Physicists' Nightmare Scenario: The Higgs and Nothing Else

Many fear the LHC will cough up only the one particle they've sought for decades. Some would rather see nothing new at all

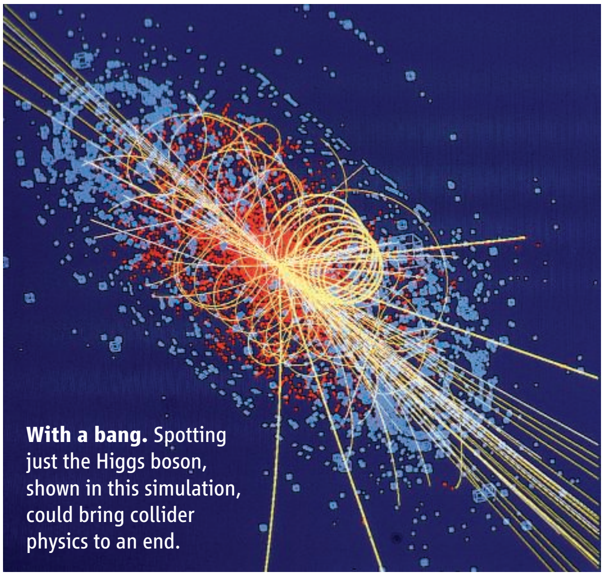
Suppose you are a particle physicist. A score of nations has given you several billion Swiss francs to build a machine that will probe the origins of mass, that ineffable something that keeps an object in steady motion unless shoved by a force. Your proposed explanation of mass requires a new particle, cryptically dubbed the Higgs boson, that your machine aims to espy. When, after 2 decades of preparation, you get ready to switch on your rig, you would fear nothing more than the possibility that you were wrong and the particle doesn't exist, right? Not exactly.

Many particle physicists say their greatest fear is that their grand new machine—the Large Hadron Collider (LHC) under construction at the European particle physics laboratory, CERN, near Geneva, Switzerland—will spot the Higgs boson and nothing else. If so, particle physics could grind to halt, they say. In fact, if the LHC doesn't reveal a plethora of new particles in addition to the Higgs, many say they would rather it see nothing new at all.

That may seem perverse, but put yourself again in the shoes of a particle physicist. In the 1960s and 1970s, researchers hammered out a theory called the standard model that, in spite of leaving out gravity and suffering from other shortcomings, has explained everything seen in collider experiments ever since and left physicists with few clues to a deeper theory. At the energies the LHC will reach, the standard model goes haywire, spitting out negative probabilities and other nonsense. So the collider has to cough up *something* new, researchers say. If it spits out only the Higgs, however, the new golden age of discovery could end as soon as it begins.

If the lone Higgs has just the right mass—about 190 times the mass of a proton—it would tie up the standard model's loose ends and leave physicists even more thoroughly stymied than before, says Jonathan Ellis, a theorist at CERN. "This would be the real five-star disaster," he says, "because that would mean there wouldn't need to be any new physics all the way up to the Planck scale," the mind-bogglingly high energy at which gravity pulls as hard as the other forces of nature. The Higgs alone could essentially mark a dissatisfying end to the ages-long quest into the essence of matter.

If, on the other hand, the LHC sees no new particles at all, then the very rules of quantum mechanics and even Einstein's special theory of relativity must be wrong. "It would mean that everything we thought we knew about everything falls apart," says Harvey Newman, an experimenter at the California Institute of Technology in Pasadena. That would thrill many but is so unlikely that it would be "essentially impossible" for the LHC to see nothing new, Newman says. Others agree.



With a bang. Spotting just the Higgs boson, shown in this simulation, could bring collider physics to an end.

CREDIT: CERN

Physicists have no similar guarantee that the LHC will reveal not only the Higgs but also exotic new particles that would point to new physics and open a new era of discovery. So the LHC is a gamble, and many are pulling for the more exciting long shots.

Quack like a Higgs

Easily the most famous particle not yet discovered, the Higgs has even been crowned the "God particle" by one Nobel laureate. In reality, however, it is merely an ad hoc solution to an abstruse problem in the standard model: how to give particles mass.

The particular challenge is to give mass to particles called the W and Z bosons, which convey the weak nuclear force. According to the standard model, the weak force that causes a type of radioactive decay and the electromagnetic force that powers lightning and laptop computers are two facets of the same single thing. The two forces aren't precisely interchangeable: Electromagnetic forces can stretch between the stars, whereas the weak force doesn't even reach across the atomic nucleus. That range difference arises because photons, the quantum particles that make up an electromagnetic field, have no mass. In contrast, the particles that make up the weak force field, the W and Z bosons, are about 86 and 97 times as massive as the proton.

Unfortunately, the persnickety standard model falls apart if theorists simply assign masses to the W, Z, and other particles. So the masses must somehow arise from interactions of the otherwise massless particles themselves. In the 1960s, Peter Higgs, a theorist at Edinburgh University in the U.K., realized that empty space might be filled with a field, a bit like an electric field, that could drag on particles to give them inertia, the essence of mass. The field would consist of a new particle, the Higgs boson, lurking "virtually" in the vacuum.

Nature appears to follow this scheme. Using it, theorists predicted the masses of the W and Z. And at CERN in 1983, the two particles weighed in just as expected, in collisions energetic enough to pop them out of the vacuum.

Now, mounds of data point to the Higgs. For example, the lifetime and other properties of the Z depend on the cloud of virtual particles flitting around it like flies swarming a rotten ham sandwich. Precise studies of the Z suggest that a Higgs at most 200 times as hefty as the proton lurks in that cloud. Comparing the masses of the W and a particle called the top quark shows a similar thing, says Gordon Kane, a theorist at the University of Michigan, Ann Arbor. "These are two completely independent pieces of evidence that there is something that walks and talks and quacks like a Higgs," Kane says. "The existence of the Higgs in the LHC range is essentially certain."

Discovering the Higgs would complete the standard model. But finding *only* the Higgs would give physicists little to go on in their quest to answer deeper questions, such as whether the four forces of nature are somehow different aspects of the same thing, says Aldo Deandrea, a theorist at the University of Lyon I in France. "If you have just a Higgs that is consistent with the standard model, then you probably don't know what to do next," he says. "What then?"

Good taste and extra dimensions

Most researchers say they'll never face that question because the LHC will discover plenty of other things. Many expect it to blast out particles predicted by a concept called supersymmetry (SUSY), which posits a heavier "superpartner" for every known particle. That may seem unduly complicated, but SUSY solves problems within the standard model, points toward a deeper theory, and may even explain the mysterious dark matter whose gravity holds the galaxies together. "SUSY is unique in that it does all these things automatically," CERN's Ellis says.

Most concretely, SUSY solves a technical problem caused by the Higgs boson itself. The Higgs, too, must be shrouded in virtual particles, and they ought to send its mass skyrocketing. SUSY would explain why the Higgs is as light as it appears to be, because mathematically the effects of partner and superpartner on the Higgs mass tend to cancel each other. SUSY would also help explain the origin of the Higgs, which is just tacked onto the standard model but emerges naturally from the structure of SUSY.

SUSY could also help unify the four forces. The standard model accounts for three of them: the electromagnetic force, the weak force, and the strong nuclear force that binds particles called quarks into protons, neutrons, and other particles. The strengths of the three increase with the energy of collisions, and if the universe is supersymmetric, then all begin to tug equally hard at precisely the same energy somewhere below the Planck scale. That should make it easier to roll them and gravity together in one grand unified theory, says Frank Wilczek, a theorist at the Massachusetts Institute of Technology in Cambridge.

SUSY might even provide the dark matter that glues the galaxies together. Physicists believe that dark matter must consist of some stable particle that barely

If it has the right mass, the Higgs and nothing else **"would be the real five-star disaster, because that would mean there wouldn't need to be any new physics."**

—Jonathan Ellis, CERN

interacts with normal matter, and the least massive superpartner might just fit the bill. With all this evidence supporting it, SUSY is almost too beautiful to be wrong, some theorists say. "All these clues could be misleading," Wilczek says, "but that would be a really cruel joke by Mother Nature—and in really bad taste on her part."

The LHC might also reveal far wilder phenomena, such as inner parts to electrons and other supposedly indivisible bits of matter, tiny black holes, or even new dimensions of space that open only at very high energies.

The spare room

could explain, for example, why gravity is so much weaker than the other forces. "Something like extra dimensions I give a very small probability," says Michael Tuts, a physicist at Columbia University. "But the potential is so big that it's very exciting."

A sure bet

None of these more exotic possibilities is guaranteed. And particle physicists say that just discovering the Higgs would be a triumph. "If the Higgs is anything like theorists predict, we will find it," says Peter Jenni, an experimenter at CERN. "We shouldn't be disappointed if we do."

Physicists also admit that, regardless of the intellectual foment it would cause, finding nothing would create problems, at least with the governments that paid for the LHC. "Just imagine if we go to the CERN Council and say, 'Thank you very much, we've just spent billions of Swiss francs, and there's nothing there,' " Ellis says. "I think they might be a tad disappointed."

However, finding only the Higgs may make life nearly as difficult for physicists trying to persuade governments to build the next great particle smasher, the proposed International Linear Collider (ILC). Costing between $10 billion and $15 billion, the ILC would map out the conceptual terrain opened by the LHC (*Science*, 9 February, p. 746). By colliding indivisible electrons and positrons, the ILC would generate cleaner collisions that should reveal details of new particles that will be obscured by the messy proton-on-proton collision at LHC.

But if the ILC has only the Higgs to study, then it becomes "a very hard sell both scientifically and politically," says David Cinabro, a particle-physicist-turned-astronomer at Wayne State University in Detroit, Michigan. "I think you'll have a really hard time arguing that's what you want $10 billion for," he says.

Others say such speculation is premature and pessimistic. "We are so used to discussing the new territory that we are going to enter that sometimes we think that we know what we are going to find," says Jos Engelen, chief scientist at CERN. "Well, we don't, and I think it will be much more exciting than we expect." That may be, but this much is certain already: Everyone hopes for more than just the Higgs.

–ADRIAN CHO

LHC Stakes *1.49 million furlongs per second.*
Purse: Nobel Prize for long-sought particles, well-motivated theoretical concepts, and speculative guesses.

DISCOVERY	COMMENTS	ODDS*
Standard Model Higgs	As good as discovered, some say	2–1
Big surprises	Expect the unexpected	2–1
Supersymmetry	Too beautiful to be wrong?	5–1
Extra dimensions	More an inspired guess than a prediction	14–1
Composite electrons, etc.	Bigger fleas have littler fleas …	14–1
Leptoquarks	Weird particles hinted at by another collider	49–1
Nothing	Be careful what you wish for	7–1

* Based on survey of roughly 300 grad students, postdocs, and professors at Fermilab, as reported in the January/February issue of *Symmetry* Magazine. Respondents could choose more than one prediction.

CREDIT: CERN