Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the 2023 Particle Physics Project Prioritization Panel

Sally Seidel, Hitoshi Murayama, Karsten Heeger

Exploring the Quantum Universe

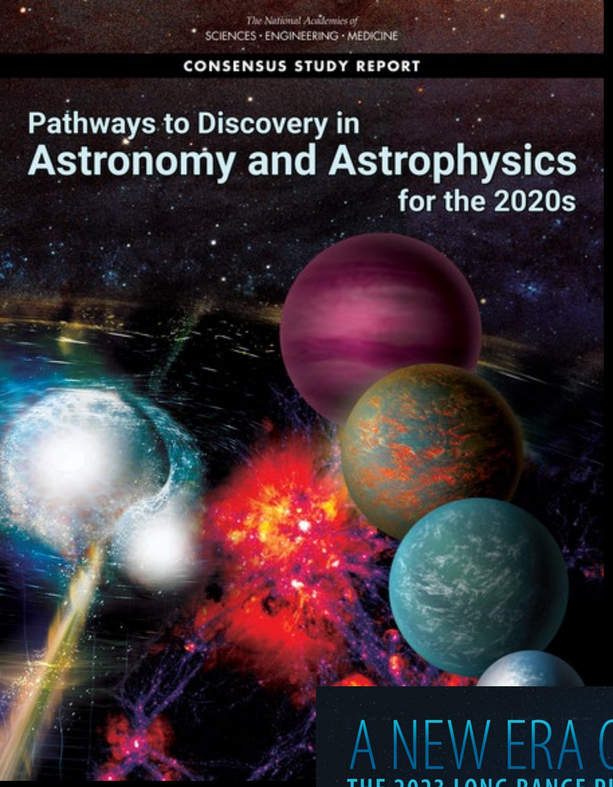
2023p5report.org

on behalf of HEPAP and P5

U.S. DEPARTMENT OF ENERGY

NSF

NASEM Board of Physics and Astronomy 05/08/2024


The National Academies of
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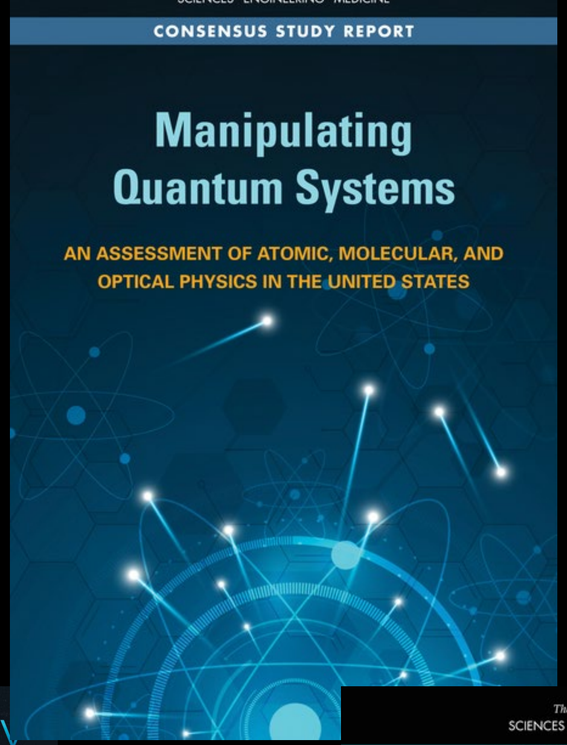
CONSENSUS STUDY REPORT
Pathways to Discovery in
Astronomy and Astrophysics
for the 2020s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Manipulating
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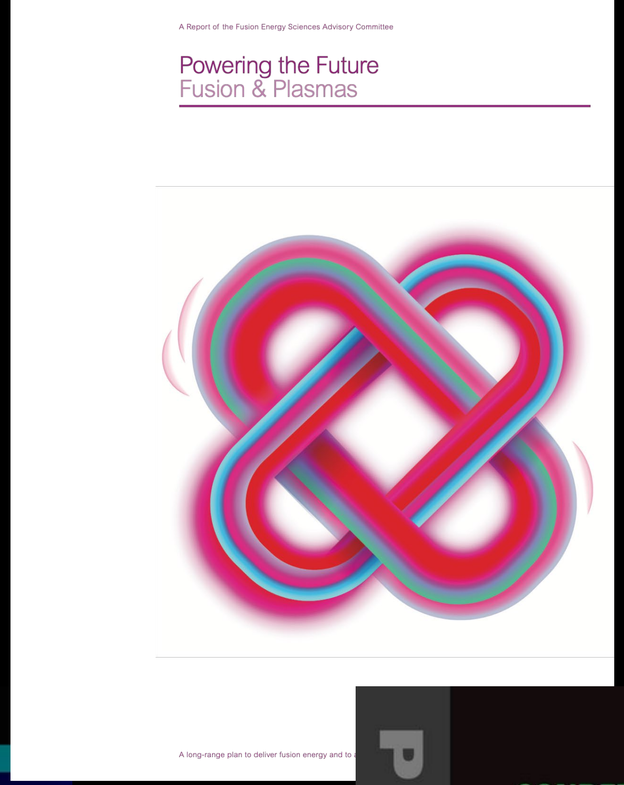
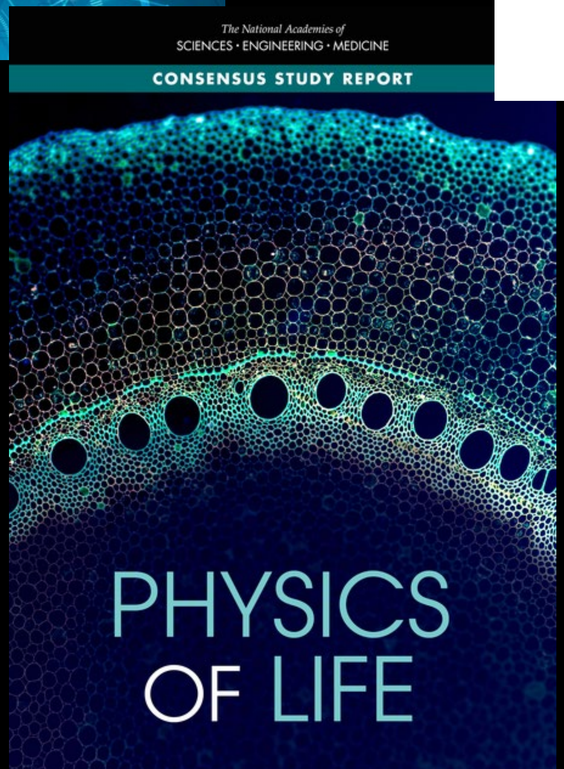
AN ASSESSMENT OF ATOMIC, MOLECULAR, AND
OPTICAL PHYSICS IN THE UNITED STATES


A Report of the Fusion Energy Sciences Advisory Committee
Powering the Future
Fusion & Plasmas
A long-range plan to deliver fusion energy and to


A NEW ERA OF DISCOVERY
THE 2023 LONG RANGE PLAN FOR NUCLEAR SCIENCE
2023 | VERSION 1.1
Measuring Ions Per Bunch in the RFQ
NSF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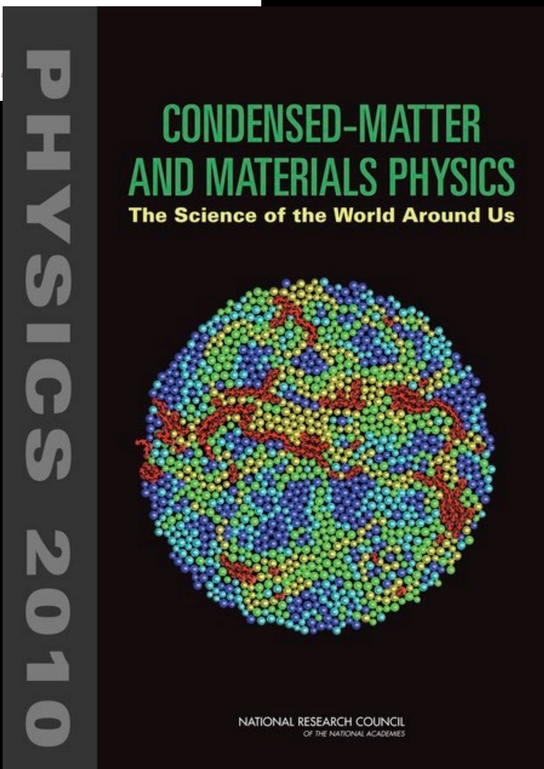
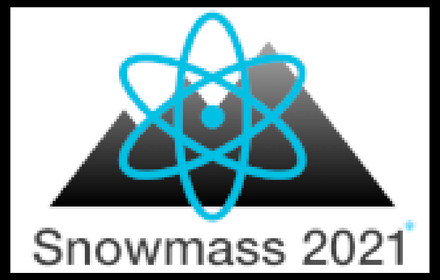

PHYSICS 2010
CONDENSED-MATTER
AND MATERIALS PHYSICS
The Science of the World Around Us
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Process for Future Planning

Community

“Snowmass”
Community Study

Organized by
APS / DPF



Particle Physics Project
Prioritization Panel (P5)

Organized by
HEPAP

Charge
Budget scenario

DOE HEP
NSF PHYS

DOE HEP
NSF PHYS

OMB
OSTP
Congress

Some Background

- HEPAP = High Energy Physics Advisory Panel
  - A standing committee that advises DOE HEP and NSF PHY
    - analogous to NSAC (DOE NP and NSF PHY), AAAC (NSF AST, NASA, DOE HEP)
  - 2 to 4 meetings a year
  - Current chair: Sally Seidel + 18 physicists
  - 1972 Federal Advisory Committee Act (FACA) and 1976 Government in the Sunshine Act require such advisory panels meet in the open
    - Impossible to discuss sensitive issues such as prioritization!
- But HEPAP can create a “subpanel” whose meetings can be closed
  - HEPAP subpanels existed for a long time
  - made recommendations on big things like SSC, or specific issues like accelerator R&D
  - program-wide long-range planning by Snowmass+P5 has been done only twice so far: 2013-2014, 2020-2023

NASEM Panels in Particle Physics

- 1972 survey of physics “Physics in Perspective” (broad)
- 1986 “Elementary-Particle Physics”
- 1988 “Research Opportunities in General Physics” (broad)
- 1998 “Elementary-Particle Physics: Revealing the Secrets of Energy and Matter”
- 2001 “Physics in a New Era: An Overview” (broad)
- 2003 “Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century” (interdisciplinary)
- 2003 “Neutrinos and Beyond: New Windows on Nature” (specific)
- 2006 “Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics”
- 2007 “Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future” (broad)
- 2010 “Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5” (broad)
- 2012 “An Assessment of the Science Proposed for the Deep Underground Science and Engineering Laboratory (DUSEL)” (interdisciplinary)
- 2024 EPP2024 “Elementary Particle Physics: Progress and Promise” (ongoing, due this year)

DPF and HEPAP on Planning

- 1982 First Snowmass: Summer Study on Elementary Particle Physics and Future Facilities
  - Responding to the new collider being built in Europe
  - Community came out strong on what will later become SSC
- 1983 HEPAP “New Facilities for the U.S. High Energy Physics Program” recommended SSC
  - 1984, 1988 DPF Summer Studies on SSC
- 1988 DPF Summer Study on High-energy Physics in the 1990s (broader)
- 1990 DPF Summer Study on High-energy Physics: Research Directions for the Decade (broader)
- 1993 Cancellation of SSC by Congress
- 1994 HEPAP “Vision for the Future of High-Energy Physics” recommended LHC
- 1996 Summer Study on New Directions for High-Energy Physics e^+e^-LC vs LHC
- 1998 HEPAP “Planning for the Future of U.S. High-Energy Physics”
  - Recommended R&D for future energy frontier machines: LC, μC, VLHC
- 2001 DPF / DPB Summer Study on the Future of Particle Physics
- 2002 “The Science Ahead, The Way to Discovery” HEPAP long range plan for U.S. high-energy physics in the 21st century, strongly recommended e^+e^- ILC

P5

- Individual small- and medium-scale projects used to be purview of lab PACs
- Around 2000, it was becoming increasingly clear that “projects” have become too big to be handled by lab PACs
- 2001 HEPAP subpanel recommended creation of Particle Physics Project Prioritization Panel (P5)
- 2003 P5
  - CDF/D0 Run II upgrades, BTeV, terminated CKM
- 2004 P5
  - Recommended staging of BTeV
- 2007 P5
  - Tevatron beyond FY09? Deferred decision

DPF and HEPAP on Planning

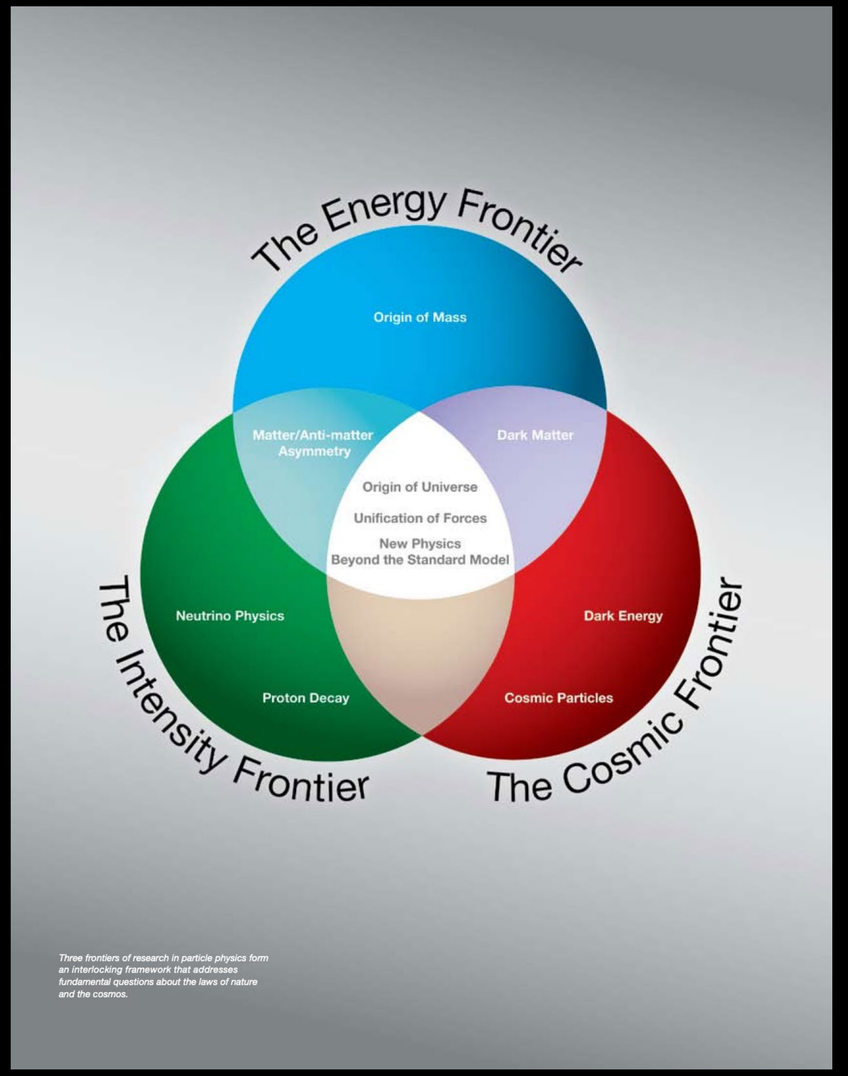
- 2007 Cost estimate for the ILC came out too high
- 2008 “US Particle Physics: Scientific Opportunities. A Strategic Plan for the Next Ten Years”
  - Supported Tevatron followed by LHC
  - recommended neutrino, dark matter, dark energy
- 2013 Community Summer Study (concluded in Minneapolis)
- 2014 “Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context”
  - recommended HL-LHC, LBNE (later named DUNE/LBNF), embraced CMB
- 2021 Snowmass 2021 (concluded in Seattle)
- 2023 “Exploring the Quantum Universe: Pathways to Innovation and Discovery in Particle Physics”

Differences from NRC panels

- HEPAP chair recommends the P5 chair in consultation with DOE/NSF
  - HEPAP chair ex officio on P5
- Solicit nominations of P5 members from the community
- P5 and HEPAP chairs appoint P5 members in consultation with DOE/NSF
  - this time Deputy Chair appointed first, and three of us worked together
- A federal employee always present even at closed meetings (FACA)
- Community inputs at closed sessions allowed
- Peer reviews optional (but had them anyway in recent P5)
- Briefing to agencies twice to make sure the recommendations are actionable
- P5 report needs to be approved by HEPAP
  - We also held an after-the-fact town hall to gain community buy-in

2008 P5

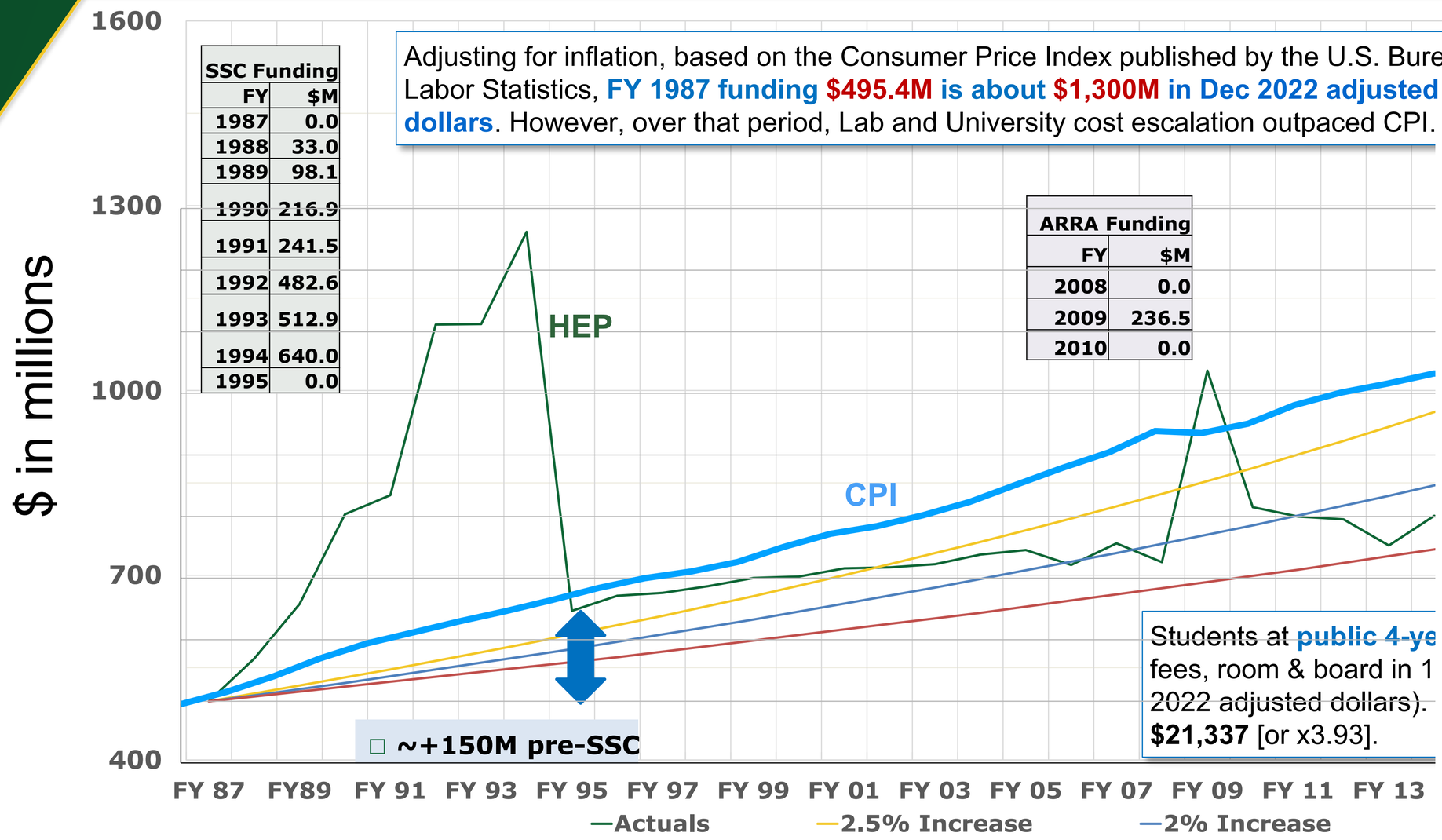
- 2008 P5 (Charles Baltay)
  - First “modern” P5 for the whole program with budget scenarios
  - Tevatron for one to two more years
  - World-class neutrino program
  - Dark matter & dark energy, LSST
- *US Particle Physics: Scientific Opportunities A Strategic Plan for the Next Ten Years*
- Coined Energy, Intensity, Cosmic Frontiers



2014 P5

- 2014 P5 (Steve Ritz)
  - 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.
- Recommended LBNE → DUNE/LBNF
- Embraced CMB in HEP
- Finally "got it right"
  - Well received in Washington
  - increased HEP budget by ~30%
  - "*Made many hard choices*"

HEP Funding in Historical Context: 1987 to Present



SSC Funding	
FY	$M
1987	0.0
1988	33.0
1989	98.1
1990	216.9
1991	241.5
1992	482.6
1993	512.9
1994	640.0
1995	0.0

Adjusting for inflation, based on the Consumer Price Index published by the U.S. Bureau of Labor Statistics, **FY 1987 funding $495.4M is about $1,300M in Dec 2022 adjusted dollars**. However, over that period, Lab and University cost escalation outpaced CPI.

ARRA Funding	
FY	$M
2008	0.0
2009	236.5
2010	0.0

IRA Funding	
FY	$M
2021	0.0

Students at **public 4-ye**
fees, room & board in 1
2022 adjusted dollars).
$21,337 [or x3.93].

Before the previous P5


1800 LoIs
548 White Papers
>1500 people
Final workshop of Snowmass 2021 Community Study
University of Washington, July 2022

Key Elements of a Successful P5

- Well informed by the science community
- Set a grand long-range vision for U.S. particle physics
- Faced budget constraints realistically
  - "Community made tough choices."
- Balanced portfolio
  - Domestic and international
  - Small, mid-scale, and large projects
- Community engagement critical to success
  - "Bickering scientists get nothing."

Harriet Kung, Snowmass in Seattle
Then interim director of HEP
Now deputy director for Science Programs

P5 Charge (dated November 2, 2022)  1/8

Dear Dr. Hewett:

The 2014 report of the Particle Physics Project Prioritization Panel (P5), developed under the auspices of the High Energy Physics Advisory Panel (HEPAP), successfully laid out a compelling scientific program that recommended world-leading facilities with exciting new capabilities, as well as a robust scientific research program. That report was well received by the community, the U.S. Department of Energy (DOE) and the National Science Foundation (NSF), and Congress as a well-thought-out and strategic plan that could be successfully implemented. HEPAP's 2019 review of the implementation of this plan demonstrated that many of the report's recommendations are being realized, and the community has made excellent progress on the P5 science drivers.

- The 2014 report was successful
- 2019 implementation review by HEPAP showed progress on the plan

As the landscape of high-energy physics continues to evolve and the decadal timeframe addressed in the 2014 P5 report nears its end, we believe it is timely to initiate the next long-range planning guidance to the DOE and NSF. To that end, we ask that you constitute a new P5 panel to develop an updated strategic plan for U.S. high-energy physics that can be executed over a 10-year timeframe in the context of a 20-year, globally aware strategy for the field.

- 2023 P5 to update strategic plan over 10-yr timeframe in 20-yr context

P5 Charge  2/8

A critical element of this charge is to assess the continued importance of the science drivers identified by the 2014 P5 report and, if necessary, to identify new science drivers that have the potential to enable compelling new avenues of pursuit for particle physics. Specifically, we request that HEPAP 1) evaluate ongoing projects and identify potential new projects to address these science drivers; 2) make the science case for new facilities and capabilities that will advance the field and enhance U.S. leadership and global partnership roles; and 3) recommend a program portfolio that the agencies should pursue in this timeframe, along with any other strategic actions needed to ensure the broad success of the program in the coming decades.

In developing the plan, we would like the panel to take into consideration several particularly relevant aspects of constructing a compelling and well-balanced portfolio:

- Re-evaluate the 2014 science drivers
- Evaluate ongoing projects
- Identify new projects
- Make science case for new facilities and capabilities
- Recommend program portfolio

P5 Charge  3/8

- A core tenet of the 2014 P5 Report is that particle physics is fundamentally a global enterprise. Thus far, the U.S. program has achieved high impact through U.S. researchers participating in the programs at world-class facilities outside the U.S. and international researchers working at world-class U.S. facilities. The recommendations developed for this report should carefully consider the current and future international landscape for particle physics. The panel's report should include an explicit discussion of the choices made in this context, including the extent to which it is necessary to construct, maintain, and/or upgrade leading U.S.hosted high-energy physics facilities so that our leadership position in the global scientific arena continues, while at the same time preserving the essential roles of, and contributions by, the National Laboratories and universities to global collaboration on large-scale initiatives.

- Remember HEP is a global field
- Support decisions to retain US leadership as a global parter
- Preserve essential roles of Universities and National Labs

- A number of the projects recommended by the 2014 P5 report are still being built, and the agencies take their commitments to complete them very seriously. Understanding the continued strength of the science case for these projects is quite valuable, and the panel should provide its assessment of these projects in this context.

- Assess science case for on-going projects

P5 Charge  4/8

- A successful plan should maintain a balance of large, medium, and small projects that can deliver scientific results throughout the decadal timeframe. We do not expect the panel to consider the large number of possible small-scale projects individually, but advice on research areas where focused investments in smallscale projects can have a significant impact is welcome.
- There are elements of DOE HEP-operated infrastructure that are a stewardship responsibility for HEP. Investments to maintain that infrastructure in a safe and reliable condition are an HEP responsibility and are outside the scope of the panel. Major infrastructure upgrades that create new science capabilities are within the scope of the charge and should be considered by the panel.
- Successfully exploiting a newly built project requires funding for the commissioning and operation of the project and to support the researchers who will use these new capabilities to do world-leading science. Funding is also needed for research and development (R&D) that develops new technologies for future projects. Scientists and technical personnel working in experimental particle physics often contribute to all these project phases, while theoretical physics provides both the framework to evolve our fundamental understanding of the known universe as well as the innovative concepts that will expand our knowledge into new frontiers. The panel should deliver a research portfolio that will balance all these factors and consider related issues such as training and workforce development.

- Maintain balance of large, medium & small projects
- Advise on science topics to focus small projects
- Assess infrastructure upgrades that create new science capabilities
- Remember costs of R&D, commissioning, and operations for future projects
- Remember that a balanced core research budget is paramount to producing science from current projects and developing ideas for new ones

P5 Charge  5/8

- Both NSF and DOE are deeply committed to diversity, equity, inclusion, and accessibility principles in all the scientific communities they support. Creating a more diverse and inclusive workforce in particle physics will be necessary to implement the plan that this panel recommends, and the panel may further recommend strategic actions that could be taken to address or mitigate barriers to achieving these goals.
- Broad national initiatives relevant to the science and technology of particle physics have been developed by the administration and are being implemented by the funding agencies. These include, but are not limited to, investments in advanced electronics and instrumentation, artificial intelligence and machine learning, and quantum information science. Potential synergies between these initiatives and elements of the recommended portfolio should be considered.

- Remember that a diverse workforce results in improved science

- Address synergies with broad national initiatives

P5 Charge - budget scenarios 6/8

We request that the panel include these considerations in their deliberations and discuss how they affect their recommendations in the report narrative.

The panel's report should identify priorities and make recommendations for an optimized particle physics program over 10 years, FY 2024–FY 2033, under the following budget scenarios:

1) Increases of 2.0 percent per year during fiscal years 2024 to 2033 with the FY 2024 level calculated from the FY 2023 President's Budget Request for HEP.
2) Budget levels for HEP for fiscal years 2023 to 2027 specified in the Creating Helpful Incentives to Produce Semiconductors and Science Act of 2022, followed by increases of 3.0 percent per year from fiscal years 2028 to 2033.

The recommended projects and initiatives should be implementable under reasonable assumptions and be based on generally accepted estimates of science reach and capability. Estimated costs for future projects and facility operations should be given particular scrutiny and may be adjusted if the panel finds it prudent to do so. Given the long timescales for realizing these initiatives, we expect the funding required to enable the priorities the panel identifies may extend well past the 10-year budget profile, but any recommendation should be technically and fiscally plausible to execute in a 20-year timeframe.

- Scenario A: 2% increase per year
- Scenario B: Budgets in Chips and Science Act, followed by 3% increase per year

- Evaluate projected project costs
- Plan should be executable in 20-yr timeframe

P5 Charge  7/8

In addition to articulating the scientific opportunities that can and cannot be pursued in the various scenarios, the panel may provide their opinions on the approximate overall level of support that is needed for core particle physics research and advanced technology R&D programs to be successful in the context of the science goals of the recommended plan.

We expect the "Snowmass" community planning reports and HEPAP's 2022 study on international benchmarking of scientific resources and capabilities will be useful inputs and that the panel will make efforts to maximize community input and participation in the overall process. Coordination and congruence with the National Academies of Sciences, Engineering, and Medicine's recent and ongoing decadal studies in astronomy, astrophysics, and particle physics are also important considerations.

- Evaluate level of core research budget and technology R&D programs

- Include Snowmass report and Benchmarking subpanel report in deliberations
- Strive towards coordination and congruence with EPP2024

P5 Charge 8/8

Finally, effective communication about the excitement, impact, and vitality of particle physics that can be shared with a general audience and other disciplines continues to be critical when advocating the strategic plan. It would be particularly valuable if the panel could re-state the key scientific questions that drive the field so that they are accessible to non-specialists and crisply articulate the value of basic research and the broader benefits of particle physics on other sciences and society.

We would appreciate the panel's preliminary comments by August 2023 and a final report by October 2023. We recognize that this is a challenging task; nevertheless, your assessments will be an essential input to planning at both the DOE and NSF.

Sincerely,

Asmeret Asefaw Berhe
Director, Office of Science
U.S. Department of Energy

Sean L. Jones
Assistant Director
Directorate for Mathematical and Physical Sciences
National Science Foundation

- Effectively communicate the 2023 P5 plan once it's finished
- Preliminary comments in August 2023
- Report due by October 2023


with five international members

Interface to EPP2024

- An NRC panel also studying the future of particle physics
- EPP2024 looks into long-term vision, dreams
  - unconstrained by budget scenarios
- Hitoshi was on EPP2024 until appointed as the P5 chair
- JoAnne and Hitoshi gave talks in their November & December 2022 meetings
- Karsten was on the panel discussion in their July 2023 meeting
- Sally gave a talk in their August 2023 meeting
- We invited EPP2024 members to all P5 town halls to make sure we get the same inputs from the community
  - We overlapped at Fermilab in March
- Hopefully what P5 recommended smoothly connect to their longer-term vision

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P5 Timetable and Process

Charge issued on Nov 2, 2022 by Dr. Berhe (DOE SC) and Dr. Jones (NSF MPS)

Panel formed by the end of January 2023

Information Gathering Phase

Snowmass Report

Open Town Halls

LBNL: February (513), Fermilab/Argonne: March (797) overlapped with EPP2024, Brookhaven: April (666), SLAC: May (512)

Virtual Town Halls

UT Austin: June (159) with an exclusive session for early career scientists, Virginia Tech, June (119)

All town halls offered live captioning and ASL

Many occasions for community engagement throughout the process as well as international partners

Deliberation Phase

Closed meetings

Austin, Gaithersburg, Santa Monica, Denver, May to August

Additional input from

Agencies Asmeret Berhe, Harriet Kung (DOE), many from DOE/HEP, NSF/PHY, NSF/AST, NSF/OPP

Government Cole Donovan (State, OSTP)

Community

International Benchmarking Panel, computing frontier, DPF leadership, previous P5 (Steve Ritz, Andy Lankford), CoV reports (Ritchie Patterson, Dmitry Denisov)

Frequent Meetings by working groups

Roll-out Phase

HEPAP approval on Dec 8, 2023

Fermilab Town Hall on Dec 11, 2023, followed by talks at collaboration meetings, conferences

outreach to wider communities, department colloquia, international partners and funding agencies, public lectures

Costs/Risks/Schedule

- One lesson from the previous P5 was some of the costs were off by a factor of ~π
- Need to understand maturity of cost estimates better
- Jay Marx (Caltech), Chair
  - Gil Gilchriese, Matthaeus Leitner (LBNL)
  - Giorgio Apollinari, Doug Glenzinski (Fermilab)
  - John Seeman, Mark Reichanandter, Nadine Kurita (SLAC)
  - Jon Kotcher, Srini Rajagopalan (BNL)
  - Allison Lung (JLab)
  - Harry Weerts (Argonne)

Jay Marx

We have received their report on June 30, 2023

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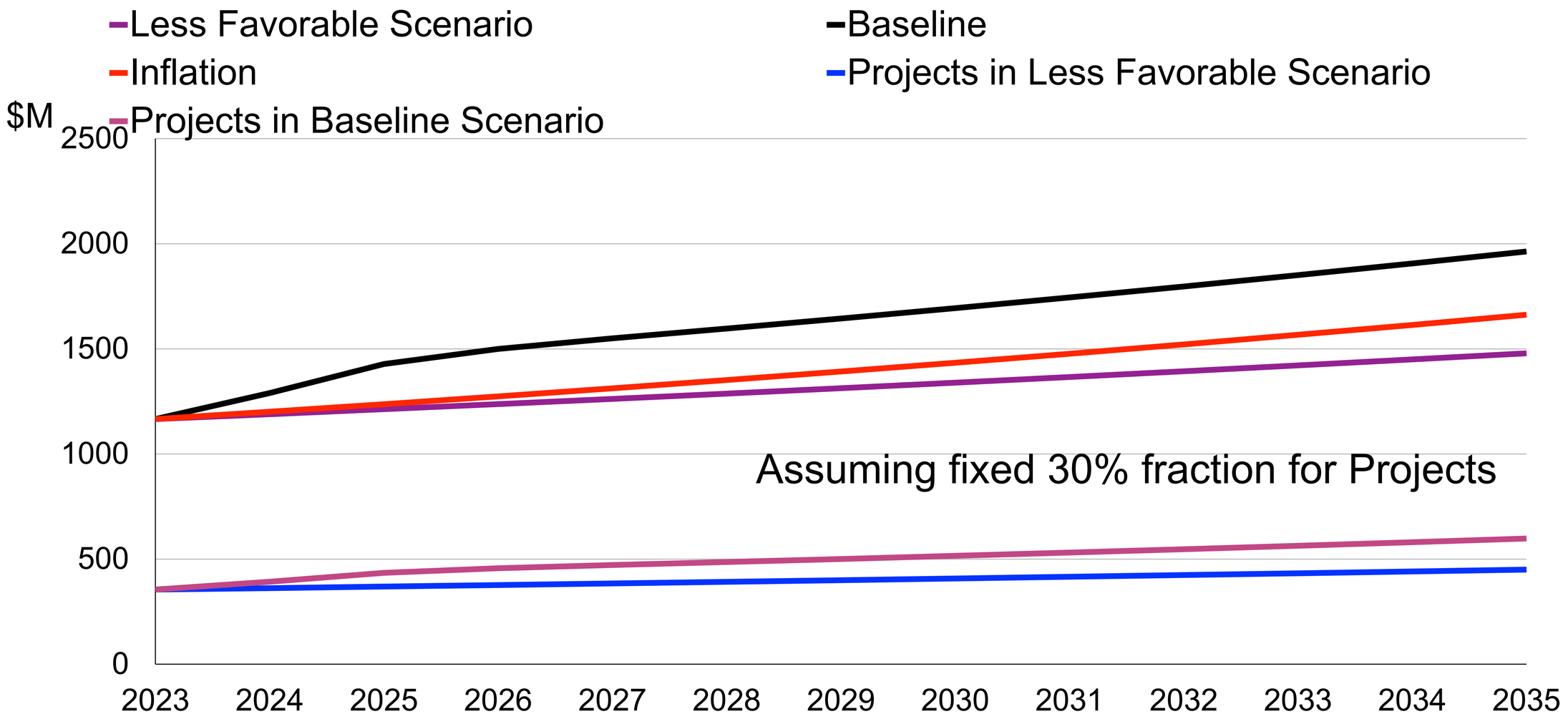
Budget Scenarios



DOE only

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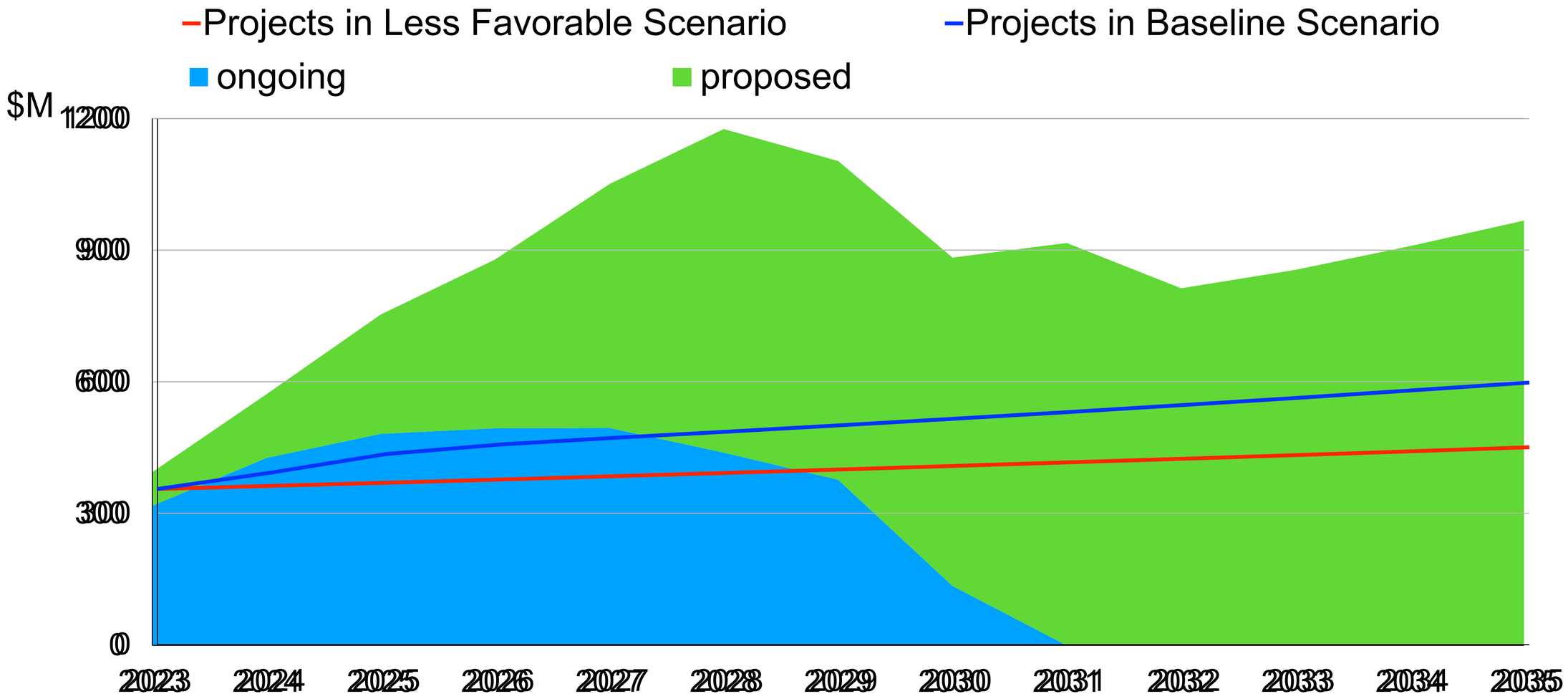
Budget Scenarios and Projects



some multi-billion-dollar projects excluded

DOE only

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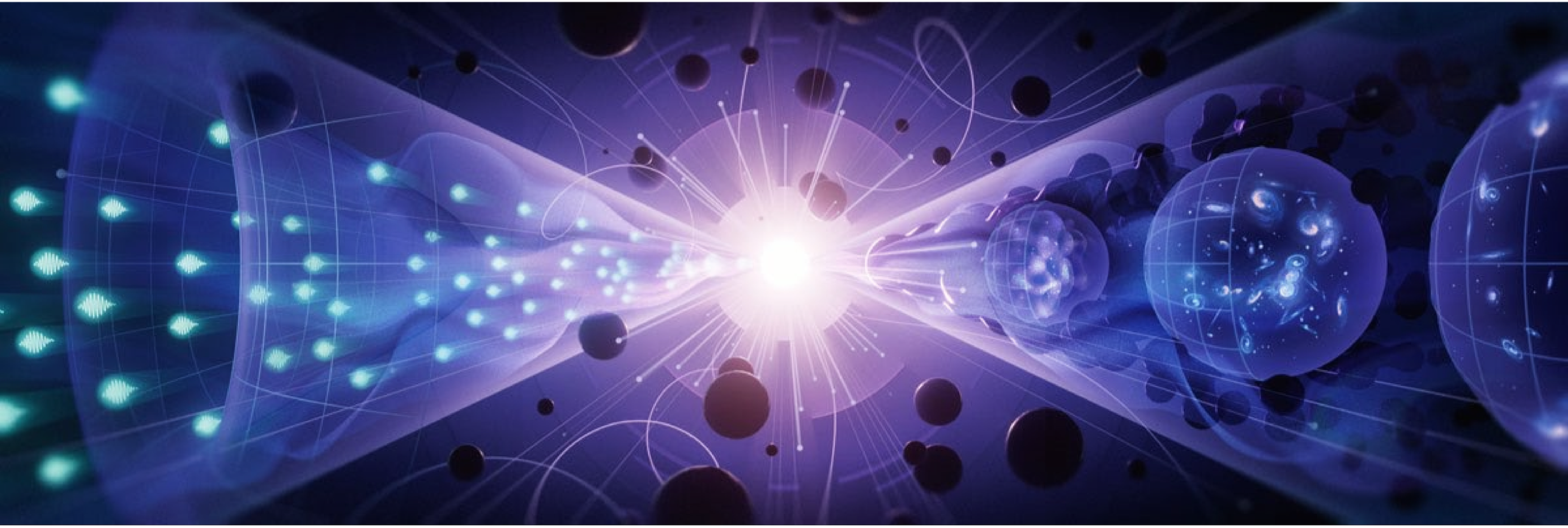
Pathways to Innovation and Discovery in Particle Physics

Report of the Particle Physics Project Prioritization Panel 2023



https://www.usparticlephysics.org/2023-p5-report/

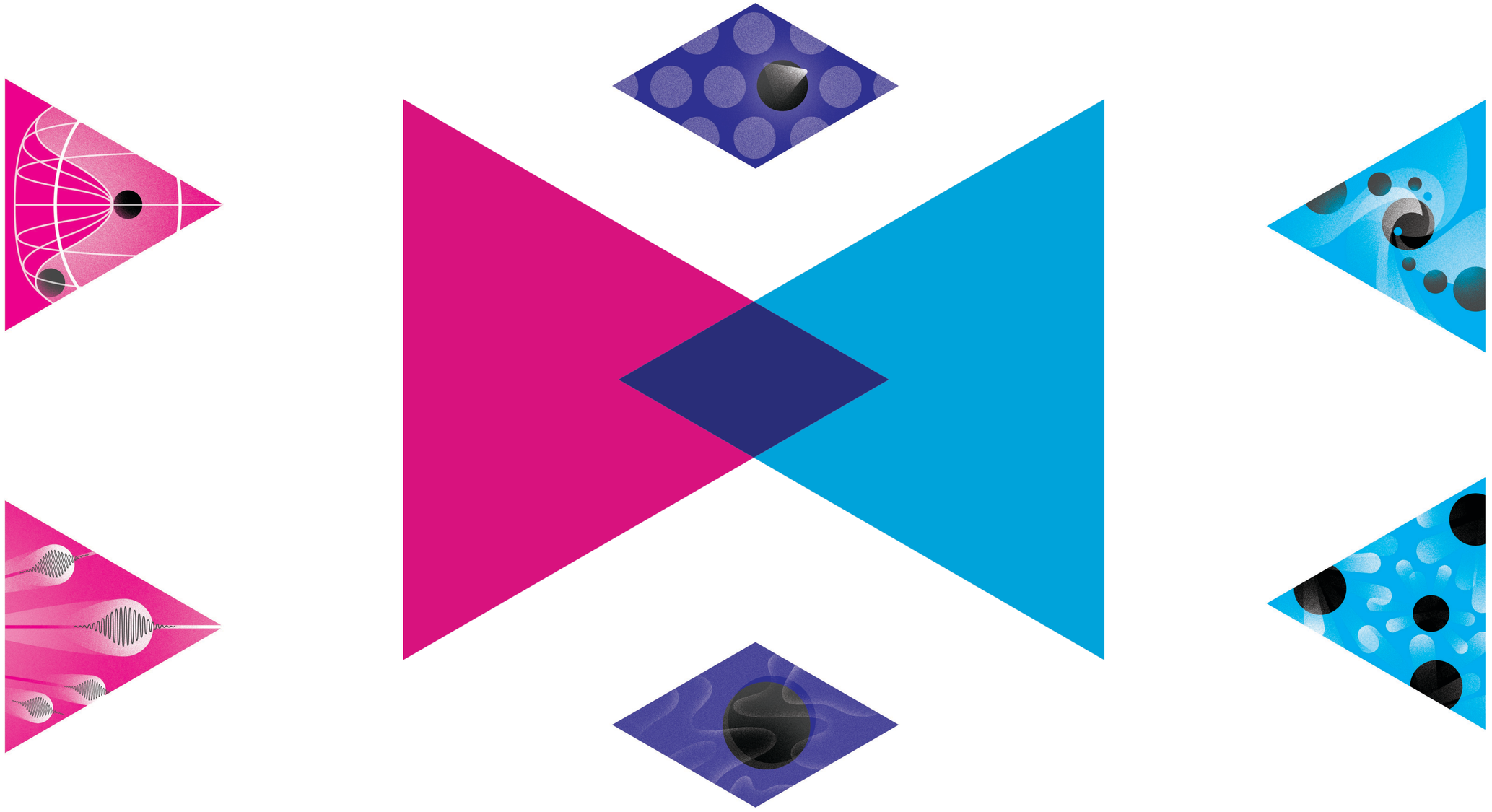
Recommendations

Science Themes & Drivers

Area Recommendations

Hard Choices

Explore the Quantum Universe



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Recommendation 1

Not Rank-Ordered

Reaffirm critical importance of the ongoing projects

As the highest priority independent of the budget scenarios, complete construction projects and support operations of ongoing experiments and research to enable maximum science. We reaffirm the previous P5 recommendations on major initiatives:

a. **HL-LHC** (x10 more data d CMS detectors, as well as Accelerator Upgrade Project) to start addressing why the Higgs boson condensed in the universe (reveal the secrets of the Higgs boson, section 3.2), to search for direct evidence for new particles (section 5.1), to pursue quantum imprints of new phenomena (section 5.2), and to determine the nature of dark matter (section 4.1).

DOE & NSF PHY

b. **The first phase of DUNE and PIP-II** (determines the mass ordering utrinos, a fundamental property and a crucial input to cosmology and nuclear science (elucidate the mysteries of neutrinos, section 3.1).

Mostly DOE

c. **The Vera C. Rubin Observatory** (scan the whole sky in every two days y Science Collaboration, to understand what drives cosmic evolution (section 4.2).

DOE & NSF AST

US leadership in key areas of particle physics

Exploring the Quantum Universe

Recommendation 1

Not Rank-Ordered

Reaffirm critical importance of the ongoing projects

In addition, we recommend continued support for the following ongoing experiments at the medium scale (project costs > $50M for DOE and > $4M for NSF), including completion of construction, operations, and research:

NSF

d. **NOvA**, **SBN**, **T2K**, and **IceCube** (*elucidate the mysteries of neutrinos*, section 3.1).
e. **DarkSide-20k**, **LZ**, **SuperCDMS**, and **XENONnT** (*determine the nature of dark matter*, section 4.1).

dark matter direct detection DOE+NSF

f. **DESI** (*understand what drives cosmic evolution*, section 4.2). DOE but on Mayall 4m Kitt Peak
g. **Belle II**, **LHCb**, and **Mu2e** (*pursue quantum imprints of new phenomena*, section 5.2).

The agencies should work closely with each major project to carefully manage the costs and schedule to ensure that the US program has a broad and balanced portfolio.

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Recommendation 2

Rank-Ordered

New exciting initiatives

a. **CMB-S4**, which looks back at the earliest moments of the universe to probe physics at the highest energy scales. It is critical to install telescopes at and observe from both the South Pole and Chile sites to achieve the science goals (section 4.2). DOE & NSF AST

b. **Re-envisioned second phase of DUNE** with an early implementation of an enhanced 2.1 MW beam—ACE-MIRT—a third far detector, and an upgraded near-detector complex as the definitive long-baseline neutrino oscillation experiment of its kind (section 3.1). Mostly DOE

c. **An off-shore Higgs factory**, realized in collaboration with **international partners**, in order to reveal the secrets of the Higgs boson. The current designs of FCC-ee and ILC meet our scientific requirements. The US should actively engage in feasibility and design studies. Once a specific project is deemed feasible and well-defined (see also Recommendation 6), the US should aim for a contribution at funding levels commensurate to that of the US involvement in the LHC and HL-LHC, while maintaining a healthy US on-shore program in particle physics (section 3.2). DOE & NSF PHY

d. **An ultimate Generation 3 (G3) dark matter direct detection experiment** reaching the neutrino fog, in coordination with international partners and preferably sited in the US (section 4.1). DOE & NSF PHY

e. **IceCube-Gen2** for study of neutrino properties using non-beam neutrinos complementary to DUNE and for indirect detection of dark matter covering higher mass ranges using neutrinos as a tool (section 4.1). NSF PHY

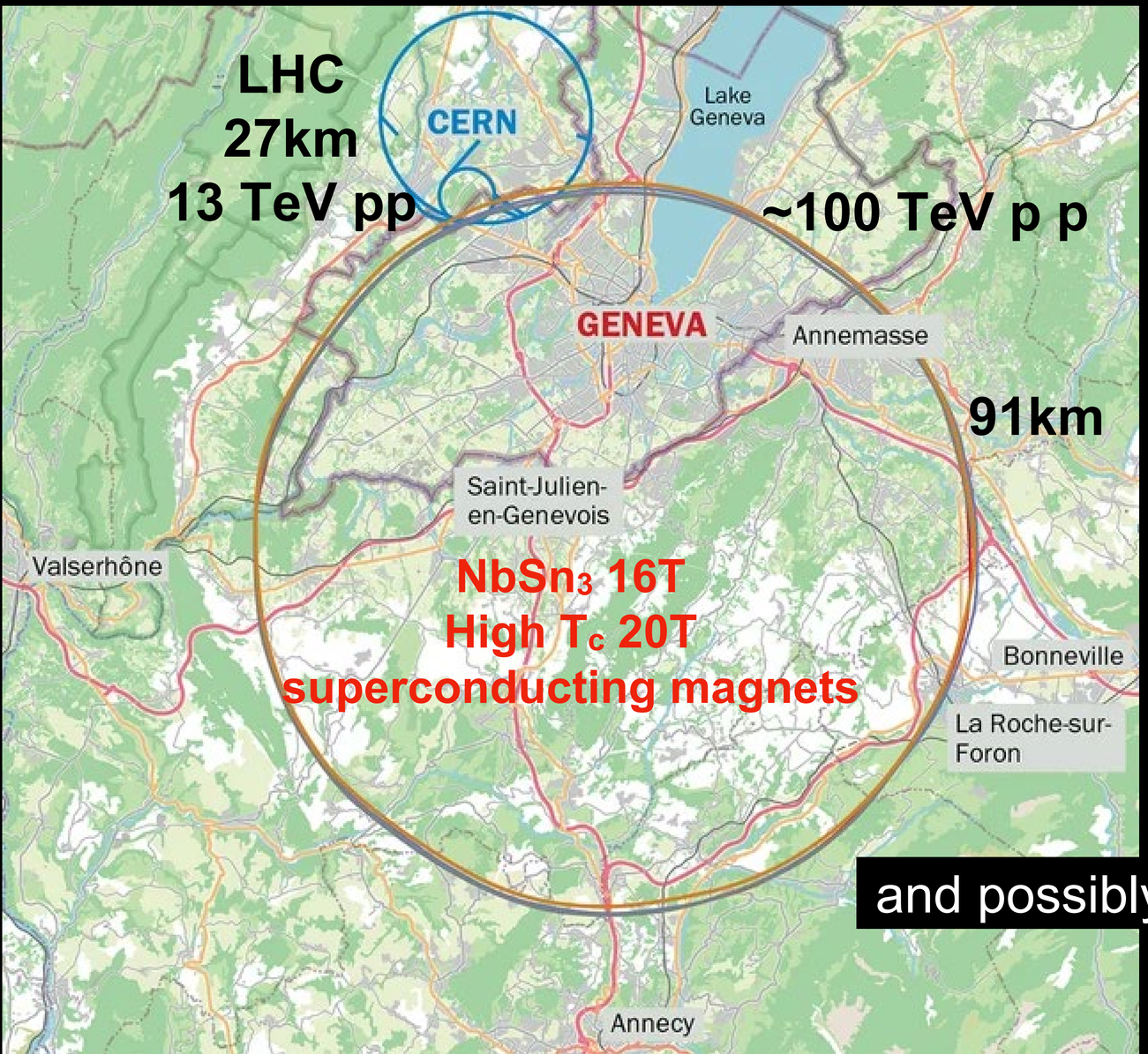
Exploring the Quantum Universe

Challenges

- **CMB-S4 and IceCube Gen2 require infrastructure at the South Pole**
  - retiring military cargo planes from 1970s, access, power needs, building
  - involved OPP at several meetings
  - "*The South Pole, a unique site that enables the world-leading science of CMB-S4 and IceCube-Gen2, must be maintained as a premier site of science to allow continued US leadership in these areas.*"
  - Unfortunately, this seems to be the road block
- **2014 P5 recommendation on DUNE would require significant additional funding**
  - proposed "re-envisioned Phase 2" to fit within the budget to achieve the same amount of data
- **Higgs factory on the US soil desired by community**
  - can't afford it, recommended "off-shore Higgs factory" instead
- **Two great designs for Dark Matter G3 experiments proposed**
  - recommended only one, preferentially on the US soil
- **Further reductions needed if budget is worse than Chips and Science Act**
  - made specific recommendations for the "less favorable" case, now this looks likely?
- **Technology development needed to go to higher energies for colliders**

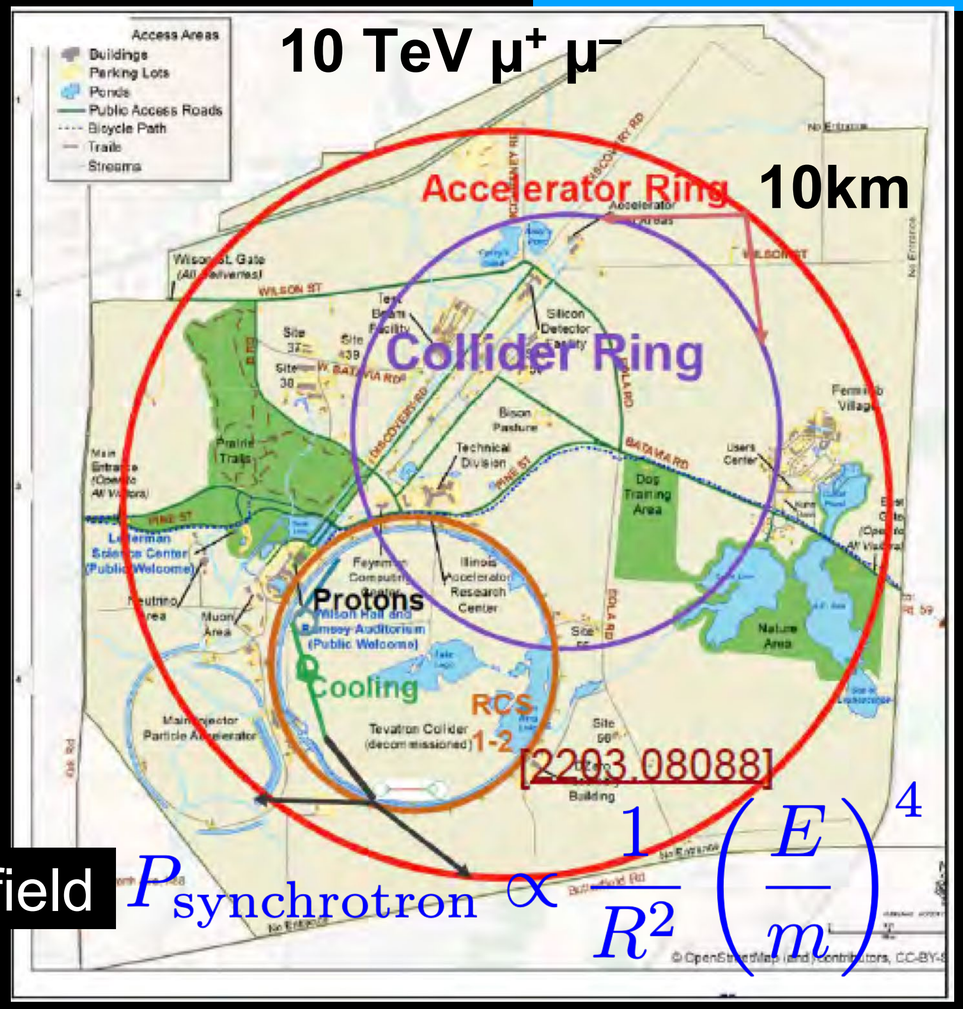
R&D will allow Fermilab to continuously expand the accelerator complex while producing world class science: *our Muon Shot!*

New enabling technologies



5% measurement of Higgs self coupling

Energy 10xLHC
Size 1/3 x LHC
Fits inside the Fermilab site



$$P_{\text{synchrotron}} \propto \frac{1}{R^2}\left(\frac{E}{m}\right)^4$$

Muon production and cooling

and possibly wakefield

Exploring the Quantum Universe

Recommendation 3

Not Rank-Ordered

Balanced Portfolio from small to large

Create an improved balance between small-, medium-, and large-scale projects to open new scientific opportunities and maximize their results, enhance workforce development, promote creativity, and compete on the world stage.

In order to achieve this balance across all project sizes we recommend the following:

a. Implement a new small-project portfolio at DOE, **Advancing Science and Technology through Agile Experiments (ASTAE)**, across science themes in particle physics with a competitive program and recurring funding opportunity announcements. This program should start with the construction of experiments from the Dark Matter New Initiatives (DMNI) by DOE-HEP (section 6.2). **$35M/yr**

b. Continue Mid-Scale Research Infrastructure (**MSRI**) and Major Research Instrumentation (**MRI**) programs as a critical component of the NSF research and project portfolio.

c. Support **DESI-II** for cosmic evolution, **LHCb upgrade II** and **Belle II upgrade** for quantum imprints, and **US contributions to the global CTA Observatory** for dark matter (sections 4.2, 5.2, and 4.1).

The Belle II recommendation includes contributions towards the SuperKEKB accelerator.

Exploring the Quantum Universe

Recommendation 4

Not Rank-Ordered

Investment in the future

a. Support **vigorous R&D toward a cost-effective 10 TeV pCM collider** based on proton, muon, or possible wakefield technologies, including an evaluation of options for US siting of such a machine, with a goal of being ready to build **major test facilities and demonstrator facilities within the next 10 years** (sections 3.2, 5.1, 6.5, and Recommendation 6).
b. Enhance research in **theory** to propel innovation, maximize scientific impact of investments in experiments, and expand our understanding of the universe (section 6.1). **$15M/yr increase**
c. Expand the **General Accelerator R&D (GARD)** program within HEP, including stewardship (section 6.4). **$10M/yr increase**
d. Invest in R&D in **instrumentation** to develop innovative scientific tools (section 6.3). **$20M/yr increase**
e. Conduct **R&D** efforts to define and enable new projects in the next decade, including detectors for an e^+e^- Higgs factory and 10 TeV pCM collider, Spec-S5, DUNE FD4, Mu2e-II, Advanced Muon Facility, and line intensity mapping (sections 3.1, 3.2, 4.2, 5.1, 5.2, and 6.3). **$8+9M/yr increase**
f. Support key **cyberinfrastructure** components such as shared software tools and a sustained R&D effort in computing, to fully exploit emerging technologies for projects. Prioritize **computing and novel data analysis techniques** for maximizing science across the entire field (section 6.7).
g. Develop plans for improving the **Fermilab accelerator complex** that are consistent with the long-term vision of this report, including neutrinos, flavor, and a 10 TeV pCM collider (section 6.6).

We recommend specific budget levels for enhanced support of these efforts and their justifications as **Area Recommendations** in section 6.

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Recommendation 5

Not Rank-Ordered

Diversity, Inclusion, Equity, Relevance to society

The following workforce initiatives are detailed in section 7:

a. All projects, workshops, conferences, and collaborations must incorporate ethics agreements that detail

The inherent curiosity driving our exploration of the natural world is a universal aspect of human nature. This shared curiosity serves as the driving force behind our commitment to strengthening and expanding this workforce, prompting us to actively seek talent from all corners of society, regions of the country, and on a global scale.

c. Comprehensive **work-climate studies** should be conducted with the support of funding agencies. Large collaborations and national laboratories should consistently undertake such studies so that issues can be identified, addressed, and monitored. Professional associations should spearhead field-wide work-climate

Treating others with respect requires maintaining a professional work environment, free from harassment and abuse. Discrimination, harassment, or bullying within a scientific collaboration harms individuals, disrupts scientific progress, and is therefore scientific misconduct.

operations and research budgets of experiments. The funding agencies should include funding for the dissemination of results to the public in operation and research budgets.

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Recommendation 6

Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed.

The panel would consider the following:

1. The level and nature of **US contribution in a specific Higgs factory** including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
2. Mid- and large-scale **test and demonstrator facilities** in the accelerator and collider R&D portfolios.
3. A plan for the evolution of the **Fermilab accelerator complex** consistent with the longterm vision in this report, which may commence construction in the event of a more favorable budget situation.

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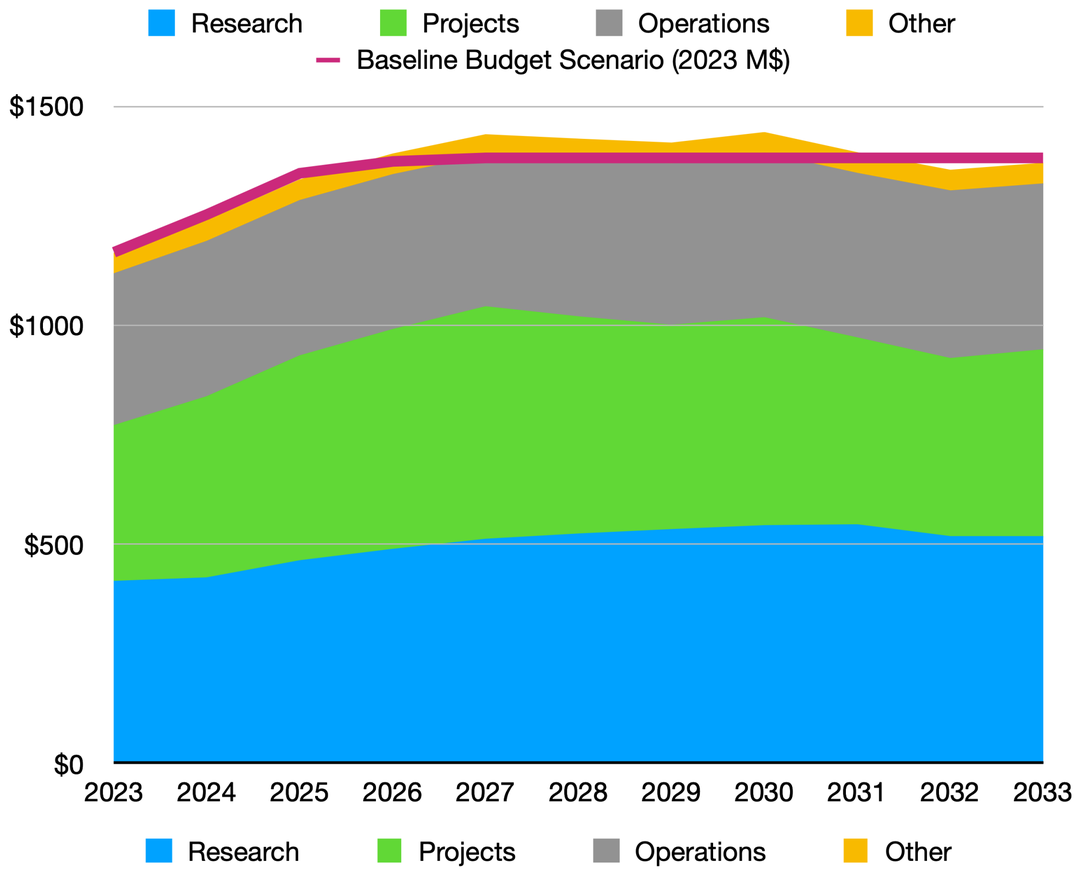
Not in the Report



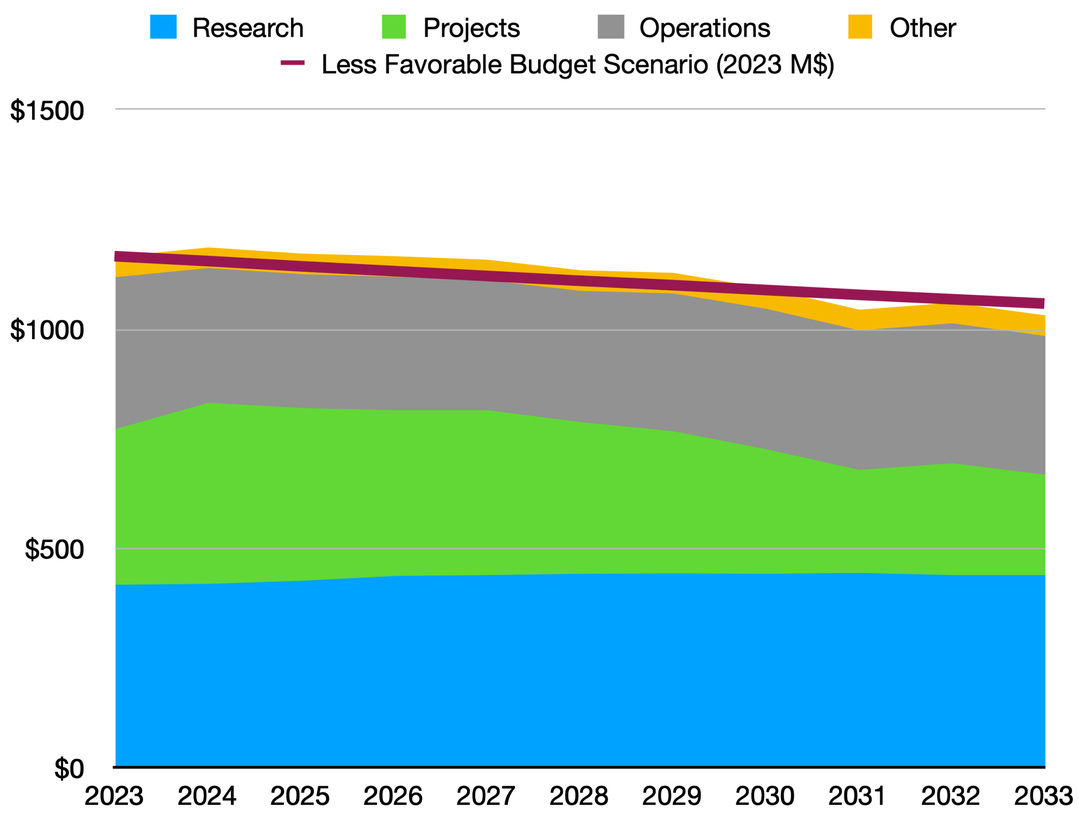


Fig. 2 Evolution of DOE budgets in Research, Projects, Operations, and Other in our budget exercise for the two budget scenarios given in the charge in 2023 dollars assuming 3% annual inflation.

Exploring the Quantum Universe

Difficult Choices

Figure 2 – Construction in Various Budget Scenarios

Index: Y: Yes N: No R&D: Recommend R&D only C: Conditional yes based on review P: Primary S: Secondary

Delayed: Recommend construction but delayed to the next decade

† Recommend infrastructure support to enable international contributions

Can be considered as part of ASTAE with reduced scope

US Construction Cost	Scenarios			Science Drivers						
>$3B	Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
onshore Higgs factory	N	N	N		P	S		P	P	
$1–3B										
offshore Higgs factory	Delayed	Y	Y		P	S		P	P	
ACE-BR	R&D	R&D	C	P				P	P	
$400–1000M										
CMB-S4	Y	Y	Y	S		S	P			P
Spec-S5	R&D	R&D	Y	S		S	P			P
$100–400M										
IceCube-Gen2	Y	Y	Y	P		S				P
G3 Dark Matter 1	Y	Y	Y	S		P				
DUNE FD3	Y	Y	Y	P				S	S	S
test facilities & demonstrator(s)	C	C	C		P	P		P	P	
ACE-MIRT	R&D	Y	Y	P						
DUNE FD4	R&D	R&D	Y	P				S	S	S
G3 Dark Matter 2	N	N	Y	S		P				
Mu2e-II	R&D	R&D	R&D						P	
srEDM	N	N	N						P	
$60–100M										
SURF expansion	N	Y	Y	P		P				
DUNE MCND	N†	Y	Y	P				S	S	
MATHUSLA	N#	N#	N#			P		P		
FPF trio	N#	N#	N#	P		P		P		

Credit:
Yurie
Murayama

particle physicists dream small

New effort to study the afterglow of big bang heads new decadal to-do list

8 DEC 2023 · 6:10 PM ET · BY ADRIAN CHO

CAREERS COMMENTARY JOURNALS Science

Particle physicists in the United States have released a long-range plan that looks less like a child's wish list and more like a parent's cautious budget. Although some physicists dream of exotic new particle colliders, the report of the ad hoc Particle Physics Project Prioritization Panel (P5) lists just five, mostly smaller projects, only two of which would operate by 2034. That's because the U.S. program, which is supported by the Department of Energy (DOE), is still busy with a massive neutrino project that has greatly exceeded its initially estimated cost and is behind schedule. Still, other physicists are encouraged by the report.

"This is better than I expected," says Daniel Akerib, a particle physicist at SLAC National Accelerator Laboratory. "I'm impressed that even given the constraints, they found a way to fit new things in."

The product of more than a year of deliberation, the new report, presented on 7 December to DOE's standing High Energy Physics Advisory Panel (HEPAP), represents the consensus view of the panel's 31 particle physicists, says Hitoshi Murayama, a theorist at the University of California, Berkeley and P5 chairman. "We never voted on anything," he says.

The report's first recommendation sets the tone, says Regina Rameika, associate director for DOE's high energy physics program, which has a $1.17 billion budget this year. The highest priority, the report says, is to "complete construction of projects and support operations of ongoing experiments." In other words, Rameika says, "We've got to finish what we've started."

Those commitments include a variety of neutrino experiments at Fermi National Accelerator Laboratory (Fermilab), massive underground detectors known as LZ and XENONnT that are striving to detect hypothetical particles of dark matter called weakly interacting massive particles (WIMPs), and a 4-meter telescope to probe the nature of the

The New York Times

Particle Physicists Agree on a Road Map for the Next Decade

A "muon shot" aims to study the basic forces of the cosmos. But meager federal budgets could limit its ambitions.

A tunnel of the Superconducting Super Collider project in 1993, which was abandoned by Congress. Ron Heflin/Associated Press


By Dennis Overbye and Katrina Miller

Published Dec. 7, 2023 Updated Dec. 8, 2023

Dan Garisto
@dangaristo

When Snowmass ended last year, I wondered how particle physicists were ever going to reach consensus that worked within a budget, was still ambitious, and didn't alienate huge swathes of the community. Somehow, the P5 report does all this.

My reporting:

12:22 AM · Dec 14, 2023 · **5,343** Views

1 14 27 4

DECEMBER 13, 2023 | 8 MIN READ

Road Map for U.S. Particle Physics Wins Broad Approval

A major report plotting the future of U.S. particle physics calls for cuts to the beleaguered DUNE project, advocates a “muon shot” for a next-generation collider and recommends a new survey of the universe’s oldest observable light

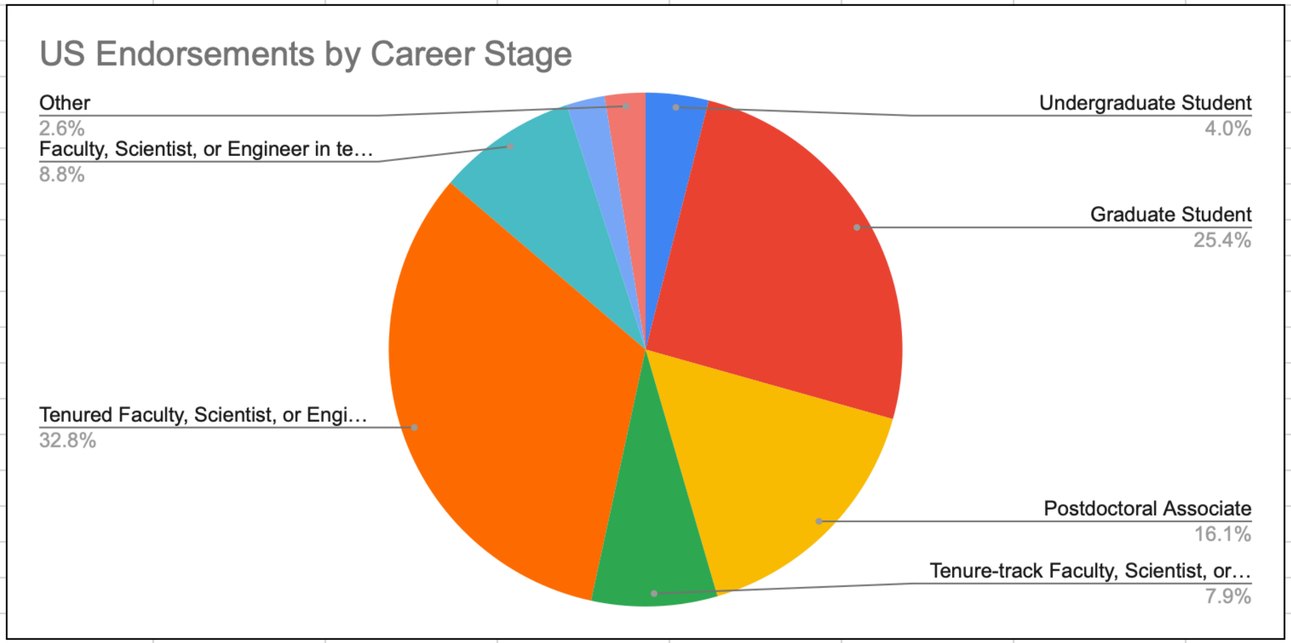
BY DANIEL GARISTO

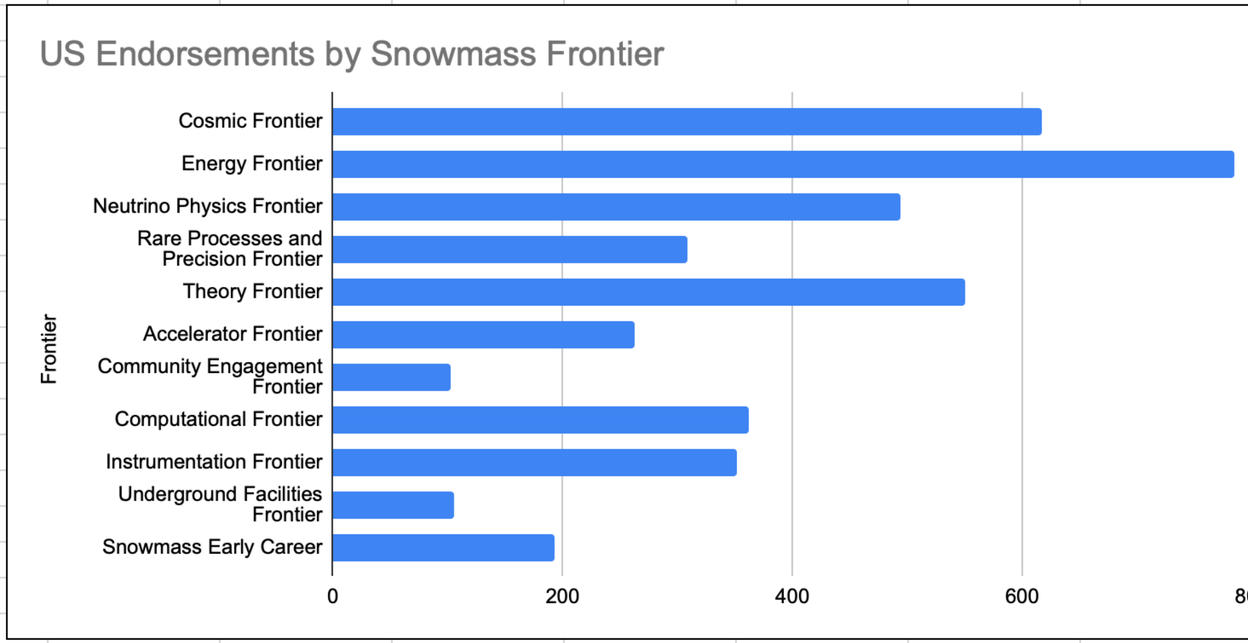
Scientific American

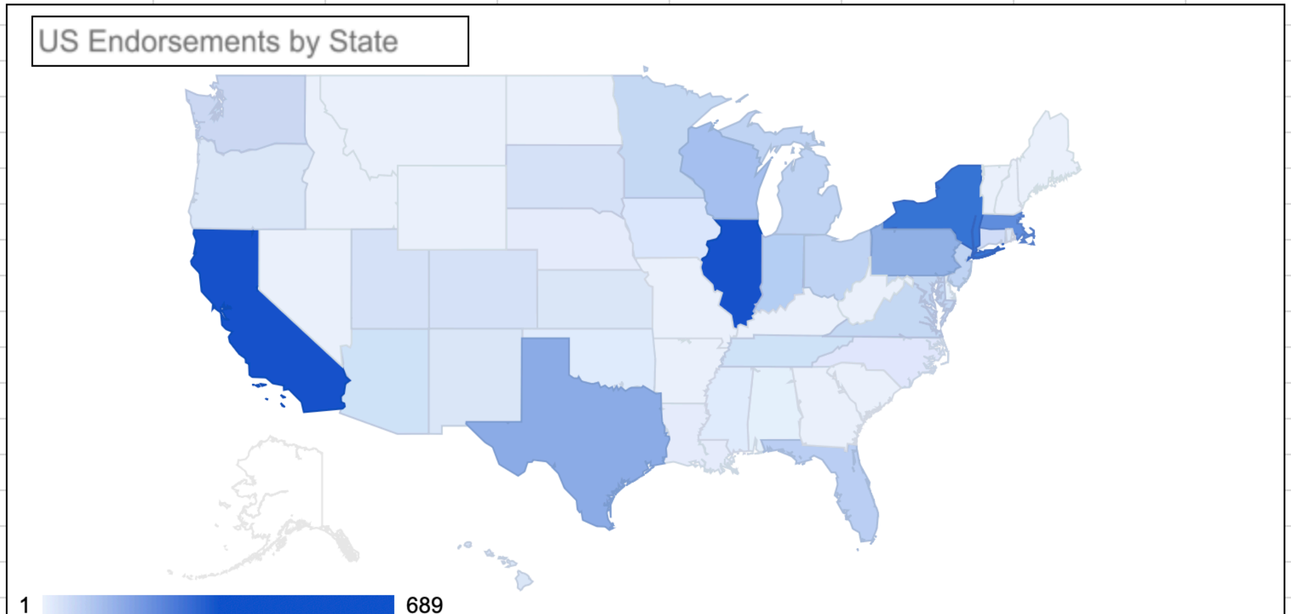
A view from the subterranean excavation for the Deep Underground Neutrino Experiment (DUNE) at the Sanford Underground Research Facility in South Dakota. Credit: Sanford Underground Research Facility

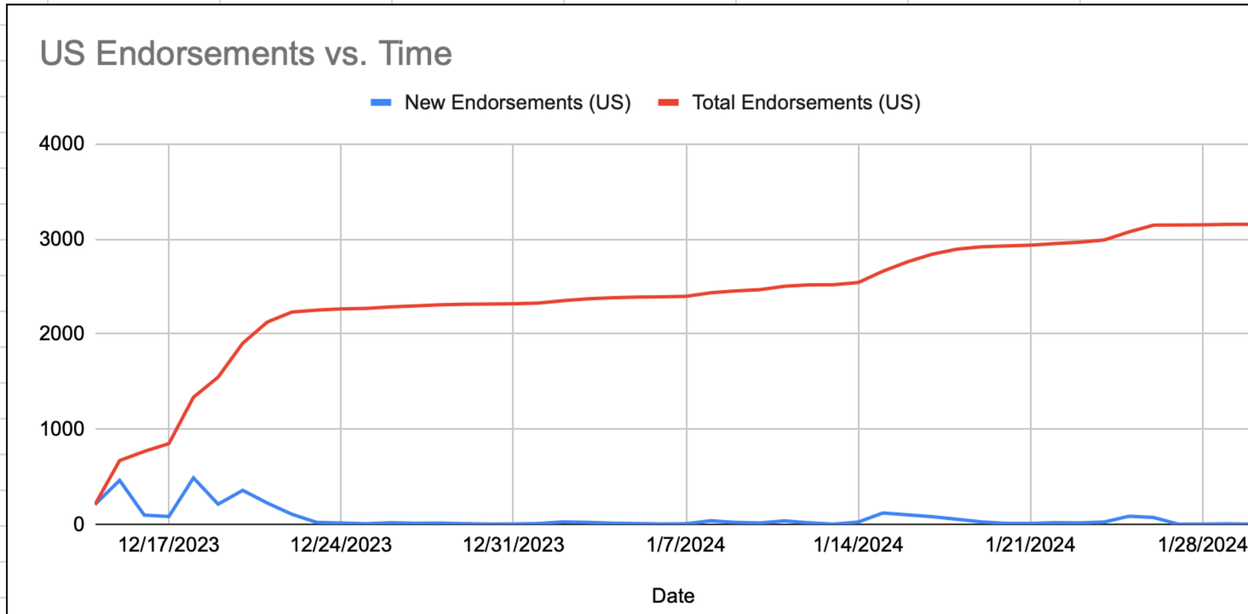
Support the 2023 P5 Report : Statistics

Number of Endorsements (Total)	Number of Endorsements (US)
3523	3157





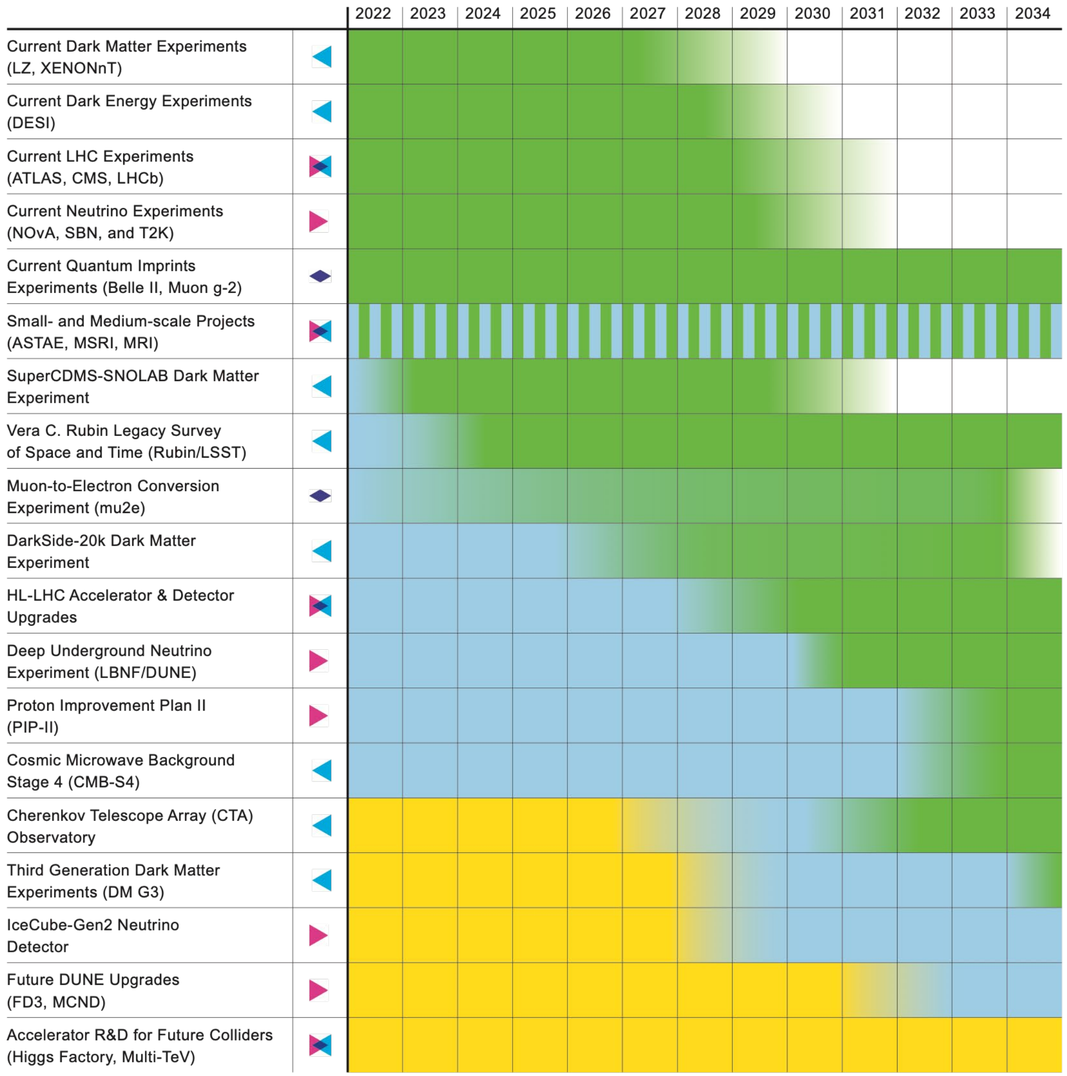


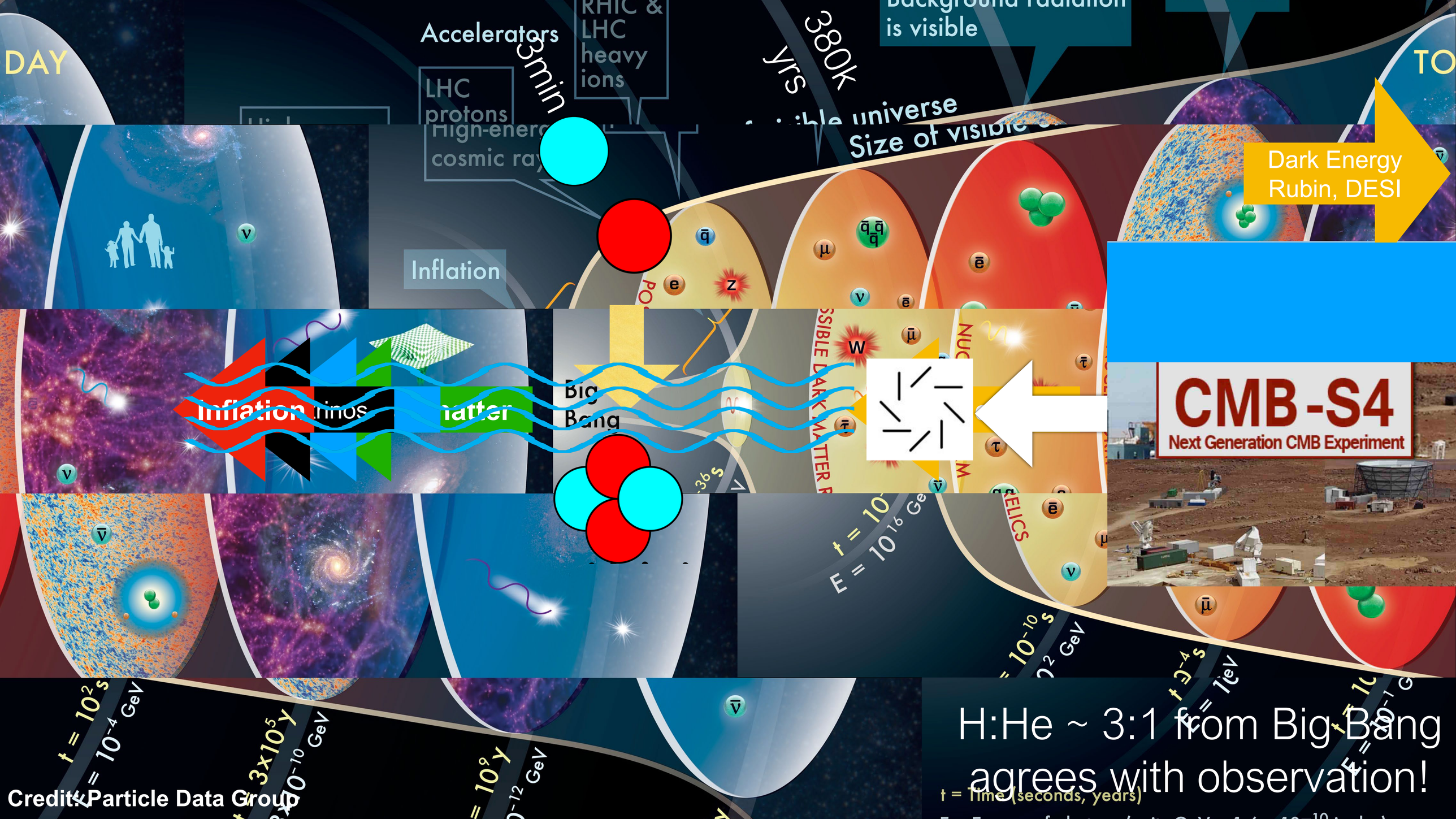


Exciting Program

Particle Physics Experiments Timeline

Phase of Experiment	Science Themes	Science Drivers
Operation & Analysis	Decipher the Quantum Realm	Neutrinos, Higgs Boson
Fabrication/Construction	Illuminate the Invisible Universe	Dark Matter, Cosmic Evolution
Conceptual & Technical Design	Explore New Paradigms in Physics	New Particles, New Phenomena





H:He ~ 3:1 from Big Bang agrees with observation!

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Implementation

- P5 report was too late for FY2025 budget request
- DOE HEP and P5 discussed comparing spreadsheets, but so far no signs from DOE
- Annual visits to the Congress by the community
  - this time 70 particle physicists
  - contacted 532 congressional offices out of 535=435+100
  - met 384 congressional offices
- Outreach to wider communities
  - international partners, funding agencies
  - physics departments, AAAC, APS
  - OSTP, appropriation committees, OMB, State Department
  - General public
- First discussion of implementations by DOE and NSF this Thursday at HEPAP

Date	Where	talk type	Event	Who requested?	Speaker
12/7/2023	Washington, DC	committee	HEPAP	DOE/NSF	Hitoshi/Karsten
12/11/2023	Fermilab	committee	P5 Townhall	DPF/Fermilab	Hitoshi/Karsten
12/12/2023	DESY	colloquium	Helmhotlz Alliance		Beate Heinemann
12/12/2023	CERN (Meyrin)	committee	CERN SPC	SPC chair	Karsten/Hitoshi
1/12/2024	Edinburgh, Scotland (virtual)	other	LZ collaboration meeting	Sally Shaw	Richard Schnee
12/13/2023	Yale	colloquium	colloquium/discussion	Yale	Karsten/Sarah
12/13/2023	Houston, TX	conference	1st Int. Workshop on Muon-Ion Colliders	Workshop SPC	Mark Palmer
12/15/2023	BNL, Brookhaven NY	seminar	town hall/discussion	BNL	Karsten Heeger
12/15/2023	AAAC	committee	AAAC	NSF	Hitoshi/Karsten
12/18/2023	Asmeret Berhe	briefing	briefing	DOE	Hitoshi/Karsten
12/19/2023	KEK, Tsukuba	seminar	seminar	Masa Yamauchi	Hitoshi Murayama
12/19/2023	BNL, Brookhaven NY	seminar	seminar for ATLAS group	Viviana Cavaliere	Sarah Demers
12/19/2023	Congressional Staffers	briefing	briefing	DOE	Hitoshi/Karsten/Abby
12/22/2023	KEK, Tsukuba	briefing	briefing	Masa Yamauchi	Hitoshi Murayama
12/21/2023	Fermilab	seminar	Colliders of Tomorrow	Sridhara Dasu	Tulika Bose
12/27/2023	MEXT	briefing	Briefing to Research Promotion Bureau	Masa Yamauchi	Hitoshi Murayama
1/5/2024	OSTP	briefing	briefing to Kei Koizumi	DOE	Hitoshi/Karsten
1/9/2024	UChicago	other	KICP/A&A Chalk Talk	Austin Joyce	Abby Vieregg
1/11/2024	University of Hawaii	colloquium	Physics colloquium	John Learned	
1/12/2024	LBNL	seminar	Annual LBNL ATLAS Meeting	Kevin Einsweiler	Hitoshi Murayama
1/16/2024	IMCC (virtual)	briefing	IMCC Steering Cmmte.	Steinar Stapnes	Mark Palmer
1/17/2024	UT-Austin	colloquium			Peter Onyisi
1/17/2024	LSST DESC (virtual)	seminar	DESC seminar	LSST DESC spokesperson	Rachel Mandelbaum & Francis-Yan Cyr-Racine
1/17/2024	Multi-lab (virtual)	committee	MDP General Meeting	Georgui Velev (MDP Mgmt)	Mark Palmer
1/18/2024	MDP Management (virtual)	other	MDP Tech. Advisory Cmmte.	Soren Prestemon	Mark Palmer
1/19/2024	Fermilab	other	Accelerator Directorate All-Hands	Alexander Valishev	Bob Zwaska
1/22/2024	University of Washington, Seattle	colloquium		Henry Lubatti	Sarah Demers
1/22/2024	South Dakota Mines	colloquium		Jingbo Wang	Richard Schnee
1/23/2024	University of New Mexico	seminar	Particle/Cosmo Seminar	David Camarena	Francis-Yan Cyr-Racine
1/25/2024	Argonne National Lab	colloquium		Christine McLean	Petra Merkel
1/25/2024	University of Florida	colloquium		Andrey Korytov	Hitoshi Murayama
1/26/2024	William & Mary	colloquium		Marc Sher/W&M	Chris Monahan
1/30/2024	Washington, DC		URA Council of Presidents	John Mester	Hitoshi/Karsten/Sally
1/31/2024	Rutgers	colloquium			Yuri Gershtein
2/2/2024	Annecy	conference	FCC Physics WS	Patrick Janot	Hitoshi Murayama
2/2/2024	CERN (Meyrin)	colloquium	CERN colloquium	Joachim Mnich	Hitoshi Murayama
2/2/2024	LBNL	conference	Physics Division Early Career Strategic Planning Event	Itay Bloch	Hitoshi Murayama
2/5/2024	UK	other	European funding agencies and community	Lia Merminga	Hitoshi/Karsten/Christos
2/5/2024	Carnegie Mellon University	colloquium	CMU/Pitt joint colloquium series	Tao Han	Rachel Mandelbaum
2/9/2024	Wheaton, IL	briefing	NOvA Collaboration	Alex Himmel	Mayly Sanchez
2/12/2024	UChicago	colloquium	EFI Colloquim	Emil Martinec	Abby Vieregg
2/12/2024	SLAC	colloquium		Marty Breindenbach	Hitoshi Murayama
2/13/2024	SLAC	conference	C3 workshop/collaboration	Emilio Nanni	Cameron Geddes
2/15/2024	MIT	colloquium		MIT	Jesse Thaler/Lindley Winslow
2/15/2024	Florida State University	colloquium		Rachel Yohay	Mayly Sanchez

government

international

Today

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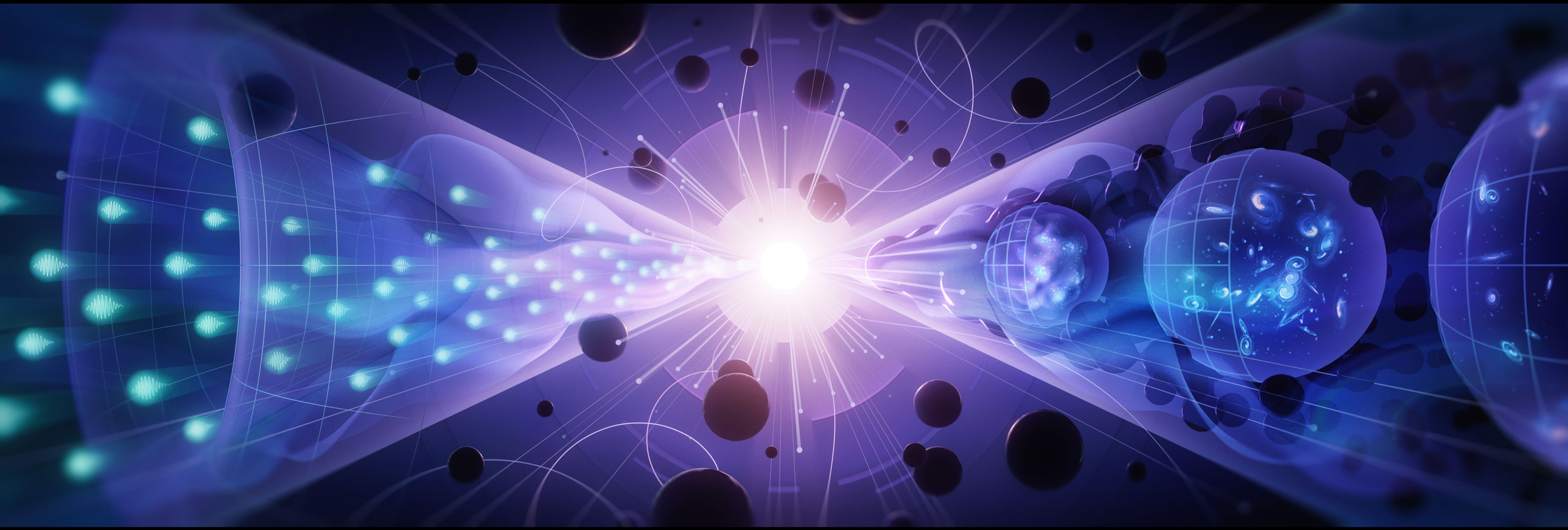

We are all very excited!