CERN experiment makes first observation of rare events producing three massive force carriers

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Modern physics knows a great deal about how the universe works, from the grand scale of galaxies down to the infinitesimally small size of quarks and gluons. Still, the answers to some major mysteries, such as the nature of dark matter and origin of gravity, have remained out of reach.

Caltech physicists and their colleagues using the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland, the largest and most powerful particle accelerator in existence, and its Compact Muon Solenoid (CMS) experiment have made a new observation of very rare events that could help take physics beyond its current understanding of the world.

The new observation involves the simultaneous production of three W or Z bosons, subatomic "mediator particles" that carry the weak force—one of the four known fundamental forces—which is responsible for the phenomenon of radioactivity as well as an essential ingredient in the sun's thermonuclear processes.

Bosons are a class of particles that also include photons, which make up light; the Higgs boson, which is thought to be responsible for giving mass to matter; and gluons, which bind nuclei together. The W and Z bosons are similar to each other in that they both carry the weak force but are different in that the Z boson has no electric charge. The existence of these bosons, along with other subatomic particles like gluons and neutrinos, is explained by what is known as the Standard Model of particle physics.

Caltech graduate student Zhicai Zhang (MS ’18), a member of the High Energy Physics research team led by Harvey Newman, the Marvin L. Goldberger Professor of Physics, and Maria Spiropulu, the Shang-Yi Ch'en Professor of Physics, is one of the principal contributors to the new observation, working together with other team members.

The events producing the trios of bosons occur when intense bunches of high-energy protons that have been accelerated to nearly the speed of light are brought into a head-on collision at a few points along the circular path of the LHC. When two protons collide, the quarks and gluons in the protons are forced apart, and as that happens, W and Z bosons can pop into existence; in very rare cases, they appear as triplets: WWW, WWZ, WZZ, and ZZZ. Such triplets of W and Z bosons, Newman says, are only produced in one out of 10 trillion proton-proton collisions. These events are recorded using the CMS, which surrounds one of the collision points along the LHC’s path. Zhang says these events are 50 times rarer than those used to discover the Higgs boson.

"With the LHC creating an enormous number of collisions, we can see things that are very rare, like the production of these bosons," Newman says.
It is possible for the W and Z bosons to self-interact, allowing W and Z bosons to create still more W and Z bosons; these may manifest themselves as events with two or three massive bosons. Still, this creation is rare, so the more bosons that are produced, the less frequent the production happens. The production of two massive bosons has previously been observed and measured with good precision at the LHC.

The creation of these bosons was not the specific goal of the experiment, Newman says. By collecting enough data, including many events with boson triplets and other rare events, researchers will be able to test the Standard Model's predictions with increasing precision and may eventually find and be able to study the new interactions that lie beyond it.

"We know from observing the rotation and distribution of galaxies that there must be dark matter exerting its gravitational influence, but dark matter doesn't fit into the Standard Model. There is no room in it for dark particles, nor does it include gravity, and it simply does not work at the energy scales typical of the early universe in the first moments after the Big Bang. We know that there is a more fundamental yet-to-be-discovered theory than the Standard Model," Newman says.

The next three-year experimental run, scheduled for 2021–24, is already being prepared. At the end of that run, the equipment will be upgraded to increase its data-collection capacity 30-fold. "There is a lot of unrealized potential. The masses of data we have already collected still represent only a few percent of what we expect to collect following major upgrades of both CMS and the LHC, at the High Luminosity LHC that is scheduled to run for 10 years beginning in 2027. We are only at the very beginning of this 30-year physics program," he says.

**More information:** A paper describing their findings, titled, "Observation of heavy triboson production in leptonic final states in proton-proton collisions at ?s = 13 TeV," is available at [cds.cern.ch/record/2714899](cds.cern.ch/record/2714899). It marks the 1000th paper published by researchers working at the Compact Muon Solenoid.

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