THE INDEPENDENT

Knocking on Heaven's Door, By Lisa Randall

Reviewed by Manjit Kumar

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Why do things weigh what they do? It seems like a simple enough question, but physicists don't know for sure why particles weigh anything at all. For the best part of 50 years they have had an answer – the Higgs boson. It plays such a fundamental role in nature that its been dubbed the "God Particle".

Attempting to answer the question of how the universe got its mass means searching for the Higgs boson. It's a nine billion-dollar enterprise involving thousands of scientists and the largest, most complex machine ever built. The Large Hadron Collider (LHC) contains an enormous 26.6km circular tunnel that stretches between the Jura Mountains and Lake Geneva across the French-Swiss border. Electric fields inside accelerate two beams of protons as they go around 11,000 times per second.

In this fascinating book, Lisa Randall, professor of theoretical physics at Harvard, explains the experimental research at the LHC and the theories that try to anticipate what they will find: "The goal... is to probe the structure of matter at distances never before measured and at energies higher than have ever been explored."

These energies should generate an array of exotic fundamental particles and reveal interactions that occurred early in the universe's evolution, roughly a trillionth of a second after the Big Bang, 13.75 billion years ago. In the debris of colliding protons, physicists hope to find the Higgs boson and get a glimpse at the nature of dark energy and dark matter that make up 96 percent of the universe.

It was 1964 when Peter Higgs conceived of an invisible field that filled the cosmos immediately after the Big Bang. As the newborn universe expanded and cooled, the field switched on. At that moment massless particles that had been travelling at the speed of light were caught in the field and became massive. The more strongly they felt the effects of the field, the more massive they became. Without this field atoms, molecules, galaxies, stars and the planets would not exist.

The Higgs field is like a field of snow that stretches forever in all directions. Beams of light move as though they have skis on: they zip through the field as if it weren't there. Some particles have snowshoes while others go barefoot and trudge around. A particle's mass is simply a measure of how much it gets bogged down in the field.

The ripples in the Higgs field appear as particles called Higgs bosons – the snowflakes that make up the cosmic snowfield, and the thing that physicists need in order to explain why stuff weighs anything. The Higgs mechanism tells how elementary particles go from having zero mass in the absence of the Higgs field to having the masses measured in experiments. The Higgs boson is a crucial part of what's called the Standard Model of particle physics. It's a construction made out of 24 fundamental building-blocks of matter: 18 of these particles are six types of quarks that come in three varieties. The remaining six are called "leptons", a family that includes electrons.

There are also other particles known as "bosons", responsible for transmitting forces of nature. The electromagnetic force is carried by photons – the particles of light. Inside atomic nuclei, quarks are stuck together by the strong force carried by "gluons". The W and Z bosons carry the weak force that is responsible for radioactive decay. "With these ingredients," explains Randall, "physicists have been able to successfully predict the results of all particle physics experiments to date."

On 10 September 2008, the world's media gathered near Geneva at CERN, home of the European Centre for Particle Physics, to watch the LHC being switched on. "People followed the trajectory of two spots of light on a computer screen with unbelievable excitement," recalls Randall.

In the months to follow, the LHC was to be cranked up to energies that would replicate those of the early universe, but nine days later euphoria transformed into despair as a malfunction triggered an emergency shutdown. After a year-long delay and repairs costing $40m, the LHC came back online in November 2009.

Yet there are other, even bigger, problems in particle physics that the LHC should help to solve. One is the hierarchy problem. The Higgs mechanism addresses the question of why fundamental particles have mass. The hierarchy problem asks the question, why those masses are what they are.

Another concerns hints about the "holy grail of physics", the so-called "theory of everything". The best candidate for such a theory is superstrings, in which particles are really little oscillating bits of "string". The different levels of "vibration" of these strings correspond to the different particles. Alas, it was later found that there were at least five different string theories. Physicists were relieved when it was discovered they were all just different approximations to a more fundamental theory called M-theory. However, the theory poses enormous conceptual and mathematical challenges.

The "super" in superstrings refers to something called supersymmetry. The LHC will be used to look for "supersymmetric particles". If found, they would provide the first tangible evidence in support of superstrings and M-theory. The proponents of superstrings and M-theory justify their creation by pointing to its elegance and beauty.

And there's the problem. The "quest for beauty", which elevates aesthetics over empirical evidence in the formulation of a theory, took centre stage in the more esoteric areas of theoretical physics and cosmology, in the absence of experimental data. An appreciation of beauty certainly has a role to play when faced with a blank piece of paper; an appeal to aesthetic criteria is part of the physicists' unshakeable belief in the underlying simplicity and beauty of nature. It is one of their most powerful guiding principles. Nature should not be more complicated than it has to be, they tell themselves.

It is this belief that motivates the search for a "theory of everything". Randall quotes Keats: "Beauty is truth, truth beauty". It can't be denied that "the search for beauty - or at least simplicity - had also led to truth".

Yet she finds the assumption "a little slippery" and readily admits that "although everyone would love to believe that beauty is at the heart of great scientific theories, and that the truth will always be aesthetically satisfying, beauty is at least in part a subjective criterion".

There is nothing wrong with speculation; it is a necessary and vital part of any science, as a first step. The danger of "truth through beauty" in physics, as Randall describes it, is that it makes a virtue of necessity. Wherever experimental evidence can be coaxed out of nature, it suffices to corroborate or refute a theory and serves as the sole arbiter of validity. As Darwin's champion Thomas Huxley once said, "science is organized common sense where many a beautiful theory was killed by an ugly fact".

Despite the delay in the LHC, it will be a source of invaluable new data that will provide stringent constraints on what phenomena or theories beyond the Standard Model can exist. We maybe on the edge of discovery, but for the moment the Higgs boson remains a hypothetical particle on which rests the weight of the universe.

Manjit Kumar's 'Quantum' is published by Icon Books