The Royal Society of Edinburgh

Exploring the Mysteries of the Universe with the large Hadron Collider

Professor Fabiola Gianotti,
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12 May 2008

How many infinities are there?

People sometimes joke that Switzerland's greatest contribution to the world is the invention of the cuckoo clock, but a group of physicists from all over the world working in Geneva are about to have the last laugh as they set off on a "great scientific adventure" which could take us back in time to the birth of the cosmos and in the process prove the existence of the "God particle" – and what makes the universe tick…

"We don't know what we will find," said Professor Fabiola Gianotti, describing some of the most important experiments ever attempted in science, "but we may see strange phenomena. Our discoveries may be a big surprise…"

Professor Gianotti was in Edinburgh to talk about the Large Hadron Collider (LHC), the world's largest and most advanced particle accelerator, which will start operations this summer at CERN in Geneva. And she spelled out the challenge as follows: "It's a great scientific adventure which will revolutionise our understanding of the basic constituents of matter and the mysteries of the universe, and rewrite the physics text books." We may not get the "theory of everything," she added, but we should make significant breakthroughs.

Based at CERN (the European Organisation for Nuclear Research), the LHC will continue the ground-breaking work which began in 1954, when the world's largest particle physics lab set out to "decipher the structure and evolution of the universe, from the infinitely small to the infinitely big" – or what Professor Gianotti calls the "two infinities."

Particle accelerators (one of the first was developed in Glasgow in the early 1950s) are used in high-energy physics research. The way they work is relatively simple – they accelerate two beams of particles around a special tunnel, close to the speed of light, using powerful electrical fields and superconducting magnets, to see what happens when the particles collide. The high-energy collision produces a stream of new particles, including things called quarks (the heaviest one weighs as much as 344,000 electrons), and the higher the energy, the heavier the particles.

LHC: Facts & Figures

CERN's latest particle accelerator is the LHC – 100 metres underground and 27km long. It will be built at a total cost of £3.5 billion, and CERN as a whole has an annual budget of about £500 million, with the UK contributing about £78 million a year – the equivalent of one cup of coffee per person, according to Professor Gianotti.

The LHC will use massive instruments to detect what is happening during collisions and identify the products of collisions, using a massive network of 100,000 computers distributed in 250 sites in 50 countries – the largest infrastructure of its kind in the world. Professor Gianotti said the data generated by the ATLAS experiment will be about 10Pb per annum, the equivalent of 20 million DVDs (enough to build a stack 20km high). And 2,100 physicists from 167 universities will study the data.

The energy involved in the experiments will be the equivalent of 20 volts for every single star in the cosmos, but Professor Gianotti reassured a questioner after the lecture that this will not lead to a giant explosion which blows up the world (at least not according to theory).

With 1,232 superconducting magnets, 7,600km of superconducting cables, temperatures of minus 270 degrees (colder than space) and 40 million collisions per second, each producing 1,000 particles, you begin to appreciate just how spectacular the LHC is. One of the detectors, for a project called ATLAS, is as high as a five-storey building. Professor David Saxon FRSE described it as "cathedral-like," while Professor Gianotti said it weighs almost as much as the Eiffel Tower.

The different detectors are like giant digital cameras, capable of taking 100 pictures per second. Using pattern recognition software, scientists will then be able to reconstruct the trajectories of the particles produced by the collisions, so they can study the origin of the events – and solve a few conundrums in the process.

Scotland's role

As well as being home to some of the pioneers of particle physics, Scotland will play a significant role in the LHC experiments. Out of the 10,000 computers which the UK will provide for the "GRID", Scotland will contribute 10 per cent of the total. Scientists at the Universities of Edinburgh and Glasgow have also been involved in the development of new detectors. Glasgow also hosted a major conference last year to discuss the ATLAS experiment.

Some theory of everything

Ultimately, asked Professor Gianotti, why invest so much in the new project? According to her, the LHC will help us answer lots of big questions, including:

1. What is the origin of particle masses?
2. What is the nature and composition of dark matter?
3. Why is there so much matter and so little anti-matter?
4. What happened in the first few moments after the Big Bang?

According to modern physicists, the standard model of particle physics cannot explain everything. There must be new particles, as yet undiscovered, and the LHC could play a key role in advancing our knowledge of these unusual particles and their interactions.

For example, a lot of attention will be focused on the search for the Higgs boson (or "God particle") first predicted in 1964 by RSE Fellow and Royal Medal recipient, Professor Peter Higgs of Edinburgh University. To detect this elusive particle would be a major breakthrough in physics, because no-one has so far been able to prove its existence, yet without it, things would simply fall apart – we would have no mass, no hydrogen, no chemistry, etc.

Another quest is to discover "dark matter" – the invisible stuff that accounts for 25 per cent of the cosmos. That may not seem very much, but matter as we know it only accounts for about five per cent of the cosmos. "The LHC will be a dark matter factory," Professor Gianotti said.

The LHC will also enable scientists to "navigate back in time to the origin of the universe," producing the same amount of energy present immediately after the Big Bang. "We are seeking answers to the fundamental questions about elementary particles and the universe," Professor Gianotti explained, "and advancing the frontiers of science."

As well as other big questions such as proving the existence of brand new dimensions, and exploring supersymmetry and forces we can't even imagine yet, CERN has stimulated development of innovative concepts and technologies, and lead to useful by-products and spin-offs in areas such as medical imaging, cancer therapy, materials science, security scanners, food sterilisation and nuclear waste transmutation. In addition to creating massive networks of computers, one of CERN's most famous spin-offs was the worldwide web. The LHC will also help to train a new generation of physicists, bringing them together in a neutral environment which promotes cooperation among different countries.

As Professor David Saxon echoed, in his warm vote of thanks at the end of the lecture, the LHC experiments remind us of Columbus setting off for the Indies and discovering America – science sometimes takes us to some very strange and unexpected places.

The LHC will clearly answer lots of big questions in science and take us faraway through space and time, but for those attending the lecture, the big question is: When will the popular Professor Gianotti come back to the RSE to tell us the results of the experiments?

– Peter Barr