What will the Large Hadron Collider reveal?

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With its successful test run at the end of 2009, the Large Hadron Collider near Geneva, Switzerland, seized the world record for the highest-energy particle collisions created by mankind. We can now reflect on the next questions: What will it discover, and why should we care?

Despite all we have learned in physics -- from properties of faraway galaxies to the deep internal structure of the protons and neutrons that make up an atomic nucleus -- we still face vexing mysteries. The collider is poised to begin to unravel them. By colliding protons at ultra-high energies and allowing scientists to observe the outcome in its mammoth detectors, the LHC could open new frontiers in understanding space and time, the microstructure of matter and the laws of nature.

We know, for example, that all the types of matter we see, that constitute our ordinary existence, are a mere fraction -- 20 percent -- of the matter in the universe. The remaining 80 percent apparently is mysterious "dark matter"; though it is all around us, its existence is inferred only via its gravitational pull on visible matter. LHC collisions might produce dark-matter particles so we can study their properties directly and thereby unveil a totally new face of the universe.

The collider might also shed light on the more predominant "dark energy," which is causing the universe's expansion to accelerate. If the acceleration continues, the ultimate fate of the universe may be very, very cold, with all particles flying away from one another to infinite distances.

More widely anticipated is the discovery of the Higgs particle -- sometimes inaptly called the God particle -- whose existence is postulated to explain why some matter has mass. Were it not for the Higgs, or something like it, the electrons in our bodies would behave like light beams, shooting into space, and we would not exist.

If the Higgs is not discovered, its replacement may involve something as profound as another layer of substructure to matter. It might be that the most elementary known particles, like the quarks that make up a proton, are made from tinier things. This would be revolutionary -- like discovering the substructure of the atom, but at a deeper level.

More profound still, the LHC may reveal extra dimensions of space, beyond the three that we see. The existence of a completely new type of dimension -- what is called "supersymmetry" -- means that all known particles have partner particles with related properties. Supersymmetry could be discovered by the LHC producing these "superpartners," which would make characteristic splashes in its detectors. Superpartners may also make up dark matter -- and two great discoveries would be made at once.

Or, the LHC may find evidence for extra dimensions of a more ordinary type, like those that we see -- still a major revolution. If these extra dimensions exist, they must be wound up into a small size, which would explain in part why we can't see or feel them directly. The LHC detectors might find evidence of particles related to the ones we know but shooting off into these dimensions.

Even more intriguing, if these extra dimensions are configured in certain ways, the LHC could produce microscopic black holes. As first realized by Stephen Hawking, basic principles of quantum physics tell us that such black holes evaporate in about a billionth of a billionth of a billionth of a second -- in a spectacular spray of particles that would be visible to LHC detectors.

This would let us directly probe the deep mystery of reconciling two conflicting pillars of 20th century physics: Einstein's theory of general relativity and quantum mechanics. This conflict produces a paradox -- related to the riddle of what happens to stuff that falls into a black hole -- whose resolution may involve ideas more mind-bending than those of quantum mechanics or relativity.

Other possible discoveries include new forces of nature, similar to electric or magnetic forces. Any of these discoveries would represent a revolution in physics, though one that had been already considered. We may also discover something utterly new and unexpected -- perhaps the most exciting possibility of all. Even not discovering anything is important -- it would tell us where phenomena we know must exist are not to be found.

Such talk of new phenomena has worried some -- might ultra-high-energy particle collisions be dangerous? The simple answer is no.

Though it will be very novel to produce these conditions in a laboratory, where they can be carefully studied, nature is performing similar experiments all the time, above our heads. Cosmic ray protons with energies over a million times those at the LHC regularly strike the protons in our atmosphere, and in other cosmic bodies, without calamity. Also, there are significant indications that nature performed such experiments early in the universe, near the Big Bang, without untoward consequences. Physicists have carefully investigated these concerns on multiple occasions.

All this may seem like impractical and esoteric knowledge. But modern society would be unrecognizable without discoveries in fundamental physics. Radio and TV, X-rays, CT scans, MRIs, PCs, iPhones, the GPS system, the Web and beyond -- much that we take for granted would not exist without this type of physics research and was not predicted when the first discoveries were made. Likewise, we cannot predict what future discoveries will lead to, whether new energy sources, means of space travel or communication, or amazing things entirely unimagined.

The cost of this research may appear high -- about $10 billion for the LHC -- but it amounts to less than a ten-thousandth of the gross domestic product of the U.S. or Europe over the approximately 10 years it has taken to build the collider. This is a tiny investment when one accounts for the continuing value of such research to society.

But beyond practical considerations, we should ponder what the value of the LHC could be to the human race. If it performs as anticipated, it will be the cutting edge for years to come in a quest that dates to the ancient Greeks and beyond -- to understand what our world is made of, how it came to be and what will become of it. This grand odyssey gives us a chance to rise above the mundane aspects of our lives, and our differences, conflicts and crises, and try to understand where we, as a species, fit in a wondrous universe that seems beyond comprehension, yet is remarkably comprehensible.

ABOUT THE WRITER

Steve Giddings is a physics professor at the University of California Santa Barbara and an expert in high-energy and gravitational physics. He co-authored the first papers predicting that black hole production could be an important effect at the LHC and describing certain extradimensional scenarios that the LHC might explore.

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