Unlocking the universe's darkest secrets: CERN

Attempting to understand the infinite majesty and order of the universe has been mankind's struggle for millennia. Thanks to work taking place on the outskirts of Geneva, we are now closer to this goal than ever before. Join *Swiss News* as we take an exclusive look behind the scenes at CERN, home to the world's largest and most exciting physics experiment: the Large Hadron Collider, where physicists are unravelling the mysteries of the infinitely large by creating the unimaginably small.

Spare sections of the Large Hadron Collider

By Matthew Beattie | Quarks, neutrinos, string theory and cats in boxes: Modern physics can be baffling; especially to somebody like me, who spent his school physics lessons electrocuting classmates with the Vanda-graph. This can be rather frustrating, as nowadays I have developed a fascination for the subject, prompted not least by – excuse the pun – the quantum leaps made by scientists in their exploration of the strange world of sub-atomic particle physics.

In a recent speech following his departure from the role of Lucasian Professor of Mathematics at Cambridge University, Professor Stephen Hawking stated, "It has been a glorious time to be alive, and doing research in theoretical physics. Our picture of the universe has changed a great deal in the last 40 years, and I'm happy if I have made a small contribution."

In no small part, that progress in our vision of the universe has been driven by research conducted at the extensive facilities of CERN, a place where scientists have been testing theories and transforming our understanding of physics for more than half a century. Spanning the borders of France and Switzerland, everything about CERN is on a scale that is, for many of us, hard to comprehend.

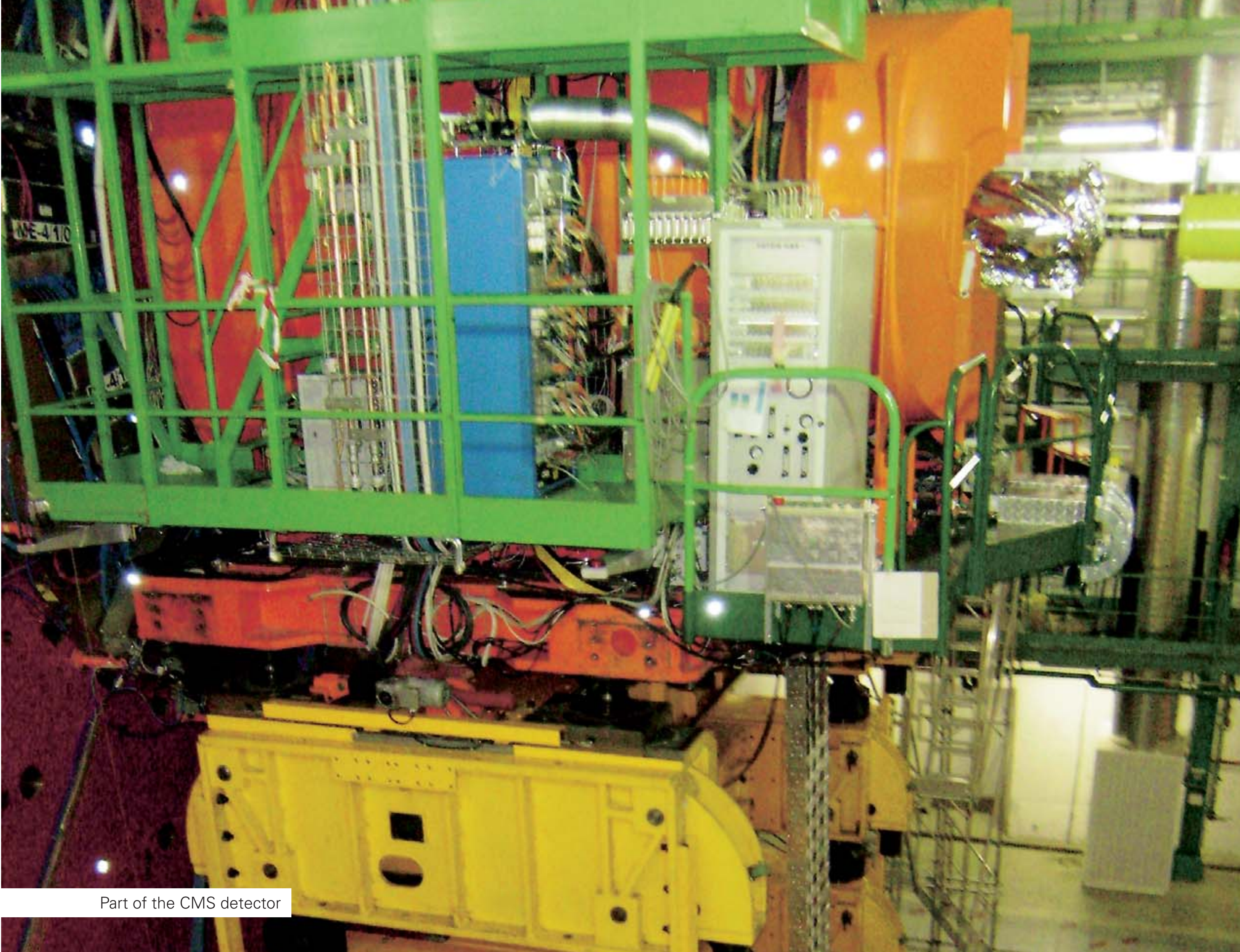
International cooperation

The LHC (Large Hadron Collider) is perhaps the best-known example of the facilities at CERN. It featured in Dan Brown's novel, *Angels and Demons* and has been the subject of countless articles and reports – especially following a malfunction in September 2008, which resulted in a major leak of helium and put the facility out of action for a year. It runs along a tunnel beneath the French and Swiss countryside in a ring totalling 27 kilometres in circumference and is the latest in a series of particle accelerators at the CERN facility.

The LHC works by firing two streams of protons (positively charged particles from the nucleus of an atom) or ions – both known as Hadrons – in opposing directions, accelerating them to 10 km per hour less than the speed of light, before smashing them together at certain points along the loop where the two beams intersect. To give you some idea of how close to light speed the particles are travelling: if the proton beam was fired alongside a beam of light towards our nearest neighbouring star, Alpha Centauri, the proton beam would arrive a mere two seconds after the light. When two particles collide, they do so with an energy density and temperature similar to those existing a few moments (around 10^{-12} seconds) after the big bang.

$E=MC^2$

Perhaps the best known of all equations, Einstein's theory of relativity explains how mass and energy are really two forms of the same thing: energy = mass multiplied by the speed of light



Part of the CMS detector

squared. Just as mass can be transformed into energy (as in an atomic bomb), so energy can be turned into mass. This is the process that takes place when two particles collide within the LHC: the energy of the impact is so concentrated that a host of new sub-atomic particles is formed. These new particles are the building blocks of the protons, neutrons and electrons, which make up an atom (think of it like Russian nested dolls). It is these sub-atomic particles that the LHC experiments will detect, allowing scientists to examine the conditions which last existed 13.7 billion years ago at the dawn of our universe.

My guide for the morning is Italian-born Paola Catapano, a science communication expert who has been working for the CERN communication group since 1994. There are few people more familiar with the LHC facilities. She has promised to give *Swiss News* the VIP tour and as she drives me to our first port of call, the CMS (Compact Muon Solenoid) detector, she chats animatedly about CERN and the LHC. I ask her about the experiments being conducted at the site.

No such thing as too many cooks

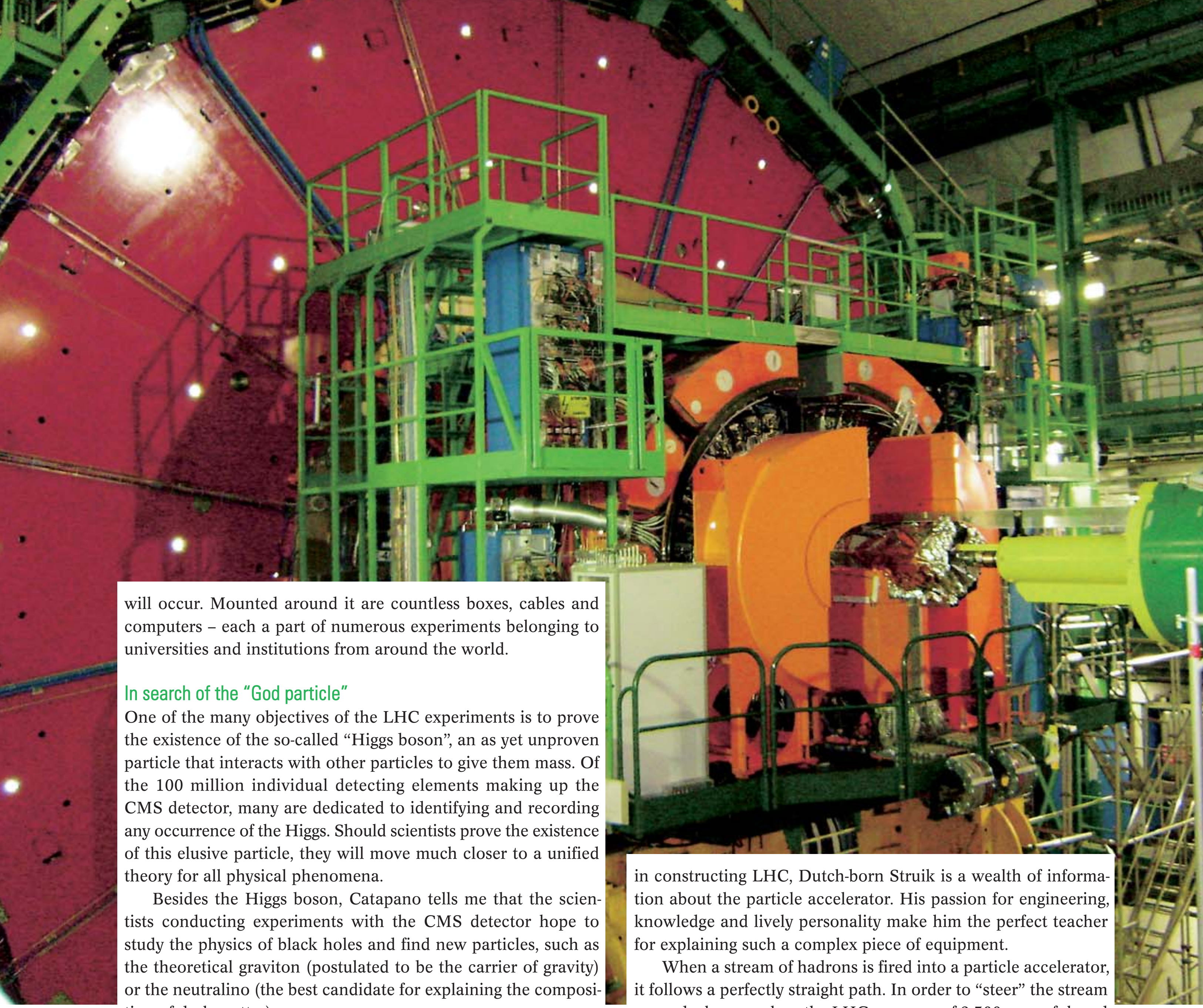
Catapano explains how there are six experiments installed around the LHC – ALICE, ATLAS, CMS, LHCb, LHCf and TOTEM. These are housed in subterranean caverns at four different points around the ring. The CMS cavern we are going to see is the furthest from the main CERN campus. "Each experiment is a collaboration of many different countries and institutes," she tells me. The CMS experiment, for example, involves more than 2,000 people, from around 180 institutes and more than 35 countries.

The LHC P5 is the enormous building housing the CMS experiment. Huge storage tanks stand in the grounds with a mass of pipes leading to the building, giving it almost the appearance of an oil refinery – although that's where the similarity ends. I am equipped with a hard hat, before being led to the lift, which will take us 100 metres below ground to the experiment site.

I've been expecting you, Mr. Bond

Stepping through the steel door and into the cavern is quite simply awe-inspiring. It may be a cliché, but the scale of the experiment took my breath away. It was like stepping onto the set of a James Bond film. I half expected to see a balding man in an electric wheelchair stroking a white Persian cat and plotting world domination. The cavern was the size of an aircraft hangar, yet it was almost filled with equipment. It was only when I noticed what appeared to be an ant-sized technician at work on part of the experiment that I was finally able to grasp the giant scale of my surroundings.

The room is dominated by a huge superconducting solenoid resembling a giant orange-coloured MRI scanner. This is designed to generate a magnetic field 100,000 times greater than that of the earth's, and it is within this behemoth that particle collisions



will occur. Mounted around it are countless boxes, cables and computers – each a part of numerous experiments belonging to universities and institutions from around the world.

In search of the "God particle"

One of the many objectives of the LHC experiments is to prove the existence of the so-called "Higgs boson", an as yet unproven particle that interacts with other particles to give them mass. Of the 100 million individual detecting elements making up the CMS detector, many are dedicated to identifying and recording any occurrence of the Higgs. Should scientists prove the existence of this elusive particle, they will move much closer to a unified theory for all physical phenomena.

Besides the Higgs boson, Catapano tells me that the scientists conducting experiments with the CMS detector hope to study the physics of black holes and find new particles, such as the theoretical graviton (postulated to be the carrier of gravity) or the neutralino (the best candidate for explaining the composition of dark matter).

Black holes

The doom-scenario of CERN opening a black hole, which will swallow us and everything around us, is a firm favourite among tabloid journalists. I ask Catapano whether there is any truth in this notion.

"There is a very small chance that we might create a micro black hole," she tells me. "However, it's important to remember that we are working on a very small scale, with tiny amounts of energy. If a black hole should appear, it would be so tiny and weak it wouldn't be able to sustain itself and would disappear immediately."

A point also made by Professor Stephen Hawking in his 2008 speech, prior to the LHC being switched on for the first time. "If the collisions in the LHC produced a micro black hole – and this is unlikely – it would just evaporate away again, producing a characteristic pattern of particles. Collisions at these and greater energies occur millions of times a day in the Earth's atmosphere, and nothing terrible happens."

Engineering the impossible

After our tour and a thorough insight into the science behind the LHC, Catapano left me in the capable hands of her partner and CERN colleague, Mike Struik. As one of the engineers involved in constructing LHC, Dutch-born Struik is a wealth of information about the particle accelerator. His passion for engineering, knowledge and lively personality make him the perfect teacher for explaining such a complex piece of equipment.

When a stream of hadrons is fired into a particle accelerator, it follows a perfectly straight path. In order to "steer" the stream around a loop, such as the LHC, an array of 9,300 powerful, and mostly superconducting, magnets is required. These magnets require much of the energy used by the LHC (when in operation, the LHC uses the equivalent electricity to that used by the whole of Canton Geneva during the same time period). Struik tells me how such a construction presented some unique challenges. Not only do the tubes down which the particles travel have to be an ultra-high vacuum, but the magnets need to be cooled with liquid helium in order to be super-conducting. Without superconductor technology (to conduct electricity without resistance), each cable would need to be as thick as a man's thigh and the LHC would require several times more power than it uses.

Rocket science

"If you go to industry and you say to them that you need instrumentation wiring, they will say 'Sure! Anything you like.' Then you say the cable needs to be able to function in liquid helium at 1.9 kelvin [-271.3°C] and they tell you, 'we can give you cables. Test them and if they work, let us know so we can include it in our brochures!'"

Every component had to be sourced and in most cases, everything had to be made especially. Struik shows me some fibreglass composite mounts, roughly the size of a toaster. "These came from a company in Spain: the same one that makes the Ariane rocket shells [for the European Space Agency] … Each

This is one of two places where Hadron streams enter the CMS detector

one will hold fifteen tons. They support the heavy magnets and inner-workings inside the external vacuum tube."

The best laid plans …

When the LHC malfunctioned in September 2008, the resulting damage released over a tonne of helium and put the apparatus out of action for a year. The cost of repairs – funded by CERN – came to around 20 million euros. The cause of the problem was a poor connection between the superconducting cable strips between two magnets. This resulted in a heat build-up and ultimately a violent rupture, which damaged about 50 magnets. I ask Struik whether the problem could happen again.

"We identified the weakness and have replaced the parts we identified as posing a risk," he notes.

The LHC has now been in operation since October 2009 and so far there have been no further malfunctions: indeed it has worked much better than expected, breaking the energy record in November to become the most powerful accelerator in the world.

Unlocking one secret reveals many more

It is still early days for the results from the LHC experiments, but there is no doubt that CERN is making progress in the field of particle physics, with experiments creating both matter and anti-matter (in 1995, scientists at CERN made the first observation of so-called anti-hydrogen). It is nevertheless worth noting that, more often than not, unravelling one of nature's mysteries reveals many more, just as peeling away one layer of an onion reveals another. But for every new layer they reveal, the intrepid CERN scientists are getting ever closer to their goal of uncovering the darkest secrets of our universe.

Inside CERN

CERN is an abbreviation of *Conseil européen pour la Recherche nucléaire* (European Organization for Nuclear Research). It was formally created in 1954 with the aim to increase the international collaboration of scientists in the field of particle physics and make it more fruitful. From an original group of 12 founding nations (West Germany, Belgium, Denmark, France, Greece, Italy, Norway, The Netherlands, the UK, Sweden, Switzerland and the then Yugoslavia), there are 20 CERN member states nowadays (by convention members must be European), with the United States, Japan, Russia, India and Israel as observers – although 85 countries use the facilities. The organisation is non-political and non-military. Its purpose is to provide the facilities for scientists, universities and researchers to conduct experiments, which would otherwise be prohibitively expensive and technically complex for them to carry out individually.

Physicists and their funding agencies from both member and non-member states are responsible for the financing, construction and operation of the experiments on which they collaborate. CERN spends much of its budget on building new machines (such as the LHC), and it only partially contributes to the cost of the experiments. The contributions of CERN's 20 member states in 2010 total SFr 1.12 billion. Switzerland contributes 2.41 per cent of this figure.

How do the CERN experiments benefit mankind?

Some examples of CERN discoveries:

The World Wide Web was invented at CERN in 1990. This hypertext-based interface was created to allow CERN scientists to exchange data in different formats. Nowadays, there are more than 100 million sites worldwide.

In 1977, CERN made their first image from a positron emission (PET) camera. Nowadays this technology can be found in medical diagnostic scanning equipment, for detailed viewing of organs, such as the human brain.

Computed tomography (CT) is a medical imaging method, used for producing 3-dimensional images from a series of X-ray images.

Permanent exhibition

The CERN Visitor's Centre permanent exhibition, *Microcosm*, is open daily from 09:00 to 17:00. For more information, visit the CERN website: www.cern.ch