

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

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, The University of Chicago
- **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: 40-year Vision Unconstrained by Budgetary Considerations

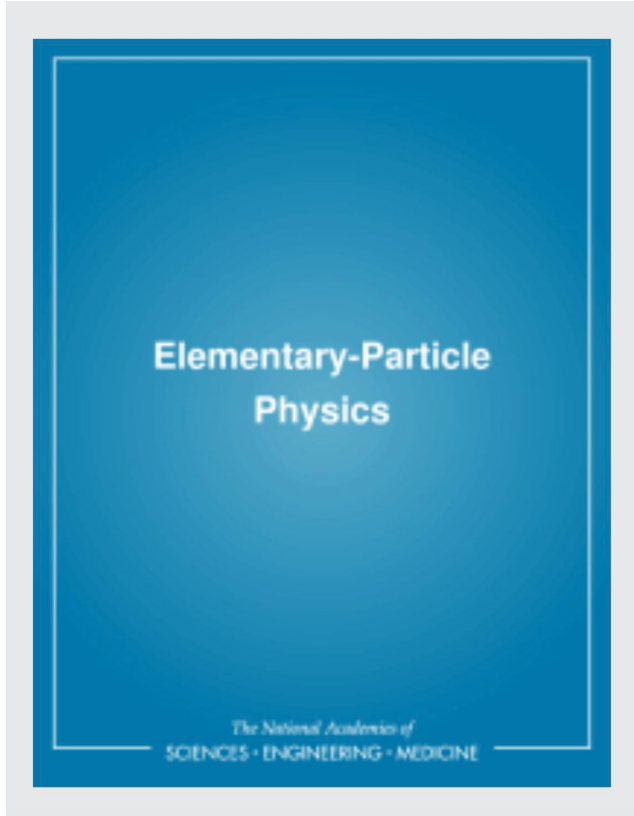
- Identify the fundamental questions in particle physics that could motivate research in the next decade and beyond, irrespective of the tools and techniques to address them.
- Distinguish which of these questions could be addressed with available experimental and theoretical tools in the coming decade 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. Complementary and co-temporal w/DOE-NSF P5

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



3 previous NRC studies of EPP

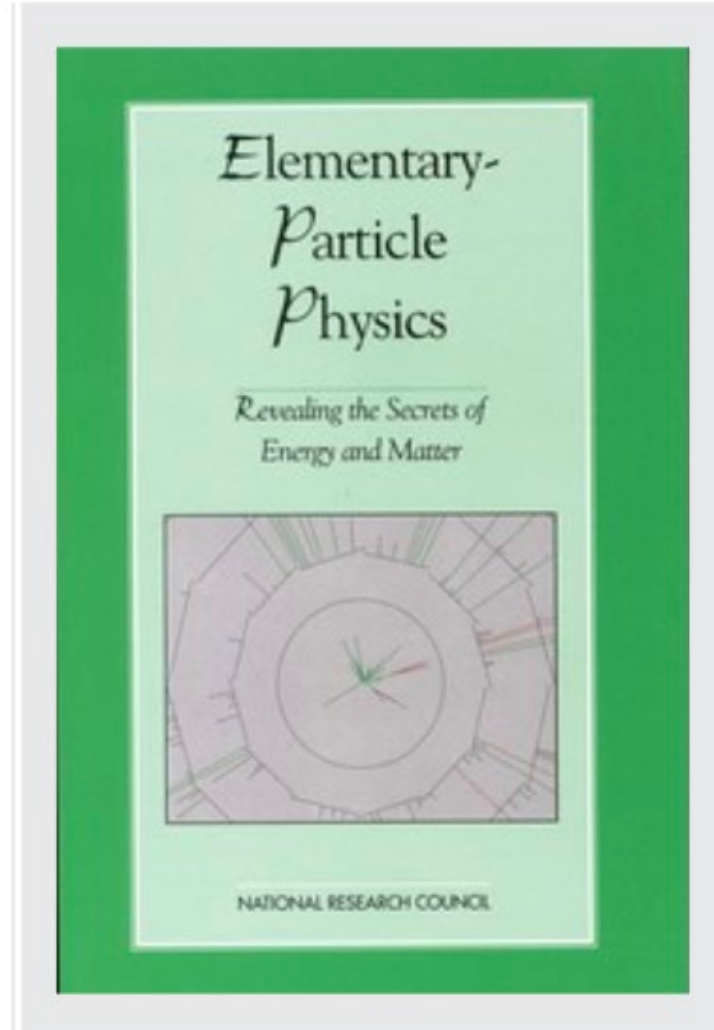


1986

Perl

NATIONAL
ACADEMIES

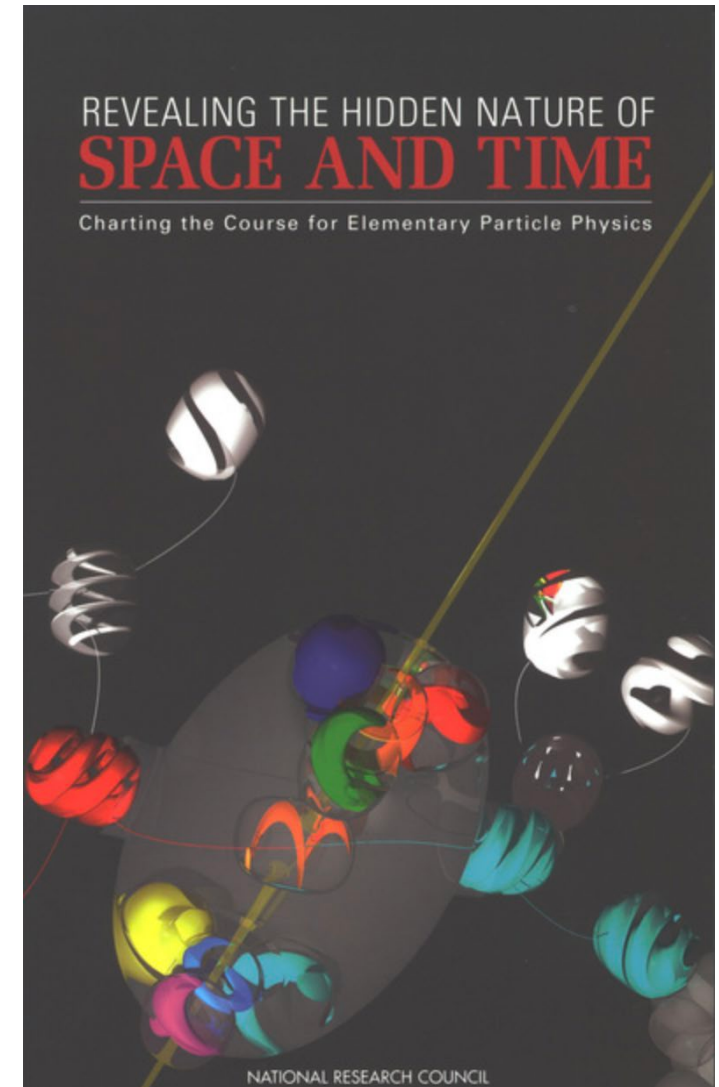
Sciences
Engineering
Medicine



1998

Winstein

BPA Fall Meeting November 20, 2025



2006

Shapiro/Dawson

Landscape since 2006 NRC Study on Particle Physics

- Energy Frontier moved from the Tevatron at Fermilab to the LHC at CERN
- The Higgs boson was discovered at the LHC and θ_{13} was measured
- Λ CDM firmly established as the consensus cosmological model
- Detection of gravitational waves from the coalescence of two 30 solar mass BHs
- Continuing internationalization of all aspects of particle physics (more than 100 nations involved)
- The growing “big tent” that today involves astronomers, astrophysicists, accelerator physicists, condensed matter physicists, nuclear physicists, computational physicists, theorists across many disciplines, and engineers
- The agenda has broadened to include understanding the origin of space, time, and the Universe, and the profound connections between them.



Big Questions that Connect Matter, Energy, Space and Time

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?



Overarching recommendation: Continue 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
 - The breadth of its activities in particle physics is unsurpassed.
 - The program in place and prioritized by P5 is characterized by its breadth, excellence and international strategy



40-Year Vision for Elementary Particle Physics

Circa 2065, we will have gained a much deeper understanding of the physical world, answered some of the mysteries that bedevil us today, and will be puzzling about new ones. What we know today will fit into a grander, more unified understanding of matter, energy, space, and time. It is impossible to predict the discoveries that will come or when they will occur; but it is easy to predict that our deeper understanding about the physical world will have impact across the sciences as well as new benefits for humankind. The global effort that made this possible will include an international Higgs Factory with strong U.S. involvement, surprising us with new insights about the Higgs; a muon collider that was once thought impossible to build, hosted by the Fermi National Accelerator Laboratory and making unexpected discoveries; and a program of dark matter studies and cosmic surveys revealing new insights into particle physics and cosmology. And the connections made across the subfields of physics and the sciences more broadly will be illuminating the power of working across discipline boundaries to the larger benefit of science. Particle physics will not only be a shining example of how the world can make progress on seemingly impossible problems, but it will also be inspiring the next generations, here and around the globe, with its amazing discoveries and mysteries yet to be revealed. In short, the future for particle physics will be even brighter than it is today.



40-Year Vision for Elementary Particle Physics

- Circa 2065, neutrinos will have revealed more of their secrets, we will have unraveled some of the mysteries of the Higgs and we will be puzzling about discoveries that will be made by exploring the 10 TeV/parton frontier.
- The global effort that made this possible will include an international Higgs Factory with strong U.S. involvement; a muon collider that was once thought impossible to build, hosted by the Fermilab; and a program of dark matter studies and cosmic surveys revealing new insights into particle physics and cosmology.
- Our deeper understanding about the physical world will have impact across the sciences as well as new benefits for humankind. In short, the future for particle physics will be even brighter than it is today.



8 Recommendations to make the vision real



New Colliders for Discovery:

Understanding the Higgs
Exploring the 10 TeV frontier



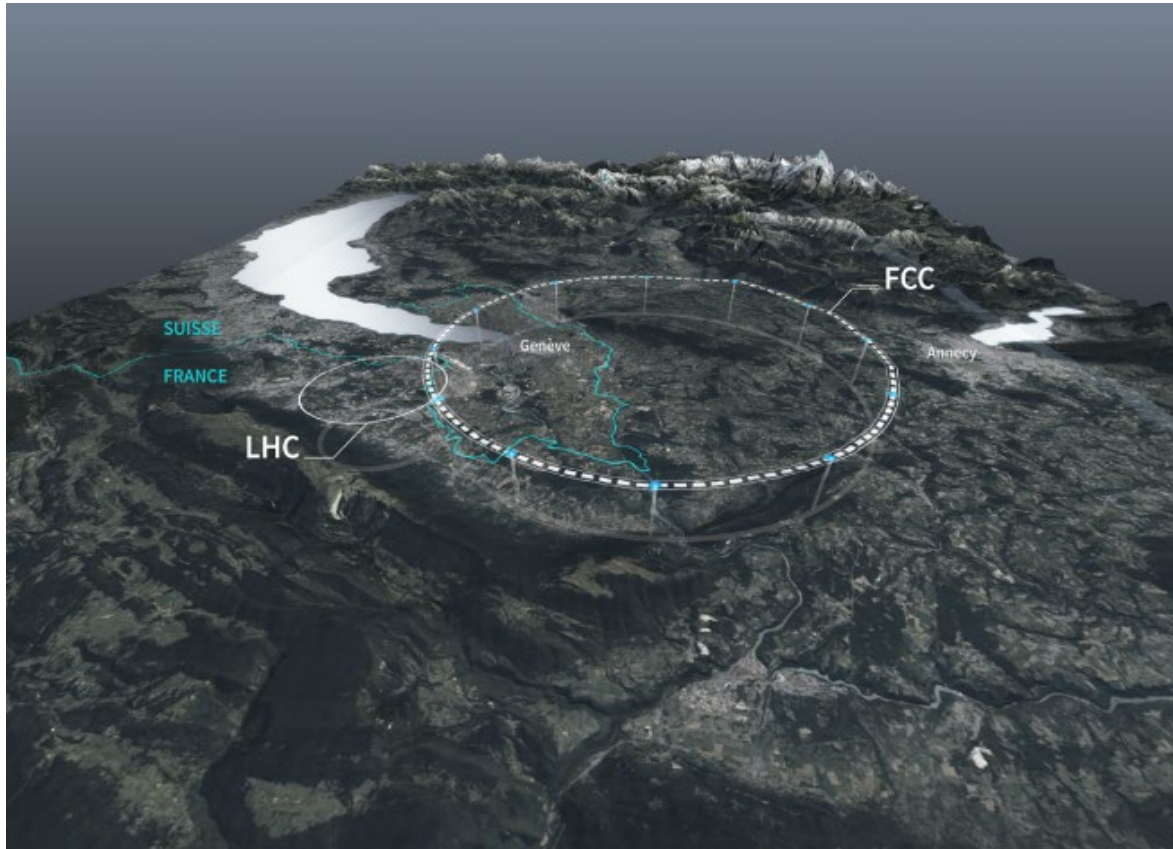
10 TeV Muon collider

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.

- 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.
- Developing a US-hosted muon collider—an unprecedented machine – will require dedicated research, development, and a technology demonstrator, all of which will drive particle accelerator innovation, as well as coordinated efforts among all national labs and international partners



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.

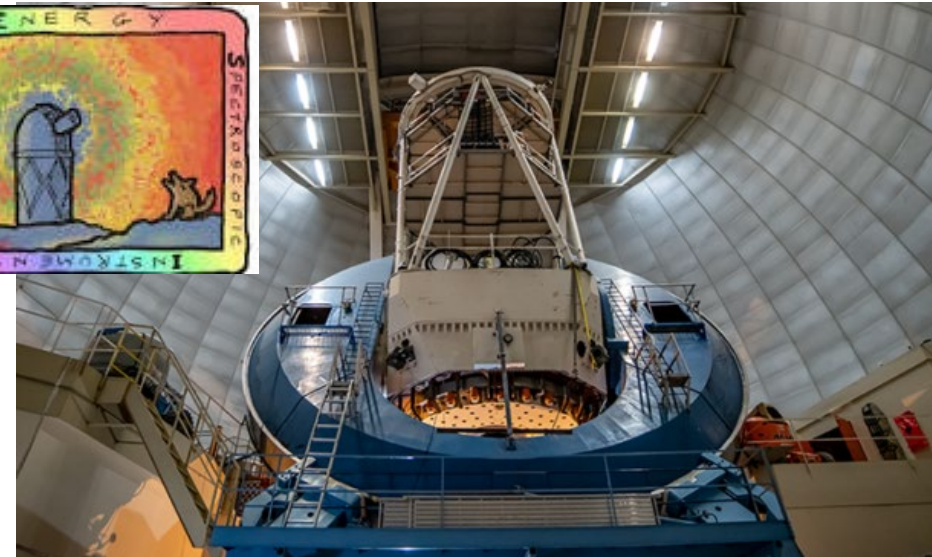
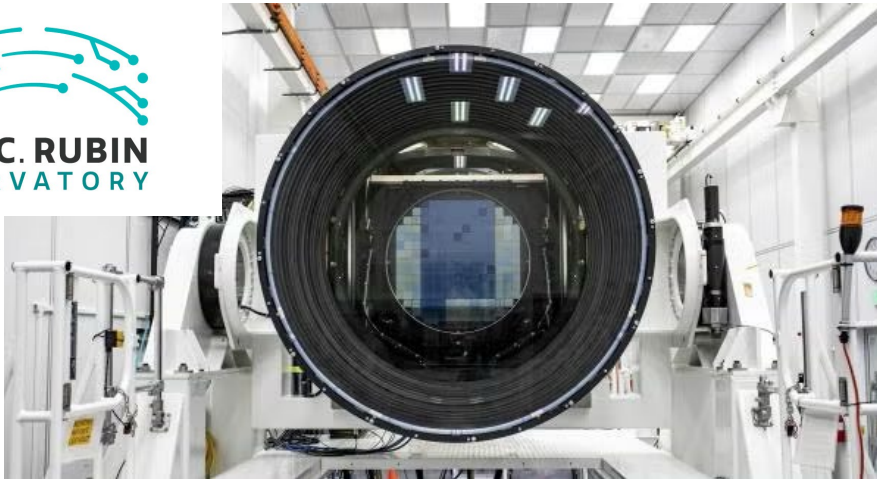
New Approaches and
Partnerships across
Disciplinary Boundaries
and Funding Agencies:
Connecting
Matter/Energy and
Space/Time



Continue the Pursuit of New Approaches

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.

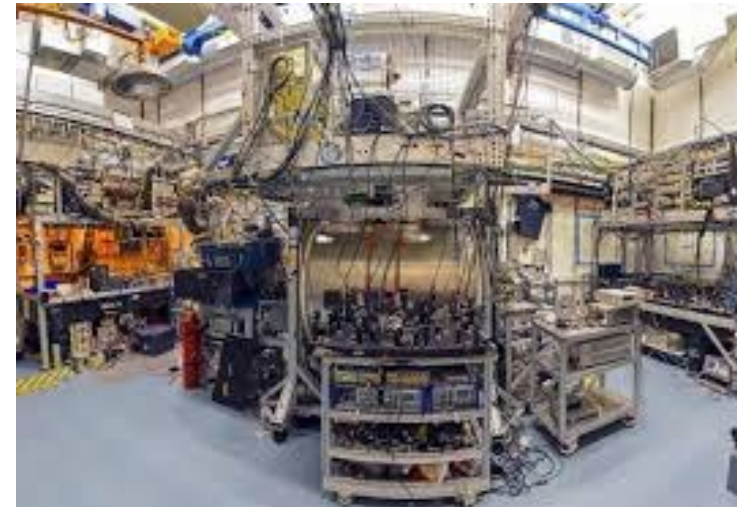
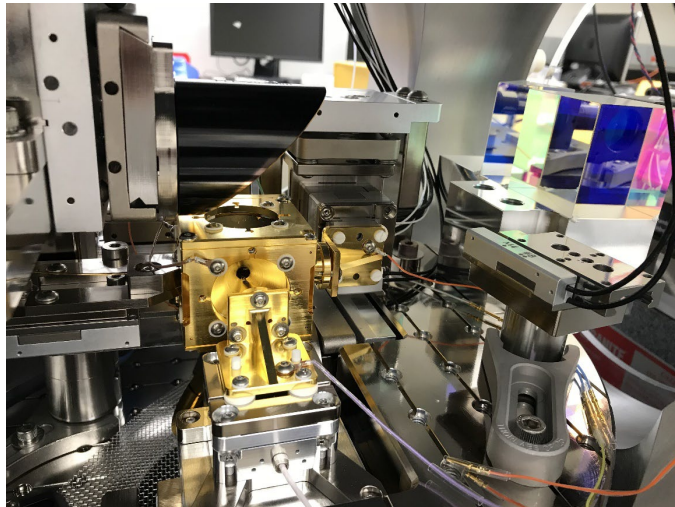
- A broad set of experiments that does not involve particle colliders are critical to addressing many of the most urgent questions in particle physics. This includes the cosmic surveys, dark matter searches and measurements, neutrino experiments and observations, particle astrophysics, and rare decays and precision measurements



New Partners/Partnerships

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
- 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.



Investing for the Future



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.



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.



International Partnerships



Continue Strengthening International Partnerships

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

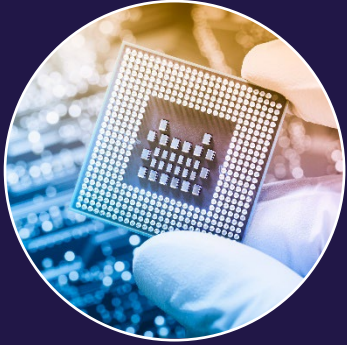
- The United States must work to strengthen international planning and coordination on all levels.
- Particle physics programs of CERN and the United States have become interdependent to the mutual benefit of both. American involvement at CERN is now a major element in the U.S. program. It is important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



Benefits of Particle Physics



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.

Dissemination



Presentations (by co-chairs)

- June 4: NSF and DOE sponsor briefings (closed)
- June 11: Public roll out
- June 12: Fermilab Town Hall (w/Fleming and Kim)
- July 28: SLAC Town Hall (w/Bucksbaum)
- July 31: DPF Community Forum
- August 24: ICFA
- August 27: FermiForward Fermilab Director Search Committee
- September 9: NASEM DEPSCOM
- September 16: Fermilab PAC (w/Tait and Kim)
- September 19: BNL Town Hall
- September 22: CERN SPC (w/Gross and Gianotti)
- September 29: EFI/UChicago colloquium



Presentations (co-chairs)

- September 30: ANL Town Hall (w/Habib)
- October 21: LBL Town Hall (w/Roe, Oddone, and Gianotti)
- November 20: NASEM BPA
- December 9 or 10: Brief DOE Undersecretary Dario Gil
- January 9, 2026: FermiForward Board (closed)
- March 2026 APS Global Summit
- July 2026: DPF Meeting, Future of Particle Physics session
- OSTP/OMB/Hill briefings: offered, waiting to hear

Our strategy: stay visible and relevant
Remember, it is a 40-year plan!



APS News Back Page (November/December)

<https://www.aps.org/apsnews/2025/11/big-tent-particle-reshaping-research>

APS NEWS | THE BACK PAGE

How “big tent” particle physics is reshaping physics research

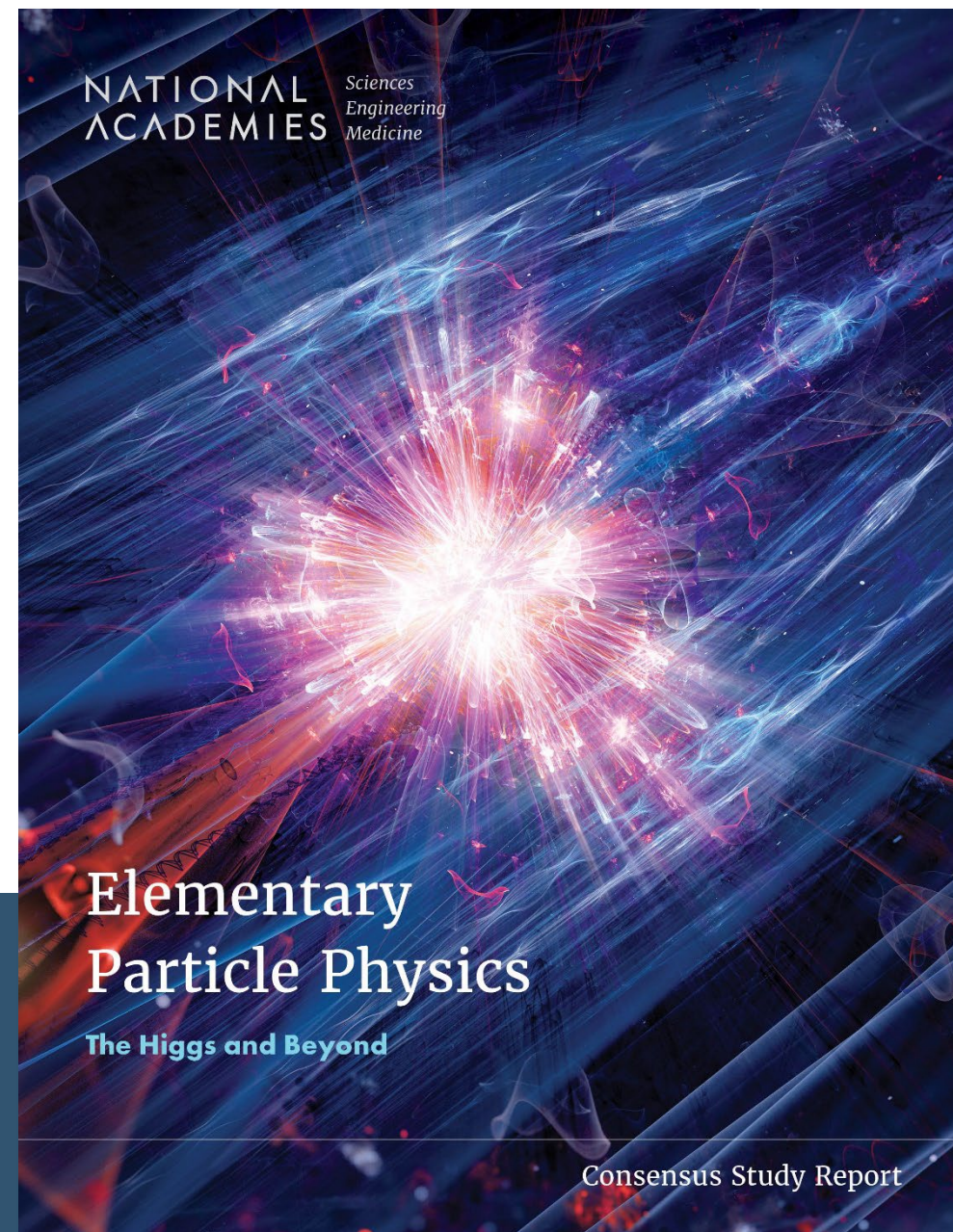
Particle physics used to rely mostly on accelerators and theory. Not anymore.

By Maria Spiropulu and Michael Turner

Nov. 14, 2025



A postdoc, Olena Karacheban, installs new instrumentation for the CMS experiment at CERN in July 2021. CERN, located outside Geneva, Switzerland, is one of many facilities where fundamental research in particle physics is taking place.
CERN



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