From the Big Bang to the next generation

Some of the most celebrated scientists in Europe met in Edinburgh in June to discuss the future of CERN, grappling with some of the most complex subjects in physics, from supersymmetry to quantum gravity and dark energy. But at the heart of their discussion was the down-to-earth issue of how to develop and run leading-edge facilities similar to CERN 30 years from now – and how to inspire the next generation of scientists...

The director of CERN (the European Organization for Nuclear Research), Rolf-Dieter Heuer, set the scene for the discussion by reviewing progress so far and describing the long-term strategy for research at the world's largest particle physics laboratory.

In the audience before him were three of the scientists whose work in 1964 has been the main focus of research using the Large Hadron Collider (LHC) at CERN – Peter Higgs and Baron François Englert, who shared the Nobel Prize in Physics in 2013 for their work in the discovery of the Brout–Englert–Higgs mechanism that explains why some fundamental particles have mass; alongside Sir Tom Kibble, who independently formulated this mechanism around the same time as Higgs and Englert and who went on to investigate consequences of the mechanism over the next few years.

Heuer began by discussing how CERN was “pushing back the frontiers of knowledge,” seeking answers to fundamental questions about the early Universe, what the Universe is made of and what mass is. To explore these questions, CERN has constructed the LHC, which creates “densities of energy never achieved before” in the hunt for evidence about how the Universe works. In the three years since it began operations, the LHC has produced some “beautiful, fantastic and disappointing” results, Heuer said. It has consolidated the Standard Model of particle physics, and “discovered the messenger” of the Brout–Englert–Higgs mechanism that explains why some fundamental particles have mass; alongside Sir Tom Kibble, who independently formulated this mechanism around the same time as Higgs and Englert and who went on to investigate consequences of the mechanism over the next few years.

“What next?” asked Heuer. “Will we understand the primordial state of matter immediately after the Big Bang, before nucleons were formed? We have found the Higgs boson, responsible for giving mass to all particles, but will we find the particles that make up dark matter?”

Heuer then confirmed a few details, primarily the fact that the new particle discovered in 2012 is indeed a Higgs boson, because the “fingerprints” have now been verified. He then explained how the Higgs field is “peculiar” because it “talks” or interacts with all other particles. If it “speaks a lot to the field, the particle gets heavier. If it speaks very little, the particle is light. And if it does not speak at all, the particle does not have any mass.” Even though this new discovery completes the Standard Model, it only describes five per cent of
the Universe, Heuer continued. “The discovery was easy”, he smiled. “Now the hard work begins.”

Part of this hard work involves understanding the properties of the Higgs boson. If the properties deviate from those expected by the Standard Model, this could help to explain the existence of particles forming dark matter (which makes up about 25 per cent of the known Universe), and provide the first hints towards an understanding of dark energy (the other 70 per cent).

Heuer then put all this in perspective by saying that CERN's work so far has used only one per cent of the collisions that we expected to see during the LHC’s lifetime, and that the challenge is to first get ten times more statistics over the next ten years. The LHC will go through a set of upgrades, which will take place over the next 20 years. In parallel, there is an ambitious plan is to create a new circular tunnel which could be as much as 100km in circumference (compared to 27km now), or a linear version 50km long which would address very similar questions but provide a different view of the collisions. The current LHC was designed in the mid-1980s and will give physicists plenty to think about for the next 20 years. The next “LHC” will have much more powerful magnets, but the big question is what physics will drive it.

The international scene is also changing quickly all the time, with China developing its own plans for another version of collider and “competition coming more from the East than the West,” according to Heuer, as US scientists focus on neutrino research and join in at CERN, rather than trying to rival or duplicate what it is doing. “Over the next 20 years,” said Heuer, “CERN will collaborate with scientists in all other regions, to ensure the vibrancy of research in all other regions.”

Heuer also pointed out that there is more to CERN than the LHC – it supports a rich programme of experiments at several other accelerators, including the Antiproton facility, which should help to reveal the difference between matter and anti-matter, as well as work in other disciplines such as medical applications and climate research.

In conclusion, Heuer sees a future for CERN in which the Europe-based facility will continue its ground-breaking research into particle physics in partnership with scientific facilities in the USA and Japan. “For the first time,” he explained, “we have a global vision for our field which goes beyond regional boundaries, with CERN playing a major role in this endeavour.”

Discussion

**Sir John Arbuthnott** (President of the RSE) asked: “Are you confident we have the people to run CERN in the future?”

**Professor Rolf-Dieter Heuer**: We have 6,000 scientists working on two big experiments, with a total of 11,000 scientists, including 3,000 PhD students, doing research and another 4,000 people on the payroll at CERN. We are a “big village with more ‘tourists’ than inhabitants”, with around 8,000 people on site at peak time. But even those post-graduates will be close to retirement 30 years from now, so we have to meet the challenge of enticing new people to work in research – and keep them there. One approach is reaching out to schools, and for the first time this year we invited schools from all over the world to come up with an idea for an experiment at CERN. This year, the winners came from Greece and the Netherlands. We also have a programme for 7-to-11-year-old students to imagine what it’s like to be a researcher at CERN, then visit us to see that we are normal human beings.
Dr Victoria Martin (School of Physics & Astronomy at the University of Edinburgh) explained how she is part of a team of 25 people working at CERN, out of a total of 40 people from the University of Edinburgh. She also described how she asks about any idea for research: “Can we do it and is it worth it?” Martin is also confident that the next generation will be keen to work at CERN, and said this would be helped by adding particle physics to the curriculum of excellence in Scotland's schools, making sure we also produce computing scientists and engineers as well as physicists.

Emeritus Professor Sir Tom Kibble (Imperial College London): Asked about the future of particle physics, Kibble welcomed the discoveries at CERN because they are the result of things first speculated about many years ago. “But there are still lots of unexplained things,” he added, and we need something new to guide us to the next stage in physics. For example, super-symmetry (which goes beyond our current knowledge) is a wonderful idea, but we have no empirical evidence yet for the theory.

Emeritus Professor Baron François Englert (Université libre de Bruxelles) said we only understand about four per cent of the Universe and there are two big things we do not understand – dark matter and dark energy. Hopefully, dark matter is a particle we simply haven't seen yet. He is also pessimistic and optimistic at the same time, saying that the point about dark energy is not that it makes up about 70 per cent of all mass, but that it is something we don't understand. “I think the answer lies in quantum gravity,” he added. “I may be wrong, but it would not be the first time!” Quantum gravity will not be easy to find and challenges the limits of human intelligence, Englert suggested.

Emeritus Professor Peter Higgs (University of Edinburgh) agreed with Englert and said that he still “pins his hopes” on super-symmetry being discovered in the next phase of experiments at CERN. He also said he hopes to survive long enough to see more interesting breakthroughs at CERN and other facilities – for example, proof of dark matter. Higgs also welcomed the new, much more global, approach to research, including US scientists focusing on neutrinos – work which complements experiments at CERN. “Neutrinos are a sign of the failure of the simple model,” he added.

In response to a question about theoretical versus applied research, Martin said she thinks there is a good mix amongst undergraduates between experimental and theoretical physicists. She looks forward to more ground-breaking research in future, adding that it is “nice to discover a new particle, but better to discover even more.”

Finally, Heuer commented about the global nature of current research, saying it is easy to stop programmes but a lot harder to start them and that, in some cases, collaborative research has been cancelled without consulting international partners. Another obstacle is support for science in general. In China, “money is no object”, but do they have the people and the right expertise? Is China, with all its resources, embarking on a national project rather than engaging in global research? “We are just evolving into a global view of the field,” he concluded, “and we must stick to that global emphasis.”

NOTE: The discussion at the RSE on 28 June 2014 was organised as part of the celebrations to mark the presentation of an RSE Royal Medal to Professor Sir Tom Kibble. On the same day, Professor Peter Higgs was awarded an Honorary Degree by the Free Université libre de Bruxelles and the Freedom of the City of Edinburgh; Professor Rolf-Dieter Heuer and Professor Baron François Englert were awarded Honorary Degrees by the University of Edinburgh.

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