Hearing Charter

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

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

Thursday, October 1, 2009
11 a.m. – 1 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 9 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 5% of the universe is made of the normal, visible matter described by the Standard Model. The remaining 95% 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.

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 (2 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

(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.

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.

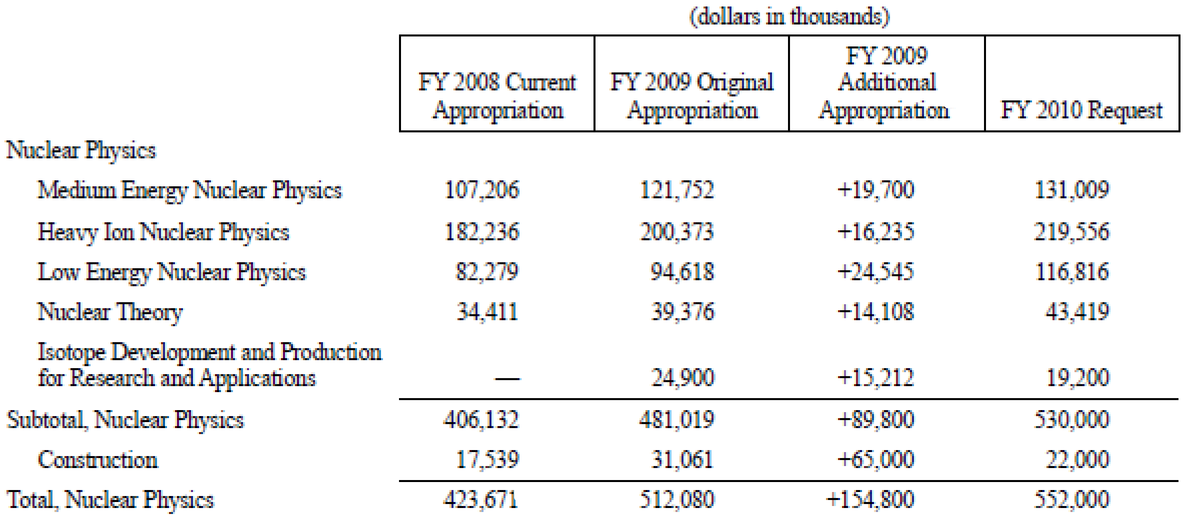
Research has shown that protons, which are positively charged, and neutrons, which are electrically neutral, are bound in the nucleus by a fundamental force named the *strong force* because it is far stronger than either gravity or electromagnetism, although it operates on smaller distance scales. As 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.

<u>NP Budget and Subprograms</u>

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



(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.

matter under substantially different conditions than those provided by RHIC, gaining additional information regarding the matter that existed during the infant universe.

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.