The Path to Global Discovery: U.S. Leadership and Partnership in Particle Physics

US LUA Meeting- December 13, 2023

The International Benchmarking Panel is a HEPAP Subpanel charged by the Department of Energy and the National Science Foundation to “develop a report providing further input on possible P5 implementation strategies, particularly in the unique international context of particle physics.”

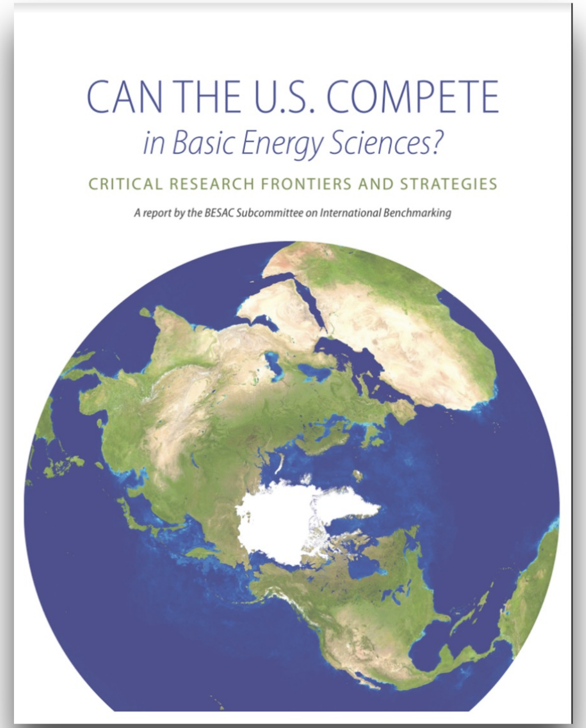
DOE Office of Science International Benchmarking

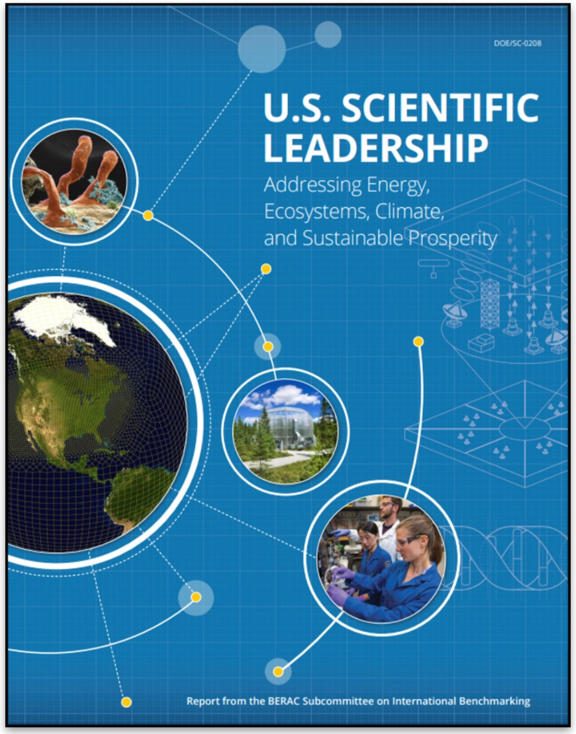
BESAC points to a “[downward overall trend in U.S. competitive advantage in all research areas identified as critical to BES’s mission].” However, there are strategic opportunities for “international collaboration…to enhance U.S. competitiveness”

“…the **BERAC** subcommittee emphasizes the critical importance of avoiding a myopic, narrow, and adversarial framing of international leadership for discovery science, the fruits of which must be realized at a global scale.”

ASCR: “The US is losing its historical leadership position in advanced scientific computing research” (from ASCAC FACA presentation, 6/2023).

FESAC: “The value and impact of such international collaborations is generally maximized by the existence and engagement of strong domestic fusion science and R&D programs.”





Strategic Plan for U.S. Particle Physics in the Global Context (2014)

Particle physics is global

"The scientific program required to address the most compelling questions of the field is beyond the finances and technical expertise of any one nation or region; nonetheless, the capability to address these questions in a comprehensive manner is within the reach of a cooperative global program."

"Hosting world-class facilities and joining partnerships in facilities hosted elsewhere are both essential components of a global vision."

"Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community."

HEPAP's Charge for the IB panel

U.S. as a leader, at home and abroad

How can the US particle physics program **maintain critical international cooperation in an increasingly competitive environment** for both talent and resources?

In areas **where the U.S. is leading, how can we sustain our roles and attract the best international partners**?

In other areas, **how can the U.S. build and maintain its reputation as a "partner of choice"?**

In general, **are there barriers** that can hinder our ability **to form effective and enduring international partnerships**?

Innovative and transformative capabilities

Identify **key areas where the U.S. currently has, or could aspire to, leadership roles** in High Energy Physics (HEP) via its unique or world-leading capabilities (i.e., advanced scientific facilities and tools), or leading scientific and technical resources, including highly trained personnel and supporting infrastructure. This may include emerging areas or opportunities that offer significant promise for leadership.

To **preserve and foster U.S. leadership roles within reasonable resource constraints,** are there particular technical areas or capabilities that could be emphasized? Are there **other technical resources and capabilities that could be leveraged to achieve these goals**, possibly through collaborations within and beyond the HEP community?

Workforce

How can programs and facilities be structured to **attract and retain talented people**?

What are the **barriers to successfully advancing careers of scientific and technical personnel** in particle physics and related fields, and how can U.S. funding agencies address those barriers?

A complete answer to these questions must address how we can **ensure that we are recruiting, training, mentoring, and retaining the best talent from all over the world, including among traditionally underrepresented groups within the U.S.**

IB Subpanel members

Members' expertise spans areas of the P5 Science Drivers (2014).
Full Draft Report is available online.

Co-Chairs: Patricia McBride (FNAL), Bonnie Fleming (FNAL/UChicago)

Mei Bai (SLAC)
Marcela Carena (FNAL)
Scott Dodelson (CMU)
Dan Dwyer (LBL)
Tova Holmes (UTK)
Tsuyoshi Nakaya (Kyoto)
Andy Lankford (UCI)
Wim Leemans (DESY)

Reina Maruyama (Yale)
Sekazi Mtingwa (NRC)
Brian Nord (FNAL)
Ian Shipsey (Oxford)
Stefan Soldner-Rembold (Manchester)
Lindley Winslow (MIT)

Ex-officio: JoAnne Hewett (SLAC) → Sally Seidel (UNM)
Editor: Holly Holt, Art Director: Michael Branigan (Sandbox Studio)

Methodology

The HEPAP International Benchmarking Panel provided input to the 2023 P5 panel.

Subcommittees and report editors

1. **Big Experiments** (LHC, DUNE, Cosmic), *Chair: A. Lankford*
2. **Small Experiments** & Instrumentation, S&C, QIS, AI/ML, *Chair: I. Shipsey*
3. **Accelerator Program**, *Chair M. Bai*
4. **Workforce**, *Chair: S. Mtingwa*

***Theory** distributed throughout subcommittees.*

How (or how not) to benchmark

- Collaboration is key to progress. **International collaboration complicates benchmarking the U.S. role**.
- **Metrics are not easy to evaluate** (e.g., scientific papers, citations).
- **Other possible metrics**: Nobel prizes, investment per capita, leadership roles
- More productive to **focus on the benefits of collaboration and the advantages of the partnerships** that advance our science globally.

Data collection

- Community **interviews**
- **Townhall** at Snowmass
- **Demographics** collected from diverse sources
- **Feedback** through our website and **surveys** from subcommittees
- Described in the Appendices.

Intertwined Science Drivers

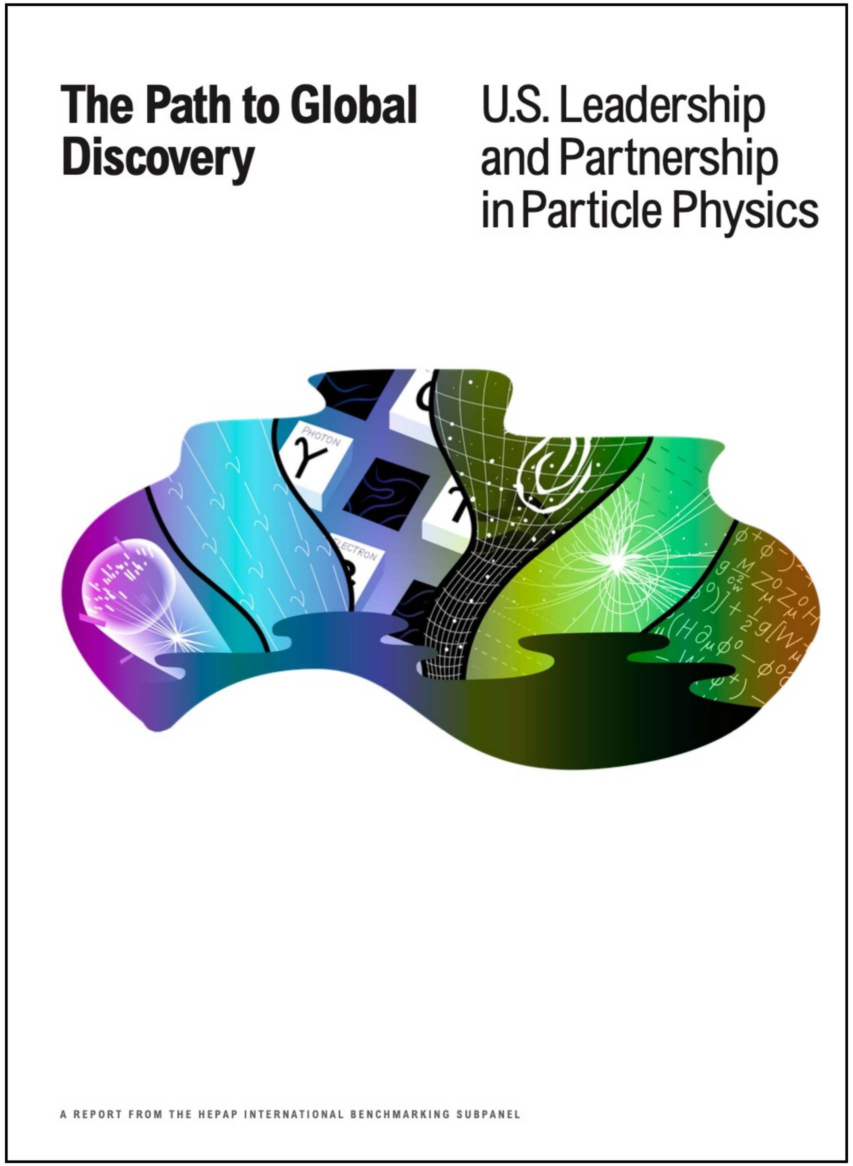
The foundation of the IB Report is derived from the science drivers from the 2014 report, but the findings and recommendations apply to the updated drivers in the 2023 report.

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

We added theory as part of this foundation.

Defining Scientific Leadership in Particle Physics in 2023

- Leadership means having the capabilities, experience, and infrastructure to contribute to a research direction in a significant way.
  - Leadership, in a collaborative field, is not always about being first.
- In identifying areas of U.S. scientific leadership, the report assumes:
  - The key U.S. scientific areas have been defined by the P5 science drivers;
  - The starting point for the report was the drivers from the 2014 P5 report; and
  - The 2023 P5 report sets a new strategic direction – and builds on the directions in the 2014 report.



Status of IB Report

- Draft findings and recommendations presented to P5, EPP Panel, HEPAP during the summer 2023.
- Report presented and approved by HEPAP on Nov. 2, 2023.
- Text finalized and available on HEPAP website and on usparticlephysics.org
- Final report with graphics to be available soon in print and online.

Collaboration

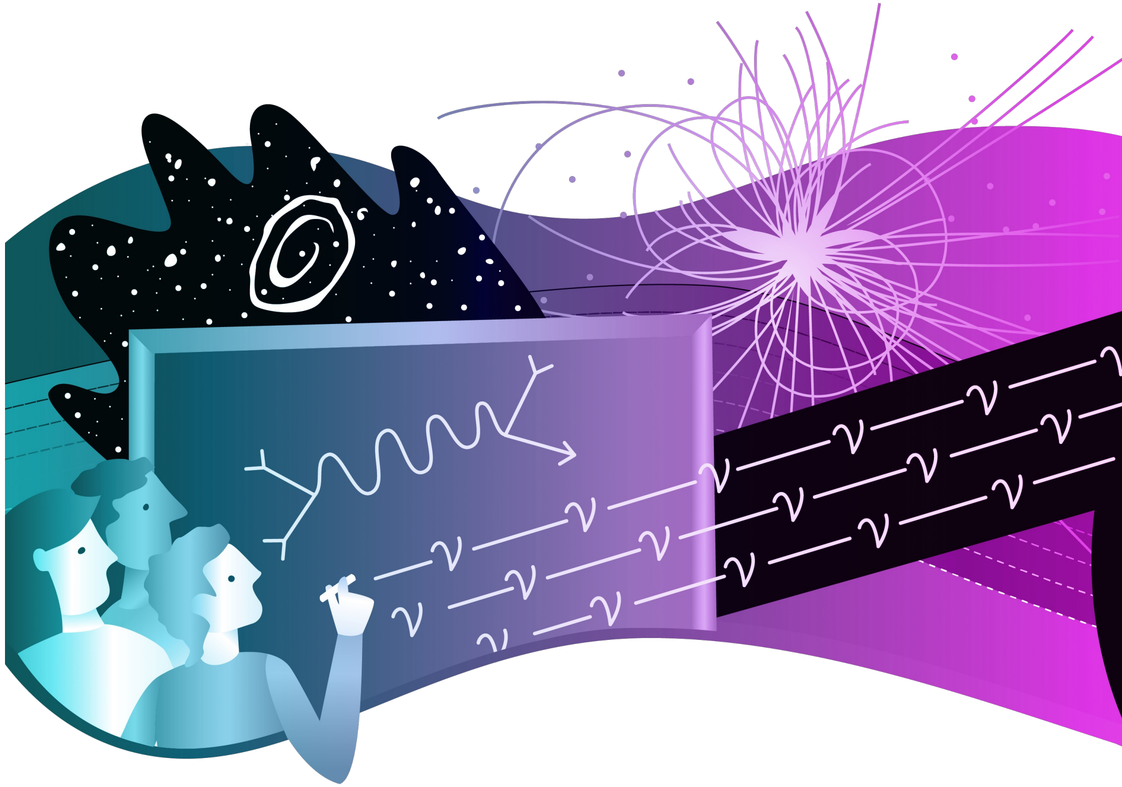
Science enabled by

Partnerships, Experiments, and Facilities

1- Scientific breadth and application

Particle physics theory and experiments address deep mysteries of the universe while advancing concepts and technology that are vital to other research fields, as well as society at large.

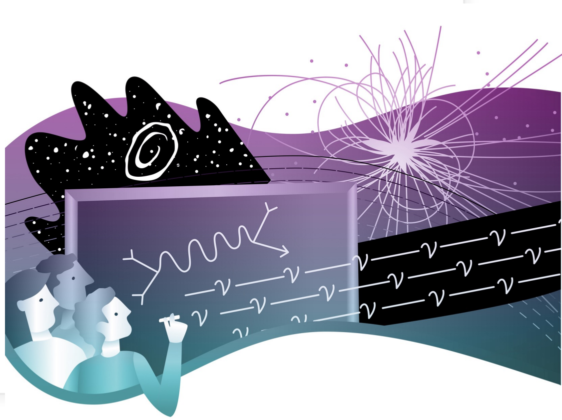
Strengthen investments to advance particle physics discoveries as well as benefits to other scientific disciplines and society.



Key Finding and ***Recommendation***

Scientific breadth and application

Key scientific areas and U.S. leadership



Finding: **The strategic plan for particle physics is developed through a community planning process culminating in the report of the HEPAP subpanel called P5.**

The 2014 strategic plan was highly successful; in the last decade, several large projects were launched, and some projects are now operating and producing scientific results.

Recommendation: **The U.S. should continue to play leadership roles in the key scientific areas defined as science drivers by P5.**

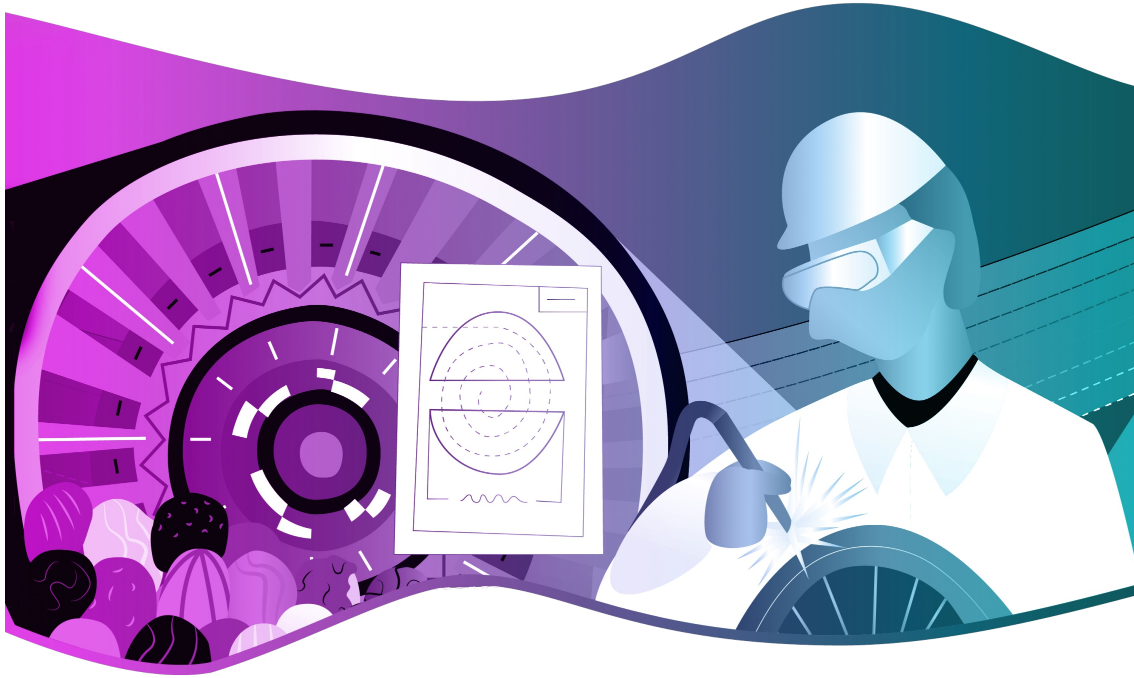
Finding: **Particle physics pushes the boundaries of technology in ways that enable research in other fields of science and that benefit society at large.**

R&D for particle physics has produced technology that is used in other fields and in society at large – accelerators, instrumentation, computing.

Recommendation: Continue to invest in technology R&D that enables new discoveries in particle physics and other scientific fields and that will lead to applications that benefit society at large.

2 – Diversity across scales and stages

The field of particle physics is a **vibrant research ecosystem**, built by an international network of partnering nations, facilities, experiments, and people. To be a leader, the U.S. must continuously **produce scientific results**, **build** facilities and experiments for the future, and **advance new ideas and technologies** that enable the discoveries of tomorrow.

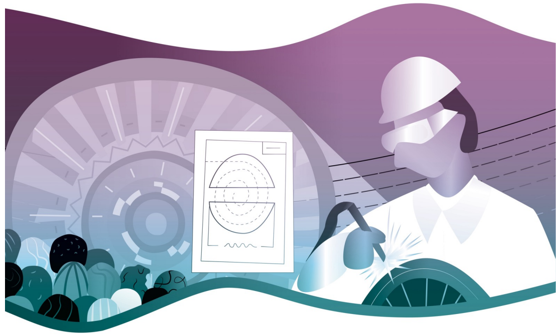


> ***Maintain a comprehensive program at home and abroad, with a range of experiment scales and strategic balance among construction projects, operations of experiments and facilities, and core research activities, including development of future facilities.***

Key Finding and ***Recommendation***

Diversity across all scales

Particle Physics as an ecosystem



Finding: Decline in support for core research threatens U.S. leadership in particle physics.

Recommendation: Reinvigorate the U.S. core research program to restore U.S. leadership in the next generation of ideas, experiments, and discoveries.

Finding: U.S. leadership entails leading on small experiments as well as leading on medium and large experiments.

Recommendations: Continue to support small projects as a component of a balanced national portfolio of experiments at all scales.

Establish a funding mechanism under which scientifically compelling, well-conceived small projects can be initiated and executed in a timely and competitive fashion.

3 – Collaborating across the globe

Frontier research in particle physics necessitates international collaboration and cooperation. The combined expertise and resources from nations around the world enable discoveries and technological advances impossible to achieve by any single nation. It is the *global* particle physics program that collectively addresses the burning scientific questions across the breadth of the field.

Continue support for and actively seek engagement with international collaborations and partnerships of all sizes.

Key Finding and ***Recommendation***

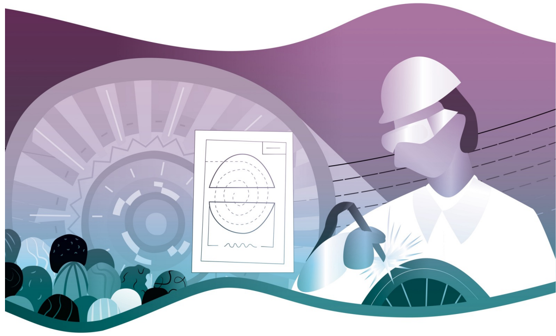
Collaborating across the globe

The roots of strong collaborations

Finding: **Strong collaborations exhibit common characteristics. Shared scientific objectives and a shared sense of responsibility are overarching common characteristics.**

Collaborating across the globe

Engage with partners in the earliest stage



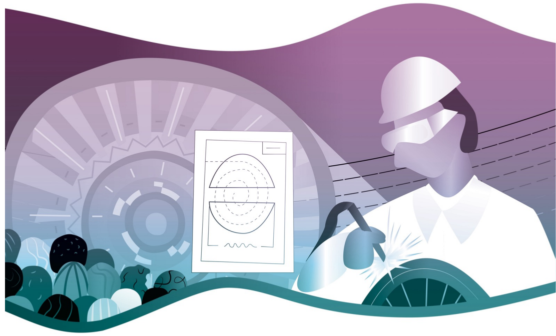
Finding: **International partnerships are strongest when partners are engaged starting from the early conceptual development of projects.**

Recommendation: **DOE and NSF should support involvement of U.S. scientists and institutions starting from the early conceptual development and R&D phase for future international experiments and accelerator projects.**

Recommendation: **Future U.S.-hosted experiments and accelerator projects should seek to engage scientists and institutions of potential international partners in the projects' early conceptual design and R&D phase, while remaining open to additional partners who may want to join later.**

Collaborating across the globe

International partnership on accelerator facilities



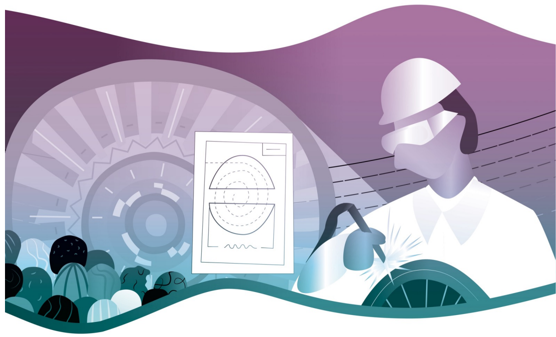
Finding: International partnership on construction of major particle physics accelerator facilities is growing. International partnerships yield more powerful capabilities for scientific discovery.

Recommendations: The U.S. particle physics program should: 1) strive to engage as partners in the construction and operation of major future particle physics accelerator facilities constructed outside the U.S. and 2) actively seek international partners to engage in the construction and operation of major future particle accelerator facilities constructed in the U.S.

Establish a collaborative U.S. national accelerator R&D program on future colliders to coordinate the participation of U.S. accelerator scientists and engineers in global energy frontier collider design studies as well as maturation of technology.

Collaborating across the globe

International experiments and accelerator projects hosted outside the U.S.



Finding: **International experiments and accelerator projects hosted outside the U.S. seek U.S. participation. U.S. participation in programs hosted outside the U.S. enables U.S. scientists to participate in the best science wherever it is done.**

Recommendation: **Continue to enable and facilitate the participation of U.S. scientists and institutions in experiments and accelerator projects hosted outside the U.S.**

Finding: **Mechanisms to support both the physical and remote participation of U.S. scientists collaborating on experiments hosted outside the U.S. are essential.**

Recommendation: **To maintain an active presence and intellectual leadership in experiments outside the U.S., support for faculty teaching buyouts or during a sabbatical should be expanded, and laboratory and university groups should support members to be based at experimental sites.**

4 – Being a partner of choice

Success in hosting and participating in international collaborations requires tailored approaches to collaboration governance and project management, host lab environments that are conducive to international research teams, and the ability to make reliable agreements with international partners.

Implement structures for hosting strong international collaborations, act with timeliness, consistently meet obligations, and facilitate open communication with partners.

Key Finding and ***Recommendation***

Being a partner of choice

Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE)

Finding: **LBNF/DUNE, the first U.S.-hosted international particle physics mega-project, has been launched successfully as a project with broad international participation. Nevertheless, its inception encountered new organizational *challenges* which offer instructive experience.**

Challenge 1: *Drive to start the DUNE scientific program as soon as possible*

Challenge 2: *Coupling of the facility LBNF and the experiment DUNE*

Challenge 3: *Integration of substantial non-U.S. deliverables within the DOE system of oversight*

Challenge 4: *The integration of construction project management and collaboration governance*

Recommendation: **DOE and NSF should convene a task force to study and recommend project management and oversight procedures that facilitate and cultivate international and interagency partnerships on large scientific research infrastructures for particle physics.**

Being a partner of choice

Host laboratory environment

Finding: A welcoming environment is critical for hosting an international experiment or facility.

Recommendation: U.S. laboratories hosting international experiments should provide an environment that encourages and supports international collaboration.

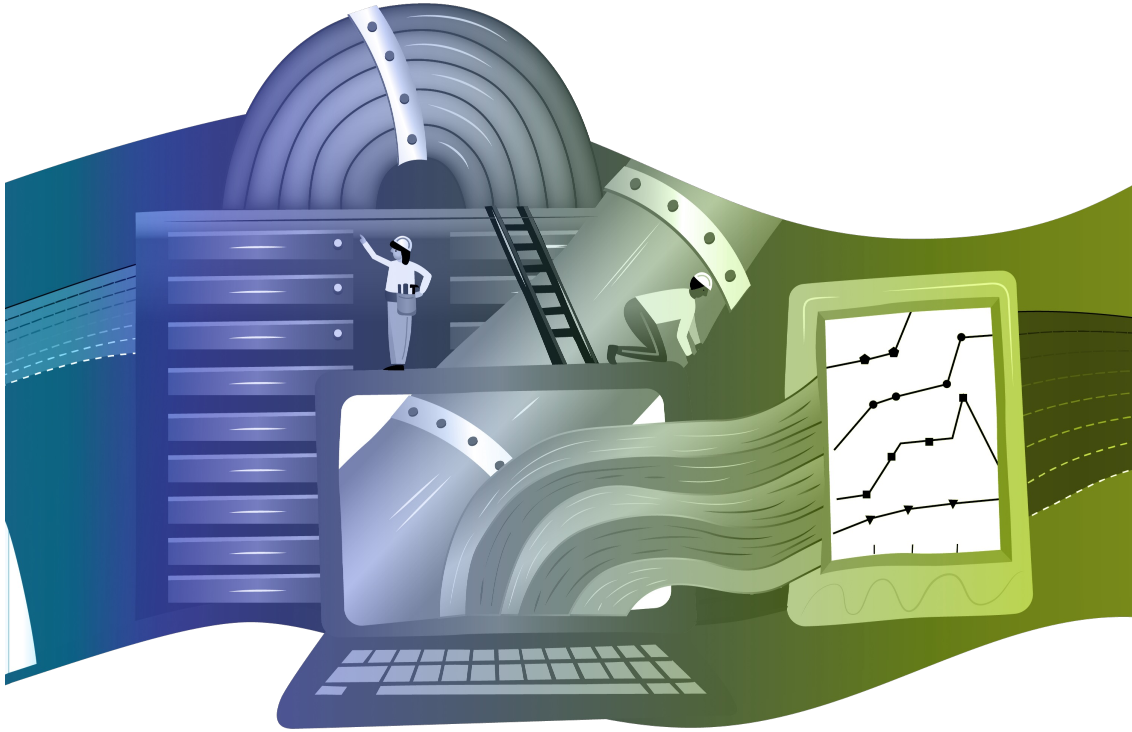
Only by providing an environment that encourages and supports international collaboration will U.S.-hosted projects be attractive to international partners. The host laboratory has a special responsibility to provide a welcoming environment. All international (and U.S.) collaborators, faculty, research and technical staff, and students, should be welcome to visit the host laboratory to work on their projects and to meet with collaborators.

Enabling Capabilities and Technologies

Science enabled by new tools, techniques and national initiatives

5 – Strengthening critical capabilities

It is our state-of-the-art expertise in the tools, technology, and techniques of particle physics that makes the U.S. a sought-after partner and gives us the ability to impact future experiments at home and abroad.



Continuously develop critical technologies to maintain and grow U.S. leadership in particle physics at home and abroad.

Key Finding and ***Recommendation***

Strengthening critical capabilities

Theory – a pillar of particle physics

From Snowmass 2021:

Theoretical particle physics seeks to provide a predictive mathematical description of matter, energy, space, and time that synthesizes our knowledge of the universe, analyzes and interprets existing experimental results, and motivates future experimental investigation.

Theory connects particle physics to other areas of physics and extends the boundaries of our understanding.

Together, formal, phenomenological, and computational theory form a vibrant interconnected ecosystem whose health is essential to all aspects of the U.S. high energy physics program.

Finding: **Theory is a foundational pillar of particle physics, and declining investment threatens U.S. leadership.**

Recommendation: **Invest in a strong and innovative theory program.**

Strengthening critical capabilities

Invest in *accelerator S&T*, *instrumentation, and software and computing*

Finding: **U.S. scientists and institutions will be partners of choice and will have the greatest impact in future international experiments hosted at home and abroad if they maintain state-of-the-art expertise in**

- **instrumentation,**
- **accelerator science and technology,**

and

- **scientific software and large-scale computing.**

Case study: LHC program at CERN

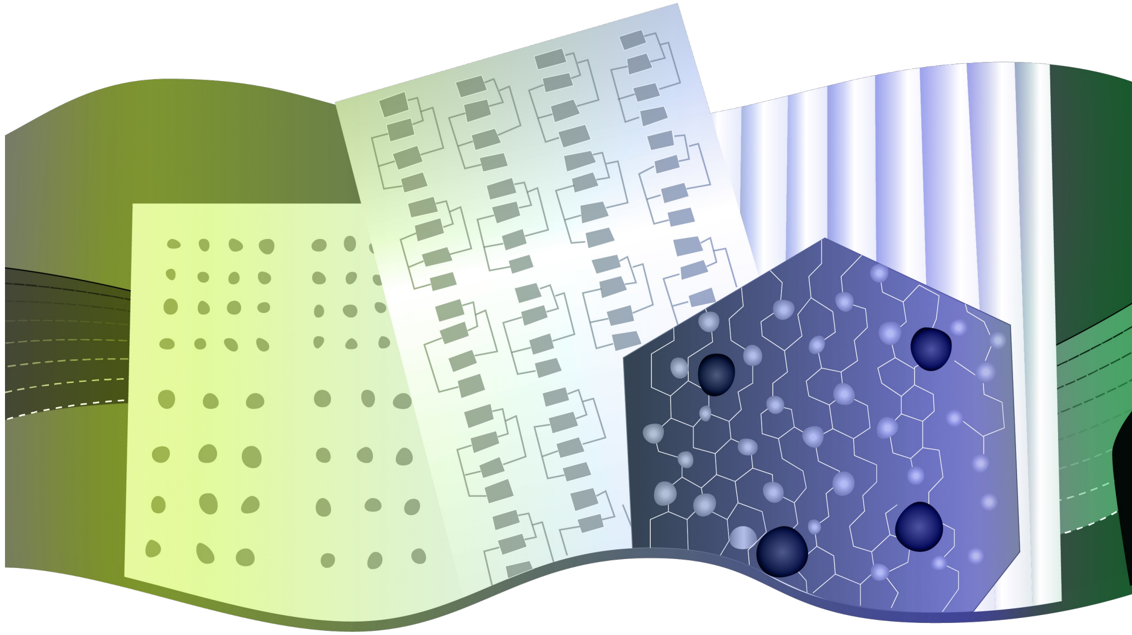
The U.S. was sought as a partner for:

- The expertise of U.S. scientists and the capabilities of U.S. institutions, and
- Their ability to assume responsibility for delivery of major portions of the detectors and significant components for the accelerator.

For example, U.S. scientists were able to **strongly impact ATLAS and CMS** because they arrived at the end of 1993 with almost a **decade of instrumentation R&D** and design experience from the SSC program.

6 – Advancing National Initiatives

The national initiatives in artificial intelligence and machine learning, quantum information science, and microelectronics are accelerating new research avenues in particle physics, and particle physics contributions to these initiatives are bringing new ideas and new technologies to a range of disciplines.



Enhance and leverage the innovative role that particle physics plays in artificial intelligence and machine learning, quantum information science, and microelectronics to advance both particle physics and these national initiatives.

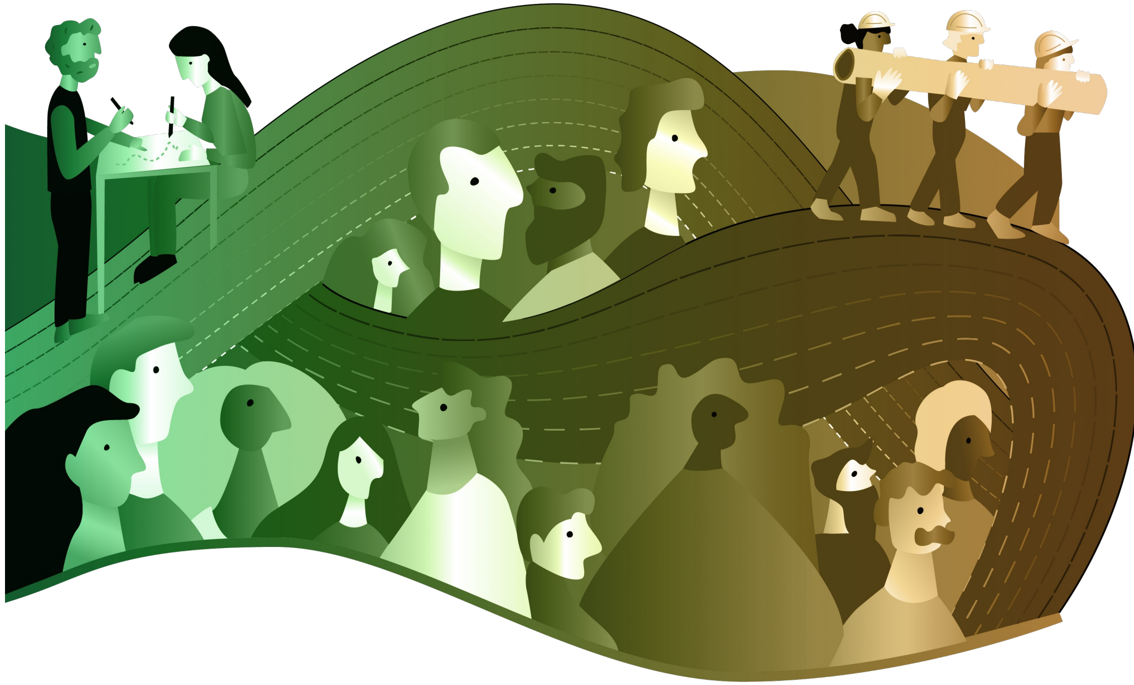
Key Finding and ***Recommendation***

Workforce

Attracting and retaining a talented, highly trained, and diverse U.S. workforce

7 – Building a robust workforce

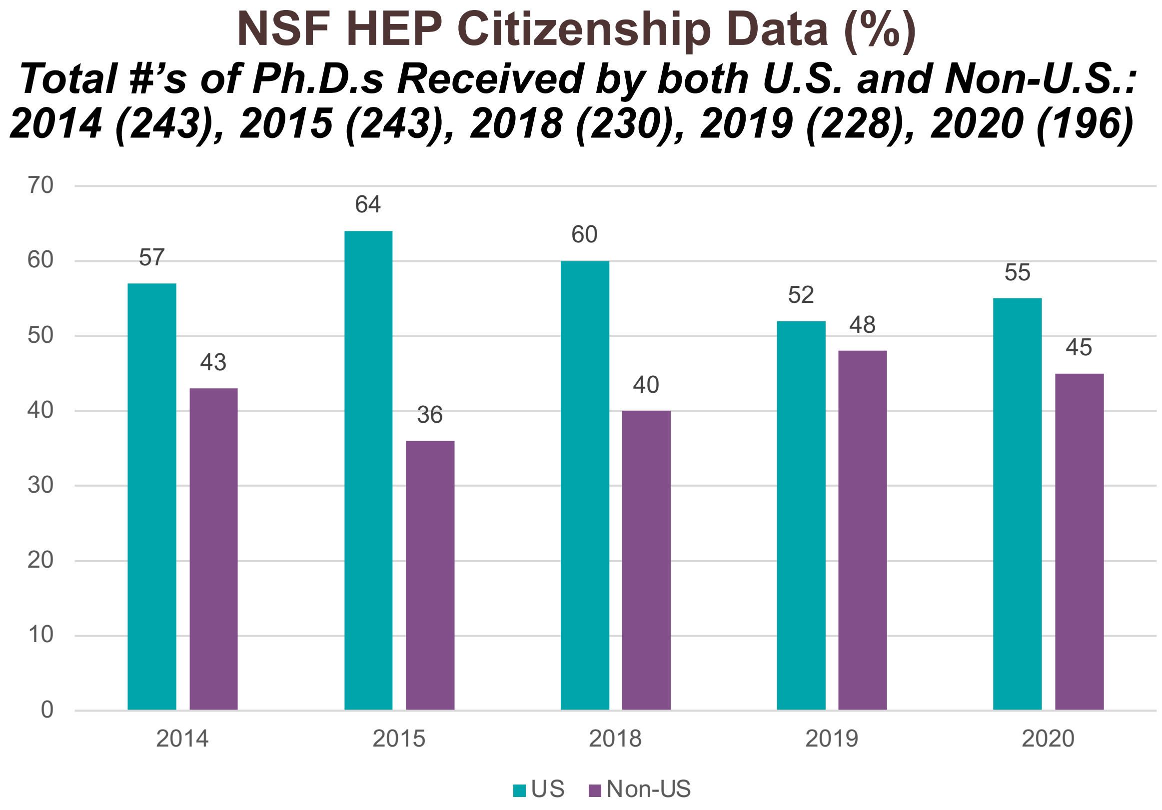
Attracting, inspiring, training, and retaining a diverse workforce is vital to the success of all particle physics endeavors and more broadly, to U.S. science and technology. A robust particle physics workforce will both leverage and be representative of the diversity of the nation.



Explore frontier science using cutting-edge technologies to inspire the public and the next generation of scientists while opening new pathways to diversify the workforce and realize the full potential of the field.

Key Finding and ***Recommendation***

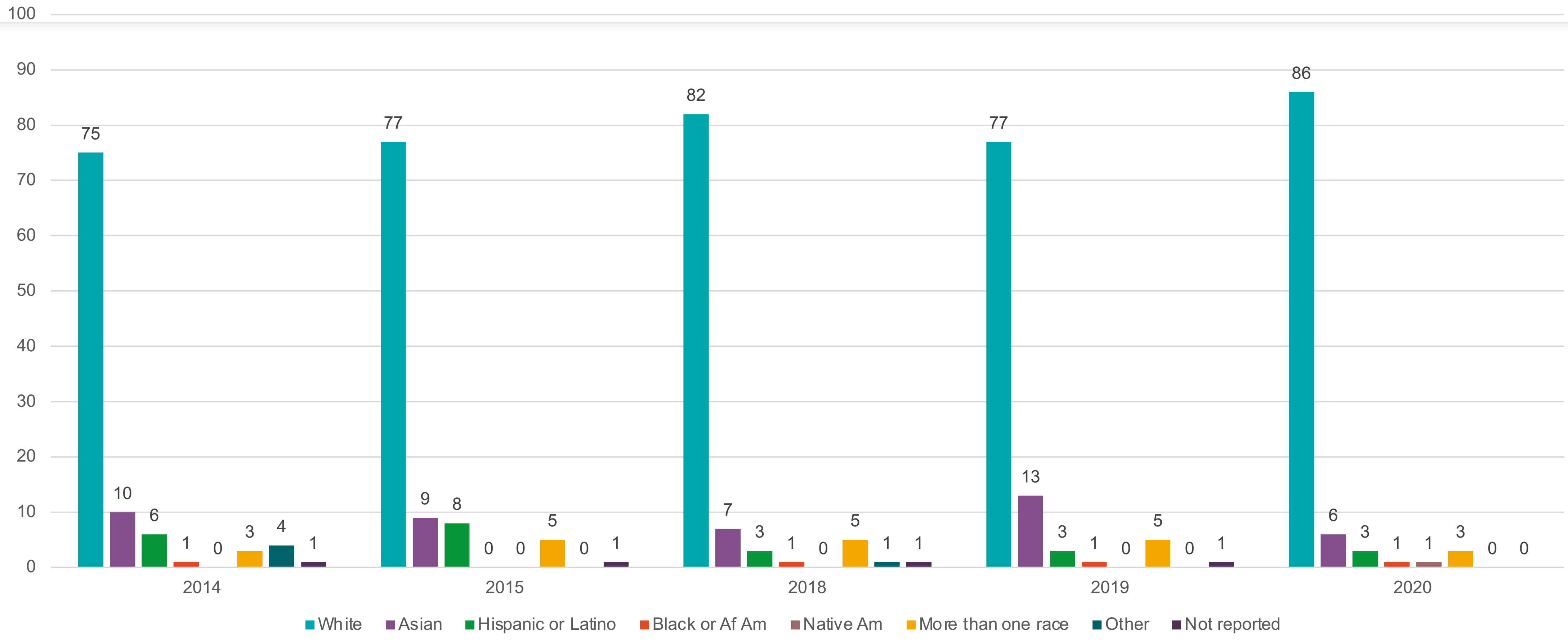
Building a robust workforce
Attraction and training



Finding: The U.S. particle physics program is enriched by international contributions but still suffers from a lack of gender and ethnic diversity, including among students and workers that are U.S. citizens.

NSF HEP Race/Ethnicity Data (%)

Total #'s of Ph.D.s received by All Race/Ethnicities:
2014 (139), 2015 (154), 2018 (138), 2019 (119), 2020 (108)



More data/plots in backup slides

Building a robust workforce

Barriers for foreign employees and collaborators to conduct research in the U.S.

Finding: **There are many impediments faced by the U.S.'s international collaborators who come to the U.S. to conduct their research. These barriers hamper the whole research enterprise.**

Recommendation: **To lessen the burden on international collaborators, DOE and NSF should coordinate with all relevant stakeholders, including the U.S. Department of State, to reduce the impediments caused by agency compliance, visa delays, and on-site security.**

To lessen the barriers to advancing careers of scientific and technical personnel in particle physics, the U.S. could benefit from regularly scheduled surveys and town halls with employees to solicit, share, and act on feedback received about the work environment. Many federal agencies use this approach.

Building a robust workforce

Workforce needs in AI/ML and QIS

Finding: **Too few artificial intelligence/machine learning and quantum information science/quantum sensing students remain in particle physics after receiving their degrees.**

- **Establish new and attractive career frameworks in AI/ML and QIS/quantum sensing, such as allowing those working in particle physics to take sabbaticals in private companies and *vice versa* and enhancing opportunities for particle physics employees to create spin-offs.**
- **2. To compete more effectively with industry in the recruitment and retention of the best talent, national laboratories should provide opportunities for engineers and technicians to work with scientists on blue sky research and provide the possibility for national laboratory researchers to launch private companies via spin-off technologies.**
-

Building a robust workforce
Workforce development in key technologies

Finding: **The U.S. needs to significantly increase the numbers of U.S. researchers and the country's workforce development capacity in key technologies of particle physics, especially instrumentation, large-scale computing, and particle accelerators.**

Finding: More long-term career opportunities are needed for specialists in **instrumentation.**

Finding: The current standard for **software and computing** training is project-specific on-the-job training. Career path limitations within the field diminish retention rates.

Finding: Over 50% of the **U.S. accelerator science and technology** workforce is trained by U.S. universities. Yet, accelerator science and technology training programs are only available at a small fraction of all U.S. universities and have limited overall support.

Recommended actions include:
1. Conduct a comprehensive study to identify areas of inadequate expertise in the U.S. particle physics workforce, such as instrumentation, accelerators, and large-scale computing.
2. Shore up deficiencies by encouraging more students to pursue those areas of study.
3. Establish more university programs offering degrees in accelerator science and technologies.

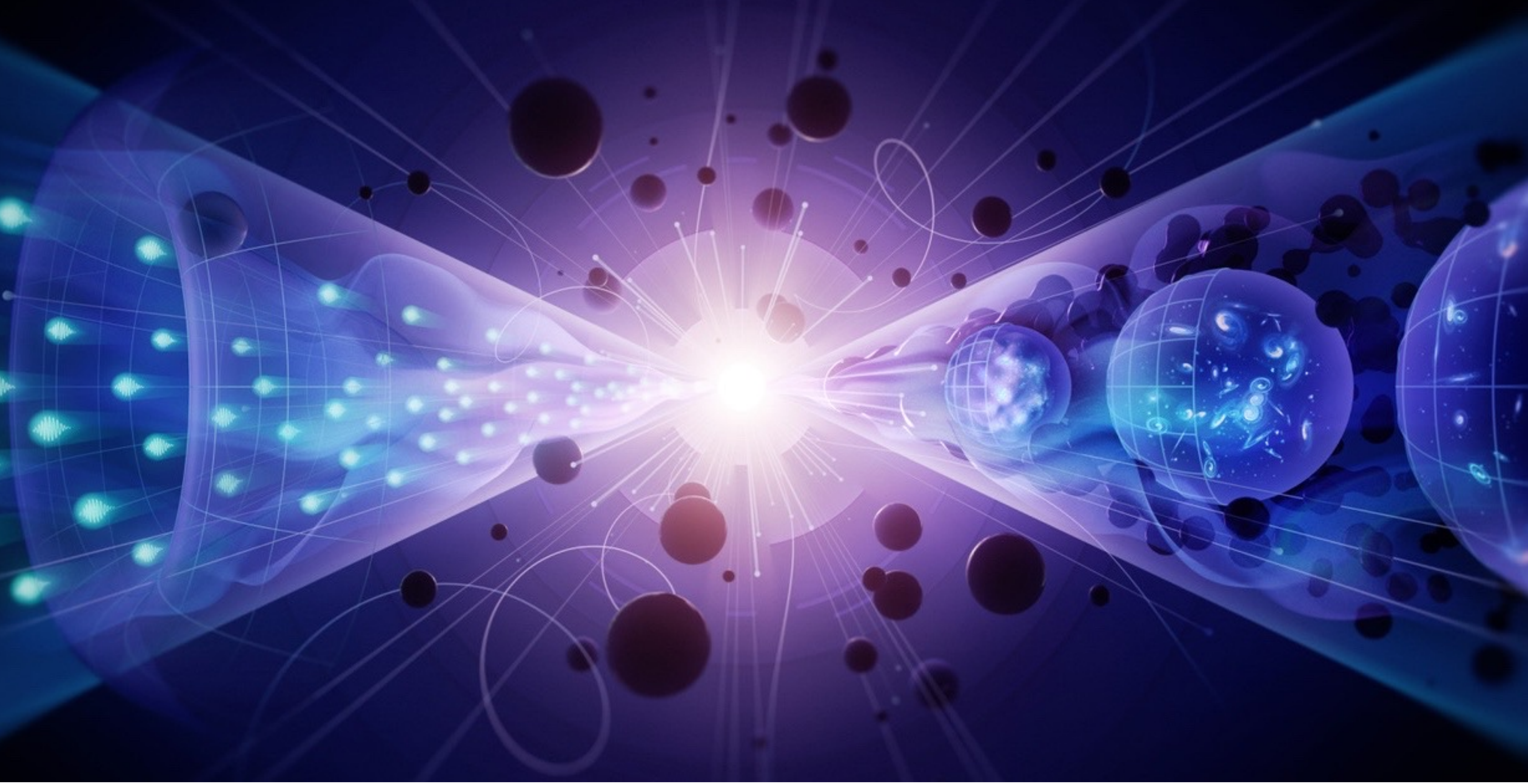
Building a robust workforce
The next generation

***Finding:* Frontier large-scale research facilities offer the most comprehensive method of answering fundamental questions while exciting and inspiring a whole new STEM workforce.**

Compelling large-scale facilities that address the fundamental questions in physics serve to inspire the next generation. However, if the U.S. does not move forward in a timely way, there will be a serious risk of a gap in technical expertise and scientific opportunities.

Planning the next facility starts with R&D and a compelling science case. Converging on a direction, was not in the charge of this panel.

***Recommendation:* A next-generation international flagship particle physics facility based in the U.S. would attract a whole new generation of scientists while boosting opportunities to train students and sustain a leading scientific workforce. The U.S. should not wait until DUNE is commissioned to embark upon its next major particle physics initiative but should move quickly to intensify its R&D program with the aim of accelerating progress in this direction to enable a timely decision.**



Conclusions

The U.S. has a long and impressive history of leadership and international collaboration in particle physics. However, **maintaining and growing this role in an increasingly global community pursuing science is not guaranteed.**

To continue to be a premier research destination for particle physics projects hosted at home, and an effective partner at leading facilities hosted internationally, **the U.S. must continue to deliver groundbreaking science today, and develop and maintain world-leading capabilities to realize the discoveries of tomorrow.**

To be attractive as a host country for international experiments, the U.S. must **embrace international collaborators as full partners,** both in science and in project management, even on experiments and facilities at the mega-scale.

Conclusions

To continue to lead in the National Initiatives, the U.S. must **ensure timely and effective execution of research** in these areas. Overall, the field must continue to realize the benefits of particle physics technologies for society at large.

Finally, the benefits accrued by a leading U.S. particle physics program are **predicated on a strong, diverse workforce**. Great care and new ideas are required to attract, train, and empower a workforce of and for the future.

Thank you

EXTRA SLIDES

Key findings and recommendations

1. **Scientific breadth and application:** Particle physics theory and experiments address deep mysteries of the universe while advancing concepts and technology that are vital to other research fields, as well as society at large.

   Strengthen investments to advance particle physics discoveries as well as benefits to other scientific disciplines and society.

2. **Diversity across scales and stages:** The field of particle physics is a vibrant research ecosystem, built by an international network of partnering nations, facilities, experiments, and people. To be a leader, the U.S. must continuously produce scientific results, build facilities and experiments for the future, and advance new ideas and technologies that enable the discoveries of tomorrow.

   Maintain a comprehensive program at home and abroad, with a range of experiment scales and strategic balance among construction projects, operations of experiments and facilities, and core research activities, including development of future facilities.

Key findings and recommendations

3. **Collaborating across the globe:** Frontier research in particle physics necessitates international collaboration and cooperation. The combined expertise and resources from nations around the world enable discoveries and technological advances impossible to achieve by any single nation. It is the *global* particle physics program that collectively addresses the burning scientific questions across the breadth of the field.

   Continue support for and actively seek engagement with international collaborations and partnerships of all sizes.

4. **Being a partner of choice:** Success in hosting and participating in international collaborations requires tailored approaches to collaboration governance and project management, host lab environments that are conducive to international research teams, and the ability to make reliable agreements with international partners.

   Implement structures for hosting strong international collaborations, act with timeliness, consistently meet obligations, and facilitate open communication with partners.

Key findings and recommendations

5. **Strengthening critical capabilities**: It is our state-of-the-art expertise in the tools, technology, and techniques of particle physics that makes the U.S. a sought-after partner and gives us the ability to impact future experiments at home and abroad.

   Continuously develop critical technologies to maintain and grow U.S. leadership in particle physics at home and abroad.

6. **Advancing national initiatives:** The national initiatives in artificial intelligence and machine learning, quantum information science, and microelectronics are accelerating new research avenues in particle physics, and particle physics contributions to these initiatives are bringing new ideas and new technologies to a range of disciplines.

   Enhance and leverage the innovative role that particle physics plays in artificial intelligence and machine learning, quantum information science, and microelectronics to advance both particle physics and these national initiatives.

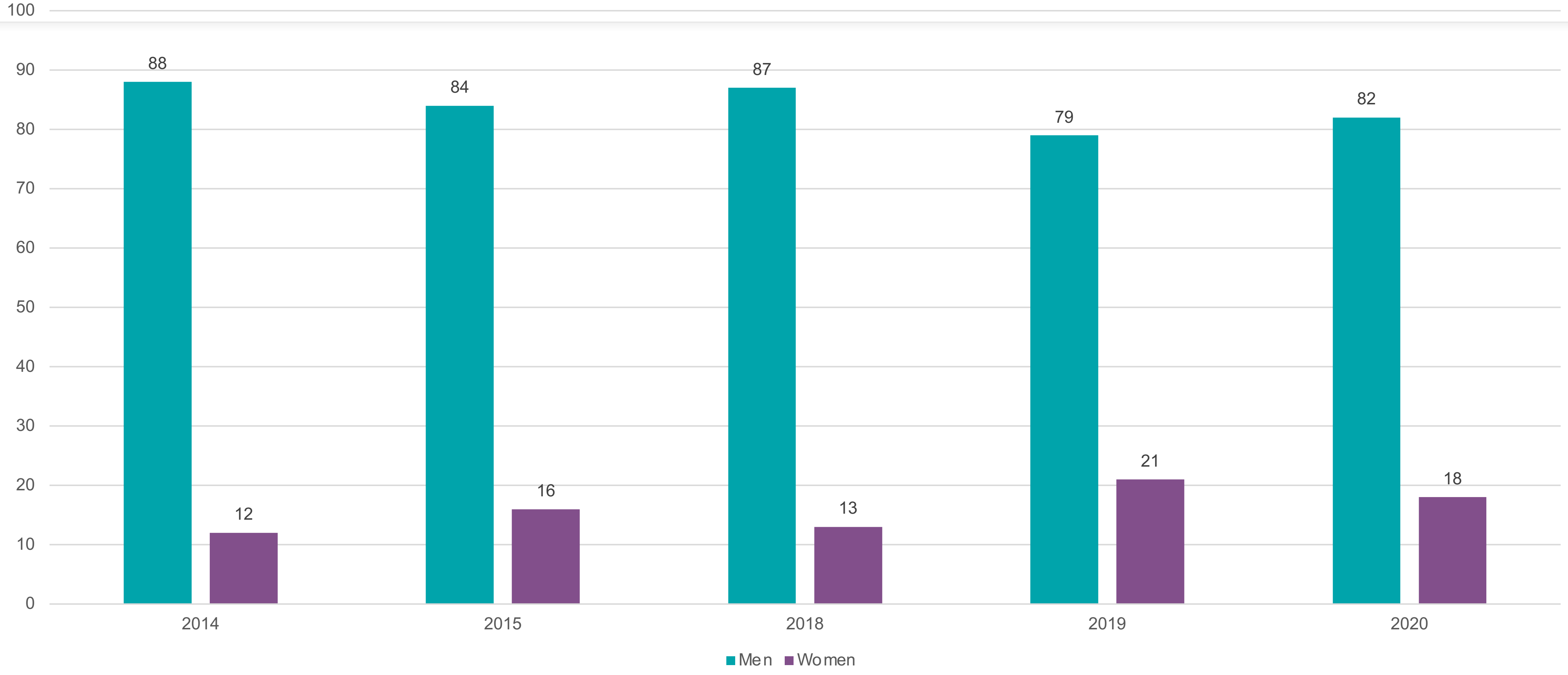
Key findings and recommendations

7. **Building a robust workforce**: Attracting, inspiring, training, and retaining a diverse workforce is vital to the success of all particle physics endeavors and more broadly, to U.S. science and technology. A robust particle physics workforce will both leverage and be representative of the diversity of the nation.

   Explore frontier science using cutting-edge technologies to inspire the public and the next generation of scientists while opening new pathways to diversify the workforce and realize the full potential of the field.

NSF HEP Gender Data (%)

Total #'s of PhDs received by both Genders:
2014 (245), 2015 (243), 2018 (232), 2019 (234), 2020 (198)



As the highest priority independent of the budget scenarios, complete construction projects and support operations of ongoing experiments and research to enable maximum science. This includes HL-LHC, the first phase of DUNE and PIP-II, the Rubin Observatory to carry out the Legacy Survey of Space and Time (LSST), and the LSST Dark Energy Science Collaboration.

Exploring the Quantum Universe

Support a comprehensive effort to develop the resources—theoretical, computational and technological—essential to our 20-year vision for the field. This includes an aggressive R&D program that, while technologically challenging, could yield revolutionary accelerator designs that chart a realistic path to a 10 TeV parton center-of-momentum (pCM) collider. In particular, the muon collider option builds on Fermilab strengths and capabilities and supports our aspiration to host a major collider facility in the US.

Pathways to Innovation and Discovery in Particle Physics