Contents

EXECUTIVE SUMMARY

ROBERTO PECCEI

University of California, Los Angeles, CA 90024

MICHAEL E. ZELLER

Yale University, New Haven, CT 06511

DAVID G. CASSEL

Cornell University, Ithaca, NY 14853

JONATHAN A. BAGGER

Johns Hopkins University, Baltimore, MD 21218

ROBERT N. CAHN

Lawrence Berkeley Laboratory, Berkeley, CA 94720

PAUL D. GRANNIS

State University of New York, Stony Brook, NY 11794

FRANK J. SCIULLI

Columbia University, Irvington-on Hudson, NY 10533

1 Introduction

Particle physics comprises the study of the most basic components of matter and the forces that govern their interactions. These subjects are the bedrock upon which the physical sciences rest, and ultimately govern such diverse phenomena as the evolution of the universe from the moment of the Big Bang, the generation of energy in the stars, the properties of atoms and nuclei, and the understanding of the forces that bind protons and neutrons and stimulate radioactive decays.

Over the past two decades, substantial progress has been made in identifying the basic constituents of matter, their patterns and relationships, and in understanding and partially unifying the fundamental forces between them. These advances are embedded in the paradigm called the Standard Model of particles and forces. This model makes predictions that agree with virtually all existing experimental data. However, the Standard Model has many components and parameters that are arbitrarily inserted to fit the observations, and it offers little insight into the deepest questions of why the observed arrangements of particles exist and how the forces governing them may be more completely unified.

A rich program of investigations can shed light on these fundamental issues and the instruments available to study them are quite varied. The Tevatron at Fermilab, currently the highest energy accelerator, can study the properties of the newly discovered top quark and can search for new particles and phenomena in a heretofore unexplored energy range. At the other extreme, experiments attempt to determine if neutrinos have mass, an issue that relates intimately to our understanding of the future of the universe. For the next decade there are facilities under construction and in operation in the United States that will continue these studies and that offer great opportunity for expanding our knowledge.

While the program that has been set in place is diverse and has great potential, there are major advances that can only be made through accelerator-based studies at energies about ten to twenty times those available at present facilities. Compelling scientific arguments persuaded particle physicists to try to reach these energies by constructing the Superconducting Super Collider

(SSC). The SSC will not be built, however, and the aspirations of the particle-physics community for understanding these fundamental issues now rest upon the recently approved Large Hadron Collider (LHC) at CERN in Switzerland and upon accelerators, yet to be proposed, that might be built in the future.

When the survival of the SSC became uncertain in the summer of 1993, the Executive Committee of the Division of Particles and Fields (DPF) of the American Physical Society began serious discussions of steps that would best help our community face the challenges of the future. These discussions were strongly influenced by the loss of the SSC and the subsequent appointment of the Drell Subpanel of the Department of Energy's High Energy Physics Advisory Panel (HEPAP) to help provide a vision for the future of the field. Since the Drell Subpanel had a specific charge and a relatively short time for deliberation, the DPF Executive Committee felt that the high-energy-physics community and the public on whose support it relies would profit by having an additional broad-based and in-depth study of the field. This study, called the Committee on Long-Term Planning, was initiated in early 1994 and its fruits are the reports contained in this volume.

This study of high-energy physics was organized on the basis of working groups. Of the eleven working groups in the study, seven dealt with specific physics topics and three with more technical areas (accelerators, particle detectors, and computers). One concentrated on structural and educational issues of the field. Broadly speaking, four of the physics working groups dealt with physics issues connected with the Standard Model, our present paradigm for particle physics, while the other three working groups focused on questions beyond our present knowledge, but whose answers are crucial for a deeper understanding of nature. The charge to each of the physics working groups was to articulate the broad range of physics questions in the group's particular area and to discuss the means by which these questions might best be addressed, in the context of existing and future facilities in the United States and in the rest of the world. Each of these working groups was asked to identify important areas of emphasis for future study.

The accelerator physics working group was charged to undertake a study of the current state of the art and of foreseeable advances in accelerator facilities for high-energy physics (HEP) research. The particle detectors working group and the computing working group were asked, respectively, to assess the likely detector technology and computational needs of ongoing and future high-energy physics experiments, considering the impact of existing and emerging technologies. Finally, the structural and educational issues working group was charged with examining various issues in our community that are of broad concern. These include the adequacy of the present advisory structure in high-energy physics; suggestions for possible additional mechanisms to more adequately plan for the future; and whether our community should seek a structured public education role and, if so, how broad should such an activity be.

Each of the working groups was led by conveners chosen among established leaders in the area under consideration. The conveners then assembled their groups by inviting other active workers in the field to participate. Most of the working groups also gathered further input from the community by holding various specialized meetings and workshops. The working groups presented their preliminary findings at a Workshop at Johns Hopkins University in May 1994, and their final reports at the DPF general meeting in Albuquerque the following August. Draft written versions of these reports were critically discussed at a retreat of all conveners with the members of the DPF Executive Committee at the Lawrence Berkeley Laboratory in October 1994. The corrected draft versions of the reports were examined one more time by an editorial board appointed by the DPF Executive Committee.

The reports of the working groups, along with their conclusions and recommendations are summarized in the following sections.

2 Precision Tests of Electroweak Theory

The theory of electroweak interactions unites the electromagnetic and weak interactions and is the cornerstone of the Standard Model. In this theory, the electroweak forces arise from interactions of four bosons, the photon, Z, and $W^{\pm}$, with the quarks and leptons of matter. Gauge symmetry is a fundamental ingredient of this theory. The gauge symmetry of the electroweak interactions implies that the masses of the photon, Z, $W^{\pm}$, and the quarks and leptons all vanish. Some mechanism is required to break this symmetry and provide the observed masses of particles. In the standard electroweak theory, the simplest way to produce this symmetry breaking is via interaction with an additional particle, called the Higgs boson.

The resulting electroweak theory depends on three primary parameters, which can be taken to be the electromagnetic fine structure constant, α, the Fermi constant of weak interactions G_F, and the mass M_Z of the Z boson. It is then possible to predict many other important quantities, such as the mass M_W of the $W^{\pm}$ bosons, in terms of these parameters. Actually, such predictions also depend in detail on quantities like the masses of the quarks and the Higgs boson. Very extensive tests of the electroweak theory have been carried out in a variety of circumstances, most notably in the production and decay of the Z boson. The agreement of these tests with the theory is remarkably good, often at the level of 1%

or better. In addition, from the slight dependence of predictions on the mass of the top quark, it is possible to estimate its mass. This prediction of approximately 175 GeV is in excellent agreement with recent direct measurements of the top mass by the CDF and D0 collaborations at Fermilab.

Despite these notable successes, more stringent tests of the electroweak interactions are important. There may well be new interactions outside the Standard Model, or new particles that are too massive to be produced and detected at current accelerators. These phenomena can cause small deviations from expectations for measurable quantities and precision measurements can provide circumstantial evidence for their existence. There is an active experimental program planned worldwide that will provide significant improvement in precision, with a substantial reduction in the errors for key electroweak parameters.

Forthcoming data from LEP at CERN and from polarized Z's at the SLC at SLAC will sharpen our knowledge of electroweak interactions at the Z. Further improvements in the accuracy with which we know the W boson's mass will provide powerful complementary information. This will come from data now being gathered at the Fermilab Tevatron Collider and from future running with the Main Injector, as well as from data from LEP 2 at CERN, a machine that is scheduled to begin operation in 1996. The ability to pin down the value of the top quark mass with high precision will also be essential for more stringent tests of the electroweak theory. Only Fermilab will have sufficient energy to explore directly the properties of the top quark until the turn-on of the LHC.

Current investigations will surely deepen our understanding of electroweak interactions and may presage new physical phenomena, whose full exploration will need higher energies. A case in point is the Higgs boson, which can be directly detected at LEP 2 if its mass is less than about 90 GeV. This search could perhaps be extended if the Fermilab Collider luminosity is upgraded significantly, but above this mass range the detection of the Higgs boson will require the LHC or a high-energy electron-positron (e^+e^-) collider. Nevertheless, precision electroweak measurements may help to further narrow the expected mass range for this possible particle.

The theory of the electroweak interactions is one of the two pillars which underlies the Standard Model, the paradigm for how the fundamental constituents of matter interact. Continued probing of this theory by experiments of increasing precision remains central to particle physics and has two principal goals:

- to refine our knowledge of the parameters that characterize the Standard Model and the breaking of electroweak symmetry, (requiring improvements in the accuracy with which we know the masses of the W bosons and of the top quark) and
- to look for small discrepancies between experiment and theory that, if found, will point to new physics beyond our present understanding.

3 Quantum Chromodynamics

Quantum chromodynamics (QCD), the theory of the strong forces between partons (quarks and gluons), is the second central ingredient of the Standard Model. In QCD, the force between quarks is carried by bosons called gluons. Indeed, an important feature of QCD is the fact that there would be a strong force even without the quarks because gluons interact with each other. The strength of the interaction, called α_S, is not a constant but depends on the energy scale at which it is measured. At the mass of the Z boson its value is about 0.12 – about a factor of 16 larger than α, the corresponding strength of the electromagnetic interaction.

Since its formulation in the early 1970's, QCD has developed into a mature theory that is well verified in a variety of experiments. While the evidence is compelling that QCD is the correct theory of the strong interactions, we cannot say that we understand all phenomena completely. This is not an entirely new situation: although we believe that quantum mechanics and electromagnetism describe completely our everyday world, we cannot yet explain quantitatively many complex phenomena. Some processes in QCD can be understood with perturbation theory (expansions of the interactions between the partons in low orders of α_S); others, such as the formation of bound states of quarks, called hadrons, cannot. In particular, at present in QCD there is still a very incomplete understanding of how perturbative regimes are connected with non-perturbative regimes; of quark confinement (the experimental absence of free quarks); of the high temperature and high density phases of quarks and gluons; and of the reason for the absence of strong CP violation.

There is a large and active experimental program worldwide pursuing different aspects of QCD. When explored at high energies, protons are seen to contain additional quark-antiquark pairs and gluons, besides the u and d quarks of the simple quark model of hadron structure. The measurements of the distributions of these parton densities has been an important thrust of high-energy physics for nearly thirty years and continues at both hadron and electron machines. Data obtained at the new electron-proton (ep) collider HERA in Hamburg show a large increase in the quark and gluon density at small values of the Bjorken scaling variable x, and may be the first indication of an eventual saturation of parton densities (a new non-perturbative domain of QCD at very high parton densities). Experiments at CERN and SLAC are giving new information on how the proton spin is shared among the constituents. Studies of jet decays of the Z's produced in e^+e^- collisions at LEP and SLAC have given very accurate understanding of the coupling and underlying structure of QCD processes, and provide insights on the differences between quark and gluon jets.

Experiments at hadron machines are a rich source of complementary information about QCD. Whereas in e^+e^- and ep collisions, one proceeds from a clean and well understood initial state to a final state involving parton jets, in hadron collisions one may study simple final states (γ, W, and Z) free from fragmentation effects but with partonic initial states that are less well understood. This complementarity is important because it allows cross checks of the effects of proton structure and fragmentation into hadrons. The very high energy of hadron colliders enables sensitive studies of QCD and the measurement of α_S at short distances from high transverse momentum production of jets and vector bosons, and their angular correlations. The increased energy, masses, and phase space available also permits new tests of gluon radiation calculations "resummed" to all orders. Further insights into the transition from a perturbative to a non-perturbative regime of QCD can come from studies of diffractive scattering and events with large kinematic gaps between clusters of particles in ep and hadron-hadron collisions.

Comparison of observations depending on the same underlying distributions provided by different measurements give important cross-checks and enhance our understanding of QCD. The high precision jet data now being gathered warrant refined theoretical calculations beyond those that currently exist, and an ongoing interaction between theorists and experimenters is both helpful and necessary for continuing progress.

Among the phenomena that may reveal surprises are systems with a high density of quarks and gluons. Such systems can be created by colliding nuclei at very high energy, which will become possible soon at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven. Heavy ion collisions offer the possibility of studying a new phase of QCD where the separate nucleons coalesce into a plasma of quarks and gluons. A major challenge here is to understand how, at early times in the collision, the transition from hadronic degrees of freedom to an equilibrated quark-gluon phase takes place. This is a field where nuclear physics and particle physics merge, and where perturbative physics, non-perturbative physics and phenomenology are essential in order to extract the desired information that these collisions can provide on high density and high temperature QCD.

Because of confinement, quarks and antiquarks are bound together by a force which increases with the distance of their separation. As a result, the properties of hadronic bound states cannot be determined by straightforward theoretical techniques. Lattice gauge calculations, treating space-time as discrete, are an important tool for probing the implications of QCD in the strong coupling regime. These methods are just now beginning to produce reliable results for low energy phenomena. With more computing power and further progress on the development of algorithms, the dream of a reliable calculation of the hadron mass spectrum and of low energy hadronic matrix elements may be close. Lattice calculations for α_S are now already competitive with perturbative derivations and should eventually provide the most precise determination of this fundamental quantity.

Even though the present experimental evidence for QCD is compelling, QCD deserves further intense experimental scrutiny in diverse circumstances to probe areas of the theory where our understanding is far from complete. These include:

- continued studies at Fermilab of the production and correlations of jets, W's, Z's, γ's, and b quarks at large transverse momentum and all angles;
- studies of hadronic final states in e^+e^- collisions with well-defined initial conditions;
- measurements aiming at elucidating the proton's structure at high energy and low x in ep collisions at HERA;
- studies of how the spin of the hadrons is carried by the underlying partons;
- exploration of diffractive phenomena in both ep and hadron-hadron colliders;
- searches for states (*e.g.*, glueballs, hybrids, and strangelets) allowed by QCD but not yet observed; and
- searches for indications of a quark-gluon plasma in high-energy collisions between nuclei at RHIC.

4 Heavy Flavor Physics and CP Violation

Our tangible world is made of electrons and up (u) and down (d) quarks, which are constituents of the proton and neutron. Neutrinos (ν's) are intangible, but also present. These four basic particles appear to be sufficient to explain ordinary matter. Nonetheless, there are two additional sets of four particles that follow the same pattern: the "second generation" of charm (c) and strange (s) quarks, with the muon (μ) and its neutrino, and the "third generation" of top (t) and bottom (b) quarks, with the tau (τ) and its neutrino. These three generations of quarks and leptons and the associated mechanism by which these particles decay into each other are an essential ingredient of the Standard Model. The reason for the triplication is unknown, but it allows the Standard Model to accommodate matter-antimatter asymmetry due in part to the phenomenon known as CP violation.

The weak interaction can turn one kind ("flavor") of quark into another. In nuclear β decay a d quark becomes a u quark while an electron and an antineutrino are emitted. There is a general propensity for quarks to remain within one family. Thus a c quark prefers to change to an s quark rather than a d quark. These propensities can be described quantitatively in terms of a unitary matrix, V, called the Cabibbo-Kobayashi-Maskawa (CKM) matrix. In this description, V_{cs} is a factor in the amplitude for a transition from a c quark to an s quark, while V_{cd} is the smaller factor associated with a transition from a c quark to a d quark.

In the Standard Model the CKM matrix arises from the mismatch between the quarks as seen by the strong and the weak interactions. Unitarity and the fact that only relative phases are observable imply that four independent real parameters determine the nine complex elements of the matrix. It is possible to test this expectation by measuring more than four of the matrix elements and seeing if they are related in the anticipated way. To do this, many different weak decay processes involving many different kinds of particles must be measured carefully.

Understanding the CKM matrix is important for two reasons. First, it seems likely that the CKM matrix is intimately connected to the process through which the quarks get their masses, that is, to the electroweak symmetry breaking mechanism. Second, the CKM matrix may also play an important role in CP violation. CP is short-hand for the joint application of the operations of replacing particles by their antiparticles (C), and replacing right handed particles and processes by left handed ones (P). The violation of CP symmetry has been seen in the decays of K^0 mesons, one type of particle containing strange quarks.

CP violation is an essential element in understanding the observed dominance of matter over antimatter in the universe. In the Big Bang, matter and antimatter should have been produced in equal amounts. If CP were an exact symmetry, this primordial matter and antimatter would have annihilated each other shortly after they were produced.

Although the CP violation that can be described by the CKM matrix may not be fully responsible for the dominance of matter in the universe, it is still important to learn all we can about it. For thirty years, the decays of K^0's has been the only source of our knowledge of CP violation. Crucial experiments at Fermilab, CERN, and Frascati in Italy, are now being readied to explore further CP violation in this system, looking for tiny effects that should help elucidate whether its origin can be traced to the CKM matrix.

The decays of B mesons, particles containing b quarks, can provide new and more complete understanding of the CKM matrix. The decays of B mesons are already being studied very effectively at CESR, the e^+e^- storage ring at Cornell, as well as at LEP and at the Tevatron collider. These studies provide direct measurement of two CKM matrix elements, V_{cb} and V_{ub}, and indirect measurements of some others. However, a full understanding of the role of the CKM matrix in CP violation requires intricate and difficult measurements on many more B decays than have been observed so far. B Factories, especially designed e^+e^- colliders with high intensities and unequal beam energies, are being built at SLAC and at KEK in Japan to facilitate these measurements.

High-energy hadron machines, including the Tevatron Collider, which collide strongly interacting particles, are more prolific sources of B mesons. However, B's are produced in only a tiny fraction of the vast number of events that reach the detectors and the B's are produced in a much more complex environment, making the desired particles and correlations more difficult to observe. Full exploitation of these high event rates will thus require advances in detector technology, particularly in the ability to "trigger" on B events (selecting B events quickly and efficiently at some stage well before events are fully processed in a computer). The high production rate of b quarks in high-energy hadron-hadron collisions has led many to suggest there should be a dedicated b physics facility based on a hadron collider. The desirability of such a facility deserves careful consideration, with attention to the additional reach it would provide beyond that given by the e^+e^- B Factories. A vigorous and dedicated b physics facility at a hadron collider may also be able to fill the gap which will result when the LEP b program ceases with the turn-on of LEP 2.

It is an old adage of particle physics that everything that is not forbidden is compulsory. But what is absolutely forbidden? A decay like $\pi^+ \to e^+\gamma$, which would violate conservation of angular momentum, certainly seems to be forbidden. Some decays which have no such fundamental problem, like $K^0 \to e^+\mu^-$, have never been observed. From the absence of such processes we infer that electron number and muon number are separately conserved. These and similar conservation "laws" are included in the Standard Model, even though no compelling theoretical reason for their existence has been found. Whether these conservation laws are absolute, however, is an experimental question which can be investigated especially well with K beams, as in the current program at Brookhaven National Laboratory. The observation of violation of any of these lepton-number rules would have profound consequences. Because we are unable to predict in which sector (s, c, b, t, or τ) evidence for such new physics might appear, our studies need to remain as broad as possible. In addition, rare decays of heavy quarks provide alternative possibilities for studying CP violation and may reveal signs of CP violation beyond that predicted by the CKM matrix.

The present U.S. experimental program in heavy flavor physics is healthy and extensive and includes:

- CLEO at Cornell (b, c, and τ),
- the Fermilab collider program (b and t),
- the Fermilab fixed target program (c and s), and
- rare K decay studies at Brookhaven (s).

In addition, there is substantial U.S. involvement in the LEP experiments at CERN (b, τ), and in BES in Beijing (c, τ).

The approved upgrades to existing U.S. facilities (Phase III of CESR plus CLEO III and the Fermilab Main Injector plus CDF and D0 upgrades) and approved new facilities (SLAC B Factory) assure a continued healthy program. However, the long-range future of K physics is less certain as Brookhaven's role shifts with the advent of RHIC, although new opportunities may arise with the turn-on of the Main Injector at Fermilab.

The mysteries of mass, flavor, and CP violation, which are likely to have deep connections to each other, compel us to continue a vigorous experimental and theoretical program of studying heavy flavor decay. The two most important goals of this research are:

- to provide enough measurements to unambiguously overconstrain the CKM matrix and clarify its role in CP violation, and
- to search for rare and forbidden decays in order to exploit their sensitivity to physics beyond the Standard Model, at mass scales exceeding those that can be directly probed at accelerators.

Continued progress towards these goals requires more joint experimental and theoretical effort in understanding the interplay of the strong, weak, and electromagnetic interactions in decay processes.

5 Neutrino Mass and Mixing

The field of neutrino physics is diverse and is carried out in experiments at university laboratories, deep underground sites, and accelerators. The scientists come from particle and nuclear physics, astrophysics, and cosmology and are comprised of both experimentalists and theorists. Experiments range from mass measurements of neutrinos in decays of particles and nuclei, to observations of neutrinos produced in our sun and in supernovae, to studies of neutrinos produced by accelerators and in reactors.

Forty years after the first direct detection of neutrino interactions with matter, our knowledge of the three families of neutrinos and their interactions has improved dramatically. However, crucial aspects of our understanding are still lacking. Many fundamental properties, particularly neutrino masses and mixing of the neutrino states, are known only as experimental upper limits. Indeed, the issue of neutrino mass is central to the question of whether the neutrino is a Dirac particle (with a distinct antiparticle) or a Majorana particle (being its own antiparticle). In the search for physics beyond the Standard Model, new information in the neutrino sector may well play an essential role.

The question of neutrino mass and mixing not only is important for particle physics, but has also enormous relevance to astrophysics and cosmology. For example, a nonzero neutrino mass would contribute to the nonbaryonic dark matter, and perhaps significantly to the total mass of the universe. If neutrinos are massive, it is likely that they mix in a manner similar to that seen in neutral K mesons. A neutrino produced as a partner of a muon will initially possess muonic nature, but as time passes, would evolve a component of electron-type or tau-type neutrino. Such changes can be observed in a variety of ways by observing neutrino interactions at a distance from the source. Several substantial indications are emerging that these neutrino oscillations might exist.

One hint is provided by the solar neutrino problem. The intensity of neutrinos produced in the interior of the sun may be calculated from known nuclear processes, which ultimately produce the radiant energy visible at the solar surface. All measurements of this electron-type neutrino intensity at the earth are considerably lower than the rates expected from the standard model of energy production from the sun. This is hard to accommodate even by highly nonstandard astrophysical or nuclear physics mechanisms.

Another hint comes from cosmic rays; measurements of neutrinos produced by the interaction of cosmic rays in our atmosphere indicate that the relative number of electron-type and muon-type neutrinos differs from expectations by about a factor of two. Neutrino oscillations of muon-type neutrinos are a serious possibility to explain this discrepancy.

Finally, very recently, another indication comes from an accelerator-based experiment at Los Alamos, where an anomalous signal might be interpreted in terms of neutrino oscillations.

Although oscillations between different neutrino species may provide an attractive explanation for some or all of these data, a full resolution of these issues with further experiments is essential. For the solar neutrino problem the next generation of solar-neutrino detectors, the Sudbury Neutrino Observatory (SNO) in Canada, SuperKamiokande in Japan and Borexino in Italy, should be able to look for signatures of solar neutrino interactions and isolate effects of electron-type neutrino oscillations independently of solar models.

Accelerator experiments may be the best way to resolve the hints of muon-type neutrino oscillation provided by the atmospheric neutrino results. Long baseline experiments sensitive to oscillations by muon-type neutrinos are being proposed for the KEK, Fermilab, and

Brookhaven accelerators and could begin taking data in the not too distant future. Oscillations of electron-type neutrinos in the same parameter range should be visible in experiments beginning shortly at the San Onofre and Chooz reactors.

New information about the nature of neutrinos is likely to make important, perhaps vital, contributions to our understanding of the universe and of what lies beyond the Standard Model. For this reason, it is important that innovative experiments exploring neutrino mass, couplings, and other properties be encouraged and that indications of nonzero mass and/or flavor mixing be vigorously pursued. Fortunately, an active program of neutrino experiments is underway or planned:

- Direct mass measurements of electron-type neutrinos in β decay are probing masses of cosmological interest. Other experiments seeking evidence for double β decay with no neutrinos may provide the first demonstration of the Majorana identity of the neutrino.
- Indications of neutrino oscillations from solar neutrinos will be probed by at least three new experiments with significant U.S. participation (SNO, SuperKamiokande, Borexino). These experiments should be able to resolve the issue of whether the observed deficit of solar neutrinos has an astrophysical explanation or instead requires neutrino mixing.
- Short baseline experiments presently underway at CERN and planned for Fermilab have the potential to explore cosmologically relevant mass ranges for ν_μ oscillations to ν_τ (or ν_e), with excellent mixing sensitivity.
- Full exploration of the hints of oscillations seen in atmospheric neutrino interactions awaits direct measurements by long baseline experiments using accelerator-generated neutrino beams.

6 Electroweak Symmetry Breaking and New Physics at the TeV Scale

The electroweak theory is based on the realization that the quantum of light, the photon, and the quanta of β decay, the $W^\pm$ bosons, are intimately related. Just as isospin, a symmetry of strong interactions, identifies the neutron and proton as partners, a new symmetry, weak isospin, identifies the electron (or rather, its left-handed piece) and its neutrino as partners.

The electroweak symmetry is far from exact. The W and Z bosons are among the heaviest known elementary particles, while the photon is the lightest, though they are related by this symmetry. Similarly, the neutrino and the electron can hardly be confused, even though they are partners.

How is the electroweak symmetry broken? The rotational symmetry of an atom can be broken by applying a magnetic field, which explicitly distinguishes the direction of the field. Theory requires that electroweak symmetry not be broken in this way, but more subtly. Without the symmetry breaking, the $W^\pm$ and Z, and all the quarks and leptons would be massless. If any progress is to be made in understanding these masses, the source of electroweak symmetry breaking must be discovered. This is one of the core questions in high-energy physics today.

In one approach to electroweak symmetry breaking, a number of scalar (spinless) particles are introduced. Some of these particles are absorbed by the W and Z bosons when they acquire masses. The remaining scalars appear as new particles. In the simplest version, there is just one such particle, the Higgs boson.

A second possibility, called supersymmetry, predicts the existence of many new particles, among them a number of scalars like the Higgs boson. While there is no direct evidence for supersymmetry, there is strong theoretical motivation for it. There is also some supporting circumstantial evidence from extrapolating the electroweak and strong couplings to high energy, where the three couplings coalesce – if supersymmetric effects are included – as they should if there is a unification of these forces at high energy (grand unification).

A third possibility, referred to as strongly coupled electroweak symmetry breaking, introduces no new scalar particles but requires that their roles be played by bound pairs of new, heavy analogs of the usual quarks, dubbed techniquarks.

Which of these theories, if any, is the correct description of nature can be determined only by experiment. Finding the Higgs boson or any of the other new particles that appear in models of electroweak symmetry breaking would be a major step forward. The negative results of current experiments bound the Higgs boson mass to be above about 60 GeV. This range will be extended to about 90 GeV at LEP 2. Supersymmetric analogs of the Higgs boson could also be discovered at this accelerator if they were light enough.

While we cannot predict the mass of the Higgs boson we do have confidence that whatever the source of electroweak symmetry breaking, there must be indications for it below about 1000 GeV (1 TeV). Therefore, it is crucial to explore the TeV energy scale to elucidate the dynamics of electroweak symmetry breaking and the associated fundamental particle spectrum. This program necessarily will be a primary focus of particle physics research in the future and, at present, can only be contemplated at the LHC.

An extensive study of the electroweak symmetry breaking sector will require a robust experimental program at the LHC. However, finding the source of electroweak symmetry breaking is not the only goal of the LHC. Our current picture of particle interactions appears incomplete so that there may well be new phenomena within the LHC's range. One possibility is that there may be more particles like the W and Z bosons, which transmit new forces. Moreover, due to its mass reach, the LHC is in an excellent position to test for low-energy supersymmetry by looking for the signatures characteristic of the decays of strongly-interacting supersymmetric particles, missing transverse momentum and multi-lepton final states. Full exploitation of the potential for these searches requires the energy and luminosity of the LHC, but the substantial luminosity improvements now being proposed for the Fermilab collider should also permit substantial progress in the next decade. For example, the upgraded Fermilab collider with $q\bar{q}$ initial states (as opposed to the gluon-gluon initial states predominating at the LHC) could allow the observation of a Higgs boson with mass up to 130 GeV in association with a W or Z.

An electron positron linear collider with total energy between 0.5 to 1.5 TeV and sufficient luminosity (beam intensity) would provide lower backgrounds and a better controlled initial state than the LHC for similar explorations. Such a machine would have greater sensitivity to weaker signals, such as Higgs bosons in supersymmetric models and low-mass weakly interacting supersymmetric particles. An electron-positron collider of appropriate energy would be an ideal laboratory for the detailed study of the properties of Higgs bosons, and a 1.5 TeV linear collider could probe a strongly coupled electroweak symmetry breaking sector. Thus, such a linear collider would be in many ways complementary to the LHC.

Physics beyond the Standard Model may appear in other ways. Unequivocal evidence for neutrino oscillations, or CP violation outside the CKM structure, or decay modes that are forbidden by the Standard Model, would have dramatic consequences. At very high energies we may find new fundamental fermions, part of a fourth generation, or extensions of the three known generations. However, this is only a speculation; such particles may or may not exist in nature. In contrast, although we do not know precisely the origin of electroweak symmetry breaking, at least we know where and at which energy clues await us.

Exploration of the TeV scale is essential for the long-term vitality of particle physics. This requires a new generation of colliders and detectors beyond those that are currently available or those that can be attained with modest upgrades. This leads us to two conclusions:

- Participation of the United States in the LHC program is important and should be vigorously supported.
- An e^+e^- linear collider with sufficient energy and luminosity could provide important opportunities for discovery at this scale, while enhancing our ability to interpret evidence for new physics from the LHC.

7 Astrophysics, Cosmology, and Unification of Forces

The fields of astroparticle physics, cosmology, and unification of forces are growing areas of research that are at the intellectual frontier of particle physics. Because the energy reach of theory has exceeded that of terrestrial experiment, the pursuit of fundamental physics has more and more come to involve astrophysics and cosmology. Today many particle physicists, both theorists and experimentalists, are working at the interface of particle physics with astrophysics and cosmology, and this trend is likely to increase.

The boundaries of particle physics now touch on cosmology, astrophysics and gravity. Our best attempts to understand some of the most basic features of the universe – the cosmic asymmetry between matter and antimatter, the tiny primordial inhomogeneities that seed the growth of all galactic structure in the universe, the mysterious dark matter, and the large-scale smoothness and flatness of the universe – involve fundamental physics. Conversely, the universe has become an important laboratory for testing our boldest ideas about the laws of Nature – supersymmetry, grand unification, and superstrings.

Most of the basic features of the universe can be explained by postulating a brief inflationary instant during which an enormous burst of expansion allows a tiny, smooth piece of the universe to grow and encompass all that we can see today. This tremendous expansion also allows quantum-mechanical fluctuations on microscopic scales to evolve into variations in the energy density on cosmological scales, explaining the origin of the inhomogeneities needed to seed structure. Inflation requires that the total mass density of the universe be equal to the critical density, balanced between a universe that expands forever and one that ultimately ceases to expand and then collapses. However, the mass density in stars is far less than this, and the study of primordial nucleosynthesis shows that the mass density in ordinary matter, luminous or not, is far less than the critical density, indicating the existence of a new form of matter, called dark matter.

Even setting aside the inflationary prediction, there is strong evidence that much, if not most, of the mass density of the universe is something other than the familiar baryons comprising atomic nuclei. No problem more dramatically demonstrates the confluence of particle physics and cosmology than that of dark matter. It appears likely that the bulk of the dark matter exists in the form of elementary particles remaining from the earliest moments. These particles might be neutrinos of mass between 5 and 25 eV, or something more exotic, like particles called axions of mass ranging from 10^{-6} to 10^{-4} eV or supersymmetric particles of mass between 10

GeV and 1 TeV.

The dark matter problem provides further impetus for the search for evidence of neutrino mass and for new, long-lived particles. Conversely, direct searches for particle dark matter in our own neighborhood, using highly innovative detectors, have the potential to discover new elementary particles.

Inflation and particle dark matter have led to the most promising explanation for how the universe evolved from a very smooth beginning to the abundance of structure that exists today – galaxies, clusters of galaxies, superclusters, voids, and great walls. This theory, involving cold (or mixed) dark matter, holds that most of the mass in the universe exists in the form of slowly moving elementary particles and that the density perturbations that seeded all the structure arose during inflation. Cold dark matter is being put to the test in many different ways: measurements of the temperature variations in the cosmic background radiation, which probe the primeval density perturbations; redshift surveys, which map the inhomogeneity that exists today; deep images of the universe taken by the Hubble Space Telescope and Keck Telescope, which reveal the recent evolution of galaxies and clusters; x-ray studies of clusters of galaxies, which allow a determination of the ratio of baryons to exotic matter; and the search for the cold dark matter particles themselves. In addition to its obvious cosmological significance, the cold dark matter theory provides a window to physics at energies up to the unification scale.

A fundamental feature of the universe is the absence of antimatter and the tiny ratio of matter to radiation (about one baryon per three billion photons). One of the great triumphs of particle cosmology is baryogenesis, which holds that the small net baryon number of the universe evolved through interactions that do not respect baryon-number conservation or CP symmetry and occurred out of thermal equilibrium. The details of baryogenesis are not yet understood, and it is possible that it involved electroweak physics. Through baryogenesis the cosmic asymmetry between matter and antimatter and CP violation are intimately linked: advances made in understanding CP violation in the laboratory will further our understanding of the baryon asymmetry of the universe and vice versa.

Neutrino experiments with astrophysical and cosmological significance range from table-top searches for nuclear decays with the emission of two electrons and no neutrinos to arrays of photomultipliers monitoring vast domains of water or ice in order to detect very-high-energy cosmic neutrino sources. Neutrinos from the supernovae of 1987 (SN 1987a) in the Large Magellanic Cloud were detected in devices intended to observe proton decay, illustrating how intertwined astrophysics and particle physics have become.

Measurements of the flux of solar neutrinos are of special astrophysical interest. The solar neutrino deficit has been a puzzle for many years and new powerful detectors are beginning to address the problem. It may be that a resolution of the solar-neutrino problem is near and will advance our understanding of both neutrino physics and the details of the solar interior.

Particle physics began with the observation of cosmic rays. Remarkably, we still understand little about the origin and propagation of very-high-energy cosmic rays. Investigations high in the atmosphere, at the surface of the earth, and in underground detectors are addressing these important questions. Larger detectors, borrowing significantly from technology developed in high-energy physics and involving high-energy physicists, are being designed.

Because astrophysical and cosmological phenomena occur over such a wide range of circumstances – from the cosmic rays to the early universe – they can be exploited to study fundamental physics in regimes beyond the reach of terrestrial laboratories. The knowledge derived has been very useful: hadronic cross sections at very high energies; nucleosynthesis limits to the number of light neutrino species (and other light particle species); cosmological limits to neutrino masses and other properties; constraints on the axion based upon neutron stars, white dwarfs, and red giant stars; and a host of limits to neutrino properties based upon SN 1987A.

The unification of the strong, weak and electromagnetic forces seems to require the inclusion of gravity and to demand its quantization. There is much important theoretical activity, ranging from the study of quantum aspects of tiny black holes and to understanding the implications of superstring theory for particle physics, gravitation, and cosmology. On the experimental side, a new era will dawn soon when the laser interferometric gravity-wave detectors being built in the U.S. (LIGO) and in Europe (VIRGO) are commissioned. These devices have the potential to detect astrophysical sources as well as sources connected with the early universe.

The closely related fields of astrophysics, cosmology, and unification of forces are flourishing. Thanks to the wealth and diversity of experimental and theoretical effort, the field is poised for major advances in our understanding of:

- solar neutrinos and the sun,
- how structure formed in the universe,
- the earliest moments of the universe, and
- the nature of the mysterious dark matter.

Despite the rosy scientific outlook, a difficult structural problem needs to be addressed:

- Because this work is intrinsically interdisciplinary, it is hard to weigh properly quite different research proposals against each other or find appropriate funding, since no agency has well-defined responsibility for the field.

8 Exploratory Theory

The remarkable success of the Standard Model is important not just for the questions it answers, but for the questions it lets us ask. Are the electroweak and strong forces, themselves, expressions of a single, unified force? Is there a yet more complete unification, one that includes gravity? What determines the number of quarks and leptons, their masses and the CKM quark mixing matrix? Speculating about these issues and exploring subjects seemingly remote from experiment are important intellectual frontiers for particle physics. Furthermore, if the past is any guide, it is likely that these deep questions will be eventually answered by the discovery of important new organizing principles.

Theoretical speculations, no matter how attractive, must ultimately be validated by experiment. Thus, although the idea of unifying the electroweak and strong interactions is compelling, the absence of proton decay at the predicted levels has served to rule out the simplest grand unified theories. Moreover, the predicted coalescence of the couplings of the electroweak and strong interactions at a single high energy also did not seem to be fulfilled in these theories. Nevertheless the idea of unification of all forces continues to be a theoretical beacon. There are attractive alternatives to the simplest grand unified models involving the possibility that nature has a symmetry, supersymmetry, that connects bosons with fermions.

If the speculation that supersymmetry exists in nature is correct, then every known particle has a yet-to-be-discovered partner with a different spin. While no supersymmetric partners have yet been found, there is some indirect circumstantial evidence that these particles exist, but have TeV-scale masses. When their effects are considered, the couplings of the electroweak and strong interactions do coalesce at high energy, as required by unification. Furthermore, supersymmetric grand unified theories also lead to longer proton lifetimes. Finally, supersymmetry also helps us understand why some particle masses are much smaller than the scale set by gravity. If these speculations are correct, supersymmetry should reveal itself directly at the energy scales which will be probed by the LHC, if not at lower energy accelerators.

Supersymmetry has additional motivation. It arises from the ambitious efforts to encompass all interactions, including gravity, in a single theory. String theory provides the hope of answering many of the hard, deep questions that face particle physics. Over the past decade, string theory has developed into a thriving discipline, with applications both inside and outside particle physics. In particular, string theory has suggested plausible extensions of the Standard Model and has motivated phenomenologically interesting interrelations among low energy parameters.

Nevertheless, string theory remains speculative, separated from the rest of particle theory and experiment. It is important to bridge this gap and find evidence for or against these speculations. Indeed, perhaps the most important attribute of exploratory theory is that it demands that even the wildest speculations should ultimately be testable experimentally.

9 Accelerator Physics, Technology, and Facilities

In the past, progress in particle physics has depended strongly on developments in accelerator physics and technology. As we reach for higher energies and the increased particle fluxes necessary to extend the frontier, continued advances in accelerator physics will become ever more important. This study has concentrated particularly on three aspects of accelerator physics: hadron colliders, electron linear colliders, and novel technologies. It has led to several conclusions concerning the need for accelerator R&D in the U.S.

Hadron Colliders

Design considerations for luminosity and energy upgrades of the $\bar{p}p$ Collider at Fermilab are important to the near-term prospects for hadron colliders. Antiproton production is the key to high luminosity in the Fermilab Tevatron. Reviews of various options revealed no insurmountable technical barriers to achieve higher luminosity, but the necessary trade-offs, costs, and the potential impact on the Main Injector program need to be evaluated carefully. Thus we recommend that:

- Continued studies and design work on schemes to increase antiproton production at Fermilab should be vigorously pursued.

Superconducting magnets are the enabling technology for the highest energy machines. If the U.S. is to remain in the forefront of accelerator physics, reassembly of a U.S. superconducting magnet R&D program is critical. Thus we also recommend that:

- Support for R&D in the area of superconducting magnet technology should be strengthened.

In this respect, significant participation in the LHC project could be a valuable and important component of a U.S. program for hadron collider R&D. Such participation would be most valuable if it were targeted toward those areas which represent the greatest challenges in moving toward the future, such as superconducting magnet and beam tube vacuum technology.

New ideas for overall systems design of a collider facility in the 30 TeV per beam energy range, which could be constructed sometime following completion of the LHC, were also explored. Although the challenges are enormous, some of the ideas seem feasible and should be explored further.

Electron Linear Colliders

The SLC has demonstrated that linear colliders can be made to work and can provide a way to reach the TeV scale in electron-positron accelerators. As a result, interest in this technique has grown considerably over the last few years and there is considerable R&D underway. Snapshots of the worldwide design and prototype research for future e^+e^- linear colliders (CLIC, JLC, NLC, SBLC, TESLA, and VLEPP) are described in the study and their critical issues evaluated. Although the basic features of these linear colliders are fairly generic, the work has led to several possible approaches.

For electron linear colliders the enabling technologies are the high gradient acceleration system, radio frequency power sources and accelerator structures. The technology required to support a next generation linear collider has made significant advances in the recent past and is expected to reach maturity during the next few years. Therefore, we recommend that:

- Facilities in various parts of the globe that test different technical issues and different technological options for linear colliders should be completed as expeditiously as possible, so that a conceptual design for a next generation linear collider based on proven technologies can be developed.

Novel Technologies

Cost played a pivotal role in the cancellation of the SSC, and is a major issue in the success of the LHC. The importance of cost will increase further due to the technical difficulties that will be encountered in producing higher energies or luminosities. Thus we are challenged both economically and technically to find new acceleration techniques in order to reach new frontiers. This implies that:

- Continued investment in generic accelerator research is required to continue to open new experimental opportunities at expanding energy and luminosity frontiers.

Wakefield, laser near-field, inverse-Cerenkov, plasma, and free-electron laser accelerators are among the methods considered in the report. Alternate particle colliders include $\gamma\gamma$ and $\mu^+\mu^-$ colliders.

10 Detectors

Progress in particle physics requires state-of-the-art detectors to exploit the increasing energy and beam intensities at accelerators. Collider detectors at hadron and electron machines have met the demands of increased data rates and higher precision through innovations in tracking, calorimetry, electronics, and computing.

Innovations in detector technology have had a major impact outside particle physics. A particularly important example is medical imaging, which benefits from the high-resolution, high-speed, high-efficiency x-ray detection pursued at high-energy physics laboratories around the world.

Accelerators now being designed will demand improvements in many aspects of particle detectors. Increased beam intensities will require the use of radiation-hard materials and electronics. The increased data rates will demand higher bandwidth data acquisition systems. Increased particle densities from very high-energy collisions will necessitate higher density, lower cost electronics. The tagging of particles with picosecond lifetimes will require improved vertex detectors and fast vertex triggers. And the use of high precision electromagnetic calorimetry will call for fast, bright, radiation-hard crystals.

There is no question that detector research and development is a vital part of the U.S. HEP program. Until recently, U.S. particle physicists were able to carry out detector R&D using funding provided by the SSC Laboratory. University physicists also benefited from funding provided by the Texas National Research Laboratory Commission. This R&D program stimulated rapid progress and brought together experimentalists from a variety of subdisciplines.

Unfortunately, the cancellation of the SSC brought these programs to an end. Much promising work was stopped or significantly slowed. At the same time, further shortfalls have been created by cutbacks in traditional sources of detector R&D funding, such as laboratory discretionary funds and university seed money. Additional pressures result from the scale of most modern detector projects, which is so large that managers are reluctant to risk adopting new and unproven technologies. Although new technologies often enjoy some support in the early phases of these projects, there is inevitably pressure to focus limited resources on a single technology.

These considerations lead us to recommend that independent support be provided for detector development work. Such an R&D program must be modest in light of tremendous pressures on the HEP budget. The administrative aspects of this program are best determined in consultation with the funding agencies. However, a few general features are desirable:

- The primary aim of the program should be to provide an incubation period for new ideas.
- Funding decisions should be based on review by a peer-review committee.
- Most projects should be limited to three years of funding, after which time their support should come from the detector projects or other sources.

- The general level of funding should total about $3M per year. This would allow about six new starts of projects with annual budgets in the $50,000 to $250,000 range.

Detector development is a vital component of high-energy physics. It is essential that the field invest in new technologies to prepare for the challenging environments of future experimental facilities.

11 Computing

Historically, high-energy physicists have made extensive use of state-of-the-art techniques in computer and communication technology. For example, particle physics experiments pioneered the use of real-time computer techniques. As collaborations grew in size and scope, particle physicists were among the first to make effective use of computer networks. Indeed, the popular World-Wide Web application was developed by high-energy physicists at CERN.

Particle physicists have long employed advanced computer analysis and simulation techniques and have made productive use of the most powerful computers available. However, as the use of computers becomes increasingly part of the mainstream, particle physicists will need to change the way in which they use and develop software. They must make the transition from being major developers of computer technology to being just one set of users among many areas of application.

Although this change may introduce some short-term problems, on balance the effect should be positive because much of the software development work that formerly fell to particle physicists will now be done by specialists. Ultimately, this will allow more time to be devoted to science. This has already long been the case for computer hardware, where the HEP community has consistently been able to exploit commercial products.

The main challenge for the future is to learn how to make good use of commercial software products in a cost-effective way. The following set of recommendations could help the community meet this challenge:

- The U.S. HEP community should formulate a coherent approach to the use of computing technology.
- Computing at U.S. HEP institutions (universities and laboratories) should be re-capitalized in a way that is compatible with current and anticipated industrial developments toward open systems.
- The U.S. should provide centers of CPU power and storage for simulation, reconstruction, and analysis, that are accessible to any HEP institution.
- Modest funding should be made available to carry out R&D in aid of this new direction.

12 Structural Issues in High-Energy Physics

This working group addressed three areas of concern: Governance and Advising, Career Issues, and Education and Outreach.

Governance and Advising

One of the important problems for the field to address is that of governance, advising, and planning. At present HEPAP plays the role of advising the government, specifically the Department of Energy, about issues concerning high-energy physics and, to some extent, helps in the planning for the field. Historically this is the only body that substantively considers the field as a whole; so far the DPF has played only a minimal role. Concerns have been raised throughout the community recently about the effectiveness, limitations, and flaws of this approach in an era of shrinking budgets and increased demand on available funds. In response to these concerns, it is important to consider additional mechanisms which might improve planning the future of the field.

This question was discussed at two open meetings held during the study as well as at town meetings held in conjunction with the work of the Drell subpanel. From those gatherings, and through deliberations among the working group and with the DPF Executive Committee, the following recommendation was formulated:

- The DPF Executive Committee should commission workshops and studies on issues of great importance to the field.
- These studies, which in general should be of short duration, would be carried out by ad-hoc panels appointed by the Executive Committee in consultation with the funding agencies and the national laboratories.
- The reports resulting from these studies should then be disseminated promptly to the HEP community and the public.

Career Issues

The cancellation of the SSC put more than 100 physicists into the job market. That, coupled with reductions in funding and the concomitant loss of employment opportunities emphasizes the importance of studying career issues.

Reliable demographic data are a prerequisite for a meaningful study. These data are now being gathered by the Particle Data Group under the auspices of both the DOE and the NSF. Obtaining accurate data, however, is only the first step toward understanding career opportunities open to high-energy physicists and devising ways to help improve career paths in the discipline. One early conclusion is that it is important for high-energy physicists to be aware of all the opportunities open to them both within and outside the discipline. Within the profession, young physicists should be educated to the needs of employers in government and industrial laboratories, as well as in universities. Conversely, it is important that potential employers be aware of how high-energy physicists can contribute to their enterprises. To foster these goals, we recommend that the DPF Executive Committee:

- should organize a Subcommittee on Careers to arrange meetings, prepare literature, and devise mechanisms to educate young colleagues about employment opportunities and the means of enhancing their prospects for obtaining jobs; and
- should consider the appropriateness of, and possible improvements in, the education of graduate students, with an eye towards enlarging the employment opportunities for those with training in high-energy physics.

Outreach and Education

The cancellation of the SSC made it particularly clear that we must increase our efforts to educate the public and those in government about the societal benefits of the pursuit of research in high-energy physics. Already substantial efforts are underway, both by individuals and by the laboratories. These form a base upon which to build.

As a result of the study, a sub-group was formed to examine ongoing outreach and education efforts and seek proposals for new directions. Named POET, for Public Outreach and Education Team, this group has begun to sensitize the high-energy-physics community to its existence, and to solicit ideas about possible future activities. To encourage these efforts we recommend that:

- The DPF Executive Committee should support the activities of the POET group as a means of enhancing the outreach and education efforts of particle physicists.

13 Conclusions

This study has highlighted the vitality and intellectual breadth of the U.S. program in the context of the international high-energy physics effort. We hope that the study has also helped to delineate for a wider audience the key elements of worldwide high-energy physics research into the first decade of the next century.

In accord with the Drell Subpanel report, we believe that the LHC program will define the high-energy physics frontier and that participation by U.S. physicists in this effort is essential. In addition, we expect that the Fermilab Main Injector, the SLAC B Factory, and Phase III of CESR, as well as the RHIC accelerator at the Brookhaven National Laboratory, will provide frontier capabilities in other fundamental areas of research.

The picture of the future U.S. accelerator-based program beyond these facilities is much less in focus. Specific groups are considering possibilities as diverse as room temperature or superconducting linear e^+e^- colliders, substantial upgrades in the luminosity or energy of the Fermilab Tevatron, and muon colliders. Although many aspects of these options were studied by the working groups, this effort did not include substantial comparisons nor was there any attempt to set priorities.

We believe that now is the appropriate time to begin to develop a coherent plan for the longer term future, based on comparison of the physics potentials of possible new facilities. It is also time to move toward a consensus for the U.S. program beyond the LHC and current upgrades to U.S. facilities, in the context of the international program.

To accomplish this, members of the U.S. HEP community should meet with individuals from other nations to compare the capabilities, feasibilities, and relative strengths of these initiatives with those of the LHC and other facilities that will likely operate in the LHC era. This type of evaluation has traditionally taken place in DPF-sponsored Snowmass workshops. Thus we propose a similar workshop to be held in the summer of 1996 to begin to address these crucial issues.