Statement of
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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 sub-atomic, 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 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.

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[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.

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.