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A REVIEW OF THE P5: THE U.S. VISION FOR PARTICLE PHYSICS AFTER DISCOVERY OF THE HIGGS BOSON

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

JUNE 10, 2014

Serial No. 113–78

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PRINTING OFFICE

89–407PDF WASHINGTON : 2014

For sale by the Superintendent of Documents, U.S. Government Printing Office
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A REVIEW OF THE P5: THE U.S. VISION FOR PARTICLE PHYSICS AFTER DISCOVERY OF THE HIGGS BOSON

TUESDAY, JUNE 10, 2014

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:04 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Cynthia Lummis [Chairwoman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6371
www.science.house.gov

Subcommittee on Energy

A Review of the P5: The U.S. Vision for Particle Physics After Discovery of the Higgs Boson

Tuesday, June 10, 2014
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. Steve Ritz, P5 Chair and Professor, University of California, Santa Cruz

Dr. Persis Drell, Director Emerita, SLAC National Accelerator Laboratory

Dr. Nigel Lockyer, Director, Fermi National Accelerator Laboratory

Dr. Natalie Roe, Director, Physics Division, Lawrence Berkley National Laboratory

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

A Review of the P5: The U.S. Vision for Particle Physics After Discovery of the Higgs Boson

CHARTER

Tuesday, June 10, 2014
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Purpose

The Subcommittee on Energy of the House Committee on Science, Space, and Technology will hold a hearing entitled, *A Review of the P5: The U.S. Vision for Particle Physics After Discovery of the Higgs Boson,* at 10:00 a.m. on Tuesday, June 10th. This hearing will examine the Particle Physics Project Prioritization Panel's (P5's) strategic plan for United States' particle physics vis-à-vis other countries just released last month. The P5 report presents a strategy for the next decade and beyond that enables discovery and maintains the United States' position as a global leader in physical sciences through specific investments by the Department of Energy's (DOE's) Office of Science and the National Science Foundation (NSF). The full report and summaries are available at http://usparticlephysics.org/p5/.

Witnesses

- **Dr. Steve Ritz,** *P5 Chair and Professor, University of California, Santa Cruz*
- **Dr. Persis Drell,** *Director Emerita, SLAC National Accelerator Laboratory*
- **Dr. Nigel Lockyer,** *Director, Fermi National Accelerator Laboratory*
- **Dr. Natalie Roe,** *Director, Physics Division, Lawrence Berkley National Laboratory*

Background

Particle physics is discovery-driven science that explores the fundamentals of matter and energy and reveals the profound connections underlying everything in existence, including the smallest and largest structures in the known universe. On the smallest scale, quarks are the most fundamental forms of matter known. Hadrons are composed of various combinations of quarks, and hadrons then form atomic particles like protons, electrons, and neutrons. On the largest scale, the current hypothesis using the standard model of cosmology is that only 5% of the known physical universe is comprised of such ordinary matter. The rest of the universe is comprised of dark matter and dark energy.

This fundamental, scientific research requires state-of-the-art, world-class facilities. Much has changed in this field since the previous P5 strategic planning report in 2008, including the discovery of the Higgs boson in 2012. Therefore, DOE and NSF charged a new P5 to provide "an updated strategic plan for the U.S. that can be executed over a ten-year timescale, in the context of a twenty-year global vision for the field."

After a comprehensive study, the P5 report has identified five intertwined Scientific Drivers that show promise over the next 20 years:

- Use the Higgs boson as a new tool for discovery.
- Pursue the physics associated with neutrino mass.
- Identify the new physics of dark matter.
- Understand cosmic acceleration: dark energy and inflation.
- Explore the unknown: new particles, interactions, and physical principles.

The P5 developed two sets of criteria for its prioritization process, one for optimization of the U.S. particle physics program and the other for the evaluation of individual projects.[1] The program optimization criteria focus on the scientific goals, opportunities for the U.S. to host leading international facilities, and sustained productivity. The individual project criteria focus on the following: (1) science; (2) timing; (3) uniqueness; (4) cost vs. value; (5) historic context; (6) feasibility; and (7) potential for U.S. particle physics leadership.

The P5 recommends the following levels of engagements:

- Large projects, in time order, include: 1) the Muon g-2 and Muon-to-electron Conversion (Mu2e) experiments at Fermilab (for more information, see: http://mu2e.fnal.gov/); 2) strong collaboration in the high-luminosity upgrades to the Large Hadron Collider (for more information, see: http://home.web.cern.ch/topics/large-hadron-collider); and 3) U.S.-hosted Long Baseline Neutrino Facility (LBNF) that receives the world's highest intensity neutrino beam from an improved accelerator complex (PIP-II) at Fermilab (for more information, see: http://lbne.fnal.gov/).

- U.S. involvement in a Japanese-hosted International Linear Collider (ILC), should it proceed, with stronger participation in more favorable budget scenarios. For more information, see: http://www.linearcollider.org/ILC/What-is-the-ILC/The-project.

- Areas with clear U.S. leadership in which investments in medium and small-scale experiments have great promise for near-term discovery of direct detection of dark matter and dark energy, including the NSF's Large Synoptic Survey Telescope (LSST) (see http://www.lsst.org/lsst/), DoE Office of Science Dark Energy Spectroscopic Instrument (see http://desi.lbl.gov/), cosmic microwave background experiments, and a portfolio of small projects that includes short-baseline neutrino experiments.

- Specific investments in particle accelerator, instrumentation, and computing research and development are required to support the program and to ensure the long-term productivity of the field.

Funding

The funding for High Energy Physics is coordinated through DOE's Office of Science (SC). The FY 2015 Administration's proposal calls for a net decrease of (-6.6%) from the FY2014 enacted level of $797 million.

Additional Reading

1. *Building for Discovery*, Strategic Plan for U.S. Particle Physics in the Global Context, Report of the Particle Physics Project Prioritization Panel May 2014. See http://usparticlephysics.org/p5/.

2. *Together to the Next Frontier*, by Nigel Lockyer, Director of Fermi Laboratories, Nature, December 2013. See: http://www.nature.com/news/particle-physics-together-to-the-next-frontier-1.14364

Chairwoman LUMMIS. Good morning. The Subcommittee on Energy will come to order.

And we welcome today's hearing titled "A Review of the P5: The U.S. Vision for Particle Physics After Discovery of the Higgs Boson." I am going to need an explanation of what that is.

In front of you are packets containing the written testimonies, biographies, and truth-in-testimony disclosures for today's witness panel . And I now recognize myself for five minutes for an opening statement.

I would like to welcome everyone to today's hearing on the status of particle physics research in the United States. Today, the Energy Subcommittee will discuss the strategic plan for U.S. particle physics in the global context offered by the Particle Physics Project Prioritization Panel, also known as the P5.

Researchers in particle physics seek to unveil the fundamental components of existence in an effort to better understand the interrelationship between space, matter, and time. The field has been highly successful, recently yielding discoveries of the heaviest elementary particle, the top quark, the tiny masses of neutrinos, the accelerated expansion of the universe, and the Higgs boson.

The P5 plan reflects approximately one year of deliberations to reach consensus throughout the particle physics community regarding the best opportunities for the United States to maintain global significance in this scientific discipline while considering three potential budget scenarios.

While the U.S. remains in a state of fiscal uncertainty, reducing overall Federal spending in order to arrive at a balanced budget should be a top priority. Yet during this process, we cannot overlook the fact that the Federal Government plays a critical role when it comes to the Nation's long-term competitiveness in the physical sciences. As noted in the P5 report, "the countries that lead these activities attract the top minds and talent from around the world, inspire the next generation of scientists and technologists, and host international teams dedicated to a common purpose." In particle physics, the U.S. is already slipping and stands to lose its position of global significance if we do not act boldly.

Basic research, such as that which is funded through the Office of Science's High Energy Physics, also known as HEP, pronounced HEP, is proper use of taxpayer funds. As the authorizing Committee of the House, we are responsible to ensure that the HEP program uses its limited funds prudently. I say this to underscore the importance of the P5, which had to make difficult choices but found a way to achieve consensus in this very competitive area of cutting-edge science and provide the U.S. particle physics program with a road map for success.

To the witnesses, I convey my admiration for your hard work for those who took part in the P5 directly and those who carry out this unique research that we will learn more about today. I want to thank the witnesses for participating in today's hearing and look forward to their testimony.

A high school colleague of mine by the name of Greg Snow became part of the team that worked on particle physics. I see you nodding. And he and I were very dear friends, high school friends, and so I have followed his career and note his excitement about

what you have done. And so I have lived vicariously through him following your work. And his excitement is contagious I might say.

So welcome. We are delighted to have you here.

[The prepared statement of Mrs. Lummis follows:]

PREPARED STATEMENT OF SUBCOMMITTEE CHAIRMAN CYNTHIA LUMMIS

I would like to welcome everyone to today's hearing on the status of particle physics research in the United States. Today, the Energy Subcommittee will discuss a strategic plan for U.S. particle physics in the global context offered by the Particle Physics Project Prioritization Panel, also known as the "P5."

Researchers in particle physics seek to unveil the fundamental components of existence in an effort to better understand the interrelationship between space, matter, and time. The field has been highly successful—recently yielding discoveries of the heaviest elementary particle (the top quark), the tiny masses of neutrinos, the accelerated expansion of the Universe, and the Higgs boson. The P5 plan reflects approximately one year of deliberation to reach consensus throughout the particle physics community regarding the best opportunities for the United States to maintain global significance in this scientific discipline while considering three potential budget scenarios.

While the U.S. remains in a state of fiscal uncertainty, reducing overall federal spending in order to arrive at a balanced budget should be a top priority. Yet during this process, we cannot overlook the fact that the federal government plays a critical role when it comes to the nation's long-term competitiveness in the physical sciences. As noted in the P5 report, "the countries that lead these activities attract the top minds and talent from around the world, inspire the next generation of scientists and technologists, and host international teams dedicated to a common purpose." In particle physics, the U.S. is already slipping and stands to lose its position of global significance if we do not act boldly.

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To the witnesses, I convey my admiration for your hard work—for those who took part in the P5 directly and those who carry out this unique research that we will learn more about today. I want to thank the witnesses for participating in today's hearing and look forward to their testimony.

Chairwoman LUMMIS. And now I recognize the Ranking Member, the gentlemen from California, Mr. Swalwell, for an opening statement.

Mr. SWALWELL. Thank you, Chairman Lummis, for holding this hearing.

I also want to thank this excellent panel of witnesses for their testimony and being here this morning. I am especially pleased to see northern California so well represented at the panel, which clearly means that this is going to be a particularly informative and productive Congressional hearing today. And that is not of course taking anything away from Dr. Lockyer.

We are here to discuss the recently released P5 report, which lays out a vision for particle physics in the United States over the next decade. The timing of this report could not be any better as we are extremely excited about the history of this field.

With the major advances that have been made over just the past couple of years such as the Nobel Prize-winning discovery of the Higgs boson, as well as the potential detection of gravitational waves first predicted by Einstein 100 years ago, we are equipped with knowledge and advancing technologies that will allow humans

to further engage our innate curiosity about everything from fundamental building blocks for the world as well as for the origin and the evolution of the universe.

However, as amazing as these developments may be and as much as we would like to continue to push the frontiers of science, we are also forced to keep in mind our currently fiscally constrained environment. This is the reason for the Department of Energy and the National Science Foundation charging the P5 panel with doing the hard work of prioritizing particle physics projects under several difficult budget scenarios, the lowest one being particularly restrictive and in my view unacceptable given the critical missed opportunities that would be required to meet it.

I also believe that the end result is a very strong product, and I want to thank Dr. Ritz for his leadership on the P5, as well as the entire P5 team for their efforts. Tough decisions were obviously being made, especially considering the long-term nature of building and operating particle physics facilities.

The Higgs boson I mentioned earlier was found using the Large Hadron Collider, which took ten years to build and will continue to operate well into the next decade. And in fact the Higgs boson existence was first projected and postulated 50 years ago. This gives us an idea of how far out the P5 had to look when working through the prioritization process, and what they produced provides policymakers with sound guidance, which we should in turn use to provide the particle physics community with the support and stability it needs to conduct complex long-term research that will help us understand far more about the nature of our universe. The United States has a long history of leadership in advanced physics, and I think that we have been presented with a report that will ensure that this continues to be the case.

Madam Chair, before I yield back, I would like to quickly congratulate Dr. Drell on being named Dean of Engineering at Stanford University. She will be the first woman to serve in that role, and that is noteworthy and worthy of our congratulations. This is even more evidence that we have truly assembled some of the top minds in the field here today.

Thank you again for holding this hearing and I am looking forward to learning more from our panel. And with that, I yield back.

[The prepared statement of Mr. Swalwell follows:]

PREPARED STATEMENT OF SUBCOMMITTEE MINORITY RANKING MEMBER ERIC SWALWELL

Thank you Chairman Lummis for holding this hearing, and I also want to thank this excellent panel of witnesses for their testimony and for being here today. I'm especially pleased to see northern California so well represented, which clearly means that this is going to be a particularly informative and productive hearing. That of course is not meant to take anything away from you, Dr. Lockyer.

We're here today to discuss the recently released P5 report, which lays out a vision for particle physics in the United States over the next decade. The timing of this report couldn't be any better, as we are at an extremely exciting time in the history of the field. With the major advances that have been made over just the past couple of years, such as the Nobel Prizewinning discovery of the Higgs boson [pronounced: BOZE-on] as well as the potential detection of gravitational waves first predicted by Einstein almost a hundred years ago, we are equipped with new knowledge and advancing technologies that will allow humans to further engage our in-

nate curiosity about everything from the fundamental building blocks of our world to the origin and evolution of the universe.

However, as amazing as these developments may be and as much as we would like to continue to push the frontiers of science, we are also forced to keep in mind our current fiscally constrained environment. This is the reason the Department of Energy and the National Science Foundation charged the P5 Panel with doing the hard work of prioritizing particle physics projects under several difficult budget scenarios—the lowest one being particularly restrictive and, in my view, unacceptable given the critical missed opportunities that would be required to meet it. I believe the end result is a very strong product, and I want to thank Dr. Ritz for his leadership of the P5, as well as the entire P5 team for their efforts.

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Thank you again for holding this hearing, and I am looking forward to learning more from our panel. With that, I yield back.

Chairwoman LUMMIS. I thank the Ranking Member. If there are any other Members who wish to submit additional opening statements, your statements will be added to the record.

Chairwoman LUMMIS. At this time I would like to introduce our witnesses.

Our first witness today is Dr. Steve Ritz, P5 Chair and Professor at the University of California at Santa Cruz. Dr. Ritz is also the director of the Santa Cruz Institute for Particle Physics at the University of California. Previously, Dr. Ritz was a Professor of Physics at the University of Maryland and Astrophysicist at NASA's Goddard Space Flight Center as well. Dr. Ritz received his Ph.D. in physics from the University of Wisconsin. We welcome you and warmly appreciate your attendance today.

Our second witness is Dr. Persis—that is a beautiful first name—Dr. Persis Drell, Director Emerita of the SLAC National Accelerator Laboratory. Dr. Drell served as Director of SLAC from 2007 to 2012. Dr. Drell is also a Professor of Physics at Stanford. Previously, Dr. Drell was the Associate Director for the research division at SLAC. She has also served as Deputy Project Manager for the Fermi Gamma-ray Space Telescope. Dr. Drell received her Ph.D. in atomic physics from the University of California.

I understand you also were one of the conceivers of the notion of the P5, which I believe has worked extremely well and we thank you for your foresight in organizing these issues.

Next, I would like to introduce—oh, good, Mr. Hultgren is here. I am so pleased because he had asked to introduce today's third witness. So at this time I would like to yield to the gentleman from Illinois, Mr. Hultgren, to introduce Dr. Roe. No, excuse me, Dr. Lockyer.

Mr. HULTGREN. Yes.

Chairwoman LUMMIS. Perfect.

Mr. HULTGREN. Thank you. I apologize for being a little bit late. I had to run by a markup in Financial Services.

But great to be with you today. Thank you all so much for being here. It really is my honor, Madam Chair, to introduce someone who is doing a great job and has become a very good friend. Our third witness today is Dr. Nigel Lockyer, Director of Fermi National Accelerator Laboratory. Previously, Dr. Lockyer served as the Director of Canada's National Laboratory for Particle and Nuclear Physics, TRIUMF. He was also Professor of Physics and Astronomy at the University of British Columbia. Prior to his work at the Canadian Physics Laboratory, Dr. Lockyer served as a Professor of Physics at the University of Pennsylvania. Dr. Lockyer earned his Ph.D. in physics from the Ohio State University.

So glad you are here. Thank you, Dr. Lockyer, and thank you for your great work at Fermi Lab.

I yield back. Thanks, Chairwoman.

Chairwoman LUMMIS. Thank you, Mr. Hultgren.

Our final witness today is Dr. Natalie Roe, Director of the Physics Division at Lawrence Berkley National Laboratory. Dr. Roe joined Lawrence Berkley in 1989 as a kindergartener apparently. No, it says as a postdoctoral fellow. I suppose those things can happen simultaneously, but it is impressive, Dr. Roe, very impressive. She has a distinguished record of research in service to the Physics Division, the laboratory, and to the national high energy physics community. Dr. Roe has been an active participant in developing the strategic vision of the Physics Division and has been a member of its Advisory Committee since 2006. Dr. Roe received her Ph.D. in physics from Stanford University.

As our witnesses should know, spoken testimony is limited to five minutes, after which Members of the Committee will have five minutes each to ask questions. Again, panel, we are delighted you are here.

I now recognize Dr. Ritz for five minutes to present his testimony.

TESTIMONY OF DR. STEVE RITZ,
P5 CHAIR AND PROFESSOR,
UNIVERSITY OF CALIFORNIA, SANTA CRUZ

Dr. RITZ. Very good, thank you. Can you hear me? Yes.

Chairman Lummis, Ranking Member Swalwell, Members of the Subcommittee, thank you for inviting me to this important hearing.

Particle physicists have come together to make a recommended plan that is driven by the science and that meets tight fiscal constraints. The plan enables leadership by the United States, resolves key issues for the field, and envisions a continuous flow of exciting and important results while making essential investments in the future. HEPAP, the FACA panel advising the DOE and NSF, considered the report carefully and voted unanimously to approve it on May 22, 2014.

As you know, particle physics explores the fundamental constituents of matter and energy, revealing profound connections underlying everything we see. The field is highly successful. There have

been major discoveries recently that point the way forward, and since 2008, three Nobel prizes related to particle physics were awarded. I would just like to add here that one of the recent Nobel laureates, Saul Perlmutter, was a member of our panel, and we very much appreciated that.

Research and particle physics inspires young people to engage with science. Particle physics is global, addressing the most compelling questions of the field is beyond the finances and technical expertise of any one nation or region. The United States and major players in other regions can together address the full breadth of the field's most urgent scientific questions if each hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere. Strong foundations of international cooperation exist with the Large Hadron Collider, LHC, at CERN, serving as an example of a successful large international science project.

Tough choices were required. Our panel understood that an important part of our job was to recommend ways for the United States to invest purposefully in areas that have the biggest impacts and that make the most efficient use of limited resources. The charge calls for planning under two specific budget scenarios with ten-year profiles reflecting current fiscal realities, as well as a third unconstrained scenario.

We started with the science. A yearlong community-wide study called "Snowmass" preceded the formation of P5, and based on this comprehensive work by the broad community, we identified five compelling lines of inquiry that show great promise for discovery over the next 10 to 20 years. These are the science drivers of the field, and they are: Use the Higgs boson as a new tool for discovery; pursue the physics associated with neutrino mass; identify the new physics of dark matter; understand cosmic acceleration, dark energy, inflation—and I assure you this inflation does not involve the consumer price index, as if you were wondering—and explore the unknown, new particles, interactions, and physical principles. I look forward to discussing these with you in more detail and why we are really so excited about them.

The prioritization is in the selection and timing of the specific projects to address these science drivers. Using an explicit set of selection criteria that we developed, we recommend some projects not be implemented and some existing efforts be reduced or terminated. Having made these choices, the field could move forward immediately with a prioritized and time-ordered recommended program, which is summarized in the report in Table 1 and includes the following features: The enormous physics potential of the LHC, which will be entering a new era with its planned upgrades, will be fully exploited. U.S. scientists continue to play very visible leadership roles, and the provided hardware would be designed and built here in the United States. The United States would host the world-leading neutrino program with an optimized set of short- and long-baseline neutrino oscillation experiments. You will hear more about that. The long-term focus of the program would be the Long Baseline Neutrino Facility, LBNF. The Proton Improvement Plan, PIP–II, project at Fermilab would provide the world's most powerful neutrino beam.

Large projects are ordered by peak construction time based on budget constraints, physics needs, and readiness criteria. This was an important thing the panel did. Several small- and medium-sized projects in areas especially promising for near-term discoveries and in which the United States is in a strong leadership position would move forward under all budget scenarios. Another important project of this type, the Dark Energy Spectroscopic Instrument, DESI, would also move forward except in the lowest budget scenario.

Specific investments would be made in essential accelerator R&D and instrumentation R&D. The interest expressed in Japan in hosting the International Linear Collider is an exciting development. Recommendation—recommended participation by the United States in project construction depends on a number of factors, some of which are beyond the scope of P5.

Six significant changes in direction are recommended. Of these I highlight here the first one: Increase investment in construction of new facilities. In constrained budget scenarios this will necessarily entail some judicious reductions in the research program. This represents a large commitment to building new experiments, which we see as essential. We titled our report "Building for Discovery." As detailed in the report and as I hope we can discuss today, the bang for the buck of relatively small incremental investments in particle physics would be really big.

The lowest budget scenario is precarious. It approaches the point beyond which hosting a large project in the United States would not be possible while maintaining the other elements necessary for mission success. Without the capability to host a large project, the United States would lose its position as a global leader in this field and international relationships that have been so productive would be fundamentally altered.

The broader impacts of particle physics research are many. These are summarized in Section 4 of the report. Topics include material science, medical imaging and therapy, computing, neuroscience, and bringing to life the earliest audio recordings.

There was continuous effort on many fronts throughout the P5 process to maintain direct community involvement. I see my time has run short so I would be happy to discuss that further with you in questions. It was a very important process and the way in which we work I think really resulted in the best possible plan for the field.

In conclusion, the P5 report offers important opportunities for U.S. investment in science, prioritized under tightly constrained budget scenarios in the charge, wondrous projects that address profound questions inspire and invigorate far beyond their specific fields and they lay the foundations for next-century technologies we can only begin to imagine. Historic opportunities await us enabled by decades of hard work and support. The U.S. particle physics community is ready to move forward.

Thank you, thank you for your support of U.S. science and for the opportunity to be here today. I look forward to hearing your thoughts and answering your questions.

[The prepared statement of Dr. Ritz follows:]

Testimony of

Steven Ritz, Ph.D.
Professor, University of California Santa Cruz
Director, Santa Cruz Institute for Particle Physics
Chair, Particle Physics Project Prioritization Panel (P5)

Before the
United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy

June 10, 2014

Chairman Lummis, Ranking Member Swalwell, and Members of the Subcommittee, thank you for inviting me to this important hearing. Particle physicists have come together to make a recommended plan that is driven by the science and meets tight fiscal constraints. The plan enables leadership by the United States in the global context, resolves key issues for the field, and envisions a continuous flow of exciting and important results while making essential investments in the future. I had the privilege of chairing the Particle Physics Project Prioritization Panel (P5), which developed and articulated this plan, and I am grateful for the opportunity to discuss with you our process and results. Much of the text below comes from our report, which HEPAP (the FACA panel advising the DOE and NSF) considered carefully and voted unanimously to approve on 22 May 2014.

As you know, particle physics explores the fundamental constituents of matter and energy, revealing profound connections underlying everything we see, including the smallest and largest structures in the Universe. The field is highly successful: investments have been rewarded recently with the discoveries of the heaviest elementary particle (the top quark), the tiny masses of neutrinos, the accelerating expansion of the Universe, and the Higgs boson. Since 2008, three Nobel Prizes related to particle physics were awarded. Current opportunities will exploit these and other discoveries to push the frontiers of science into new territory at the highest energies and earliest times imaginable. For these reasons, and more, research in particle physics inspires young people to engage with science.

Particle physics is global. The countries and regions that lead the field attract top minds and talent from around the world, inspire the next generation of scientists and technologists, and host international teams dedicated to a common purpose. Addressing the most compelling questions of the field is beyond the finances and the technical expertise of any one nation or region; nonetheless, the capability to address these questions is within reach of a cooperative global program. The U.S. and major players in other regions can together address the full breadth of the field's most urgent scientific questions if each hosts a unique world-class facility at home and partners in high-priority facilities hosted elsewhere. Strong foundations of international cooperation exist, with the Large Hadron Collider (LHC) at CERN serving as an example of a successful large international science project. Reliable partnerships and clearly defined roles and responsibilities are essential for success. Building international cooperation is an important theme of our report, and this perspective is finding worldwide resonance in an intensely competitive field.

The field has a vibrant, entrepreneurial spirit, with great ideas for excellent new projects, but these far exceed what can be executed with currently available resources. Tough choices were required. Our panel understood that an important part of our job was to recommend ways for the U.S. to invest purposefully in areas that have the biggest impacts and that make most efficient use of limited resources.

Since the 2008 P5 report, two major U.S. particle physics facilities have terminated operations, and inflation-adjusted funding in the U.S. for particle physics has continued to decline. In addition, primarily because of earlier strong investments, landmark discoveries have been made that inform choices for future directions. A new P5 panel was therefore charged to provide "an updated strategic plan for the U.S. that can be executed over a ten-year timescale, in the context of a twenty-year global vision for the field." The Charge calls for planning under two specific budget Scenarios, with ten-year profiles reflecting current fiscal realities:

A: FY2013 budget baseline flat for three years, then escalating at 2% per year
B: FY2014 President's budget request baseline flat for three years, then escalating at 3% per year

as well as for an unconstrained Scenario C. As the Charge states, these were considered "...not as literal budget guidance, but as an opportunity to identify priorities and make high-level recommendations."

We started with the science. A yearlong community-wide study, called "Snowmass", preceded the formation of our new P5. A vast number of scientific opportunities were investigated, discussed, and summarized in Snowmass reports. Based on this comprehensive work by the broad community, we identified five compelling lines of inquiry that show great promise for discovery over the next 10 to 20 years. These are the science Drivers:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles.

The Drivers are deliberately not prioritized because they are intertwined, probably more deeply than is currently understood. For example, some of the new physics models designed to solve other problems in particle physics also predict particles that could compose the dark matter; furthermore, the Higgs boson and neutrinos may interact with the dark matter. Other connections are possible, and there are good reasons to suspect that these deeper connections exist. Indeed, discovering those deep connections is a primary goal of the field. A selected set of different experimental approaches that reinforce each other is therefore required. These experiments sometimes address several Drivers. For example, collider experiments address the Higgs, Dark Matter, and Exploration Drivers. Furthermore, cosmic surveys designed to address dark energy and inflation also provide unique and

timely information about neutrino properties. The vision for addressing each of the Drivers using a limited set of experiments—their approximate timescales and how they fit together—is given in the report. What is learned at each step will inform the next steps.

The prioritization is in the selection and timing of the specific projects, which are categorized as large, medium, or small based on the construction costs to the particle physics program. To enable an optimal program, given recent scientific results and funding constraints, and using an explicit set of selection criteria, we recommend some projects not be implemented, others be delayed, and some existing efforts be reduced or terminated. Having made these choices, the field could move forward immediately with a prioritized and time-ordered recommended program, which is summarized in the report in Table 1 and includes the following features:

- The enormous physics potential of the LHC, which will be entering a new era with its planned high-luminosity upgrades, would be fully exploited. The U.S. continues to play essential roles in LHC construction, operations, and physics analysis, and U.S. scientists have very visible leadership roles. As in the past, the provided hardware would be designed and built in the U.S.
- The U.S. would host a world-leading neutrino program with an optimized set of short- and long-baseline neutrino oscillation experiments. The long-term focus of the program would be the Long Baseline Neutrino Facility (LBNF). The Proton Improvement Plan-II (PIP-II) project at Fermilab would provide the world's most powerful neutrino beam.
- Large projects are ordered by peak construction time, based on budget constraints, physics needs, and readiness criteria, as follows: completion of the Mu2e experiment at Fermilab, the high-luminosity LHC upgrades, and LBNF. Figure 1 in the report shows this time ordering, as well as the continuity of physics results across the program throughout the timeframe considered by P5.
- The interest expressed in Japan in hosting the International Linear Collider (ILC) is an exciting development. Participation by the U.S. in project construction depends on a number of important factors, some of which are beyond the scope of P5 and some of which depend on budget Scenarios. As the physics case is extremely strong, all Scenarios include ILC support at some level through a decision point within the next 5 years.
- Several medium and small projects in areas especially promising for near-term discoveries and in which the U.S. is in a strong leadership position, would move forward under all budget scenarios. These are the second- and third-generation dark matter direct detection experiments, the particle physics components of the Large Synoptic Survey Telescope (LSST) and cosmic microwave background (CMB) experiments, and a portfolio of small neutrino experiments. Another important project of this type, the Dark Energy Spectroscopic Instrument (DESI), will also move forward, except in the lowest budget Scenario.
- With a mix of large, medium, and small projects, important physics results will be produced continuously throughout the twenty-year P5 timeframe. In our

budget exercises, we maintained a small projects portfolio to preserve budgetary space for a set of projects whose costs individually are not large enough to come under direct P5 review but which are of great importance to the field. This is in addition to a small neutrino experiments portfolio, which is intended to be integrated into a coherent overall neutrino program.

- Specific investments would be made in essential accelerator R&D and instrumentation R&D. The field relies on its accelerators and instrumentation and on R&D and test facilities for these technologies.

Several significant changes in direction are recommended:

- Increase investment in construction of new facilities. In constrained budget scenarios, this implies an increased fraction of the budget devoted to construction, and this will necessarily entail some judicious and painful reductions in the fractions of the budget invested in the research program and in operations. This represents a large commitment to building new experiments, which we see as essential. Particle physics is a dynamic field, with researchers nimbly changing course to invent and pursue great new opportunities.
- Reformulate the long-baseline neutrino program as an internationally designed and funded program, with Fermilab as host.
- Upgrade the Fermilab proton accelerator complex to produce the world's most powerful neutrino beam, redirecting former Project-X activities and temporarily redirecting some existing accelerator R&D toward this effort.
- Increase the planned investment in second-generation dark matter direct detection experiments.
- Increase particle physics funding of CMB research and projects in the context of continued multiagency partnerships.
- Based on new physics information, realign activities in accelerator R&D with the P5 strategic plan. Redirect muon collider R&D and consult with international partners on the early termination of the MICE muon cooling R&D facility. In the general accelerator R&D program, focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid- and far-term accelerators.

As discussed in the report, budget Scenario B allows for a balanced program. Scenario A differs from B by approximately $30M per year until FY2018, and thereafter has a one percent per year escalation difference. While seemingly relatively small, these differences would have very large short- and long-term impacts. Relative to Scenario A, Scenario B would enable the large scientific returns of DESI, world-leading accelerator and instrumentation development research would not be curtailed, U.S. research capability – including a thriving theory program – would be maintained, the Mu2e experiment at Fermilab would be completed on time, the long-baseline neutrino program would proceed without delays, and third-generation dark matter direct detection capabilities would be fully developed on time. As valuable as each of these items is, they simply do not fit in Scenario A. The bang for the buck of the incremental investment would be really big.

Scenario A is precarious: it approaches the point beyond which hosting a large ($1B scale) project in the U.S. would not be possible while maintaining the other elements necessary for mission success, particularly a minimal research program, the strong U.S. leadership position in a small number of core, near-term projects, which produce a steady stream of important new physics results, and advances in accelerator technology. Without the capability to host a large project, the U.S. would lose its position as a global leader in this field, and the international relationships that have been so productive would be fundamentally altered.

The recommendations for the unconstrained budget Scenario C focus on three additional high-priority activities: develop a greatly expanded accelerator R&D program that would emphasize the ability to build future-generation accelerators at dramatically lower cost; play a world-leading role in the ILC experimental program and provide critical expertise and components to the accelerator, should this exciting scientific opportunity be realized in Japan; and host a large water Cherenkov neutrino detector to complement the LBNF large liquid argon detector, unifying the global long-baseline neutrino community to take full advantage of the world's highest intensity neutrino beam at Fermilab.

I'd like to add a few words about our process, which is also described in Appendix C of the report. The work by P5 grew directly from the preceding community-wide study, and there was a continuous effort on many fronts throughout the P5 process to maintain direct community engagement, including workshops, physical and virtual town halls, consultations, presentations, and a public submissions portal. We had a deeply engaged panel, consisting of leaders from the U.S. and abroad, who looked beyond their own subfields to craft an optimal plan for the whole field. In our deliberations, no topic or option was off the table. Every alternative we could imagine was considered. We operated by consensus: even when just one or two individuals voiced concerns, we worked through the issues. Toward the end of the process, a draft of the report was sent to eleven community members for peer review, and their thoughtful and frank comments helped to improve the quality of the report considerably.

In conclusion, the P5 report offers important opportunities for U.S. investment in science, prioritized under the tightly constrained budget scenarios in the Charge. Wondrous projects that address profound questions inspire and invigorate far beyond their specific fields, and they lay the foundations for next-century technologies we can only begin to imagine. Historic opportunities await us, enabled by decades of hard work and support. The U.S. particle physics community is ready to move forward.

Thank you very much for your interest in this work and the opportunity for me to share these results.

Steven Ritz

Professor of Physics

last revised: June 2014

RESEARCH INTERESTS

High Energy Particle Physics and High Energy Astrophysics

Most recent projects and main roles:

- 2013-present: LSST Camera Project Scientist
- 2003-2009: Fermi Gamma-ray Space Telescope (nee GLAST) Project Scientist
- 2004-2013: Fermi Large Area Telescope (LAT) Deputy PI

Co-Investigator or Collaboration Member on these experiments:

- 2013-present LSST
- 1996-present: Fermi/GLAST
- 1988-1998: ZEUS at DESY
- 1986-1988: ALEPH at CERN
- 1984-1988: TASSO at DESY

EMPLOYMENT HISTORY

2010-present: SCIPP Director, UCSC (Associate Director 2009-2010)
2009-present: Professor of Physics, UCSC
2005-2009: Adjunct Professor of Physics, University of Maryland, College Park
1998-2009: Astrophysicist, Particles and Fields, NASA/Goddard Space Flight Center
1996-1998: Associate Professor of Physics, Columbia University, New York, NY
1990-1996: Assistant Professor of Physics, Columbia University, New York, NY
1988-1990: Post Doctoral Research Scientist, Columbia University, Nevis Labs

EDUCATION

1988	Ph.D., Physics, University of Wisconsin-Madison
1982	M.A., Physics, University of Wisconsin – Madison
1981	B.A., with High Honors in Physics, and Music, Wesleyan University, Middletown, CT

HONORS AND AWARDS

NASA Outstanding Leadership Medal
Fellow, American Physical Society
Sloan Foundation Fellow in Physics
Bertman Prize in Physics, Wesleyan University

RECENT PROFESSIONAL ACTIVITIES and COMMUNITY SERVICE (partial list)

2013-14 Chair, Particle Physics Project Prioritization Panel (P5)
2010-13 NASA NAC Astrophysics Subcommittee (APS) member and chair of PhysPAG
2010-present LIGO Astronomy and Astrophysics Advisory Panel (chair starting in 2011)
2010 NRC Panel on Implementing Recommendations from the `New Worlds, New Horizons' Decadal Survey
2009 Chair, NSF-DOE Particle Astrophysics Scientific Assessment Group (PASAG) for HEPAP
2009-2010 NRC Astro2010 "Decadal Survey" Committee
2009-present Editorial Board, Reports on Progress in Physics, Institute of Physics, London
2008-2013 Fermilab Physics Advisory Committee (PAC), Chair in 2013

Chairwoman LUMMIS. Thank you, Dr. Ritz.
I now recognize Dr. Drell to present her testimony.

TESTIMONY OF DR. PERSIS DRELL,
DIRECTOR EMERITA,
SLAC NATIONAL LABORATORY

Dr. DRELL. Chairman Lummis, Ranking Member Swalwell, Members and staff of the Subcommittee, I too am very pleased to be here today to provide my perspective on the future of particle physics in light of the new P5 report.

It is a particular pleasure for me to participate in these hearings. Twelve years ago I was part of the HEPAP subpanel that recommended the creation of P5. We believed that such a prioritization process would be essential in ensuring that we judiciously use the available resources in our field—both human and financial—to pursue a balanced, diverse, and exciting program. It is not possible to pursue all of the scientific opportunities we see before us. We must choose wisely.

In my opinion, this most recent P5 report does an outstanding job of setting the path forward for U.S. particle physics. Fully recognizing that resources are constrained, the report sets forth a staged plan focusing on the most compelling science, building on U.S. strengths across the field, ensuring that the United States retains a leadership role in this important area of research.

Before discussing the report, it helps to remember why having a healthy particle physics program is important for our Nation. I will start with the science. Particle physics asks very basic and fundamental questions about the world we live in. It is incumbent on us to pursue the answers to those questions, as has every great society that has preceded us for millennia.

In addition, the fundamental nature of these questions draws interest to science generally. Just look at the excitement over the discovery of the Higgs. And while many factors go into an individual's decision to pursue a career in science, the idea of big fundamental questions out there just waiting to be answered is certainly one enticement.

Finally, particle physics is an essential part of the fabric of the physical sciences in the United State. It contributes broadly to other disciplines and benefits enormously from research in other fields.

A vivid illustration of the interplay between different scientific fields comes from SLAC National Accelerator Lab, where I was the director from 2007 to 2012. SLAC was born as a particle physics laboratory. We turned off our last accelerator for particle physics in 2008. In 2009 we turned on the world's first x-ray free-electron laser, the Linac Coherent Light Source. The LCLS is a tool for chemistry, for biology, for materials science, for condensed matter physics. It is not a tool for particle physics. However, its rapid early success relied on years of research and development in particle physics aimed at making precision-controlled beams of electrons for future linear colliders.

The challenge we have been facing for some time now is how to craft a healthy particle physics program in the United States with constrained resources and an increasingly international environ-

ment. The P5 subpanel has done an outstanding job of charting our course. They started, as Dr. Ritz said, with the science. To be successful we need to focus on and prioritize the opportunities that give us the most transformational scientific advances and attract the best talent.

Following a yearlong process of engaging the community, P5 articulated five intertwined science drivers for the field and then developed criteria for their prioritization process and evaluated the projects against those criteria to craft the program for the future. The P5 process engaged the entire community, both laboratories and the university community. The transparency and inclusivity of the process were phenomenal and exceptionally well done. The community is deeply in debt to the leadership shown by Dr. Ritz. The plan P5 crafted reflects the voices, priorities, and thoughts of many in our community. It is the reason the community can stand behind this plan.

In ending, I would like to note that the field of particle physics in the United States and in the world is changing dramatically. We used to define ourselves solely in terms of our primary accelerator tools, but to quote the former White House Science Advisor Jack Marburger, "Opportunities have emerged for discovery about the fundamental nature of the universe that we never expected and technology places those discoveries within our reach."

Going forward, we must have a program that allows us to focus efforts across a broad variety of tools to realize the new scientific opportunities. That includes observatories in space, telescopes on mountains, sensitive detectors in deep caves under the earth, in addition to our traditional accelerator tools.

The plan outlined by P5 and supported by the particle physics community is a realistic, executable roadmap for a new era and it will enable a future of discovery that is every bit as exciting as our past. It was hard but the results are worth the effort. This roadmap will allow the field to move forward and to deliver success.

Thank you for the opportunity to share my views with you today.

[The prepared statement of Dr. Drell follows:]

Testimony of

Persis Drell, Ph.D.
Professor
Stanford University
SLAC National Accelerator Laboratory

Before the
United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy

A Review of the P5: The U.S. Vision for Particle Physics after Discovery of the Higgs Boson

June 10, 2014

Chairman Lummis, Ranking Member Swalwell and Members of the Subcommittee, I am pleased to be here today to provide my perspective on the future of particle physics in the United States, particularly in light of the new report from the P5 subpanel of the High Energy Physics Advisory Panel, also known as HEPAP.

It is a particular pleasure for me to participate in these hearings. Twelve years ago, I was part of the subpanel that recommended the creation of P5, the Particle Physics Project Prioritization Panel, which is charged with advising HEPAP and the agencies on priorities for scientific projects within our field. We believed that prioritization would be essential in ensuring that we judiciously use the available resources in our field – both human capital and financial – to pursue a diverse and exciting program in particle physics. A balanced program is necessary for the vitality of our field, and only can be achieved if we manage our resources well. It is not possible to pursue all of the scientific opportunities we see before us. We must choose wisely.

In my opinion, this most recent P5 report does an outstanding job of setting a path forward for the U.S. particle physics program and making those difficult choices. Fully recognizing that resources are constrained, the report sets forth a staged plan that focuses on the most compelling science, builds on U.S. strengths across the field, and ensures that the United States retains a leadership role in this important area of research.

Before discussing the P5 report, it helps to remember why having a healthy particle physics program is important for our nation. There are many interrelated factors that make a compelling argument for a strong particle physics program in the U.S.

I will start with the science. Particle physics asks very basic and fundamental questions about the world in which we live. What is the nature of the universe? What are we made of? It is incumbent on us to pursue the answers to these questions, as has every great society that has preceded us for millennia.

In addition, the fundamental nature of the questions related to particle physics draws interest to science generally. Two recent examples are the excitement over the discovery of the Higgs boson at the Large Hadron Collider at CERN, and the tremendous interest in the recent announcement that we may have observed evidence of gravitational waves in the cosmic microwave background. This latest result, which was quite unexpected, may provide a long-sought smoking gun for the theory of cosmic inflation, and a window into the first epochs of our universe.

People of any age and background can understand and relate to these ideas in some way. And while many factors go into an individual's decision to pursue a career in science, the idea of big, fundamental questions out there just waiting to be answered is certainly one enticement.

Finally, particle physics is an essential part of the fabric of the physical sciences in the United States, contributing broadly to other disciplines such as accelerator

science and large-scale computing, and benefiting enormously from research in other fields.

A vivid illustration of the interplay between different scientific fields comes from SLAC National Accelerator Laboratory, where I was director from 2007 to 2012. SLAC was born as a particle physics laboratory. We turned off our last accelerator for particle physics in 2008, and our particle physics program is now primarily focused on mid-scale experiments probing the mysteries of dark matter and dark energy.

In 2009 we turned on the world's first X-ray free-electron laser, the Linac Coherent Light Source, whose ultra-short, ultra-bright X-ray pulses are revolutionizing our ability to look at matter on the atomic scale. The LCLS is a tool for chemistry, biology, materials science and condensed matter physics. It is not a tool for particle physics. However, the spectacular early success of this wonderful new scientific tool relied on years of R&D aimed at making precision-controlled beams of electrons for future linear colliders for high energy physics. Moreover, the volumes of data produced by the LCLS are far beyond what most scientists who use X-rays were used to. We were able to use the tools and expertise developed for particle physics at the lab to deliver dramatic early science with these large data sets.

And the benefits cut across fields in both directions. For instance, superconductivity was discovered by and is studied by condensed matter physicists. Every accelerator being built for particle physics – from the LHC to the Long Baseline Neutrino Facility and perhaps, someday, an International Linear Collider – relies on superconducting technology, and advances in understanding superconductivity will benefit particle physics directly.

The challenge we have been facing is how to craft a healthy particle physics program in an increasingly international environment where, in fact, the premier accelerator operating at the highest energy is in Europe. For the first time, we are operating a truly global machine with the LHC, and that has led to great changes in our field.

What is the path forward for a healthy particle physics program in the United States for the future? The P5 subpanel has done an outstanding job of charting our course. They started with the science. To be successful, we will need to focus on and prioritize the opportunities that will give us the most transformational scientific advances and will attract the best talent.

Following a year-long process of engaging the community, P5 articulated five intertwined science drivers for the field, as you have heard from Dr. Steve Ritz:

- Use the Higgs boson as a new tool for discovery

- Pursue the physics associated with neutrino mass

• Identify the new physics of dark matter

• Understand cosmic acceleration: dark energy and inflation

• Explore the unknown: new particles, interactions and physical principles.

These drivers highlight some of the most exciting areas of research within particle physics: They recognize that with the discovery of the Higgs boson, we now have a new tool we can use to examine our understanding of matter at its most fundamental level. They highlight the mysterious neutrinos as particles so bizarre in their properties and behaviors that they defy a clear understanding. They emphasize our continuing struggle to understand the 95 percent of the universe that is made of what we call dark matter and dark energy, things we fundamentally don't know or understand. Finally, the drivers acknowledge that we ***know*** we don't have a complete understanding of the world around us at its most basic and fundamental level, and we ***know*** there are surprises ahead for us.

Having articulated the science goals, P5 then developed two sets of criteria for their prioritization process: one for the optimization of the program, and another for the evaluation of individual projects against those criteria in order to craft a program for the future of the field.

The transparency of the process and the clarity of the P5 arguments are essential for the community. The integrity of the process was incredibly important in order to get the community to support the outcome of the prioritization process. In addition, the P5 process engaged the entire community. There were several components to this engagement to ensure everyone's voice was heard:

- A website was maintained that contained information, frequent news, meetings, and a submissions portal with a public archive.
- There were three large public meetings.
- There were three physical town hall meetings and three virtual town hall meetings. The virtual town halls were particularly effective for hearing from younger members of our scientific community.
- More than 500 physicists convened in a nine-day "Snowmass" community study meeting to work through and digest the P5 input.
- A special effort was made to reach out to younger colleagues; this included a Twitter feed and emails to Snowmass Young Physicist mailing lists and to principal investigators urging them to inform their students and postdocs about the process.

Literally thousands of physicists across the U.S. participated in these events, and the committee received hundreds of written inputs. The transparency and inclusivity of this process were phenomenal and exceptionally well done. The process reflects the voices, priorities and thoughts of many in our community, and conveys the excitement so many of us feel about the scientific frontiers that should be pursued. It

is the reason that the community can stand united behind this plan.

Let me end on a somewhat philosophical note. The field of particle physics in the United States and in the world is changing dramatically. We used to define ourselves solely in terms of our primary tools – the big atom smashers or accelerators that let us collide particles at the highest possible energies to uncover the basic building blocks of matter. But, to quote the former White House Science Advisor, Jack Marburger, "Opportunities have emerged for discovery about the fundamental nature of the universe that we never expected, and technology places these discoveries within our reach." We must have a program that allows us to focus efforts across widely separated disciplines to realize the new scientific opportunities. That includes a broad variety of observatories in space, telescopes on mountaintops and sensitive detectors in deep caves under the earth, in addition to our traditional accelerator tools.

The plan outlined by P5, and supported by the particle physics community, is a new beginning for particle physics. It is a realistic and executable roadmap for a new era and it will enable a future of discovery just as exciting as our past, with a balanced program exploiting a wide range of tools. This was hard, but the results are worth the effort. This roadmap will allow the field to move forward and to deliver success.

Thank you for the opportunity to share my views with you today.

Persis S. Drell
Professor, Stanford University and SLAC National Accelerator Laboratory

Persis S. Drell is Professor of Physics at Stanford University and Professor and Director Emerita at SLAC National Accelerator Laboratory. She received her B.A. in mathematics and physics from Wellesley College in 1977. She received her Ph.D. in atomic physics from the University of California, Berkeley, in 1983. She then switched to high-energy experimental physics and worked as a postdoctoral scientist with Lawrence Berkeley National Laboratory. She joined the faculty of the Physics Department at Cornell University in 1988. In 2000, she became head of the Cornell high-energy group; in 2001, she was named deputy director of Cornell's Laboratory of Nuclear Studies. In 2002, Dr. Drell accepted a position as Professor and Associate Director, Research Division at SLAC. She was the Deputy Project Manager for the Fermi Gamma Ray Space Telescope 2004-2005. In 2007 she was named Director at SLAC. She stepped down from the SLAC Directorship in 2012. Her current research activities are in Particle Astrophysics and Free Electron Laser science.

Dr. Drell has been the recipient of a Guggenheim Fellowship; a National Science Foundation Presidential Young Investigator Award; she is a fellow of the American Physical Society; a member of the American Academy of Arts and Sciences; and a member of the National Academy of Sciences. In 2012 she was the recipient of the 2012 Helmholtz International Fellow Award for outstanding scientific achievement.

Chairwoman LUMMIS. Thank you, Dr. Drell.

And now the Chair recognizes Dr. Lockyer for your opening statement.

TESTIMONY OF DR. NIGEL LOCKYER, DIRECTOR, FERMI NATIONAL ACCELERATOR LABORATORY

Dr. LOCKYER. Thank you. Good morning, Chair Lummis, Ranking Member Swalwell, Congressman Hultgren, and other Members.

The P5 report lays out a bright future for particle physics community and the Fermilab strongly supports the recommendations of the P5 report and it has embraced its role in implementing the strategic vision for the field. If implemented, the report should maintain and reinvigorate U.S. leadership in particle physics.

For the benefit of the Ranking Member, Fermilab is located 42 miles west of Chicago in Batavia, Illinois. It is a 68,000—I wish it was—a 6,800 acre laboratory, 1,700 employees, 2,100 users. It has the largest accelerator complex in the United States and delivers the most intense beams of neutrinos not only at Fermilab but also to Minnesota. So the beams themselves travel through the earth, which is one of the more interesting properties of neutrinos. They travel through just about anything.

Fermilab is largely open to the public and is the home of a small bison herd, better known as buffalo, and Fermilab is managed by Fermilab Research Alliance, a partnership between the University of Chicago and the URA, an association of 88 universities. Forty thousand K through 12 students participated in activities at Fermilab last year. Eight thousand visitors took tours or dropped into the Lederman Science Center, and over 1,000 college and university students are involved in on-site program and internships.

So to put things in a little bit of context, the United States has been amongst the leaders in particle physics for the last several decades. Fermilab operated the highest energy collider in the world. The United States pioneered superconducting magnet technology and built the first large superconducting accelerator, the Tevatron, which was 4 miles in circumference. Over 1,000 graduate students received Ph.D.'s and over 1,000 scientific papers were published from that program. The discovery of the top quark, as you heard from the Chair, was the crowning achievement, the heaviest fundamental particle ever observed. Today, the Large Hadron Collider has the highest energy in the world.

So what is next for the United States? P5 has endorsed a portfolio of projects. I will comment on three: the LHC, the ILC, and neutrinos, LBNF. Our goal is to have one optimal accelerator-based neutrino program in the world—okay—and not three suboptimal facilities, so strictly limited by fiscal and human resources and not by the ambitions of the scientists. We are trying to collect everybody together into one single program.

P5 recommends we fully exploit the Large Hadron Collider. The program has tremendous discovery potential, and I think the anticipation in our community is really something when you ask people about what they expect to come out of the program in the next few years. It is going to be the highest energy again. They are stepping up the energy and, you know, everybody is quite excited about that.

So the existing science, as you mentioned, attracts some of the brightest students into physics. U.S. technology contribution to the LHC in the future is critical. The high field magnet technology has now evolved to yet a new type of conductor, niobium 310, and the United States is the only place that makes that. That has been done with a collaboration by DOE Office of Science labs, Brookhaven, Lawrence Berkeley lab, and Fermilab.

The P5 report is supportive of U.S. involvement in the International Linear Collider. The 20-mile-long accelerator has been designed by a global team over the last decade and Japan is now seriously considering hosting the machine. The United States and Fermilab is well suited to contribute technically to the machine. In fact, it is hard to imagine Japan being able to proceed without our partnership. It is truly a huge undertaking and certainly worthy of a global project.

Our community has decided that neutrinos are where the action is. You have 100 billion neutrinos going through your thumbnail per second as you sit here in this room. The particle indeed is very mysterious and continues to surprise physicists after every major measurement. It has to be important.

P5 envisioned a program of experiments over short distances and one over a long distance, all the way to the Sanford Underground Research Facility in Lead, South Dakota. The old Homestake mine where Ray Davis, my officemate at the University of Pennsylvania, did his work to earn the Nobel Prize for detecting neutrinos from the sun.

For LBNF there is a near detector and a far detector, one at Fermilab and one in South Dakota. The detector would sit about a mile underground and be, at least in the present configuration, 40,000 tons of liquid argon, or liquid air if you like.

The impact of fundamental physics is significant, too. Fermilab is making a concerted effort to commercialize its technology to help create jobs for Americans, build industries, and contribute to society. Today, we see small, portable, high-powered accelerators as having the potential to have major impact on numerous industries such as microelectronics, transportation, and the national gas industry. I am happy to expand upon these in our discussions.

Finally, let me say again that the P5 report lays out a bright future for the U.S. particle physics community in the global context. The report has made clear choices and Fermilab is beginning to implement these choices along with our colleagues at OHAP and the Department of Energy.

[The prepared statement of Dr. Lockyer follows:]

Testimony of

Nigel S. Lockyer, Ph.D.
Director
Fermi National Accelerator Laboratory (Fermilab)

Before the

United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy

June 10, 2014

Chairman Lummis, Ranking Member Swalwell and Members of the Subcommittee, I appreciate being invited here today to provide the Fermilab view on the future of particle physics in the US and in the context of the new report from the P5 subpanel of the High Energy Physics Advisory Panel. The P5 report lays out a bright future for the particle physics community and Fermilab strongly supports the recommendations of the P5 report and has embraced its role in implementing the strategic vision for the field.

Fermi National Accelerator Lab (Fermilab) is unique to DOE as it is a single-program laboratory and the only one devoted to particle physics. The laboratory's 1732 employees, and 2097 users drive discovery in particle physics by building and operating world-leading accelerator and detector facilities, performing pioneering research with national and global partners, and developing new technologies for science that support US industrial competitiveness. Fermilab's accelerator complex is the nation's largest and produces the world's most powerful high- and low-energy neutrino beams. Fermilab Research Alliance, LLC manages Fermilab for the Department of Energy. FRA is an alliance of the University of Chicago and the Universities Research Association Inc., a consortium of 88 universities. Fermilab's 6800 acres site, much of which is open to the public, is located 42 miles west of Chicago, in Batavia Illinois, and includes a small herd of bison.

The context for the P5 report "Building for Discovery" can best be understood by a quick summary of recent history of the U.S. participation and leadership in the field. Until 2012, the Tevatron Collider at Fermilab operated at the highest energy in the world for 26 years. To develop and operate the Tevatron, Fermilab pioneered superconducting magnet technology – a capability which now enables other fields in science and energy. It was the world's first large accelerator (4 miles in circumference) using superconducting magnet technology. As a testament to the role these DOE facilities play in the education and training of the nation's next generation workforce, there were 1047 peer reviewed scientific publications and 1021 Ph.D students that graduated from the two main experiments. Scientifically speaking, the discovery of the top quark, the heaviest fundamental particle ever observed, was the crowning achievement.

Fast forward to today, the Large Hadron Collider (LHC) at CERN, Geneva Switzerland, now provides the highest energy particle collisions and will do so for the foreseeable future. The rapid discovery of the Higgs Boson in 2013 is a tremendous testament to the technical skill and devotion of thousands of scientists and engineers from around the world in constructing what has been argued to be the most complex scientific instrument ever built. The LHC has been a huge success by any measure and the U.S. role is not insignificant – with over 2000 U.S. scientists, comprising over 25% of the total number of scientists involved. Clearly the US should be proud of their contribution to this worldwide effort.

With this as the context, based on extensive community input, the recent P5 report

lays out a decade long plan for the US particle physics community and clearly identifies the central role of Fermilab within that plan. Congress routinely asks the scientific community to set priorities. The P5 recommendations endorse a portfolio of projects that will keep the US at the frontiers of the field. It plays to the strengths of the US program such as accelerator and detector technology, big data, and data analysis. Accelerator stewardship is our field's preeminent core technology that will drive future scientific discovery in particle physics, in related sciences, such as the accelerator-based light sources at Argonne National Laboratory (ANL), Brookhaven National Lab (BNL), Lawrence Berkeley National Lab (LBNL), and the SLAC National Accelerator Laboratory (SLAC), as well as in new technologies to create future businesses.

The plan also would ensure the LHC program is fully exploited. The US contribution to the high luminosity upgrade is critical, as the quadrupole magnets utilize a new high field strength superconducting wire technology, Nb3Sn, never before used in an accelerator. This magnet technology was developed by Fermilab, BNL, and Lawrence Berkeley National Laboratory (LBNL) by extensive R&D over the last twenty years. Our field has a laudable history of producing superconducting accelerator magnets, which was a primary genesis for MRI magnets now found in nearly every hospital throughout the nation.

The P5 report also highlights the excitement over potential major discoveries in the areas of dark matter and dark energy. My colleague on the panel, Natalie Roe, will expand upon these.

The P5 report also recognizes the importance of U.S. based efforts and recommends that Fermilab hosts the world accelerator-based neutrino flagship project, the Long Baseline Neutrino Facility, LBNF. The global partnership model for neutrinos is appropriate because of the large scale of the experiment. We do the science together but at the end of the day, we own the technology intellectual property (IP) that has broad value to the nation.

The LBNF project will build on the momentum generated by the existing Long Baseline Neutrino Experiment (LBNE) collaboration, which already comprises over 500 scientists, 83 institutions and 10 countries. Tremendous progress has been made in preparing for the neutrino beams and the so called near-detector at Fermilab and the huge far-detector located 800 miles to the west in the Sanford Underground Research Facility (SURF) at the Homestake mine is South Dakota. SURF has been built with funds from the state of South Dakota, generous private donations, and federal funding, creating a modern state of the art underground laboratory. The far-detector will sit almost a mile underground. Core samples have been taken and the conditions are now known to be ideal. The R&D phase is ready to move into the detailed design stage. With the strong endorsement of the P5 report, the team is ready to grow quickly and move rapidly forward.

Let me back up and explain why we should even care to study neutrinos. The

neutrino is the most prevalent particle with mass in the universe. It has to be important. As one of the most mysterious of particles we have studied it continues to surprise its practitioners at each step of discovery. There are properties of neutrinos, such as the ultra-tiny mass, the type of mass, and the nature of matter and anti-matter that continue to confound the standard model of particle physics. At this moment, there are 100 billion neutrinos passing through your thumbnail per second, mostly generated in the core of the sun, but we can also make them. However, not one will leave a trace. In order to study neutrinos, massive detectors are required and intense neutrino beams from accelerators will enable the mysteries of these particle to be further unraveled.

To be a global leader in a project like this and be successful, Fermilab and the U.S. must be a reliable partner, as we are in the LHC abroad, throughout the lifetime of the project. We have already begun intense discussions to enable the vision of this project to be a reality. Fermilab has begun conversations with CERN, Italy, UK, India, Brazil, and Japan on the subject of forming a new collaboration on neutrinos, building on the success of LBNE collaboration. This enlarged international partnership will offset the U.S. share of the total project cost and leverage the tens of millions of dollars invested to date.

In addition, the technology to generate these neutrinos will be transformative for the field and the world. Accelerators at Fermilab today produce the most powerful beams of neutrinos in the world, comparable to that of the sun. In order to study the mysterious properties of the neutrino, even more intense beams are required. The scientific pressure to produce more and more intense beams of neutrinos demands more powerful and more energy-efficient accelerator technologies. We are pleased that the P5 report endorsed the PIP-II superconducting radiofrequency (SRF) linear accelerator project that once constructed will ensure the US continues to lead the world with the most powerful neutrino beams. It will also ensure the US leads in the SRF accelerator technology. The Department of Energy has recently recognized Fermilab with one of its prestigious early career awards in this area.

The SRF accelerator technology is taking the world by storm and has the potential for enormous scientific and economic value. One scientific example is the International Linear Collider (ILC). Japan is now seriously considering hosting this approximately 20 mile long accelerator using SRF technology. The P5 report highlights the potential exciting science if it is constructed.

Many breakthroughs in SRF technology came from R&D associated with the initial development aimed at the ILC. Fermilab is launching a new commercialization initiative, for the first time in its history, to exploit this technology for applications in natural gas, microelectronics, transportation, cleaning of flue gas, and water treatment.

The P5 report lays out a bright future for the particle physics community and Fermilab strongly supports the recommendations of the P5 report and has embraced its role in implementing the strategic vision for the field. Along with our DOE Office of Science partner labs, Argonne National Laboratory, Brookhaven National Laboratory, Jefferson Lab, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, and SLAC National Laboratory, we are excited, energized, and up to the challenge.

Nigel Lockyer

Biography

Nigel Lockyer began his tenure as director of Fermi National Accelerator Laboratory, America's premier laboratory for particle physics research, on September 3, 2013.

An experimental particle physicist, Lockyer was most recently director of TRIUMF, Canada's national laboratory for particle and nuclear physics. He was also a professor of physics and astronomy at the University of British Columbia.

Under his leadership, TRIUMF formulated a vision for ascending the world stage in nuclear physics using rare-isotope beams to address some of the most fundamental questions in science. Lockyer expanded the laboratory's operations by 25 percent, earning a reputation as a national leader and team-builder. He also developed a strong working partnership among Canada's major science laboratories and built international collaborations.

Prior to leading TRIUMF, Lockyer was a professor of physics at the University of Pennsylvania. His research focused on high-energy particle experiments at the energy frontier, with an interest in testing fundamental symmetries and studying the heaviest quarks. While at Pennsylvania, Lockyer developed his interest in the applications of physics to real-world problems; he worked with the Penn Medical School on proton therapy for cancer and detectors for medical physics.

He has served at Fermilab in a variety of capacities dating back more than 25 years. Lockyer performed research for many years at the "Collider Detector at Fermilab" experiment at the laboratory's Tevatron particle accelerator, serving as the experiment's co-spokesperson from 2002 through 2004. CDF achieved world acclaim for discovering and studying the top quark, one of the fundamental building blocks of nature. He was a Fermilab guest scientist from 2001 to 2005 and a visiting scientist during the summers of 1987 and 1988.

Born in Scotland and raised in Canada, Lockyer received his graduate education in the United States. He earned his B.S. in physics from York University in Toronto and his Ph.D. in physics from The Ohio State University.

He is a Fellow of the American Physical Society and a recipient of the society's 2006 Panofsky Prize for his leading research on the bottom quark.

8/27/13

Chairwoman LUMMIS. Thank you, Dr. Lockyer. And we don't know why those buzzers go off when they do, but we appreciate your unflappability with regard to that.

I now recognize Dr. Roe to present her testimony.

TESTIMONY OF DR. NATALIE ROE,
DIRECTOR, PHYSICS DIVISION,
LAWRENCE BERKLEY NATIONAL LABORATORY

Dr. ROE. Thank you, Chairman Lummis, Ranking Member Swalwell, distinguished Members of the Subcommittee, and thank you for inviting me to participate in this important hearing.

I completed my graduate studies in particle physics 25 years ago at SLAC. My thesis experiment had roughly a dozen scientists, cost less than $1 million, and it was built, commissioned, took data, and published its main results all during my time as a grad student.

Today, the Large Hadron Collider is a multibillion-dollar machine. The design of the LHC began over 20 years ago and each of the four experiments has several thousand physicists. With suitable upgrades, the LHC will likely continue for another 20 years. This increase in scale, in size, in dollars, in time, and in human capital is necessary to extend our reach to higher energies and higher intensities.

Although I have witnessed these dramatic changes in our field, small- and intermediate-scale projects, such as the one I participated in at Stanford, still have tremendous potential to make groundbreaking discoveries. This was recognized in the P5 report, which stressed the value of a balanced portfolio, and my goal today is to explain this recommendation of P5 and provide a few key examples of small- and medium-sized projects with big potential.

As evidenced by my personal experience, these smaller projects provide excellent training for students and postdocs. Smaller experiments can go after "blue-sky" ideas. They can be nimble and take risks with the potential to shake up the field. A prime example of what can come out of a small project is a project started in the early 1990s called the Supernova Cosmology Project, led by a young physicist named Saul Perlmutter. Saul's plan was to use supernovae, or exploding stars, to measure the rate at which gravity was causing the expansion of the universe to slow down. In what is now a famous result, Saul and his team had measured enough supernovae by 1998 to conclude that the expansion of the universe was in fact accelerating. The expansion was going faster and faster. In other words, some force counteracting gravity is at work in the universe. We call it dark energy because we just don't know what it is.

The result was completely unexpected and it was a dramatic event for the physics community. This work, this small project, ultimately led to a Nobel Prize. Saul's discovery has attracted the attention of scientists all over the world and inspired a new generation of students to study physics. Out of this small experiment a whole new field of research has been created and our concept of the universe has been fundamentally changed forever. Obviously, the return on the Federal Government's investment in this case was huge.

And dark energy remains one of the biggest unanswered questions in fundamental physics today. Much more precise data is needed to figure out which of the many proposed theories is correct. The Dark Energy Spectroscopic Instrument, or DESI, is one of the small-scale projects recommended by P5 that could tackle this problem. DESI reuses an existing telescope at Kitt Peak, Arizona, and installs a new instrument and dedicates it to a wide-area survey of the universe. DESI will bring a new level of precision to the study of dark energy and could be built for about $40 million over four years. DESI would enable the United States to remain a leader in dark energy research into the next decade.

P5 also recommended that the United States should remain a leader in the search for dark matter. Dark matter outweighs normal matter by about 6 to 1, and without it, the stars in our galaxy would fly off into space. A deep underground site to carry out this type of dark matter search already exists in the United States in the State of South Dakota. It is called the Sanford Underground Research Facility, or SURF. SURF hosts the world's current most sensitive dark matter experiment and it could provide a home for one of the next-generation dark matter experiments that P5 recommended. SURF is also where the neutrino detectors for the long baseline neutrino facility that Nigel discussed will be located.

Particle physics has come very far in the past century, finally discovering the long-sought Higgs boson, only to realize that we do not understand what makes up 95 percent of the universe, the mysteries that we call dark matter and dark energy. This is both humbling and exciting. P5 has recommended a carefully selected set of interlocking experiments, including a number of small- to medium-sized projects in this cosmic frontier. This program is optimized to achieve the most cost-effective approach in our quest to further understand the nature of matter, energy, space, and time.

Thank you for your attention. I very happy to answer any questions you may have.

[The prepared statement of Dr. Roe follows:]

Testimony of

Natalie Roe, Ph.D.
Physics Division Director
Lawrence Berkeley National Laboratory

Before the

United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy

June 10, 2014

Chairman Lummis, Ranking Member Swalwell and distinguished Members of the Subcommittee, thank you for inviting me to participate in this important hearing. The nation's capacity to innovate, grow its economy and advance societal solutions depends on our ability to conduct basic research today. You and your colleagues' review and consideration of the Report of the Particle Physics Project Prioritization Panel will help to ensure that today's scarce resources are targeted strategically to ensure the best return on the federal investment and maintain a vital and world class physics research program in the United States. Thank you for undertaking this important hearing.

My name is Natalie Roe and I am the Director of the Physics Division at Lawrence Berkeley National Laboratory. Berkeley Lab is part of the U.S. Department of Energy's Office of Science national laboratory system. It is managed by the University of California (UC) and is charged with conducting unclassified research across a wide range of scientific disciplines. Home to 13 Nobel Prizes, the Lab was founded in 1931 by Ernest Orlando Lawrence, a UC Berkeley physicist who won the 1939 Nobel Prize in physics for his invention of the cyclotron, a circular particle accelerator that opened the door to high-energy physics and to the many other scientific, industrial and medical applications of accelerators today. It was Lawrence's belief that scientific research is best done through teams of individuals with different fields of expertise, working together. His teamwork concept is a Berkeley Lab legacy that continues today.

It is an honor to be here today and to play a small role in your consideration of the P5 report. My testimony will focus on the P5 recommendation that small and medium sized projects continue to play an important and robust scientific role in the nation's high energy physics portfolio of experiments. Doing so will help keep us in the forefront of scientific advancement, provide important training and education opportunities, and ensure a steady flow of world-leading scientific results on a broad front.

I completed my graduate studies in particle physics twenty-five years ago at SLAC. Since then the field has changed dramatically – it has become a much more international endeavor and the scale of its flagship experiments has grown tremendously. My thesis experiment had roughly a dozen scientists and cost less than $1M to build. It was built, commissioned, took data and published its main results all during my time as a grad student.

Today, the Large Hadron Collider is a multi-billion dollar machine, financed primarily by Europe. The design of the four experiments at the LHC began over 20 years ago, and each of them has several thousand physicists. Two years ago the ATLAS and CMS experiments announced the discovery of the Higgs boson, a long-sought cornerstone in particle physics. With suitable upgrades, the LHC will likely continue for another 20 years. This increase in scale – in size, in dollars, in time, and in human capital - is necessary to extend our reach to higher and higher energies, or

in the case of the Long Baseline Neutrino Facility, to higher intensities in pursuit of new particles, new types of interactions and a better understanding of our Universe.

Although the field has changed dramatically, as P5 recognized, small and intermediate scale projects, such as those in which I participated at Stanford, still play an important role in particle physics and have tremendous potential to make ground-breaking discoveries. P5 stressed the value of a balanced program that includes experiments at a variety of scales. Below, I will provide a few key examples of small and medium sized projects with big potential.

As evidenced by my personal experience, these smaller projects provide excellent training for students and postdocs, who can take on major roles and responsibilities and see their work through to fruition much sooner. Smaller experiments can also go after "blue-sky" ideas, they can be nimble and take risks with the potential to shake up the field. A healthy portfolio of experiments should include a good mixture of these smaller projects, and P5 has been wise enough to call this out as a priority.

Many of these small to medium size experiments are in the so-called Cosmic Frontier, the study of dark energy, dark matter and the early Universe. The US is already a leader in this area, and a strong particle physics program would ensure that we stay there.

A prime example of what can come out of a small experiment is a project started in the early 1990s to measure the rate at which the expansion of the universe is decelerating due to the attractive force of gravity. The Supernova Cosmology Project, as it was called, involved a small team of scientists and graduate students, led by a young physicist named Saul Perlmutter. Saul's plan was to use supernovae, or exploding stars, because their light is so bright it reaches earth over billions of years of cosmic time. He developed a method to detect these rare events in a predictable way and a technique to calibrate them as standard candles.

In what is now a famous result, Saul and his team had measured enough supernovae by 1998 to conclude that the universe was not decelerating at all, but was in fact accelerating – the expansion was going faster and faster. In other words, some force counter-acting gravity was at work in the Universe. This result was completely unexpected and a dramatic event for the physics community. It would probably not have been believed - except that a competing team arrived at a similar result. This work, this "small" project, ultimately led to a Nobel Prize for Saul and for the leaders of the other team.

Saul's discovery has attracted the attention of scientists all over the world and inspired a new generation of students to study physics. It has unleashed a wave of scientific creativity that has generated thousands of new theories, technical concepts, experimental ideas and computational methods. Out of this small experiment a whole new field of research has been created and our concept of the

Universe has been fundamentally changed forever. Obviously, the return on the federal government's investment was huge.

Although we call this accelerating expansion "dark energy", this is really just scientific jargon to say we have no idea what it is. Is it a failure of general relativity on very large distance scales? Could it be Einstein's cosmological constant? Or could it be something very strange, a new energy field in the Universe? Is it related in some way to the Big Bang or the initial period of rapid expansion known as inflation? We still do not know, and dark energy remains one of the biggest unanswered questions in fundamental physics today. Much more precise data is needed to figure out which theory is correct.

The Dark Energy Spectroscopic Instrument, or DESI, is one of the small-scale projects recommended by P5 that would tackle this problem. DESI re-uses an existing telescope at Kitt Peak, Arizona that was scheduled by the NSF to be retired from service. By installing a new instrument on this telescope and dedicating it to a wide area survey of the Universe, DESI will bring a new level of precision to the study of dark energy by mapping the locations of millions of galaxies and quasars, constructing a map going back over billions of years of cosmic time. This exciting project has attracted dozens of institutions and is now an international collaboration of almost 200 scientists. It could be built for about $40M over four years. Although DESI does not fit in the most stringent budget scenario P5 was charged to evaluate, it could become a reality with a modest increase in funding. This would enable the US to remain a leader in dark energy research into the next decade, when the Large Synoptic Survey Telescope (LSST), will begin taking data from a mountaintop in Chile. DESI and LSST employ complementary techniques that together will reveal whether new laws of space and time are responsible for cosmic acceleration.

Another example of a medium sized experiment that P5 recommended is the next generation of experiments that are studying the faint glow from the early Universe, the so-called cosmic microwave background (CMB) radiation. A next generation Stage 4 CMB experiment would give us a more detailed snapshot of the infant Universe, shedding light on the conditions that existed more than 13 billion years ago.

P5 also recommended that the US should remain a leader in the search for dark matter. We call it dark matter because it doesn't shine, like stars and galaxies, but we know it is there through its gravitational effects. Dark matter outweighs normal matter by about 6 to 1 and without it the stars in our galaxy would fly off into space. Dark matter is omnipresent but very weakly interacting, so to have a chance of detecting it we have to build very quiet, low background detectors deep underground that are sensitive to very low signals produced when dark matter occasionally collides with normal matter. P5's recommendation supports another class of small to medium scale experiments to address dark matter that will advance the frontiers of our knowledge of the dark universe.

A deep underground site to carry out this type of dark matter search already exists in the US in South Dakota. It is called the Sanford Underground Research Facility (SURF). SURF has been built with funds from the state of South Dakota, generous private donations, and federal funding, creating a modern state of the art underground laboratory on the site of the former Homestake gold mine. In addition to hosting LUX, currently the world's most sensitive dark matter experiment, SURF could provide a home for one of the next generation dark matter experiments (G2 DM) that P5 recommended.

SURF is also where the neutrino detectors for the Long Baseline Neutrino Facility will be located. As Nigel Lockyer has already described, these detectors will detect a neutrino beam generated at Fermilab after it has traveled almost 800 miles through the earth's crust, from Illinois to South Dakota. During this long journey, the neutrinos produced at Fermilab have time to morph into different states before they are detected at SURF. By comparing the behavior of neutrino and anti-neutrino beams, LBNF may reveal clues that could explain how our matter-dominated Universe came into being.

Particle physics has come very far in the past century, discovering the quarks and leptons, the gluons, the W and Z bosons, and finally, the long-sought Higgs boson - only to realize that we do not understand what makes up 95% of the Universe, the mysteries we call dark energy and dark matter. P5 has recommended a carefully selected set of interlocking experiments, including a number of small to medium sized projects. This program is optimized to address the five science Drivers efficiently within tight budget constraints, to achieve the most cost effective approach in our quest to further understand the nature of matter, energy, space and time.

Thank you very much for your attention. I am very happy to answer any questions that you may have.



Natalie Roe
Physics Division Director
Lawrence Berkeley National Laboratory

Natalie Roe is an experimental particle physicist and observational cosmologist. She earned her undergraduate degree in Physics from Harvard, and her Ph.D. at Stanford. She joined the Lawrence Berkeley National Laboratory in 1989, where she is currently the Physics Division Director. Natalie is a founding member of the Berkeley Lab Women Scientists and Engineers Council and is co-leading a laboratory-wide initiative to improve diversity and inclusion at the Lab.

Highlights of her research career include analysis of W and Z boson decays at the Fermilab Tevatron, the study of CP violation in B mesons at the SLAC asymmetric B Factory, and most recently, large astronomical surveys designed to study the mystery of dark energy including the Baryon Oscillation Spectroscopic Survey (BOSS), the Dark Energy Survey (DES) and the Dark Energy Spectroscopic Instrument (DESI).

Natalie has a strong interest in instrumentation and has worked on the D0 electromagnetic calorimeter, led the design and construction of the Silicon Vertex Tracker for the BaBar experiment, and was the Instrument Scientist for the BOSS experiment. As group leader for the LBNL MicroSystems Laboratory for almost 10 years, she was responsible for the fabrication of the science CCDs for both DES and BOSS.

Natalie has served on many community panels including HEPAP, the NSF Physics Division Committee of Visitors, the FNAL PAC and the FRA Committee of Visitors, and the Neutrino Science Advisory Group, and she is a past Chair of the APS Division of Particles and Fields. She has also been a member of the International Committee on Future Accelerators and the DESY Scientific Council, and currently serves on the CERN Scientific Policy Committee and the Scientific Council of the Institut de Recherche sur les Lois Fondamentales de l'Univers (IRFU) in Saclay, France.

Chairwoman LUMMIS. I thank the witnesses for being available for questioning today and for your really exciting testimony.

I remind our Members that Committee rules limit questioning to five minutes. And so at this point I will open the round of questioning. So I recognize myself for five minutes.

Now, in your report, the P5 recommends that the budget fraction for construction increased to 20 to 25 percent. And I understand right now it is around 16, so my first question is for you, Dr. Ritz. How did the P5 come to this determination and what is the significance of the likely outcome if DOE adopts this recommendation?

Dr. RITZ. Yes. Thanks for the question. This was one of the tough issues. In a constrained budget scenario where there is a top-line number, if you increase the fraction devoted to projects, that means it comes from some other place. And in this case the other parts of the budget are in research, in the research program and operations. And in the planning there has been recently a reduction in the research program, and we endorse that and said that at least in the leanest budget scenario, that was going to be necessary, that the program that you get if you don't devote the necessary resources for building things was just not going to get us where we needed. And that is why we called the report "Building for Discovery." So this was a very tough choice, something that was discussed quite a bit. There are recommendations in the report about how to manage that—those expenditures judiciously, particularly for the research program.

Chairwoman LUMMIS. So this recommendation has implications for the colleagues at the table, so I want to ask Dr. Lockyer and Dr. Roe this question. How will the P5's recommendation to increase the budget for construction affect operations and research at your respective labs?

Dr. LOCKYER. Good question. So, first of all, I will say that we are in agreement with the idea that you have to really build for the future. So, as I tried to mention the context of where we are now is that we just come off being the leaders in the world in particle physics, having the highest energy machine, and now the question is what is for the future? And so you have to build something, and in order to do that, that comes through the project funding line.

So now the issue is how do you shrink the research program and how do you shrink the operations? And the answer is carefully. I think we have to do that. We know we have to do that. But in terms of shifting workforce and so on, we will be moving people that would normally work on operations and move them into these research projects, which actually for a lot of engineers and scientists is a nice shift.

Chairwoman LUMMIS. Dr. Roe?

Dr. ROE. I would just mention that we have already seen a contraction of our research program. I believe that all of the national labs that have HEP program have already had reductions in force, and it has been a painful process but one that we recognize as necessary in order to increase our investment in exciting projects that will inspire young scientists and keep the United States at the forefront of particle physics. So it is a sacrifice that we have already been making and that we realized may have to continue.

Chairwoman LUMMIS. Dr. Drell, I do have a question for you as well. Given your experience in this field, how do you view this specific recommendation by the P5 and is it worth the tradeoff?

Dr. DRELL. I also agree with the others that it absolutely is worth the tradeoff, that it is painful for today but it is what makes the future possible, and therefore, I completely support it.

Chairwoman LUMMIS. Have any of you had experience with leveraging the construction component by having universities or States in the event of its expansion in the United States contribute to this because of the opportunities it provides for economic development, for the recruitment of world-class intellectual prowess to their States, and all that means for a community?

Dr. RITZ. Yes, very much. That is a great question. As a university member, let me just say that universities and laboratories work in partnership wonderfully together. Having students, postdocs, resident universities which still have some infrastructure for producing detectors at experiments is a wonderful way; it is also an extremely efficient way of building these experiments. So, yes, it is an extremely important part of the field. It has been a challenge to maintain the infrastructure at universities with the overall shrinking capability, but it is core to our field. I am sure Nigel and Natalie would agree.

Chairwoman LUMMIS. I thank you. My time is expired. And now I yield to the Ranking Member, Mr. Swalwell.

Mr. SWALWELL. Thank you, Chair. And thank you to the witnesses and, Dr. Lockyer, thank you for telling me about Fermilab. You have a faithful advocate in Congressman Hultgren, and I am now assured that you were put on this panel for more reasons than just separating the Berkeley and Stanford witnesses, who at home would be at odds with each other.

Dr. Roe, I understand that you and your colleagues had to make a number of tough decisions under a difficult set of budget trajectories, and I commend you for rising to this challenge so that Members of Congress, without particle physics degrees, don't have to make these decisions without your guidance.

And I am, however, concerned about the consequences of the lowest budget scenario that you were required to consider, and with that in mind, I wanted to talk a little bit about DESI and why that is so important to improving our understanding of dark energy. And if you could also talk a little bit about what the sense of impacts on the U.S. physics community would be if this experiment was not allowed to move forward.

Dr. ROE. Well, thank you very much for that question, Representative Swalwell.

DESI is really a unique experiment in that it can make these very precise measurements of dark energy extending back billions of years in cosmic time, but at a cost that is very modest considering that its reach can rival expensive space mission capabilities. And the key is to recycle this existing telescope that the NSF has at Kitt Peak in Arizona that they were planning to retire. So we are making use of an existing facility, outfitting it with a modern robotics fiber fit spectrograph that we can measure 5,000 galaxies at a time with. And there is a lot of excitement around this project and it would certainly send a very discouraging message to the

many young scientists who have already voted with their feet to join this collaboration, they are excited about the science, eager to take on major roles and responsibilities.

And also if we can't proceed with DESI, it would send a negative message to our many collaborators from 10 countries who have indicated that they wish to invest here in this experiment and they may decide to try to do this experiment themselves in Europe or Asia if—rather than wait for us to commit if we can't do it.

Mr. SWALWELL. And, Dr. Roe, speaking of Europe or Asia, if DESI is funded and moves forward as a project, what will it be able to accomplish that cannot be accomplished or will not be accomplished by LSST or by the European dark energy missions and experiments that are expected?

Dr. ROE. Well, DESI is very complementary to these other missions, as was called out in a community report on dark energy that the Department of Energy asked for two years ago. Basically, whereas DESI uses spectroscopic techniques, measuring the spectrum of galaxies, LSST uses imaging techniques, taking pictures of galaxies. And by doing these different approaches, they can constrain dark energy with different and complementary methods. Because it is such an unexpected phenomenon, we feel that we need confirmation from multiple techniques to really understand what is going on. So they really fit together in a planned program.

Mr. SWALWELL. Great. Thank you, Dr. Roe.

And, Dr. Drell, as you mentioned in your testimony, this is not your first P5 rodeo so to speak. You were pivotal in the creation of the first P5. And I was wondering if, thinking broader, you could—can you envision this process that the P5 undertook—can it and should it be applied to other areas of research that require long-term prioritization of projects under challenging budget scenarios, and if so, any examples?

Dr. ROE. So actually other fields use processes that they are not called P5 but they have a similar outcome and are tuned to the specific circumstances of those fields for——

Mr. SWALWELL. How about fields that aren't using it that you think would benefit if they took this process?

Dr. ROE. I think most of the fields that I can think of, astronomy and astrophysics with its Decadal Survey, x-ray science with the BSAC subpanels, nuclear physics, they have a very good process. The fields that I am aware of that really need to do this have their ways of doing it. It is I think in some ways hardest in high energy physics because of the huge opportunity costs of our projects. They are so long that you make a decision now and it really constrains the program many, many years in the future. And that—it was that additional element of opportunity cost we felt wasn't being taken into account in 2002.

But I think actually we, in the P5 process, learned from how other fields do it, and in the way of science, they will learn from how this was done as they go forward in their planning.

Mr. SWALWELL. Great. Thank you and I yield back the balance of my time.

Chairwoman LUMMIS. I thank the gentleman.

And when I was in college, I studied the biological sciences and found myself with a considerable amount of physical sciences def-

icit in my own intellectual capabilities. So I marvel at your capabilities intellectually and the excitement that you bring.

But we do have one Member of this Committee that is at your level and I recognize him now, the gentleman from Kentucky, Mr. Massie.

Mr. MASSIE. I am definitely not at your level, but let's manage expectations here.

So please bring it down to our level a little bit here. Can you explain, any of you, the significance of the Higgs boson and why Congressmen and Congresswomen should be interested in that discovery and also the location of that discovery? Dr. Ritz.

Dr. RITZ. Sure. I would be happy to do that.

It is really an amazing time in physics, and let me try—rather than try to describe electroweak symmetry breaking and all the technical terms people try to explain, let me step back a minute and just try to give you a sense of why we are so excited about it.

And it really reminds me of a story when I was a graduate student and I earned my keep by being a TA. We had intro physics labs. I actually really enjoyed teaching the biological science students. Actually at Santa Cruz it is great. And there was one of these labs that you probably remember, it wasn't all that exciting, involved a plunger and a piston and a spring kind of like a pinball thing, you know. And I said, well, you know what, let's—why don't you take that and aim the thing at some angle and calculate where the thing is going to land, put a piece of paper there. And, you know, one of the students did it and he, you know, thank goodness, it hit spot-on and he was just so excited about that. I will never forget this, that he just wrote in his laboratory book in all caps, Newton's laws allowed me to predict where this was going to land; physics really works. He was just so excited.

So fast-forward from Newton's time to the late 1800s when people studying electricity and magnetism realized they are actually two different aspects of the same thing, okay. Electricity and magnetism are actually unified forces, and that became the basis of all the technology that we enjoy today.

Now, come to our era. There is another force. There aren't that many forces; that is what is amazing. There is another force that can be unified yet with electricity and magnetism that is called the weak force. So here is the really interesting thing and that is related to that student back in Wisconsin. You take all of these phenomena that we see in our experiments and you can write down the theory that is really abstract and it involves all these terms that take a long time to explain. It is really beautiful stuff. It is fantastic. You look at that and you say this all works if this other phenomenon that we never thought to look at, that we never in a million years would think to do, and it took us 30 years or 40 years of experiment to find, we built the machines and we did it and it was there, okay. Science doesn't really get any better than that. We understand it at a profound level.

Now, what the significance of the Higgs is going to be it is just too soon to tell. It is a fantastic new discovery. It is a new—entirely new kind of particle and, you know, as you can tell, I think we are extremely excited about it.

Now, the—you asked about where. So it was discovered at the Large Hadron Collider facility at CERN. The United States, I believe, should be very proud of our role in that discovery. We had leadership in the two experiments that discovered it. It was our hardware that helped to make it possible. And for the next step these high luminosity upgrades, the upgrade to the machine, this is absolutely the best game in town. It won't happen, it can't happen without our know-how, as Nigel said. And it truly is a world discovery.

Mr. MASSIE. So for everybody here, CERN is in Switzerland or——

Dr. RITZ. Yes. Actually, the particles cross the border between France and Switzerland.

Mr. MASSIE. And probably——

Dr. RITZ. It is an open border.

Mr. MASSIE. —some are escaping into the universe, too, right?

So let me just play devil's advocate here——

Dr. RITZ. Sure.

Mr. MASSIE. —and I assure you this is being devil's advocate. Why can't the United States just kind of sit back and wait for the rest of the discoveries to happen in Switzerland and let our international partners—just ride on their coattails?

Dr. RITZ. Sorry? Nigel——

Mr. MASSIE. Yes.

Dr. RITZ. —would you like to answer that? Sure.

Dr. LOCKYER. Sure. I think the main issue here is the technology associated with that for me, from my standpoint. So as I mentioned before, CERN relies on the United States for the next phase of the machine to be building the high field magnets, which give it the high luminosity, which allows you to do the new physics. We keep that technology. We own that technology and so that is the technology that I think is going to be important when we try and apply it to the commercial side of things. So you don't lose any of that.

At the same time, your scientists are working at the absolute forefront of the field and they come back excited about what they have learned; the students come back excited about what they have learned. They are not all going to stay in the field. In fact, roughly half of them go into business and in other areas of—you know, that they pursue in their careers.

Mr. MASSIE. Occasionally engineers get lost in Congress, too.

Dr. LOCKYER. They do. But I think that is—you know, so there are benefits both on the people's side and on the technology side, and it works both ways actually.

Mr. MASSIE. Thank you very much. My time is expired.

Chairwoman LUMMIS. When I first met my colleague, Mr. Massie, who is a graduate of MIT and holds dozens of patents, I asked him, tell me something you hold a patent in. And he said, well, I hold a patent in how one can feel non-matter. And I said to him how did you know that would be of any significance? And he said I didn't and I still don't. And someday somebody will make that next step, and in some ways that is what you are doing. That is what is so exciting and pioneering about it.

Mr. MASSIE. Well, one thing is for certain. I used to work in virtual reality and I am back in virtual reality.

Chairwoman LUMMIS. The Chair completely understands that statement.

I now recognize the gentleman from Illinois, Mr. Lipinski.

Mr. LIPINSKI. Thank you, Madam Chair. Thank you for holding this hearing.

I try to understand particle physics but I am only an engineer, so I have a hard time reaching those levels, but it is very good to see you, Dr. Drell. I understand you are the new chair of—Dean of Engineering at Stanford, where I got an engineering degree out there, so I was very happy to hear that. And good to see you, Dr. Lockyer. I think Representative Hultgren will be probably asking questions next on this, and I know it is a great facility we have there in Illinois out in his district.

First of all, let's talk a little bit about more generally. I was very happy to get connected with David Kaplan and Mark Levinson when they were first really starting on "Particle Fever," the movie. And I highly recommend the movie. I gave the introduction here in Washington for the premiere of the movie. The weekend it premiered in Chicago, I went to the movie and David was there and answered questions afterwards, and I never expected to see the kind of excitement that came out of that movie for the audiences. But I never expected that anyone could put together a movie to make particle physics really interesting and somewhat understandable. It helped me better understand—after spending many, many hours over the years talking about particle physics, the movie did a great job of helping me to understand, okay, what we are talking about. Help an engineer try to understand what we are talking about with particle physics.

But it is great to see and I—you know, I said the way the movie ended with the discovery of the Higgs boson but still leaving sort of the cliffhanger of, okay, what does this mean now? I said, well, it is just a perfect setup for the sequel, but we are all waiting to see what—where we go from here.

But I wanted to ask Dr. Lockyer about the Illinois Accelerator Research Center. I know the Department of Energy and the State of Illinois are in the partnership to build that, and once completed, the center is going to conduct research and help establish partnerships between the scientific and business communities to solve problems related to energy, the environment, medicine, and national security.

I think that this is something where we see—in our roles here, it is hard sometimes to make the case for basic research and funding of basic research and people want to see results—what does this mean to us, as Dr. Massie was getting at there. A lot of times you don't know, you don't know for a long time, but we see it somewhere. But when we are talking about this center, can you say a few words about what you hope you will be able to do in terms of economic development and job growth?

Dr. LOCKYER. Thanks for the question.

The Illinois Accelerator Research Center is the—sort of the focus of Fermilab's attempt to commercialize the technology associated with article physics and in particular accelerators. So maybe I will give you an Illinois example and you can apply it to the rest of the country. So, for example, high power electron accelerators can be

used to polymerize hydrocarbons, which means, you know, the bonds can be rearranged in a way that changes the texture and the behavior of the material. One example is radial tires are treated with electron beams to make them harder, so obviously that is a good thing.

So what we are looking at now, for example, is looking at asphalt. So asphalt is a combination of gravel and bitumen, and we are looking at changing the chemical structure, the bitumen, so that the asphalt is harder and lasts longer. You know, $80 billion of money goes into paving roads in the United States, so if you can make a road last an extra year, it is a big deal. So we envision being able to treat the asphalt as you lay the pavement down with portable accelerators. You have seen us in the highways where they lay the asphalt and you try and stay away from it because it is a mess in terms of traffic, but we can imagine mounting small accelerators on the back of that vehicle and hardening the road as you lay it down. And so we have started that kind of research. That is just one of the examples were looking at but there is a number of other ones I could give you afterwards if you would like.

Mr. LIPINSKI. I appreciate that. And as an engineer and a Member of the Transportation Committee, I can appreciate it and understand. So thank you. I will yield back.

Chairwoman LUMMIS. As you can see, our Members from Illinois are rightly proud of what is occurring at Fermi and I now turn to one of them, the gentleman from Illinois.

Mr. HULTGREN. Thank you.

Madam Chair, first of all, I ask unanimous consent to enter into the record a letter from the American Physical Society supporting the P5 process and its plan for the future of particle physics in the United States.

Chairwoman LUMMIS. So ordered.

[The information appears in Appendix I]

Mr. HULTGREN. Well, thank you, Chairwoman Lummis, so much. Thank you to all of our witnesses for being here today. I know sometimes my colleagues do get tired of me talking incessantly about Fermilab, so it is great to have some people here who actually know what is going on there before the Subcommittee and the great things that you are doing in this very important field.

Since the shutdown of the Tevatron, I know how hard the community has been working to find the next frontier we will be embarking upon. We have heard the Secretary talk about the community getting on board for a plan, and that is why I am so grateful for the work of P5 that you did to put forward a responsible plan taking into account the budget constraints for this vision, which ensures projects that could be funded and realistically executed. I would like to thank Dr. Ritz and everyone involved for their hard work that they put into this. From everything I hear, the community has accepted this plan and is appreciative for it, as I am as well.

Dr. Lockyer, at this time there are only six universities offering graduate programs to train accelerator scientists and technologists here in the United States. This is often a field that is self-selected and we need to maintain a leadership role just to maintain the capabilities and expertise we already have. I wondered if you could

explain the PIP–II upgrades, what they will make available to Fermilab and to the community as a whole. Besides just a long-based neutrino experiment, what other experiments will this technology and R&D allow the community to do?

Dr. LOCKYER. Thanks for that. The PIP–II project, Proton Improvement Plan at Fermilab, is the one I am personally excited about because it really goes to the heart of what our field is trying to emphasize, which is accelerator research. The technology associated with it we were referred to as superconducting radio frequency technology. We are pushing the envelope in what you can do with that. It has applications in other fields. It has applications in commercialization. And because it is new and because it is a challenging project to build, it will allow us to stay at the cutting-edge of accelerator research over the next decade and provide the most powerful neutrino beams in the world. So again, that will be our competitive advantage on the science side.

It is also a great place for training students, and I agree, there is a shortage of accelerator physicists. The schools that do offer accelerator programs are the top schools in the country. We are working with Northern Illinois University to create a program there. The new President Doug Baker is very committed to doing that. And so I see that there is numerous opportunities we have to impact our field on that.

Mr. HULTGREN. And I appreciate that and I think that is such an important story again for all of us to be reminded of is the great cooperation that is going on there but also preparation that needs to happen.

Dr. Lockyer and Dr. Ritz, since the report has been published, there have been some questions from the community as to whether LBNE will need to be completely reworked to create the international facility the report is pushing for. I wondered is this the case, and if not, how will LBNE be rolled into LBNF? Should our international partners have faith that our previous work is relevant and continued project engineering and design work is worthwhile?

Dr. RITZ. Well, let me start and then hand it over to Nigel.

The answer is yes. I think they should have faith. I think the report is actually a resounding endorsement of the science. It is in a sense, to quote President Reagan, throw deep, that this is—the community spoke very clearly at the Snowmass meeting and also our international colleagues and their expression of interest have said they really want this to be a capable experiment. So this is something that is going to take the world neutrino community to come together to have—to make happen, and we are in an excellent position in the United States to host this facility both with Fermilab and the San Fernando Valley research facility.

And let me hand this over to Nigel, who is also of course working on the implementation.

Dr. LOCKYER. Yes. I think this is one of the more challenging aspects of the P5 report for Fermilab and for the community. I think it is necessary to—in order to have the absolute optimal experiment put together that you have all your friends there, you invite their ideas, and so we are going through a process now where we

are asking whether the international community can see themselves being engaged in what we have started.

We think we have done a great job so far and made tremendous progress, and I see that this—the P5 report just gives us more momentum because they see us having success, not only success in—technical success but also in terms of getting our community behind us. So I am very confident that we are going to see Europe get on board. Already CERN has said they want to be part of this. The U.K. and Italy have said they want to be part of this. Brazil has said they want to be part of this. So I see this is just—it is coming together now because I think the P5 report has just made us look more serious about what we are doing.

Mr. HULTGREN. Well, again, my time is expired but I do want to just thank you all so much. It has been a challenging couple of years and this is an exciting time. I feel it we are right there and you all have been such a key part of that. So thank you. We want to help. We want to get this message out to our colleagues of how important this is right now.

So, Chair, thank you for holding this hearing and I yield back.

Chairwoman LUMMIS. I thank the gentleman.

And before I recognize the gentleman from Texas, I want to alert our panel as to the plan here. We would love to have a second round of questioning if you are available. I will be turning the Chair over to the gentleman from Illinois, Mr. Hultgren, and Mr. Lipinski of Illinois will assume the Ranking Member Chair. Mr. Swalwell and I are going to step out and discuss the markup of the authorizing legislation that includes funding for high energy physics. So please excuse us as we have a sidebar in the back room.

And I now thank you again for being here.

I do recognize the gentleman from Texas, Mr. Veasey, and turn the Chair over to Mr. Hultgren.

Mr. VEASEY. Thank you, Madam Chair.

I did want to—I have a question about international research projects and wanted to direct my question to Dr. Lockyer.

I know that you are familiar with the ITER, which is being built in France and will be the first large-scale magnetic fusion facility in the world to produce net power. As has been mentioned multiple times, the LHC is under the Franco-Swiss border near Geneva, and Japan is bidding to host the International Linear Collider. Some may consider the fact that all of these next-generation major research facilities are being built in places outside the United States as evidence that we are losing our global leadership in research and innovation and was wondering what you think about those concerns that have been expressed.

Dr. LOCKYER. Thanks for the easy question. The—I think the situation is changing. The global situation is changing with very large projects, and that is why I think it is so critical that the United States host its own large project and we are seeing the P5 report as putting forward the idea that we would host a neutrino project.

These are very different from, let's say, the ITER project, which is perhaps an example you want to stay away from in terms of challenges. It has had management challenges; it has had cost challenges. I usually draw your attention to our collaboration with CERN, which has been so successful. The project itself was capped.

We delivered—the United States delivered what it needed to, everybody else did. It was done on time, on schedule. It had tremendous success, as you know, with the Higgs boson.

So I believe our field actually knows how to do international projects. We have demonstrated that. And so I don't have the same concerns that maybe people who want to put ITER and hosting a science project in the same sentence. They are quite different.

Mr. VEASEY. Well, how will we benefit? Like how will the United States benefit? I know Dr. Roe wants to answer that and she can answer that and jump right into this, too. How does the United States benefit from these international research projects even if they are being conducted overseas? I think any of the panelists—Dr. Roe, if you want to answer—go back to that and then answer that as well, too.

Dr. ROE. Thank you. Thank you for the question. I think we do benefit by participating in international projects in many ways because our scientists, our engineers, our students contribute. We develop new ideas, we develop technologies, and we benefit our local economy by building things that are then installed overseas. But we don't want all of the leading particle physics projects to be overseas. If we do, we are likely to witness a brain drain where many of the most talented young scientists that are trained in the United States will pursue the better opportunities abroad. And we have long benefited from the influx of the best and the brightest coming here to pursue an education and the research opportunities that we offer, and a reversal of this trend I think would be very, very bad for the United States.

Mr. VEASEY. Thank you.

Dr. LOCKYER. I completely agree with her answer. I think the issue is an exchange, and I believe that—as I said, that we should be hosting the project but we also benefit by going abroad. And as I mentioned earlier, our technology most of the time is developed in this country, stays in the country, is used for our own purposes, and yet we benefit from working with the best and the brightest around the world in these projects.

Mr. VEASEY. Thank you. I yield back my time.

Mr. HULTGREN. [Presiding] Thank you.

We will now move to a second round of questions and I will yield to myself for five minutes.

First question in the second round here addressed to Dr. Lockyer and Dr. Drell. I wonder, can you both explain the collaboration between high energy physics and other programs in DOE, especially basic energy sciences and specifically drawing attention to LCLS–II upgrades. How did this process work and what continued R&D work is necessary in HEP to complete these kinds of upgrades and build other new light sources? Also, while HEP is the steward of accelerator R&D, will it always be work in HEP that drives this technology?

Dr. DRELL. Let me start and then maybe Nigel will complete.

From the SLAC perspective, we have this magnificent opportunity to build LCLS–II building on fabulous science with LCLS. As you know, LCLS–II will involve a superconducting electron accelerator. We have no expertise in building superconducting electron accelerators at SLAC, but it is the way the system works in

the DOE that the laboratories have competencies that are very often unique to those laboratories and we help and support each other. This has gone on for some time. And for the LCLS–II we reached out to Fermilab and to Jefferson lab and to Cornell, who are the world-leading experts in this technology, and they will then help us and build that for us.

I would like to say that this is a remarkably efficient process. It means that rather than having duplicative competencies at different labs, we instead use our unique expertise to support each other and it is going extremely well in the case of LCLS–II. SLAC could not on its own build that facility without the help of our partners, and we appreciate that they prioritize it extremely highly and it benefits science broadly in the Nation, and that is really our goal.

Dr. LOCKYER. You know, I would second that and I would give you another example. So the P5 report talked about the cosmic microwave background as a new area that high energy physics would get involved in, and that also is a collaboration of various laboratories bringing different expertise to the table. So again, SLAC, Berkeley, Argonne, Fermilab work together to develop a chip, to mount chips, and each lab plays a different role working with the broader university community at the same time.

So I think we all know what we do well and what we don't do, and I think the idea that the labs work together makes tremendous sense to me and I am seeing that more and more all the time, and I know the Secretary is very much a big fan of doing that. And so we are doing it and it is quite successful.

Mr. HULTGREN. Good. I do think it is an important message for Members of Congress to understand and to see again this ecosystem of how it works. We understand oftentimes our own labs but don't understand how the working together, how important that is and the ripple benefits across education but also into the private sector as well, so I think it is great. Thank you.

Dr. Ritz and also Dr. Lockyer, going back to your work with GLAST, you seem to be in a unique position to discuss how work in high energy physics is also affecting what we observe in outer space, whether it be dark matter, dark energy, or inflation. Can you talk about the expertise HEP will bring to the table for the next generation of space observatories and experiments such as LSST, which was also a top priority of the Decadal Survey?

Also, what does neutrino science have to contribute to the understanding of the big bang and supernovas?

Dr. RITZ. Oh, so much there. Great, thank you. Yes.

So of course science doesn't know about all these different stovepipes that we invent just so that we can get our work done, and there are areas that fall—there are really important aspects of science and great opportunities that fall between fields, and it is extremely important that they get done. Our report addresses that, as did the Decadal Survey that you mentioned, that by combining forces and doing the funding in a way that—in a multidisciplinary, multiagency sort of way that matches the science output or the science yield that benefit each of the different disciplines, we think this is a great way to go and it makes a big difference.

Particle physicists are really great at building large-scale, highly integrated systems, large numbers of channels, very precise measurements, very careful attention to errors, great detail to pull out the physics, okay, and combining that with the expertise of our astronomer friends and colleagues that if you are going to use the universe as a laboratory and make observations, you better talk very carefully and directly and collaborate with people who understand astronomy and astrophysics, that by working together you can pull out new information. So that is extremely important and extremely interesting.

Neutrinos are a great example of a particle that just doesn't know which science discipline they belong to. There is particle physics, there is nuclear physics. Each play really important roles and we work really well together on this actually.

You would be surprised but, as Nigel said, neutrinos are all over the place. They actually had an influence on the growth of the structure that we see in the universe today. And by making these observations with telescopes and looking at the growth of structure—in other words, how did all the matter collect that we see—you can actually get information on the mass of neutrinos. And this—it looks to us to be one of the best ways in the near term of learning about neutrino properties, so what a wonderful connection that these things have and it is really going to accelerate progress we think.

Mr. HULTGREN. Dr. Lockyer, anything quickly?

Dr. LOCKYER. Yes. Quickly I will just say supernova is when a star dies and collapses and sometimes you create what is called a neutron star, and during that process you emit lots of anti-neutrinos. LBNF will be waiting there ready to observe those and we would see thousands of them as opposed to what has been observed so far from a famous event, 1987, we saw 10. And so the difference in scale is now humongous.

Mr. HULTGREN. Great. My time is expired. I recognize my colleague, Congressman Lipinski, for five minutes.

Mr. LIPINSKI. Thank you. And unfortunately, I don't have the time so I won't be taking five minutes right now.

I just want to make sure that I thank all of you for the work that you have done, the work on P5, which I think is extraordinary, really helps to light the way of where we need to go. And I assure you that, yes, probably everyone on this committee who is not from northeastern Illinois gets sick and tired of hearing Randy talk about the—about Fermi, so he certainly does probably every hearing that we have, does a good job with that, and about high energy physics in general. But thank you for your work, and I was hoping that the Chair would still be here and I was going to recommend to her that we do a Congressional Committee trip out to Fermi, out to the Bay Area because there is no two better places to go than to the Chicago area and the Bay Area. I have been to Fermi, I have been to SLAC, I have been to Lawrence Berkeley. I would be very happy to go back out there and happy to take a side trip to Santa Cruz also. I have been to Santa Cruz, not onto the campus, but have been to the Santa Cruz Boardwalk a few times.

But thank you for your testimony and thank you for all the work that you are doing.

Mr. HULTGREN. I think that is a great suggestion and I will echo that as well to the Chair.

I do want to thank the witnesses for their valuable testimony and the Members for their questions. The Members of the Committee may have additional questions for you, and we will ask you to respond to those in writing. The record will remain open for two weeks for additional comments and written questions from Members.

The witnesses are excused and this hearing is adjourned. And thank you all.

[Whereupon, at 11:22 a.m., the Subcommittee was adjourned.]

Appendix I

Additional Material for the Record

SUBMITTED STATEMENT OF EDDIE BERNICE JOHNSON, RANKING MEMBER, COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

OPENING STATEMENT

Ranking Member Eddie Bernice Johnson
Committee on Science, Space, and Technology

Hearing of the Energy Subcommittee
A Review of the P5: The U.S. Vision for Particle Physics After Discovery of the Higgs Boson

June 10, 2014

Thank you Chairman Lummis for holding this hearing today, and I would also like to thank the witnesses for being here.

The U.S. physics community is well-recognized for its world leadership in shedding light on the mysteries of the universe. Your major contributions to the recent, Nobel Prize-winning discovery of the Higgs boson *[pronounced: BOZE-on]* is just one more example of this. Yet what I also find remarkably impressive is the ability of the community to set priorities and make tough decisions about its future to ensure that we have the strongest program we possibly can, even in a difficult budget environment. That's what this report that we're reviewing today clearly demonstrates.

That said, this report also provides a clear warning about the consequences to our leadership, and even more importantly, to the advancement of the frontiers of science if we end up adopting the lowest funding scenario that you were asked to consider. I frankly believe that you should be rewarded for the hard work it must have taken to set these carefully considered priorities under such difficult constraints. And I believe this is one area on which many of my colleagues on the other side of the aisle and I can find some agreement.

I look forward to discussing this further with each of you today. With that I yield back the balance of my time.

ARTICLE SUBMITTED BY REPRESENTATIVE RANDY HULTGREN

American
Physical
Society

One Physics Ellipse
College Park, MD 20740-3844
Tel: (301) 209-3269
Fax: (301) 209-0867
www.aps.org

President
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Editor in Chief
Gene D. Sprouse
Stony Brook University (On Leave)

June 6, 2014

The Honorable Cynthia Lummis
Chairwoman, Subcommittee on Energy
House Committee on Science, Space, and Technology
2321 Rayburn House Office Building
Washington, DC 20515

The Honorable Eric Swalwell
Ranking Member, Subcommittee on Energy
House Committee on Science, Space, and Technology
2321 Rayburn House Office Building
Washington, DC 20515

Dear Chairwoman Lummis and Ranking Member Swalwell:

As President of the American Physical Society (APS), representing more than 50,000 scientists in universities, industry and national laboratories, I applaud the efforts of the U.S. Particle Physics Project Prioritization Panel (P5) in developing an exemplary strategic plan for the future of U.S. particle physics. The P5 report, "Building for Discovery," comes at a time when American particle physics is at a tipping point. The flagship research field has seen federal support for its activities decline in real terms by more than 50 percent over 25 years, and it no longer enjoys a large major facility in the United States.

The P5 report notes that particle physics in the 21st century has become an international endeavor, and the U.S. research community continues to make substantial contributions to advances in the field, boasting the largest contingent of scientists involved with the thrilling discovery of the Higgs particle at CERN's Large Hadron Collider two years ago. Today, the U.S. community remains the acknowledged global leader in accelerator technology.

But the P5 document, which represents the work of nearly 1,000 physicists during the course of one year and reflects the field's consensus view, carries a stark warning for policymakers and lawmakers: "Without the capability to host a large project," the report notes, "the U.S. would lose its position as a global leader in this field, and the international relationships that have been so productive would be fundamentally altered."

Particle physics, or high-energy physics, has a long track record of extraordinary accomplishments, not simply in its own realm of scientific discovery, but also through its impact on other scientific fields and technologies that have widespread utility. Breakthrough discoveries, such as the Higgs boson, often grab headlines and may capture the public's imagination. But the advances stemming from particle physics have been central to the development of synchrotron light sources upon which biologists, chemists and material scientists heavily rely; MRI machines that have become standard tools for medical diagnosis; proton accelerators that find applicability for treating cancer; the World Wide Web and the browsers that have transformed 21st century commerce; and many other less visible technological applications. Additionally, theoretical advances in particle physics now provide essential knowledge for cosmology, nuclear physics and condensed matter physics. And just as important as all of these, the exciting discoveries in fundamental science inspire our youth to study science and to continue the American tradition of innovation, which is at the heart of our economic well-being.

APS supports the report's two central recommendations that (1) the U.S. host a world-class, international facility, such as the Long Baseline Neutrino Facility to be based at Fermilab, and (2) the U.S. continue partnering in high-priority facilities located in Europe and Asia. However, doing so while maintaining the other elements necessary for a successful particle physics research program will require stronger federal support of the field.

Against the backdrop of constrained budgets, P5 was charged with the unenviable task of prioritizing research projects. With the number of excellent projects far outweighing available resources, the panel made difficult choices and designed a decade-long research program under three budget scenarios. APS strongly agrees with the P5 report's assertion that the lowest budget scenario is precarious and severely threatens our nation's standing in the field.

This is a challenging time for U.S. particle physics. As the field forges into unexplored territory, inspiring the next generation of budding scientists and engineers, U.S. policymakers must decide whether our nation will continue to be a leader in the field or whether it will allow it to fade into the background.

The P5 report, "Building for Discovery," provides a community vision for the future of the flagship field and roadmap for making it a reality. It offers a balanced strategy for the U.S. to regain momentum in a field where we have long been the leader. The report leaves policymakers with two choices: increase federal support and make smart investments, enabling the U.S. to maintain a world-class particle physics program and continue to be a leader in unlocking the mysteries of the universe; or allow federal support to decline even further than it already has, forcing the U.S. to step back from being a global leader in particle physics and send some of our most talented scientists abroad to achieve their dreams. For me, the choice is clear. We must renew our commitment to a field that has served our nation well in so many ways for more than half a century.

Sincerely,



Malcolm R. Beasley
President of the American Physical Society

cc: The Honorable Lamar Smith
The Honorable Eddie Bernice Johnson

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