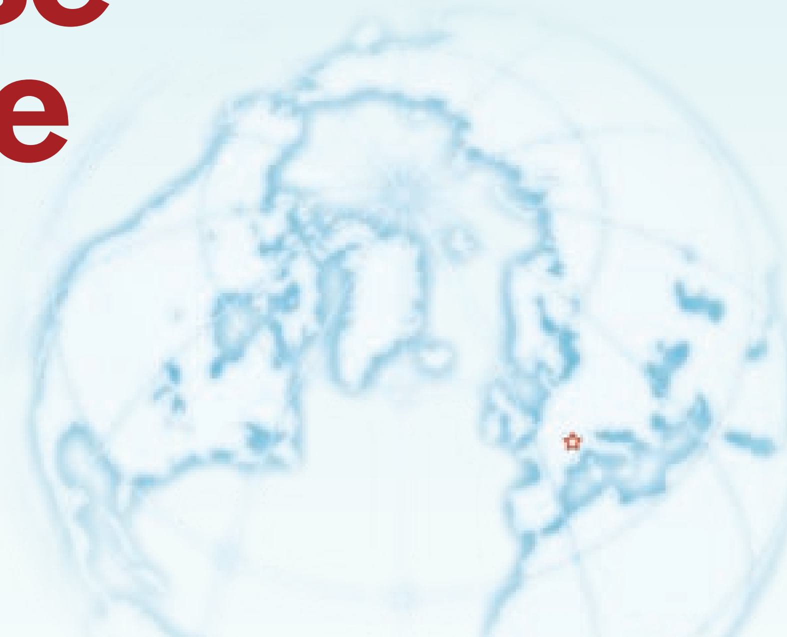
Across the ocean, yet close to home

By Katie Yurkewicz



Among the 10,000 people from around the world who are working on the Large Hadron Collider, 1000 hail from universities and national labs in the United States.

The Large Hadron Collider is the world's next-generation particle accelerator. Arguably the most ambitious scientific endeavor ever undertaken, the $8.7 billion project at CERN, the European particle physics lab in Geneva, Switzerland, has been in the works for more than two decades. When it begins operating in mid-2008, scientists predict that its very-high-energy collisions will yield extraordinary discoveries about the nature of the physical universe.

The LHC project has two equally important aspects: the collider itself and its six particle detectors, each one a self-contained experiment. The collider, nearing completion in a 27-kilometer ring deep below the Swiss-French border, will accelerate two beams of protons in opposite directions to a whisker below the speed of light. For most of their split-second journey around the ring, these hair-thin beams will travel in separate vacuum pipes; but at four points, in the hearts of the main experiments, they will collide at energies of 14 trillion electronvolts. These massive experiments—huge both in size and in worldwide participation—are known by their acronyms: ALICE, ATLAS, CMS, and LHCb. They are the tools physicists will use to turn particle collisions into scientific breakthroughs.

Building the LHC and its experiments has required the efforts of some 10,000 scientists, engineers, technicians, and students from almost 60 nations. More than 1000 of these hail from 93 universities and national laboratories in the United States. Researchers from US institutions have made vital contributions to all aspects of LHC construction, and are now looking forward to the next phase, when they will see collisions begin, watch data start flowing, and spend many a sleepless night searching for the tracks of particles whose existence would transform our understanding of the universe.

Putting the C in LHC

The heart of the LHC project is the collider itself, and the heart of the collider is a series of thousands of superconducting magnets. They create the extremely high magnetic fields needed to accelerate particles to high energies, guide them in circles, and focus them for collision. Such fields are possible today only with superconducting technology, which requires that the magnets be cooled to nearly absolute zero—colder than outer space—by superfluid helium.

The LHC's particle collisions will reach energies seven times higher than those achieved at Fermi National Accelerator Laboratory's Tevatron, the most powerful particle collider operating to date. Building a machine capable of reaching those energies has proved a formidable task;

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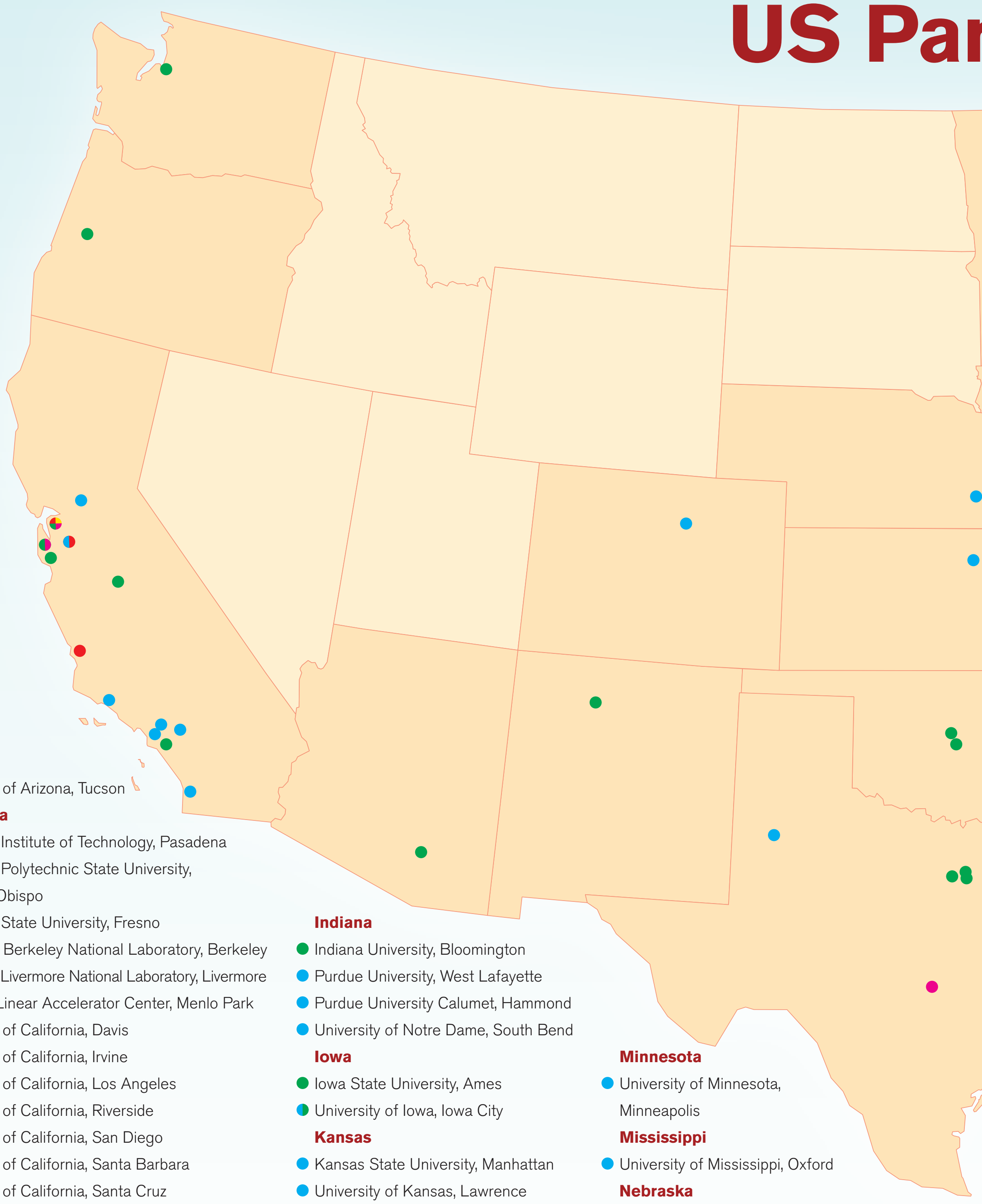

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California
- California Institute of Technology, Pasadena
- California Polytechnic State University, San Luis Obispo
- California State University, Fresno
- Lawrence Berkeley National Laboratory, Berkeley
- Lawrence Livermore National Laboratory, Livermore
- Stanford Linear Accelerator Center, Menlo Park
- 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
- University of California, Santa Cruz

Colorado
- University of Colorado, Boulder

Connecticut
- Fairfield University, Fairfield
- Yale University, New Haven

Florida
- Florida Institute of Technology, Melbourne
- Florida International University, Miami
- Florida State University, Tallahassee
- University of Florida, Gainesville

Illinois
- Argonne National Laboratory, Argonne
- Fermi National Accelerator Laboratory, Batavia
- Northern Illinois University, DeKalb
- Northwestern University, Evanston
- University of Chicago, Chicago
- University of Illinois at Chicago
- University of Illinois at Urbana-Champaign

Indiana
- Indiana University, Bloomington
- Purdue University, West Lafayette
- Purdue University Calumet, Hammond
- University of Notre Dame, South Bend

Iowa
- Iowa State University, Ames
- University of Iowa, Iowa City

Kansas
- Kansas State University, Manhattan
- University of Kansas, Lawrence

Louisiana
- Louisiana Tech University, Ruston

Maryland
- Johns Hopkins University, Baltimore
- University of Maryland, College Park

Massachusetts
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- Brandeis University, Waltham
- Harvard University, Cambridge
- Massachusetts Institute of Technology, Cambridge
- Northeastern University, Boston
- Tufts University, Medford
- University of Massachusetts, Amherst

Michigan
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- University of Michigan, Ann Arbor
- Wayne State University, Detroit

Minnesota
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Mississippi
- University of Mississippi, Oxford

Nebraska
- Creighton University, Omaha
- University of Nebraska, Lincoln

New Jersey
- Princeton University, Princeton
- Rutgers State University of New Jersey, Piscataway

New Mexico
- University of New Mexico, Albuquerque

New York
- Brookhaven National Laboratory, Upton
- Columbia University (Nevis Laboratory), New York
- Cornell University, Ithaca
- New York University, New York
- Rockefeller University, New York
- State University of New York at Albany
- State University of New York at Buffalo
- State University of New York at Stony Brook
- Syracuse University, Syracuse
- University of Rochester, Rochester

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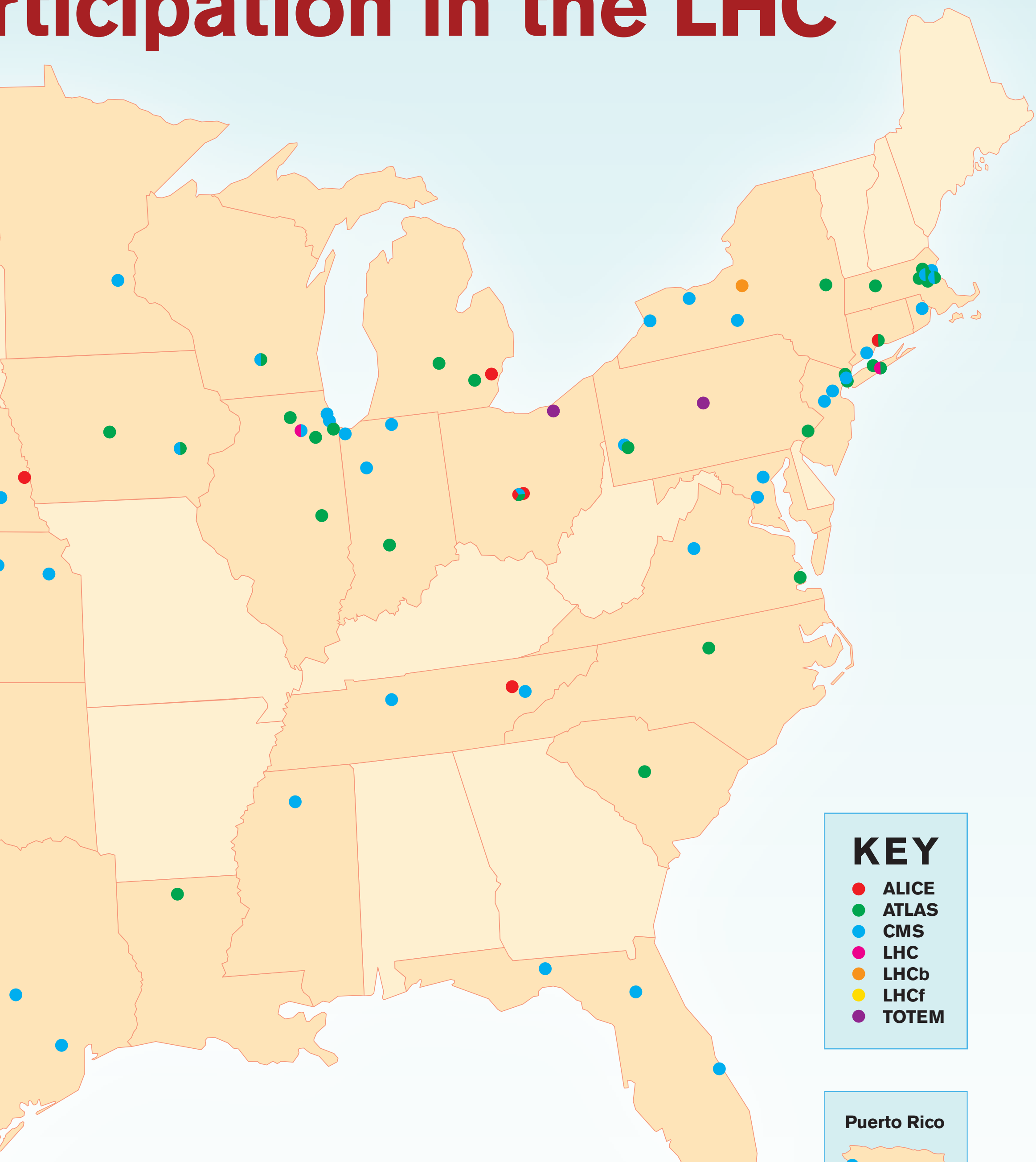

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- Ohio Supercomputer Center, Columbus

Oklahoma
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- University of Oklahoma, Norman

Oregon
- University of Oregon, Eugene

Pennsylvania
- Carnegie Mellon University, Pittsburgh
- Penn State University, University Park
- 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
- Oak Ridge National Laboratory, Oak Ridge
- Vanderbilt University, Nashville
- University of Tennessee, Knoxville

Texas
- Rice University, Houston
- Southern Methodist University, Dallas
- Texas A&M University, College Station
- Texas Tech University, Lubbock
- University of Texas at Arlington
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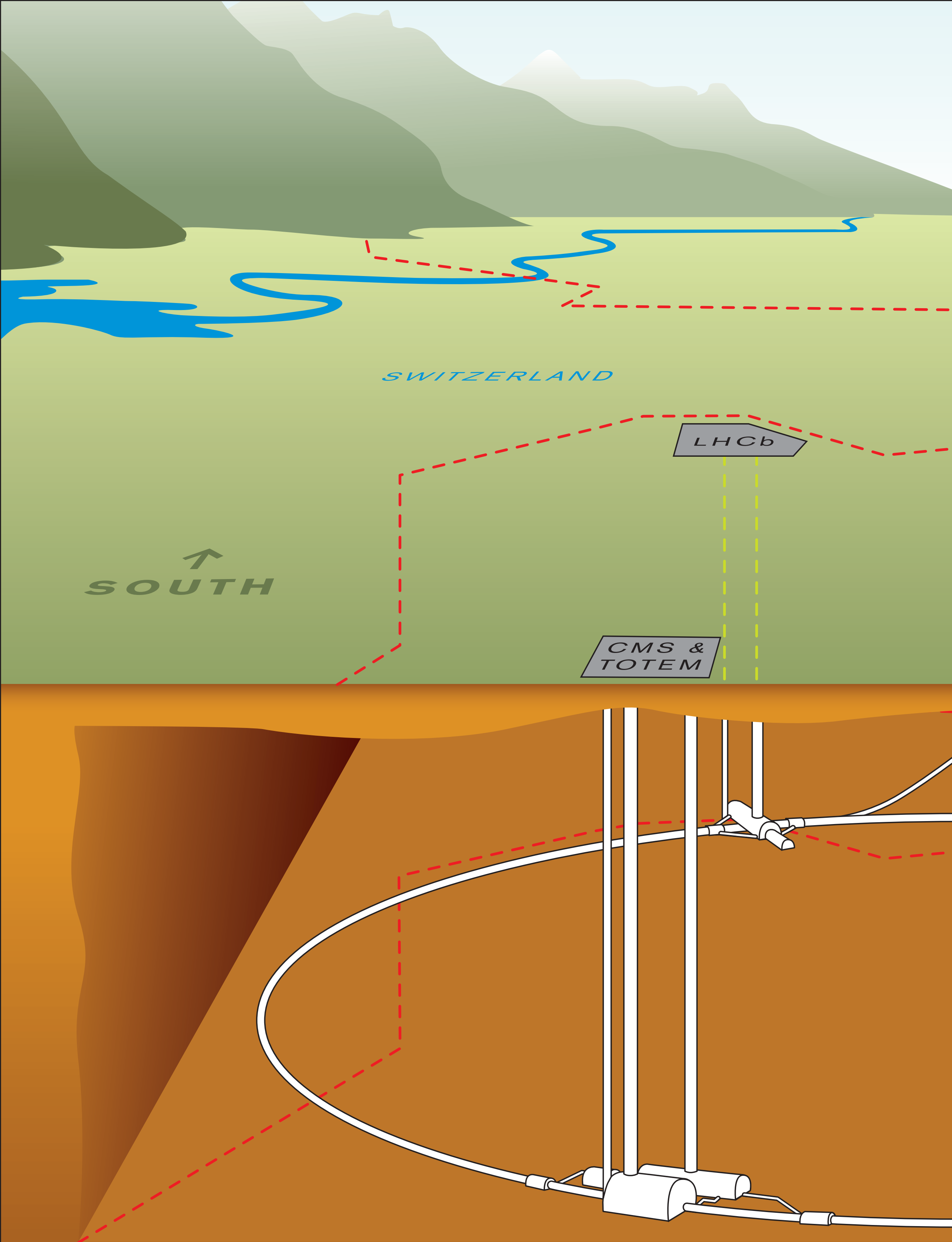
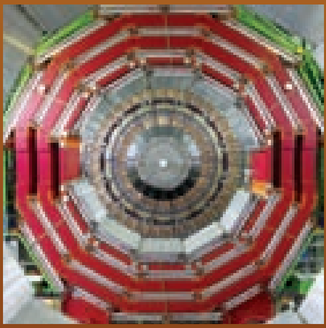
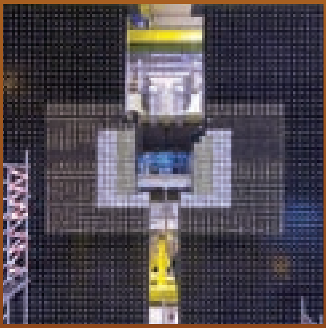


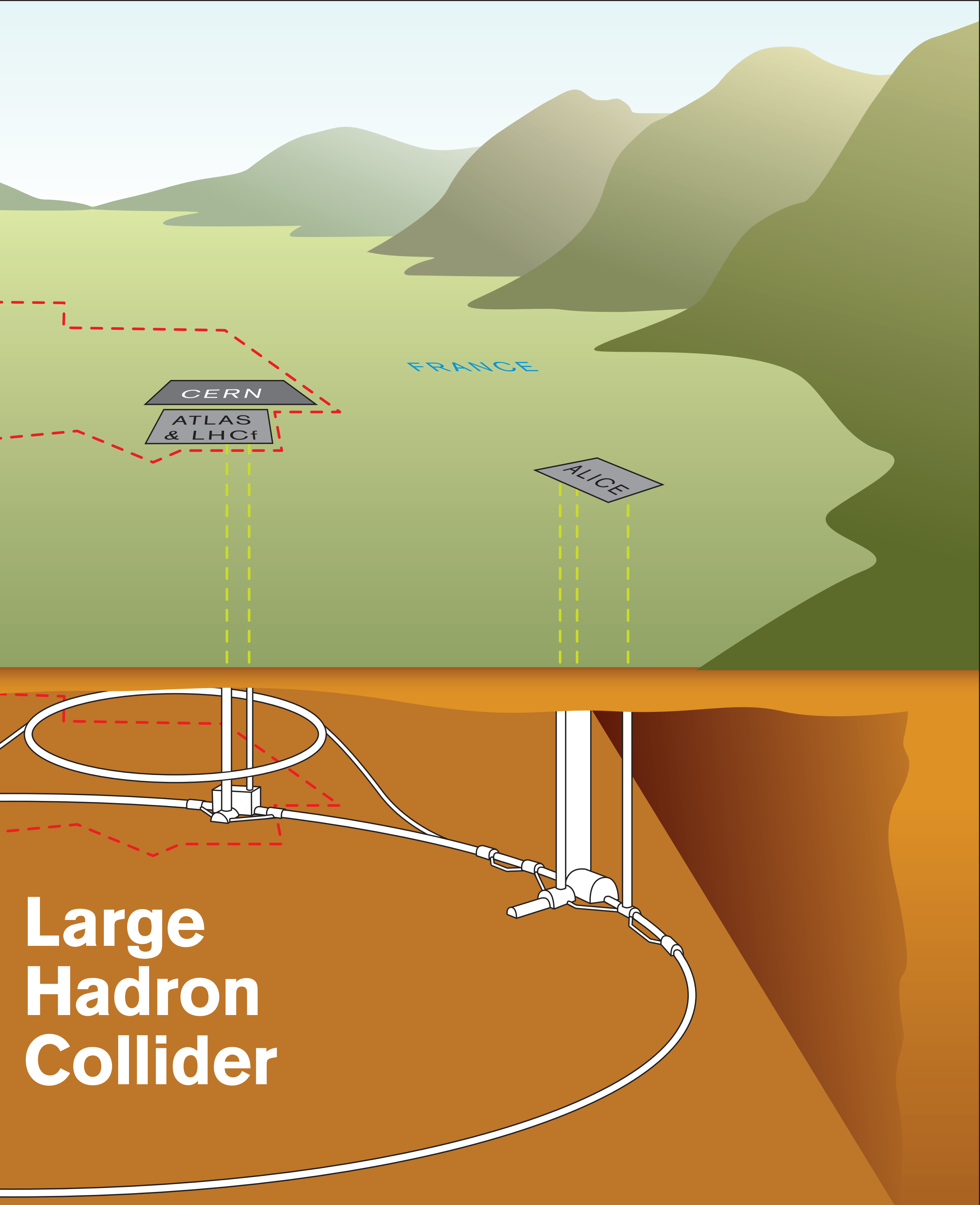

CMS

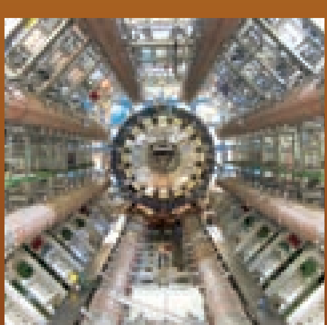

TOTEM

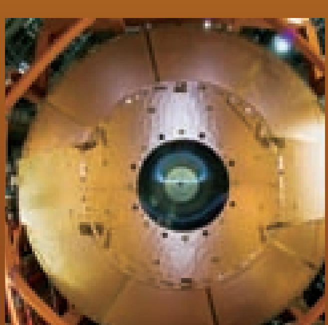

LHCb


CERN

Large Hadron Collider




ATLAS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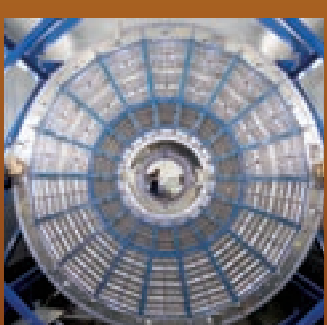
ALICE

now, with LHC construction almost complete, focus has turned to testing, cooling, testing again, and preparing to accelerate beams.

"The LHC is ten times bigger than the Tevatron," says LHC Project Leader Lyn Evans from CERN. "Every step of the way has been challenging: getting it approved, getting the hardware solid, getting through budget crises, handling technical difficulties, and now getting the whole thing to work together."

Solving mysteries

Physicists hope the LHC's experiments will reveal new worlds of unknown particles and explain why those particles exist and behave as they do. Scientists will also search for the origins of mass, study the universe as it existed shortly after the big bang, and try to uncover hidden symmetries of the universe and extra dimensions of space.

The two biggest LHC experiments are ATLAS and CMS. ATLAS, measuring 148 feet long, 82 feet wide, and 82 feet high is the largest, while CMS, weighing in at 13,000 tons, is the heaviest. Each involves approximately 2000 physicists from some 35 countries. These scientists will search for new particles and phenomena, measure the properties of previously discovered quarks and bosons with unprecedented precision, and be on the lookout for completely unexpected physics.

"The most exciting discoveries are the ones you don't anticipate," says CERN theoretical physicist John Ellis. "People looked into the first microscope and saw a whole new world of bacteria that they didn't know existed. It could be that way again."

The 1000-member ALICE collaboration will use collisions of lead ions to study the quark-gluon plasma, a state of matter that existed just after the big bang. The ALICE detector may also provide vital information about run-of-the-mill proton collisions in the early days of LHC operation, paving the way for physicists with the ATLAS and CMS experiments to identify unusual collisions that may reveal new physics.

The aim of the LHCb experiment is to measure rare decays of *B* mesons—particles containing a bottom quark. Such decays happen very rarely in the familiar world of observed particles, but more frequently in scenarios such as supersymmetry, in which every particle has a heavier superpartner. If LHCb's 600 scientists find these decays, it could be the first evidence of new physics phenomena.

"If you compare the LHC to an earthquake, ATLAS and CMS may produce something that shatters our understanding of the universe—a really big earthquake," explains Ellis. "But earthquakes often have tremors that precede them and tell you something big is coming. LHCb could generate such tremors."

On a much smaller scale are the LHCf and TOTEM experiments. Built around the ATLAS and CMS collision points, respectively, these experiments have very specific aims. The 21-member LHCf experiment will contribute to the understanding of ultrahigh-energy cosmic rays that bombard the Earth. The 80-member TOTEM experiment will measure particles flying off at very small angles from the LHC's proton-proton collisions, allowing scientists to study physical processes that can't otherwise be explored.

Frequent fliers

With their part in LHC construction almost complete, US scientists from institutions in 30 states and Puerto Rico, supported by the US Department of Energy's Office of Science and by the National Science Foundation, prepare to play key roles in the discoveries to come. These scientists and students may make their contributions from the United States, travel to CERN for short periods, or live at CERN full time.

"US particle physicists want to do the best science, no matter where the facilities may be," says Fermilab's Joel Butler, program manager for US participation in CMS. "Institutions in the US will further increase their level of involvement over the next few years, and pretty soon the LHC could be what most US particle physicists will be working on."

During the last dozen years, US scientists have helped build the LHC experiments' complex detectors and their intricate computing systems. They are now focused on testing and preparing for startup, and will soon be operating the detectors and analyzing the data as it emerges. Graduate students play a vital role; they often spend several years doing research at their home universities before moving to CERN to gain hands-on experience.

"There are probably about 100 people from US ATLAS institutions at CERN now," says Columbia University's Michael Tuts, project manager for US ATLAS. "We expect that to ramp up, but it depends on the reality of funding and budgets. It's more expensive to send people to CERN, and institutions have had to adjust budgets at home."

One way to increase international collaboration while keeping costs down is through remote monitoring and operations. This year saw the opening of the LHC@FNAL Remote Operations Center, through which scientists at Fermilab can monitor conditions at the CMS experiment and the LHC accelerator and participate in high-definition videoconferences with colleagues at CERN.

"We've been pioneers in remote operations," says Butler. "We're separated from CERN by many thousands of miles of ocean and six to nine time zones. This will keep a part of the US community that can't easily go to CERN—due to funding limitations or academic, professional, or family responsibilities—more engaged in the experiment."

The US contributed to the construction of the LHC accelerator through a $200 million project funded by the DOE's Office of Science. More than 100 accelerator scientists are already involved in research and development for future LHC upgrades.

The detectors are nearly complete, the global computing system is almost ready, and parts of the collider are already cooled to nearly absolute zero. After more than two decades of preparation, the LHC will produce its first proton collisions in 2008. Excitement is growing among US scientists, their colleagues, and the rest of the world.

"I would like to be in the ATLAS control room at the right time to see that very first collision," says Columbia's Tuts. "Seeing everything finally working together will make all those plane trips worth it."