Testimony of

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Subcommittee on Energy
of the House Committee on Science, Space, and Technology

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

Introduction

Distinguished members of the subcommittee, I am honored to speak with you about high energy physics. The views and words that I present here today are my own, on behalf of the HEP community. The research we do probes the smallest constituents of matter, the building blocks of our universe, in an attempt to do nothing less than address the most fundamental questions of humanity: How did our universe come to be? How does it work? And how do we fit in?

But investing in physics research goes beyond helping us understand the very world around us. On that quest, we also push the boundaries of knowledge and develop the technologies that directly improve our lives. Scientific collaboration in particle physics brought us the World Wide Web. Particle accelerators inspired medical technologies including MRIs. Antimatter allows us to detect cancers. Our work may sound like science fiction, but it is reality. Thanks to decades of efforts by dedicated particle physics researchers, we are now doing things once seemed impossible, like building quantum computers and sending particle beams hundreds of miles through the earth to study their oscillations.

There are many big questions around matter, energy, space and time left to answer, and the United States is a world leader in this research. But to continue leading the investigations into these big questions, we need sustained investment in our field's priorities, including our infrastructure, people and research programs.

It is an exciting time in physics: Before us, we see new knowledge, new applications and a vast, transformative potential for the future. We hope the U.S. can continue to lead the charge into the great unknown.

Basic research

Particle physics is a global endeavor. Sustained, long-term funding and international collaboration have led to major breakthroughs, such as the long-awaited discovery of the Higgs boson in 2012. Through the recommendations of the Particle Physics Project Prioritization Panel (P5), the United States has emerged as a leading force driving discovery on the most urgent scientific studies. New discoveries and world-leading science facilities supported by HEP have also inspired and attracted the next generation of talent in STEM careers and at DOE national labs.

Neutrino physics and LBNF/DUNE

The P5 report recommended that the Fermi National Accelerator Laboratory, or Fermilab — of which I am the director — lead the largest and most complex research program on neutrinos ever undertaken. Neutrinos are minuscule particles with surprising properties; they are ubiquitous and the most abundant matter particles in the universe, yet we know very little about them. What we *do* know is that they could hold keys to some of the biggest questions in particle physics, such as: Why is there matter in the universe? How do black holes form? How has our universe evolved?

Fermilab is uniquely suited to host the world's flagship neutrino facility and facilitate an international neutrino research program. The Long-Baseline Neutrino Facility (LBNF) will provide the infrastructure for the massive Deep Underground Neutrino Experiment (DUNE), the largest international scientific project on U.S. soil. LBNF crews are now excavating caverns a mile underground at Sanford Lab in South Dakota that will house enormous particle detectors.

Meanwhile, more than 1,400 DUNE collaborators from over 35 countries and 200 institutions are designing, building and contributing the cutting-edge detector technology that will fill these caverns in order to study these elusive particles. Among our international collaborators is CERN, a Fermilab sibling laboratory in Geneva, Switzerland, home to the LHC. Notably, LBNF/DUNE marks the first time in its 60-year history that CERN is investing in a physics project outside Europe. Despite international partnerships and contributions and tremendous progress in constructing LBNF/DUNE, the project faces international competition. Japan is moving quickly on a competing project, known as Hyper-K, to build one of the world's largest neutrino experiments by 2027. The continued engagement and involvement of our international partners requires the U.S. to continue its commitments to HEP and meet project milestones to execute the best science and stay ahead of international competition.

PIP-II

LBNF/DUNE will be powered by an upgrade to Fermilab's accelerator complex known as PIP-II. The new superconducting particle accelerator is a testament to the global support for big physics research hosted in the United States. It is the first particle accelerator built in the U.S. with significant contributions from international partners, with major contributions from institutions in France, India, Italy, Poland and the United Kingdom.

Powered by the new accelerator, Fermilab will produce the most intense high-energy neutrino beam in the world, enabling the exploration of new physics. The unprecedented numbers of particles produced by the accelerator will help uncover theoretically predicted — but yet unobserved — phenomena that we expect are either incredibly rare or incredibly difficult to detect. The sheer numbers of particles will help draw out the subtle behaviors that would otherwise remain hidden.

In parallel, the high-power proton beams will enable muon-based experiments to search for new particles and forces at unprecedented levels of precision. Similarly, the proton beam power from PIP-II could drive a facility to support a diverse physics program. In fact, each experiment facilitated by the PIP-II upgrade provides new windows to the subatomic world.

The new machine supports Fermilab's leadership position in high energy physics, and, importantly, PIP-II's leading-edge design will pave the way for future advances in accelerator technology.

CMS and LHC

U.S scientists play an integral role in the success of research at the Large Hadron Collider at CERN. Department of Energy National Labs help design and build upgrades to the magnets at the heart of the accelerator through the LHC Accelerator Upgrade Program. Fermilab is the host lab for U.S. participation in the CMS experiment, which co-discovered the Higgs boson. (The U.S. contingent of CMS makes up nearly 30% of the collaboration.) Hundreds of collaborators across the United States are working on upgrades to the LHC experiments to handle increased amounts of data and information.

In addition to designing and building particle detector components, U.S. LHC collaborators develop machine learning and artificial intelligence algorithms to sift through petabytes of data to better understand the building blocks of matter. With the increasing involvement of machine learning and artificial intelligence in every facet of our lives, our contributions to these fields is of paramount importance to our continued leadership in the AI ecosystem.

Fundamental particles and forces

Recent measurements have put cracks in our theoretical framework for the subatomic world and may point the way toward exciting new discoveries. Results from Fermilab's Muon g-2 and CDF experiments as well as the LHC at CERN have generated thousands of headlines and captured global attention. For example, the Muon g-2 news earned over 3500 top-tier media mentions and more than 19B potential audience reach over several months, indicating the public's continued interest in fundamental physics and what it tells us about the world we live in. Muon g-2 and the LHC are gathering more data, and upcoming results have the potential to transform our understanding of the subatomic world. The Muon-2-electron conversion experiment at Fermilab is under construction and promises to probe the behavior of muons with unprecedented precision.

Using the cosmos as laboratory

Dark matter makes up about 95% of the mass of our universe yet it remains one of the greatest unsolved mysteries of science. Next-generation experiments in the U.S. will continue to home in on this invisible substance. Without a doubt, discovering what comprises this long-sought matter will be a major milestone in physics history. Meanwhile, advanced telescopes led by the national labs are illuminating dark energy, the force behind what holds our universe together and that is responsible for space's accelerating expansion. Large-scale experiments such as the Large Synoptic Survey Telescope, Dark Energy Camera and Dark Energy Spectroscopic Instrument position the U.S. at the forefront of this research.

Emerging technologies

Because of the cross-cutting nature of research, scientists working in high energy physics can foster applications well beyond particle physics. Researchers use their ingenuity, techniques and skills to advance technologies in emerging areas such as quantum science, artificial intelligence, machine learning and microelectronics.

Quantum

With their expertise working with particles at the smallest scales, physicists are essential to developing quantum information science. HEP researchers are adapting tools from particle accelerators to extend the lifetime of quantum information and build quantum computers, which will have ramifications for fields as diverse as finance, medicine and national security. Fermilab leads one of the five DOE national quantum centers and is leading the way in quantum materials, computing, sensors and communication building toward a quantum internet.

Artificial intelligence and machine learning

The high energy physics community contributes to the growing fields of AI and ML, which underpin technologies in many industries, by advancing new technologies and using them to solve some of the most difficult problems in science. Scientists develop these tools to process and analyze the trillions of datapoints common in large physics experiments. They also expand these techniques to support the equipment itself, making smarter telescopes and self-driving particle accelerators. Additionally, HEP provides a unique role in the process of workforce development to the national AI ecosystem, collaborating with academia and industry partners and training an AI workforce with challenging scientific applications.

Microelectronics

Large-area detectors for high energy physics must operate reliably over the lifetime of the experiment in compact geometries and resource-constrained extreme environments, such as cryogenic temperatures. These restrictions have led the HEP community to develop custom microelectronics with complex in-pixel processing and reconfigurable data-driven architectures.

Over the last decade, Fermilab has successfully applied the concepts developed for high energy physics to other areas such as X-ray detectors for synchrotron sources and free-electron lasers. We are now developing deep cryogenic electronics for quantum systems, as well as on-chip machine learning for on-detector data processing.

The workforce of the future

High energy physics is a powerful training ground that attracts students and helps build the STEM workforce of the future. Fermilab is home to 114 postdoctoral researchers, 273 graduate students and 52 undergraduate students, and we reach more than 100,000 students a year through science education programming. Students and researchers at Fermilab design and build state-of-the-art technologies, glean insights from mountains of data, and develop both the creativity and know-how to bring the imagined into reality.

Fermilab also strives to attract the greatest diversity of talent. For example, Fermilab supports a broad array of fellowship programs for underrepresented minorities and groups in STEM in areas such as accelerator engineering, superconducting quantum materials and theoretical physics, to bring world-class research and development opportunities to a diverse group of young engineers and scientists. These physicists help us move toward the next discovery. And those who decide to transfer those skills into industry provide expertise found nowhere else.

Leading a global community

The timing of this testimony before Congress is especially important as scientists are now convening for Snowmass, the decadal planning exercise that outlines the future vision of particle physics research. The results of Snowmass will be used to develop the next 10-year P5 plan that prioritizes major projects and experiments to maintain U.S. leadership. Once again, the United States will have the opportunity to lead in cutting-edge research areas. We have the world-class facilities, people, and research programs that will continue to thrive and deliver results, so long as we continue to invest in them. By showing our commitment to funding HEP, we marshal the best and brightest from around the world to join us in the quest to answer the universe's biggest questions.

Conclusion

I thank the members of this distinguished subcommittee for your time. Your continued support for the DOE Office of Science's High Energy Physics research program means we can investigate the mysteries of matter, energy, space and time — enabling the scientific discoveries that will define the future, increase knowledge and improve lives both here in the United States and around the world.

Lia Merminga

Lia Merminga began her tenure as director of Fermi National Accelerator Laboratory in April 2022. An internationally renowned accelerator physicist, Merminga previously led the Proton Improvement Plan II (PIP-II) project at Fermilab, an essential enhancement to Fermilab’s accelerator complex that will provide powerful, high-intensity proton beams, enable the world’s most intense neutrino beam to the flagship Long-Baseline Neutrino Facility and the Deep Underground Neutrino Experiment (LBNF/DUNE), and drive a broad physics research program.

Merminga has held major scientific leadership roles at SLAC National Accelerator Laboratory in California; TRIUMF in Vancouver, Canada; and the Thomas Jefferson National Accelerator Facility in Virginia. Merminga earned a bachelor's degree in physics from the University of Athens, in Greece, master's degrees in physics and mathematics and a Ph.D. in physics from the University of Michigan, in Ann Arbor. She is a Fermilab Distinguished Scientist, a fellow of the American Physical Society, and a graduate of the Department of Energy's Oppenheimer Energy Science Leadership Program. She has served on numerous international scientific committees and was one of the authors of the 2014 Particle Physics Project Prioritization Project (P5) plan.