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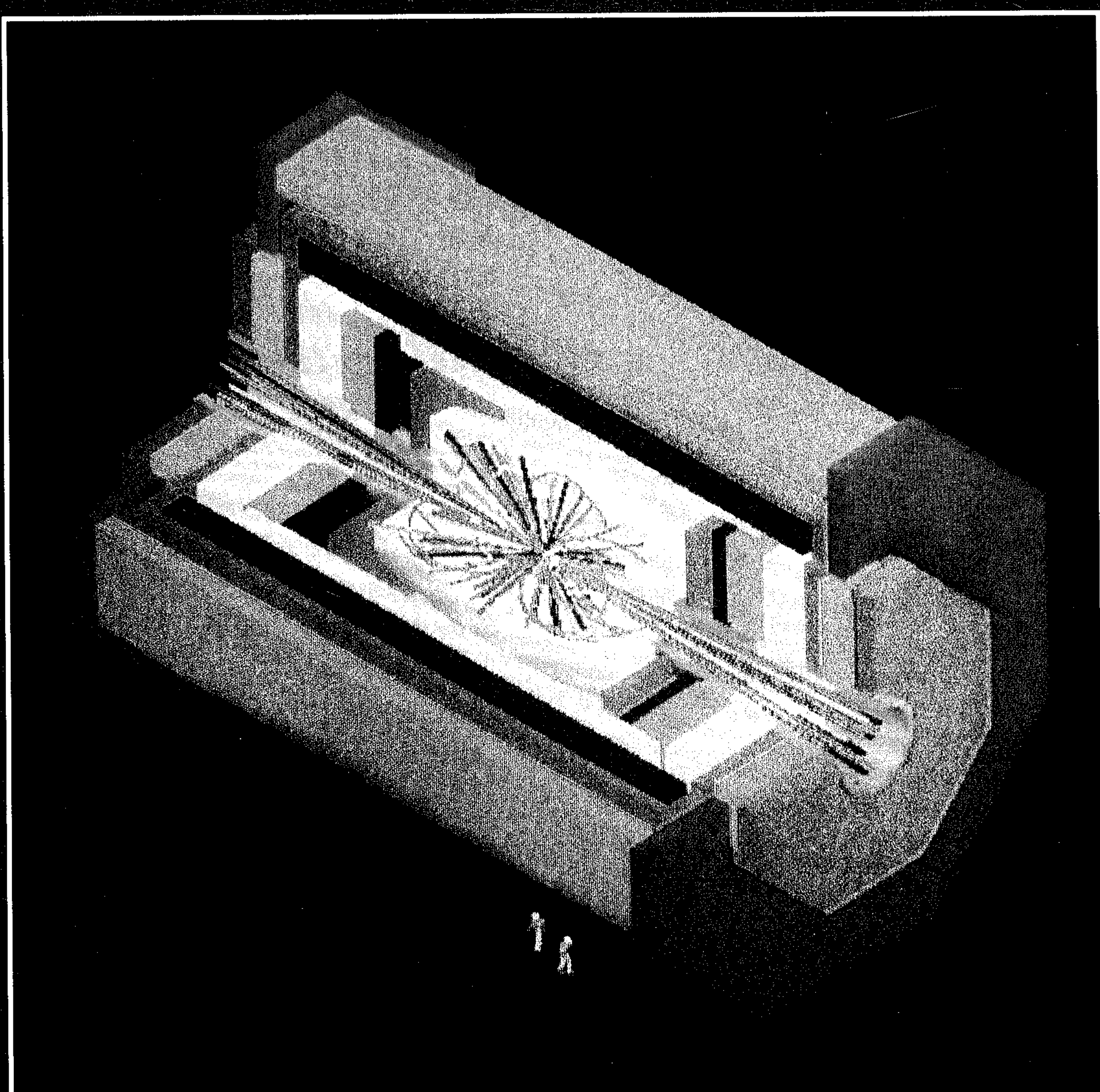

Beam Line

A PERIODICAL OF PARTICLE PHYSICS

SUMMER 1991 VOL. 21, NUMBER 2

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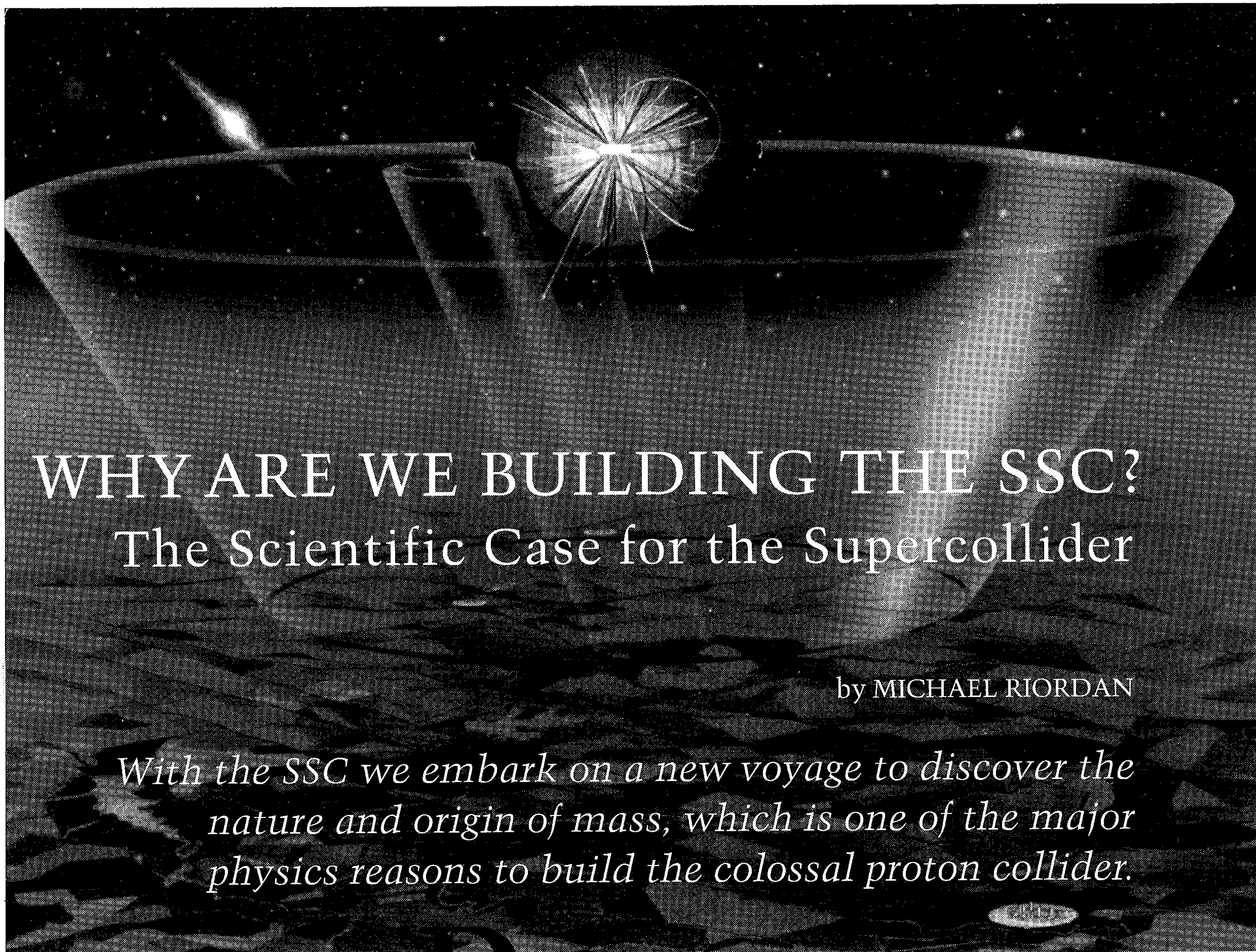
Cover: Computer-generated model of the detector being designed by the Solenoidal Detector Collaboration for the SSC. This image was produced by the new Intergraph CAD system using I/EMS software at the SSC Laboratory, which merged an image of the detector with another of a proton-proton collision. Responsible for this effort are SSCL Physics Research Division colleagues Jon Piles, Kurt Pennington, Lori Okay, and Chris Johnson.

CONTENTS

FEATURES

DEPARTMENTS



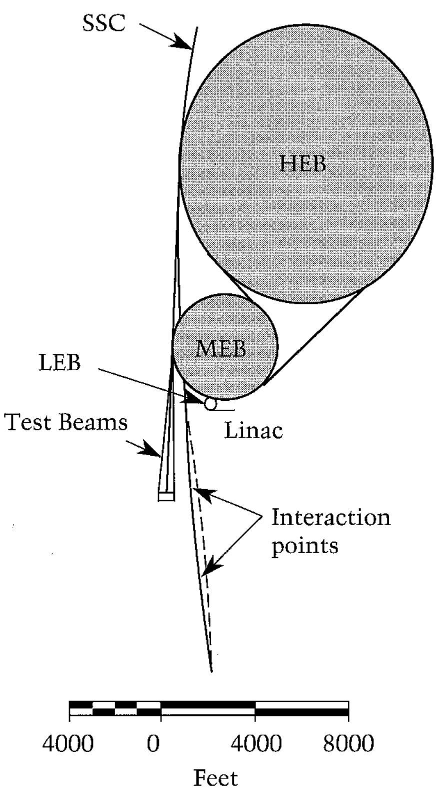
WHY ARE WE BUILDING THE SSC?

The Scientific Case for the Supercollider

by MICHAEL RIORDAN

With the SSC we embark on a new voyage to discover the nature and origin of mass, which is one of the major physics reasons to build the colossal proton collider.

DURING THE REMAINDER OF THIS DECADE the United States and its partners will be building the Superconducting Super Collider in Texas at a cost of more than 8 billion dollars. When completed, it will be the largest and most expensive scientific instrument ever built, with a vast "discovery reach" far exceeding that of any existing machine. But policymakers and the general public—and even physicists in other fields—have only a vague idea of the scientific purposes for which this collider is being built. One common notion is that the SSC is intended solely to hunt for the hypothetical Higgs particle. Although this search is indeed a major goal and an important design criterion, the SSC has enormous potential to do important research and make other exciting discoveries.



Schematic layout of the SSC injector complex, a portion of the collider ring, and the test beam area. The dashed line indicates a future beam bypass.

In recent years physicists have made tremendous advances in understanding the fundamental building blocks of Nature and the forces acting between them. All matter is now known to be composed of elementary particles called "leptons" and "quarks." Like quarks, of which all atomic nuclei are composed, leptons are incredibly tiny—less than 10^{-18} meter across, or more than ten thousand times smaller than the familiar proton and neutron. For all we know today, they may have absolutely no size at all. Leptons and quarks interact with one another by swapping a third category of elementary particles called "gauge bosons." During the past two decades, particle physicists have established that two other forces in Nature—the strong force that binds quarks together and the weak force responsible for radioactive decay—are also carried by gauge bosons.

This concept of matter, as built up from quarks and leptons interacting through the agency of gauge bosons, has come to be known as the Standard Model of particle physics. It has emerged from extensive theoretical and experimental research conducted during the last 30 years by physicists throughout the world. One of its key tenets is that leptons and quarks occur in families containing two leptons and two quarks apiece. There are strong indications that only three such quark-lepton families exist.

Another important feature of the Standard Model is the fact that the weak and electromagnetic forces, previously thought to be completely distinct, are actually just two different aspects of a single fundamental force, known as the "electroweak" force. At low energies characteristic of everyday life, they appear quite different, but at the very high energies that occurred during the Big Bang origin of the Universe (and can be replicated using the SSC), the weak and electromagnetic forces become quite similar. We say they are "unified" into the electroweak force. Such an elegant unification of two forces into one occurred previously in the nineteenth century, when the electric and magnetic forces were shown to be two separate aspects of the electromagnetic force.

Using the Standard Model, physicists have been able to explain most experimental phenomena about the elementary particles. But there are many puzzling features of the subatomic world that it cannot explain. Why are there three and only three families of quarks and leptons? Are they truly elementary particles, or do they themselves possess size and structure? Can the strong and electroweak forces be unified still further into a single, all-encompassing Force? Why do quarks, leptons, and gauge bosons possess the masses they do? And what, in fact, is this mysterious property of matter called mass?

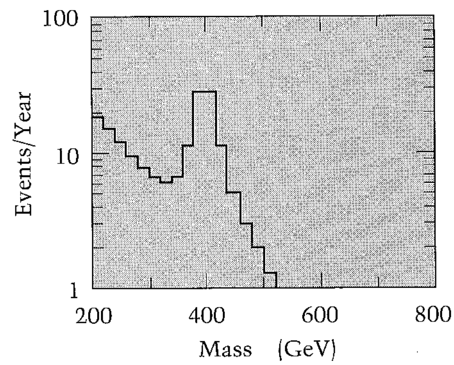
AMONG THE MOST interesting of the unsolved mysteries are the last two questions, which the SSC is explicitly designed to answer. During the 1960s, theoretical physicists were able to unify the electromagnetic and weak forces by adapting an idea from solid state physics to explain the origin of mass. According to this idea, dubbed the "Higgs mechanism" after one of its authors, Edinburgh theorist Peter Higgs, empty space is not really empty at all but contains an all-pervasive field known as the Higgs field. Like fish in water, we act within the context of this ubiquitous field, taking its effects for granted, but we are oblivious of its existence.

Different kinds of elementary particles are supposedly coupled to the Higgs field with different strengths; the self-energy each particle obtains due to this attachment is reflected in what we recognize as its mass. The ponderous *W* and *Z* bosons, the carriers of the weak force, are tightly coupled to this field, which is why they are the heaviest known elementary particles. By contrast, the photon is not coupled to the Higgs field at all and therefore has no perceptible mass. Because of this great disparity in the masses of their force-carrying particles, the weak and electromagnetic forces appear so unlike each other when they are actually just two different aspects of one and the same fundamental force.

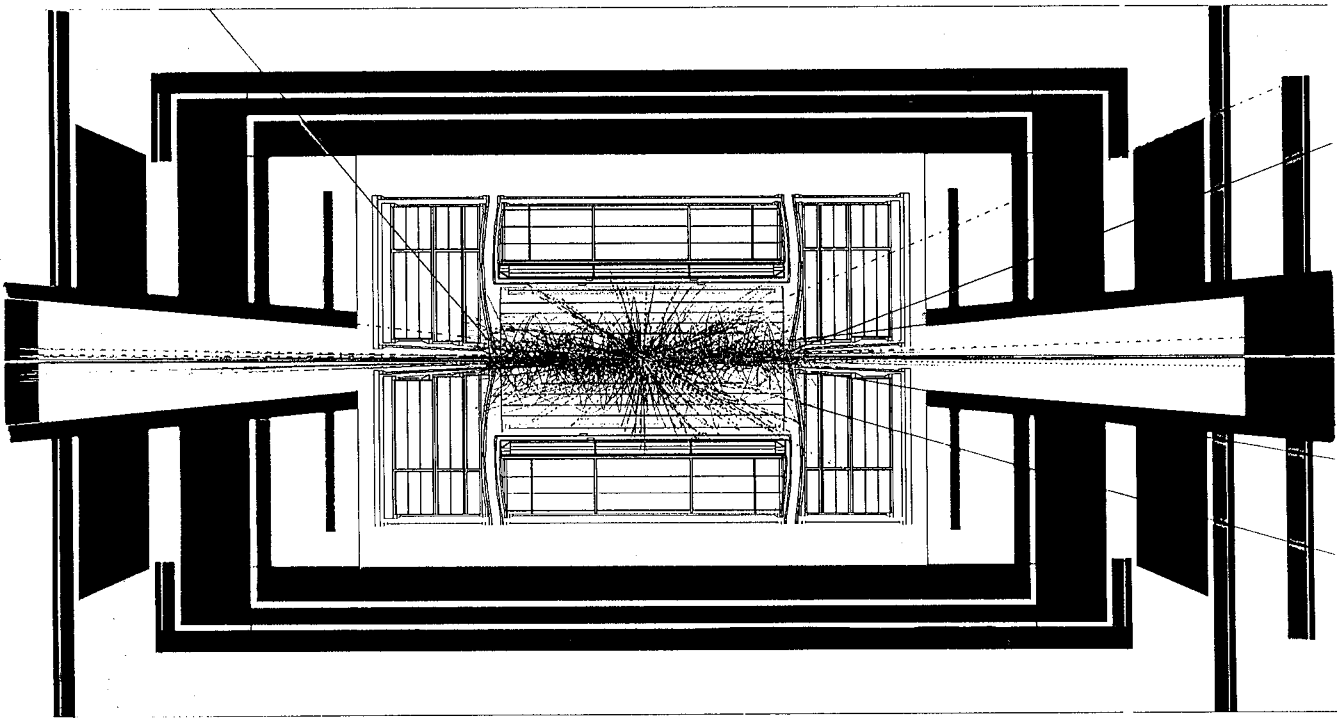
The Higgs mechanism (or something like it) is a crucial element of the Standard Model. Without knowing very much about its specific details, theoretical physicists used it to help unify the weak and electromagnetic forces and to predict the existence of the *W* and *Z* bosons. For all we know from theory, the Higgs field may be one field or several fields. Given the great variety of elementary particle masses, which range over at least ten orders of magnitude, it could well be that more than a single field is involved. Even if it were one and only one field, we would still have to confront the mystery of why the various particles couple to this field so differently. In response to such questions, theoretical physicists can offer a wide variety of intriguing speculations but no conclusive answers. To understand the origin of mass, we need to *probe* the Higgs field, and for that purpose we need to build the SSC.

Physicists often talk about searching for the Higgs *particle,* or Higgs boson, not the Higgs field. What's the connection? This manner of speaking arises from the wave particle duality that is essential to quantum mechanics, which governs behavior in the subatomic world: all objects have both a wave nature and a particle nature, but one or the other may become more apparent in any given situation. Consider electromagnetic radiation, for example. We can think of it macroscopically as a classical wave or ripple coursing through the electromagnetic field. By shaking electrons up and down in a radio transmitter, we send electromagnetic ripples known as radio waves emanating out in all directions. At higher energies and frequencies (faster shaking), it is more convenient to think microscopically, in terms of a particle called the photon, which is the quantum of the electromagnetic field. X rays and gamma rays are high-energy photons—particles of light.

The Higgs boson, then, is the quantum or particle that corresponds to ripples in the Higgs field. How do we make a Higgs boson? By "shaking" other particles (preferably very massive ones) hard enough to induce these ripples—just as we shake charged particles like the electron to make ripples in the electromagnetic field. One good way to attempt to



The mass distribution of Z-boson pairs that would be observed if there is a Higgs boson with a mass of 400 GeV. The distribution also includes events from background surces other than the Higgs boson decay.



How a Higgs boson might appear in one of the SSC detectors. In this simulation, a Higgs boson decays into a pair of Z bosons, each of which decays into a pair of quarks, leading to four jets of hadrons hitting the detector elements.

make a Higgs boson is by producing the heaviest known elementary particles, which should be much more strongly coupled to the Higgs field than the other, lighter particles. Indeed, searches for light Higgs bosons (those with masses less than that of the *Z*) in the decay products of the *Z* have already occurred at the CERN electron-positron collider LEP. Based on the absence of any evidence for them in these experiments, we can already say that the simplest possible versions of the Higgs boson must be heavier than 45 GeV. Eventually these kinds of searches should find any Higgs bosons that happen to come in lighter than the *Z*, which has a mass of 91 GeV.

Even if such a light Higgs boson were discovered, however, the search would not be over. Not by any means. Such a discovery, in fact, could well be an indication that there are several Higgs bosons, with more to be discovered at masses *above* that of the *Z*. Here is where the SSC comes in. To produce such ponderous Higgs bosons we must concentrate tremendous amounts of energy in a very small volume—far smaller, say, than that of a proton. We have to "shake" the Higgs field very hard, that is, in order to generate observable disturbances in it. The SSC is designed to concentrate sufficient energy in a small enough volume to create Higgs bosons that are heavier than the *Z*.

The SSC is the only collider either under construction or on the drawing boards that can cover the full range of masses from that of the *Z* to about 2 TeV (two trillion electron volts). Somewhere in this mass range, we must either find a Higgs boson (or bosons) or discover entirely new and unusual phenomena (see next page). Otherwise the Standard Model, which can account so well for how particles behave at the collision energies attainable today, would become inconsistent. Something must give by the time we reach the 2 TeV level. So the SSC is essentially guaranteed to encounter important new physics—either a Higgs boson or something else even more interesting—in its accessible energy range.

In a larger sense, however, the SSC will allow us to examine the very mechanism by which particles came to have masses in the first place. Such a mechanism must have come into play at about a trillionth of a second into the Big Bang, when conditions were so hot and so dense that particle collisions occurred at enormous energies that only the SSC will be able to replicate. Before that moment the weak and electromagnetic forces were essentially the same; physicists say there was a symmetry between the two. After that moment, as the Universe cooled and collision energies fell, this symmetry became broken; the *W* and *Z* boson acquired large masses, and the weak force became different from electromagnetism. By recreating the conditions that existed at this key turning point in the evolution of the Universe, the SSC will allow physicists to study this process of symmetry breaking in great detail and to discover the origin of mass itself. It should answer one of the key scientific question of today.

SO FAR WE HAVE been considering the Higgs boson (or bosons) as if it were an elementary particle, but there is another possibility. Especially if it proves to be very massive, on the order of 600 GeV or more, the Higgs boson could be *composite;* like protons and pions, it could be made of elementary constituents such as quarks or other, analogous particles. For this to occur, however, there would have to be some kind of new and extremely strong force capable of binding these constituents very tightly together into a compact object smaller than 10^{-18} meter across. Such a new force, which would generate a rich spectrum of composite particles with masses around 1 TeV, would be an extremely exciting and very important discovery—probably much more important than the discovery of a Higgs boson itself.

As the experimental lower limit on the mass of the heaviest quark—the top quark—climbs toward 100 GeV, there has been growing speculation that a Higgs boson might be a marriage of a top quark bound up tightly with its antiquark. Because the top quark is far more massive than the other quarks (the next heaviest, the bottom quark, weighs in at about 5 GeV), it may have a special role to play in whatever mechanism is responsible for generating mass, according to this line of reasoning. Another possibility is for Higgs bosons to be made up of a pair of particles known as "techniquarks" held together by "technigluons"—in a manner analogous to how a quark and an antiquark are bound together by gluons to make a pion or a kaon. The force carried by the technigluons would have to be at least a thousand times more powerful than the strong force carried by gluons between quarks.

In the same vein, quarks and leptons might themselves be composite particles whose internal structure is simply not apparent at the energies that can be produced at existing colliders. Some physicists have speculated that quarks and leptons are just too numerous to be the ultimate elementary particles and therefore must be made of still tinier entities. By smashing quarks together at energies well in excess of 1 TeV, which can be accomplished at the SSC, we might be able to excite this internal structure (if it exists), and learn something about it. With this new collider we should be able to search for structural features as tiny as 10^{-20} meter across, which is about a factor of 20 smaller than it is possible to examine today.

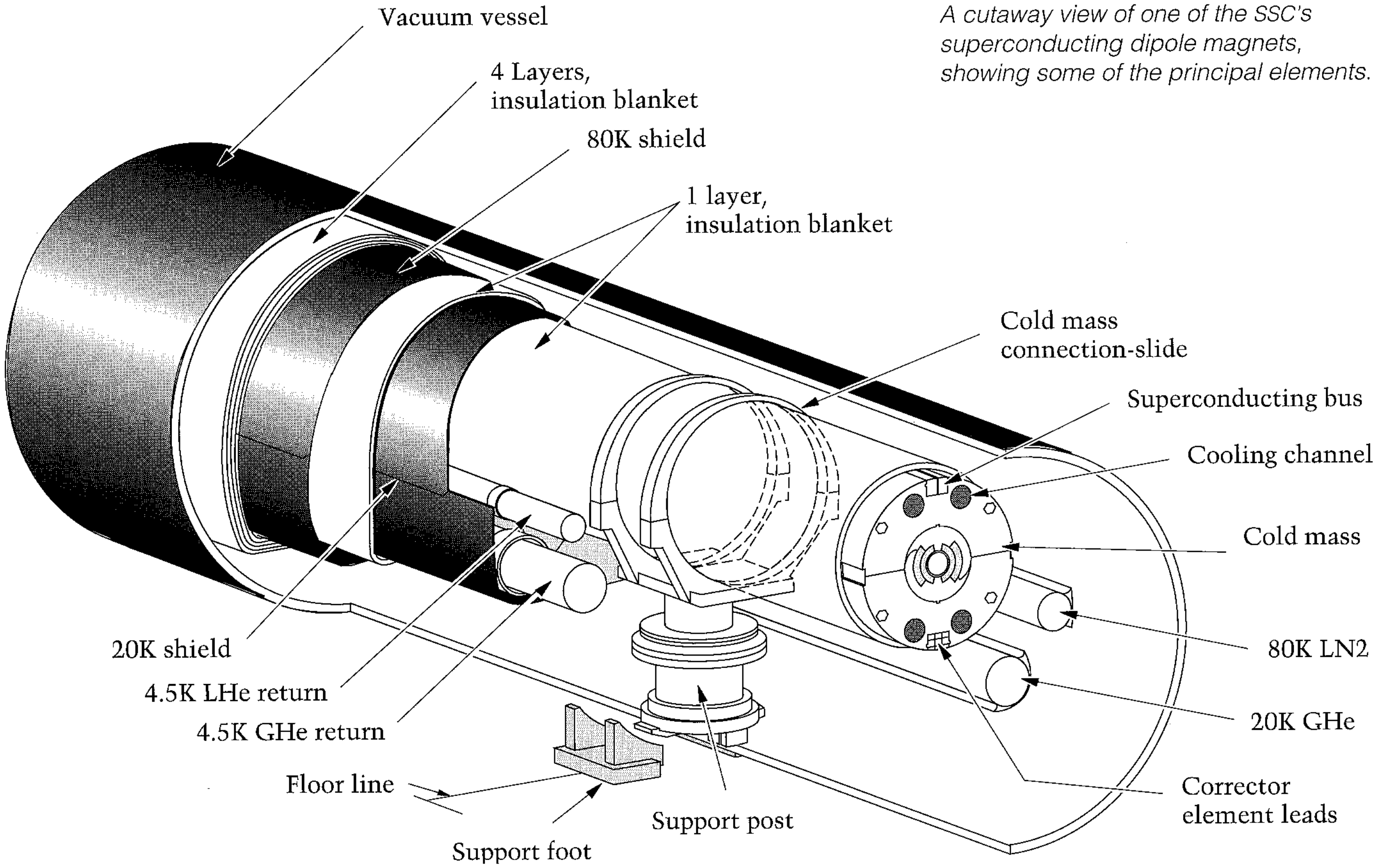
In all of these compositeness scenarios, there is a new element required—the existence of an extremely powerful new "fifth force" to bind these objects tightly together. If the Higgs boson, the quarks or the leptons proved not to be elementary particles after all, then some such force would simply have to exist. Its discovery and the determination of its properties would be as exciting as the discovery of a Higgs boson, if not more so.

COLLISIONS BETWEEN protons at the SSC will create many billions of bottom quarks and about a hundred million top quarks per year, allowing physicists to make detailed experimental studies of these heaviest of all known quarks. Our understanding of their properties and behavior has been limited so far by the quantities of them that have been produced and detected at existing accelerators or colliders. (The top quark, in fact, has not even been officially discovered yet!) This situation will change dramatically at the SSC, which will create a veritable flood of these heavy quarks.

There is enormous interest today in learning how the bottom quark disintegrates into lighter objects. Particle physicists believe that such disintegrations may exhibit a small difference, or asymmetry, between the behavior of matter and that of antimatter. Such an asymmetry, which has been observed so far only in the decays of neutral kaons, may be the reason there is far more matter than antimatter in the Universe. Obtaining more information about this asymmetry could help physicists answer the fascinating question, "Why are we here?"

To measure such an asymmetry, physicists will have to produce and detect almost a billion bottom quarks. Several groups are currently designing new electron-positron colliders (where detection of the bottom quarks is relatively straightforward) to do just that. Production will be no problem at the SSC, although detection may prove difficult. If detectors can be built to identify even a small fraction of the bottom quarks produced by the SSC, then a detailed search for this asymmetry will be possible there.

If the top quark falls in the mass range consistent with predictions of the Standard Model it should be discovered during the 1990s using the Tevatron Collider at Fermilab. Detailed studies of its properties and



A cutaway view of one of the SSC's superconducting dipole magnets, showing some of the principal elements.

behavior will then be done at the SSC, which will produce far greater quantities. Because it is so massive (at least 89 GeV according to current results and probably even more massive than the *Z* particle), the top quark is an extremely interesting object that may be closely linked to whatever mechanism causes mass. Studies of its behavior are therefore high on the list of objectives for particle physicists.

BECAUSE THE SSC provides a huge, twenty-fold jump in collision energy over what is currently available at present-day colliders, it will offer a tremendous potential for the discovery of new particles or phenomena. Such discoveries can completely revamp our understanding of subatomic physics (as happened during the mid-1970s with the surprise discovery of the *J*, psi and tau particles at Brookhaven and SLAC). To produce a given particle it is necessary to concentrate sufficient energy to contribute at least its mass. Higher energy colliders have a big advantage here over low-energy machines because collisions with the necessary total energy occur much more frequently. The SSC should be able to produce new particles (should they exist) with masses ranging from a few hundred GeV all the way up to several TeV—a range where no other collider in existence today can even begin to compete.

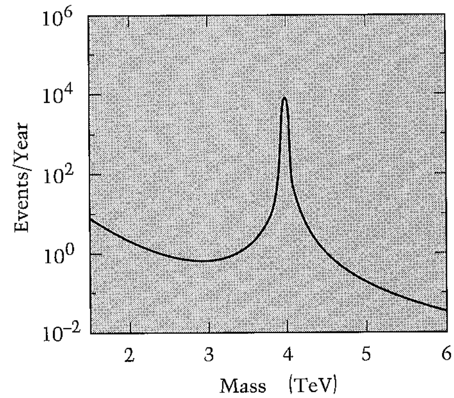
As usual, theoretical physicists have already predicted a number of hypothetical particles that might exist in the energy range accessible at the SSC. Some of these new particles would be extremely interesting because their existence would help to resolve bothersome anomalies, quandaries and problems that have turned up in the Standard Model and its various possible extensions. Besides the techniquarks and technigluons mentioned above, these hypothetical particles include extra gauge bosons similar to the *W* and *Z*, and the so-called "supersymmetry" particles.

Many theories predict the existence of extra gauge bosons, known as W' and Z', that may act as carriers of additional weak forces, which are not apparent at present-day energies. Such forces have not yet been observed, according to these ideas, because any W' and Z' bosons that exist must be substantially more massive than the *W* and *Z*—and therefore act over much smaller distances. If they had masses between about 500 GeV and 8 TeV, extra gauge bosons could be discovered at the SSC (in a manner similar to the way the *W* and *Z* bosons were found in 1983 at CERN's proton-antiproton collider). Such a discovery would be an extremely important step in extending our understanding of the weak force.

Another area of intense theoretical interest goes under the general rubric of supersymmetry, or "SUSY" for short. This is a large class of theories that can provide a stronger foundation for the Standard Model; they essentially double the number of elementary particles by positing the existence of a SUSY partner for each of the known particles—"squarks" for quarks, "sleptons" for leptons, "photinos" for photons, "gluinos" for gluons, etc. At the cost of this apparent complexity in the fundamental particle table, such SUSY theories can resolve troubling mathematical inconsistencies that arise in the Standard Model (with only the minimal Higgs mechanism to explain the origin of mass). All SUSY theories require the existence of multiple Higgs bosons, one of which could be lighter than the Z particle. If a light Higgs boson turned up at LEP, it could be an indication that more Higgs bosons (and SUSY particles) were waiting to be found in the SSC energy range.

Although there has been strong theoretical interest in the possible existence of SUSY particles (and even some "discoveries" that were later shown to be spurious), none have yet been found. Sensitivities of existing colliders extend only up to about 100 GeV for some of these particles and to substantially less than that for the rest. So it is entirely possible that SUSY particles exist but have higher masses than currently accessible and therefore have escaped detection. If they are to solve the mathematical problems of the Standard Model, however, SUSY particles should have masses of 1 TeV or less, which would fall well within the range detectable at the SSC. Indeed, recent measurements at LEP suggest that SUSY particles with masses on the order of 1 TeV may be needed to unify the strong, weak and electromagnetic forces. SUSY particles will be a prime target for physicists working at the SSC.

If any of these anticipated new particles turn up at the SSC, it would likely be a discovery more important than finding a Higgs boson, which would only *confirm* existing ideas about the Standard Model, not extend them. And the above ideas by no means exhaust the possibilities for particle discoveries there. Theory is an imperfect crystal ball that has often proved cloudy in the past. The most important discovery to occur at the SSC may well be some particle or phenomenon that has not even been anticipated yet. Such was the case at each of the three previous national laboratories for particle physics built in the United States: Brookhaven, SLAC and Fermilab. The famous quark theory, for example, had not even been formulated when construction of SLAC began in 1961. So it is crucial to keep an open mind when asking what kinds of weird new things might turn up at the SSC. We may not, and probably do not, have the full answer yet. The key point to remember is that the SSC has truly *enormous* discovery potential because of its huge leap in available collision energy.



The mass distribution of electron-positron and muon pairs that would result from the decays of a new Z' gauge boson with a mass of 4 TeV.

DURING THE PAST DECADE, cosmology and elementary particle physics have become increasingly intimate partners. Studies of the macrocosm and microcosm overlap more and more every year. To understand what happened at the high temperatures and great densities of the Big Bang, we must know how particles behave at the energies that were characteristic of these early moments. At about a microsecond (10^{-6} second) into the Big Bang, for example, collisions were occurring between quarks and leptons with typical energies of 1 GeV or so. Because we can easily generate such energies in colliders today, we understand the corresponding particle interactions and can reach solid conclusions about conditions in the Universe at that time.

The SSC will operate at energies far higher than available at present-day colliders, giving us an important new window on physical processes that occurred in the Big Bang. It should be able to simulate conditions prevailing at about a picosecond (10^{-12} second) after the primordial explosion that gave birth to the Universe, when the temperature was about 10^{16} degrees—or about a *billion* times hotter than the core of the Sun. In effect, we will be able to examine the mechanism of symmetry-breaking by which the entire Universe passed from a condition wherein the electromagnetic and weak forces were similar to one where they are now very different. Cosmologists liken this process to a phase-transition, such as the freezing of water to make ice.

Two key questions for cosmology are the nature of "dark matter"—the invisible matter thought to contribute more than 90 percent (and perhaps as much as 99 percent) of the mass of the Universe—and the origin of the enormous structures that have been recently observed in the heavens, with sizes measured in the hundreds of millions of light-years. Answers to these questions are increasingly thought to lie in that very first picosecond of existence, whose particle interactions only the SSC will be able to examine.

> *With the SSC we embark on a new voyage to discover the nature and origin of mass.*

One of the leading candidates for the mysterious dark matter, for example, comes from among the roster of SUSY particles. The lightest of the bunch—a neutral particle generically referred to as the "neutralino"—should be absolutely stable. If they were produced in sufficient quantity during that first picosecond, neutralinos could easily make up the great majority of the Universe. Thus the discovery of a SUSY particle would have monumental implications for our understanding of cosmology. The SSC will be the only collider able to cover the full range of masses thought to be possible for these particles.

Another important way the SSC can contribute to cosmology is by a detailed study of the symmetry-breaking mechanism itself. The smoothness of the Universe at the very largest distances—and perhaps even the large-scale structures just mentioned above— are now thought to have arisen during a similar symmetry-breaking phase transition that occurred at about 10^{-35} second, when typical energies were 10^{14} GeV or more. Ripples or topological defects in the very fabric of space-time that would have originated at this moment might well have become the "seeds" to which matter was drawn by the force of gravity, eventually forming the enormous structures that astronomers have recently discovered stretching hundreds of millions of light-years across the heavens. The energies at which this earlier phase transition occurred are far too high to duplicate in any collider scientists can build today. But by studying an analogous process at the much "lower" energies of the SSC, we may well gain valuable insights into it.

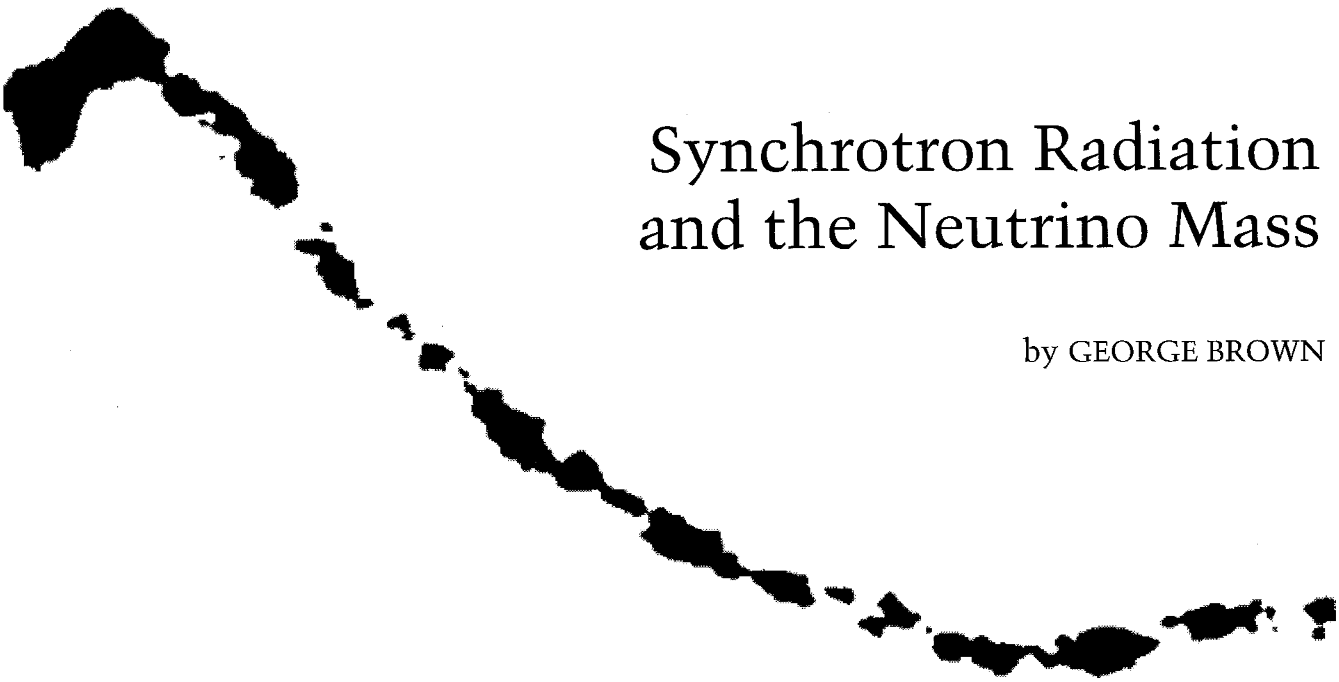
These are just a few of the important cosmological questions the SSC can address. No doubt others will arise before it begins operating at the end of this decade. The SSC will become the primary tool by which scientists can simulate—and thereby study—the extreme conditions that occurred at a pivotal moment in the evolution of the Universe.

ALTHOUGH THE SSC has been designed to resolve the mystery of why things have mass, there is obviously a wide variety of other important issues in particle physics and cosmology that it can address. If history is any guide, we probably do not even know how to ask some of the crucial questions it can help answer. The SSC will have a guaranteed payoff of supreme importance to our understanding of matter, and because of the huge leap it makes in collision energy, it will also permit scientists to take a giant step into much more speculative regions of the unknown.

It is similarly difficult to assess the likely impact on technology and society of the discoveries that will emerge from the SSC, except to say they will probably be vast. We live in a century whose technologies are heavily dependent on our detailed understanding of the behavior of electric charge, a crucial property of matter, and its associated field—the electromagnetic field. Nobody could have anticipated such an outcome when most of the research upon which this understanding is based was being done in the nineteenth century. With the SSC we embark on a new voyage to discover the nature and origin of mass, another key property of matter, and to understand its associated field. Who can pretend to anticipate today what will emerge during the twenty-first century from the knowledge this epochal voyage will provide? ○

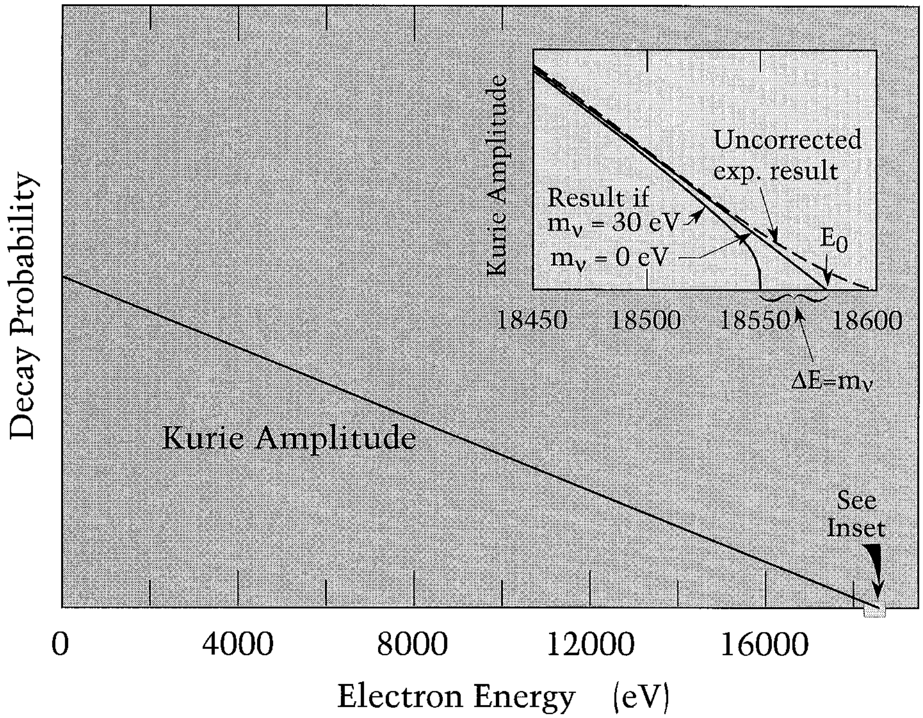
Synchrotron Radiation and the Neutrino Mass

by GEORGE BROWN



Synchrotron radiation is used to calibrate a Los Alamos tritium-decay experiment.

MOST PHYSICISTS recognize synchrotron radiation as a "spinoff" technology derived from high-energy physics. Ultraviolet and x radiation emitted by energetic, circulating electrons has proved extremely useful in a wide variety of basic and applied research in such areas as physics, chemistry, biology, materials science, and medicine. Few of us realize that particle physics itself has been the beneficiary of its own progeny. But that is indeed the case. Measurements made recently by a group from Stanford Synchrotron Radiation Laboratory (SSRL) and the University of Oregon played an important role in attempts to establish the mass of the neutrino.



The curve marked "Kurie Amplitude" is effectively the probability of observing an escaping electron with a certain kinetic energy. If the accompanying neutrino (which is not observed) were absolutely massless, the curve would be a perfectly straight line throughout, and it would intercept the horizontal axis at an energy of 18,580 eV, as shown in the inset. If the neutrino carried a mass of, say, 30 eV, the line would curve toward the horizontal axis 30 eV earlier, at 18,550 eV. The curve is now known to follow the straight line so closely that a mass greater than 13 eV can be ruled out.

ONE OF THE MOST fundamental of the elementary particles, the neutrino, was first proposed informally over 60 years ago by Wolfgang Pauli, to account for the missing energy in radioactive decay. The hypothetical particle was soon named by Enrico Fermi (from the Italian for "little neutral one") in a bold publication that established the basic principles of the weak interaction. We now know that neutrinos are a class of objects that help shape both the world of elementary particles and the universe as well. In the Standard Model, there is a distinct neutrino paired with each of the three known leptons: electron, muon, and tau. These are known to be either massless or very nearly so. In fact, in the case of the electron neutrino, measurements up to 1981 indicated that it weighed less than about 28 electron-volts—or less than one ten-thousandth the mass of the electron.

Then, in 1981, a Russian group published a definitive mass of 35 electron volts! This startling result was quite unsettling to the elementary particle physics community for two reasons, one esthetic and one cosmological. At 35 eV, the electron-neutrino would be by far the lightest known elementary particle with mass. Why this odd mass? And this neutrino would now be a key player in determining the evolution of the universe! Cosmologists believe that they have a pretty good idea about how many electron neutrinos are whizzing about the universe as relics of the primordial explosion at the beginning of the universe, known as the "big bang." There are so many of them, about 400 in every cubic centimeter, that with a mass of 35 eV, these neutrinos would contribute enough mass, to "close" the universe and eventually reverse its expansion. Just as scientists were becoming comfortable with the idea of an infinitely large and infinitely long-lived universe, the *little neutral one* took center stage!

Needless to say, this result was sufficiently disquieting that several groups undertook to repeat and refine the Russian measurements. One group, composed of scientists from the Los Alamos National Laboratory chose to repeat an earlier measurement on the decay of tritium nuclei. As it happens, a tritium nucleus is unstable, decaying into a helium nucleus by ejecting an electron and its companion neutrino. For the experts, the reaction looks like $pnn \rightarrow ppn + e^- + \bar{\nu}_e$. Now the neutrino is so elusive that there is no chance of catching it in this experiment; the only hope is to observe the electron, measure its energy precisely, and determine how much is missing. The balance must have been carried off by the neutrino, because the helium nucleus is so massive that it cannot carry off any significant energy. By determining the end point of the energy spectrum, the Los Alamos scientists hoped to measure the mass of the neutrino.

But this group was disappointed to discover that their apparatus was not quite good enough to test the Russian result accurately. In order to understand the sensitivity of their equipment, they attempted to simulate tritium decay by studying a similar nuclear decay, that of radioactive krypton. An isotope of krypton (known as ^{83}Kr), emits an electron like tritium, except that no neutrino is involved. What really happens is that the nucleus emits an x ray, which often does not escape the atom; instead, it collides with an atomic electron in the K shell and ejects an electron of just 17,820 eV (this process is known as K conversion).

At the time most physicists thought that the electron emerging from the krypton atom had a very well defined energy, but no one had really proved this. The Los Alamos measurements suggested that the energy was really *not* so well defined, but they were worried that perhaps their spectrometer was at fault, calling the whole experiment into question.

Neutrinos, they are very small.
They have no charge and have
no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they
simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold shoulder steel and sounding
brass,
Insult the stallion in his stall,
And, scorning barriers of class,
Infiltrate you and me. Like tall
And painless guillotines, they fall
Down through our heads into
the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed—you call
It wonderful; I call it crass.

—John Updike

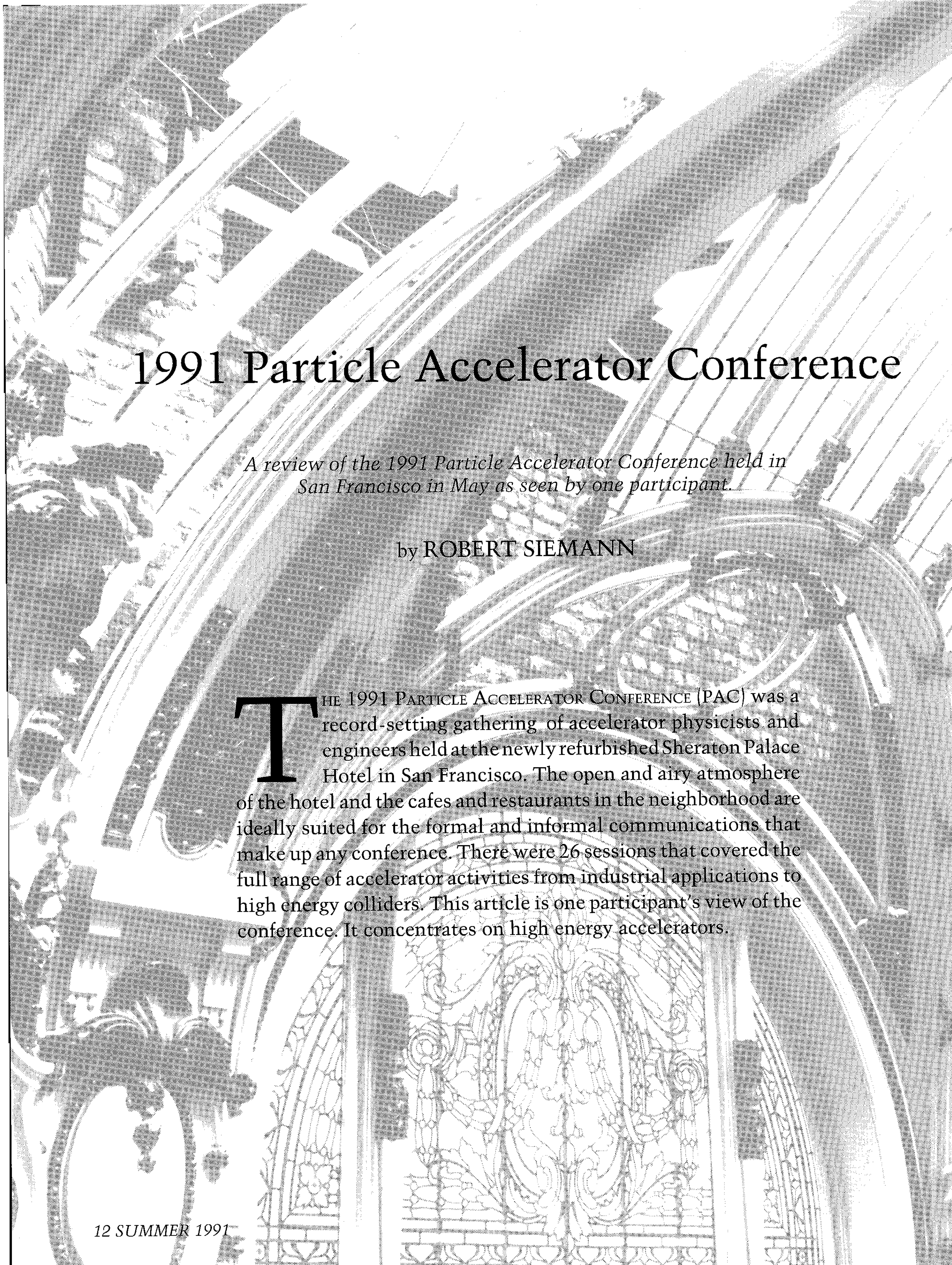
WHAT WAS NEEDED at this point was a way to understand how a krypton atom behaves when an x ray collides with it. In the case of radioactive krypton, the x ray comes from the nucleus. Why not instead bring in a photon from the outside world and study it that way?

The new SSRL beam lines on PEP provide exactly the kinds of x rays required, and it happens that an SSRL/University of Oregon group happened to have just the right experiment for the job. The experiment was carried out in December, 1988, on the region 5B undulator, parasitic to the TPC experiment in Interaction Region 2. A beam of x rays, with a precise energy of 15,225 eV selected by a silicon monochromator, bombarded a gas krypton target, and the emerging electrons, ejected by the x rays, were carefully measured. Since the K-shell electrons are bound to the nucleus with an energy of 14,325 eV, the team expected a sharp "line" at 15,225 eV – 14,325 eV = 900 eV.

Much to everyone's surprise, the electrons emerged with a much larger spread of energies than people had expected. The Los Alamos spectrometer was all right after all, and the original measurements on krypton and tritium could now be believed. In fact, the PEP results could be used to provide a sensitive compensation for the experimental uncertainties of the Los Alamos instrument. Atomic physicists also found the krypton results intriguing and have been working hard on mathematical models to explain the surprising results.

With this renewed confidence in their spectrometer, the Los Alamos scientists could now assert that the neutrino, if it had any mass at all, was certainly lighter than 13 eV. Thus, the *little neutral one* of Enrico Fermi is far too small to close the universe all by itself. Since the visible matter in the universe (stars and galaxies) are also too light to close the universe, it is either open with an infinite volume, or perhaps there are other invisible candidates. But that is another story!

[*Note added in proof:* The alert reader may have noticed recent reports of evidence of a neutrino with about 17,000 eV mass. These experiments show a very tiny bump at the beginning of the otherwise straight line shown in the graph on the preceding page. This has been interpreted as evidence for a very heavy neutrino, with a mass of 17,000 eV, emitted perhaps one percent of the time. The deails of the bump have not yet been convincingly confirmed, and the interpretation is subject to wide debate. If these experiments are confirmed, they would add a strange twist to the measurements described earlier. The very light (or massless) neutrino would be the favored decay particle of the nucleus, but a very heavy brother would occasionally be emitted instead.]



1991 Particle Accelerator Conference

A review of the 1991 Particle Accelerator Conference held in San Francisco in May as seen by one participant.

by ROBERT SIEMANN

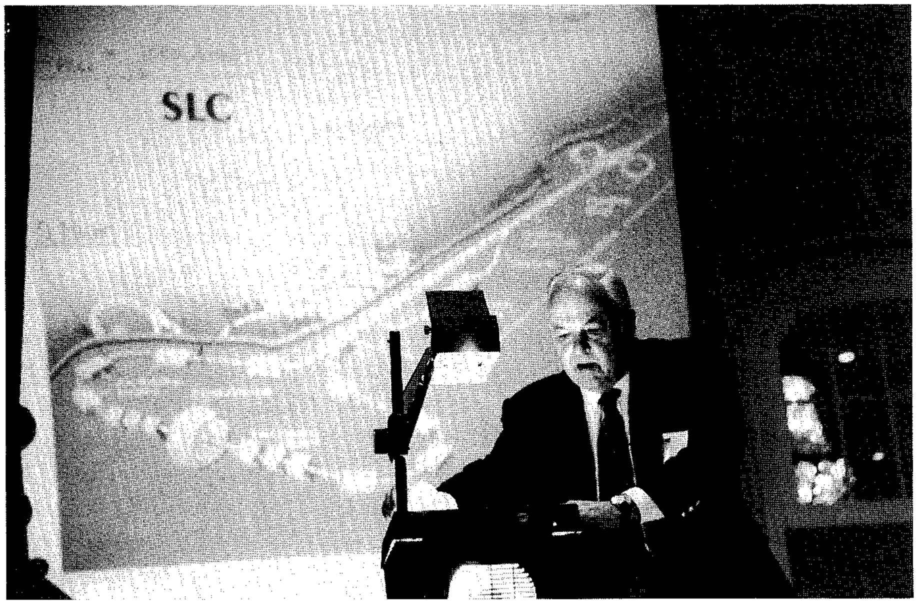
THE 1991 PARTICLE ACCELERATOR CONFERENCE (PAC) was a record-setting gathering of accelerator physicists and engineers held at the newly refurbished Sheraton Palace Hotel in San Francisco. The open and airy atmosphere of the hotel and the cafes and restaurants in the neighborhood are ideally suited for the formal and informal communications that make up any conference. There were 26 sessions that covered the full range of accelerator activities from industrial applications to high energy colliders. This article is one participant's view of the conference. It concentrates on high energy accelerators.

HADRON COLLIDERS were conspicuously absent from the opening plenary session on the physics and technology challenges of accelerators, but these challenges and the progress in meeting them was a major theme of this conference. The superconducting proton ring of HERA was completed in late 1990 and commissioned with beam in April, 1991, less than a month before the conference. This impressive success was covered in papers by Bjorn Wiik, Peter Schmüser, and Ferdie Willeke. The superconducting magnets, the heart of the accelerator, were purchased from industry, with several different firms supplying the materials and performing fabrication and assembly. The results were impressive: the minimum quench currents were more than 25% above that required for operation, and the field quality exceeded specifications. This first experience with large-scale procurement of superconducting accelerator magnets is a sound precedent for the SSC and LHC to build upon.

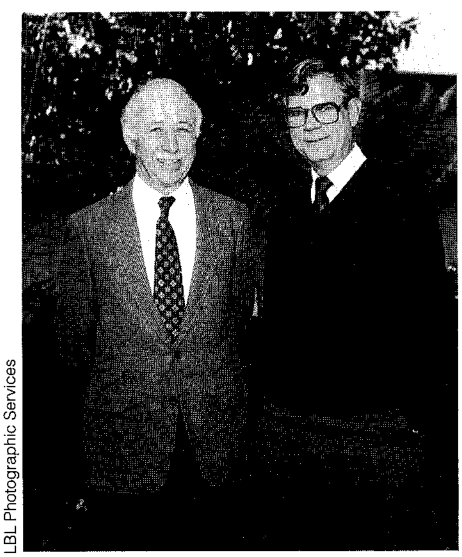
Recently, the European accelerator community established its own European Particle Accelerator Conference series, and, as a result, this year's PAC had a distinctly western hemisphere flavor. The SSC was represented strongly, while there were few technical papers about the LHC. The SSC magnet was described in an invited paper given by Robert Palmer and in numerous poster presentations. The dipole has been redesigned to increase the aperture to 5 cm and improve the operating margin. The results to date on short magnets are gratifying; these magnets exhibit little training, achieve the desired operating margin, and have good field quality. The emphasis of the SSC magnet program is now on long magnets and on laying the groundwork for industrial production.

In an impressive talk David Larbalestier summarized the progress in understanding and improving the limitations of NbTi conductor technology. The extrinsic effects introduced in material processing (e.g., the variation in the cross-sectional area of a filament) are better understood and have been brought under control. The immediate payoff was the improvement in critical current density and reduction in filament size for the SSC and LHC. Larbalestier's talk concentrated on another aspect of the reduction of extrinsic effects: the properties of NbTi conductor are now being determined by intrinsic properties such as the effective flux pinning force. His experiments now concentrate on these intrinsic properties. Heat treatment, Nb/Ti ratio and rolling are all found to affect the critical current density and high field performance. This work promises increases in critical current density by a factor of two or more (!) when the experiments are completed and the knowledge gained in the laboratory is translated into industrial practice.

Tevatron luminosity upgrades were summarized by Steve Holmes in an invited talk and described in detail in poster presentations. The technical aspects of operating the Tevatron with separated orbits, the linac energy upgrade, the anti-proton source improvements, and the Main

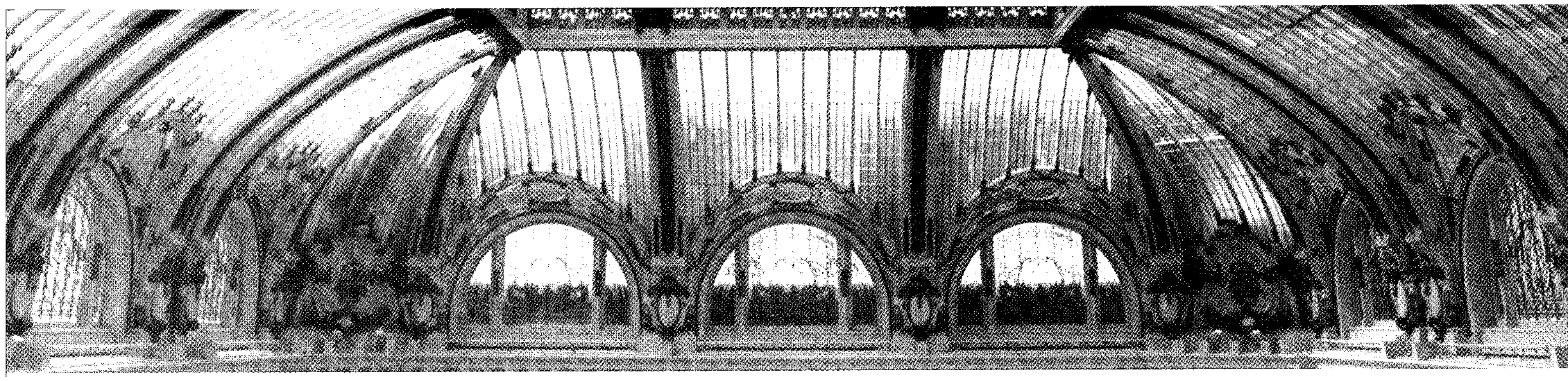


SLAC Director Burton Richter discusses details of the SLC in his opening talk at the recent Particle Accelerator Conference in San Francisco.



LBL Photographic Services

Conference Chairman, Matthew Allen (left), of SLAC and Program Chairman, Klaus Berkner, of Lawrence Berkeley Laboratory. These two institutions, with assistance from Los Alamos National Laboratory and under the auspices of IEEE., organized this year's PAC at the newly restored Sheraton Palace Hotel.



Injector are well in hand. The prospects are good for the Tevatron reaching its goal of $5\times10^{31}cm^{-2}s^{-1}$ by 1996 as planned, and with these upgrades the Tevatron will be one of the centerpieces of international high energy physics research through the end of this century and beyond.

BURT RICHTER GAVE the opening talk of the conference discussing linear colliders. The general parameters of the next linear collider come from high energy physics and are reasonably well agreed upon: E_{cm} = 0.5 to 1.0 TeV, L = 1 to 10×10^{33} $E^2_{cm}(TeV^2)$. The problems of designing such a collider are interconnected ones of cost, technical feasibility and beam dynamics. Four basic approaches were outlined by Richter, and most were expanded upon in other talks. The room-temperature, S-band approach makes use of the extensive knowledge and experience with S-band (~3 GHz) technology used throughout the world. The relatively low frequency simplifies some aspects of the beam dynamics by reducing wakefields, but a large number of bunches must be accelerated per rf pulse for reasonable efficiency. This would be a high-cost approach without improvement in modulators and other rf hardware. Its proponents at DESY and Dortmund are working hard on these improvements, but unfortunately their work was not presented at the conference.

Linear colliders based on superconducting rf were described in a spirited talk by Hasan Padamsee. He stressed that the use of superconducting rf changes parameters substantially from those of a room-temperature rf collider. It relaxes some of tolerances that come from beam-produced wakefields and considerations of energy efficiency. An international collaboration, the TESLA collaboration, is developing this concept, and the work is concentrated on increasing the acceleration gradient and reducing costs that are estimated at present to be a factor of five or more above where they need to be for a cost-effective solution.

The intermediate frequency (X-band, ~10 GHz) approach being pursued by SLAC and KEK was introduced by Burt Richter and discussed extensively by Ron Ruth in another talk. It is a compromise among beam dynamics (emittance preservation) that favors low frequencies, efficiency that favors high frequencies, and the use of technology that is an extension of S-band experience. There has been substantial progress in the development of this linear collider concept. BNS (Balakin, Novokhatsky & Smirnov) damping can control single-bunch wakefields (the required energy spread is less than that now used in the SLC). Accelerator structures with damping and mode-frequency spreads reduce wakefields that couple bunches, and new methods of steering minimize dispersion and wakefield effects. X-band klystrons and pulse compression for increasing peak power are being developed and prototyped. Another aspect of this work is the Final Focus Test Beam being constructed at SLAC by an international collaboration. Dave Burke talked about this beam that will be used to test the complex optics of future final focus systems.

CLIC, the CERN linear collider, pushes to high frequencies (~30 GHz) and uses an advanced two-beam rf power source that has the advantage of not needing a myriad of power tubes and modulators. The high frequency puts a stress on emittance preservation, and there is a need for new ideas. Wolfgang Schnell summarized this work, including high performance alignment techniques and rf quadrupoles for reducing the effects of wakefields.

The experience being gained at the SLC has a strong, direct impact on all these concepts for future linear colliders. It is one of the critical factors influencing technical judgments about designs. This experience was presented in an invited talk by Nobu Toge and in numerous posters and oral presentations covering all aspects of the SLC, including hardware and software systems, beam-based diagnostics, measurement techniques and apparatus, feedback, and background control.

Overall, linear colliders have matured. The SLC is better understood, and the work on future linear colliders is concentrating on the details of a few approaches. There was nothing revolutionary, but there was a body of solid work that is the foundation for future colliders. As Richter concluded in his talk, continuing progress can be expected, and within several years a clearly preferred direction should emerge.

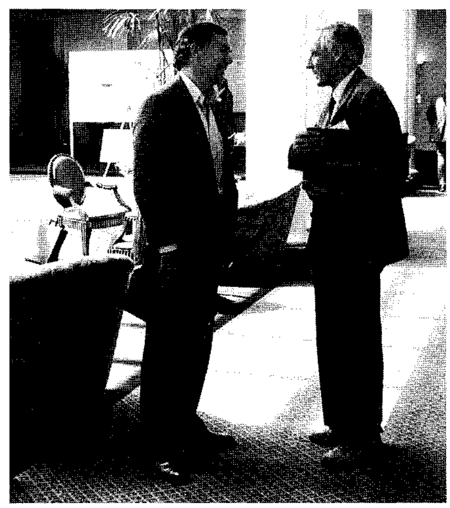
B factories were the other e^+e^- colliders featured at the conference. These machines have evolved substantially over the past few years. All serious proponents are working on asymmetric storage ring colliders. The challenges, discussed in a plenary session talk by Mike Zisman, LBL, are to store large beam currents and a large number of bunches without deleterious effects to and/or from the vacuum chamber, the rf system, and the high energy physics experiment. Interaction region configurations are dominated by considerations of beam-related backgrounds. Talks by Nari Mistry and Hobey DeStaebler focused on the vacuum and background issues, respectively, and there were many interesting posters about rf (both normal and superconducting), vacuum systems, feedback, and magnetic lattice design. Proposals for B factories have already been submitted to the U.S. funding agencies; the work that was reported is the basis of these proposals.

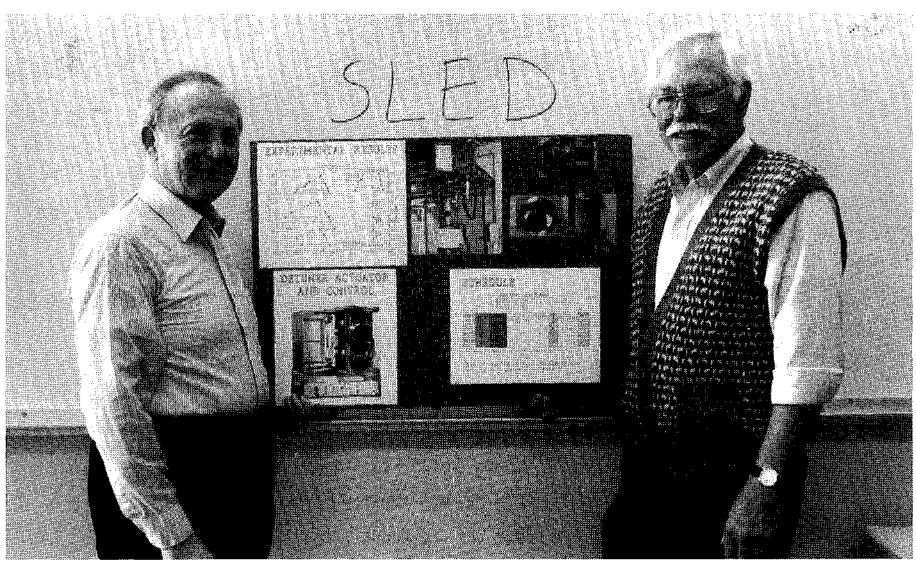
THE EVOLUTION of a scientific field can be judged by what is missing from a conference as well as what is there. This year there were two conspicuous absences. One, the LHC, is discussed above and presumably is attributable to the success of the European Particle Accelerator Conference; however, Leon Lederman, in the closing session, presented the near and far future plans of proton machines, while Carlo Rubbia gave us CERN-specific details and Roy Schwitters talked about the SSC. The second absence is disturbing: Advanced accelerator concepts were not well represented. These concepts stimulate accelerator physics by mixing wide-ranging ideas from the forefront activities in high current beams, lasers, FELs, and high energy accelerators. The leaders of the accelerator community should be thinking about this absence and about reviving advanced accelerator activities.

This year's PAC was the fourteenth in a series organized under the auspices of the IEEE (Institute of Electrical and Electronics Engineers). The newly formed Division of the Physics of Beams of the American Physical Society (APS) has selected the PAC for its annual meeting on the (alternate) years that it meets. The IEEE, APS, and the U.S. Particle Accelerator School (USPAS) each recognized scientists who have made important contributions at the banquet. IEEE prizes for accelerator technology were awarded to Dave Farkas and Perry Wilson for their work on rf pulse compression, and to David Larbalestier, University of Wisconsin, and Ron Scanlan, LBL, for superconducting magnet development. Glen Lambertson, LBL, and Wolfgang Schnell received the annual prizes of the USPAS, which also honored R. Wideroe with a special tribute recognizing his pioneering work on linacs and betatrons. The APS awarded the prestigious R. R. Wilson Prize to J. R. (Reggie) Richardson for the work that has led him to be considered the father of modern cyclotrons, and a member of the next generation, Jeffery Calame, was given the first APS award for outstanding doctoral thesis research.

The conference was a success in providing a delightful atmosphere for informal discussions and in presenting a stimulating formal program that reflected the current state of the field by featuring the accelerators that will be the physics facilities of the future. ○

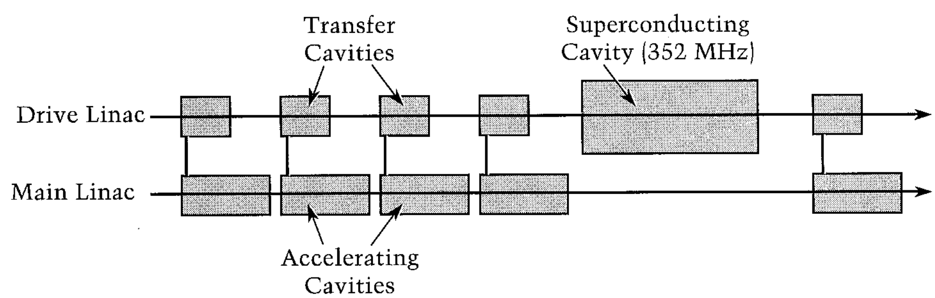
Below (top): APS Wilson Prize winner Reggie Richardson, UCLA/TRIUMF. Middle: Ron Ruth, left, of SLAC and Wolfgang Schnell, CERN, engage in hallway conversation at the Palace. Bottom: Accelerator technology award winners from SLAC, David Farkas, left, and Perry Wilson pose before a poster on SLED, the SLAC Energy Doubler.





The CERN Linear Collider

IAN WILSON



Two-beam accelerator scheme.

CERN IS STUDYING THE FEASIBILITY of building a 2 TeV e^+e^- linear collider called CLIC to enable high energy physics experiments to be extended into a range of energies where circular machines would be crippled by synchrotron radiation.

The main difficulty associated with the design of linear colliders is the generation of adequate luminosity, which should increase with the square of the energy and exceed $10^{33}\text{cm}^{-2}\text{s}^{-1}$ for CLIC. The luminosity can be enhanced by increasing the repetition rate of the accelerator (1.7 kHz for CLIC), but since this raises the required electrical power (which is generally felt should not exceed 200 MW), further enhancements are achieved by increasing the number of particles per bunch to 5×10^9 and shrinking the vertical beam size at the interaction point to 12 nm.

Each of the two arms of the collider is composed of an e^+ or e^- source, a damping ring at about 3 GeV to reduce the emittance, a small section for bunch compression and pre-acceleration to 10 GeV, a classical traveling-wave radio-frequency main linac accelerating section, and a final focus system.

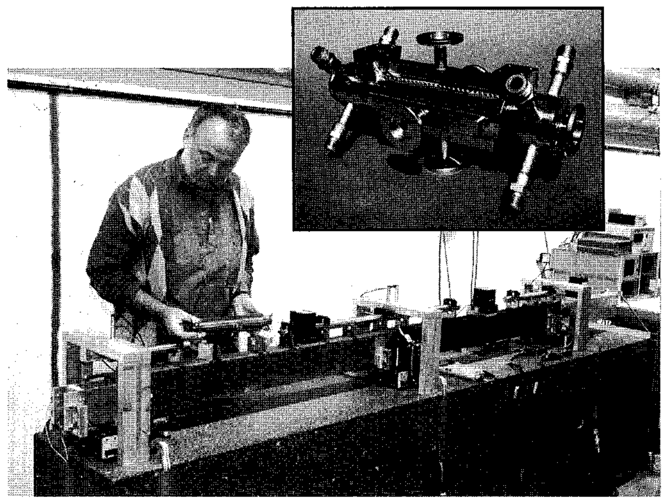
An obvious design aim is to make the main linacs as short as possible to keep the cost down, which implies high accelerating gradients. Since the average rf power increases with increasing gradient but is inversely proportional to the square of the frequency, there is a big incentive to operate at high frequencies. The choice of 30 GHz is a distinctive feature of the CLIC design. At this frequency, fabrication problems, alignment tolerances, and wakefield effects seem just manageable but demand state-of-the-art technology to achieve or overcome them. In spite of this choice and a relatively modest gradient of

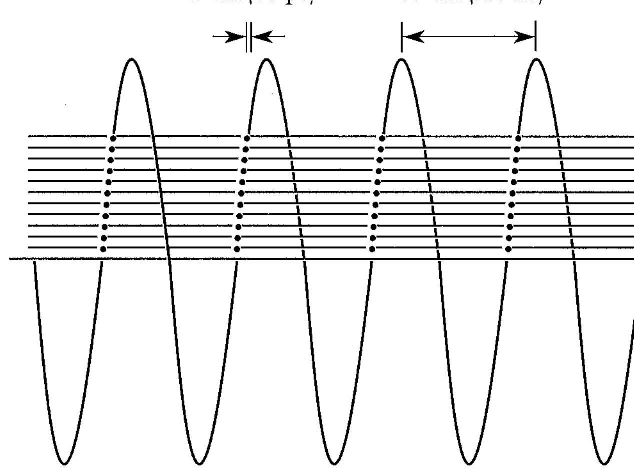
80 MV/m, the total peak power required is 150 MW per meter of main linac, but only for a duration of 11 ns per pulse. Rather than using individual power sources (for example, klystrons with peak powers of several hundred MW every few meters), a two-beam scheme is proposed. This is the second distinctive feature of the CLIC design.

The idea is to have a 3–5 GeV high intensity electron linac, or drive linac, running in parallel with the main linac. The bunched drive beam is decelerated in so-called transfer structures, where rf power at 30 GHz is generated and fed via a standard waveguide to the high-gradient accelerating structures. Periodic replacement of the energy lost by the beam to the transfer structures is made by short sections of 6 MV/m superconducting cavities driven by 350 MHz 1 MW klystrons. A total length of 2.5 km is required per linac. The superconducting cavities and klystrons already developed by CERN for LEP are ideal for this application.

A PROMISING DESIGN for the transfer structure has now been found. The structure must have an extremely low shunt impedance (a few ohms/m) and be sufficiently open to avoid creating self-decelerating and self-deflecting wakefields by the intense drive beam. It consists of a 15-mm-diameter circular beam tube coupled to the broad side of a power-collecting rectangular waveguide through a row of coupling holes. The output waveguide cut-off and coupling-hole spacing are chosen such that the beam is synchronous with the backward TE_{10} wave of the output waveguide at 30 GHz. The rf pulse length is controlled by the length of the coupling sections. By placing output waveguides on both sides of the beam tube, 160 MW/m can be extracted from a 50-cm-long section.

The required 30 GHz, 11 ns power pulse to drive the main linac accelerating sections is generated in this structure by driving it with four bunch trains each composed of eleven 1-mm-long bunches of 10^{12} electrons spaced by 1 cm (see figure on right). By arranging





Top: The CLIC active alignment micro-movement test facility. Inset: a 30-cell prototype CLIC accelerating section. Bottom: Generation of the drive beam by interlacing the outputs of eleven pre-accelerators and periodic re-acceleration in 350 MHz superconducting cavities.

the drain time of the transfer structure to be equal to the period of the drive linac, the four 2.8 ns power pulses of each train appear at the output waveguide as a single 11.2 ns continuous pulse.

It is proposed to generate this drive beam by interlacing the outputs of a battery of eleven preaccelerators each producing one bunch per bunch train. Use of laser-illuminated photocathodes with picosecond pulses is expected to produce the required 10^{12} particles per bunch. Best results so far have been achieved with a Cs_3Sb photocathode and a 266 nm laser. It is anticipated, however, that a further bunch-compression stage will be necessary to obtain the 1 mm bunch length. In order to study the feasibility of this relatively complex scheme, an experimental CLIC test facility (CTF) is being built. It includes a photocathode in an rf gun, a beam line acting as magnetic spectrometer, acceleration to about 60 MeV, and rf power generation at 30 GHz.

Each of the two main linacs is composed of 45750 27-cm-long iris-loaded traveling-wave accelerating sections. The aperture diameter is 4 mm, the cell diameter 8.7 mm, the group velocity 0.082 c and the fill time 11.2 ns. The rather large aperture-to-wavelength ratio of 0.2 enables the destructive effect of single-bunch transverse wakefields (which are inversely proportional to the cube of the aperture) to be held within reasonable limits. The 35 mm outer diameter, which is machined to a precision and concentricity with the beam aperture of ±1 micron, serves as the reference for alignment. Individual cells are pumped by four vacuum manifolds through radial holes. These holes may turn out to be output waveguides or damping slots channeling out unwanted energy associated with transverse deflecting modes, if a suitable design for such a scheme can be shown to be worthwhile. The damping out of long-range transverse wakefield effects would enable multiple bunches to be accelerated on the same rf pulse and would result in a corresponding increase in luminosity.

IT IS PART OF OUR PLAN to use microwave quadrupoles for single-bunch wakefield stabilization. Such quadrupoles, featuring simultaneous acceleration and time-dependent transverse focusing, can be obtained by giving a fraction of the accelerating sections a circular aperture in a flat (quasi-rectangular) cell. The role of the quadrupole is to create a spread in the wavelengths of the transverse oscillations of the particles within a bunch, with the result that the tail is focused more strongly than the head, thus compensating the transverse wakefield kick (this is called BNS damping).

The small emittances required in CLIC to achieve the design luminosity must be conserved through the main linacs as the beam passes from the damping rings to the final focus. This sets very tight tolerances on the transverse misalignment of the components (typically 1 micron for quadrupoles and 5 microns for the accelerating sections) and can only be achieved through active feedback using micro-movers and a signal from a beam-position monitor with micron resolution. An active alignment test facility has been built in an unused underground tunnel at CERN to study this problem, and controlled submicron movements have been achieved (see photograph on previous page). An important problem is matching the beam's energy spread at the end of the linac to the final focus energy acceptance of 0.6%. The beam acquires a natural energy spread of about 2.5% because of the high single-bunch energy extraction of 5% from the accelerating sections. Matching at the final focus, however, now seems possible by canceling the longitudinal wake with the rf voltage (flattening the resulting accelerating gradient variation over the bunch) by adjusting the rf phase for a given bunch length and population. With such energy distributions and discarding 15% of the particles from the tails, a minimum rms energy spread of 0.1% has been achieved for a bunch length of 0.17 mm and 6×10^9 particles.

FROM THE EDITORS' DESK

LIMITATIONS OF TIME and of distance have caused former Editorial Advisory Board members Martin Perl and John Matthews to quit; we have benefited from their advice, guidance, and wisdom. The new Advisory Board members will be David Hitlin from Caltech, and Robert Cahn and Stewart Loken from Lawrence Berkeley Laboratory.

STAN WOJCICKI'S ARTICLE in the previous issue of the *Beam Line,* "Looking Ahead: The Next 15 Years in U.S. High Energy Physics," has elicited a lot of interested comment.* This is the kind of policy/opinion/perspective article that is likely to engage many of our readers. We look forward to more writing of this ilk from prospective authors. Perhaps this means you; if so, suggest something, and let's talk about it.

IT IS OUR SAD TASK to report here on the recent deaths of two of our colleagues in the field of particle physics, Clicerio Avilez and Richard Blumberg. At the time of his death at age 45, Avilez was the director of the Instituto de Fisica at the University of Guanajuato in Leon, Mexico. He devoted his career to carrying out his belief that Mexican participation in elementary particle physics was an important way to foster scientific and engineering growth in Latin America. He, more than any other person, kept reminding our community that we have knowledgeable Mexican colleagues who are capable of building accelerators and doing research with them. Even though what he was trying to establish there seemed modest by standards of developed countries, his ideas oftentimes bordered on heresy in his own country. In addition to prevailing attitudes against such esoteric research, he had to battle a bureaucracy that made acquiring even used computers a super-human accomplishment.

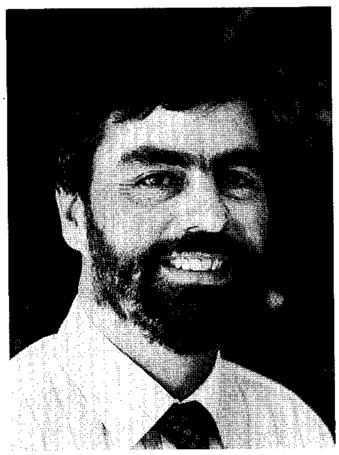
Richard Blumberg was well known in bubble chamber circles, having begun his career at the U. C. Radiation Laboratory (now Lawrence Berkeley Laboratory) in Luis Alvarez's bubble-chamber group. He was responsible for much of the mechanical design of the sequence of bubble chambers that began with the 4-inch model and culminated in the famous 72-inch chamber. He came to SLAC in 1964 and was part of the team that designed the 40-inch chamber, the first really fast-cycling production bubble chamber. After SLAC's bubble-chamber program reached conclusion, Blumberg helped to convert the Argonne 4-meter bubble-chamber magnet, which was headed for the scrapyard, for use in the High Resolution Spectrometer at PEP.

Rene Donaldson   Bill Kirk

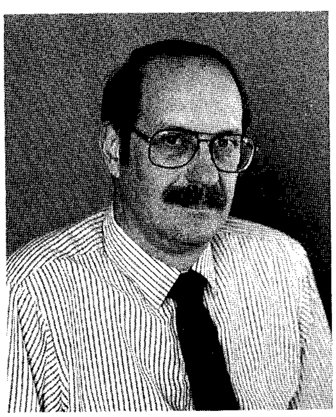
*The comment on Wojcicki's article was word-of-mouth. For those who know how to write also, our BITNET electronic mail address is BEAMLINE@SLACVM. We even have a mail address (see inside front cover), but we presume that letter-writing is a lost art.

CONTRIBUTORS

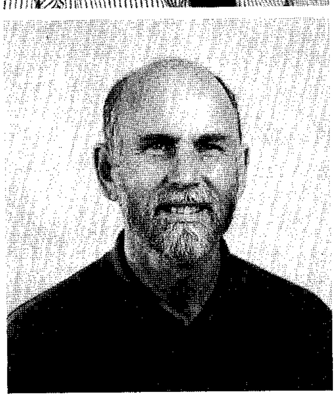
MICHAEL RIORDAN is contributing editor of the *Beam Line*. Currently Staff Scientist and Assistant to President John Toll at Universities Research Association in Washington, D.C., he is the author of *The Hunting of the Quark* and co-author with David Schramm of the recently released book about dark matter, *The Shadows of Creation*.



GEORGE BROWN is a member of the Applied Physics and Stanford Synchrotron Radiation Laboratory (SSRL) faculties of Stanford University. He is former head of SSRL's Accelerator Research and Operations Division. His graduate work at Cornell University in high energy physics in the early 1970s led him into a synchrotron radiation research program at Bell Laboratories. In 1977 he came to Stanford where he has applied his knowledge of accelerators and x-ray research to problems in physics, biology, and diagnostic medical imaging. In September, he will join the faculty of the University of California at Santa Cruz where he will teach and stay active in SSRL's diverse research program.



ROBERT SIEMANN is a Professor in the Accelerator Theory and Special Projects Department at SLAC. He spent the last 17 years at Cornell University and is well known throughout the world for his expertise in accelerator physics. He has worked on a number of high energy accelerators, including CESR, the Tevatron, and the SLC and has written extensively about the single beam stability, beam diagnostics, and the beam-beam interaction in electron-positron colliders. At present he is concentrating on aspects of the SLC operation including heading the Positron Task Force that has recently succeeded in obtaining record-breaking positron yields.



IAN WILSON is a senior engineer in the RF Group of CERN's SPS-LEP Division. During 1978–1989 he played a major role in the design, construction, and commissioning of the rf system for the LEP machine. In 1987 he joined the CERN study group on linear colliders and is now leading a small team that is developing accelerating structures and alignment systems for the 30 GHz main linac. He is interested in all aspects of accelerators and recently lectured at the CERN Accelerator School in Oxford on rf technology.

DATES TO REMEMBER

Sep 9–14	Workshop on Physics and Experiments with Linear Colliders, Saariselka, Finland (Paula Eerola, Research Institute for High Energy Physics, SEFT: Siltavuorenpenger 20C, SF-00170 Helsinki, Finland)
Sep 16–27	CERN Accelerator School: Advanced Accelerator Physics, Noordwijkerhout, Netherlands (S. von Wartburg, CERN Accelerator School, SL Division, 1211 Geneva 23, Switzerland, BITNET CASNIK@CERNVM).
Sep 30–Oct 2	DESY Theory Workshop: The Standard Model at High Temperature and Density, Hamburg, Germany (H. Satz, Theory Division, CERN, 1211 Geneva 23, Switzerland, or SATZ@CERNVM).
Oct 2–5	International Workshop on Electroweak Physics Beyond the Standard Model, Valencia, Spain (invitation may be requested from Dr. Moliner, Department of Theoretical Physics, University of Valencia, 46100 Burjassot, Valencia, Spain).
Oct 13–17	Third Annual SSC Fall Meeting, SSC: The Project, The Progress, The Physics, Corpus Christi, TX (P. Hale, SSCL, Users Office, MS 2080, 2550 Beckleymeade Avenue, Dallas, TX 75237, or SSCPHYS@SSCVX1).
Oct 28–31	1991 Accelerator Instrumentation Workshop, Newport News, VA (Cela Callghan, CEBAF Center, MS 12A, 12000 Jefferson Avenue, Newport News, VA 23606, or APD@CEBAFVAX).
Nov. 5–11	Lattice 91, International Symposium on Lattice Field Theory, Tsukuba, Japan (Masanori Okawa, National Laboratory of High Energy Physics, KEK, Tsukuba, Ibaraki-ken, 305 Japan or LAT91@JPNKEKVM).
Nov 11–15	International Conference on Accelerator and Large Experimental Physics Control Systems, Tsukuba, Japan (S. Kurokawa, KEK, Tsukuba, Ibaraki-ken 305 Japan).
Nov 26–29	Second KEK Topical Conference on e^+e^- Collision Physics, Tsukuba, Japan (T. Matsui, KEK, Tsukuba, Ibaraki-ken, 305 Japan or TOPIC91@JPNKEKVM).
Jan 6–17, 1992	U. S. Particle Accelerator School, Austin, TX (USPAS, Fermilab, MS 125, P. O. Box 500, Batavia, IL 60510 or USPAS@FNAL).
Mar 16–20	General Meeting of the American Physical Society, Indianapolis, IN (W. W. Havens, Jr., American Physical Society, 335 E. 45th Street, New York, NY 10017)
Mar 16–20	CERN Accelerator School: Magnetic Measurement and Alignment, Montreux, Switzerland (S. von Wartburg, CERN Accelerator School, SL Division, 1211 Geneva 23, Switzerland, or BITNET CASMAG@CERNVM)
Mar 24–28	Third European Particle Accelerator Conference (EPAC 92), Berlin Germany (H. Bottcher, EPAC 92 Conference Secretariat, Einsteinufer 1, D-1000, Berlin, Germany)
Apr 13–15	SSC Physics Symposium, Madison, WI (Linda Dolan, Physics Department, University of Wisconsin, Madison, WI 53706 or LDOLAN@WISCPHEN)

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