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

Presented to HEPAP on November 2, 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.”

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 relevant to the 2014 P5 Science Drivers.

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)

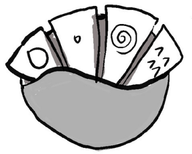
Reina Maruyama (Yale)
Sekazi Mtingwa (NRC)
Brian Nord (FNAL)
Ian Shipsey (Oxford)
Stefan Soldner-Rembold (Manchester)
Lindley Winslow (MIT)

Ex-officio: JoAnne Hewett (SLAC) → Sally Seidel

Methodology

*The HEPAP International Benchmarking Panel provides input to the current P5 panel but is **not P5**.*

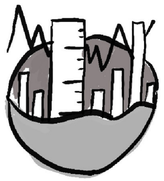
Subcommittees



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*

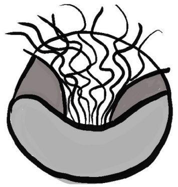
***Theory** distributed throughout subcommittees.*

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.

Report outline, by the chapter

1. **Introduction**
2. **The Science Drivers**
3. **Collaboration**

- Key F&R 1: Key scientific areas and U.S. leadership
- Key F&R 2: Particle physics as an ecosystem
- Key F&R 3: Importance of Collaboration
- Key F&R 4: How to be a partner of choice

Science enabled by partnerships, experiments, and facilities

4. **Enabling Capabilities and Technologies**

- Key F&R 5: Foundational pillars and unique capabilities: theory, instrumentation, accelerator development, and scientific computing
- Key F&R 6: Particle physics and the National Initiatives

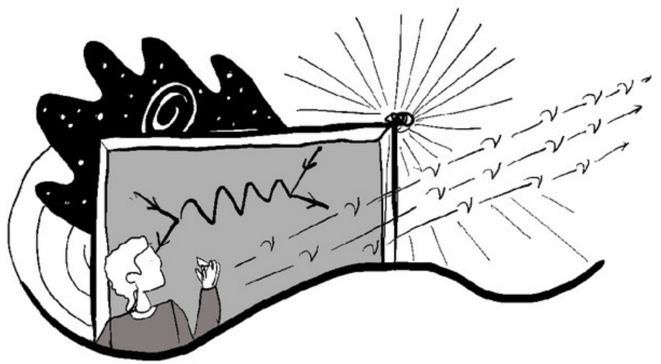
Science enabled by new tools, techniques and national initiatives

5. **Workforce**

- Key F&R 7: Inspire, recruit, train, and retain a talented and diverse workforce

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

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 are defined by the P5 science drivers;
  - The starting point for the report is the drivers from the 2014 P5 report; and
  - The 2023 P5 report will set a new strategic direction – and builds on the directions in the 2014 report.

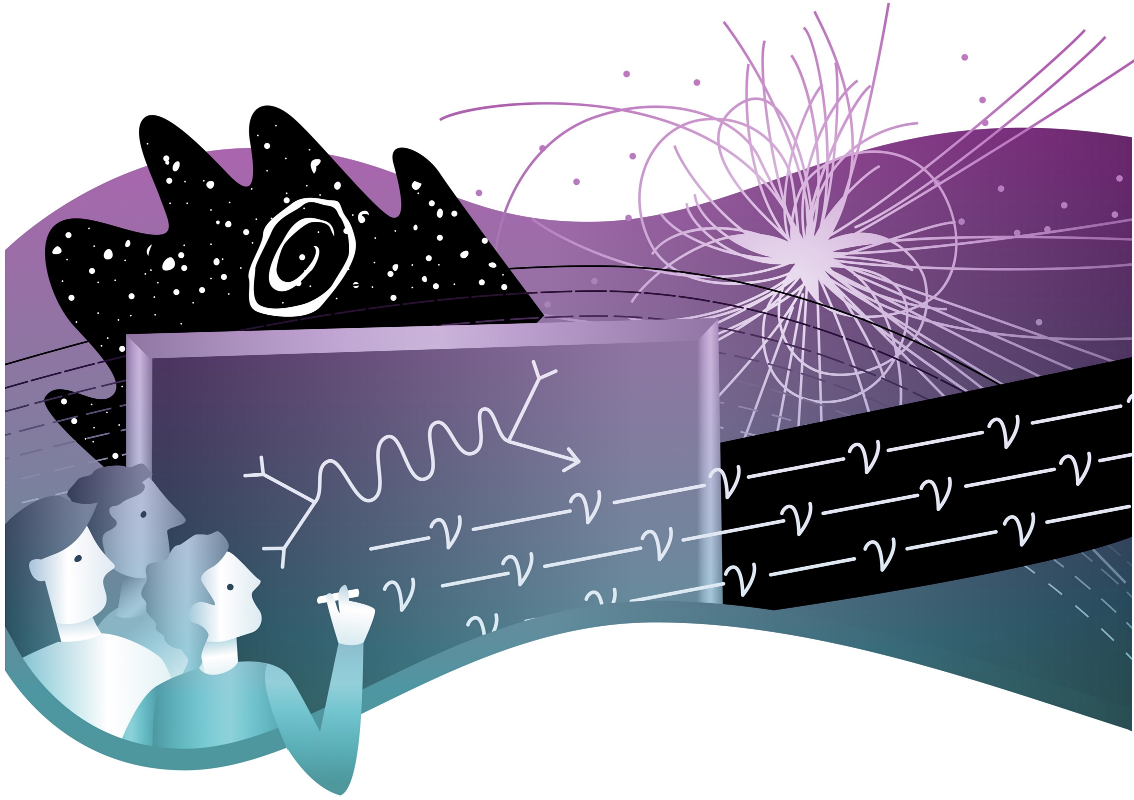
Collaboration

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.

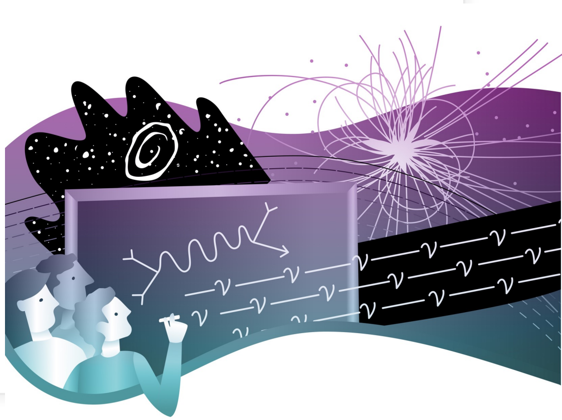


Strengthen investments to advance particle physics discoveries as well as benefits to other scientific disciplines and society.

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.**

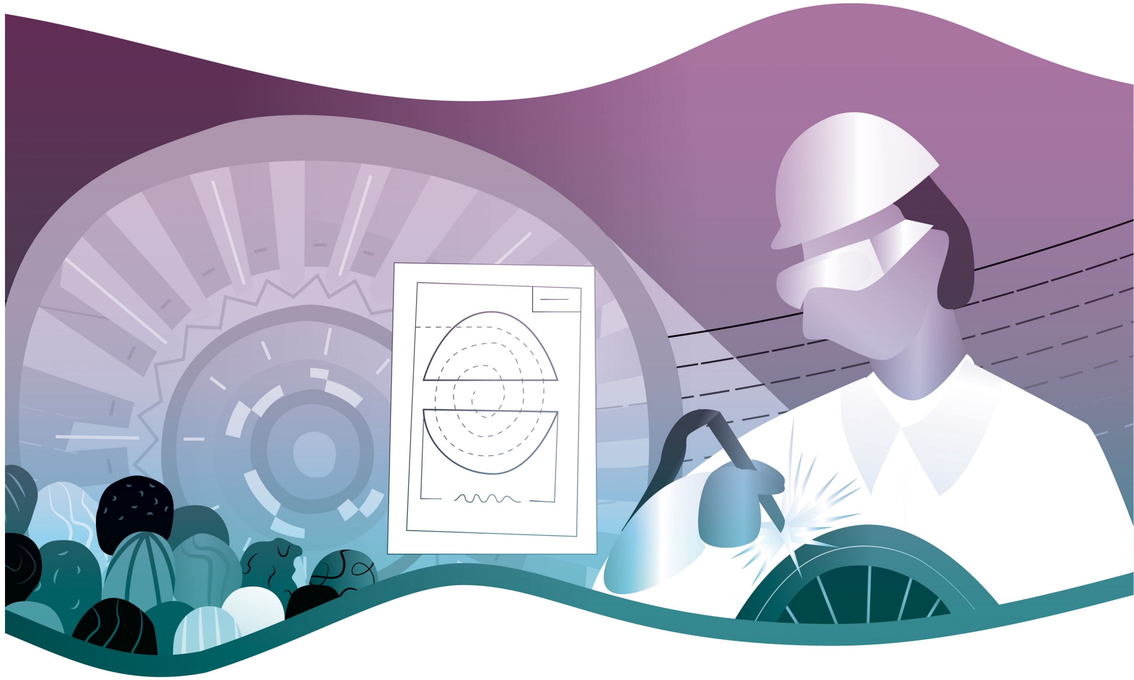
Finding: **Particle physics pushes the boundaries of technology in ways that enable research in other fields of science and that benefit society at large.**

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.

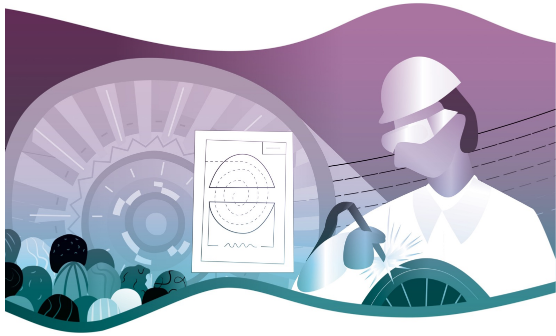


> ***Maintain a comprehensive program at home and abroad, with a range of experiment scales and strategic balance among construction projects, operations of experiments and facilities, and core research activities, including development of future facilities.***

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.

Small Projects are essential

The U.S. HEP community of national laboratory and university groups working on small projects is vibrant and continues to innovate and push the bounds of what is possible to measure by harnessing cutting-edge technology including quantum sensing and AI/ML.

- Experiments of all scales — large, medium, and small — accomplish impactful science.
- Experiments at different scales frequently complement one another, particularly at the cosmic and intensity frontiers.
- Demonstrator-scale and small projects lay the foundation for future larger experiments. Leadership entails leading on small experiments as well as leading on large experiments.
- Small projects are also outstanding training grounds for students and postdocs, allowing them to experience the whole life cycle of an experiment.
- The 2014 P5 report recommended the support for experiments at all scales.
- Groups from other nations are nimbler in moving from concept to data-taking experiments than in the U.S. This affects US scientists with respect to both their ability to partner with non-US groups and their ability to compete with non-US groups. Hence, it affects US leadership.

Small Projects – Considerations

The U.S. needs a mechanism that enables the U.S. community to be nimbler in starting new small-scale projects.

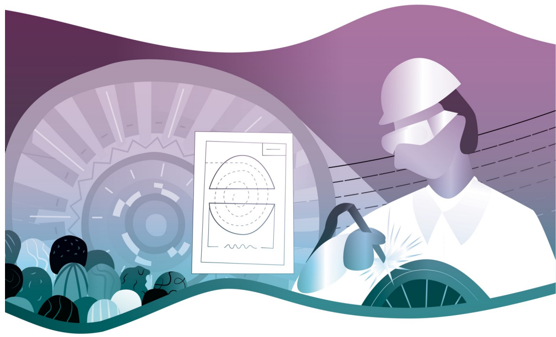
- A well-defined funding model would enable equitable international contributions while simultaneously maintaining U.S. Leadership.
- One example is the Dark Matter New Initiatives (DMNI); however, these projects are expected to be funded at least 75% by DOE which discourages DMNI collaborations from entertaining opportunities for significant international partnerships.

The small project portfolio would benefit from both NSF and DOE support.

- Explicitly, these projects can benefit from expertise of lab personnel and from lab capabilities.

Diversity across all scales

Particle Physics as an ecosystem

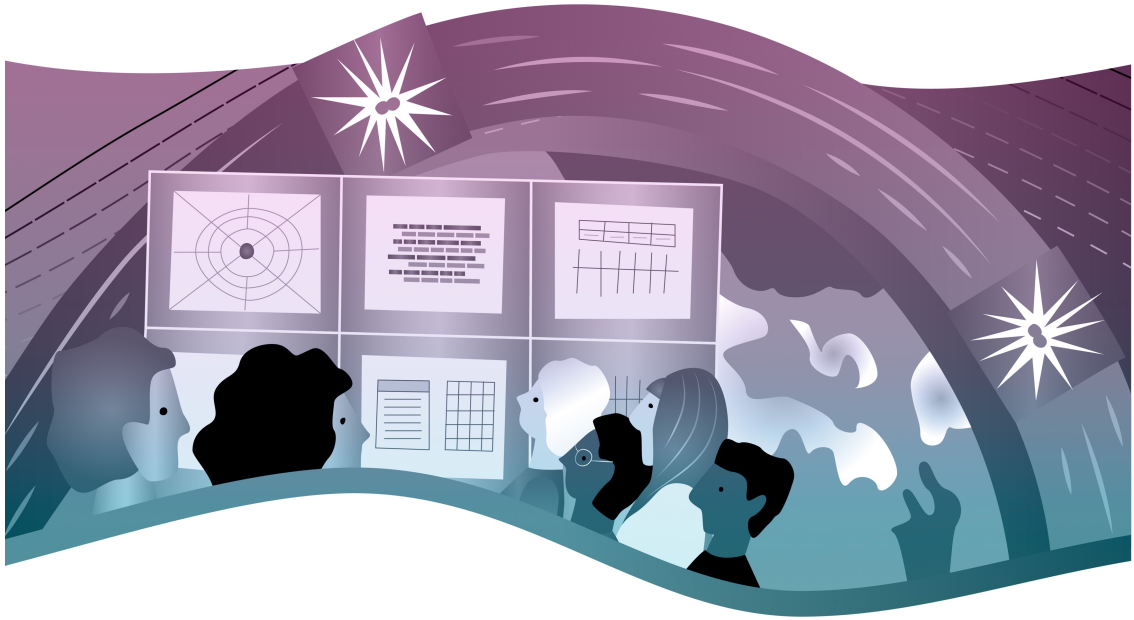


- *Finding;* The U.S. particle physics program is part of a global research ecosystem. More scientific advances can be realized through international partnerships.

Recommendation: **The U.S. strategic planning processes should take into consideration the global particle physics ecosystem in setting priorities. International partnerships that create a compelling scientific program with a healthy global balance among the lifecycle stages — construction, operations, and core research activities — should be sought.**

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.

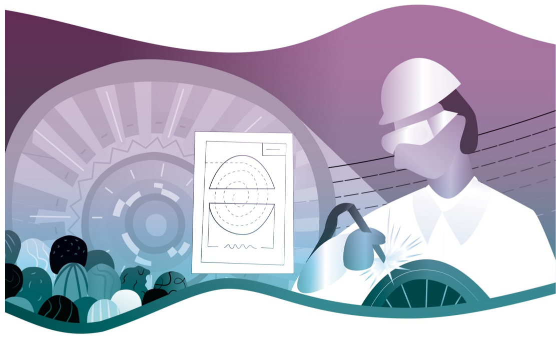


Continue support for and actively seek engagement with international collaborations and partnerships of all sizes.

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.**

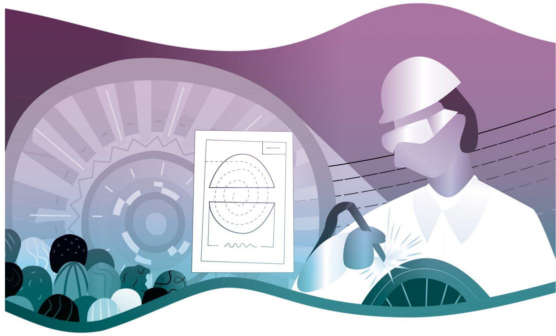
Recommendation: **Collaborations should strive to establish an organizational structure and governance model that enables and cultivates the shared characteristics of current and past successful strong collaborations.**

Successful Collaboration

- shared scientific objective(s)
- shared decision making
- shared governance
- shared sense of ownership
- shared sense of responsibility
- shared problem solving
- shared credit
- shared authorship
- shared sense of success
- shared values
- shared culture
- shared respect

Collaborating across the globe

Engage with partners in the earliest stage

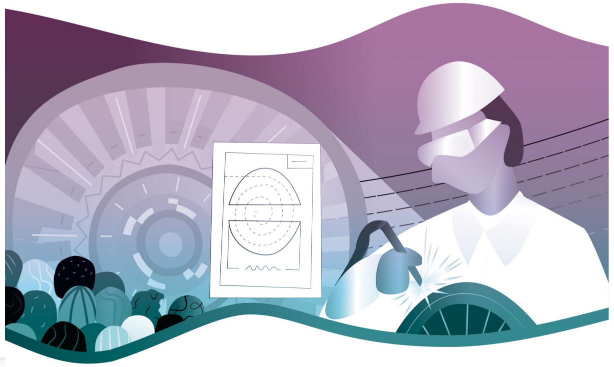


Finding: International partnerships are strongest when partners are engaged starting from the early conceptual development of projects.

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.

Engage with partners in the earliest stage



Impact:

Only if someone takes part in a project from the beginning can they influence the course of the project (technically, from the design viewpoint, culturally, etc.), and the project can only benefit fully from the capabilities and expertise of partners if all partners participate through all phases of the experiment.

Ownership of the project:

The sense of shared ownership is more pronounced if partners engage from project inception.

Building and sharing the same culture:

Development of a shared culture is significantly more likely if participants work together from the beginning and through all phases of a project.

Fairness of contributions to the project:

If partners join a project late, when the project is essentially complete, then the original partners will have borne an unfair share of the construction costs, even if all partners share in the operating costs.

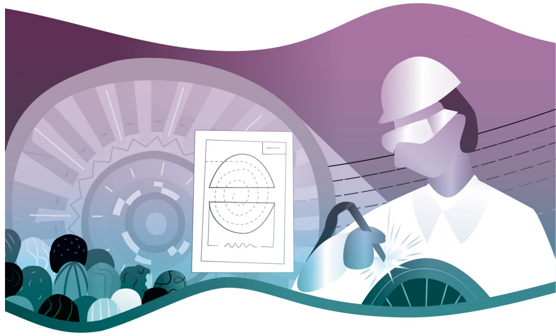
- **BABAR**:
- International partners were engaged in the conception of BABAR, resulting in a strong international partnership with a strong sense of shared ownership.

- **ATLAS & CMS construction:**
- U.S. groups joined the experiments after the experiments' conceptual designs were complete and their Letters of Intent were submitted.
- The major impact that U.S. scientists had on both experiments could have been even more significant if U.S. scientists had had the opportunity to participate in the conceptual design and in early technology selections.

- **ATLAS & CMS upgrade projects:**
- U.S. groups have participated in the upgrades since their earliest conceptual phases.
- The impact of the U.S. on the upgrades is on equal footing with the impact of major international partners and is stronger with respect to the experiments' original construction.

Collaborating across the globe

Collaboration governance



Finding: **Shared governance and shared responsibility are principles observed in successful partnerships and large collaborations.**

Recommendation: **Formally agree among partners on an international governance structure early during the formation of the international project.**

There is no unique or single best governance structure.

The structure should reflect science goals, infrastructure and facility requirements, and sharing of responsibilities.

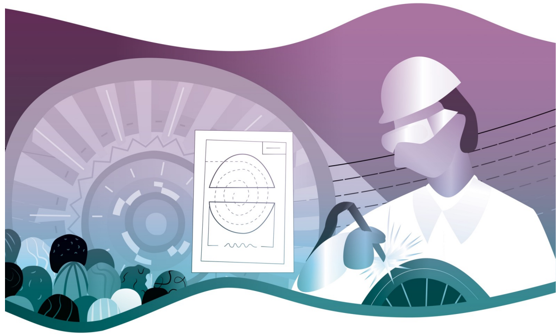
It is best to agree upon the governance structure early in the existence of the collaboration and necessarily early in the development of the project.

Sample governance structures:

- **Host-led (e.g., US-led) project with international partners**
  - Tend to be based on bilateral agreements between U.S. and international partner agencies
- **CERN model (e.g., LHC experiments) with sharing of responsibilities**
  - CERN model for experiments has evolved to being based upon multilateral agreements.
  - CERN model for facilities (e.g. LHC & HL-LHC) currently follows a host-led model.

Collaborating across the globe

International partnership on accelerator facilities



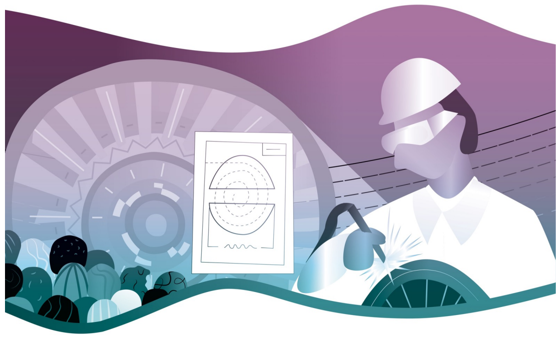
Finding: International partnership on construction of major particle physics accelerator facilities is growing. International partnerships yield more powerful capabilities for scientific discovery.

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***

U.S.-hosted projects from mid to mega scale

The U.S. is considered a strong partner in international high-energy physics experiments.

- Innovation in instrumentation, technical competency of US scientists, the strength of the national laboratory and university systems, and the breadth and capacity of the U.S. program are common positive themes expressed by the international HEP community.

Historically, the US funding model has focused on largely national projects, with non-US partners providing well-defined contributions but not sharing responsibility for the overall project.

- Differs from the international governance structure of CERN experiments and facilities.

The governance structure of truly international scientific projects needs to reflect the shared responsibility for the scientific success of the project and the commitment of all partners to provide the necessary resources.

- It requires a culture of collaboration and cooperation, based on good communication and trust in the ability of the partners to deliver.
- The goal of such a structure is to achieve joint ownership and shared responsibility for the success of the project, as well as other aspects of the science program.
- Early definition of governance structure enhances this goal, as does early engagement of scientists and early engagement of funding agencies.

Being a partner of choice
Governance of U.S.-hosted projects

The governance of international partnerships on particle physics projects can be broadly characterized as following either the host-led model or the CERN model.

The principal distinction between the two models is that the *host usually carries the largest responsibility* in the host-led model, whereas *sharing of responsibility* is more distributed in the CERN model.

Both models have been successful, and the CERN model is found to work well when the project's degree of financial sharing is high.

BaBar was a highly successful U.S.-hosted international partnership.

DESI is a current example of a successful U.S.-hosted international partnership.

The PIP-II accelerator project has established an effective governance structure for international partnership for accelerator facility construction.

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
Cosmic Surveys

Finding: **Partnerships between DOE High Energy Physics and NSF Astronomy have produced path-finding advances and capabilities in the study of dark matter, dark energy, and inflation.**

Recommendation: **Future cosmic survey projects should engage with U.S. agencies to develop a plan for strong, strategic international partnerships across all stages of the project lifecycle, including conceptual design and construction, in order to realize next-generation capabilities and scientific opportunities. Plans should include sharing of responsibilities and leadership opportunities with international partners.**

Particle Physics with the Rubin Observatory –

DESC, the science collaboration, has an organizational structure akin to the particle physics model.

LSST (now the Simonyi Survey Telescope) was principally a U.S. interagency construction project - the international fraction of the overall investment in construction was not large.

CMB-S4 Collaboration and Project –
The CMB-S4 Collaboration is currently about one-third international scientists from 54 collaborating international institutions in 20 nations.

CMB-S4 (project) is still in relatively early stages of recruiting international partners on the project.

International partnership will lead to 1) more capable facilities and experiments and 2) a stronger global particle physics program.

Being a partner of choice

Impediments to being the partner of choice

Finding: Being a reliable partner is essential to international collaboration, and especially to hosting international partnerships.

Recommendation: Discuss and communicate with international partners before making decisions that affect partners. Seek ways to mitigate the impact of necessary U.S. decisions on international partners.

Finding: The uncertainty of the annual U.S. appropriations process is an impediment to good international partnership, whether the partnership's project is hosted in the U.S. or abroad. Continuity of funding is especially important for U.S.-hosted experiments in both the construction and operations phases because of its importance to international partners.

Recommendation: Stakeholders in the U.S. executive branch and in Congress should understand the negative consequences — both immediate and long term — of abrupt reductions in funding, including the negative impact on international partners.

Is the U.S. a reliable partner?

Being a reliable partner is essential to international collaboration.

The U.S. has not always been viewed as a reliable partner.

- Such perceptions can be an obstacle to consideration of the U.S. as a partner of choice.
- *We find that this issue arises largely because of inadequate communication between U.S. decision makers and international partners.*

Some historical incidents giving rise to the view that the U.S. not a reliable partner:

- 1993 – termination of the SSC
- 2003 – termination of the CDF & D0 silicon tracker upgrade projects
- 2005 – termination of BTeV
- 2008 – termination of the SLAC *B*-factory program
- 2011 – decision not to extend Tevatron running

Being a partner of choice
Host laboratory environment

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.

U.S. as Host – a welcoming environment is critical

A welcoming and safe environment is critical for hosting an international project or facility.

The host laboratory has a special responsibility to provide an environment that encourages and supports international collaboration.

- Facilities for international collaborators, e.g., offices and onsite accommodation
- Support for visas
- Unhindered access to the laboratory.
  - We are particularly concerned about the exclusion of scientists from full participation in the experiments based on their place of birth.
- Support through fellowship and associate programs, accessible to collaborators independent of background and nationality, are desirable.

The principles of equity, diversity, and inclusion should govern the policy of both the host laboratory and the international collaboration.

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 foundational 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.**

DOE HEP has seen an 18% reduction in research funding from 2012 to 2022 in addition to the loss of purchasing power due to inflation estimated to be 26%. This is true both at the national laboratories and at the universities but is felt more strongly at universities. The flat funding at NSF EPP equates to a 26% reduction accounting for inflation.

Theory enables the discovery science of the future

- **The U.S. particle theory community has benefited tremendously over many decades from sustained government investment.** This has resulted in a long history of seminal accomplishments and Nobel Prize-winning discoveries by particle theorists at U.S. institutions. Today, **the U.S. particle physics theory community remains at the forefront of the full breadth of particle physics**, from formal foundational questions to phenomenological and computational theory efforts in direct support of experiments.

- 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.

- U.S.-based theoretical particle physics research **is noteworthy for its creativity** and has taken a leading role in the expansion of particle theory, particularly through **developing connections to astrophysics, cosmology, QIS, AMO, condensed matter physics, nuclear physics, computer science, etc**. The theory community has remained responsive to experimental developments. One of its special strengths is innovation that often initiates new experimental programs.

Strengthening critical capabilities

Accelerator science and technology for particle physics

Finding: **Areas of accelerator science and technology in which the U.S. is identified as a leader and is sought as a partner in accelerator projects outside the U.S. include superconducting magnets, superconducting and normal radio frequency, high brightness particle sources, and advanced beam physics including modeling and techniques of high intensity and brightness beam physics.**

Recommendation: **In the AS&T areas in which the U.S. is identified as a leader and a partner of choice, R&D investment should keep up with increasing performance demands, technological challenges, and investment in other regions.**

Ongoing effort worldwide seeks to **advance high field magnet technology** with innovative magnet designs and using novel materials with higher transition temperatures and a larger critical field, such as niobium-tin (Nb3Sn) and HTS (High-Temperature Superconductor). The U.S. has been a leader in both in magnet design and in Nb3Sn and HTS materials, but both China and Europe have been investing and plan to invest at comparable and/or higher levels of funding than the U.S. R&D portfolio in this field.

The U.S. is a leader in both **SRF** (Superconducting Radio Frequency) acceleration **and normal conducting RF** (Radio Frequency) **acceleration.**

Strengthening critical capabilities

AS&T R&D areas in which U.S. leadership is challenged

Finding: Funding for AS&T R&D in Europe is growing. Key areas of AS&T in which the U.S. was formerly a leader and in which the U.S. is now falling behind or in which U.S. leadership is now being seriously challenged include

1) collider beam physics, technology, and operation;
2) plasma wakefield acceleration R&D; and
3) fabrication of accelerator components and systems.

Recommendation: 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.

Recommendation: Develop a strategic plan to maintain leadership in plasma wakefield acceleration as needs for R&D facilities evolve and research programs abroad grow.

Strengthening critical capabilities

AS&T R&D areas in which U.S. leadership is challenged

Finding: **Funding for AS&T R&D in Europe is growing. Key areas of AS&T in which the U.S. was formerly a leader and in which the U.S. is now falling behind or in which U.S. leadership is now being seriously challenged include**

1) **collider beam physics, technology, and operation;**
2) **plasma wakefield acceleration R&D; and**
3) **fabrication of accelerator components and systems.**

Finding: **The manufacturing supply chain for key accelerator components and systems is dominated by foreign companies.**

The DOE Office of Science (DOE SC) now purchases slightly more than half of all key accelerator components from foreign sources.

Recommendation**: Increase the investments in supply chain development for accelerator components and systems in the challenge areas identified by the DOE Office of Accelerator R&D and Production.**

Strengthening critical capabilities

Invest in instrumentation development to enable the discovery science of the future

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.**

Recommendation: **DOE HEP and NSF Physics should support an active, continuous program of instrumentation R&D, and facilitate the development of instrumentation R&D collaborations at home and abroad.**

Case study: ATLAS & CMS

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.

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. SSC detector R&D provided a fertile ground for developing new experimental techniques and gaining invaluable expertise. Many developments for the SSC made it into LHC detectors.

Invest in **Instrumentation research and development** to enable the discovery science of the future

Europe is renewing an ambitious, collaborative, coordinated program of detector R&D.

…the U.S. particle physics community has played a prominent role in several of the very successful CERN RDs. The U.S. should build on this by participating in the ECFA DRDs and engage with the broader instrumentation R&D community within and beyond particle physics…

Snowmass 2021 Instrumentation frontier recommendations:

1) *Advance performance limits of existing technologies and develop new techniques and materials, nurture enabling technologies for new physics, and scale new sensors and readout electronics to large, integrated systems using co-design methods.*
2) *Develop and maintain the critical and diverse technical workforce, and enable careers for technicians, engineers and scientists across disciplines working in HEP instrumentation at laboratories and universities.*
3) *Double the U.S. Detector R&D budget over the next five years, and modify existing funding models to enable R&D consortia along critical key technologies for the planned long-term science projects, sustaining the support for such collaborations for the needed duration and scale.*
4) *Expand and sustain support for blue sky R&D, small-scale R&D, and seed funding. Establish a separate agency review process for such pathfinder R&D, independently from other research reviews.*
5) *Develop and maintain critical facilities, centers, and capabilities for the sharing of common knowledge and tools, as well as develop and maintain close connections with international technology roadmaps, other disciplines, and industry.*

Strengthening critical capabilities

Software and computing – essential for particle physics

***Finding:* The U.S. is globally recognized as a leader in software and computing for the field of particle physics.**

***Recommendation:* U.S. particle physics should capitalize on its deep experience as leaders in scientific software and computing development as well as the country's emerging high-performance computing and cloud systems of unprecedented scale.**

The field should also leverage its potential to create national scale collaborations for software and computing, spanning experiments, DOE national laboratories, and universities; collaborations should leverage computer and data science expertise beyond the field of particle physics.

Software and Computing (S&C) is essential to all modern particle physics experiments and many theoretical studies.

The size and complexity of S&C initiatives are now commensurate with that of experimental instruments, playing a critical role in experimental design, data acquisition, and instrumental control, reconstruction, and analysis.

Invest in **software and computing** to enable the discovery science of the future

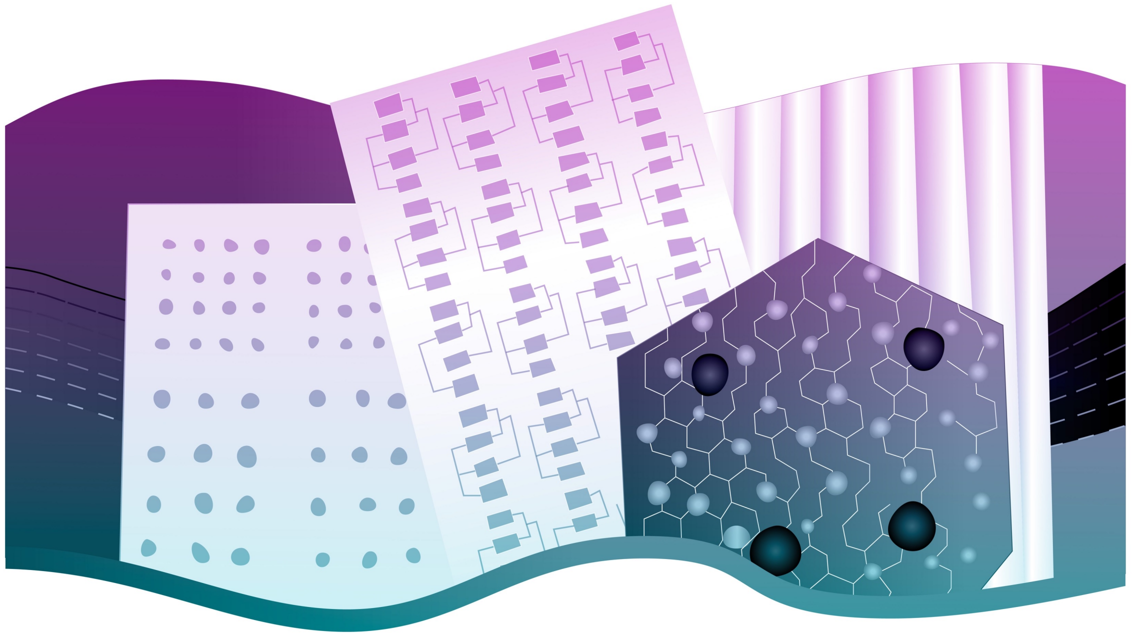
A number of successful **cross-cutting S&C research centers and institutes** have emerged to enhance the field of particle physics. Such multi-institutional collaborations have the potential to leverage both the multidisciplinary strengths of the universities and the particle physics-specific depth of the expertise at the national laboratories.

Significant progress has been made in **adapting software applications for the effective use of hardware accelerators** and in preparation for future exascale computing resources. Federal programs in this area include the DOE ECP (Exascale Computing Project), DOE SciDAC (Scientific Discovery through Advanced Computing), DOE CCE (Center for Computational Excellence), Computational HEP more generally, and the NSF IRIS-HEP (Institute for Research and Innovation in Software for HEP).

The external computing landscape has changed dramatically since the early 2000s. Two of the largest changes are the **availability of resources** and credible **alternatives to dedicated purpose-bought computing systems**, and the **advent of specialized computing architectures like GPUs and FPGAs**. In 2022, the U.S. had an undisputed leadership position in the deployment of HPC (High-Performance Computing) facilities available to science.

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.

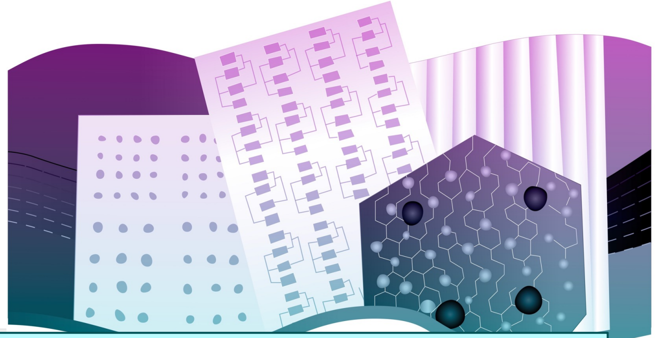


Enhance and leverage the innovative role that particle physics plays in artificial intelligence and machine learning, quantum information science, and microelectronics to advance both particle physics and these national initiatives.

Key Finding and ***Recommendation***

Advancing National Initiatives

Artificial intelligence and machine learning – drivers of discovery



Finding: **Artificial intelligence is impacting every element of the cycle of inquiry in particle physics.**

Recommendation: **To retain U.S. leadership in the application of artificial intelligence and machine learning to particle physics, enhance funding in this area as it is an important driver of discovery.**

Deep Learning (DL) research in particle physics has been extremely successful. It has provided sizeable improvements in experimental performance that would have otherwise required expensive detector upgrades, e.g. ATLAS &CMS have improved b-jet tagging at large momentum by a factor of ~ 3.

DL is central to future experiments, such as DUNE and those at the HL-LHC. New research directions are being opened, thanks to novel applications directly exploiting raw data. This is made possible due to a close collaboration between different regions, in particular the U.S. and Europe.

Invest and innovate in **AI/ML**

Within particle physics, **AI is impacting every element** of the cycle of inquiry from hypothesis generation and simulations/theories to triggering, instrument control, and design to data analysis. This has critical implications for scientific discovery, workforce development, and interactions between academia and industry

- There is widespread, international perception in the particle physics community that the U.S. particle physics community was the first to strongly embrace AI/ML and is an intellectual leader, although other regions are now catching up.
- U.S. funding for AI/ML specifically directed to particle physics is tracked; this is not the case for Europe (e.g., CERN). Therefore, it is not possible to compare funding for AI/ML in particle physics between the U.S. and Europe.
- U.S. HEP funding agencies solicit proposals for AI/ML. For AI/ML it also comprises a fraction of the funding DOE allocates to HEP group grants. (PIs are asked to list AI/ML activities in DOE grant proposals.)
- NSF physics-related AI/ML R&D ranges from foundational through delivery as cyberinfrastructure through the IAIFI (Institute for Artificial Intelligence and Fundamental Interactions), A3D3 (Accelerated Artificial Intelligence Algorithms for Data-Driven Discovery) and IRIS-HEP institutes, as well as through smaller projects and base grants.

Collaborate and innovate in **AI/ML**

Future directions for U.S.-Europe collaboration in AI/ML

U.S.-Europe ML for PP collaboration could be strengthened, exploiting existing opportunities for common funds.. Creating a common program between the EU's research funding bodies and the DOE and NSF could be a unique opportunity to join forces to facilitate the exchange of ideas. For Europe, it would be a key element to facilitate collaboration with U.S. technology companies investing in deep learning research. For the U.S., it would consolidate a well-established program of international collaboration in fundamental research with Europe, Thanks to its strength in AI research and investment in HPC centers, the U.S. would play a prominent role.

AI beyond physics analysis

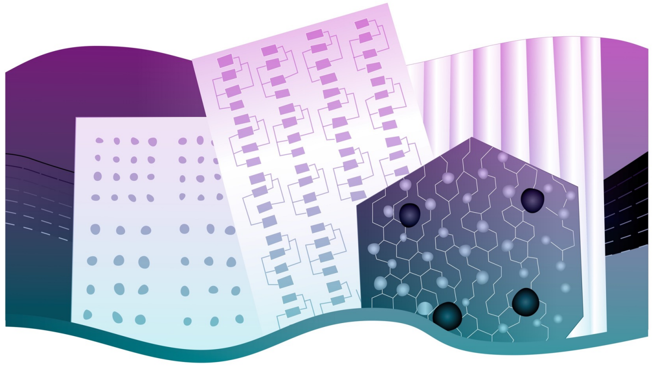
AI is also being developed for instrument operations, such as accelerator controls and telescope observation scheduling.

Physics data as verification of AI algorithms

Particle physics makes an excellent proving ground for ML research; because the field generates large datasets, it has an excellent model (the Standard Model) and a well-tested high-fidelity GEANT4 detector simulation.

Advancing National Initiatives

Quantum information science opens new vistas for particle physics



Finding: **Quantum information science is driving innovation in particle physics, which in turn creates new capabilities and new ideas for quantum information science.**

Recommendation: **Establish a funding mechanism for a suite of small-scale experiments that have the potential to advance the scientific goals of the U.S. particle physics program to capitalize on the recent investments made in quantum sensing. These small experiments should be at the technical cutting edge of this rapidly progressing international field and world-leading. Funding should be timely, recognize the interdisciplinary character of this field, and be sufficient to ensure the rapid successful completion of these experiments.**

Quantum sensors are at the heart of new non-accelerator particle physics experiments including searches for ultra-light dark matter (expanding the discovery space by 21 orders of magnitude) new forces, variations in the fundamental constants, and the electron dipole moment, the absolute measurement of the electron-neutrino mass, and the detection of gravitational waves at frequencies between LIGO and LISA. The technologies include qubits, superconducting nanowire detectors, quantum detectors based on the same technique as magnetic resonance imaging, atomic clocks and atom interferometers.

Invest and innovate in **Quantum Sensing**

- There is a strong perception among international quantum sensing practitioners that the U.S. is the global leader in **quantum sensing for particle physics.**
- The National Quantum Information Act (NQIA, 2018) supports the DOE HEP Quantum Information Enabled Discovery QuantISED program.
- The NQIA **established multiple national DOE and NSF research centers** designed to serve as hubs for innovation and scientific advancement in QIS.
- The component of **NQIA QIS funding that supports US particle physics is larger than QIS funding for particle physics in any other western nation.**
- **China is investing heavily in QIS** but does not disclose its funding; it is beginning to invest in QIS for HEP.
- There is strong international competition in this fast-paced area. To retain U.S. leadership in QIS for HEP, **enhanced funding is necessary**.
- The U.S. funding model is **interdisciplinary in character**, which in turn fosters an interdisciplinary community which is essential in this field and is a particular **strength and advantage of the U.S.** and should be maintained.

QIS Research centers

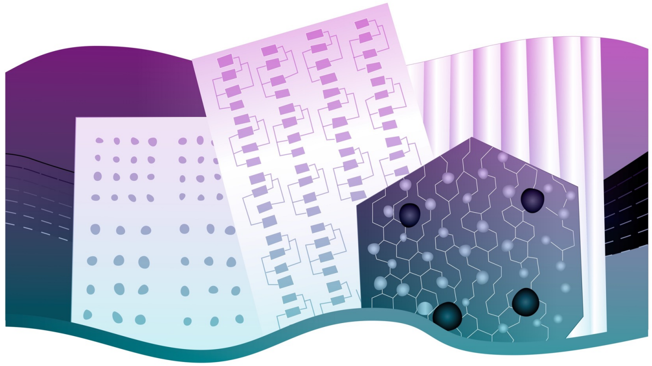
The Superconducting Quantum Materials and Systems (SQMS) Center led by Fermilab, has the primary goal to understand and mitigate quantum decoherence, and to deploy superior quantum systems to advance applications in quantum algorithms and sensing. At SQMS, the technology and expertise developed by the HEP community, primarily based on the needs of particle accelerators, provides exceptional theoretical and experimental resources to advance the physics of decoherence.

Fermilab constructs cavity oscillators with the highest Q-factor in the world. This is a crucial contribution that HEP make to the national quantum ecosystem and an example of the mission of HEP benefiting from engaging with QIS and the national quantum ecosystem benefiting from engaging with HEP. The oscillators, when coupled to a qubit, create a powerful new quantum information processing platform with potential for impact in HEP and more broadly.

There is also a strong HEP presence within other DOE National QIS Research Centers for example the QSC at ORNL

Advancing National Initiatives

Microelectronics – an essential technology



Finding: **Application Specific Integrated Circuits (ASICs) are ubiquitous in particle physics, in other scientific disciplines, and in society. ASICs are an essential part of almost every detector technology in particle physics.**

Recommendations:

DOE HEP and NSF Physics should regenerate and maintain at a leadership level expertise in microelectronics for particle physics instrumentation. Efforts should include support of both targeted and generic R&D in microelectronics to advance microelectronics applications as well as to maintain expertise and to attract talent. DOE HEP and NSF Physics should exploit synergies with the needs of other parts of the DOE Office of Science and NSF programs.

The agencies and the community should work together to establish a program providing cost-effective access to design licenses and tools and to foundries for national laboratories and universities. Consider a program that extends across the DOE Office of Science and the NSF Mathematical and Physical Sciences Directorate.

The majority of detector instrumentation R&D in particle physics requires ASIC development.

The challenges include the ability to develop ASICs that can operate in the extreme environments of high radiation, high data rates, low temperatures, and/or outer space.

Invest and innovate in **Microelectronics**

ASICs are ubiquitous both in society and in our field; ASICs are a key part of almost every detector technology.

In recent years, US leadership in custom IC design has slipped or lapsed, with experiments more frequently looking to CERN or other European groups for IC designs.

ASIC R&D, both targeted and generic is **needed to maintain the relevance of U.S. High Energy** Physics contributions in the international arena.

Foundry access is crucial, the cost is high, and few foundries will engage with particle physics. The work is exceptionally specialized and depends on a stable long term HEP workforce.

The advent of Europractice, funded by the European Union, has given HEP ASIC developers at CERN and across European institutions an advantage by providing a brokerage service to lower costs across industry and academia.

Establishing in the U.S. **cost-effective access to licenses and tools and high-priority, cost-effective access to foundries** would benefit ASIC development beyond DOE HEP and NSF Physics, e.g. broadly across the DOE Office of Science and NSF programs.

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.

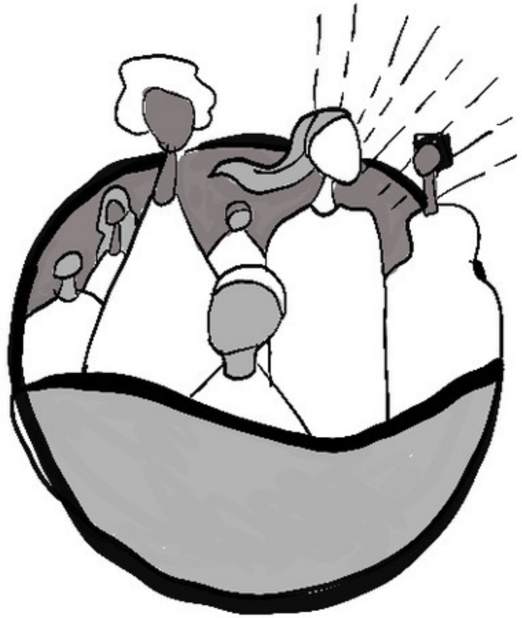
Explore frontier science using cutting-edge technologies to inspire the public and the next generation of scientists while opening new pathways to diversify the workforce and realize the full potential of the field.

Key Finding and ***Recommendation***

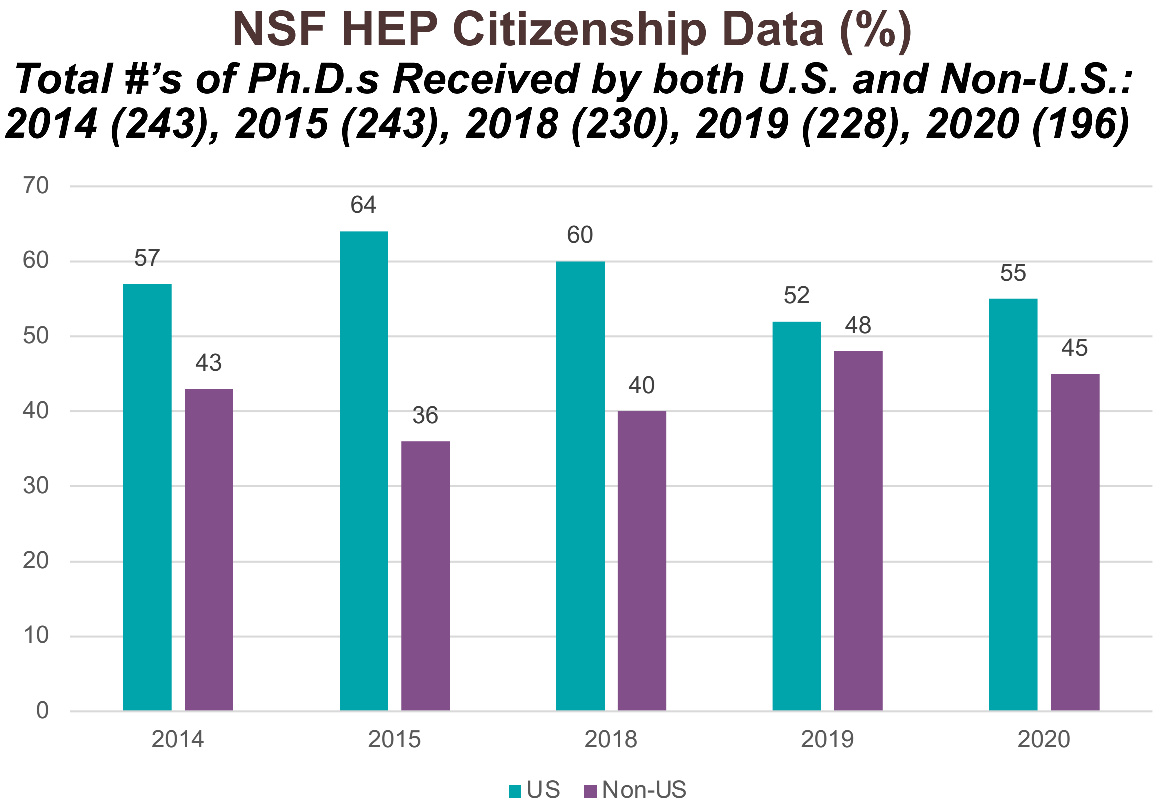
Methodology: HEP Workforce Data

A large quantity of data was collected from AIP, NSF, U.S. national laboratories, international research collaborations, and foreign organizations. The categories of the data included the following:

- *Gender*
- *Race/Ethnicity*
- *International/non-US citizens*
- *Ph.D.s received for students based at the national laboratories*
- *Undergraduate and Graduate Internships*
- *Faculty Visitors at the national laboratories.*



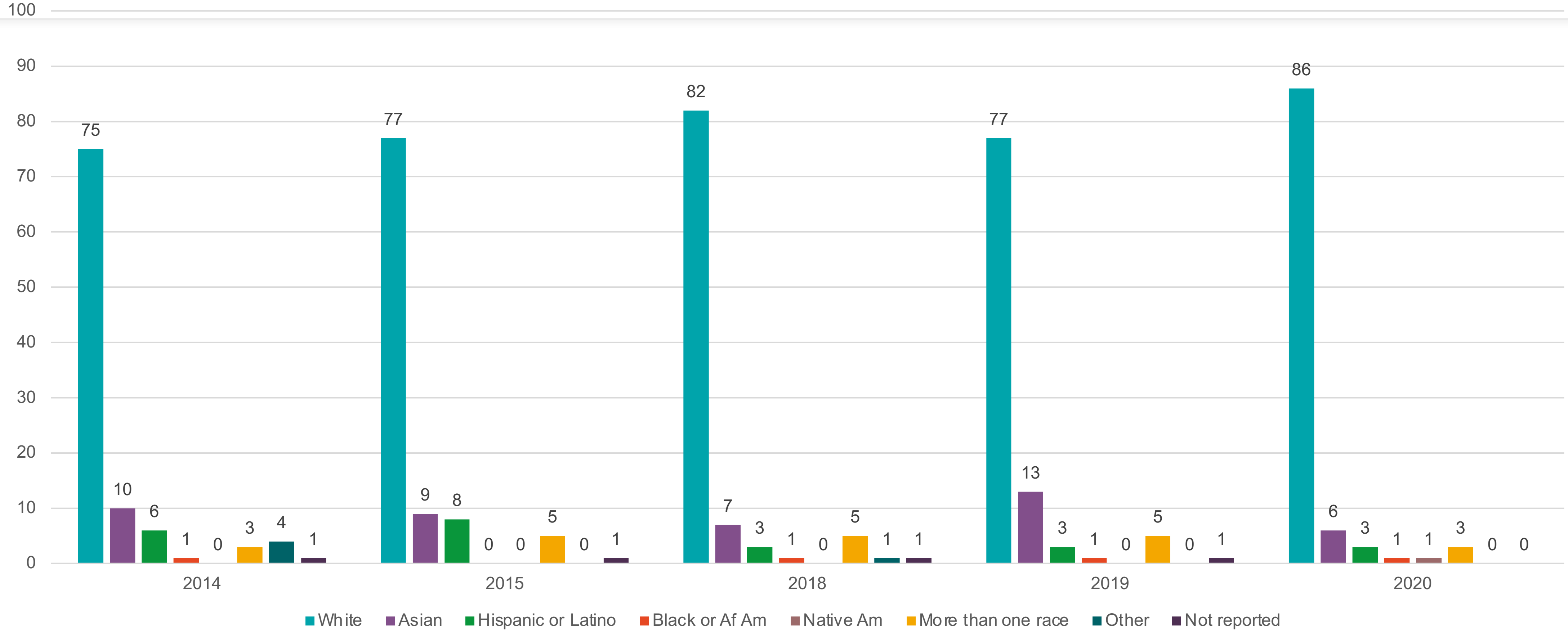
Building a robust workforce
Attraction and training



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

Attracting and training the workforce

The U.S. particle physics program should strive to attract a diverse community in all senses of that word to secure leadership and innovation. In particular, the U.S. should do more to provide compelling, inclusive, and equitable opportunities for U.S. citizens. Some concrete actions include:

- Create a program to send national laboratory and university researchers to colleges and universities that do not have particle physics programs to excite students about the field and waiting career opportunities. Include visits to MSIs and small two- and four-year colleges.
- DOE should increase the number of university joint/bridge faculty positions that it funds at the 50% level, with the goal of increasing particle physics positions at MSIs.
- Significantly increase the numbers of both undergraduate and graduate internships and other longer-term opportunities in particle physics at the national labs and universities. Ensure that participation in one program during one year does not preclude participation in another program during another year.
- Place a high priority on best practices for ensuring the cultural competency of managers at the national laboratories to hire, promote, and retain a diversity of researchers in the particle physics workforce. DOE should continue its commitment to develop and implement best practices in the area of diversity, equity, and inclusion.
- Collect and report statistics on the HEP workforce, and track their evolution over time across levels: laboratories, collaborations, and nation-wide. Align categorizations for consistent comparison across different datasets.

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 and collaborators to solicit, share, and act on feedback received about the work environment.

Building a robust workforce

Workforce for enabling technologies

Finding: **Progress in particle physics relies on advances in the state-of-the-art in enabling technologies. Advances in technology rely, in turn, on the ability of particle physics to attract, train, and retain a highly skilled technical workforce.**

Recommendation: **Develop a framework to attract, train, and retain a highly skilled technical workforce.**

Within the enabling technologies, national technological networks and multi-institution centers can promote communication, cross-fertilization, pooling of resources, and creation of research teams to tackle particularly challenging problems. Such networks and centers increase not only the effectiveness of working within the field but also the attractiveness, contributing to the ability of particle physics to retain its workforce.

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.**

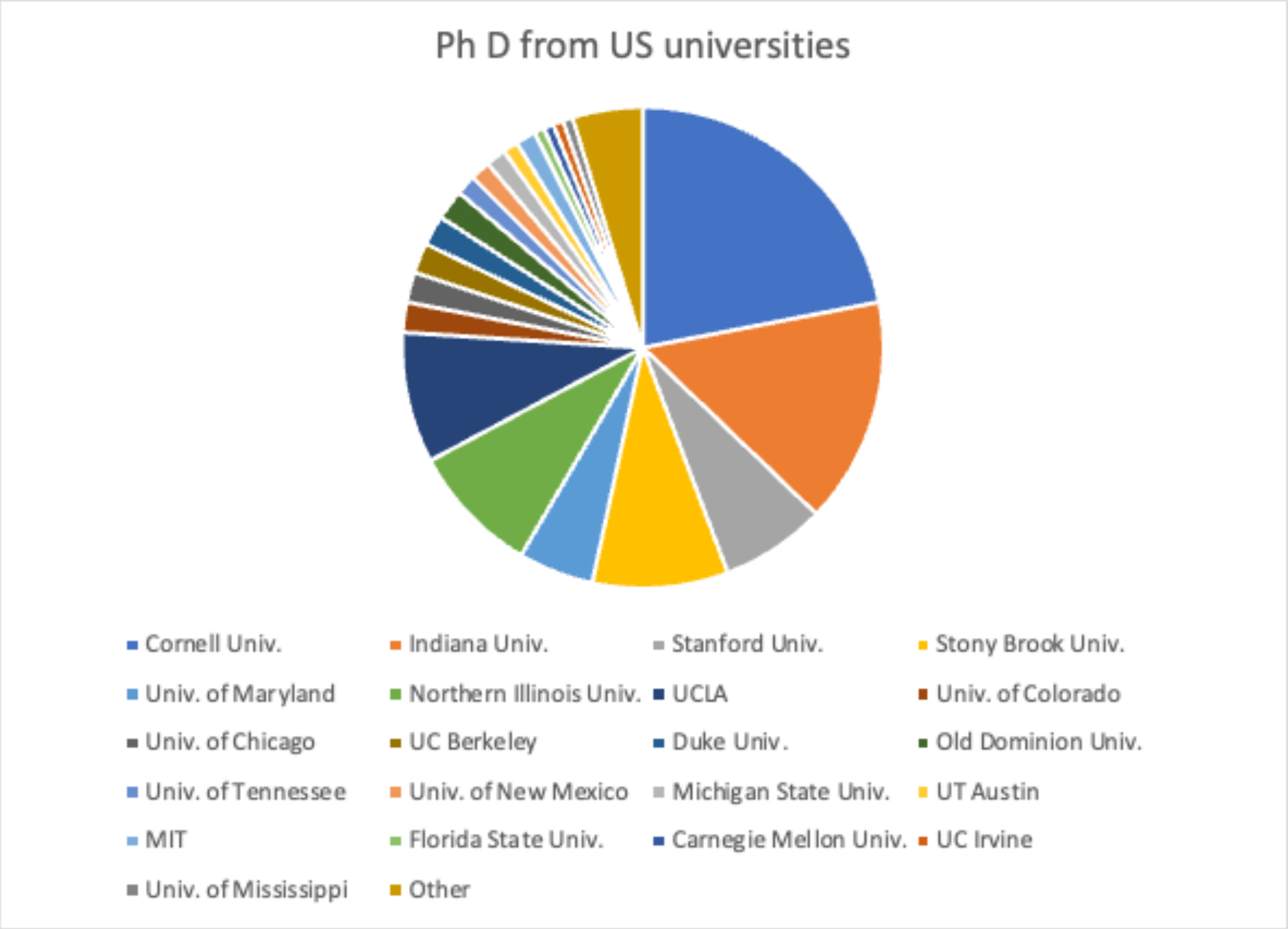
Finding: The current standard for **software and computing** training is project-specific on-the-job training. Career path limitations within the field diminish retention rates.

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.

Past Accelerator Ph.D.s Granted in the U.S.

Four U.S. universities have produced over 50% of the US-trained accelerator scientists and engineers.

It is notable that the Ph.D. program at Indiana University, which produced a large fraction of the degrees, no longer exists.



Building a robust workforce

Workforce development in key technologies:
Instrumentation, accelerator science and technology, and large-scale computing

Recommendations: **Attract, nurture, recognize and sustain the careers of physicists, engineers and technicians dedicated to the development of <u>instrumentation, accelerator science and technology, and large-scale computing.</u>**

Recommended actions include:

- 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.
- Shore up deficiencies by encouraging more students to pursue those areas of study.
- Establish more university programs offering degrees in accelerator science and technologies.

Building a robust workforce

Workforce needs for 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.

Recommendations: **Develop new career frameworks to grow and retain the U.S. AI/ML and QIS/quantum particle physics workforce.**

1. **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 needs in microelectronics

Finding: Microelectronics, and ASICs (Application Specific Integrated Circuits) in particular, are ubiquitous in particle physics. In the U.S. particle physics community, there is a shortage of both specialist ASIC design engineers and particle physicists sufficiently knowledgeable in ASIC design to work effectively with ASIC designers and to review systems designed with ASICs. These factors limit U.S. leadership in this crucial area of the field.

Recommendation: DOE should fund and work with universities to create an enhanced integrated program to train university Ph.D. and Master's students in system design of the experiment and subsystem design of the detector and readout and appropriate implementation and design of ASICs for the detector readout.

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, the is 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. Converge on a direction, is the task of P5 – not 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.**

HEP Workforce – in conclusion

The US HEP program should strive to attract a diverse community in all senses of that word to secure leadership and innovation

- Across HEP it is imperative to focus on promoting and increasing the representation of women, and those from African-American, Hispanic, Indigenous and other underrepresented backgrounds.
- US particle theorists have a major role in training the STEM workforce of students and postdocs that significantly contribute to US industry and US economic competitiveness.
- Particle physics training involves special skills including applied math, data science and, most recently, quantum information science.
- Looking forward to the future of US HEP -especially over the 30-50 year program timescales we are now discussing for future projects – it is most important to carefully consider inclusion of geographical regions that are developing capacity and could become major contributors to the field in the future.

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.

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

Thank you to subpanel, our contributors, readers, and to HEPAP.

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.

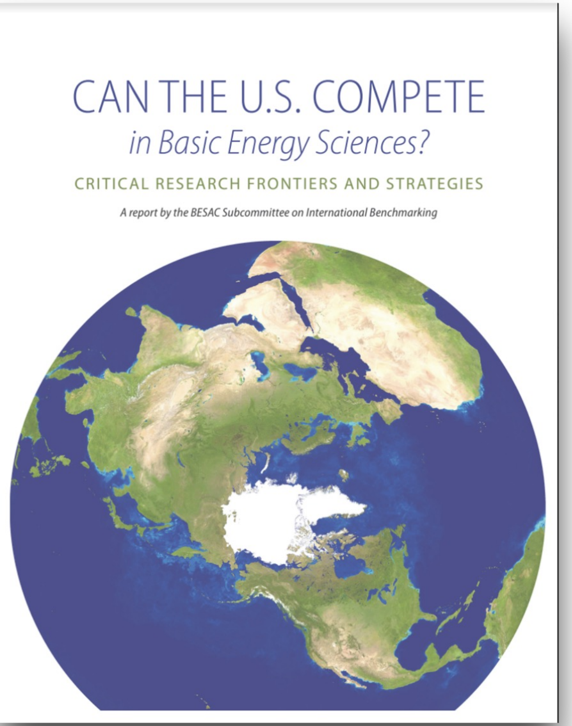
EXTRA SLIDES

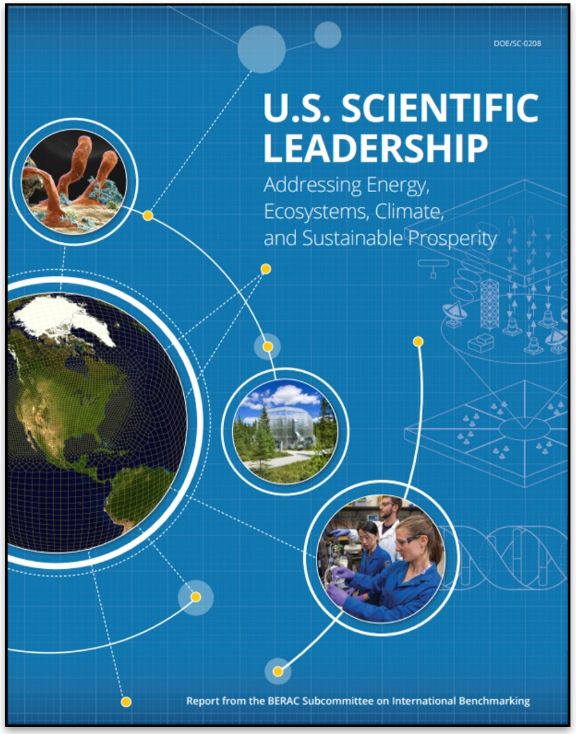
DOE SC International Benchmarking/ Competitiveness Charge

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).





Methodology – input from large experiments

Interviewed multiple leaders of a suite of major present and recent experiments, along with selected individuals:

- Both US leaders and non-US leaders
- Both US-hosted expts. & expts. hosted abroad
- *e.g.* Fabiola Gianotti, Nigel Lockyer, Jim Yeck

Sample questions for US-hosted experiments:

- Did you perceive obstacles that constrained the degree or quality of international participation, either generally or in nation-specific ways?
- How is your experiment governed, and how did your governance model affect (i.e. facilitate or hinder) international participation?

Sample questions for experiments hosted abroad:

- In what areas did you seek U.S. participation? Why these areas?
- To what areas were U.S. contributions key or critical? (consider construction, operation, software & computing, physics analysis, collaboration leadership)
- Identify key areas where the U.S. currently has, or could aspire to, leadership roles in HEP. (These areas could be as broad as neutrino physics or more specific such as liquid noble ionization detectors.)

List of experiments interviewed:

ATLAS
CMS
LHCb

BABAR
BELLE/BELLE-II

SK/T2K/HK
Daya Bay
LBNF/DUNE

Rubin/DESC
CMB-S4

Methodology – Input from Small Experiments

Conducted interviews and consultations via email to multiple leaders of a set of small experiments, along with selected individuals:
- Both U.S. leaders and non-U.S. leaders
- Both U.S.-hosted experiments & experiments hosted abroad

Sample questions for experiments hosted abroad (note: questions are mostly the same as those for the big experiments subcommittee):

- In what areas did you seek U.S. participation? Why these areas?
- To what areas were U.S. contributions key or critical? (consider construction, operation, software & computing, physics analysis, collaboration leadership)
- Identify key areas where the U.S. currently has, or could aspire to, leadership roles in HEP. (These areas could be as broad as neutrino physics or more specific, such as liquid noble ionization detectors.)

Sample questions for U.S.-hosted experiments (mostly the same as those for the big experiments).

- Did you perceive obstacles that constrained the degree or quality of international participation, either generally or in nation-specific ways?
- How is your experiment governed, and how did your governance model affect (i.e., facilitate or hinder) international participation?

List of experiments consulted:

LZ
XENON-nT
Mu2e
g-2
K0TO
nEXO
GADZOOKS!
COHERENT
Project-8
MINERvA
DESI
ADMX
DMRadio
OSCURA
TESSERACT
LDMX
CCM

Invest in **accelerator research and development** to enable the discovery science of the future

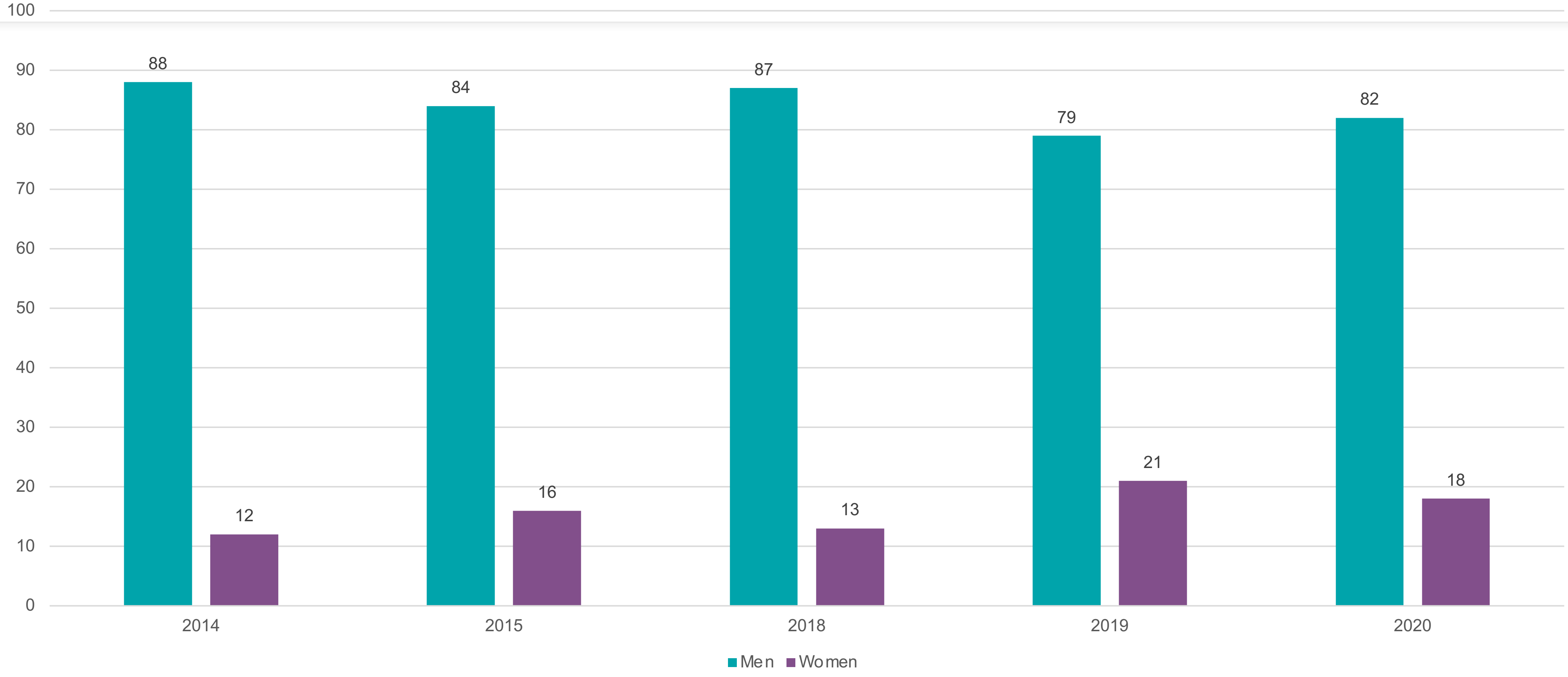
Methodology:

- The accelerator sub-committee interviewed:
  - the DOE ARDAP associate director,
  - the GARD program manager of OHEP,
  - leaders of large-scale projects (e.g., PIP-II, EIC, HL-LHC, RHIC as well as LARP), and
  - representatives of accelerator S&T principal investigators from universities and national laboratories (i.e., PIs from SLAC, FNAL, LANL, LBNL, Cornell University).

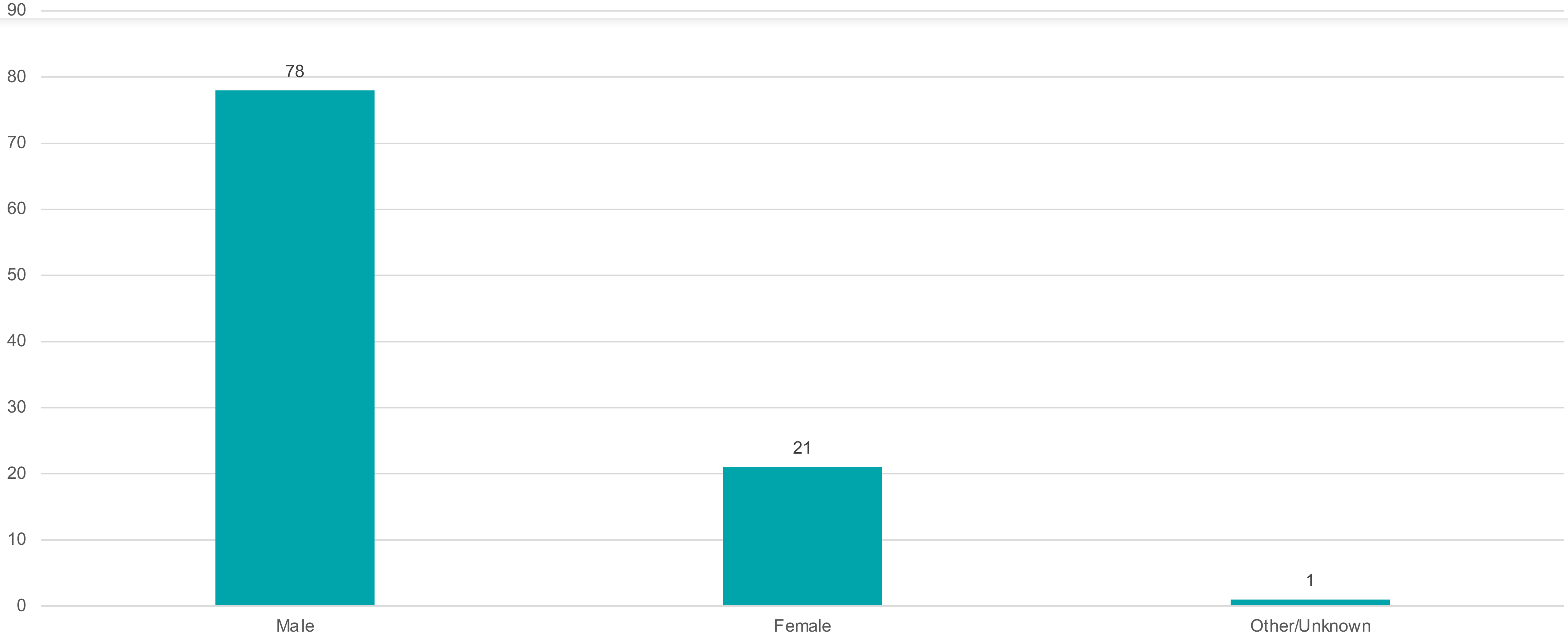
DOE ARDAP Accelerator R&D and Production
GARD (General Accelerator R&D)
PIP-II
EIC
HL-LHC
RHIC
LARP
AS&T PIs (Accelerator Science and Technology)

NSF HEP Gender Data (%)

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



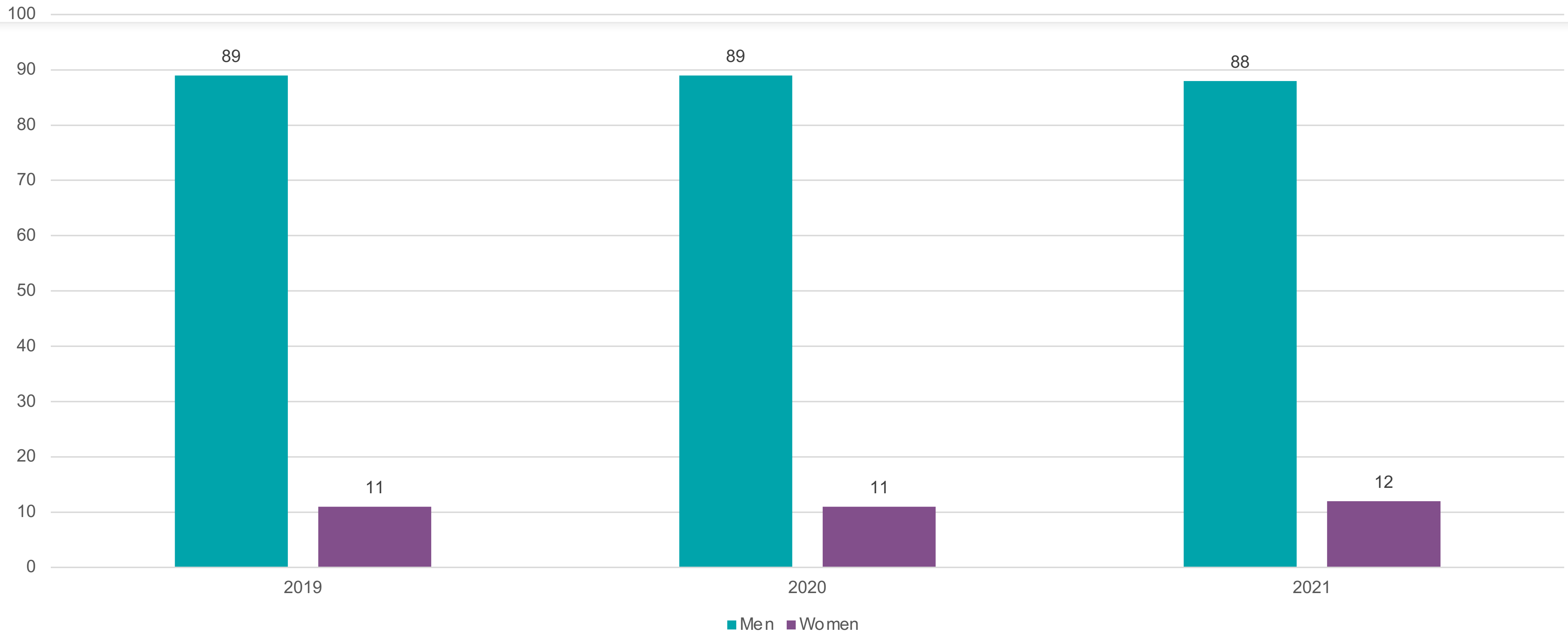
IOP HEP Special Interest Group Year 2022 (%)
Gender Membership Data by % of Total Members
Total Membership: 860



BNL HEP Gender Workforce Data (%)

Total Size of Staff: 2019 (147), 2020 (151), 2021 (159)

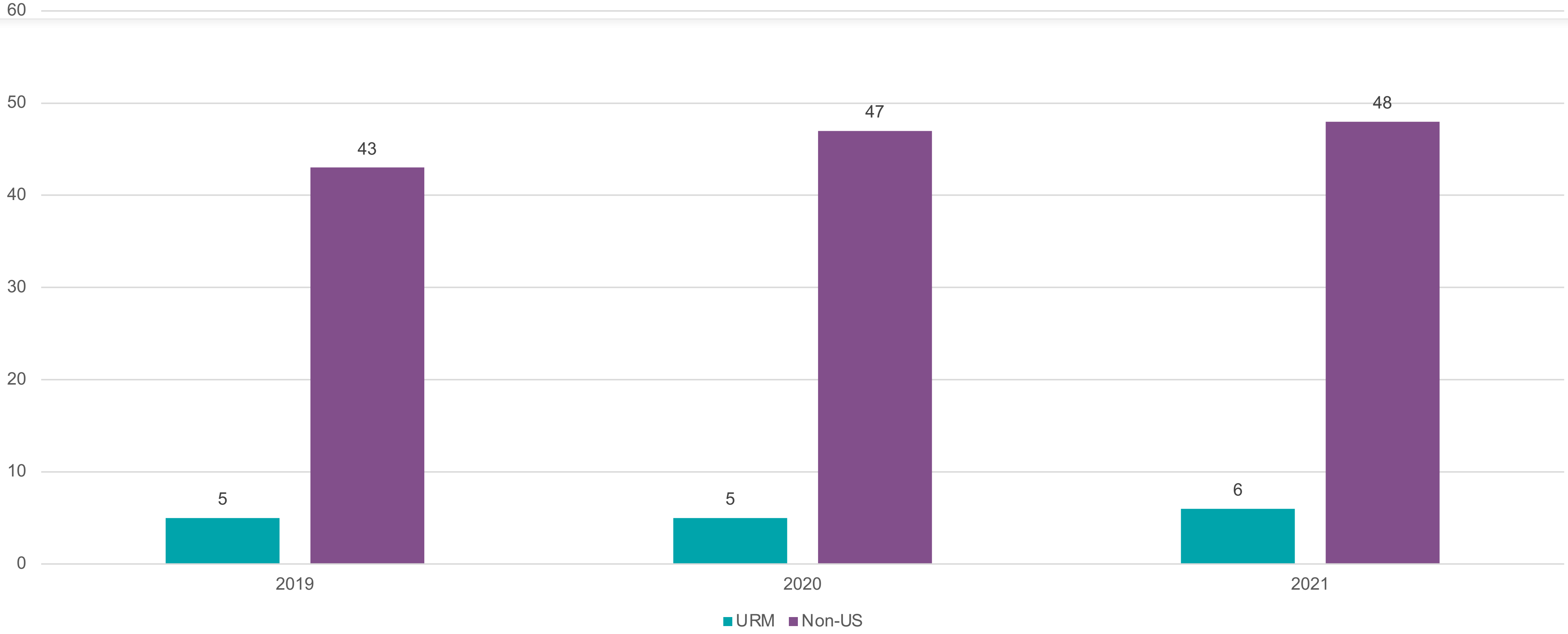
Staff: Scientific, Professional, Technicians, and Postdocs



BNL HEP Ethnicity and Citizenship Workforce Data (%)

Total Size of Staff: 2019 (147), 2020 (151), 2021 (159)

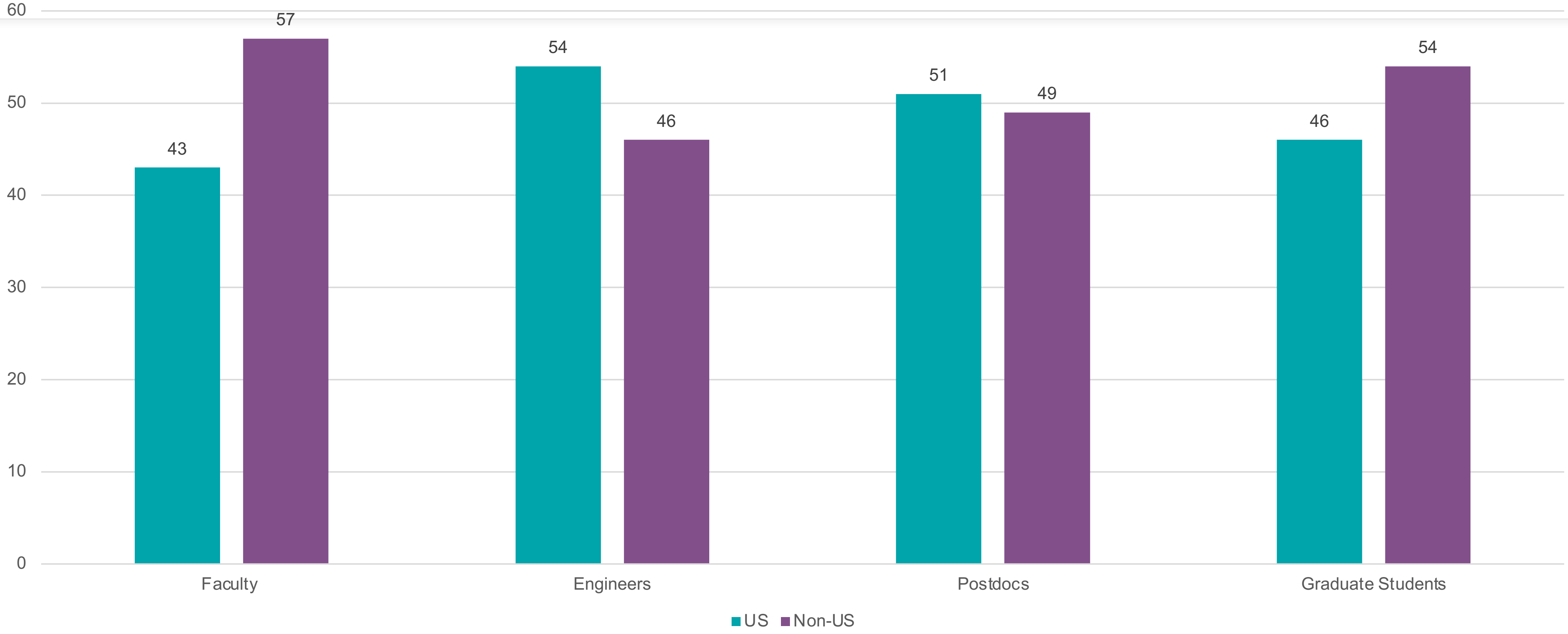
Staff: Scientific, Professional, Technicians, and Postdocs



DUNE 2022 Citizenship Workforce Data (%)

Total Size of Staff: Faculty (668), Engineers (153), Postdocs (255), Graduate Students (329)

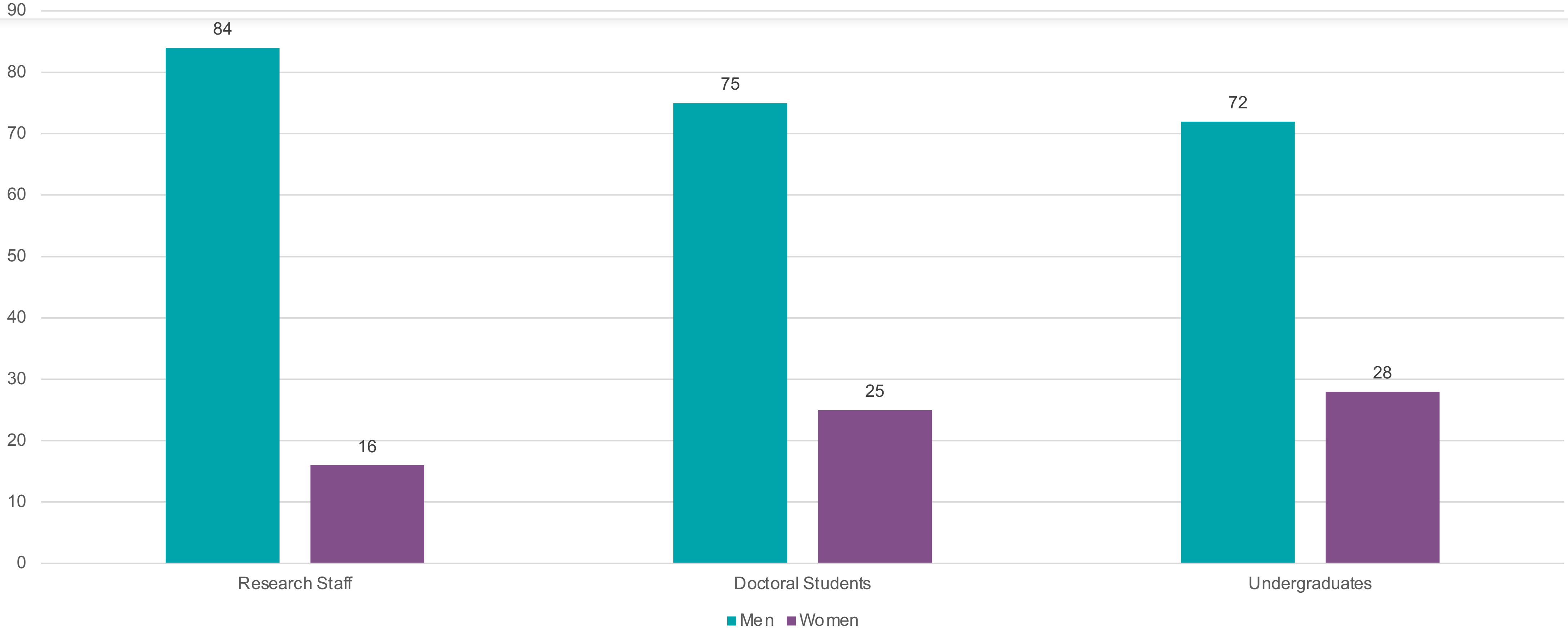
DUNE does not collect information on gender.



CMS Year 2022 Gender Workforce Data (%)

Total Size of Staff: Research (3084), Doctoral Students (1050), Undergraduates (978)

Research Staff: PhD Physicists, Engineers



ATLAS Yr 2016 Gender Workforce Data (%)

Total Size of Staff: Research Staff (2471), PhD Students (1080), Master's Students (443), Undergrad/Summer Students (234)

Research Staff: PhD Physicists, Engineers, Technicians