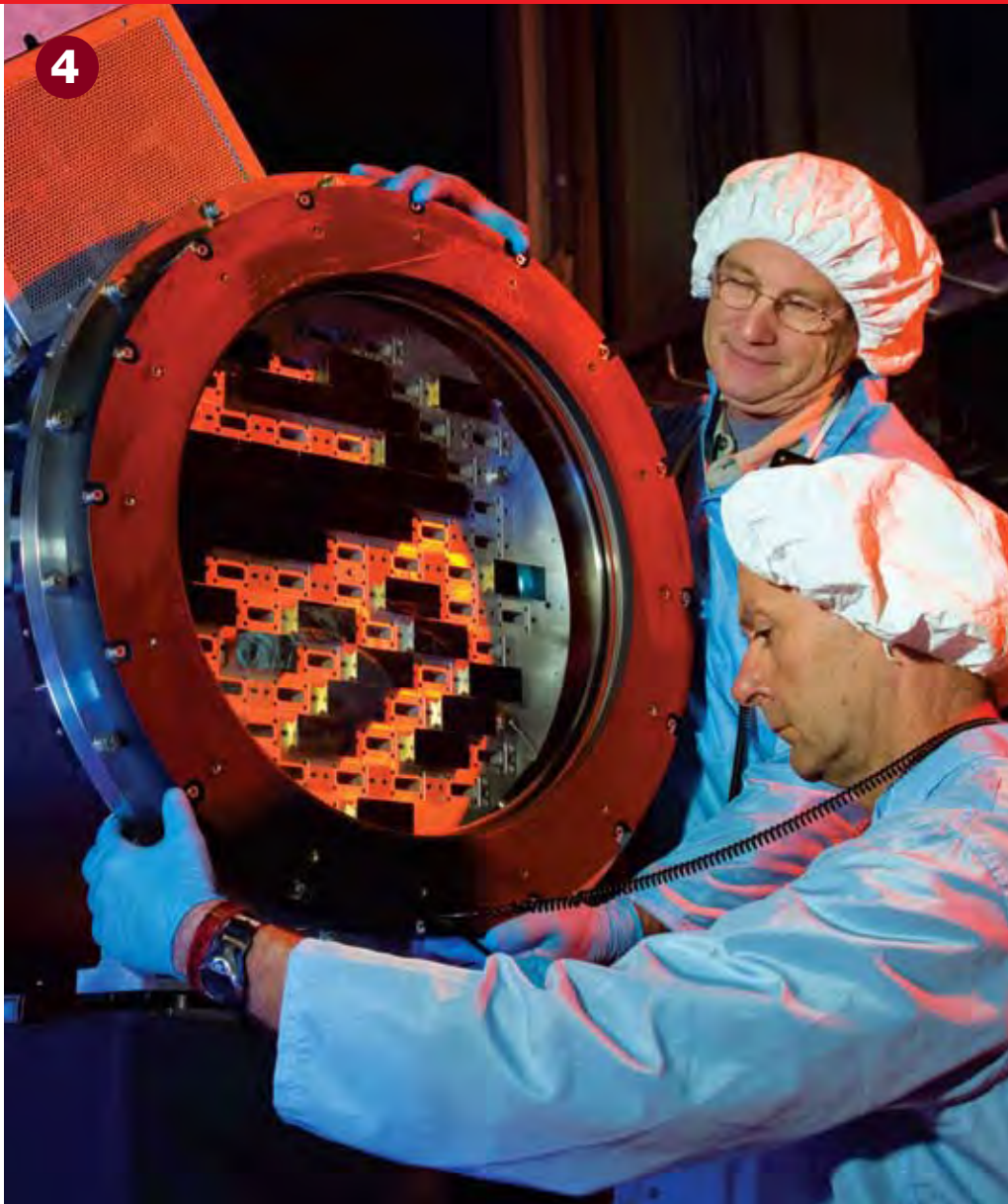
1 The Pierre Auger Observatory uses two complementary techniques to look for cosmic rays. Its 24 fluorescence telescopes operate on clear nights.



3 A single, high-energy cosmic ray can create a particle shower that covers up to 10 square miles of the Pierre Auger Observatory.



Dark Energy Survey / Dark energy accounts for 70 percent of all energy and mass in the universe. Yet we know very little about this ubiquitous substance, which speeds up the expansion of the universe. Fermilab is building a 520-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.



4

In a Fermilab clean room, technicians check the alignment of the front window of a full-scale prototype of the Dark Energy Camera.

5

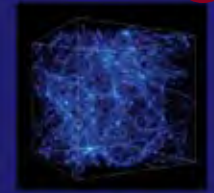
Gravity slows the expansion of the universe. In the last five billion years, dark energy has caused the expansion to speed up.

The Expansion of the Universe

5

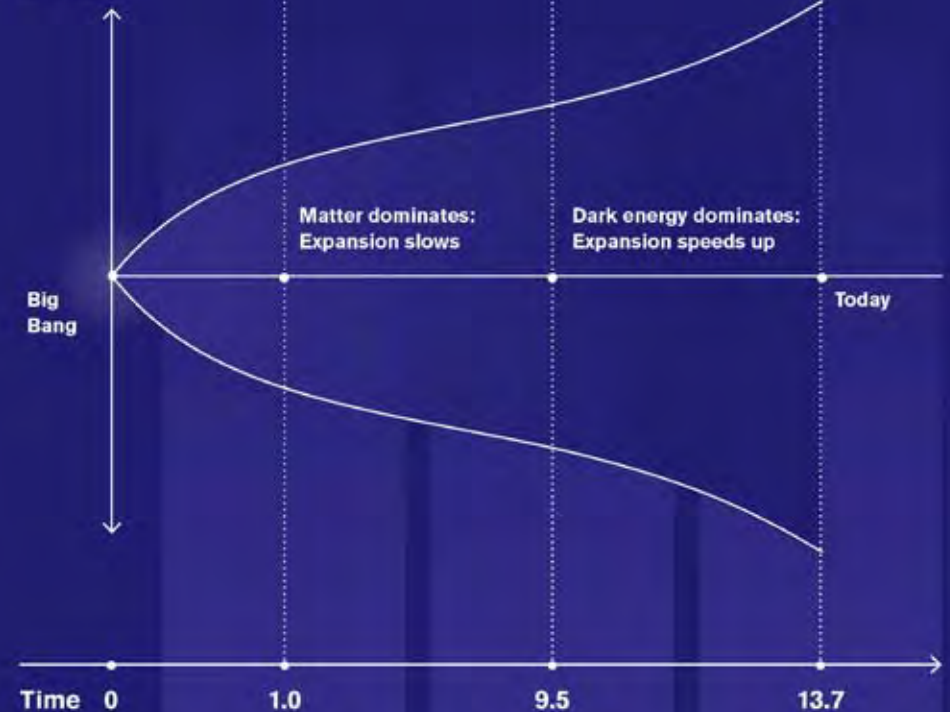
Galaxy Formation

Over billions of years, gravity draws matter together into a web of structure. The bright spots are where galaxies form.



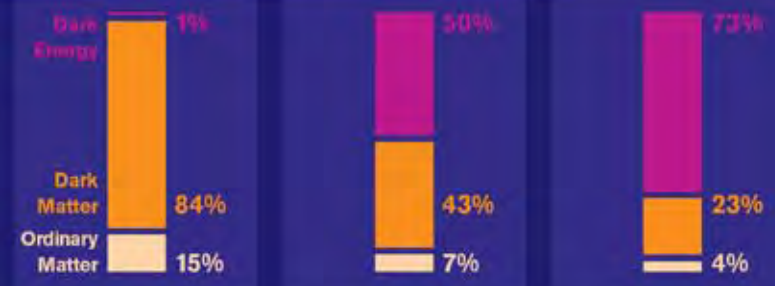
Size of the Universe

Not to scale



Not to scale;
In billion years

Energy and Matter Content

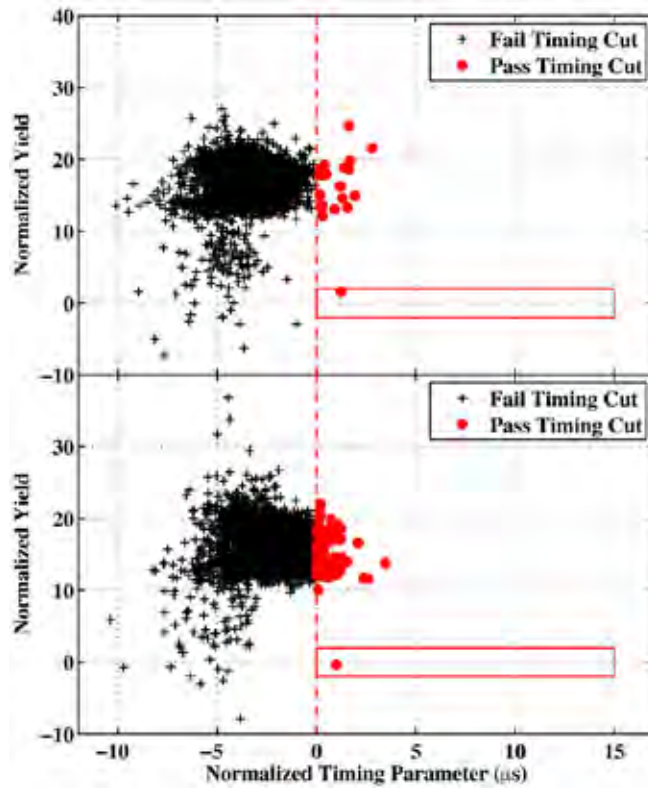


Simulations and visualization of galaxy formations by Andrey Kravtsov, The University of Chicago, and Anatoly Klypin, New Mexico State University

CDMS / Discoveries made during the past few decades tell us that a form of invisible matter holds the universe together. Dark matter accounts for 80 percent of all the matter in the universe. It exerts a gravitational force that has shaped our universe. The CDMS experiment, located a half mile underground in the Soudan mine, might have recorded the first whispers of dark-matter particles streaming in from space.



1



2



3



1

The CDMS experiment uses five towers with stacks of crystalline detectors to listen for vibrations caused by dark-matter particles striking ordinary matter.

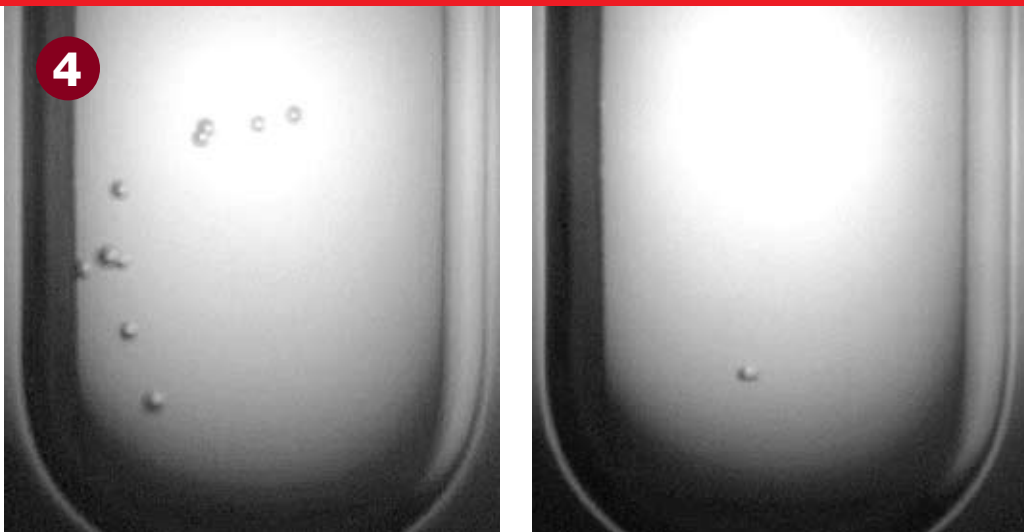
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In late 2009, CDMS experimenters made headlines when they announced the observation of two candidate events for dark-matter particles.

3

The CDMS collaboration, which includes 59 scientists from 18 institutions, plans to build a larger detector to trap more dark-matter candidates.

COUPP / Scientists use different techniques to detect dark-matter particles. COUPP employs bubble chambers to catch a glimpse of those particles. If a dark-matter particle traverses a chamber and collides with an atom in the chamber's liquid, the collision will create heat and cause the formation of a bubble. An automated camera records the bubbles in the chamber.



GammeV / The members of the GammeV collaboration use lasers and strong electromagnets to search for particles that could explain the origin of dark matter and dark energy. Their first experiment set stringent limits on axions, which are candidates for dark-matter particles. Now, a new tabletop experiment allows GammeV to look for hypothetical dark-energy particles.

4
COUPP can distinguish between the bubbles created by particles such as neutrons and the bubbles that dark-matter particles would create.

5
COUPP scientists are improving their odds of discovery by changing from a 1-liter bubble chamber to a larger vessel that can hold 30 liters of liquid.

6
GammeV scientists use laser light for a tabletop experiment that represents the first dedicated test of a dark-energy model in a laboratory.



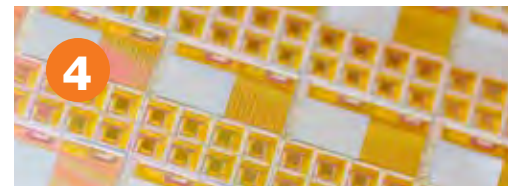
Benefits to society

From the construction of the first particle accelerators in the 1930s to the latest 21st-century innovations, the revolutionary ideas and technologies of particle physics have entered the mainstream of society and transformed the way we live. Today, more than 17,000 accelerators are in operation around the world— in industry, in hospitals and at research institutions. PET scans, superconducting wire, synchrotron light sources, cancer treatment, grid computing and the development of the World Wide Web are just some of the applications that have come from particle physics laboratories.



1

Particle beams can scan shipping containers for contraband materials.



2

The auto industry uses particle accelerators to treat the material for radial tires, reducing the use of solvents that pollute the environment.

3

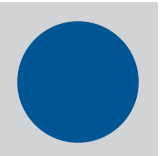
Companies use electron accelerators to turn plastic into the sturdy, heat-shrinkable film that protects DVDs and keeps meat and produce fresh.

4

The semiconductor industry relies on accelerators to implant ions in silicon chips. The process alters the way the material conducts electricity.

5

Physicists hope to improve the safety of artificial heart valves by making them with a material treated by a particle accelerator.



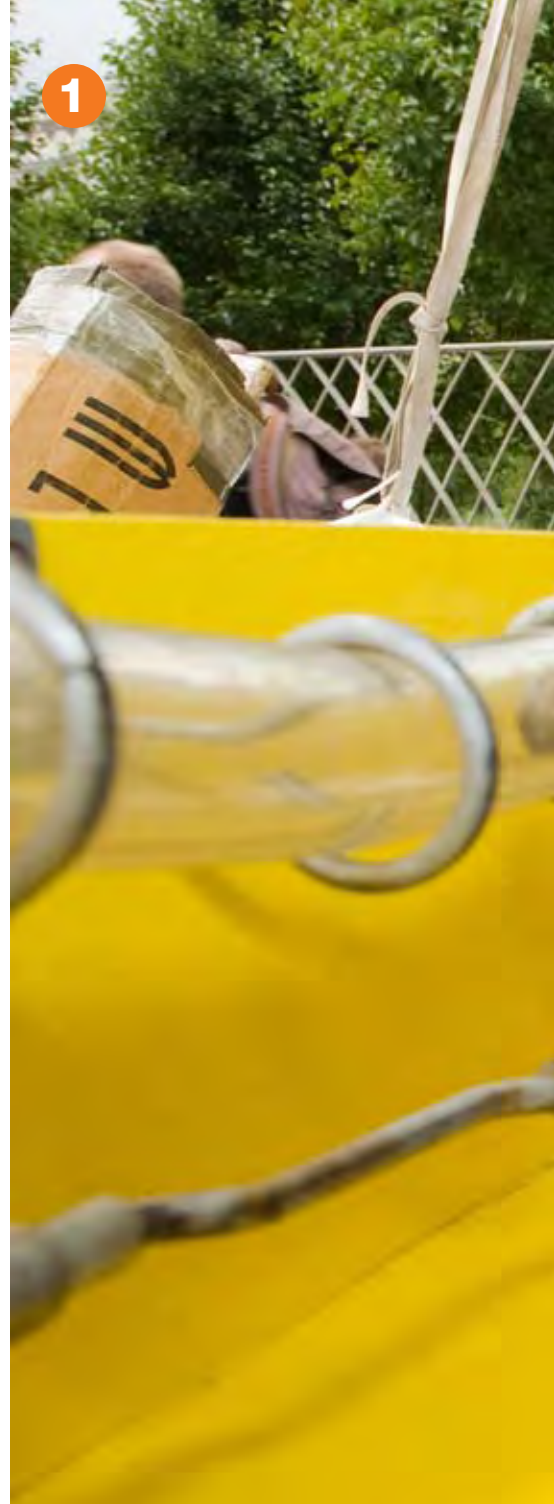
Education

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.

	FY2008	FY2009
K-12 students		
Students participating in activities at Fermilab	17,943	18,730
Students visited in classrooms by Fermilab staff	11,521	12,918
Students participating in other Fermilab activities offsite	130	10,353
Total	29,594	42,001
College/university students		
Students involved in onsite programs or internships	3,025	3,418
Ph.D.s received working at Fermilab (1,622 total Ph.D.’s received since 1974)	92	51
Teachers		
Teacher training	about 1,000	about 1,000
Online education		
Fermilab education Web site hits per year	7.3 million	9 million

Other educational outreach

- Fermilab operates the Lederman Science Center, a free, hands-on science education center open six days a week.
- Fermilab staff serve as research mentors to high school students. Students learn about careers in science, engineering and computing.
- Fermilab offers internships for college students studying physics, engineering, computing, ecology and journalism.
- Fermilab’s Saturday Morning Physics Program offers a nine-week course for about 300 local high school students a year.
- Fermilab’s Ask-A-Scientist program allows local residents to meet with physicists, engineers and computer scientists at an open house on the first Sunday of every month.
- Fermilab helped found and continues to partner with SciTech, a hands-on science museum in Aurora.
- Fermilab has donated prairie plant seeds to more than 40 schools since 1993.



1 Children explore how accelerators work using a simple experiment set up by Fermilab staff at the Science Chicago LabFest in downtown Chicago.

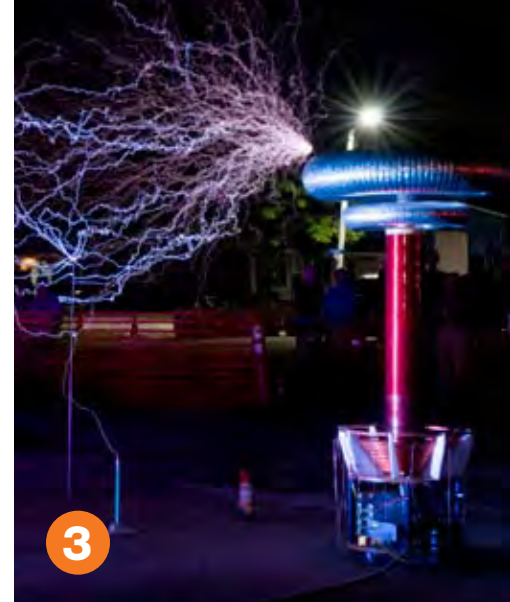


2

Pond sweeping, an outdoor educational activity for children, is one example of Fermilab's efforts to promote science education.



2



3



4

4

Each winter, Fermilab's Education Department holds a Family Open House with hands-on experiments for more than 3,000 parents and children.



5

5

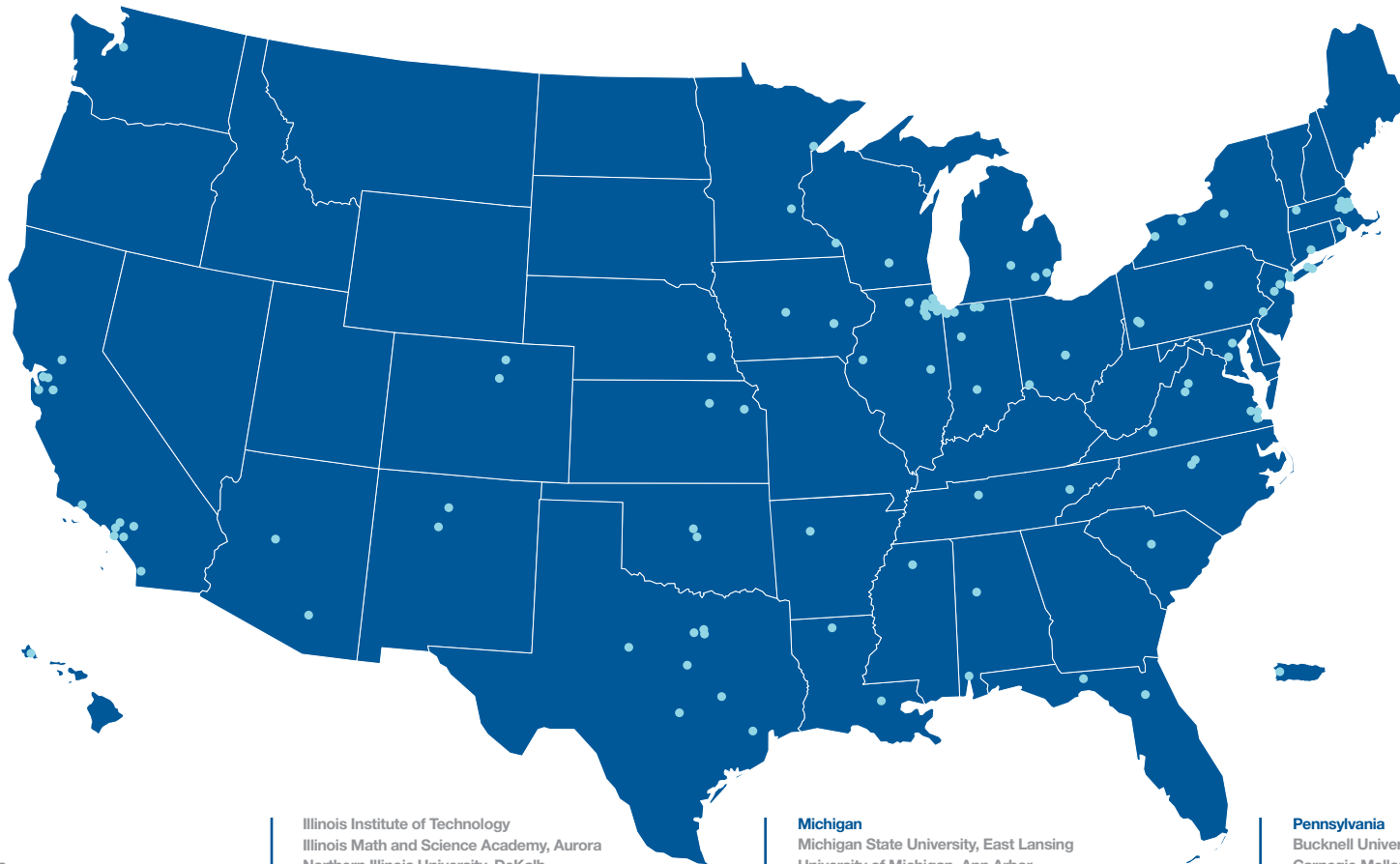
Fermilab's education outreach helps children understand how the universe works.



Fermilab connection

Fermilab serves some 3,000 scientists from 34 states and 33 nations. They collaborate on experiments at the Energy, Intensity and Cosmic Frontiers of particle physics to open doorways of discovery on the universe.





Alabama

University of Alabama
University of South Alabama

Arizona

Embry Riddle Aeronautical University
University of Arizona, Tucson

Arkansas

Arkansas Tech University, Russellville

California

California Institute of Technology, Pasadena
California State University
Lawrence Berkeley National Laboratory, Berkeley
Lawrence Livermore National Laboratory, Livermore
Stanford University
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

Colorado State University, Fort Collins
University of Colorado, Boulder

Connecticut

Yale University, New Haven

Florida

Florida State University, Tallahassee
University of Florida, Gainesville

Hawaii

University of Hawaii at Manoa

Illinois

Argonne National Laboratory
Benedictine University
Elmhurst College
Enrico Fermi Institute

Illinois Institute of Technology

Illinois Math and Science Academy, Aurora
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

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

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

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

North Carolina

Duke University, Durham
University of North Carolina

Ohio

Ohio State University, Columbus
University of Cincinnati

Oklahoma

Langston University
Oklahoma State University, Oklahoma City
University of Oklahoma, Norman

Pennsylvania

Bucknell University
Carnegie Mellon University, Pittsburgh
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

Tennessee

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 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, Blacksburg
University of Virginia, Charlottesville

Washington

University of Washington, Seattle

Wisconsin

University of Wisconsin, Madison

List as of January 2009



Milestones

In 2009, Fermilab set records for proton-antiproton collisions at the Tevatron accelerator. Physicists expanded the horizons of particle physics in experiments at the Energy, Intensity and Cosmic Frontiers.

January / Technicians complete the first assembly of a string of 3.9-GHz superconducting cavities at Fermilab.

Feb. 10 / Four Indian institutions sign a Memorandum of Understanding with Fermilab to collaborate on superconducting materials and superconducting acceleration technology.

March 9 / CDF and DZero announce the discovery of collisions that produce single top quarks, proof of a second kind of subatomic production mechanism for top quarks.

March 13 / CDF and DZero narrow the search for the elusive Higgs boson, setting more stringent constraints on the particle's mass.

March 18 / CDF finds evidence of a new composite particle, $Y(4140)$, whose curious characteristics may reveal new ways that quarks can combine to form matter.

March / DZero obtains the world's most precise measurement of the mass of the W boson.

April 1 / The MINERvA neutrino experiment observes the first interactions of neutrinos with carbon and hydrogen atoms.

May 1 / Officials from the U.S. Congress, the U.S. Department of Energy, Fermilab and the University of Minnesota break ground for the NOvA experiment in Minnesota.

May 27 / The ArgoNeuT experiment, which uses a new neutrino detection technology, records the first neutrino signals.

June 29 / CDF announces the discovery of the Omega-sub- b baryon, a distant relative of the proton.

July / Fermilab begins the upgrade of its neutrino beamline from 400 to 700 kilowatts for the NOvA project.

August / Construction begins on a high-availability computing center at Fermilab.

September / Working with Fermilab and other DOE laboratories, a U.S.-based manufacturer produces the first SRF acceleration cavity that meets the performance goal for the next-generation linear accelerator.

Sept. 28 / The Department of Energy announces Mission Need for the MicroBooNE neutrino experiment at Fermilab.

October / Technicians begin installing the first cryomodule in Fermilab's new superconducting radio-frequency test accelerator facility.

December / The Muon-to-Electron Conversion Experiment (Mu2e) receives DOE's Mission Need approval.

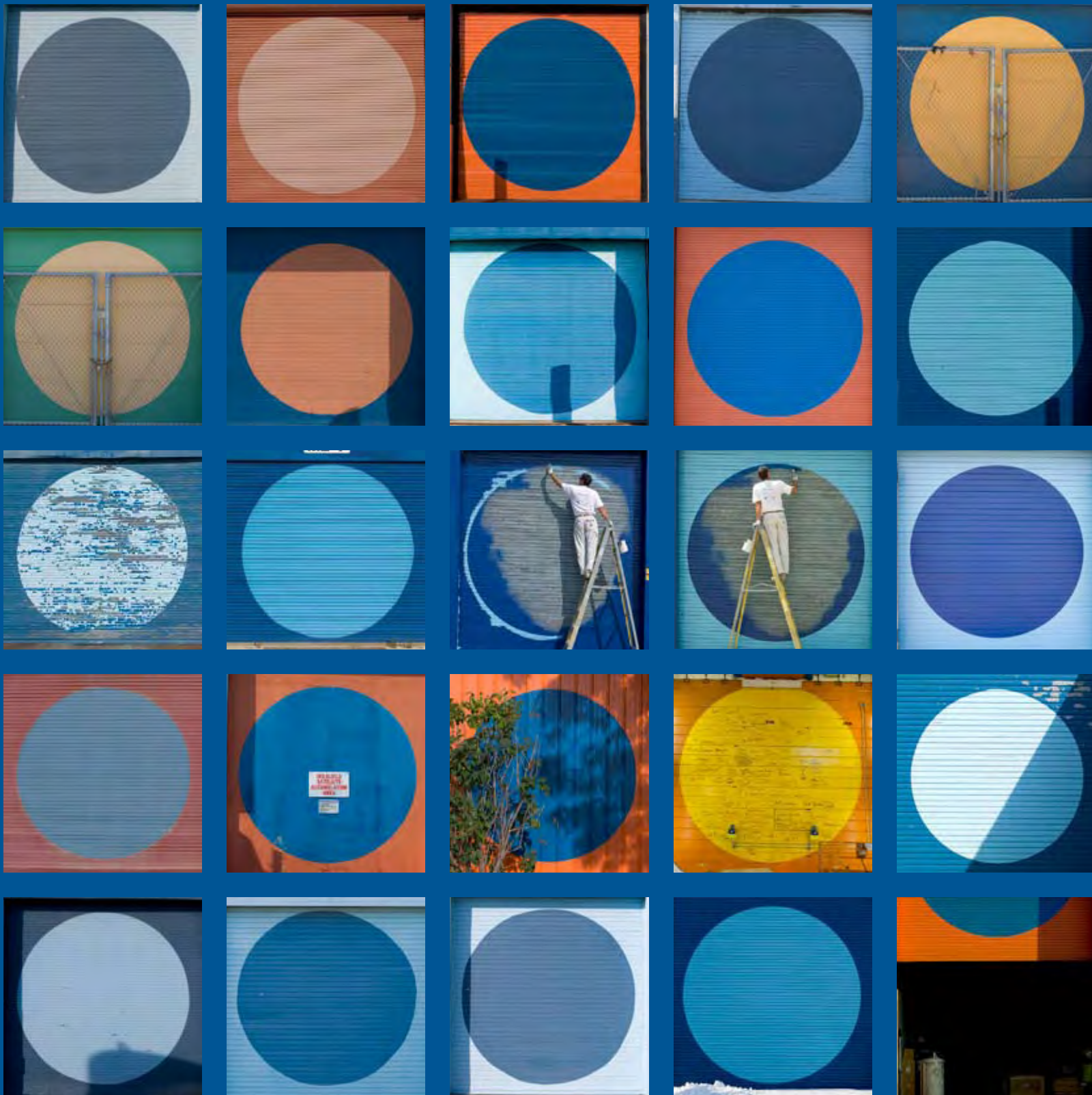
Dec. 4 / A superconducting prototype magnet made of niobium-tin achieves its design goal of 200 Tesla/m.

Dec. 8 / Scientists in the LHC Remote Operations Center at Fermilab observe the first particle collisions in the CMS detector at CERN at the world-record energy of 2.36 TeV.

Dec. 17 / The Cryogenic Dark Matter Search announces the observation of two candidate events for dark-matter particles.

Dec. 21-27 / The Fermilab accelerator complex sets a record for the hours of particle collider operation in a single week, producing 151 hours of physics data.






Fermilab

Kirk Road and Pine Street
 P.O. Box 500
 Batavia, Illinois 60510

630.840.3000

www.fnal.gov
fermilab@fnal.gov



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ENERGY

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