NATIONAL ACADEMIES
Sciences
Engineering
Medicine

Elementary Particle Physics: The Higgs and Beyond

Committee on Elementary Particle Physics

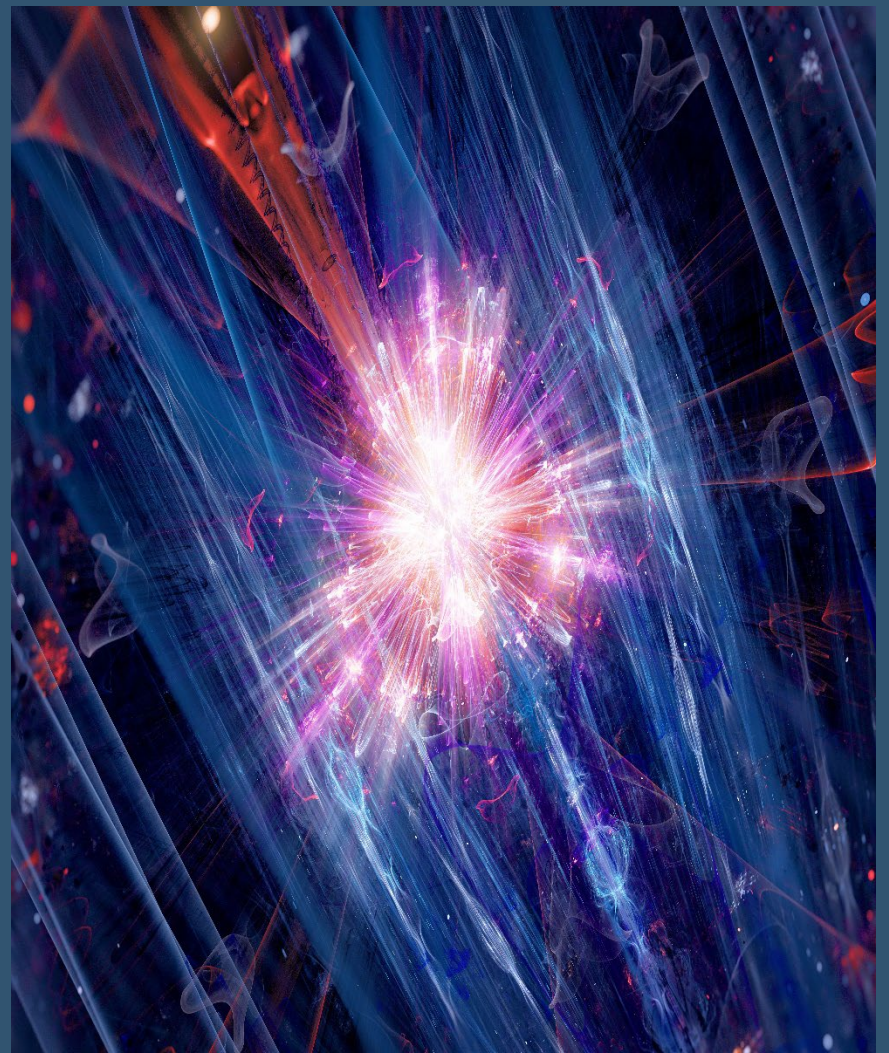
Board on Physics and Astronomy

Dr. Maria Spiropulu and Dr. Michael Turner, EPP2024 Co-Chairs

Download the report and report resources:
nationalacademies.org/epp

PUBLIC BRIEFING – JUNE 11 2025

Background



01

Committee Membership

- **Maria Spiropulu**; *Co-Chair*, California Institute of Technology
- **Michael S. Turner**; NAS, *Co-Chair*, UCLA
- **Nima Arkani-Hamed**; NAS, Institute for Advanced Study
- **Barry C. Barish**; NAS, California Institute of Technology
- **John F. Beacom**; The Ohio State University
- **Philip H. Bucksbaum**; NAS, Stanford University
- **Marcela Carena**; Perimeter Institute for Theoretical Physics
- **Bonnie Fleming**; NAS, Fermilab/UChicago
- **Fabiola Gianotti**; NAS, CERN
- **David J. Gross**; NAS, University of California, Santa Barbara
- **Salman Habib**; Argonne National Lab
- **Young-Kee Kim**; NAS, Fermilab/UChicago
- **Piermaria J. Oddone**; NAS, Emeritus Fermilab/Lawrence Berkeley National Laboratory
- **Fulvia Pilat**; Oak Ridge National Laboratory
- **Natalie Roe**; Lawrence Berkeley National Laboratory
- **Tim Tait**; University of California, Irvine

Staff

- Tarini Konchady, Co-Study Director
- Daniel Nagasawa, Co-Study Director
- Colleen Hartman, Board Director (until May 2025)
- Arul Mozhi, Acting Board Director (since May 2025)
- Linda Walker, Program Coordinator

J. Ritchie Patterson (Cornell University) resigned from the committee on October 28, 2024 and was not involved in final report.

Chanda Prescod-Weinstein (University of New Hampshire) resigned from the committee on April 5, 2024 and was not involved in final report.

Statement of Task from DOE and NSF

The National Academies of Sciences, Engineering, and Medicine will convene an ad hoc committee to:

- Identify the fundamental questions in particle physics that could motivate research in the next decade and beyond, irrespective of the tools and techniques to address them.
- Distinguish which of these questions could be addressed with available experimental and theoretical tools in the coming decade and which could require new techniques or approaches.
- Suggest technical research areas that could provide particle physics with new tools needed to enable new techniques and approaches.
- Suggest different ways of thinking and alternative approaches from other areas of science that could be incorporated into and benefit the overall particle physics enterprise.

NB: In agreement with the sponsors, the committee interpreted ‘next decade and beyond’ as a 40-year time horizon and that workforce was implicitly included in the scope of the charge.

Learn more on the study website: **nationalacademies.org/epp**

Information Gathering and Report Development

- First meeting held immediately after Snowmass 2021 (June 2022)
- Had 18 information gathering meetings, including:
  - Early Career Town Hall (13 October 2022)
  - U.S. CERN Early Career Particle Physics Community Town Hall (14 February 2023)
  - U.S. CERN Particle Physics Community Town Hall (14 February 2023)
  - Fermilab Early Career Particle Physics Community Town Hall (21 March 2023)
  - Fermilab Particle Physics Community Town Hall (21 March 2023)
- Input included reports out of Snowmass 2021 and the Particle Physics Project Prioritization Panel
- Committee compiled input and developed report with full committee consensus
- Prior to release, report underwent extensive National Academies peer-review process and approval

Learn more about the study process: **nationalacademies.org/about/our-study-process**

Exploring the Fundamental Nature of the Universe

- Elementary particle physics is the modern expression of the human quest to understand the basic building blocks of nature and the rules that govern the physical world.

- To address the big questions of the field, particle physics now involves astronomers, astrophysicists, accelerator physicists, condensed matter physicists, nuclear physicists, computational physicists, theorists across many disciplines, and engineers.

The Big Questions

What explains the pattern of forces and matter?

Why is there more matter than anti matter in the universe?

Why is the Higgs boson so light and how does it interact with itself?

What is the nature of dark matter and dark energy?

How are the atomic and sub-atomic and gravitational forces unified?

What is the origin of space-time and the universe?

Maintaining U.S. Leadership in Particle Physics

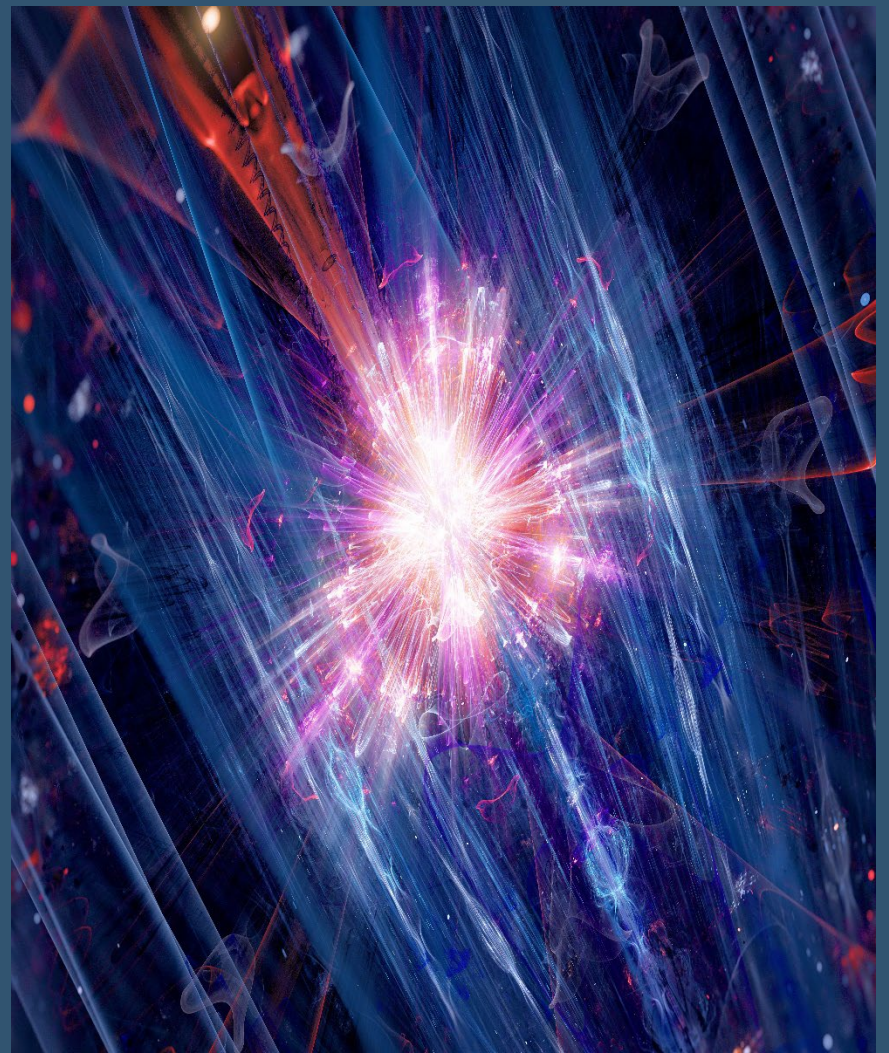
- The scope of the program of activities needed to address the agenda of particle physics is broader and more diverse than ever, and it is beyond the resources, both human and fiscal, of any single nation.

- The United States is a leader in particle physics today and is well positioned to continue to lead in the future. It has the workforce and material resources needed; it has a powerful system of universities, national laboratories, and industry; and the breadth of its activities in particle physics is unsurpassed.

The Report's 40-Year Vision for Elementary Particle Physics

- The United States will be hosting a previously-thought-impossible muon collider and playing a key role in the international Higgs factory.
- Our deeper understanding about the physical world will have impact across the sciences and enable new benefits for humankind.
- Connections made across the subfields of physics and other sciences will advance particle physics as well as the other fields.
- By making progress on seemingly impossible problems and with its profound discoveries, particle physics will inspire the next generations.

Recommendations



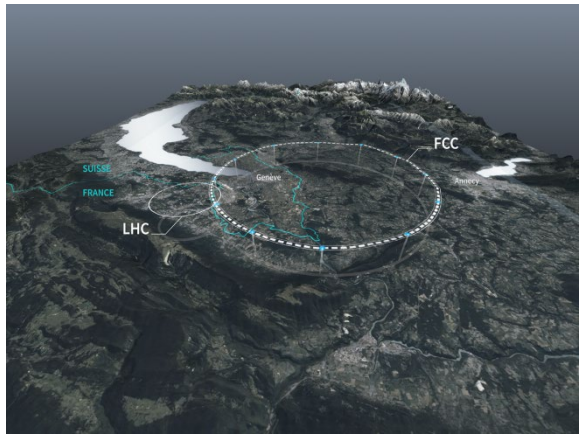
02

Host the World's Highest Energy Elementary Particle Collider

Recommendation 1: The United States should host the world's highest-energy elementary particle collider around the middle of the century. This requires the immediate creation of a national muon collider research and development program to enable the construction of a demonstrator of the key new technologies and their integration.

- Developing a US-hosted muon collider—an unprecedented machine requiring dedicated research, development, and a technology demonstrator followed by a feasibility study—would solidify U.S. leadership in particle physics and drive accelerator innovation.
- A collider with approximately 10 times the energy of the Large Hadron Collider is crucial to address the big questions of particle physics.
- A muon collider combines the physics advantages of an electron-positron and a proton-proton collider, with a much smaller size.

Participate in the Future Circular Collider Higgs Factory



Recommendation 2: 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.

- Determining whether the Higgs is elementary or has substructure has huge ramifications for the future of particle physics.
- Active participation in a Higgs factory is crucial for the U.S. particle physics community.
- U.S. involvement would ensure a leading role in cutting-edge technology and provide valuable training for the next generation of physicists.

Continue the Pursuit of New Approaches and Innovation

Recommendation 3: The United States should continue to pursue and develop new 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.

- The United States has the world-leading program in non-collider particle physics, both in its breadth and its depth
- This includes the cosmic surveys, dark matter searches and measurements, neutrino experiments and observations, particle astrophysics, and rare decays and precision measurements

A broad set of experiments that does not involve particle colliders are critical to addressing many of the most urgent questions in particle physics.

Opportunities through New Partnerships Across Discipline and Funding Boundaries

Recommendation 4: The United States should explore new synergistic partnerships across traditional science disciplines and funding boundaries.

- Cross-disciplinary work leads to innovation and breakthroughs, but impediments for scientists engaged in such work are significant, including overcoming artificial barriers between offices and agencies.

- Particle physicists are often early adopters and adapters of advances in other areas of science and technology. Many connections have been and are being made with nuclear physics, atomic physics, particle astrophysics and astronomy.

Invest in Sustained Research and Development

Recommendation 5: The United States should invest for the long journey ahead with sustained research and development funding in accelerator science and technology, advanced instrumentation, all aspects of computing, emerging technologies from other disciplines, and a healthy core research program.

- The long journey to realize the extraordinary opportunities for discovery in particle physics will require sustained and steady support of the scientists who carry out the work and targeted investments in research and development that will make the ambitious projects possible.
- Theory is a key part of a healthy core research program and enables connections across different subfields.

Navigate Looming Workforce Shortfalls

Finding: The design and construction of future colliders and neutrino sources will require a large number of accelerator scientists. This, and the demand for such scientists in other scientific fields, industry and in medicine, will create a shortfall, estimated to be a factor of 3 to 4. Moreover, fewer than 10 U.S. universities currently offer graduate education or programs in accelerator physics.

Finding: Elementary particle physics is competing with other scientific fields for resources and also with industry for talent.

It is essential to the future of elementary particle physics in the United States that it address its workforce issues, including a shortfall in the number of accelerator scientists, and growing barriers to international exchanges.

Recruit and Retain the Talented Workforce

Recommendation 6: The federal government should provide the means and the particle physics community should take responsibility for recruiting, training, mentoring, and retaining the highly motivated student and postdoctoral workforce required for the success of the field's ambitious science goals.

- Future success of the field will continue to be reliant on recruiting and retaining the very best PhD students and postdocs from across the nation and around the world to the U.S. particle physics effort.
- These researchers form an important part of the trained technical and entrepreneurial talent that helps the United States maintain its influence in advanced technology as well as in science.
- Non-traditional funding sources such as philanthropic organizations and industry present new opportunities to support early-career scientists.

Continue Strengthening International Partnerships

Finding: The number of nations engaged in particle physics research has grown to nearly 100 as has their capabilities. No single nation dominates the field as the United States once did.

Finding: The program of activities needed to address the agenda of particle physics is beyond the resources – human and fiscal – of any single nation, and planning and coordination are essential to success.

Continue Strengthening International Partnerships

Recommendation 7: The United States should engage internationally through existing and new partnerships and explore new cooperative planning mechanisms.

- The United States must work to strengthen international planning and coordination on all levels.
- Particle physics programs of CERN and the United States have become interdependent to the mutual benefit of both. American involvement at CERN is now a major element in the U.S. program. It is important for the United States to be more involved in the decision-making process.
- The United States has a rich history of successful collaboration with beyond Europe, notably with Japan, Korea, and India. Strengthening those partnerships is beneficial to the United States and to the field.

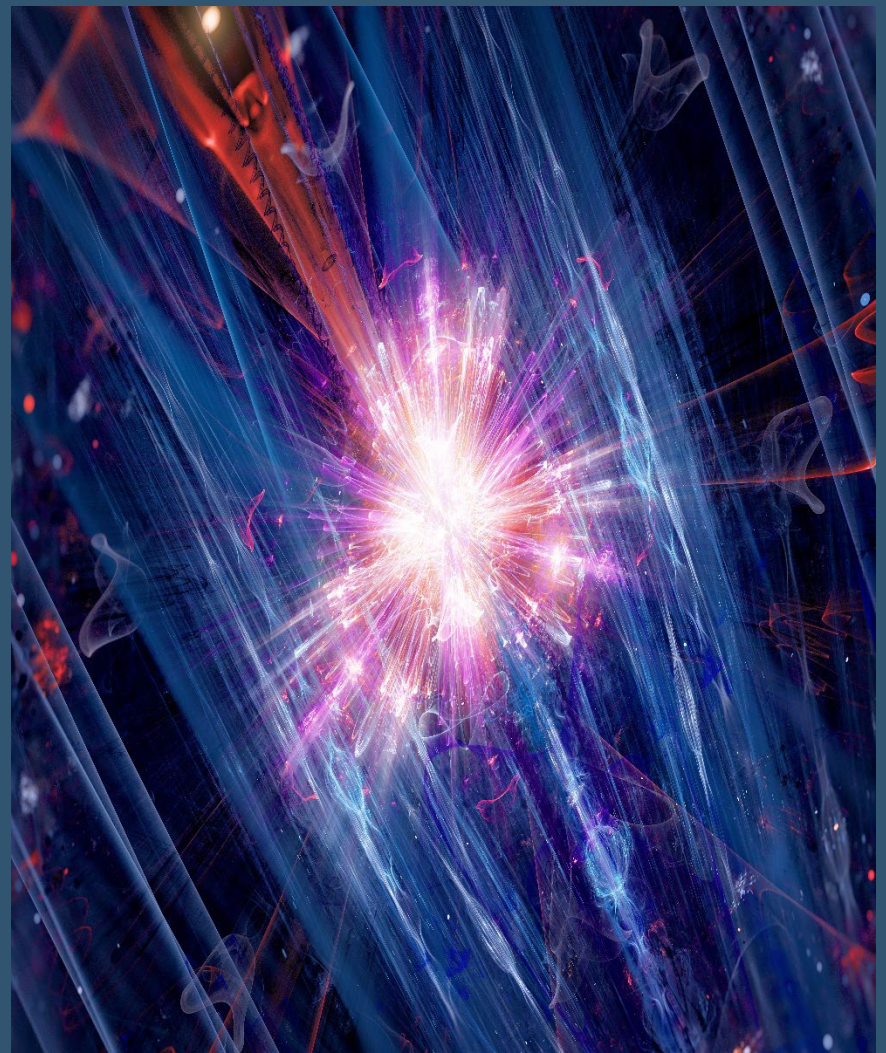
Energy Management

Recommendation 8: Funding agencies, national laboratories, and universities should work to minimize the environmental impact of particle physics research and facilities.

- Most importantly, this includes optimizing the energy footprint of accelerators, detectors, and computing infrastructure, as well as innovating new technologies for practices with broad applicability outside the field.

- A multipronged approach must be taken in developing the technologies necessary to make future accelerators affordable and energy-efficient.

Benefits of Particle Physics



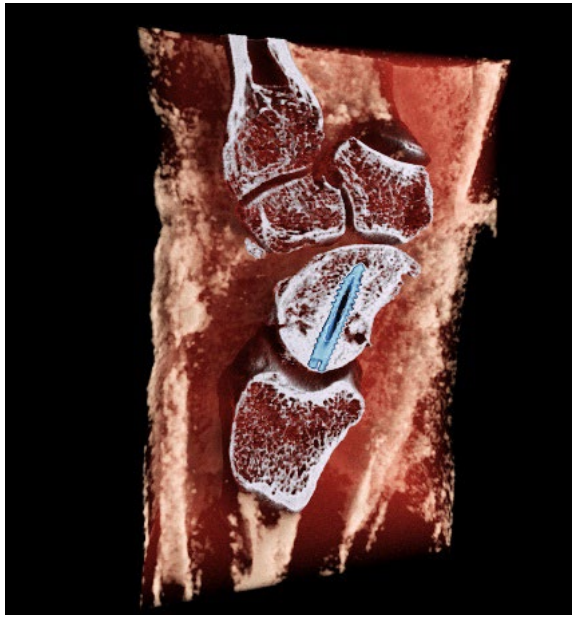
03

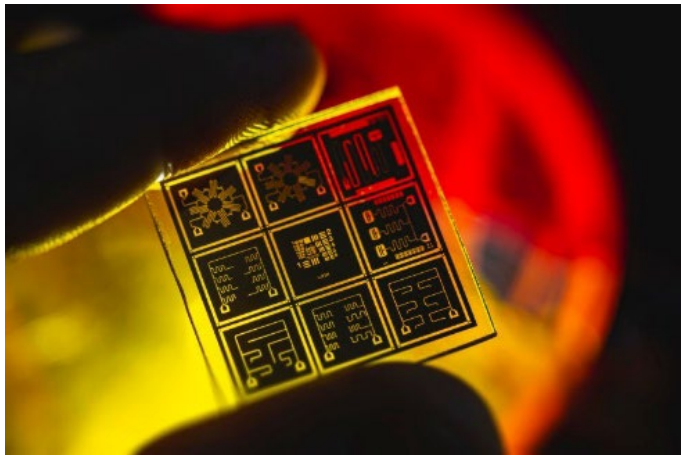
Pioneering Emerging Technologies and Enabling New Applications

- **Accelerators:** Particle physics has been the primary contributor to the development of accelerators, enabling semiconductor fabrication, medical imaging and therapeutics that cannot be achieved by other means, and a great variety of industrial applications.

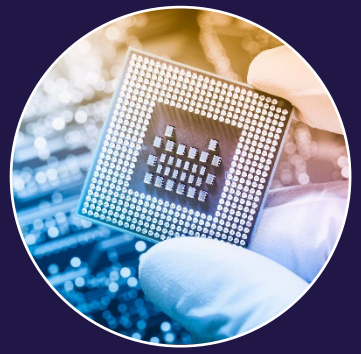
- **Detectors:** Detection and measurement of particles is essential for the field, leading to the development of innovative quantum sensing technologies with unprecedented precision.

- **Computing:** Particle-physics research requires powerful computational technologies, serving as an early adopter and pioneer for new technologies such as High Performance Computing, quantum computing, and AI/ML.





Who Benefits?



Industry

More than 24,000 accelerators in the United States have been built for a great variety of industrial applications, especially for the semiconductor industry.

Medicine

New, more effective, or cost-efficient therapies for deep tumors. Production of medically critical isotopes at proton accelerators.

National Security

MeV gamma rays produced by electron linear accelerators are in extensive use for scanning of cargo containers that enter the country.

Computation

Development of machine learning and artificial intelligence techniques, including important contributions in the areas of pattern recognition and anomaly detection.

The Broader Workforce

Particle physics graduate students and postdocs find prominent careers outside the field in industry, government, and education.

Particle Physics Benefits the Nation and Humanity

- Technological developments in particle physics have enabled and/or sped up their development more broadly, with important societal impacts.
- Particle physics is an essential component of the nation's scientific fabric and has synergistic interactions with many other fields.
- Historically, the long-term benefits associated with seeking to understand the fundamental rules that govern the physical world include the advances and discoveries in chemistry, electricity, atomic energy and quantum mechanics that make the modern world possible. In particular, the technological applications of quantum theory, from chips to sensors, underpin the current information age.
- *Conclusion: The United States should continue its leadership in elementary particle physics because of its many benefits to science, the nation and humanity.*

Thank You.

Submit questions at
slido.com
Meeting Code **2543 103**

Download the report and report resources:
nationalacademies.org/epp