

# Elementary Particle Physics The Higgs and Beyond

Elementary particle physics reflects the human quest to understand the basic building blocks of nature and the rules that govern the physical world. This quest has led not only to critical scientific advancements but to technology breakthroughs driving state-of-the-art medical treatments, innovative manufacturing techniques, and new capabilities in quantum computing, as well as ancillary benefits such as the precursor to the World Wide Web.



At the request of the Department of Energy and the National Science Foundation, the National Academies conducted a study to explore the long-term goals and future ambitions for particle physics.<sup>1</sup> *Elementary Particle Physics: The Higgs and Beyond* presents a bold 40-year vision for the field and highlights critical actions necessary to make this vision reality.

Particle physics is the foundation for advancing scientific understanding across disciplines, and a robust national enterprise in this area offers the prospect of exciting and highly impactful discoveries. Maintaining U.S. leadership in particle physics will require significant support and investments in both the highly skilled workforce and new instruments needed to move the field forward.

#### **BUILDING A U.S.-BASED MUON COLLIDER**

To solidify U.S. leadership in particle physics and drive accelerator innovation, the United States should build the world's highest-energy elementary particle collider around the middle of the century. A muon collider—which would combine the advantages of an electron-positron and a proton-proton collider at a much smaller size—is necessary to address the most profound questions in particle physics.

Because a machine that collides unstable elementary particles like muons has never been attempted before, the United States should immediately create a national muon collider research and development program in coordination with international partners to demonstrate the collider's technical feasibility.

### PARTICIPATING IN THE HIGGS FACTORY

The Higgs boson, discovered in 2012, is responsible for giving mass to elementary particles. Determining if the Higgs is an elementary particle or has substructure has huge ramifications for the future of particle physics and understanding of the fundamental nature of matter in the universe.

Exploring these questions calls for sustained, cutting-edge particle research. Therefore, the United States should participate in the international Future Circular Collider Higgs factory currently under study at CERN to unravel the physics of the Higgs boson. Contributions from U.S. universities, national laboratories, and industry will help ensure the success of the initiative.

<sup>&</sup>lt;sup>1</sup> Around the time the committee was formed, the Department of Energy and the National Science Foundation also convened the Particle Physics Project Prioritization Panel to set a near-term plan for the field, informed by the 2021 U.S. Community Study on the Future of Particle Physics.

# RECRUITING AND MAINTAINING THE PARTICLE PHYSICS WORKFORCE

Future successes in particle physics are reliant on recruiting and retaining the best PhD students and postdocs from around the nation and the world, while competing with other scientific fields and industry for talent. For example, there is an anticipated shortfall in accelerator scientists, whose work will be essential to design, develop, and construct future colliders and neutrino sources. It is essential to the future of elementary particle physics in the United States to address these workforce issues.

A highly motivated student and postdoctoral workforce is required to achieve the ambitious science goals of the field. The United States should provide the means and the particle physics community should take responsibility for recruiting, training, mentoring, and retaining this workforce.

## **BENEFITS TO SCIENCE AND SOCIETY**

For decades, particle physics has revolutionized technologies from manufacturing and medicine to national security and computing. Accelerators are a critical component for semiconductor manufacturing and have made a wide range of life-saving medical treatments possible. Work in particle physics is contributing to transformational advances in machine learning, artificial intelligence, and quantum sensing, and accelerator technology protects the nation with cutting-edge instrumentation capabilities.

By implementing the report's vision, the field's worldleading scientific and technical workforce will not only pursue its science but will also continue to advance mathematics and theoretical research, computational methods, accelerator technology, and broad areas of instrumentation well beyond their present state leading to untold potential applications and benefits to the U.S. scientific enterprise, the economy, and society.

## SUPPORTING THE SCIENTIFIC AND TECHNICAL FOUNDATION FOR PARTICLE PHYSICS

To achieve this ambitious 40-year vision for particle physics, sustained investment in groundbreaking science and innovation for the future is critical. The United States should:

- continue to pursue and develop new theoretical and experimental approaches to questions ranging from neutrino physics and tests of fundamental symmetries to the mysteries of dark matter, dark energy, cosmic inflation, and the excess of matter over antimatter in the universe;
- explore new collaborative partnerships across traditional science disciplines and funding boundaries; and
- invest in sustained research and development for accelerator science and technology, advanced detector instrumentation, computing and data analytics, new and emerging technologies, and a healthy core research program.

The program of activities needed to achieve particle physics breakthroughs is beyond the resources—human and fiscal—of any single nation, and there are now nearly 100 nations engaged in particle physics research. The United States can strengthen and leverage its prominent position in particle physics by strategically investing in international partnerships. With a long and successful track record, these partnerships will continue to provide unique opportunities to U.S. scientists and boost U.S. capabilities in hosting and managing major projects.

NATIONAL ACADEMIES

The National Academies provide independent, trustworthy advice that advances solutions to society's most complex challenges. www.nationalacademies.org



To learn more, visit nationalacademies.org/epp.