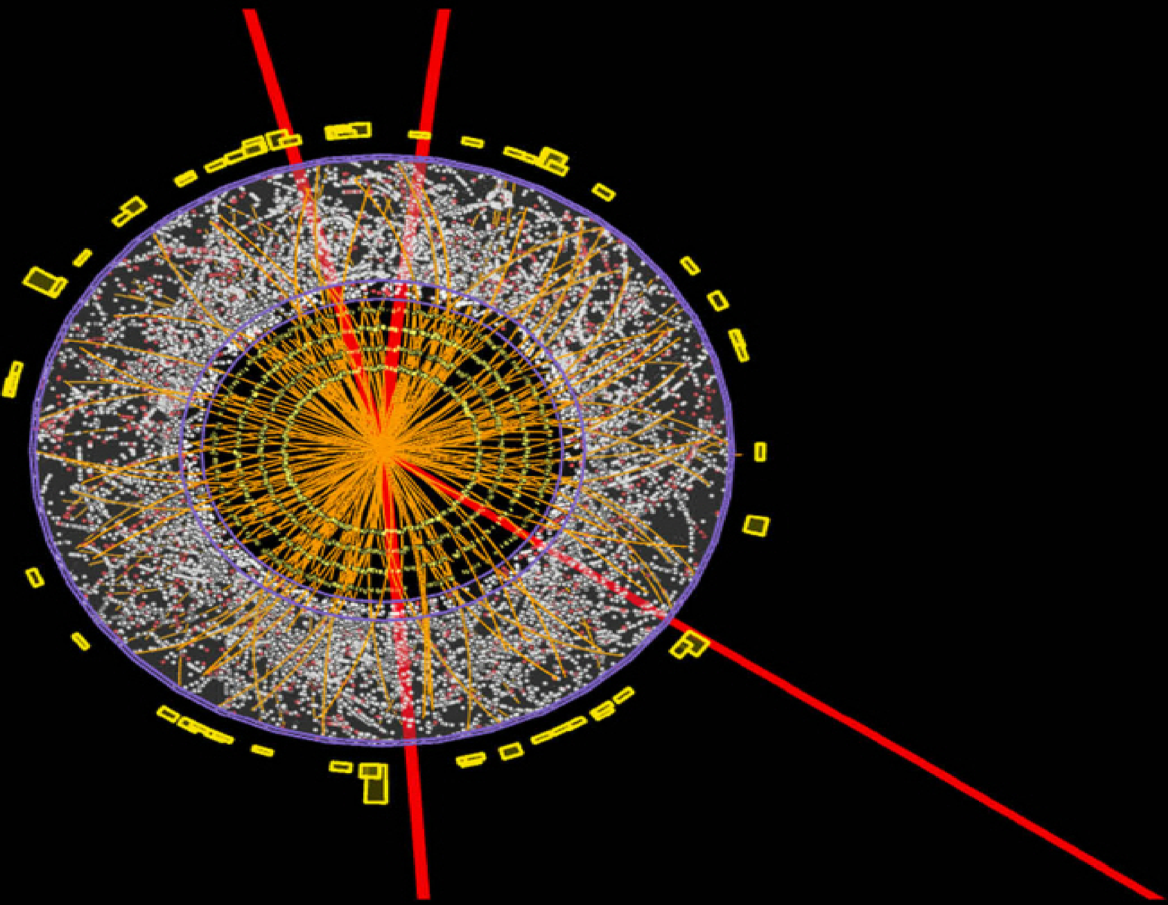
HIGGS DISCOVERY

THE POWER OF EMPTY SPACE



LISA RANDALL

AUTHOR OF *KNOCKING ON HEAVEN'S DOOR*

About the Author

Professor Lisa Randall studies theoretical particle physics and cosmology at Harvard University. Her studies have made her among the most cited and influential theoretical physicists, and she has often appeared on radio and TV.

Professor Randall’s book *Warped Passages: Unravelling the Mysteries of the Universe’s Hidden Dimensions* was included in the *New York Times* ‘100 notable books of 2005’, and she was included in the list of *Time* magazine’s ‘100 Most Influential People of 2007’ and was featured in *Newsweek’s* ‘Who’s Next in 2006’ as ‘one of the most promising theoretical physicists of her generation’. She has received numerous awards and honors for her scientific endeavors.

She is a member of the National Academy of Sciences, the American Philosophical Society and the American Academy of Arts and Sciences, and an Honorary Member of the Royal Irish Academy and Honorary Fellow of the Institute of Physics. Her latest book is *Knocking on Heaven’s Door: How Physics and Scientific Thinking Illuminate our Universe*.

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ON JULY 4, 2012, along with many other people around the globe who were glued to their computers, I learned that a new particle had been discovered at the Large Hadron Collider (LHC) near Geneva. In what is now a well-publicized but nonetheless stunning turn of events, spokespeople from CMS and ATLAS, the two major LHC experiments, announced that a particle related to the Higgs mechanism, whereby elementary particles acquire their masses, had been found. I was flabbergasted. This was actually a discovery, not a mere hint or partial evidence. Enough data had been collected to meet the rigorous standards that particle physics experiments maintain for claiming a new particle's existence. The accumulation and analysis of sufficient evidence was all the more impressive because the date of the announcement had been fixed in advance to coincide with a major international physics conference occurring in Australia that same week. And what was more exciting still was that the particle looks a lot like a particle called the Higgs boson.

A Higgs boson is not just a new particle, but a new type of particle. The thrill in this particular discovery was that it was not simply a confirmation of definite expectations. Unlike many particle discoveries in my physics lifetime, for which we pretty much knew in advance what had to exist, no physicist could guarantee that a Higgs boson would be found in the energy range that the experiments currently cover—or even found at all. Most thought something like a Higgs boson should be present in nature, but we didn't know with certainty that its properties would permit experiments to find it this year. In fact, some physicists, Stephen Hawking among them, lost bets when it was found.

This discovery confirms that the Standard Model of particle physics is consistent. The Standard Model describes the most elementary components that are known in matter, such as quarks, leptons (like the electron), and the three nongravitational forces through which they interact—electromagnetism, the weak nuclear force, and the strong nuclear force. Most Standard Model particles have nonzero masses, which we know through many measurements. The Standard Model including those masses gives completely consistent predictions for all known particle phenomena at the level of precision of a fraction of a percent.

But the origin of those particle masses was not yet known. If particles had mass from the get-go, the theory would have been inconsistent and would have made nonsensical predictions such as probabilities of energetic particles interacting that were greater than one. Some new ingredient was required to allow for those masses. That new ingredient is the Higgs mechanism, and the particle that was found is very likely the Higgs boson that signals the mechanism's existence and tells how it is implemented. With improved statistics, which is to say with more information after the experiments run longer, we will learn more about what underlies the Higgs mechanism and hence the Standard Model.

Though a discovery was indeed announced, it was in fact made with some of the caution I had come to expect from particle physics announcements. Because the measurements had identified barely enough Higgs boson events to claim a discovery, they certainly didn't yet have enough data to measure all the newly discovered particle's properties and interactions accurately enough to assure that it is a single Higgs boson with precisely the properties such a particle is expected to have. A deviation from expectations could turn out to be even more interesting than something in perfect accord with predictions. It would be conclusive evidence for a new underlying physical theory beyond the simple model that implements the Higgs mechanism that current searches are based on. This is the sort of thing that keeps theorists like me on our toes as we try to find matter's underlying elements and their interactions. Precise measurements are ultimately what tell us how to move forward in our hypotheses. The Higgs boson is a very special particle indeed and we ultimately want to know as much as we can about it.

Whatever has been found—*the* Higgs boson, the particular implementation of the Higgs mechanism that seems simplest, or something more elaborate—it is almost certainly something very new. The interest from the public and press has been very gratifying, indicating a thirst for knowledge and scientific advances that humanity to a large extent shares. After all, this discovery is part of the story of the universe's evolution as its initial symmetry was broken, particles acquired masses, atoms were formed, structure, and then us. News stories featured members of the public who were fascinated but weren't necessarily quite sure by what. Perhaps the ultimate recognition of the pervasiveness of Higgs boson awareness was the appearance of jokes and spoof news stories indicating the interest—but also some of the bewilderment.

So I'm writing this to respond to many of the questions I've been asked—to share what the discovery means and to explain a bit about where it takes us. Some of what I'll say is already in chapters from my previous books, *Warped Passages* and *Knocking on Heaven's Door*; a chapter from *Knocking on Heaven's Door* is appended to this text. These previous books didn't isolate the Higgs boson for extra special attention; rather they covered many topics, including information about the collider, the larger physics story for which this is the capstone, and the nature of science itself. They give the larger context of which this discovery is one—albeit a very important—part. But at least