Division of Particles & Fields

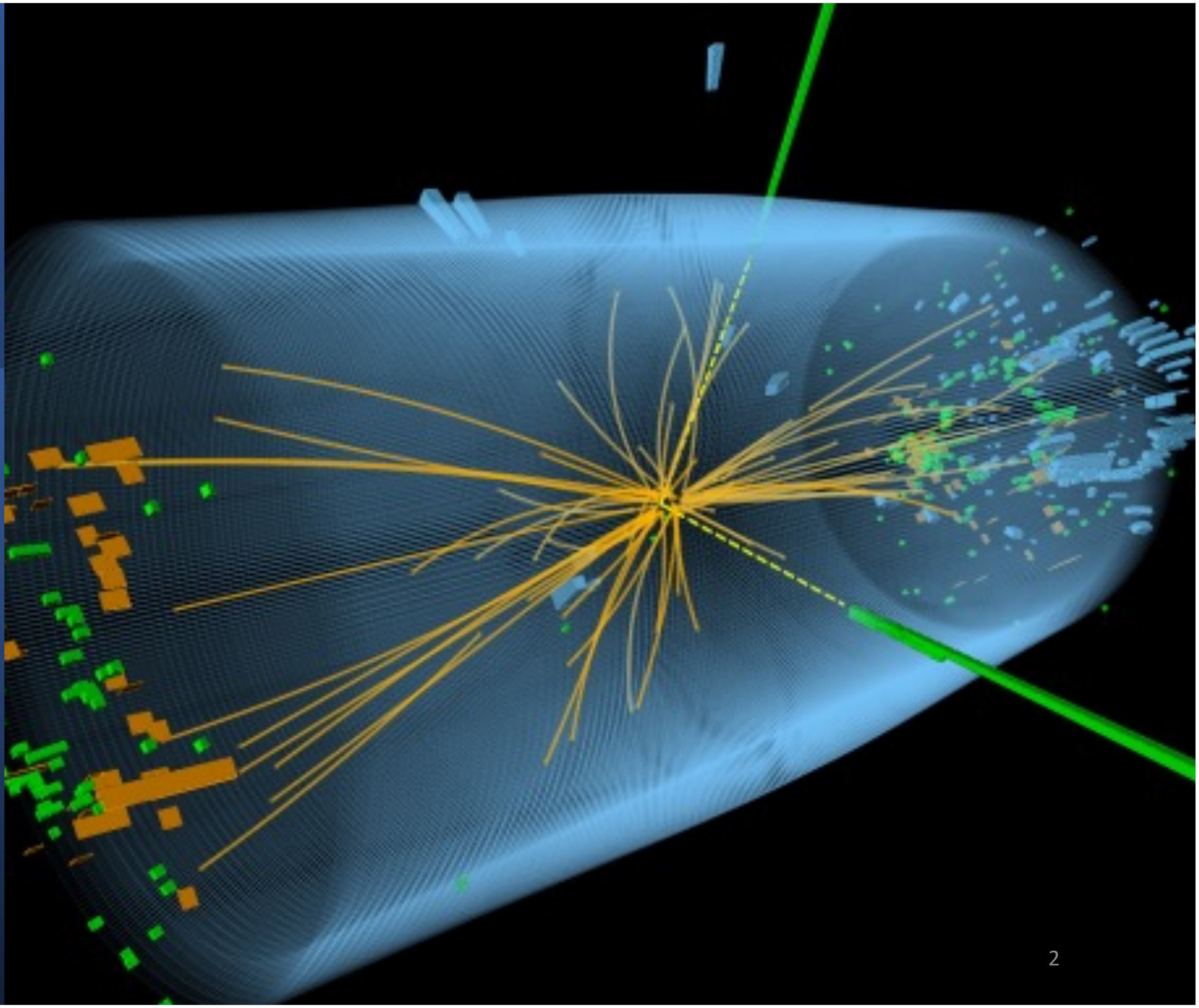
UC San Diego

Planning for U.S. High-Energy Physics

R. Sekhar Chivukula, DPF Chair

Multi-Boson Interactions 2023, UC San Diego

Planning for US High-Energy Physics The "Snowmass/P5 Process"



The last “Snowmass” occurred in 2013

A year-long community-wide effort,
culminating with
“Snowmass on the Mississippi”
July 29 – August 6, 2013

(~700 in-person participants)

Snowmass 2013 highly successful:

(Report by December 2013)

https://www.slac.stanford.edu/econf/C1307292/

The year-long process laid out a roadmap

for **great science opportunities**,

resulted in broad community buy-in.

essential inputs to P5

"Particle Physics Project Prioritization Panel" (P5)

A subpanel of HEPAP (DOE and NSF)

- Projects prioritized according to funding scenarios
- Science research directions in HEP
- Federal funding profile for the current and near-future projects in the decade.

P5 Report, May 2014

Distilled from the Snowmass 2013 inputs, five Science Drivers for the field:

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

- 29 recommendations
- Projects prioritized according to funding scenarios

As a result, highly impactful on the

- Directions/achievements in HEP
- Federal funding profile

for the current and near-future projects in the decade.

And then, after P5, it's important to work together for the whole program in a unified manner.

Community Letter

- **In support of P5 Report**
- **Sent to Energy Secretary Moniz & to NSF Director Cordova**
- **2095 signatures gathered in 1st week and sent with letter**
- **2331 signatures collected in total**

Drafted and assembled by the "HEP Community P5 Rollout Committee",
a joint committee of:

- **APS Division of Particles and Fields**
- **Users organizations of Fermilab, SLAC, and US LHC**

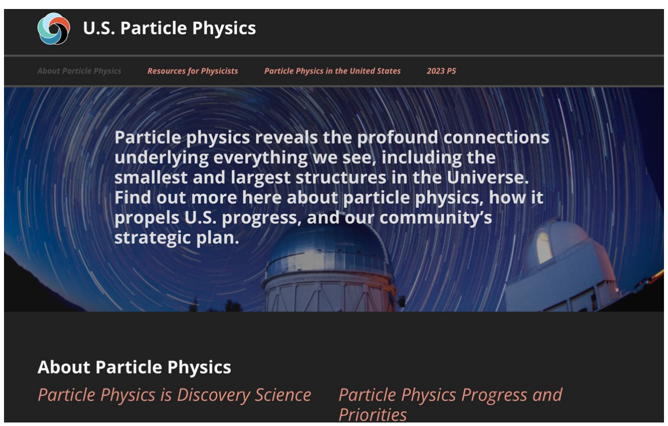
The letter was effective at communicating the broad support in the US particle physics community for the P5 report
- an important message in light of our reputation as a "fractious" community

Many thanks to community members for their support of the P5 report,
& thank you for initiative to HEP Community P5 Rollout Organizing Committee*

* The HEP Community P5 Rollout Organizing Committee consisted of: Daniel Akerib, Robert Bernstein, Pushpa Bhat (Co-Chair), Edward Blucher, James Brau, Raymond Brock, Sally Dawson, Robin Erbacher, Yuri Gershtein, Howard Haber, Nick Hadley, JoAnne Hewett, Harvey Newman, Nicola Omodei, Laura Reina, B. Lee Roberts, Jonathan Rosner, Sally Seidel, Ian Shipsey (Co-Chair), Michael Tuts, Breese Quinn, Michael Sokoloff, Nikos Varelas, Hendrik Weerts

Briefing materials updated yearly … used in UEC/SLUO/USLUO yearly DC trips

- https://www.usparticlephysics.org
- Every year, working with DPF, and Users Groups, and others, materials about the whole field are developed and updated for interactions with decision makers in Washington and elsewhere.



Building for Discovery

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

usparticlephysics.org

The P5 Report provides the long-term strategy and priorities for U.S. investments in particle physics.

The top three priorities in 2023

Strengthen support for particle physics research at universities and national laboratories, which includes data analysis, R&D, design of new experiments, and a vibrant theory program. As emphasized in the P5 Report, these activities are essential for the success of the field. They are crucial for extracting scientific knowledge from all the great new data, developing new methods and ideas, maintaining U.S. leadership, and training the next generation of scientists and innovators.

Advance the High-Luminosity Large Hadron Collider (HL-LHC) accelerator and ATLAS and CMS detector upgrade projects on schedule, continuing the highly successful LHC program and bilateral partnership with CERN.

Advance the Long-Baseline Neutrino Facility (LBNF), Deep Underground Neutrino Experiment (DUNE), and Proton Improvement Plan-II (PIP-II), working with international partners on the design, prototypes, initial site construction, and long-lead procurements.

These carefully chosen investments will enable a steady stream of exciting new results for many years to come and will maintain U.S. leadership in key areas.

Particle physics is both global and local. Scientists, engineers, and technicians at 190 universities, institutes, and laboratories throughout the U.S. are working in partnership with their international colleagues to build high-tech tools and components, conduct scientific research, and train and educate the next generation of innovators. Valuing equity, diversity, and inclusion, the field is committed to increasing participation of underrepresented groups. Particle physics activities in the U.S. attract some of the best scientists from around the world.

The P5 strategy continues to be very successful. Even with extraordinary challenges due to COVID-19, there was great progress.

Recent results

Researchers at **Fermilab** demonstrated an important new technique, called optical stochastic cooling, to make **more intense particle beams**.

The **LZ dark matter detector** in South Dakota published its first results, providing important new constraints on the particle identity of dark matter and promising greater sensitivity with continued data taking.

The LHC experiments reported many important and precise results. The remarkably productive ATLAS and CMS experiments have each produced more than 1,000 refereed publications. The advances in precision are represented well by the new measurements of fundamental properties of **Higgs boson** decays that provide a sensitive tool for discovery of new physics. The new precision measurement of the W-boson mass by CDF at Fermilab further motivates precision studies at the LHC. The **LHCb experiment** also discovered new configurations of quarks, measured the rate of antimatter production in proton collisions, and reported an intriguing deviation from expectation in B-meson decays.

Theoretical physicists have discovered connections among quantum entanglement, information, and gravity, suggesting novel ideas about the emergence of spacetime.

The **MicroBooNE** and **MINERvA neutrino experiments at Fermilab each published new results**: MicroBooNE placed limits on additional types of exotic neutrinos, and MINERvA probed protons using antineutrinos. The KamLAND-ZEN collaboration published an important new bound on whether neutrinos can be their own antiparticles.

Program advances in 2022

Building upon the historic bilateral U.S.-CERN agreements, U.S. and CERN scientists successfully continued their cooperative partnership at the LHC and the international neutrino program hosted by Fermilab. The LHC experiments, ATLAS and CMS, successfully passed their high-luminosity upgrade CD-2/3a reviews. The LHC will restart operations in spring 2023 after technical improvements during the winter.

The **LBNF/DUNE-US** project successfully passed a CD-1RR review as well as CD-2/3 reviews to complete excavation of underground caverns, now well past 50% complete, and to outfit the completed caverns. Mass-production of components for the first **DUNE** far detector has started. So far, government-to-government agreements with 10 countries have been signed for LBNF/DUNE, PIP-II, and the Short Baseline Neutrino program at Fermilab, with more in progress. The PIP-II accelerator project, needed for reaching LBNF physics goals, passed its DOE CD-3 milestone, opening the way to construction, which is expected to be complete in 2028.

The **Vera C. Rubin/LSST Camera** is now fully assembled at SLAC and is on track for delivery to the Observatory in the first half of 2023. The LSSTCam Project received the DOE Secretarial Achievement Award. **The Dark Energy Spectroscopic Instrument (DESI)** continued its five-year survey, collecting 18 million galaxy and quasar redshifts so far, and is ahead of schedule.

The next-generation cosmic microwave background facility, CMB-S4, which was ranked highly in both the NAS Decadal Survey of Astronomy & Astrophysics and the 2014 P5 report, is progressing. CMB measurements uniquely probe **physics of the early universe**, at energies far beyond what can be studied at earth-bound accelerators, and can also reveal fundamental neutrino properties.

Looking forward

All eyes are on the LHC, as its sensitivity to new physics will continue to improve through vastly greater data volumes and new deep-learning data analysis methods. The experiments will extend their discovery reach and probe the Higgs boson's properties with ever greater precision for many years to come. Despite COVID and funding constraints, the HL-LHC upgrade projects are progressing. The LHC continues to break energy and luminosity records.

Eagerly anticipated new data from operating experiments will advance the understanding of the intertwined Science Drivers identified in the P5 Report. At the LHC, the accelerator is on track to resume operations this spring for data-taking by the successfully upgraded experiments. Looking upward, the first data release from the DESI dark energy spectroscopic survey is expected in 2023.

Particle physicists are expanding efforts to develop and apply artificial intelligence (AI) techniques to the operation of accelerators and experiments, data analysis, and simulations, opening new avenues for scientific discovery.

Theoretical and experimental particle physicists are advancing Quantum Information Science (QIS), providing solutions to problems in computation, data analysis, sensors, and simulations, with several notable recent results.

The particle physics theory community will continue to play key roles in interpreting results from current experiments, motivating future experiments, and pursuing answers to the deepest questions.

Looking beyond the current P5 horizon, and guided by new results, U.S. particle physicists engaged in the Snowmass community planning process, in which opportunities in all areas of the field were discussed in depth. The output of the process is available as essential input to the new P5, which is now developing the strategic plan for 2024 and beyond. To inform choices, the U.S. is also working with partners worldwide on the development of concepts for facilities that could be hosted in the U.S. and abroad.

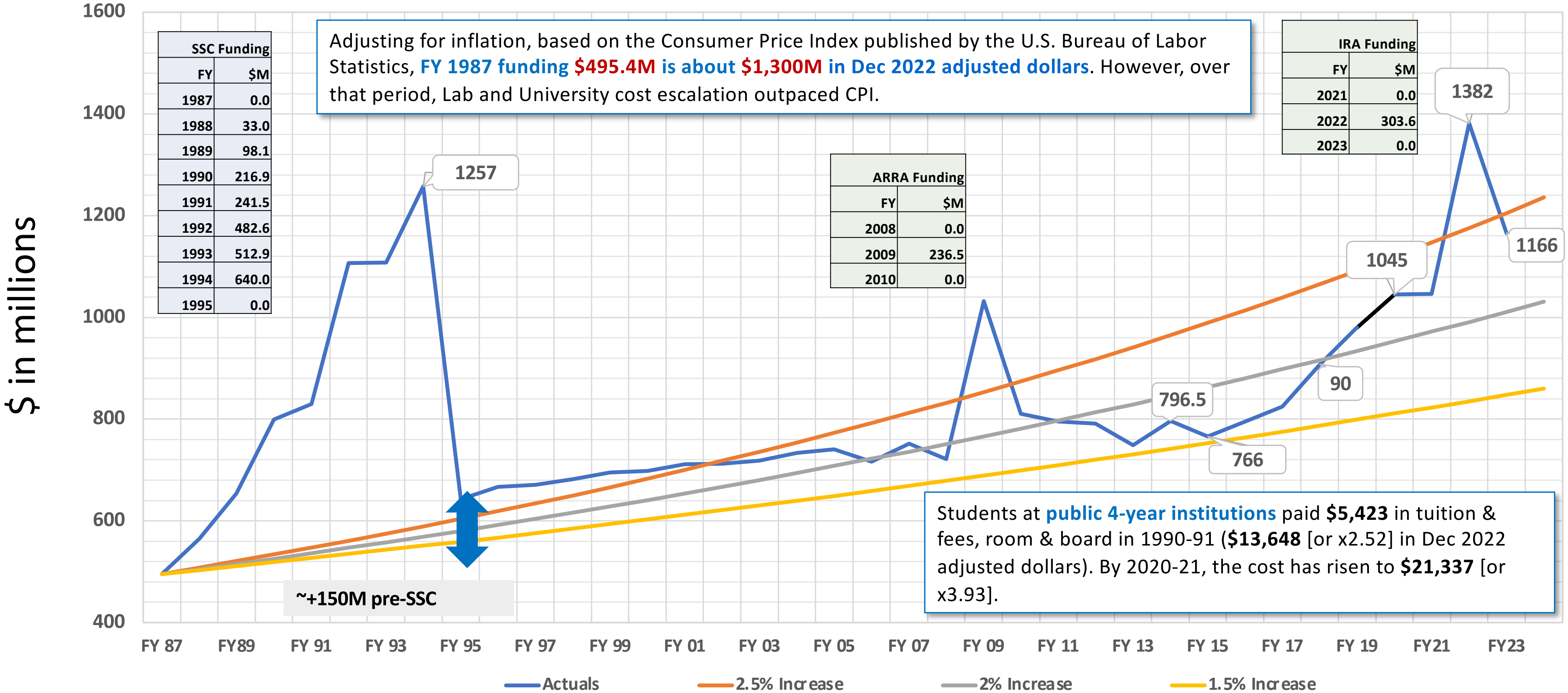
U.S. researchers are pursuing R&D on advanced technologies to enable future generations of accelerators and detectors with a wide variety of applications in science, medicine, and industry.

Building for Discovery

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

usparticlephysics.org

HEP Funding in Historical Context: 1987 to Present



Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

The "results" of the last Snowmass/P5 process and follow-up were good!

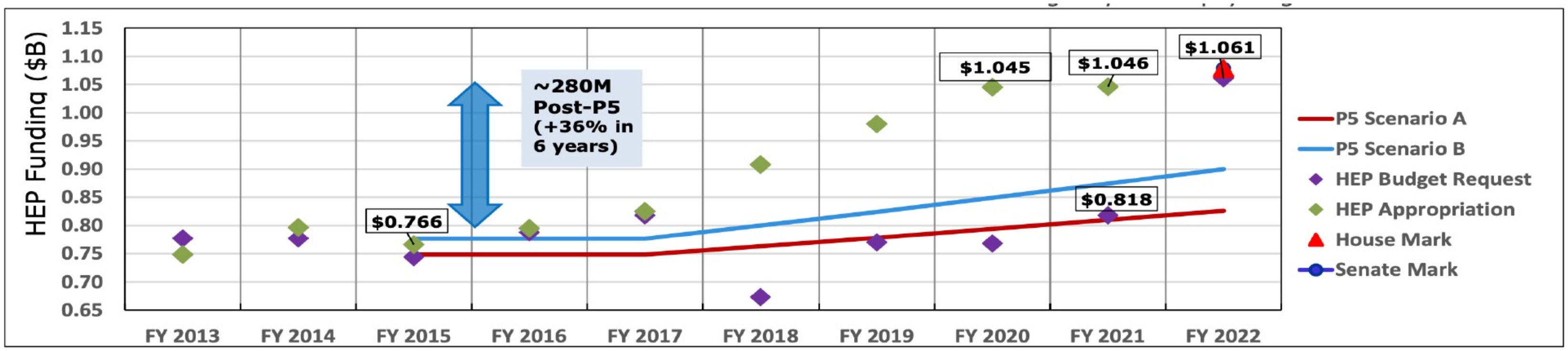
Spawned numerous U.S. International agreements

- U.S. – CERN Agreement, May 2015
- UK – U.S. Science & Technology Agreement, Sep 2017
- DOE-DAE Project Annex II on Neutrino Research, Apr 2018
- U.S. – Italy Neutrino Agreement, Jun 2018

………

- U.S. – CERN FCC and HL-LHC Agreement, Dec 2020

CERN – FNAL HL LHC Agreement, Mar 2021

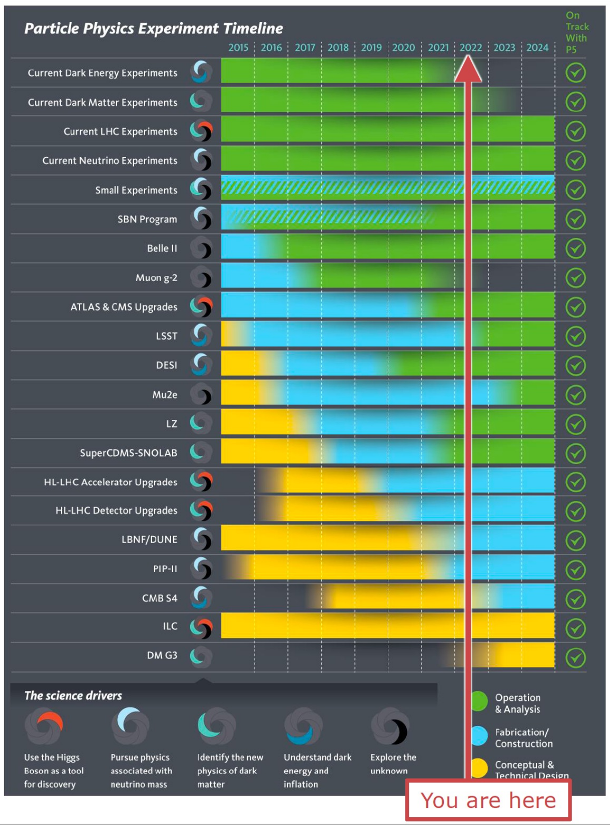


JoAnne Hewett, HEPAP Chair

Note Text from the “Chips and Science Act”:

- Further Activities.--Section 305 of the Department of Energy Research and Innovation Act (42 U.S.C. 18645) (as amended by subsection (c)), is amended by adding at the end the following: ``(g) Facility Construction and Major Items of Equipment.–
- ``(1) Projects.--Consistent with the Office of Science's project management practices, ***the Director shall, to the maximum extent practicable, by incorporating the findings and recommendations of the 2014 Particle Physics Project Prioritization Panel (P5) report entitled `Building for Discovery',*** support construction or fabrication of–
- ``(A) an international Long-Baseline Neutrino Facility based in the United States;
- ``(B) the Proton Improvement Plan II;
- ``(C) Second Generation Dark Matter experiments;
- ``(D) the Legacy Survey of Space and Time camera;
- ``(E) upgrades to detectors and other components of the Large Hadron Collider; and
- ``(F) the Cosmic Microwave Background Stage 4 project; and `
- `(G) other high priority projects recommended in the most recent report of the Particle Physics Project Prioritization Panel of the High Energy Physics Advisory Panel.

P5 9 Years in: Many projects completed/in progress



Successful implementation of the 2014 P5 strategy continues

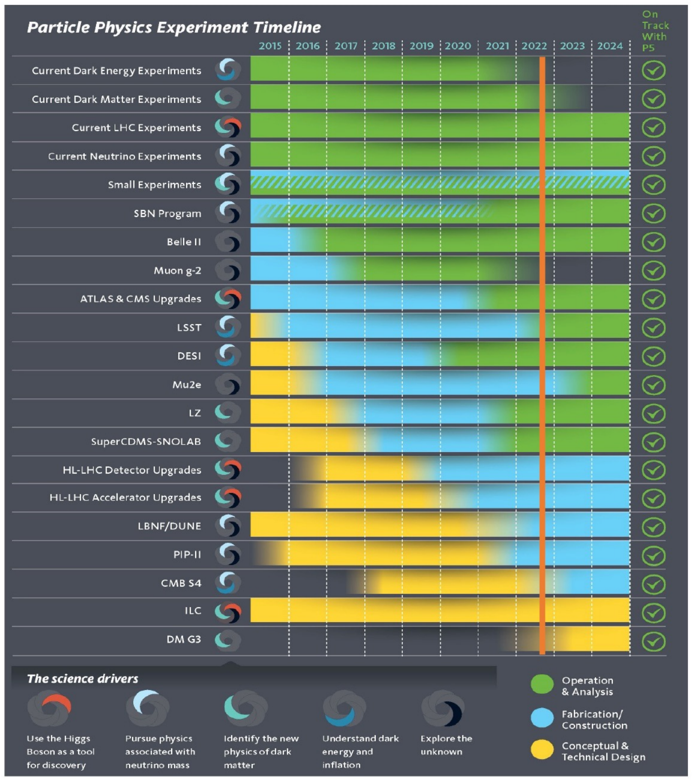
Continuous physics analyses and output throughout the "P5 envisioned" 10-year plan

Even with extraordinary challenges due to COVID-19, there was great progress!

- **Projects fully funded or ongoing as of FY 2022:**
  - **Initial Phase-1 LHC detector upgrades: ATLAS and CMS**
  - **Mu2e**
  - **SuperCDMS at SNOLAB (DM-G2)**
- HL-LHC accelerator and detector upgrade projects underway
- LBNF/DUNE & PIP-II schedules advanced due to strong support by the U.S. Administration & Congress; Muon g-2 is operating
- DESI, LZ and LSSTCam (for Rubin Observatory) projects completed; CMB-S4 in concept planning
- Broad portfolio of small projects running

Harriet Kung
Deputy Director
DOE Office of Science

We’ve succeeded … time for a new plan



Healthy HEP program requires a mix of project stages

JoAnne Hewett


Snowmass 2021

Community Summer Study (CSS) and Workshop

- Community Planning Meeting on Oct 5-8, 2020 (Official planned start)
- **Snowmass Day (post-pause restart): September 24, 2021**
- **Snowmass Community Summer Study started (July 17, 2022) Home Page for Seattle, July 17-26, 2022**

Snowmass 2021 organization

10 Frontiers	80 Topical Groups
Energy Frontier	Higgs Boson properties and couplings, Higgs Boson as a portal to new physics, Heavy flavor and top quark physics, EW Precision Phys. & constraining new phys., Precision QCD, Hadronic structure and forward QCD, Heavy Ions, Model specific explorations, More general explorations, Dark Matter at colliders
Frontiers in Neutrino Physics	Neutrino Oscillations, Sterile Neutrinos, Beyond the SM, Neutrinos from Natural Sources, Neutrino Properties, Neutrino Cross Sections, Nuclear Safeguards and Other Applications, Theory of Neutrino Physics, Artificial Neutrino Sources, Neutrino Detectors
Frontiers in Rare Processes & Precision Measurements	Weak Decays of b and c, Strange and Light Quarks, Fundamental Physics and Small Experim[illegible]pton Number Violation, Charged Lepton Flavor Violation, Dark Sector at Low Energies, Had[illegible]
Cosmic Frontier	Dark Matter: Particle-like, Dark Matter: Wave-like, Dark Matter: Cosmic P[illegible]ion: The Modern Universe, Dark Energy & Cosmic Acceleration: Cosmic [illegible] Acceleration: Complementarity of Probes and New Facilities [illegible]
Theory Frontier	String theory, quantum gravity, black holes, Effec[illegible]rmal QFT, Scattering amplitudes, Lattice gauge theory, Theory t[illegible] phenomenology, BSM model building, Astro-particle physics and [illegible]ce, Theory of Neutrino Physics
Accelerator Frontier	Beam Physics and Accel[illegible]trinos, Accelerators for Electroweak and Higgs Physics, Multi-TeV [illegible]ond Colliders & Rare Processes, Advanced Accelerator Concepts, A[illegible]ets, Targets/Sources
Instrumentation Frontier	[illegible], Solid State Detectors & Tracking, Trigger and DAQ, Micro Pattern Gas [illegible]onics/ASICS, Noble Elements, Cross Cutting and System Integration, Radio Detection
Computational Frontier	[illegible] Algorithm Parallelization, Theoretical Calculations and Simulation, Machine Learning, Storage and [illegible]ing resource access (Facility and Infrastructure R&D), End user analysis
Underground Facilities and Infrastructure Frontier	Underground Facilities for Neutrinos, Underground Facilities for Cosmic Frontier, Underground Detectors
Community Engagement Frontier	Applications & Industry, Career Pipeline & Development, Diversity & Inclusion, Physics Education, Public Education & Outreach, Public Policy & Government Engagement
Snowmass Early Career	to represent early career members and promote their engagement in the Snowmass 2021 process; to build a long-term HEP early career community

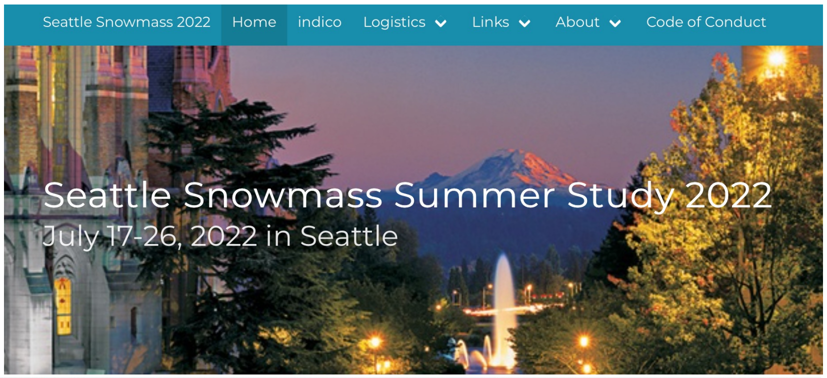
30 Frontier conveners, ~250 Topical Group conveners,
>40 Inter-Frontier Liaisons, ~25 Early Career Liaisons.

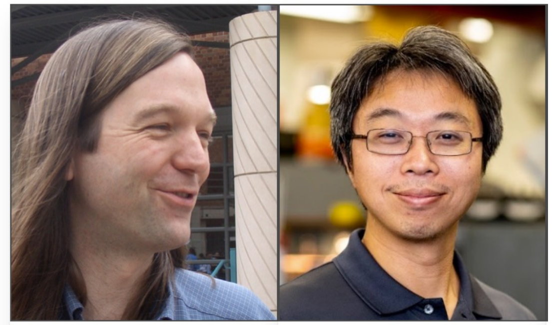
Broad coverage and connection to global science community!

Community Summer Study (CSS): Snowmass 2021

July 17 – 26, 2022 @ UW – Seattle

http://seattlesnowmass2021.net





Gordon Watts
email
Co-Chair of Local Organizing Committee, Co-Chair of Program Committee

Shih-Chieh Hsu
email
Co-Chair of Local Organizing Committee, Co-Chair of Program Committee

Participants

Number of in-person participants: 743

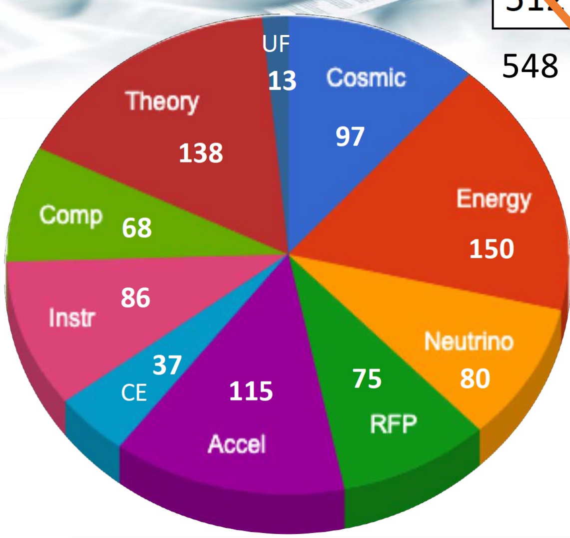
Number of virtual participants: 654

Local Organizing Committee/Volunteer/Press: 58

Total number of participants: 1397

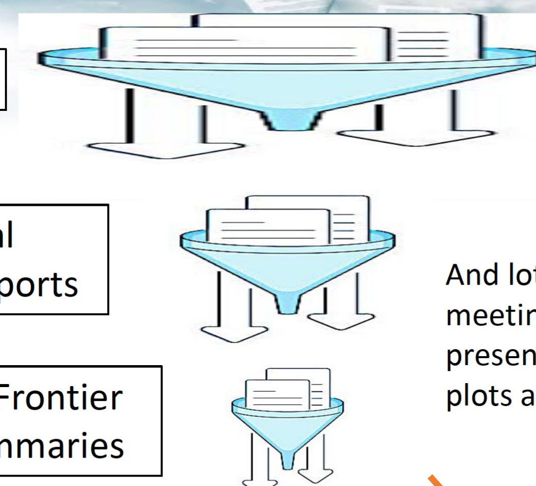
Covid Cases: ~35

Output of Snowmass – referenced at PAQS



512 White Papers

548



79 topical group reports

10 Frontier Summaries

(Plus 2 additional reports…)

And lots of meetings and presentations and plots along the way

Executive Summary by October

COMPLETED Jan 2023

We are grateful for the large number of international particpants – including many from India!

Prisca Cushman, UMinn, DPF Chair 2019

Snowmass Proceedings

- https://www.slac.stanford.edu/econf/C210711/

Proceedings of the 2021 US Community Study on the Future of Particle Physics

(Snowmass 2021)

organized by the APS Division of Particles and Fields

These proceedings are dedicated to the memory of Meenakshi Narain (1964-2023), in honor of her many contributions to Snowmass 2021.

The US Community Study on the Future of Particle Physics (Snowmass 2021) was a grassroots study to plan for US particle physics in the decade 2025-2035 with an eye towards the following decade. Snowmass 2021 was organized by the APS Division of Particles and Fields, with input and collaboration from the Divisions of the Physics of Beams, Astrophysics, Nuclear Physics, and Gravitational Physics. It began with a kick-off meeting at the 2020 APS April Meeting and a Community-wide Planning Meeting in October of 2020. Because of the COVID pandemic, the study was paused between January and September 2021. The study finally concluded at the Community Summer Study meeting at the University of Washington, July 17-26, 2022.

On to P5

Snowmass was WONDERFUL!!!

Snowmass results will be critical input to P5

- The hard work was impressive and is an important documentation of visions for our field

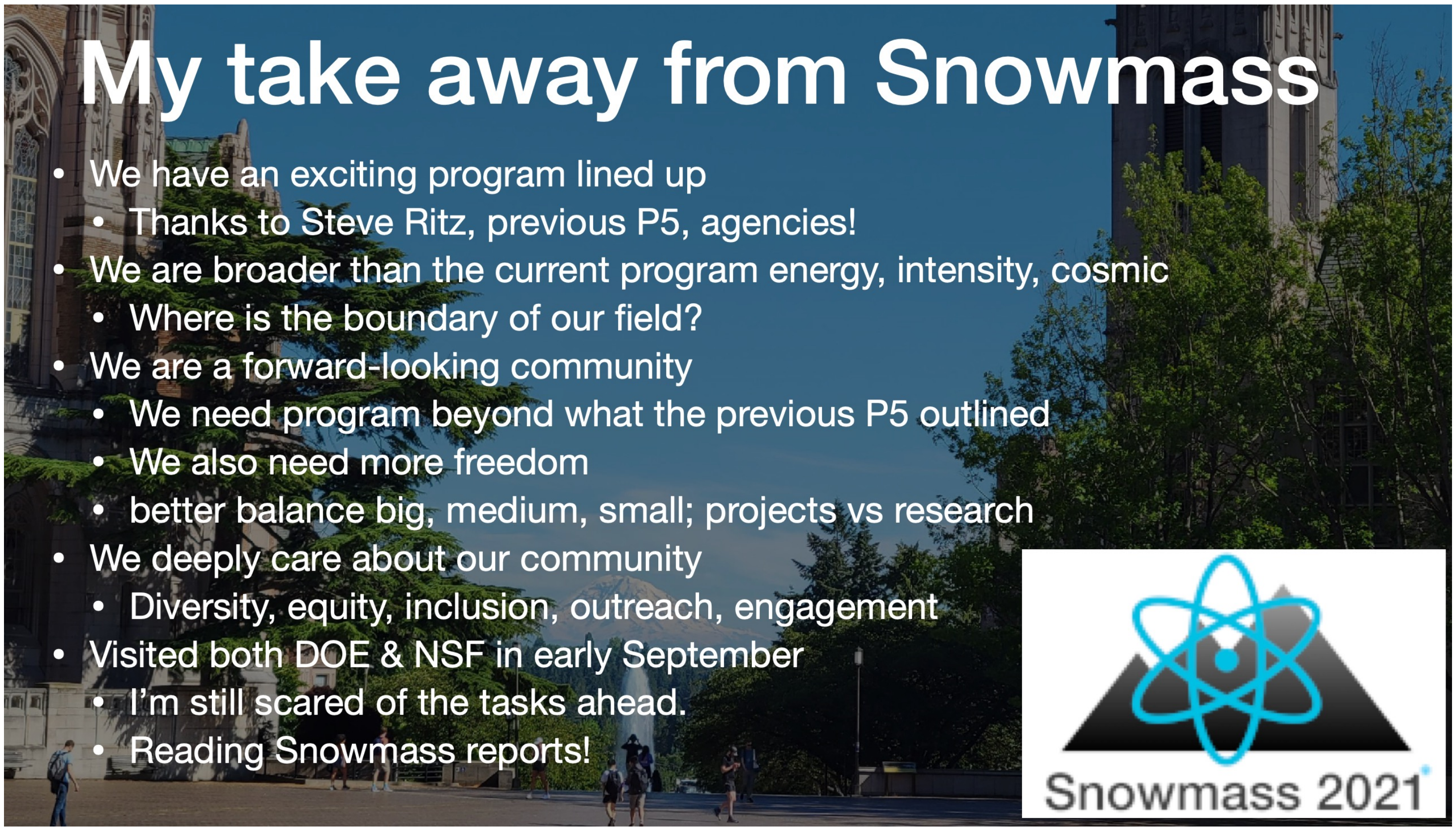
Turning towards P5

- Every idea presented at Snowmass will receive due consideration
- **(P5)** Report is not written
- Decisions are not made
- P5 will take a fresh look at our project program
- P5 is a process and the process will be followed

Next P5 chair:

JoAnne Hewett

Hitoshi's Snowmass take aways…



Considerations for Next P5

- Grand, long-term, and global vision for U.S. particle physics
- Realistic budget scenarios
- Balanced portfolio of small/mid-scale/large projects
- Must consider a holistic view of program
  - Project costs
  - Operations costs
  - Research program to deliver the science
  - Technology R&D for the future
- Community engagement, including this week's Snowmass study process, remains critical to success

Note added – recent good funding news:

IRA - $304M APPROPRIATION to HEP

CHIPS and Science Act – recommends increases to NSF/DOE

(Harriet Kung)

Holistic View Large-scale projects

Decadal Overview of Future Large-Scale Projects

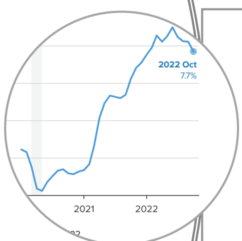
Frontier/Decade	How do we develop enabling technology for long-term vision in a fashion executable in 20 years?	
Energy Frontier	U.S. Initiative for the Targeted Development of Future Colliders and their Detectors	
	US role?	Higgs Factory Scope? Technology? Complementarity?
Neutrino Frontier	LBNF/DUNE Phase I & PIP- II	DUNE Phase II (incl. proton injector)
Cosmic Frontier	Cosmic Microwave Background - S4 Spectroscopic Survey - S5* Scope?	Next Gen. Grav. Wave Observatory* Line Intensity Mapping* Do we embrace them?
Big, small, new?	Multi-Scale Dark Matter Program (incl. Gen-3 WIMP searches)	
Rare Process Frontier		Advanced Muon Facility Scope? Other science?

Table 1-1. *An overview, binned by decade, of future large-scale projects or programs (total projected costs of $500M or larger) endorsed by one or more of the Snowmass Frontiers to address the essential scientific goals of the next two decades. This table is not a timeline, rather large projects are listed by the decade in which the preponderance of their activity is projected to occur. Projects may start sooner than indicated or may take longer to complete, as described in the frontier reports. Projects were not prioritized, nor examined in the context of budgetary scenarios. In the observational Cosmic program, project funding may come from sources other than HEP, as denoted by an asterisk.*

Ongoing HEP Budget Challenges & Opportunities

Core Research

Our recent Committee of Visitors report encouraged HEP to increase research effort and broaden workforce engagement to better match needs for operation of the new experiments and support ongoing construction activities



Inflation

FY 2022 IRA funding to HEP projects enabled the flexibility to mitigate inflationary impacts to core research, access to facilities, and infrastructure investments. HEP increased FY 2023 research and facilities/operations funding by ~8% over FY 2022. Inflation remains a risk for the foreseeable future

Supply Chain

Reliable supply of highly specialized components, materials, and techniques. How to mitigate risk from sole source vendors (cost and schedule), early industry obsolescence (techniques and components), and supply chain economics

Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

2014 P5 Analysis: High-Level Takeaways

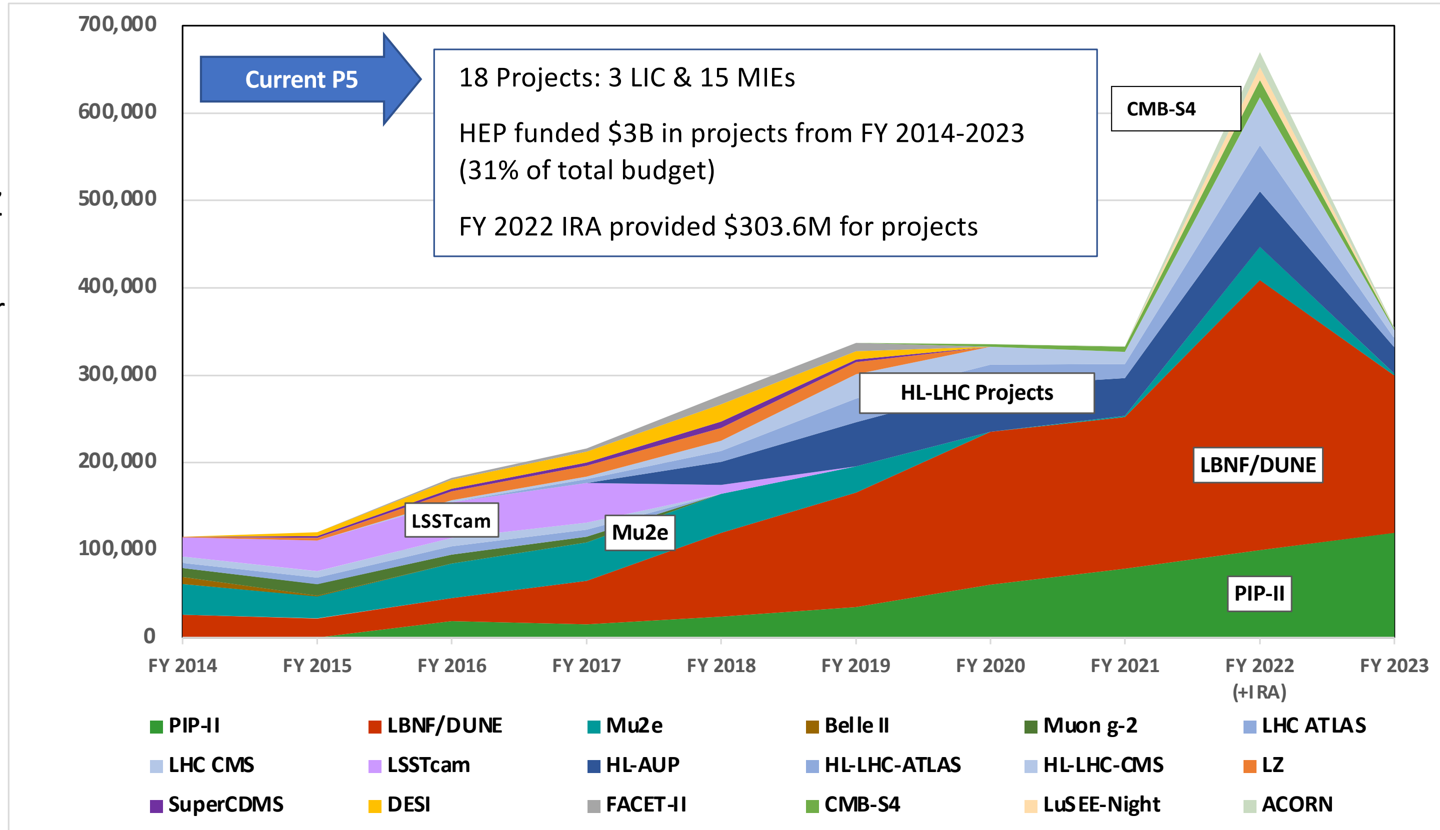
Particle Physics ***Project*** *Priority Panel: Focus on Building for Discovery*

- We all agree that P5 has been extremely successful. HEP budget has increased by >40% since FY 2015.
- While the P5 subcommittee did an excellent job in balancing the new and proposed projects, as well as Research & Facilities – this effort was designed with incomplete HEP budget input
- In many cases, the new projects are at least an **order of magnitude larger than previous generation experiments**
- The **growth for Research and Facilities associated with the P5 experiments was significantly underestimated**
  - By FY 2022, the imbalance with Projects had outpaced by **100M the optimal support** to both core Research and long-term R&D; modernization of SC User Facilities; and Operations of new experiments
- Consider for the 2023 P5 subcommittee: Particle Physics ~~Projects~~ Program Priority Panel
  - What is the **right-size of Research** to design, build, install, commission, and deliver science on new projects? How best to incorporate the scientific enterprise into the overall planning for projects?
  - Has the design and development of new projects include **robust planning for transition to Operations**, lifecycle, and decommissioning?
  - In which **ongoing and emerging R&D areas of national priority** does particle physics lead and/or partner?
  - Incorporate diversity, equity, inclusion, and accessibility into all decision making. Not as an add-on.

Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

2014 P5* Analysis: HEP Projects

- 2014 P5 report provided a roadmap for agencies to implement
- Total Project Costs increased for all approved MIEs (from HL-LHC Upgrades to DESI to LZ to SuperCDMS-SNOLAB to Muon g-2) offset by:
  - Delayed/reduced funding for ILC, DM G3, Small Projects, CMB-S4 (~$200M)
  - FY 2022 IRA (~$130M)
    - Also to mitigate COVID impacts
- Recommend applying additional risk contingency to 2023 P5 MIE funding estimates to better
  - Establish project timelines
  - Increase implementation flexibility
  - Manage stakeholder expectations



* ACORN and LuSEE-Night not in 2014 Report

Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

2014 P5 Analysis: HEP Facilities & Operations

FY 2014-2023 ($k)

Increase demands on SC User Facilities

- **Provide higher beam intensity**
- **Manage increasing data processing and storage**
- **Support a growing user population**

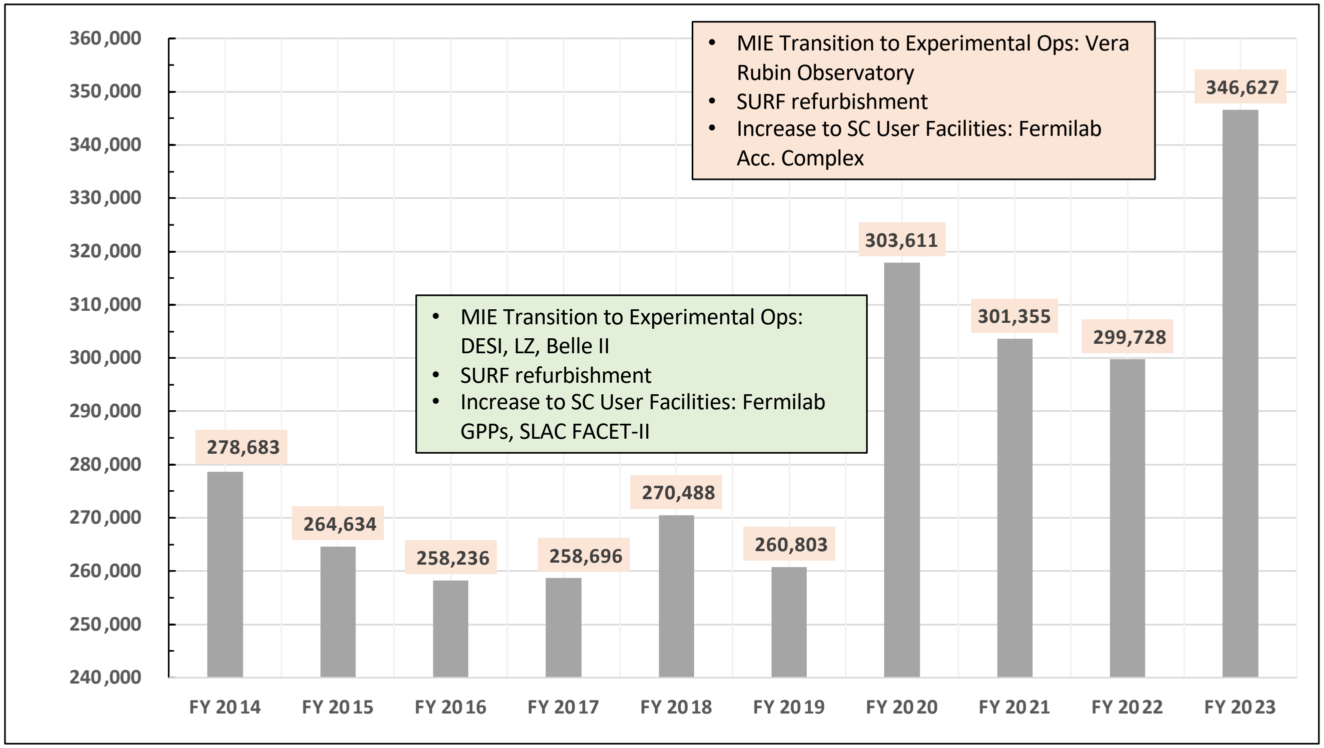
SURF refurbishment

Lab Infrastructure

Cosmic Projects Transition to Experimental Operations

Interagency coordination

International agreements



- 2014 P5 report reflected relatively flat funding profile for facilities (~$250M/year)
- P5 implementation demanded much greater resources for both MIE transition to experimental operations, and upgrades and modernization to SC User Facilities

Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

2014 P5 Analysis: Research

High Energy Physics	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Research	360,932	334,225	320,816	321,892	334,750	348,534	364,434	383,419	386,974	448,506
SBIR/STTR	21,601	20,768	20,847	22,151	24,427	24,095	25,212	25,465	25,298	15,867
Facilities/Ops	278,683	264,634	258,236	258,696	270,488	266,556	317,310	303,616	299,728	346,627
MIE Projects	84,305	109,373	129,001	128,761	137,935	144,815	107,044	81,500	98,000	57,000
Total "Discretionary"	745,521	729,000	728,900	731,500	767,600	784,000	814,000	794,000	810,000	868,000

- Research has increased steadily from FY 2016. New peak funding in FY 2023
- However, many factors **created a cumulative effect** adversely impacting the Core Research program
  - Cost of doing business has increased significantly, year by year, reducing the buying power of research dollars
  - University Research community continues to grow
  - Administrative & SC Research Initiatives not considered in 2014 P5 strategy
    - QIS, AI/ML, Microelectronics, etc. have grown from $18M in FY 2018 to >$110M in FY 2023
    - **Research Initiative alignment with Core Research: high (50%), medium (25%), low (25%)**

"Spare a dollar for some lab consumables, buddy?"

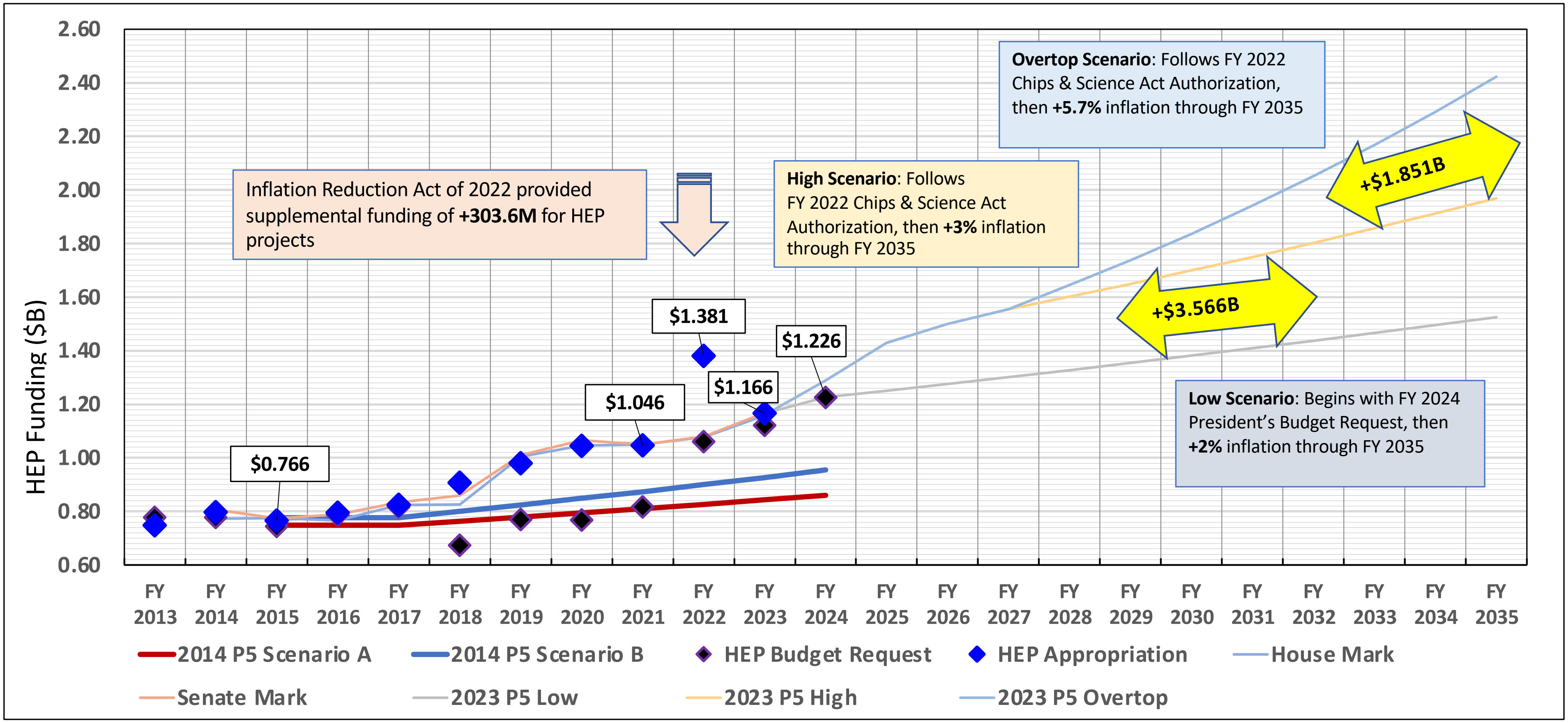
Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

Charge to a 2023 P5 Subcommittee

- Diverse workforce results in improved science
- HEP is a global field
- Support decisions to retain US leadership as a global partner
- Assess science case for on-going projects
- Preserve essential roles of Universities and National Labs
- Balanced core research budget is paramount to producing science
- Address synergies with broad national initiatives
- Remember costs of R&D, commissioning, and operations for future projects

Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

2023 P5 Budget Scenarios



Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting

FY 2024: High ($1.290B) vs. Low ($1.226B) Scenarios

Notable variances and impacts

High

Projects

- LBNF/DUNE ramps +$75M to $255M
  - Follows CD-1RR project funding profile
- PIP-II @$125M; CMB-S4 @25M
- HL-LHC ATLAS & CMS Upgrades, ACORN continue
- Assume no new mission needs

Facilities/Ops

- 2-3% increase across the board
- $4.9M Fermilab Accelerator Improvement Project (AIP)
- Ramp up DUNE Collaboration Support

Research

- Constant level of effort (assume 5% inflation)
- New lines for Directed R&D and P5 Research Hub
  - Former might be magnets, horns/targets
  - Latter might be university collaborative proposal

Low

Projects

- CMB-S4: -$16M, delay CD-1

Facilities/Ops

- Hold most costs flat from FY 2023

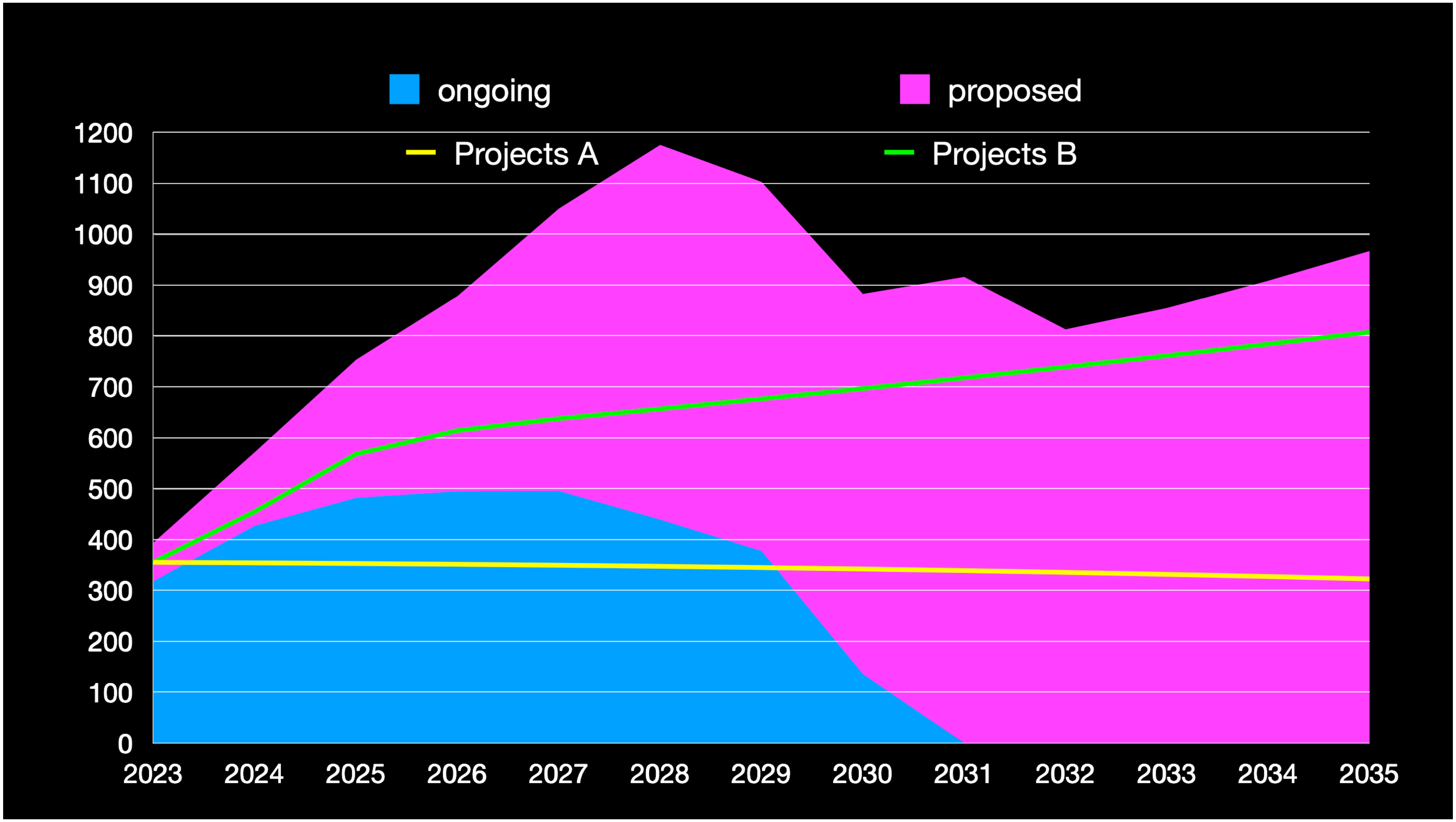
Research

- -$48M (-10%) below High Scenario, and -$26M (-6%) below FY 2023 funding levels
- With 5% year-to-year inflation (FY 2023 to FY 2024), resulting impact is a reduction of up to -11% on constant level of effort
  - Limited options to mitigate Reduction in workforce

No discretionary resources to start any new efforts

	High	Low
Research Fraction	37.44%	35.70%
Facilities/Operations Fraction	27.93%	29.16%
Projects Fraction	34.63%	35.14%
LIC Fraction	*29.14%*	*30.99%*
MIE Fraction	*5.49%*	*4.15%*
Year to Year Fraction Increase	10.68%	5.17%

Alan Stone, DOE, Aug. 2023 prepared for HEPAP Meeting


ongoing
proposed
Projects A
Projects B
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035

But wait, there's more…

International Benchmarking Subpanel & NAS Elementary Particle Physics 2024 (EPP 2024)

International Benchmarking Panel

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".

Mei Bai (SLAC), Marcela Carena (FNAL), Scott Dodelson (CMU), Dan Dwyer (LBL), Tova Holmes (UTK), Andy Lankford (UCI), Wim Leemans (DESY), Sekazi Mtingwa (NRC), Tsuyoshi Nakaya (Kyoto), Brian Nord (FNAL), Ian Shipsey (Oxford), Stefan Soldner-Rembold (Manchester), Lindley Winslow (MIT), Bonnie Fleming (Yale, Co-Chair), Patricia McBride (FNAL, Co-chair), JoAnne Hewett (HEPAP Chair, ex-officio)

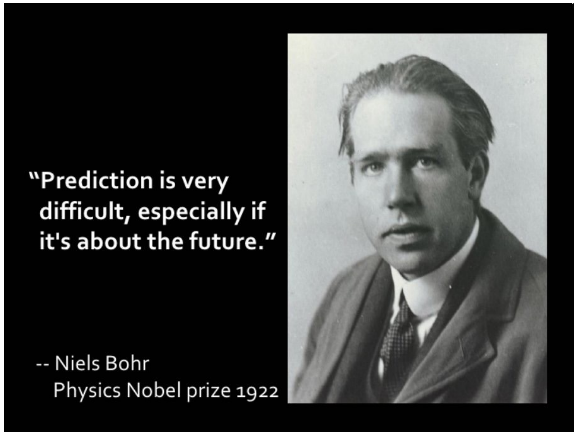
Elementary Particle Physics 2024: Progress and Promise

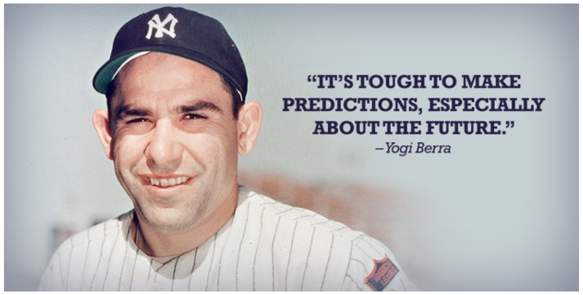
Committee of Elementary Particle Physics

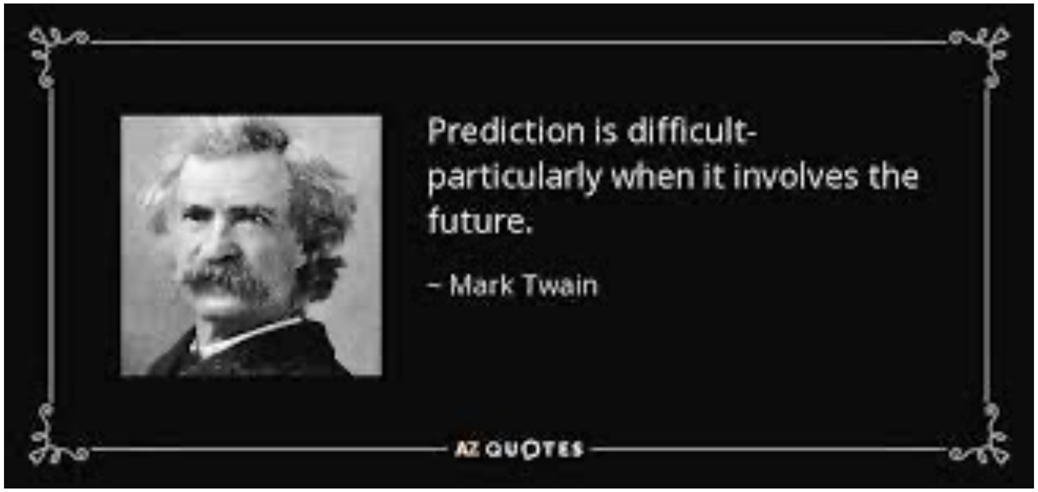
Board on Physics and Astronomy

Dr. Maria Spiropulu and Dr. Michael Turner, EPP2024 Co-Chairs

Personal Observations







Lessons from the Last Snowmass/P5 Process

- Collaboration with our agency (DOE and NSF) and global partners is essential.
- A coherent and balanced plan is essential.
  - Across "subfields"
  - Small, Medium, and Large Experiments
  - Fund "enabling" subfields
  - **Research and Projects?**
- A consistent message from our community is helpful.

There continues to be strong support for carrying through on the elements of the previous plan: HL-LHC, Dune Phase 1, LSST/Vera Rubin, etc.

The last plan succeeded – and the elements of a new successful plan exist!

New plan can only succeed with demonstrated community support.

“NEW” issues we must address…

- **Balance support for projects and R&D** (Kung: “holistic” approach)
  - Theory, Accelerator, Detectors
  - R&D trains and supports students and postdocs … the future of US HEP
- **Mix of short-term and long-term, small, medium, and large, projects.**
  - Need a continuous stream of opportunities for young scientists, even though the time-scales of our large projects continue to increase!
- **We need sustained and impactful outreach to the public and to government engagement, to create excitement and justify support.**
- **Address the (lack of) Diversity, Equity, and Inclusion in our field.**
  - If US particle physics is to be healthy in 10 years, let alone for the balance of the century, we must do a better job of including people from all backgrounds.

Probable events that we must be prepared for …

- The Electron-Ion Collider is highest priority for Nuclear Physics … “authorization” for construction funding was included in the “Chips and Science Act”.
  - The EIC will likely be the next big collider in the US – how can HEP collaborate with nuclear physics so EIC construction is a stepping stone to a potential new HEP collider in the US?

- CERN preparations for FCC-ee, with an eye toward FCC-hh, continue. A formal decision to proceed could come within the next five years.
  - What role will the US play, and how should this be integrated into US plans for a future collider – and how will we decide whether to join?

The next few years could be very bumpy ...

- Overall, HEP did very well in 2022:
  - FY23 DOE HEP Office of Science Appropriation $1.17B (+8% from FY22)
  - FY23 NSF Appropriation $9.87B (+12%, but core research "at least level"?)
  - $304M one-time HEP appropriation in "Inflation Reduction Act"
  - "Chips and Science" authorizes $1.29B for FY23, and continuing increases beyond.
- BUT: How will budgets fare under the new Congress?
  - Continuing resolution may be one outcome ... might leave funding levels at the authorized FY23 levels.
  - Some in Congress are asking for a roll-back to FY22 levels (-8% from FY23)...

What can you do?

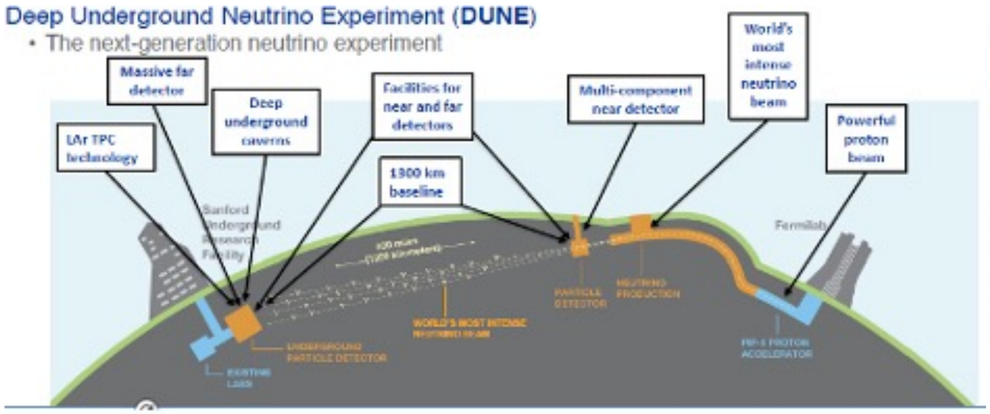
- Get informed – review background material now, be prepared to review and consider P5 report when it comes out.
- Try to view US particle physics as a whole…
  - Consider the output of P5 and, **hopefully, show your support.**
- Join DPF and APS
  - DPF is the only organization that represents US HEP as a whole.

Snowmass Summary and Outlook

- The Seattle meeting was a success, with a large in-person and remote presentation, with a total of over 1300 participants.
  - **The US HEP community showed great commitment and resilience to complete the process to this point – and did so in the face of great challenges!**
- Snowmass Report complete, we've handed off to P5.
- **We expect that we will emerge from this 2022/23 Snowmass/P5 process with a program that will enable us to do great physics and will have the same or higher level of community support than we achieved in 2013/14.**

Backup: Snowmass Conclusions

Large Projects: Neutrino Frontier



LBNF/DUNE-US Project + DUNE Int'l Project

Capability Description	Phase I	Phase II
Beamline		
1.2MW (includes 2.4MW infrastructure)	X	
2.4MW		X[1]
Far Detectors		
FD1 – 17 kton	X	
FD2 – 17 kton	X	
FD3		X[2]
FD4		X[2]
Near Detectors		
ND LAr	X	
TMS	X	
SAND	X	
MCND (ND GAr)		X

Note 1: requires upgrades to LBNF neutrino target and upgrades to Fermilab accelerator complex. The LBNF facility is built to support 2.4MW in Phase I.
Note 2: Caverns and cryo-infrastructure built in Phase 1

Neutrino Frontier Message

- A future program with a healthy breadth and balance of physics topics, experiment sizes, and timescales, supported via a dedicated, deliberate, and ongoing funding process, is highly desirable.
- Completion of existing experiments and execution **of DUNE in its full scope** are critical for addressing NF science drivers
- To exploit these new opportunities directed R&D needs to be supported.
- Strong and continued support for neutrino theory is needed.
- There are unique opportunities for NF to contribute to leadership of a cohesive, HEP-wide strategic approach to DEI and community engagement, which is urgently needed.

Joel Butler

Energy Frontier

It is essential to

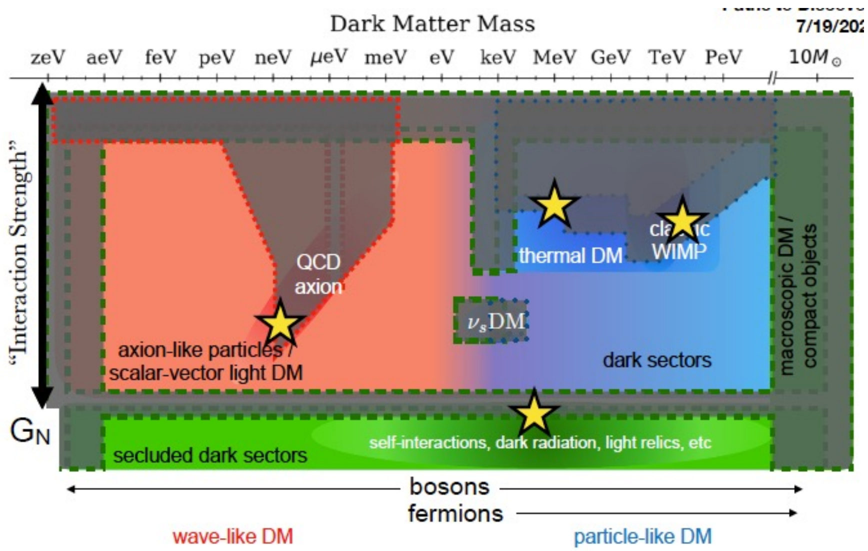
- Complete the LHC and HL-LHC program,
- Start now a targeted program for detector R&D for Higgs Factories
  - **Support a fast start of the construction of a Higgs factory**
- Ensure the long-term viability of the field by developing **a multi-TeV energy frontier facility such as a muon or hadron collider.**
- The US EF community has a renewed interest and ambition to bring back energy-frontier collider physics to US soil while maintaining its international collaborative partnerships and obligations, e.g. with CERN.
  - A US-sited linear e+e- collider (ILC/CCC) **(Cold Copper Collider)**
    - Exploring other e+e- collider options to fully utilize the Fermilab site
    - I sense that elements of the community at Snowmass are frustrated by a timeline which now appears to produce the next new collider about 25 years from now
  - Hosting a 10-TeV range Muon Collider
- Instrumenting uncovered parts of phase space in ATLAS and CMS (e.g. Faser, Mathusla) provides a "mid-scale" addition to the program and new opportunities for innovation and leadership

Joel Butler

Cosmic Frontier/Dark Matter

- The space of dark matter models encompasses a dizzying array of possibilities, representing many orders of mass and couplings.
- But there is a plan: ‘**Delve Deep, Search Wide**’ employs a range of direct searches for WIMPs interacting with targets on Earth, indirect searches for annihilation products, and cosmic probes based on structure, to scrutinize priority targets such as WIMPs and QCD axions, while broadly scanning parameter space, leaving no stone unturned.

- The next big project is CMB-S4
  - Endorsed as a “start” by P5 in 2014
  - **Has CD-0 from DOE**
- 2022-2036: Build and operate CMB-S4 (current large project)
- 2024: Target date for CD-0 for Spec-S5 (next large project)
- 2029: Begin CD process for LIM, GWO (future large project)



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Rare Processes and Precision Measurements Frontier

- **B- physics:**
  - **Strong support for US participation in LHCb and its next upgrade, Upgrade II.**
  - **Strong support for continued participation in BELLE**
- Beam dump searches for Dark Matter
- Possible light quark physics experiments, e.g. REDTOP
- **Possible Muon Facility (AMF) at FNAL**
  - Would employ PIP-II and additional machine upgrades to enable a world-leading facility to study **Charged Lepton Flavor Violation** in all three muon modes: $\mu^- N \rightarrow e^- N$; $\mu \rightarrow e\gamma$; and $\mu \rightarrow 3e$
    - Two new small rings for $\mu^- N \rightarrow e^- N$ and $\mu^- N \rightarrow e^+ N'$ and at high-Z and additional x100 in rate
    - x100-1000 more beam for $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$ than are possible at PSI
    - a possible DM experiment
  - possible muonium-antimuonium oscillation experiment
  - possible atomic physics studies with muonia
  - possible muon EDM experiment

Would like the PHYSICS of FLAVOR to be a SIXTH "DRIVER"

Joel Butler

Overview of the Large Scale Projects For the Four Experimental Physics Frontiers

<table>
<tr><th colspan="3">Decadal Overview of Future Large-Scale Projects</th></tr>
<tr><th>Frontier/Decade</th><th>2025 - 2035</th><th>2035 -2045</th></tr>
<tr><td rowspan="2">Energy Frontier</td><td colspan="2">U.S. Initiative for the Targeted Development of Future Colliders and their Detectors</td></tr>
<tr><td></td><td>Higgs Factory</td></tr>
<tr><td>Neutrino Frontier</td><td>LBNF/DUNE Phase I & PIP- II</td><td>DUNE Phase II (incl. proton injector)</td></tr>
<tr><td rowspan="2">Cosmic Frontier</td><td>Cosmic Microwave Background - S4
Spectroscopic Survey - S5*</td><td>Next Gen. Grav. Wave Observatory*
Line Intensity Mapping*</td></tr>
<tr><td colspan="2">Multi-Scale Dark Matter Program (incl. Gen-3 WIMP searches)</td></tr>
<tr><td>Rare Process Frontier</td><td></td><td>Advanced Muon Facility</td></tr>
</table>

Table 1-1. *An overview, binned by decade, of future large-scale projects or programs (total projected costs of $500M or larger) endorsed by one or more of the Snowmass Frontiers to address the essential scientific goals of the next two decades. This table is not a timeline, rather large projects are listed by the decade in which the preponderance of their activity is projected to occur. Projects may start sooner than indicated or may take longer to complete, as described in the frontier reports. Projects were not prioritized, nor examined in the context of budgetary scenarios. In the observational Cosmic program, project funding may come from sources other than HEP, as denoted by an asterisk.*

Joel Butler

Theory Frontier

- Support the essential role of theory similar to (and at least as strong as) recommended by the European Strategy Update, both in relation to projects and in its own right.
- **Support for a balanced program of Projects and Research, as both are essential to the health of the field.**
- **Support for people, especially early career, who are the key "infrastructure" of Research.**
- **Support for targeted funding advancing the physics goals.** (E.g. LQCD Project, LHC Theory Initiative, Neutrino Theory Network, QIS, AI/ML, Exascale Computing Project, SciDAC…)

Joel Butler

Accelerator Frontier

- To enable the near-to medium-term future, AF needs
  1. An integrated **National Future Collider R&D Program** in OHEP to engage in the design and to coordinate development of the next generation collider projects such as: ILC, CLIC, FCC-ee, CCC/HELEN, a multi-TeV Muon Collider, or hadron collider.
- To enable medium- and long-term future, we an active R&D program in labs and universities aimed at general accelerator R&D that is critical in developing technologies and options for future HEP accelerators (but does not develop accelerator proposals), e.g.
  1. General Accelerator R&D (GARD)
  2. Accelerator and Test facilities

Computational Frontier

- With the end of the Moore's Law era, we will be using accelerators (GPUs, FPGAs, Vector units), parallelism within events, common systems, High Performance Computing Centers for production
  - There will be many changes
- CompF recommends the creation of a standing Coordinating Panel for Software and Computing (CPSC) under the auspices of **DPF** mirroring the panel for advanced detectors (CPAD) established in 2012
  - *Promote, coordinate, and assist the HEP community on Software and Computing, working with scientific collaborations, grassroots organizations, institutes and centers, community leaders, and funding agencies on the evolving HEP Software and Computing needs of experimental, observational, and theoretical aspects of the HEP programs. The scope should include research, development, maintenance, and user support.'*
- Long-term development, maintenance, and user support of essential software packages cutting across project or discipline boundaries is largely unsupported.
- Research and development (R&D) for software and computing cutting across project or discipline boundaries receive insufficient support.
- Scarcity of personnel and expertise jeopardizes the ability for full and optimal use of heterogeneous and high performance computing (HPC) resources

Joel Butler

Instrumentation Frontier

- Double the US Detector R&D budget over the next five years and modify existing funding models to enable R&D Consortia along critical key technologies for the planned long term science projects, sustaining the support for such collaborations for the needed duration and scale
  - CERN RD Collaborations for targeted and coordinated detector R&D wildly successful. We recommend the establishment of a similar model of R&D Consortia in the US,
- Advance performance limits of existing technologies and push new techniques and materials
- Develop and maintain the critical and diverse technical workforce, and enable careers for technicians, engineers and scientists across disciplines working in HEP instrumentation, at laboratories and universities
- Expand and sustain support for blue-sky, table-top RD, and seed funding.
- Develop and maintain critical facilities, centers and capabilities for the sharing of common knowledge and tools, as well as develop and maintain close connections with international technology roadmaps, other disciplines and industry.

Joel Butler

Community Engagement Frontier

- Major Goals
  - It is critical that we all agree on the importance of everyone working together in CEF to organize and develop our ongoing CE efforts in a coherent manner focused on improving our HEP community and achieving the vision we are defining for our field.
  - A structure must be established within HEP for taking ownership and responsibility for implementing CEF recommendations and monitoring their progress across the entire field.
- Structural Change
  - All stakeholders form a P5-equivalent panel to shepherd CEF recommendations
    - Must have direct connection to multiple streams of resources
    - As opposed to P5: agencies fund/implement projects, so P5 lives within DOE/NSF
  - Review CEF Integration in Snowmass
    - Perhaps do major work on field-wide CEF planning asynchronously, enhance participation
    - Other Frontiers could still report on CEF activities during Snowmass

Nevertheless, significant work was done over a very wide range of topics:

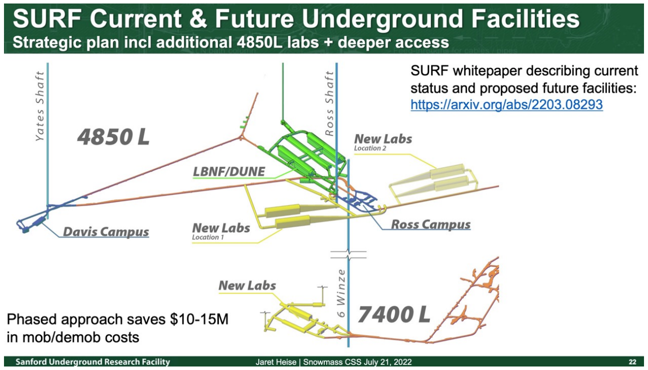
- Applications and Industry
- Career Pipeline and development
- Diversity, Equity, and Inclusion
- Physics Education
- Public Education and Outreach
- Public Policy and Government Engagement
- Environmental and Societal Impacts (sustainability)

By far the most disturbing problem the conveners encountered was the extremely low participation in CEF by members of our field.

Joel Butler

Underground Frontier

- Neutrinos, rare processes, and cosmic frontier experiments and enabling R&D require more space than available
- Leverage the LBNF excavation enterprise to increase underground space at SURF in a timely and cost-effective way to allow the US to compete for siting next generation WIMP dark matter experiments
- Make SURF an SDSTA-managed DOE User Facility to foster cross-cutting underground science in the US
- Invest in the diversity of people and expertise required for the design, installation, integration, and operations of this increasingly complex program



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Some High-level Conclusions - I

- The science questions that HEP seeks to answer continue to be the ones identified in the 2013 Snowmass Report and so eloquently and succinctly summarized by P5 in the formulation of its Five HEP Science Drivers. These five drivers have guided US HEP for nearly a decade with great success. There was a consensus in Snowmass that these drivers were still relevant for the next decade.
  - There was a suggestion that the physics of flavor, currently included under the fifth driver, be more specifically recognized given the current tensions between recent results in this area and the Standard Model. An assessment of the current and projected status of HEP relative to the P5 Drivers is given below.
- The portfolio of projects should continue to include a healthy breadth and balance of physics topics, experiment sizes and timescales, supported via a dedicated, robust, ongoing funding process.
- Completion of existing experiments and operation of DUNE and the HL-LHC programs, priorities of the 2104 P5 are critical for addressing the science drivers for the near term and for much of the next two decades.
- Strong, robust support for the research program is essential to analyze the data from the existing and planned experiments, plan upgrades and future programs and projects, and educate the next generations of researchers and technical experts.
- Strong and continued support for formal theory, phenomenology and computational theory is needed, as are stronger, targeted efforts connecting theory to experiment.

Some High-level Conclusions - II

- Both R&D directed to specific future projects and generic research needs to be supported in critical enabling technologies such as accelerators, instrumentation/detectors and computation, and in new ones such as quantum science and machine learning.
- An overall strategy, with overarching goals, for HEP engagement with five interrelated communities: HEP itself and the broader academic community, K-postdoc education, private industry, government policy makers, and the broader society, should be formulated. A structure for achieving these goals should be provided, along with the necessary resources, should be provided.
- The HEP community should institute a broad array of practices programs to reach and retain the diverse talent pool needed for success in achieving our scientific vision.
- A cohesive, strategic approach to promoting diversity, equity and inclusion in high-energy physics, and to improving community outreach and engagement, is required