Uncovering the Secrets of the UNIVERSE

CERN operates the world's most powerful particle accelerator to answer our most pressing questions about the fundamental nature of the universe.

Images courtesy of CERN

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Have you ever questioned the nature of existence? Have you wondered how we got here, how it all started, and what's keeping it going? For most of us, it's not long before we realise that these matters are beyond our comprehension. Yet these are some of the questions being tackled by the scientists at CERN—the world's leading research body for particle physics.

CERN has an outstanding history of scientific and technological innovation, which has led to landmark breakthroughs like the invention of the World Wide Web and the discovery of the Higgs boson. While we are more likely to associate individuals like Tim Berners-Lee, Peter Higgs, and François Englert with these transformative innovations, CERN has been the driving force behind these and many other significant projects.

CERN originated in the wake of World War II: in 1951, UNESCO adopted a resolution to establish the European Organization for Nuclear Research to address the dearth of scientific research at the time. By 1954, CERN's 12 founding member states had ratified the convention, and CERN began its groundbreaking work in fundamental nuclear physics—the quest to understand the basic building blocks of matter and the forces that act between them. Today, that work has evolved into the modern field of particle physics.

"When CERN was founded 60 years ago, it was built on two very important pillars," Rolf Heuer, CERN's Director-General explains. "The first one was to build an institute which goes beyond national boundaries to bring the research in fundamental physics up to a world standard. The founders of CERN realised that research is the only way to reach the goal of having a well-functioning, advanced society. The second pillar was to at least moderate, if not completely stop, the brain drain out of Europe, which was occurring at the time."

Another key point of CERN's mandate is to achieve these goals in the most peaceful way possible. The organisation's convention explicitly forbids the application of CERN's research for military purposes. "This initial vision developed further and further throughout the 60 years of CERN's existence, as more and more countries joined," Rolf says.

"For a few years now, we have been going beyond the borders of Europe and opened institutional ›

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participation in CERN to countries all over the world, regardless of their geographical location. This has been a huge development for us." The number of member states has grown by nine since CERN's inception, and the organisation has also opened up a range of other opportunities for involvement.

First, there is associate status for states where full membership is either not possible or not feasible. Associate members contribute less than a full member would, and in return receive a more limited range of the benefits of membership. Then there are many states and organisations with cooperation agreements and contracts spread throughout the world. And finally, the status of observer is reserved for international organisations. Observers, such as UNESCO under whose auspices CERN was first established, attend meetings of the CERN council, but are not involved in the organisation's decision-making processes. CERN's reach is truly global.

It takes significant funding to run such an extensive research organisation, from building and maintaining its incredible technology, to employing its dedicated staff. CERN's core budget is provided by its member states, while institutions that use CERN's facilities contribute to financing its experiments and globally distributed computing infrastructure.

As Rolf says, "CERN is an organisation, not a business." Furthermore, the entire world is able to benefit from CERN's discoveries, since the laboratory publishes all its results under an open-access model. "Despite the fact that only a certain number of nations are financially contributing to the laboratory, the research we perform and the results we produce are free for everyone to access, once they pass the peer-review threshold.

"It is very important that CERN is not only an institute for the scientists from the countries that support us, but for people all over the world. It has been this way since the very beginning."

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In addition to its structural expansion, CERN's research program has undergone significant development, as new and exciting discoveries have come to light. "The scope of the questions we are asking has evolved dramatically over time," Rolf explains.

"The research itself has developed from nuclear physics to particle physics. We've moved on from asking what matter is made of to asking why it behaves the way it does. Particle physics studies the fundamental constituents of the universe, and the forces that govern their behaviour. We are now trying to answer questions about why these constituents can physically exist at all, and how the universe has evolved since its beginning."

Finding the answers to such challenging questions calls for some of the most advanced research equipment the world has ever seen. CERN uses purpose-built particle accelerators like the Large Hadron Collider (LHC) along with particle detectors to observe the interactions of fundamental particles as they collide. As the name suggests, particle accelerators work by speeding up beams of particles, then directing these beams towards each other in a collider, or towards a stationary target in other facilities at CERN. The results of these collisions are recorded and analysed.

The LHC is the world's largest and most powerful particle accelerator to date. The 27-kilometre ring accelerates particles until they almost reach the speed of light, guiding them using powerful superconducting electromagnets. The LHC's four major particle detectors—ATLAS, CMS, ALICE, and LHCb—are located at the points where beams are brought into collision.

Rolf explains that projects like the LHC take decades to execute. "For smaller projects, while it is important for a lab like CERN to have diversity in its program, there are also many examples of world-class particle physics research being carried out elsewhere, at the national level. But really big projects like the LHC are different. They can take 40 years from start to finish, and ›

they need a major international lab like CERN to succeed. Such projects begin with the establishment of a consensus as to what kind of facility is needed, along with the parallel development of the necessary technology, and they are accompanied by a very strong process of scrutiny from the very beginning.

"One policy we have here is not to do whatever interesting scientific project is possible, but instead to focus our efforts on the ones which can only be done at CERN. So each project must be scientifically unique—that is, it must tell us something new—and we at CERN should provide the research community with the unique facilities necessary to execute it.

"We have a number of independent committees, which assess the physics, scrutinise the cost estimate, and keep track of the progress throughout each stage. The first step is to ask whether the physics is relevant and interesting. If someone has an idea, it might not be feasible yet, but if one can see feasibility on the horizon then you can start with a study and then look into the technology and cost.

"The second step is to start a research and development project, which takes a few years. From this, you can see which road to go down; for example, which instruments we have to build, or which magnets or accelerating structures we will use. But all this has to be developed extensively, and that takes several years.

"Then, you get an idea of what you can do with such an instrument, which aspects of physics you can assess or measure. Once all this is positively evaluated, you propose it to your stakeholders, which in our case are the representatives of the countries that contribute to CERN. The project is discussed and scrutinised again within this forum. Depending on the funding available, it might be staged so that you start with a smaller project and go to a larger project later.

"Then, of course, you start to commission and construct the whole thing, and all the while a committee and the stakeholders are following the progress. Then, after all of this work, you switch on the accelerator and start data taking. You have to go through the same process as you did for the accelerator, for each experiment performed, working with the committees and the stakeholders. The LHC was proposed in 1984, so that project started more than 30 years ago."

Given the enormous amount of time, thought-power, and effort that goes into these large-scale projects at CERN, it is especially rewarding when a result like the discovery of the Higgs boson is delivered. "It is rewarding for the people who are responsible for setting it up, of course, but it is also rewarding for those who are in office at the time that a project comes to fruition," Rolf says.

"We are in the fortunate situation that all the directors-general, from the time when the LHC was first discussed in 1984, to today, are still with us and could enjoy the results of the discovery of the Higgs boson three years ago." This work, which earned Peter Higgs and François Englert a Nobel Prize in 2013, is significant not only because it confirms a prediction made by the Standard Model in physics, but also because without the underlying Brout-Englert-Higgs mechanism, we simply would not be here to ask the questions.

The Standard Model represents humanity's best understanding of how the fundamental particles of the universe behave under the influence of all the fundamental forces, with the exception of gravity, which remains a challenge for future generations of scientists. By identifying a particle consistent with the Higgs boson, the international teams working at CERN have provided key evidence in favour of the Standard Model. The discovery has certainly been a pinnacle of Rolf's time as director-general at CERN, and of his career in particle physics as a whole.

"I started as the director-general in 2009, and of course I oversaw the start-up of the LHC and finally the discovery of the so-called Higgs boson. This has been a very important breakthrough, because without this particle we could not physically exist—we would decay almost instantaneously—so this is vital to our understanding of the development of the universe."

"As a particle physicist, you have to go to the accelerator; the accelerator will not come to you."
- Rolf Heuer

Rolf started out doing his diploma in nuclear physics, but decided towards the end of his studies that, in his own words, "the nucleus is too large for me." He then embarked on his lifelong exploration of particle physics, to study the smallest constituents of matter. To pursue this interest, he sought out a role at the German laboratory for particle physics in Hamburg—DESY.

"As a particle physicist, you have to go to the accelerator; the accelerator will not come to you. With this in mind, after working at DESY for some years, I moved toward CERN, because they had the next big project on the horizon. In 1984, I got a staff position at CERN, and step by step I became more responsible for one of the larger experiments which was being conducted at the time.

"I stayed at CERN for 15 years, and for the last five was leader of this large experiment, and then I got a professorship at the University of Hamburg. I went back to Hamburg for 10 years and was looking into other projects, but in particular I was looking to bring the German laboratory closer to CERN, and ›

especially to the LHC. After five years with the university, I became research director at the laboratory in Hamburg.

"Another five years passed, and then CERN called me back in 2009 as the director-general, and I will remain in that role until the end of 2015." Although he won't mention it himself, Rolf has been awarded many times for his contributions to physics, and has received many honorary degrees.

In his position as director-general of CERN, Rolf keeps an eye on the day-to-day activities of the organisation. He also manages all of CERN's long-term projects, ensuring that it continues to deliver the crucial infrastructure, resources, and people required to maintain its position as a world-leading research institute.

Rolf has witnessed many groundbreaking projects throughout his time at CERN. "In my own experience, the most memorable projects at CERN involve the discovery of fundamental particles, like the W and Z bosons, which are responsible for carrying one of the fundamental forces of nature.

"Essentially, every project using the accelerators here is a memorable project, at least for the physicists and scientists and engineers involved. Over the past 60 years, we have seen the procession of a natural or logical chain of more and more powerful instruments, and higher and higher resolution concerning the investigation of fundamental particles."

Not all of the projects at CERN have revolved around the LHC though. Back in 1989, when Tim Berners-Lee was working at CERN, he invented the World Wide Web. As a result, the first server, browser, and website in the world were all built and hosted on Berners-Lee's NeXT computer, which is still in CERN's possession today (currently on loan to the Science Museum in London). In 1993, CERN made the software for the World Wide Web openly available royalty-free, in order to disseminate it around the globe.

Berners-Lee's original proposal was to create a network—or 'web'—of hypertext documents. Hypertext documents are

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essentially documents accessible via browsers, which contain clickable references to other pages—more commonly known as hyperlinks. It's a little known fact that Berners-Lee's original browser was a browser and editor combined, allowing people to publish hypertext documents as well as read them. As the web took off, it took a long time for that initial vision to be fulfilled with the advent of the universal authorship that we know today.

In 2013, CERN reinstated the world's first website to its original address, http://info.cern.ch, after undertaking an extensive project to preserve and restore the first files that went online. The original website provides information about the World Wide Web project, how to build your own webpage, and how to locate information on the internet. You can access it via CERN's official website.

As the birthplace of all of this incredible technology, it's easy to imagine CERN's buildings as slick, glassy, modern cocoons for its state-of-the-art scientific instruments—but you'd be forgetting the fact that CERN ›

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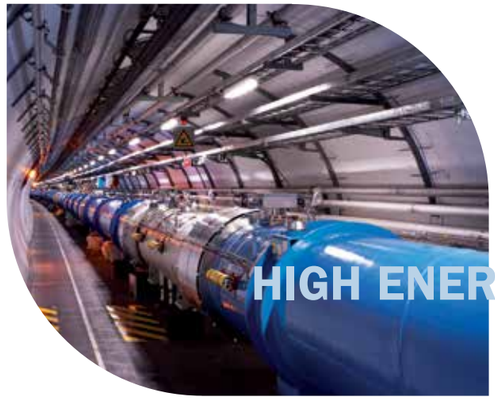
FROM BASIC RESEARCH



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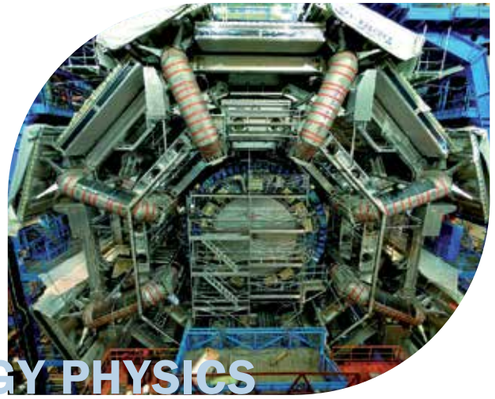

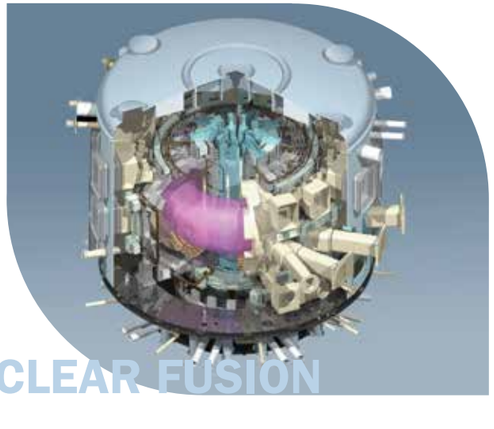

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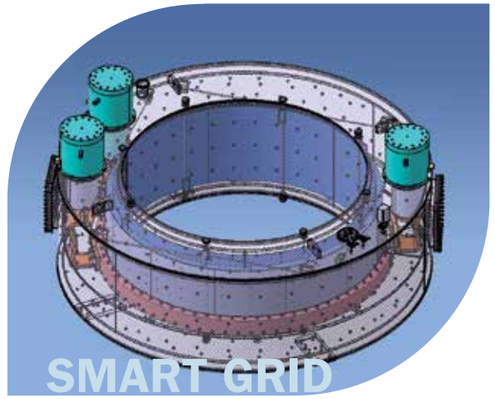

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was established over 60 years ago. This means that one of Rolf's current challenges is something that most of us have gone through at one time or another—renovations.

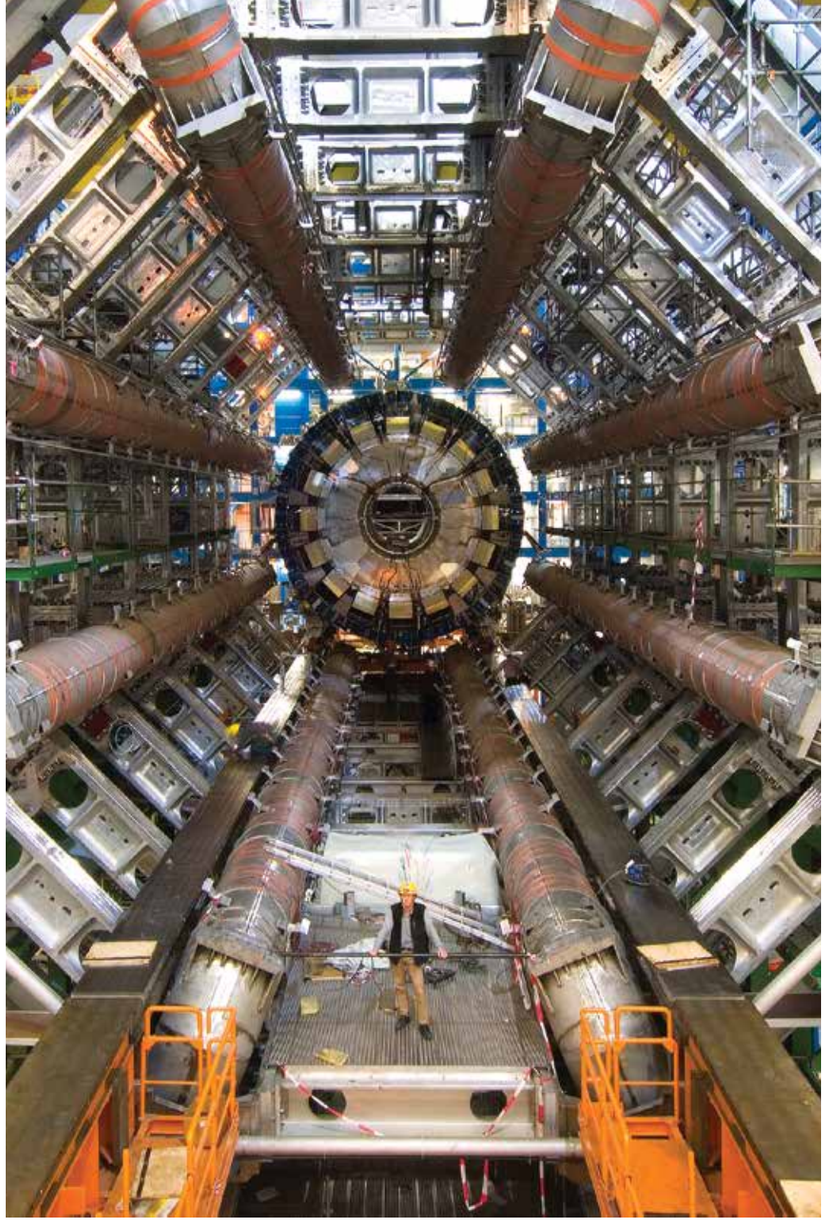
"When you have a 60-year-old house, where you have only the most necessary renovations, and you face a lot of problems—sometimes the roof is leaking, for example—it doesn't help you if you have the most modern electronics, if the roof is leaking," Rolf says.

"Everything is relative here: we need to invest a bit more in renovation. It's a bit of a problem for us, because renovation is needed but none of the funding agencies like to talk about renovation. They like to talk about the scientific instruments—the accelerators—as being where the money should go.

"However, the most modern accelerator doesn't help you if the buildings where you're working are decaying. This is why we have set up a medium-term plan of 10 or 15 years across the whole laboratory to identify which are the most urgent repairs, where the most maintenance efforts are needed, and where is it better to build a new building and tear down the old one.

"We have been going for 60 years, and we are clearly still an attractive venture, since we are still getting applications for new memberships from countries looking to join. This means that we had better offer them a place which is up to modern specifications, in order to work as an institute of the twenty-first century."

With its sixtieth anniversary in 2014 on top of all its recent successes, CERN has had plenty to celebrate. "I have celebrated our sixtieth anniversary at least 20 times," Rolf quips. "The first major celebration took place on the first of July 2014, at UNESCO headquarters in Paris, because CERN was founded under the oversight of UNESCO, and the



convention was signed subject to ratification on the first of July 1953: that was the start."

There were two other major celebrations in Europe and New York in 2014. "We ended our official celebration in Europe on 29 September at CERN. That was CERN's official birthday—29 September 1954—which is the date when the majority of the founding members had ratified the convention.

"Then we had another very important celebration, which was on 20 October at UN headquarters in New York. Within the framework of the General

"The collaboration with CERN generated an extraordinary transfer of immediately applicable know-how for ASG and Columbus: ASG expressed it in the industrialisation of hadron therapy and IMPT applications, whereas Columbus could a leap into MgB2 cables performance." - Vincenzo Giori, CEO, ASG Superconductors

Assembly, one of the events was a celebration marking 60 years of science for peace and development at CERN. We had some very special guests in attendance for this event."

UN Secretary-General Ban Ki-moon spoke at the event, as did his predecessor Kofi Annan. The President of the UN General Assembly, Sam Kutesa, also gave a speech. "Because of this, we had a very high-level event, which raised the awareness within the UN and New York of the importance of the research in general, and CERN in particular," says Rolf.

In addition to these three main events, CERN also facilitated events for all of the member states that wanted to celebrate the sixtieth anniversary in their respective countries. "I proposed this to show that CERN is not sitting statically in the Geneva area,

"It's up to us old guys to motivate and bring these young people forward, to attract them to science, and to keep them in science."
- Rolf Heuer

but that CERN is there for the member states, and shows it by initiating a celebration inside its respective member states—and most of them did it."

While celebrating his organisation's achievements, Rolf also recognises the importance of preparing for the future. He has set down two key focus areas for the development of CERN: enhancing scientific education, and preparing exciting projects for the future.

"I think the focus on youth is absolutely mandatory, because who else will bring us forward, if not the youth of today? It's up to us old guys to motivate and bring these young people forward, to attract them to science, and to keep them in science.

"We need to ensure that young people are scientifically literate, so that they can help us progress toward the UN's sustainable development goals, which everyone is talking about." The sustainable development goals build on the UN's millennium development goals, and set out an ambitious plan to eradicate poverty, address climate change, and protect human rights, among other aims.

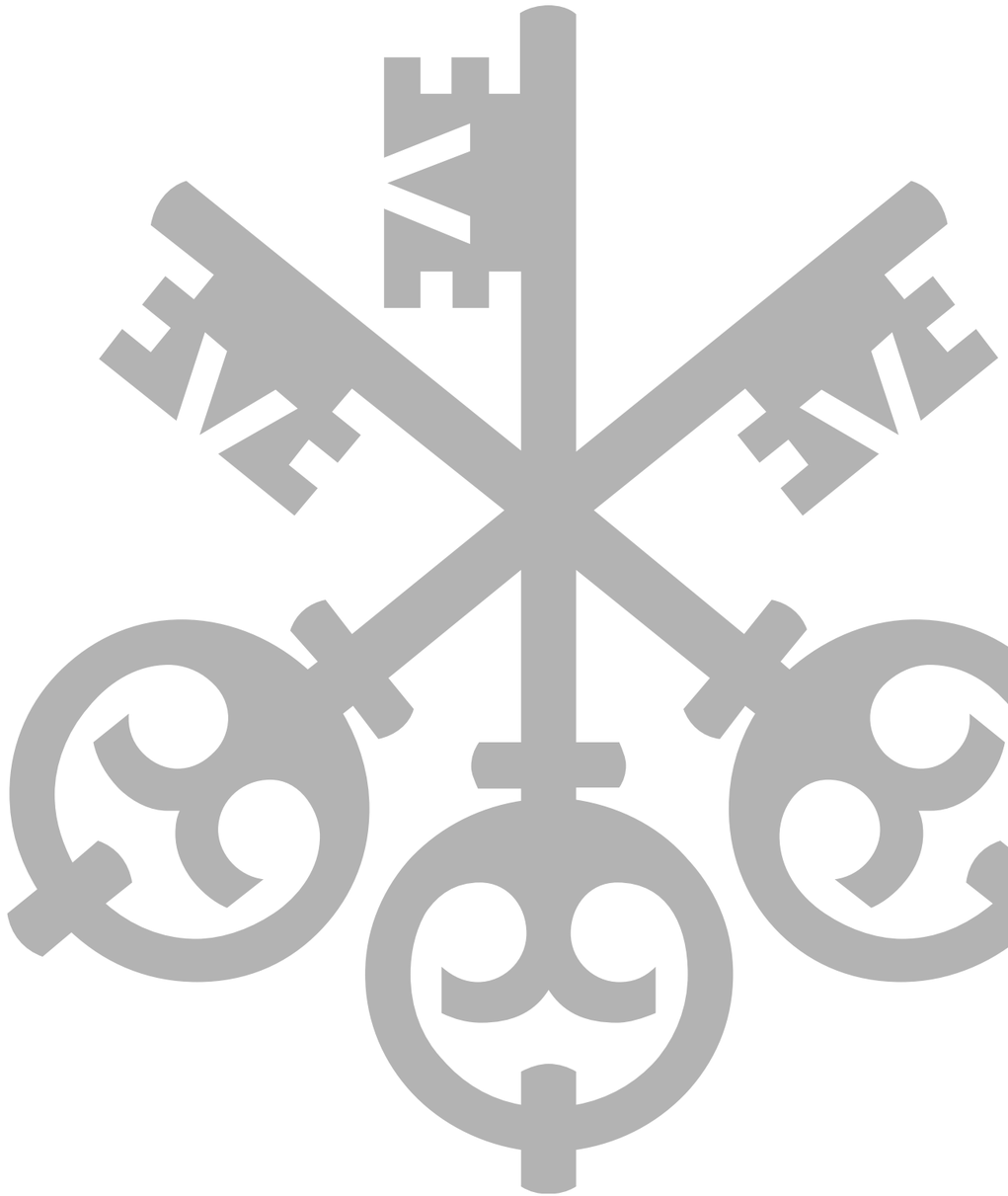
"In order to meet these outcomes, you need educated people, and you need to train people for that. Today, there is a shortage not only of scientists, but also of engineers. In every country, each time I talk to politicians, its always the same: they say, 'We have a shortage of engineers'.

"If you clear your mind and imagine the world without anything based on the past 150 years of research—electricity, quantum mechanics, et cetera—then you have nothing left! We should not make the mistake of saying we have everything we need now. We should prepare the ground for future generations.

"Preparing the ground for future generations means that we have to train them, and we should not only start with university students, nor with high-school students; we have to start in primary school. Moreover, we also have to start with the teachers; this is very important. In all these areas we try to help by providing our droplet into the ocean of all the efforts."

CERN runs a number of courses for physics teachers, ranging from three days to three weeks, from its headquarters in Geneva. It also organises National Teacher Programmes taught at CERN in the teachers' native languages. "We have around 1,000 teachers going through all of our courses each year.

"If you have motivated teachers, and multiply them by the number of high-school students they have over the years, I think you can help a lot in educating people and making an impact. I always found that in school, I felt most enthused ›



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**Source: Morningstar/Swiss Fund Data Swiss Promoters report (as of 30 September 2014)

about the subjects that had the most enthusiastic teachers."

Rolf is also preparing for long- and short-term projects for CERN to undertake in the future. "CERN has a policy of having a flagship, and at the moment this is the LHC, which is the largest microscope and accelerator on earth. So, our short- and medium-term plans revolve around that."

In December 2014, Rolf announced that the LHC is getting ready for its second run after a two-year hiatus. During this break, the equipment was modified and improved to run at nearly double the energy compared to its first run. After scrupulous testing of the LHC and its detectors, the accelerator will be switched on in March 2015.

"As a leading research institution, CERN is constantly looking for the best technology to support the science and at Danfysik, we must therefore develop our skills and manufacturing know-how. These go hand in hand, one is a prerequisite for the other."
- Frank Ebskamp, Chief Executive Officer, Danfysik

In his announcement, Rolf said: "With this new energy level, the LHC will open new horizons for physics and for future discoveries. I'm looking forward to seeing what nature has in store for us." However, this is by no means the only exciting prospect on CERN's horizon.

"When you have a flagship, you also need some smaller boats in your fleet. In the same way, we also need a broad basis of diverse physics research into topics like antimatter, dark matter, and the origins of the universe." Though they may sound like concepts out of a science-fiction novel, antimatter and dark matter are thought to play a crucial role in our universe.

British physicist Paul Dirac originally postulated antimatter in 1928. He proposed that for every particle in existence, there is a corresponding antiparticle, with an opposite electrical charge. Yet in practice, scientists observe much less antimatter than matter in the universe. To find out why this might be, CERN has built the Antiproton Decelerator, which effectively makes antimatter for scientists to study.

Dark matter, on the other hand, has been postulated to explain how galaxies are holding themselves together. The galaxies in our universe are rotating at such a pace that the gravitational pull of observable matter could not possibly be strong enough to hold them together.

Hence, scientists suspect that there is some kind of mysterious, unobservable matter conferring extra mass—and therefore extra gravitational pull—within these galaxies, effectively holding them together. It may well be possible to produce dark matter at CERN's LHC.

Another project that Rolf is excited about is the Proton Driven Plasma Wakefield Acceleration Experiment—AWAKE, for short. This experiment has the potential to allow future colliders to achieve higher levels of energy over shorter distances than ever before, by using the power of wakefields, created by injecting proton beams into a huge, 10 metre plasma cell.

"Our aim is to continue for the next 15 to 20 years with this clear program of diverse physics research, plus the research at the flagship, and that will bring us up to 2030 or 2035," Rolf says. "In parallel, by gathering information from research at CERN and other facilities around the world, we will be able to determine which direction CERN should go with its next flagship project.

"The next flagship might be a more powerful or higher resolution supermicroscope, a circular collider which is larger than the LHC, or a different accelerator which uses electrons rather than protons to accelerate. Such an instrument would look at the same questions as the LHC but from a new angle.

"You can compare our process in particle physics to astrophysics. In astrophysics, you are not getting your results from only one telescope; you have ground-based telescopes, you have space-based telescopes, and you combine all of the results together to get a much better picture.

"In our case, we combine the results from different types of accelerators to get this better picture. However, in order to decide which type of accelerator we would like to build, we need a bit more information from instruments like the LHC."

CERN's profile is continuing to grow on the global stage, as the scientific community seeks to reach outward and engage the world in its discoveries. Rolf is playing his part, having written his first piece for popular website *The Huffington Post* late last year, exhorting European Commission President Jean-Claude Juncker to keep science at the heart of policymaking.

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The rest of 2015 will be a busy time for Rolf, as he prepares to hand over the role of director-general to his successor, Dr Fabiola Gianotti. "It has been a pleasure to work with her for many years. I look forward to continuing to work with her through the transition year of 2015, and am confident that CERN will be in very good hands." ◦