INVESTIGATING THE NATURE OF MATTER, ENERGY, SPACE, AND TIME

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

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Appendix: Additional Material for the Record

INVESTIGATING THE NATURE OF MATTER, ENERGY, SPACE, AND TIME

THURSDAY, OCTOBER 1, 2009

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 11:04 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Paul Tonko [Vice Chairman of the Subcommittee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
RANKING MEMBER

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE AND TECHNOLOGY

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Committee on Science and Technology
Subcommittee on Energy and Environment

Hearing on

Investigating the Nature of Matter, Energy, Space and Time

Thursday, October 1, 2009
11:00 a.m. – 1:00 p.m.
2318 Rayburn House Office Building

Witness List

Dr. Lisa Randall
Professor of Physics
Harvard University

Dr. Dennis Kovar
Director
Office of High Energy Physics
U.S. Department of Energy

Dr. Piermaria Oddone
Director
Fermilab National Accelerator Laboratory

Dr. Hugh Montgomery
Director
Thomas Jefferson National Accelerator Facility

HEARING CHARTER

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

Investigating the Nature of Matter, Energy, Space, and Time

THURSDAY, OCTOBER 1, 2009
11:00 A.M.–1:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, October 1, 2009 the House Committee on Science & Technology, Subcommittee on Energy and Environment will hold a hearing entitled *"Investigating the Nature of Matter, Energy, Space, and Time."*

The Subcommittee's hearing will receive testimony on the fundamental physics research activities of the Department of Energy (DOE) Office of Science conducted through the High Energy Physics (HEP) and Nuclear Physics (NP) programs. It will also examine how these areas are related to the work of other DOE program offices and other federal agencies.

Witnesses

- **Dr. Lisa Randall** is a Professor of Physics at Harvard University. Dr. Randall will provide an overview of our current level of understanding of matter, energy, and the origins of the universe, as well as the major questions that remain.
- **Dr. Dennis Kovar** is Director of HEP, and the former Director of NP. Dr. Kovar will testify on DOE's current research activities and future plans in these areas, as well as HEP and NP's roles in advancing accelerator research and development for a variety of applications relevant to industry and other federal agencies.
- **Dr. Pier Oddone** is Director of Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois. Dr. Oddone will testify on his vision for Fermilab following the expected shutdown of its primary research facility within the next three years.
- **Dr. Hugh Montgomery** is Director of Thomas Jefferson National Accelerator Facility (JLab) in Newport News, VA. Dr. Montgomery will testify on the capabilities that JLab provides to the U.S. and international nuclear physics communities, as well as JLab's accelerator technology development and science education activities.

Background

On August 2, 1939, Albert Einstein wrote to then President Franklin Roosevelt. Einstein told him of efforts in Nazi Germany to purify uranium-235, which could be used to build an atomic bomb. It was shortly thereafter that the U.S. Government began the Manhattan Project, which expedited research to produce a viable nuclear weapon before the Germans. This endeavor assembled several of the most renowned physicists of the 20th century from all over the world, including Robert Oppenheimer, Niels Bohr, Enrico Fermi, and Edward Teller. After the end of World War II, many of these physicists remained in the U.S. and resumed research in the fundamental nature of matter, energy, space, and time, otherwise known as *particle physics.* The Department of Energy (DOE) and its predecessors have historically supported significant programs of research and education in particle physics from this point forward. Today, the DOE Office of Science's High Energy Physics (HEP) and Nuclear Physics (NP) programs explore this area of research at nine DOE national laboratories and over 100 U.S. universities, employing approximately 4,000 scientists.

High Energy Physics

High energy physics is a branch of physics that studies the fundamental building blocks of matter and energy, and the interactions between them. It is called "high energy" because many of these particles do not occur under normal circumstances in nature, but can be created and detected during energetic collisions of other particles, as is done in large research facilities known as particle accelerators. Modern particle physics research is focused on subatomic particles, which include atomic constituents such as electrons, protons, and neutrons (protons and neutrons are actually made up of fundamental particles called *quarks*), as well as a wide range of more exotic particles. Research in high energy physics has led to a deep understanding of the physical laws that govern matter, energy, space, and time. This understanding has been formulated in what is called the "Standard Model" of particle physics, first established in the 1970s, which successfully describes nearly all observable behavior of particles and forces, often to very high precision. Nevertheless, the Standard Model is understood to be incomplete. The model fails at extremely high energies—energies just now being created in particle accelerators—and describes only a small fraction of the matter and energy filling the universe. Surprising new data reveal that only about five percent of the universe is made of the normal, visible matter described by the Standard Model. The remaining 95 percent of the universe consists of matter and energy whose fundamental nature remains a mystery.

A world-wide program of particle physics research is underway to explore what lies beyond the Standard Model. To this end, HEP supports theoretical and experimental studies by individual investigators and large collaborative teams. Some of them gather and analyze data from accelerator facilities in the U.S. and around the world while others develop and deploy sensitive ground and space-based instruments to detect particles from space and observe astrophysical phenomena that advance our understanding of fundamental particle properties. Some of the key questions the HEP program addresses include:

Do all the forces we are familiar with really come from just one?

All the basic forces found in the universe, such as gravity and electromagnetism, could be various manifestations of a single unified force. Unification was Einstein's great, unrealized dream, and recent advances in a branch of physics known as *string theory* give hope of achieving it. Most versions of string theory require at least seven extra dimensions of space beyond the three we are used to. The most advanced particle accelerators may find evidence for extra dimensions, requiring a completely new model for thinking about the structure of space and time.

How did the universe come to be?

Prevailing measurements and theory describe the universe as beginning with a massive explosion known as the Big Bang, followed by a burst of expansion of space itself. The universe then expanded more slowly and cooled, which allowed the formation of stars, galaxies, and ultimately life. Understanding the very early formation of the universe will require a breakthrough in physics, which string theory may provide.

What is dark matter? How can we make it in the laboratory?

Most of the matter in the universe is invisible to us, and we can detect its existence only through its gravitational interactions with normal matter. This "dark matter," first identified in 1933, is expected to at least partly account for what appears to be missing matter in the universe, as evidenced by the calculated vs. the observed rotational speeds of galaxies. This matter is thought to consist of exotic particles that have survived since the Big Bang. Experiments are currently being carried out to try to directly detect these exotic particles in space as well as produce them in particle accelerators that briefly recreate similar conditions to the Big Bang.

And what is dark energy?

The structure of the universe today is a result of two opposing forces: gravitational attraction and cosmic expansion. In 1998, it was discovered through cosmic observations that the universe has been expanding at an accelerating rate for approximately six billion years. The cause of this accelerating expansion which now appears to dominate over gravitational attraction has been labeled "dark energy" by scientists, though so little is known about it that even calling it a form of energy may be misleading. More and other types of data along with new theoretical ideas are necessary to make progress in understanding its fundamental nature.

What is the origin of mass?

The only particle predicted by the Standard Model which has yet to be found experimentally is called the *Higgs boson*, which would be responsible for generating mass in other fundamental particles. The current generation of particle accelerators is expected to either confirm its existence or rule it out.

What happened to the antimatter?

The universe appears to contain very little *antimatter*. Antimatter is made up of antiparticles, which have the same mass and opposite charge of their associated "normal matter" particles. For example, the antiparticle of the electron, which is negatively charged, is the positively charged antielectron, also called the *positron*. Antimatter is continually produced by naturally occurring nuclear reactions, but its existence is brief because it undergoes near immediate annihilation after coming into contact with its normal matter counterpart. The Big Bang, however, is expected to have produced equal amounts of both matter and antimatter. This is borne out by the study of high-energy collisions in the laboratory. Precise accelerator-based measurements may shed light on how the matter-antimatter asymmetry arose.

What are neutrinos telling us?

Of all the known particles, *neutrinos* are perhaps the least understood and the most elusive. The three known varieties of neutrinos were all discovered by HEP researchers working at U.S. facilities. Trillions pass through the Earth every moment with little or no interaction. Their detection requires intense neutrino sources and large detectors. Their tiny masses may imply new physics and provide important clues to the unification of forces. Naturally occurring neutrinos are produced by cosmic ray interactions with the Earth's atmosphere, by supernovae, and in the interior of stars. These can be studied in space as well as on the ground using intense neutrino sources such as nuclear reactors and advanced accelerators.

HEP Budget and Subprograms

HEP is divided into five subprograms that are organized around the tools and facilities they use and the knowledge and technology they develop. Details on current and proposed funding for HEP can be found in Table 1.

(dollars in millions)	FY 2008 Appropriation	FY 2009 Appropriation	FY 2010 Request
Proton Accelerator-Based Physics	371.7	402.5	443.0
Electron Accelerator-Based Physics	57.2	31.0	26.4
Non-Accelerator Physics	75.8	100.9	99.3
Theoretical Physics	60.0	64.8	67.2
Advanced Technology R&D	138.1	196.6	183.0
Total, High Energy Physics	***702.8***	***795.7***	***819.0***

Table 1: Budget table for the DOE Office of Science's High Energy Physics program. FY 2008 and FY 2009 are appropriated levels, and FY 2010 is the Administration's request level. This does not include $232.4 million in funding from the American Recovery and Reinvestment Act of 2009, of which the Department currently plans to allocate $55 million for a joint project in neutrino research between Fermilab and the University of Minnesota, $106.4 milion in accelerator R&D projects, and $71 million in various other education and infrastructure projects.

The *Proton Accelerator-Based Physics* subprogram exploits two major applications of proton accelerators. Due to the high energy of the collisions at the Tevatron Collider (two trillion electronvolts, or TeV) at Fermilab in Batavia, IL and the Large Hadron Collider (14 TeV maximum) at CERN in Geneva, Switzerland, and the fact that particles interact differently at different energies, these facilities can be used to study a wide variety of scientific issues. (CERN, the world's largest particle physics laboratory, was formally a French acronym, but is now officially the European Organization for Nuclear Research. It is pronounced *sern*.) By colliding intense proton beams into fixed targets, proton accelerators are also capable of producing large samples of other particles which can be formed into beams for experiments. The

U.S. high energy physics community has recently proposed a new project that would utilize the high-power proton beam at Fermilab to produce intense secondary beams of neutrinos for unique new experiments after the Tevatron shuts down within the next three years.

- The **Large Hadron Collider (LHC)** will be the world's largest and highest-energy particle accelerator. DOE and the National Science Foundation (NSF) invested a total of $531 million in the construction of the LHC and its detectors. This U.S. contribution was delivered on budget and three months ahead of schedule last year. DOE provided $200 million for the construction of accelerator components, $250 million for the design and construction of several major detectors, and continues to support U.S. scientists' work on the detectors and additional accelerator R&D. NSF has focused its $81 million of support on funding university scientists who have contributed to the design and construction of these detectors. The total project cost of the LHC is expected to be approximately €3.7 billion, or ~$5.4 billion in today's U.S. dollars. More than 1,700 scientists, engineers, students and technicians from 94 U.S. universities and laboratories currently participate in the LHC and its experiments.

  The LHC began facility test operations on September 10th, 2008. Nine days later, these operations were halted due to a serious electrical fault. Taking into account the time required to repair the resulting damage and to add additional safety features, the LHC is currently scheduled to be operational again in mid-November 2009. The U.S. contributions to LHC have met all performance goals to date, and CERN is taking full financial and managerial responsibility for this repair.

The *Electron Accelerator-Based Physics* subprogram utilizes accelerators with high-intensity and ultra-precise electron beams to create and investigate matter at its most basic level. Since electrons are small, fundamental point-like particles (unlike protons, which are relatively heavy composites of quarks and force-carrying particles) they are well-suited to precision measurements of particle properties and precise beam control. The next generation of accelerator after the LHC is likely to be a high-energy electron facility that can probe LHC discoveries in detail.

The *Non-Accelerator Physics* subprogram supports particle physics research best examined by utilizing ground-based telescopes and detectors typically in partnership with NSF, as well as space-based telescopes in partnership with NASA. Scientists in this subprogram investigate topics such as dark matter, dark energy, neutrino properties, and primordial antimatter. Some of the non-accelerator particle sources used in this research are cosmic rays, neutrinos from commercial nuclear power reactors, the Sun, and galactic supernovae.

- NSF has proposed to build the **Deep Underground Science and Engineering Laboratory (DUSEL)** in Homestake Mine, South Dakota, which closed its mining operations in 2002, and DOE is currently considering becoming a significant partner in this project. If completed, DUSEL would be the deepest underground science facility in the world, 8,000 feet below ground, which would enable unique experiments in neutrino physics and dark matter, among other areas.
- A **Joint Dark Energy Mission (JDEM)** has been proposed as a joint NASA–DOE partnership. JDEM would make precise measurements of the expansion rate of the universe to understand how this rate has changed with time. These measurements are expected to yield important clues about the nature of dark energy. JDEM has rated among the top recommended projects in reports on high energy physics research needs by the National Academies since 2003, as well as reports by the National Science and Technology Council and the Administration's High Energy Physics Advisory Panel (HEPAP). A Memorandum of Understanding (MOU) between DOE and NASA on advancing JDEM was issued in November 2008.

The *Theoretical Physics* subprogram provides the vision and mathematical framework for understanding and extending the knowledge of high energy physics. This program supports activities that range from detailed calculations of the predictions of the Standard Model to advanced computation and simulations to solve otherwise intractable problems. Theoretical physicists play key roles in determining which experiments to perform and in explaining experimental results in terms of underlying theories that describe the interactions of matter, energy, space, and time.

The *Advanced Technology R&D* subprogram develops the next generation of particle accelerator and detector technologies for the future advancement of high-energy physics as well as other sciences. It supports research in the physics of particle beams, fundamental advances in particle detection, and R&D on new technologies and research methods relevant to a broad range of scientific disciplines, including accelerator technologies that can be used to investigate materials for energy applications as well as biological processes for medical applications. HEP has been designated the lead program within the DOE Office of Science to develop a coordinated strategy for next generation accelerators that can meet the Nation's wide variety of basic and application-oriented research needs.

Nuclear Physics

The mission of the DOE Office of Science's Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. Nuclear matter consists of any number of clustered protons and neutrons which makes up the core of an atom called its nucleus. The fundamental particles that compose nuclear matter are each relatively well understood, but exactly how they fit together and interact to create different types of matter in the universe is still largely not understood. To answer the many remaining questions in this field, NP supports experimental and theoretical research—along with the development and operation of specially designed particle accelerators and other advanced technologies—to create, detect, and describe the different forms of nuclear matter that can exist in the universe, including those that are no longer found naturally.

Research has shown that protons, which are positively charged, and neutrons, which are electrically neutral, are bound in the nucleus by a fundamental force named the *strong force* because it is far stronger than either gravity or electromagnetism, although it operates on smaller distance scales. As scientists delved further into the properties of the proton and neutron, they discovered that each proton and neutron is composed of three tiny particles called quarks. Quarks are bound together by yet other particles called *gluons*, which are believed to be the generators of the strong force. One of the major goals of nuclear physics is to understand precisely how quarks and gluons bind together to create protons, neutrons, and other *hadrons* (the generic name for particles composed of quarks) and, in turn, to determine how all hadrons fit together to create nuclei and other types of matter.

NP Budget and Subprograms

NP is organized into five subprograms. Details on current and proposed funding for each can be found in Table 2.

The *Medium Energy* subprogram primarily utilizes two NP national facilities in addition to several other facilities worldwide to examine the behavior of quarks inside protons and neutrons. The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (JLab) in Newport News, VA provides high quality beams of electrons that allow scientists to extract information on the quark and gluon structure of nuclei. CEBAF also uses these electrons to make precision measurements of processes that can provide information on why the universe is primarily made up of matter rather than antimatter, which is relevant to HEP as described above. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) in Upton, NY provides colliding beams of protons to probe the proton's structure. This subprogram also supports one university Center of Excellence at MIT to develop advanced instrumentation and accelerator equipment.

The *Heavy Ion* subprogram tries to recreate and characterize new and predicted forms of matter as well as other new phenomena that might occur in extremely hot, dense nuclear matter, conditions which may not have existed naturally since the Big Bang. Measurements are carried out primarily using very energetic heavy ion collisions at RHIC. Participation in the heavy ion program at the LHC also provides U.S. researchers the opportunity to search for new states of matter under substantially different conditions than those provided by RHIC, gaining additional information regarding the matter that existed during the infant universe.

(dollars in thousands)	FY 2008 Current Appropriation	FY 2009 Original Appropriation	FY 2009 Additional Appropriation	FY 2010 Request
Nuclear Physics				
Medium Energy Nuclear Physics	107,206	121,752	+19,700	131,009
Heavy Ion Nuclear Physics	182,236	200,373	+16,235	219,556
Low Energy Nuclear Physics	82,279	94,618	+24,545	116,816
Nuclear Theory	34,411	39,376	+14,108	43,419
Isotope Development and Production for Research and Applications	—	24,900	+15,212	19,200
Subtotal, Nuclear Physics	406,132	481,019	+89,800	530,000
Construction	17,539	31,061	+65,000	22,000
Total, Nuclear Physics	423,671	512,080	+154,800	552,000

Table 2: Budget table for the DOE Office of Science's Nuclear Physics program. FY 2008 and FY 2009 are appropriated levels, and FY 2010 is the Administration's request level. The FY 2009 Additional Appropriation column represents the Department's plans for additional funding to be allocated from the American Recovery and Reinvestment Act of 2009, of which the $65 million in Construction would accelerate a planned upgrade of the flagship research facility at JLab.

The *Low Energy* subprogram primarily utilizes two NP national user facilities to examine how protons and neutrons are bound into common and stable nuclei vs. rare and unstable nuclei. The Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory in Argonne, Illinois is used to study questions of nuclear structure by providing high-quality beams of all the stable elements up to uranium as well as selected beams of short-lived nuclei. These allow for experimental studies of nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics. The Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory provides beams of short-lived radioactive nuclei that scientists use to study exotic nuclei not normally found in nature. The future Facility for Rare Isotope Beams (FRIB), which Michigan State University has recently been selected to host, is a next-generation machine that will further advance the understanding of rare nuclei and the evolution of the cosmos. The subprogram also supports four university Centers of Excellence, three (at Duke University, Texas A&M University, and Yale University) with unique low energy accelerator facilities and one (at the University of Washington) with infrastructure capabilities for developing advanced instrumentation. The subprogram also partners with the Department of Defense's National Reconnaissance Office and the United States Air Force to support limited operations of a small facility at the Lawrence Berkeley National Laboratory that will help advance improvements in radiation hardness of electronic circuit components against damage caused due to cosmic rays.

The *Nuclear Theory* subprogram provides the theoretical underpinning needed to support the interpretation of a wide range of data obtained from all the other NP subprograms and to advance new ideas and hypotheses that stimulate experimental investigations. This subprogram supports the Institute for Nuclear Theory at the University of Washington, where leading nuclear theorists are assembled from across the Nation to focus on frontier areas in nuclear physics. The subprogram also collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies with its support of the National Nuclear Data Center at BNL. These databases are an international resource consisting of carefully organized scientific information gathered from over 50 years of nuclear physics research worldwide.

The *Isotope Development and Production for Research and Applications* subprogram supports the production and development of techniques to make isotopes that are in short supply for medical, national security, environmental, and other research applications. This subprogram is described in more detail in the Charter for the Committee on Science and Technology, Subcommittee on Energy and Environment hearing entitled "Biological Research for Energy and Medical Applications at the Department of Energy Office of Science" held on September 10th, 2009.

Mr. TONKO. This hearing will come to order.

Good morning. I am Paul Tonko, a Member of the Subcommittee. Chair Brian Baird is unfortunately unable to join us this morning because of circumstances beyond his control and so I will be chairing the first portion of the hearing, which will focus on *Investigating the Nature of Matter, Energy, Space, and Time.*

Today's hearing will explore the Department of Energy (DOE) Office of Science's research activities in high energy and nuclear physics and their collaboration with related programs and projects carried out by the National Science Foundation and the National Aeronautics and Space Administration (NASA) as well as our international partners.

In 1939, Albert Einstein sent a letter to President Franklin Roosevelt warning him of Germany's advances in creating an atomic bomb. This spurred the President to begin the Manhattan Project, which gathered many of the greatest physicists of the 20th century from all over the world to successfully beat the Germans in a race of scientific and technological progress. After the end of the war, many of these physicists remained in the United States to resume their research in the basic nature of matter, energy, space, and time, a field also known as particle physics. Our country has historically supported significant research programs in these areas from that point forward.

Today, DOE alone has proposed a 2010 budget of over $1.3 billion for particle physics research and related technology development, which would continue to support about 4,000 scientists in over 100 universities and nine DOE national laboratories. In this hearing I hope to get a better understanding of what fundamental questions remain to be answered, and what the American taxpayers are receiving in return for this investment. This subcommittee certainly supports exploring fundamental areas of science with uncertain or even unknowable outcomes, but the level of that support should always be well justified.

The Administration's High Energy Physics Advisory Panel made important progress in this direction with the release of its 10-year strategic plan, which set research and project priorities under a series of realistic budget scenarios. I look forward to learning more about whether and how this plan is being implemented.

And with that I would like to thank this excellent panel of witnesses for appearing before the Subcommittee this morning.

And I yield to our distinguished Ranking Member, Mr. Inglis, for his opening statement.

Mr. INGLIS. Thank you, Mr. Chairman, and thank you for holding this hearing. This subcommittee has held several hearings over the last few months examining the diverse mission of DOE's Office of Science. We have heard about their research efforts in energy vehicle technologies and biological sciences.

Today we turn to perhaps the most fundamental research activities in all of science, investigating the building blocks of energy and matter. So we are here to learn at the Einstein level and I feel somewhat unprepared for class, I must tell you. I think I know this much, though: in the Manhattan Project, we found a way to harness the energy of atoms for weaponry of massive strength. Fifty years later we are searching for the most basic understanding of the nature of the universe. Out of this research we gain an understanding of electricity, communication technology, X-rays and other conveniences. We also delve into the fundamental nature of matter, energy, space and time, inspiring our insatiable human curiosity to answer large metaphysical questions about why and how.

Current lines of investigation in this field are very exciting. We are simultaneously exploring the edges of the universe, matter we cannot directly observe and a particle that lends mass to everything around us. While this research will give us some interesting answers, it will certainly inspire many more questions, and that is what science is all about.

I look forward to hearing from our distinguished panelists about this fascinating course of research. Thank you, Mr. Chairman, and I yield back the balance of my time.

[The prepared statement of Mr. Inglis follows:]

PREPARED STATEMENT OF REPRESENTATIVE BOB INGLIS

Good morning and thank you for holding this hearing, Mr. Chairman.

This subcommittee has held several hearings over the last few months examining the diverse mission of DOE's Office of Science. We've heard about their research efforts in energy, vehicle technologies, and biological sciences. Today we turn to perhaps the most fundamental research activities in all of science: investigating the building blocks of energy and matter.

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I think I know this much, though: In the Manhattan Project we found a way to harness the energy of atoms for weaponry of massive strength. Fifty years later, we're searching for the most basic understanding of the nature of the universe.

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I look forward to hearing from our distinguished panelists about this fascinating course of research. Thank you again, Mr. Chairman, and I yield back the balance of my time.

Mr. TONKO. Thank you, Mr. Inglis.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairman Baird follows:]

PREPARED STATEMENT OF CHAIRMAN BRIAN BAIRD

Today's hearing will explore the DOE Office of Science's research activities in high energy and nuclear physics, and their collaboration with related programs and projects carried out by the National Science Foundation and NASA—as well as our international partners.

In 1939, Albert Einstein sent a letter to FDR warning him of Germany's advances in creating an atomic bomb. This spurred the President to begin the Manhattan Project, which gathered many of the greatest physicists of the 20th century from all over the world to successfully beat the Germans in a race of scientific and technological progress. After the end of the war, many of these physicists remained in the U.S. to resume their research in the basic nature of matter, energy, space, and time, a field also known as particle physics. Our country has historically supported significant research programs in these areas from this point forward.

Today, DOE alone has proposed a 2010 budget of over $1.3 billion for particle physics research and related technology development, which would continue to support about 4,000 scientists in over 100 universities and nine DOE national laboratories. In this hearing I hope to get a better understanding of what fundamental questions remain to be answered, and what the American taxpayers are receiving in return for this investment. This Subcommittee certainly supports exploring fundamental areas of science with uncertain or even unknowable outcomes, but the level of that support should always be well-justified. The Administration's High Energy Physics Advisory Panel made important progress in this direction with the release of its 10-year strategic plan, which set research and project priorities under a series of realistic budget scenarios. I look forward to learning more about whether and how this plan is being implemented.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. Thank you, Mr. Chairman, for holding today's hearing to receive testimony on the High Energy Physics (HEP) and Nuclear Physics (NP) research conducted through the Department of Energy (DOE) Office of Science.

This subcommittee has held several hearings to discuss the research activities of the Office of Science, and I appreciate the opportunity to hear from our witnesses today about current HEP and NP research opportunities. In recent years, this research has uncovered new forms of matter, and we now understand that our Standard Model of particles and matter covers only five percent of the actual building blocks of the universe.

For several decades, the U.S. was the world leader in HEP and NP research. However, since the decision to delay the construction of the International Linear Collider, several key research centers and labs have shut down and become obsolete. At the same time, Europe and Japan have continued to make major investments in constructing new laboratories and developing new techniques for exploring particle physics. With the construction of the Large Hadron Collider in Geneva, European investment in HEP and NP is 150 percent higher than U.S. investment. I would like to hear from the DOE what plans, if any, are in place to revive HEP and NP research in the U.S. Further, how Congress and this subcommittee can support efforts to return the U.S. to its position of leadership.

Finally, I am pleased to welcome Dr. Pier Oddone, Director of Fermilab in Batavia, IL. Dr. Oddone and his colleagues are at the forefront of particle physics, and I applaud their work. Fermilab's Tevatron is the second-largest particle accelerator in the world, and in 1995 Fermilab scientists were the first to discover the top quark. I was pleased to learn of Fermilab's receipt of $103 million in funding from the *American Recovery and Reinvestment Act of 2009.* I would like to hear from Dr. Oddone how Fermilab will use these funds to further its research efforts.

I welcome our panel of witnesses, and I look forward to their testimony. Thank you again, Mr. Chairman.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Good morning, Mr. Chairman. Welcome to the panelists, who are here this morning to testify at a subcommittee hearing entitled *"Investigating the Nature of Matter, Energy, Space, and Time."*

It is valuable for Subcommittee Members to be informed of the physics research activities of the Department of Energy (DOE) Office of Science.

Today, we will specifically hear about research conducted through the High Energy Physics (HEP) and Nuclear Physics (NP) programs.

Texas has a large contingency of universities whose research is supported by these programs. The institutions include:

- Baylor University
- Prairie View A&M
- Rice University
- Southern Methodist University
- Texas A&M
- Texas Tech. University
- University of Texas at Arlington
- University of Texas at Austin
- University of Texas at Dallas

I am proud that Texas takes advantage of competitive research grant funding through the Department of Energy (DOE) Office of Science.

The work of particle physics research employs approximately 4,000 American scientists. It is done both by individual investigators and large collaborative teams. Its foundation was laid by the likes of Albert Einstein, Robert Oppenheimer, Niels Bohr, Enrico Fermi, and others. The research helps us understand the beginning, composition, and organization of the universe.

Particle physics research has yielded so many public benefits, such as cancer therapies. We have better diagnostic machines, more sophisticated tools for national security, and more efficient superconducting materials. We have improved drug development and better understand global weather patterns.

The World Wide Web was developed to give particle physicists a tool to communicate quickly and effectively with globally dispersed colleagues around the Nation. The study of particle physics helps us to understand matter's most basic forces and how they interact with one another.

Yes, much of the research may be hard to understand or translate into real life. When we ask only for translational research or real-life linkages, we can stifle the creative thought process. As Dr. Randall stated in her testimony, America is a land of opportunities for creative, intelligent people. It is a place that invests in abstract, basic research to enable creative thinkers to do their work, unfettered. We attract people like Dr. Piermaria Oddone, who dreamed as a child in Peru to be a part of the amazing discoveries occurring in the United States. To continue to bring the world's talent to our doorstep, we must provide opportunities to attract them.

Instruments to study particle physics include the Large Hadron Collider, which cost about $5.4 billion in today's U.S. dollars and involves more than 1,700 scientists, engineers, students and technicians. It is disappointing that, nine days after commencing operations, the Collider experienced a serious electrical fault. However, the level of investment in this research should deliver the clear message that Congress sees great value in particle physics research.

The scientific community believes that, once in operation, the Collider will help us understand more about what gives the most elementary particles their mass. Dr. Oddone points out that education in science, technology, engineering, and math is impacted by particle physics research. Indeed it is.

Discoveries spark the imaginations of young people, who dream of studying the origins of stars, the planets, and how mass and energy relate. Those bright minds are our innovators of tomorrow. We must reach out to them and somehow show them that this research is occurring, and that it is valuable to them. Particularly for disadvantaged students, we must show them that a career in nuclear physics research is attainable. There is so little ethnic diversity in the research workforce in this area of science. I would like to challenge each of you to work at your laboratories and universities to do the important outreach that is required for these students to see the opportunities.

Again, I am grateful that distinguished scientists who are also good communicators have come here today to share the state of our understanding in this area.

Welcome. Thank you, Mr. Chairman. I yield back the remainder of my time.

Mr. TONKO. I now will introduce the panel. It is my pleasure to introduce who will be our first witness, Dr. Lisa Randall, who is a Professor of Physics at Harvard University. We welcome Dr. Randall, as do we Dr. Dennis Kovar, who is the Director of the Office of High Energy Physics and former Director of the Office of Nuclear Physics at DOE, and I believe our colleague, Representative Lipinski, would like to introduce our next panelist.

Mr. LIPINSKI. Thank you, Chairman Tonko.

It is my pleasure to welcome Dr. Pier Oddone, the Director of Fermi National Accelerator Laboratory in Illinois. Fermilab is the largest accelerator in the United States, and under Dr. Oddone's leadership it has been a vital tool in advancing our understanding of the universe. Dr. Oddone's distinguished career has been four decades, taking him from MIT to Princeton to California, where he served as the Deputy Director of the Lawrence Berkeley National Laboratory and was a leading researcher at Stanford's Linear Accelerator Center, or SLAC. As a Stanford alumni, I would like to move from Berkeley to Stanford. He is most celebrated for inventing a new kind of particle accelerator, the Asymmetric B Factory, to help us understand why there isn't more antimatter in the universe. Thank you, Dr. Oddone, for being here and I look forward to his testimony.

Mr. TONKO. And again, welcome, Dr. Oddone. And finally, we have Dr. Hugh Montgomery, who is Director of Thomas Jefferson National Accelerator Facility, the JLab, in Newport News, Virginia. As we begin hearing from our witnesses, might I just make a point of information available. We have just been solicited to vote for what will be a series of three votes. I am told that Dr. Randall's testimony is slightly longer than her fellow witnesses, so what I think may work best here is to hear the testimony of Dr. Randall and then allow for us to go vote and then resume the hearing if you can bear with us, please. It seems to be life in Washington. I am learning as I go. So with that, please, Dr. Randall.

STATEMENT OF DR. LISA RANDALL, PROFESSOR OF PHYSICS, HARVARD UNIVERSITY

Dr. RANDALL. Thank you for having us here today. This is kind of amusing. It is a little bit like class on the first day when everyone is sitting in the back here afraid to hear about the physics.

But what we are going to tell you today, what we would like to tell you is the kind of questions we are exploring today. We are exploring the universe at larger and smaller scales than ever before, and that is really important because that is the way we find out new things. We get away from what we experience in our everyday life. We go to these extremes of distances and energy, which is why we have these extreme experiments that are set up. Astrophysical probes let us see out into the universe whereas particle physics experiments currently at Fermilab, and hopefully soon LSC, we are going to look at smaller distances and higher energies than we ever have before. And what we will try to convince you very briefly is that we could be at the verge of revolutionary discoveries.

And I just thought I would say a couple of words and I am not going to read all this, but the questions are abstract, and we heard about the Manhattan Project in the introductory remarks. We hear about applications. I think it is always very important to keep in mind that when these fundamental discoveries are made, no one has ever predicted what their applications would be yet they have revolutionized the universe, and I think there are so many people out there who just want to know the answers to these questions. That is one of the reasons we are here. It is one of the reasons we are a leader but it is also what gives us leadership at universities. It is one of the reasons we have the best universities, the smartest people here that go on to do physics and other things. So I think we don't want to get too focused when we ask what is the application of any particular project because in the end the results seem to have worked out pretty well.

Our goals as particle physicists are to understand matter's most basic elements and the forces through which they interact. You all probably know about the atom but we are going inside the atom. We are going inside the atom to explore what is inside the nucleus. What is inside the nucleus seems to be particles called quarks, pulled together through forces called the strong nuclear force which is communicated through particles called gluons. But in addition to those particles we know about that are there in all matter we have seen, there seems to be heavier quarks. We know that there are heavier quarks. We don't know their purpose. We don't know why they have the masses that they have. We know of four fundamental forces. We don't know what the relationships among them are or should be. And these are the kinds of questions we are trying to answer. We really are on the verge of getting some insight into questions about mass and fundamental particles very soon.

We would also like, of course, not just to have a list of particles. The list isn't that extensive but we want to really understand the connections. We want to understand what is the underlying theoretical framework which connects them all, because that gives us some deep understanding of what is fundamentally out there. We are not just trying to enumerate particles, we are trying to really see what is the fundamental description? How does this work? That fundamental description might be connected to something as exotic as string theory, which is based on the idea that rather than particles, we have fundamental oscillating strings. It could give us a deeper understanding of space-time. This is quite remarkable but it could be that understanding space better could actually explain properties of fundamental particles. Particles could be separated within a context of even extra dimensions in space, and if I have a moment I will mention that possibility.

Really, trying to answer these questions has led us to some very exotic scenarios, but they are not just out there as crazy ideas. Really, it is following through. It is not just metaphysics. It really is trying to follow through, what are the consequences of what we have seen? And what are the ways within the context of theories we do understand that we can actually solve these questions?

We also are working on connections to cosmology particle physics. Of course, we know what is out there. We know how the universe has evolved. Knowing how the universe has evolved tells us about fundamental particles, and that has given rise to some very interesting connections to, for example, dark matter studies.

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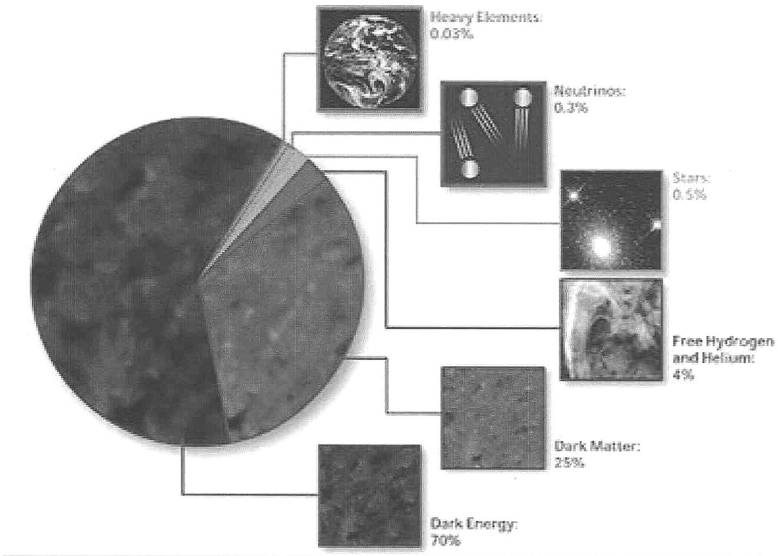
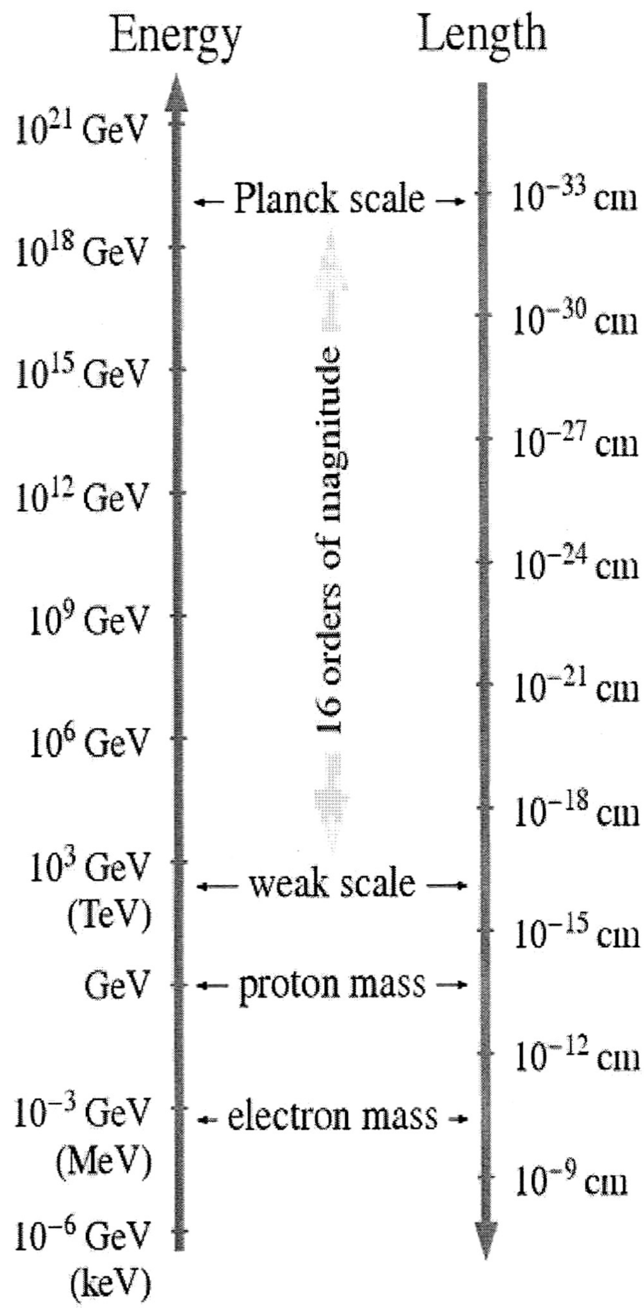


This is probably hard to see but basically this is just stating that there are some pretty big questions out there in cosmology; primarily, what is out there in the universe? What constitutes the 25 percent of matter that we haven't seen yet? What constitutes the 70 percent of the energy that seems to out there that we don't yet understand?

One of the questions that we really do hope to address—


Energy
Length
10^21 GeV
10^18 GeV
10^15 GeV
10^12 GeV
10^9 GeV
10^6 GeV
10^3 GeV (TeV)
GeV
10^-3 GeV (MeV)
10^-6 GeV (keV)
← Planck scale →
16 orders of magnitude
← weak scale →
← proton mass →
← electron mass →
10^-33 cm
10^-30 cm
10^-27 cm
10^-24 cm
10^-21 cm
10^-18 cm
10^-15 cm
10^-12 cm
10^-9 cm

—this looks more complicated than I intended but one of the questions that we want to address now is the question of what is the origin of the mass scale that we know about. We know right now, right now experiments are exploring something called the weak energy scale. It is a particular energy scale. It is about 100 to 1,000 times the mass of a proton when we relate energy and mass through $E = mc^2$, and at that energy scale we really will answer some of the questions we have had as particle physicists for the last 30 years or so—questions like, why do particles have mass? Why do fundamental particles have mass? Questions like, why is that mass scale what it is? And the interesting thing is that quantum mechanics and special relativity tell us that the mass scale just doesn't make sense unless there is something else very interesting happening at that energy scale. That is to say, we expect to find some indications of some new underlying physics that could be as exotic as extensions of symmetries of space and time, extension of space itself. It is almost inevitably going to be something profound.

I am sure that my fellow panelists will talk more about this, but it is really a particularly interesting time because the Large Hadron Collider is about to turn on and really we do hope to see some answers to this question. And this is just to stay that it could be that it could discover evidence, it could just discover new particles, it could discover—you have probably heard of what is called the Higgs particle, but it could discover particles that even travel in extra dimensions. We really do have reasons to believe that there is very interesting new physics that is really right around the corner if we can explore these higher energy scales. And just to give a simple example, it could be that when we collide together protons we make this new particle that travels in extra dimensions. What is so interesting is that these particles, even though they are involved in extra dimensions—and I know I haven't told you what extra dimensions are, but it is the idea that we have dimensions beyond the three we see. But it could be that even though those particles are there, they still can decay back into our universe so that we can see them in these elaborate detectors that have been built that I am not going to have time to tell you about but I am sure my fellow panelists will.

It seems I have actually stuck to time, which is kind of amazing, mostly because I am from New York and talk really fast. But we really do have a new world view at this point. That is to say, we are about to embark on investigation of scales of which we are fairly confident we should be able to find out what is happening, and what is so interesting is that that same energy scale could be connected to the dark matter of the universe for reasons I don't have time to explain but feel free to ask. And it could be connected to the scales that will be explored with gravity wave detectors. It is very interesting. The scale has appeared in several different contexts. There are many new results in theoretical physics. There are intriguing possibilities for our universe. We have seen how the theories can connect together the ideas, but it is very important for us to really have the experiments to tell us which are the right directions. These are all very nice ideas, at least we think so, but we would like to know which are really out there in the universe. We are not just doing abstract mathematics. We really want to know what is it. And any of these discoveries would be things that would make us really change fundamentally our view of what the universe is made of.

Some of the most exciting physics that we know should have answers is involved at this weak scale that we are exploring. There are many questions at many energy scales but we are at the cusp of exploring an energy scale which we know is interesting, and as I said, it is also involved in dark matter experiments. So this is wonderful overlap of experimental cosmology and theoretical developments and this could be a revolutionary discovery. How can we choose not to explore?

So I am just going to close with my favorite picture, which shows that there could be a lot more out there in the universe. An amusing fact was when I put this picture in I didn't realize it was the Chateau de Sion, the painting that is there, which is right near CERN. Thank you.

[The prepared statement of Dr. Randall follows:]

PREPARED STATEMENT OF LISA RANDALL

It's an exciting time for physics. We are currently exploring the universe at larger and smaller scales than ever before. Astrophysical probes let us see out into the Universe at the largest observable scales. Particle experiments set to investigate the fundamental nature of matter smaller distances and higher energies than ever before.

Admittedly, the questions we ask can be very abstract in their detailed formulation—so much so that people sometimes question the merit of our enterprise, which doesn't have the obvious and immediate impact of other more applied or more people-oriented research. But at the root of what we explore are questions as basic as what are the fundamental building blocks of matter? What is out there in the universe that we cannot yet see? And how did the universe evolve into its current state? The ability to ask—and to answer these questions—and to formulate them precisely enough that we know answers should exists—is what makes people, and up to this point Americans, special.

Some of the very features that make the field so esoteric and so challenging are also what makes it critical as a way of maintaining leadership in scientific, technical, and creative fields. If you want to attract the best people to do the most creative things, challenges are vital. We've maintained the best universities and had the most innovative companies for the last half century for a reason.

So what are the questions we ask and what will it take to answer them? We want to understand matter's most basic elements and the forces through which they interact. We'd like to connect observed particles, interactions, and phenomena to underlying theoretical frameworks. That might be string theory, which posits fundamental underlying vibrating strings at the heart of all matter. Or these studies might yield a deeper understanding of space time. Are the three dimensions of space that we see all there are? Or are there dimensions to the universe that are different and so far completely hidden from view? It could be that there are parallel universes less than a centimeter away that we have not yet seen. It would be revolutionary to discover that the Universe is so much richer than we have so far observed.

We want to connect what we learn about fundamental particles to how the universe has evolved. And we'd like to understand the implications of cosmological observations for particle physics. Can we understanding the origin of the universe and structures that we see?

The chief particle physics questions today center around the origin of the masses of fundamental particles and why they are at the scale we have observed them to be. This is no small questions since quantum mechanics and special relativity tell us that it is extremely unlikely without something very interesting going on to maintain the hierarchy of mass scales that is necessary to develop interesting physical theories—and the world as we know it. Without what we call "fine-tuning" of parameters—or something new and profound—it seems that masses would be nothing like what we have seen. We want to understand both where mass comes from and what protects the mass scale.

That latter question has led to explorations as profound and admittedly speculative as the search for additional dimensions of space. It could be that space time is distorted in a way that keeps gravity weak and masses as they should be.

And most remarkably we should soon be able to test these ideas. The Large Hadron Collider, the giant machine colliding together two beams of protons at seven times higher energy than has yet been achieved on Earth, should be able to explore what physical theory accounts for the phenomena we have observed. For example, when protons collide they can turn into energy, and that energy (through $E = mc^2$) can turn into particles that travel in the extra dimensions. Those particles might escape, or they might decay into the detectors which are specially designed to identify these decay products and piece together what was originally there.

By studying the energy scales that the LHC will explore, we might also understand what accounts for dark matter, the matter in the universe whose gravitational effects we observe but which don't emit or absorb light. In addition to the LHC, this is an interesting experimental era for the study of cosmology and dark matter in particular. Many particle theorists currently explore the cosmological implications of physical theories that might underlie the Standard Model. Dark matter will be tested directly, in experiments on Earth where the small probability that dark matter will interact is enhanced by providing big vats of target material. Dark matter will also be tested through the possibility that dark matter particles can annihilate with each other and give rise to photons or antiparticles that we can measure astronomically.

Our job as theorists is to understand experimental implications and suggest what might be present so that we won't miss it when it is produced in the laboratory or in space. Experiments are complicated and the many subtle ways to find what lies beyond the Standard Model challenges us all to rise to the occasion.

There are many new ideas and results in theoretical physics that follow from our better understanding of the implications of Einstein's theory of gravity and our particle physics models. There are intriguing possibilities to explore and test, both with theory and experiments. Many of these ideas center on the scales that the LHC will explore. These ideas—ones as exotic as extra dimensions or as relatively straightforward as the so-called Higgs mechanism for generating msas—could soon be tested. Given that we are at the cusp of this new understanding of the nature of the universe, how can we choose not to explore?

BIOGRAPHY FOR LISA RANDALL

Lisa Randall is Professor of Theoretical Physics and Studies Particle Physics and Cosmology. Her research concerns elementary particles and fundamental forces and has involved the development and study of a wide variety of models, the most recent involving extra dimensions of space. She has made advances in understanding and testing the Standard Model of particle physics, supersymmetry, models of extra dimensions, resolutions to the hierarchy problem concerning the weakness of gravity and experimental tests of these ideas, cosmology of extra dimensions, baryogenesis, cosmological inflation, and dark matter. Professor Randall earned her Ph.D. from Harvard University and held professorships at MIT and Princeton University before returning to Harvard in 2001. She is a member of the National Academy of Sciences, the American Academy of Arts and Sciences, a fellow of the American Physical Society, and is a past winner of an Alfred P. Sloan Foundation Research Fellowship, a National Science Foundation Young Investigator Award, a DOE Outstanding Junior Investigator Award, and the Westinghouse Science Talent Search. In 2003, she received the Premio Caterina Tomassoni e Felice Pietro Chisesi Award, from the University of Rome, La Sapienza. In autumn, 2004, she was the most cited theoretical physicist of the previous five years. In 2006, she received the Klopsted Award from the American Society of Physics Teachers (AAPT). In 2007, she received the Julius Lilienfeld Prize from the American Physical Society for her work on elementary particle physics and cosmology and for communicating this work to the public. Professor Randall's book, *Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions*, was included in the *New York Times*' 100 notable books of 2005.

In 2008, Prof. Randall was among *Esquire Magazine*'s "75 Most Influential People of the 21st Century". Randall was included in *Time Magazine*'s "100 Most Influential People" of 2007 and was one of 40 people featured in *The Rolling Stone 40th Anniversary* issue that year. Prof. Randall was featured in *Newsweek*'s "Who's Next in 2006" as "one of the most promising theoretical physicists of her generation" and in *Seed Magazine*'s "2005 Year in Science Icons".

Mr. TONKO. Thank you very much, Dr. Randall, and very interesting testimony and thank you for the sidebar compliment regarding New Yorkers. We appreciate that.

We are now going to recess for about 20 minutes, and Dr. Kovar, we will resume with you leading off with your testimony. That allows us then to cast our three votes and return. So we can recess for 20 minutes.

[Recess.]

Mr. LIPINSKI. [Presiding] I call the hearing back to order. We heard—before the votes we heard the testimony of Dr. Randall, so I hope we won't be interrupted again by votes but it is possible we will be, but right now we will move on to Dr. Kovar. So Dr. Kovar, you are recognized.

STATEMENT OF DR. DENNIS KOVAR, ASSOCIATE DIRECTOR FOR HIGH ENERGY PHYSICS, OFFICE OF SCIENCE, U.S. DEPARTMENT OF ENERGY

Dr. KOVAR. Mr. Chairman, Ranking Member Inglis and Members of the Committee, thank you very much for the opportunity to testify on the High Energy and Nuclear Physics Program at the Department of Energy at the Office of Science. I am Dennis Kovar. I served as Director of the Nuclear Physics Program for nine years and since October 2007 I have been serving as Director of the Office of High Energy Physics. I am very pleased to be here today to share with you my perspectives on these programs.

The scientific fields of high energy and nuclear physics emerged in the first half of the 20th century as physicists began to study the fundamental constituents of matter and their interaction. In the 1950s because of the great activity and the interest in these areas, the Department of Energy's predecessor agency, the Atomic Energy Commission, established research programs in these scientific fields. These research programs are now in the Department of Energy's Office of Science. Their mission is to deliver discovery science. They do this by nurturing, developing and supporting the research capabilities needed to position the United States at the scientific frontiers of these fields, to make significant discoveries and advance our knowledge. High energy physics, or particle physics, focuses on discovering and characterizing the fundamental building blocks of matter, while nuclear physics focuses on understanding how these fundamental building blocks combine to give rise to matter as observed in nature and the laboratory. Over the last half century the Department of Energy programs have delivered outstanding discovery science. The United States has emerged as a global leader in the major scientific success of both fields. The results have been impressive. Twenty-six Nobel Prizes awarded in high energy and nuclear physics over the past 58 years went to physicists in the United States, supported primarily by DOE. These programs have over this period had an enormous impact on society through the new knowledge and technologies that emerged from their research. These have enabled applications in industry, computing, medicine and pharmaceuticals, national security and other scientific fields. Both programs have now developed strategic plans for maintaining the U.S. leadership roles and participating in major discoveries in these scientific fields in the future. These plans have been developed with the input of their respective federal advisory committees and the broad national and international scientific communities. They have been formulated to address the most promising scientific opportunities in a manner that will complement and enhance international efforts so as to optimize the science that will emerge globally.

The Department of Energy's High Energy Physics and Nuclear Physics Programs also have important stewardship components that serve the Department and national needs beyond the scope of research. For the High Energy Physics Program, it is fundamental and long-term accelerator science relevant to next-generation accelerators, and for nuclear physics, it is isotope development and production. U.S. scientific leadership and the associated benefits to the Nation are realized through sustained federal support and by federal investments in scientific infrastructure and research facilities. Our understanding of the laws of nature and the physical universe have been profoundly altered by these discoveries made at U.S. facilities by U.S. scientists. These discoveries reveal new behaviors that raise new questions and in some cases totally unexpected questions. These questions inspire curiosity and wonder. They inspire ingenuity, pride and innovation and motivate discovery. The resulting advances in technology and knowledge serve both science and society.

That concludes my testimony. Thank you, Mr. Chairman, for providing this opportunity to discuss high energy physics research programs and our plans for the future. I would be pleased to answer any questions you might have. Thank you.

[The prepared statement of Dr. Kovar follows:]

PREPARED STATEMENT OF DENNIS KOVAR

Thank you Mr. Chairman, Ranking Member Inglis, and Members of the Committee for the opportunity to appear before you to provide testimony on the High Energy Physics and Nuclear Physics programs in the Department of Energy's (DOE's) Office of Science (SC). I served as Director of the Nuclear Physics program for nine years, from 1998 to October 2007, and I have been Director of the Office of High Energy Physics since October 2007. I am pleased to be here today to share with you my perspectives on these programs.

Introduction

The fields of high energy physics (also known as particle physics) and nuclear physics, seek to understand and explain the physical world all around us—from the sub-atomic to the astronomical. Particle physics focuses on discovering and characterizing the fundamental building blocks of matter. Nuclear physics focuses on understanding how these fundamental building blocks combine to give rise to matter as observed in nature and in the laboratory.

Both fields address questions that seem intractable: What is the origin of mass? What do the stars tell us about the fate of the Universe? Can we discover and create novel forms of matter? What if an understanding of the fundamental building blocks of matter at the smallest scales is not enough to explain the character of the atomic nucleus, the elements, or materials? Later in this testimony, I hope to explain how experiments with neutrinos, fundamental particles associated with some forms of nuclear decay, aim to reveal missing components of a theoretical model that could explain why most particles have mass while others do not. I will describe astronomical measurements that could answer some of our questions about dark energy—a form of energy hypothesized to account for anomalous observations about the rate of expansion and ultimate fate of the Universe. I will explain how particle colliders exploit the duality of mass and energy to produce, detect, and ultimately characterize novel particles of matter. I will also mention how ongoing studies of Quantum Chromodynamics (QCD) are helping to explain why some composite, but still subatomic, particles are more than the sum of their fundamental particle constituents.

These questions inspire curiosity and wonder. Among the skilled scientists engaged in high energy and nuclear physics research, they also inspire ingenuity and motivate discovery. The resulting advances in technology and knowledge serve both science and society. For example, the desire for a deeper understanding of the fundamental constituents of matter has revealed a hierarchy of matter's building blocks: protons and neutrons bind together to form the atomic nucleus; quarks, in turn, are the components of protons and neutrons. Along the way, discoveries were made about radioactive decay—a process exploited by, for example, medical imaging technologies—and nuclear fission. Many of these discoveries were made possible by purpose-built research facilities supported by DOE—for example, particle accelerators. In many cases, breakthroughs in technology and design in these facilities have led to advances in diverse areas, such as light sources for materials research and tools for homeland security.

In this testimony, I describe the current frontiers for both high energy physics research and nuclear physics research and describe how the research programs of the Office of Science contribute to scientific advances in these areas. I also discuss each program's relationship to U.S. and international partners and the anticipated benefits of continued U.S. leadership, including benefits to science and to the Nation. To begin, however, I would like to describe the origins and scientific breadth of the programs.

The Origins of the High Energy and Nuclear Physics Programs

The scientific study of high energy physics and nuclear physics emerged in the first half of the 20th century as physicists began to study the fundamental constituents of matter and their interactions. This began in 1909 with a famous experiment by physicist Ernest Rutherford. The experiment involved firing a beam of helium ions at a thin sheet of gold foil and measuring how the ions scattered. The scattering pattern suggested that each atom has at its center a small, dense, positively charged core, which Rutherford named the nucleus. Over the next decades physicists learned that all matter on Earth is built of subatomic particles, now known as electrons, protons, and neutrons.

Following the invention of particle accelerators, the second half of the 20th century witnessed a rapid progression of new discoveries. Accelerators enable physicists to propel charged particles to high speeds, focus them into beams, and collide them with stationary targets or other beams. The products of the collisions of common particles of matter enable the observation of their constituent subatomic particles and new short-lived particles. These collisions can convert matter into energy as described by Albert Einstein's equation, $E = mc^2$. With these experiments physicists discovered that protons and neutrons from the atomic nucleus are composed of more fundamental particles known as quarks. The quarks and electrons that constitute everyday matter belong to families of particles that include other, much rarer particles. They also learned that particles interact through just four forces: gravity, electromagnetism, and two less familiar forces known as the strong force and weak force.

In the 1950s, the Department of Energy's predecessor agency, The Atomic Energy Commission, established research programs supporting high energy and nuclear physics to take advantage of the scientific opportunities identified by early atomic science and made possible by technology and accelerator-based research. Over the last half century these programs delivered outstanding discovery science, and the United States emerged as a global leader in the major scientific thrusts of both fields. U.S. leadership was made possible by sustained support for researchers at both universities and national laboratories and by federal investment in scientific infrastructure for new or upgraded accelerator facilities. These facilities positioned the U.S. to do experiments at the scientific frontier. Our understanding of the laws of nature and the physical universe was profoundly altered by the discoveries made at these facilities by our scientists. These discoveries revealed behaviors that sparked new, and in some cases, totally unexpected questions.

The increase in the energy of particle accelerator beams enabled particle physicists to discover the creation of many new unexpected short-lived particles. A theoretical framework known as the Standard Model was developed to describe and predict the behavior of these particles with extremely high levels of precision. The Standard Model is currently the best theory for explaining the relationship between matter and the fundamental forces that govern particle interactions. The development and precise testing of the Standard Model rank among the crowning achievements of 20th century science.

DOE-supported physicists have played leading roles in the development of the theoretical foundations and in many of the major experimental discoveries in particle physics. For example, all six quarks and three of the six elementary particles known as leptons were discovered at DOE accelerator laboratories. DOE-supported physicists also played leading roles in the theoretical development of the Nuclear Shell Model, Nuclear Collective Model, and the models for stellar burning and nucleosynthesis—the process of creating new atomic nuclei from preexisting neutrons and protons—all of which form the foundations of nuclear physics today. DOE laboratories and experiments played major roles in verifying these nuclear physics models. Twenty of the 26 Nobel Prizes awarded in high energy and nuclear physics over the past 58 years were to physicists in the United States supported primarily by DOE.

The DOE High Energy and Nuclear Physics Programs

Like other programs in the Office of Science, the Office of High Energy Physics (HEP) and the Office of Nuclear Physics (NP) have two signature components to their respective programs. First, both programs support a robust portfolio of fundamental research at universities and national laboratories strategically structured to serve the DOE mission in discovery science. This includes the development of advanced accelerator and detector technology that is important to the advancement of their fields and relevant to other scientific disciplines and applications. Second, both programs support the design, construction, and operation of world-class scientific user facilities that position the U.S. at the scientific frontiers of high energy and nuclear physics. The HEP and NP programs also have important stewardship components that serve DOE and national needs beyond the scope of high energy or nuclear physics research. For HEP, it is fundamental and long-term accelerator science relevant to next-generation accelerators, and, for NP, it is the national isotope development and production program.

Both programs have developed strategic plans with the input of their respective Federal Advisory Committees and the broad national and international scientific communities.

The HEP program supports a range of research and scientific tools focused on three interrelated scientific frontiers:

- *The Energy Frontier*, where powerful accelerators are used to create new particles, reveal their interactions, and investigate fundamental forces.
- *The Intensity Frontier,* where intense particle beams and highly sensitive detectors are used to pursue alternative pathways to investigate fundamental forces and particle interactions by studying events that occur rarely in nature.
- *The Cosmic Frontier,* where ground-based and space-based experiments and telescopes are used to make measurements that will offer new insight and information about the nature of dark matter and dark energy to understand fundamental particle properties and discover new phenomena.

The NP program has come to focus on three broad yet interrelated scientific frontiers:

- *The Quantum Chromodynamics (QCD) Frontier,* where predictions are sought for the properties of strongly interacting matter, and questions about what governs the transition of quarks and gluons into pions and nucleons[1] are asked.
- *The Nuclei and Nuclear Astrophysics Frontier,* which focuses on understanding how protons and neutrons (themselves combinations of quarks and gluons) combine to form atomic nuclei and how those nuclei have arisen during the 13.7 billion years since the birth of the cosmos.
- *The Fundamental Symmetries and Neutrinos Frontier*, which focuses on developing a better understanding of the neutron and the neutrino—the nearly undetectable fundamental particle produced by the weak interaction that was first detected in nuclear beta decay—providing evidence for physics beyond the Standard Model.

The study of neutrinos features in both the Intensity Frontier of the HEP program and the Fundamental Symmetries Frontier of NP. These endeavors are complementary and coordinated with distinct motivations. The HEP program seeks to exploit the role that neutrinos play in the Standard Model to better understand the origins of mass and the forces affecting matter. The NP program seeks to better understand the nature of the neutrino in terms of its mass, whether it has a distinct

[1] Pions are the lightest mesons, which are composed of one quark and one antiquark. The term *nucleon* refers to either a neutron or a proton, as both can be found in the atomic nucleus.

antiparticle, and the role that neutrinos play in the processes and forces affecting atomic nuclei.

The strategic plans for the HEP and NP programs also consider investments made by other U.S. federal agencies and international research organizations, recognizing that large accelerator and detector experiments have become costly and can take many years to implement. The HEP and NP programs engage in several efforts to coordinate and collaborate with high energy physics and nuclear physics programs around the world to maximize scientific opportunities and maintain leadership in key scientific thrusts.

In particular, both HEP and NP work closely with the National Science Foundation (NSF) in many partnerships. These working relationships and partnerships are greatly facilitated by the fact that the HEP and NP Federal Advisory Committees are jointly chartered by DOE and NSF. HEP has also partners with the NSF and the National Aeronautics and Space Administration (NASA) Astrophysics program on ground-based and space-based observatories. NP has working relationships with NASA, the U.S. Air Force, National Reconnaissance Office (NRO), and U.S. Navy for utilization of particle beams and infrastructure at NP facilities.

Scientific Facilities and International Collaborations

Historically, the HEP and NP programs have pursued the development of large, one-of-a-kind particle accelerator facilities, which are utilized by large international scientific collaborations. The most prevalent model for collaborating on international facilities, a model that has evolved over the past few decades, involves the host country or host region building and operating a new facility that provides particle beams for experimentation, and the host collaborating with other countries around the world to build and operate the detectors that use these beams. During the period that one forefront facility operates, other new next-generation facilities or upgrades are being planned for construction and operation in the next decades. This provides a balance of world-class facilities in diverse geographical regions. If the cost of a new facility is too expensive for a single country or region, there is typically a reexamination of the international collaboration. In this regard the ongoing 12 GeV Upgrade for the Continuous Electron Beam Accelerator Facility (CEBAF), the planned Facility for Rare Isotope Beams (FRIB), and the proposed upgrade of Fermilab's accelerator capabilities for a world-class Intensity Frontier program are all elements of the international scientific programs in nuclear and high energy physics.

There are several strategic requirements of HEP and NP science due to the long timescales and the international nature of these collaborations—consensus needs to be reached by the national and international partners on what will be done; long-term commitments need to be made and honored; and the work must be "projectized" and managed internationally.

Future of the HEP Program

In HEP's strategic plan, the next years will see a transition from currently operating facilities (Tevatron Collider and Main Injector at Fermilab) to intensive R&D, design, and construction of new research capabilities. A balance among research, facility operations, and construction for future opportunities will be maintained. The plan enhances and develops a U.S. leadership role in the three main scientific thrusts of particle physics: the *Energy Frontier*, currently explored by the Tevatron and the Large Hadron Collider (LHC), with a teraelectron volt (TeV) lepton collider envisioned as the next-generation discovery tool; the *Intensity Frontier*, encompassing high-power proton- and electron-based accelerators used for neutrino physics and studies of very rare processes that give unique insights into the unification of forces; and the *Cosmic Frontier*, which embodies a wide range of studies using non-accelerator-based techniques and ultra-sensitive particle detectors.

Long-range plans for each frontier revolve around the scientific questions addressed by major new facilities:

The Energy Frontier: At the Energy Frontier, there is a strong case for operating the Tevatron Collider program through FY 2011 to compete for scientific discoveries with the LHC during this period. Possible scientific deliverables over the next five-year period are discoveries of the Higgs boson and supersymmetric particles. LHC suffered technical problems in commissioning, but is now scheduled to start operations late in 2009. HEP support for LHC detector operations, maintenance, computing, and R&D is necessary to maintain a U.S. role in these experiments. The HEP plan allows for U.S. participation in the LHC accelerator and detector upgrades. Details of the scope of U.S. involvement in these upgrades are currently under consideration.

The Intensity Frontier: At the Intensity Frontier, the Neutrinos at the Main Injector (NuMI) Off-Axis Neutrino Appearance (NOνA) project at Fermilab is planned to begin operations with a partially completed detector in 2013. The NuMI beamline will operate in its current configuration through FY 2011 for the Main Injector Neutrino Oscillation Search (MINOS) and MINERνA, and will undertake a year-long shutdown in FY 2012 to upgrade the beam power for the NOνA experiment. The future direction of the intensity frontier involves further upgrades to the Fermilab proton beam power, construction of high intensity beamlines for neutrino and rare decay experiments, and the fabrication of detectors capable of utilizing these intense beams to make significant discoveries.

The upgraded intense proton beam would enable searches for extremely rare decays that can probe for new physics well beyond the Energy Frontier, such as muon to electron conversion, and a new dedicated beamline and experiment to explore this science. A new neutrino beamline together with a large underground detector located at a large distance from Fermilab would provide capabilities for a next generation of neutrino oscillation measurements. Over a ten-year period, we expect some realignment of professional skills at Fermilab as the laboratory transitions from the operations-dominated Tevatron program to the construction-dominated neutrino and rare decay program. Significant results from NOνA, MINERνA, and other precision measurements will emerge over the next decade, keeping the U.S. at the forefront of these studies, even as the infrastructure needed for a world-leading program in neutrino studies will have been put into place. This, along with rare decay searches, will provide Fermilab with a robust, continuous program of world-leading physics in the decade after the end of the Tevatron Collider program.

The Cosmic Frontier: DOE is partnering with the NASA and NSF in the fabrication of forefront ground-based and space-based particle astrophysics observatories for exploration of the Cosmic Frontier. HEP will collaborate with NSF on a staged program of research and technology development designed to directly detect dark matter particles using ultra-sensitive detectors located underground. These detectors will eventually push current limits on direct detection of dark matter down by a factor of 1000. HEP anticipates working with NASA on a Joint Dark Energy Mission (JDEM) and with NSF on possible ground-based dark energy measurements. These projects for direct detection of dark matter and ground- and space-based observatories focused on dark energy are planned to begin fabrication in the out-year timeframe and to begin operations in the latter part of the next decade which will allow the United States to maintain scientific leadership at the Cosmic Frontier.

Future of the NP Program

The United States is today a world leader at the Quantum Chromodynamics scientific frontier because of the federal investments made in the last decade in CEBAF and RHIC (Relativistic Heavy Ion Collider). The NP program is among the world leaders in the frontier of Nuclei and Nuclear Astrophysics, with efforts focused at ATLAS and the HRIBF (Holifield Radioactive Ion Beams Facility) and three university accelerator facilities. In addition, participation in forefront neutrino experiments has made the U.S. among the world leaders in the third frontier of nuclear science, Fundamental Symmetries and Neutrinos. Each of these frontiers is bolstered by a strong community of nuclear theorists.

The strategic plan of the NP program over the next five years is to support university and laboratory scientists and engineers, operate existing facilities, invest in research capabilities to maintain leadership in the program's scientific thrusts, and produce research and commercial isotopes important for the Nation. The NP program is designed to deliver significant discoveries and advances in nuclear science and to produce the knowledge, advanced detectors, and accelerator technologies needed to participate in a broad range of scientific and technical applications. The Nuclear Science Advisory Committee's (NSAC) long range plan points toward the mid- and longer-term priorities to accomplish the NP scientific program, recommending investments that will enable compelling research and assure U.S. leadership in nuclear science.

The priority investment for the Medium Energy subprogram is the completion of the 12 GeV CEBAF Upgrade project, which will double the energy of the CEBAF electron beam. The project includes construction of a new experimental hall to exploit the added capability and upgrades to current detectors and instrumentation. This major CEBAF Upgrade will provide the opportunity for new discoveries and a more complete understanding of the mechanism of quark confinement—one of the puzzles of modern physics. This project will position CEBAF to remain the international center for these studies for the next decade.

The focus of the Heavy Ion subprogram will be on implementing a second generation of experiments at RHIC with higher beam luminosity and greater detector sensitivities to fully characterize and understand the recently discovered new states of matter. A complementary effort will be pursued with the heavy ion program at the LHC, which will enable U.S. participation in studies of hot, dense nuclear matter in a higher energy regime. This community will be working with the medium energy community to develop the scientific case and technical feasibility for a possible future electron-ion collider.

Within the Low Energy subprogram the Nuclear Science Advisory Committee recommends construction of the next generation Facility for Rare Isotope Beams (FRIB) to advance the frontier of nuclei and nuclear astrophysics. The Low Energy subprogram is currently conducting R&D and conceptual design for FRIB. When it begins operations in about a decade, FRIB will provide a world-leading capability to explore the structure of the rarest of nuclei and address the nuclear reactions that power stars and stellar explosions. In the interim, the NP program is making investments in research capabilities that will allow U.S. researchers to participate in forefront rare isotope beam studies around the world in preparation for the FRIB program.

The NP program also supports U.S. participation in international neutrino experiments that use nuclear physics techniques. These experiments are focused on neutrino-less double beta decay studies to determine whether neutrinos are their own antiparticle and to provide information on the neutrino's mass. Ongoing efforts in this area include the Italian-led CUORE (Cryogenic Underground Observatory for Rare Events) project and the Majorana Demonstrator R&D project to determine the feasibility of a full scale Majorana experiment.

Concluding Remarks

Thank you, Mr. Chairman, for providing this opportunity to discuss the High Energy Physics and the Nuclear Physics research programs at the Department of Energy. This concludes my testimony, and I would be pleased to answer any questions you may have.

BIOGRAPHY FOR DENNIS KOVAR

Dr. Dennis Kovar has been serving as the Associate Director of Science for High Energy Physics since October 15, 2007. He served as the Associate Director of Science for Nuclear Physics (NP) from July 2003 until assuming his present responsibilities. In 2007 he also served as a co-Acting Deputy Director of the Office of Science. Dr. Kovar obtained his B.S. in Physics from the University of Texas in 1964 and his Ph.D. in Nuclear Physics from Yale University in 1971. He held a postdoctoral appointment at Lawrence Berkeley National Laboratory before joining the scientific staff at Argonne National Laboratory (ANL) in 1973.

He came to the Department of Energy from ANL in 1990 and served as Program Manager for Heavy Ion Nuclear Physics (1990–1998), Project Officer for RHIC (1996–1999) and Director of the Division of Nuclear Physics (1998–2003), prior to becoming the Associate Director of Science for Nuclear Physics. As an experimental nuclear physicist, he produced over 90 refereed articles, primarily in the area of low energy heavy ion nuclear reactions, nuclear structure and particle detection techniques and instrumentation. He is a fellow of the American Physical Society and the American Association for the Advancement of Science. Dr. Kovar was honored with the Presidential Rank Award for Meritorious Service in 2005 and the Presidential Rank Award for Distinguished Service in 2008.

Mr. LIPINSKI. Thank you, Dr. Kovar.

The Chair will now recognize Dr. Oddone.

STATEMENT OF DR. PIERMARIA J. ODDONE, DIRECTOR, FERMILAB NATIONAL ACCELERATOR LABORATORY

Dr. ODDONE. Thank you for inviting me to be a witness at this hearing.

Before I emphasize some of the points in my written testimony, I would like to start with a personal note. I grew up in Peru, far away from any ability to do any of this kind of research. In the 1950s the United States was the beacon for this type of research. Wonderful discoveries were being made. The frontier was being expanded. And I decided as a teenager I wanted to be a physicist and I went to my parents and I told them so. This was a very strange notion for them, and I must say they had the wisdom and probably the intestinal fortitude to actually send a 17-year-old on his own to the United States to study physics. And so I am here after five decades, participating, witnessing and contributing to the tremendous opportunities that have been made possible by the federal research in this basic field of science and I hope that you in the future will continue to support this as your predecessors have done.

Let me emphasize some points. The first one, as Lisa said, physics has never been as exciting as it is right now. We are closing in on the Higgs with both the Tevatron and soon with the Large Hadron Collider (LHC). We may discover supersymmetry that would pair each particle that we know about with another one with different properties of angular momentum but would, more importantly, expand our notion of space-time and how we see space-time and relativity. Physicists would be terribly disappointed if nature had not used this symmetry. It is so wonderful. By God, it should be used in nature. We are with neutrinos studying this very elusive particle with accelerators, with nuclear reactors, using neutrinos from the atmosphere, and these neutrinos may in fact explain why the world is made out of matter and not just a soup of photons that comes through the annihilation of matter and antimatter in equal parts.

When we study the cosmos, we have been able to tie the world of the very small and the very large in a way that the big structures in the universe we understand as the subatomic fluctuations at the very beginning of the universe. And further we study the cosmos and we realize that everything that we knew about it is about five percent of what is there. Dark energy and dark matter dominate the content of the universe.

The United States has been a leader in this field through its existence and that is the second point I want to emphasize, but that leadership is now in danger. The field has become global. We use facilities everywhere where we can do the physics. Europeans have come and used Fermilab for the last 10 years when they were building the Large Hadron Collider. We have 1,500 physicists working at the LHC now from the United States, and this balance of facilities and this world use of facilities that is so powerful in advancing the field depends on the balanced investment in the various regions. That has become at this point unbalanced and that is where the threat comes from. We have closed most facilities and in five years we will close the Tevatron in the United States, whereas other regions have built facilities that now give them an advantage in how they approach this field. Well, it is a problem, but it is a problem that has a solution.

The advisory panel through its Physics Project Prioritization Panel, or P5, has put together a powerful plan at the three frontiers, the three thrusts of particle physics: the energy frontier where we try to study the very small with the highest energy machines, the intensity frontier on which Fermilab will now concentrate that depends for its progress on producing the greatest numbers of particles. There we will study neutrinos, very rare processes, and the keystone of that program is a new facility at

Fermilab which we call, for the moment, Project X. It would be the most intense facility in the world, giving a beam of neutrinos to the DUSEL Laboratory funded by the NSF at the Homestake Mine in South Dakota. And the program as it is presently designed also opens the possibility for the return to the energy frontier that is now dominated by the Large Hadron Collider in Europe by developing accelerators and the technologies necessary, to make progress after the LHC.

Let me conclude. Maintaining leadership in this fundamental field is essential. It is essential because it asks the most fundamental questions. It is hard to imagine leadership in science for a country without really attacking these questions. It develops new technologies as it expands and moves the frontiers of the world as we know it. We are always pushing the envelopes of technology and this has led to computational and communication technologies. The Web is an example. The particle accelerators that we have developed are used in medicine, in industry, for modifying materials in homeland defense and security and so are the detectors that are very complex and that we have developed. Finally, it contributes to the education of a technical workforce both directly through international involvement—every major physics department is involved in particle physics—but also because it attracts young people to science. Those kinds of questions really, like it did for me, attract young people to science. They may do many things as they develop their interests, and people who enter this career are prepared to work in large disciplinary teams and make advances cooperatively across the world in this complex global environment. The United States must remain a beacon of science and a leader in particle research if it is going to derive the benefits in education in technological advances and in science in general. Thank you very much.

[The prepared statement of Dr. Oddone follows:]

PREPARED STATEMENT OF PIERMARIA J. ODDONE

The State of Particle Physics in Our Nation

Today I will describe the state of my field of research, high-energy particle physics. Before examining the major questions in particle physics, I would like to start with a personal note. I was born in Peru and grew up far away from any possibilities of doing this kind of research. In high school, reading about the amazing discoveries and pace of research in nuclear physics and beyond, I was attracted to physics and proposed to my parents that I become a physicist. This was, for them, a very strange notion. The beacon for the world in this kind of research at the time was the United States. My parents had the wisdom to ship me to the U.S. to study physics at MIT. Today I am honored to come before you after nearly five decades of witnessing, participating in and benefiting from the fantastic research opportunities in our country that have been made possible by federal support of discovery science in particle physics.

Particle physics has never been more exciting. Experiments at the Tevatron collider at Fermilab and soon at the Large Hadron Collider at the European particle physics laboratory CERN are closing in on the elusive particle—the Higgs boson—that we believe endows elementary particles with their mass. But in addition we may find something even more astonishing: that for every particle known today, a new and previously unseen twin exists, heavier and spinning in a different way. This discovery would herald a new understanding of space-time and the Theory of Relativity. Furthermore, several generations of experiments using accelerators, reactors, the sun and cosmic rays are advancing our understanding of neutrinos, elusive particles that, together with their heavy counterparts yet to be discovered, may be responsible for the matter in our universe.

In the last five decades we have moved from a complete lack of understanding of the bewildering variety of newly discovered particles to a remarkable understanding of how all of these hundreds of particles fit together in a simple and beautiful framework. This modestly named "Standard Model" has produced a transformation of how we think of the universe: how it began and our place within it. This remarkable intellectual achievement is the result of a powerful interplay between theorists and the experimental physicists and engineers that have built some of the most technologically advanced facilities ever created. The Standard Model has only four fundamental forces and only a few elementary constituents, namely, six quarks and six leptons. At the same time that we have made discoveries that confirm this simple conceptual paradigm, we are discovering a growing number of profound mysteries that cannot be resolved within it. One can say that our progress has been as great in expanding what we know as in expanding our awareness of a vast landscape we know nothing about.

As we have advanced in our understanding of particle physics, we have discovered the deep connection between the world of the very small that we study with accelerators and the world of the very large that we observe in the cosmos. The largest objects in the universe, galaxies and cluster of galaxies, originated in the subatomic quantum fluctuations in the earliest moments of the universe. Many of the mysteries that confront us, such as the discovery of dark matter and dark energy as primary components of our universe, or the nature of neutrinos and their transformations, cannot be explained within our current understanding of particles and forces, and yet such explanations must exist. This tension between what we have observed and what we can explain is driving theorists to develop many alternative frameworks to account for these phenomena. A great expansion of our experimental horizons will soon take place with the start of the Large Hadron Collider (LHC) in Geneva, Switzerland. The LHC promises an extraordinarily exciting and productive period in the world of science as these theories confront experimental reality and we make new discoveries, perhaps beyond anything so far imagined.

The extreme technical demands of particle physics experiments lead to inventions of unanticipated utility. Many innovations have come out of the development of accelerators, fast computational techniques, data mining and processing and particle detector technologies as described more extensively in Appendix 3. These innovations benefit society and the economy, such as

1) nuclear medicine and the use of isotopes for treatment and for metabolic studies;
2) the use of accelerators in proton and neutron cancer therapies;
3) the development of light sources and neutron sources to advance many fields of science, including materials science, atomic and molecular science, chemical sciences, nanosciences and biosciences;
4) industrial accelerators to sterilize food, modify materials, or inspect components;
5) radiation detectors used in scanning applications for medical diagnosis;
6) radiation detectors for national security and other detection purposes;
7) development of advanced computer technology, spurred by early application of computers for particle physics data-taking, pattern recognition and analysis on a massive scale;
8) new massive computer architectures, inspired by the boundless needs for computational power for quantum chromodynamics calculations;
9) advance of the greatest distributed computing systems in the world, grid computing, launched by the need for computational resources to mine and model data;
10) perhaps the best known example of an application of particle physics technology, the creation of the World Wide Web at CERN, the European particle physics laboratory. Impelled by the need for communications across continents on many different platforms, U.S. particle physics laboratories quickly followed—and so did the world;
11) Future applications of accelerator technologies: safer sub-critical nuclear reactors, transmutation of nuclear waste; bench top accelerators for material, chemical and biological research.

Research in particle physics plays an important role in science, technology, engineering and mathematics (STEM) education. Making discoveries about the world around us has excited humankind for centuries. The real possibility of understanding matter, energy, space and the evolution and fate of the universe generates excitement around the globe; it is a strong driver of scientific exploration, and it attracts young people to science. For those who choose to pursue particle physics, our discipline prepares students not only for careers in particle physics but for any career in which large, multidisciplinary teams tackle complex scientific and technological problems. Federal support of particle physics research has trained thousands of scientists. At my institution, Fermilab, alone, more than 1,700 young scientists have received their Ph.D.s in the last three decades.

The field has become progressively more international, demanding new forms of cooperation between the world agencies that support science. As more countries have invested in particle physics research the scientific collaborations to build accelerators and large detector facilities can typically involve dozens of countries and more than a hundred institutions. Coordination on a global scale is now common and will become more so in the future. The U.S. position in this global context of scientific cooperation and diplomacy is changing. We have been very much at the leading edge, attracting large investment from global partners to the U.S. For example, the groups operating the CDF and DZERO detectors in the Tevatron, Fermilab's proton-antiproton particle collider, each have hundreds of physicists. About 40 percent of these physicists hail from dozens of countries beyond our shores, bringing their resources and knowledge to the U.S. Similarly, nearly half of the support for BaBar, the detector in the Asymmetric B–Factory at SLAC, came from Europe. In a reversal of flow, today nearly 1,500 physicists from the U.S. participate in LHC experiments in Europe, roughly 25 percent of all users of that facility.

The free international sharing of facilities that has characterized our field has long been dependent on a balance of investments by various countries and regions over time, primarily by Europe and the U.S. but also with significant investments by Japan and China. Today, however, there is a growing imbalance that should raise grave concern. While the U.S. has either been the leader in particle physics research or shared leadership with Europe, that leadership is about to pass wholly to Europe with the start-up of the LHC. Europe's annual investment in particle physics is at least twice as large as that in the U.S. The capital value of their facilities will exceed that of the U.S. by an order of magnitude when the Tevatron shuts down. Nearly all major U.S. facilities, the Asymmetric B–Factory at SLAC, the Tevatron at Fermilab, the CESR collider at Cornell and the AGS at Brookhaven have either been shut down for particle physics research or will be shut down within two years. The last upgrade to a particle physics accelerator facility in the U.S. was the construction of the Main Injector at Fermilab, completed ten years ago, in 1999. It will be the one remaining facility devoted to particle physics in the U.S. once the Tevatron shuts down, and it will have strong competition from an advanced new facility starting in Japan at JPARC.

The future for discovery science in particle physics in the U.S. will depend critically on following a clear scientific roadmap that establishes pioneering research facilities to replace our aging facilities. Last year the High Energy Physics Advisory Committee, or HEPAP, developed a comprehensive plan for the field. This plan can be funded within the resources anticipated for the Office of Science during the next decade. It contains a set of balanced investments in the three great lines of inquiry of particle physics, all of them driving toward a unified understanding of nature:

1) The *Energy Frontier*, where we directly produce new particles and explore new phenomena;
2) The *Intensity Frontier*, where neutrinos and rare particle processes tell us indirectly about new phenomena at energies even beyond the LHC; and
3) The *Cosmic Frontier*, where we study natural phenomena arising from the early universe that ultimately will connect to our understanding of particles and forces.

The executive summary of this HEPAP plan "U.S. Particle Physics: Scientific Opportunities" is included in this testimony as Appendix 2. Support for the HEPAP plan at the three frontiers is essential for a vigorous world-leading program in particle physics. And a vigorous and healthy program in this fundamental field of science is essential for us as a nation to derive the practical benefits that come from pushing the boundaries of science and technology, to provide a beacon for scientists and students from the U.S. and the world and to continue as the leader in discovery science.

Appendix 1

The Major Questions in Particle Physics

Appendix 2

"U.S. Particle Physics: Scientific Opportunities"

Chapter 1: Executive Summary

Appendix 3

"U.S. Particle Physics: Scientific Opportunities"

Chapter 2: Particle Physics in the National and International Context

2.1 Long-Term Value of Research in Fundamental Sciences

2.2 Benefits to Society

2.3 The International Context

Appendix 1

The Major Questions in Particle Physics

The Standard Model Framework has transformed the way we look at the world around us. It encompasses the forces and particles that we are familiar with, from nuclei to atoms to chemistry to biology. We used to think this was what the world is made of. Today, we know better: it is only some five percent of the matter and energy in the universe. The vast majority of the universe is dark matter and dark energy, still totally mysterious and detected only through their gravitational effects on the cosmos. Observations in space, deep underground and, most powerfully, in experiments at particle accelerators will ultimately reveal the particles and forces that underlie dark matter and dark energy.

Profound question such as these arise when we confront the Standard Model with observations of the universe around us and fail to find an answer within it. It is clearly an incomplete framework that must be radically expanded to bring a unified understanding of nature.

Some of the questions that arise when we confront the Standard Model with cosmological observations are:

- What is the nature of dark matter? Is it a simple particle or a complex set of particles and interactions?
- What is the nature of dark energy?
- Why is the universe we see made out of matter and not equal parts of matter and anti-matter as the Standard Model would have it? Do neutrinos provide the answer?
- What new forces acted at the Big Bang to produce the distribution of matter we see today?
- How will the universe evolve and what is its end-point?

Other profound questions arise when we join the Standard Model with gravitation:

- Do all forces unify in a single framework?
- Are there extra dimensions of space?
- Are there hidden sectors not yet observed because they are too massive or because they interact weakly with our world?

Further questions arise from the Standard Model itself:

- What mechanism endows elementary particles, those without any internal structure, with mass?
- Does the Higgs particle that theoretically endows elementary particles with mass actually exist?
- What is the nature of neutrinos and what do their tiny masses and transformations tell us?
- Do heavy neutrinos exist in the early universe and explain how matter came to dominate?
- Why are there three families of similar elementary particles and not some other number: two or four or more?
- Why is there such a vast difference in the masses of the quarks, a factor greater than 10,000, from the quarks that make up the proton to the top quark?
- Why are the neutrino masses so light, a million times smaller than the electron mass?

These questions sound almost theological. It is a feature of the remarkable age of experimentation and discovery we live in that we can expect to answer many of them in the next few decades.

Further Reading:

1) National Academy of Sciences Report “ Connecting Quarks to the Cosmos: Eleven Science Questions for the New Century”, (*http://www.nap.edu/openbook.php?isbn=0309074061*)

2) National Academy of Sciences Report “ Revealing the Hidden Nature of Space and Time: Charting a Course for Elementary Particle Physics” (*http://www.nap.edu/catalog/11641.html*)

Appendix 2

A U.S. Roadmap for Particle Physics

The field is currently progressing along the roadmap of the Particle Physics Project Prioritization Panel whose May, 2008 report was recommended by the High Energy Advisory Committee and serves as a guide: "US Particle Physics Opportunities: A Strategic Plan for the Next Ten Years" (*http://www.er.doe.gov/hep/files/pdfs/P5—Report%2006022008.pdf*). The Panel was convened at the request of the DOE and the NSF to produce a realistic plan for particle physics under several budget scenarios. This plan proposes to develop the three frontiers of particle physics in a balanced way and has replaced the previous DOE strategy that was aimed at hosting the International Linear Collider early in the next decade. The reason for the changed strategy was the large cost estimate for the International Linear Collider and the absence of new information on the required energy scale—something that only research at the LHC will provide. The cost estimate for the International Linear Collider was developed rigorously by the world particle physics community and it allowed our policy-makers to determine that such a plan could not be realized any time soon and that a new strategy was required for the health of the field in the U.S.

One important aspect of this plan is the need for cooperation in major projects across government agencies. The planned Joint Dark Energy Mission requires a strong partnership between the DOE and NASA. The development of the world-leading neutrino program in the U.S. with a new beam from Fermilab aimed at the Deep Underground Science and Engineering Laboratory at the Homestake mine, South Dakota, 1,300 km away, requires a strong partnership between the DOE and the NSF. While partnerships between NASA and DOE have been successful in the past such as in the case of the Fermi satellite, and partnerships between the DOE and NSF have been successful such as in the case of LHC, these new projects are much larger and will demand even closer collaboration.

In the section below I reproduce in its entirety the Executive Summary of the Particle Physics Project Prioritization Panel: "U.S. Particle Physics Opportunities: A Strategic Plan for the Next Ten Years".

1. EXECUTIVE SUMMARY

Particle physics is a central component of the physical sciences, focused on the fundamental nature of matter and energy, and of space and time. Discoveries in this field, often called high-energy physics, will change our basic understanding of nature. The Standard Model of particle physics provides a remarkably accurate description of elementary particles and their interactions. However, experiment and observation strongly point to a deeper and more fundamental theory that breakthroughs in the coming decade will begin to reveal.

To address the central questions in particle physics, researchers use a range of tools and techniques at three interrelated frontiers:

- The Energy Frontier, using high-energy colliders to discover new particles and directly probe the architecture of the fundamental forces.
- The Intensity Frontier, using intense particle beams to uncover properties of neutrinos and observe rare processes that will tell us about new physics beyond the Standard Model.
- The Cosmic Frontier, using underground experiments and telescopes, both ground and space based, to reveal the natures of dark matter and dark energy and using high-energy particles from space to probe new phenomena.

As described in the box on pages X–XX, these three frontiers form an interlocking framework that addresses fundamental questions about the laws of nature and the cosmos. These three approaches ask different questions and use different techniques, but they ultimately aim at the same transformational science.

The changing context

Recent reports, including the National Research Council's "Revealing the Hidden Nature of Space and Time" (the EPP2010 report) and earlier P5 reports, have discussed the outlook for the field of particle physics in the United States. The scientific priorities have not changed since those reports appeared, but the context for the scientific opportunities they describe has altered.

Particle physics in the United States is in transition. Two of the three high-energy physics colliders in the U.S. have now permanently ceased operation. The third, Fermilab's Tevatron, will turn off in the next few years. The energy frontier, defined for decades by Fermilab's Tevatron, will move to Europe when CERN's Large Hadron Collider begins operating. American high-energy physicists have played a leadership role in developing and building the LHC program, and they constitute a significant fraction of the LHC collaborations—the largest group from any single nation. About half of all U.S. experimental particle physicists participate in LHC experiments.

As this transition occurs, serious fiscal challenges change the landscape for U.S. particle physics. The large cost estimate for the International Linear Collider, a centerpiece of previous reports, has delayed plans for a possible construction start and has led the particle physics community to take a fresh look at the scientific opportunities in the decade ahead. The severe funding reduction in the Omnibus Bill of December 2007 stopped work on several projects and had damaging impacts on the entire field. The present P5 panel has developed a strategic plan that takes these new realities into account.

Overall recommendation

Particle physics explores the fundamental constituents of matter and energy and the forces that govern their interactions. Great scientific opportunities point to significant discoveries in particle physics in the decade ahead.

Research in particle physics has inspired generations of young people to engage with science, benefiting all branches of the physical sciences and strengthening the scientific workforce. To quote from the EPP2010 report:

> *"A strong role in particle physics is necessary if the United States is to sustain its leadership in science and technology over the long-term."*

The present P5 panel therefore makes the following overall recommendation:

> **The panel recommends that the U.S. maintain a leadership role in world-wide particle physics. The panel recommends a strong, integrated research program at the three frontiers of the field: the Energy Frontier, the Intensity Frontier and the Cosmic Frontier.**

The Energy Frontier

Experiments at energy-frontier accelerators will make major discoveries about particles and their interactions. They will address key questions about the physical nature of the universe: the origin of particle masses, the existence of new symmetries of nature, the existence of extra dimensions of space, and the nature of dark matter. Currently, the Tevatron at Fermilab is the highest-energy collider operating in the world.

> **The panel recommends continuing support for the Tevatron Collider program for the next one to two years, to exploit its potential for discoveries.**

In the near future, the Large Hadron Collider at CERN in Geneva, Switzerland will achieve much higher collision energies than those of any previous accelerator, to explore the energy range we call the Terascale. The LHC represents the culmination of more than two decades of international effort and investment, with major U.S. involvement. Experiments at the LHC are poised to make exciting discoveries that will change our fundamental understanding of nature. Significant U.S. participation in the full exploitation of the LHC has the highest priority in the U.S. high-energy physics program.

> **The panel recommends support for the U.S. LHC program, including U.S. involvement in the planned detector and accelerator upgrades.**

The international particle physics community has reached consensus that a full understanding of the physics of the Terascale will require a lepton collider as well as the LHC. The panel reiterates the importance of such a collider. In the next few years, results from the LHC will establish its required energy. If the optimum initial energy proves to be at or below approximately 500 GeV, then the International Linear Collider is the most mature and ready-to-build option with a construction start possible in the next decade. A requirement for initial energy much higher than 500 GeV will mean considering other collider technologies. The cost and scale of a lepton collider mean that it would be an international project, with the cost shared by many nations. International negotiations will determine the siting; the host will be assured of scientific leadership at the energy frontier. Whatever the technology of a future lepton collider, and wherever it is located, the U.S. should plan to play a major role.

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For the next few years, the U.S. should continue to participate in the international R&D program for the ILC to position the U.S. for an important role should the ILC be the choice of the international community. The U.S. should also participate in coordinated R&D for the alternative accelerator technologies that a lepton collider of higher energy would require.

The panel recommends for the near future a broad accelerator and detector R&D program for lepton colliders that includes continued R&D on ILC at roughly the proposed FY 2009 level in support of the international effort. This will allow a significant role for the U.S. in the ILC wherever it is built. The panel also recommends R&D for alternative accelerator technologies, to permit an informed choice when the lepton collider energy is established.

The Intensity Frontier

Recent striking discoveries make the study of the properties of neutrinos a vitally important area of research. Measurements of the properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for the evolution of the universe. The latest developments in accelerator and detector technology make possible promising new scientific opportunities in neutrino science as well as in experiments to measure rare processes. The U.S. can build on the unique capabilities and infrastructure at Fermilab, together with DUSEL, the Deep Underground Science and Engineering Laboratory proposed for the Homestake Mine in South Dakota, to develop a world-leading program of neutrino science. Such a program will require a multi-megawatt-powered neutrino source at Fermilab.

The panel recommends a world-class neutrino program as a core component of the U.S. program, with the long-term vision of a large detector in the proposed DUSEL and a high-intensity neutrino source at Fermilab.

The panel recommends an R&D program in the immediate future to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D on the technologies for a large multi-purpose neutrino and proton decay detector.

Construction of these facilities could start within the 10-year period considered by this report.

A neutrino program with a multi-megawatt proton source would be a stepping stone toward a future neutrino source, such as a neutrino factory based on a muon storage ring, if the science eventually requires a more powerful neutrino source. This in turn could position the U.S. program to develop a muon collider as a long-term means to return to the energy frontier in the U.S.

The proposed DUSEL is key to the vision for the neutrino program. It is also central to non-accelerator experiments searching for dark matter, proton decay and neutrino-less double beta decay. DOE and NSF should define clearly the stewardship responsibilities for such a program.

The panel endorses the importance of a deep underground laboratory to particle physics and urges NSF to make this facility a reality as rapidly as possible. Furthermore the panel recommends that DOE and NSF work together to realize the experimental particle physics program at DUSEL.

Scientific opportunities through the measurement of rare processes include experiments to search for muon-to-electron conversion and rare-kaon and *B*-meson decay. Such incisive experiments, complementary to experiments at the LHC, would probe the Terascale and possibly much higher energies.

The panel recommends funding for measurements of rare processes to an extent depending on the funding levels available, as discussed in more detail in Sections 3.2.2 and 7.2.3.

The Cosmic Frontier

Although 95 percent of the universe appears to consist of dark matter and dark energy, we know little about either of them. The quest to elucidate the nature of dark matter and dark energy is at the heart of particle physics—the study of the basic constituents of nature, their properties and interactions.

The U.S. is presently a leader in the exploration of the Cosmic Frontier. Compelling opportunities exist for dark matter search experiments, and for both ground-based and space-based dark energy investigations. In addition, two other cosmic frontier areas offer important scientific opportunities: the study of high-energy particles from space and the cosmic microwave background.

The panel recommends support for the study of dark matter and dark energy as an integral part of the U.S. particle physics program.

The panel recommends that DOE support the space-based Joint Dark Energy Mission, in collaboration with NASA, at an appropriate level negotiated with NASA.

The panel recommends DOE support for the ground-based Large Synoptic Survey Telescope program in coordination with NSF at a level that depends on the overall program budget.

The panel further recommends joint NSF and DOE support for direct dark matter search experiments.

The panel recommends limited R&D funding for other particle astrophysics projects and recommends establishing a Particle Astrophysics Science Advisory Group.

Enabling technologies

The U.S. must continue to make advances in accelerator and detector R&D to maintain leadership at the Intensity and Cosmic Frontiers of particle physics; to allow for a return to the Energy Frontier in the U.S.; and to develop applications for the benefit of society.

The panel recommends a broad strategic program in accelerator R&D, including work on ILC technologies, superconducting rf, high-gradient normal-conducting accelerators, neutrino factories and muon colliders, plasma and laser acceleration, and other enabling technologies, along with support of basic accelerator science.

The panel recommends support for a program of detector R&D on technologies strategically chosen to enable future experiments to advance the field, as an essential part of the program.

Benefits to society

The drive to understand the world around us is a basic part of our humanity. Research in fundamental science provides the ideas and discoveries that form the long-term foundation for science and technology as a whole, which in turn drive the global economy and our very way of life. Each generation of particle accelerators and detectors builds on the previous one, raising the potential for discovery and pushing the level of technology ever higher. From the earliest days of high energy physics in the 1930s to the latest 21st century initiatives, the bold and innovative ideas and technologies of particle physics have entered the mainstream of society to transform the way we live. Section 2 addresses these benefits in more detail.

Unique to particle physics is the scale of the science: the size and complexity not only of accelerators and detectors but also of scientific collaborations. For example, superconducting magnets existed before Fermilab's Tevatron accelerator, but the scale of the accelerator made the production of such magnets an industrial process, which led to cost-effective technology for magnetic resonance imaging. The World Wide Web was invented to solve the problem of communicating in international collaborations of many hundreds of physicists. The scale on which particle physicists work results in innovations that broadly benefit society.

Particle physics has a profound influence on the workforce. The majority of students trained in particle physics find their way to diverse sectors of the national economy such as national defense, information technology, medical instrumentation, electronics, communications, transportation, biophysics and finance—wherever the workforce requires highly developed analytical and technical skills, the ability to work in large teams on complex projects, and the ability to think creatively to solve unique problems.

The international context

The scientific opportunities provided by particle physics bring together scientists from every corner of the globe to work together on experiments and projects all over the world. Both the technical scale and the costs of today's largest accelerators and experiments put them beyond the reach of any single nation's ability to build or operate. Particle physics projects now take shape as international endeavors from their inception. As the costs and scale of particle physics facilities grow, international collaboration becomes increasingly important to the vitality of the field. Global cooperation, a hallmark of particle physics research, will be even more important in the future.

The Large Hadron Collider accelerator and detector system, for example, drew from innovation and expertise in Europe, the Americas and Asia to deliver the cutting-edge technology required for this next-generation collider program. The proposed LHC upgrades will likewise have continuing and very significant contributions from these regions. The successful programs at the KEK and SLAC *B* factories and at the Tevatron provide additional examples of the benefits of international collaboration. These scientific collaborations take on new significance as beacons for free and open exchange among men and women of science of all nations. They offer an inspiring model for cooperation from a field long known for its leadership in international collaboration.

As particle physics moves into the future, the balance of the physical location of the major facilities among the regions of the world will be key to maintaining the vitality of the field in each region and as a whole. In developing a strategic plan for U.S. particle physics, the P5 panel kept the international context very much in mind.

The funding scenarios

The funding agencies asked the panel to develop plans in the context of several DOE funding scenarios:

A. Constant level of effort at the FY 2008 funding level
B. Constant level of effort at the FY 2007 funding level
C. Doubling of budget over ten years starting in FY 2007
D. Additional funding above the previous level, associated with specific activities needed to mount a leadership program.

The FY 2007 DOE funding level was $752M; the FY 2008 level was $688M. Constant level of effort here means that the budget increases with inflation in then-year dollars. The panel also received guidance on NSF budget assumptions. Interagency collaboration on particle physics experiments has become increasingly important. The plan presented in this report depends on such collaborative funding among DOE, NSF and NASA.

The panel evaluated the scientific opportunities for particle physics in the next 10 years under the various budget scenarios.

Scenario B: Constant level of effort at the FY 2007 level

The scenario of constant level of effort at the FY 2007 level, Scenario B, would support major advances at all three interrelated frontiers of particle physics. At the Energy Frontier, the Fermilab Tevatron would run in 2009, but the planned run in 2010 to complete the program could not take place due to budgetary constraints. The LHC experiments would be well under way. These experiments will likely make significant discoveries that could change our fundamental understanding of nature. R&D would go forward on future lepton colliders. At the Intensity Frontier, the MINOS, Double Chooz, Daya Bay and NOvA experiments would yield a greatly improved—if not complete—understanding of the fundamental properties of neutrinos. Precision measurements, limited to a muon-to-electron conversion experiment, would be carried out and the U.S. would participate in one offshore next-generation B Factory. On the Cosmic Frontier, greatly improved measurements shedding light on the nature of dark energy would come from the DES, JDEM and LSST projects. The next generation of dark matter search experiments would reach orders-of-magnitude greater sensitivity to—perhaps even discover—particles that can explain dark matter.

Under Scenario B, the U.S. would play a leadership role at all three frontiers. Investments in accelerators and detectors at the LHC would enable U.S. scientists to play a leading role in the second generation of studies at the Energy Frontier. Investments in facility capabilities at the Intensity Frontier at Fermilab and DUSEL would allow the U.S. to be a world leader in neutrino physics in the following decade. Funding of the cutting edge experiments studying dark matter and dark energy would insure continued U.S. leadership at the Cosmic Frontier. Investments in a broad strategic accelerator R&D program would enable the U.S. to remain at the forefront of accelerator developments and technologies focused on the needs of the U.S. program at the Energy and Intensity Frontiers.

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Scenario A: Constant level of effort at the FY 2008 level

Budget Scenario A would significantly reduce the scientific opportunities at each of the three frontiers compared to Scenario B over the next 10 years. It would severely limit scientific opportunities at the Intensity Frontier during the next decade. Scenario A would require canceling planned experiments and delaying construction of new facilities. It would slow progress in understanding dark energy at the Cosmic Frontier and R&D toward future accelerator facilities at the Energy Frontier. It would cut the number of scientists, as well as graduate students and postdoctoral fellows. Scenario A would unduly delay projects, extending them over a longer period.

Scenario A would most profoundly limit studies at the Intensity Frontier, with a negative impact on both neutrino physics and high-sensitivity measurements. It would require cancellation of the NOvA neutrino experiment that is ready for construction. The MINERvA experiment could not run beyond FY 2010 due to lack of funds to operate the Fermilab accelerator complex. Consequently, a first look at the neutrino mass hierarchy would be unlikely during the next decade, and experimenters could not measure neutrino cross sections, including those important to future long-baseline neutrino oscillation experiments. The U.S. could not contribute significantly to the next-generation overseas *B* factories that will carry out unprecedented studies of matter-antimatter asymmetry and searches for new processes in the quark sector. Furthermore, this budget scenario would delay the construction of a high-intensity proton source at Fermilab by at least three to five years. This delay would in turn severely compromise the program of neutrino physics and of high-sensitivity searches for rare decays at the Intensity Frontier in the subsequent decade.

For dark-energy studies at the Cosmic Frontier, Budget Scenario A would delay DOE funding for the ground-based LSST telescope.

This budget scenario could not support the investment in new facilities for advanced accelerator R&D, important for future accelerators both at the energy frontier and for other sciences. As discussed above, it would also delay the construction of a high-intensity proton source, postponing the establishment of a foundation for energy frontier studies at a possible future muon collider.

Scenario A would require an additional reduction of approximately 10 percent beyond the FY 2008 cuts in the number of scientists over the 10-year period. It would lead to a significant drop in the number of graduate students and postdoctoral fellows. Scenario A's drought in R&D coupled with delays in facility construction imposed during this decade would limit scientific opportunities in the subsequent decade.

Overall, while this funding level could deliver significant science, there would be outstanding scientific opportunities that could not be pursued. It would sharply diminish the U.S. capability in particle physics from its present leadership role.

Scenario C: The doubling budget

Budget Scenario C would support a world-class program of scientific discovery at all three frontiers in the decade ahead. It would provide strong support for the development of future research capabilities and of the scientific work force. Programs could move forward at a more efficient pace, with reduced costs, more timely physics results and increased scientific impact.

At the Energy Frontier, this budget scenario would extend the discovery potential of the Fermilab Tevatron Collider by supporting operation in FY 2010. Budget scenario C would provide robust funding for exploitation of the LHC physics potential. It would increase operations funding for U.S. groups working in Europe on the LHC and provide the needed personnel support at both universities and national laboratories for LHC detector and machine upgrades.

Progress toward a future lepton collider is a very high priority of the field worldwide. Should results from the LHC show that the ILC is the lepton collider of choice, funding in this scenario would support R&D and enable the start of construction of an ILC abroad. If LHC results point to another lepton collider technology, its R&D would advance. Increased funding for muon collider R&D would lead to an earlier feasibility determination for a neutrino factory and perhaps a muon collider.

Scenario C would significantly advance the exploration of physics at the Intensity Frontier. Construction of a new high-intensity proton source at Fermilab, which would support both neutrino physics and precision searches for rare decays, would be complete. Scenario C would enable an earlier construction start than would Scenario B and would shorten the construction time. It would also advance the design and construction of a beamline to DUSEL and would reduce the overall cost and risk of both these projects. Efforts to develop the technology for large-scale liquid argon or water Cerenkov detectors for neutrino physics and proton decay would benefit greatly from increased funding, leading to an earlier construction start, shorter construction period and reduced risk for a large underground detector at DUSEL. Scenario C would enable the high-sensitivity neutrino experiment to operate during the decade, providing great sensitivity to matter-antimatter asymmetry in neutrinos. Scenario C would also enable new rare K-decay experiments highly sensitive to new physics.

At the Cosmic Frontier, Scenario C would advance the exploration of dark energy by enabling the timely completion of the two most sensitive detectors of dark energy, the JDEM space mission and the ground-based LSST telescope. Scenario C enables strategic, large-scale investments in exciting projects at the boundary between particle physics and astrophysics, the study of high-energy particles from space. Without these investments, the U.S. will likely lose leadership in this rapidly developing area.

Budget scenario C would provide needed additional funds to advance accelerator R&D and technology goals. These goals go well beyond preparation for possible participation in ILC. Accelerator goals for the field include advancing the development of key enabling technologies such as superconducting rf technology, high-field magnet technology, high-gradient warm rf accelerating structures, rf power sources, and advanced accelerator R&D, all of which could greatly benefit from increased funding.

Increased funding in Scenario C would allow a robust detector R&D program in the U.S. to prepare for future experiments at both the energy and intensity frontiers.

Budget Scenario C provides desperately needed resources to rebuild university and laboratory infrastructure that has eroded during lean funding years and would allow retention and hiring of needed laboratory and university technical staff. This budget scenario would provide additional support for university groups, further addressing the pressing needs enunciated in several recent reports, among them the National Academy's "*Rising Above the Gathering Storm*."

Scenario D: Additional funding

The following scientific opportunities would justify additional funding above the level of the funding scenarios discussed above.

A lepton collider will be essential for the in-depth understanding of new physics discovered at the LHC: the source of the masses of the elementary particles, new laws of nature, additional dimensions of space, the creation of dark matter in the laboratory, or something not yet imagined. Major participation by the U.S. in constructing such a facility would require additional funding beyond that available in the previous funding scenarios.

The study of dark energy is central to the field of particle physics. DOE is currently engaged with NASA in negotiations concerning the space-based Joint Dark Energy Mission. If the scale of JDEM requires significantly more funding than is currently being discussed, an increase in the budget beyond the previous funding scenarios would be justified.

The Three Frontiers of Particle Physics

What are the most basic building blocks of the universe? What are the forces that enable these elementary constituents to form all that we see around us? What unknown properties of these particles and forces drive the evolution of the universe from the Big Bang to its present state, with its complex structures that support life—including us? These are the questions that particle physics seeks to answer.

Particle physics has been very successful in creating a major synthesis, the Standard Model. At successive generations of particle accelerators in the US, Europe and Asia, physicists have used high-energy collisions to discover many new particles. By studying these particles they have uncovered both new principles of nature and many unsuspected features of the universe, resulting in a detailed and comprehensive picture of the workings of the universe.

Recently, however, revolutionary discoveries have shown that this Standard Model, while it represents a good approximation at the energies of existing accelerators, is incomplete. They strongly suggest that new physics discoveries beyond the Standard Model await us at the ultrahigh energies of the Terascale. The Large Hadron Collider will soon provide a first look at this uncharted territory of ultrahigh energy; a future lepton collider will elucidate the new phenomena with great precision.

A striking development in neutrino physics is the discovery that the three kinds of neutrinos, which in the Standard Model are massless and cannot change from one type to another, do in fact have tiny masses and can morph from one kind to another. This discovery has profound implications not only for the Standard Model but also for understanding the development of the early universe.

The accelerating expansion of the universe, yet another remarkable discovery, implies the existence of a mysterious entity, a dark energy that makes up almost three quarters of the energy-matter content of the universe, driving it apart at an ever-increasing rate. Dark Energy has interesting properties that could change our understanding of gravity.

Astrophysical observations have also revealed that about a quarter of the universe consists of an unknown form of matter called dark matter. No Standard Model particle can account for this strange ingredient of our universe. In the next decade, the combination of LHC results and dedicated dark-matter-search experiments promise to shed light on dark matter's true character.

All these discoveries make the field of particle physics richer and more exciting than at any time in history. New accelerator and detector technologies bring within reach discoveries that may transform our understanding of the physical nature of the universe.

A set of interrelated questions, articulated in several previous reports, defines the path ahead:

1. How do particles acquire mass? Does the Higgs boson exist, or are new laws of physics required? Are there extra dimensions of space?

2. What is the nature of new particles and new principles beyond the Standard Model?

3. What is the dark matter that makes up about one quarter of the contents of the universe?

4. What is the nature of the dark energy that makes up almost three quarters of the universe?

5. Do all the forces of nature become one at high energies? How does gravity fit in? Is there a quantum theory of gravity?

6. Why is the universe as we know it made of matter, with no antimatter present? What is the origin of this matter-antimatter asymmetry?

7. What are the masses and properties of neutrinos and what role did they play in the evolution of the universe? How are they connected to matter-antimatter asymmetry?

8. Is the building block of the stuff we are made of, the proton, unstable?

9. How did the universe form?

Physicists address these questions using a range of tools and techniques at three frontiers that together form an interlocking framework of scientific opportunity.

The Energy Frontier
Experiments at energy-frontier accelerators will make major discoveries leading to an ultimate understanding of particles and their interactions. Outstanding questions that present and future colliders will address include the origin of elementary particle masses, the possible existence of new symmetries of nature, the existence of extra dimensions of space, and the nature of dark matter. Experiments at the energy frontier, at the LHC and at a future lepton collider, will allow physicists to directly produce and study the particles that are the messengers of these new phenomena in the laboratory for the first time.

The Intensity Frontier
Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for the understanding of the evolution of the universe. The US program can build on the unique capabilities and infrastructure at Fermilab, together with the proposed deep underground laboratory at Homestake, to develop a world-leading program of neutrino science. Such a program, not possible at the large collider facilities, will require a multi-megawatt-powered proton source at Fermilab. Incisive experiments using muons, kaons or *B* mesons to measure rare processes can probe the Terascale and beyond.

The Cosmic Frontier
Ninety-five percent of the contents of the universe appears to consist of dark matter and dark energy, yet we know very little about them. To discover the nature of dark matter and dark energy will require a combination of experiments at particle accelerators with both ground- and space-based observations of astrophysical objects in the distant cosmos.

The three frontiers of research in particle physics form an interlocking framework that addresses fundamental questions about the laws of nature and the cosmos.

These three approaches ask different questions and use different techniques, but they are ultimately aimed at the same transformational science. Discoveries on one frontier will have much greater impact taken together with discoveries on the other frontiers. For example, the discovery of new particles at the energy frontier, combined with discoveries from the intensity frontier about neutrinos and rare processes, may explain the dominance of matter over antimatter. Synthesizing discoveries from all three frontiers creates the opportunity to understand the most intimate workings and origins of the physical universe.

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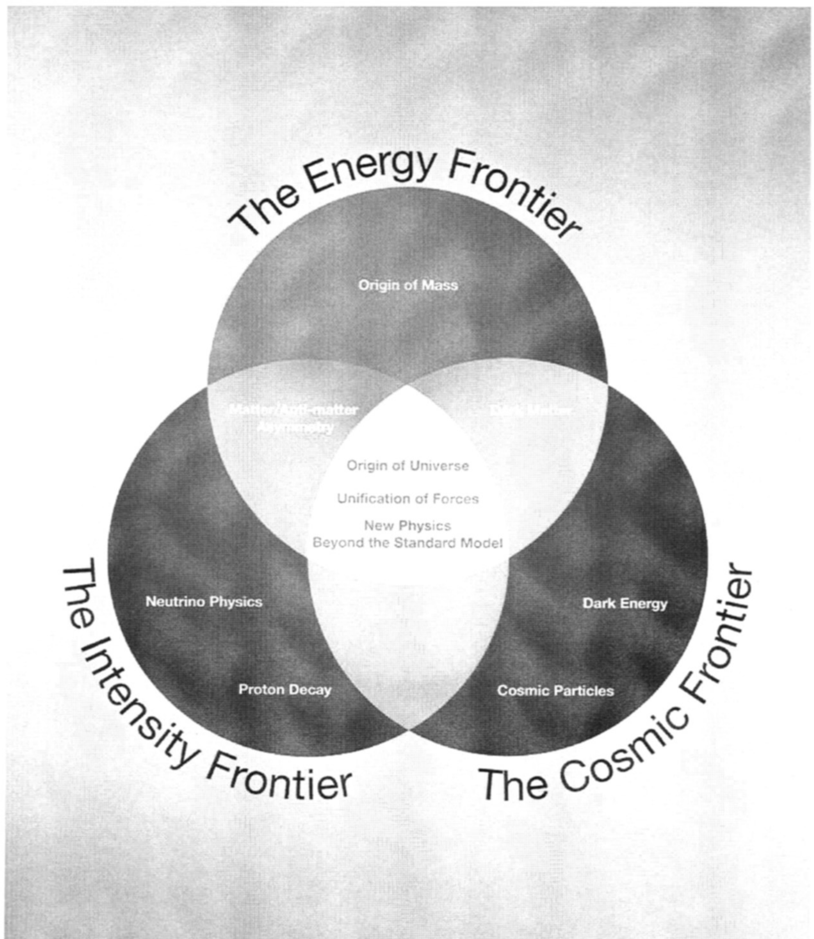

Three frontiers of research in particle physics form an interlocking framework that addresses fundamental questions about the laws of nature and the cosmos.

Appendix 3

Economic and Societal Benefits

Although the purpose of particle physics research is to gain knowledge about the world around us and is not directly focused on applications, much of the research requires the development of new techniques. Particle physics is also not directly focused on education, but it has great impact as it inspires the young to technical and scientific careers and trains students rigorously who work in the field. The field thus contributes broadly through applications and education to the economic benefit of the society.

The attraction of Fermilab to young students is remarkable. Either directly or indirectly through their teachers we have connections to more than 30,000 students and 2,000 teachers yearly in grades K through 12th. For many years we have hosted Saturday Morning Physics bringing students from the local high schools to Fermilab. Science fairs at the laboratory bring thousands of guests of all ages. Cosmic ray chambers at high schools allow students and their teachers to build a network to study extensive cosmic ray showers in the atmosphere.

Those students attracted to scientific careers will pursue advanced degrees in many of our research universities, all of which have strong particle physics groups that collaborate here and in Europe on forefront experiments. Fermilab has produced more than 1,700 Ph.D.s with nearly half coming from abroad. These students are trained technically and trained to work cooperatively with colleagues across the world. It is not unusual in particle physics collaborations to have colleagues from countries that are in conflict and at each other's throats working together to solve research problems at work or when breaking bread together.

Innovation has characterized particle physics. As technologies have found broad application, particle physicists cannot claim all the credit since as technologies evolve they advance in broad multi-disciplinary fronts with many contributors. It is possible however to trace the origin of technologies to the early applications that establish their foundations. On these foundations industry produces practical products and tools. A study of these applications was done in connection with the Particle Physics Prioritization Panel of the HEPAP advisory committee in 2008 and its conclusions are reproduced below.

2. PARTICLE PHYSICS IN THE NATIONAL AND INTERNATIONAL CONTEXT

2.1. LONG-TERM VALUE OF RESEARCH IN FUNDAMENTAL SCIENCES

The drive to understand the world around us is a basic part of our humanity. Research in fundamental science provides the ideas and discoveries that form the long-term foundation for science and technology as a whole, which in turn drive the global economy and our very way of life.

In 2005, a panel of nationally recognized experts from across the spectrum of science and society, chaired by Norman Augustine, retired Chairman and Chief Executive Officer Lockheed Martin Corporation, produced *"Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future."* To quote from the report:

> *"The growth of economies throughout the world has been driven largely by the pursuit of scientific understanding, the application of engineering solutions, and the continual technological innovation. Today, much of everyday life in the United States and other industrialized nations, as evidenced in transportation, communication, agriculture, education, health, defense, and jobs, is the product of investments in research and in the education of scientists and engineers. One need only think about how different our daily lives would be without the technological innovations of the last century or so."*

The *"Gathering Storm"* report makes the following recommendation:

> *"Sustain and strengthen the Nation's traditional commitment to long-term basic research that has the potential to be transformational to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life."*

The *"Gathering Storm"* report was influential in forging a bipartisan accord in Washington to strive toward global leadership in science for the U.S. by doubling the funding for research in the physical sciences over the next decade, among other actions.

Particle physics is a central component of the physical sciences, focused on the fundamental nature of matter and energy, and of space and time. Discoveries in particle physics will change our basic understanding of nature. Particle physics has inspired generations of young people to get involved with science, benefiting all branches of the physical sciences and strengthening the scientific workforce.

To quote from another National Academies report, "*Charting the Course for Elementary Particle Physics,*" the work of a panel including leaders from both science and industry and chaired by economist Harold Shapiro:

> "*A strong role in particle physics is necessary if the United States is to sustain its leadership in science and technology over the long-term.*"

That report continues:

> "*The committee affirms the intrinsic value of elementary particle physics as part of the broader scientific and technological enterprise and identifies it as a key priority within the physical sciences.*"

Besides its long-term scientific importance, particle physics generates technological innovations with profound benefits for the sciences and society as a whole.

2.2. BENEFITS TO SOCIETY

It's a simple idea. Take the smallest possible particles. Give them the highest possible energy. Smash them together. Watch what happens. From this simple idea have come the science and technology of particle physics, a deep understanding of the physical universe and countless benefits to society.

Each generation of particle accelerators and detectors builds on the previous one, raising the potential for discovery and pushing the level of technology ever higher. In 1930, Ernest O. Lawrence, the father of particle accelerators, built the first cyclotron at Berkeley, California. He could hold it in his hand. Larger and more powerful accelerators soon followed. After a day's work, Lawrence often operated the Berkeley cyclotrons through the night to produce medical isotopes for research and treatment. In 1938, Lawrence's mother became the first cancer patient to be treated successfully with particles from cyclotrons. Now doctors use particle beams for the diagnosis and healing of millions of patients. From the earliest days of high energy physics in the 1930s to the latest 21st century initiatives, the bold and innovative ideas and technologies of particle physics have entered the mainstream of society to transform the way we live.

Some applications of particle physics—the superconducting wire and cable at the heart of magnetic resonance imaging magnets, the World Wide Web—are so familiar they are almost clichés. But particle physics has myriad lesser-known impacts. Few outside the community of experts who study the behavior of fluids in motion have probably heard of the particle detector technology that revolutionized the study of fluid turbulence in fuel flow.

What is unique to particle physics is the scale of the science: the size and complexity not only of accelerators and detectors but also of scientific collaborations. For example, superconducting magnets existed before Fermilab's Tevatron, but the scale of the accelerator made the production of such magnets an industrial process, which led to cost-effective technology for magnetic resonance imaging. The World Wide Web was invented to solve the problem of communicating in an international collaboration of many hundreds of physicists. The scale on which particle physicists work results in innovations that broadly benefit society.

Selected examples from medicine, homeland security, industry, computing, science, and workforce development illustrate a long and growing list of beneficial practical applications with origins in particle physics.

Medicine: cancer therapy

The technologies of particle physics have yielded dramatic advances in cancer treatment. Today, every major medical center in the Nation uses accelerators producing X-rays, protons, neutrons or heavy ions for the diagnosis and treatment of disease. Particle accelerators play an integral role in the advance of cancer therapy. Medical linacs for cancer therapy were pioneered simultaneously at Stanford and in the UK in the 1950s using techniques that had been developed for high energy physics research. This R&D spawned a new industry and has saved millions of lives.

Today it is estimated that there are over 7,000 operating medical linacs around the world that have treated over 30,000,000 patients.

Fermilab physicists and engineers built the Nation's first proton accelerator for cancer therapy and shipped it to the Loma Linda University Medical Center, where it has treated some 7,000 patients. Relative to X-rays, proton therapy offers important therapeutic benefits, especially for pediatric patients. The Neutron Therapy Facility at Fermilab has the highest energy and the deepest penetration of any fast neutron beam in the United States. Neutrons are effective against large tumors. More than 3,500 patients have received treatment at the Neutron Therapy Facility.

Medicine: diagnostic instrumentation

Particle physics experiments use an array of experimental techniques for detecting particles; they find a wide range of practical applications. Particle detectors first developed for particle physics are now ubiquitous in medical imaging. Positron emission tomography, the technology of PET scans, came directly from detectors initially designed for particle physics experiments sensing individual photons of light. Silicon tracking detectors, composed of minute sensing elements sensitive to the passage of single particles, are now used in neuroscience experiments to investigate the workings of the retina for development of retinal prosthetics for artificial vision.

Homeland security: monitoring nuclear nonproliferation

In nuclear reactors, the amount of plutonium builds up as the uranium fuel is used, and the number and characteristics of anti-neutrinos emitted by plutonium differ significantly from those of anti-neutrinos emitted by uranium. This makes it possible for a specially doped liquid scintillator detector monitoring the anti-neutrino flux from a nuclear reactor core to analyze the content of the reactor and verify that no tampering has occurred with the reactor fuel. Lawrence Livermore National Laboratory has built and is testing a one-ton version of this type of detector, originally developed by high energy physicists to study the characteristics of neutrinos and anti-neutrinos, as a demonstration of a new monitoring technology for nuclear nonproliferation.

Industry: power transmission

Cables made of superconducting material can carry far more electricity than conventional cables with minimal power losses. Underground copper transmission lines or power cables are near their capacity in many densely populated areas, and superconducting cables offer an opportunity to meet continued need. Further superconducting technology advances in particle physics will help promote this nascent industry.

Industry: biomedicine and drug development

Biomedical scientists use particle physics technologies to decipher the structure of proteins, information that is key to understanding biological processes and healing disease. To determine a protein's structure, researchers direct the beam of light from an accelerator called a synchrotron through a protein crystal. The crystal scatters the beam onto a detector. From the scattering pattern, computers calculate the position of every atom in the protein molecule and create a 3–D image of the molecule. A clearer understanding of protein structure allows for the development of more effective drugs. Abbott Labs' research at Argonne National Laboratory's Advanced Photon Source was critical in developing Kaletra®, one of the world's most-prescribed drugs to fight AIDS. Next-generation light sources will offer still more precise studies of protein structure without the need for crystallization.

Industry: understanding turbulence

Turbulence is a challenge to all areas of fluid mechanics and engineering. Although it remains poorly understood and poorly modeled, it is a dominant factor determining the performance of virtually all fluid systems from long distance oil pipelines to fuel injection systems to models for global weather prediction. Improvements to our knowledge will have payoffs in reducing energy losses in fuel transport, improving efficiency of engines and deepening our understanding of global climate behavior. Technology developed for particle physics and applied to problems of turbulence has extended our understanding of this difficult phenomenon by more than tenfold. Silicon strip detectors and low-noise amplifiers developed for particle physics are used to detect light scattered from microscopic tracer particles in a turbulent fluid. This technique has permitted detailed studies of turbulence on microscopic scales and at Reynolds numbers more than an order of magnitude beyond any previous experimental reach.

Computing: the World Wide Web

CERN scientist Tim Berners-Lee developed the World Wide Web to give particle physicists a tool to communicate quickly and effectively with globally dispersed colleagues at universities and laboratories. The Stanford Linear Accelerator Center had the first web site in the United States, Fermilab had the second. Today there are more than 150 million registered web sites. Few other technological advances in history have more profoundly affected the global economy and societal interactions than the Web. Revenues from the World Wide Web exceeded one trillion dollars in 2001 with exponential growth continuing.

Computing: the Grid

Particle physics experiments generate unprecedented amounts of data that require new and advanced computing technology to analyze. To quickly process this data, more than two decades ago particle physicists pioneered the construction of low-cost computing farms, a group of servers housed in one location. Today, particle physics experiments push the capability of the Grid, the newest computing tool that allows physicists to manage and process their enormous amounts of data across the globe by combining the strength of hundreds of thousands of individual computers. Industries such as medicine and finance are examples of other fields that also generate large amounts of data and benefit from advanced computing technology.

Sciences: synchrotron light sources

Particle physicists originally built electron accelerators to explore the fundamental nature of matter. At first, they looked on the phenomenon of synchrotron radiation as a troublesome problem that sapped electrons' acceleration energy. However, they soon saw the potential to use this nuisance energy loss as a new and uniquely powerful tool to study biological molecules and other materials. In the 1970s, the Stanford Linear Accelerator Center built the first large-scale light source user facility. Now, at facilities around the world, researchers use the ultra-powerful X-ray beams of dedicated synchrotron light sources to create the brightest lights on Earth. These luminous sources provide tools for protein structure analysis, pharmaceutical research and drug development, real-time visualization of chemical reactions and biochemical processes, materials science, semiconductor circuit lithography, and historical research and the restoration of works of art.

Sciences: spallation neutron sources

Using accelerator technologies, spallation neutron sources produce powerful neutron beams by bombarding a mercury target with energetic protons from a large accelerator complex. The protons excite the mercury nuclei in a reaction process called spallation, releasing neutrons that are formed into beams and guided to neutron instruments. Using these sophisticated sources, scientists and engineers explore the most intimate structural details of a vast array of novel materials.

Sciences: analytic tools

Particle physicists have developed theoretical and experimental analytic tools and techniques that find applications in other scientific fields and in commerce. Renormalization group theory first developed to rigorously describe particle interactions has found applications in solid state physics and superconductivity. Nuclear physics uses chiral lagrangians, and string theory has contributed to the mathematics of topology. Experimental particle physicists have also made contributions through the development of tools for extracting weak signals from enormous backgrounds and for handling very large data sets. Scientists trained in particle physics have used neural networks in neuroscience to investigate the workings of the retina and in meteorology to measure raindrop sizes with optical sensors.

Workforce development: training scientists

Particle physics has a profound influence on the workforce. Basic science is a magnet that attracts inquisitive and capable students. In particle physics, roughly one sixth of those completing Ph.D.s ultimately pursue careers in basic high-energy physics research. The rest find their way to diverse sectors of the national economy such as industry, national defense, information technology, medical instrumentation, electronics, communications, biophysics and finance—wherever the workforce requires highly developed analytical and technical skills, the ability to work in large teams on complex projects, and the ability to think creatively to solve unique problems.

A growing list

The science and technology of particle physics have transformational applications for many other areas of benefit to the Nation's well-being.

- Food sterilization
- Medical isotope production
- Simulation of cancer treatments
- Reliability testing of nuclear weapons
- Scanning of shipping containers
- Proposed combination of PET and MRI imaging
- Improved sound quality in archival recordings
- Parallel computing
- Ion implantation for strengthening materials
- Curing of epoxies and plastics
- Data mining and simulation
- Nuclear waste transmutation
- Remote operation of complex facilities
- International relations

At this time there exist few quantitative analyses of the economic benefits of particle physics applications. A systematic professional study would have value for assessing and predicting the impact of particle physics technology applications on the Nation's economy.

2.3. THE INTERNATIONAL CONTEXT

The scientific opportunities provided by particle physics bring together hundreds of scientists from every corner of the globe to work together on experiments and projects all over the world. Both the technical scale and the costs of today's large accelerators put them beyond the reach of any single nation's ability to build or operate. Particle physics projects now take shape as international endeavors from their inception. These scientific collaborations take on new significance as beacons for free and open exchange among men and women of science of all nations. They offer an inspiring model for cooperation from a field long known for its leadership in international collaboration.

Collider experiments have had strong international collaboration from the outset. Experiments at CERN, Fermilab and SLAC combined the strengths of U.S., European and Asian groups to achieve the ground-breaking discoveries that define particle physics today. Accelerator design and construction is now a joint effort as well. American accelerator physicists and engineers helped the Europeans build the Large Hadron Collider at CERN and collaborated with the Chinese to build the Beijing Electron-Positron Collider. The GLAST project involves a seven-nation collaboration of France, Germany, Italy, Japan, Spain, Sweden and the U.S.

Japan is currently constructing a 50–GeV proton synchrotron at the Japan Proton Accelerator Research Complex. The JPARC synchrotron will produce an intense neutrino beam aimed at the large Super-Kamiokande detector to study neutrino oscillations and matter-antimatter asymmetry. This experiment has significant U.S. participation, as did its predecessors. U.S. physicists are also working on two overseas reactor neutrino experiments, Daya Bay in China and Double Chooz in France.

The KEK B–Factory and the Belle detector continue to operate, and plans are under way to significantly increase the collider's beam intensity to improve sensitivity to physics beyond the Standard Model. Modest U.S. participation continues in this collaboration. At lower energies, the new BEPC–II collider in China is about to start operation. A number of U.S. groups are working on its experimental program.

Cosmic Frontier experiments have also involved international collaboration, but on a smaller scale due to the hitherto modest size of the experiments. Here too, however, the magnitude of future experiments makes international collaboration essential.

Planning for the future of the field is also international. Both HEPAP and P5 have members from Europe and Asia, essential for understanding the current and future programs in those regions at all three scientific frontiers in particle physics.

The transformation occurring in the international scene has presented challenges to this panel. Free access for physicists of all nations to the world's accelerators rests on the assumption that each region takes its share of responsibility by building and operating such facilities. In recent decades, each region hosted major collider experiments and a variety of smaller experiments. But now, with the end of both the Cornell and SLAC collider programs and with the Fermilab Tevatron collider about to complete its program in the next few years, the map of the field is changing rapidly. Most of the accelerator-based experiments in the near-term will occur overseas. The panel has given careful consideration to how the changing international context will affect the ability of the U.S. to pursue most effectively the extraordinary scientific opportunities that lie ahead and to remain a world leader in the field of particle physics.

BIOGRAPHY FOR PIERMARIA J. ODDONE

Oddone was appointed Director of Fermi National Accelerator Laboratory in July, 2005. Fermilab, a U.S. Department of Energy Laboratory, is managed by Fermi Research Alliance (FRA), a partnership of the University of Chicago and the Universities Research Association (URA). Fermilab advances the understanding of matter, energy, space and time through the study of elementary particle physics. Fermilab provides cutting edge particle accelerators and detectors to qualified researchers to conduct basic research at the frontiers of particle physics and related disciplines. Fermilab also has a vital program in particle astrophysics and cosmology linking the physics of elementary particles to the evolution and fate of the Universe.

Oddone was previously Deputy Director of the Lawrence Berkeley National Laboratory, with primary responsibility for the scientific development of the laboratory and its representation to the agencies. Achievements during his tenure as Deputy Director include gaining the National Energy Super Computer Center (NERSC), launching and developing the Joint Genome Institute (JGI), breaking ground on the Molecular Foundry (the LBNL nanosciences center), establishing major new programs in quantitative biology, astrophysics and computer science and exploiting the Advanced Light Source (ALS).

Oddone's research has been in experimental particle physics and based primarily on electron-positron colliders at the Stanford Linear Accelerator Center (SLAC). He invented the Asymmetric B–Factory, a new kind of elementary particle collider to study the differences between matter and antimatter and worked in the development of the PEP II Asymmetric B–Factory at SLAC (a second one was built in Tsukuba, Japan) and the formation of the large international collaboration, BaBar, to exploit its physics opportunities. Together with the Belle detector in Japan, BaBar discovered the violation of matter-antimatter symmetry in the decay of particles containing the b quark. Hundreds of researchers have exploited the B–Factories over the last decade, developing a precise understanding of the quark model. Oddone received the 2005 Panofsky Award of the American Physical Society for the invention of the Asymmetric B–Factory. He is a Fellow of the American Physical Society. He was elected as Fellow of the American Academy of Arts & Sciences in 2008. He also is a member of the Executive Council of the National Laboratory Directors Council (NLDC).

Oddone was born in Arequipa, Peru, and is a U.S. citizen. After receiving his undergraduate degree from MIT, Oddone received his Ph.D. in Physics from Princeton University followed by a post-doctoral fellowship at Caltech. He joined the Lawrence Berkeley National Laboratory in 1972.

Mr. LIPINSKI. Thank you, Dr. Oddone.

Dr. Montgomery.

STATEMENT OF DR. HUGH E. MONTGOMERY, PRESIDENT, JEFFERSON SCIENCE ASSOCIATES, LLC; DIRECTOR, THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

Dr. MONTGOMERY. Thank you, Mr. Chairman, Ranking Member Inglis and Members of the Committee for the opportunity to appear before you. As you might notice, I have a slight accent. I have been an active researcher in Europe and in the United States for my entire professional career and I am currently Director of one of your great attractors, the Thomas Jefferson National Accelerator Facility, Jefferson Lab in Newport News. I am going to concentrate a little on the nuclear physics aspect of this hearing.

The hearing has a grand and beautiful title: *Investigating the Nature of Matter, Energy, Space and Time*. It could be argued that this has been the program since man stood on two legs. Indeed, for those of you who think that nuclear physics does not affect you, I point out that nuclear physicists study the building blocks that make up 99 percent of the mass of our everyday world. Since nuclear physics was born about a century ago, much has been learned and some of the fundamental structures of nuclei have been delineated, but much still remains a mystery. Now, while nuclear physics is a basic science, it is also important for the impacts it has on society, some of which I will mention later. Our field also creates a cadre of highly intellectual, highly educated individuals capable of addressing the problems facing our society.

Three research thrusts provide the framework that defines nuclear physics. Each of these thrusts offers the potential for discovery and each is a way to examine the universe and the nature of matter. The Continuous Electron Beam Accelerator Facility, CEBAF, at Jefferson Lab is the world leader in incisive studies of properties of the nucleon and the nuclei, distributions of the constituent quarks and gluons, their motion and their spin. A truly fascinating aspect of nature is that the masses of the protons and neutrons arise not from the masses of the quarks within them but rather from their interactions. This is Einstein's $E = mc^2$ at work. Complementary research is conducted at Brookhaven National Laboratory where the Relativistic Heavy Ion Collider (RHIC) compresses protons and neutrons in high energy collisions between gold nuclei. This actually melts the nuclei and the constituents, the quarks and gluons, form a liquid by a plasma that is believed to have existed in the first moments of the universe.

The study of the structure of complex nuclei also leads to an understanding of how stars and planets are formed from nucleo-synthesis. Reactors in different parts of the world are used by U.S. physicists to study ghost-like particles called neutrinos. The latter is an example from the branch of our field labeled fundamental symmetries.

Now, nuclear physics enjoys a relatively high profile, largely due to its role in nuclear weapons and nuclear energy. This only hints, however, at the potential that nuclear physics holds for society. Radiation imaging techniques developed for nuclear physics experiments at Jefferson Lab have led to inexpensive mobile devices that detect cancer early and save lives. Each year I and maybe one or two of you get a stress test using radioactive isotopes and positron-electron tomography to ensure that the blood flows through the right parts of my heart.

Nuclear physicists are essential not only in the university classroom. They also assume critical roles in society, in fields such as national defense and environmental research and in industry. These working scientists make essential contributions to the education of our citizens in this increasingly technological society.

Now, the United States continues to be the world leader in the construction and operation of large nuclear physics facilities. We are upgrading existing accelerators, for example, doubling the energy of CEBAF, and we will soon start construction of the Facility for Rare Isotope Beams at Michigan State University. Vigorous operation of these and other facilities, RHIC, for example, will underpin a superb science program for the next decade and more. And on the horizon, we are developing an Electron Ion Collider that will form a crucial cornerstone for the field in the subsequent decades.

In summary, nuclear physics is a key contributor to science and society. I believe it is an endeavor worthy of the support of the people of this country.

I would like to thank you again for this opportunity and will be happy to try to answer your questions. And if I could just use the "orange time" in my presentation, I would like to suggest that we read the panels behind you. It says on the left, "For I dipped into the future, far as human eyes could see, saw the vision of the world and all the wonder that that would be," and on the right it says, "Where there is no vision, the people perish." Thank you.

[The prepared statement of Dr. Montgomery follows:]

PREPARED STATEMENT OF HUGH E. MONTGOMERY

Thank you Mr. Chairman, Ranking Member Inglis, and Members of the Committee for the opportunity to appear before you to provide testimony on the question of *"Investigating the Nature of Matter, Energy, Space, and Time."* While I have only been Director of the Thomas Jefferson National Accelerator Facility, Jefferson Lab for the past year, I have been an active researcher in the field, here and in Europe, for my entire professional career. I am pleased to offer you my perspective on the subject with emphasis on that part covered by the programs of the Office of Nuclear Physics in the Office of Science of the Department of Energy.

This hearing has been given a grand and beautiful title, *"Investigating the Nature of Matter, Energy, Space, and Time."* It could be argued that this has been the program of mankind since man stood on two legs. For those who may think that nuclear physics does not affect you, I would point out that nuclear physicists study the building blocks that make up 99.9 percent of the mass of our everyday world. We seek not only a concise description of matter but also to describe the interactions between the building blocks of matter and the way that elements can exist.

About a century ago, Rutherford performed experiments which suggested strongly the existence of a nucleus within each atom. With those experiments nuclear physics was born. A major transition took place in the middle of the twentieth century with the development of accelerators, enabling us to probe and manipulate the nucleus. While much has been learned and some of the fundamental structure of nuclei has been delineated, much still remains a mystery. To achieve the goal of finding the building blocks of the universe, it is therefore imperative to continue this quest with the more powerful experimental techniques that become available with technological progress.

Nuclear physics is a basic science and in my testimony I will discuss aspects of that fundamental science, an historical perspective of the field, its accomplishments, and a look to the future. However, nuclear science is also important for the impacts it has on society. These impacts come not only from the fundamental understanding that results from our research but from the tools and technologies developed both from our evolving understanding of nuclei themselves and from the novel apparatus devised to obtain that understanding. They range from nuclear magnetic resonance imaging, to radioactive tracer tagging (used in biological research and cancer detection), to accelerators (used for applications as diverse as cancer treatment and semiconductor manufacturing, as well as for basic research in many fields), to nuclear power and nuclear weapons. The search for basic knowledge in nuclear physics also generates a cadre of highly-educated individuals, who often apply their training in nuclear physics to a broad range of problems faced by society.

Since a complete discussion of the subject of nuclear physics is beyond the scope of this testimony, I will rely on the testimonies of my colleagues in this hearing for some of the underpinning context for my remarks. For example, I believe that Dr. Kovar's testimony will include a complete sketch of the governance and support of nuclear physics within the United States. It is indeed important to recognize that both the Department of Energy Office of Science and the National Science Foundation provide support for research facilities and research physicists in this field.

There are three major components of the field of nuclear physics, which I will briefly summarize.

For the first seventy years of the last century, nuclear physicists developed a description of nuclei and their properties in terms of the then-known building blocks, protons and neutrons, and their interactions. In 1968, we discovered that the nucleons had constituents, which we dubbed *quarks* and we invented *gluons* to bind them together and developed a theory, which we named *quantum chromodynamics,* to describe their interactions. A truly fascinating aspect of nature, at this extraordinarily small distance scale, is that the masses of the protons and neutrons arise not from the masses of the quarks, but rather from the gluons, which carry their interactions. It is interesting to speculate on the consequences of this for the technology of the next fifty years.

The Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Facility, Jefferson Lab, has become the world leader in incisive studies of properties of the nucleon and the nuclei associated with the distributions of quarks and gluons, their motion and their spin. The accelerator was built a little more than a decade ago using an innovative, superconducting radio frequency, acceleration technique. The current experimental program, with six billion (or giga)-electron-volt (six GeV) beam energy and with exquisite control of the electron spin, has opened new windows on the distributions not only of quarks and gluons, but also of their spin. We are now in the midst of an upgrade project to raise the energy to 12 GeV in order to extend this knowledge. The additional energy will also allow us to search directly for configurations where the glue plays a predominant role, as predicted by the theory but not yet seen. This work has the potential to tell us why we have never yet seen an isolated quark or gluon.

Complementary research at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory compresses protons and neutrons in high energy collisions between gold nuclei. This raises the temperature of the nuclear matter to many thousands of times that of the sun. The nuclei then melt, forming a quark-gluon liquid much as ice melts into water. This liquid, which exhibits spectacular properties, is believed to have existed in the first moments of existence of the universe.

The structure of complex nuclei continues to be a challenging subject with new frontiers to be explored. The conventional view of a nucleus is that it is built up of protons and neutrons. We label the element using the number of the protons. That is the property which distinguishes lead from gold, or helium from hydrogen. The numbers of neutrons are also important and it is their presence that changes hydrogen into deuterium and tritium, or Uranium-235 (the component which makes a nuclear fuel "enriched") into Uranium-238. Our interest today is in manipulating these building blocks of our universe by working with rare isotopes and radioactive beams to find the maximum numbers of protons or neutrons that we can insert into a given nucleus. These studies lead to the understanding of processes like nucleosynthesis, the physics that underlies the existence of the stars and the planets and the relative abundance of their constituent elements. Work is just underway to build a major new facility in the U.S., the Facility for Rare Isotope Beams at Michigan State University, to help address these questions. At Jefferson Lab, a planned experiment to measure the radius of the neutrons in lead will provide input to understanding neutron stars.

In some radioactive decays of nuclei, in particular in β decay, neutrinos are produced. The study of these ghost-like particles has historically been a very important component of nuclear physics. Recently there was some beautiful work employing nuclear reactors such as the KamLand experiment, executed in Japan. The Daya Bay neutrino oscillation experiment is under construction in China, enabled by funding support for U.S. physicists in international collaborations. These are examples from the third branch of our field, which is often labeled as "fundamental symmetries."

Together these three research thrusts (quantum chromodynamics, nuclear structure and astrophysics, and fundamental symmetries), while always shifting, are the framework within which nuclear physics has defined itself. Each of the directions offers the possibility of discovery; each is a way to examine the universe and its building blocks. I have emphasized the experimental thrusts within the field, but to realize a description also requires a theory. Quantum chromodynamics is rich enough to potentially describe not only the quarks and gluons and their interactions, but also the nucleons and hadrons and their interactions. But executing the calculations is a challenge. Nuclear physics theorists have helped to design dedicated computer chips, have helped to connect desktop computers in innovative ways, and are now turning to the graphics engines to supplement the traditional supercomputer resources they need for their work.

Of all the sciences, nuclear physics enjoys a relatively high profile due to the prominence of nuclear weapons in the story of the second half of the twentieth century as well as the use of nuclear fission for nuclear power. Just across the James River from us in Surry, Virginia are two nuclear reactors, which supply electricity that is clean and reliable. If we can manage the surrounding political issues, nuclear power could play a major role in providing energy for the human race. Since the discovery of radioactivity, the use of nuclear properties for medical treatment has become part of our everyday life. Within the past ten years, the radiation imaging techniques, developed for nuclear physics experiments at Jefferson Lab, have led to the development of fresh approaches to mammography and the deployment of inexpensive, mobile commercial devices that detect cancers earlier and save lives. Each year I, and perhaps others among you, get a stress test that uses radioactive isotopes and positron electron tomography to check that my blood is flowing to the right parts of my heart. The production of these isotopes is another important byproduct of the nuclear physics research we do. Nuclear physicists are essential not only in the university classroom. They assume critical roles in society, in fields such as nuclear energy and nuclear medicine and in industry more generally, a fact demonstrated in detail by the Cerny report.

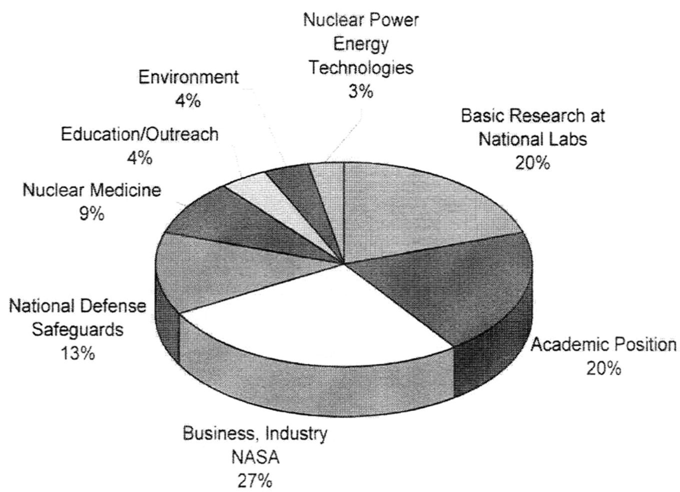

Figure 1: Survey of Nuclear Physics graduates 5-10 year past doctorate from NSAC Education in Nuclear Science Report (November 2004)

In addition, the contributions of working scientists to the education of the citizens of our increasingly technological society are not only desirable but essential.

Nuclear physics depends on large facilities, and the United States continues to be a world leader in the construction and operation of these facilities. These include the devices at the National Superconducting Cyclotron Laboratory at Michigan State University, CEBAF at Jefferson Lab, and the Relativistic Heavy Ion Collider at Brookhaven. (This list is not exclusive, and U.S. nuclear physicists also work at other facilities located at laboratories and universities across the globe.) We are upgrading the existing accelerators, for example taking CEBAF to 12 GeV, and will soon start construction of the Facility for Rare Isotope Beams at NSCL. Vigorous operation of these and other facilities will underpin a superb science program for the next decade and more. What we see on the horizon, as was indicated in the 2007 long range plan for the field, is an Electron Ion Collider. This could be thought of as a higher energy version of the functionality currently provided by CEBAF at Jefferson Lab. The discussions of the physics case and of some design concepts are currently under way. We are looking to converge on the choice of the site in a few years and expect to set a goal of construction towards the end of the next decade. This would take our search for, and understanding of, the building blocks of the universe to the next stage from the nuclear physics point of view. It would form a crucial cornerstone for the field in the subsequent decades.

The state-of-the-art nuclear physics facilities in the United States are also available to collaborating scientists from around the globe. As hosts we benefit from the influx of young talented scientists who participate in the research; some write a doctoral thesis in their home institutions while others collaborate as postdoctoral researchers. They contribute to the science and often seek positions in academe and industry in this country. They represent a valuable ancillary source of stimulus for the research and development in our economy and supplement our internal educational process. Our DOE Office of Science national laboratories are great attractors for scientific talent from across the world.

I mentioned earlier how the ability to construct accelerators transformed the field of nuclear physics. Today, accelerators underpin not only their traditional use for particle and nuclear physics but also a broad range of materials science, medicine and biology. The ability to construct a broad range of accelerators is a primary core competency associated with the Office of Science laboratories. The devices we have today, including the superconducting Continuous Electron Beam Accelerator Facility at Jefferson Lab, could not have been built with the technologies of 1980. Research and development across a broad suite of technologies and with a time-to-use ranging from one to thirty years and more is essential. Support for this work from the multiple Office of Science programs, which benefits and is carried out in multiple locations with the relevant core competencies, is an important role for the Department of Energy. If this expertise is ensured, we will be able to build the accelerator we will need ten years from now to retain world leadership.

I have attached to this testimony references to several key documents and reports that I utilized in its preparation. I have tried to impress on you how nuclear physics contributes in an essential way to our search for the building blocks of our universe, that this search is enormously exciting, and that the United States plays a major role. In addition I hope that I have also demonstrated that this science plays an essential role in our daily lives keeping us warm or cool, spawning new tools and technologies, improving our quality of life, and even saving our lives. It also trains bright young scientists who contribute to the U.S. in many different ways. I believe it is an endeavor worthy of the support of the people of this country. Thank you again for this opportunity, I would be happy to try to answer your questions.

Document references:

The Frontiers of Nuclear Science: A Long Range Plan, Nuclear Science Advisory Committee, December 2007; *http://www.sc.doe.gov/np/nsac/nsac.html*

Journey into the Heart of Matter, The Department of Energy's Office of Science Office of Nuclear Physics, 2006; *www.sc.doe.gov/np/publications/NPbrochure_2006.pdf*

Education in Nuclear Science Report (November 2004); *http://www.sc.doe.gov/henp/np/nsac/docs/NSAC_CR_education_report_final.pdf*

BIOGRAPHY FOR HUGH E. MONTGOMERY

Hugh E. Montgomery is the Director of the Thomas Jefferson National Accelerator Facility (Jefferson Lab).

As the Lab's Chief Executive Officer, he is responsible for ensuring funding for the Lab and for setting policy and program direction. In addition, he oversees the delivery of the Lab program and ensures that Jefferson Lab complies with all regulations, laws and contract requirements. Montgomery also is responsible for developing and ensuring relationships with Jefferson Lab's stakeholders.

In addition to serving as the third Director in the history of Jefferson Lab, Montgomery is the President of Jefferson Science Associates, LLC. JSA is a joint venture between the Southeastern Universities Research Association and CSC Applied Technologies formed to operate and manage Jefferson Lab.

An internationally recognized particle physicist, Montgomery began his career in 1972 as a research associate at the Daresbury Laboratory and Rutherford High Energy Laboratory in Great Britain. In 1978, he became a staff member at CERN in Geneva, Switzerland, where he remained until joining the staff at Fermi National Accelerator Laboratory in Batavia, IL, as an associate scientist in 1983. Montgomery spent the next 25 years of his career at Fermilab, occupying a number of positions of responsibility within the laboratory management before being named Associate Director for research at Fermilab, a position he held until joining Jefferson Lab in 2008. As Associate Director, he was responsible for the particle physics and particle astrophysics research programs at Fermilab.

Montgomery's research has focused on expanding the understanding of the fundamental components of our universe and how they interact. He was involved with muon scattering experiments at CERN and Fermilab, and in the DZero Experiment on the Fermilab Tevatron Collider. Active on the experiment for 12 years, he was co-spokesman from 1993–99, which covered the time of the observation of the top quark.

In addition to presenting numerous invited talks internationally, Montgomery has been actively engaged in many professional committees. Notably, as well as participating in two HEPAP Sub-panels, he served as: a member of the Review of Department of High Energy Physics of Tata Institute for Fundamental Research located in India; a member of the FOM Review of NIKHEF in Holland; a member of the APS Panofsky Prize Committee; Chairman of the Elementary Particle Physics Review Committee, Helmholtz Society, Germany; Chairman of the Atlas Oversight Committee, STFC, England; member of the SLAC Policy Committee; Chair of the Evaluation Committee of Istituto Nazionale di Fisica Nucleare and the Large Hadron Collider Committee, CERN.

A native of Great Britain, Montgomery earned a Bachelor's and Ph.D. in physics from Manchester University, England.

DISCUSSION

Mr. LIPINSKI. Thank you, Dr. Montgomery, and I do appreciate you pointing those out. Those are here in the room and I think few of us ever look up and see what is written there. I remember when I first started on this committee that I did that, but it is something that we forget to look at and we forget those messages up there for us.

COMMUNICATING WITH THE PUBLIC

I want to thank all our witnesses for their testimony. Let me begin right now the first round of questions, and the Chair will recognize himself for five minutes. This is obviously a field that is not easy for everyone to understand and I don't claim that I have a great understanding of all of it. Two years ago when I was visiting Stanford and SLAC, I had the opportunity to meet Pierre Schwab. I don't know if anyone is familiar with him. But what really stood about Mr. Schwab is that he calls himself a high energy physics groupie. He is an entrepreneur, a software engineer. He is not a physicist. But he is a man who is fascinated by the research that we are discussing today and the fundamental questions that it can answer. He donated $1 million of his own money to Stanford's Kavli Institute for Particle Astrophysics and Cosmology. I bring him up because you seldom see anyone outside of people who are physicists really getting involved, talking, having the interest in what we are having a hearing on today. I know Dr. Randall has done work to make extra dimensions and warped passages more accessible to laypeople, but I think we need to do more of that, especially in a time of large federal deficits, increasingly expensive experiments, you know, just trying to get the money to be able to put towards this research.

So my question for the whole panel, I will start with Dr. Randall, what can DOE and research community in general do to better communicate its goals and triumphs and plans to the general public?

Dr. RANDALL. That is an excellent question. I just want to start by saying that I have found when I have talked to people that once people have the opportunity to hear about the science they are interested. I think a lot of people are afraid or will stay away from it, but once they take seriously the fact that you are listening to them, that you want to hear their questions, they provide opportunities for people to hear about it. There are many more people interested than you would imagine. That is not to say everyone is, and I don't think everyone should be necessarily, but people that want to know about it should have the opportunity to know about it. I think of many times I have been in towns where the cab driver is like, really, you are lecturing about this? And then the lecture hall would be full. I mean, thousands of people will show up to listen to this kind of thing if they know about it.

Having said that, I think that is a difficult question. I mean that is more, almost a PR question, you know, how do you make people aware of things.

Mr. LIPINSKI. Well, we are—because we have to respond to our constituents, the American public, unfortunately, you know, if you want to look at it that way for the scientific aspect of it, that is——

Dr. RANDALL. That is not said in a negative way, just so you know. It is just that this is not—it is not my area of expertise. I mean, what I did is, I tried to say I made a big effort to write a book where the information is there for people who want to know about it so that it is accessible to them, so people who want to understand the science can. But I think that there is a lot of people who watch TV, who read newspapers that wouldn't read a book, and I think the answer there is that it really has to be out. It should be out there more in the news. It should be out there more in TV, media, but I think that is where people get their information and I think there should be more of a sense that people have—they shouldn't be as afraid of learning about science, and there should be a sense they are being listened to. Even the question of black holes at the LHC—this comes up in every lecture I give practically—well, are you going to make black holes that destroy the world? And you give a scientific answer and everyone is happy. I have never heard someone say no, no, no, I still don't believe you. I mean, I think they want you to know that they are worried, they want to know that you are listening to them, that you have addressed these worries and that there is interest in science there. And I think that there has to be more of that opportunity. I don't know where that would be but I think that science reporting—I mean, I do worry that in this era where newspapers are facing troubles that science reporting will be one of the things that gets cut and I think that is exactly the wrong direction to go in at this point, especially when science is so essential to so many things that we are doing today.

Mr. LIPINSKI. You have done an excellent job with the work that you have done, Dr. Randall.

Dr. RANDALL. Thank you very much for that.

Mr. LIPINSKI. I thank you for doing that.

Any other comments, what can be done? Dr. Oddone, and then we will go to Dr. Montgomery.

Dr. ODDONE. Our community is learning how to do this better and better. At Fermilab, we hold, for example, a public lecture roughly on a monthly basis. We have had 900 people—Lisa Randall was there—from the community come and listen to this. Through our education program with children, Saturday Morning Physics—I think Representative Biggert's son actually took advantage of that—we reach many, many children and we have programs to train teachers so we are actually working with the new generation probably, you know, reach 2,000 teachers and some 30,000 K–12 students on this activity.

And I think we have also created vehicles like *Symmetry Magazine* to reach a much broader audience, and so I think the community is getting much more sophisticated about actually realizing that it is ultimately the public that supports our research and they have to be part of this venture.

Mr. LIPINSKI. Dr. Montgomery.

Dr. MONTGOMERY. My theme is a little similar to Pier's. When I arrived in Newport News a year and a half ago, the lady next door came with cookies and introduced herself and asked me what I was going to do, and I told her I was going to direct the Jefferson Lab, and she immediately launched into praise for the laboratory's participation in the science education in the schools around there. I think that certainly where we have the labs, the little bit of funding that goes toward the education and involvement directly with the community is an enormous winner for everything associated with the program, and the kids that come in and visit are really impressed by just the small amount of time that a scientist will spend with them and they are enormously excited by the coolness of the things that we have in the labs.

Mr. LIPINSKI. I think you are right on target with that and I actually have legislation to encourage the National Labs to work with museums for science education. We are—we have votes again but at this time I am going to move on to Mr. Inglis. I recognize Mr. Inglis for five minutes and then decide how we are going to proceed from there. Mr. Inglis.

Mr. INGLIS. Thank you, Mr. Chairman. In the interest of time, let me defer to Dr. Ehlers, who actually will have more interesting questions than I would have, I think. So Dr. Ehlers.

STRING THEORY

Mr. EHLERS. I thank the gentleman for yielding. I hope they are interesting questions, partially interesting comments. We will just go down the line as time permits.

Dr. Randall, first of all, I have to congratulate you. You destroyed a—I grew up in the Midwest and we have a widespread belief there that you have just disproved our belief there, that you come from New York and that is why you talk rapidly. Midwesterners believe probably to a person that the reason New Yorkers speak so rapidly is to cover up that they don't know what they are talking about, but you effectively disproved that here. Just a quick question, my curiosity. Unfortunately, being a good Member of Congress takes about 80 hours a week, which leaves me no time to keep up with modern physics, but you mentioned string theory. Is there any experimental proof or any experimental results that corroborate string theory or is it still rather speculative theoretical work?

Dr. RANDALL. I am afraid string theory is speculative, theoretical work, and that is because it is addressing questions that are simply beyond the energies and distances that we can explore. Having said that, though, it is important to understand that string theory has also given rise to ideas that add accessible skills and ideas which are still rather exotic sounding to probably most people here, including ourselves, such as extra dimensions of space or supersymmetry, which Pier mentioned. I mean, actually developing string theory led to the development of supersymmetry, which might be around the corner. It could be at low energies. So I guess my point is that even though string theory itself probably won't be tested in the foreseeable future, that is not to say that it is not giving rise to theoretical ideas that can change our view of the universe and that can actually be tested.

Mr. EHLERS. If they are corroborated.

Dr. RANDALL. Well, they are tested. I didn't mean that they are proven.

NEXT GENERATION ACCELERATORS

Mr. EHLERS. Okay. Dr. Kovar, you mentioned next-generation accelerators, and Dr. Montgomery I believe referred to that too, or Dr. Oddone. What do you see on the horizon in next-generation accelerators?

Dr. KOVAR. So I think there are all sorts of possibilities. There are examples of—there is a technique that is called Wakefield acceleration, a plasma Wakefield accelerators of beams, which may make it possible to have a tabletop accelerator that you can use for medical purposes or for scanning materials for security. There is a whole range of opportunities and we are organizing a workshop in Washington, D.C., on October 26 where we are bringing in a group of experts and people, people from the scientific community, from the medical community, from the security community, from the industrial community and those interested in energy and environment. And, we are going to try to identify those areas in which there is potential for significant advancements and what the impact would be in terms of productivity or in terms of breakthroughs, and we are going to put that together. We have a workshop and there is going to be a report to the Office of Science and the Office of High Energy Physics and hopefully we are going to—you will see in that report exactly what that potential is going to be, but I think there is—I think it is extremely important for the Nation. We historically had been leaders in accelerator science and in terms of accelerator technology. Because of the investments that Pier mentioned in Asia and in Europe, in next-generation capabilities—those investments have been made over the last decade—we now find that that technology has been transferred to those economies. The preferred vendors for certain accelerator components are no longer in the United States and so I think it is extremely important for us to make these investments. I think it is important for science but I also think it is very important for the Nation and our economy.

INTERNATIONAL COOPERATION

Mr. EHLERS. Dr. Oddone, I think you made the same point about the need for the United States to once again take the lead with the major facility here. When I first got here, Newt Gingrich became Speaker and, as you know, he is very interested in science and technology. He gave me the assignment of writing the national science policy, which was a huge task for one person to try in his first year in office. We actually did it. It was the first one written since the Endless Frontier in 1945, which shows that the scientific community was just resting on their laurels in terms of just going ahead. I am not counting that I wrote an extremely good report but one aspect I pointed out in there, and that is that most—in many areas, frontiers of research were becoming so difficult, so expensive, so complex that we would be forced into international cooperation if we wished to proceed. I recommended that we recognize that and proceed on that as a policy. It didn't happen as part of our policy but it is happening in fact with ITER now developing in France. We simply decided we didn't want to put enough money in and by "we" I mean the Congress. And——

Mr. LIPINSKI. Dr. Ehlers.

Mr. EHLERS.—the Large Hadron Collider, the same situation, and I realize my time is expired, but I assume we will come back. You can think about the question in the meantime: What mechanism should our nation set up with other nations so that this will be part of our policy and not happenstance that we join with the Large Hadron Collider because Congress killed the Superconducting Super Collider, et cetera? So we will get back to that when we come back from votes.

Mr. LIPINSKI. Thank you, Dr. Ehlers. I hate to interrupt you because you certainly have the great knowledge up here amongst us. We are—I think at this time because of where we are on this vote moving on to another question may take a little time. Unfortunately, we are going to have to recess and ask our witnesses to come back again, probably 25 minutes. I will run back after the third vote and get us started again, and just to have an opportunity to ask a couple more questions. So the hearing stands in recess.

[Recess.]

Mr. LIPINSKI. The hearing will come back to order.

Unfortunately, things work very differently here in Congress than they do in the laboratory. You continually get called away unfortunately and it doesn't give a lot of time for concentration, but we are back, and the Chair is going to come back and chair but before that I will start us off again, because we are going to have votes again relatively soon. The Chair will recognize Mr. Inglis for five minutes.

Mr. INGLIS. Thank you, Mr. Chairman, and we want to get quickly back to Dr. Ehlers so that he can get another round of questions.

DARK ENERGY AND MATTER

A question for you, though. We had a wonderful opportunity to visit the Ice Cube in Antarctica and saw the work being done there on neutrinos. So help me understand, a layman understand a little bit of this, Dr. Randall. What is the—how is a—neutrinos are related to dark energy in what way? I mean, it is a mystery to us. Is this right?

Dr. RANDALL. There are two different things out there, dark matter and dark energy. Dark matter, we really—I would say we are on the cusp of understanding dark matter. We have a real hope. It is really at scales that we are about to probe. We have many different types of experiments that look at both directly, which is to say—the point is, dark matter doesn't interact very strongly, so in order to increase the probability you need huge. So there are huge targets of whatever that could look for dark matter or there are other types of astronomical experiments that look for the annihilation products of dark matter, so dark matter can annihilate with itself and produce things that we can observe astronomically like photons or neutrinos or whatever. So what the Ice Cube could be connected to is dark matter. Dark energy is very mysterious and requires a whole different set of types of explanations which we could talk about independently. But dark matter is stuff that is just like particles. We know about it. It is just that it doesn't interact with light as much, but it means that it has particle properties that we are familiar with. So what we can look for in something like the Ice Cube is, for example, annihilation products that come out when dark matter—from dark matter annihilation or studying neutrinos directly. So you have these big targets which allow—basically, you are, you know, buying a lot of lottery tickets. You know, you are increasing the probability that even though these neutrinos interact so weakly, you are providing the opportunity for it to have some interaction that you can actually record.

Mr. INGLIS. Right. So what is—I think we have heard some percentages here this morning, but what is the percentage that we think we know of energy, we can detect some percentage——

Dr. RANDALL. The amount of stuff that we know what it is, is really—is very small. It is maybe five percent. Now——

Mr. INGLIS. This is of matter?

Dr. RANDALL. And that is to say that is stuff that we really understand, like the kind of matter that is here in this room that we are made up of. You know, it is funny because everyone is always shocked to find out that 25 percent is dark matter and 70 percent is dark energy, but I always actually found it kind of remarkable that the stuff we know about is as big a fraction as it is. I mean, why should the rest of the universe—I mean, because we are just making a statement that it interacts in the way the stuff we are familiar with does. That is to say it interacts in a way that it emits and absorbs light, which is really the only way we have had to see things. Really, to see its interaction with light is essentially how we look out into the universe. And it could be that there is matter that for whatever reason doesn't emit or absorb light or does it at a much lower level, and that could well be dark matter. The really interesting thing theoretically seems to be that it could be connected to this very same interaction scale that we are probing today at colliders, because what do you need to have—so what do we need to actually have dark matter out there? Well, you need something that is stable, that hasn't decayed, and you need something that has the right density to be out there in the abundance that we see it today, which is to say in the early universe we can predict how much was annihilated, how much is left today, and its interaction scale is set by this very same weak scale. It turns out, and it could be a coincidence or it could be something deep and meaningful, that it gives you the right abundance to be dark matter today. So from that perspective, it is actually—if there really is something new at the weak scale, which we assume there is, perhaps it is less mysterious why there should be dark matter out there.

Mr. LIPINSKI. So of the matter that we know of, your estimate is we know five percent. Ninety-five percent then would be in the category of dark matter or in——

Dr. RANDALL. Well, like we said, 25 percent is dark matter so matter is stuff like made up of particles that clump together. It forms galaxies. It forms objects. The rest of it is something which is even more mysterious in many ways. It is something that Einstein told us was allowed. It is just energy, and it is called dark energy, but really it is just energy that can be out there permeating the universe. It still emits gravity but it doesn't clump, so it is not acting the way matter acts. It is really just there in terms of its gravitational effect and the energy that is distributed throughout the universe, and it is a very big mystery. I mean, it was one of the major discoveries to realize that it is there at all, but why it has the particular amount it has, why it has a comparable amount to the rest of the matter that we know about, why it is not huge, which is what actually quantum mechanics and special relativity would tell us, it is one of the big mysteries that we face today. So understanding dark energy could lead to some very—any explanation is going to give some deep insight into what is out there.

Mr. INGLIS. Very interesting. Thank you.

Thank you, Mr. Chairman.

REALIZING THE TAXPAYER INVESTMENT

Chairman BAIRD. Thank you. Good to be here. Sorry I am a good bit late but I thank you for your presence and my colleagues as well. I want to first say I am very interested in what you are doing, the work you are doing. I have had a long interest in physics. I am not anywhere near Dr. Ehlers but I have had a passionate interest in it. But at the same time we have a $10 trillion debt, the deficit is going to exceed $1 trillion, and to be perfectly blunt, you all are on a pretty expensive end of the spectrum and there is an awful lot of other things we could spend the money on. So help us understand, what do we get for the money? I mean, if I have got to go home and tell my fishermen and my loggers and my steelworkers and my laborers and my homemakers and my nurses and everybody whose tax dollars are going to fund your big projects, what do we get for it?

Dr. ODDONE. Let me tackle that one.

Chairman BAIRD. You are a brave man. I admire that.

Dr. ODDONE. I think the first thing that you get out of it is really a place at the frontier, the opportunity to expand knowledge, and it is in a way that is very powerful. If you think of how our civilization will be remembered centuries from now, the progress that we make in understanding the universe around us is what will really be enduring and will remain as understanding for humanity, and I think when we invest in this area of science, we are at that frontier and we are expanding that frontier. So I think it is an opportunity for inspiring young people to go into science and it is something that I think responds to some very deep human emotion of discovering the world around you. So that is the first thing that we are motivated by and that you get. But when you do that, when you are at the frontier and when you learn something, it is passed along and you now put it away and you think well, what I don't understand is the next step. You are forced to invent, to stretch the technology, to really take things way beyond the place at which you found them. And if you look at the history of particle physics, we have done that from the beginning of accelerators and detectors. Today you can look at how we use accelerators, medical accelerators by the thousands and accelerators in industry to modify materials, to put ions in place, how we have learned to do very fast pattern recognition with computers from early computer technology, how, when we try to tackle these global projects, physicists invented the World Wide Web as a way in which they could all talk to each other across dozens of countries, dozens of different technical platforms. The tools that come out of accelerator physics are employed now in light sources and neutron sources with a wide variety of applications. So I think the second thing you get is that drive that says, "these problems are so hard yet they are so inspiring," that it leads to invention, it leads to us really thinking very, very hard about what the technological barriers are that prevent us from actually responding to those questions that Lisa asked there. And so I think that is the second part that you get.

I think the third part that you get is the fact that this type of science really influences science technology, engineering and math education in a very broad spectrum. At the highest spectrum of very technical people, if you look around the universities, this type of research is a vital part of any physics department. It is an intellectual part of our universities. It brings students and they work at these problems and it is part of the miracle of American enterprise that the universities, in fact, contribute so much to our development across a broad front. Science is a very important part in asking those questions, a very important part of bringing students into physics and in technical careers. We see it at Fermilab at a much younger age. We have a marvelous program, very talented people, 200 volunteers that go into the community, thousands of children that come to Fermilab, and it is an inspiring thing to ask these questions and try to understand how the world is put together, these deep mysteries of dark energy, dark matter, why the world is dominated by matter and not matter and antimatter. They ask the most profound questions, very unlike the question you just asked in the sense that they don't ask about why, you know, you cost us a lot of money and why should we be doing this. They really only ask the questions that intrigue them and they are brought into this field, and they may not come in as high energy physicists someday, but they have been inspired to look at the world in a different way. So I think those are the three things you get.

Chairman BAIRD. Thank you.

Dr. Montgomery.

Dr. MONTGOMERY. Yes, I would like to respond a little bit in the vein that we talked earlier. I refer to myself as the Director of Jefferson Lab. I wrote an article which appeared on a page on our web site in which I try to explain that in fact when you are sitting in Europe, as I once was, or in China or in Japan and you look to the United States, you don't only see Harvard. You actually see Fermilab and Jefferson Lab and Brookhaven National Lab and LDL and Stanford's linear accelerator. And those great attractors actually bring scientists, both students who come here but also the participants in the experiments, and some significant fraction of those people actually want to stay. Given our difficulty in educating our society to a level which can actually function in today's technological age, that is a major augmentation of our system. I think it is a small piece but a very important piece of why and what you get from our labs.

Chairman BAIRD. Good points.

Dr. Ehlers.

INTERNATIONAL COLLABORATION AND MORE ON NEXT GENERATION ACCELERATORS

Mr. EHLERS. Thank you, Mr. Chairman. First of all, just a side issue but it is something that Dr. Baird and I are both very interested in. Dr. Oddone, you mentioned that you immigrated to this country to study physics. It is a good thing you did it when you did because if you tried to come to this country now to do it, you would have a much more difficult time getting in. And we have spent time lobbying with the State Department and Homeland Security to try to ease this transition of scientists, and I was just telling Dr. Baird the other day about my son who is a geophysicist and has left this country and gone to a very attractive position in Europe, in Germany, to be specific. And when he came in, no prior permission, went down to register, took 15 minutes, it was all over. Compare that to what you have to do to import scientists from other countries. So I hope you will join with both of us in trying to impress upon the Congress, upon the government, upon Homeland Security and so forth that we really have to be certain to allow the scientific talent to continue to come into this country because if you don't get that talent, they now have other places they can go and you are not going to get your next generation of accelerators if you don't get in the next generation of really bright people. So just a little editorial comment there.

I didn't have much in the way of other questions. You have already answered some of my questions about dark energy and dark matter, but just getting back to a question I had asked before we went to vote, and that is the next-generation accelerators, and I think Dr. Oddone and Dr. Montgomery haven't had a chance to respond yet, but I am very interested in that question because you may reach a point where it is no longer appropriate to use accelerators to continue as Dr. Randall mentioned. Maybe you are going to be doing more work with cosmic rays at some point just because that may be the cheaper way to try to learn what you need to learn. I don't know. What comments do you have?

Dr. ODDONE. Let me answer that in two ways. The first one has to do about international collaboration. You had asked how the world is coming together so that for the next major facility it doesn't happen because we decided to cancel something like the Superconductor and Super Collider. I think there are multiple levels in which this international collaboration happens. We have many relations, laboratory to laboratory, that are very healthy, so if you look at Tevatron, for example, 40 percent of the collaborators in physics are from Europe and 40 percent of the capital contributions have come from Europe. If you look at the Large Hadron Collider, there is very significant investment of the United States in this facility. We participated in it. We have a remote operation center at Fermilab and it is a great opportunity for us. I think these models have worked and they represent a facility that is either regional or national with international participation, where there is an anchor facility or region that basically establishes the facility and invites international participation. That model has been very successful for us. There are new models being explored for what might happen in a great new global facility similar in scale to the LHC where many countries would come together to try to do that, and there is a group. It is not officially constituted. I think it is more of a club called Funding Agencies for Large Colliders in which all the agencies of interested countries from Europe, the United States, China, Japan, Russia and so on participate. They are trying to coordinate that global issue to see if we build a new facility how should we decide where it goes, what kind of governance should we have and so on. So the level of world cooperation among the agencies is now much higher than ever before in trying to understand how one would move such a large facility.

The other comment that I would make concerns your remark about perhaps we ought to do something with cosmic rays that might be cheaper, and——

Mr. EHLERS. By the way, I was not being very serious about that.

Dr. ODDONE. I understand, but I should say the following. The observations that we make of the cost in the natural world lead us to all sorts of questions and contradictions that we want to explore, but ultimately we believe this finds the resolution in understanding the particles in the fields that underlie all of this. And we don't know of any other way really to explore that world other than with accelerators. We will find phenomena. We may find a dark matter particle, for example, deep in a mine, a natural one, and then the question will be, well, what is it? And I think until we produce it at the Large Hadron Collider, we will not know really what is behind it. So I think it is very important to connect the large world that we see outside with the world that underpins it, which is really the world of the very small that we study with accelerators. So I don't think anytime soon we could say that we would replace one particular thrust like the energy frontier with accelerators or the intensity for dealing with accelerators purely with cosmological observation.

Mr. EHLERS. All right. By the way, if you want to find dark matter in the mine, you might want to go to coal mines.

Dr. Montgomery.

Dr. MONTGOMERY. So I would like to address your question in two pieces also. The first is that not all accelerators are the same. In fact, for nuclear physics, what we would really like, as I mentioned in my testimony, is if you like, the machine of the future would be an electron ion collider and that would provide different capabilities, different characteristics than, for example, you might look for a particle physics accelerator. And that in turn allows me to point out that in fact we sometimes discuss how are going to build the next big accelerator, the accelerators are what we are discussing. In fact, if you look at the science of the Office of Science in the Department of Energy, then accelerators underpin the science in basic energy sciences, in nuclear physics and in particle physics. The whole spectrum is underpinned by the ability to build accelerators of different types. And if you look at the laboratories that you have, then you will find, for example, that Jefferson Laboratory is well known for its superconducting radio frequency acceleration technology but it is not well known for magnets, and then Lawrence Berkeley Lab is known for magnets a little bit it is not known at all for superconducting radio frequency. And so in thinking about the next accelerators that we build, then the laboratories have to work together. And so it is important that the Office of Science in general, Department of Energy maybe more broadly, ensures that the full spectrum of capability in accelerator science, whether it be magnets, radio frequency technology of whatever that it is required to build the accelerator in 10 or 15 years from now is present in one or other of the laboratories so that together they can build that accelerator.

Mr. EHLERS. Thank you very much, and I apologize, Dr. Randall.

Dr. RANDALL. Just since I was accused of saying it, I just want to reiterate a little bit what Pier said, which is that I think that there really are different ways of exploring new physics, and the essential point to high energy accelerators is that it is the only way to directly explore what is there. We can get all sorts of indirect clues, but if you think about it in any other context of your life, whenever you have had an indirect clue, you very rarely know what is really going on. I mean, the only way to really understand the details of what is out there is to get to the energies where we can make these kind of things and explore their properties. That is not to say that we don't learn a lot by exploring the cosmos, but it is a very different sort of thing, and of course, if we want to know if something is dark matter, the cosmos is actually a very good place to look because that is where we know it is lurking. But if we want to understand detailed properties of the fundamental nature of matter, the kind of experiments that we can do when we can have control and create things here on Earth and make the stuff directly, have it right here to study, it is just a completely different type of question that you can ask in that case.

Mr. EHLERS. The point is, with an accelerator you can run more of a controlled experiment. With the cosmic rays, you take what you get.

I apologize. I am very late for another meeting I am supposed to be at and so I have to leave, but thank you very much for a very enlightening session here. Thank you.

MORE ON BEST USE OF TAXPAYER MONEY

Chairman BAIRD. I will ask—with the indulgence of my friend, Mr. Inglis, I will ask one last question. So I am going to continue a line of discussion that I began a second ago and follow up in a couple of ways. You look at the Superconducting Super Collider which was really a lot of money spent and got nothing really out of it, and—I mean out of the failed project in Texas, and Large Hadron Collider, you know, tremendous amount of money, great expectation. You fire the thing up and it sort of self destructs, not entirely, I understand, but we now read this sort of, "well, that is okay, it can still do some pretty cool stuff." I am paraphrasing here but it certainly—I am sure nobody is more disappointed than you folks in the scientific community. But there might be one group of people a little bit more disappointed, and that would be the taxpayers who say look, we put a hell of a lot of money into this thing on promise that certain things would be achieved and now it is not going to be achieved. If that happened in lots of other aspects of government, there would be investigations. I mean, you guys would be here before one of these very unpleasant oversight committees where somebody would be glowering at you. And you get to skate, I mean partly because you know stuff we haven't a clue what you are doing, and I think that is neat. I admire your knowledge. I admire your intellect. But there is a kind of a core responsibility that goes with it that says Bob and I and the rest of us up here, we have got to go to the aforementioned people I talked to and we have to say to them, we are going to take your money and invest it on your behalf. And you get taxpayer dollars in one of two ways: either people trust you, which is rare, or you threaten them, which is the underlying motive. You say, we are going to put a gun to your head and take your money to put it towards the Large Hadron Collider, which then is going to melt its connections the first time we fire it up. Walk me through your mental process, because it is not just about the cost and yes, there are some neat things that happen, side effects and some neat direct discoveries. But there are also opportunity costs, opportunity costs to the folks whose money we take is, "I could have spent that on my kids' education, a new car, repairing the roof." But the opportunity costs on a broad societal scale is, we have thousands of other problems and the money we spend on the big gizmos you folks work with is money we can't spend on other things that might actually have more immediate and more direct benefit to a society and economy that are in trouble. Walk us through how you—other than just "gosh, we are really curious and we really want to get this," how do you rationalize the economic costs? I mean, how do you say yes, if we spend X amount of new money on the new ILC which will then afterwards have the next ILC or whatever, how do you do it? Give us some insights into that. What goes on in your heads and in your organizations?

Dr. KOVAR. Let me take a cut at this because this is what I have to do every year when we present our budget to Congress. There are several ways of answering this question. One part of it has to do with those things that we have control over, and so within the Office of Science we work very hard to set up project management practices so that when we start projects we bring them in on cost, on schedule and they perform. And we work very hard to do it but you have got to remember that everything we do here—it is sort of along the line of what Pier talked about is one of a kind. Generally it is an advance. It is defining the state of the art. So it is high risk, okay? Part of the benefits that we have—and I want to point out that our contribution to the LHC is sitting there and it is working, I mean, as best we can tell. Knock on wood, I mean, but it is working. On the other hand, I want to point out that it is a very complicated machine, and there are two gentlemen to my left who know about these much better than I do, but it is the most complicated accelerator that has been built. And so down the road it is going to run, it is going to work, but it is not good right now. Two months from now when it starts running, a lot of people will breathe a big sigh of relief but the expectation is that it is going to run at some point.

Now, for part of this investment that the country has made, we have already reaped the benefits. I mean, the next generation of electronics, the silicon detectors, the next generation superconducting magnets. For example, in the United States we developed something through our R&D program that is niobium-tin. It is a new alloy that we use for superconducting magnets and I think ITER placed an order to the United States for $60 million to produce that for the facility in France. That was developed in the United States. It is going to be spent in the United States. During this period of time there is a whole generation of students and it turns out 20 percent remain in the field. The other 80 percent are in industry, they are in government, they are in national labs and security and medical facilities, so it turns out those investments are the investments and I think the thing that you also get, and it is—I am going to repeat a little of what Pier and Mont described. I mean, we are in fact addressing these questions that just are spectacular in terms of their interest for the general public, you know, my cousins and my uncles in Texas, they appreciate it. I come and talk to them and they are just fascinated by it. However, there are a whole bunch of questions where there are remarkable breakthroughs but they are so technical and only the experts can really appreciate it. And we should develop a way, a language, so we can communicate that to you.

But the other part of this is all of these benefits to society, and it is the job that any program manager, federal program manager has in trying to convey exactly what these benefits to society are and how do we document that in a way that you can explain. You know, my wife is a nurse and she understands making people better and what the benefits of this are. These longer-term benefits really need to be articulated better, okay? And in that regard, I think the Office of Science now has put together a workforce plan where we are beginning to invest in bringing in kids and teachers to our national labs on a much larger scale. And so part of this is I think educating the American public as to what science is, giving them some context. I think all of these are things that I think are very important but, you know, in the context of health care and Social Security down the road and national security, I know all of you have an enormous responsibility and these are really very tough problems, but in the context. Earlier before you came in we looked at what is on the wall here, you know, "Where there is no vision, the people perish." I think some of these longer-term things are just very important for our society. I am not sure that I answered your question.

Chairman BAIRD. It was appreciated and I thought you were very insightful.

Does anyone else want to take a quick run? I don't want to belabor it too much, but with Mr. Inglis's indulgence, it is a matter I struggle with. And then Dr. Randall, we will let you finish.

Dr. MONTGOMERY. So you picked two particular examples, SSC (Superconducting Super Collider) and LHC. First of all, I think they are different beasts, but you picked in fact the two projects which have had difficulty, let us say, have had challenges. But—this is true, but there are also a number of devices which you have supported which do work, which have been spectacular successes.

I know, for example, and you may not but it is certainly true that our colleagues like Dr. Kovar and some sitting behind me actually apply, if you like, metrics to the way our accelerators perform. And each year as lab director I submit our performance against those metrics and that folds into the money that we get in the subsequent years so there are metrics. And we are successful in a large number of the accelerators, it is not confined to Jefferson Laboratory. Fermilab has had success with the Tevatron. The SLAC B Factory was spectacular. The Relativistic Heavy Iron Collider in Brookhaven has done very good work. So you are getting real scientific measurements and return on your dollars in general. I just wanted to make that point so that it is not entirely a question of, did you deliver on the LHC yet or not? Thank you.

Dr. RANDALL. So I want to say a couple of things. One is just a basic fact about the accelerators which I think is important to know. So when the SSC was designed and started to be developed, physicists sat down and said what would we like to have if we really could make a machine that will really probe the physics that we know is there that we really want to understand. That was the design people came up with, and with the LHC they had an existing tunnel and that is important because the existing tunnel had a fixed size. The SSC would have been much bigger, which meant that magnets had to be stretched to the limit of the technology that was possible. So everyone knew when the LHC was being designed it is something that is pushing various technology to the limit, and when that happens, there are often times when things don't work immediately. So just in the context of asking the physics community, I mean I think everyone in the physics community, at least in this field, would have said the SSC would have been the obvious way to go. I would still say, you know, if we could fund it, it would be the way to go. And had we done that, it would work, and just, it is important to keep in mind the Tevatron where Pier is has been remarkably successful. I think it doesn't get enough adulation, in fact, because it has been extended to energies and luminosities beyond what was ever prepared in the beginning. So when physicists have the opportunity to do what they really want to do when it is available, it has been successful, and in terms of the LHC, it is just, I mean, we are disappointed but it is just a question of time at this point, which means to get these things up and running. But the SSC would still have been a better machine. It would have been three times the energy. There is just no comparison. And so I mean, I do think it is tragic that that was stopped and it would have been running by now.

I think in terms of the other questions you asked, I mean, this is something I am actually curious about. Whenever they compare science funding, it always gets compared to, you know, I don't know, saving babies or something. I mean, there are a lot of things we spend money on that aren't necessarily directly working for the benefit of humanity. And I think in terms of, when we ask what it is to make progress, we really have to think about what is the role of government, what do we want to be funding, and the government is working on things that wouldn't happen otherwise. If it is something that an entrepreneurial interest is going to take over, then it will happen. It is things that are more strategic, more long-term that ultimately will have benefits but don't necessarily have them in the next second. And the kind of physics that we are doing, I mean, it is a different type of science than a lot of other types of science, in that we are formulating very precise questions at very remote energies and distances. We will make progress, and a lot of the other types of science are very important but it is not—you hear a lot of buzz but it is different than actually making progress in the sense of 20 years down the line you can say, what do we have? And here we have some definite goal and we do know what it means to make an event. That is not to say one should be done at the expense of another but it is just a very different type of thing and I think there is a strong argument for it.

Dr. ODDONE. I appreciate the struggles that you have with the many practical problems that the Nation faces and how to make a judgment about what should be invested in this. In the end it really has to be justified by the results. Now, it is not fair to say the SSC was a bad idea because it never produced anything. Well, Congress stopped it so it never produced anything, so it is not really in some sense an example of a failed science project. And I think it is too early to judge on the LHC. Our laboratory, even though we compete in terms of finding the Higgs-Boson with our Tevatron and so on, we have sent some of our best people over to CERN to help them understand the issues that were involved in that machine, and I completely agree with you that our field is in deep, deep trouble globally if we do not deliver on the Large Hadron Collider. So our intent is absolutely to deliver and I hope that if you have a hearing two or three years from now you actually would tell me, you know, why didn't we do that rather than, in some sense, letting the Europeans do it? Because the kinds of things that will be discovered will in fact set the tone for the world for what is really coming in our way that is unimagined.

A lot of the science that we do is absolutely neat, but I say it is imaginable. I can imagine how I modify a molecule to dock in some substance that I can then use to affect disease. I can imagine how I may modify a surface, the atomic surface of a material in order to get a better material. There are lots and lots of things in science that are absolutely neat, wonderful, I support them and they are imaginable. I think when we actually tackle the questions that Lisa has asked, when we open this new regime, the Large Hadron Collider will be seven times the energy, 30 times the intensity that we have, we really are poking into the unimaginable. We may be astounded at what we find, things that we haven't been able to even imagine. We have lots of imagination. We have made all these theories and so on but we actually—that is the nature of the frontier. We may be going towards the spices in India but we may run into America, in some sense, with the Large Hadron Collider. And I think that is what you are getting a ticket at the table for, to be there and be doing those things.

Chairman BAIRD. Thank you. I appreciate very much the testimony, your expertise and your patience with us as you try to educate us on matters rather arcane to most of us on the Committee. With that, the hearing stands adjourned with the gratitude of the Members. Thank you very much.

[Whereupon, at 1:52 p.m., the Subcommittee was adjourned.]

Appendix:

ADDITIONAL MATERIAL FOR THE RECORD

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Superconducting Particle Accelerator Forum of the Americas
100 M St. SE, Suite 1200
Washington, DC 20003

Hon. Brian Baird
Chairman, Energy and Environment Subcommittee
Science and Technology Committee
2350 Rayburn House Office Building
Washington, DC 20515

Oct. 3, 2009

Dear Chairman Baird:

The Superconducting Particle Accelerator Forum of the Americas, SPAFOA, a not-for-profit industry forum registered in the District of Columbia. Our activities are totally supported by member dues. The goal of the SPAFOA is to provide a partnership between our industry members and government funded superconducting accelerator programs during their design, component prototyping, manufacturing, siting and installation.

We appreciate this opportunity to submit written testimony providing our views on the need for and value of an integrated formal industrialization program during the R&D phases of major DOE science programs. Integrating the systems engineering, manufacturing, and equipment operational capabilities of industry with the world class research capabilities on the National Laboratories on these programs would be mutually beneficial. For example, the laboratories would gain industry's expertise in manufacturing and assembly to incorporate into laboratory prototypes, thus lowering equipment costs and increasing end use reliability. Industry would gain a better understanding of the fundamental parameters that impact component performance allowing it to modify designs for future commercial applications.

The SPAFOA therefore recommends the Energy and Environment Subcommittee request DOE to adopt an industrialization approach during the planning and implementation of major programs. Further elaboration on this issue is shown on the attached white paper, ''Industrialization of Advanced Accelerator Technology,'' which was submitted to the DOE Accelerators for Americas Future symposium and workshop on Oct. 26–28.

Thank you for your consideration in this matter.

Kenneth O. Olsen, P.E.	Dr. John V. Dugan
President	Vice President

Kenneth O. Olsen
Superconducting Particle Accelerator
Forum of the Americas
Industry Working Group

Industrialization of Advanced Accelerator Technology

Introduction:

The accelerator symposium working groups are charged with identifying the Nation's future R&D needs for accelerator technology in five distinct application areas. Government R&D investments in accelerator technology for science programs over the decades has lead major technological advances. In order for these advances to benefit society in multiple applications, they must be implemented by the private sector. Also, since the Nation's accelerator R&D expertise resides mostly at the national labs and universities, it is anticipated that many of the working groups' recommendations will require government R&D investment to further advance the state of the art. However, in order for American industry to expedite the adoption of these technologies and compete in the global marketplace for government and private sector applications, the government must develop a formal industrialization program to integrate the country's industrial base into their R&D programs.

Industrialization activities must be focused on two distinct market sectors;

- Federal: The federal sector R&D is dominated by DOE's Office of Science and to some degree National Science Foundation programs at the national laboratories and universities. Industry must become a true partner in these R&D efforts to gain the necessary technical design background. Conversely, industry can educate the laboratories on manufacturing, installation and operability of deployed systems.
- Commercial: The commercial sector tends to adopt advanced technologies developed and deployed by the government. Generally this occurs once the major technical risks have been reduced. Perhaps the best example of this is in aerospace where technologies developed for the military migrate to commercial aviation over time.

Objective:

Industrialization of accelerators will prepare industry to cost-effectively produce accelerator components and systems. The main objective must be to reduce the learning curve through technology transfer and provide industry with the support needed to bridge the gap between R&D and deployment, especially for commercial applications. Industrialization requires two-way technology transfer during the early stages of government sponsored accelerator R&D to educate industry on the R&D programs and technical progress of accelerator programs in the labs and to educate the laboratories on production engineering and post deployment operational issues such as reliability and maintainability that should be integrated into their R&D activities. Industry needs to develop the capability to cost effectively respond to requests for low production specialty products and develop production expertise to manufacture large quantities of accelerator components to meet the requirements on future large science programs such as the International Linear Collider (ILC).

Global Activities:

The potential of advanced accelerator technology applications has initiated the formation of government-academia-industry coordinating groups in many parts of the world. Asia and Europe have recognized the importance of accelerator industrialization and have set up programs to integrate it into their accelerator programs. Since these regions have different laws and cultural backgrounds, one cannot do an across the board comparison of their activities to the situation in America. However, it is clear they recognize the importance of industry, academia, and government cooperation. It is also reasonable to assume that they are partially or totally supported by government funds. A brief description of each is a follows:

Japan: The "Advanced Accelerator Association Promoting Science and Technology," referred to as the Advanced Accelerator Association (AAA) was established in June 2008 to facilitate Industry-Government-Academia collaboration and to promote and seek various industrial applications of advanced accelerator and technologies derived from R&D, excluding creating new drug, biotechnology and medical uses. As of April 1, 2009 the AAA had a total of 100 members, two-thirds from industry. AAA activities include worldwide outreach of significant advanced accelerator developments, seeking ways to handle intellectual property within the ILC project and integrating manufacturing technologies from a variety of industrial fields to create innovative scientific technologies.

Europe: The "European Industry Forum for Accelerators with SCRF Technology" (EIFast) was founded in October 2005 to maintain and further strengthen the position of European science and industry in SCRF. As a united voice of European research and industry, EIFast promotes the realization of European and global SCRF projects. The organization has 47 current members, the large majority of whom are from the European industrial base. The organization interfaces with two main scientific programs: The European X-Ray Laser Project (XFEL) and the ILC.

An industrial forum was established in the Americas in 2005 to support the ILC Americas Regional Team industrialization efforts, called the Linear Collider Forum of America. That forum recently reorganized based on the delays of the projected ILC program schedule and expanded its program coverage to all SCRF based accelerator programs in the Americas. It is now called the Superconducting Particle Accelerator Forum of the Americas. The forum has 16 current members and is totally supported by private sector member dues.

Approach:

This symposium and subsequent workshops will be examining the past, present and future of accelerators in five major application areas. It is assumed that the large majority of accelerator technology advances will occur in the R&D areas within discovery science area since they will be developing leading edge technology. The design and construction of these accelerator based activities, the majority of them incorporating superconducting technology, will advance the state-of-the-art which will then be transferred to security, energy, medical, and industrial applications. A knowledgeable industrial base will expedite this transfer process and prepare industry to compete in the global marketplace.

The importance of industrialization became apparent within the three regions supporting the ILC program. The technical specifications, production quantities, and original program schedule placed a significant challenge on industry in Asia, Europe, and the Americas. Clearly a post R&D industrial briefing would present a steep learning curve and would not be adequate to meet these requirements. There are several other government programs in the Americas that, when taken together, accumulate into a significant requirement for the accelerator industry. A sample of these is as follows:

- Continuous Electron Beam Accelerator facility (CEBAF) Upgrade, JLAB
- Relativistic Heavy Ion Collider, (RHIC) BNL
- Energy Recovery LINAC, BNL
- Facility for Rare Isotope Beams (FRIB), MSU
- Project X, Fermilab
- Cornell Energy Recovery Linac
- Mo99 Production, TRIUMF
- U.S. Navy Free Electron Laser (FEL) Ship Self Defense, ONR

Therefore, government must develop a comprehensive industrialization program for these activities to prepare industry to compete on a level field with its global competitors. Other parts of the world have developed approaches to integrate their industries with government activities. Within the U.S., the program must take into account the various legal constraints and available incentives that are unique to the country such as the Buy America Act, Stimulus Funding, CRADAs, SBIRs, cost sharing contracts, personnel exchanges to collaborate with on-site R&D activities at the laboratories, etc. Failure to do so will greatly weaken the ability of our industries to compete in the global marketplace. Note that an industrialization program which focuses funding primarily through the SBIR program is not acceptable to industry.

Recommendations:

The following recommendations are suggested to implement a formal industrialization component for government funded accelerator R&D activities:

1. DOE SC should assign a role of accelerator R&D program coordinator within the Director's senior staff. This person can examine the cross-cutting opportunities across SC for R&D program integration among HEP, NE, other areas of DOE and other federal agencies and department.

2. Establish an accelerator technology advisory group of laboratories, universities, component producers and end-users to develop innovative ways to transfer government funded technologies to the private sector.
3. Examine the various DOE contractual and cost sharing methods available to the laboratories to work collaboratively with industry during the R&D phases of major accelerator programs.
4. Place more emphasis on demonstration and financing incentives for commercial accelerator applications.
5. Require program plans for government funded accelerator R&D projects to include an industrialization element with a funding commitment.

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