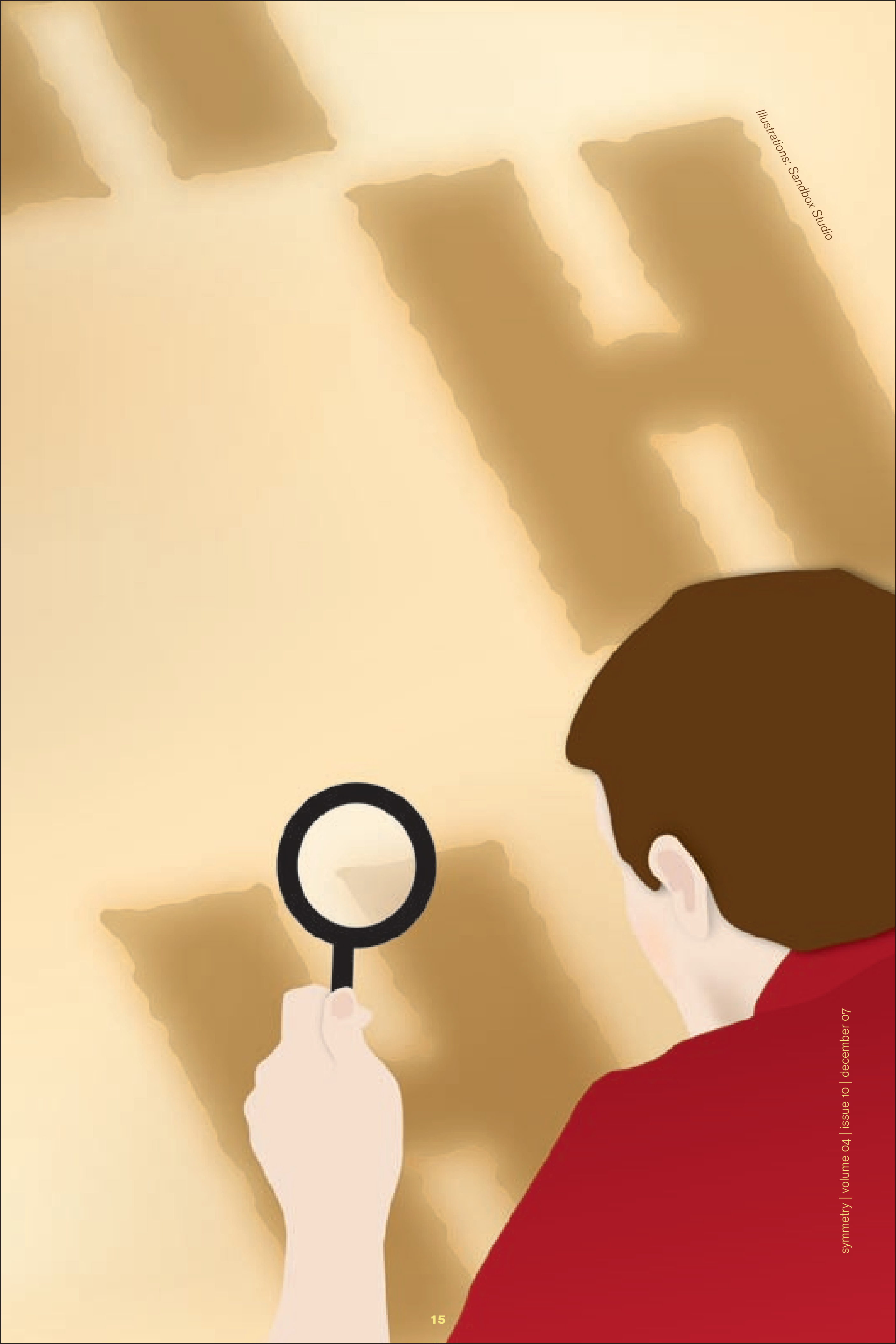
Entering Higgs habitat

By Heather Rock Woods

A powerful new collider will allow scientists to explore the territory where the long-sought Higgs particle–maybe even a whole family of them–resides.

They sound like Zen koans: The Higgs field bestows mass on other particles, but its own mass is unknown. It pervades the universe, but no one has seen its physical manifestation, the Higgs particle. It's the only missing piece of the Standard Model of particles and forces, but the model accounts for just four percent of the universe.

Less puzzlingly, but just as important, physicists think the Higgs field is responsible for giving mass to some particles but not others. It acts like a gooey, universe-sized bucket of molasses. As particles travel through the field, some interact with the molasses more strongly than others. Those that interact most become heaviest, while those that don't interact at all are left without mass. Without this fundamental phenomenon, the world would be a different place: heavy atoms wouldn't hold together; all elementary particles would be massless, zipping around at the speed of light; the reactions that stoke stars would go faster, slower, or not at all.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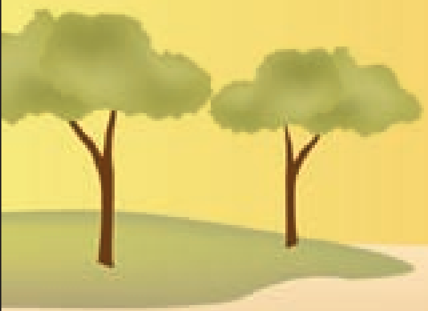


Discovering the Higgs particle and pinning down how much it weighs will ultimately make or break theories that explain, for example, the nature of the dark matter that makes up nearly a quarter of the universe.

After more than 20 years of searching, physicists think they will finally find this elusive particle at the Large Hadron Collider, now being set up in an underground tunnel near the Geneva, Switzerland, headquarters of CERN, the European particle physics lab.

Why is this omnipresent entity so hard to find? What makes the search different this time?

Cranking up the energy

One reason the Higgs particle is hard to find is because nobody knows how much it weighs, which means no one knows exactly where to look. While the Standard Model is clear about what roles the Higgs fulfills, it doesn't offer very practical parameters for conducting the search.

Thanks to Albert "$E=mc^2$" Einstein, physicists recognize that energy and mass are interchangeable. Particle masses are expressed in terms of energy, usually in units of GeV, or billions of electronvolts. Physicists create new particles by packing more energy into particles that are traveling at nearly the speed of light. When these particles collide, they free all that energy, which coalesces into new particles. The heavier the particle you want to create, the more energetic the collision needs to be.

The Higgs could have any mass up to about one trillion electronvolts, or TeV—about 1000 times heavier than a hydrogen atom. If it's on the lighter side, the Higgs could be within the scope of today's most powerful accelerator, the Tevatron collider at Fermi National Accelerator Laboratory in Illinois; scientists at two experiments there are racing to find its footprints.

The Higgs hasn't turned up at any of the energies—up to 115 GeV—that accelerators have explored so far. The LHC opens new territory to the search. It's the first accelerator that will provide access to the full range of habitat where the Higgs can live. If the Higgs predicted by the Standard Model exists—and the Standard Model has been right about everything it has predicted so far—it will be seen at the LHC. In fact, the LHC might even observe five or 12 kinds of Higgs, if closely related theories like supersymmetry are also correct.

Finding the Higgs "will not be easy. We have to suffer," says CERN physicist Fabiola Gianotti, deputy spokesperson for the LHC's ATLAS detector collaboration. "But that way, the satisfaction will be even bigger."

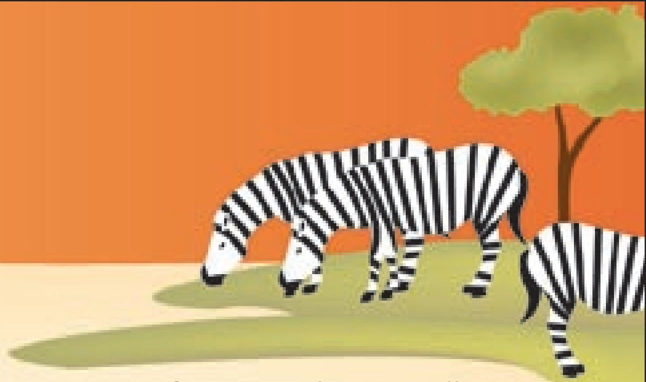
Not empty-handed

While the Higgs remains unseen for now, physicists have some idea of where to look. One direct search took place at LEP, the Large Electron-Positron collider, which used to inhabit the tunnel where the LHC is now being commissioned. That expedition saw teasing hints of a Higgs particle at 115 GeV, the upper limit of LEP's power. The signal, however, was too weak to rule out random fluctuations. Reluctantly, after keeping the collider running an extra month to take more data, CERN shut down the experiments in 2000 to begin LHC construction.

Indirect searches also support the idea of looking at the lower end of the range of possible masses—closer to 100 billion electronvolts than to a trillion. Experiments at two colliders, the Stanford Linear Collider in California and LEP at CERN, put boundaries on the possible mass of the Higgs by making extremely precise measurements of the *Z* particle.

The *Z* and *W* particles mediate the weak force, the driver of radioactive decays that power the sun. Thanks to the Higgs, both are heavy, with masses of 91 and 80 GeV, respectively. (In contrast, the Higgs field does not confer mass on other types of particles that transmit fundamental forces, such as the strong force that binds atoms and the electromagnetic force that radiates light and heat.)

Precise measurements of the *Z* made with LEP and the Stanford collider detected slight perturbations that were consistent with the presence of a Higgs particle. This data, combined with other precision measurements from all over the world, points with high probability to a Higgs mass no greater than 144 GeV.



Luck and luminosity

There's still a chance that the Higgs will turn up before the LHC switches on in 2008. Scientists analyzing data from the Tevatron collider at Fermilab are crossing their fingers, hoping for luck and enough particle collisions, or luminosity, to discover the Higgs first.

The Tevatron can't cover the full Higgs habitat, but it could be sensitive to Higgs tracks in the vicinity of 160 GeV. In December 2006, long-time Higgs searcher John Conway of the University of California, Davis caused a stir by describing in a blog the "bump" his group saw at around 150 GeV. But by last fall, with 80 percent more data, the bump had melted away, just another random fluctuation.

To maximize the Tevatron's odds, "We need more data, improved triggering, and better analysis," says Conway, who has been a part of the Higgs hunt for almost 20 years. "We are doing all of these. Will it be enough?"

Even though the Tevatron routinely produces 175 GeV top quarks, which are quite possibly heavier than the Higgs, the Higgs isn't as easily produced.

Tracks in the dirt

While the LHC offers tremendous energy reach, creating huge numbers of particles with energies up to 14 TeV, Higgs particles won't just appear like a herd of zebra on a savanna. Scientists have to find their tracks in the dirt—or, in this case, the decay patterns they leave in detectors. If the Higgs is heavy, its decay pattern will be completely different than if it is light. In addition, whatever its mass, the Higgs particle would not always disintegrate in the same way; it has preferred decay paths as well as rarer routes. To spot the varying patterns left by the transitory Higgs, physicists need to search not just with the equivalent of binoculars, but with microscopes and telescopes, for tracks that can look as different as slug slime from bear scat.

So rather than twisting the dial on an analog radio to sweep across increasing frequencies, searchers will have to use different techniques to pick up the signals of Higgs particles of different masses. For example, if the Higgs is about 190 GeV, heavier than the indirect measurements predict, it will predominately decay into a pair of *Z* particles that in turn make four electrons or four muons. This would be the easiest way to find the Higgs at the LHC. But if the Higgs is very light, the most common decay is to a pair of *b* quarks. Unfortunately, LHC collisions will make so many *b* quarks that the Higgs signal would be inaudible, like a favorite radio station overwhelmed by static. Instead, researchers will have to look for the less distinct signal of two photons generated in a much rarer Higgs decay.

"If nature chose 115 GeV, it's one of the most difficult corners for the LHC," says Su Dong, head of the Stanford Linear Accelerator Center's participation in the ATLAS detector collaboration at LHC.

Physicists will have to monitor all these channels of decay using multiple analytical techniques. "You have to look everywhere," affirms SLAC theorist JoAnne Hewett.

More than one?

The Higgs occupies a strange place in the taxonomy of physics. "The Higgs lives on the boundary. Is it a known particle or an unknown?" asks Su Dong. Based on the success of the Standard Model, the existence of the Higgs has become so accepted that it doesn't even rank on some lists of new particles to be discovered. Moreover, the Higgs seems to solve the problems that crop up with the Standard Model at very high energies, making it handy theoretically.

But what if the Standard Model is wrong? Successful as it is, the model is clearly incomplete; for instance, it doesn't account for the dark matter and dark energy that make up 96 percent of the universe.

There might be no Higgs, or multiple Higgses. No experiment has ruled out these concepts. While theorists and experimentalists clearly expect to see the Higgs, or something just like it, they're really hoping the LHC will uncover one of those more spectacular scenarios.

The multi-Higgs scenario occurs in a theory called supersymmetry, which suggests that every particle in the Standard Model has a heavier partner. If the theory is correct, there could be multiple Higgs particles and more than one Higgs field.

Finding supersymmetry particles is one of the main goals of the LHC experiments; and thanks to the rapid rate at which they are produced, supersymmetry particles may well be one of the collider's first discoveries, making our universe both more crowded and more exciting. There's even a chance that both supersymmetry and the Higgs could surface first at the Tevatron, if it produces collisions at a high enough rate.

"There are a million models, so many different possibilities. That's the exciting thing," says Sally Dawson, a Brookhaven National Laboratory theorist and co-author of *The Higgs Hunter's Guide*. "The more you can measure, the more you can pin down the underlying story."

What if the Higgs doesn't show itself? "That would be the biggest discovery of all," says Su Dong.

Such a conundrum would hasten the pace of new thinking. In the meantime, physicists are building their nets, cleaning their binoculars, weatherproofing their boots, and preparing to track the Higgs's first tangible footprints.