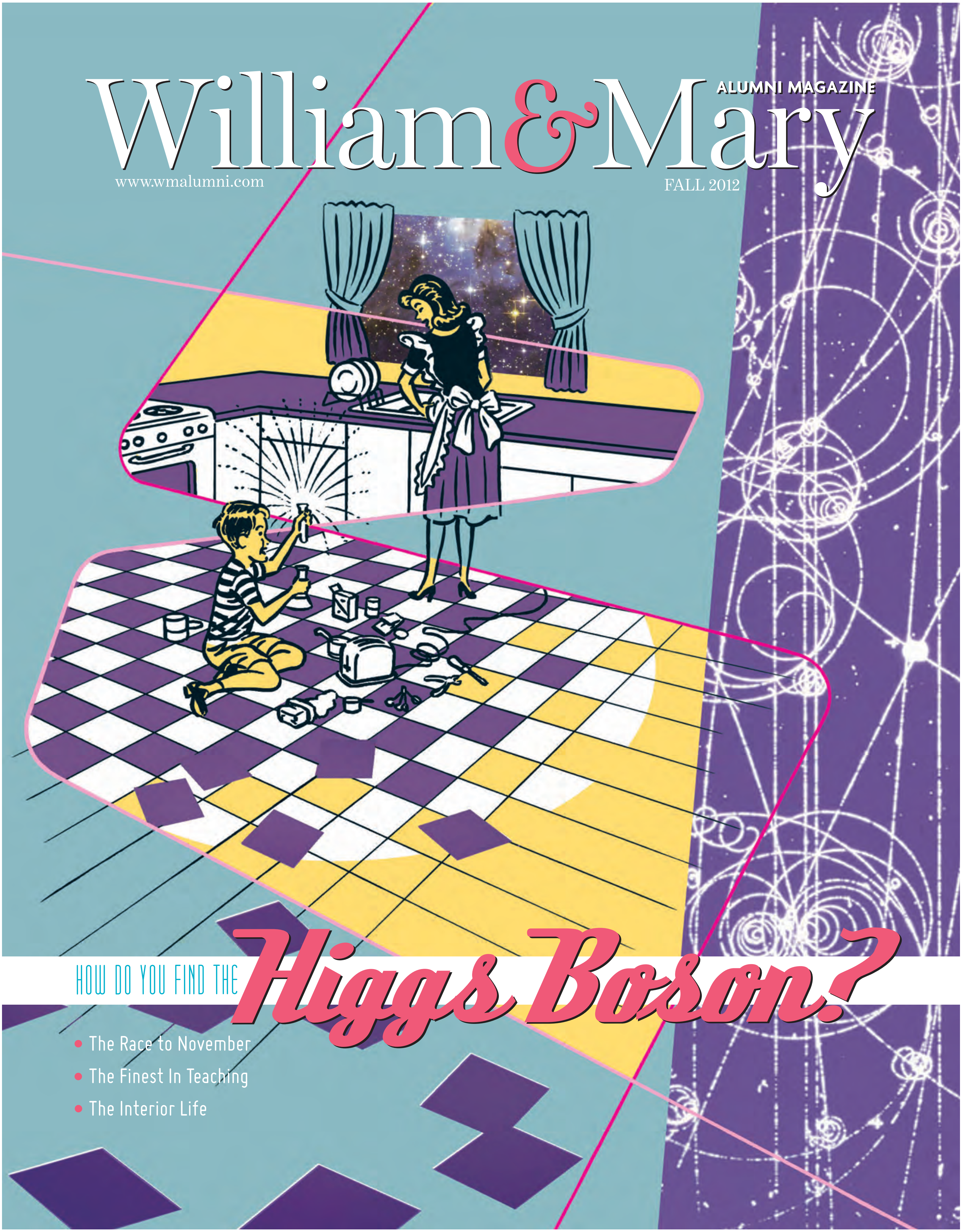
William & Mary

ALUMNI MAGAZINE

www.wmalumni.com

FALL 2012



HOW DO YOU FIND THE Higgs Boson?

- The Race to November
- The Finest In Teaching
- The Interior Life


NOTHING
SOMETHING

Better Living Through Particle Physics

W&M Physicists Delve Into Big Questions in Little Spaces

Story By Ben Kennedy '05   Illustrations By Jonathan Carlson

One of the biggest mysteries about the nature of the universe has been solved.

Probably. They're not 100 percent sure yet. So they're still looking.

In July, researchers at the *Organisation européenne pour la recherche nucléaire* in Switzerland (better known as CERN) made a major scientific announcement. Using the powerful Large Hadron Collider (LHC), they had discovered — with a surprisingly high degree of certainty — what they believe to be the long-awaited Higgs boson.

"The *raison d'etre* for the Higgs boson is to explain how the fundamental particles have mass," says William & Mary physicist Josh Erlich. Mainstream physics research has been focused on what's called the "standard model" for decades (see p. 47); the Higgs boson was the last piece of the model yet unproven.

But now they think they've got it — which, in some ways, might actually be a problem.

W&M Physics professor Marc Sher first began writing about the Higgs in 1978, a decade or so after Peter Higgs and others first theorized about it. He figured researchers at one of the many precursors to the LHC would discover the Higgs by, oh, 1982 or so.

But they didn't find it. It soon became clear that they couldn't have. Particle accelerators are very large, frequently circular structures that move subatomic particles at extremely high speeds in order to smash them into each other. By observing the resulting collision, scientists can see what other, even tinier particles come out, and how they decay. The

subatomic particle's mass is described by an equivalent measure of gigaelectron volts (GeV) involved in the collision; remember, $E=mc^2$. The more energy the accelerator can produce, the better results they can get. And the facilities in the '80s and '90s just weren't powerful enough.

Theoretically, the standard model predicted a Higgs boson, or Higgs-like particle, based on the math alone. Sher and researchers like him have run incredibly complex calculations to look at how a Higgs might behave while interacting with other fundamental particles.

"I've been doing other things, too, but I always keep coming back to taking the Higgs system in the standard model and extending it to two or more Higgs bosons," says Sher.

> "There's just so much data, it's like the Library of Congress every second or two. It's not trivial to go through."

Enter the LHC. Begun in 1998 to replace its predecessor, the Large Electron-Positron Collider, the LHC is 27 kilometers in diameter and sits 100 meters below the ground. After some initial hiccups, the LHC went online in 2009 as the most powerful instrument ever built for particle physics.

The LHC was supposed to nail down the truth: either there's a Higgs or there's not. But three years passed; it became clear 2012 was "make or break time." Marc Sher started to get nervous.

Then, on the 4th of July, the announcement came. Something that appeared to be very much like the Higgs boson was discovered at 125 GeV, a value only achievable by the LHC.

"As a layman, I would say, I think we have it," said Rolf-Dieter Hauer, director general of CERN. The *Telegraph* of London quoted other scientists who described it as akin to the discovery of DNA or the Moon landing.

"If they had seen nothing, it would mean everything I've done is worthless," says Sher, who was quoted in the media's Higgs stories. "For me, it was a great relief." But science still isn't quite sure.

"We don't know it's the Higgs," he says. "It looks like a duck, walks like a duck, swims like a duck, quacks like a duck, and it's exactly what you expected a duck to be. However, you don't know what kind of duck it is."

"The way it was presented too often was, 'OK, they found the Higgs, now we can shut down,'" he says.

The Higgs would be nice, but Sher wants even more to discover.

As the last unproven piece of the standard model puzzle, the Higgs boson is seen by some as the end of the line, joining the other bosons, electrons, muons and neutrinos already in place. To others, especially advocates of what physicists call supersymmetry, there is more hope for additional particles.

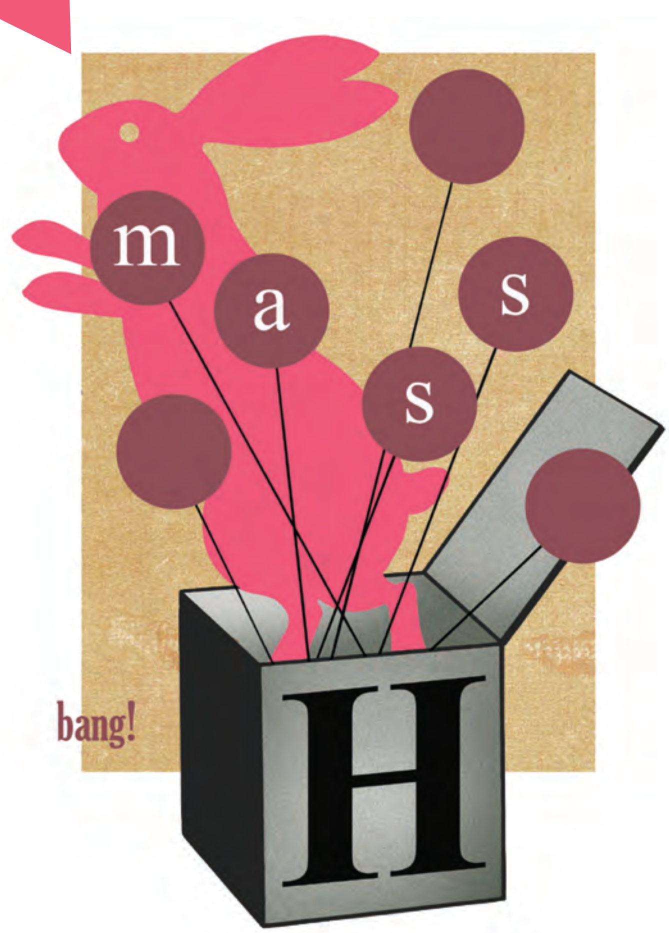
For another thing, CERN could turn out to be wrong. There are variations in the data produced before July that could indicate something else is at work.

"There are still skeptics among the particle physics community who cling to alternative interpretations of the particle that was recently discovered at CERN," says Prof. Erlich, "leaving open the possibility that Nature has tricked us into believing that a distant cousin of the Higgs boson is really the Higgs boson itself."

"If it hadn't been there, there were so many interesting things that could have been there," says Sher.

Alternatively, Sher is worried that the Higgs could be "it." The relief he felt at the CERN announcement was tempered by a new worry. When the LHC closes and reopens at an even more powerful level in 2014, what if they realize there are no new particles to discover?

After all, not everyone actually wanted to find it — one physicist wrote an article called "Why I Would Be Very Sad If A Higgs Boson Were Discovered" — in the hopes of a more complex problem to solve in its place. Some of that uncertainty will be erased by the end of the year. CERN is still running the LHC "like mad," says Sher, and already has twice the data it did at the July announcement. More data means more



certainty, as scientists eliminate statistical fluctuations to get a fuller picture of the Higgs' behavior.

"There's just so much data, it's like the Library of Congress every second or two," he says. "It's not trivial to go through."

When so much information is being produced, scientists have to narrow down the data to focus on what they're actually looking for. So tons of stuff is just being thrown out. Even CERN can't handle it all.

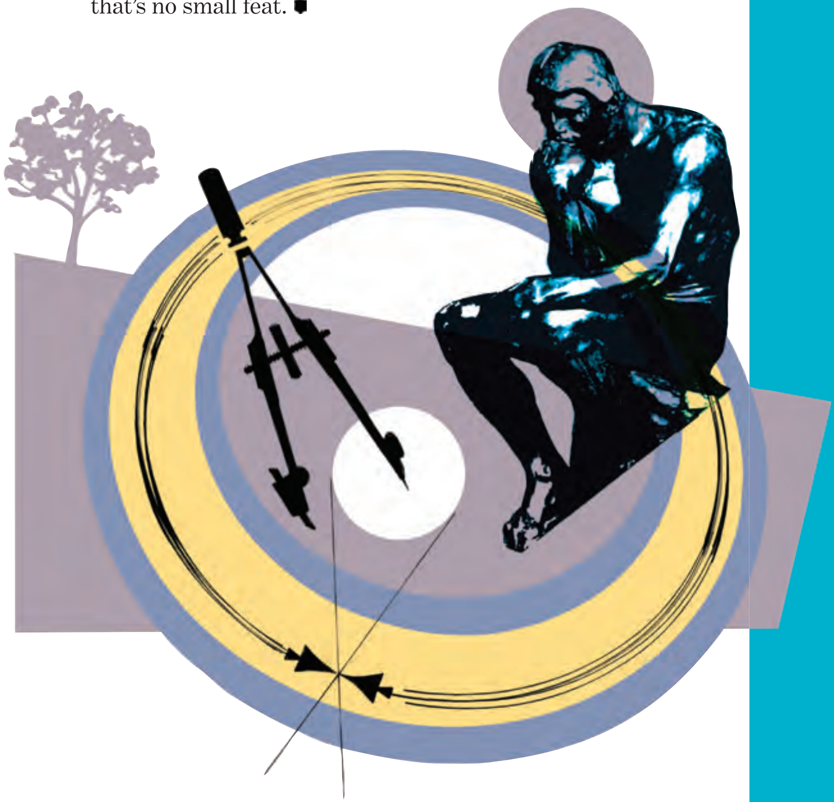
Sher's last paper dealt with some of those concerns. Before CERN's announcement, he had discussed the idea there might be two or more Higgs. But he made a few other suggestions. First, he theorized that the two Higgs bosons have differing masses. Then he assumed the 125 GeV Higgs was the heavier one, and went to work.

"What would you have to do to avoid [the lighter Higgs] having been seen in the past?" he asks. "There are accelerators that would have seen it ... so you can find parameters where it would have been missed."

These calculations are not done underground in Switzerland, but on Sher's computer in Williamsburg. Most particle theory is done this way. And 15 pages of code later, Sher's team of researchers had their results, which would be widely read by the physicists at CERN and elsewhere.

Of course, all this presumes there are not just one, but two Higgs bosons. No one is sure yet, but Sher thinks they'll have a better idea by December when the LHC has been running a while longer. Already there are hints there might be a second Higgs at 132 GeV, but only whispers.

In the near future, though, there's more science to do at these smallest scales. For Marc Sher, the knowledge that the Higgs boson is real (or something like it) means the long hours theorizing about predicted behavior of these incredibly short-lived particles was rooted in real, observable fact. For a theorist dedicated to the tiniest of elemental particles, that's no small feat. ∎



What is a boson?

Most people are familiar with the basic subatomic particles: electrons, protons and neutrons as well as a few of the fundamental properties of nature like electromagnetism and gravity. Physicists know that protons and neutrons are actually made up of other particles called quarks and that still more exotic particles such as neutrinos and muons show up as the residue from high-energy collisions inside particle accelerators.

The standard model of physics attempts to unite these forces and particles into a single model that describes how the universe is put together. It breaks the universe down into three types of particles: quarks, leptons and bosons. Quarks and leptons make up all of the matter. Bosons transmit the fundamental properties.

For example, electrons are actually one of the six types of leptons while protons and neutrons are composite particles and are each composed of three different types of quarks. Photons are a type of boson that transmit the electromagnetic force and the Higgs boson transmits the property of mass.

Not all mass is acquired by interactions with the Higgs boson. Composite particles such as the proton and neutron gather much of their mass from the quarks that they are composed of. The electron, however, is an elementary particle and so all of it's mass is attributed to the Higgs. Without the Higgs, the world as we know it would not exist. Any slight difference in the mass of the electron would result in a world where atoms are either too reactive to be stable or too inert to produce all of the molecules that make up life on our planet.

Why is it hard to find?

Unlike every-day objects that we're familiar with, the Higgs boson is an inherently unstable particle. In order to produce a Higgs boson, you need to smash two protons together at extremely high speeds. Even then, only a tiny fraction of those collisions will result in the production of a Higgs boson. Furthermore, on the off-chance that a collision does produce a Higgs boson, the Higgs only pops into existence for an instant before it decays, producing a spray of quarks, leptons and other types of bosons.

Not all Higgs bosons decay in the same way. Luckily, a small fraction of Higgs bosons decay in a way that the LHC can detect. The difficulty arises due to the fact that the results of a decaying Higgs are also identical to the results of the sea of other decaying particles inside the collider. This makes it extremely difficult to pick out the faint signals of a rare decaying Higgs among the noise of other energetic events.

Because of this, finding a Higgs is less like discovering buried treasure than it is like picking out the faint ringing of a distant cell phone from the front row of a raging rock concert.

By Del Putnam