Findings & Draft Recommendations

from the

HEPAP International Benchmarking Panel

Presented to HEPAP on August 7, 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."

Presentation outline

- Charge context and rationale
- Panel membership
- Report themes
- Key findings and draft recommendations
- Report overview and chapter-specific findings and recommendations
- Conclusions

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."

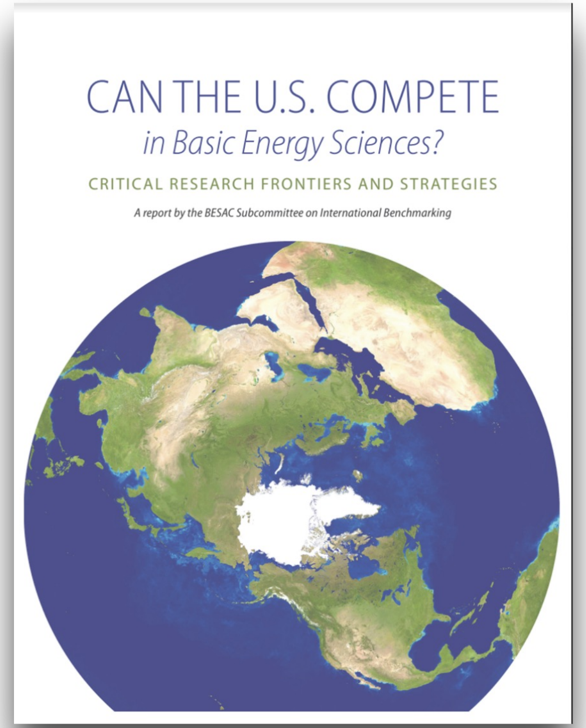
"Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community."

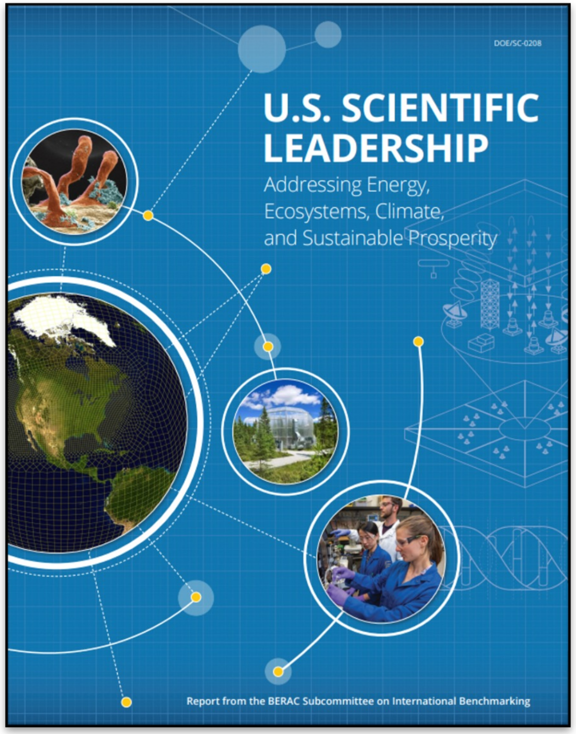
DOE SC International Benchmarking/ Competitiveness Charge

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).





HEPAP's Charge

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**?

Leading U.S. 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?

U.S. 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.**

Subpanel

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)

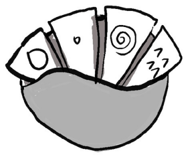
Reina Maruyama (Yale)
Sekazi Mtingwa (NRC)
Brian Nord (FNAL)
Ian Shipsey (Oxford)
Stefan Soldner-Rembold (Manchester)
Lindley Winslow (MIT)

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

Methodology

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

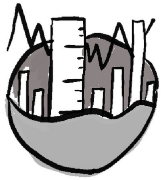
Subcommittees



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*

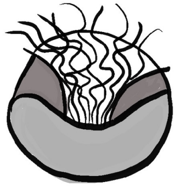
***Theory** distributed throughout subcommittees.*

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

Report themes

Particle Physics - Collaboration and Competition

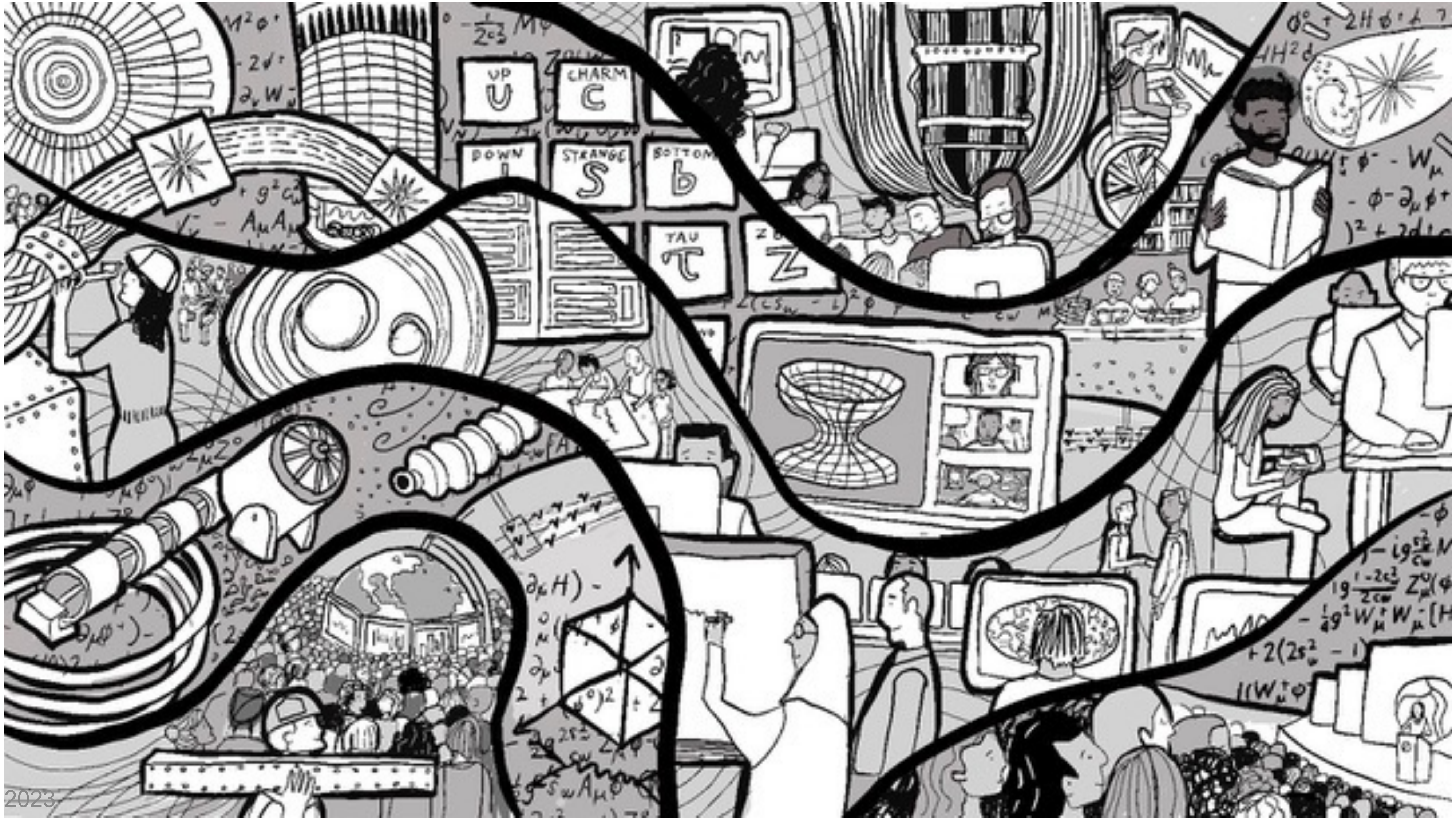
- **Collaboration in HEP** across groups, institutes, countries, and regions **is the norm.**
- **Collaboration combines intellectual and financial resources** to tackle small to big questions.
- **Competition, even within collaborations, is critical for advancement of ideas.**
- Collaboration and competition **lead to development of key capabilities and a strong workforce**.

Particle Physics - Leadership and Partnership

- **Leadership can be defined by influence**: the extent to which individuals, organizations, or countries are able to set priorities and accelerate progress towards meaningful scientific results.
- **Leadership is about achieving the best science.**
- **Partnership is taking joint ownership** of programs or objectives. International facilities rely on clear and balanced partnership for sustained success.

In the end, it is all about doing the best science.

Sandbox draft artwork illustrating report themes



Key findings and recommendations (draft)

1. **Scientific breadth and application:** Particle physics experimental discoveries and accompanying theory address the deepest mysteries of the universe while at the same time advancing ideas and accompanying technology that are vital to other research fields and society at large.

   Strengthen investments to realize particle physics benefits across scientific fields and by society.

2. **Importance of collaboration:** Understanding the smallest scales in nature often requires the largest experimental efforts. Success in particle physics requires, for many efforts, but in particular for these massive undertakings, international collaboration and cooperation. The combined expertise and resources from nations around the world enable discoveries and technological advances difficult to achieve by any single nation.

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

3. **How to be a partner of choice:** Success in international collaborations requires reliable partnerships, early engagement, and joint ownership.

   Act with timeliness, meet obligations, and engage in open communication to remain an international partner of choice.

Key findings and recommendations (draft)

4. **Importance of critical capabilities and technologies:** U.S. leadership in global collaborations requires capitalizing on the U.S.'s unique capabilities including accelerator and detector technologies.

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

5. **Critical U.S. national initiatives:** U.S. leadership and investment in national initiatives in Quantum Science, AI/ ML, and Microelectronics are critical to particle physics and U.S. Security and prosperity.

   Remain a leader in Quantum Information Science, AI/ ML, and Microelectronics, and pursue strategic partnerships where relevant.

6. **Importance of a robust workforce:** A robust particle physics workforce will both leverage and be representative of the diversity of the nation. Attracting, inspiring, training, and retaining a diverse workforce is vital to the success of particle physics and more broadly to U.S. Science and Technology.

   Explore frontier science using cutting-edge technologies to inspire the public and next generation of scientists. Open pathways for an expanded workforce to realize the potential of the field.

Report outline, by the chapter

Science enabled by **Partnerships, Experiments, and Facilities**

A. Invest and engage as major partners in international discovery science from small- to large-scale experiments and facilities

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

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

Technical Areas and **Capabilities/ Competition**

C. Invest in theory, accelerator and instrumentation development and computing to enable the discovery science of the future

D. Invest and innovate in (compete to win?) AI/ML, quantum information science, and microelectronics

Innovative and transformative U.S. capabilities

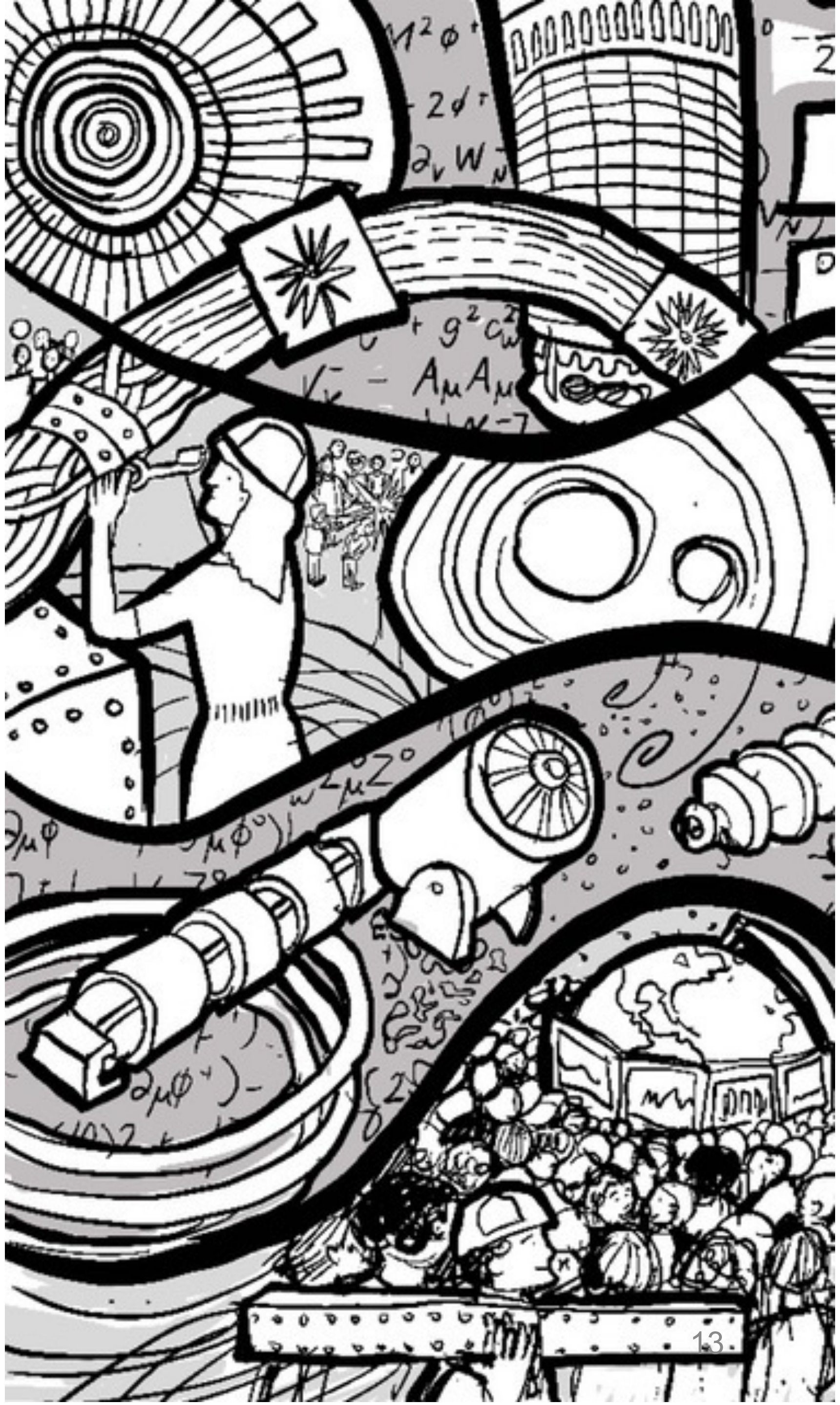
Workforce

E. Inspire, recruit, train, and retain a talented and diverse workforce

U.S. workforce

Science enabled by **Partnerships, Experiments, and Facilities**

Invest and engage as major partners in international discovery science from small- to large-scale experiments and facilities



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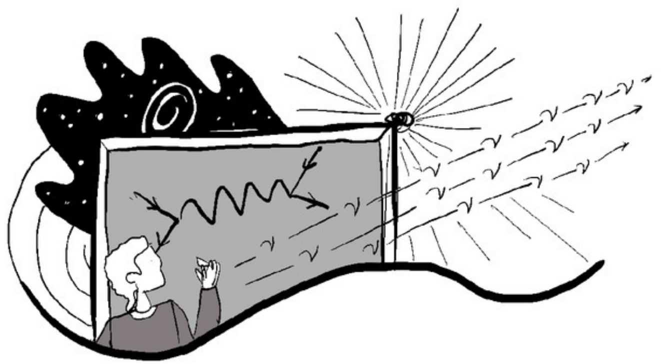
Defining Scientific Leadership in Particle Physics in 2023



- Our Charge: “Identify key areas where the U.S. currently **has, or could aspire to**, leadership roles …”
- The primary goal of the field is discovery science. In the U.S., P5 sets the roadmap for the field.
- In identifying areas of U.S. scientific leadership, the report assumes:
  - The key areas to consider are defined by the P5 science drivers;
  - The starting point for the report is the drivers from the 2014 P5 report; and
  - The U.S. already holds leadership roles in these key areas.
- **Draft Recommendation: The U.S. should continue to play leadership roles in the key scientific areas defined as science drivers by P5.**

Why do we build large experiments/facilities?

- Experimental particle physics advances through sharing ideas and by developing, constructing, or adapting tools needed for accelerators, detectors and computing.
  - The search for new physics involves complex scientific instruments and simulations.
  - Understanding the smallest scales drives the development of high energy accelerators and large facilities/experiments.
  - Particle physics experiments create massive amounts of data – modern computing tools are required to uncover the physics.
- It has become more the norm to form collaborations or partnerships to combine expertise and resources from groups/nations around the world to construct and operate our larger facilities/experiments.
- The design and construction of the largest facilities can take years of planning and many years to construct.
- ***Continue support for and actively seek engagement in international collaborations of all sizes.***

The Roots of Strong Collaborations

Common characteristics of successful collaborations emerged.

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

These attributes are readily observed in successful large collaborations.

Engage with partners in earliest stages of projects

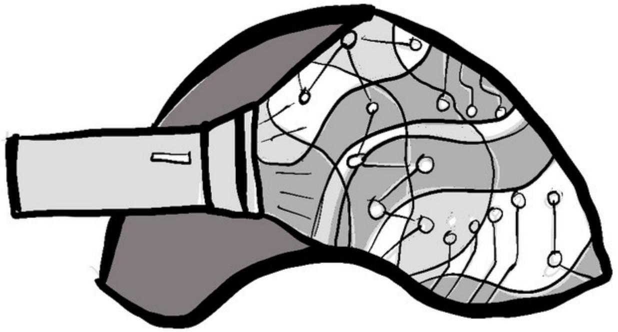
Finding: International partnerships are strongest when partners are engaged in the early conceptual development of projects.

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.

Benefits of early engagement



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.

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.

Draft Recommendations:

- **DOE and NSF should support involvement of U.S. scientists and institutions in the early conceptual development and R&D for future international experiments and accelerator projects.**
- **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.**

Governance structures

Shared governance and shared responsibility are principles observed in successful large collaborations.

A governance structure needs to be agreed upon by the international partners and their funding agencies.

- 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.

DUNE, although inspired by the CERN-model, is organized as a hybrid of both models.

PIP-II is a host-led partnership with international partners

Governance structures continued - with recommendations

Findings:

- The international collaboration governs itself by the framework of the governance structure, with oversight provided by the host institution and the funding agencies.
  - The independence of the international collaboration, particularly for scientific goals and priorities, is essential for the success of ambitious experiments.
- National projects within the overall international project (facility/experiment) normally coordinate the progress of their work independently, with overall coordination by an integrated project management system.
  - Decisions that impact national projects need to be reviewed by the overall coordinating body and should not be imposed unilaterally by one body.

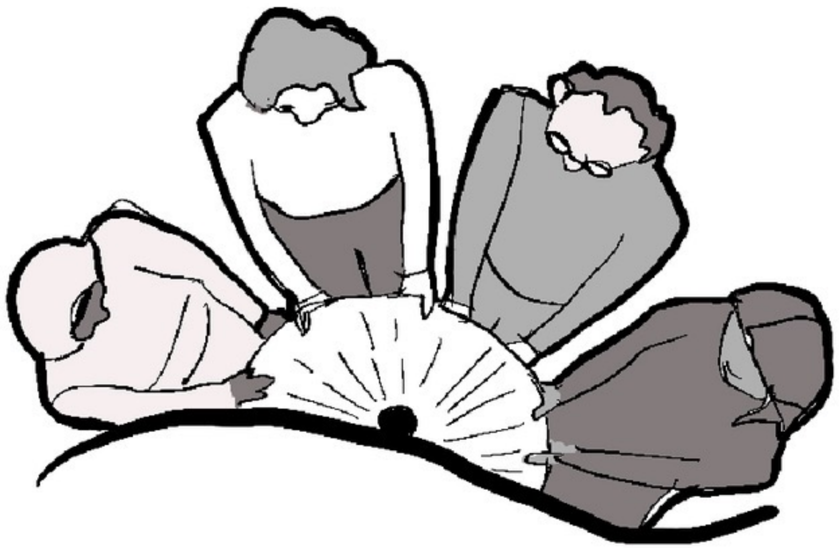
Draft Recommendations:

  - **Formally agree among partners on an international governance structure early during the formation of the international project.**
  - **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 hosted by the U.S.**

Funding mechanism for projects

Findings and Considerations:

- CERN's budget stability and ability to borrow facilitate the planning and establishment of new projects
- The lack of long-term funding in the U.S. is an impediment to good international partnership, whether the project is hosted in the U.S. or abroad
- Unpredictable budgets and abrupt reductions in budgets can lead to inefficiencies and sometimes to loss of competitiveness
- Maintaining construction projects on planned profiles in times of declining budget is important, but it negatively impacts facility operations and/or scientific research and R&D.
- Stable funding of U.S.-hosted projects is especially important in order that international scientists and other nations see the U.S. as a reliable partner and are willing to partner on U.S.-hosted projects
- It is important to determine the funding and international participation models of a project early on and communicate them in a transparent fashion.
- **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 impact on international partners.**



Experiments hosted abroad

when scientific opportunities are available elsewhere

U.S. as partner of choice

US participation is in demand for major experiments hosted outside the U.S. and abroad is often essential to achieve the science goals.

International experiments seek US participation for US experience, expertise, technology, and technical capabilities, including experience in operating large-scale facilities.

The expertise and resources of the national labs are an attraction that make the U.S. a partner of choice.

Draft Recommendation:

Continue to enable involvement of US scientists and institutions in experiments hosted outside the U.S.

Opportunities for US scientists

For many experiments, leadership positions depend on presence at the experimental site (or 100% effort).

- For non-US-based experiments, this puts U.S. scientists at a disadvantage relative to scientists based at institutions closer to the experiments, for whom frequent short trips are a possibility.
- In general, this means long-term presence of scientists at the experimental site is necessary. For faculty members, this typically requires a teaching buy-out.

Draft Recommendation:

To maintain an active presence and intellectual leadership in experiments outside the U.S., support for faculty teaching buy-out or support during a sabbatical should be expanded, and laboratories and university groups should support members to be based at experimental sites.

Small Projects are Essential

Note: By small projects we mean expenditures of $1M - $100M. By demonstrator-scale we mean expenditure at or below $1M.

- Over the last decade the US HEP community has successfully developed a suite of pathfinder demonstrators and small experiments to search for dark matter, make measurements of neutrino cross-sections, and explore signs of new physics in the neutrino sector.
  - These US-based experiments complement the global program of international projects in HEP and build on US leadership in key areas of S&T. They also provide a unique opportunity for the training of young scientists.
- Quantum sensors and advanced instrumentation developed jointly by U.S. consortia of national laboratories and universities have enabled new approaches to study the nature of dark matter, probe neutrino mass, and study cosmic evolution.
  - U.S. scientists have played a leadership role in the development of these technologies and their application to fundamental science.
- New mechanisms are needed to guarantee the continued support of small projects, an invaluable part of the HEP program.

Small Projects - Findings

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, for example, Italy and Germany, 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.

Once a project is funded and begins, mid-project cancellations without due cause should be avoided.

- It is important to have a proper mechanism to terminate projects if they turn out to be not viable or competitive.
- The decision process should be well communicated to all partners in the project.

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

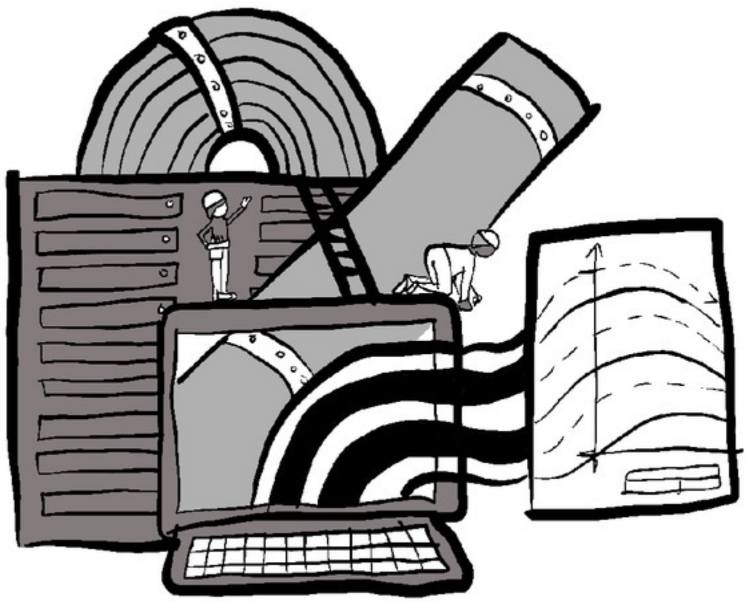
- Explicitly, these projects can benefit from expertise of lab personnel and from lab capabilities.

Small Projects – Draft Recommendations

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

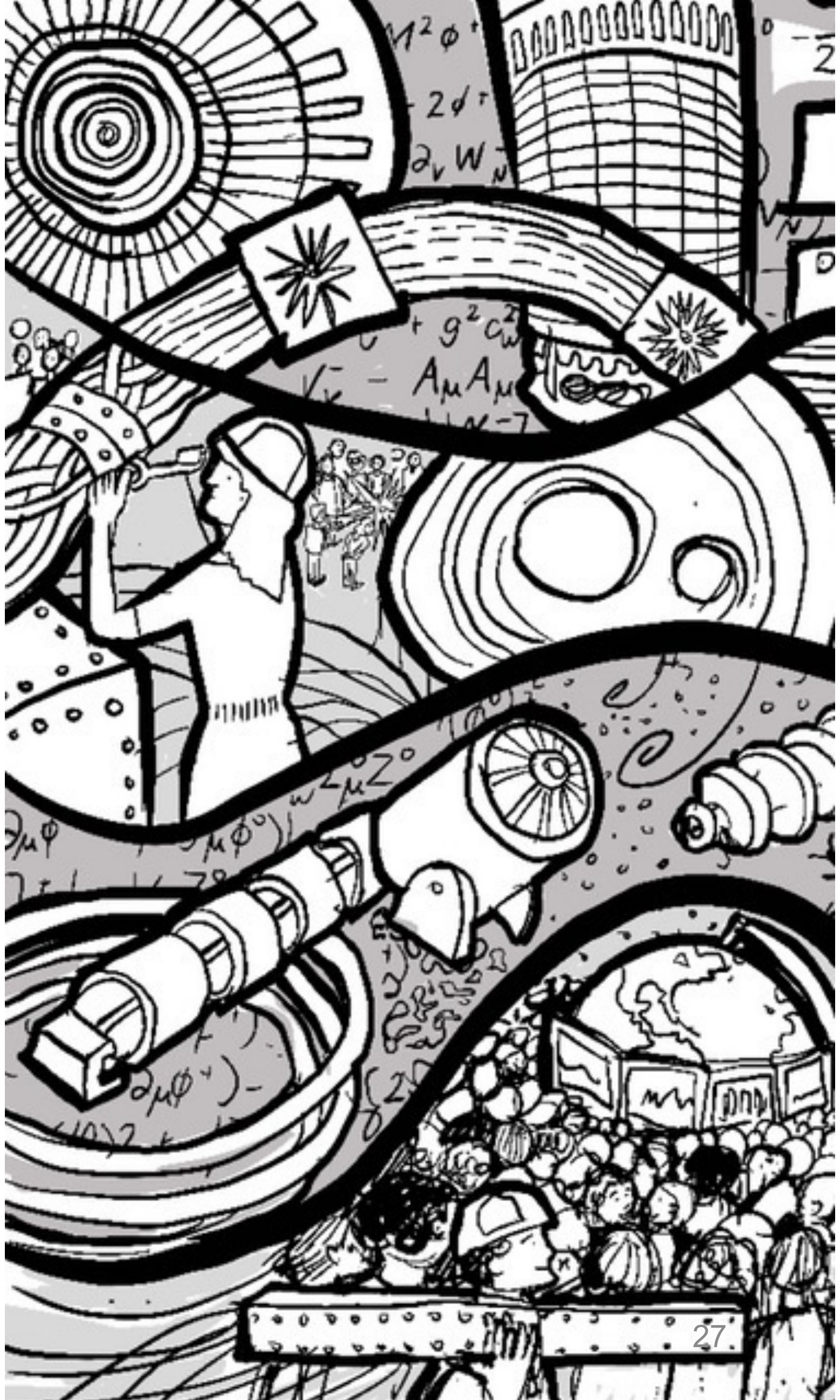
Establish a funding mechanism under which scientifically compelling, well-conceived small projects can be initiated and executed in a timely and competitive fashion.

- A dedicated funding line for small projects could be a possible component of an effective funding mechanism.



Science enabled by **Partnerships, Experiments, and Facilities**

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



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.

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
- 2010 – decision not to extend Tevatron running

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

Focus on DUNE - Findings

LBNF/DUNE is the first U.S.-hosted international particle physics mega-project. It has been launched successfully as an international project with broad international participation.

- LBNF & DUNE – Early Project phase
  - LBNF was conceived as a U.S. project with a small number of international partners, whereas
  - DUNE was conceived as a U.S.-hosted, international partnership inspired by the model of CERN experiments.
- LBNF/DUNE is the first U.S.-hosted international particle physics mega-project. It has been launched successfully as an international project with broad international participation.
- The treatment of LBNF/DUNE as a single DOE construction project (i.e., coupling the facility and experiment) made realizing DUNE as a full international partnership more challenging.
  - Note: LBNF/DUNE is now broken into subprojects.
    - Although some subprojects continue to maintain aspects of both facility and experiment.
    - This change is an improvement and eliminates some of the issues.

Learning from the DUNE experience

- DUNE benefits significantly from the critical expertise and resources of its international collaborators. Engaging international partnerships was challenge and went slowly.
  - Partners engaged in the conceptual design phase are more easily integrated and develop stronger shared ownership.
  - It takes time to build and form a strong collaboration:
    - To make technical decisions on experiment's concept and sharing of responsibilities for deliverables,
    - To accommodate significant non-U.S. deliverables and maximally benefit from the expertise of partners.
  - Engagement of the scientists, partner institutions and the funding agencies early is critical in collaboration building
- The governance of DUNE is based on bilateral agreements - whereas CERN experiments are based on multilateral agreements.
  - Collective discussion of and decision on governance structure creates a stronger sense of shared ownership and shared responsibilities among the partners.

U.S. - hosted projects/facilities – Draft recommendations

Recall the earlier recommendation:

DOE and NSF 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 hosted by the U.S.

- Recommended procedures should be consistent with Agencies' policies yet should provide the flexibility needed by the funding agencies of international partners.

Engage international partners early in the conceptual development of U.S.-hosted experiments and facilities in order to:

- **Make the project attractive to potential partners;**
- **Achieve a strong sense of shared ownership; and**
- **Maximally benefit from the expertise of partners**

Recall the earlier recommendation:

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

Cosmic surveys

Findings:

- To date, U.S.-hosted cosmic surveys have been strong U.S. interagency projects.
  - DOE-HEP and NSF (mostly NSF-AST)
  - International partnership on projects (e.g., Rubin) has been relatively small.
  - International science collaboration (e.g., Rubin's Dark Energy Science Collaboration - DESC) is considerable.
  - There are international contributions for operations (e.g. Rubin) and for software (via the Rubin Science Collaborations e.g. DESC). Data rights require special consideration for cosmic surveys.
  - Note: the DOE mission-driven science model & the NSF PI-funded model differ.
  - Note: funding sources & models in other countries vary for cosmic surveys.

Comments and considerations:

- **Future cosmic survey projects should strive for greater international partnership, including shared leadership.**
- Also, convey to international partners the details of U.S. funding, and educate ourselves about the flexibility that some partners funding agencies allow.

U.S. as Host

A welcoming 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.

- Welcoming environment is critical.
  - 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.

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

Technical Areas and **Capabilities / Competition**

Invest in theory, accelerator and instrumentation development, and computing to enable the discovery science of the future

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Invest in **theory** to enable the discovery science of the future

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

- **Findings:** The U.S. high energy theory community has benefited tremendously over many decades from sustained government investment. The results have been spectacular: there is a long history of 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, fundamental, 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.

Invest in **theory** to enable the discovery science of the future

Theoretical particle physics research in the US has **three principal sources of support:** (i) DOE Office of High Energy Physics (HEP) and NSF Elementary Particle Physics; (ii) university support in the form of faculty positions, graduate student assistantships, endowed fellowships and the support of programs at university-based research centers; and (iii) private funding for targeted initiatives. Additionally, some in-kind funding comes through computational facilities and occasionally from NASA for astrophysics and cosmology. NSF supports approximately one third of the university program but does not support the national labs.

HEP funding for U.S. institutions, especially at DOE but also at NSF, **has not kept pace with inflation in the past decade**. In the case of DOE, there has been a reduction in research funding of 18% from 2012 to 2022, plus inflation. This is true both at national labs and universities but felt even more strongly at universities.

The relative disinvestment in HEP theory in the U.S. has led to a weakening of U.S. leadership in established programs and of its competitive and innovative edge in recent decades. Formal areas of theory remain largely dominated by the U.S., although these areas increasingly benefit from private funding.

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

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

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

Findings:

Stemming from particle and nuclear physics, accelerator science and technology (AS&T) has both grown as an independent field and become an indispensable instrument of many other scientific fields (e.g., materials science, biology, chemistry). AS&T also delivers enormous social and economic benefits, realized through medical, manufacturing, and other applications.

To ensure AS&T continues to flourish and enable future discoveries, strong programs in fundamental research and mission-targeted developments are critical. Robust programs will not only benefit the competitiveness of U.S. research fields that depend on AS&T, but also help to train, attract, and retain the best and brightest future workforce.

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)

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

Findings:

- The U.S. continues to be a global leader in accelerator R&D in the following topics:
    - high field magnets,
    - high-gradient RF technology both superconducting and normal conducting,
    - high-brightness beam generation and techniques,
    - advanced beam dynamics, and high energy beam cooling.
- Accelerator science & technology areas challenged by other countries are:
    - collider R&D, plasma wakefield acceleration concept.
    - accelerator component manufacturing, and supplier chain.
    - R&D infrastructure, including test facilities.
- While the overall funding of the HEP GARD program has been flat, the actual investment in R&D has declined in proportion to facility operations costs and spending on construction projects.

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

Draft Recommendations:

- **Establish a U.S. multi-institutional collaborative program on R&D for future energy frontier colliders to coordinate the participation of U.S. accelerator scientists in global design studies and technology development and demonstration to:**
  - **ensure U.S. engagement & impact on global efforts for next-generation energy frontier colliders, and**
  - **secure continuity for the expertise that will be required for future U.S.- based accelerator facilities.**
- **Increase investments in the challenge areas identified by ARDAP to further strengthen domestic suppliers for key accelerator components and systems.**
- **Increase investment to revitalize HEP Accelerator Science & Technology in order to**
  - **sustain US leadership in key areas,**
  - **develop new accelerator technologies,**
  - **construct domestic science & technology facilities,**
  - **be a leading contributor to international accelerator facilities, and**
  - **train the next generation.**

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

Method: interviews and consultations with expert practitioners in the field, both U.S. and international

Findings:

- **U.S. scientists and institutions will be partners of choice and will have great impact in future international experiments hosted abroad if they maintain state-of-the-art expertise in technology and techniques of high energy physics.**
- ECFA Detector R&D program: Europe is renewing an ambitious, collaborative, coordinated program of detector R&D.

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

Conclusions:

- **The U.S. needs to maintain an active, continuous program of instrumentation R&D, avoiding lapses between projects, and supporting both medium-term and long-term R&D, in order that U.S. scientists can strongly impact their future international collaborations, play leadership roles, and attract the best talent to their research activities.**

- **To achieve this, establishing a structure of U.S.-based multi-institutional (university and lab) research and establishing collaborations around common R&D technology projects or goals would help harness the crucial expertise that exists in U.S. universities to augment what exists at the U.S. labs and should be encouraged.**

Draft recommendation:

- **DOE and NSF should support an active, continuous program of instrumentation R&D and facilitate the establishment of R&D collaborations.**

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

The US is recognized globally as a leader in software and computing for HEP.

Findings:

- Software and Computing (S&C) are essential to all HEP experiments and many theoretical studies, e.g. Lattice QCD
- The size and complexity of S&C are now commensurate with that of experimental instruments, playing a critical role in experimental design, data acquisition/instrumental control, reconstruction, and analysis. S&C often plays a leading role in driving the precision of theoretical calculations and simulations.
- Over the last decade, every experimental result and many theoretical insights were possible due to advances in S&C.
- A number of successful cross-cutting S&C research centers and institutes have emerged to enhance HEP science. Such multi-institutional collaborations have the potential to leverage both the multi-disciplinary strengths of the universities and the HEP-specific depth of expertise at the laboratories
- Significant progress has been made adapting HEP software applications for effective use of hardware accelerators, and in preparation for future exascale computing resources; programs in this area include the DOE Exascale Computing Project (ECP), Scientific Discovery through Advanced Computing (SciDAC), the Center for Computational Excellence (CCE), Computational HEP more generally, and the NSF Institute for Research and Innovation in Software for HEP (IRIS-HEP).

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

Findings:

- The deep learning revolution that started in the last decade is having wide impact on all aspects of HEP.

- The U.S. has outsized impact on software and computing (S&C) for LHC experiments. S&C were an enabling technology from the beginning of the data-intensive LHC experiments, continue to be crucial as LHC luminosity has increased, and will become even more critical in the HL-LHC era. The experience gained benefits developments of S&C for U.S.-hosted neutrino and cosmic frontier experiments, and other sciences as they become increasingly data intense. U.S. investment in S&C has produced high yields.

- The external computing landscape has changed dramatically since early 2000s: (I) the availability of resources and alternatives to dedicated-purpose bought computing systems; and (ii) the advent of GPUs and FPGAs. Amazon and Google cloud facilities both dwarf by orders of magnitude the combined resources of the WLCG.

- In the future, HEP will be an exascale science with exabytes of data collected, processed, and analyzed annually by each large collaboration. To process the data, a continuum of dedicated, rented, and contributed computing centers connected to each other and to massive data distribution facilities will be needed. The system will be built on a foundation of high-performance networks. Dedicated analysis facilities are in development to solve the I/O challenges of condensing petabytes of data into manageable analysis samples in close to real-time.

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

Conclusion:

HEP in the U.S. should aspire to maintain its leadership role in integrating external and dedicated resources for data intensive science for HEP and beyond. This involves continuing to develop expertise in data distribution and access at massive scale; networking to move tens of petabytes per day; the efficient use of heterogeneous architectures; and cyber security, authorization, and cost modeling.

Draft Recommendation:

U.S. HEP should capitalize on its deep experience as leaders in scientific software and computing development, as well as on emerging HPC and cloud systems of unprecedented scale. It should also leverage our potential to create national scale collaborations for software and computing, spanning experiments, DOE laboratories and universities, and including computer/data science expertise beyond HEP.

This combination will be a fertile base to create a complete ecosystem of high-performance distributed computing for HEP and for data intensive science more generally.

Technical Areas and Capabilities / Competition

Invest and innovate in AI/ML, quantum information science, and microelectronics

Invest and innovate in **AI/ML**

Findings:

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

- AI/ML is considered a high-priority area of research and innovation worldwide, but funding, culture, and activities vary widely by country.
- In the West, U.S. HEP is first in investment in AI/ML followed by Europe. China does not disclose its funding. However other metrics such as number of publications and citations place China first and the U.S. second.
- 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, A3D3 and IRIS-HEP institutes, as well as through smaller projects and base grants.

Invest and innovate in **AI/ML**

AI/ML, and more broadly data science, is disrupting the HEP workforce by providing alternative employment options. Once the AI/ML skillset is acquired, new opportunities open in academia and in industry. In this way AI/ML in HEP is an effective training ground for future AI/ML professionals and a positive contribution by AI/ML HEP to society. However, this success inevitably makes it difficult to retain AI/ML HEP trained scientists for HEP.

Additionally, it is difficult to recruit and retain international students and early-career scientists in AI/ML due to U.S. visa limitations and related bureaucracy, which seem to be worsening.

Conclusion:

The U.S. particle physics community benefits from strong SC-wide targeted funding and NSF Institute-class funding for AI/ML which has been crucial to its world-leading position in the application of AI/ML to particle physics and has enabled discovery. This funding level should be enhanced and maintained beyond the targeted funding period in order to retain leadership in this very competitive field.

Draft Recommendation:

To retain US leadership in this crucial field, enhance funding for AI/ML which is an important driver of the discovery science of particle physics.

Invest and innovate in **Quantum Sensing**

Ideas and methods of quantum information science (QIS) are finding wide application in particle physics. These QIS areas include quantum sensing, quantum computing and simulation, and application of ideas in quantum information to aspects of quantum field theories and gravity.

Findings:

- It is a widely held perception in the international community that the U.S. leads the world in **quantum sensing for particle physics and fundamental physics more generally**.
- 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 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.
- The component of NQIA QIS funding that supports US HEP is larger than QIS funding for HEP 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.

Invest and innovate in **Quantum Sensing**

Draft Recommendation:

Establish a funding mechanism for a suite of small- and mid-scale experiments that can advance the scientific goals of the US HEP program to capitalize on the recent investments made in quantum sensing. Funding should be timely and in line with the rapidly progressing landscape of the field to retain and advance U.S. leadership of quantum sensing for particle physics.

The benefits for HEP and QIS are expected to be mutual. Quantum sensing for HEP is a demanding set of applications at the limits of the sensitivity of quantum sensors. To increase the sensitivity of the experiments HEP stimulates further innovation in quantum sensing by the QIS community with corresponding benefits to the QIS community as they apply this innovation to other applications.

Invest and innovate in **Microelectronics**

Findings:

ASICs are ubiquitous both in society and in our field; ASICs are a key part of almost every detector technology. Today, the challenges are the ability to develop ASICs to handle the extreme environments of high radiation, high data rates, low temperatures and outer space. This work is closely connected to instrumentation needs in BES, NASA and for stockpile stewardship. Foundry access is crucial, the cost is high, and few foundries will engage. The work is exceptionally specialized and depends on a stable long term HEP workforce.

This ASIC challenge is faced by the U.S. and the international community.

The U.S. had outsized impact and contributions in front-end electronics of LHC experiments across many detector systems.

Unfortunately, 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.

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

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

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.

Invest and innovate in **Microelectronics**

Draft Recommendations

DOE HEP and NSF Physics should regenerate, and maintain at a leadership level, expertise in microelectronics for particle physics instrumentation. This 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 Office of Science and NSF programs.

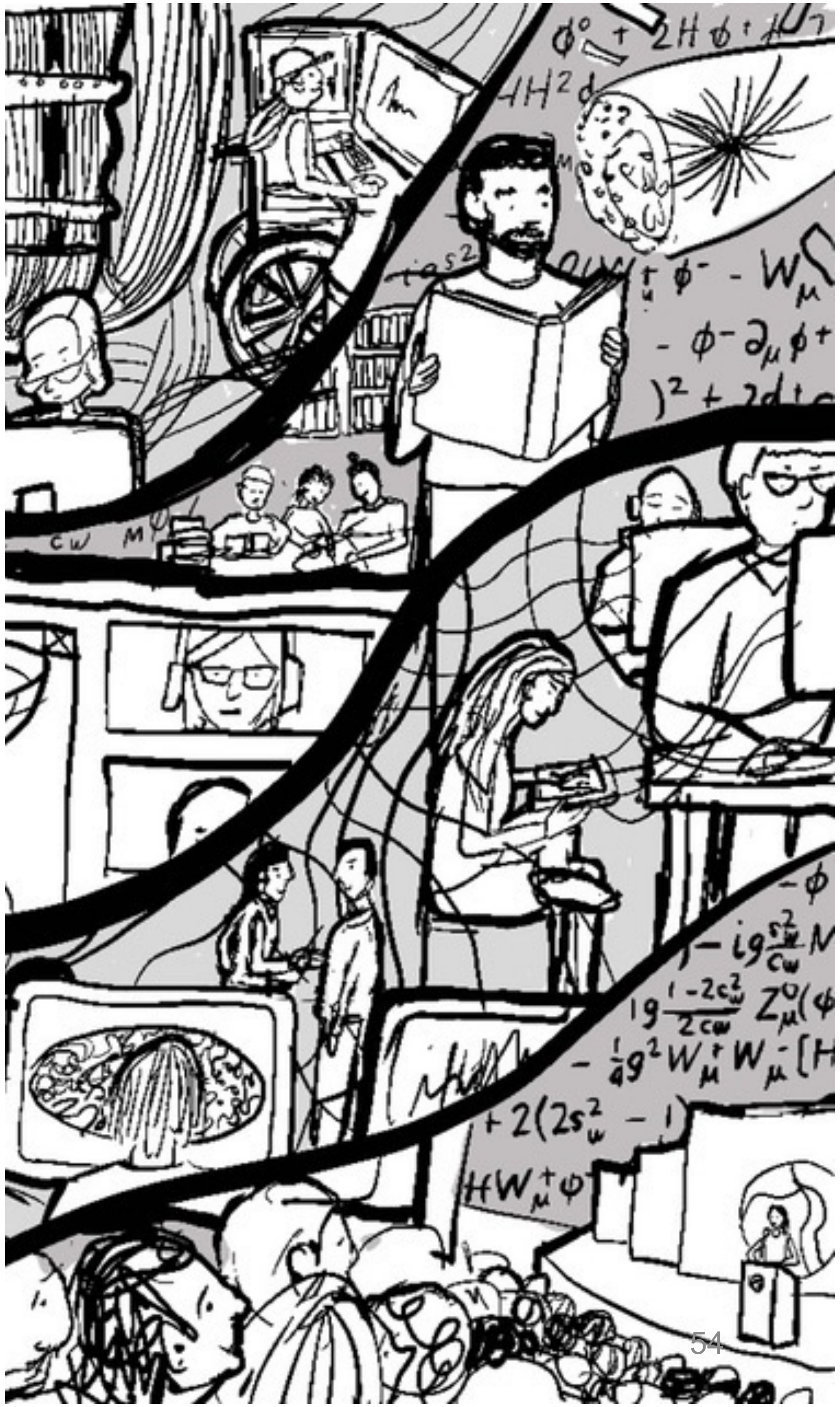
Establish a program providing cost-effective access to design licenses and tools and to foundries for national laboratories and universities. Consider a program that extends across the Office of Science.

Enable a national organization that promotes cross-coordination among U.S. laboratories and universities and that pools resources toward common development.

Encourage an environment in support of workforce training to maintain an effective workforce.

Workforce

Inspire, recruit, train, and retain a talented and diverse workforce



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Workforce – Big Picture:
Attracting and Retaining a Talented, Highly Trained, and Diverse U.S. HEP Workforce

- The U.S. must develop and maintain world-leading capabilities in key technologies of HEP, especially particle accelerators, instrumentation, and large-scale computing.

- There is a need to significantly increase the numbers of talented, highly trained researchers in those areas.

- To do so, it is imperative for the HEP community to **provide compelling, inclusive, and equitable opportunities** for all those who want to explore the secrets of the universe at their most fundamental level.

- The U.S. HEP community has always benefited from having a flow of people from diverse backgrounds, owing mainly to those from the international community.

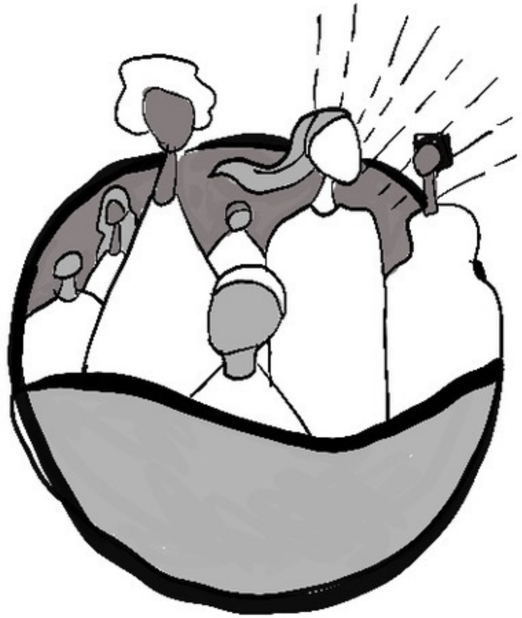
  - However, recent restrictions placed on scientists and engineers from overseas are concerning, especially those placed on people from 'sensitive' countries.

  - Many researchers, especially students and postdocs, have to make a difficult choice of not being able to see their families for years or go home and not be able to return to the U.S. Those stuck abroad often must endure months without pay, as they cannot be paid overseas.

Methodology: HEP Workforce Data

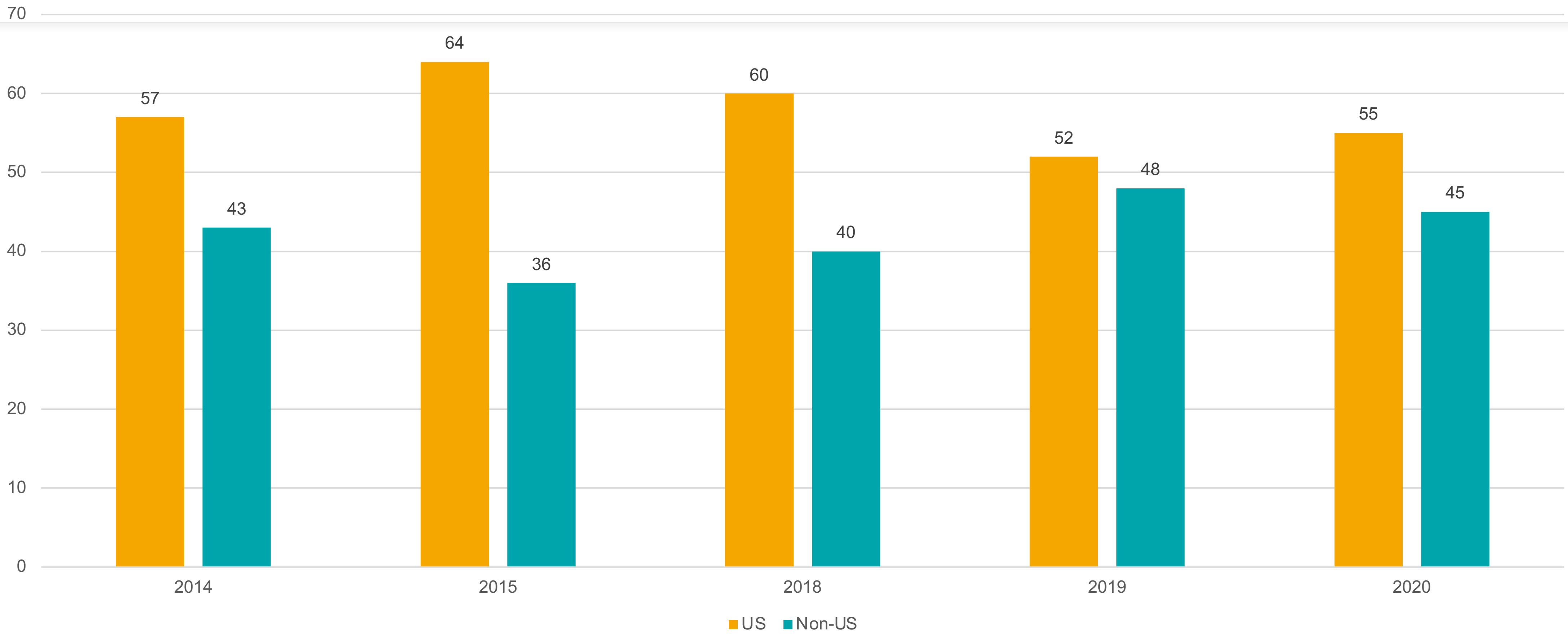
A large quantity of data was collected from AIP, NSF, U.S. national laboratories, international research collaborations, and foreign organizations. The categories of the data included the following:

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



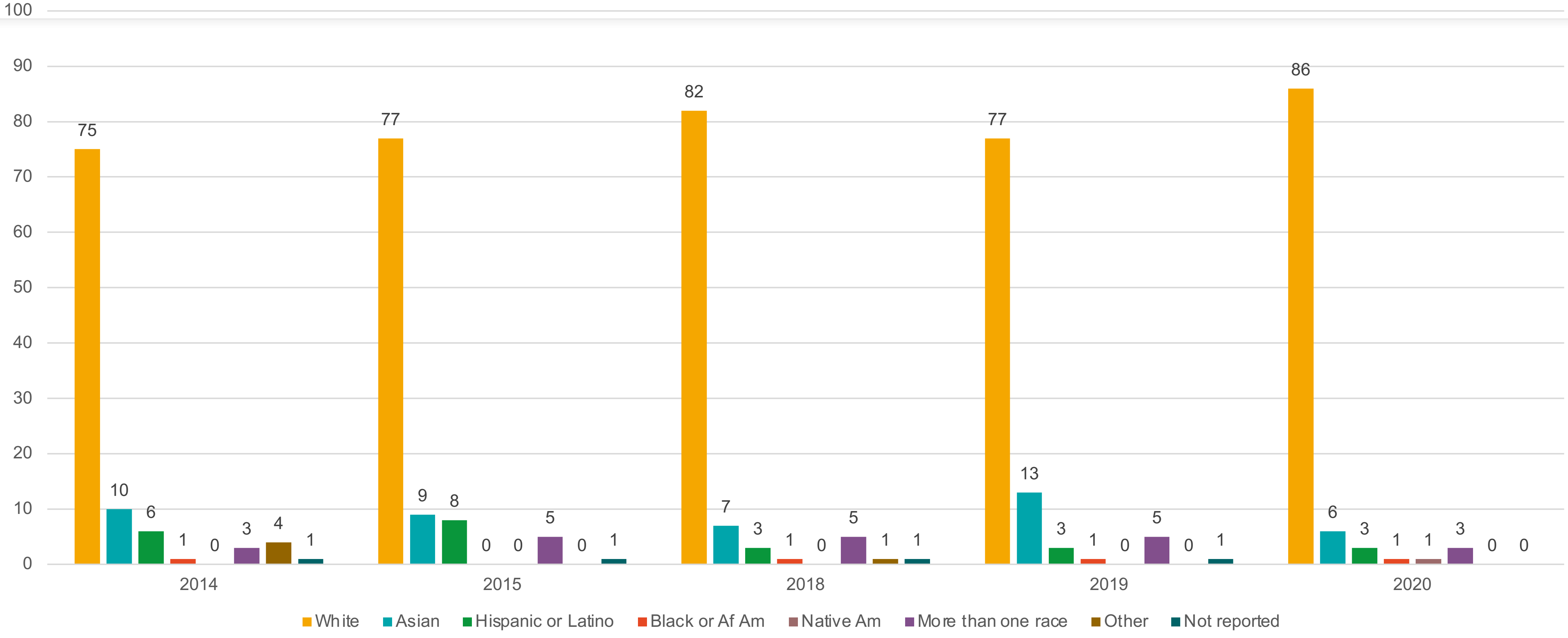
NSF HEP Citizenship Data (%)

Total #'s of Ph.D.s Received by both U.S. and Non-U.S.: 2014 (243), 2015 (243), 2018 (230), 2019 (228), 2020 (196)



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)

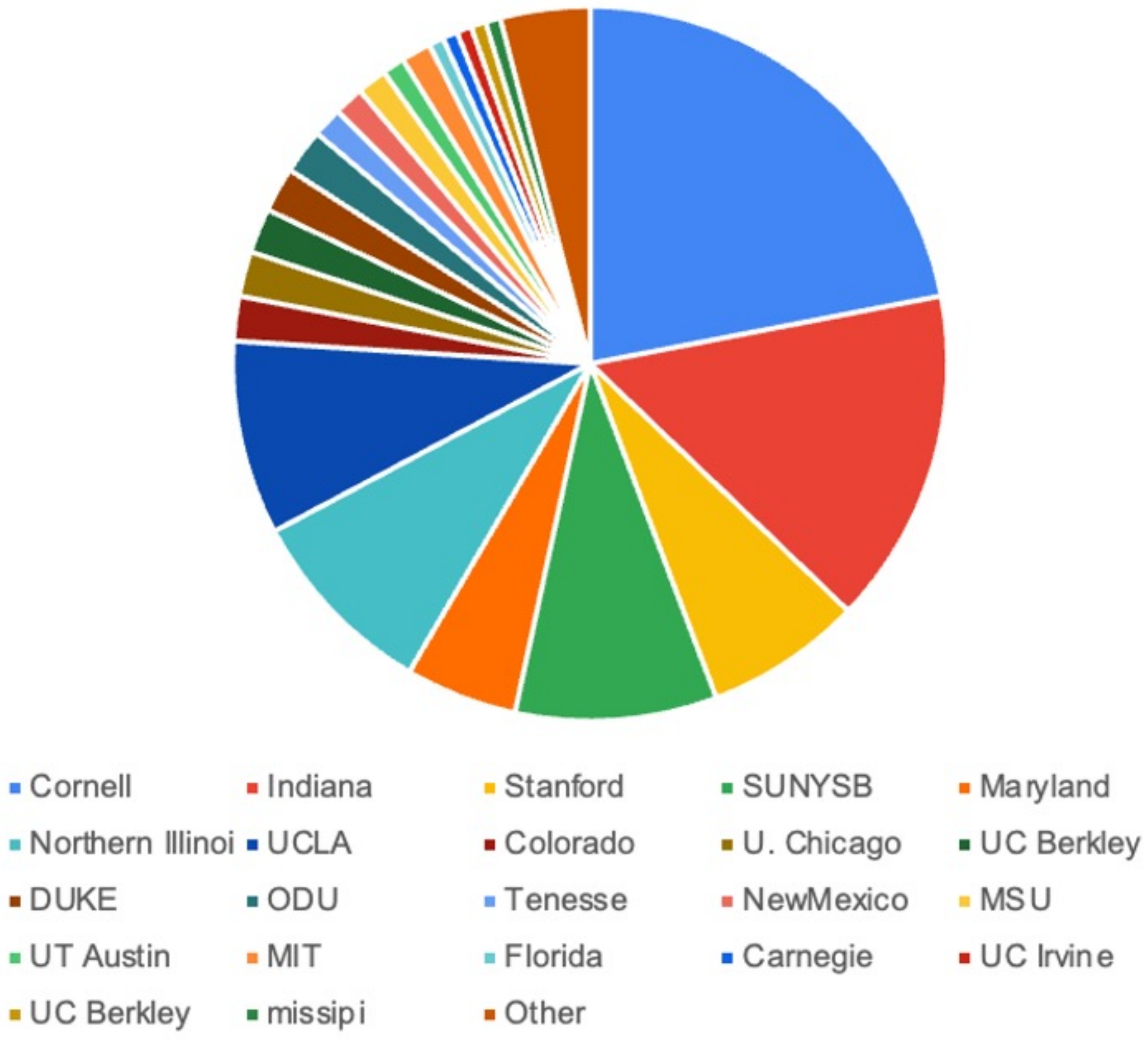


More data/plots in backup slides

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.



Workforce - Conclusions

- **The US. has made little progress in increasing the gender and ethnic diversity of its HEP community, which is reflected in the workforce data.**
- **The U.S. has been extremely effective in the training and attracting of foreign-born/foreign nationals in HEP to staff its major research facilities.**
- **More should be done to provide compelling, inclusive, and equitable opportunities for U.S. citizens who desire to study and participate in particle physics and related fields.**
- **There are many impediments faced by the U.S.'s international collaborators who come to the U.S. to conduct their research including visa issues, access to laboratories and issues related to research security. This hampers the whole research enterprise.**
- **The U.S. needs to further enhance education in accelerator science and technology.**

HEP Workforce

- 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 colliders – 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.

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

Workforce - Draft Recommendations

- The US should not wait until DUNE is commissioned to embark upon its next major HEP program and related facilities. A large, next-generation, U.S.-based HEP facility would attract a whole new generation of HEP scholars, while boosting faculty research and academic funding.
- Conduct a comprehensive study to identify areas with a shortage of experts in the U.S. HEP workforce, such as accelerators, instrumentation and large-scale computing, and shore up those deficiencies by encouraging more students to pursue those areas of study. Moreover, <u>DOE should increase the number of university faculty bridge positions that it funds at the 50% level.</u>
- 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.
- Significantly increase the numbers of both undergraduate and graduate internships and other longer-term opportunities in HEP at the national labs and universities. Ensure that participation in one program does not preclude participation in another.

Workforce - Draft Recommendations (cont'd)

- **Place a high priority on best practices for ensuring the cultural competency of managers at the national laboratories in order to hire, promote, and retain a diversity of researchers in the HEP workforce.**
- **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 visa issues, access to laboratories and issues related to research security.**
- **To lessen the barriers to advancing careers of scientific and technical personnel in HEP, 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.**

Conclusions

The U.S. is and should remain a leader in particle physics, a highly collaborative and competitive field addressing the most fundamental questions in the universe

Investment in key capabilities will enable the discovery science in the future.

Particle physics aims to inspire and train the next generation workforce.

The HEPAP International Benchmarking Subpanel is wrapping up its deliberations.

- **The recommendations have been discussed with the committee and are nearly final.**
- **Draft Report in August 2023**
- **Final report to be submitted to HEPAP in Fall 2023**

Key findings and recommendations (draft)

1. **Scientific breadth and application:** Particle physics experimental discoveries and accompanying theory address the deepest mysteries of the universe while at the same time advancing ideas and accompanying technology that are vital to other research fields and society at large. ***Strengthen investments to realize particle physics benefits across scientific fields and by society.***
2. **Importance of collaboration:** Understanding the smallest scales in nature often requires the largest experimental efforts. Success in particle physics requires, for many efforts, but in particular for these massive undertakings, international collaboration and cooperation. The combined expertise and resources from nations around the world enable discoveries and technological advances difficult to achieve by any single nation. ***Continue support for and actively seek engagement in international collaborations of all sizes.***
3. **How to be a partner of choice:** Success in international collaborations requires reliable partnerships, early engagement, and joint ownership. ***Act with timeliness, meet obligations, and engage in open communication to remain an international partner of choice.***
4. **Importance of critical capabilities and technologies:** U.S. leadership in global collaborations requires capitalizing on the U.S.'s unique capabilities including accelerator and detector technologies. ***Advance critical technologies to maintain and grow U.S. leadership in particle physics at home and abroad.***
5. **Critical U.S. national initiatives:** U.S. leadership and investment in national initiatives in Quantum Science, AI/ ML, and Microelectronics are critical to particle physics and U.S. Security and prosperity. ***Remain a leader in Quantum Information Science, AI/ ML, and Microelectronics, and pursue strategic partnerships where relevant.***
6. **Importance of a robust workforce:** A robust particle physics workforce will both leverage and be representative of the diversity of the nation. Attracting, inspiring, training, and retaining a diverse workforce is vital to the success of particle physics and more broadly to U.S. Science and Technology. ***Explore frontier science using cutting-edge technologies to inspire the public and next generation of scientists. Open pathways for an expanded workforce to realize the potential of the field.***

Summary of Draft Recommendations (not a complete list)

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

Advance critical technologies to maintain and grow U.S. leadership in particle physics at home and abroad. Remain a leader in critical areas in Quantum Information Science, AI/ ML, and Microelectronics, and pursue strategic partnerships where relevant.

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

DOE and NSF should support involvement of U.S. scientists and institutions in the early conceptual development and R&D for future international experiments and accelerator projects.

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.

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.

Future cosmic survey projects should strive for greater international partnership, including shared leadership.

Summary of Draft Recommendations (not a complete list)

Invest in a strong and innovative theory program.

Establish a U.S. multi-institutional collaborative program on R&D for future energy frontier colliders to coordinate the participation of U.S. accelerator scientists in global design studies and technology development and demonstration to:

- ***ensure U.S. engagement and impact on global efforts for next-generation energy frontier colliders, and***
- ***secure continuity for the expertise that will be required for future U.S.- based facilities***

Increase investments in the challenge areas identified by ARDAP to further strengthen domestic suppliers for key accelerator components and systems.

Increase investment to revitalize HEP AS&T in order to:

- ***sustain US leadership in key areas,***
- ***develop new accelerator technologies,***
- ***construct domestic S&T facilities,***
- ***be a leading contributor to international accelerator facilities, and***
- ***train the next generation.***

DOE and NSF should support an active, continuous program of instrumentation R&D and facilitate the establishment of R&D collaborations.

Summary of Draft Recommendations (not a complete list)

U.S. HEP should capitalize on its deep experience as leaders in scientific software and computing development, as well as on emerging HPC and cloud systems of unprecedented scale. It should also leverage our potential to create national scale collaborations for software and computing, spanning experiments, DOE laboratories and universities, and including computer/data science expertise beyond HEP.

To retain US leadership in this crucial field, enhance funding for AI/ML which is an important driver of the discovery science of particle physics.

Establish a funding mechanism for a suite of small- and mid-scale experiments that can advance the scientific goals of the US HEP program to capitalize on the recent investments made in quantum sensing. Funding should be timely and in line with the rapidly progressing landscape of the field to retain and advance U.S. leadership of quantum sensing for particle physics.

Summary of Draft Recommendations (not a complete list)

DOE HEP and NSF Physics should regenerate, and maintain at a leadership level, expertise in microelectronics for particle physics instrumentation. This 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 Office of Science and NSF programs.

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 Office of Science.

Enable a national organization that promotes cross-coordination among U.S. laboratories and universities and that pools resources toward common development.

Encourage an environment in support of workforce training to maintain an effective workforce.

The US should not wait until DUNE is commissioned to embark upon its next major HEP program and related facilities. A large next-generation US-based HEP facility would attract a whole new generation of HEP scholars, while boosting faculty research and academic funding.

EXTRA SLIDES

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).

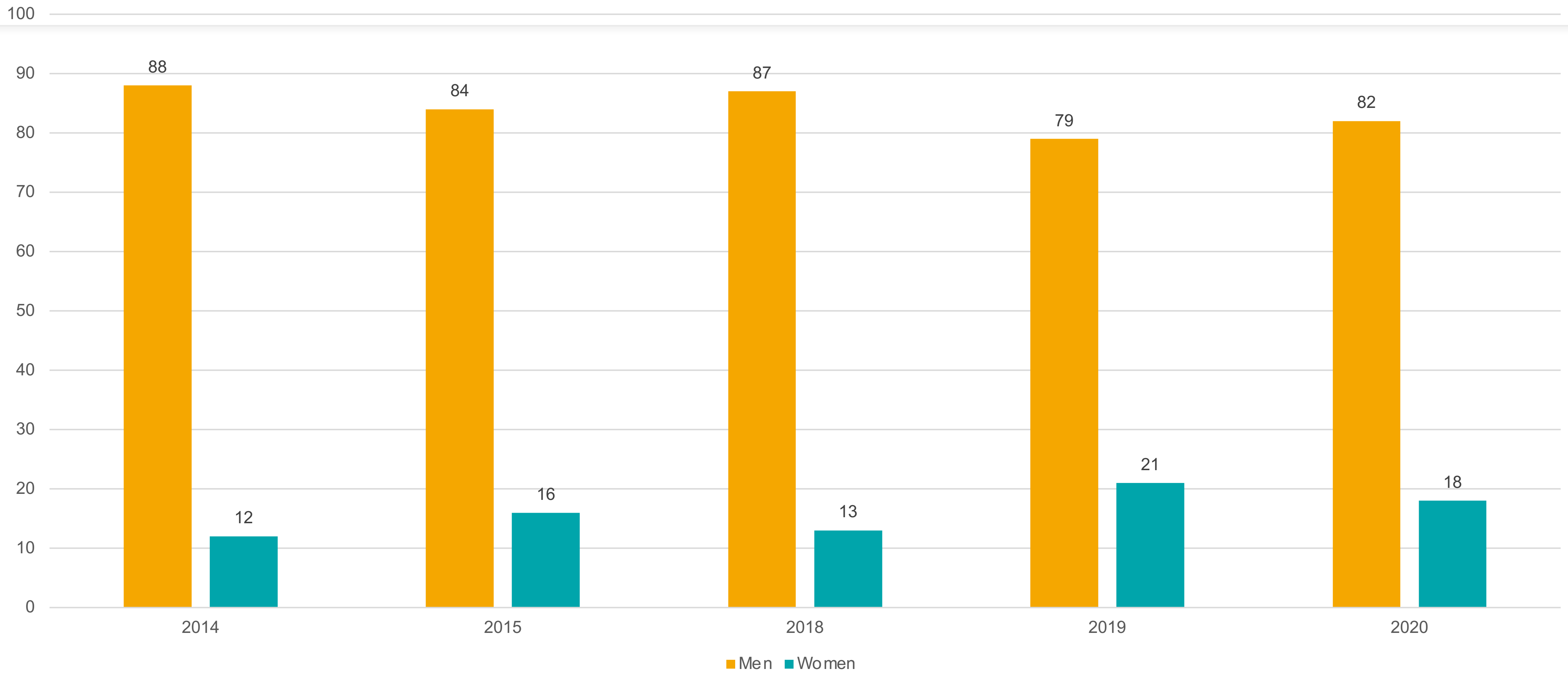
- Did you perceive obstacles that constrained the degree or quality of international participation, either generally or in nation-specific ways?
- How is your experiment governed, and how did your governance model affect (i.e., facilitate or hinder) international participation?

List of experiments consulted:

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

NSF HEP Gender Data (%)

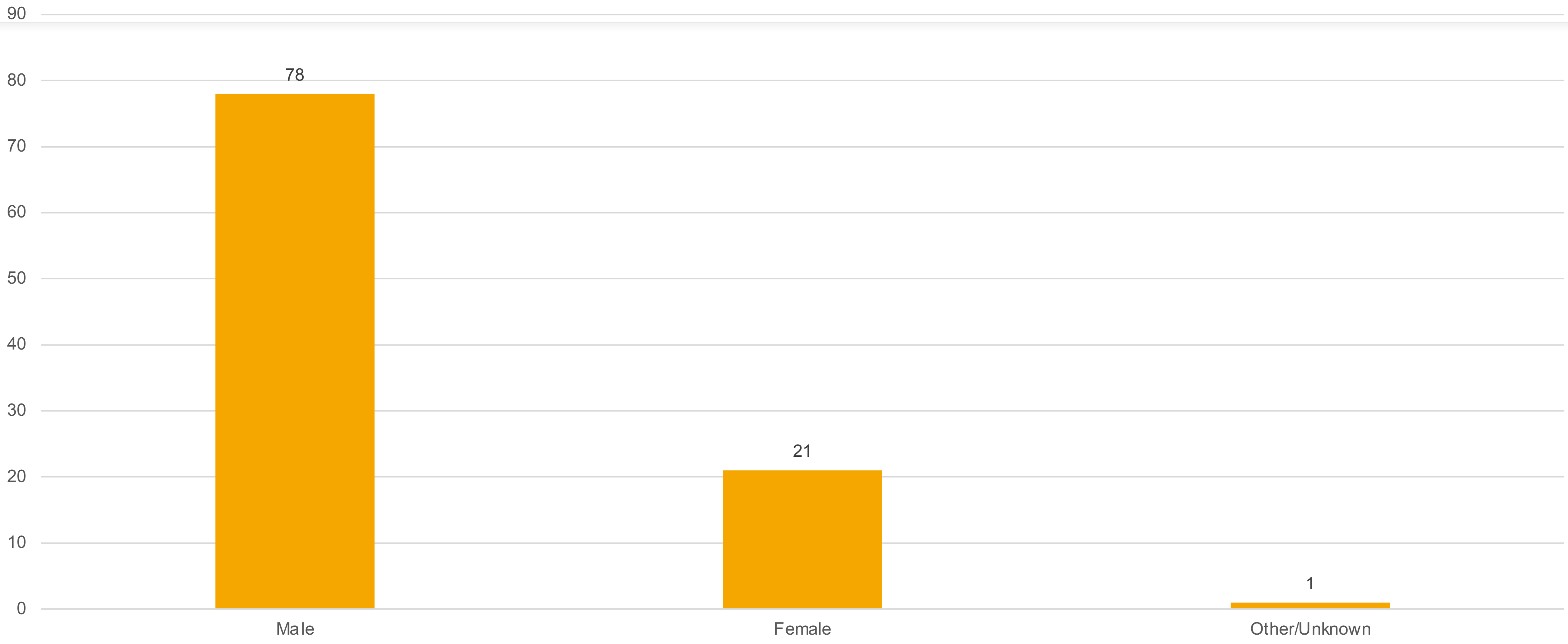
Total #'s of PhDs received by both Genders:
2014 (245), 2015 (243), 2018 (232), 2019 (234), 2020 (198)



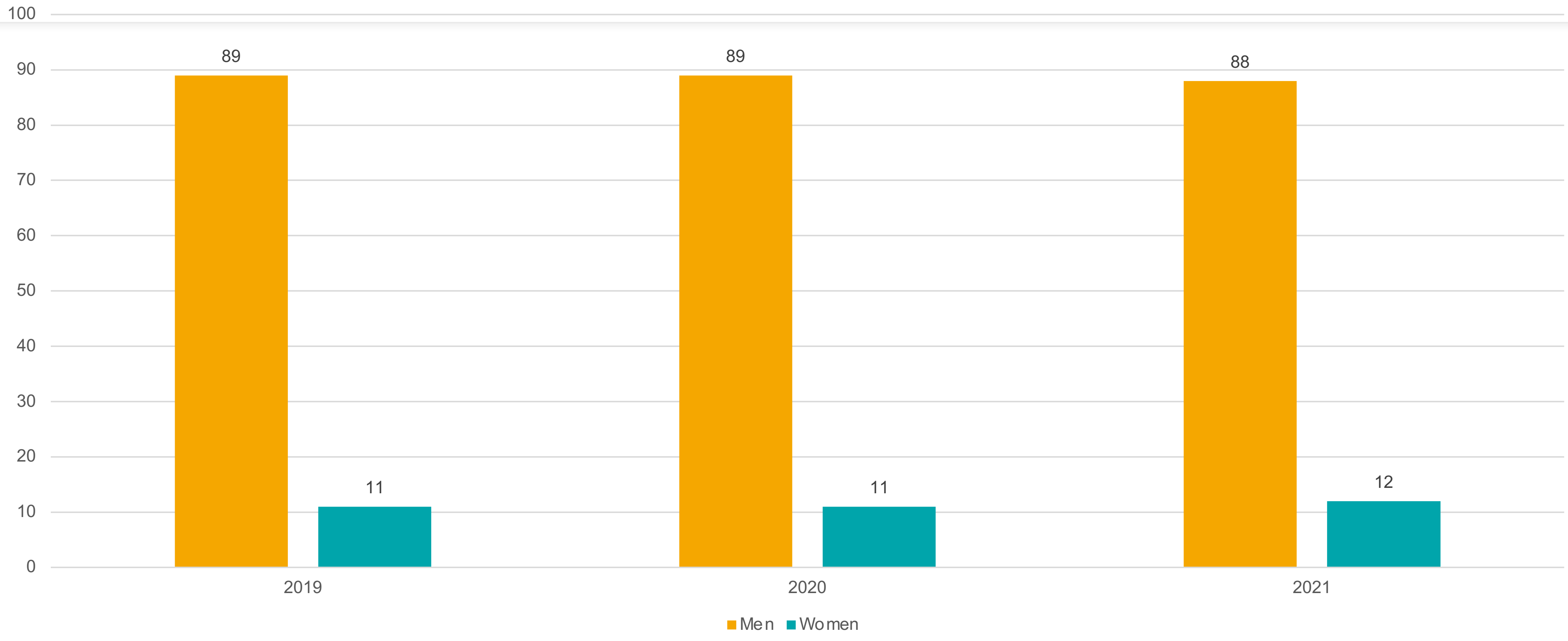
IOP HEP Special Interest Group Year 2022 (%)

Gender Membership Data by % of Total Members

Total Membership: 860



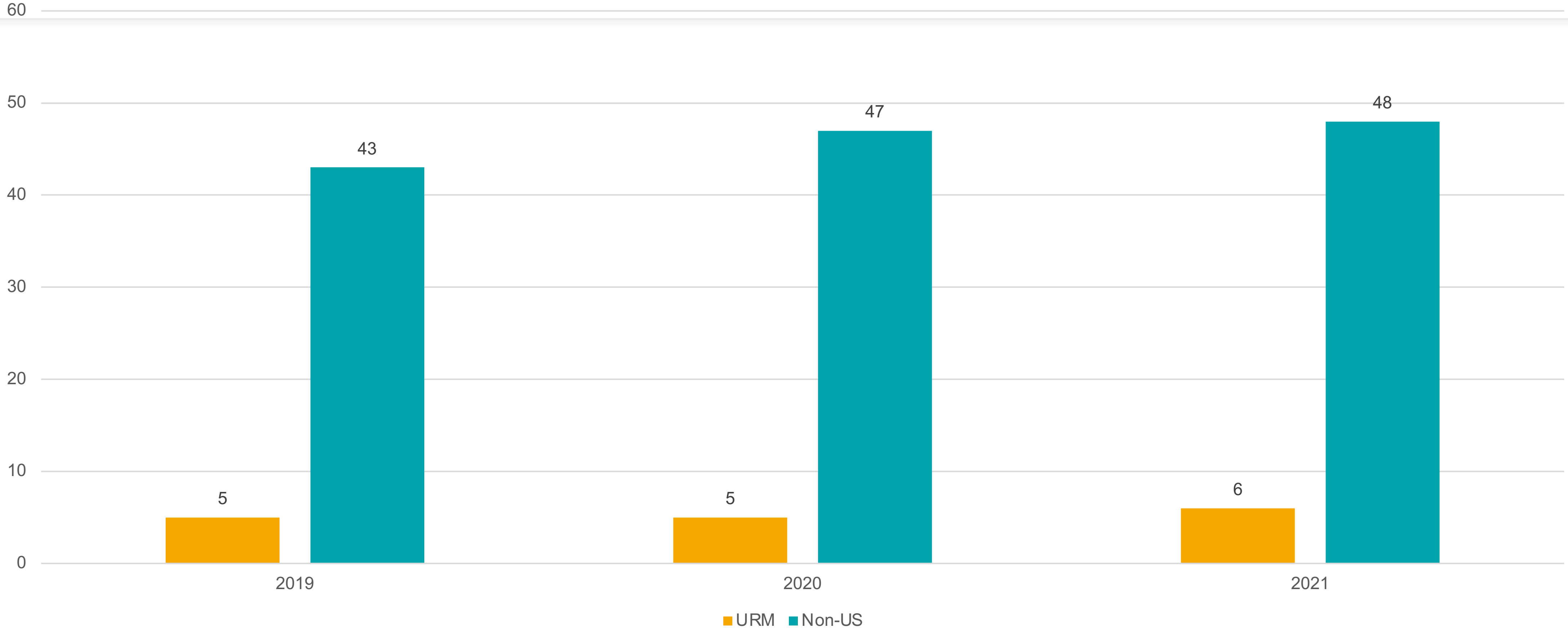
BNL HEP Gender Workforce Data (%)
Total Size of Staff: 2019 (147), 2020 (151), 2021 (159)
Staff: Scientific, Professional, Technicians, and Postdocs



BNL HEP Ethnicity and Citizenship Workforce Data (%)

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

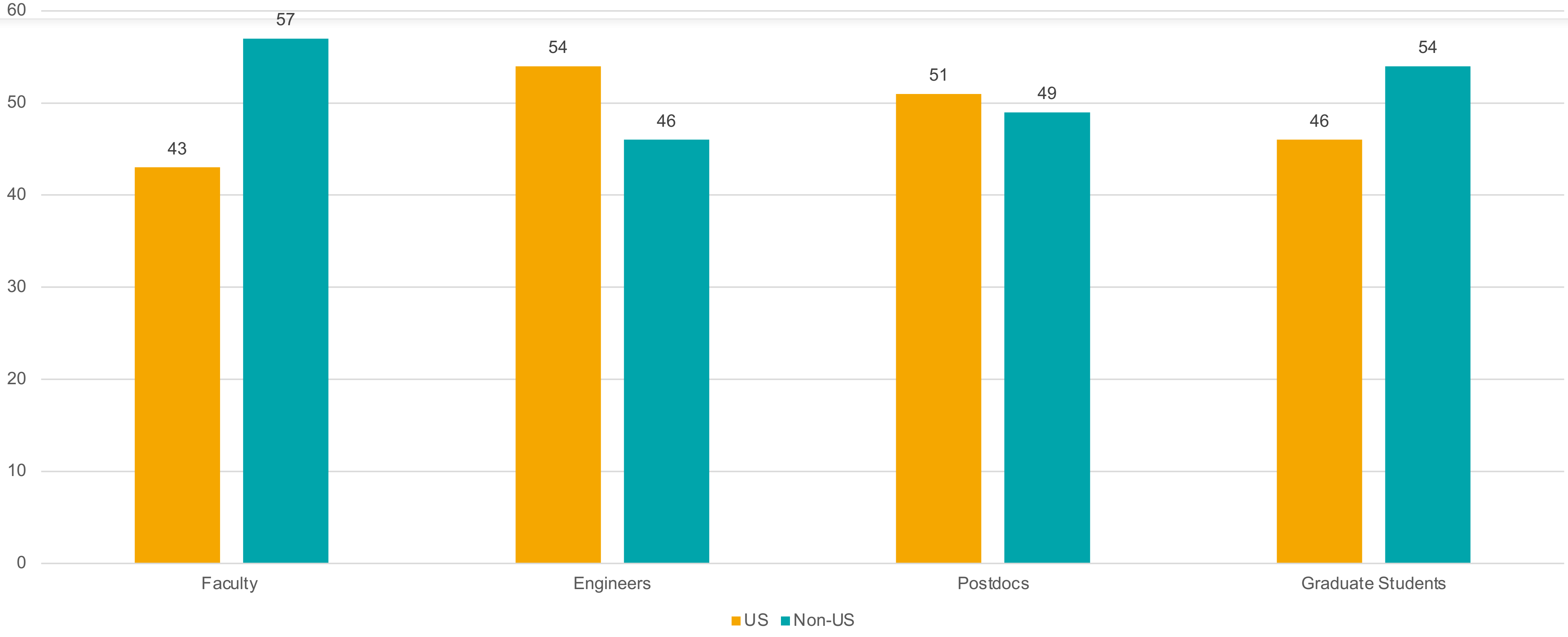
Staff: Scientific, Professional, Technicians, and Postdocs



DUNE 2022 Citizenship Workforce Data (%)

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

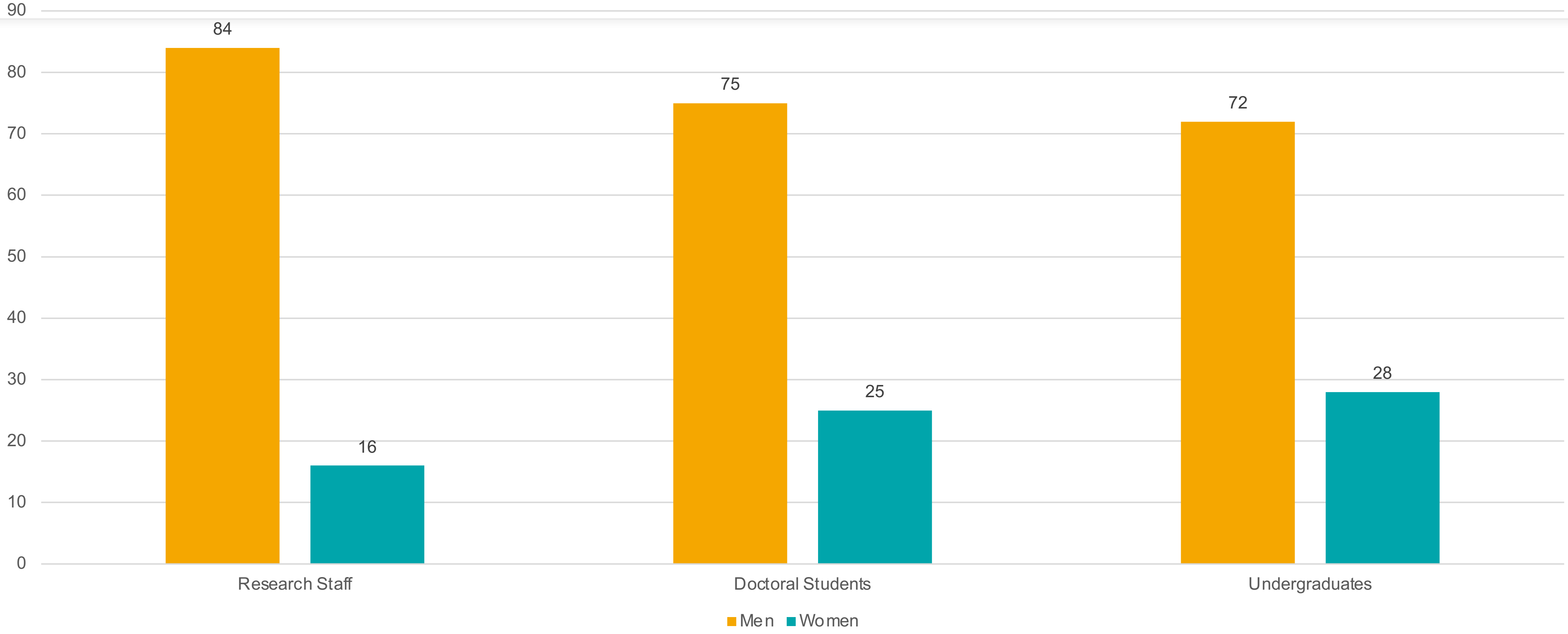
DUNE does not collect information on gender.



CMS Year 2022 Gender Workforce Data (%)

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

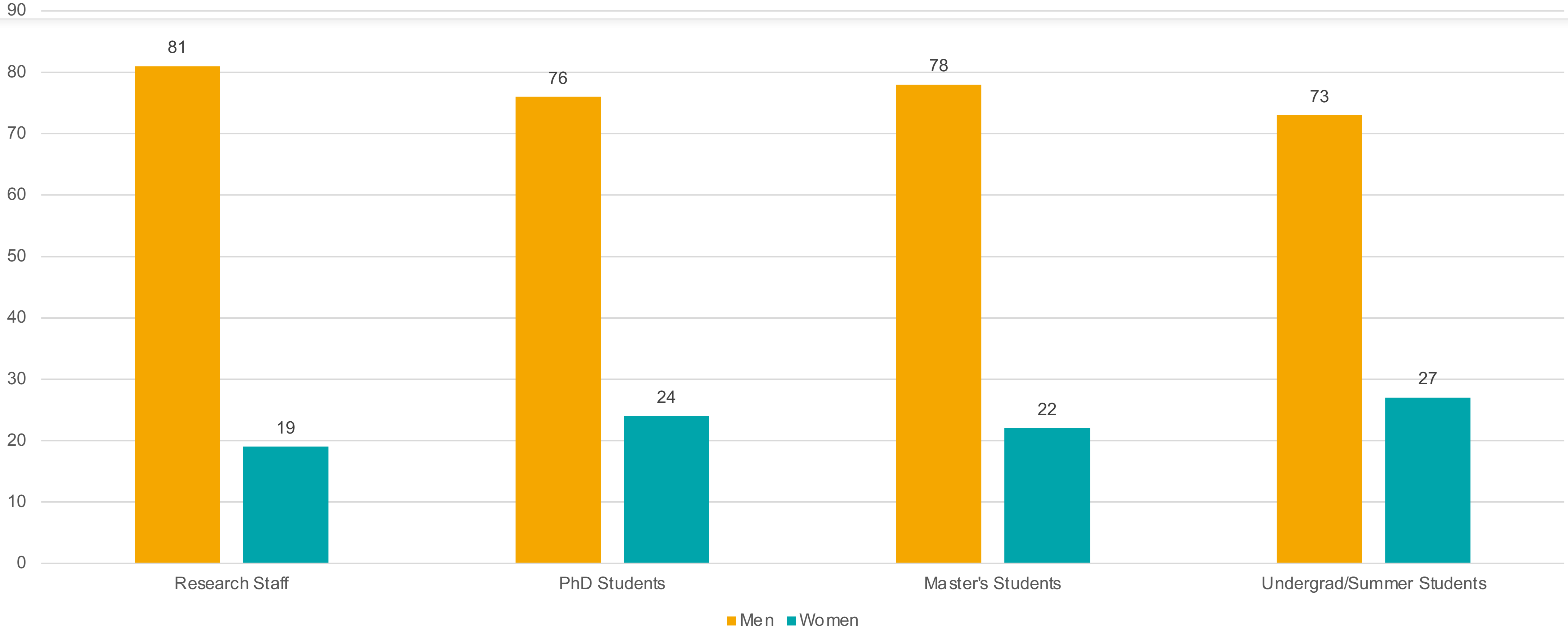
Research Staff: PhD Physicists, Engineers



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



Additional Workforce recommendation

- Detector R&D at universities is a point-of-entry for students, from both undergraduate and graduate student cadres, into particle physics and STEM more generally. The laboratory experience of detector R&D is a magnet for students. At universities at large, and especially at large public universities, laboratory experience on detector R&D can attract diverse groups of students into STEM. Nevertheless, support for detector R&D at universities, including support for technical personnel and senior scientists expending a portion of their effort on R&D, has declined substantially over the past decades.

    - Draft Recommendation: Substantially increase support for detector R&D at universities, as a means of advancing detector technology and as a means of expanding a skilled STEM workforce.