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U.S. to contribute $531 million to CERN's Large Hadron Collider project

8 DECEMBER, 1997

Geneva, 8 December 1997. U.S. and European officials today signed an agreement for U.S. participation in the Large Hadron Collider (LHC (http://wwwlhc01.cern.ch/)), a particle accelerator under construction near Geneva, Switzerland. When completed in 2005, the 27-kilometre circumference accelerator will be the most powerful in the world.

The new accelerator is being built at CERN[1], the European Laboratory for Particle Physics. It will bring protons into head-on collision at higher energies than ever achieved before to allow scientists to penetrate still further into the structure of matter. The LHC will give scientists tools to address the persistent mysteries of matter and energy such as: What gives the particles of matter their mass? Why is there more matter than antimatter in the universe? What is the invisible Dark Matter that accounts for so much of the universe?

Secretary of Energy, Federico Pena, the director of the National Science Foundation (http://www.nsf.gov/), Neal F. Lane, the Director-General of CERN, Christopher Llewellyn Smith, and the president of the CERN Council, Luciano Maiani signed the agreement in the Old Executive Office Building in Washington, D.C. While there is a long history of international collaboration in high energy physics experiments, this is the first time the U.S. will contribute significantly to the construction of an accelerator outside the U.S. The agreement is also the first between CERN and the U.S. government.

At the signing Professor Llewellyn Smith said: *"This is an historic event. American participation in the LHC will inject a wealth of scientific experience, excellence and characteristic exuberance into the project. The real winner is science as the collaboration of leading High Energy physicists from all parts of the globe working on the LHC will mix a powerful cocktail - a whole which is much stronger than its parts. This global collaboration in science sets an excellent precedent and a model for other fields to follow."* (Click here for full text) (http://wwwas.cern.ch/Press/us_lhc.html)

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diffusion of innovative technologies and for international collaboration."

John H. Gibbons, assistant to the president for science and technology, noted at the ceremony that, *"increasingly in fundamental research, no one country can go it alone. International collaborations have become an integral part of our domestic science program - they provide major tangible benefits at modest costs and serve to boost our national competitiveness in both technology development and in fundamental science."*

Secretary Pena said, *"Today, we are embarking on an extraordinary scientific journey. This agreement builds on the long tradition of successful international cooperation that the Department of Energy (http://apollo.osti.gov/html/doe/whatsnew/hottopic.html)'s laboratories and our nation's universities have created with their counterparts around the world. I have no doubt that when the history of the next 50 years is written, the Large Hadron Collider and all of the science, new ideas and technologies it spawns will be a major chapter."*

NSF Director Lane said, *"The LHC is unquestionably science at the frontier, and the potential educational benefit is just as exciting and unprecedented. The project promises to spark dramatic increases in public awareness and appreciation for particle physics and for science and engineering generally."*

The participation of the US in the LHC project will bring a double benefit to CERN. The influx of experience and intellectual strength is perhaps as important as the commitment to provide goods and services for the LHC. Specifically, the U.S. Department of Energy will provide components and materials valued at $200 million for use in the accelerator. Three of the department's national laboratories, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory and the Fermi National Accelerator Laboratory, will use $110 million to design and produce advanced systems for the accelerator's interaction regions where the detectors are located. The remaining $90 million will be used for procurements from U.S. industrial firms.

The United States will also provide a contribution of components valued at $331 million to the massive detectors, known as ATLAS and CMS, with $250 million from the Department of Energy and $81 million from the National Science Foundation. The detectors are being built by large international collaborations of more than 4,000 scientists and engineers in 45 countries in six continents. More than 550 U.S. scientists from nearly 60 universities and six of the Department of Energy's national laboratories in 25 states are collaborating on designing and fabricating the detector components. About 25 percent of the U.S. experimental high energy physics community are expected to do research at the Large Hadron Collider. This participation in the LHC will help U.S. researchers remain at the forefront of high energy

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The LHC has an estimated total cost of 2.6 billion CHF and is being built inside the existing LEP accelerator tunnel that crosses the French-Swiss border. In the collider, radio frequency energy will accelerate two beams of protons to close to the speed of light. Powerful superconducting magnets will guide the counter-rotating beams to collision points around the accelerator. The collision energy of 14 trillion electron volts will be seven times greater than the world's present highest energy accelerator, the Tevatron at the Department of Energy's Fermilab. The LHC's particle detectors, five stories high and weighing thousands of tons, will record the shower of subatomic particles from the collisions, which will occur at the rate of one billion per second. Scientists will then use computers to study the most interesting collisions in order to understand better the fundamental nature of matter and energy.

The LHC will break new ground not only in physics research and technology but also in international collaboration, with scientists from every region of the world represented in the construction of the LHC accelerator and the major experiments. Japan has already made a generous contribution of 8.85 billion Yen. An agreement was signed in March 1996 with India providing for a contribution to the LHC accelerator with a net value for CERN of $ 12.5 million. An agreement was signed with Russia in June 1996 which provides for a contribution to the LHC accelerator and detectors, each with net values for CERN of 67 million Swiss Francs. Canada will contribute an in-kind contribution to the LHC during the first half of the construction period with a value of $ 30 million Canadian.

CERN invented the World Wide Web and more information on the LHC can be found at: http://www.cern.ch Photographs that can be downloaded from: http://www.cern.ch/Press/

Background for signing of U.S./CERN Agreement

Building the world's largest particle accelerator

CERN - the European Laboratory for Particle Physics - is one of the world's largest scientific research laboratories. An early European joint venture, CERN was founded in 1954 and straddles the French- Swiss border west of the city of Geneva. CERN's nineteen Member States - Austria, Belgium, the Czech Republic, Denmark, Hungary, Germany, France, Finland, Greece, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, and the United Kingdom - provide the budget (870.1 million Swiss francs in 1997) in proportion to their national revenues.

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particles which populated the early universe. Detectors, built around the collision points, record the brief existence of these particles, re-enacting moments in the evolution of the early universe.

As early as 1977, during preparatory discussions for building the Large Electron Positron collider (LEP) at CERN, it was clear that excavating the LEP tunnel would make more economic sense if it could be reused for a successor machine. Thus, while LEP was being designed and built in the early '80s, groups at CERN were busy looking at the longer term future. After many years of work on the technical aspects and physics requirements of such a machine, their dreams came to fruition in December 1994 when CERN's governing body, the CERN Council, voted to approve the construction of the Large Hadron Collider (LHC).

The LHC will be built from high powered superconducting magnets each 15 metres long. These magnets will hold two beams of protons rotating in opposite directions on a steady course around the ring, as superconducting accelerating cavities 'kick' them almost to the speed of light at energies of up to 14 TeV, higher than have ever been reached in accelerators. When these proton beams collide, at fixed crossing points, their combined energy of motion will produce an intense micro-fireball which will shoot out hundreds of new particles. These flashes of energy will probe the interactions between the tiny quark constituents hidden deep inside the colliding protons and reveal how Nature works at the most fundamental levels.

The Technology

To build instruments capable of creating such extreme conditions and then analysing the results with extraordinary precision is a daunting challenge; it demands advances in many highly complex technologies. The success of the LHC is directly linked to the ability of CERN's scientists, in close collaboration with industry, to push the limits of known technology way beyond today's frontiers.

The LHC ring will contain some 1260 superconducting bending magnets. These magnets are among the most technologically challenging components of the machine. Superconductivity is a property that some materials acquire at very low temperatures, when their resistance to the passage of electrical current more or less disappears. Under these conditions, large currents can flow easily through superconductors of small cross-section. This means that compact magnets can be built and operated for much lower cost than conventional 'warm' magnets made with copper or aluminium conductor. The only energy consumption of a superconducting magnet is that needed to refrigerate the conductor so that it remains superconducting.

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completely separate rings of magnets were built.

For LHC protons to reach their collision energy of 14 TeV, the high technology superconducting electromagnets have to sustain a field of 8.36T (Tesla) , the highest ever used in an accelerator. To achieve this, the cable windings must be cooled to a temperature of 1.8K (-271.2 1⁄4C); even colder than outer space (2.7K). A major milestone in magnet development was passed when the first prototype LHC bending magnet was successfully tested at CERN on 14 April 1994. In the tests, the magnet, in its cryostat filled with superfluid helium, surpassed the LHC design field of 8.36T at the first attempt. The magnet has since reached a field of 9.5T, giving a secure margin beyond the design field. In December of the same year, a full prototype section of the LHC was operated for the first time. The magnet string has since be put through strenuous testing, simulating over ten years of operation. The results have been extremely encouraging, confirming that the key technical choices made for the construction of the LHC magnets were correct.

To study the collisions of the tiny quarks locked deep inside protons requires a microscope on a larger scale than ever before built. But the microscope alone - the LHC itself - is not enough. Researchers using it have to have sharp eyesight. Their electronic 'eyes' come in the form of particle detectors. The LHC will have two general purpose detectors called ATLAS and CMS, each as high as a five-storey building, built like a Russian doll, with one module fitting snugly inside the other around the beam collision point at the centre. Two smaller detectors, ALICE and LHC-B, will also be built to concentrate on specific areas of physics. Each module of the LHC's detectors, packed with state-of-the-art technology, is custom-built to do a special observation job before the particles fly outwards to the next layer. The interesting reactions when the hard quark grains in LHC's colliding protons clash head-on are extremely rare. Most of the time they graze past each other with little disturbance, providing less interesting physics.

To see enough interesting hard quark collisions, the physicists have to push for very high proton-proton collision rates. Collision rates are measured by what is called luminosity - the luminosity of a two-beam collider is the number of particles per second in one beam multiplied by the number of collisions per unit area in the other beam at the crossing point. LHC aims to reach luminosities a hundred times higher than achieved in any existing experiment. To accomplish this, LHC's proton bunches, strung like beads on a chain 25 nanoseconds - 25 thousand millionths of a second - apart, will sweep through each other some 40 million times per second, each time producing about 20 interactions of one kind or another. Only one in a billion of these will be a hard quark collision, and the detector's data capture system has to select and filter out this event and get to work on it rapidly, so as not to miss the next one. Searching for a needle in a haystack seems easy in comparison.

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work, several promising new technologies have been refined to a stage where they are now being incorporated in to LHC detector components.

The technological challenges of the LHC demand breaking new ground in superconductivity, high-speed electronics, cryogenics, super-computing, vacuum technology, material science and many other disciplines. The new technologies developed for LHC will become the fertile ground in which seeds for new hi-tech industries can flourish.

The Physics

Over the last two decades, physicists have painstakingly pieced together a consistent picture of the subnuclear world known as the 'Standard Model'. All experimental results have so far confirmed this picture. However, the 'Standard Model' has too many unknown quantities to be the ultimate theory. The LHC has enormous discovery potential, as it will be penetrating a totally unexplored energy region where physicists are convinced that evidence for physics beyond the Standard Model should appear.

The most important enigma facing particle physicists today concerns mass. While the concept of mass may well appear so fundamental that it should be beyond question, particle physics has thrown up many puzzling questions about the nature of mass, questions which are not answered by the Standard Model. For instance, unlike the chemical elements, the fundamental particles in physics show no regularity in their masses. The tau lepton is some 17 times heavier than the muon, and 3491 times heavier than the electron. Other, similarly mysterious ratios are found among quarks, while neutrinos may even be massless. The Standard Model is unable to explain these masses, and a major task for particle physicists is to uncover the origin of mass. Is there some underlying reason why quarks and leptons have their particular masses? Why do these masses vary so much, and why do some particles have mass while others are massless?

Answers to such questions may be provided by the subtle 'Higgs' mechanism which suggests that particles acquire mass by interacting with a force field, the Higgs field, which is everywhere present. The discovery of an associated particle or particles, the Higgs boson(s), would be evidence for this field. No sign of Higgs particles has yet been seen, but calculations based on the Standard Model suggest something has to show up when quark energies reach the TeV scale. This is exactly the energy range which the LHC has been designed to explore and whatever the Higgs mechanism is, the LHC will surely reveal it, opening up an entirely new era in our understanding of Nature.

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planets and all of the stars only add up to about one tenth of existing matter. The other nine-tenths we call 'Dark Matter'. One explanation for Dark Matter envisages the existence of stable, as yet undiscovered, particles and the most recent results from LEP suggest that a new family of particles may exist at precisely the energy which the LHC will explore. The discovery of these new, 'supersymmetric' particles could explain what makes up the vast majority of our Universe.

Another fundamental question posed by cosmologists is "Why does the matter in the Universe exist?" At the time of the Big Bang, matter and antimatter should have been produced in identical amounts. The Universe should then have had a very short life, because these two different sorts of particles annihilate each other. Nonetheless, the Universe has survived as predominantly matter. In the 1960s, Soviet theorist Andrei Sakharov formulated an explanation for the dominance of matter over antimatter, based on a small asymmetry in the behaviour of matter and anti-matter particles. In 1973, Japanese theoreticians showed that a Universe made up of three families of quarks and leptons could satisfy Sakharov's requirements. The subsequent confirmation at CERN of the existence of exactly three matter particle families suggests that this theory may be the right approach to explaining the present state of the Universe. There is still an enormous amount of work to be done on this subject and the LHC will be the perfect tool to allow physicists to examine this asymmetry of matter and antimatter by detailed studies of the behaviour of the quark known as the beauty quark. This is the question which will be addressed by the LHC-B detector.

The LHC is the Swiss Army Knife of particle accelerators. Its versatility allows it to be turned to several different tasks, primarily because it occupies the same site as other CERN colliders and particle sources. Accelerated heavy ions such as lead nuclei may be produced in CERN's accelerator complex and injected into the LHC. Collisions between these chunks of matter produce very large concentrations of energy, allowing studies of the "quark-gluon plasma", a state of matter which may have existed shortly after the Big Bang, and might still be around today in the cores of collapsed stars. The ALICE detector is designed specifically with this study in mind.

A Laboratory for the World

Since the mid-1980s the number of scientists from all over the world using CERNs facilities has increased enormously. Currently more than 6500 users, over half of the planet's experimental high-energy physicists, carry out fundamental research at CERN. This user community, coming from all parts of the world, is living proof that CERN welcomes inter-regional collaboration which benefits all and boosts the progress of science. The LHC, the only machine capable of addressing problems way beyond today's frontiers of high energy

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The foundation of CERN in the post-war years set a precedent in uniting the nations of Europe to carry out high quality research. The LHC now offers the exciting opportunity of establishing a model for future world-wide collaboration in 'Big Science'.

1. CERN, the European Laboratory for Particle Physics, has its headquarters in Geneva. At present, its Member States are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom. Israel, Japan, the Russian Federation, Turkey, the European Commission and Unesco have observer status.

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