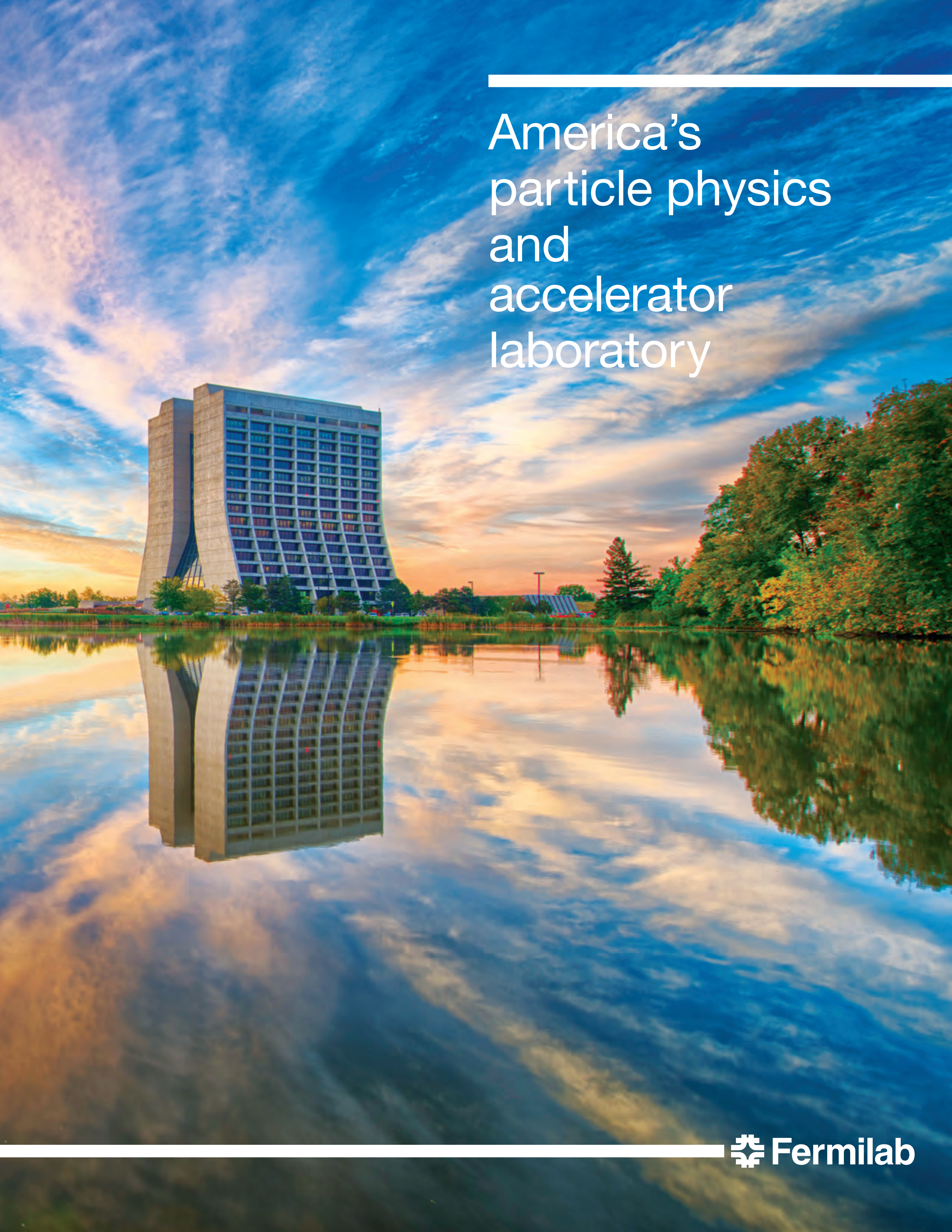
America's particle physics and accelerator laboratory



Fermilab

Home of the world's most powerful neutrino beam

Leader in accelerator and detector technology

International center for particle physics research

U.S. DEPARTMENT OF ENERGY | Office of Science

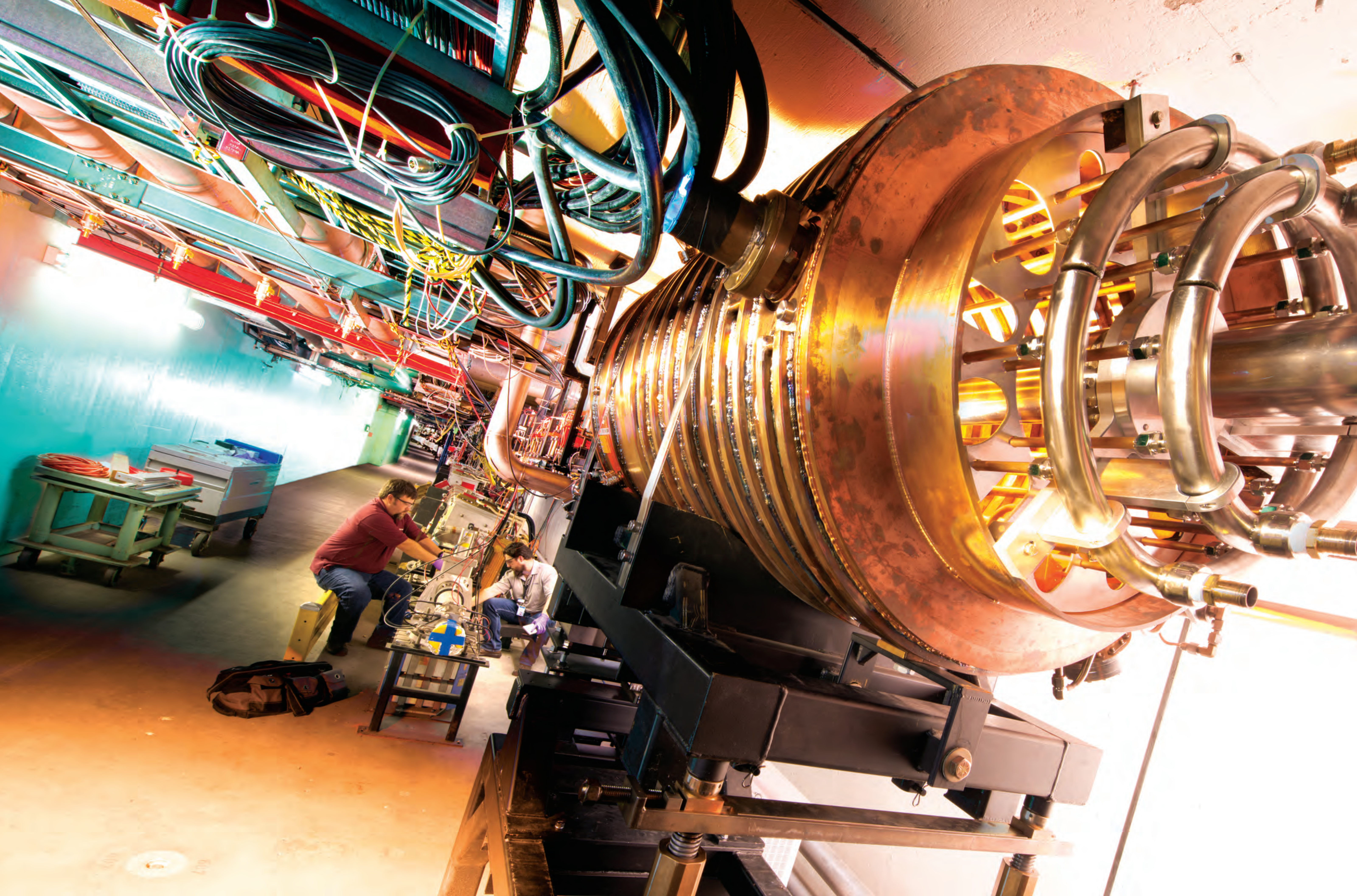
Fermi National Accelerator Laboratory is a U.S. Department of Energy Office of Science laboratory operated under contract by the Fermi Research Alliance LLC.

Particle physicists explore the building blocks of matter to answer questions all of us have asked ourselves.

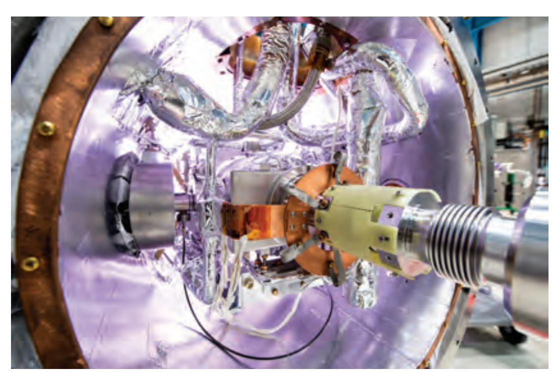
How does the universe work? What is it made of? How did it evolve, and what will be its fate? What else is out there that we can't see?

Fermilab scientists, engineers, and technicians design and build some of the most sophisticated technology in the world to answer these questions.

In the process, they solve problems closer to home—all from a lab in the heart of the Illinois prairie.



The premier particle physics laboratory in the United States



Fermilab advances accelerator technology, such as the superconducting radio-frequency cavities that produce powerful beams for research around the world.

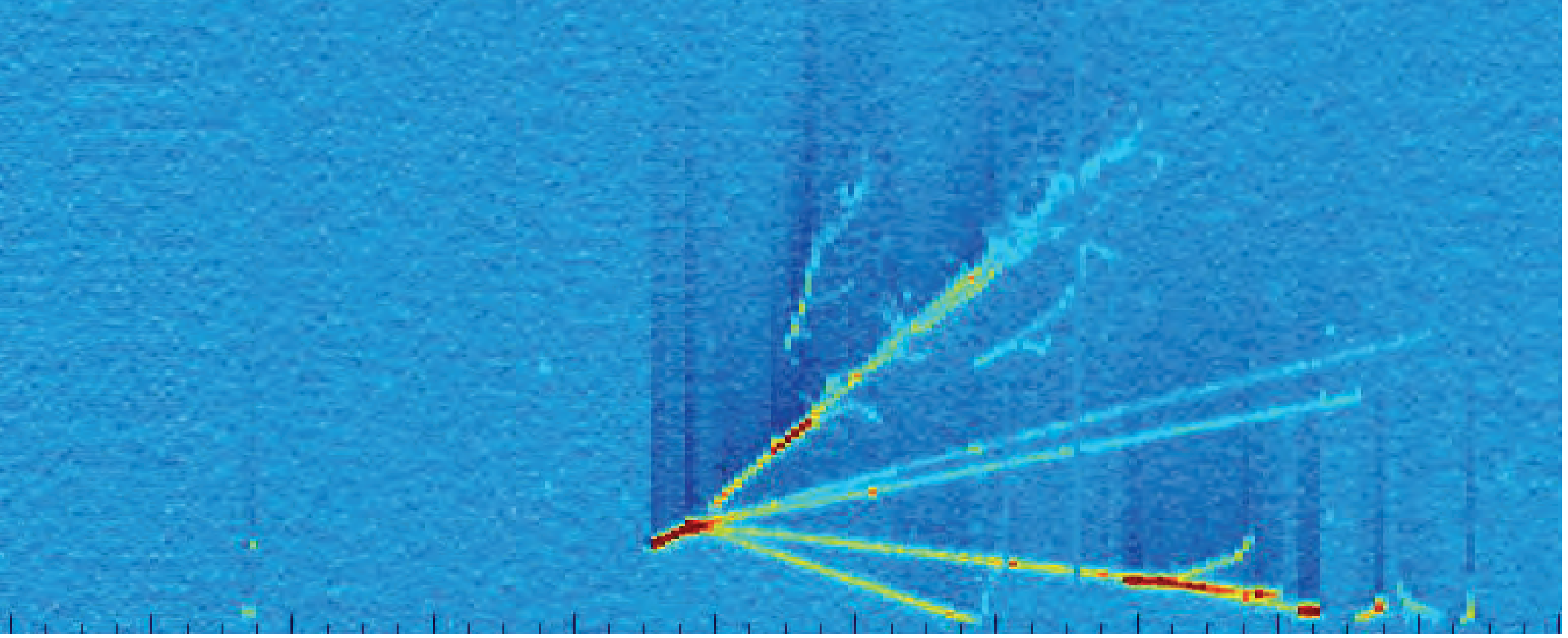
In 2012, scientists working on the Large Hadron Collider's ATLAS and CMS experiments announced the discovery of the long sought-after Higgs boson, a particle scientists think may give all others mass. Fermilab is the U.S. hub for the CMS experiment.

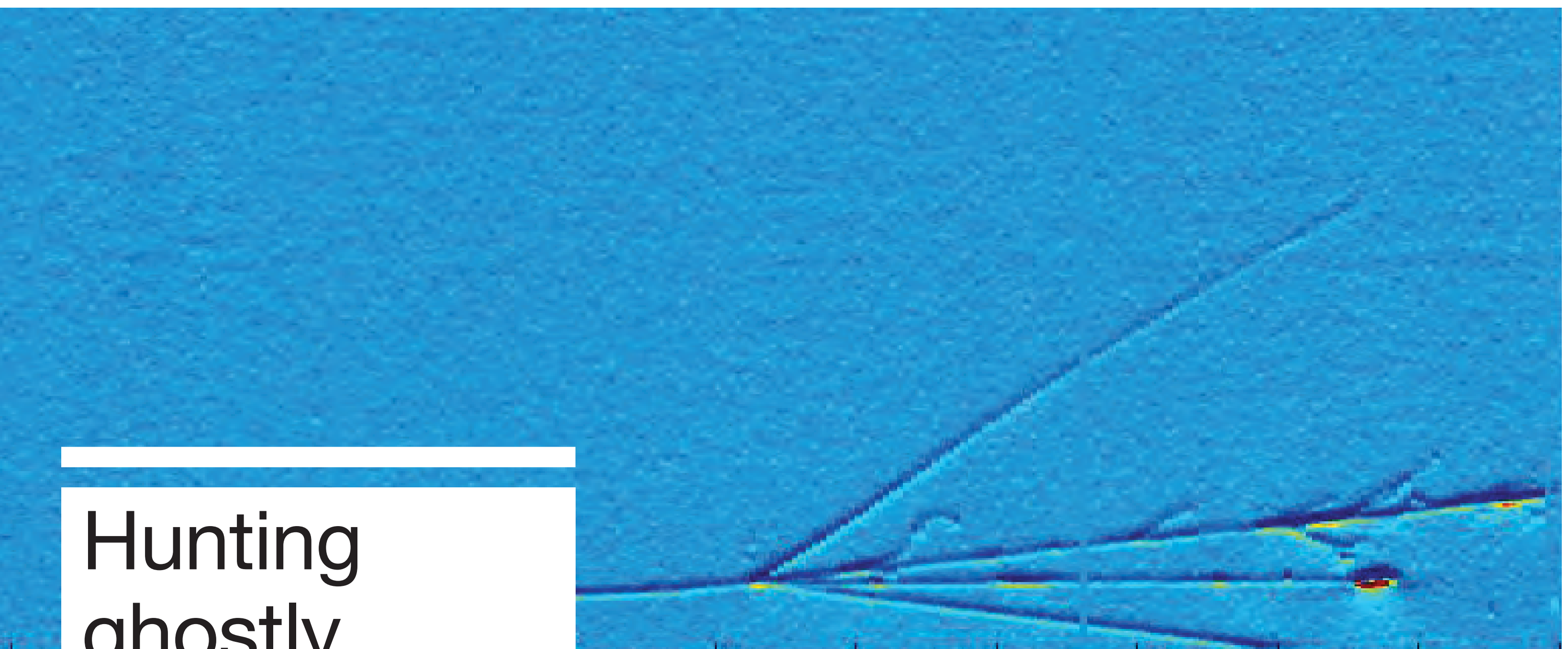
Fermilab's scientists work with thousands of physicists around the world to conduct experiments that probe the nature of matter, energy, time, and space.

Neutrino experiments allow scientists to explore beyond the Standard Model of physics, complementing research at the Large Hadron Collider.

For almost five decades, Fermilab employees have been inventing, building, and operating some of the biggest—and coolest—machines in the world, all to observe nature's tiniest particles and distant cosmic phenomena. At Fermilab, scientists discovered the top and bottom quarks, saw the first direct evidence for the tau neutrino, mapped the composition of protons and antiprotons, and found a quasar 27 billion light-years away. Physicists are continuing this tradition of discovery with a slew of new experiments that probe neutrinos, muons, and more.

Today thousands of scientists, engineers, and students work with Fermilab each year. Together we're operating and upgrading our powerful accelerators and detectors, analyzing mountains of data in our high-tech computing facilities, and designing new experiments to better understand the most mysterious aspects of the universe. This means things like helping discover the Higgs boson, searching for dark matter and dark energy, and unraveling strange particles that live on the very edge of detection.





Hunting ghostly particles

Liquid-argon detectors catch glimpses of neutrinos' rare interactions with matter. A comprehensive R&D and test program that uses a suite of neutrino detectors on the Fermilab site is aimed at the construction and operation of massive liquid-argon detectors for the proposed Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment.

Scientists use Fermilab's powerful accelerators to create and investigate some of the most mysterious particles in the universe.

They're small, nearly massless, and so antisocial they make hermits look friendly. Meet the neutrino, a mysterious particle that interacts with matter so rarely, it is often called the ghost particle.

These elusive particles could play a key role in answering the question of how we came to exist. Early in the universe, matter and antimatter should have formed in equal amounts, ultimately annihilating everything. Scientists think neutrinos could have tipped the cosmic balance early on, creating a universe dominated by matter and making it possible for us to be here today.

Neutrinos come in three varieties and change among them as they travel. Scientists are studying this oscillation and searching for additional kinds of neutrinos. To explore the nature of how these particles change over long distances, the international scientific community is proposing the Deep Underground Neutrino Experiment that will use two detectors far apart—one close to the neutrino source at Fermilab and another 800 miles away in South Dakota. The neatest part? The neutrinos head to the distant detector straight through the Earth, no tunnel required.

Scientists measure the neutrino beam at its origin at Fermilab and again at gigantic distant detectors, such as the 14,000-ton NOvA detector in Minnesota.

How do we measure neutrinos?

Neutrinos are made in stars, in the Earth's core, and even in bananas. They pass through everything—planets, people, and potatoes alike. Take a look at your hand; a trillion neutrinos pass through it every second. Finding these little particles is a challenge, to say the least. So how do scientists do it?

Build big targets
Researchers make massive structures so that neutrinos are more likely to interact with their experiments.

Send powerful beams
Fermilab produces the most densely packed beam of neutrinos in the world and aims it toward near detectors on site and far detectors in other states.

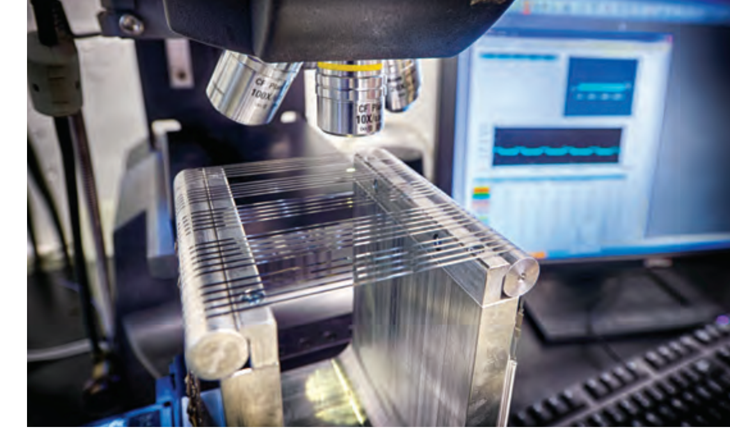
Gather the clues
Neutrinos bump into atoms in the detector, causing light and electrons to be released. These signals are then captured by sophisticated electronics.

Read tracks
Different neutrino interactions create unique particle trails. Scientists use these tracks to identify and measure the original neutrinos.

This ring-shaped experiment, Muon g-2, will measure a property of the muon with four times more precision than any previous experiment of its kind. Muon g-2 reuses a 50-foot-wide electromagnet that journeyed in one piece over 3,200 miles from New York.

Discovering new physics with muons

Mu2e uses an ultrasensitive detector to look for muons changing in a particular way that scientists have never seen before. The international Mu2e collaboration develops and crafts precision parts that create, guide, and track the muons through the S-shaped experiment.



State-of-the-art detectors will measure particles with the most precision to date, searching for cracks in scientists’ understanding of the universe.

Learning more about the muon, a heavy cousin of the electron, could show places where the current understanding of physics breaks down—leading to new knowledge. Research into muon physics complements studies at the Large Hadron Collider, Fermilab’s neutrino beams, and telescopes taking wide-ranging surveys of the night sky.

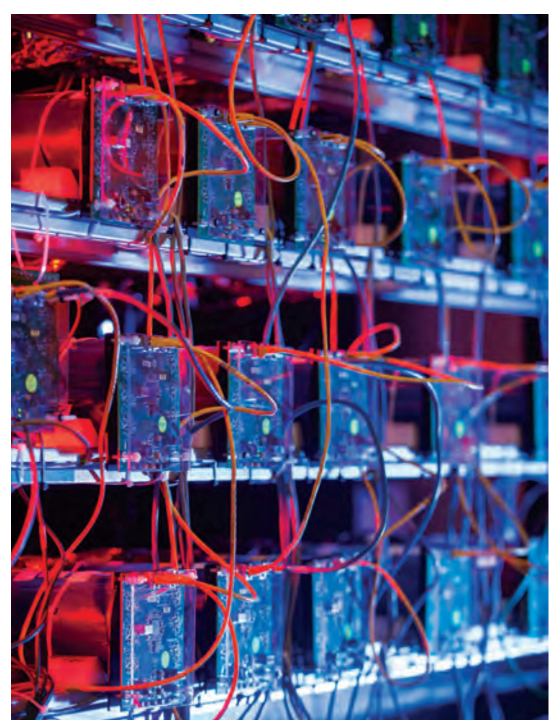
In a new Muon Campus, scientists are transforming Fermilab’s old antimatter factory into a brand-new facility that will feed intense muon beams to two experiments. Fermilab’s powerful accelerator complex will make around one quintillion muons for one experiment alone; that’s as many muons as there are grains of sand on all the world’s beaches.

Zipping around at nearly the speed of light, muons headed for both experiments will run headlong into ultrastrong magnetic fields made possible by supercooled magnets. The first experiment will study how muons “spin” in a magnetic field; the second will search for a possible new type of transformation of a muon into an electron.

Deviations in either experiment from what is predicted by our current models means a big step toward discovering new particles and forces.

Accelerating scientific discovery

Researchers from around the world use Fermilab's two test beams to vet their detectors and advance new technologies. Engineers are also making improvements to Fermilab's accelerator complex, which already produces the most intense neutrino beam in the world.



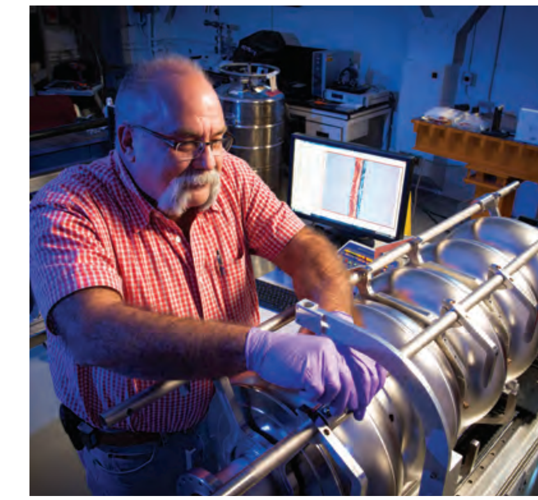
Fermilab partners with other laboratories to bring premier accelerator technology to their research—whether that's superconducting magnet coils for Jefferson Lab or cavities to improve SLAC's X-ray laser.

Fermilab scientists, engineers and technicians develop the next generation of particle physics technology.

Fermilab expertise and equipment helps power the most sophisticated experiments in Illinois, across the United States, and around the world. Parts designed and engineered here find homes at laboratories, in accelerators, and on telescopes around the globe, and scientists from near and far use our facilities to develop and test their own equipment.

Fermilab is a leading center for the development, assembly, and testing of superconducting radio-frequency (SRF) cavities, the technology of choice around the world for the next generation of particle accelerators. SRF cavities switch electric fields millions of times per second to propel particles forward. Future projects, including a proposed major upgrade of the Fermilab accelerator complex, will use SRF cavities to generate powerful particle beams and shoot them to targets up to 800 miles away.

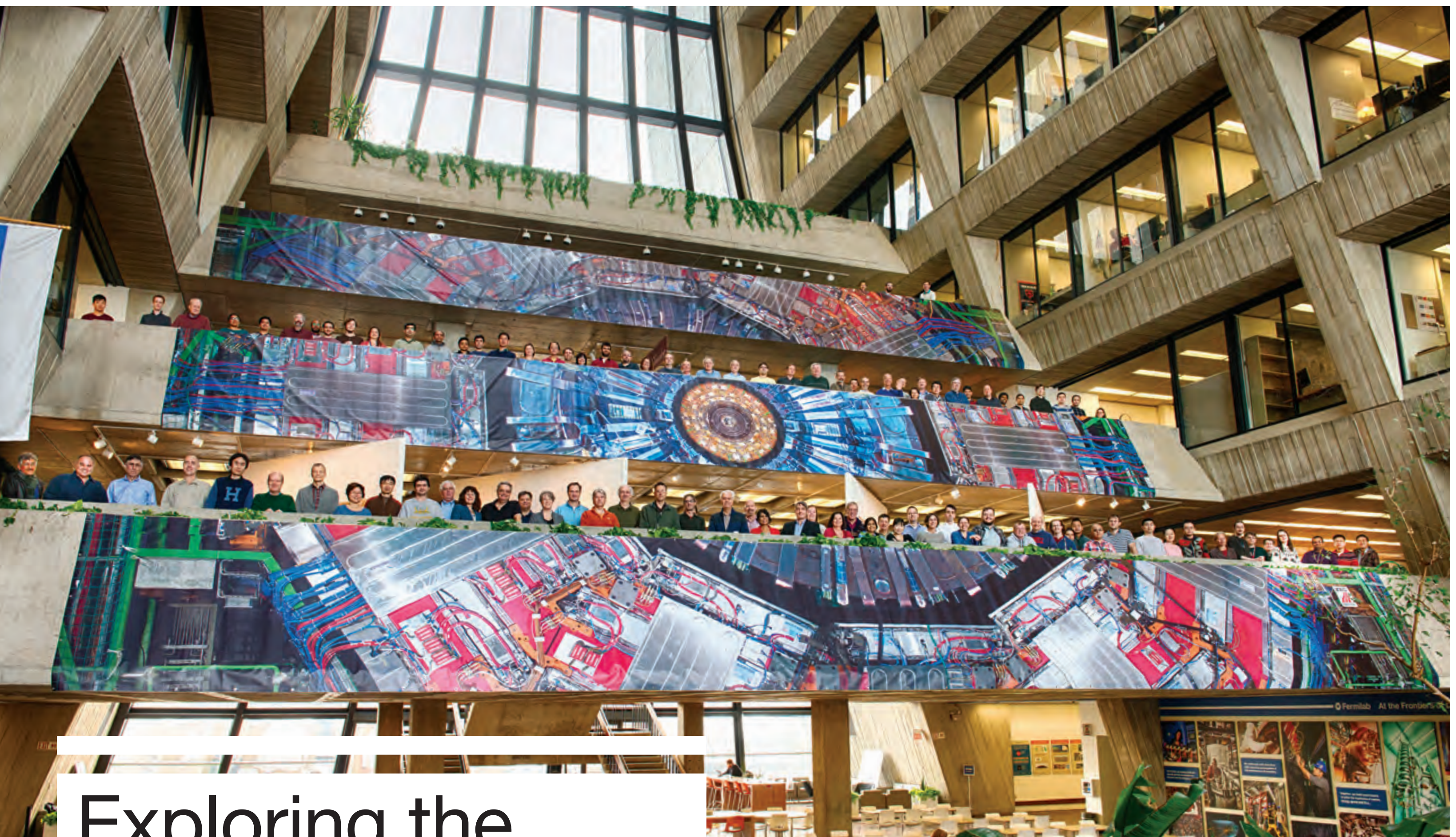
The laboratory is also a hub for the development of powerful superconducting magnets such as those that focus beams into collision at the Large Hadron Collider at CERN in Switzerland. Fermilab is working again with CERN and its other partner laboratories to make shorter but more powerful magnets for the major upgrade of the LHC in 2020. Laboratory scientists and technicians have also contributed critical parts to experiments around the globe, including detector components, electronics, software, and computing system designs. On-site computing facilities and monitoring stations support experiments and researchers located thousands of miles away.



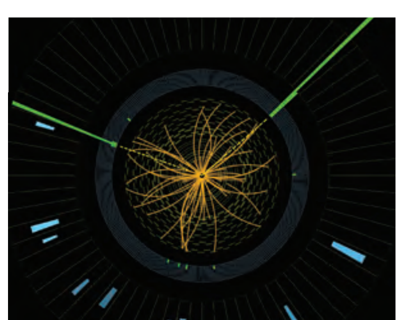
Advancing industry

To delve ever deeper into the mysteries of matter, Fermilab scientists have developed a symbiotic relationship with industry that drives the development of state-of-the-art technologies. One example: Advanced Energy Systems, a privately held company based in Medford, NY, and Princeton, NJ, builds particle accelerator components such as superconducting radio-frequency cavities and other research tools for national laboratories. It has grown into a multimillion-dollar business designing new technologies for discovery science, homeland security, defense, and environmental remediation.

Scientists conduct thousands of hours of shifts from Fermilab's Remote Operations Center for the Large Hadron Collider. Their work on the CMS experiment located at CERN helped lead to the discovery of the Higgs boson.

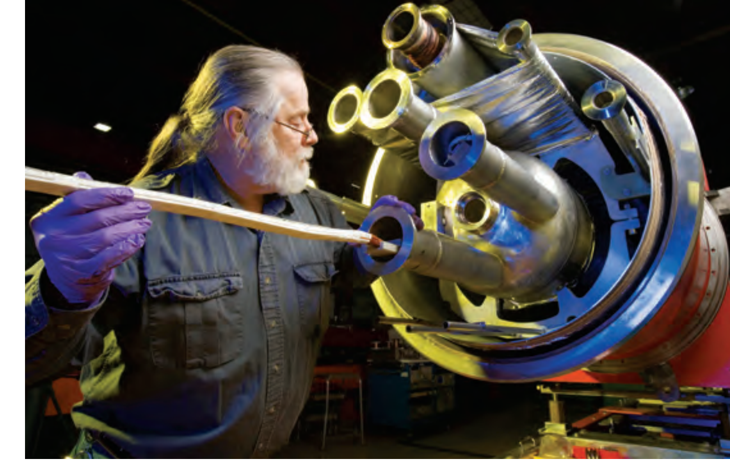


Exploring the highest energies



More than 4,000 people from 42 countries work on the CMS collaboration, which uses a massive detector to study trillions of energetic particle collisions. Fermilab serves as the hub for U.S. physicists working on the experiment.

Fermilab researchers and engineers are instrumental to the Large Hadron Collider's success. They built the magnets that guide the proton beams into collision as well as sections of the CMS detector, which measures collision debris.



Fermilab's Tier-1 computing center processes data for the CMS experiment and supports the research activities of scientists around the world.

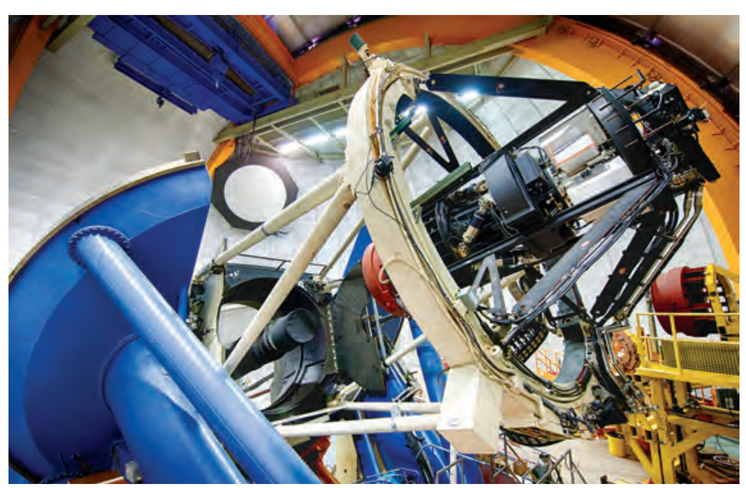
Fermilab resources and expertise drive science at the Large Hadron Collider.

No lab is an island. The size and scale of today's particle physics projects require international collaborations to plan, build, and carry them out—often over the course of decades. The ultimate example of this cooperative spirit is the Large Hadron Collider at the CERN lab in Geneva, Switzerland, built by more than 10,000 people from dozens of countries, including thousands from the United States. Collaboration gets results: the LHC was used to discover the Higgs boson in 2012 and, after a two-year-long pause for refurbishment, is back on the hunt for new particles and forces.

Fermilab is a critical partner on the LHC, supporting the participation of almost 1,000 U.S. scientists in the CMS experiment that co-discovered the Higgs boson. The lab's powerful computing center ensures that scientists have quick access to vast quantities of data for analysis, and an on-site Remote Operations Center means that U.S. scientists and students can monitor their detector from 4,000 miles away.

The laboratory also plays a crucial role in supplying components for the CERN-based accelerator and detector. The powerful magnets that focus LHC beams into collision and many critical pieces of the CMS detector were assembled and tested at Fermilab before the collider started up and smashed energy records in 2009. Now scientists, engineers, and technicians in Illinois are working with partners across the country to design and build the next generation of magnet and detector technology for LHC upgrades that will power new discoveries about the very fabric of our universe.

Journey to the dark side



The Dark Energy Camera, based at Cerro Tololo Inter-American Observatory in Chile, can see light from up to 8 billion light-years away and captures more than 100,000 galaxies in each snapshot.

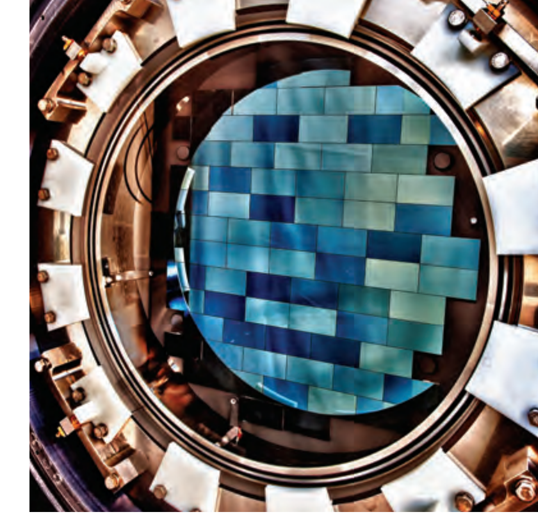
With experiments atop mountains and far below the Earth's surface, Fermilab measures the cosmos to learn about our past, present, and future.

The universe is a mystery. Scientists can account only for four percent of the "stuff" in the cosmos—things like planets, stars, and people. The remainder is dark matter, an invisible substance that makes up most of the mass in the universe, and dark energy, which is speeding the expansion of space. But what are these strange particles and forces that govern our world?

Fermilab is helping scientists build the experiments that will find out. Dark matter hunters are working on an ultrasensitive detector destined for North America's deepest underground laboratory. There, towers of crystals will wait for impacts from dark matter candidates called WIMPs, or weakly interacting massive particles.

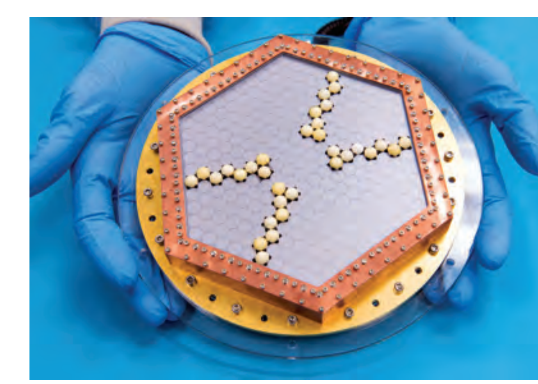
Meanwhile, dark energy detectives are staring at the sky. They use one of the world's most powerful cameras, a 570-megapixel behemoth built at Fermilab, to image 5,000 square degrees of southern sky. This Dark Energy Survey has already discovered more than 1,000 supernovae and mapped millions of galaxies to help us understand the accelerating expansion of our universe. Fermilab scientists are also developing detectors for the next stage of the South Pole Telescope, a project that will help researchers to better understand both neutrinos and the initial vast expansion of our universe.

The Super Cryogenic Dark Matter Search uses towers of disks made from silicon and germanium to search for particle interactions from dark matter.



Material progress

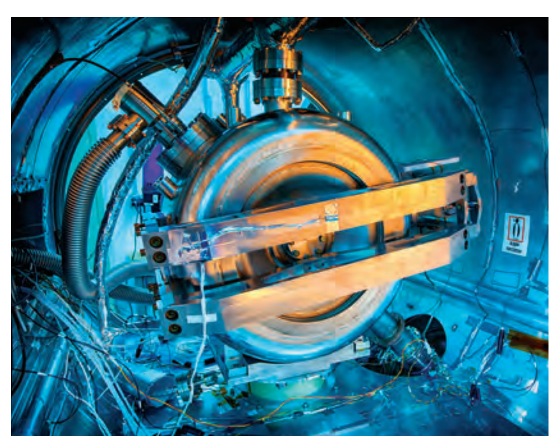
To capture the faint light of distant galaxies, astronomers use equipment called charge-coupled devices, or CCDs, built from special silicon. The material is ultrasensitive to infrared light and enables a new generation of astronomical observations that, among other things, aim to solve the mystery of dark energy. More than 60 CCDs are in place on the Dark Energy Camera, which scans the night sky to take pictures of galaxies. DOE laboratories also use the material to build supersensitive X-ray detectors. First developed for particle collider experiments, this silicon technology is now commercially available.



The South Pole Telescope will use precise detectors to map the light left over from the big bang and learn more about the early evolution of the universe.

Partnering to improve your life

To speed technology transfer, Fermilab created the Illinois Accelerator Research Center, a cutting-edge facility that will unite scientists and engineers from Fermilab, Argonne, and Illinois universities with industrial partners.



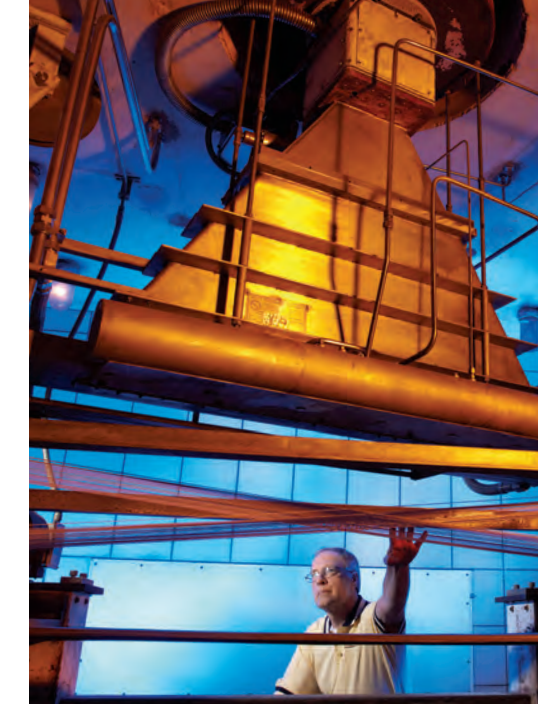
Technologies developed for science make a difference to your health, wealth, and security.

Technologies originally developed by physicists to answer questions about the universe are hard at work every day making your life better. Right now, more than 30,000 particle accelerators around the world are treating cancer, sterilizing medical equipment and food packaging, shrink-wrapping turkeys, and helping create the silicon chips that power your cell phone.

Computing advances for particle physics have made a huge impact on the planet. The World Wide Web was created to help particle physicists collaborate internationally. Complex software toolkits used to simulate the behavior of particles are used by the medical and aerospace industries.

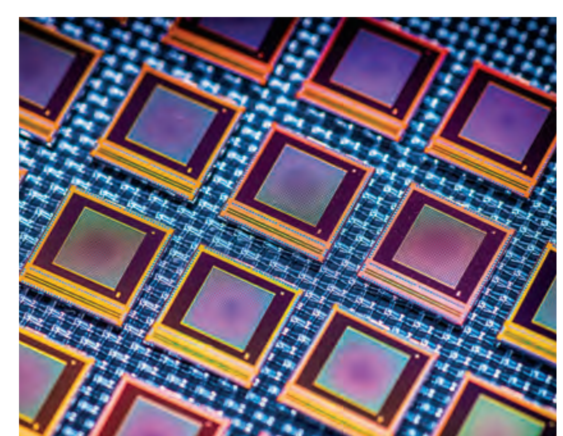
Particle detector technology helps in unexpected ways, too—by scanning cargo at ports, testing the integrity of equipment, and even helping you get an accurate weather forecast.

New facilities at Fermilab will encourage greater partnership with local and national industries, spurring advances and applications that will benefit everyone.



Industrial applications

Accelerators take on crucial roles outside of scientific discovery in areas you might not expect, like designing car parts, curing the ink on cereal boxes, and creating the most absorbent diapers. They're also used to 3-D print medical implants made of strong metals or polymers. Researchers found that the microscopic makeup of an implant influences how a patient's body accepts it. Crafting these precise medical devices with accelerators can reduce inflammation and rejection, improving surgical outcomes and patient mobility.



Fostering industrial partnerships will create innovative uses for detector and accelerator technology, which can lead to new products and businesses or improve those that already exist.

Fermilab by the numbers

5 tons	The Dark Energy Survey camera weighs 5 tons and is mounted on the Victor M. Blanco Telescope in Chile.
30 petabytes	Fermilab's computing center has 30 petabytes of disk storage, 70,000 computing cores, and the ability to store 1,000 petabytes on tape.
50 feet	Muon g-2's massive superconducting magnet is 50 feet in diameter and will produce a magnetic field 30,000 times that of Earth.
230 Ph.Ds	Since 2008, the work on ATLAS and CMS experiments at the LHC has resulted in 230 doctoral degrees for U.S. students.
800 miles	The proposed Long-Baseline Neutrino Facility will send neutrinos 800 miles through the Earth to the Deep Underground Neutrino Experiment in South Dakota.
1,090 people	As the U.S. headquarters for the LHC's CMS experiment, Fermilab provides scientific, technical, and organizational support for over 1,000 physicists, engineers, and students.
2,300 physicists	Fermilab sees more than 2,300 users each year. These physicists use Fermilab facilities to carry out their research.
10,000 times	The Mu2e experiment will be 10,000 times more sensitive to a special muon transformation than previous experiments.
40,000 students	Every year Fermilab employees visit about 25,000 students in classrooms and host more than 15,000 students at the lab.
$500 billion	Particle accelerators contribute more than $500 billion to the global economy every year in products and services.

Fermilab explores the universe, captures imaginations, and inspires future generations.

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Inside front cover image: Fermilab's Main Injector particle accelerator
Inside back cover image: A Dark Energy Camera picture of a barred spiral galaxy

Fermilab

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The Fermilab site is open to the public. Learn more at Fermilab's website at fnal.gov and follow the lab on Facebook (facebook.com/Fermilab) and Twitter (@Fermilab).