Cosmic Frontier Experimental Program

DOE/HEP report to the AAAC

December 15, 2023

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Office of High-Energy Physics

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- HEP Program Guidance, News
- Cosmic Frontier Program Update
- Budget

The Vera C. Rubin Observatory. El Peñón peak of Cerro Pachón, in the Coquimbo Region of northern Chile

U.S. DEPARTMENT OF ENERGY | Office of Science

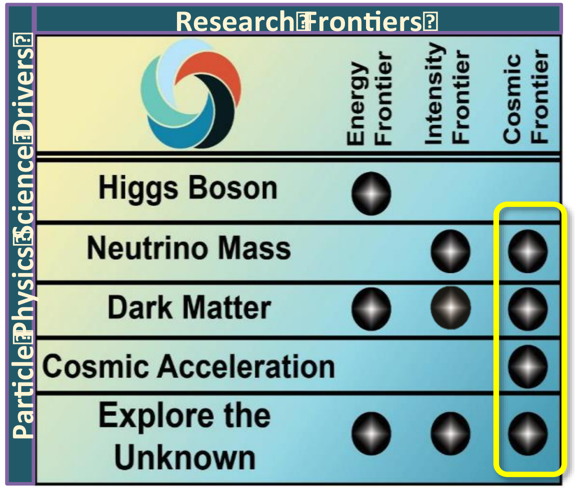
HEP Program Guidance, News

Guidance used to Develop Program

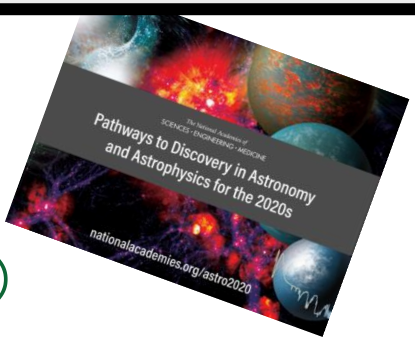
PASAG (2009) – gave criteria we use to determine HEP roles & responsibilities

Astro2010 recommended DOE/NSF partnership on LSST (Rubin)

P5 (2014) strategic plan recommended science & project priorities aligned with the P5 science drivers -- in Dark Energy, Dark Matter, CMB projects + small projects.



- **Cosmic Acceleration:**
  - **Dark Energy**: build **LSST (Rubin) & DESI**
  - **CMB**: support as part of the core program within multi-agency context; carry out multi-agency **CMB-S4** project later in the decade
- **Dark Matter:** suite of "generation 2" direct detection experiments to detect DM particles
- **Neutrino Mass** – survey experiments provide information on neutrino properties
- **Explore the Unknown** – always of interest!



Astro2020 recommended:

- **DOE/NSF partnership on CMB-S4**
- **Dark Ages** identified as Discovery Area → cosmological probe with great potential
- Efforts on diversity, equity, inclusion, demographics, data, etc. (joint with NSF & NASA)

Guidance used to Develop Program

Community Input

- Snowmass 2022 (community input and ideas), Astro2020 (Nov. 2021), + others

→HEPAP – reports to both DOE and NSF

HEPAP study reports (Note: HEPAP reports to both DOE and NSF)

- HEPAP International Benchmarking study – completed Nov. 2023
- HEPAP Particle Physics Project Prioritization Panel (P5) study – completed Dec. 2023

2 new HEPAP subpanels being set up

See Mike Procario's talk at HEPAP on 12/7/23:
https://science.osti.gov/-/media/hep/hepap/pdf/Meetings/2023/New-Charges-for-HEPAP.pdf

- Committee of Visitors (COV) for the HEP Facilities Division
- Office of Science wide Facilities Construction Project subpanel study

→National Academies study continuing:

- Elementary Particle Physics 2024 (EPP2024)

https://www.nationalacademies.org/our-work/elementary-particle-physics-progress-and-promise

HEPAP International Benchmarking study

Charge: https://science.osti.gov/-/media/hep/hepap/pdf/202203/SignedHEPAPChargeLetterIntlBenchmarkingFY2022Report03022022signedsbsj.pdf

→ Purpose was to consider the unique international context of particle physics, and how we can best position the U.S. program and its researchers for success in this evolving landscape.

How can the U.S. 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"?
- Are there barriers that can hinder our ability to form effective and enduring international partnerships?

Identify key areas where the U.S. currently has, or could aspire to, leadership roles in 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.

- 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 in to achieve these goals, possibly through collaborations within and beyond the HEP community?

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?
- 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.

HEPAP International Benchmarking study

Presentation to HEPAP (11/2/23)
https://science.osti.gov/-/media/hep/hepap/pdf/202311/HEPAPBenchmarking_Nov_2023.pdf
Report → https://science.osti.gov/-/media/hep/hepap/pdf/202203/International_Benchmarking_HEPAP_2023112.pdf

Findings and Recommendations were provided in 3 main areas, with 7 sets of findings, *recommendations*

A. 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.

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.

HEPAP International Benchmarking study

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.

HEPAP International Benchmarking study

B. 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.

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.

C. 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.

HEPAP P5 report

DOE/HEP thanks the panel for the tremendous job they did over the last year leading to this excellent report.

- **It will take a while for DOE to read the report and develop plans based on the recommendations.**

➔See Hitoshi Murayama's P5 report talk at this AAAC meeting

Charge
https://science.osti.gov/-/media/hep/hepap/pdf/202212/2022-601_Charge_Letter_P5-2022_AAB_and_SJ_Signed.pdf
- 2 funding scenarios provided by HEP

12/7/23 P5's presentation to HEPAP
https://science.osti.gov/hep/hepap/Meetings/202312

12/8/23 draft report (draft approved by HEPAP but there may be some wording updates)
https://science.osti.gov/-/media/hep/hepap/pdf/Reports/P5Report2023_120123-DRAFT-to-HEPAP.pdf

Office of Science (SC) Facilities subpanel

Follow on to previous SC-wide prioritization studies that were carried out in 2004 & 2013

Charge letter (12/1/23) → https://science.osti.gov/-/media/hep/hepap/pdf/2023-Berhe-Facilities-Charge.pdf
-- Each of the 6 SC panels will carry out a subpanel study, complete by May 2024

- **Similar criteria to the previous charges.**
  - The potential to contribute to world-leading science in the next decade.
  - The readiness for construction.
- **"In its deliberations, the subcommittee should reference relevant strategic planning documents and decadal studies."**

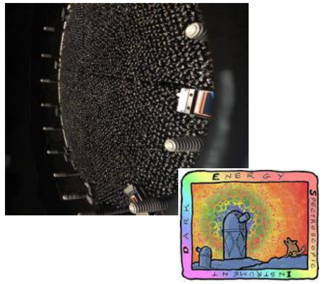
HEP is supplying a list of pre-CD3 projects over $100M to consider (though the panel may add more)

- Near term: LBNF/DUNE (has 5 subprojects), CMB-S4
- Mid term: Accelerator Complex Enhancement Main Injector Target (ACE-MI+T), Advanced Accelerator test facilities, DUNE far detector upgrade
- Far term: Future Energy Frontier collider, DUNE near detector upgrade, Stage 5 Spectroscopic Survey Instrument, Accelerator Complex Booster replacement

Cosmic Frontier

- Program Update

Cosmic Frontier:
Current Program Based on 2014 P5 recommendations is Continuing



ADMX AXION DARK MATTER EXPERIMENT

SUPER CDMS Cryogenic Dark Matter Search

LZ

Cosmic Acceleration – Phases of the Cosmos

- Nature of **Dark Energy** using imaging & spectroscopic surveys
  - Stage 3 - ***eBOSS*** *(completed 2020)*, **DES** doing final data analyses
  - **Stage 4** - **DESI** (operating)
    - **LSST** Camera (completed, now commissioning) for Rubin Observatory (ops planning; survey starts ~ mid-2025) with **DESC** (planning)
- Peer into era of **Inflation** with **SPT-3G (operating), CMB-S4 (concept design)**

Dark Matter:

- Direct Detection searches (WIMPs, Axions) using a variety of methods and technologies:
  ADMX-G2, LZ, SuperCDMS SNOLAB, Dark Matter New Initiative (DMNI) concepts
- Indirect searches: ***VERITAS, HAWC,*** **Fermi-LAT** (now ops only), **AMS** on ISS

Small Projects: Search for the **Dark Ages** signal using **LuSEE-Night** pathfinder

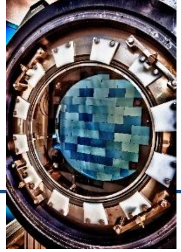
Neutrino properties constrained using dark energy & CMB measurements

Exploring the Unknown - Always interested in New Physics!

Black: HEP support ended
Green: support continues

Recommended by 2014 P5

Dark Energy Survey (DES), Dark Energy Camera (DECam)



DARK ENERGY SURVEY

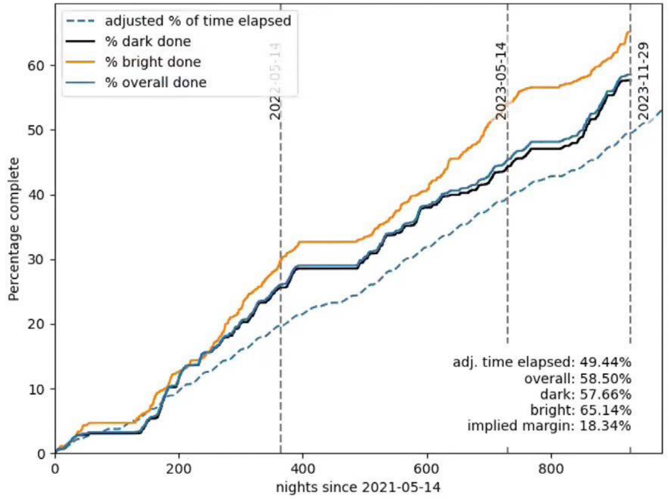
DOE and NSF partnership

- Fermilab led fabrication of 570Mpix DECam; NSF led telescope upgrades, data management system
- Both agencies supported operations on NSF's Blanco telescope at CTIO in Chile
- 6-year imaging survey of 5100 sq-deg completed Jan. 2019

- Collaboration is working on Year 6 data analyses. Data will subsequently be made public.
- FNAL will provide long term support for image-level & database-level specialty cosmology-quality data products currently being produced and/or stored in multiple domains.

Cosmic Acceleration: Dark Energy
→Dark Energy Spectroscopic Instrument (DESI)

World's first Stage IV dark energy project → Will measure spectra of > 40 million galaxies to trace the universe's history.
DESI is the world's premier multi-object spectrograph w/5,000 fibers, positioned robotically.



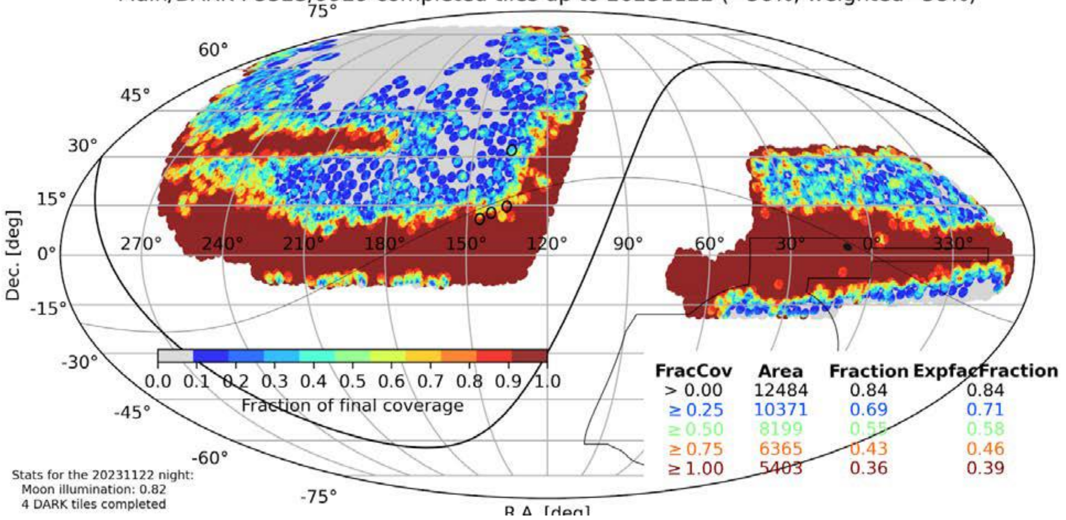
DOE/LBNL Project: Instrumentation, Data Management System, & Upgrades of NSF's Mayall telescope (including MOSAIC camera).
Operations: DOE provides full support ("leases") for the Mayall telescope at Kitt Peak.

Collaboration

- Jan. 2021 to end of Nov., the collaboration has submitted or published 74 papers.
- Collaboration will unblind the Year-1 data for the Ly-a, BGS, LRG, ELG, and quasar BAO and RSD measurements.

Maintenance & Operations:

- Limited in-person shifts have re-started now that the road to Kitt Peak is fully reopened
- A more secure network architecture has been established at DESI and the Mayall telescope. Access to critical systems from the outside is allowed now only through an "SSH Bastion" system that requires Multi-Factor Authentication



Collaboration is planning the proposed DESI-II, for extended operations for higher redshift measurements.

As of end of November, DESI is running ~ 4.5 months ahead of schedule. The dark time coverage is shown in the figure above

Vera C. Rubin Observatory

- **A next-generation, ground-based facility, providing repeated imaging of faint and time-variable astronomical objects across the entire southern sky every few nights for ten years**

NSF (AURA) & DOE (SLAC) partnership, with private, international contributions

Construction/Commissioning responsibilities

NSF – observatory, telescope, data management, EPO

DOE (SLAC) – LSST Camera fabrication completed (Sept.2021); now doing Camera commissioning as well as efforts on the 9-CCD Commissioning Camera (ComCam), data quality, verification studies, and overall project roles

Facility Operations (50/50 NSF/DOE funding) planning and ramp-up activities continue

- In-kind contributions agreements
- Data management, data facility planning in full swing
- DOE (SLAC) - primarily responsible for the US Data Facility (USDF) , Camera maintenance and operations, and has roles in overall management roles and data quality studies

Schedule:

- End March 2024 – LSST Camera ships to Chile
- Aug. 2024 – Camera ready for full system assembly, integration and test
- Jan. 2025 – System First Light
- LSST survey starts ~ 4 to 7 months after system first light

LSST Camera

Camera electro-optical (EO) and functional testing had been scheduled to re-start end of August 2023. While pumping down, a vacuum leak developed in a feedthrough flange. After assessing the details and mitigations, the leak was repaired, and testing was restarted end of October.

- EO and functional testing is going well & is planned through mid-Feb 2024

- Camera shipment from SLAC to Chile planned for end March 2024.

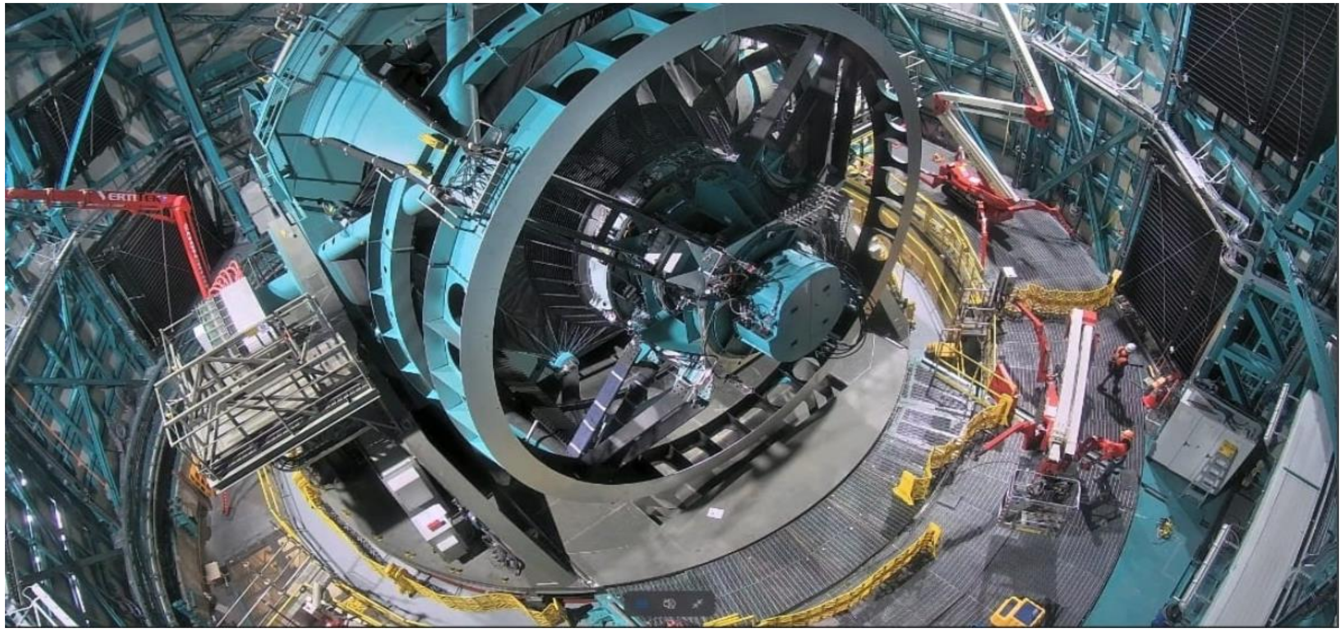
Camera showing L1 lens

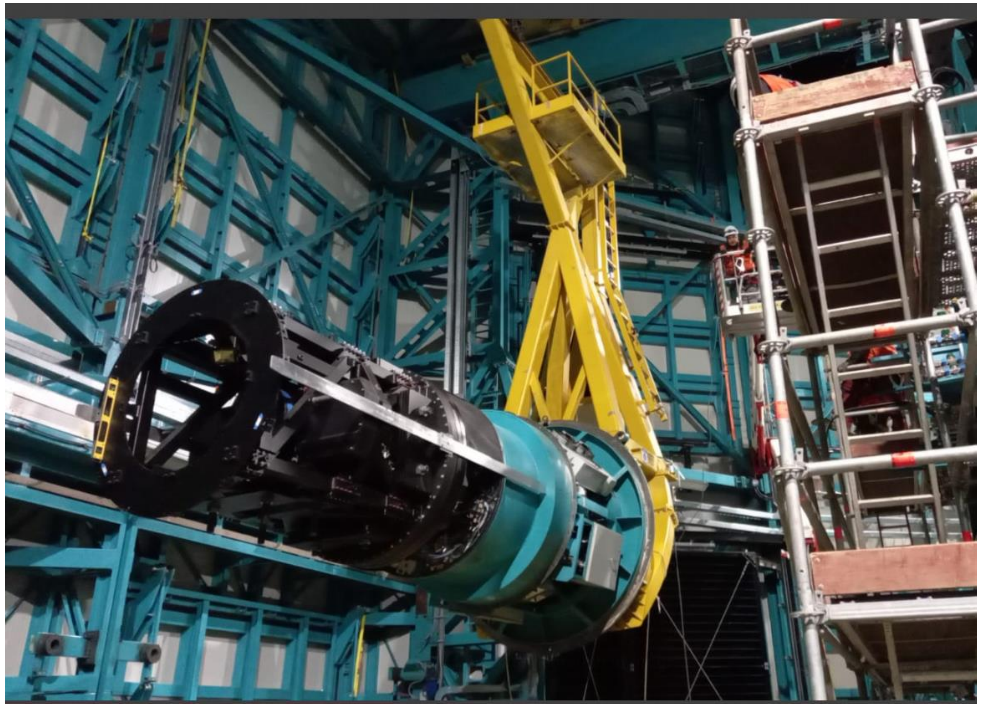
Filters

Glass Filter Installation

Rubin - ComCam

ComCam is back on the Telescope for system testing





US Data Facility at SLAC

At SLAC's S3df/SRCF → Modern datacenter: 6 MW capacity

Rubin's USDF:

- Hybrid model with hardware and initial services at SLAC.
- Rubin has a multi-site processing model → SLAC plus annual catalog processing also in the UK and France; transfers of test data demonstrated
- Rubin Science Platform (user access) is in the Google Cloud

Current efforts:

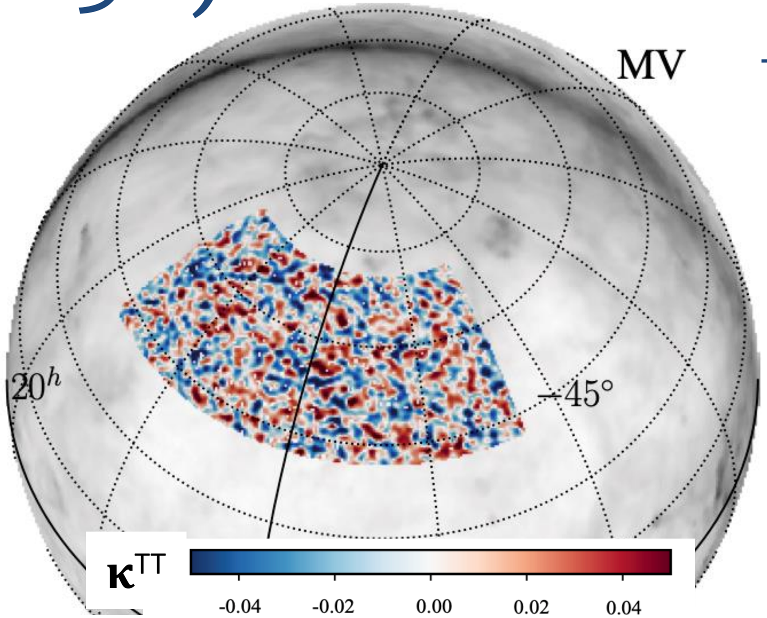
- **initial testing of realistic data transfers from summit**
- **Delivering AuxTel data from the summit and doing prompt processing**
- **Preparing for multi-site processing using HSC precursor data**
  - Using LHC tools for workflow (PanDA) and data mgmt (Rucio)
- **Planning Data Previews in 2024 and 2025**

S3df/SRCF: SLAC Shared Science Data Facility (s3df) –Stanford Research Computing Facility

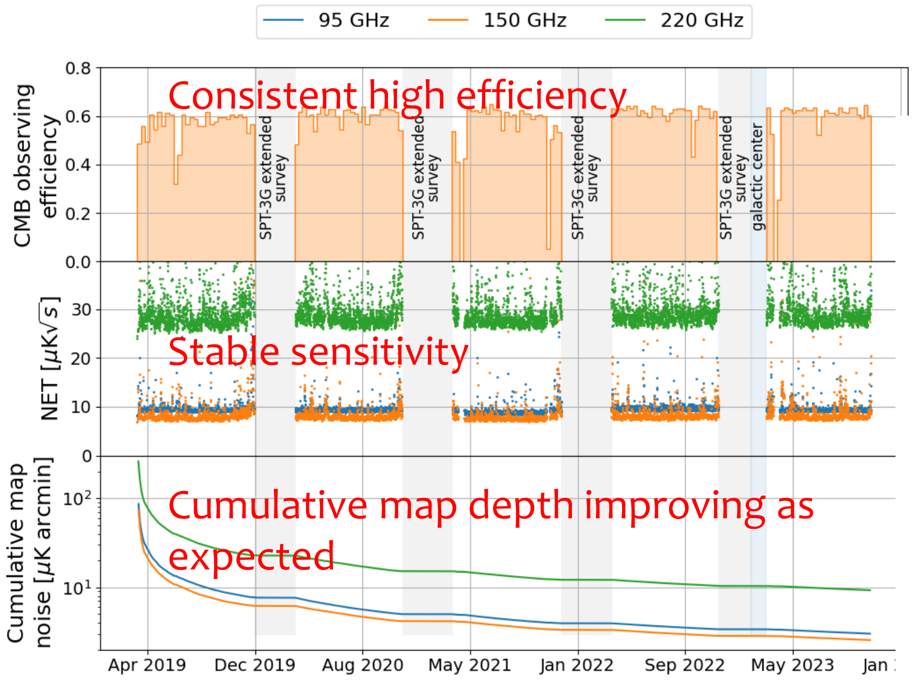
South Pole Telescope 3rd Generation (SPT-3G)

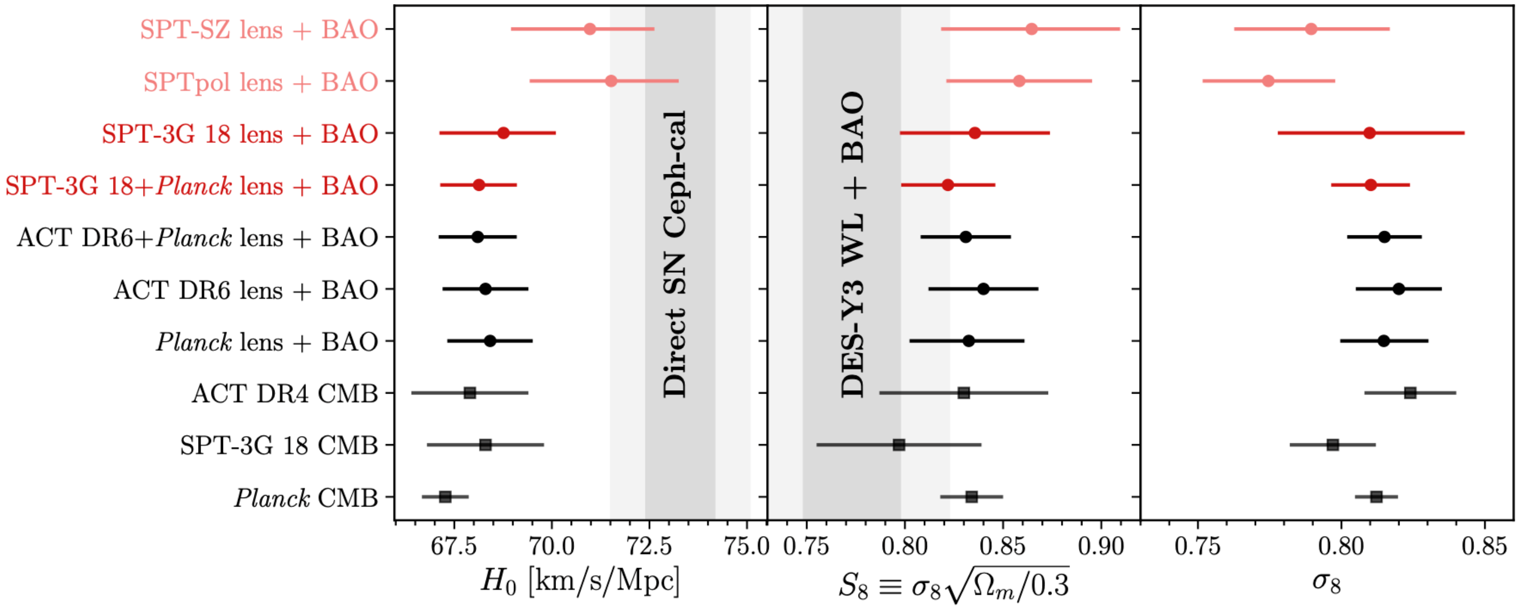
SPT-3G: NSF & DOE partnership

- 5th full year of survey completed; smooth operation with high observing efficiency
- Cosmology results from initial 2018 SPT-3G data using joint TT, TE and EE power spectrum measurements published (Balkenhol et al. PRD, 2023)
- CMB gravitational lensing result published (Pan et al., PRD, 2023)



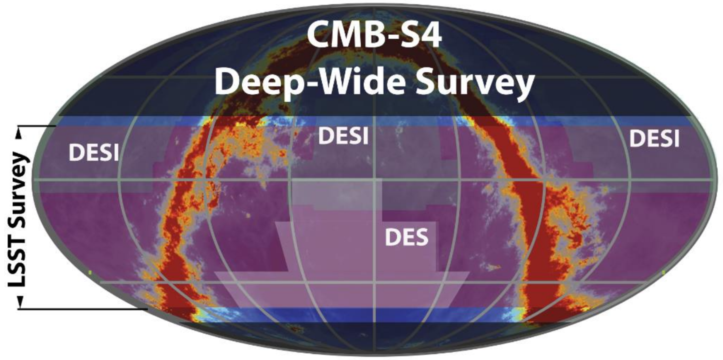
Constraints consistent with ΛCDM. H_0 & S_8 consistent with other CMB experiments; slight tension with 'local probes'

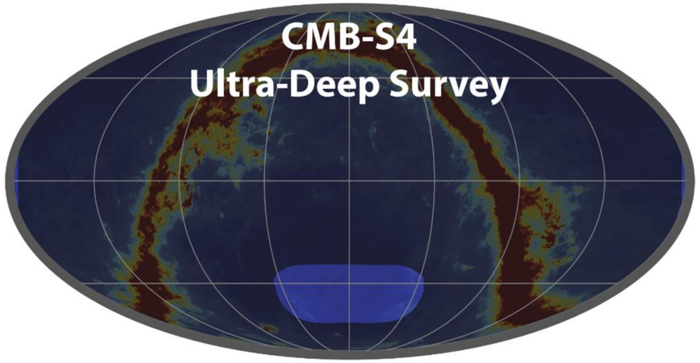




Cosmic Acceleration
CMB-S4 (Cosmic Microwave Background Stage 4)

- 2014 P5 recommended CMB-S4 as a joint DOE/NSF
- CD-0 in 2019; MIE project approved FY2021
- Astro2020 recommended CMB-S4 as 2nd priority for ground-based astronomy/astrophysics
- DOE/HEP has been working with NSF to move CMB-S4 forward.
- In December 2022, the Project reported an alternative design that will address South Pole infrastructure and logistics constraints and will still meet all the science goals.
  - This is the design that was proposed to P5.





CMB-S4, with both sites, was the top recommended new project by P5.

A Director's review (charged by LBNL and U Chicago management) was held in November 2023. The committee reported:

"…the project progressed well and key elements are in place including a well-defined conceptual design developed through a rigorous process, a well-developed and effectively operating management structure, and a solid and well-documented conceptual-design-level project plan"

Summary

HEP Cosmic Frontier
Summary & Future Planning

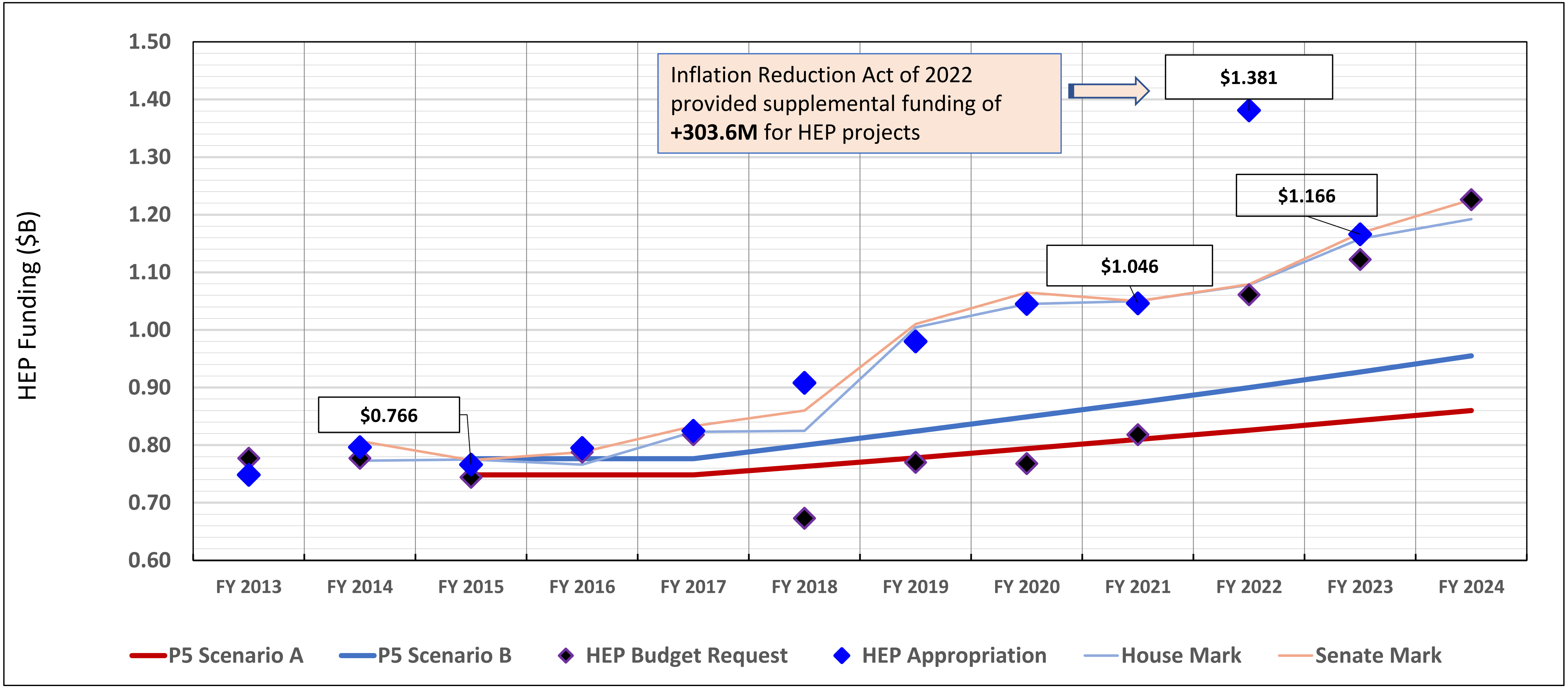
- HEP continues to carry out the 2014 P5 strategic plan:

- **FY 2024 – we are in a continuing resolution**
  - FY 2025 – the President's Request budget has been developed
    - FY 2026 – work will start on this in the spring

- Future – Guidance provided by 2023 International Benchmarking, P5

BACKUP - BUDGET

HEP Budget History 2013 to Present
Note: We are still in a Continuing Resolution



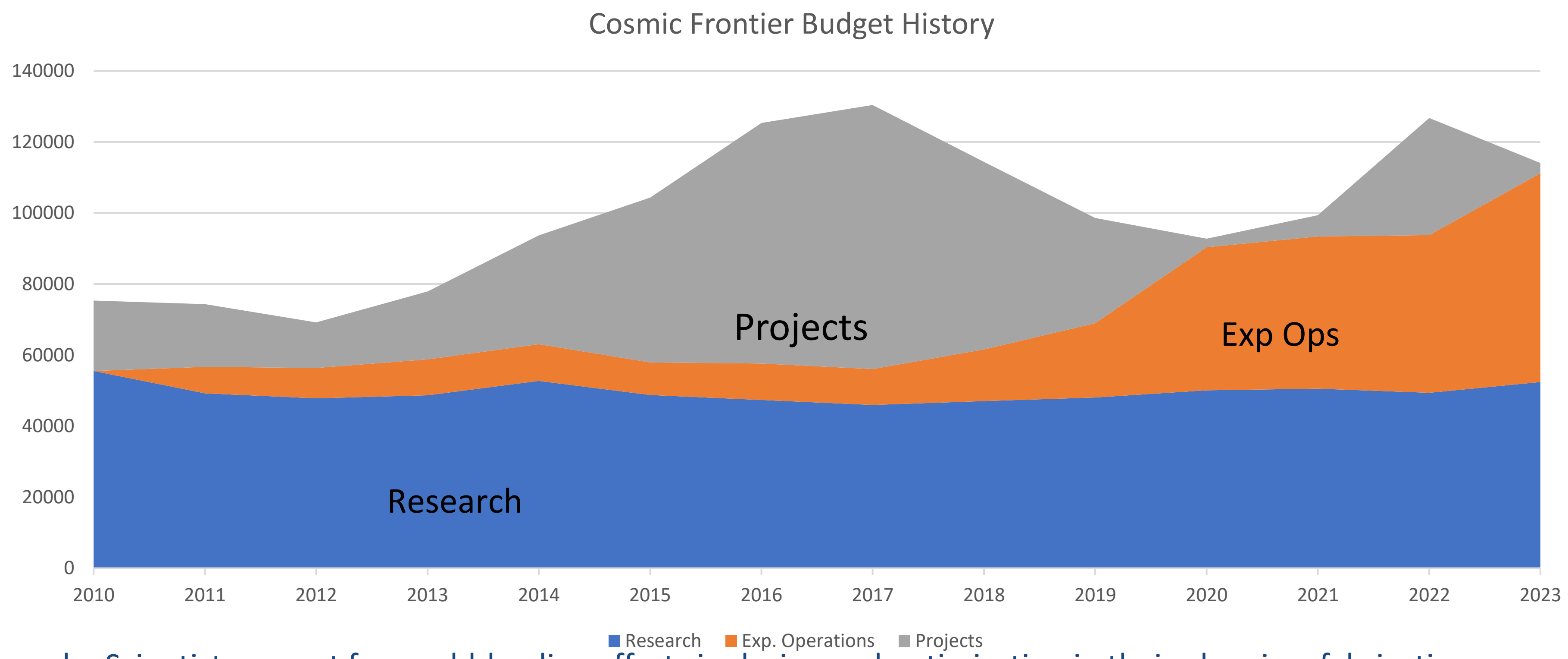
- U.S. Congress continues to show strong support for executing the 2014 P5 strategy, and for accelerating the pace of projects

Cosmic Frontier Budget – FY2021 – FY2024

Cosmic Frontier ($K)	FY2021 Actual	FY2022 Actual	FY2022 Inflation Reduction Act	FY2023 Actual	FY2024 Request
Research	50,521	49,395		52,417	48,048
Research (Univ+Lab)	*43,901*	*42,513*		*45,698*	
Future R&D	*1,700*	*1,475*		*1,979*	
AI/ML Research	4,920	5,407		4,740	
Exp. Ops.	42,880	44,350		58,810	61,830
Projects: CMB-S4, LuSEE-Night (FY22)	6,000	23,000	11,893	1,000	9,000
Total	**99,401**	**116,745**	**11,893**	**108,227**	**120,342**

NOTES:
- The amounts shown in the table do not include workforce costs or SBIR/STTR funds.
- FY 23 Request was $92.9M

Cosmic Frontier Budget History



FY22 Project includes funds from the Inflation Reduction Act

Research: Scientist support for world-leading efforts in design and optimization in their planning, fabrication, commissioning, operations and data production/analysis.

Experimental Operations: Commissioning and facility operations planning for LSST/Rubin; operations of FGST/LAT, SPT-3G, ADMX-G2, DESI, LZ; pre-operations activities for SuperCDMS-SNOLAB. As the current Projects complete, estimated needs ramps up to ~ $55M to $60M by FY2024; levels to ~ $40M by FY2030.

Projects: CMB-S4, LuSEE-Night (all funds in FY22); SuperCDMS completed in FY23

Future opportunities: Compelling Cosmic Frontier Projects will be considered and supported within available overall HEP project funds. Guidance from Astro2020, Snowmass, P5 (2023)

BACKUP – HEPAP International Benchmarking report (Nov2023), detailed recommendations

HEPAP International Benchmarking study – Detailed Recommendations

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https://science.osti.gov/-/media/hep/hepap/pdf/202311/HEPAPBenchmarking_Nov_2023.pdf
Report - https://science.osti.gov/-/media/hep/hepap/pdf/202203/International_Benchmarking_HEPAP_2023112.pdf

Findings and Recommendations were provided in 3 main areas, with 7 sets of findings, recommendations

A. 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.

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

HEPAP International Benchmarking study – Detailed Recommendations

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.

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

HEPAP International Benchmarking study

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.

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

HEPAP International Benchmarking study

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.

- **[for LBNL/DUNE] 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.**
- **[for Cosmic Surveys] 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.**
- **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.**
- **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.**
- **U.S. laboratories hosting international experiments should provide an environment that encourages and supports international collaboration.**

HEPAP International Benchmarking study

B. 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.

- **Invest in a strong and innovative theory program.**
- **[for Accelerator Science and Technology]**
- **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.**
- **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.**
- **Develop a strategic plan to maintain leadership in plasma wakefield acceleration as needs for R&D facilities evolve and research programs abroad grow.**
- **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.**
- **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.**
- **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.**

HEPAP International Benchmarking study

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.

- **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.**
- **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.**
- **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.**

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C. 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.

- **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.**
  - **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.**

HEPAP International Benchmarking study

C. Workforce - *Attracting and retaining a talented, highly trained, and diverse U.S. workforce*

7. Building a robust workforce continued

- Send national laboratory and university researchers to colleges and universities that do not have particle physics programs to enlighten students about the excitement of the field and waiting career opportunities. Include visits to MSIs and small two- and four-year colleges. Travel costs should be covered by the national labs or universities sending speakers.
- Acknowledge the tremendous efforts of the funding agencies to be more inclusive. Such programs are essential for all the aforementioned categories of colleges and universities.
- DOE should increase the number of university joint/bridge faculty positions that it funds at the 50% level.
- 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 excellent commitment to develop and implement best practices in the area of diversity, equity, and inclusion

- 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.
- Develop a framework to attract, train, and retain a highly skilled technical workforce.

HEPAP International Benchmarking study

C. Workforce - *Attracting and retaining a talented, highly trained, and diverse U.S. workforce*

7. Building a robust workforce continued

- **Attract, nurture, recognize and sustain the careers of physicists, engineers and technicians dedicated to the development of instrumentation, accelerator science and technology, and large-scale computing.. 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.
- **Develop new career frameworks to grow and retain the U.S. AI/ML and QIS/quantum particle physics workforce.**
  - **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.**
  - **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.**
- **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.**
- **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.**

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