CERN restarts Large Hadron Collider

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After more than two years of maintenance and upgrades, proton beams are again circulating at the world's most powerful particle accelerator, the Large Hadron Collider (LHC). More than 60,000 particle physicists at the European Organisation for Nuclear Research (CERN) and across the world are preparing to renew their research into the fundamental underpinnings of matter.

The LHC is an international physics experiment operated by scientists and engineers from more than 100 countries, in spite of ever increasing tensions between rival nation-states. Its existence speaks to the productive capacity of humanity when put to use for the purpose of scientific inquiry and not mass oppression. It is worth noting that the operation of the Large Hadron Collider to date has cost less than the development and creation of a single new US aircraft carrier, the USS Gerald R. Ford.

The collider is a 27-kilometer underground ring that accelerates and bends particles—either protons or lead nuclei—to just below the speed of light in counter-rotating beams. At four points, the two beams are made to collide, producing showers of particles that are analyzed by the four main detectors of the collider, given the names CMS, ATLAS, ALICE and LHCb.

Initially, the beams will remain near their injection energy of 450 gigaelectronvolts (GeV, the unit of mass/energy used in high-energy particle physics) as the collider undergoes its commissioning. This process will take place over the next several days, as operators check all the systems of this complex machine before increasing the energy of each beam. It is expected that the LHC will produce proton-proton collisions of 13 teraelectronvolts (TeV), almost double the energy of the previous run, before the start of summer.

The work done during the 25-month technical stop is itself a technical marvel. Each of the more than 1,600 superconducting magnets was checked to ensure the highest possible electrical output and new protections were added. Ten thousand new electrical connections were created to protect against rogue currents. The cryogenic conditions required to maintain superconductivity (a state where electrical currents encounter no resistance) were improved and strengthened. The inside of each beam pipe has been specially coated to make the vacuum more secure.

The end result is that protons in the beam pipe move faster than light does in air (although, of course, slower than the speed of light in a vacuum) and the vacuum that the particles travel through is purer than that of outer space.

As a result of the improved technical aspects of the LHC, the number of scientific experiments that can be done will increase. The proton beams have been focused from a diameter of 75 micrometers to 48 micrometers and the time between proton bunches has been reduced from 50 nanoseconds to 25 nanoseconds. This means that the number of proton-proton collisions will increase from 600 million to more than 1 billion every second. LHC experiments will generate more than 30 petabytes of data every year.

Though the collider was not running over the last two years, physicists were still poring over the colossal amount of data collected since 2009. The most exciting result was announced March 17 at the 50th session of the Rencontres de Moriond, where the CMS and ATLAS experimenters presented for the first time their combined results on the mass of the Higgs boson. The Higgs was initially discovered in 2012 and confirmed in 2013. Using both data sets, the Higgs has been measured to have a mass of 125 GeV, with a measurement precision of better than 0.2 percent. This is one of the most precise measurements the LHC has ever made. Both collaborations will deepen their study of the Higgs with the LHC restart.

The Higgs boson was the last unobserved

fundamental particle of the Standard Model of particle physics, which provides the most advanced theory of the fundamental particles of nature and describes their interactions. The Brout-Englert-Higgs mechanism, first postulated in 1964 and through which the existence of the Higgs boson was predicted, is suspected to be the source of mass for all elementary particles.

Another result was the discovery by the LHCb collaboration of two new baryons, particles similar in structure to protons. The two particles, the Xi_b’- and Xi_b*-, were predicted by the Standard Model but never before seen. They give insight into the dynamics behind b-quarks, a relatively poorly understood particle.

A different particle physics experiment at CERN, COMPASS, produced a key measurement of the strong interaction in February. The strong interaction (or force) binds together quarks to make protons, neutrons, pions, kaons and other types of particles. It also ensures that protons and neutrons stick together in atomic nuclei, rather than flying apart from the electromagnetic repulsion of the protons. COMPASS found experimentally that the degree to which combinations of quarks can be shaped and stretched closely matches to theory.

Now that the Higgs has been found, the focus will shift on to the great many unknowns that still pervade humanity’s understanding of matter. One example is an anomaly in how a transient particle, the B+ meson, decays. Current physics predicts that its two decay chains, involving the electron and its heavier cousin the muon, should be identical. However, the LHC says the electron decay happens 25 percent more frequently than the muon decay. If this discrepancy holds in the second run of the LHC, it is likely an indication of the influence of a particle beyond the Standard Model.

Supersymmetry is another esoteric area of research that will be pursued in the coming years. Supersymmetry, or SUSY, is an extension of the Standard Model that predicts a much more massive “superpartner” for each particle already known. So far, nothing pointing to this theory has been discovered, though it is thought that the LHC can generate the energies needed to produce the massive particles. If true, it holds the possibility of explaining the astrophysical phenomena of dark matter.

As is now known, dark matter pervades the universe and is more than five times more common than normal matter. And yet, it emits no light and so has only been detected indirectly (though conclusively) by its gravitational interaction with galaxies and galactic clusters. There is a possibility that through supersymmetry, the LHC will discover the connection between what is observed at the cosmological level and what happens on the smallest scale of matter.

Even if supersymmetry is ruled out, that does not mean the LHC won’t discover dark matter. Under the SUSY framework, dark matter consists of one type of particle, probably the superpartner of the photon or neutrino. However, other theories of dark matter predict a whole slew of new particles, similar to the veritable zoo we have now, but not detectable by conventional means. Either discovery would open up a whole new vista in understanding the universe.

Other avenues of research include the effort to unify general relativity and quantum mechanics. These two pillars of modern physics describe their specific areas extraordinarily well. Yet, when the attempt is made to combine the two theories to study black holes or the Big Bang, they fail spectacularly. Developing such a theory of “quantum gravity” is critical to understanding such events.

While the Large Hadron Collider does not promise to fully resolve such questions, it will no doubt point researchers in the right direction. The contradictions with what is known and unknown will slowly emerge, leading to the development of models that integrate old and new physics into an even greater whole.