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University Grants Program Subpanel Report

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Executive Summary

Particle physics in the United States stands at a crossroads. On the one hand, it is a time of great opportunity. The CERN Large Hadron Collider (LHC) and new experiments in astrophysics, cosmology, and neutrino physics promise to revolutionize particle physics and, quite possibly, our understanding of the universe itself. When the LHC begins operation and the three U.S. collider programs[1] shut down, a major focus of U.S. particle physics will move offshore. This new era of scientific opportunity will challenge program management and force a new focus in the particle physics portfolio. In this new portfolio, the balance between large and small groups, old and new ones, infrastructure and research personnel, laboratories and universities, must change to match the evolving scientific opportunities.

Particle physics (also called high energy physics—HEP) is a vital component of the national scientific program. It addresses important and challenging questions, ranging from the nature of matter at the smallest imaginable scales to the structure and composition of the universe. In recent decades, particle physicists have made dramatic advances, identifying basic constituents of the subatomic world, together with the laws governing their interactions. Recently, we have been faced with the astounding realization that we can only account for a small fraction of the matter that makes up the universe. Today, we are exploring the frontier of the quantum universe, seeking the origin of mass for the elementary particles, the identity of the missing mass in the cosmos, and the nature of the dark energy that dominates the universe.

Particle physics drives many exciting and important explorations in the basic sciences and has a remarkable record of contributing to the nation's technical strength. Particle physics research has advanced computing from the very early days of computer miniaturization to the development of the World Wide Web. Today the tradition continues: HEP research is a key driver of grid computing, providing unparalleled access to high-throughput computing utilizing networked facilities. Particle beams are being used for medical treatment and biological and materials research. Particle physics research continues to advance the design and manufacture of new electronics chips. Over the past decades, industry has continued to regard students trained in particle physics as an important talent pool—a source of individuals whose highly coveted advanced technical skills are enhanced by their experience in global collaboration.

The recent 2006 National Academies report "Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics" (EPP2010) addressed why and how the U.S. should maintain leadership in elementary particle physics. It highlighted the compelling science facing the field, together with the field's role in inspiring young scientists, attracting the best minds from around the world, and helping drive U.S. technological innovation. U.S. physicists have played leading roles in advancing the field to the present threshold of discovery. The U.S. program now focuses on fulfilling the potential of the LHC, which includes a luminosity upgrade (Super LHC—SLHC); R&D on the International Linear Collider (ILC); preparation for a bid to host the ILC; and experiments in astrophysics, cosmology, and neutrinos, together with a variety of smaller-scale experiments. This opening of multiple scientific frontiers is exciting, providing the field with a wealth of new opportunities to explore.

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[1] Fermilab Tevatron, SLAC PEP-II, and Cornell CESR.

This program requires investments, in both the national laboratories and the universities. The labs and the universities are equally vital components of a robust physics portfolio that combines human and facility resources to advance science. Current examples of the strong partnership between the labs and the universities include collaboration on the LHC and ILC programs, as well as collaborative work toward developing the U.S. program in astrophysics, cosmology, and neutrinos. This partnership forms the backbone of the success of the U.S. high energy physics program.

The focus of this report is explicitly on the role of universities in high energy physics research—their accomplishments, their centrality, and the challenges they face. While maintaining this sharp focus, the subpanel does not intend to overlook the enormous contributions of colleagues at the national laboratories, at institutes, or in industry. The roles these entities play are clearly important. However, the University Grants Program has not been examined for a very long time. The subpanel thus believes that more sustained attention to this program is important to the success of the entire U.S. effort in particle physics.

Universities contribute mightily to the partnership described above. University physicists provide scientific leadership; most particle physics experiments and many innovative techniques were initially conceived at universities. Today, university R&D efforts drive the future of the field. For instance, university researchers are at the forefront of many recent initiatives in the non-accelerator area, particularly particle astrophysics. Universities' combined mission of research and education rewards creativity and innovation and promotes a diverse program of science and scientific techniques.

Universities also provide opportunities for cross-disciplinary interactions with colleagues in other fields, such as condensed matter physics, electrical engineering, mathematics, computer science, biology, and sociology. Collaboration with outside experts in these fields leads to new directions for both theory and experiment. In addition, universities bring considerable resources to the national program through their financial support of personnel, equipment, and infrastructure. While the cross-disciplinary opportunities at the national labs are restricted to those activities within the labs' mission scope, no such boundaries limit cross-disciplinary research at universities. Universities, therefore, provide a greater opportunity to pursue such cross-disciplinary activities, of a wider scope.

Universities are also the principal training ground for physics students and postdocs. The training they provide produces scientists whose talents advance the field and, more broadly, drive the innovation economy. Universities are the portal inviting entrance to groups underrepresented in the sciences. Investing in strong experimental and theoretical programs at universities increases our nation's technological strength, global competitiveness, and scientific diversity.

The committee's report can be summarized through a set of findings and recommendations. The primary findings are as follows:

- **The EPP2010 report articulated the scientific priorities for the coming decade. Realizing its vision requires a partnership between the universities and the national**

laboratories. Each is a vital component of a robust investment portfolio in particle physics.

- **University groups make theoretical breakthroughs, develop innovative detector technologies, and initiate novel experimental approaches. In addition, they perform most of the analysis of the data from high energy physics experiments. These university strengths draw undergraduates to science and bring some of the world's best minds to our graduate programs.**

- **A thriving university research program advances science and nourishes the technical strength of our nation.**

- **University groups are sources of innovation. They are competitive, entrepreneurial, and diverse in their strengths, their students, and their science. Successful groups require:**

    - **Compelling scientific questions**
    - **Outstanding personnel**
    - **Freedom to innovate**
    - **Sufficient infrastructure**
    - **A clear and timely review path for their proposals**

- **University researchers are helping lead the LHC; developing the SLHC and ILC detectors; initiating new experiments in astrophysics, cosmology, and neutrino research; and inventing new strategies for exploring particle physics. Many of these experiments are expanding the boundaries of the field.**

This report's recommendations flow from these findings. The primary recommendation is based on the committee's conclusion that the University Grants Program must be strengthened to achieve the goals of the U.S. particle physics program:

- **The University Grants Program must be strengthened in order to achieve the goals of the national high energy physics program, as articulated by EPP2010. This requires increased investment and careful attention to building and sustaining levels of personnel and infrastructure necessary for successful university research groups.**

While this strengthening does require some additional funding, as documented in this report, the scale of this funding is at about 1% of the HEP budget. This sum should be accessible from a portion of the redirections that will result when the labs cease operating their colliders. For example, although the national program will not be supporting collider operations in the U.S., it will need to support the remote stationing of hundreds of U.S. physicists and students overseas, 90% of them from universities.

Indeed, as the collider energy frontier moves abroad, and more experiments are not necessarily located at the U.S. national labs, the committee expects the universities' role to become even more important in sustaining U.S. leadership in the field. For this reason, the committee makes a number of recommendations to ensure that universities can meet this challenge. All strengthen the elements required for university groups to succeed:

- **Group sizes should be sustained, and increased where appropriate and supported by peer review. The agencies should make a special effort to support long-term research scientists as an integral part of this group structure, particularly when they provide expertise essential to the experimental program or leadership at a remote laboratory.**

- **Funding directed at university-based theoretical particle physics for the purpose of increasing the number of HEP-grant-supported graduate students should be given a higher priority in the overall HEP program. Support for students and postdocs doing calculations related to upcoming experiments is particularly urgent.**

- **University-based technical development should be funded at a level commensurate with its great importance. The investment should be adequate to provide the necessary equipment, technical and engineering support, and infrastructure.**

- **The University Grants Program should fund the development and mounting of small and mid-scale university-based experiments that are highly rated by peer review and, where appropriate, by the Scientific Assessment Groups (SAGs) and the Particle Physics Project Prioritization Panel (P5). This may require supplements to the University Grants Program.**

In the coming era, the University Grants Program needs to be nimble and well managed, able to react quickly to emerging scientific opportunity. In particular, the balance between large and small groups, old and new ones, infrastructure and research personnel, laboratories and universities, should evolve in response to the changing priorities and goals of the field. To facilitate this process, the committee applauds and endorses Committee of Visitors (COV) reviews, suggests changes to P5's SAGs, and recommends a new University Grants Program Committee to provide timely advice to program managers:

- **A University Grants Program Committee (UGPC) should be formed to consult with University Grants Program agency managers on the issues facing the University Grants Program. The chair of this committee should be chosen cooperatively by both agencies and by the chairs of the High Energy Physics Advisory Panel (HEPAP) and the American Physical Society Division of Particles and Fields (DPF), Division of Astrophysics (DAP), and Division of Particle Beams (DPB). This chair should serve as a spokesperson for the university community.**

The chair of the UGPC will be well suited to representing the university community, much as the lab directors represent their communities. He or she will be expert on the University Grants Program and in close contact with the agencies and the lab directors. The UGPC would inform HEPAP about the University Grants Program as HEPAP considers the health of the field as a whole. The UGPC, for example, would provide advice on such issues as the balance of university group sizes and investment in university infrastructure. The UGPC is intended to recommend priorities for funding the University Grants Program in general—for example, group sizes, theory support, travel costs, and infrastructure. The UGPC is not intended to recommend priorities among scientific programs, as does HEPAP or P5.

As our field experiences increasing diversification, the scientific questions are expanding. Much of the laboratory fixed-target program has been replaced by experiments in astrophysics and cosmology; by other experiments, such as neutrino mass searches, that use "nature's beams"; and by yet others that use the techniques of other disciplines to address questions of interest to particle physics. No clear mechanism exists for the review and funding of experiments that are not based at a lab. Such an effective mechanism could be produced, however, through evolution of the existing SAGs and P5.

- **The SAGs should regularize their role in reviewing projects.**
    - **Each SAG should actively monitor and prioritize the experiments and R&D in its area. It should evaluate both physics goals and technical design.**
    - **The SAGs should report to P5, timing their reports so that they are available to P5 when needed.**
    - **The SAGs should review all experiments with expected construction costs above $5M, along with smaller ones seeking review. This includes both experiments that are affiliated with a U.S. laboratory and those that are not. Additional SAGs should be created as needed to cover all areas (taking care to avoid proliferation).**
    - **HEPAP should establish mechanisms for prioritizing experiments whose cost is above $5M but below the P5 threshold. The prioritization process should take advantage of input from the SAGs and should reflect the breadth of the field.**

- **We applaud the COV process and endorse its continuation. Among the issues that future COVs should address are:**
    - **Mechanisms for the consistent review of lab- and university-based researchers**
    - **The competitive review of proposals, through panels or other means, within the University Grants Program**
    - **The workload of University Grants Program staff**
    - **Implementation of a DOE database comparable to the one used by NSF that makes institutional, funding, demographic, and programmatic information readily available**

University innovation is a key to the future, vital to both clearly identified programs such as the SLHC and ILC and to those that are now being developed. Many such initiatives add great diversity and vibrancy to the field. The committee recommends that the program directly support technical innovation and promote it in other ways, for example, by utilizing university infrastructure for major projects when doing so is cost-effective and by allowing universities flexibility in how they spend research funds:

- **As much as possible, universities should be funded through merit-based peer-reviewed proposals, rather than through specific project-based funds.**

The mainstay of the University Grants Program is the proposal-driven peer-review grant system, which supports students and postdocs and affords universities the opportunity to explore new areas. Recently, however, support levels for the physics base program have declined in favor of funding designated for specific programs or channeled through specific projects. While these projects are needed, and while this system provides effective project management, it has detrimental side effects for the University Grants Program, such as reducing flexibility and restricting research that is purely exploratory.

- **The agencies should support university technical infrastructure as part of grants, including hardware development. In addition, project managers should utilize university resources because they are economical and effective, and they should report on this optimization at major project reviews.**

U.S. participation in the LHC and other overseas experiments requires additional travel and subsistence costs, as well as investments in remote conferencing, data networking, and computing. Three recommendations directly address issues that arise from overseas operations:

- **The agencies should continue their efforts to ensure that the vision for LHC computing is realized. This includes working across and within agencies to ensure sufficient network and computing capacity.**

- **The agencies should support efforts to ensure that both U.S. sites and key sites abroad are equipped with remote videoconferencing systems that are reliable, robust, and readily available.**

- **The agencies should support the increased travel and subsistence costs of university researchers participating in the LHC and other overseas experiments.**

Finally, university researchers are extensively involved with community outreach. Through QuarkNet and local programs, university scientists have developed deep roots in their communities:

- **The agencies should foster outreach by, for example, funding new positions dedicated to facilitating and coordinating university outreach efforts.**

The LHC in particular offers a special opportunity to engage undergraduates in science:

- **Additional support should be made available to enable undergraduates and high school teachers to participate in experiments offshore. In addition, support should be continued for an NSF Research Experiences for Undergraduates (REU) program at CERN, following discussion of its structure with representatives of interested university groups.**

The next decade may bring some of the most profound discoveries in the history of particle physics. With a vigorous University Grants Program, the United States will be in a strong position to maintain and sustain world leadership in this endeavor.

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1 Overview

Elementary particle physics is on the threshold of a new age of discovery. The advances and breakthroughs of the last century have led to exciting new questions about the structure of the universe and to a new generation of instruments with unprecedented sensitivity and reach.

These opportunities are emerging at the same time as the contours of research in elementary particle physics are shifting rapidly. When the Large Hadron Collider (LHC) starts up and the three U.S. collider programs close[2], a major focus of U.S. particle physics will move offshore. This represents a substantial shift in the way particle physics is carried out in the United States. The results will challenge program management and force a new focus in the particle physics portfolio. In this new portfolio, the balance between large and small groups, old and new ones, infrastructure and research personnel, laboratories and universities, will need to evolve to match the scientific opportunities. In the U.S., many of the most promising new initiatives, including some in astrophysics and cosmology, are centered at universities. More than ever before, U.S. universities must play a leading role in advancing the science in order to sustain U.S. leadership in the field.

In view of the changing landscape facing university high energy physics programs, the High Energy Physics Advisory Panel (HEPAP) formed the University Grants Program Subpanel (UGPS) in the summer of 2006. The charge presented to the UGPS, its membership, the processes it used to acquire community input, and a guide to its specific responses to the charge are presented in the appendices. In this final report of the UGPS, we examine the changing patterns facing the field, assess the many new opportunities in research and education for university groups in elementary particle physics, and attempt to think afresh about potential synergies between the university community and the national laboratories. Our goal is to articulate a new vision for the University Grants Program in the U.S.

At the high energy frontier, the LHC will soon give us direct access to the Terascale—an energy regime named for the tera-electron volts needed to reach it—and thus the potential to discover the mechanism of particle mass generation, supersymmetry that links mass particles with force particles, and the dark matter making up most of the universe and extra dimensions. Meanwhile, new and highly sensitive experiments are attempting to detect directly the unknown particles that comprise the dark matter of the universe, observe time-reversal symmetry violation through electric dipole moments, and see lepton number violation through neutrino-less double beta decay. Planned neutrino oscillation experiments, sensitive to even small mixing effects, may reveal CP violation in the leptonic sector.[3] A new generation of Earth-based experiments and space missions will probe details of the dark energy, invoked to account for the acceleration of the universe, and observe gravitational radiation.

These exciting frontiers are opening as important accelerator-based programs in the U.S. are approaching the end of their scientific life spans. The opportunities on the immediate horizon

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[2] Fermilab Tevatron, SLAC PEP-II and Cornell CESR.

[3] For explanations, see individual subsections in section 3.

offer a wide breadth of new directions for the field that will only be explored through the leadership of university researchers. Looking further to the future, an impressive worldwide planning and R&D process is well under way for the International Linear Collider (ILC), and accelerator research is generating a host of new and promising ideas for major advances in energy reach.

Theoretical research is also broadening its range and addressing ever more important and challenging questions. Lattice Quantum ChromoDynamics (QCD), now providing new quantitative accuracy, is placing increasing demands on computational support. String theory, incorporating quantum gravity and shaped by compelling ideas of consistency and symmetry, has captured the attention of many in the theoretical community. Problems in cosmology and astrophysics are equally attractive, drawing a broad spectrum of theorists. Many others continue to develop and explore models of Terascale physics that extend the Standard Model, which will be directly tested at LHC energies. Further, as we enter the LHC era, there is a growing need for more phenomenological work, which is critical for collider physics.

Realizing these aspirations will require the aggressive participation of both the national laboratories and the universities. The laboratories provide facilities for LHC data analysis, tools and expertise required for developing the ILC, and beams for neutrino experiments. Universities will lead U.S. analysis of LHC data; carry out most of the theoretical calculations necessary to interpret it; lead the design of the Super LHC (SLHC) upgrade and ILC detectors and contribute to ILC accelerator technology; and conceive and design new experiments in astrophysics, cosmology, and neutrino research. Irrespective of the eventual ILC site, strong U.S. university leadership at this frontier facility is vital to continued U.S. leadership in worldwide HEP.

The nation's universities are home to 80% of U.S. researchers in particle physics. They bring dynamism, leadership, innovation, and creativity. They attract excellent students, both graduate and undergraduate, who are eager to pursue new ideas, tackle challenging problems with tenacity, and leap at the opportunity to take novel or ambitious approaches. They attract superb faculty members, hired and promoted on the basis of their drive, entrepreneurialism, and accomplishment. They are diverse in terms of their facilities, their areas of strength, their geographical regions, and the aspirations of their students.

Further, the broad range of research activities at universities makes them natural crucibles for interdisciplinary thinking and collaboration. Theorists in elementary particle physics, for example, have often drawn on work in condensed matter theory, and vice versa. The development of the highly sensitive detectors critical for modern research relies strongly on work in low-temperature physics, materials science, and condensed matter physics. Joint seminars, informal discussions, and chance encounters provide the innovative ideas essential for progress.

In order to realize their potential, however, university groups require an appropriate framework. A faculty member with a new idea for a detector technology must have the flexibility to hire a graduate student, or redirect a postdoc to the task, if the technology is to come to fruition. A professor with a new strategy for electronics readout needs access to an engineer, not once but many times, as she pushes through from concept to working device. Another with a novel idea for analyzing LHC data must have the tools necessary for remote conferencing with his students and postdocs at CERN and with other physicists. A university researcher applying techniques from condensed matter physics to a dark matter search needs a timely and definitive path for the review of the experiment.

In this report, we specifically identify five elements that must be in place for university groups to achieve their potential. They are:

Compelling scientific questions. University groups in particle physics now have an unusually crisp set of questions and goals before them. These include exploration of the Terascale and the study of dark matter, dark energy, and neutrino oscillations.

Outstanding personnel. University groups require excellent students, postdocs, research scientists, and faculty to build and operate detectors, analyze data, and assume leadership responsibilities. The number and mix of personnel depend on a group's scientific goals.

Freedom to innovate. University physicists are most productive when they can follow their ideas and go where they see the best science. They will flourish when they have sufficient resources to innovate.

Sufficient infrastructure. New technologies and experiments require specialized electronics, devices, and parts. Developing these is almost always an iterative process that proceeds most efficiently if engineering support and shops are located at or near the universities themselves. Data analysis, particularly of enormous samples like those from the LHC, requires a robust, high bandwidth and a reliable network, adequate computing cycles, and system support.

A clear and timely review path for proposals. Physicists need a clear process for the peer review of new initiatives and proposals. This process should apply both to experiments and proposals in the mainstream of the field and to those that lie near its boundaries or are interdisciplinary. The process should produce a definitive response to every submitted proposal in a timely manner.

Stewardship of these elements necessary for strong university groups will have enormous benefits for the field, for the laboratories, and for our society as a whole. An idea for particle acceleration developed today may be the basis of a next-generation collider. A new detection technique may make an otherwise expensive experimental approach affordable. The careful theoretical calculations of a university physicist may enable sweeping conclusions to be drawn from experimental measurements. Students, both undergraduate and graduate, drawn by the exciting research at universities, will go on to become the scientists of tomorrow.

In keeping with its charge, the subpanel has keenly focused on the role, accomplishments, and prospects of the University Grants Program. In doing so, it is not the subpanel's intent to minimize the very significant contributions to the enormous success of the field that have stemmed from colleagues in other sectors—including the national laboratories, institutes, and industry. Nor is the subpanel ignoring the important roles these entities will undoubtedly play in the future. The subpanel does note, however, that unless proper attention is directed to the health of universities during this period of transition, the entire field will suffer. The subpanel further notes that the redirection of a very modest sum to the University Grants Program—on the order of 1% of the overall HEP budget—will address the principal issues identified here. Such a redirection should be feasible, and even expected, in the context of the shifting responsibilities of the overall HEP program

The subpanel has also examined the priorities for the use of funds redirected to the University Grants Program. The first priority is to support university participation in the LHC experiments and their upgrades. This includes sustaining the sizes of participating university groups, supporting theory students and postdocs engaged in phenomenological calculations of LHC physics, and investing in university infrastructure in support of the LHC experiments and their upgrades. The second priority is to support R&D on the ILC. This includes sustaining the sizes of university groups working on ILC R&D and investing in university infrastructure in support of the ILC detectors and accelerator. The third priority is to support experiments in astrophysics, cosmology, and neutrinos, together with a variety of smaller-scale experiments. This includes sustaining the sizes of university groups working on these programs, investing in university infrastructure to support R&D and construction of these experiments, and supporting theory students and postdocs engaged in phenomenological calculations for these programs.

The years ahead may be the most exciting ever in particle physics. Unprecedented opportunities exist at the Terascale and in astrophysics, cosmology, and neutrino research. Renewed investment in the universities will enable the U.S. to realize the current promise and foster future U.S. leadership in science and technology.

2 The Particle Physics Research Program at Universities

2.1 Scientific Goals of Particle Physics

We now know with certainty that matter on Earth is composed of elementary particles called quarks and leptons, interacting via force particles called gauge bosons. The theoretical framework that describes this structure is known as the Standard Model of particle physics. It is a correct and quantitative description of the subatomic world down to the tiniest distances probed so far, tested in recent years to very high accuracy at distances that are a small fraction of the nuclear dimension. Furthermore, the existence of the Standard Model allows cosmologists to understand much about the very first instants of the universe itself.

But what lies beyond the Standard Model? That is the central question that drives particle physics today. A variety of clues, both theoretical and experimental, suggests that new physics is waiting to be found—just over the horizon, but within our reach. First and foremost, the mathematical consistency of the Standard Model itself demands new physics at the Terascale. It might come in the form of a Higgs particle, a new form of matter responsible for the origin of mass, or something even more curious. Most theories of Terascale physics predict a host of new phenomena—new particles and forces that imply new laws of nature.

During the past decade, neutrinos were discovered to have tiny masses. Neutrino masses are forbidden in the Standard Model itself—so something new must be responsible. One possibility is that the neutrino masses are a sign of grand unification, the emergence of a single theory of strong and electroweak interactions at energies far beyond the Terascale. Ultra-light neutrino masses are a generic prediction of such theories. It is even possible that the neutrino masses are an avatar of new dimensions of space. What are neutrinos telling us?

Perhaps the most shocking discovery of all has come from cosmology. During the past decade, we have been humbled to learn that quarks and leptons make up only 4% of the stuff of the universe. Another 25% is composed of some new form of dark matter, which has been "seen" so far only through its gravitational effects but has not been identified. Even more mysterious is the dark energy making up another 70% of the universe, which is responsible for its accelerating expansion. The source of this dark energy is also a mystery. What, then, are dark matter and dark energy? All we know is that they are something new, something not contained within the Standard Model.

The questions confronting us are indeed compelling, touching upon many neighboring fields of science, including astrophysics, cosmology, and nuclear physics. Moreover, the answers promise to be exciting, ranging from new particles to new forces to new laws of nature. The great success of the Standard Model allows us to sharpen our questions and shape our tools, with powerful accelerator experiments exploring the Terascale and astronomical observatories viewing the cosmos from Earth and in space. These tools also include dark matter and neutrino detectors placed deep underground and table-top laboratory experiments searching for tiny signals that would shed light on the questions we face.

As we have seen, the National Research Council's 2006 report on the field, "Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics" (EPP2010), recognized that the scientific opportunities facing particle physics have never been greater. The report prioritized these opportunities as follows: first the exploration of the Terascale through the LHC program and the proposed ILC, then experiments in cosmology and particle astrophysics, followed by a staged program in neutrino physics. These experiments, which address the most compelling scientific questions facing the field, form the context of the present report.

As we approach this task, it will be helpful to keep in mind EPP2010's call for a diverse approach to the task at hand:

> "A broad array of scientific opportunities exists in elementary particle physics, and it is not possible to foretell which will yield important new results soonest. Two of the greatest discoveries of the last decade—the discovery of nonzero neutrino masses and of dark energy—were quite unexpected and arose from experiments that did not use accelerators, the tools characteristic of many other advances in particle physics. Thus, there is a strong need for supporting a variety of approaches to current scientific opportunities.
>
> It is important to maintain a diverse and comprehensive portfolio of research activities that encompasses university-based students and faculty, national laboratories, and activities conducted in other countries. Even during periods of budgetary stringency, sufficient funding and diversity must be retained in the pipeline of projects so that the United States is positioned to participate in the most exciting science wherever it occurs."

The particle physics of the twenty-first century promises to be increasingly interdisciplinary. The university-based community—with physicists from a variety of backgrounds who have close connections to scientists in neighboring fields—is thus poised to play a leading role in the science ahead.

2.2 University Activities in Particle Physics

2.2.1 Universities and Particle Theory

Universities are central to U.S. particle theory because most theoretical work is done at universities. Indeed, university contributions to formal theory are especially strong: almost all U.S. research in string theory and mathematical physics is done at universities or at research institutions closely associated with universities, such as the Institute for Advanced Study at Princeton, the Kavli Institute for Theoretical Physics at Santa Barbara, and SLAC at Stanford University.

Universities' programs of theoretical research also attract students. University theorists train both theoretical and experimental graduate students in particle physics. Theorists teach most of the advanced courses in field theory and particle physics, mentor theory students in research, and often excite students through introductory talks and seminars. Many of these graduate students go on to pursue careers in particle physics. Others, however, successfully utilize their training in other professions involving physics, technology, applied mathematics, and computation.

Theorists also inspire and drive experimental programs at universities, identifying important topics, delineating possibilities, doing calculations needed to determine the signatures of possible new physics and to estimate Standard Model backgrounds, and contributing to the interpretation of new physics discovered in future experiments. An example of the role played by theorists can be found in the precision electroweak program carried out at the LEP, SLC, Tevatron, and HERA colliders and in neutrino and other experiments. This program established the validity of the Standard Model at the level of radiative corrections, constrained top quark and Higgs masses, strongly limited new physics below the TeV scale, and supported supersymmetric gauge coupling unification. None of these successes would have been possible without the major involvement of theorists. Similar synergies exist in flavor physics and in many other areas of particle physics.

Theorists at universities have many opportunities to interact with scientists in other subfields, leading to important cross-fertilization of ideas and techniques. Theorists partner with scientists in overlapping fields such as astrophysics, cosmology, general relativity, and mathematics, as well as in other fields, including condensed matter and atomic-molecular-optic (AMO) physics, which can employ related techniques.

Most research projects in theoretical particle physics, whether supported by the DOE or the NSF, are carried out by individuals or in small groups, typically consisting of one or two senior researchers and one or more graduate students and/or postdocs. The composition and dynamics of such groups can take many forms and often shift from project to project. Often one or two senior researchers may formulate the basic idea for an investigation, which may be vague in its initial phase, while graduate students or postdocs do much of the explicit calculation. All of the collaborators typically get together to brainstorm about the project's direction or about possible new projects. Some theorists tend to carry out major long-term research programs involving several closely related projects that collectively explore a major area, such as the physics implications of extending the gauge symmetry of the Standard Model. Others tend to move from topic to topic, exploring a number of interesting ideas of smaller scope. There are occasional exceptions to the small-group paradigm, involving larger collaborations in major computational projects, such as the Coordinated Theoretical-Experimental Project on QCD (CTEQ), which carries out detailed analyses of the quark and gluon distributions in the proton, or the U.S. Lattice Quantum ChromoDynamics (QCD) collaboration, which carries out lattice calculations of strong interaction effects relevant to precision flavor physics. These larger collaborations involve multiple institutions, but effort is often subdivided, the various components carried out by small subgroups that function in much the same way as other small theoretical groups.

These small groups or subgroups are usually located at a single university, lab, or institute. However, collaborations spanning two or more institutions are also common. Such collaborations stimulate the field by allowing the interaction of individuals with complementary knowledge or skills that are often not available within a single institution. These long-distance collaborations may be carried out via e-mail, telephone, video conferencing, and occasional visits. They often originate when theorists meet at conferences or at institutes such as the Aspen Center for Physics or the Kavli Institute for Theoretical Physics at Santa Barbara. Ideas for new projects, whether or not they are carried out at a single institution, frequently arise from the formal and informal discussions that take place at these meetings. Such interactions allow theorists to keep up with advances in the very broad range of theoretical particle physics topics, as well as advances in experiments and in related areas such as cosmology and mathematics. The formulation and investigation of new ideas in theoretical physics require a strong mix of creativity, extensive knowledge of the field, and technical tools. Extensive interaction with other scientists, facilitating brainstorming, collaboration, and the sharing of information, is thus critical for theoretical research, and adequate support for travel and communications is essential.

While graduate students and postdocs are mentored by their professors and senior researchers, they also learn a great deal from each other. This educational component, which is just as important as their formal course work and training, requires a critical mass of people at their home institutions, as well as the opportunity to participate in advanced summer schools, such as the Theoretical Advanced Study Institute, and in conferences and workshops. Some graduate students in theoretical particle physics still write traditional dissertations, involving one extended investigation carried out individually. However, it is now also common for a graduate student to write a number of papers in collaboration with small groups and then to combine the results into a coherent thesis emphasizing the aspects on which he or she has focused.

As theoretical particle physics encompasses a number of overlapping areas, a brief description will help explain what theorists actually do. The term “phenomenology” is sometimes used to describe all non-formal theory. However, it most accurately refers to the area of theoretical work that is most directly related to experiment. This includes detailed calculation of the predictions of the Standard Model, including the use of lattice techniques to deal with QCD at scales where it is strongly coupled. It also includes the prediction of models of new physics; the identification of useful signatures or analysis methods; and the collection and interpretation of experimental data, often combining the results of different experiments and types of experiments. Work of this kind requires close interaction with experimenters, and it is thus very helpful for phenomenologists and experimenters to be present at the same institutions.

Another class of research is sometimes characterized as model-building—or “bottom-up”—physics. This involves the construction and study of possible theories that incorporate or improve upon the Standard Model, usually involving new physics manifesting at the TeV scale. The model builder must identify classes of models and their motivations, determine which models are allowed or excluded by existing experiments and by cosmological and astrophysical constraints, and work out their predictions and signatures. Two major examples of efforts in this class are supersymmetry, which extends and improves upon the Standard Model, and a variety of theories that replace or modify the Higgs mechanism of the Standard Model with some alternative dynamical method of breaking electroweak symmetry. Another class includes theories involving extra dimensions of space. In all of these, close interaction with phenomenologists, formal theorists, experimenters, and astrophysicists is essential.

Finally, formal—or "top-down"—theory attempts to formulate fundamental theories, such as superstring or grand unified theories, that might provide a unified description of all of particle physics, including gravity, and a framework for ideas in cosmology, such as inflation. Such work, often very mathematical, frequently leads to advances in mathematics as well as physics. The energy scale in most such theories is far higher than we can hope to probe directly in the laboratory. It is therefore challenging, but essential, to connect these formal theories with experiment, and an increasing number of "string phenomenologists" are trying to do so.

The boundaries between these areas are not sharp, and communication among practitioners focused on the different concentrations is extensive. Thus, theoretical particle physics involves a broad range of ideas that link our most fundamental ideas of nature with experiment with overlapping fields such as cosmology and mathematics. The conception and development of theoretical ideas and the training of young scientists require extensive interaction and communication among theorists, experimenters, and others.

Though the universities are strong in formal theory, there has been a decline over the years in conventional particle theory (phenomenology), for a variety of reasons. Phenomenology embraces a number of different areas, including data analysis, collider physics, computational physics, perturbative QCD, lattice field theory, model building, flavor physics, and neutrinos; it overlaps with such areas as strings, astrophysics, and cosmology. All these areas are important; but those directly connected with the LHC are increasingly critical. The entire LHC experimental program requires a strong theoretical component involving calculating Standard Model backgrounds and new physics processes, together with interpreting the experimental results and teasing out their implications. However, the number of theorists working on such topics in the United States, especially at the universities, is inadequate. For example, there are only a handful of people in the U.S. working on computational physics, such as event generators. Many more will be needed to fully utilize the physics potential of the LHC. It is important that much of this effort be centered at universities because (a) much of the experimental analysis will be done at universities, and (b) a university presence is needed to attract graduate students.

A general concern is the overall decline in the agencies' support of graduate students in theory, both formal theory and phenomenology. This decline makes it difficult to train a sufficient number of students. The problem is aggravated by increasing competition for the limited number of available teaching assistantships (TAs) from students in other subfields of physics.

2.2.2 Universities and Particle Physics Experimental Programs

The roles of university particle physicists in experimental programs have been traditionally diverse, whether supported by NSF or DOE. In all large groups, and in most medium and many smaller groups, these diverse roles have included the following:

1. **Experiment Conception.** University physicists have conceived most ideas for new experiments. These ideas emerge as natural follow-ups to previous experimental results or through the collaboration and inspiration of theorists. While experimentalists and theorists exist at both laboratories and universities, the synergy between them can be mainly attributed to university researchers within and across campus boundaries.

2. **Experiment Proposal.** University physicists have been largely responsible for translating conceptions into actuality. The proposal process existed long before Program Advisory Committees (PACs) were convened by the directors of the national laboratories.

3. **Experiment Leadership.** The leadership and management of high energy physics experiments have largely come from university faculty, and collaborations have long been built around university spokespersons.

4. **Experiment Research and Development.** A combination of university and laboratory efforts has allowed the basic R&D necessary to mount experiments. In the "early days," such work could be done at university labs, perhaps in conjunction with beam time at other labs. In recent years, however, such work has increasingly been performed at national laboratories in conjunction with potential experiments or at universities through targeted R&D proposals. In either case, university technical staff has been necessary, whether shared in physics departments or in particle physics–operated shops.

5. **Experiment Design and Engineering.** Originally (by and large until the 1970s), experiments were designed and engineered by university faculty and their technical staffs and colleagues. Over the last twenty-five years, however, as projects have grown in size and complexity, the national laboratories have assumed a larger role. Nevertheless, it is still common practice for university faculty and their engineering and technical staffs to carry significant responsibility for the design and engineering of detector components. Indeed, except for certain very large detector components, arrangements have traditionally been worked out within experimental project management structures (with management responsibility largely coming from laboratory staff) for contracted efforts back at university labs. The existence of university shops and technical staff has made this arrangement possible. Even though detectors have become terribly complex and enormous in scale, university groups still carry significant responsibility for their engineering and construction.

6. **Experiment Construction.** Even though experimental hardware ultimately is brought together at laboratory sites, university faculty and senior scientists often manage the installation and commissioning of particle physics apparatus. While in many cases this requires a full-time laboratory presence, leaves and buy-outs have made it possible for university personnel to take on such responsibilities. This means that within the university particle physics community, a unique set of individuals exist who have experience in professional, technical project management.

7. **Experimental Data Collection.** The 24/7 responsibility for efficient and reliable data collection has been shared among university and laboratory scientists at all levels: faculty,

scientific staff, postdocs, and graduate students. This onerous but satisfying task has traditionally been left to the universities, requiring a frequent and/or extended presence at the accelerator laboratories. It should be noted that this requirement is independent of any academic calendar and that the resulting combination of substantial absences and continuing teaching and university responsibilities places a considerable strain on university faculty.

8. **Experimental Operations.** University faculty, scientific staff, postdocs, and graduate students share the responsibility of operating the detector equipment that they have built. This involves running diagnostics both online while the data is being taken, to identify problems for quick repair, and offline, to validate the data taken in a particular detector for physics analysis. It also involves the repair of equipment and the maintenance of repair facilities. Often this requires detector calibration and dedicated data runs for detector equipment, followed by analysis of this special data. Such activity has a direct impact on the quality of an experiment's physics results. The quality of the calibration and resolution of specific detector elements is decisive in producing experimental results. As in the case of experimental data collection, these 24/7 responsibilities represent a considerable strain on university personnel, and it is vital that they be strongly supported.

9. **Experimental Data Reduction.** In the "early days," analysis of experimental results could be performed quickly by only a few people, sometimes wholly contained within a single university. However, as experiments became increasingly complex in the 1970s, data reduction tasks began to require computing resources located near actual data acquisition sites. Likewise, the computing and storage requirements reached a scale demanding centralized resources that only laboratories could afford to purchase and maintain. For many years, the data were reduced into increasingly more compact record formats, which became small enough to be portable through media or through electronic transfer to university sites. However, such compaction inevitably results in the loss of detailed information. Many of the resulting recalibrations, realignments, or bug fixes thus require centralized reprocessing. Until only recently, such secondary passes could be performed at universities. Now, they are performed over grids linking university and external laboratories together into virtual organizations that share identical software releases and distribute the load of reprocessing, which often occurs while original processing with new data is still ongoing. This "gridification" of near-raw reprocessing has brought universities back into the center of data reduction, requiring the creation of large analysis centers on campuses, with the attendant benefit of a renewed particle physics presence on campuses and additional university support of these facilities.

10. **Experimental Data Analysis**. Wholly separate from raw data processing and reprocessing are the actual assembly of analyzed physics objects into events and the comparison of potential signals and backgrounds. This effort is one of two parallel paths involving computing and analysis functions: analysis of the actual data and understanding of the hardware's capabilities, going hand-in-hand with the increasingly precise whole-detector simulation through specialized Monte Carlo codes. The latter path, again, has in many cases outgrown the capabilities of centralized laboratory resources, becoming a shared responsibility of the universities connected by the grid.

11. **Experimental Results Dissemination.** The responsibility of writing papers and guiding results through the publication and conference process has been largely shared in larger experiments, but the realities of university life—with its constant pressures regarding job searches and promotion—have typically left the dissemination task to be primarily undertaken by university junior scientists, postdocs, or assistant professors.

12. **Results Interpretation and Extrapolation.** Once results have been disseminated, interpretation and competitive comparison begin. Interpretation has traditionally been a contribution of the theoretical physics community and thus, again, almost universally a function of universities. In recent years, the complexity of determining systematic uncertainties has led to a more collaborative environment between theorists and experimenters. These communities are broadly made up of university researchers.

3 Current Research Frontiers

Universities are deeply involved in a wide spectrum of frontier experiments in particle physics. The previous section presented the general roles played by university researchers in particle physics. This section provides a summary of the specific experimental programs in which university researchers have taken leadership roles.

3.1 The Tevatron, LHC, and SLHC R&D Programs

Hadron collider experiments will dominate the energy frontier of particle physics for many years. The Fermilab CDF and DØ experiments do so today; the LHC experiments will soon take their place. The upgraded CDF and DØ detectors have added capabilities to exploit the increased luminosity from Tevatron Run II. The greatest opportunity for a new discovery in particle physics, for at least the next two years, lies with CDF and DØ. They are performing the only measurements of the top quark; precise measurements of electroweak parameters; important studies of QCD; an extensive exploration of the B-sector; and searches for new physics, including supersymmetry and a heavy W (and Z). The recent running of the Tevatron has been good and is producing a substantially enhanced physics sample. University groups are playing leading roles in all aspects of CDF and DØ. University physicists led the analyses of recent results from these experiments, such as B_s mixing. These experiments cannot be sustained without a continued substantial university role. Further decreases in university physicist participation may reduce the viability of further Tevatron collider operations and the ability to fully exploit this world-class data sample.

CDF and DØ have about 670 and 650 collaborators, respectively. Fermilab personnel make up about 10% of CDF and 8% of DØ. Universities, then, contribute the largest group of personnel working on these experiments. Further, many undergraduates belonging to university groups are not counted among the collaboration total, thus increasing the number even further. In addition, university personnel have played key roles in all phases of realizing CDF and DØ, from proposal to conceptual design, prototyping, and fabrication. Members of university groups continue to play leading scientific and technical roles in these experiments. In many cases, vital detector, online, and offline experts are all members of university groups.

Soon the LHC will begin operations and data taking. As noted earlier, the LHC physics program has been endorsed as the highest priority for particle physics by the EPP2010 report, P5, and HEPAP. The LHC, which will operate at 7 times the energy and 100 times the luminosity of the Fermilab Tevatron, is due to start taking physics data in 2008, with initial running expected to yield up 10 fb^{-1} of luminosity. The LHC thus holds great discovery potential for many physics channels. Almost all of the allowed Higgs mass range will be covered with 10 fb^{-1} of data, and with 30 fb^{-1}, the range will be covered with a significance of more than 7 standard deviations.

As of September 2006, U.S. groups contributed 590 of the 2,200 CMS physicists, engineers, and graduate student signing authors, as well as 48 of the 181 institutes, with 510 personnel coming from 47 U.S. universities. U.S. ATLAS contributed 280 scientific authors out of a total of 1,700, and 35 institutions out of 162 institutions. Approximately 70% of U.S. ATLAS personnel are from university groups; and 32 of its 35 institutions are universities. University groups are providing over 80% of the total U.S. personnel on the LHC.

The U.S. LHC program is closely managed and reviewed by both DOE and NSF through the Joint Oversight Group (JOG). The personnel requirements of the program are closely scrutinized to determine an adequate level of support for maintenance and operations (M&O) of the U.S.-supplied parts of the ATLAS and CMS detectors, as well as strong participation in the physics analysis. In 2007, the number of LHC university collaborators includes 570 Ph.D. physicists and 230 graduate students. Of these, at least 160 Ph.D. physicists and 90 graduate students are resident at CERN. By 2015, this number is planned to include 700 Ph.D. physicists and 300 graduate students, of which at least 200 Ph.D. physicists and 150 students are expected to be resident at CERN. As a specific example, the U.S. CMS M&O plan requires the long-term stationing of 120 U.S. physicists at CERN, mostly from universities. During the summer of 2006, about 90 university postdocs and students were working on CMS at CERN. This level of effort is consistent with the U.S. leadership role in the LHC program, particularly considering the fact that European LHC collaborators not stationed at CERN are still closer to the facility. Their strong presence can only be offset by more U.S. collaborators or by more stationed at CERN. Since the University Grants Program supports about 90% of U.S. physicists and almost all U.S. students on the LHC, the burden of providing sufficient physicists falls on the University Grants Program.

In order for the U.S. to continue its leading role, university groups must sustain personnel levels and station many more physicists at CERN, leading to substantially increased costs at a time when the purchasing power of funding agency support for university groups has been declining. In 2007, the reviewed additional annual cost of stationing a Ph.D. physicist at CERN runs between $15K for a postdoc and $25K for a faculty member, while the additional cost for a student is $10K. The additional cost to the University Grants Program of sustaining this level of effort is $4M in 2007 and is expected to climb, with inflation and increased personnel levels, to $5.5M in 2015.

This poses a significant challenge to the University Grants Program, given the history of flat-flat funding.

In order to allow university scientists not resident at CERN to be active and leading participants in the experiments and data analysis, the U.S. ATLAS and CMS collaborations have partnered with the national laboratories to develop physics analysis support centers. These are described in section 3.1.1.

University infrastructure, crucial for supporting ATLAS and CMS construction, now is critical for supporting maintenance and operations. Project-supported university electronic and mechanical engineers are responsible for dozens of LHC electronic systems and complex mechanical structures. The unique expertise represented by their institutional memory is being counted on for long-term support.

The major portion of the computing resources for LHC physics analysis and simulation is being provided by highly leveraged university grid facilities and by university computing professionals who are developing grid tools, software, and networking through the NSF LHC Tier 2 computing program. Since the national labs can no longer provide sufficient computing resources for major collider experiments, the support of university computing facilities has played an increasingly important role. This is appropriate, as much of the middleware required for grid computing has been developed at universities. In addition, many interdisciplinary opportunities for collaboration on high-throughput computing are centered at universities. The deployment of computing at universities leverages their power, cooling, and network infrastructure, resulting in a very cost-effective partnership. In many cases, universities have also contributed considerable computing hardware. The LHC Tier 2 facilities and the personnel necessary to operate them have significantly increased university computing capabilities, while also increasing the burden placed on the core University Grants Program personnel necessary to supervise them.

Assuming the nominal LHC luminosity profile, the LHC Interaction Region (IR) quadrupole life expectancy is less than ten years, and the time to reduce the statistical errors of measurements by a factor of 2 will exceed five years by 2012. The LHC luminosity upgrade, the SLHC, is being designed to yield a ten-fold increase over LHC luminosity, to 1.0×10^{35}, by about 2015. The integrated luminosity of the SLHC program is thus expected to be roughly ten times that of the LHC, or about 3000 fb^{-1} per experiment. Such high statistics could be used to combine different Higgs production and decay modes to form ratios of the Higgs couplings to bosons and fermions. At the SLHC, these ratios should be measurable with ~10% precision. The SLHC will extend the discovery domain for massive MSSM Higgs, SUSY, and new gauge bosons. The mass reach for extra dimensions will also be increased.

The SLHC presents a number of experimental challenges, such as radiation damage to detectors and an increased pileup of additional overlapping events. Both the ATLAS and CMS tracking systems would need replacement, as might calorimetry in the forward direction due to radiation damage. The ATLAS and CMS trigger and DAQ systems would need to be rebuilt to operate at the SLHC. Because of the increased occupancy of each crossing at the SLHC, L1 trigger systems would experience degraded performance with respect to the algorithms used for the LHC. The DAQ system would experience larger event sizes due to greater occupancy. Additional trigger information from the rebuilt tracking systems could reduce the L1 trigger rate or could be used earlier in the higher-level triggers.

U.S. university groups are already beginning the R&D program for the SLHC, particularly focusing on the detector elements for which the U.S. is responsible. European labs and funding agencies are already calling for proposals; European efforts are moving quickly toward the long R&D process necessary for the upgrades. In order for the U.S. particle physics community to remain integral to the leadership of the LHC program, U.S. university groups must engage in a robust SLHC R&D program, supported by an adequate level of funding. This R&D will need to be ramped up rapidly in the upcoming years to prepare for delivery of new trigger, tracker, and other detector systems by 2015. U.S. university groups will need to play a leading role in these detector upgrades, particularly in cases where the U.S. is already responsible for the detector elements. Moreover, an additional level of effort will be required to perform this R&D,

while analyzing LHC physics results and meeting existing maintenance and operations responsibilities.

3.1.1 LHC Physics Analysis Support in the U.S.

U.S. scientists aim to be major contributors to the early physics discoveries that are expected to result from research at the energy frontier. Essential to this goal will be U.S. ATLAS and CMS physicists' efficient (and early) access to the data, their access to modern computing tools (hardware and software), and their ability to carry out research and discuss new ideas at or near their home institutions while the experiment is being mounted at the laboratory in Geneva. A new model of physics research and data analysis—necessary to accommodate the sheer scope and complexity of the national effort, with most U.S. physicists stationed in the U.S. while the experiment is carried out overseas—is being implemented in this country for the first time. While the approaches of U.S. physicists involved in ATLAS and CMS have some differences in this respect, they share the same essential goals.

ATLAS has three regional Analysis Support Centers (ASCs): one at Brookhaven National Laboratory (BNL), one at Argonne National Laboratory (ANL), and one at Lawrence Berkeley National Laboratory (LBNL). The geographical distribution facilitates access to the ASCs by collaborators all over the U.S. Their function is to provide office and meeting space to collaborators, host U.S. ATLAS personnel who can provide technical assistance to U.S. ATLAS groups in performing their analysis, act as a regional site for the organization of seminars and training sessions for large groups of researchers, and serve as a home base for some members of the Analysis Support Group (defined and described below). The ASCs facilitate strong collaborations between the Tier 1 and Tier 2 computing centers and with various ATLAS physics and performance groups.

An Advisory Committee gives input and advice to each of the three ASCs, usually in the form of a yearly report on its activities. Numerous Analysis Jamborees have been held at the ASCs since they were formed in March 2006. These meetings bring collaborators with experience in analysis and software development together with newcomers.

In addition to the ASCs, an Analysis Support Group (ASG) provides dedicated assistance for physics analysis. The ASG consists of a group of experts from U.S. ATLAS universities and laboratories. The ASG provides the required software and analysis support to the collaboration through regional interactions at the ASCs and through direct contacts via the Web or e-mail. In addition to software expertise and support, ASG members have extensive knowledge of the ATLAS detectors and associated electronics. They provide their knowledge of hardware to facilitate physics analysis where needed. The U.S. ATLAS community has made great use of ASG members at the ASCs, and ASG members have also visited universities to provide one-on-one personal assistance. By design, ASG members represent the leading experts in specific fields, who, in addition to their ASG responsibilities, continue to devote time to the overall progress of ATLAS.

Physicists in U.S. ATLAS have in some cases formed smaller collaborations between institutions and individuals sharing common physics interests. The ATLAS analysis support structure model, anticipating this need for the formation of smaller groups inside of the larger ATLAS collaboration, formed Analysis Forums (AFs) in the U.S., each with its own convener. The AFs are meant to serve as vehicles for U.S. groups with common physics interests, allowing them to meet and discuss their analyses. These meetings have a working character, group members presenting detailed aspects of their work and receiving feedback from other experts. The physics analysis support structure, including the AFs, ensures good representation and promotes the visibility of U.S. efforts and young U.S. physicists in ATLAS.

The U.S. CMS collaboration has formed a single LHC Physics Center (LPC), at Fermilab. Located on the eleventh floor of Wilson Hall, the LPC is designed to ensure that the U.S. provides the strongest possible assistance to international CMS in software preparations for Day 1 and to enable physics analysis from within the U.S. Its goal is to guarantee that the many collaborators who prefer to remain mostly in the United States, or must do so, can contribute optimally to the many tasks required in order for the CMS experiment to produce physics, acting as full members of the CMS team. The LPC's main goals are to facilitate the participation of U.S. physicists in CMS data analysis and scientific research; to provide services that enable all U.S. CMS physicists to participate effectively in CMS, in particular by helping U.S. CMS stay synchronized with CMS; to help generate and maintain strong positive relationships between U.S. CMS and international CMS; and to facilitate a graceful transition between currently operating experiments and CMS for those physicists participating in both, maximizing the manpower available during the transition period.

To address these goals, the LPC provides a physical location where CMS physicists can find experts on all aspects of data analysis, software, and event processing, working during hours convenient for U.S.-based physicists, and a coordination point for experts residing at sites all over the U.S. It encourages, fosters, and helps optimize distributed work and daily collaboration among groups located throughout the U.S. and overseas groups, during feasible working hours. The LPC achieves this through training, guidance, and the regular use of software tools for analysis and collaborative tools. It provides a base for workshops/conferences/gatherings on LHC physics, a facility to assist in the training of graduate students and postdocs, and a center that fosters the training of students and postdocs working at their home institutions. The LPC is vital to the development of software and physics analysis in the U.S., providing opportunities for U.S. physicists to organize their contributions to CMS physics, along with a "Remote Operations Center" (ROC) that CMS physicists can use to participate in data taking and quality control for the CMS experiment in the U.S.

Facilities at the LPC, which is close to the Fermilab Tier 1 computing center, include meeting rooms, video conferencing capabilities, offices, computers, printers, and secretarial and computer support. In addition, the ROC is located on the ground floor of Fermilab's Wilson Hall. This well-equipped, dedicated remote monitoring center maintains the optimal connection to CMS data taking and LHC running, supporting the commissioning and operation of both the LHC accelerator and CMS. Recent activities at the ROC have included the development of monitoring tools—for example, data quality monitoring (DQM), test-beam data analysis, data quality monitoring shifts and fast analysis during the first CMS cosmic runs, and contributions to large-scale silicon tracker cosmic tests.

The LPC has also hosted a number of workshops and schools. Over seventy first- and second-year graduate students attended the “winter-break” introduction to CMS in January 2006. During the summer, typically more than fifty university personnel are stationed at the LPC. The LPC, closely linked with the Fermilab theory group and other theory groups near Chicago, is also fully synchronized with overall CMS physics coordination through U.S. members who are part of the overall CMS physics organization. The LPC is organized into physics working groups that are individually embedded in their respective CMS physics working groups. These working groups are the heart of the LPC, providing an informal yet intense platform for work on the fundamental foundations of future LHC physics analysis and ensuring that expertise in all necessary areas is available at the LPC.

The LPC is run by the LPC Management Board (LPC-MB), chaired by the LPC Coordinators. The LPC-MB directs the LPC program of work; draws up policies; and coordinates with CMS, with the Fermilab CMS Center, with the U.S. CMS Research Program, and with U.S. CMS. The LPC-MB works to ensure that stakeholders and those who provide efforts and funding are kept fully informed. It takes responsibility for ensuring that its decisions are appropriately supported. U.S. CMS has also set up an Advisory Board for the LPC, providing a mechanism allowing the LPC to elicit collaboration-wide advice and assessing LPC status and plans on a regular basis.

3.2 The ILC R&D Program

The discoveries of the LHC will require follow-up that can only be done with the ILC. For example, the Higgs boson should be discovered at the LHC, since indications are that its mass is under 200 GeV/c^2. Some of its properties will then be measured at the LHC. Faced with large backgrounds, however, LHC measurements will be limited. The ILC, with its small backgrounds and decay-independent detection, is necessary to determine the precise nature of the Higgs boson and thus to advance theoretical understanding of electroweak symmetry breaking.

Though the Standard Model provides the simplest explanation of precision measurements, it is not likely to be the complete theory. One possibility is new supersymmetric space and time coordinates, with corresponding supersymmetric particles (sparticles). Such particles, if they exist, are likely to be discovered at the LHC (squarks and gluinos), but the LHC would likely miss those related to leptons (sleptons) and perhaps some of the neutralinos. The ILC would be necessary to detect and study these particles and measure their mass, spin, parity, and mixing parameters. The ILC would make the most precise measurement of the lightest sparticle, important as a dark matter candidate, and could make critical measurements of its couplings. These capabilities complement those of the LHC, making the combination of the two colliders much more powerful than either of the two could be individually.

The ILC would also make measurements important in other theories, such as the hypothesized extra spatial dimensions. Again, the interplay between measurements at the LHC and the ILC would be invaluable. This synergy would extend the long history of joint discoveries in hadron and lepton experiments.

Within the University Grants Program, a large interest and need exists for strong efforts on ILC R&D, both on accelerator issues and for the detectors. A recent survey of the community (by Gollin and Pitts[4]) found that at least 51% of experimental particle physics groups have participated in an ILC R&D proposal. Of the eighty-one groups that responded to the survey, 77% had participated or had plans to participate in the future.

The ILC accelerator effort is substantial, its many needs and opportunities well matched to the capabilities of university physicists. While the university role in the field has traditionally been primarily directed toward detector hardware efforts, with some accelerator projects, a larger role for university researchers on the accelerator side is anticipated for the ILC. In 2002, the University Consortium for the Linear Collider (NSF directed) and the Linear Collider R&D group (DOE directed) were formed to foster involvement in accelerator projects. This effort led to a proposal that whose support has increased in the intervening years. The Global Design Effort (GDE) administers the university accelerator R&D project program. ILC accelerator physicists have facilitated this process by defining and publicizing important, small-scale projects, appropriately sized for a university effort. This has been very effective in bringing university physicists into the accelerator work.

The ILC detector demands significant advances over current capabilities, even exceeding some of those of the LHC experiments. Requirements that differ from those of the LHC experiments, or upgrades, call for an additional R&D effort. The technology challenges include high granularity calorimetry, billion-pixel uncooled vertex detector sensors, very thin mechanical supports, triggerless readout, integrated electronics, and operation in a 5 Tesla solenoidal field. Specifically, the opportunity to make precision measurements of decay vertices near the interaction is driving the development of new vertex detector sensors with space point precisions of a few microns and readout in one or a few bunch crossings. The need to separate charged tracks from gamma rays in the electromagnetic calorimeter is driving the development of a very highly granular silicon-tungsten electromagnetic calorimeter, again with single bunch crossing timing and minimum ionizing particle sensitivity. A final example is the development of detectors, based on resistive plate chambers (RPCs) or gaseous electron multipliers (GEMs), to achieve high granularity sensitivity in the hadron calorimeter, enabling separation of neutral hadron interactions within a high energy jet. Universities bring a powerful intellectual force to bear on these goals and are currently playing key roles in all of these detector developments.

A wide spectrum of capabilities is found within the university community. Many original concepts for detector technologies have emerged from universities in the past, acting either independently or as key collaborators with national laboratories. University scientists are particularly capable of making seminal intellectual contributions. Students and postdocs working within university groups provide an important resource for executing focused R&D tasks within a well-structured group environment. Partnerships with laboratory scientists have also led to well-balanced teams for many projects. The contributions of university groups, however, have

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[4] http://www.hep.uiuc.edu/home/g-gollin/Linear_collider/University_ILC_Engagement.pdf

been hampered by weak university technical infrastructure, the result of a many-year reduction in support. A reversal of this trend, strategically increasing infrastructure, would strengthen university groups' contributions to laboratory-university partnerships.

While many university groups have long been interested in pursuing ILC R&D, and while some have devoted serious attention to it, the results have been limited by available funding. Recently, LCD R&D support from DOE and NSF has begun to increase, helping to bring to fruition developments that had been planned for several years. Additional future increases would signal that the ILC is moving ahead, drawing a larger level of interest and participation from the university community. This is a critical precursor to U.S. participation at a credible level in ILC detector collaborations, as well as detector design, construction, and operation.

Under the leadership of Barry Barish, the focus of GDE efforts to realize the ILC has been on collider design and R&D. The World Wide Study has coordinated the preparation for experiments, including R&D. Research directed toward the ILC collider is dominated by the national laboratories. However, in 2006, eighteen university groups received support for ILC accelerator-related research, and university contributions to the collider will continue to be important. U.S. participation in the present phase of detector design and R&D lags behind the European effort; it must significantly increase to ensure U.S. leadership opportunities in the emerging detector collaborations. The current manpower needs is about 100 FTEs—graduate students, engineers, and associated staff personnel. The documented FTE effort on ILC R&D in the U.S., however, is about 45, significantly lower than needed and, indeed, inadequate, given the ILC's priority for the field. A fraction of this effort is currently centered at the universities. Within the next few years, though, this effort must increase to about 150 FTEs in the U.S., with about half within the universities. The GDE roadmap includes a completed engineering design in 2010, when the approval process could begin. Construction could start in 2012, based on this engineering design, so that by 2015, construction would be well under way, requiring additionally increased manpower—estimated at about 200 FTEs from the U.S. community working on the detectors. The present University Grants Program level of effort shortfall is not consistent with U.S. intentions to host the ILC.

The U.S. detector effort must increase significantly and mature on the same timeframe as that of the other ILC partners. Only with strong university participation and leadership will this be possible.

3.3 Theoretical Support for Experiments at the LHC and ILC

A key component of a strong Terascale physics program (at the LHC and the ILC) is a strong theoretical program involving the calculation of Standard Model backgrounds and new physics processes, together with interpretation of the experimental results. However, as pointed out in this report, the number of theorists working on such topics in the United States, especially at the universities, is inadequate. Addressing this vital need requires an additional level of effort.

3.4 Dark Matter and Dark Energy Science at Universities

In addition to neutrino masses and oscillations, there are now two other clear indications of physics beyond the Standard Model: dark matter and dark energy. In both cases, the evidence comes from astrophysical observations. Both the dark matter and the dark energy problems have a direct bearing on our attempts to understand the constituents of the universe and the interactions that take place between them. The challenge of investigating the nature of dark matter and dark energy is being addressed by teams that blend the particle physics and astrophysics communities, using a diverse array of tools and approaches. This places particular demands on interagency cooperation, appropriate project selection, and program management.

University groups play a pivotal role in both dark matter and dark energy research, often in strong partnership with national laboratories. Student interest in this subfield is very high, and both academic departments and national laboratories are expanding their activities in this arena.

Upcoming experiments at the LHC have a direct bearing on dark matter science, reinforcing the connection between physics on the largest and the smallest of scales.

The Dark Matter Problem: What Makes Up Most of the Mass in the Universe?

There is now overwhelming evidence that objects in the universe exhibit accelerations that exceed what is expected from the gravitational attraction of luminous matter. On the scale of galaxies, rotation curves and 3-d kinematics of luminous tracers indicate a factor-of-ten discrepancy between the observed motions and what is expected from the known stars and gas. On the scale of clusters of galaxies, we infer a much greater mass than we can account for in stars and gas. On the cosmological scale, measurements of the average mass density of the universe exceed the amount of ordinary “baryonic” matter produced in the Big Bang.

The apparent fact that the observed amount of mass in the universe vastly exceeds the quantities predicted by nucleosynthesis calculations indicates the existence of unknown particles. Particle physics candidates for the dark matter span 18 orders of magnitude in mass.

Attempts to identify the nature of the dark matter fall into two categories:

- direct detection experiments, which search for interactions between particles and laboratory apparatus, and
- indirect detection efforts, which search for evidence of antiparticle/particle annihilation.

An overview of the university community’s efforts in dark matter research was recently presented in the HEPAP Dark Energy Task Force (DETF) subpanel report.[5] University groups play a pivotal role in dark matter science, sometimes in partnership with national laboratories. Searches for WIMPs are well under way and are now probing regions in SUSY parameter space. A number of promising new approaches to direct detection are under development, much of the

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[5] http://www.science.doe.gov/hep/DETF-FinalRptJune30,2006.pdf

necessary pioneering work being done in university groups. The national effort to develop a low background deep underground facility will play an important role in future developments in this arena.

The interplay between university and national laboratory teams is essential to the nation's success in dark matter science. For example, the Cryogenic Dark Matter Search (CDMS) direct detection experiment blends the strengths of numerous university groups and multiple national laboratories. In addition, detector technology has migrated from the university sector into an axion detection experiment operated at a national laboratory.

Dark Energy: Antigravity from the Vacuum?

The recent discovery of the accelerating expansion of the universe presents us with one of the most profound open questions in the physical sciences. One of the two teams that announced the discovery of the accelerating universe was based at a national laboratory, while the other was a consortium of university scientists. The discovery of dark energy challenges our understanding of the interface between gravity and particle physics. It also challenges our ability to undertake science that resides at the interface between fields, in this case particle physics and astronomy. The DETF report lays out a staged approach to making a transition from the discovery phase to the measurement phase of dark energy science.

University groups have a special role to play in measuring the properties of dark energy, motivated by a desire to better understand the underlying physics. The currently favored techniques (supernova Hubble diagrams, baryon acoustic oscillations, cluster abundances, and weak lensing) all require access to substantial amounts of telescope resources, and the majority of large-aperture U.S. optical and IR telescope resources are controlled by universities. Projects that use astrophysical tools to address problems in fundamental physics are well suited to universities, where particle physicists have ready access to colleagues in astronomy who are intimately conversant with the challenges and pitfalls of astrophysical observations.

Given the profound impact of the dark energy problem on fundamental physics, it is imperative that we continue to address the challenges posed through interagency support and interdisciplinary research.

3.5 Neutrino Physics

Universities have played a strong role in neutrino physics from the field's inception. The "two-neutrino" experiment that took place at BNL moved the field in an innovative new direction, advancing our understanding of neutrinos and the weak interaction but also creating the techniques necessary for accelerator-based neutrino experiments. This experiment was conceived by Lederman, Steinberger, and Schwartz at Columbia University, where the detector was also constructed. The discovery and exploitation of the neutrino neutral-current phenomena, the first indication of electroweak unification, also owed much to strong university contributions on the CITF and HPWF neutrino beam experiments at Fermilab. The universities' decisive role in neutrino physics has continued to the present, with over 75% of currently running experiments being led by university physicists.

Neutrino physics can be divided into three major components: the study of neutrino properties, the use of neutrinos as tools to understand strong and electroweak interactions, and the use of neutrinos to probe astrophysical objects and phenomena (including Earth). Recently, neutrino oscillation measurements have provided the first window into physics beyond the Standard Model, with unequivocal evidence that neutrinos have mass. The study of neutrino properties has been recently focused on determining the mass and mixing of neutrinos, as well as their Majorana or Dirac nature. Of particular interest is determining whether neutrino mixing exhibits CP violation, since this may hold the key to explaining the matter-antimatter asymmetry in the universe. Studies of neutrino properties have encompassed a broad range of experimental techniques, from neutrino oscillation studies using solar, atmospheric, reactor, or accelerator neutrinos to single and double beta decay experiments using various isotopes and detectors. The diversity of these experiments demonstrates the unique breadth available through a strong university-based program.

From the beginning, a synergy has existed between neutrino astrophysics and particle physics. While solar neutrino experiments began as a probe of solar properties, they wound up discovering neutrino oscillations and neutrino mass, providing the first real evidence of physics beyond the Standard Model. Similarly, measurements of the Z^0 width have constrained the number of light neutrinos, which has had a profound impact on astrophysical models. Detection of neutrinos from SN1987a set important limits on neutrino mass and contributed to our understanding of supernova physics. Geoneutrino experiments will probe the properties of our own planet. IceCube will search for an understanding of the source of the high energy cosmic rays that may result from the acceleration of protons in astrophysical accelerators or from top-down processes associated with exotic massive objects. IceCube will also search for the signature of dark matter annihilation into neutrinos.

Many of these programs have been initiated through universities, with university groups playing leading experimental roles. Further, many of these neutrino experiments do not demand laboratory facilities and so may be mostly university based and managed. Neutrino astrophysics is a case in point: the major experiments in the field, such as IceCube and Anitia, are managed, led, and funded through universities.

The other part of the neutrino physics program is related to using neutrino beams as a tool to improve our understanding of the strong and electroweak interactions. Neutrinos hold a unique place in the Standard Model because they are neutral and only interact through the weak interaction. Neutrino experiments have played a key role in determining nucleon structure through measurements that isolate the valence and strange quark distributions. Cross-section measurements have not only provided information on the nucleon form factors and the dynamics of nucleon resonance production but are also a crucial component of neutrino oscillation measurements with improved precision. Using neutrinos as a tool for these studies typically demands an accelerator-produced neutrino beam, and thus, these experiments are laboratory based. On the other hand, most of these experiments have been initiated and led by university physicists in collaboration with other lab and university scientists.

The current and near-future U.S. neutrino program spans a broad range of experiments, mainly probing neutrino properties. This suite of ongoing and near-term experiments will cover direct neutrino mass measurements, neutrino-less double beta decay searches, reactor-based neutrino oscillation experiments, and accelerator-based experiments to probe neutrino oscillations with greater precision and measure neutrino cross-sections. The following briefly describes many of the ongoing and proposed experiments in the field, focusing on university scientist leadership and participation.

- Direct neutrino mass measurements:
  - KATRIN (strong U.S. university participation and leadership).

- Reactor neutrino measurements:
  - KAMLAND (strong U.S. participation from inception, including university and LBNL groups).
  - Double Chooz (strong U.S. university participation from inception, with major responsibility for calibration and veto system).
  - Daya Bay (U.S./China partnership, with U.S. labs and universities providing major project oversight and leadership).

- Solar neutrino experiments:
  - Super-K, Homestake, SAGE, GALLEX, and SNO: Experiments leading to spectacular progress in understanding neutrinos from the sun and their oscillations (strong U.S. university participation).
  - Borexino: A next-generation solar neutrino experiment with sensitivity to the lower-energy ^{7}Be neutrinos, which may probe new regions of oscillation phenomena (strong U.S. university leadership from inception through construction).
  - SNO-Plus: The next phase of the SNO experiment, replacing the heavy water with a scintillator, allowing ^{7}Be neutrino measurements and geoneutrino detection for earth science (strong U.S. university participation).
  - GENIUS, MOON, LENS, HERON, and EBubble: Solar neutrino detector experiments focused on reducing detected threshold to see pp solar neutrinos (strong U.S. university leadership and development).

- Neutrino telescopes:
  - IceCube (and its predecessor, Amanda): Unique facility for performing neutrino astronomy (strong U.S. university leadership and technical contributions).
  - ANITA, SALSA, Rice, and radio/acoustic upgrades to IceCube: Radio telescope detection of ultra-high energy cosmic-ray neutrinos (strong U.S. university leadership on experiments and techniques).
  - HiRes Fly's Eye, Current Auger, Future Telescope Array: Ultra-high energy cosmic-ray shower detectors (strong U.S. university leadership).

- Double beta decay:
  - EXO: University/lab partnership developing innovative technique using single atom trapping (U.S. university-lab collaboration).

    - Majorana: Research focused on developing a next-generation large ^{76}Ge detector (U.S. university-lab collaboration).
    - CUORE: Experimental search using tellurium crystals with thermistor readout. The technique was tested successfully using a 40-kg prototype called Cuoricino (European/U.S. collaboration, with both U.S. lab and university participation).
    - GERDE: Phased program starting with 20 kg of existing enriched ^{76}Ge crystals, which will be augmented with more crystals in later phases (European collaboration with no U.S. participation at the present time).

- Accelerator neutrino experiments:
    - MiniBooNE: Short baseline neutrino oscillation search using the Fermilab Booster (strong U.S. university leadership, in collaboration with Fermilab and LANL, involving key contributions to construction, hardware, and software).
    - SciBooNE: International collaboration (U.S./Japan/UK) to measure cross-sections important for next-generation long-baseline experiments (strong U.S. university participation).
    - MINOS: Long-baseline neutrino oscillation experiment using a neutrino beam from the Fermilab main injector (strong U.S. university participation and leadership, in collaboration with Fermilab and BNL, involving key contributions to detector construction, hardware, and software).
    - Minerva: Neutrino cross-section measurement experiment that exploits the capabilities of the Fermilab NuMI beam. The measurements are important for next-generation oscillation experiments such as NOVA (strong U.S. university leadership, featuring collaboration between particle and nuclear physics).
    - T2K: Long-baseline off-axis neutrino oscillation experiment using a neutrino beam from the new JPARC accelerator (strong U.S. university participation and leadership in building the near detector and possibly a 2-km detector, in collaboration with BNL).
    - NOVA: Proposed long-baseline off-axis neutrino oscillation experiment using an upgraded neutrino beam from the Fermilab main injector (strong U.S. university participation and leadership, including design and construction).
    - Liquid argon neutrino detector (strong U.S. university participation, in collaboration with Fermilab and BNL).
    - Future very long-baseline experiments (strong U.S. university leadership in developing such a program, in conjunction with the U.S. Deep Underground Science and Engineering Laboratory—DUSEL).

3.6 Flavor Physics

The six types (“flavors”) of quarks exhibit a pattern of masses and weak interaction transition rates that has yet to be explained. Flavor physics, the study of transitions between the different quarks, has played a central role in the development of our current level of understanding of particle physics. (There is an analogous lepton flavor physics.)

A major goal of elementary particle theory is to unravel the underlying mechanism that explains the observed quark masses and their mixing patterns, simultaneously providing an explanation for the observed CP violation. The thrust of the experimental effort in flavor physics is focused on stringently testing the highly constrained CKM framework and perhaps revealing its breakdown. Toward this end, the recent emphasis in flavor physics has been on measurements of the individual elements of the CKM matrix. In the Standard Model, these are all related to four fundamental parameters, so measurements of more than four elements over-constrains the system; discrepancies between values derived from different ways of determining the parameters could reveal the existence of a more complicated framework. One major recent accomplishment was the precision measurement of the magnitudes of eight of the nine transition elements, plus independent determinations of the CP-violating phase. The consistency between these measured values is one of the great successes of the Standard Model.

A related focus of flavor physics is the measurement of transitions that, in the context of the Standard Model, proceed via second-order weak interactions in which heavy-particle intermediate states briefly exist as quantum fluctuations. Such processes include weak-interaction transitions between quarks that have the same electric charge but different flavors—so-called flavor-changing-neutral-currents (FCNC) and particle-antiparticle mixing transitions. If other, as yet undiscovered, heavy particles exist that also couple with quarks, these could provide additional paths to mediate these second-order processes and, thereby, produce discrepancies between measured transition rates and their predicted values. Studies of these processes through current experiments have probed physics at the TeV scale and higher; some of the most stringent limitations on new theories are derived from measurements of FCNC processes, such as a b-quark decaying to an s-quark plus a gamma ray, and the rate for mixing between the B_s meson and its antiparticle.

Our current knowledge of flavor physics, and the flavor structure of the Standard Model, is derived from nearly sixty years of experimentation. Early experiments performed by university-based groups used cosmic rays and on-campus synchrocyclotrons. These evolved into more elaborate programs, focused on studying s-quark transitions in K meson decays at regional and national accelerator facilities, most of them initiated and carried out by university-based research teams. The major current activities in the field are studies of the b quark, using specialized “B factories” at SLAC (the BaBar experiment at PEPII) and at KEK in Japan (the Belle experiment at KEKB). These experiments are exploiting luminosities that exceed those of previous facilities by nearly two orders of magnitude, allowing b- and c-quark properties to be measured with unprecedented precision. In addition, the CLEO experiment at Cornell is making a number of unique precision measurements of certain rare c-quark transitions. The CDF and DØ experiments at the Tevatron include major efforts in these areas. Recently, in a major breakthrough, these experiments made first measurements of the B_s meson mixing rate.

University groups bear major responsibilities in all of these research activities. The BaBar experiment, for example, is an international effort involving eighty-one institutions, thirty-six from the U.S. The current BaBar spokesperson is a U.S. university researcher. The Belle experiment is being executed by an international collaboration that includes four U.S. university groups, and one of its co-spokespersons is a U.S. university physicist. The CLEOc effort is an entirely a North American university-based activity, and the groups focused on flavor physics in the CDF and DØ collaborations include many U.S. university researchers.

Flavor physics theory is also a largely university-based activity. Important recent developments, such as heavy-quark-effective theory and soft-collinear-effective theory, were developed primarily by university-based theorists. Further, precise measurements of the CP-violating phase of the CKM matrix exploit techniques initially proposed by U.S. university-based theorists.

Experimentally, the next major step in flavor physics is to repeat the measurements that constrain the CKM matrix elements, using transitions that involve only second-order processes, and see if the resulting values agree with measurements from the allowed first-order processes. In addition, studies of the detailed properties of very rarely occurring B and D meson decay modes also exist. In the U.S., the BaBar, CLEOc, and TeVatron experiments will terminate sometime during the next two to three years. Future U.S. participation in flavor physics studies will need to be centered at facilities abroad. LHCb, a large experiment dedicated to flavor physics, will operate at the LHC. BESIII, an experiment especially designed for c-quark physics, will begin operation in Beijing in early 2008. An important, albeit small, component of U.S. university-based researchers is participating in both the LHCb and the BESIII experiments. These two experiments only cover a small subset of the outstanding issues in flavor physics. Many important questions could be uniquely addressed in an e^+e^- collider, but only with much higher luminosity than the current facilities offer. Designs have been advanced for “Super-B factories” at KEK and at Frascati, proposing to push the luminosity frontier upward by two orders of magnitude beyond the current PEPII-KEKB-defined state of the art. U.S. university physicists are central to both the KEK and the Frascati efforts.

3.7 New Frontiers

The research fields discussed above all had their genesis in speculative ideas that gradually became productive research directions. As in the past, new research frontiers continue to emerge today. In particle physics, the evolution from ideas to mature scientific programs has often required matching important questions with new technologies. Sometimes the questions drive the development of technologies, and sometimes the technologies open doors to the questions. Not all speculative ideas evolve into new programs, but that is the nature of speculative exploration.

The university research program in elementary particle physics plays a special role in the development and nurturing of emerging new frontiers. Important strengths of university groups include their proximity to the broad panorama of science at a typical university and the significant creativity that students at all levels provide. In addition, many universities are able and eager to seed speculative research in a manner that complements R&D at a program-driven laboratory.

Because of these strengths, university groups have historically played important roles in defining the directions of the field. This trend continues today. As an illustration, we focus here on two representative examples of programs at different scales: (a) "underground science," a large field that will require a national facility in the U.S.; and (b) "boundary science," where the techniques of atomic physics and questions of particle physics intersect. The former effort takes place at a literally geological scale, while the latter can occur on the proverbial table-top.

Cosmic-Ray Physics. Ninety-five years after their discovery, the origin of high energy cosmic rays is still unknown. The HIRES and Auger experiments, conceived and led by university faculty, have measured cosmic rays above 10^{20} eV and have recently seen evidence for the predicted steepening of the spectrum due to the GZK cutoff. In addition, university faculty led the development of a first generation of ground-based gamma-ray detectors (including Whipple and Milagro in the U.S.) that have discovered numerous sources of TeV gamma rays. It is now clear that non-thermal sources of high energy gamma rays abound. Pulsar wind nebulae, supernova remnants, micro quasars and massive binaries in our galaxy are seen to produce gamma rays up to 100 TeV, indicating that they are likely sources of galactic cosmic rays. Active galactic nuclei have been observed to emit flares of TeV gamma rays with factors-of-ten variability in flux on the time scales of minutes. Gamma-ray bursts are the most energetic phenomena in the universe, emitting enormous amounts of energy in bursts lasting only on the order of seconds. The current generation of experiments seeks to understand the gamma-ray production mechanisms behind these sources and whether these gamma sources also accelerate hadrons. VERITAS, HESS, and MAGIC are studying the sky with enhanced sensitivity and making impressive new discoveries.

The GLAST satellite to be launched at the end of 2007 will reveal thousands of new sources at GeV energies. To complement GLAST, a next generation of wide-field ground-based TeV gamma-ray detectors (AGIS, CTA, and HAWC) is being planned in both Europe and the U.S. These new detectors will allow us to map the sky, search for the gamma signature of dark matter in the halo of our galaxy, and study extremely energetic transient phenomena. The U.S. effort is being led by university researchers.

This burgeoning field lies on the border between physics and astronomy. Many of the scientists working in this area have come from traditional HEP experiments, and many of the students trained on these experiments continue with careers in HEP. The field must have a mechanism allowing it to compete for funding. The SAG mechanism described in this report is essential, especially since the SAGENAP committee, which reviewed and approved the current generation of experiments, is no longer in existence.

Underground Science. Universities have played a major role in the development of underground science laboratories in the U.S. for elementary particle physics. For example, the University of Minnesota was instrumental in the construction of an underground science laboratory in the Soudan Mine in the mid-1980s. Since its construction, this facility has hosted non-accelerator and accelerator neutrino experiments, as well as an active cold dark matter search program.

In the past decade, it has become evident that many new particle physics experiments could benefit from a new major facility that provides multiple experimental areas deep underground. These experiments demand sensitive measurements in which the detectors are shielded from the surface cosmic-ray flux. Such experiments span a variety of topics and technologies—from detectors sensitive to neutrinos from accelerator and non-accelerator sources, to detectors that search for weakly interacting dark matter on Earth. At the same time, it has become increasingly clear that the need for a major underground facility is shared by scientists working in fields outside of particle physics: biologists, geoscientists, and engineers all have a major research stake in such a facility.

University groups have been developing and defending the scientific case for such a facility, including identifying and coordinating with collaborators from other fields. Universities have leveraged their internal resources, geographic diversity, and ties to state governments to move from the scientific case to detailed proposals for actual facilities. After extensive scientific review, the NSF is now engaged in the site-selection process for the Deep Underground Science and Engineering Laboratory (DUSEL) as a step toward a full proposal for construction of the facility. This new project promises to be a major part of the national roadmap for elementary particle physics.

Atomic Physics Techniques to Probe Small Violations of Symmetries. Spectroscopic techniques developed for atomic physics have been used successfully to probe for breaking of symmetries either predicted or forbidden by our models of the fundamental interactions. In fact, the first weak neutral-current measurement without a neutrino was on a “table-top,” not at an accelerator: the precision measurement of atomic parity violation from the weak force by Carl Wieman’s group and others. Most recently, tests of CPT symmetry in anti-hydrogen have been performed at CERN, a coordinated effort involving multiple disciplines. The successes of these programs would not have been possible without the intellectual exchange between the atomic physics and particle physics communities.

The heirs of these efforts today include ideas for improving the measurement of the electron electric dipole moment. The presence of such a dipole moment would violate time-reversal symmetry, but the physics that might reveal itself at the LHC and ILC might first be discovered through a measurement of a non-zero moment. Current proposals include ideas for improving these measurements by several orders of magnitude, to a sensitivity approaching 10^{-31} e-cm, well into the region of interest that overlaps with high energy frontier physics.

These two examples reveal many of the best features of emerging frontiers at universities. Both areas benefit from the intersection between elementary particle physics and technology from or needed by other fields. Both are forward-looking enterprises whose physics programs do not fit within the standard mission of any existing laboratory facility in the U.S. It is this entrepreneurial instinct that drives the development of new areas of research, which defines another unique characteristic of the University Grants Program.

3.8 The Expanding Frontier

The University Grants Program is entering a period that portends major changes, as exploration of the Terascale begins at the LHC and plans evolve for its continuation at the SLHC and the ILC. New revelations about the origin of mass and possibly even space-time itself will certainly emerge and inspire more experiments. The program in neutrino physics is robust and expanding. The suite of ongoing and near-term experiments covers direct neutrino mass measurements, neutrino-less double beta decay searches, reactor-based neutrino oscillation experiments, and accelerator-based experiments to probe neutrino oscillations with greater precision and measure neutrino cross-sections. Future opportunities also abound for flavor physics, with LHCb, BESIII, and possible Super-B factories at KEK and Frascati. New experiments are emerging in studies of dark matter and energy, underground science, and atomic physics experiments designed to probe small symmetry violation. Continued U.S. leadership in particle physics requires dedicated exploration of these scientific opportunities by U.S. university scientific personnel.

4 Sharing the Adventure

Particle physicists at universities play a host of vital roles that have an impact well beyond the field itself. While many aspects of the field are difficult for those outside it to understand, particle physicists have made great strides in sharing the excitement of their work with students and members of the public, including members of groups currently underrepresented in physics. Academic high energy physicists also assume important scientific and leadership roles within the university and fully participate in the interdisciplinary nature of academic life, the very significant resulting synergies with other scientific disciplines making a strong impact on the broader university environment.

University-based physicists also strive to increase the participation of underrepresented groups in the field through various programs. Indeed, universities act as the portals through which underrepresented groups enter the field. Strong support of universities strengthens the field's capability to attract underrepresented groups so that its diversity can improve.

4.1 Education

One primary focus of university physicists is obviously to educate future scientists, engineers, health-care professionals, and science teachers at the undergraduate, graduate, and even postdoctoral levels. University physicists offer formal course work focused on general physics, as well as on specialized topics in particle physics and laboratory techniques. They provide career mentoring, lecture on current research topics, and supervise research experiences. Much of this effort is directed toward students who will pursue specific careers in physics research, whether in high energy physics or in another subfield. The next generation of physics researchers, then, at both universities and national laboratories, must necessarily receive their academic training from university-based physicists.

While many of these instructional efforts are centered at graduate institutions, an important component of the HEP community does originate at undergraduate institutions. The best opportunity students at undergraduate institutions have for experience in particle physics comes from partnerships between graduate universities active in particle physics and undergraduate institutions, through such programs as the NSF Research Experiences for Undergraduates (REU) program.

The instructional efforts of university physicists also have a much wider impact. Exposure to exciting frontier research at the undergraduate level is vital in getting students to become interested in science, and particle physics is especially fascinating for many students. These students may eventually pursue careers in other areas of science or physics or become engineers, all essential to our society's health and progress. Similarly, many students, motivated to enter graduate school in physics by their interest in particle physics, later successfully switch to other important areas. More generally, undergraduate courses on introductory particle physics provide a tremendous opportunity to engage the general population in the excitement of particle physics and other areas of science. Indeed, recent studies[6] have shown that adult science literacy among the general population is strongly correlated with exposure to science through even one course at the college level.

4.2 Outreach

Scientific public outreach has a long history. For example, Michael Faraday, profoundly influenced by his experiences as a youngster attending public lectures at the Royal Society, subsequently "gave back" to his community throughout his professional life through his own public lectures and demonstrations. Faraday worked hard at these lectures and worked hard at learning to present them well. His public legacy is the still-running Christmas Lectures series, which Faraday inaugurated in 1825. For almost two hundred years, only those in London could benefit from the Christmas Lectures. Now, however, new traditions are becoming increasingly possible, their benefits reaching worldwide audiences: today's public scientific venues include not only television but podcasting, video casting, physics blogs, and YouTube. As discoveries come in from the Tevatron, SLAC, LHC, and neutrino experiments, ample opportunities will exist to promote the same kind of excitement that Faraday experienced and later nurtured.

If the discovery of the top quark is any guide, the next steps beyond the Standard Model will generate considerable interest across the globe. Presumably, a string of discoveries will be made as the LHC and neutrino programs evolve, and careful planning will be necessary to provide useful and timely material for the public, press, and governments as new physics starts to appear. The InterActions Collaboration is taking important steps in this direction (see below and section 6.1.2).

From the early days of "plain English" explanations of publications from the DØ experiment at Fermilab, efforts at communicating with the public regarding the excitement of particle physics have expanded enormously into a truly global arena. To this end, the LHC community is actively collaborating with the CERN Public Affairs Office, along with Fermilab and SLAC.

Indeed, a sizeable segment of the population is fascinated by developments in string theory, neutrinos, traditional particle physics, and related areas in cosmology and astrophysics. Outreach efforts in these areas, then, provide an excellent way to increase the scientific awareness of the general public. Similarly, outreach to students and teachers at the elementary and high school levels is vital to encourage students to pursue careers in science and technology—or even simply to be scientifically literate. Furthermore, outreach efforts that involve undergraduate students in research significantly increase the likelihood that the participating students will choose to attend graduate school. Again, particle physicists at universities play an important role in reaching out to all of these audiences.

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[6] Jon D. Miller, *Civic Scientific Literacy across the Life Cycle,* paper presented at the annual meeting of the AAAS, Feb. 17, 2007.

Many university-based physicists contribute to the excellent and comprehensive outreach programs carried out by the national labs or by the large experimental collaborations where they undertake their research. University-based physicists also strive to increase the participation of underrepresented groups in the field through various programs. Each of the national high energy physics laboratories features an educational outreach center that generates events and materials for the benefit of students, teachers, and the general public. Working together (with NSF and DOE support), the labs' communications offices have established the InterActions Collaboration (http://www.interactions.org), a central resource for communicators in the field of particle physics. This Web site provides links to current particle physics news from the global press, high-resolution photos and graphics from particle physics laboratories all over the world, links to education and outreach programs, and information about science policy and funding. In preparation for the start-up of the LHC, the ATLAS and CMS collaborations are generating interest in particle physics around the world by holding master classes for high school students, making detector images available as electronic files, providing T-shirts and puzzles, producing award-winning movies, posting animated segments and interviews on YouTube, and publishing brochures and fact sheets. The Contemporary Physics Education Project (CPEP) continues its long-standing tradition of producing outstanding wall-charts, educational materials, and interactive Web sites on particle physics, cosmology, nuclear physics, and related topics (e.g., Particle Adventure, Universe Adventure). In February 2007, the American Association of Physics Teachers (AAPT) distributed a new CPEP poster on the history and fate of the universe to eleven thousand physics teachers. The new I2U2 (Interactions in Understanding the Universe) collaboration proposes to develop a portfolio of online collaborative labs for classrooms and science museums that will further strengthen the educational outreach activities of grid-based scientific experiments.

Other academic particle physicists establish outreach programs at their home institutions. While the high energy physics outreach program at any given college or university cannot usually be as extensive as those carried out by the labs or the major experimental collaborations, colleges and universities nevertheless cover much wider geographical areas and therefore reach a more diverse population than the labs or collaborations possibly can. In particular, a variety of university-based programs for local elementary and high school students and teachers flourishes in communities across the country. Some of these programs are held at the schools themselves and others at universities; some take place in the summer and others during the academic year. They may focus on inner-city, suburban, or rural schools. Some consist of a single annual event; others, like those in the NSF's GK–12 program, link faculty and graduate students with particular K–12 schools for many years. Whatever their format or location, these programs benefit all their participants significantly, reaching students from groups underrepresented in the sciences, economically disadvantaged students, and academically advanced students.

Such university-based particle physics outreach, aimed at K–12 schools, can range from a single faculty member active in a local school district to international collaborations involving multiple institutions. While more than 250 programs featuring public talks, hands-on activities, workshops, classroom materials, tours, mentoring, research participation, and online activities are described in the online particle physics Education & Outreach Database, the following are just a few of the larger-scale projects in which university physicists are deeply involved.

CROP is a statewide outreach project whose goal is to involve Nebraska high school students, teachers, and college undergraduates in a multifaceted, hands-on research effort to study extended cosmic-ray air showers. CROP's organizers have established a national collaboration (NALTA) to study air-shower arrays the size of North America by joining forces with other regional and state-sized projects at the University of Alberta (ALTA); Caltech, UC Irvine, and Cal State Northridge (CHICOS); the University of Washington (Walta); the University of Victoria (VICTA); the University of Illinois at Chicago (CLASA); the Florida Institute of Technology (FTASA); the University of Rochester (PARTICLE); the University of Tennessee (TECOP); and the University of Texas Arlington (TECOSE).

QuarkNet is yet another national-scale collaboration, with centers at fifty-two universities and labs. QuarkNet is focused on engaging high school teachers and students from twenty-six states in ongoing particle physics experiments, especially ATLAS and CMS, as well as particle astrophysics experiments. The teachers involved in QuarkNet undertake research with scientist mentors during the summer and then bring the excitement of that experience back to their classrooms; the students then analyze real particle physics data online in their own classrooms, communicating their results to other student teams and to scientists at the major national labs. Other recent Quarknet initiatives include the development of an eLab portal that allows such student teams to take advantage of grid-computing resources.

The intercontinental CHEPREO collaboration, involving Florida International University, the University of Florida, Florida State University, Caltech, and collaborators in Brazil, encompasses an integrated program of research, cyberinfrastructure, and educational outreach. Its participants have developed modeling techniques and workshops with applications ranging from middle school mathematics, to college-level physics, to teacher education, to CMS research.

Particle physicists also contribute significantly to the Research Experiences for Undergraduates (REU) and Research Experiences for Teachers (RET) programs, sponsored by the NSF. These programs support the active participation of undergraduates and K–12 teachers in ongoing research programs or in projects designed especially for REU or RET participants. Topics range from accelerator physics, electronics, and detector development, to dark matter, neutrino, and cosmic-ray searches, to string theory, strongly coupled gauge theories, and extra dimensions. The array of universities and colleges involved in these two programs is very broad: public, private, rural, and urban research universities and technical institutes; liberal arts colleges and minority-serving institutions. Those institutions preparing programs for summer 2007 include Baylor, Chicago, Colorado, Columbia, Cornell, Georgia Tech, Hampton, Indiana, Lehigh, Michigan, Michigan State, Minnesota, New Mexico, Notre Dame, Ohio State, Oklahoma, Pittsburgh, Purdue, Rochester, RPI, SUNY Stony Brook, Texas A&M, UC Davis, UCLA, Wayne State, and William and Mary. Such programs provide an important opportunity to attract underrepresented groups into particle physics.

Many university outreach programs have developed materials to be used by high school teachers who wish to include particle physics topics in their curriculum. Teachers who work directly with particle physicists—through K–12, QuarkNet, NALTA, RET, and similar programs—often receive both materials or equipment and direct instruction in how to employ them in class or with student clubs. In addition, certain programs facilitate the development of new lesson plans and exercises by teams including teachers and particle physicists. Some of these educational modules may focus on introducing new concepts about the subatomic structure of matter; others use particle physics applications, such as a determination of the top quark's mass, to illustrate introductory physics concepts like conservation of momentum. Even teachers who have not yet directly worked with particle physicists can access these materials online at sites such as those maintained by CPEP, Fermilab, and QuarkNet. It would be very useful for the particle physics community to establish a central repository for these materials and then advertise its existence in the publications of the AAPT and other national professional teacher organizations.

It is also worth mentioning that many university-based high energy physicists have written monographs for the general public on topics ranging from the Standard Model of particle physics to such non-standard particle physics models as supersymmetry, string theory, and extra dimensions, including even the esoteric and ersatz particle physics featured in *Star Trek*. Authors including Brian Greene (Columbia), Gordon Kane (Michigan), Sheldon Glashow (Boston), Marcelo Gleiser (Dartmouth), Alan Guth (MIT), Michio Kaku (CCNY), Lawrence Krauss (Case Western), Leon Lederman (University of Illinois, Chicago), Robert Oerter (George Mason), Lisa Randall (Harvard), Bruce Schumm (UC Santa Cruz), Leonard Susskind (Stanford), and Steven Weinberg (University of Texas, Austin) have all recently penned such popularizing books. As a quick look on Amazon.com will confirm, such books sell well, their purchasers often returning to buy more books on related topics. Many of these authors are also widely sought for public lectures, media interviews, and appearances in science documentaries—all of which bring their words and our field to even broader audiences.

Finally, a number of Web sites provide extensive links detailing all of the particle physics outreach efforts discussed here. A few useful examples are sites hosted by CPEP, Interactions.org, the American Physical Society (APS), the APS Division of Particles and Fields, and the American Institute of Physics. In addition, the electronic physics-preprint archiving system arXiv.org has established archives on several topics related to physics educational outreach, including Physics Education, Physics and Society, and History of Physics.

4.3 The Broader University Community

Particle physicists also contribute significantly to their university communities outside the classroom. For example, many become department chairs or deans or take on other leadership roles at their home institutions. They frequently serve on university committees related to large-scale computation or quantitative literacy and participate in internal reviews for other science departments—or external reviews for other institutions. They are active in course development, including interdisciplinary team-taught courses aimed at non-science majors, and in establishing and maintaining teaching laboratories. Academic high energy physics groups have also played a major role in creating and supervising departmental infrastructure in computation, electronics, and machining to support detector development and fabrication and data analysis. These facilities typically also provide services to other science and engineering departments across the university.

One vital aspect of the university environment is that it encourages collaboration and cross-fertilization with other disciplines and other subfields of physics. Sometimes this leads to progress on topics of current interest in high energy physics, such as joint work in nuclear or particle astrophysics and cosmology, involving nuclear physicists and astrophysicists; work on materials related to detector development, involving materials scientists and engineers; projects in cyberinfrastructure and grid computing, involving engineers and computer scientists; and studies of low-dimensional and strongly coupled quantum field theories, involving colleagues in condensed matter physics. In other cases, ideas initially raised in the particle physics community become topics of research in other subfields. For example, parity violation and dipole moments are of deep interest now in atomic, molecular, and optical physics; the properties of the quark-gluon plasma are being explored by nuclear physicists; and dark matter candidates appearing in theories beyond the Standard Model are playing a key role in cosmology. The flow of ideas can also, of course, run in the other direction, as when the Higgs mechanism propagated from condensed matter theory to particle theory.

Such beneficial interdisciplinary connections often involve the flow of people, as well as ideas. Individuals initially in postdoctoral or faculty positions in particle physics, for example, have migrated into other academic scientific disciplines, including condensed matter physics, medical technology, and biology. This flow of expertise is facilitated by the interdisciplinary nature of the university community and has certainly enriched a broad array of research fields. Others have moved from the academic to the industrial or business communities, in fields such as financial modeling, device design, and telecommunication—again facilitated by training and contacts gained through university experience in high energy physics.

A strong physical and intellectual particle physics presence within academe is essential, both to fully realize the opportunities inherent to the university environment and to maintain the impact of particle physics on scientific research and development in the universities and beyond.

4.4 The Broader Research Community

Universities provide a natural environment for creating and cultivating cross-disciplinary partnerships that spread far beyond the campus boundaries, leading to new disciplines and new technology. Such partnerships have led to the development of new disciplines that span the boundaries of traditional areas of study, as, for example, in the rapidly growing fields of particle astrophysics and particle cosmology. These partnerships have also, importantly, provided the impetus for important new technical developments—developments that benefit both particle physics and the broader research community, such as the use of synchrotron radiation produced by electron storage rings as a research tool for condensed matter physics and the biological sciences. Advances in material science laboratories often translate into more powerful superconducting magnets for accelerators and detectors and superconducting RF structures with higher accelerating gradients. Theoretical physicists and their on-campus mathematician colleagues also frequently enjoy the benefits of close mutual interactions. Large-scale data-processing systems developed by experimental particle physicists to deal with their experiments' increasingly demanding computing requirements, for example, are made possible by campus expertise in information technology and then frequently go on to find applications in other fields of research.

4.4.1 Scientific Partnerships

Particle Astrophysics. Cosmic rays have long provided an important resource for the study of elementary particle physics. In the earliest days of particle physics, the muon, the π and K mesons, and the light hyperons were discovered via their production by cosmic rays. More recently, neutrino mass and the phenomenon of neutrino oscillations were established through cosmic-ray experiments. It has also become clear that, in addition to being useful for studying particle properties, cosmic rays provide important astronomical information. The measured flux of neutrinos from the sun and the detection of neutrinos from SN 1987a provided important verification of stellar models. High energy cosmic gamma-ray measurements, carried out jointly by particle physicists and astronomers, discovered unexpected astronomical sources of gamma rays. Astronomers and particle physicists are now collaborating on future land- and space-based high energy particle detectors to search for astronomical sources of ultra-high energy cosmic rays. Their university partnerships are especially enhanced by the close relationship that typically exists between the astronomy and physics departments. In some cases, the two fields are even combined into the same department; in others, faculty have joint appointments in both.

Big Bang Cosmology. The relationship between cosmology and subatomic physics began sixty years ago with the realization that nuclear physics rates measurable in university laboratories could be used to determine nuclear abundances produced about one minute after the Big Bang. The understanding of times even before the Big Bang requires knowledge of the interaction properties of quarks, leptons, and the heavy W and Z bosons. Particle physics measurements of CP violation in the quark and neutrino sector and searches for proton decay have implications for these earlier times. WIMP searches underground, in space, and at accelerators may provide the key to understanding the nature of the dark matter. Partnerships that have developed between researchers studying the very small and those studying the very large have helped transform cosmology from a speculative exercise into a data-driven, highly quantified branch of science.

4.4.2 Shared Technologies

Applications of Accelerators to Other Disciplines. Electron accelerators and storage rings are important tools for elementary particle physics research. However, one major problem encountered in early electron storage ring operation, done by a few university-based accelerator physicists, concerned the energy losses caused by the emission of synchrotron X-rays. On-campus colleagues in material science realized that these same X-rays, while troublesome to accelerator builders, could serve as an important research tool in the study of condensed matter. This realization led to the emergence of a new dimension of research that is pursued in specialized facilities at laboratories throughout the world. Free electron lasers, invented at a multidisciplinary laboratory centered at the on-campus particle physics facility at Stanford University, are now used worldwide for myriad scientific, technical, and medical purposes.

Detector and Electronics Technologies. Particle physics detector and electronics requirements frequently overlap with those of other disciplines, leading to important partnerships. For example, large-scale CCD detectors are used both in linear collider experiments and in optical telescopes. Flat-screen display technologies are being adapted by university particle physicists for use as photo sensors in next-generation underground neutrino and proton decay detectors. Low-power/low-noise electronics, developed for satellite- and balloon-based particle physics detectors, are proving useful for logging atmosphere-monitoring signals. Three-dimensional, edge-sensitive silicon pixel detectors, invented by university particle physicists to address the demanding requirements of the LHC and SLHC experiments, are being used by molecular biologists for high-speed X-ray measurements of protein structures and by medical researchers for low-dosage mammography.

Large-Scale Data Acquisition and Computing. Particle physics experiments have always pushed the state of the art in sizes of data samples and computing requirements. For example, the Sloan Digital Sky Survey is an optical telescope experiment with huge data acquisition requirements that is being performed by a collaboration of astronomers and particle physicists. Data and computing requirements for upcoming optical telescope facilities such as PanSTARRS and LSST will push the state of the art even further, driven by the LHC experiments. University particle physicists and computer scientists have partnered with other campus researchers to harness and share the power of all available campus computing resources to make high-throughput computing a widely available research tool. For example, the Grid Laboratory of Wisconsin (GLOW), initiated by the university's particle physics group, now spans eleven domains: Astrophysics, Biostatistics and Medical Informatics, Chemical and Biological Engineering, Chemistry, Computer Sciences, Engineering Physics, Genetics, Genomics, Materials Science and Engineering, Medical Physics, and Physics. Scientists using this campus grid have been able to increase greatly their computing throughput, thereby increasing the range and complexity of the problems they study.

Advances in Superconducting Materials. Accelerator-based experimental particle physics is usually limited by the field strengths in accelerator and detector magnets. However, advances in superconducting technology, made in condensed matter laboratories, translate into an extension of the particle frontier and improved detection capabilities. The ultimate power of the ILC—the next major step in accelerator-based elementary particle physics research—will be determined by the maximum field gradients that can be maintained in superconducting RF cavities. Campus-based material scientists are carrying out forefront research in this area.

5 Meeting the Scientific Goals

Having described the rich set of current research activities in particle physics, and having explored the universities' key role in the execution of current frontier programs, we turn our attention to investigating how well universities are positioned to meet future goals.

5.1 The Future of the University Grants Program: An Evolving Model

There are three different ways in which the U.S. particle physics landscape will change over the next decade. First, the large laboratory-based experimental programs will move almost entirely to Europe. Second, the lifetime of an experiment, from conception through operation, will often be measured in decades. Finally, the U.S. program will likely be dominated by a few large, offshore facilities and a collection of increasingly diverse reactor, small-scale-precision, astrophysics, and cosmic-ray experiments. U.S. universities are particularly suited to making the transition to this new research world.

There is no doubt that the future U.S. particle physics program will need a new model. This new model will need to accommodate the fact that up to half the field is or will be involved in the LHC and its upgrades. Beyond that, there is growing involvement in accelerator and detector development for the ILC, as well as a diverse and developing program of other experiments. However, this transition is being threatened by a number of issues that will require assertive action if the strength of the University Grants Program is to be restored.

First, regarding the LHC and its associated upgrades, it is vital for the U.S. to ensure an adequate number of new students; an expanded phenomenology program; sufficient computing and networking resources to allow effective participation in and leadership of data analyses; increased support for an effective U.S. presence at CERN; and sufficient university infrastructure to allow successful bidding for—and execution of—major upgrade projects.

Regarding the ILC, it is critical that the U.S. provide immediate support for priority areas of detector development, allowing the nation to recover from several years of slippage with respect to the other countries dominating the field's forefront. More U.S. particle physicists will be needed on the ILC program to maintain U.S. leadership in the face of strong overseas competition and to form a strong base of support for a U.S. bid to host the facility. Overall, a well-supported University Grants Program, focused on recruiting, educating, and training young scientists, is vital.

In the areas of small-scale precision, astrophysics, and cosmic-ray experiments, the field must retain the ability to respond effectively to new directions that may result from discoveries at the LHC and eventually at the ILC. This too requires adequate university support, allowing the development of new ideas and the subsequent successful execution of related new experiments.

5.2 The Sense of the Community

Much hope for the continued vitality of the field rests with the perceptions and expectations of the members of the particle physics research community and of students contemplating related careers. The subpanel made an extraordinary effort to solicit input from as broad a cross-section of the community as possible. The subpanel administered surveys (as described below) and held town hall meetings at Fermilab; at the 2006 Division of Particles and Fields (DPF) meeting in Honolulu; and at SLAC, MIT, and CERN. Further, of course, researchers from throughout the country directly approached many subpanel members.

The subpanel, as part of its fact-finding mission on behalf of the University Grants Program, conducted a survey of university principal investigators (PIs), designed to solicit both quantitative and qualitative information (see appendix 10.6 for a copy of the survey). This survey was administered to all DOE and NSF PIs, this group defined liberally to incorporate PIs on all grants funded in the past year (including some small grants for setting up workshops and conferences, etc.). NSF provided e-mail lists for all of its PIs in elementary particle physics (EPP), particle and nuclear astrophysics (PNA), and theory. DOE was unable to provide such a list of e-mail addresses, but it did provide a list of PIs and their institutions, which allowed the committee to locate e-mail addresses in most cases. The Survey Monkey tool was used to administer the survey to a total of 180 DOE PIs and 227 NSF PIs in January 2007. A total of 268 responses were received, representing 125 institutions. The response rate was 72% for DOE PIs and 61% for NSF PIs. The quantitative questions were analyzed in an Excel spreadsheet, and the charts were viewed and discussed by the UGPS committee. A subpanel member read the responses to each of the nine qualitative open-answer questions and prepared and presented a summary of these responses, along with some typical comments, to the full panel. Following is an overview of the most important survey results.

5.2.1 University Infrastructure

When asked, “How has the availability of technical personnel at your institution for the design, construction, and operation of experiments changed over the past ten years?”, over half the respondents said that it was somewhat reduced (31%) or much reduced (26%). By contrast, none said it was much improved, and 11% described it as somewhat improved. From the 125 institutions responding to the survey, a total of 22.5 mechanical engineers, 60.5 electrical engineers, 115 technicians, and 74 computing support personnel were identified. Support for these technical personnel included substantial university funds (20–35%, depending on category). DOE and NSF support for engineering staff was about equally divided between ongoing grant support and project-specific support. DOE base grants support between 22 and 29%, depending on category, and DOE projects support between 14 and 30% of technical personnel. The rest comes from NSF base and project grants, university support, and “other.”

By contrast, the availability at universities of physical facilities for experimental work has not changed much in the past ten years: 37% described it as “about the same,” with the remainder equally divided between “improved” and “reduced.” An open-ended question asked

PIs to describe their facilities, and many, with obvious pride, responded with an impressive list of clean rooms, machine shops (often subsidized), high-bay areas, electronics shops, computer facilities, and so on. Another open-ended question, inviting additional comments, concerns, or suggestions regarding technical infrastructure at universities, drew responses pointing out that universities provide a cost-effective alternative to national laboratory shops and emphasizing the notion that students and postdocs benefit significantly from the opportunity to design and build experimental apparatus in the university environment. Others mentioned the fact that strong university technical infrastructure also attracts undergraduates to particle physics and stimulates creative ideas for new experimental approaches.

Considerable concern was expressed over the decline in technical infrastructure and the difficulty of finding the support necessary to keep trained engineers and technicians available in-between projects. Ideas for improving the situation included sharing resources among different university departments and setting up centers of technical expertise to be shared by several universities that are in geographical proximity.

5.2.2 High Energy Physics in University Departments

The survey included several questions that attempted to elicit a picture of the overall health of high energy physics within university departments. For example, respondents, when asked to estimate the anticipated number of retirements and new faculty positions in the field over the next five years, indicated that the number of new positions slightly exceeded expected retirements (253 versus 215). Student interest in high energy physics was deemed steady compared to five years ago, respondents reporting that they evaluated almost two qualified applicants for every one thesis student accepted into their group.

DOE and NSF provided most of the support for experimental graduate students, with only 16% coming from universities, although universities provided slightly over half of the support for theory graduate students.

Many respondents noted concern that teaching assistantship (TA) support for theory students was becoming increasingly difficult to come by, as other disciplines sought to increase the number of students so supported. Even experimental graduate students are increasingly being asked to TA for longer periods of time, limiting their ability to travel to remote experiments to take data and making it more difficult for them to complete their theses. Many respondents stated that student support was declining at the same time that costs per student were rising, due to new rules regarding tuition remission and benefits. One possible solution offered was for the agencies to fund graduate traineeships that would be separate from the base grant and would require some institutional cost sharing.

In response to an open-ended question about the status of high energy physics in university physics departments, opinions were mixed. Some expressed concern that the trend toward offshore experiments and the reduction in technical work done at the universities themselves were together reducing the visibility of high energy physics, making it more difficult to attract top students. Others, in contrast, noted the prestige attached to working at big facilities like the Tevatron and the LHC, expressing optimism that major discoveries in the next few years would give the field a boost. Further, some respondents noted that many other disciplines are also starting to rely on large facilities located off-campus, so in a sense, high energy physics is leading the way. Several respondents also stressed increased interest in astrophysics and cosmology, which is leading to greater cooperation with faculty in these areas.

5.2.3 Distribution of Research Effort

The survey also asked respondents about their current and planned future areas of research. The current distribution of research efforts is shown in Figure 1. It is interesting to note that by 2012, half of the FTE effort in the field will be devoted to the LHC (almost double the current level of effort), while the second-largest effort in 2012 is expected to be in astrophysics and cosmology. Respondents were also asked to describe their R&D efforts, with the results summarized in Figure 2. It is important to note that the R&D effort is broadly distributed across all areas. Theorists were asked a similar question, with the results shown in Figure 3. Overall, the largest research area, both now and in five years, is particle phenomenology. The second largest is astrophysics and cosmology, where significant growth is expected by 2012.

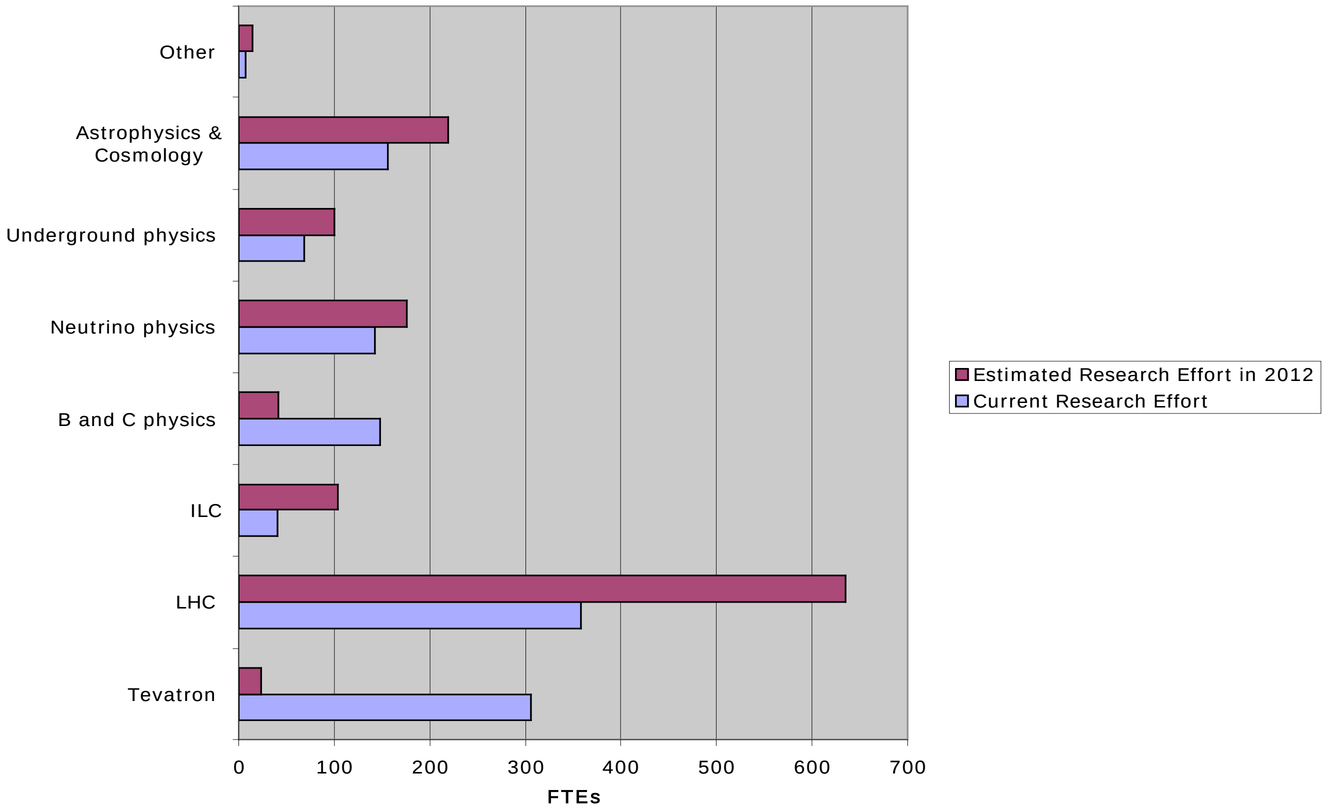

Figure 1. Survey response: current distribution of research effort in FTEs (faculty, postdocs, and students) and anticipated effort distribution in 2012.

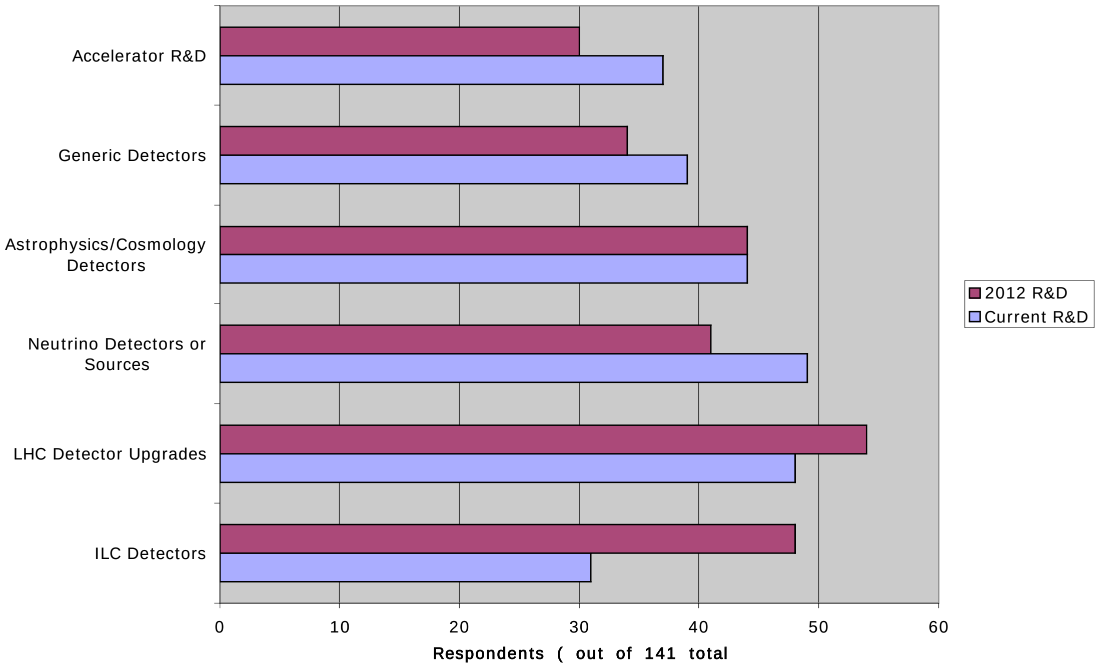

Figure 2. Survey response: current distribution of R&D effort and anticipated R&D distribution in 2012.

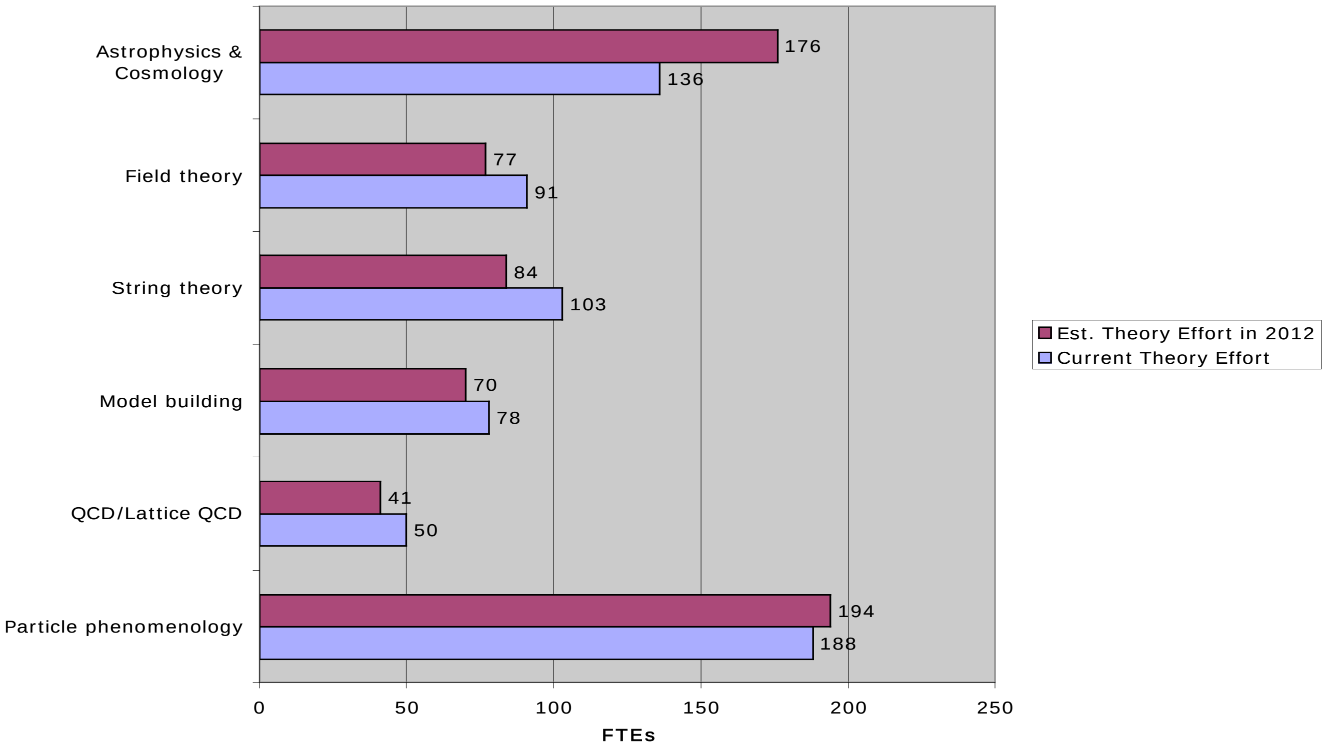

Figure 3. Survey response: current distribution of theoretical research effort in FTEs and anticipated distribution in 2012.

5.2.4 Program Management

A final area of inquiry concerned the management of the HEP program by DOE and NSF. There was very little dissatisfaction with the peer-review process, with only 12% reporting that it did not work well and 24% saying it worked very well (the remainder describing it as working “OK”). The main complaint focused on the overall level of funding. In general, respondents seemed to think that the ideal approach lay somewhere between the DOE model, with steady funding levels that do not change much over time despite a group’s accomplishments or lack thereof, and the NSF model, with more dramatic fluctuations that sometimes make it difficult for faculty to maintain their group. In answer to an open-ended survey question regarding agency barriers to research, a number of concerns were voiced. Most respondents felt locked out of support from opportunities arising in an agency other than the one providing their primary grant support. In projects where DOE and NSF both provide support, the approval process and post-award management were felt to be time-consuming and burdensome. Interdisciplinary projects within the same agency were also deemed challenging, due to lack of communication between programmatic areas. Given the large number of scientific opportunities in research areas at the interface between traditional disciplines, this is a matter of particular concern.

5.2.5 Open Survey

Because it involved some aspects of current program management, the qualitative, open-ended portion of the survey was conducted anonymously, responses tagged for the respondent’s place of employment (university, national laboratory, other); position (graduate student, postdoc, tenure-track faculty, tenured faculty, research staff, other); and primary source of research support (DOE/HEP, other DOE, NSF/Physics, other NSF, other federal, none). In total, there were 251 respondents and 1,238 separate responses to all of the questions (see appendix 10.6). Table 1 shows the rate of response in each category.

On the whole, the responses suggest eagerness for the next phase of experiments at the LHC and the international neutrino program. Respondents were optimistic that the near future will yield exciting results, relaying some evidence that students are anticipating this excitement, as applications to graduate school and interest in high energy physics seem to be on the rise. At the same time, however, respondents indicated concern about the steadily decreasing level of support for the University Grants Program; indeed, for many this is a crisis-level concern. Respondents expressed general unease regarding the time scales of future projects, especially the initiation of the ILC. Finally, respondents noted growing concern about how physics departments will view the field of high energy physics during the coming period of increased offshore activities. Some anecdotal evidence indicates that hiring patterns, traditionally supportive of high energy physics, may shift in favor of other exciting physics fields.

Table 1. Responses to the Open Survey

	Percent response	**Response total**
Place of employment		
University	84.5	212
National Laboratory	13.1	33
Other	2.4	6
Position		
Graduate Student	12.7	32
Postdoc	8.4	21
Tenure-track faculty	11.2	28
Tenured faculty	49.8	125
Research Staff	14.3	36
Other	3.6	9
Primary source of federal research support		
DOE/HEP	65.3	164
Other DOE	2.4	6
NSF/Physics	21.9	55
Other NSF	1.2	3
Other federal	2.8	7
None	6.4	16

Respondents also stressed their concern over the situation of students in high energy physics. Because of eroding support, more and more theoretical graduate students are being required to teach more and more of the time. This is unfortunate for at least two reasons: first, it lengthens the time to degree; and second, it signals to physics departments a hint of declining support for HEP research, exacerbating hiring worries. The magnitude of this problem is further enhanced because some departments are finding TA support more difficult to sustain within their own institutions. Respondents produced some evidence that experimental graduate students are being asked to take on TA appointments.

Respondents also emphasized the problem of declining support for research assistantships (RAs) and declining technical infrastructure—plainly matters of grave concern. Many suggested that the balance between DOE funding for national laboratories and for the University Grants Program should be reconsidered.

Concern also focused on “boundary issues.” The well-known difference in support levels between DOE-funded programs and NSF-funded programs was noted. For example, of those who responded to the question asking whether the “two agency” model is “good for HEP,” essentially none of the individuals funded through NSF agreed (only 1 out of 21), while essentially all of those funded through DOE agreed (63 out of 64). The committee also studied this question and determined that a major strength of the U.S. HEP program is the fact that it is supported by two agencies, each with different strengths and approaches to its research programs. The sentiment expressed by NSF grantees might change if there were more opportunities to transfer between the agencies for programmatic needs. Prominent among the boundary issues generating concern were matters of fairness in the grant process—for example, the “branding” of certain whole institutions as “belonging” to one agency or the other and the subsequent inability of these institutions to break free from such de facto labeling. Further, disciplinary boundary issues seem to arise because of "siloing," or bureaucracies, within individual agencies. For example, interdisciplinary or cross-disciplinary matters between high energy physics and nuclear physics, or high energy physics and astrophysics, often lead PIs into pursuing circular or nonconvergent avenues in arranging support. In addition, because of "institutional labeling," whole programs can risk being viewed as off-limits to researchers located at institutions that are not funded by an agency associated with these programs. The community was split in its analysis of the peer-review process at the agencies, with most suggesting that the NSF procedures are largely successful, while the burden carried by the officers of the large DOE program is managed well, considering the tight funding picture.

Outreach to both the K–12 arena and the general public was also generally emphasized, with DOE-funded individuals indicating a desire for more support for such activities and most NSF-funded individuals indicating satisfaction with their support level. Thus, while the missions of the two agencies are very different in this regard, a number of DOE-supported respondents clearly would appreciate greater support for their outreach efforts.

5.3 University Grants Program Manpower and Infrastructure

To achieve the scientific goals of the university particle physics program, a certain sustained level of manpower and resources is obviously necessary. As discussed above, this is a time of significant change in the structure of the particle physics program: several large experiments and associated facilities are about to terminate, many in the community are largely focused on the offshore LHC, and intense R&D is planned for the ILC. Understanding the manpower, resources, and infrastructure needs in this fluid environment requires a careful assessment of the present situation and of the factors that will influence these areas as we move forward. This section, like the previous one, draws significantly on the results of the survey that was carried out across the U.S. particle physics community.

5.3.1 Students

The survey requested information on the number of students (undergraduate and graduate; experimental, theory, and accelerator) for each PI and their sources of support (DOE, NSF, project funds, or non-federal). It found that 76% (DOE) and 86% (NSF) of PIs have at least some undergraduates engaged in experimental activity. This is in contrast to only 17% (DOE) and 29% (NSF) of PIs who have undergraduates working on theory projects. However, it is undoubtedly easier to find meaningful projects in the experimental area than it is to find theoretical projects. Only 32% (DOE) and 45% (NSF) of PIs have undergraduates working on accelerator projects. This is an area that could benefit from more active recruiting, particularly in view of the many smaller accelerator development projects that have been identified for the ILC and the exciting prospects for developing advanced acceleration techniques. Involving undergraduate physics and engineering students in research is an excellent and low-cost way of boosting the flow of people into the field; it should be strongly encouraged.

As noted earlier, respondents indicated that the level of student interest in particle physics has remained roughly constant, compared to five years ago. As will become clear below, however, this situation presents our community with an acute dilemma: while there is a sustained level of interest in the field, it is endangered by a continuously declining ability to recruit students and to support them effectively once they are engaged.

This declining support for the university particle physics program is reflected in the fact that the field now supports just half of the number of qualified students who apply for positions leading to a Ph.D. This represents a significant loss for the country as a whole, as well as directly for particle physics, since the training a typical particle physics graduate student receives is excellent preparation for many diverse careers. Indeed, the payoff of boosting support for particle physics graduate students would extend well beyond the immediate field.

Those responding to the survey were asked to share any additional comments or concerns regarding undergraduate or graduate students in their groups. They were particularly invited to remark on the relative use of TAs and RAs to support students in both experiment and theory and to comment on how this has changed over the past ten years.

The overwhelming response stressed that the level of (NSF and DOE) grant support for RAs for graduate students is insufficient and has indeed been declining over the last decade. At the same time, respondents noted that the cost of supporting a graduate student on a grant has increased, especially because of stricter university requirements regarding tuition remission and fringe benefits.

As a result, particle physics groups routinely rely on other sources of funds for all or part of their graduate student support. One major resource is TA positions for particle physics students, addressed in more detail below. Some respondents noted that their universities have limited fellowship support for some students. A handful also mentioned seeking outside support from other federal agencies. Many said that they had been forced to turn away qualified students due to a lack of grant support. Some also indicated that students had turned down the chance to join a particle physics research group because other departmental areas could promise steadier RA support, rather than a mixture of TA and RA support.

A significant number of respondents noted that the lack of grant support had specifically led to pipeline issues and opportunity costs. Having a very limited number of students on a strict funding timeline makes it difficult to cope when a student leaves for personal reasons (leaving the project understaffed), when a student does not graduate as quickly as expected (backing up the intake of new students), or when there is a fluctuation in the number of good applicants (forcing a PI to turn away promising candidates).

Respondents also emphasized the fact that particle physics groups routinely rely on TA support as part of their strategy to help their students reach graduation. For the majority, this support comes during their first couple of years of graduate school, before the student joins a research group. However, theorists have come to use TA support quite heavily even for senior students, due to a lack of grant support for RAs. A handful of experimentalists mentioned that they have also recently started to use some TA support for senior students because of declining grant funds.

Survey respondents brought up several difficulties caused by this reliance on TA support. First, spending time as a TA slows senior students' research progress (increasing their time to graduation) and hampers experimental students' ability to travel to particle physics labs. Second, TA support is also currently a declining resource for particle physics at many institutions, because university administrations are providing less overall TA money to physics departments, departments are reducing the number of semesters any student may spend as a TA, or other physics subfields are requesting more TA slots. Third, if a particular research group (usually particle physics theory) makes unusually large demands on the available TA slots, this creates friction and resentment within the department as a whole.

The overall picture—of declining support for particle physics students, overuse of supplemental TA support, and the turning away of qualified candidates—is in sharp contrast to the observed sustained level of interest in the field. Immediate steps clearly need to be taken to reverse these negative trends.

5.3.2 Postdocs

The typical level of support for experimental postdocs is one to two FTEs per PI, while for theory postdocs, the number is less than one-half per PI. Given the choice between hiring more graduate students and taking on a postdoc, many faculty members will opt for the latter when faced with limited available funding. However, while this may seem be the best solution in terms of immediate research workload, the long-term negative effects of this choice on the field as a whole are clear.

Postdocs are widely recognized as an invaluable resource for university faculty members, who rely on postdocs to sustain research while they carry out their many other duties. This is particularly the case for postdocs located at remote laboratories. However, a considerable cost overhead is usually associated with such remote postings (e.g., at CERN for the LHC) because of significant differences in the cost of living between the home institution and the remote location. The additional expense is essential if postdocs are to be maintained at experimental locations, where they often carry out mission-critical tasks, and it should be supported by the agencies.

5.3.3 Senior Research Scientists

The survey results show that most PIs (75%) have at least part of an FTE experimental senior research scientist working for them, with a majority (66%) reporting a full FTE or better in this category. Senior research scientists' involvement in theory and accelerator development is considerably smaller.

The survey invited comments on agency policies and practices regarding support for senior research scientists and research faculty. In response, many noted that DOE and NSF do not support these positions at their institutions and in many cases even actively discourage them—an observation that is somewhat surprising, considering the widespread reported existence of such positions. Opinion was about evenly divided on the question of whether or not senior research scientists should be supported by the federal agencies. Those opposed to agency support suggested that the universities should instead be responsible for this support. They noted that it is unfair to support research scientists on long-term appointments if this leads to the hiring of fewer postdocs but also stressed that it would be inhumane to drop support for long-term senior scientists who have contributed much to the field.

Those in favor of agency support for these positions stressed the essential expert leadership and continuity roles senior research scientists play in experiments, particularly when based at a major laboratory, and further emphasized their indispensability in view of the teaching and other responsibilities of regular faculty. It was suggested that the contributions and effectiveness of senior research scientists must be carefully evaluated. If this evaluation is positive, then the agencies should support these individuals without prejudice. The panel supports this approach regarding these valuable members of the field.

5.3.4 Faculty

The survey shows a broad range of sizes for both experimental and theoretical groups, ranging from one to eight or more FTEs, with only a small number of FTE faculty engaged in accelerator projects. This diversity in group size is generally seen as a strength of the particle physics University Grants Program, in which large groups involved in major experimental and/or theoretical efforts coexist with smaller groups or even individuals. In this regard, it is essential that an individual physicist with a new idea has the potential to obtain support for the development of that idea.

Survey responses indicated that slightly more open particle physics faculty positions (a weighted average of 1.3 per department) are anticipated than the number of anticipated retirements of particle physics faculty (a weighted average of 1.1 per department). While this is a positive indication of the health of particle physics within university physics departments, it will inevitably increase requests for funding support to sustain these young faculty members.

In response to a question regarding the use of start-up packages for the support of new particle physics faculty, the survey found that in general, start-up packages seem to be similar to those awarded in the past or somewhat higher. They are still substantially smaller than those for other physics fields, in the $100K~200K range for new junior faculty and larger for senior hires. Most respondents reported that these funds were used for graduate student and postdoc support, while newly recruited faculty tried to secure a grant. Only about 15% of the respondents reported that start-up packages provide a significant source of new infrastructure.

Respondents further expressed a serious concern that the agencies might see the existence of a start-up package as a substitute for providing federal assistance for new faculty, thus undermining their support.

5.3.5 Technicians and Engineers

Survey responses revealed that for electrical and mechanical technicians, electrical and mechanical engineers, and computing support personnel, most PIs receive little or no general (i.e., non-project) technical support in their groups from federal sources. The only minor exception is somewhat greater availability of computing support personnel, who generally receive a greater level of support from non-federal (university) sources. This situation highlights the difficulty—often brought up in our town hall meetings—of maintaining the continuity of technical support between projects in the absence of any local support.

Responses to a general survey question regarding the change in availability of such technical support for the design, construction, and operation of experiments over the past ten years clearly indicated a significant reduction in this area. This reduction compromises the ability of U.S. university particle physics groups to bid for and take on major detector projects.

5.3.6 Physical Resources

Survey responses indicated that the facilities available to experimental particle physics groups for experiment construction and operation have, on average, remained about the same over the last ten years. However, many facilities are not solely supported by particle physics funds, and availability can thus heavily rely on collective support across the research groups in a physics department.

Most PIs have access to departmental or group machine shops, either free or at reduced rates. They generally have more limited access to electronics shops, clean rooms, and nano-fabrication facilities. Approximately one-third of respondents have access to some sort of high-bay area. A majority have access to a computing cluster, many with substantial capabilities in terms of CPU and disk space.

Respondents were invited to share any additional comments or concerns regarding universities' technical infrastructure. In general, they noted that it is no longer possible to maintain sufficient particle physics infrastructure at universities because of steady deterioration and attrition. Arguing that technical infrastructure and manpower cannot be sustained using only project funds, they stressed the notion that base support is needed to buffer the long times in-between projects. Indeed, funding is so low at some institutions that universities are starting to take away particle physics laboratory space. While other sources of funding for infrastructure and technical manpower can alleviate the situation, agency funding is vital if capabilities are to be maintained. Multi-university sharing can help, but it is not viewed as a genuine long-term solution to the problem.

Clearly, university-based technical capability is vital to students and postdocs, whose training becomes difficult or impossible when technical capability is restricted to the labs. Respondents emphasized that university infrastructure is generally more cost-effective than infrastructure at the labs. Moreover, it facilitates non-project-specific work, therefore allowing greater innovation.

Finally, industry capabilities and consultant engineering services have improved over the years, and universities sometimes take advantage of these resources to participate in and accomplish technical projects. The downside of this “outsourcing” approach, which avoids the overhead costs and demands of a continuously maintained technical staff and infrastructure, is that it does not provide the student/postdoc training necessary for the future of the field.

5.3.7 Manpower and Infrastructure: Summary

Overall, the field of high energy physics faces several critical manpower and infrastructure problems. Declining graduate student support affects the intake of new physicists and therefore the future of particle physics overall. This is an especially urgent matter that must be addressed by the agencies without delay. Postdocs are also vital to the health of particle physics, and with a significant fraction of U.S. activities in the field now located offshore, the issue of cost-of-living adjustments demands immediate attention. Agencies must clarify their policies regarding support of senior research scientists, who provide essential expertise for experiments. Finally, particle physics–specific physical infrastructure, and the associated technical manpower, has undergone serious erosion. If future experimentation is to prosper, these critical facilities must be maintained at a viable level.

6 Collaboration, Education, Outreach, and the Campus

The U.S. particle physics program has included international collaboration for decades. With a healthy and broad U.S. program in place, many U.S. researchers have long worked at domestic particle physics facilities, which have also welcomed and benefited from the collaboration of foreign scientists from all over the world. Likewise, a certain number of U.S. scientists have chosen to take their experimental activities to foreign laboratories, such as DESY, CERN, and KEK, matching their needs to facilities' specific capabilities. Such scientific exchange, beyond being simply successful, is vital to scientific progress.

In the past two decades, the number of U.S. scientists working in Europe has increased substantially with the LEP project at CERN and, more recently, the LHC at CERN. There has also been important U.S. participation at DESY for HERA, at KEK for Belle, and at other foreign facilities. With LHC operation beginning at the end of 2007, a new era will open up, increasing overseas participation of U.S. scientists even further. Indeed, this facility is a centerpiece of the U.S. program, so effective U.S. participation is critical. The LHC will dominate global particle physics for at least the coming decade, and U.S. scientists must develop new strategies to meet the challenges of this new era. While a solid physical presence at CERN is important, successful remote operations and physics analysis activities are also essential.

Many difficulties must be overcome as much of the U.S. particle physics effort becomes focused on CERN. Living expenses for those residing overseas are significant, and travel to Europe must also be supported at a level that allows serious contributions by scientists who remain resident in the U.S. Communication among scientists on both sides of the Atlantic must be efficient and effective. Time-zone differences complicate communication even further, particularly on the West Coast, where the time shift is more than one workday. Postdocs and graduate students working at CERN need senior supervision, a role that is often assumed by senior research associates.

In addition, at the same time that a significant CERN presence is necessary, it is vital that university groups maintain a viable presence and activity level at their home institutions. This is important not only for fully exploiting U.S. scientific manpower but also for fostering university support and integrating students into the research enterprise. Faculty will need support to function on both fronts, at CERN when residing on campus and on campus when residing at CERN. These new operation modes will also require new communication technologies. All of these challenges will certainly lead to even greater barriers, as yet unrealized, and these must be surmounted as they arise.

Beyond the need for enhanced communication tools, other requirements and resources include data and software systems that allow data and physics analysis to go on at universities, regional analysis centers to augment the distributed efforts, phone and video conferencing capabilities, remote document presentation systems, application sharing, Web casting and archiving, e-mail and instant messaging, computer-supported conference management, and document repositories. All these must be robust and of high quality if their use is to be efficient and effective. They must be available both at CERN and at the universities, and they must work together seamlessly. Planning and procurement must therefore be coordinated, requiring an appropriate level of dedicated resources. The LPC at Fermilab is a model for one type of regional center that can foster and augment the remote activities of university groups.

The LHC represents a major step forward into the new era of remote operations. Much will be learned from this shift. The U.S. ambition to host the ILC demands concomitant preparations to assist remote operations for collaborators in the rest of the world. Effective development in this area will be essential to the country's ability to assume the role of hosting a global laboratory. Such preparation will also help facilitate applications of similar tools for smaller onshore and offshore international collaborations.

Another significant issue for visiting scientists participating in experiments or conferences in the U.S. has been the recent difficulty in obtaining visas. The open circulation of scientists, along with their freedom to collaborate, communicate, and disseminate scientific information, is an important goal of the scientific community. Since September 11, 2001, enhanced security measures to secure U.S. borders have raised the level of scrutiny of visa applicants, slowing down the process. Ironically, then, the difficulties foreign scientists wishing to visit the U.S. earlier faced from their own governments have been replaced, in the post–Cold War period, by new U.S. government restrictions. Efforts to address this situation within the scientific community have improved it somewhat, but much more remains to be done. Scientists' application process has been streamlined, and the faster processing has been helpful, but the results can still be unpredictable for scientists from certain countries. It is important that the U.S. scientific community work together with the government to develop a national strategy to promote international scientific exchange. Our future role in international projects depends on it.

6.1 Opportunities for Education, Outreach, and the Campus

University-based physicists are different from laboratory-based physicists because they work with students—in class as teachers and in their labs as research mentors. This educational mission is not just a "value-added" to research; it is a way of life, a commitment. The experience of university-based experimenters is also distinguished by the need for long and/or frequent periods spent away from home. Most physics departments (and, it is to be hoped, most families) have come to accept this condition. However, as this report has consistently emphasized, the field's immediate future will see ever more of this peripatetic lifestyle. With all running accelerators offshore, professional and private relationships are going to require renegotiation. At the same time, the science of the next decade will be groundbreaking. It will thus need to be explained clearly to a public that might find it interesting to witness the struggle for answers "as it happens." Here, too, the educational mission of university particle physics programs has a role.

While the broad need for outreach was explored earlier, the following sections detail challenges to effective education and outreach and specifically address important issues facing the field on campus.

6.1.1 Education

One of the cultural shifts of the 1990s, following the downfall of the Superconducting Supercollider (SSC), was a growing, acute awareness of the need to make particle physics more accessible to the citizens who pay for it. This awareness coincided with the increased NSF emphasis on the connection between research and education and outreach, and with the concurrent NSF requirement that every grant proposal should indicate what "broader impacts" would result from a proposed activity. This requirement, usually interpreted as referring to fostering "[the] integration of research and education through the programs, projects and activities it supports,"[7] explicitly encourages grantees to devote some of their NSF funding to education and outreach. In contrast, DOE grantees face no such requirement, and PIs cannot explicitly use grant funds in this manner.

The survey question regarding "education and outreach" generated more responses than any other, respondents overwhelmingly emphasizing the importance of this activity and expressing their belief that education and outreach are part of their personal missions. Roughly, the responses centered on two themes: respondents funded by NSF tended to believe that their agency placed appropriate or too much emphasis on outreach, while those funded by DOE tended to feel that their agency should place greater emphasis on outreach. (A few DOE-supported scientists indicated that they voluntarily devoted some of their effort to outreach in spite of the lack of agency support.) The particle physics community overall, as evidenced by both their responses and their behavior, is clearly passionate about encouraging the dissemination of science among students, teachers, and the general public. Its members are eager to see how the coming science will stimulate even greater outreach opportunities.

K–12 Education. Every major laboratory and a number of individuals and groups now participate in programs that bring the science of particle physics to the educational community. These programs combine many features: classroom contact with K–12 students; programs that bring students to laboratories and campuses; programs that provide teachers with support for teaching physics; and programs that produce materials for paper, Web, or computerized distribution. The essential question for the next era concerns the degree to which these efforts will change quantitatively (i.e., producing more of the same) or qualitatively.

The primary quantitative change will stem from the coherence of so many physicists working on so few projects. Approximately four thousand physicists from around the world will be participating on LHC experiments, which will lead to the production of more educational tools, Web sites, CDs, books, and so on. This output will come through centralized experiments' efforts, individual national efforts, local university efforts, and the work of individuals. The increased output will be a positive consequence of the coming concentration on a few experiments: best practices can be shared, and overall quality will increase.

Paradoxically, however, this quantitative opportunity also poses a danger: the emergence of potentially hundreds of (well-meaning) similarly motivated products may result in a wasteful

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[7] Grant Proposal Guide, NSF 04-23, September 2004.

and confusing duplication of effort. This argues for the enhanced need for coordination not only within experiments but also across experiments. It also suggests the need for increased partnering with the K–12 education establishment within our universities. Of course, the degree to which the agencies can foster such boundary-crossing efforts remains to be seen.

Undergraduate Education: Research Experiences for Undergraduates. One important program in the education of undergraduate physics students is the NSF-funded REU. While this program is not specific to particle physics, particle physicists traditionally have accepted REU students into both experimental and theoretical groups. One particular REU program at the University of Michigan does focus on particle physics, in particular LHC physics, by offering students residence at CERN (see http://www.um-cern-reu.org/).

It has long been a common practice for many particle physics groups to participate in the REU program by involving undergraduate students in work at U.S. laboratories, rather than on campus. This approach involves extra planning because of undergraduates' typical age. However, host U.S. particle physics laboratories have excellent support facilities (on-site dormitories, security, and emergency services), and groups inclined to pursue this avenue also have on-site graduate students, postdocs, and research associates who can serve as local mentors for undergraduates. Undergraduates at U.S. laboratories, then, are safe and comfortable, living in a largely familiar environment. It is obviously less feasible, however, for single particle physics groups to send individual nineteen-to-twenty-one-year-olds to a foreign country for the summer. While the University of Michigan REU program has been of sufficient size, with enough resources, to offer in-residence mentoring and familiar support to its young people, it is unlikely that "regular" REU programs could individually sponsor safe and productive CERN experiences for one or two students.

A new mechanism should thus be considered that either replicates the centralized University of Michigan REU program or creates a new, differently organized one. For example, a consortium of U.S. universities might be considered. In such an arrangement, a joint REU grant might be proposed among dozens of U.S. particle physics groups or as a supplement attached to each of their individual programs. Either way, if multiple universities were involved in a single CERN REU program, the group would be of sufficient size to allow the necessary stability and support. Students would still recognize that their "allegiance" was to the particular REU university that had accepted them, but they would be cooperatively hosted and mentored as a group while at the CERN site. This would clearly require a high level of coordination and entail increased traveling and per diem costs for the students themselves, as well as significant administrative support. However, the international nature of such a broad program would be groundbreaking for REU, providing a remarkable opportunity for any young physics student. It is even conceivable that such a cooperative agreement would allow students to incorporate their REU experience into their university's study-abroad program, perhaps even receiving credit for their work. All in all, opportunities exist for a sizable expansion of this program, in spite of the challenges.

By any measure, the REU program has been a resounding success, both as a significant influence on students and, frankly, as a recruiting device for departments. Many REU students are invited back to attend graduate school. Indeed, the program is now so mature that faculty are now being hired who themselves benefited from earlier REU experiences.

Undergraduate Education: General Education. U.S. colleges and universities are currently focused on the growing consideration of general education reform. While it has been widely reported that Harvard University is currently reviewing its "core" curriculum, faculty all across the U.S. are engaged in consideration of what constitutes a well-educated college student. At the forefront of many of these discussions is students' experience with, and appreciation of, the physical sciences and "quantitative reasoning." Harvard University's 2007 "Report of the Task Force on General Education" declares:

> "The success of a general education program depends on many things, but the bottom line is great teachers offering great courses. It will take time, imagination, and resources to accomplish this: teachers need to be recruited from the Faculty, courses need to be developed with the new guidelines for general education in mind, and departments need to be involved in mounting departmental courses for general education credit."

This "bottom line"—great courses taught by great teachers—clearly applies to particle physics. Indeed, one population segment that has not received much attention in physics outreach efforts is non-science undergraduates. For example, while astronomy courses for non-science students are offered on every campus in the nation (one recent estimate is that roughly three hundred thousand students annually take a general education course in astronomy at universities, colleges, and community colleges), very few such courses are taught on particle physics. While a casual search reveals hundreds of astronomy textbooks for general education students, there are no comparable textbooks on elementary particle physics.

Because we know that extraordinary events in the field are about to unfold, there is a story here that is worth telling well. Particle physics is esoteric, but it is also highly visible: detectors, Feynman diagrams, accelerator laboratories, graphs, and animations—all these aspects of the narrative can be directed at any educational level. With no more mathematics than required in general astronomy, then, a sophisticated story of ongoing frontier science can be relayed to undergraduates. Since most universities and colleges require credits in broad areas ("physical sciences," "biological sciences," etc.), undergraduate students often choose to take courses with titles like "Stars in the Universe," "Physics for Poets," or "How Things Work." If presented well, general courses on particle physics and cosmology—the paradigmatic "Inner Space, Outer Space" subject—would be a popular offering on any campus.

The task of creating courses of the same size and complexity as those offered in general astronomy is a huge one, especially given the impressive array of supplementary materials that accompany any undergraduate textbook today. No single one of us is likely to be able to create either a competitive set of digital tools or text materials. Therefore, collaboration within the particle physics community should be encouraged, with faculty working together toward building syllabi, graphical tools, reading material, and so on, in order to spread the considerable burden of creating a new course for potentially hundreds of students.

Such a joint cross-campus project, to our knowledge, has never before been attempted. Generally, as faculty, we tend to think of our individual campuses and teaching techniques as intensely personal domains. However, ours is such an inherently collaborative discipline that a shared effort directed toward this area might bring particle physics to the general student body in a particularly exciting way. Support for such an effort should be an agency priority, especially within the NSF, which emphasizes science education as one of its specific missions.

6.1.2 Public Outreach

Public outreach can take at least two broad forms: public appearances in the media or in home communities, and the production of digital, paper, and video materials for public use. For public appearances, coordination of the community's expertise could largely consist of simply pooling presentation materials for colleagues and sharing experiences. This is already being done to some degree within each experiment and within host laboratories, but these coordination efforts are largely lab-focused, managed as they are by laboratory public relations staff. Since there are so few laboratories and so many universities, a way to explicitly tie LHC public relations to U.S. universities must be found.

Many particle physicists already gladly break ground in new venues, and all particle physicists can benefit from the collection of our colleagues' experiences. The InterActions Collaboration (http://www.interactions.org/), which coordinates working portal interactions, has created an excellent, centralized location for collecting best practices. This effort could be profitably expanded through increased personnel and greater involvement with the university community. Currently, the InterActions Collaboration includes only laboratories and national institutes, but universities might be incorporated. Expanding Interactions.org into the academic community would greatly enhance the collection of useful resources, allowing slides, syllabi, movies, digital tools, and so on to be harvested in a more inclusive fashion. Finally, Interactions.org could provide a visible portal connecting public venues with physicists willing to talk about particle physics.

While there is indeed something charming (and frankly amazing) about the numerous efforts put forth by hundreds of individual physicists, proactive coordination—perhaps through Interactions.org—would facilitate critical sharing of ideas, tools, and best practices.

6.1.3 Other Sciences

Particle physics has traditionally been seen as a relatively independent-minded subdiscipline. As the field has evolved into its current form, physicists from other areas have commonly expressed amazement at how differently our field functions when compared to theirs: particle physicists are off-campus much of the time; we work within huge collaborations; and we are focused on decades-long projects, often laboring for years before a "payoff." But these are "lifestyle" differences, having nothing to do with physics itself. The recent astrophysics–particle physics connection is one of the more visible examples of the ties linking particle physics and other physics subdisciplines.

While the intellectual overlaps among field theory, phase transitions, and broken symmetries have yielded crucial connections, practical "know-how" is also important. Among the first precision tests of the Standard Model, for example, were atomic parity violation experiments performed by AMO practitioners, who had the skill and experience to pursue experimental questions in their domain. Overlaps with certain areas of nuclear physics have always existed, made all the more apparent in the RHIC experiments and solar and reactor neutrino experiments. Such "know-how" overlaps with other disciplines, yielding answers to questions traditionally associated with particle physics, are healthy and should be encouraged.

Yet intellectual and practical overlaps can be problematic, as the funding agencies are organized around subdisciplinary boundaries, and these domains are somewhat more resistant to cross-funding—especially when resources must move from one funding office to another, or shift between agencies, or are granted to people not traditionally funded in the office in question. This difficulty is further exacerbated when traditions and cultures are mixed, as between astronomy and particle physics.

Such boundary issues are difficult to sort out and even more difficult to fix. As we draw closer to the resolution of truly fundamental questions left unanswered by the Standard Model, a redoubling of particle physics outreach efforts is warranted, even "down the hall," within physics departments themselves. To that end, particle physicists must make concerted efforts to give department colloquia on high energy physics topics, attend colloquia in other disciplines, and present invited talks at non–particle physics annual meetings. Like the largely independent outreach and educational efforts detailed above, such ambassadorship properly acknowledges our debt to other physics subdisciplines.

On a more tangible front, future facilities will require R&D on issues that will benefit from the participation of experts in surface science and unique materials science. It remains to be seen just how well such cross-collaborations will fare, beyond a few specific projects, but this effort rests largely within the accelerator physics community thus far. It might later extend into novel detector design. Opportunities for collaboration with condensed matter physics should be made a priority.

Certainly in the early days of massively parallel computing, and more recently with grid computing and the associated need to reliably manage continent-sized, high-speed, high-density computer networks, some segments of the computer science community have come together with particle physics. Likewise, large-scale database technologies and the scaling that may or may not be feasible as data sets become increasingly massive might draw particle physicists into collaborations with their computer science colleagues. In this regard, visualization requirements, high-density computing needs, pattern recognition problems, and database challenges might bring particle physicists into increasing contact with the computational biology community, as it too struggles with increasingly sophisticated projects. In fact, even the computer graphics community might have access to capabilities and tools that could help particle physics experimentalists—not only to reproduce objects and the time-dependence of events but even to evolve toward new visual techniques of discovery.

Fostering contacts outside of strictly technical domains might lead to interesting new avenues of exploration. Anthropological studies have already been done on the particle physics "tribe." As it becomes more and more global and monolithic, experts in the social sciences might find it educational to be welcomed into the particle physics community. Similarly, since "history" is about to be made, scientifically, the history and philosophy of science communities might also be interested in collaboration, even firsthand access to the very real philosophical questions that will arise as the pressure to announce (or not announce) results becomes increasingly intense.

Finally, the sheer weight of organizing work across as many as twelve time zones, among literally thousands of people, demands new technologies allowing the integration of computers, grid, and people. In fact, the technical and sociological problems related to "gridifying people" remain unsolved, and the relatively new field of information science might thus become an increasingly important collaborator, even a necessary one if particle physicists are to work effectively.

In the end, university-based physicists know that important "outreach" opportunities lie beyond our physics buildings, on other parts of campus.

6.1.4 University Life

One significant issue that will require continued attention is centered within individual physics departments. Particle physics has enjoyed considerable support within most physics departments over the decades. But if the next two decades are at all like the last two, physics as a whole will continue to expand into many new areas of exciting research, areas that will compete with particle physics for valuable faculty positions.

If university-based experimental particle physics becomes synonymous with absent faculty and declining program resources, then open positions in particle physics will surely be subject to stiff competition in many departments. If, on the other hand, university-based particle physics demonstrates a pattern of increased campus presence of faculty, postdocs, and graduate students, and rising program resources, then the number of faculty necessary to do all of the work will likely be assured in most departments. The challenge, obviously, is to create circumstances that will guarantee the latter scenario.

Two challenges face U.S. LHC experimenters—challenges that paradoxically could lead to this more promising scenario. The first involves real estate: the number of "seats" available at CERN will be much lower than the U.S. has traditionally enjoyed at host laboratories in the past. Large and medium-sized groups will therefore have some personnel based at CERN, but significant numbers will either remain on their home campuses or be stationed at regional analysis centers, such as the CMS facility at Fermilab. The second challenge facing LHC physicists is the fact that the data reduction responsibilities will necessarily be dispersed across the world. In the U.S., this means that considerable computing resources for reconstruction, calibration, simulation, and data reduction tasks will largely be located on college campuses, and computing models will need to be robust enough to support these responsibilities using grid-based analyses. Thus, more than the usual number of physicists will be remaining at “home,” and so will much of the data.

6.2 Collaborative Tools

“On site” at host laboratories has traditionally been the center of the action for experimenters. Important hallway conversations have occurred on site; key computing tricks have been developed and revealed on site; and important, informal support from individual experts has been centered on site. Typically, all of these important means of collaboration were available within a short walk of those who needed them.

Replicating this immediacy—keeping U.S. physicists “in the loop”—is thus a significant challenge. How can thousands of remotely located physicists be as heavily involved as if “they were there”? The set of human-computer tools designed to “gridify people” is collectively referred to as “collaborative tools.” Their development constitutes an active research focus program among many disciplines and within numerous private companies.

To most particle physicists, “collaborative tools” simply means “video conferencing,” which has taken one of two forms: either commercial solutions (now typically Polycom equipment), with H.323 IP-based frameworks such as ESNET, or internally developed solutions, such as VRVS or now EVO. The transition to the efficient use of video conferencing has not been seamless. There is still a constant struggle between users and their host laboratories over sufficient video-capable space and sufficient funds used to renovate this space for proper acoustics and to maintain support personnel. Some laboratories have been more welcoming of these efforts than others, and some groups have been more capable than others of using modern, unobtrusive systems.

The use of video conferencing has required behavioral adjustments as well, and these have come slowly. In most collaborations, it is now standard for all talks to be posted on the Web before a presentation and for participants in the dominant room to be more aware of camera and audio configurations. Some might argue that this push to the pre-preparation of digital talks has led to a less spontaneous and productive working environment, and they would be right. Nevertheless, progress is being made in this area. Large-sized video systems—whole walls that are always turned on, inviting informal as well as formal contact—will be within reach during the lifetime of the scope of this report. Many of the business community’s efforts have been directed toward the creation of tools to facilitate better remote work, fostering informal as well as formal video conferencing.

Thus, taking video conferencing seriously is absolutely essential for the kind of U.S. physics involvement that the community expects. The move from ISDN- to IP-based video means that data and video can now be integrated, driven by computer applications. The need for the highest-bandwidth networking capabilities for LHC tiered computing centers also means that particle physics groups will be increasingly connected over very fast lines. Accommodating these datalinks to data and video traffic may lead to much-improved video opportunities. Costs will of course be associated with upgrading and equipping university rooms and desktops, and costs will probably also be associated with helping to provision even foreign laboratories' infrastructure. On the other hand, the costs of not devoting sufficient resources to this vital collaborative tool are incalculable. The most recent and complete study of this issue for the LHC collaborations, 2005's "RTAG 12: Collaborative Tools,"[8] concluded:

> "One cannot overstate the fact that the absence or inadequacy of high quality, robust and coherent collaborative tools at CERN and the other member institutes has been and continues to be very costly to the LHC collaborations. Quantification of these losses in terms of resources is nearly impossible to estimate, but one can consider some very concrete and familiar cases and then try to extrapolate."

Looking further, collaboration across large distances and many time zones demands much more than just more and better video conferencing. The development of new tools designed to aid collaboration is now the focus of technical and social research within information science and computer science programs.

In the last ten years, high energy physics has relied on essentially three collaborative tools: the telephone, e-mail, and video conferencing. These aids to distributed work functioned acceptably in the 1990s, when they constituted the state of the art in remote collaboration. However, as the Internet and the World Wide Web (a particle physics inspiration) took hold, success in the world economy required international businesses to respond to the challenge of working across multiple time zones in near-real time. Indeed, much of the business community is now significantly ahead of particle physics in approaches to bringing people together in ways that most closely replicate "being there." Many corporations (e.g., Procter and Gamble, Toyota, Industrial Light and Magic, Ford Motor Company, Mayo Clinic, Dow Chemical, W. R. Grace and Company, Boeing Corporation) have famously met this challenge with the creation of their own tools and the adaptation of their cultures to this new way of working. These examples of success all share one feature: the effective adoption of new technologies has gone hand in hand with a conscious effort at fostering a simultaneous cultural evolution. Some companies have even sponsored social events within remote environments, across time zones.

The kind of work that particle physicists do is not so different from that required of any technically oriented commercial firm. Two basic forms[9] of collaborative work can be identified:

- **Synchronous work:** personal discussions, seminars, tutorials, presentations, working groups, brainstorming
- **Asynchronous work:** document editing, code development, shared data analysis, instrument monitoring, Web portal content creation/retrieval

The goal is to map these two forms of collaborative work onto existing and future tools:

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[8] S. Goldfarb et al., "Report of the LHC Computing Grid Project," CERN-LCG-PEB-2006-07, Apr. 27, 2005, p. 53.

[9] e.g., D. Agarwal, "Finding and Supporting Collaboration Needs and Opportunities," Lawrence Berkeley Laboratory, talk at Shaping Collaboration, Dec. 2006.

- **Synchronous tools:** *telephones* (landline, cell, VOIP), *audio conferencing* (speakerphone, conference calling), one-to-one video conferencing, *active many-to-one video conferencing* (meetings), *active many-to-one presentations* (large lectures/seminars), "always on" virtual hallways or media spaces, whiteboarding, desktop sharing (either through remote login or through true sharing tools such as VNC or commercial applications such as NetMeeting)
- **Asynchronous tools:** *e-mail,* blogs, *wikis,* RSS feeds, video IM (VIM), video logs (vlogs), video mail, podcasting, *archived Webcast streaming* (Real Video, YouTube, Synchomatic), *digital archives* (CVS, digital asset management, team sites, team spaces)
- **Semi-synchronous tools.** text-based instant messaging (IM, or "chat"), text messaging, shared Web spaces, simultaneous document authoring tools (now becoming nearly synchronous)

The italicized items are those that are used routinely in the current particle physics culture. Some individuals do use other tools, such as one-to-one video conferencing, desktop sharing, and instant messaging, but the vast majority do not.

Ironically, however, many businesses routinely use all of these tools, and some have even found it important to bundle many of them into single integrated desktop appliances. Even those in the particle physics community who regularly use the minimum collaborative tools must still make do with a separate program for each application. (EVO, the successor to VRVS, bundles multiple tools into a single application.)

The funding agencies should support a comprehensive review of the business use of collaborative tools, with an eye toward their application to particle physics. Implementation and adoption of such tools are known to be difficult, but there are lessons to be learned in this regard as well. Any review of tool development, then, should include a collection of best practices for new usage.

The need for the particle physics community to continue to support multiple platforms makes the integration of tools a complex challenge. The field, however, should set as its goal a suite of tools created within a single GUI that would mix desktop (and hand-held) "presence aware" semi-synchronous tools, such as IM, allowing seamless escalation to synchronous personal video, with shared, secure document retrieval, coupling these in turn to simultaneous document authoring and archiving—all monitored by intelligent digital agents to keep the user aware at all times of project updates. Again, from RTAG 12:[10]

> "Integration of all of these features [scheduling, agenda posting, storage of electronic documents, a globally accessible address book, presence detection] into one multi-platform distributable interface is highly desirable. It is important that current activities in industry be followed closely, as new systems are under development to integrate video conferencing (human presence), web conferencing (remote document presentation), and presence detection (meeting preparation, notification and triggering)."

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[10] See S. Goldfarb et al., p. 8; ref. 3, RTAG 12, p. 8.

These solutions will be possible only if pushed by a sophisticated awareness of the opportunities and if not necessarily limited to homegrown projects. Ultimately, flexibility may very well be essential to charting the future course of particle physics, if the field is to take advantage of unpredictable developments. Today's market is very volatile: yesterday's good idea becomes tomorrow's acquisition (witness the recent incorporation of Writely into the "Google Docs and Spreadsheets" suite of Web-based office tools).[11] Microsoft is also pursuing a viable set of collaborative tools through its SharePoint Products and Technologies.

In the end, if U.S. particle physicists see the coming opportunities and conclude that the potential gains are clear, and if rollout of applications is conducted consciously and intelligently, then adoption will come. However, most members of the particle physics community are unaware of what is even now possible, and this lack of information needs to be remedied. The agencies should sponsor usability studies that evaluate (a) "homegrown" collaborative tools, (b) off-the-shelf collaborative tools and integrated products, and (c) possible enterprise solutions tailored to particle physics' specific needs. Such an evaluation should include products that currently exist, as well as those that might seem preposterous in 2007 but will surely become feasible in the near future. Indeed, in this arena, the near future comes very quickly.

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[11] As an example, imagine a suite of writing tools in which multiple people could work on the same document at the same time with full archiving and versioning, but never exchanging a word processing file. Imagine that always-alert software agents detected asynchronous editing and alerted each author when changes had been made to a joint document. Or imagine a meeting in which minutes were produced by all participants simultaneously while the meeting was in progress. Some of this is possible now, through multiple applications.

7 Funding Model and Program Management

The particle physics University Grants Program currently operates under two different models of funding and program management, provided by the two funding agencies, the NSF and the DOE Office of Science. In general, it is very healthy to have two funding agencies with two different approaches, both dedicated to supporting the best possible science. Both agencies do a good job, often under difficult circumstances, given the overall decline in funding for the physical sciences over the last decade.

7.1 NSF

NSF support for particle physics comes through several different programs within the Physics Division. The majority of the funding, about $50M/year, is provided by Experimental Particle Physics (EPP) through the University Grants Program, support for CESR/CLEO, and the LHC Research Program. Additional support is derived from Particle and Nuclear Astrophysics (PNA), Theoretical Physics, and Physics Frontier Centers. Significant further support is obtained through programs funded collaboratively with the Offices of Multidisciplinary Research, International Science and Engineering, Cyberinfrastructure, and the Directorate for Education and Human Resources. The total funding, combining all sources, was about $95M in FY06.

The EPP university grant portfolio was funded in 2006 at $19M (excluding Cornell), from which amount 67 funding awards were made to research groups. This support covers 251 faculty, 177 postdocs and research scientists, and 184 graduate students (based on the 2005 program review). The average annual grant size is $260K, and grants are renewed at three-year intervals. After a three-year review, the funding level is established for the next three years. This has the advantage of giving university groups a known budget three years in advance, but it also holds disadvantages for groups that come up for renewal in a low budget year—and that may well suffer the consequences. NSF program officers do their best to alleviate this problem through the use of supplements.

Levels of NSF EPP funding in coming years will emerge from the NSF Physics Division process of developing a multiyear plan. Elementary particle physics and allied fields, as well as facilities, are included in the mix. A number of programs (e.g., DUSEL) are of sufficient size and scope that the Physics Division alone cannot fund them; hence, the MPS Directorate, as well as the broader Major Research Equipment and Facilities Construction (MREFC) process, must be included. The NSF budget request for FY08 includes a component for the Physics Division with an 8% increase over FY07. If this is actually enacted, EPP will also benefit. The NSF regards the University Grants Program and base grant funding support as fundamental cornerstones of its program (across all of physics). As a strategic principle, base program support in a given FY will not be allowed to drop below 50% of the portfolio. This principle has now been in force over a number of years. The NSF hopes to follow the ACI plan of doubling its budget over a period of ten years. This should allow for significant growth in base program support, as well as the development of new initiatives.

As for future planning of specific program components, the LHC continues to be a priority. The operations program has reached full annual funding in FY07 and will continue at this level through FY11. Support continues for research groups working on Tevatron, CLEO-c, and BaBar, as well as numerous experiments in the neutrino program. The CLEO-c and CESR programs are being wound down, although analysis of CLEO-c data is expected to continue for a reasonable period beyond the cessation of experimental operation in FY08. Extensive support exists for non-accelerator physics and for particle astrophysics through PNA. Theory is another priority area, and the NSF has indicated its intent to strengthen it. Programs in the inception or growth phase that are currently of interest to NSF include SLHC, DUSEL, ILC, and APPI. Of these, DUSEL is the highest priority for new construction and will be an MREFC candidate. APPI, SLHC, and ILC R&D will likely fit as mid-scale instrumentation programs. Full ILC participation will require the highest levels of engagement at the NSF and government-wide.

EPP has a staff of 2 federal employees and 3.5 rotators. One-third of the university groups are reviewed every year, based on evaluations conducted through mail-in reviews and a comparative review by a panel convened at NSF to prioritize funding for all the groups up for renewal in a given FY. Proposals, limited to fifteen pages, are uploaded electronically into FastLane, an NSF-wide document management system. This system creates an e-Jacket for each proposal, and all reviews and program officer notes, along with the rationale for final funding decisions, are entered into the e-Jacket. This makes reviewing funding decisions and collecting information about the reviewing process very convenient.

Additionally, the largest grants (to Chicago, Columbia, and Cornell) receive site panel visits every three years. At the recommendation of the NSF Physics Committee of Visitors, program officers are also making an effort to schedule site or reverse-site visits with mid-scale and smaller groups. This year, NSF initiated an additional panel review to assess the LHC aspects of proposals submitted to the base program. The CAREER grant program, which supports junior faculty, is also reviewed by an internal panel of program officers.

As noted earlier, it is often difficult for NSF-funded institutions to obtain funding to participate in DOE-funded projects. The DOE and the NSF have cooperated on several large projects, but smaller projects tend to be funded by only one agency.

Theoretical work in particle physics is primarily funded through the Elementary Particle Theory and the Astrophysics and Cosmology Theory programs, both falling under the rubric of Theoretical Physics. The combined budget of these two programs is $11.8M for FY2007. The Theoretical Physics program supports 13 university groups and also provides grants to 66 individual PIs. Indeed, a major thrust of the theoretical program as a whole is the support of individual PIs, their students, and their postdocs. In total, the Theoretical Physics program supports approximately 130 PIs, 60 postdocs, and 50 graduate students. The reviewing process is identical to that for work funded through the EPP program. In 2006, the "LHC Theory Initiative" was launched to provide theoretical support for the LHC. This initiative will ramp up in three years, eventually supporting 4 postdocs and 5 students. The theoretical program also supports CTEQ, the Aspen Center for Physics, and the University of Colorado's TASI. The KITP Theory Institute at UC Santa Barbara, supported as a Physics Frontier Center, hosts many extended workshops and conferences.

The NSF supports undergraduate education through internships under the REU program and through research at undergraduate-only institutions under the Research at Undergraduate Institutions (RUI) program. The NSF pays special attention to support for women and minorities, and its mission includes an explicit emphasis on education and outreach ("broader impacts")—concerns that must be addressed by all university grant proposals.

The NSF convenes a Committee of Visitors (COV) to review the Mathematical and Physical Sciences (MPS) division every three years; the last such review took place in 2006. The EPP review committee found that the NSF electronic database for proposals works very well and was a great aid to the review process. The program officers were able to use it to generate statistics and to address strategic issues. Concern was expressed that only one permanent federal EPP employee was insufficient, but this concern has since been addressed with an additional hire. Concern was also expressed about the previously noted effect funding fluctuations have on universities whose programs are reviewed in a bad budget year. Further, the full COV recommended that NSF develop a better funding mechanism for intermediate-scale projects—ones that exceed the MRI limit ($2M)) but are well below the scale of MREFC initiatives (>$100M). Another area of general COV concern stressed that NSF must consider the life-cycle costs of all projects in order to avoid repeating the tragedy of the RSVP project cancellation.

7.2 DOE

DOE supports particle physics through the Office of High Energy Physics (OHEP), funding the University Grants Program at about $110M/year. There are five OHEP program officers, most of whom also have other responsibilities. OHEP University Grants Program funding supports 235 groups at 101 universities, including accelerator and non-accelerator-based experiments, as well as theory. A total of 528 faculty, 466 postdocs and research scientists, and 465 graduate students were supported in FY05. The average funding per faculty member is approximately $230K, and the median is $180K for experimental groups. In theory, the average and the median are both around $100K per faculty member. Much DOE support goes to groups working on long-term research programs. This tends to promote stability and generally results in only modest year-to-year fluctuations. The DOE provides opportunities for new young faculty to receive grant funding through initiatives such as the Outstanding Junior Investigator (OJI) program, which supports junior faculty with grants that are typically about $75K/year. The OJI program is very competitive; last year, 8 awards were distributed out of 65 proposals, and a total of only 238 awards have been made since 1978. Even if a faculty member is not awarded an OJI grant, however, the rigorous review of proposals submitted to the OJI competition can still result in a modest grant.

OHEP funding for the University Grants Program has been flat in then-year dollars, at about $100M, since 1992. In FY07 dollars, university funding peaked in 1992 at about $150M/year and has declined in real value since then. This reflects an overall decline in funding for particle physics. The total number of faculty, postdocs, research scientists, and students supported by OHEP has also declined, though not as much as total funding, from 1,685 in 1992 to 1,459 in 2005.

Starting from present levels of funding, and projecting continued "flat-flat" funding of DOE core program support of scientists, postdocs, and students amid 3% inflation, would result in a decline in program-supported scientists, postdocs, and students, as shown in Figure 4. If funding were to increase at 3% per year to match inflation, and if this were to provide a constant level of effort, the profile of FTEs distributed by activity category would resemble Figure 5. However, these profiles do not include the impact of supporting personnel overseas, as documented above, which would require a 4% increase over 2007 levels, rising to 5.5% in 2015, in order to sustain the constant level of effort shown in Figure 5.

As shown in DOE FTE projections, there is shrinkage in university manpower in the "flat-flat" budget scenario; if the additional expenses of overseas operations are included, the inflation-compensated scenario of 3% increases per year would not be supported without a higher level of funding increase, of 4–5%. The needed increases are not "one-shot" additions, marked for specific projects. Single-year additions, while helpful, do nothing to alleviate the steady reduction in core peer-reviewed support of students, postdocs, and scientists. One cannot hire personnel on a one-year, one-time basis of support, nor can personnel contribute meaningfully to a program in such a short time. Funding these personnel through the large detector project offices does not address the problem either, as funds from this project mostly do not support students, postdocs, and scientists, and as these funds are specifically directed toward completing a specific project task.

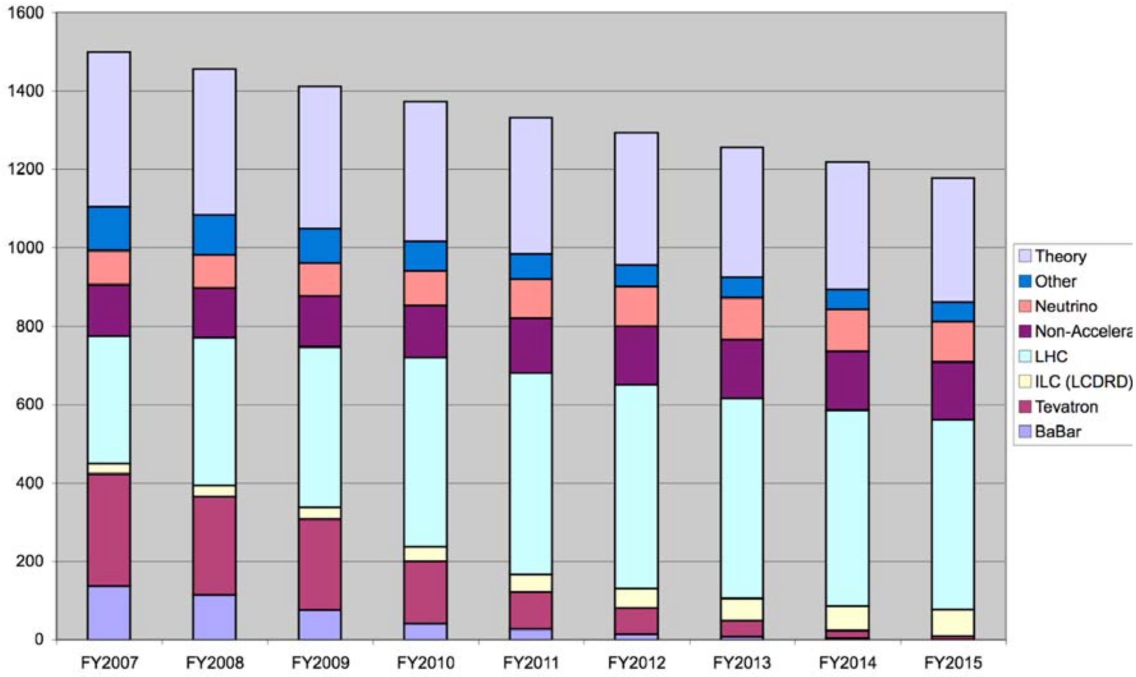

Figure 4. DOE University Grants Program activities by FTE, assuming "flat-flat" funding and 3% inflation.

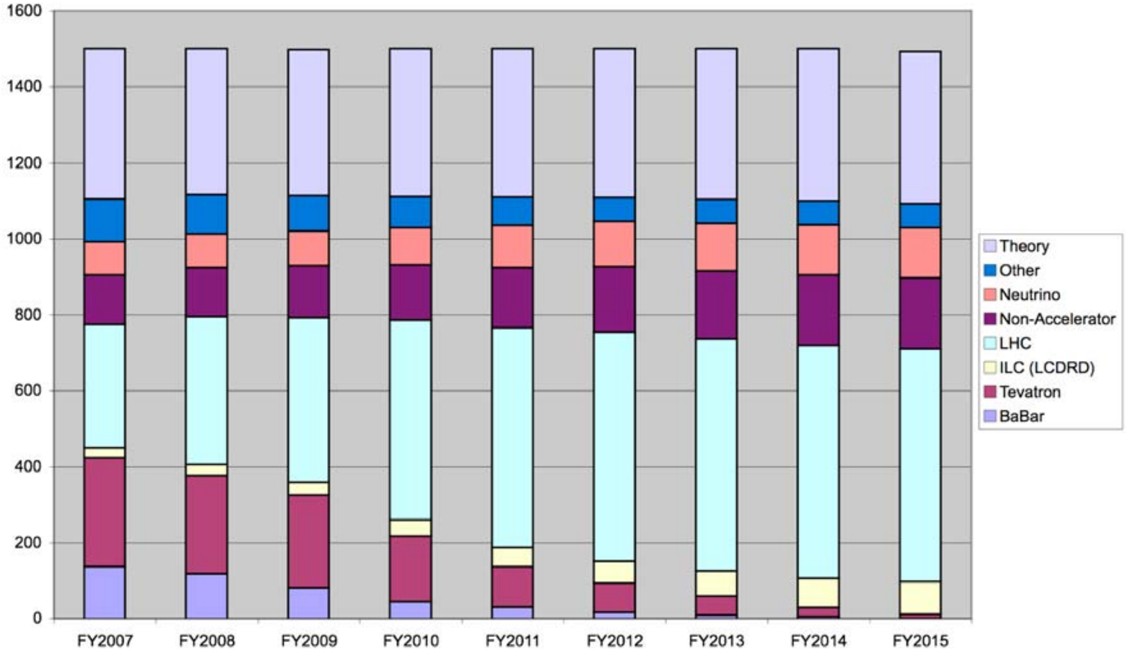

Figure 5. DOE University Grants Program activities by FTE, assuming constant level of effort, with 3% inflation and 3% increases in annual funding (from DOE OHEP planning documents).

The “flat-flat” budget scenario is not consistent with the support of students, postdocs, and scientists necessary for effective U.S. strong participation in the LHC and its upgrade; for vigorous R&D on the ILC; for preparation for a bid to host the ILC; or for additional experiments in astrophysics, cosmology, and neutrinos, together with a variety of smaller-scale experiments. It is notable that these budget scenarios include the effects of the conclusion of the B-factory and the Tevatron collider program, demonstrating that support for university students, postdocs, and scientists is inadequate even when program redirection is properly included. For example, there is little ramp-up of students, postdocs, and scientists to work on the ILC. Again, the level of effort on the ILC is inconsistent with U.S. plans to make an effective bid to host this facility. When the higher costs of doing more science overseas are taken into account, even the inflation-compensated scenario of 3% increases per year does not provide sufficient support for ILC R&D, while also supporting SLHC R&D and new initiatives in astrophysics, cosmology, and neutrinos. Further, no room remains here for the exciting new ideas emerging from university researchers.

As mentioned earlier, the costs for travel and subsistence in support of research on overseas experiment are rising substantially. The DOE university program has provided some relief through supplementary travel funds for physicists working at CERN on the LHC. This program has been very helpful, but the amount of funding available is much less than the need.

New proposals submitted to OHEP, including OJI proposals, are administratively reviewed by program officers and then, if deemed appropriate, sent out for mail review by at least three external reviewers. Funding decisions are made by OHEP program officers based on reviews, internal priorities, and the availability of funding. Grant renewals occur every three years and follow a similar process, which may also include a site visit, sometimes with consultants for larger groups. Reviewers may receive more than one grant to review in order to make indirect comparisons. Recent proposal guidelines impose page limits, which make the proposal-review process more manageable, especially when several proposals are reviewed at once. However, the subpanel finds that the OHEP University Grants Program staff has a very heavy workload for its size. Funding levels are determined each year for all groups, so that the overall availability of funding affects all grants equally.

OHEP was reviewed by one COV in April 2004 and by another in June 2007. In the past, the committee's ability to review funding decisions has been limited, due to the lack of an electronic document system. The COV recommended implementation of an electronic document database and comparative reviews that include both university and laboratory research programs and noted that interagency barriers to research still exist despite a great deal of recent progress in this area.

8 Findings and Recommendations

8.1 The University Role in Particle Physics

Particle physics inspires our young, attracts some of the best minds from around the world, and drives technical innovation. For these reasons, the 2006 National Research Council report "Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics" (EPP2010) argued that the U.S. should strive to maintain a leadership role in this field. Moreover, it outlined a program for doing so. This program included strong participation in the Large Hadron Collider (LHC); vigorous R&D on the International Linear Collider (ILC); preparation for a bid to host the ILC; and experiments in astrophysics, cosmology, and neutrinos, together with a variety of smaller-scale experiments.

Accomplishing these goals requires investment in both the national laboratories and the universities. The laboratories, for example, will be central to developing ILC technology and the U.S. bid to host. They will also provide essential facilities for LHC data analysis and beams for neutrino experiments. For their part, the universities will analyze the data from the LHC; develop the theoretical underpinnings for interpreting the LHC data; develop the detectors for the ILC and devices enabling the ILC accelerator; and design experiments in neutrinos, cosmology and other areas, as well as construct key components and analyze their data. The laboratories and universities are equally vital components of a robust investment portfolio in particle physics.

What do universities contribute to the portfolio? First, they are great sources of creativity and innovation. They are developing fast silicon sensors, high-speed electronics, novel techniques for ultrafast beam extraction, new technologies for remote collaboration, and strategies for harnessing widely distributed computing power. They created strong focusing accelerators; applied Monte Carlo techniques and neural nets to data analysis; invented the Standard Model and Quantum ChromoDynamics (QCD); and initiated the experiments that discovered CP violation, neutrino oscillations, and the top quark.

The universities are young and fresh, the steady influx of bright, energetic students and postdocs stimulating innovation. They demand new ideas and generate others of their own. When new directions come up, students and postdocs pursue them with vigor. When obstacles surface, they grapple with them tenaciously and often succeed in overcoming them. Moreover, universities include not only particle physicists but also condensed matter physicists, electrical engineers, materials scientists, computer scientists, biologists, and sociologists. Interactions with these experts in other fields stimulate new thought and provide enabling expertise.

The universities are entrepreneurial and competitive. The intellectual vigor of the universities attracts superb physicists. Faculty are hired and promoted for their ability to break new ground, inspire, lead, build, and innovate. University high energy physics groups compete with each other and with other areas within the same university. For their part, the universities bring financial resources to particle physics. They provide faculty salaries and, through start-up packages and occasional bridging funds, support postdocs and technical staff.

The universities are diverse. University groups are embedded in departments that have strengths in specific disciplines and foster special ties between different areas. They belong to universities with different priorities and technical facilities. They attract students from different backgrounds, who will go on to contribute to society in different ways.

Finally, universities also bring considerable resources to the national program through their financial support of personnel and infrastructure (e.g., subsidized shops) and the purchase of research equipment.

> ***Finding:*** The EPP2010 report articulated the scientific priorities for particle physics in the coming decade. Realizing this vision requires a partnership between the universities and the national laboratories. Each is a necessary component of a robust investment portfolio in particle physics.
>
> ***Finding:*** University groups make theoretical breakthroughs, develop innovative detector technologies, and initiate novel experimental approaches. In addition, they perform most of the analysis of the data from high energy physics experiments. These university strengths draw undergraduates to science and bring some of the world's best minds to our graduate programs.
>
> ***Finding:*** A thriving university research program advances science and nourishes the technical strength of our nation.

What are the characteristics of a thriving university group? This committee has identified five:

1. **Compelling scientific questions.** The university community in particle physics now has an unusually crisp set of questions and goals. They include exploration of the Terascale and the study of dark matter, dark energy, and neutrino oscillations.
2. **Outstanding personnel.** University groups require excellent students, postdocs, research scientists, and faculty to build and operate detectors, analyze data, and assume leadership responsibilities. The number and mix depend on a particular group's scientific goals.
3. **Freedom to innovate.** University physicists are most productive when they can follow their ideas and go where they see the best science. They will flourish when they have sufficient resources to innovate.
4. **Sufficient infrastructure.** New technologies and experiments require specialized chips, devices, or parts. Developing these is almost always an iterative process that proceeds most efficiently if engineering support and shops are located at or near the universities themselves. Data analysis, particularly of enormous samples like those from the LHC, requires a robust, high bandwidth, a reliable network, adequate computing cycles, and system support.
5. **A clear and timely review path for their proposals.** Physicists need a clear process for the peer review of new initiatives and proposals. This process should apply both to experiments and proposals in the mainstream of the field and to those that lie near its boundaries or are interdisciplinary. The process should produce a response to every submitted proposal in a timely manner.

Universities will play a pivotal role in the physics—and likely revolutions—of the coming decade. They will analyze data from the LHC; develop detectors for the LHC upgrade and the ILC; contribute to ILC accelerator design; and drive innovations in astrophysics, cosmology, neutrino physics, and other areas. They will also provide tools for interpreting these extraordinary data. Even though the LHC is centered in Europe, the U.S. has the opportunity to play a primary role. Already, U.S. physicists command many of the leadership positions in the ATLAS and CMS experiments. For the next ten years, the universities will be the place where the rubber meets the road.

This program is demanding. It requires substantial investment in the U.S. LHC effort, including the added costs of working offshore; extensive technical development aimed at the SLHC and ILC detectors; initiatives in astrophysics, cosmology, and neutrinos; and a strong program in theoretical physics. Accomplishing these goals requires an expansion of the University Grants Program.

> ***Finding:*** University groups are great sources of innovation. They are competitive, entrepreneurial, and diverse in their strengths, their students and their science. Successful groups require:
> - Compelling scientific questions
> - Outstanding personnel
> - Freedom to innovate
> - Sufficient infrastructure
> - A clear and timely review path for their proposals
>
> ***Finding:*** EPP2010 identified expanding opportunities for universities in particle physics. University researchers are helping lead the LHC; developing the SLHC and ILC detectors; initiating new experiments in astrophysics, cosmology, and neutrinos; and inventing new strategies for exploring particle physics. Some experiments are expanding the boundaries of the field.
>
> ***Recommendation:*** The University Grants Program must be strengthened in order to achieve the goals of the National HEP program, as articulated by EPP2010. This requires increased investment and careful attention to building and sustaining the levels of personnel and infrastructure necessary for successful university research groups.

In the coming sections, we address ways in which the University Grants Program must evolve in order to ensure that the universities can fulfill their vital role in particle physics.

8.2 University Researchers

Scientific progress depends on outstanding students, postdocs, and other university scientific staff. These individuals run analysis programs, build hardware, and do detailed calculations. They also come up with many of the best new ideas in the field. Strong support for graduate students, postdocs, and research scientists is an essential ingredient of a strong university group.

8.2.1 Theory

University theory groups have made pivotal contributions to our understanding of the universe, but typical grants now support less than one-half of a postdoc and one-half of a student per PI. The austere conditions for particle theory come at a time when the need for theoretical calculations is urgent. Interpretation of the data from the LHC will be possible only if the necessary theoretical calculations are in place. Similar calculations are also essential for other areas of research, including neutrino physics and astrophysics and cosmology.

> ***Finding:*** Funding for theoretical particle physics is now so lean that few graduate students receive support through research assistantships. Students must find funding from other sources, primarily teaching assistantships, but even these are often in limited supply. As a result, superb students are lost, and others spend much longer than necessary in graduate school because of the sustained need to teach.
>
> ***Finding:*** Theoretical calculations that provide for the interpretation of experimental results are essential to the advancement of particle physics and will be essential to the full exploitation of the LHC, ILC, and other experiments of the coming decade. Yet the number of physicists carrying out these studies in the U.S. is small. More students are needed to increase this number.
>
> ***Recommendation:*** A higher priority in the overall HEP program should be given to funding directed at university-based theoretical particle physics for the purpose of increasing the number of grant-supported graduate students. Support for students and postdocs doing calculations related to upcoming experiments is particularly urgent.

8.2.2 Experiment

University groups in experiment place a high priority on sustaining their current number of graduate students, postdocs, and research scientists. Indeed, even under substantial budget pressure, many groups have sacrificed in other areas in order to retain their students and postdocs. Now, as experiments move overseas, many university groups are again strained because of the need to maintain a critical mass at both sites.

Long-term research scientists are critical to elementary particle physics because of the long duration of modern experiments. Research scientists often provide additional value for experiments at distant locations, where they can provide on-site expertise and leadership, as well as guidance for students and postdocs during periods when faculty are occupied with university teaching. Research scientists at universities greatly increase the effectiveness of university-supported faculty. As is appropriate for long-term staff, the universities apply a high threshold for promotion to research scientists, many using criteria similar to those required for faculty tenure: namely, strong performance in publication, experiment leadership, and in some cases student mentoring.

The optimum size of a research group depends on the research in which it is engaged. In many cases, there exists a minimum group size below which the research program becomes unfeasible. The funding agencies should use the peer-review system to determine the effectiveness of the size of individual research groups by requesting feedback from reviewers regarding the match between a group's resources and its proposed research. The overall program is weakened when peer-reviewed funding of a group is maintained below the level at which the group can be effective, rather than the funding being terminated. However, there is no universal minimum group size. Even a single investigator working on a theory calculation can be effective. Again, the appropriate group size depends on the proposed research program.

> ***Finding:*** University groups require students, postdocs, and sometimes research scientists in order to be effective. The number and mix of personnel depend on the research program and should be determined with input from peer review. Many university groups now struggle to maintain sufficient personnel.

> ***Recommendation:*** Group sizes should be sustained, and increased where appropriate and supported by peer review. The agencies should make a special effort to support long-term research scientists as an integral part of this group structure, particularly when they provide expertise essential to the experimental program or leadership at a remote laboratory.

The agencies should support creative approaches for funding research scientists in order to get the full benefit of their talents. For example, a research scientist based at one university might work with groups at other universities participating in the same experiment as part of their collaboration. The agencies should be encouraged to facilitate research scientists' movement between projects or institutes as programs evolve.

8.3 Innovation

Future experiments in particle physics are never accomplished with past technologies. For decades, in virtually each generation of experiment, novel detection techniques have played crucial roles in making difficult measurements possible. Sometimes a measurement motivates a new technique; sometimes a new technique inspires a possible measurement. Universities have excelled in this sort of innovation. Some university groups have nurtured local expertise in particular technical areas such as electronics, exotic materials' design and fabrication, and computing and software development. Indeed, the confluence at universities of faculty in diverse areas such as computer science, electrical engineering, and condensed matter physics, as well as particle physics, fosters innovation.

The need for innovation is great. The SLHC, now on the horizon, presents formidable challenges in vertex detection and triggering. The ILC presents substantial challenges in beam monitoring, vertex detection, and calorimetry. Innovation will also drive future experiments in neutrino physics, astrophysics, and cosmology and will determine the feasibility of very high energy particle accelerators.

> ***Finding:*** The SLHC and ILC urgently need technical development. For the ILC in particular, U.S. investment lags behind both the number of proposals and the level of

investment being made abroad. Technical development is also crucial for other future experiments.

Recommendation: University-based technical development should be funded at a level commensurate with its great importance. The investment should be adequate to provide the necessary equipment and technical and engineering support.

The mainstay of the University Grants Program is the proposal-driven grant system, which supports students and postdocs and affords universities the opportunity to explore new areas. Recently, however, support levels for the physics base program have declined in favor of funding designated for specific programs or channeled through specific projects. While these projects are needed, and while this system provides effective project management, it has detrimental side effects for the University Grants Program.

One consequence is a decrease in flexibility in the University Grants Program. Universities use primarily peer-reviewed core program money to support students and postdocs, to support research in areas outside projects, and to develop new ideas. As such support declines in favor of project-based support, university groups must choose either to decrease the number of students or postdocs or to reduce other research, often including research that is more exploratory in nature.

Finding: The shift of support from core grants to project funds makes it more difficult for university groups to adapt smoothly to changes in the physics program, diminishes support for students and postdocs, and inhibits undirected research and the development of new ideas.

Recommendation: As much as possible, universities should be funded through merit-based peer-reviewed proposals, rather than through specific project-based funds.

The committee believes that it should be possible to fund the vast majority of research personnel through the basic peer-reviewed program. For efforts such as ILC R&D, where some central coordination is useful, the agencies may seek advice on funding allocations from program managers. However, the committee urges the agencies not to be overly prescriptive in their planning. In general, the best physics program will be realized if researchers, informed by plans for facilities and major projects, are allowed to make their own management choices and propose their own research directions.

8.4 Infrastructure

“Infrastructure” refers to the tools that enable university researchers to accomplish scientific goals. For researchers developing hardware, important infrastructure includes associated equipment and engineering support. Those working on data analysis require access to the data and to reconstruction and analysis software. Those working on an experiment removed from their university need communication infrastructure. Most researchers will fall into at least two of these categories over the next decade, and many will fall into all three.

8.4.1 Technical Infrastructure

The universities are home to engineers and technicians with long experience in particle physics. Likewise, university machine shops and electronics shops often were born in service to particle physics, even on campuses where they are no longer dedicated to this field. Moreover, because of nimble management, innovation, resourcefulness, large-scale leveraging in equipment purchases, and the need to compete for university projects, these resources are often very economical. University undergraduates—potential recruits for scientific careers—also offer eager hands to work on construction projects. The university technical infrastructure and the training it affords for the production of a technically and scientifically literate workforce are vital to the mission of the American Competitiveness Initiative.

With the decline in university grants, engineering and technical support at universities has shifted almost completely to project funds. Thus, the retention of these resources depends on their continuous use by projects, since universities no longer have the base funding support necessary to retain engineering and technical personnel when project funding is interrupted. While project managers sometimes avail themselves of university resources, they often either do not utilize them or do not utilize them continuously. As a result, university resources are underutilized and often lost, and fewer undergraduates have the chance to participate in research. The university resources that remain are at risk. If resources are made available for the support of university infrastructure, advice about the overall strategy for their allocation should be sought from the University Grants Program Committee (see section 8.6).

> ***Finding:*** University technical infrastructure nurtures innovation and provides valuable training for students. It has seriously declined due to erosion of the core University Grants Program.
>
> ***Finding:*** The universities offer a cost-effective infrastructure of technical facilities and support staff, their expertise often well matched to the needs of major projects. Moreover, carrying out projects at universities enhances student training.
>
> ***Recommendation:*** The agencies should support university technical infrastructure, including hardware development, through grants. In addition, project managers should utilize university resources, which are economical and effective, and they should report on this optimization at major project reviews.

8.4.2 Computing Infrastructure

LHC computing poses an enormous technical challenge. This task will be distributed around the world through “tiered” computing facilities. Given state-of-the-art networking capabilities and adequate computing resources, every university should be able to participate in data analysis. Many computing challenges facing the LHC are shared by other particle physics experiments.

Network bandwidth, security, and reliability will be critical. Advances in network technology are not a primary mission of high energy physics, although many of the field’s members have made seminal contributions in this area. However, as a field that relies on the continual advancement of networking, elementary particle physics has a direct interest in decisions about the future of networking R&D.

Successful university computing, for groups involved in both the LHC and other experiments, depends upon connectivity between individual researchers and data. While the backbone of this system for the LHC—the link between Fermilab and CERN—reliably operates with high throughput, and connections to the next-tier sites are also receiving attention, the tertiary legs of the network, which will bring the data to university desktops, remain fragile. Indeed, the specifics of the model for researcher data access are only now being worked out. Completing this model and providing the hardware and network necessary to make it function effectively are essential.

> ***Finding:*** LHC scientists, with agency support, have developed a vision that will address the enormous computing challenges of the LHC and provide university researchers with efficient access to data and software. This computing infrastructure is likely to benefit other experiments in particle physics as well.
>
> ***Recommendation:*** The agencies should continue their efforts to ensure that the vision for LHC computing is realized. This includes working across and within agencies to ensure sufficient network and computer capacity.

8.5 Overseas Presence

Never before has the U.S. university high energy physics program been faced with the concentration of its primary research activity at a distant site outside the United States. Participation is critical during all phases of an experiment, from installation to commissioning, and through decades of data collection and analysis. Thousands of meetings are required annually to advance the prospects of scientific discovery, including meetings with globally distributed colleagues who are analyzing data or making decisions on major experimental directions. These remarks are directed specifically to the large-scale U.S. presence at CERN, but many of them apply equally well to other overseas locations, such as Japan, Argentina, Chile, and so on.

Travel to CERN is part of the solution. However, because of the distance, the high cost of international travel, and space limitations, it will not be possible for all U.S. physicists to be on-site at CERN much of the time. In a departure from the past, when faculty members could reasonably hope to travel to U.S. sites weekly or biweekly, the time required to travel to Europe will hinder frequent trips during semesters because of teaching or departmental commitments.

Stationing students, postdocs, and RAs at CERN is also a part of the solution, but it is an expensive part. Nevertheless, this is often required to support U.S.-built detector components. The cost of a postdoc resident at CERN is significantly greater than that of one stationed in the U.S.

> ***Finding:*** U.S. participation in the LHC and other overseas experiments requires additional travel and subsistence costs,

> ***Recommendation:*** The agencies should support the increased travel and subsistence costs of University researchers participating in the LHC and other overseas experiments.

Given the high costs of travel, remote conferencing is a highly valuable, but not a full substitute. The World Wide Web was created at CERN to enhance the collaboration of scientists. Since then, particle physicists have developed VRVS, and now EVO, and the computing group at Berkeley has developed the ESnet ad-hoc video service.

These tools have yet to reach their full potential. Neither CERN nor many U.S. universities are adequately equipped with video conferencing hardware; CERN lacks key support personnel; network failures often compromise transmission; and in some cases, while the core equipment may be present, conference room acoustics are inadequate. Finally, features that would enhance the utility of video conferencing software, such as integrated document management and automatic archiving, remain under development.

> ***Finding:*** Working abroad presents special challenges to U.S. researchers. Among the challenges is the need to provide for U.S.-based personnel's participation in critical meetings.

> ***Recommendation:*** The agencies should support efforts to ensure that both U.S. sites and key sites abroad are equipped with remote conferencing that is reliable, robust, and readily available.

The subpanel believes that collaborative tools are at the crux of effective participation in the LHC and other remote experiments and that, even after basic video conferencing functionality is achieved, U.S. participation abroad will benefit strongly from further technological advances in this area.

8.6 The Path Forward: Experiment Review and Funding

The nature of small and mid-scale experiments in particle physics has evolved radically over the last fifteen years. Fifteen years ago, the fixed-target program accounted for many of the smaller experiments, and the role of reviewing these experiments belonged naturally to the national laboratories and their Physics Advisory Committees (PACs). A university researcher with a proposed experiment would speak with members of the lab staff, submit a proposal to the lab PAC, and iterate with the PAC and lab management, and eventually a decision would be reached.

However, today no such clear roadmap exists for a university researcher wishing to carry out an experiment in many areas of particle physics. As our field experiences increasing diversification, the scientific questions are expanding. Much of the laboratory fixed-target program has been replaced by experiments in astrophysics and cosmology; by other experiments, such as neutrino mass searches, that use “nature’s beams”; and by yet others that use the techniques of other disciplines to address questions of interest to particle physics. Examples of the latter include atomic parity violation searches, electric dipole moment searches, and some accelerator research. There is no clear mechanism for the review and funding of experiments that are not based at a lab. An effective mechanism could be produced through evolution of the existing Scientific Assessment Groups (SAGs).

The problem is particularly acute for mid-scale experiments, costing from $5M to $50M. While small experiments may be accommodated through proposals within the University Grants Program and, in the case of the NSF, the Major Research Instrumentation (MRI) program, review and funding avenues for mid-scale experiments are sparse and ill-defined. It is beyond the scope of this committee to devise a mechanism for reviewing mid-scale proposals; however, the committee hopes that HEPAP will take up the task.

> ***Finding:*** A clear, coherent, timely path for the review of every experimental initiative helps ensure that the best experiments receive support and that they are carried out as promptly as funds and technical readiness permit. This path needs to encompass small and mid-scale experiments, some of which lie near the boundaries of the field and some of which are centered at universities.
>
> ***Recommendation:*** The Scientific Assessment Groups (SAGs) should regularize their role in reviewing projects.
>
> - Each SAG should actively monitor and prioritize the experiments and R&D in its area. It should evaluate both physics goals and technical design.
> - The SAGs should report to P5, timing their reports so that they are available to P5 when needed.
> - The SAGs should review all experiments with expected construction costs above $5M, along with smaller ones seeking review. This includes both experiments that are affiliated with a U.S. laboratory and those that are not. Additional SAGs should be created as needed to cover all areas (taking care to avoid proliferation).
> - HEPAP should establish mechanisms for prioritizing experiments whose cost is above $5M but below the P5 threshold. The prioritization process should take advantage of input from the SAGs and should reflect the breadth of the field.

Just as the review of small and mid-scale experiments often used to fall to the laboratories, so did the job of funding their development and construction. Many modern small and mid-scale experiments, however, make little or no use of national laboratory expertise or facilities, and new mechanisms must be found for funding them.

> ***Finding:*** As the field of particle physics becomes more interdisciplinary, an increasing number of small and mid-scale experiments are centered at universities.
>
> ***Recommendation:*** The University Grants Program should fund the development and mounting of small and mid-scale university-based experiments that are highly rated by peer review and, where appropriate, by the SAGs and P5. This may require supplements to the University Grants Program.

8.7 University Grants Program Evolution and Representation

The University Grants Program is dynamic and should evolve with the goals of the field. Successful evolution, however, demands a series of balancing acts between competing needs: between large- and small-scale physics, between personnel and equipment, between experiment development and operation, between the two agencies themselves, between mature areas within the field and emerging ones, and sometimes between the energy of young groups and the experience of continuing ones.

> ***Finding:*** The University Grants Program will be most effective if the balance between competing needs adapts continually to the changing physics program and expanding scientific opportunities.
>
> ***Finding:*** The agencies have made great strides in working cooperatively, but grantees of one agency still sometimes encounter obstacles to working on projects sponsored by the other. Boundaries also remain between programs and divisions within each agency.
>
> ***Finding:*** The scientific success of particle physics requires a strong voice to articulate the essential role of the universities in fostering innovation, leading experiments, and training the nation's students.
>
> ***Recommendation:*** A University Grants Program Committee (UGPC) should be formed to consult with University Grants Program managers of both agencies on the issues facing the University Grants Program. The chair of this committee should be chosen cooperatively by both agencies and by the chairs of HEPAP, DPF, DPA, and DPB and should serve as a spokesperson for the university community.

The chair of UGPC will be well suited to representing the university community, much as the lab directors represent their communities. He or she should be expert on the University Grants Program and in close contact with the agencies and the lab directors. The position's term should be more than one year. Participation by the chairs of HEPAP, DPF, and DPB in selecting the chair is necessary to ensure that he or she has the standing to act as a representative of the university community. The UGPC should inform HEPAP about the University Grants Program as HEPAP considers the health of the field as a whole. The UGPC would provide advice, for example, on issues such as the balance of university group sizes and investment in university infrastructure. The UGPC is intended to recommend priorities for funding the University Grants Program in general—for example, group sizes, theory support, travel costs, and infrastructure. The UGPC is not intended to recommend priorities among scientific programs, as does HEPAP or P5. We anticipate that HEPAP will solicit reports on the health of the University Grants Program from the UGPC chair. We also anticipate that this person will be a recognized, strong voice not only within the agencies but also to the executive branch and Congress.

At present, the lab directors speak for the labs, but the university community has no analog to speak for its needs. HEPAP and its chair, as well as P5, the DPF, and the DPB, represent the entire HEP community and do not thus speak exclusively for the university community. The chair and members of HEPAP, for example, are not supposed to represent specific constituencies, but the entire field. The university community, then, lacks a coherent voice. This is particularly a problem in the changing world of HEP, where the scientific interests of the national labs and the universities may diverge. Giving the university community a clear voice will lead to improved collaboration, greater understanding, and a stronger national program. It will reduce the frustrations and morale problems that were repeatedly reported to this committee in the course of its work—frustrations that can lead to conflicts between the lab and university communities.

The success of particle physics depends on the success of the University Grants Program. This is as true today as ever before. Particle physics will best achieve its scientific goals if the strengths of the universities are widely understood and if the resource balance between the university and laboratory programs is continually adjusted to reflect the evolving needs of the field. In order to achieve this, the University Grants Program needs a strong, central advocate.

The NSF has invited regular reviews by COVs for a number of years, and recently, the DOE initiated a similar process.

> ***Finding:*** Regular COV reviews help the agencies adjust to the changing needs of the field and enhance the transparency of the review process. Triannual COV reviews are a long-standing practice at the NSF and have recently been implemented at the DOE.
>
> ***Recommendation:*** We applaud the COV process and endorse its continuation. Among the issues that future COVs should address are:
>
> - Mechanisms for the consistent review of lab- and university-based researchers
> - The competitive review of proposals, through panels or other means, within the University Grants Program
> - The workload of University Grants Program staff
> - Implementation of a database by the DOE comparable to that used by the NSF to make institutional, funding, demographic, and programmatic information readily available

The first two of these items have been the subject of prior DOE COV recommendations. The database referred to in the final item would improve the transparency of the funding process by demonstrating that funds and research personnel are dispersed according to field priorities. Ideally, in the long run, the DOE and the NSF will combine database information annually. Reports showing averages and trends should also be made available.

8.8 Broader Impacts

Undergraduates come to scientific research in general and to particle physics in particular from a wide variety of backgrounds, including small teaching colleges, large research universities, prestigious women's colleges, and historically black colleges and universities. Many of today's top physicists decided to pursue a career in science based on experiences they had as undergraduates working on real experiments. Now that many experiments are operating overseas, we have the opportunity not only to engage our students in the excitement of science but also to engage them in international collaboration. Whether these students go on to become particle physicists or to work in some other field, they will carry this valuable experience with them.

> ***Finding:*** Undergraduates thrive in research, and those who so participate are more likely to pursue careers in science and technology.
>
> ***Finding:*** The LHC and other experiments abroad offer a spectacular opportunity to engage undergraduates and high school teachers in research. This research experience will be particularly powerful for those who spend time at the experiment site.
>
> ***Recommendation:*** Additional support should be made available to enable undergraduates and high school teachers to participate in experiments offshore. In addition, support should be continued for an REU program at CERN, following discussion of its structure with representatives of interested university groups.
>
> (Undergraduates with interests other than particle physics may also be able to participate at the LHC. For example, students in computer science, engineering, or the social sciences could be convened to assess LHC collaborative tool needs.)

Particle physics has the power to capture the public imagination. It can draw high school students to careers in science and technology. Experience in research often attracts college students to graduate school. Above all, communication about particle physics helps create a public that cares about science and values scientific literacy. Perhaps just as important, public outreach provides a mechanism for scientists to share the fruits of their work as a way of expressing gratitude for the generosity of the public funding of research.

Many university particle physicists reach out to the public. They engage high school students in research, they host Quarknet or REU programs, they take lecture-demonstrations to neighborhood schools, and they develop popular Web sites about their research. They do this in spite of the fact that their efforts receive little practical support. These physicists could surely do more if additional support were available, and with additional support other physicists might take the plunge.

> ***Finding:*** University particle physicists have developed successful outreach efforts, such as Quarknet, CROP, and many REU programs. They have devised ways to share the excitement of elementary particle physics with high school students, teachers, and undergraduates. They have also engaged the public in science through Web sites and popular lectures. Some do this because of NSF mandates, but all do this out of individual commitment.
>
> ***Recommendation:*** The agencies should foster outreach by, for example, funding new positions dedicated to facilitating and coordinating university outreach efforts.

These facilitators could compile public lectures, develop exciting Web sites, suggest course material for non-science undergraduates, provide syllabi and activities that high school teachers can bring to their classrooms, and develop other outreach material. They could also provide support for groups initiating programs such as Quarknet or REU. The facilitators could be based either at universities or at national labs and possibly connected to members of the InterActions Collaboration.

9 Conclusions

Elementary particle physics is on the threshold of a new age of discovery. This opportunity and its importance to the U.S. are discussed in the report “Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics” (EPP2010). The research opportunities envisioned in this report build on a half-century of research that has largely been driven by the intellect and innovation of university-based research groups. Key to past success have been the identification of compelling scientific questions, outstanding personnel, the freedom to innovate, sufficient infrastructure, and a clear and timely review path for promoting the best new ideas.

The University Grants Program is entering an era of expanded opportunities as exploration of the Terascale at the LHC begins and as it will continue at the SLHC and the ILC. There is a robust, growing program in neutrino physics. Opportunities abound for flavor physics. New experiments are emerging in studies of dark matter and dark energy, underground science, and atomic physics experiments to probe small symmetry violation. Continued U.S. leadership in particle physics requires exploration of these scientific opportunities by U.S. university-based scientific personnel.

Approximately 80% of all researchers in particle physics are based at universities. The future of the field depends upon universities’ ability to continue to attract, train, and mentor top students from the U.S. and abroad, thereby strengthening the country’s scientific and technical base. University environments naturally provide opportunities for interactions with scientists in other subfields, often leading to important cross-fertilization of ideas and techniques. University scientists’ freedom to follow their creative instincts has long been—and will continue to be—a critical element of the program’s success.

Today, the U.S. elementary particle physics community is faced with exciting prospects but also with daunting new challenges. The major domestic accelerator-based programs are approaching the end of their scientific life spans. Much of the forefront research of the next decade will be based abroad. A central theme of the EPP2010 vision is the compelling case it makes for the U.S. hosting a future global facility, the ILC. The realization of this ambition, and U.S. researchers’ ability to play leadership roles in this frontier suite of scientific investigations, demands the committed and supported involvement of university-based researchers.

Over the past twenty years, funding pressures have led to reductions in the manpower supported by university groups. These losses have been most severe among students and postdocs, who are the future of the field. Methods of operation are also changing. Particularly, increased travel costs preclude frequent travel between a researcher’s home campus and the experimental facility.

As we have seen, university-based physicists have played a central role in the development of our current theoretical understanding. Theorists at universities, like experimentalists, have ready access to scientists in other subfields, leading to vital and stimulating cross-fertilization. The intellectual growth of the field is critically dependent on the strength of the theoretical part of the program. Support for young theorists, particularly in phenomenology, is essential.

For the University Grants Program to be effective, for it to thrive, it must be maintained and strengthened. Many critical issues have been identified here: the importance and value of long-term research scientists; the special challenges presented by overseas collaborations and solutions to these challenges, the need for technical support at the universities to ensure innovation, the benefit of regularized review processes, the importance of small-scale experiments and the particular challenges they face, and the impact of merit-based reviews. The University Grants Program plays a vibrant outreach role, bringing the excitement of particle physics to the broader public. University resources, where they still exist, are economical and effective; project managers must utilize them to ensure their preservation. The agencies' utilization of regular reviews by Committees of Visitors is valuable, a mechanism allowing the understanding of issues and the development of potential solutions. For these issues to be profitably addressed, a University Grants Program Committee, as proposed here, could consult with University Grants Program managers, headed by a chair who speaks with credibility on behalf of the universities before the agencies and other governmental bodies.

Appendix 10.1 summarizes the subpanel's responses to the specific items presented in its charge. While such a summary is useful for checklist purposes, we caution the reader that, because of the complexity of many of the issues, a full understanding of the subpanel's response requires a review of the expanded discussion, found in the relevant sections of the text.

The University Grants Program has played a major role in setting the stage for the coming revolution in fundamental physics, highlighted by the discoveries anticipated at the LHC. Maintaining a healthy University Grants Program is critical to realizing the future goals of the U.S. elementary particle physics program, including the ambitious goal of hosting the ILC.

10 Appendices

10.1 Guide to Specific Responses to the Charge

The charge given to the subpanel was quite unique. The questions posed were broad, and the subpanel was given the flexibility to respond without constraint. These questions have been answered one or more times throughout this report. We provide a brief summary of these responses below, designed to act as a convenient guide to the report, not as a substitute for its detailed conclusions.

Goals	*In broad terms, what should be our goals and objectives in supporting the University Grants Program? Is there an overall consensus on these goals that is communicated to and well understood by all stakeholders?*	The goals and objectives presented in EPP2010 are fully endorsed by the subpanel. The broad consensus within the community—that these are the shared aspirations of the field—was used as the basis for subpanel deliberations.
Scope	*What considerations apply that would serve to define the scope of the University Grants Program?*	The scope of the program should ultimately be determined by the quality and scope of the existing research base, the scientific opportunities, and the national will to play a leadership role within the field.
Quality	*Appraise the scientific and technical quality of the work being supported by the University Grants Program.*	Based on the rigorous nature of proposal reviews, the work of COVs for both agencies, the involvement of U.S. researchers in path-breaking research, and the leadership positions held by U.S. particle physicists in the major international collaborations, we judge that the University Grants Program is of exceptionally high quality.

Relevance	*Assess the impact of the University Grants Program on the national and worldwide high energy physics efforts. Are there areas that are overemphasized, significantly undersupported, or missing altogether?*	The impact of the U.S. University Grants Program on the worldwide high energy physics effort is enormous. Relevant evidence is seen from U.S. participation and leadership in numerous major projects. We find no areas in which emphasis is judged to be excessive. We note that increased investments in small-to-medium-scale experiments may yield significant benefits. We also note that phenomenology and the support of theory graduate students need attention. We further note that insufficient funding has been provided to support researchers working at offshore sites.
Manpower	*Does the University Grants Program have the correct number and distribution of university researchers at all levels to meet program objectives, including faculty, senior research staff, postdocs, graduate students, and professional staff for the near, mid-, and longer term?*	Carrying out the program articulated in EPP2010 will not be possible in an environment where university groups receive in their base programs a continually declining level of constant-effort support, as has been the case for the past decade. We believe that if the nation is committed to sustaining a leading role in high energy physics and preparing to host the ILC, this situation must be addressed. (See chapter 7.)
Resources	*Does the University Grants Program have the correct amount and distribution of resources to carry out its program scope? Include an assessment of the relevant contributions from allied programs in DOE, NSF, and elsewhere. How should the program respond in the event of an increase or a decrease in available resources? In addition to financial resources, consider the need and availability of technical infrastructure at the universities.*	The current resource allocation profile does not allow for the optimum engagement of university groups in the program articulated in EPP2010. There is a shortage of resources needed to support LHC participation, ILC R&D, LHC-upgrade R&D, and small and mid-scale experiments. The result is a loss of scientific opportunities and the potential loss of bright young people who would opt to pursue work in the field. (See chapter 7.) Increased support would permit the deficiencies identified in this report to be addressed. Decreases in support would result in further loss of scientific productivity.

Structures	*Do we have the right model of university funding, or do we need to revise or create new models for university research activity and support?*	The subpanel believes that the current model for university involvement in high energy physics research is the most appropriate one for the present period. The model simply needs to be properly supported.
Management	*Examine how the programs are managed and overseen. How is the performance of the University Grants Program optimized with respect to the overall goals and priorities? Suggest how management and performance might be improved, if appropriate.*	Considerable attention was directed to the management of the University Grants Program. We conclude that the relevant program offices are making commendable efforts to manage complex programs under difficult conditions. We have provided advice on how improvements could be made, including adopting new advisory structures to help with setting program priorities and to continually assess the vitality of the University Grants Program.
Broader Impacts	*Consider the impact of the University Grants Program's reach to the broader community—to other research disciplines, to the public and private sector in research and education, and in workforce development.*	University high energy physicists have made very important contributions to scientific outreach. They have spawned important programs such as QuarkNet and Research Experiences for Undergraduates. Significant programs have also been created to enhance scientific literacy in the general public and to interest young students in scientific exploration.

10.2 Subpanel Process

The University Grants Program Subpanel (UGPS) was formed in response to a request from the High Energy Physics Advisory Panel (HEPAP) in the summer of 2006. The charge to the UGPS (appendix 10.3) and a list of its members (appendix 10.4) are presented below.

The UGPS held seven meetings:

1. At the Dulles Airport in September 2006
2. On the University of Michigan campus in Ann Arbor in October 2006
3. At Fermilab in November–December 2006
4. At SLAC in January 2007
5. On the MIT campus in Cambridge in February 2007
6. On the campus of Johns Hopkins University in Baltimore in March 2007
7. At Dulles Airport in April 2007

Town hall meetings were held in conjunction with the Fermilab, SLAC, and MIT meetings. In addition, a subset of the membership met with users at CERN in January 2007 and at the November 2006 DPF meeting in Honolulu. Reports on UGPS activities were made by the subpanel chair at the October 2006 and February 2007 HEPAP meetings and at the meeting of the National Academy of Sciences Board on Physics and Astronomy in November 2006.

Prior to the subpanel's first meeting, in September 2006, each of its members was assigned a topic and asked to research it and write a brief report. These reports were then used to prepare the committee to address its charge. Specifically, members were assigned to investigate:

1. Overlaps with prior studies
2. The evolution and impact of high energy physics research at universities
3. Models of high energy physics university research
4. Human resources
5. Funding
6. University culture
7. University infrastructure
8. The dilemma of university detector groups
9. Theory
10. Computing in universities
11. Collaborative tools
12. Research scientists
13. Education
14. Spin-offs
15. Management of the University Grants Program
16. Astrophysics in high energy physics

The reports were circulated before the September 2006 meeting and then discussed during it.

The subpanel then created four subcommittees to divide responsibilities:

1. The Writing Subcommittee
2. The Program Administration Subcommittee
3. The Data Collection Subcommittee
4. The University Model Subcommittee

The UGPS further solicited input from the U.S. particle physics community on the general issue of support to university-based groups in the field. (The initial letter that was sent to the high energy physics community via the DPF mailing list is provided in appendix 10.5.) Subsequent community input was received via e-mails, phone calls, and personal exchanges. A UGPS Web site was set up with the aim to

1. Advertise the subpanel's existence to the high energy physics community
2. Describe the subpanel's plans and status
3. Provide a relevant discussion board or blog
4. Create e-mail accounts for subpanel members
5. Solicit survey information from the high energy physics community, to be used by the subpanel in assessing the University Grants Program

A subpanel subcommittee further established an online survey Web site inviting input from both DOE and NSF PIs. The survey is provided in appendix 10.6. The survey is linked to the subpanel URL at http://www.pa.msu.edu/~brock/file_sharing/ugps.

Town hall meetings were held at four of the UGPS gatherings—at DPF, FNAL, SLAC, and the MIT meetings. A smaller such meeting was held with those users present at CERN in January 2007. These meetings witnessed lively exchanges among several members of the high energy physics community. In every case, the issues brought up in personal exchanges, and through U.S. mail and e-mail transmittals, were thoroughly discussed by the subpanel.

10.3 Subpanel Charge

The subpanel was created in response to a request made in a letter sent from Robin Staffin, DOE, and Joseph Dehmer, NSF, to Melvyn Shochet, HEPAP, on June 12, 2006. The letter requested a comprehensive review of the DOE and NSF high energy physics University Grants Program. It included a specification of the details to be included in the review (also see appendix 10.1):

In broad terms, what should be our goals and objectives in supporting the University Grants Program? Is there an overall consensus on these goals that is communicated to and well understood by all stakeholders?

What considerations apply that would serve to define the scope of the University Grants Program?

Appraise the scientific and technical quality of the work being supported by the University Grants Program.

Assess the impact of the University Grants Program on the national and worldwide high energy physics efforts. Are there areas that are overemphasized, significantly undersupported, or missing altogether?

Does the University Grants Program have the correct number and distribution of university researchers at all levels to meet program objectives, including faculty, senior research staff, postdoctoral fellows, graduate students, and professional staff for the near, mid-, and longer term?

Does the University Grants Program have the correct amount and distribution of resources to carry out its program scope? Include an assessment of the relevant contributions from allied programs in DOE, NSF, and elsewhere. How should the program respond in the event of an increase or a decrease in available resources? In addition to financial resources, consider the need and availability of technical infrastructure at the universities.

Do we have the right model of university funding, or do we need to revise or create new models for university research activity and support?

Examine how the programs are managed and overseen. How is the performance of the University Grants Program optimized with respect to the overall goals and priorities? Suggest how management and performance might be improved, if appropriate.

Consider the impact of program reach to the broader community—to other research disciplines, to the public and private sector in research and education, and in workforce development.

10.4 Subpanel Membership

Thomas Appelquist, Yale University
Jonathan Bagger, Johns Hopkins University
Keith Baker, Yale University
James Brau, University of Oregon
Raymond Brock, Michigan State University
Jordan Goodman, University of Maryland
Paul Langacker, University of Pennsylvania
Kevin McFarland, University of Rochester
Homer Neal (Chair), University of Michigan
Steve Olsen, University of Hawaii
Ritchie Patterson, Cornell University
Natalie Roe, Lawrence Berkeley National Laboratory
Randy Ruchti, ex officio, National Science Foundation

Michael Shaevitz, Columbia University
Elizabeth Simmons, Michigan State University
Wesley Smith (Vice-Chair), University of Wisconsin
Chris Stubbs, Harvard University
Andy White, University of Texas at Arlington
P. K. Williams, ex officio, Department of Energy

10.5 Letter to the Membership of the Division of Particles and Fields

The following letter was sent to the DPF e-mail list on October 31, 2006:

Dear Colleagues,

I am writing to inform you of the status of the HEPAP subpanel study on the high energy physics University Grants Program (UGPS). Our subpanel was charged last summer by the Department of Energy (DOE) and the National Science Foundation (NSF) to examine the current state of high energy physics at our nation's universities and to recommend steps to be taken to insure the program's vitality in the decades ahead.

The EPP2010 study conducted by the National Academies provided a roadmap for the future of U.S. HEP. The university part of this program was not detailed in that study. Part of the task of the UGPS subpanel is to provide these details, as well as to assess how the U.S. University Grants Program can remain robust during this period of significant transition of U.S. domestic facilities and growing importance of international and interdisciplinary collaboration.

The charge given to the subpanel by Robin Staffin (DOE) and Joseph Dehmer (NSF) is quite broad (http://www.science.doe.gov/hep/UniversityChgJune12,2006.pdf). Specifically, we have been asked to provide a response that addresses the following topics:

- Goals: In broad terms, what should be our goals and objectives in supporting the University Grants Program? Is there an overall consensus on these goals that is communicated to and well understood by all stakeholders?
- Scope: What considerations apply that would serve to define the scope of the University Grants Program?
- Quality: Appraise the scientific and technical quality of the work being supported by the University Grants Program.
- Relevance: Assess the impact of the University Grants Program on the national and worldwide high energy physics efforts. Are there areas that are overemphasized, significantly undersupported, or missing altogether?
- Manpower: Does the University Grants Program have the correct number and distribution of university researchers at all levels to meet program objectives, including faculty, senior research staff, postdocs, graduate students, and professional staff for the near, mid-, and longer term?
- Resources: Does the University Grants Program have the correct amount and distribution of resources to carry out its program scope? Include an assessment of the

relevant contributions from allied programs in DOE, NSF, and elsewhere. How should the program respond in the event of an increase or a decrease in available resources? In addition to financial resources, consider the need and availability of technical infrastructure at the universities.

- Structures: Do we have the right model of university funding, or do we need to revise or create new models for university research activity and support?
- Management: Examine how the programs are managed and overseen. How is the performance of the University Grants Program optimized with respect to the overall goals and priorities? Suggest how management and performance might be improved, if appropriate.
- Broader Impacts: Consider the impact of program reach to the broader community—to other research disciplines, to the public and private sector in research and education, and in workforce development.

Such a charge provides the university high energy physics community an unusual opportunity to articulate issues of concern and to help develop plans to sustain the vibrancy of the nation's HEP programs. Our report is due to be delivered to HEPAP in April 2007.

Two meetings of the subpanel have taken place, and we have received input from agency officials and field leaders on agency budget profiles, proposal review processes, human resource statistics, the Tevatron program, the SLAC program, neutrino physics, the LHC program, the non-accelerator physics programs, the ILC, computing, high energy theory, education, and outreach.

The data collection phase of our work is continuing, and we now wish to seek broad input from the high energy physics community. To this end, we will be participating in the Town Hall event on November 2, 2006, at the upcoming Hawaii DPF meeting. We will also be holding open sessions at our subpanel meeting at Fermilab on November 30–December 1. Furthermore, a similar session will be held at the meeting of the subpanel at SLAC on January 8–9, 2007. An additional meeting of the subpanel is currently planned to take place at MIT on February 8–9, 2007. Plans for other meetings are pending.

We invite you to share your thoughts with the subpanel by visiting our Web site at http://www.pa.msu.edu/~brock/file_sharing/ugps/./. I also note that you may be an individual selected to complete a specific survey in the near future; if so, we hope you will take the time to share your responses with us.

This is a critical time for our field, and the current HEPAP subpanel study is an opportunity for us all to play a role in charting our course forward.

Sincerely yours,

Homer A. Neal, Sr. (for the UGPS subpanel)

10.6 Subpanel Online Survey

A. Introduction

1. University:

2. PI's name:

3. What agency provides the majority of your group's funding?

B. Technical Infrastructure

4. Provide an estimate for the level of technical infrastructure in your group by fraction of full-time effort (FTE) and source of support, for FY06. Include only those personnel supported at least in part by grants for which you are responsible as PI. Round to the nearest selection in the drop-down menu; due to rounding, the sum may not exactly equal the value you enter in "Total FTE." If your group has no personnel in these categories, skip to the next question.

5. How has the availability of technical personnel at your institution for the design, construction, and operation of experiments changed over the past ten years?

6. Please summarize the physical facilities your group can access for the construction and operation of experiments, such as machine shops, clean rooms, high-bay areas, computing clusters, etc. Include any detailed information that is readily available, such as approximate square footage, number of CPUs, or percent time available to your group. If detailed information is not easily available, a general description is fine.
If your group does not have access to any physical facilities, skip to the next question.

7. How have the facilities available to your group for construction and operation of experiments changed over the past ten years?

8. For new faculty appointments, are start-up packages provided by your university a significant source of new infrastructure? How do start-up packages now compare to those of ten years ago?

9. What area(s) of R&D does your group work on? Select all R&D topics you are currently working on and those you expect to be working on in five years.

10. Please share any additional comments or concerns you may have regarding the technical infrastructure at HEP universities, including policies and practices for supporting infrastructure by the funding agencies and any suggestions you have to preserve, strengthen, and make the best use of these important resources.

C. Students

11. Provide an estimate of the number of students in your group and their source of support in FY06. Include only those students for whom you are responsible as PI. Round to the nearest selection in the drop-down menu; due to rounding, the sum may not exactly equal the value you enter in "Total FTE."

12. What is your general impression of student interest in high energy physics, compared to five years ago?

13. How does the availability of funding limit the number of graduate students in your group? Indicate the number of interested, qualified students you typically evaluate, on average, for each Ph.D. thesis student accepted into your group.

14. Please share any additional comments or concerns you may have regarding undergraduate and graduate students in HEP university groups. In particular, we are interested in the relative use of TAs and RAs to support students in experiment and theory, and how this may have changed over the past ten years.

D. Demographics

15. Provide an estimate of the number of postdocs in your group and their source of support in FY06. Include only those postdocs for whom you are responsible as PI. Round to the nearest choice in the drop-down menu; due to rounding, the sum may not equal the value you enter in "Total FTE."

16. Provide an estimate of the faculty and senior research scientists in your group in FY06. Round to the nearest choice in the drop-down menu; due to rounding, the sum may not equal the value you enter in "Total FTE."

17. Please offer any comments you have on the policies and practices of agency support for senior scientists/research faculty.

18. How many HEP faculty retirements do you anticipate in your department in the next five years?

19. How many new HEP faculty positions do you anticipate in your department in the next five years?

20. The field of high energy physics has evolved over time toward larger experiments and longer time scales, with major facilities often located far from participating university groups, and students and postdocs often based at remote sites. How has this affected the status of HEP in your own department? Are you confident or concerned about the future? Please be explicit and make suggestions about how to approach the future of HEP in the academic setting.

E. Program Management

21. As PI for your HEP university grant, how well do you feel the current peer-review process is working?

22. If you have reviewed grant proposals for DOE or NSF, or have been involved in any DOE or NSF panel reviews or site visits, please give us your opinion as a reviewer on how well the peer-review process works.

23. Please provide any further comments or suggestions on the peer-review process for university grant management by DOE and/or NSF. Be sure to indicate to which agency your comment refers.

24. Please comment on your experiences with interagency barriers or with working in areas of research that span management divisions across or within agencies (e.g., interdisciplinary research).

F. Current and Future Research Directions

25. Current and projected experimental research effort:

Estimate the total FTEs in your group (faculty, postdocs, and students) for each general experimental area listed below, now and five years from now. For faculty, use fraction of research time, and for all others, use fraction of full-time effort (FTE).

26. Current and projected distribution of theoretical research effort:

Estimate the total FTEs in your group (faculty, postdocs, and students) for each general area listed below, now and five years from now. For faculty, use fraction of research time, and for all others, use fraction of full-time effort (FTE).

G. Your Thoughts and Comments

27. Please share any general comments or concerns you have about the HEP University Grants Program. What is working, and what could be improved? Your feedback is important, and confidentiality will be respected.