# THE MACHINE MAKER

He did more than anyone to build the Large Hadron Collider. This year he saw it finished — and then break down. **Geoff Brumfiel** profiles the LHC's project leader, *Nature*'s newsmaker of the year.

LYNDON REES EVANS gets up from his desk and crosses his sparsely furnished office to a shelf filled with notebooks. He pauses before choosing one and bringing it to the table. He opens it as fondly as if it were a family scrapbook, flipping through pages crowded with diagrams, budgets and the business cards of mid-level government bureaucrats. Finally he gets to what he was looking for: a photocopied drawing of a conference table. Most of the writing on the diagram is in Japanese, but around the table's edge someone has written names, including Evans's, in English. The date at the top is also in English: 2 March 1995. "This was it, this was the key meeting," he says. He points to a Japanese character written in a corner. "They even showed where the flowers were."

Most laboratory notebooks — like most family scrapbooks — don't record the place settings at meetings with Japanese parliamentarians. But this is the laboratory notebook, or rather one of many notebooks, of the largest scientific experiment ever constructed: the Large Hadron Collider (LHC), a particle accelerator at CERN, the European high-energy physics laboratory near Geneva, Switzerland. The LHC represents a level of ambition never before seen in physics, an ambition so monumental that its realization required it to become the first truly global experimental undertaking. It consists of hundreds of thousands of tonnes of extremely powerful machinery looped round a tunnel 27 kilometres long. Much of this hardware is chilled to within two degrees of absolute zero by a liquid helium system much larger than any seen before.

For most physicists, the LHC story — a new chapter in their discipline's history — has yet to begin. For Lyn Evans it is almost over. After a decade and a half of daily devotion to getting the machine built, he is due to retire at roughly the same time that the LHC will start to generate data. At 63, he is still never more than a quick recap away from being up to speed on every detail of its design and engineering. At one point he more or less redesigned it single-handedly on his kitchen table. Since he joined the project in 1993 he has built relationships with the world's physicists, politicians and industrialists to ensure its support; he has travelled to factories in Europe, North America and Japan to see its components forged; and he has tackled enormous technical challenges — the most recent and dramatic being a galling accident just weeks after the machine was first turned on. "He's the guy who made the LHC," says Chris Llewellyn Smith, a friend and former director-general of CERN. "That is what's going to be on his tombstone."

"There were several clever people, but Lyn was really exceptional." — Walter Scandale

## Rise and fall

When Evans left his house in Versonnex, France, on 10 September 2008, he was heading for the biggest scientific media event of the year. But that sort of slipped his mind. He didn't even mention to his wife that he would be on television a little later on. He was entirely focused on the experiment.

At the CERN campus, which sits on the Swiss border about ten kilometres away, the car park by the main entrance was crammed with broadcast trucks and satellite dishes. Soon, the LHC's normally hushed control room was packed with news anchors, past laboratory directors and distinguished scientists. It was 'beam day' — the day on which protons would circulate around the LHC for the first time. "I have rarely been in such a stressful situation," Evans says later; he has a lilting Welsh accent that he has kept during four decades of living in France and Switzerland, and a stutter that becomes more pronounced when he is nervous.

The machine's eight sectors turn on one by one. There's a cheer each time the beam first passes through a sector; but it is the last sector — the one that completes the loop — that really counts. The cameras focus in on Evans's round face as he stares at a wall of flat-screen monitors. "So it will be on the next cycle — in about one minute," he says haltingly to the crowd. He completes the countdown in French: "*Trois … deux … un … et zéro*." Suddenly, two bright dots appear on a screen, a sign that protons have made it all the way round. The control room bursts into applause. Evans's face slackens into a broad smile. He moves around the consoles, shaking hands with the individual members of his team. "*Merci*," he tells them all. "Well done."

The circulation of that beam puts the LHC on to more front pages the next day than any scientific event since the sequencing of the human genome. Just circulating the beam, though, is not enough. A second, counter-rotating beam has to be put through the machine. Then the current has to be upped, the acceleration increased, the beams focused to the point at which, when they cross inside vast buried detectors, the head-on collisions between protons are frequent enough to offer up a wealth of data. All that will take weeks, maybe months.

Then, nine days into the process, disaster strikes. On an otherwise quiet Friday morning, physicists in the LHC's control room were slowly pumping up the current in the magnets in the region called sector 3–4 to see whether the magnets would work as designed. Suddenly, their screens lit up with alarms. According to the computer, more than 100 magnets inside the machine had 'quenched' or lost their superconductivity. Uncontrolled quenches can be disastrous. Currents of many thousands of amperes can be handled quite safely by superconductors, but they will turn magnets to slag if they encounter even a little electrical resistance. Those in the control room knew that what had happened in sector 3–4 was serious even before a second set of alarms warned of falling oxygen levels along a subsection of the tunnel. Then, the entire sector's power cut out. The operators were literally in the dark about what was happening five kilometres away, more than a hundred metres below the French countryside.


M. BRICE/CERN

"I was over in the personnel department haggling about some recruitment problem when I got a call," Evans says. He rushed across the lab to the control room. At first, he says, he couldn't understand how so many magnets would quench simultaneously. But he and others soon realized that the quench was by design. The LHC had automatically brought the magnets out of their superconducting state to protect them. At the same time — and probably for the same reason — it had sprung a leak. The oxygen alarms had been triggered by helium escaping onto the tunnel.

Two months later, sporting jeans and a red Geneva Squash Club sweatshirt, Evans introduces me to the culprit behind both quench and leak. The tops of the Jura mountains to the west are obscured by cloud, the Alps to the south nowhere to be seen. We are in a blocky industrial building on the edge of the campus, where four of the LHC's superconducting magnets are scattered about in various stages of disassembly amid shelves of vacuum flanges and copper tubing. A handful of technicians move between them.

From afar, the magnets look like 15-metre sections of what might be a Franco–Swiss oil pipeline. Their long steel tubing is painted an evening-sky blue, and some have "LHC dipole" in white lettering on their side. Running through each dipole are the two pipes that carry the colliding proton beams in opposite directions around the machine.

"This is the famous busbar that burned," says Evans, pointing at a small ribbon of niobium–titanium alloy, no wider than his own thick index finger, sticking out of the end of a dipole magnet. To an untrained eye, it is almost indistinguishable from the dozens of other superconducting wires that supply the magnets with current. The busbar, however, is the mainstay of the machine's electrical system. It distributes the primary current between all the magnets in a given sector. During installation, the busbar ribbon leading from each magnet must be connected manually to the next by brazing. Evans and his team now think a bad braze


M. BRICE/CERN

Under repair: dipole magnets hauled out of the LHC's tunnel after the accident.

lay behind the accident. When it came undone, 8,700 amps of current vaporized a half-metre length of the ribbon and punctured the LHC's heavy vacuum insulation. The liquid helium it protected boiled instantaneously. The outer shell gave the gas boiling off nowhere to go; in places the pressure built up to 20 atmospheres, prying magnets loose of their steel anchors. All told some 53 magnets were affected.

Now it all needs to be fixed: the damaged magnets must be replaced, the underlying causes sorted out. If a busbar braze bursts again the team has to be sure it won't fill up the system with high-pressure helium. To that end, relief valves need to be added all through the machine.

Before the accident, Evans had hoped to provide the world's waiting physicists with the LHC's first collisions by November 2008. Now, the machine will not start running again until summer 2009, and probably not do any serious physics until 2010. The frustration is all the worse because the team got so close to getting things to work first time. "This was the last circuit on the last sector, so it was a bitch," Evans says. "Fortunately, I've had some hard problems in the past."

## The antimatter opportunity

The hard problems that established Evans's reputation at CERN came about when the lab took a gamble on an utterly new technique in the 1970s. There was a revolution under way in particle physics, and part of its promise was to confirm a prediction that the electromagnetic force and the weak nuclear force were aspects of the same underlying process. This unification called for new particles, called the *Z* and *W* bosons, which were suddenly highly sought after. Unfortunately, no accelerator had remotely enough oomph to produce any of them. The big machines — the Main Ring at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois (see 'Making it big'), and the Super Proton Synchrotron (SPS) at CERN — were designed to shine their protons on to fixed targets. In fixed-target physics, only a small fraction of the energy in any of those protons is used to make new particles, and neither the Main Ring nor the SPS had any chance of making the new bosons.

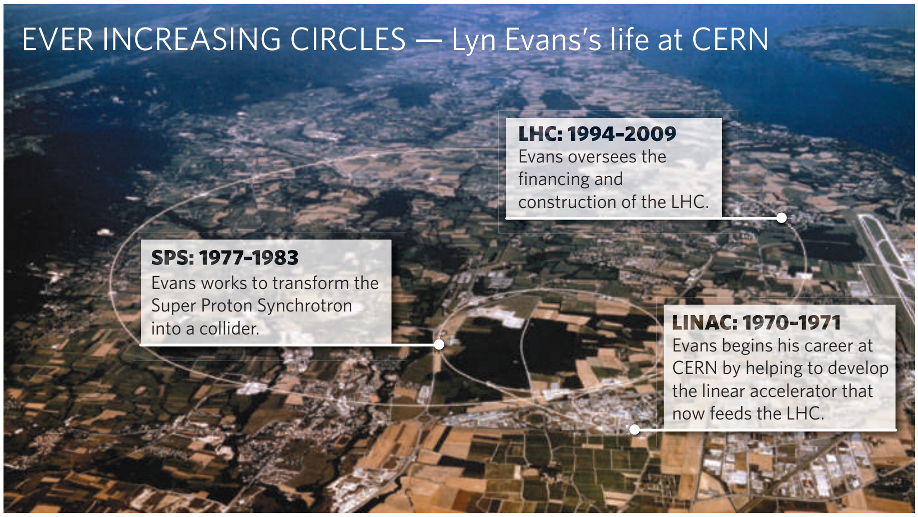
**"Lyn started working like hell on the accelerator. And he made quite a lot of changes." —** Chris Llewellyn Smith

In machines that contained two counter-rotating beams it would be possible to arrange head-on collisions between particles — collisions in which a large fraction of the energy released went into producing new stuff. They could make *W*s and *Z*s. The problem was that proton colliders were hard to build; there had only ever been one, a CERN machine called the Intersecting Storage Rings, or ISR, and it operated at much too low an energy to make *W*s and *Z*s. There seemed no way forward until Carlo Rubbia, a gifted and monumentally ambitious Italian physicist, started touting a cunning plan: turn one of the big proton machines into a collider by putting a beam of antiprotons into the same tube as the protons circulating in the opposite direction. Fermilab baulked at this outrageous idea, but CERN — a previously rather humdrum lab keen to up its game — gave it a shot.

The project required all CERN's technical tenacity. Antiprotons had to be made from scratch (contrary to the novels of Dan Brown, CERN does not have stocks of antimatter just lying around) and accumulated over weeks, carefully sequestered from regular matter and 'cooled' into a tight beam. Evans took on the complex calculations needed to describe how the particles in such beams would ricochet off one another as they travelled together around the SPS's ring. He then helped to design a set of magnets that could keep the beam tightly packed. "There were several clever people, but he was really exceptional," says Walter Scandale, a long-time CERN physicist who has worked with Evans throughout his career. "I'm speaking of the top 5% at CERN."

Before the SPS, Evans had not necessarily been committed to a career at CERN. A few years after he arrived in the 1970s he was offered a job at the Joint European Torus, a European fusion experiment at Culham, near Oxford, UK. "I brought the offer home and my wife, for reasons known only to her, decided she wanted to stay here," he says. He was unhappy with the decision. "I didn't see where the next step was going in accelerators." After the proton–antiproton work he could see the next step clearly. The challenge of marshalling beams of powerful particles had bewitched him, and CERN was the best place to put it to work on a truly epic scale.

This speciality of Evans's, accelerator physics, is an odd one. It is scientifically demanding, but to an outsider it sounds like a secondary, almost menial, role: the exciting theory-overturning physics is what comes out the other end. Insiders, though, know that accelerator physicists are absolutely crucial, and CERN's culture reflects that. As Philippe Lebrun, who directs the lab's accelerator technology department, puts it: "The accelerator theorists are a kind of aristocracy."



CERN

In his childhood, few would have taken Evans for any sort of aristocrat. He was born in 1945 in the Welsh mining town of Aberdare. His father worked down the pit and died of the lung disease silicosis when Evans was just 11. Evans's mother took a job at a school canteen, struggling to support Lyn and his younger brother Peter. It is not a time that Evans is keen to talk about; but he does say that, although it was difficult, he was "perfectly happy". "I played for the town football team, I played rugby, I had a good social network." He got a place in the local grammar school, but describes himself as an undisciplined student until, around the age of 16, he started to get enthusiastic about science. Trying to remember the appeal, he thinks of newspaper stories of hydrogen bombs and fusion power that was too cheap to meter. "All these things were happening, and that just sort of gelled with my own interests and my abilities," he says. "I found science easy."

He received top grades in his A-level exams, and went to the University of Wales in Swansea. He started in chemistry but soon switched to physics, staying at Swansea to complete a PhD on fusion energy. On a weekend home in Aberdare he met his wife Lynda, and the couple married in 1967. His adviser, Colyn Grey Morgan, had connections to CERN and convinced the young physicist to apply for a fellowship at the laboratory. Evans had no knowledge of how particle accelerators worked, but his fusion work had focused on stripping gas molecules of their electrons, so he started there, turning hydrogen atoms into protons in a way that suited the accelerator he was working on. "That was my baptism," he says. "I've come all the way from the hydrogen bottle."

The hydrogen bottle led to a linear accelerator, the fixed-target version of the SPS and finally the antiproton work that turned the SPS into a collider. Thanks to Evans and others like him, the gamble that CERN had taken paid off spectacularly. The first *W* and *Z* bosons were found in 1983. A year later, Rubbia got a Nobel prize for the discovery — as did Simon van der Meer, the accelerator physicist whose cooling technique had made it possible. For Evans the real significance of the project was what it suggested might be possible in the future. "For me it was the essential prototype," he says. "Although the LHC was far over the horizon in those days, this is where we learned the physics of intense stored particle beams."

The next machine at CERN, though, was to be different; it would work with electrons, not protons. The Large Electron–Positron collider (LEP) was in some ways technically quite simple; it could manage quite well without superconducting dipoles and the like. But at the same time it was, as the name made clear, large. To be big enough to further the study of *Z*s and *W*s, it had to have much more tunnel than the SPS. And that was a good thing. Rubbia, who became head of CERN in 1989, knew that he would never get the money to build a big proton machine from scratch. Somewhere down the line, though, putting a proton machine into a tunnel that had already been dug might be quite feasible. Before LEP was even finished, Rubbia was forcefully advocating the idea of a similarly vast proton collider as a follow on: the LHC.

CERN started to put more effort into the LHC's design. But many European politicians had doubts about actually building it. The United States, stung by its failure to discover the *W*s and *Z*s, was building a much bigger 87-kilometre superconducting supercollider, which would achieve energies three times higher than the proposed LHC. How could CERN's machine be anything other than an also-ran?

**"It was a totally crazy scenario. But one that was swallowed by the German government."**
**— Lyn Evans**

### Collide and conquer

In 1993, Llewellyn Smith arrived to replace Rubbia at the same time that Giorgio Brianti, who was leading the LHC project, was planning retirement. Llewellyn Smith needed to appoint a replacement.

"It became pretty clear to me that Lyn was the right guy to do the job," he recalls. In 20 years Evans had worked on practically every accelerator at the laboratory, which would be useful knowledge; several of them would have to be run together into a cascade of pre-accelerators to provide the LHC with its beam. And for all his CERN experience, Evans was only 47 years old. He would be able to see the project through to its completion. Evans accepted the position immediately, and although he was not officially scheduled to take over until 1994, he began a vigorous redesign of the machine. "Lyn started working like hell on the accelerator," Llewellyn Smith recalls. "And he made quite a lot of changes."

In October 1993, as Evans was in the midst of reworking the LHC design, the US Congress dropped a bombshell. Furious with projected cost overruns and poor management at the US supercollider project, it withdrew its funding for the accelerator, even though construction had already begun.

The supercollider's cancellation put the LHC back in the game. In fact, it made it the only game in town. But it could still prove too rich a game for the blood of CERN's member states. Evans trimmed hundreds of millions of Swiss francs from the budget. However, in June 1994, Britain and Germany, two of the most powerful members of CERN's council, baulked at the price tag of 2,350 million Swiss francs (US$1,590 million).

Evans and Llewellyn Smith hatched plan B: a design in which the LHC would initially be built with only two-thirds of its superconducting magnets. In terms of physics it was unthinkable — it would cripple the machine's capabilities — but politically they knew that it might be the only way to get the CERN council's support. Once they had that support, Evans and Llewellyn Smith could go and get the rest of the money from elsewhere — from Japan, which had been a reluctant partner in the superconducting supercollider, and perhaps also from the humbled Americans.

So Evans found himself the Sunday before a crucial trip to Bonn working furiously at his kitchen table to finalize a design that, he believed, could never produce groundbreaking science. "It was a totally crazy scenario," he says. "But one that was swallowed by the German government." The project won approval from the council in December 1994, and Evans and Llewellyn Smith were given two years to find the money for the full-power machine. Suddenly the shy physicist, who had spent his entire career cloistered at CERN, was thrust into the unexpected role of international diplomat — a role he would find fascinating.

"I was mystified at first," he recalls of his early visits to Japan. "We would have ten courtesy visits in the morning, just in and out, covering all the bases. We drank so much green tea." But Evans is in many ways a natural negotiator. He is quiet and deferential, but also confident and engaging, especially when speaking one-on-one. "He never says what doesn't need to be said," says Peter Limon, a high-energy physicist from Fermilab who worked with Evans on bringing the United States into the project. "That's sort of the definition of a diplomat."

"Evans never says what doesn't need to be said." — Peter Limon

The efforts paid off. In June 1995, some ¥5 billion (US$50 million) appeared for the project, wrapped up with emergency spending in the wake of the Kobe earthquake. "With no warning at all, we had the announcement of a contribution," Evans says. "That started the ball rolling." In the cash-strapped Russian Federation, a complex arrangement was worked out whereby CERN and the Russian government each paid for a third of parts supplied. "The third third, nobody knew where it came from," he says. "It was just cheap labour."

By the end of 1996, CERN had secured contributions from Japan, India, Canada and Russia, and had a strong signal of interest from the US government. Then came the 'kick in the teeth': Britain and Germany announced at the last minute that they would not meet their 1994 commitments. But the council allowed CERN to make up the shortfall with loans from the European Investment Bank. By 1996, construction work on the project had begun — and Evans's role changed yet again, from designer to diplomat to something more like a foreman.

### Organized chaos

You might expect a laboratory based on the border of France and Switzerland that measures the fundamental symmetries of existence to be a supremely orderly and Cartesian sort of place. You would be wrong; it is in fact decidedly higgledy piggledy. Its gently decaying post-war buildings, to take one example, are identified in such a way that numbers 30, 112 and 376 sit side-by-side — half a kilometre away from building 31. Either through force of habit or tradition, the thousands of physicists and engineers from dozens of nations who work at the lab organize themselves in the manner of academics: they set up small and often loose collaborations; when absolutely necessary they will

## Making it big

**A machine as ambitious as the LHC could only be undertaken by a vast multinational organization. Other big science projects have come about differently — and with very different characters at the helm.**

"Perhaps we were his slaves, but we liked it," declared George Ellery Hale's younger brother, who along with his sister had been recruited to help the teenaged Hale build a substantial laboratory in their Chicago home. "We always had the belief that with him we were going to do things that were mysterious."

That charisma and leadership led Hale to become a driving force in the new science of astrophysics. In 1892, 24-year-old Hale approached Charles Yerkes, a shady financier who had renewed his fortune in Chicago after being run out of Philadelphia. Yerkes had already turned down a request from the recently founded University of Chicago in Illinois to build a biology laboratory, but Hale was evidently more persuasive. Emphasizing that he wanted to build the biggest telescope in the world, and that it would preserve Yerkes's name for posterity, Hale extracted enough money to build the Yerkes Observatory in rural Wisconsin and get his 102-centimetre refracting telescope up and running by 1897.

Hale later moved to California, where he found prime observing sites in the mountains overlooking Los Angeles, and made contact with a fresh supply of entrepreneurs eager to indulge in grand philanthropic gestures. The result, in the early twentieth century, was a series of what were then the world's greatest telescopes: the 152-centimetre reflector telescope on Mount Wilson, then the 254-centimetre Mount Wilson telescope — the instrument Edwin Hubble used to discover the expansion of the Universe — and finally the 508-centimetre Mount Palomar telescope, which was completed after Hale died in 1938.


**George Hale drove astrophysics in the 1890s.**

In the late 1920s, meanwhile, a young, South Dakota-born physics professor named Ernest Lawrence also headed west. Feeling hemmed in by Yale's academic atmosphere, Lawrence tied his ambitions with those of the rising University of California, Berkeley. There, after building the first cyclotron in 1931 — a palm-sized machine that could accelerate protons to 80,000 electronvolts — he immediately hatched plans for larger accelerators. "Lawrence was young, he was bursting with energy, his enthusiasm swept me off my feet," recalled one early collaborator. "He would try to outdo you in seizing the implications and possibilities" of any new idea put to him, said another. Eager young physicists began to show up on his doorstep asking to be put to work. Lawrence also proved adept at charming money out of the nouveau riche of California, seizing on the largely unproven medical benefits of particle beams as a way to attract donations.

One young physicist whose career got an early boost from research funds under Lawrence's control was Robert Wilson, who put together a committee to decide on a course of action. Paperwork can meet with something approaching deliberate disregard.

Evans's style is much in line with that culture. Understandable, as he has worked there all his life; necessary, too, as imposing any other style might prove impossible; and probably wise, as CERN has brought in groundbreaking mega projects one after the other. True to CERN culture he oversaw the LHC project with a group of around half-a-dozen advisers. The bulk of the daily work was carried out by teams that resemble academic lab groups, each responsible for a subsystem or a sub-subsystem, but overall scheduling remained the preserve of Evans's core team alone. It was an approach seen by some as aloof. Still, when someone ran into a technical problem, Evans would be one of the first on the scene to help. He would get his hands dirty literally and metaphorically; he would take the hours needed to understand a cooling system in the most painstaking detail.


A taste of things to come: Evans with his machine's much sought-after quarry.

F. COFFRINI/AFP/GETTY IMAGES

Some at the lab, particularly the engineers, see a downside to Evans's loose, confederate approach. At the start of the project he didn't have all the stringent, quality-control procedures that were needed, says Gerard Bachy, a mechanical engineer who has since retired from the laboratory. "It's not just paperwork at all," he says. "You have to have full traceability for each bit and piece — it's a very complicated machine." And Evans's readiness to mingle on the floor of the machine shop, although often appreciated, left some middle managers feeling out of the loop. There were frayed egos and crossed wires.

A consequence of what one engineer describes as Evans's

later became the first director and guiding spirit of the National Accelerator Laboratory (NAL) in Batavia, Illinois, subsequently renamed the Fermi National Accelerator Laboratory (Fermilab).

### More for less

Wilson was something of swashbuckler, pushing ahead with design changes for the original NAL accelerator that yielded higher particle energies for less than the anticipated cost. Barry Barish, now at the California Institute of Technology in Pasadena, recalls how he and another young Fermilab colleague proposed a new way to make neutrinos — and found that Wilson was not only eager to hear their suggestion, but also willing to take a chance on trying it. "Wilson was very adventurous and had lots of confidence in himself," Barish says. He made mistakes, but always believed he could fix them and move on.

Barish later undertook a big task of his own, overseeing construction of the US National Science Foundation's Laser Interferometer Gravitational Wave Observatory (LIGO) at two sites, in Louisiana and Washington, during the 1990s. The people who build such one-of-a-kind, sophisticated projects have to be scientists with an aptitude for management, he says. "The hardest thing is to make the instrument as good as you can to meet science goals" within the restrictive setting that government funding and oversight inevitably entails.

**Ernest Lawrence built the first cyclotron.**

NEW YORK TIMES/GETTY IMAGES

Particle physics, with its complex detectors and need for large scientific teams, seems to have become a breeding ground for big-science managers. Jerry Nelson, for instance, left particle physics and returned to an early interest in astronomy because he didn't savour the prospect of working with 50-person teams. But when he joined a study of the future of ground-based astronomy at the University of California, Santa Cruz, he began advocating a new segmented-mirror design that would make huge mirror diameters both technically feasible and affordable. He then became the project scientist for the Keck Observatory in Hawaii.

Taking a new technology from demonstration projects to a working telescope brings with it an unavoidable tension between the scientific desire to tinker and improve, and the managerial responsibility to stick to budgets and schedules, says Nelson. For Keck he worked with project manager Jerry Smith, who had overseen several space and astronomy initiatives at NASA's Jet Propulsion Laboratory in Pasadena, California. Nelson says that part of his job was to argue for changes that would benefit the project, whereas Smith's role was to limit risk. The arrangement "worked very well", Nelson says. Smith could be "tough to get along with, but I always understood his perspective".

Although neither Nelson nor Barish claim any premeditation in their career paths — Barish says he was drawn into big projects because "the most exciting science requires the most complex instruments" — both seem to have settled into a niche that few scientists would aspire to, let alone succeed at. Nelson is now project scientist for the Thirty Meter Telescope, an instrument that will take segmented mirror technology far beyond the 10-metre aperture of the two Keck telescopes. It is due to begin construction in 2009. Barish, although still associated with LIGO, is now director of the global design effort for the International Linear Collider: a proposed electron–positron collider that would be a companion to the Large Hadron Collider. **David Lindley** "soft control" of the project became apparent towards the end of 2000. Six years after the LHC's initial approval, CERN's council wanted a new cost estimate. As auditors looked in more detail at what had already been spent, they realized that the project was likely to run over budget by about 20%. Evans, now the accomplished diplomat, pushed hard for the lab's director, an Italian particle theorist named Luciano Maiani, to break the news to the member states gently. Instead, Maiani presented the cost overrun to an open council meeting in September 2001, along with a bald request for the inflated budget needed to cover it. The council members were furious. Robert Aymar, a French physicist with a background in nuclear fusion and a long history on large projects was called in to mount a full review of the lab's management. Evans was an obvious and possibly politically expedient target. "Many people were shooting at Lyn," recalls Lucio Rossi, who oversaw the making of the LHC's magnets.

But Aymar did not fire Evans. He was more worried about the generally fragmented culture at CERN, which made it hard for the lab to focus and prioritize, than about Evans's specific handling of the LHC. Aymar says that although he recognized Evans's faults, there were many more reasons to keep him on than to fire him: he was popular with the staff and he was willing to work to keep a better track of future costs. Above all he really understood the machine, and could manage the complex relations between its millions of components and the thousands of people and organizations responsible for them.

Evans repaid the confidence. Aymar took over as director-general of CERN in 2004, and soon thereafter the machine was faced with a major crisis: the system that fed liquid helium to the magnets proved too poorly manufactured to be used. After that it was a design flaw in some of the magnets. Then there were problems with the connections between sections of beamline. Every time, Evans's calm, low-key approach and overall grasp of the project let him reorder the responsibilities of CERN staff and outside contractors, keep the council calm and find the workaround. "He is the one who is able to control the technical part of the project, which is by far the most important," says Aymar today.

Vanishing point: the LHC stretches out into CERN's future.

M. BRICE/CERN

### The Last Hadron Collider?

Although the setbacks were weathered, there were costs to doing so: the problems with the liquid-helium system, for example, delayed completion by nearly a year. The lost year now facing the machine is thus not unprecedented. But it has come about in a much more public way.

Sitting in a kitchen that adjoins the LHC's control room, Evans maintains his usual upbeat attitude. "When the damn thing works, it will be the scientific tool for really crossing the frontier into new knowledge," he says. Throughout the winter — during which the LHC would normally be shut down anyway, as electricity costs a lot more — engineers are working double shifts to replace dozens of magnets and to repair those damaged in the incident. Meanwhile, new diagnostic tools are being developed to spot faulty connections before they can cripple the machine.

The first collisions cannot come soon enough for the lab's frustrated detector physicists, many of whom have had PhD theses and sabbaticals derailed by the accident. Evans has found himself the subject of more than one ad hominem attack in physics chat rooms and blogs; he knows because he Googles to find out.

If Evans is confident that the LHC can get through this just as it got through earlier slip-ups and crises, he is less certain about CERN's long-term future. Each generation of accelerators becomes larger and more expensive. The next machine the community wants to build will be an electron machine, like LEP, but linear rather than a loop. If its 30-kilometre rifle barrel is ever built, it is unlikely to be in the suburbs and farms around CERN. There are, currently, no plans for any further proton machines after the LHC, although the LHC itself could be upgraded. The first proton collider was built at CERN: the last one may have been, too. The CERN that Evans came to in the 1970s, about to occupy the commanding heights of particle physics for the rest of the century, is nearing the end of its time. Quite a few of Evans's younger colleagues have moved from the LHC to the new international fusion project in France, ITER. Evans says that if he were starting now, he might head in the same direction.

But he sees no rush for CERN to diversify out of particle physics. "The flagship for the next 20 years at CERN will be the LHC." Due to retire in 2010, Evans plans to split the subsequent years between the local golf courses and some part-time work on the upgrade plans. "I kid myself that it's not going to leave a void," he says, knowing that it will. "The ability to step away is something that I'm going to have to test myself on."

Building the LHC has taken his days, his evenings and his weekends. He has so much unused holiday from his years devoted to the machine that he had originally been planning to quit the project next October, months shy of retirement, to use it up. Now he has to face the faint worry that even then it might not be working. It won't be for lack of effort by him and his team — but it will mean a change of plan.

"If it still isn't working," he says matter-of-factly, "I certainly will not take my vacation." ■

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