Large Hadron Collider resumes operations

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Scientists operating the Large Hadron Collider (LHC) have successfully re-started the 27-km-long particle accelerator after its winter hibernation, beginning a new season of data taking for 2018, its seventh year of operation.

The LHC is operated by approximately 10,000 researchers and engineers at CERN (the European Organisation for Nuclear Research), located in Geneva, Switzerland. It accelerates large numbers of protons, one of the particles within the atomic nucleus, to velocities near the speed of light and travelling in opposite directions.

Each beam contains 2,556 “bunches” comprising 120 billion protons. These beams are focused to collide at a fixed point where their energy is converted to mass, producing a shower of particles. These particle showers are observed by several particle detectors in order to study the complex series of interactions that created them.

The detectors feature superconducting electromagnets which guide the particles generated from the collisions into concentric rings of particle detectors and energy measurement devices. In turn, these collect huge amounts of data that are analysed by clusters of supercomputers to reconstruct the physical events within the experiment.

The collider and its auxiliary systems are deactivated each winter to facilitate maintenance and upgrade work. This infrastructure was gradually reactivated, extensively tested, and ramped up to its full operating performance, culminating in this year’s first scientifically useful collisions at the end of April.

The primary LHC physics experiments, situated at four points around the ring of the accelerator, are ATLAS, CMS, ALICE and LHCb. These collect tens of billions of gigabytes of data, an amount necessary in order to make the staggeringly accurate measurements needed to analyse physical processes at the subatomic scale.

Scientists have recently published several results based on the analysis of data collected at the LHC during previous years.

This month, the international collaboration of scientists working on the Compact Muon Solenoid (CMS) general-purpose detector published a paper detailing the first confirmed direct observation of an important phenomenon involving the Higgs boson and the most massive fundamental particle, the top quark. The ATLAS team, the other general-purpose LHC experiment, announced similar results.

The Higgs boson mediates the Brout-Englert-Higgs or BEH mechanism, which was first predicted by François Englert, Robert Brout and Peter Higgs in 1964 and confirmed using data collected by the Large Hadron Collider in 2013. It explains an inconsistency between the masses of three fundamental particles—the photon, W boson and Z boson—as well as the difference in masses between fundamental particles more broadly. Lastly, the Higgs completes the “periodic table” of particle physics, known as the Standard Model.

The particular physical interaction being used to study the Higgs boson in the most recent study is the creation of a Higgs in association with a pair of particles comprising a top quark and its antimatter counterpart. The Higgs boson, due to the laws of quantum mechanics, may briefly fluctuate into a top quark/anti-top quark pair that rapidly annihilate each other to produce a photon pair. The interaction strength, or “coupling,” between the Higgs boson and the top quark determines the probability that this process may occur. This interaction is particularly useful to study because of how massive the top quark is, more than 170 times greater than a proton and about 38 percent greater than the Higgs.

In fact, because the top quark is more massive than the Higgs boson, this interaction requires the superhigh-energy environment at the LHC. The process is also very rare and required the combination of results from several data sets, taken at different energy levels, to achieve a measurement of the strength of the interaction between these particles with the necessary precision. These measurements confirm predictions based on the existing models of particle physics.

"These measurements by the CMS and ATLAS collaborations give a strong indication that the Higgs boson has a key role in the large value of the top quark mass. While this is certainly a key feature of the Standard Model, this is the first time it has been verified experimentally with overwhelming significance," said ATLAS spokesperson Karl Jakobs. (See: a video interview with LHC scientists.)

Another important measurement was announced in April by the ATLAS collaboration when they announced their first high-precision measurement of the mass of the W boson. This particle, discovered at CERN in 1983, is one of the two elementary particles that mediate the weak force that causes nuclear processes such as radioactive decay.

The measurement was derived from the observation of around 14 million W bosons in 2011. ATLAS spokesperson Tancredi Carli said, "Achieving such a precise measurement despite the demanding conditions present in a hadron collider such as the LHC is a great challenge. Reaching similar precision, as previously obtained at other colliders, with only one year of Run 1 data is remarkable."

The complex analysis took five years to complete. The result is consistent with a number of earlier measurements and further confirms current theories. However, the W boson mass may be theoretically predicted with a greater precision than it can be currently observed. This means that the future holds great potential for the rigorous testing of current theories or the discovery of new physics.

These recent results from the Large Hadron Collider point both to the correctness of the contemporary understanding of particle physics and also indicate that there is a great deal about nature that we still don't know. Currently, modern physics understands the properties of subatomic particles very well. However, the theories have yet to incorporate the astrophysical phenomena of "dark matter" and "dark energy," which make up an estimated 95 percent of the energy density of the Universe. Neither do the current theories describe how gravity operates on a subatomic scale. There is still much work to be done.

Physicists at CERN will play a key role in this. In 2018, they are aiming to gather 20 percent more data than in 2017, involving approximately 6 million billion proton-proton collisions. Next year, a two-year period of maintenance and upgrades will begin, laying the groundwork for the High Luminosity LHC (HL-LHC) upgrade aiming to increase performance 10-fold by 2025, by increasing the rate of particle interactions. This will improve the statistical analysis of rare interactions and enable the high-precision measurements required to probe further the fundamental laws of nature.