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LHC upgrades could reveal whether Higgs boson is 'standard'

A new run at the Large Hadron Collider in 2015 could open the door to new theories.

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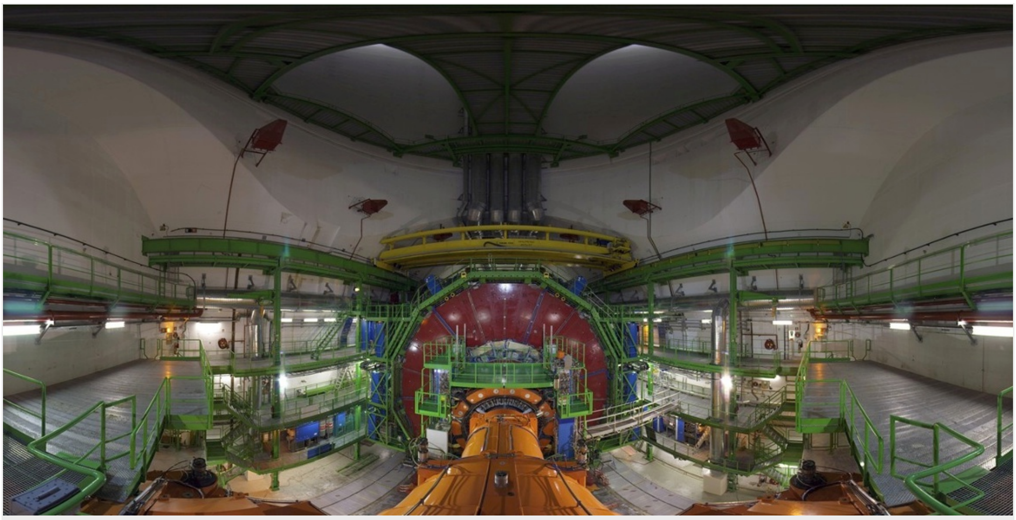

CERN

The 'cavern' that hosts the CMS detector at the Large Hadron Collider.

If it looks like a Higgs, and acts like a Higgs, it's probably a standard Higgs boson. That's the drift from the latest measurements at CERN's Large Hadron Collider (LHC), where physicists have been carefully characterizing the new particle they discovered in 2012. So far, every test at the Geneva accelerator confirms that the new particle closely resembles the Higgs boson described by the Standard Model of particle physics. These results resoundingly confirm the Higgs theory first put forward in 1964 by Robert Brout, François Englert and Peter Higgs — and helped win the latter two the Nobel prize last year. (Brout died in 2011, making him ineligible for the award.)

Scientists are eager to detect deviations from this idea, however, which might reveal a deeper layer of physics. For instance, if the Higgs boson decays to lighter particles at slightly different rates than predicted, it could indicate the presence of new, exotic particles interfering with those decays. Whereas the most recent results show no sign of such interference, the next phase of the LHC could offer new insights; it is set to start operating at higher energies in early 2015. At those energies, the Higgs boson may open the door to a new theory of physics that more fully explains the universe. "With the discovery of the Higgs boson we didn't finish a quest, we actually started a whole new line of research," says Paul Padley, a physicist at Rice University who works on the LHC's Compact Muon Solenoid (CMS) experiment. "That's going to be our job in the next decades, is studying this in great detail."

When physicists first sighted the Higgs at the LHC, they identified it through its decays into other bosons — specifically, gauge bosons, which are force-carrying particles such as the photon (carrier of the electromagnetic force) and the *W* and *Z* bosons (carriers of the weak force). Now, however, CMS researchers have reported in *Nature Physics*[1] that they see evidence for the Higgs decaying into fermions — the class of particles that includes the electrons and quarks that make up atoms (see 'Higgs particle linked to matter, not just force, particles'). The Standard Model also predicts such decays, but they were not a foregone conclusion.

The Higgs boson is thought to be related to an invisible Higgs field that pervades all of space. As particles travel through that field, their interactions with it give them mass. The original finding that Higgs particles decay into other bosons confirmed the Higgs field can interact with bosons. Now the latest results show that the field can interact with fermions as well. The finding supports the idea that a single, Standard Model Higgs boson explains how all particles get their mass. But some hypotheses suggest that multiple types of Higgs bosons — and therefore Higgs fields — exist and that each kind is responsible for bestowing mass on certain kinds of particles.

“This new result doesn’t rule out other Higgs bosons, but it gives additional support to the Standard Model being correct right now,” says theoretical physicist Ayres Freitas of the University of Pittsburgh. “But there’s also the possibility that there are two Higgs bosons and they basically share the job, with both contributing part of the mass to particles.”

With more data from LHC’s next run, physicists may be able to confirm or rule out that option. Right now, the uncertainties on how often the Higgs boson decays into fermions — and therefore, how strongly the Higgs field 'couples', or interacts, with them — are imprecise. “It could be the case that the coupling of the currently discovered particle is larger or smaller than what the Standard Model predicts, and this deviation would then be compensated for by a second Higgs boson,” Freitas says. And, if extra Higgs bosons exist, the LHC might be able to produce them outright when it starts operating at higher energies next year.

Since the collider opened in 2008 its maximum energy was 8 tera–electronvolts (TeV). When the LHC ends its current hiatus and starts up again in the spring of 2015, it should be able to reach energies of 13 TeV, thanks to improved superconducting magnets that line the accelerator’s 27-kilometre-long underground ring. Stronger magnets can accelerate the protons injected into the ring to higher speeds than before, ensuring that when they collide the explosions will be even more energetic. The new-and-improved LHC will also bunch the colliding protons more tightly together, creating a denser beam and giving it what physicists call a higher “intensity” that should enable more head-on collisions. All in all, physicists expect the next run of the LHC to produce 300 times more Higgs bosons than its previous stint. “This increased rate will translate into higher precision measurements of the Higgs boson’s properties,” Freitas says. For example, the new data should improve calculations of how strongly the Higgs field interacts with various particles, including both bosons and fermions, by a factor of two or three, he says. “It definitely opens up the chances for seeing something we haven’t seen so far, but we don’t know what nature has in store for us.”

One option for a deeper theory of physics beyond the Standard Model is supersymmetry — the idea that for every known fundamental particle a 'supersymmetric' partner particle exists. So far, no sign of such particles has materialized but the enhanced LHC could be powerful enough to create supersymmetric particles themselves. And even if it doesn’t, the LHC could prove their existence in subtler ways. These particles could show up as quantum phantoms, appearing and disappearing just as fast out of nothingness, while the Higgs boson decays into more mundane particles, for example. More precise measurements of Higgs decay rates could reflect whether this is happening. “Sometimes progress is made not by discovering big new things but seeing that the properties of what you’re seeing aren’t quite what we expected them to be,” Padley says.

The Standard Model also does not account for dark matter, which is thought to be made of invisible particles that do not interact with regular particles, yet make up the bulk of the matter in the universe. “The Higgs boson interacts with particles that have mass, so there is a distinct possibility that the Higgs could interact with dark matter particles,” says CMS researcher Richard Cavanaugh of the Fermi National Accelerator Laboratory and the University of Illinois at Chicago. If the Higgs does decay into dark matter particles, for example, they would fly out of the LHC without ever being detected. Yet their absence— and the absence of enough other decay products — could make an impression.

Ultimately, no one knows what the coming years at LHC will bring, but the host of enticing possibilities has scientists on the edges of their seats. “This is just one of the most exciting times to be a physicist,” Cavanaugh says. “I wake up in the morning with goose bumps because of where we are.”

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References

1. The CMS Collaboration *Nature Phys.* http://dx.doi.org/10.1038/nphys3005 (2014).