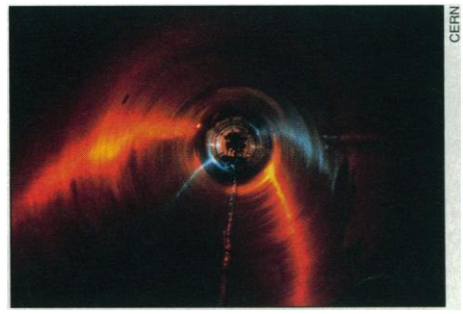
CERN: Alone on the Frontier

The SSC's demise opens the way for Europe's high-energy physicists to dominate their field. But first they must win final approval for their own accelerator and work out terms for U.S. participation

GENEVA—When the U.S. Congress delivered the coup de grâce to the Superconducting Super Collider (SSC) in October, the reaction among physicists here at CERN, Europe's premier particle physics center, was decidedly mixed. The frontiers of high-energy physics will now be CERN's alone to explore early in the next century—assuming the lab's leaders can persuade Europe's recession-prone governments not to turn their backs on CERN's own megamachine, the Large Hadron Collider (LHC). Yet few are celebrating the loss of the LHC's chief rival. "The fact that the Americans are now in big trouble, for us, is bad," says outgoing CERN director-general Carlo Rubbia. "I think that science needs competition."

The LHC is now high-energy physicists' best—perhaps only—hope for breaking out of the confines of the Standard Model, a theory of particles and forces that has dominated their field for a decade and is now fairly well mapped out. Collisions generated by existing particle accelerators simply lack the energy to give a good chance of yielding the exotic beasts that may lie beyond the Standard Model, such as the Higgs boson—a hypothetical entity deemed necessary to explain why other fundamental particles have mass. Now that the SSC has been canceled, the LHC's proton-proton collisions will provide "the only way to get at that [energy] scale," says Christopher Llewellyn Smith, the Oxford University theoretical physicist chosen last fall to succeed Rubbia as CERN's director-general.

That's why the minds of physicists across the globe will be focused on Geneva today (17 December), when Llewellyn Smith and Rubbia outline to CERN's governing council the first fully costed technical proposal for the LHC. The council meeting marks the beginning of months of intense negotiations that CERN's leaders hope will lead to approval of the LHC by delegates from the lab's 19 member countries at a second council meeting next June. Llewellyn Smith declined to reveal the precise cost estimates in the new proposal before today's meeting, but *Science* has learned that the total comes to 2.63 billion Swiss francs (about $1.8 billion), excluding labor costs. This includes the cost of building the accelerator, preparing the experimental halls, and a small contribution toward the cost of its detectors. Llewellyn Smith, who formally takes over from Rubbia on 1 January, now has to persuade CERN's members, especially cash-strapped Germany, that the machine is worth this cost. And he will be looking to the United States, and other nations whose physicists were planning to work on the SSC, to come up with some construction costs—and, later, operating costs. "The first half of next year will be interesting, from a diplomatic point of view," says Llewellyn Smith dryly.



Doubling up. The LHC will be housed in LEP's existing 27-kilometer tunnel.

He has one big selling point: The price tag is a bargain compared to the $11 billion estimated for the SSC. It can be done on the cheap because the LHC would be built inside the 27-kilometer circular tunnel that houses CERN's existing mainstay, the Large Electron Positron (LEP) collider. But the new figure is still around 10% higher, after inflation, than the working estimate drawn up in 1989.

The new plan calls for a start to be made on installing the new collider in 2000, with full operation in 2003. That would give physicists from 1995 to the end of 1999 to work with LEP200, an upgraded version of LEP with double its present energy. LEP200's electron-positron collisions will yield pairs of W bosons, rather than the Z bosons LEP has made until now—which will allow physicists to measure the W's mass accurately and verify their understanding of the electroweak interaction. That will add one of the final pieces to the Standard Model jigsaw.

LEP would then be mothballed, to await a possible revival later next decade when its electron beam could be collided against the LHC's protons, repeating at higher energy experiments now taking place on the HERA machine at Germany's DESY laboratory. If LEP200 throws up some new, totally unexpected physics, startup of the LHC would be delayed to give physicists more time to operate LEP200. But even if this does not happen, the project will proceed at a more leisurely pace than originally envisaged. CERN once hoped to bring the LHC online as early as 1998 and alternate between use of the new collider and LEP200 for a few years. The reason for the slippage is that there's no longer any incentive to try to get in ahead of the SSC—indeed, the new timing was first proposed last spring, when the completion date for the SSC was delayed to at least 2002.

The LHC's Proposed New Timetable

2005 **Sometime after 2005:** LEP's electron beam collided against LHC's protons
2004
2003 **2003:** Experiments begin using the LHC
2002 **2002:** LHC commissioning
2001
2000 **2000:** LHC installation begins
1999
1998
1997
1996
1995 **1995-99:** Operation of the LEP200 upgrade
1994 **June 1994:** CERN council votes on the final LHC proposal
1993 **December 1993:** Rubbia and Christopher Llewellyn Smith present to the CERN council a plan to build the LHC for 2.63 billion Swiss francs
1992 **December 1991:** CERN's council declares that "the LHC is the right machine...for the future of CERN"
1989 **1989:** CERN director-general Carlo Rubbia estimates that the LHC will cost 2 billion Swiss francs
1988
1987
1986
1985
1984 **March 1984:** CERN/European Committee for Future Accelerators workshop discusses the idea of building a Large Hadron Collider in the LEP tunnel

Powerful argument

The key scientific question swirling around the LHC is whether it would be powerful enough to reveal all of the exotic particles that would have been visible to the SSC.

Because the LHC would be built in CERN's existing tunnel, it would be limited to an energy of 14 TeV—only about one-third that promised by the 84-kilometer SSC. The reason: More energy is required to bend the particles around a tighter ring. When they were pushing for their own machine, some of SSC's proponents implied that the LHC would be too puny to perform its main task. CERN physicists have always responded, however, that what their machine lacks in energy it will make up for in luminosity.

The LHC's luminosity, the density of protons in its beamlines, will be 10 times the figure proposed for the SSC. And with more proton collisions and more rare, high-energy impacts among the resulting shower of quarks and gluons, CERN physicists are confident that their machine will have the muscle to find the Higgs boson—or bosons, as some theorists predict more than one. They also believe it has a good chance of finding a suite of new particles anticipated by supersymmetry, a theory many physicists believe is required to derive a Grand Unified Theory linking all of the four forces of nature apart from gravity. "The combination of energy and luminosity should give us the physics reach one needs," says Walter Hoogland, one of CERN's two research directors.

Intra-European politics

Llewellyn Smith will be taking these arguments to CERN's member countries in the coming months. First, however, he must resolve a serious dispute with Spain, which has refused to pay its CERN dues for the past 2 years. "It's leading to a very significant cash-flow problem," says Hoogland. The Spanish complain that they get little for their $50 million-a-year subscription, especially in terms of the value of the contracts placed by CERN with Spanish companies. Last Friday, however, a high-level CERN delegation, including both Llewellyn Smith and Rubbia, visited Madrid to discuss the problem, raising hopes that a solution will soon be found. This will probably involve giving Spain a temporary reduction in its subscription of between 10% and 30% for 3 to 5 years.

If Spain's problems can be taken care of, the main question mark hanging over the LHC's future will be Germany's attitude toward the project. For some time, the German delegates to the CERN council have not expressed much enthusiasm for the project, in part because of the economic hardship forced by German unification. Germany would also like to see some physics return on its investment in DESY's HERA machine before moving on to another major accelerator project.

The more relaxed timetable now being proposed for the LHC may, however, be more to Germany's liking. Moreover, says a senior official in the German research ministry, "We don't want to be a one-country minority opposing this project." Nevertheless, Germany does not yet seem ready to back full funding of the entire project. One idea being discussed within the research ministry is to propose a conditional approval, which would give the LHC a preliminary go-ahead next June but allow CERN's members to review this decision 3 years later, in light of progress on the development of its detectors.

International contributions

Llewellyn Smith's problems with his member states would be eased if he could find a way to persuade nonmembers—especially the United States—to come up with some of the construction and operating costs in return for access to the machine. Already, some of the physicists who were participating in the SSC have asked to join LHC collaborations. But Llewellyn Smith faces a classic catch-22: He cannot realistically expect nonmember governments to chip in until the LHC is approved, but some member nations may be unwilling to commit themselves to the project until they get a clear signal that nonmember countries that stand to benefit will put some cash on the table.

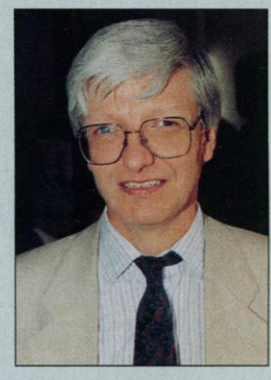
The issue of foreign participation in CERN has, in fact, long been a sore point. Some member countries are already unhappy that physicists from nonmember states represent one-fourth of those using the lab. These include more than 400 American physicists now working full-time in Geneva—far more than the number of European particle physicists working at American labs. For this reason, Llewellyn Smith says, he expects CERN's members to demand that nonmember states contribute toward the LHC's operating costs as well as construction costs. Such a demand would, however, break with high-energy physics' traditional "open door" policy, under which physicists work for free in foreign labs. That worries outgoing CERN director-general Rubbia: "I hope we are not going to get into a GATT type of warfare."

Llewellyn Smith has an additional worry: U.S. physicists seeking funds to buy into the machine may end up competing with their colleagues chasing money for a planned 1998 upgrade of Fermilab's Tevatron accelerator—and ex-SSC director Roy Schwitters warns that the issue could get bogged down in a wider debate about the future of the U.S.

A Leader by Consensus

It's hard to imagine two more different personalities than the incoming and outgoing CERN director-generals. For the past 5 years, Italian Nobelist Carlo Rubbia has led the lab from the front, with a whirlwind of energy that often left close colleagues struggling to keep up the pace. "Carlo is a force of nature," says Hannu Miettinen, CERN's head of communications.

In contrast, Christopher Llewellyn Smith, a quietly spoken Oxford University theorist, has an understated leadership style that relies on consensus building and methodical planning. His colleagues say, however, that this makes him ideal for the top CERN job. Oxford particle physicist Roger Cashmore points to the fact that in the late 1980s Llewellyn Smith merged Oxford's five separate physics departments into a single unit, without appearing to make any enemies. "People felt that their point of view had been given a proper airing," says Cashmore.



In the hot seat. Christopher Llewellyn Smith.

These diplomatic skills will be needed over the next few months, as Llewellyn Smith struggles to rally CERN's member states behind the proposed Large Hadron Collider project (see main story). As an aide in this delicate politics, he has appointed CERN theorist and former European Physical Society president Maurice Jacob to head a new office that will closely monitor the views of CERN's member states. Too often in the past, says Jacob, CERN's management has responded to deep concerns from member governments only when they became full-blown crises. "You can manage a crisis, but very often, it leaves scars," he says.

Rubbia appears happy to be handing over the directorship to someone else. "I want to go back to science," he says. His current plan is to divide his time between exploring accelerator-driven nuclear power (*Science*, 26 November, p. 1368) and heading up a proposed proton decay experiment called ICARUS, due to start running by 1998 at Italy's Gran Sasso underground laboratory. And despite the marked contrast in the two men's leadership styles, Giorgio Brianti, a 39-year veteran of CERN who is now associate director for future accelerators, says the changing of the guard is "about the smoothest I have seen."

–P.A.

National Laboratories, of which Fermilab is one. Furthermore, CERN may find itself hosting several dozen ex-SSC physicists from Japan and Canada, and deals with each country may require lengthy negotiation.

Detector collaborations

Europe's physicists are, however, eager to enlist help from their former SSC competitors—and not just for financial reasons. "LHC will be a very difficult machine," says Pierre Darriulat, CERN's other research director, who points to detector development as a key area of collaboration. Because SSC researchers were already well along with detector development when their machine was canceled, their experience will be especially valuable in building detectors that can spot the signature of the Higgs boson amid a cacophony of other events. The two LHC detectors, dubbed ATLAS and CMS—which will cost about $300 million each and must be paid for largely from outside the CERN budget—have already been selected. CERN has now delayed by more than 6 months, to the end of 1994, the date by which full technical designs must be ready, so that the groups can enroll members of the SSC's experimental teams.

The courtship began last week at a meeting held at CERN to discuss future collaboration between detector groups. The ATLAS and CMS teams, which together already involve almost 1700 scientists, can each accommodate more than 200 additional members. Bill Willis of Columbia University, cospokesman for the SSC's GEM detector, expects a maximum of 400 U.S. physicists to join detector groups.

Detector collaborations have traditionally entailed cost sharing, so a U.S contribution in return for accommodating SSC refugees would be expected. It could also make a big difference to the schedule. "Without the Americans, we were talking about staging the detectors," says CMS spokesman Michel Della Negra—starting with simpler versions requiring only about three-fourths funding, and building up to full capacity only after several years of operation. With a U.S. financial contribution, the complete detectors might be ready in time for the LHC's startup.

Llewellyn Smith will clearly have an interesting first 6 months on the job juggling these issues. He declined to comment in detail last week on the likely reaction of CERN's member states to the new LHC proposal, saying only that the SSC's cancellation makes the LHC "scientifically mandatory." And despite the political uncertainties, the new CERN director-general believes this argument will win through: "Before, I felt very confident we'd get approved. Now, I feel it's certain, somehow." Most of the world's high-energy physicists hope he's right.

–Peter Aldhous

HUBBLE TELESCOPE

Repairs Rekindle 3-Year-Old Dreams

Pictures of 4-billion-year-old galaxies from the Hubble Space Telescope earned astronomers Alan Dressler and Augustus Oemler a bit of scientific limelight and coverage last year by the national media. Where ground telescopes had shown only smudges of light, the space telescope revealed a garden of spiral and elliptical galaxies. "But that was only a tantalizing hint," says Yale's Oemler, of what lies ahead if NASA's recent repair mission succeeded in correcting the telescope's blurry vision. They now hope Hubble will provide an even clearer window on the early history of the universe, revealing evidence of collisions and cannibalism among these ancient galaxies.

NASA

To the rescue. Astronauts Kathryn Thornton *(top)* and Thomas Akers install a new solar array panel on the Hubble telescope.

With the astronauts from the Space Shuttle Endeavor safely home after completing five space walks to repair the $1.5-billion Hubble, many astronomers are again dreaming of exploring distant stars, galaxies, supernovae, and quasars and getting a better handle on the size and age of the universe. Although many researchers were able to do notable observations during the 3.5 years since the Hubble was launched, the blur caused by its improperly ground main mirror served as a constant reminder of the instrument's limitations. "A lot of us tried to salvage what we had planned," says Abjihit Saha of the Space Telescope Science Institute in Baltimore. "But everybody suffered."

Over the next 6 to 10 weeks, technicians will adjust the Hubble's newly installed set of corrective mirrors and the mirrors built into the new main camera. Once these tests are finished, astronomers hope the telescope will finally live up to its promise. Among those lining up to find out are Saha and Alan Sandage of the Carnegie Institution, who hope to sharpen estimates of the size and age of the universe by resolving individual stars, known as Cepheid variables, in intermediate-distance galaxies, and then using them to measure the distance to galaxies containing brighter objects—type 1A supernovae. Establishing the brightness of these supernovae (and showing they are approximately all the same) will give astronomers a much longer yardstick with which to measure out to yet more distant galaxies. Their first observations also made headlines last year, but the team's data on only two galaxies didn't convince their colleagues. "We need a larger sample size," Saha says. The repaired Hubble should open up their view to eight or nine more galaxies.

Other astronomers had counted on the Hubble to tell them whether distant galaxies harbored massive black holes. Astronomers Tod Lauer of the Kitt Peak Observatory in Arizona and Sandra Faber of the University of California, Santa Cruz, have collected some compelling pictures of galaxies with very dense centers, but what's missing is a measure of the speeds of stars whirling around the center of the galaxies. They hope the corrective mirrors on the Goddard High Resolution Spectrometer, one of the three instruments on Hubble fixed with the Corrective Optics Space Telescope Axial Replacement (COSTAR), will sharpen the resolution enough to close the case for massive black holes.

Jon Holtzman of Arizona's Lowell Observatory has been using the Hubble to look at oddball galaxies, such as one that appears to be a conglomerate of two merged galaxies, but the flaws in the telescope precluded him from taking such quantitative measure as the brightness and color of its stars. Holtzman also hopes to revive a project to measure the ratio of bright, heavy stars to faint, light ones throughout the Milky Way and nearby galaxies. The flawed mirror made it impossible to measure the brightness of faint stars without contamination from neighbors. His target is a better understanding of two important astronomical puzzles—how stars form and how galaxies evolve with time.

For Holtzman and others, the biggest frustration with a flawed Hubble was using an instrument intended to work so much better. "We were able to do some things," he says, "but it was a far cry from what it should have been." After spending $550 million on this high-stakes mission, NASA has repaired some of the damage to its own reputation—and to the dreams of astronomers like Holtzman.

–Faye Flam