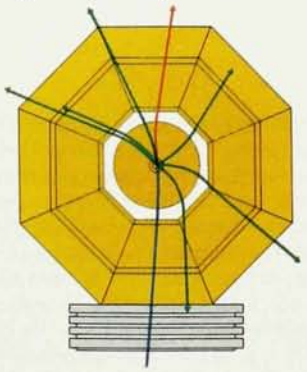
Electron and positron are annihilated at the heart of the CLEO detector at Cornell, producing bottom and anti-bottom quarks. In this reconstruction electrons are red, muons are blue and hadrons are green. (Courtesy of Martin Perl, SLAC.)



Elementary-particle physics

In the past 20 years the subnuclear world—which, due to a seemingly endless supply of "elementary" particles, was once likened to a zoo—has become a gratifyingly orderly place. The Elementary-Particle Physics Panel of the physics survey committee begins its report with a summary of the astounding progress of the last two decades: the emergence of a standard model of the universe as being made of quarks and leptons bound together by photons, gluons and W and Z particles; the unification of the weak and electromagnetic forces in a single gauge-field theory; the understanding of baryon and meson structure in terms of quantum chromodynamics; the theory of interacting quarks and gluons; the possibility of a grand unification of all of the forces of nature; and the convergence of elementary-particle physics and cosmology, each helping to elucidate the other. So much, the panel report explains, has been achieved. But many questions remain:

▶ What is the origin of mass, and what sets the masses of the different elementary particles? Is the Higgs hypothesis—which seeks to explain the breaking of symmetry—correct, and can the Higgs particles be found? If the Higgs hypothesis is wrong, what will replace it?

▶ Are there quark and lepton generations beyond the three already known? Why do these particles form generations?

▶ Are the quarks and leptons truly elementary, or does matter have a still deeper level of structure?

▶ Are new theoretical ideas like technicolor and supersymmetry correct? Can the strong and electroweak interactions be unified?

▶ Are there as yet undiscovered fundamental forces?

These are some of the questions that intrigue and challenge elementary-particle physicists in the United States and abroad. With the aid of existing accelerators and those already under construction important tests of the standard electroweak theory and quantum chromodynamics will be carried out, along with explorations of the predictions of unified theories of the strong, weak and electromagnetic interactions.

Much of the refinement and testing of the standard model will take place at existing electron–positron storage rings (SPEAR, DORIS, CESR, PETRA, PEP and soon TRISTAN) and the fixed-target accelerators (AGS, SPS and the Tevatron). These machines are valuable for performing "low-energy" tests: studies of the static properties of hadrons, such as their magnetic moments, charge radii and masses; studies of polarization effects in hadron physics; further detailed studies of "quarkonium" states in the J/Ψ and ϒ families; investigation of scaling violation in deep-inelastic scattering of electrons, muons and neutrinos from nuclei; and much more.

The next generation of higher-energy colliders, now under construction, will among other things allow the detailed study of the W and Z particles along with their decay products. The Stanford Linear Collider and the LEP facility at CERN are both electron–positron colliders. LEP will consist of a storage ring 9 km in diameter, which will eventually use superconducting accelerator cavities to achieve a center-of-mass collision energy of around 200 GeV.

The technology of electron–positron storage rings is now well understood. In optimizing the design, the dominant consideration is always the energy lost to synchrotron radiation emitted by the electrons and positrons as they whirl around the ring. Energy lost to synchrotron radiation, which increases as the fourth power of the beam energy and inversely as the bending radius, must be continuously replaced by a radiofrequency accelerating system. As a result the price of electron–positron storage-ring accelerators soars with beam energy.

An alternative to e^+e^- storage rings is now being constructed at the Stanford Linear Accelerator Center. The Stanford Linear Collider, which should be operational in 1987, avoids synchrotron-radiation loss by accelerating the electrons and positrons with the existing Stanford linear accelerator. The accelerated particles will emerge from the two-mile-long linac into separate collider arcs, which will carry them to a head-on collision. The maximum energy will be around 140 GeV and there will be only one interaction region for experiments. By comparison, LEP will have four interaction regions and, with the addition of superconducting cav-

Panel on Elementary-Particle Physics

Martin L. Perl, Stanford Linear Accelerator Center, *chairman*
William T. Kirk, Stanford Linear Accelerator Center, *report editor*
Charles Baltay, Columbia University
Martin Breidenbach, Stanford Linear Accelerator Center
Gerald Feinberg, Columbia University
Howard A. Gordon, Brookhaven National Laboratory
L. W. Jones, University of Michigan
Boyce D. McDaniel, Cornell University
F. S. Merritt, University of Chicago
Robert B. Palmer, Brookhaven National Laboratory
James M. Paterson, Stanford Linear Accelerator Center
John Peoples Jr, Fermi National Accelerator Laboratory
Chris Quigg, Fermi National Accelerator Laboratory
David M. Ritson, Stanford University
David N. Schramm, University of Chicago
Donald C. Shapero, National Research Council
A. J. S. Smith, Princeton University
Mark W. Strovink, University of California, Berkeley

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Section of the 16-GeV electron–positron storage ring CESR at Cornell University. While particle-physics experiments are carried out at its two intersecting regions, synchrotron radiation is used for a host of other experiments.

ities, an ultimate energy of 200 GeV. But it will also cost four to five times as much as SLC.

Both SLC and LEP will be "Z^0 factories," copiously producing Z^0 particles from e^+e^- collisions above 100 GeV. Precise measurements of the Z^0 mass and lifetime may be confronted with detailed theoretical predictions. The lifetime and production rates are also measures of the numbers of quark and lepton species that occur as decay products. This information could provide, among other things, a determination of the cosmologically important number of light-neutrino species. The Higgs boson may also be observed.

The study of the charged W particles will be the main province of the Tevatron Collider, a 2-TeV proton–antiproton storage ring at Fermilab. The masses of the W particles are critical parameters in the electroweak theory. Should there be another intermediate boson, weighing up to about 500 GeV, beyond those predicted by the standard model, experiments at the Tevatron should find it. A favorite possibility in theoretical speculations is a right-handed $W^\pm$. And if the mass of the Higgs boson does not exceed 100 GeV, this too could be found. In any case, the Tevatron represents the first sortie into the unexplored region above several hundred GeV.

By early in the 1990s QCD and the standard electroweak theory will have been thoroughly scrutinized with the aid of these machines. Although the unexpected should always be expected, it is possible that efforts to understand why these theories work and to construct more complete descriptions of nature will receive no additional experimental guidance from phenomena uncovered by the generation of machines now under construction. To get this guidance will require higher-energy accelerators. In particular the panel strongly advocates the construction of a 40-TeV, high-luminosity proton–proton collider, the Superconducting Super Collider.

Initial planning for SSC began at a meeting in Snowmass, Colorado, in 1982. Design studies conducted since then have shown that a conservative extension of existing or near-term technology can lead to the successful achievement of such a machine. Crucial to this judgment was the definitive verification at Fermilab's Tevatron of the practicality of using superconducting technology to obtain beams of very high energy.

In its scale, the SSC project far exceeds any of the world's existing high-energy-physics facilities. The Reference Design Study envisions a six-year construction period, which would mean completion in 1994 if construction were begun in fiscal 1988. The cost is estimated at $2.70 to $3.05 billion in 1984 dollars (not including the cost of research equipment, preconstruction R&D and possible site acquisition).

The panel report stresses the importance of accelerator projects such as SLC and SSC in keeping the United States at the forefront of the international effort to understand the subnuclear world. Two decades ago, the panel points out, the United States was the dominant force in elementary-particle research. This is no longer the case: Western Europe and Japan have expanded their contributions to the point where they are truly competitive.

Not all experiments important to the understanding of elementary-particle physics are performed at accelerators. Large underground detectors search for proton decay and measure the rate of neutrino production by the Sun; cosmic-ray studies explore very-high-energy particle interactions; diverse experiments search for magnetic monopoles, free quarks and neutrino mass; atomic-physics experiments provide important tests of quantum electrodynamics and search for small violations of fundamental symmetry principles. The value of these experiments, the panel notes, is substantial: "It is appropriate that some fraction of the particle-physics national program be devoted to experiments that do not use accelerators."

—Bruce Schechter □