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A Tumultuous Year at the LHC

Physicist Lisa Randall describes the turbulent first year after the collider's premature celebration.

by Lisa Randall

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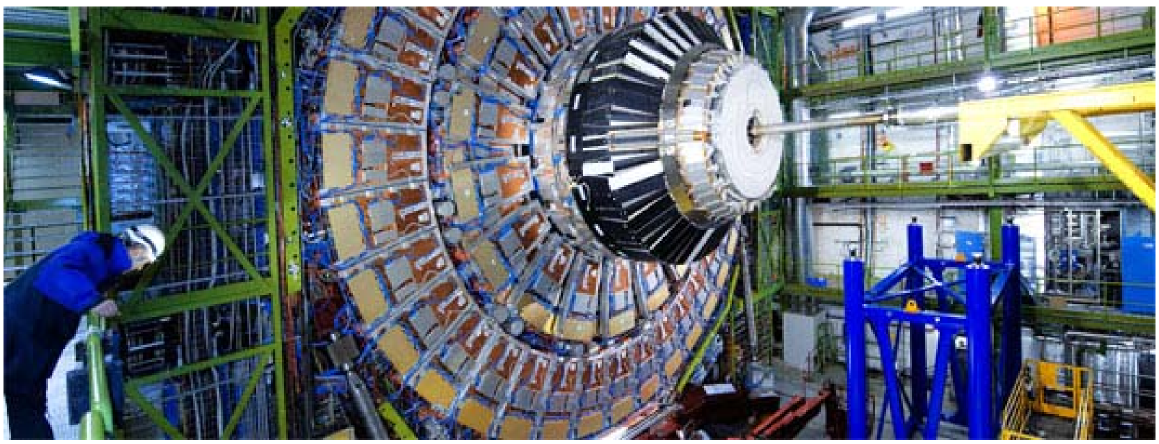


Claudia Marcelloni/CERN

On October 21, 2008, in accordance with some overly optimistic scheduling, 1,500 physicists and world leaders gathered outside Geneva to celebrate the inauguration of the biggest, most international, most expensive, most energetic, most ambitious experiment ever built. I enjoyed the day, which was filled with speeches, music, and—as is important at any European cultural event—good food. And despite anxieties (more on that later), everyone was filled with hope that these experiments would shed light on some of the mysteries surrounding mass, the weakness of gravity, dark matter, and the forces of nature.

The machine in question is, of course, the Large Hadron Collider (LHC). The name is literal, though admittedly uninspired. The LHC is indeed large, containing a 27-kilometer circular underground tunnel that stretches between the Jura Mountains and Lake Geneva near the French-Swiss border. This tunnel's depth varies from 50 to 175 meters underground; the uneven terrain was in fact an interesting constraint on the tunnel's depth and location. Electric fields inside this tunnel will accelerate two beams of protons (which belong to a class of particles called hadrons, hence the collider's name) as they go round and round, more than 10,000 times each second. Then—and here's where all the action happens—magnets will guide the two proton beams so that they collide in a region smaller than the width of a human hair. When this collision happens, some of the energy of the accelerated protons will be converted to mass (that's what Einstein's famous formula, $E = mc^2$, tells us). In fact, the energy will be so high that the ingredients inside the proton—particles called quarks and gluons—will collide and convert to energy. And with these collisions and the energy they release, new elementary particles, heavier than any seen before, can be created.

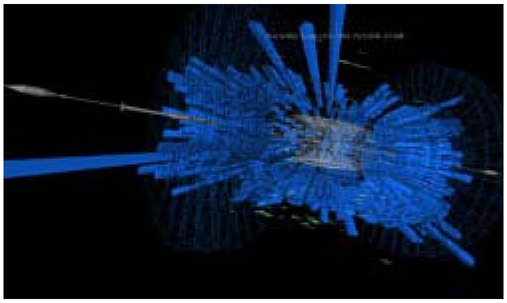
The day's events did not yet celebrate discovery but instead recognized the potential of the LHC and the triumph of the many countries that participated in its creation. An international community of scientists and officials began planning the LHC more than 20 years ago at CERN (the acronym stems from the original name, Conseil Européen pour la Recherche Nucléaire). CERN is a miracle of international cooperation, with scientists from 85 countries participating. The cost of the LHC is about $10 billion, of which CERN has paid two-thirds; CERN's 20 member countries contribute according to their means, ranging from 20 percent from Germany to 0.2 percent from Bulgaria. Although the United States isn't officially part of CERN, many American physicists work there, and we've put in $531 million.

You might remember that on September 10 last year CERN fired up its two proton beams with so few hitches that the results exceeded expectations. On that day, for the first time, two proton beams traversed the enormous tunnel in opposite directions. This involved commissioning the injection elements, starting the controls and instruments in the ring, checking that the magnetic field would keep the protons in the ring, and making sure all the magnets worked to spec and could be run simultaneously. Amazingly, the first time that could be done was the evening of September 9! Yet everything worked as well as or better than planned.

When I visited last October, everyone had stories about the excitement of September 10. Millions of people all around Europe tuned in to watch the graphs of the protons' progress, which on the screen simply looked like two dots traversing a ring. The beams started slightly off direction, but people sat mesmerized as the path was modified so the protons could successfully circulate around the full circumference of the ring. Not everyone knew what he or she was watching, but everyone with eyes glued to the screen knew that something significant was in store. Meanwhile, inside CERN the thrill was palpable as physicists and engineers gathered in auditoriums to watch the same thing. The first beam went around the ring for a few turns. Each successive burst of protons was adjusted slightly so that soon the beams were circulating hundreds of times. At this point the LHC outlook seemed extremely promising.

But a little more than a week later the mood was seriously dampened. On September 19 engineers were preparing to attempt the first collision of the two beams. Sadly, this was a lot less successful. Before the collision could happen, as scientists were trying to ramp up the current and energy, something went wrong with a connection of the bus bar between magnets, creating an electrical arc that punctured the helium enclosure and caused large quantities of liquid helium to be released (helium is necessary to cool the superconducting magnets that guide the beams around the ring). This created a large amount of pressure, which in turn displaced the magnets that focus the protons, destroyed what needs to be a vacuum, damaged insulation, and contaminated the beams with soot—not exactly what we had been hoping for.

I learned more about the backstory during my visit. Keep in mind that the ultimate goal for collisions is a center of mass energy of 14 TeV, or trillion electron volts. I realize these might be unfamiliar units by which to measure energy, so to give some perspective, it is seven times the energy of the Tevatron particle accelerator at Fermilab in Illinois, which is presently the highest-energy machine, and 15,000 times the energy contained in the mass of a single proton at rest.



To attain this high energy, the proton beams are accelerated as they go around the tunnel and their paths are kept circular by dipole magnets. The bigger the tunnel, the less energy is required to keep the beams in the correct route. More acceleration is required when the circle is smaller.

The tunnel at CERN was already fixed in size since it had been used for a previous experiment—LEP (the Large Electron-Positron collider), for those who have followed particle physics developments over the years. The fixed tunnel size meant the LHC would require higher-field magnets than had ever been used on this scale before to allow for the high energy of the LHC. The decision was made to keep the energy down to only about 2 TeV for the first run to make sure everything functioned properly. Later the engineers planned to increase it to 10 TeV for the first actual data runs.

On September 12 a transformer broke, causing some small delays. In the meantime, scientists continued testing each of the tunnel's eight sectors up to 5.5 TeV. Everything worked until the last sector. The crippling accident occurred when the energy was being raised from about 4 to 5.5 TeV, which required between 7,000 and 9,300 amps of current. This was the last moment for something to go wrong, and it did.

We are lucky that engineers and physicists are able to fix things before true operations begin. The accident, nonetheless, meant that the October 2008 celebration was premature. Although many CERN scientists were unhappy about the timing of the event, I saw the day more as a contemplation of this triumph of international cooperation. Many of the foreign partners were visiting for the first time. The person seated next to me during the ceremony worked for the European Union in Geneva but had never set foot inside CERN. Having seen it, he was hooked and plans a return visit with his colleagues.

A few of the speeches were truly encouraging and inspirational. The French prime minister, François Fillon, spoke of the importance of basic research and how the world financial crisis should not prevent scientific progress. The Swiss president, Pascal Couchepin, spoke of the merit of public service. Professor José Mariano Gago, Portugal's minister for science, technology, and higher education, spoke about valuing science over bureaucracy and the importance of stability for creating important science projects.

One of the more interesting displays was located in the building where the magnets were tested; you could walk around and see the various pieces and how they fit together. The magnets (which are linked to a cryogenic system) are 15 meters long, which was in itself impressive to see. And there was a display with the piece called the bus bar, a superconducting cable that connects a dipole magnet that guides the beams around the ring to a quadrupole magnet that focuses the beams for a collision; splices that hold the cable together were the culprit in the LHC mishap.

Over the past year mechanisms have been put in place to detect similar problems before they can do any damage and to look for heat sources throughout. Fifty-three magnets (14 quadrupole and 39 dipole) have been replaced in the sector of the tunnel where the incident occurred. In addition, more than four kilometers of the vacuum beam tube have been cleaned, a new restraining system for 100 quadrupole magnets is being installed, 900 new helium pressure release ports are being added so that helium won't do so much harm in the future, and 6,500 new detectors are being added to the magnet protection system. With these new systems to monitor and stabilize the LHC, the kind of pressure buildups that introduced all the damage should be avoided.

We don't know how long it will take before we start getting answers from the LHC. Some discoveries may happen within a year or two; others could take a decade. It is a little anxiety-provoking, but the results will be mind-blowing, so the nail-biting should be worth it.

For those of you who were relieved by the delay because you thought LHC collisions would create black holes that would destroy the earth, let me assure you that your worries were misplaced. Black holes at the LHC are not even conceivable unless space and gravity are very different from what we thought. Gravity just isn't powerful enough otherwise. Even if black holes could form, Stephen Hawking's insight tells us that black holes radiate, and the minuscule ones suggested for the LHC would radiate away their energy immediately. Further, cosmic rays create particle collisions of comparable energy all the time, and if dangerous black holes could exist, they would have already destroyed all the structures we observe in the universe.

So the LHC won't create dangerous objects. Rather, the particles that it ultimately creates should help answer deep and fundamental questions. We hope to learn about the origin of the mass of elementary particles and why those masses are what they are. Why isn't everything whizzing around at the speed of light, which is what matter would do if it didn't have mass? How is it that some force carriers are heavy and others, like the photon that communicates electromagnetism, have no mass? And why do the masses of all these particles have the values that they do? This question has to do with what is known as the Higgs sector. Searches for the particle called the Higgs boson will tell us whether our ideas about how elementary particle masses arise are correct. If current theory is correct, we know quite a lot about this particle's interactions, but we don't yet know its mass. So both of the large experiments at the LHC searching for the Higgs boson—CMS and ATLAS—have elaborate and well-defined search strategies in place.

We also hope to learn what underlies dark matter, the elusive stuff throughout the universe whose total weight is five times that of ordinary matter, but which remains invisible because it doesn't emit or absorb light. Interestingly, stable particles that might be produced at the LHC should have about the right mass and interaction strength to match the inferred properties of dark matter. Exploring this energy scale should tell us which are the most likely candidates and maybe even expose the right one.

And we might learn about the nature of space itself. One theory that another physicist, Raman Sundrum, and I propose suggests there could be an extra dimension in the universe responsible for the weakness of gravity we feel here. Another universe separated from us in an extra dimension could be right next door—that is, separated by an infinitesimal distance—yet not seen. Because of the energy that will be achieved at the LHC, we hope to be able to explain the weakness of gravity and to find out whether an extra dimension of space is just an outlandish idea or an actual fact about the universe.

If our theory is correct, we would expect the LHC to be able to produce particles called Kaluza-Klein (KK) modes. These are particles with interactions similar to those of the particles we know but with heavier masses because they have additional momentum contained in an extra dimension. Only once the energy level is high enough can these particles be produced. The discovery of KK particles would provide an exciting insight into a greatly expanded world.

Another major search target is a supersymmetric theory. Supersymmetric models posit that every fundamental particle of the standard model (the particles that we know exist—electrons, quarks, and so on) has a partner—a particle with similar interactions but different quantum mechanical properties. If the world is supersymmetric, there should be many unknown particles that could soon be found.

Models are just suggestions for what might be out there. We don't yet know what will be found. These models might correctly describe reality, but even if they do not, they suggest search strategies that will tell us the distinguishing features of as yet undiscovered matter.

The LHC presents a unique opportunity to create new understanding and new knowledge. Physicists are eagerly looking forward to what it will teach us. Will it be extra dimensions? Extra symmetries of space-time? Something completely unforeseen? We don't know. But let's look forward to discovering the answers. Nothing will ever replace solid experimental results.