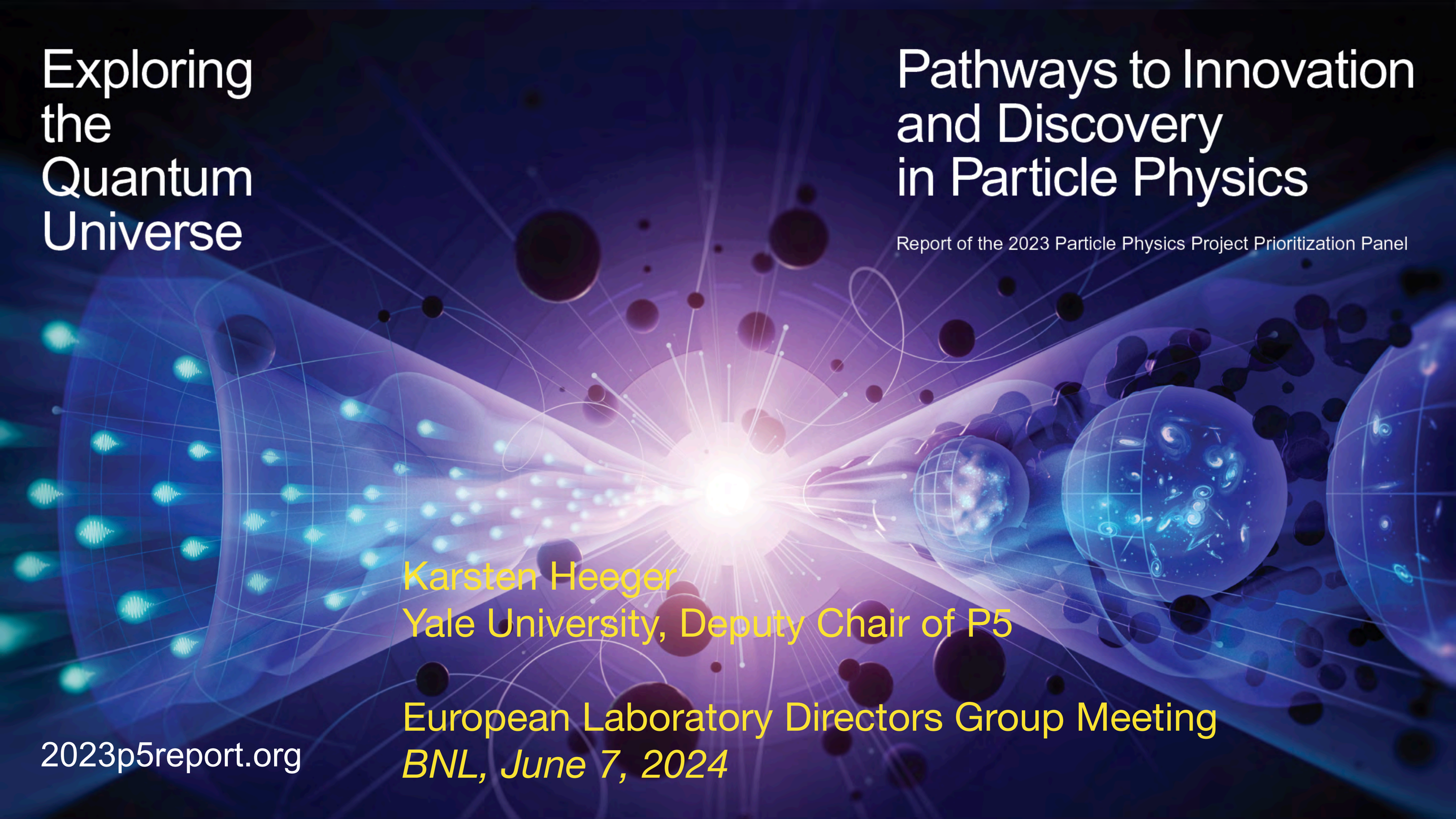

Exploring
the
Quantum
Universe
Pathways to Innovation
and Discovery
in Particle Physics
Report of the 2023 Particle Physics Project Prioritization Panel
Karsten Heeger
Yale University, Deputy Chair of P5
European Laboratory Directors Group Meeting
BNL, June 7, 2024
2023p5report.org

US Process for HEP Planning

Community

Snowmass 2021

"Snowmass"
Community Study

Organized by
APS / DPF

Advisory Panel

DOE SC
NSF MPS

Charge
Budget scenario

Particle Physics
Project
Prioritization Panel (P5)

Organized by
HEPAP

Exploring the Quantum Universe

Implementation

DOE HEP
NSF PHYS

OMB
OSTP
Congress

+ international partners

P5 and HEPAP

- **P5 = Particle Physics Project Prioritization Panel**
- **P5 is a subpanel of HEPAP (High Energy Physics Advisory Panel)**
- P5 responds to charge, makes recommendations to HEPAP
- Establishes scientific priorities taking into account cost and schedule information
- Provides a 10-year strategic plan for given budget scenarios within 20-year vision
- Implementation of P5 plan is up to the agencies
- P5 builds on community input, community support is essential

Brief History of HEP 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

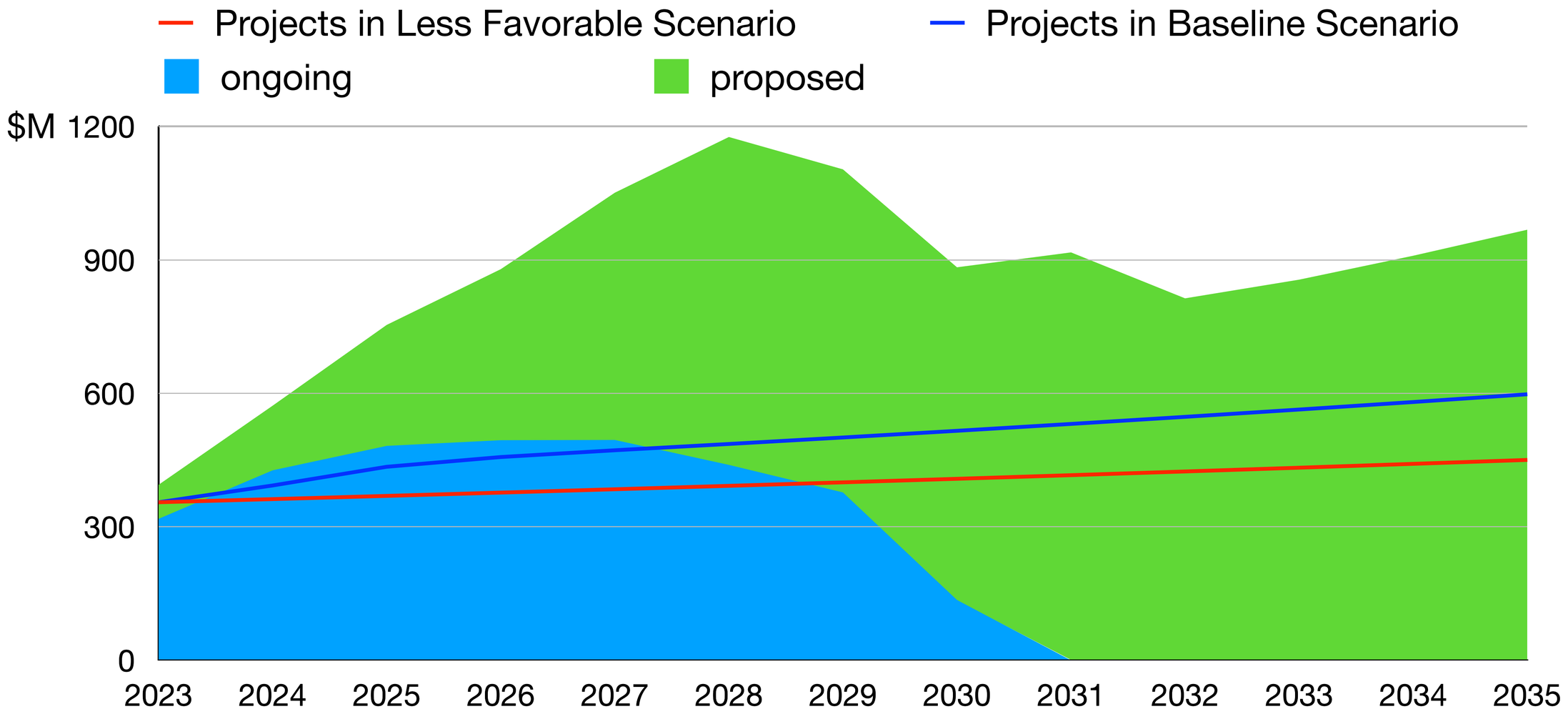
- 2021 Snowmass 2021 (concluded in Seattle)
- 2023 “Exploring the Quantum Universe: Pathways to Innovation and Discovery in Particle Physics”

Lessons Learned from HEP Planning

- Developing a compelling and fiscally responsible plan that has widespread support from the field is a must if we want sustained support
- Completing projects on schedule and within the budget is crucial to increasing our support
- A strong and broad ecosystem of theorists and experimentalists, R&D, and small & large projects is essential for the field's long-term health
- People are our most precious resource
- It's an honor and privilege to do research into the nature of the Universe. We must be good stewards of our field.


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

Proposed Projects Exceed Budgets



not including on-shore Higgs factory

DOE only

Charge to the 2023 P5 Subcommittee

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

Issued on Nov 2, 2022
signed by Asmeret Berhe (Director of DOE Office of Science), Sean Jones (Director of NSF MPS)

Subcommittee on Costs/Risks/Schedule

Exploring the Quantum Universe

Critical to understand maturity of cost estimates and risks and schedule for prioritization of projects within budget scenarios

Lesson from previous P5 that some of the costs were off by a factor of ~π

Subcommittee

- **Jay Marx (Caltech), Chair**
- Gil Gilchriese, Matthaeus Leitner (LBNL)
- Giorgio Apollinari, Doug Glenzinski (Fermilab)
- Mark Reichanadter, Nadine Kurita (SLAC)
- Jon Kotcher, Srini Rajagopalan (BNL)
- Allison Lung (JLab)
- Harry Weerts (Argonne)

Jay Marx

Committee provided low, medium, and high estimates with schedules

Prioritization Principles

Exploring the Quantum Universe

In the process of prioritization, we considered **scientific opportunities, budgetary realism, and a balanced portfolio** as major decision drivers.

Large projects (>$250M)
• Paradigm-changing discovery potential, world-leading, Unique in the world

Medium projects ($50–250M)
• Excellent discovery potential or development of major tools, world-class, Competitive

Small projects (<$50M)
• Discovery potential, well-defined measurements, or outstanding technology development, World-class, Excellent training grounds

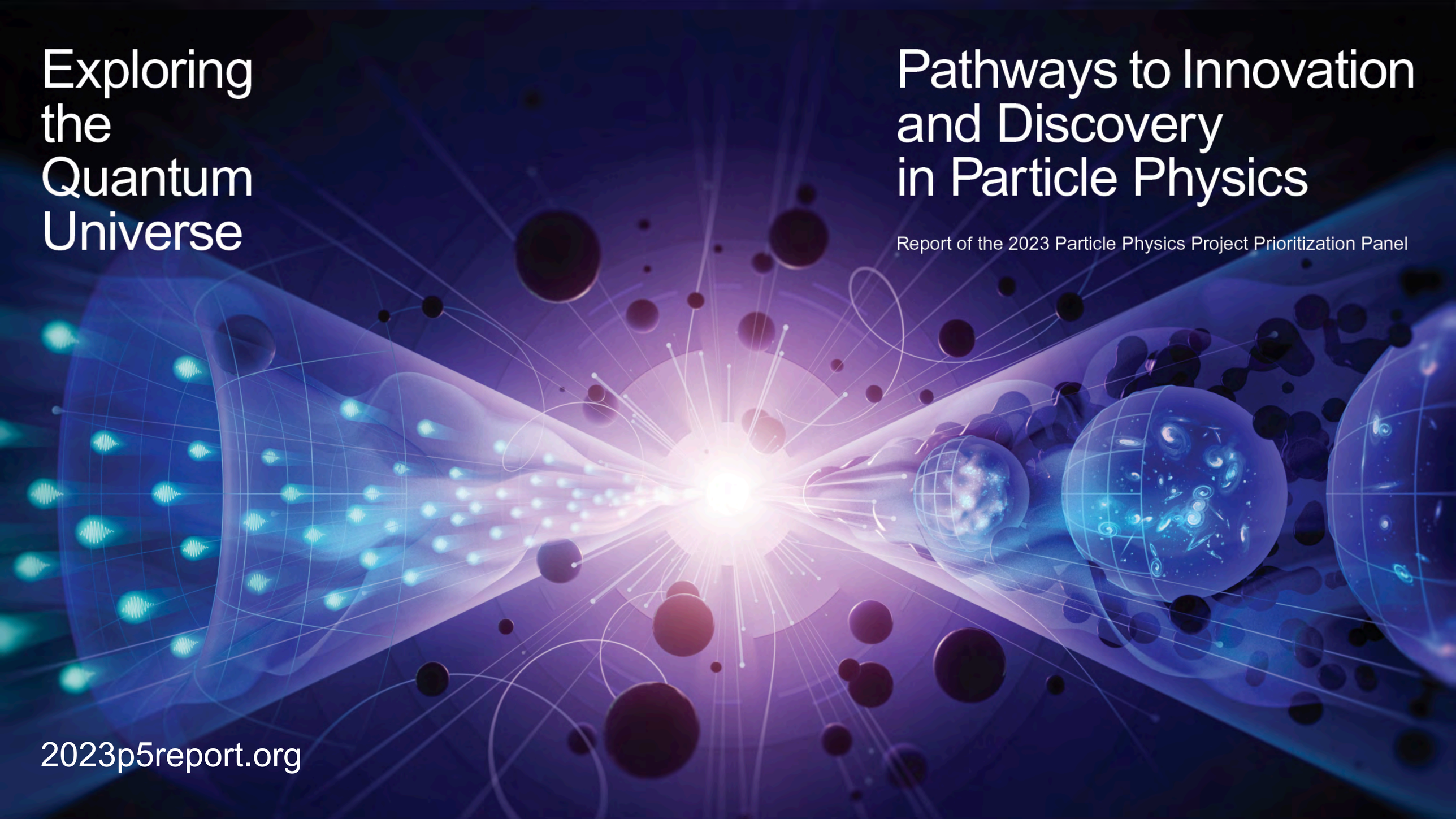
Overall program should

- leverage **unique US facilities and capabilities,** engage with **core national initiatives** to develop key technologies,
- develop a **skilled workforce** for the future that draws on all talent
- realize **effective engagement and partnership in international endeavors**

Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the 2023 Particle Physics Project Prioritization Panel



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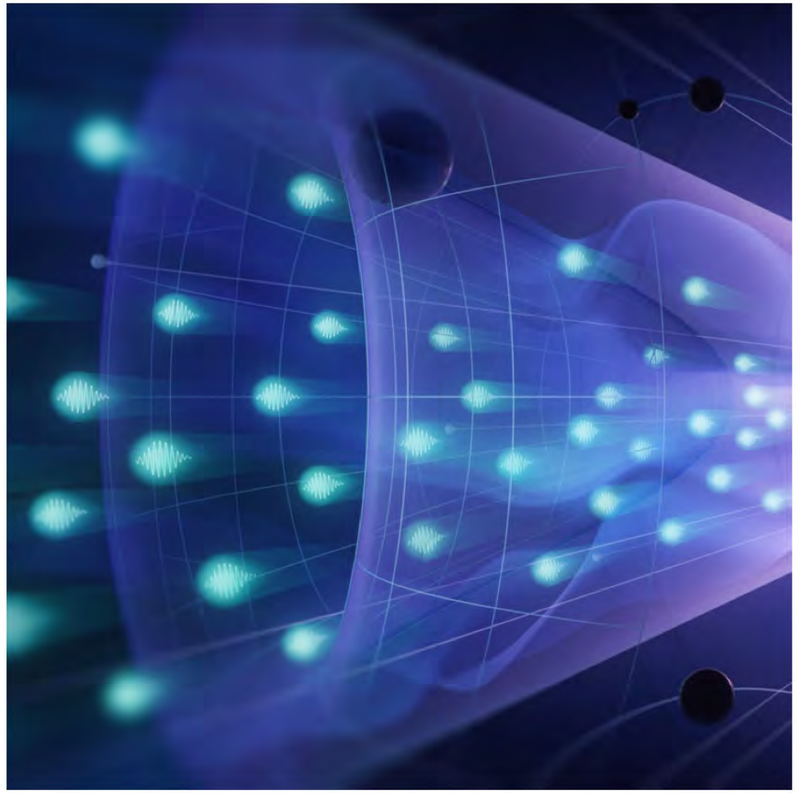
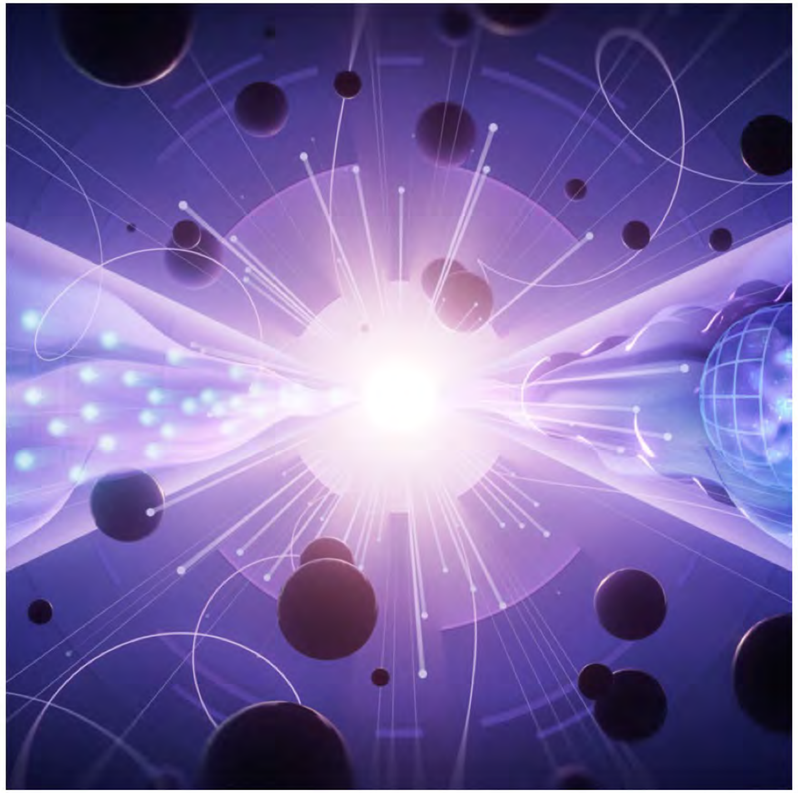


Decipher the Quantum Realm

Elucidate the Mysteries of Neutrinos

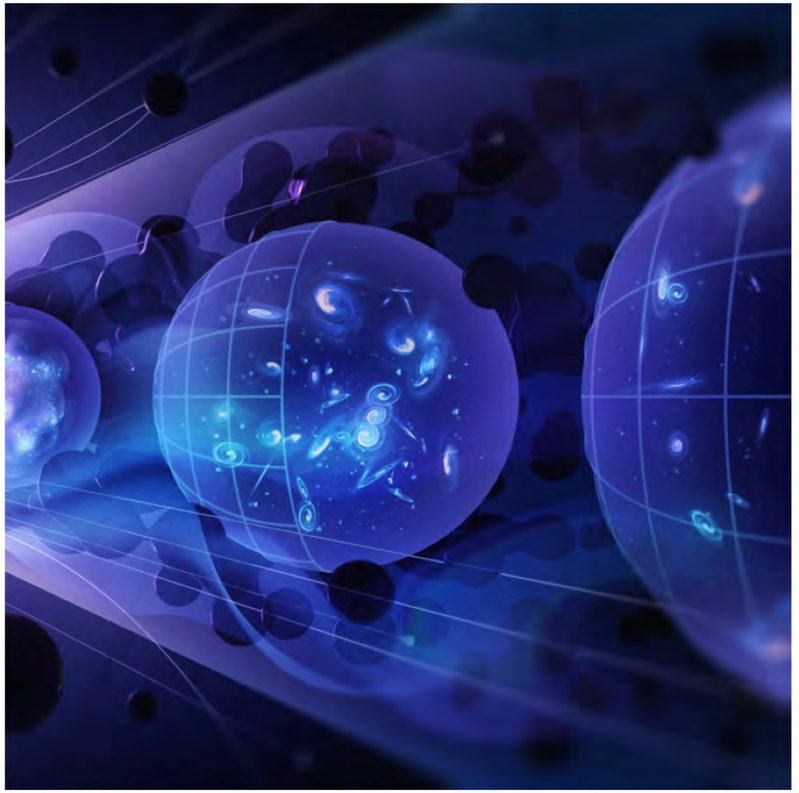
Reveal the Secrets of the Higgs Boson



Explore New Paradigms in Physics

Search for Direct Evidence of New Particles

Pursue Quantum Imprints of New Phenomena



Illuminate the Hidden Universe

Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

Exploring the Quantum Universe

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** (including ATLAS and 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** to determine the mass ordering among neutrinos, 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** to carry out the LSST, and the LSST Dark Energy 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 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

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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).

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.

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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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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

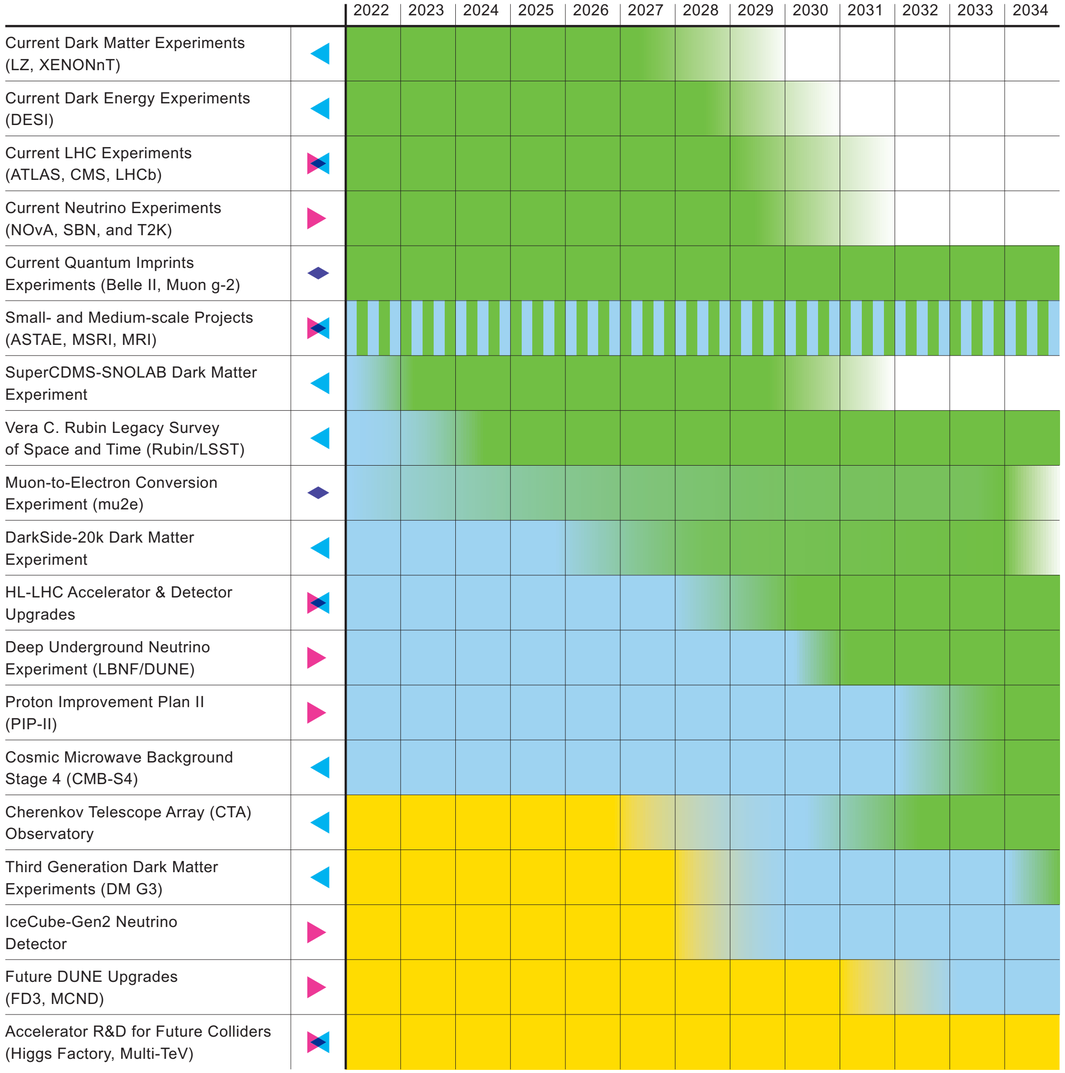
Can be considered as part of ASTAE with reduced scope

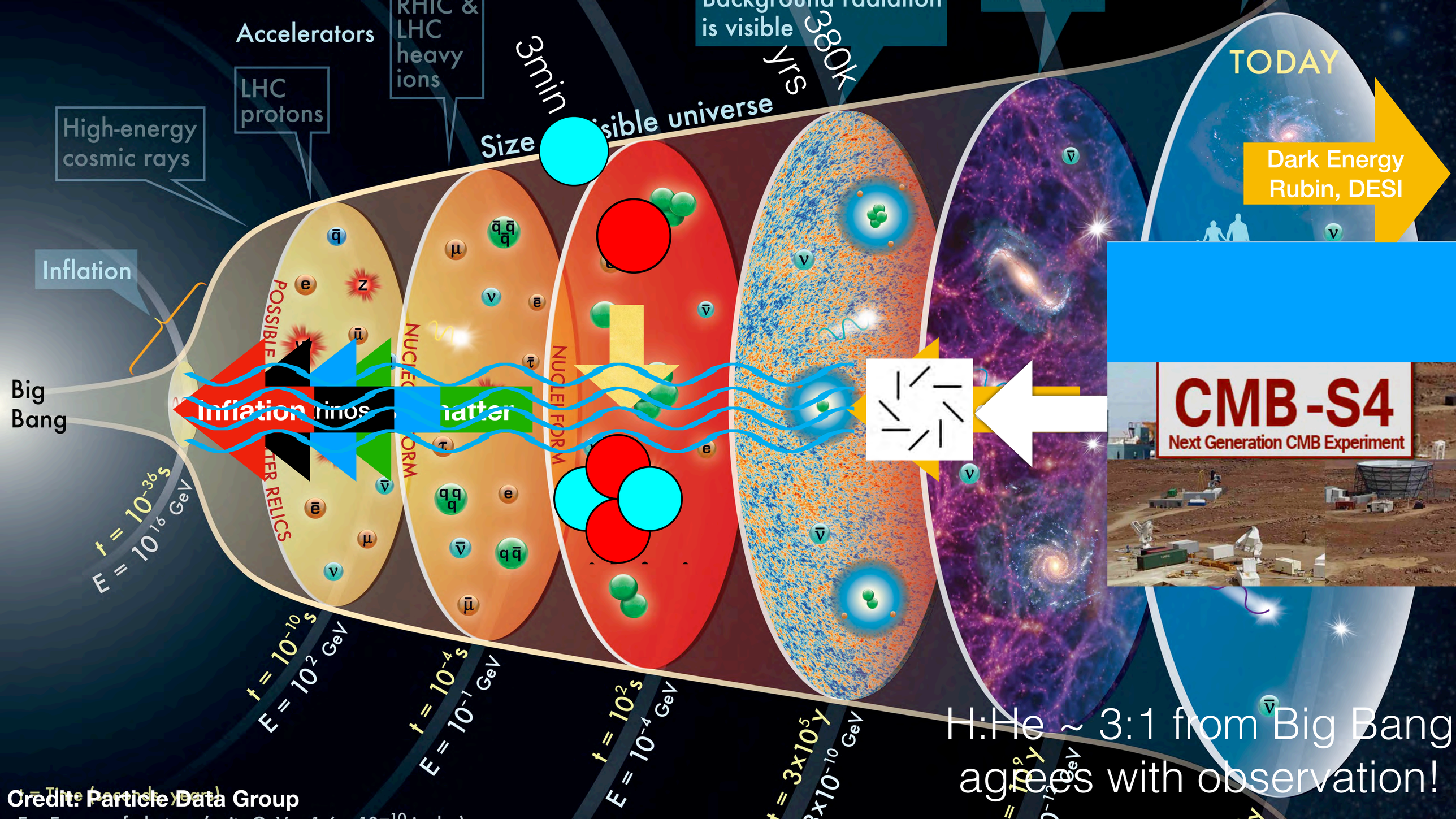
US Construction Cost	Scenarios			Science Drivers						
>$3B	Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
onshore Higgs factory	N	N	N		P	S		P	P	
$1–3B										
offshore Higgs factory	Delayed	Y	Y		P	S		P	P	
ACE-BR	R&D	R&D	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		

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




Accelerators
RHIC & LHC heavy ions
LHC protons
High-energy cosmic rays
Inflation
Big Bang
3min
380k yrs
Size of visible universe
Background radiation is visible
TODAY
Dark Energy
Rubin, DESI
CMB-S4
Next Generation CMB Experiment
Inflation
POSSIBLE MATTER RELICS
NUCLEOSYNTHESIS
NUCLEI FORM
t = 10^-36 s
E = 10^16 GeV
t = 10^-10 s
E = 10^2 GeV
t = 10^-4 s
E = 10^-1 GeV
t = 10^2 s
E = 10^-4 GeV
t = 3x10^5 y
E = 3x10^-10 GeV
t = Time (seconds, years)
H:He ~ 3:1 from Big Bang
agrees with observation!
Credit: Particle Data Group

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

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.

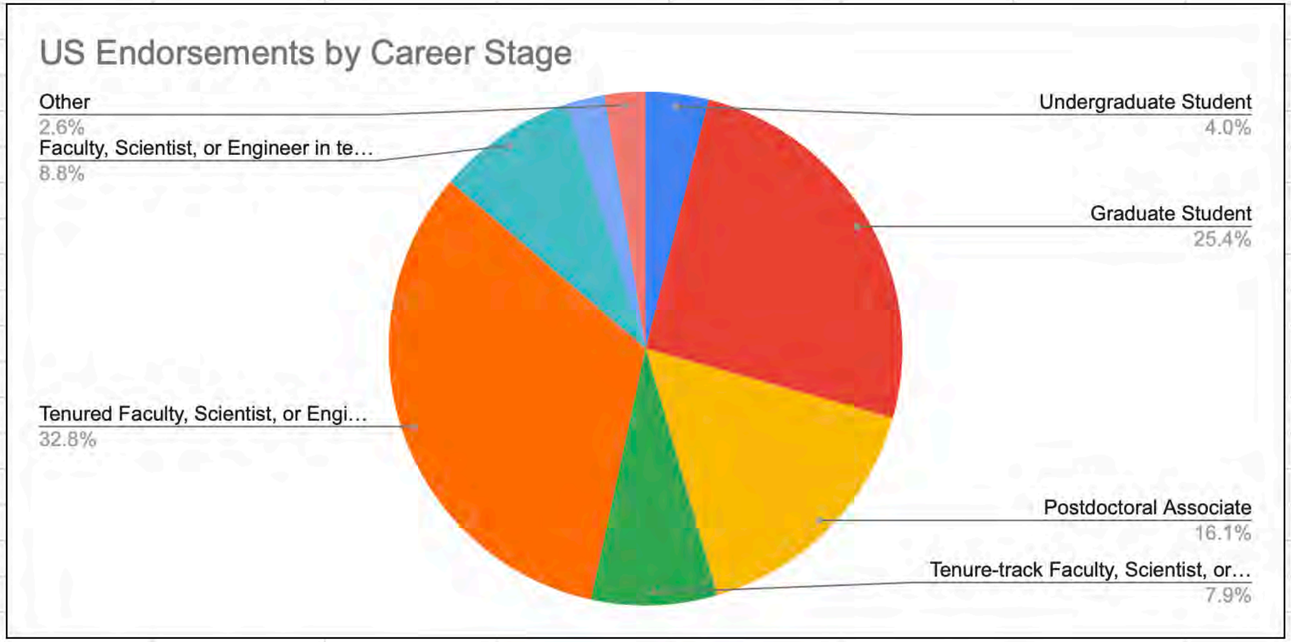
A tunnel of the Superconducting Super Collider project in 1993, which was abandoned by Congress. Ron Heflin/Associated Press

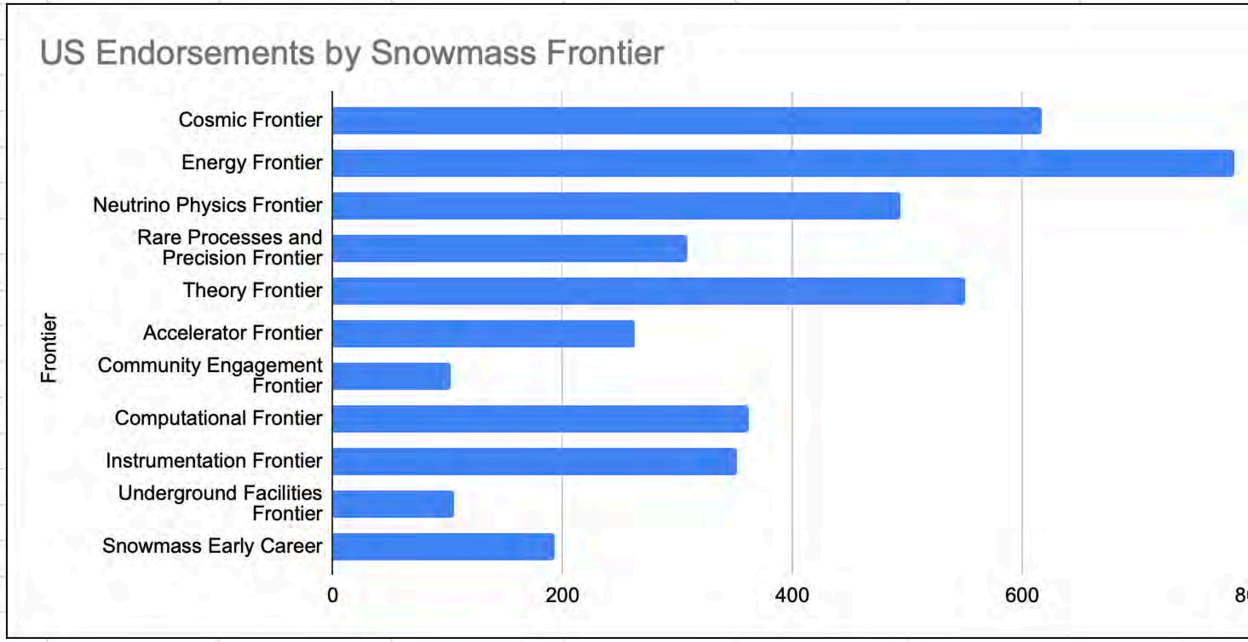

By Dennis Overbye and Katrina Miller

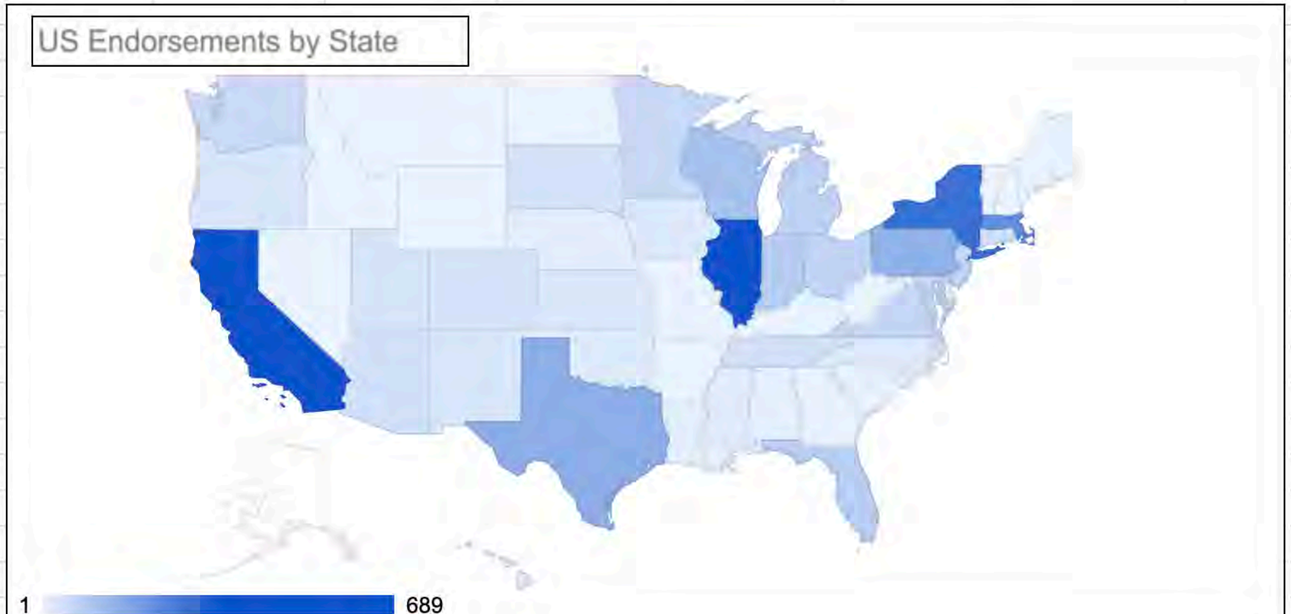
Published Dec. 7, 2023 Updated Dec. 8, 2023

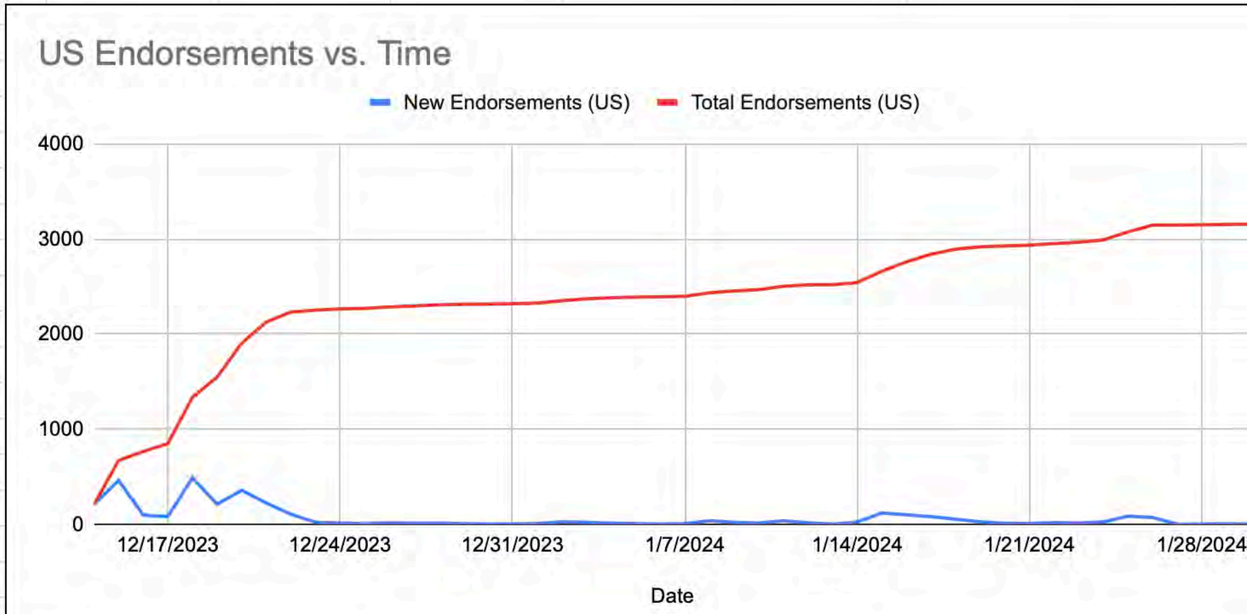
Support the 2023 P5 Report : Statistics

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










reached out to 532
offices out of 538

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.*"
- **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**

United States Senate
WASHINGTON, DC 20510

March 14, 2024

The Honorable Frank Kendall III
Secretary of the Air Force
1670 Air Force Pentagon
Washington, DC 20330-1670

Dear Secretary Kendall,

We write to you regarding the recapitalization of the LC-130H fleet. Flown by the New York Air National Guard's 109th Airlift Wing (AW), the LC-130H is the only ski-equipped heavy airlift aircraft capable of traveling to the Arctic and Antarctica, and the 109th AW is the only US military unit in the world that operates these planes and supports the polar airlift mission set. However, as these planes approach the end of their service life, LC-130H operators and aircrew face a dangerous level of uncertainty during airlift missions. This uncertainty jeopardizes our ability to project power in the Arctic and Antarctic. Therefore, it is imperative that the Air Force recapitalize the entire LC-130H fleet in order to prioritize flight safety and ensure we can effectively meet the requirements of the Department of Defense's (DoD) Arctic Strategy.

US Northern Command (NORTHCOM), which oversees the polar airlift mission, has expressed the urgent need to recapitalize the LC-130H fleet with the newer J model to be able to operate in the Arctic and Antarctic environments. NORTHCOM has also spoken to the unique capabilities that the LC-130H provides, as demonstrated by the 109th AW's participation in annual NORTHCOM-led exercises such as Arctic Edge and Arctic Eagle. The 109th AW provides year-round logistical support for the National Science Foundation's (NSF) polar science research missions in Greenland, Antarctica, and the Arctic, delivering 100% of the materials and equipment for the rebuild of the South Pole Station. These science support missions executed by the 109th AW in turn help enhance DoD's polar mission readiness.

With an impeccable safety record, the 109th AW has executed these critical missions for more than 30 years, and New York is proud to serve as the home to this elite unit and one-of-a-kind capability. However, the majority of the existing LC-130H fleet were built in the 1970s, operate on technology developed in the 1950s, and as a result of being in service for all 12 months of the year, are quickly approaching the end of their service life. Although they have received upgrades, they are constantly suffering reliability issues and high maintenance costs. Additionally, nearly all of the LC-130Hs have parts that require total replacement, but—due to their age and being the only aircraft of its kind—many of those parts are no longer manufactured. With a mission capability rate of roughly 50%, it is apparent that modernization efforts alone are not enough to secure the fleet's long-term sustainability.

Furthermore, it is important to recognize the national security implications of failing to recapitalize the LC-130 fleet. Amid rising global tensions and the rapidly evolving geopolitical landscape, the North and South Poles have grown in their strategic importance to the US's ability to compete with Russia and the People's Republic of China (PRC), both of whom have expanded their presence in the polar regions. As the only ski-equipped aircraft capable of operating in Arctic and Antarctic environments, the LC-130 provides mission critical logistical support to regions that conventional aircraft cannot access. The LC-130 is a centerpiece of US efforts to maintain a strategic advantage in the polar theaters.

For all of these reasons, we urge you to prioritize the recapitalization of the LC-130 fleet. We look forward to your response and are prepared to assist however possible to protect this crucial mission and support the critical contributions of the 109th AW.

Thank you for your prompt attention to this important matter. Please do not hesitate to reach out to our offices with any questions.

Sincerely,

Charles E. Schumer
United States Senator

Kirsten E. Gillibrand
United States Senator

Attempt to improve the South Pole by replacing the LC-130 fleet

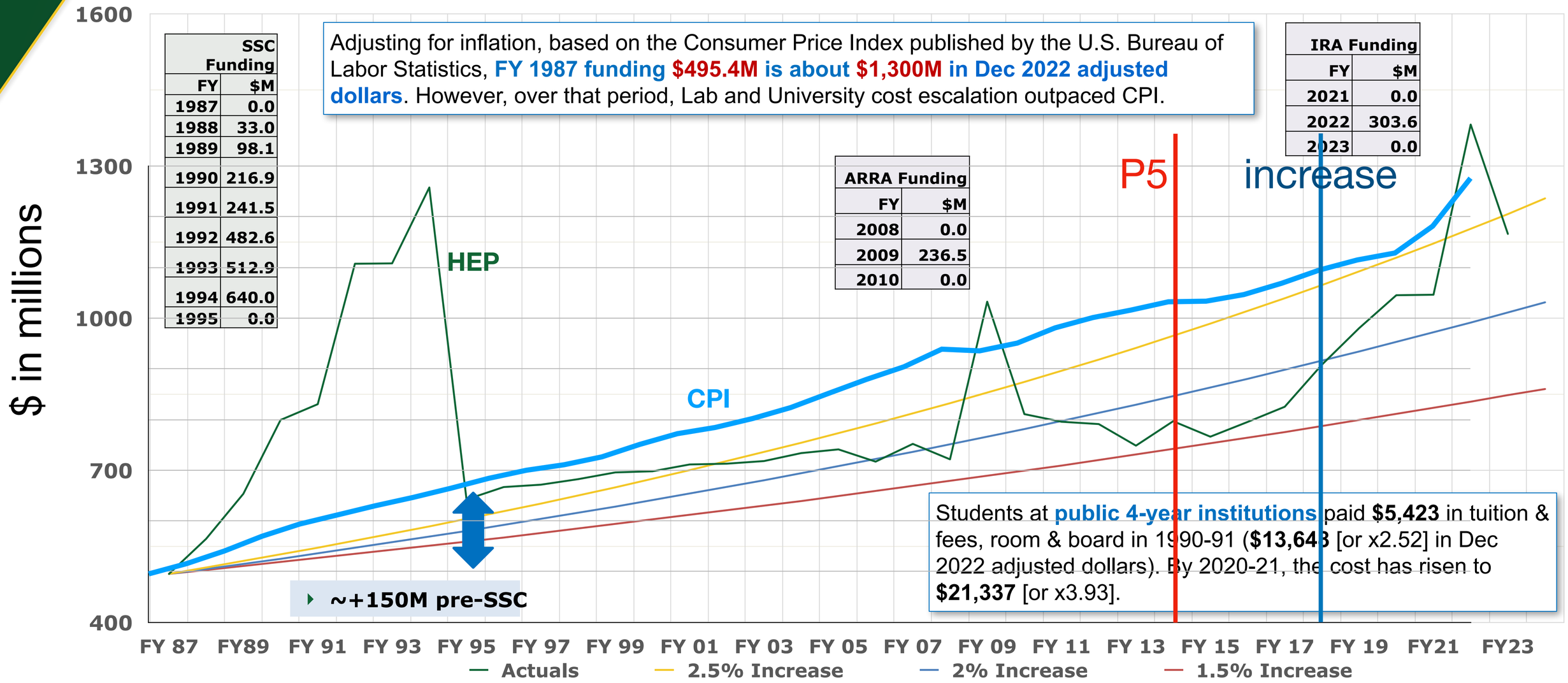
Also a letter in the House

DOE HEP Facilities Subpanel

		Science Assessment				Technical Readiness		
		Absolutely central	*Important*	*Lower priority*	*Don't know*	*Ready to initiate construction*	*Significant scientific/ engineering challenges remain*	*Mission and technical requirements not fully defined*
		A	B	C	D	A	B	C
LBNF/DUNE Phase 1		●				●		
LBNF/DUNE Phase 2	ACE-MIRT	●				●		
	FD3	●				●		
	MCND	●					●	
FD4					●		●	
CMB-S4		●				●		
Spec-S5		●				●		
G3 Dark Matter		●					●	
Off-Shore Higgs Factory		●				●		
AATF - kBELLA		●					●	
ACE-BR					●			●
10 TeV pCM Collider		●						●

See N. Roe's presentation

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.

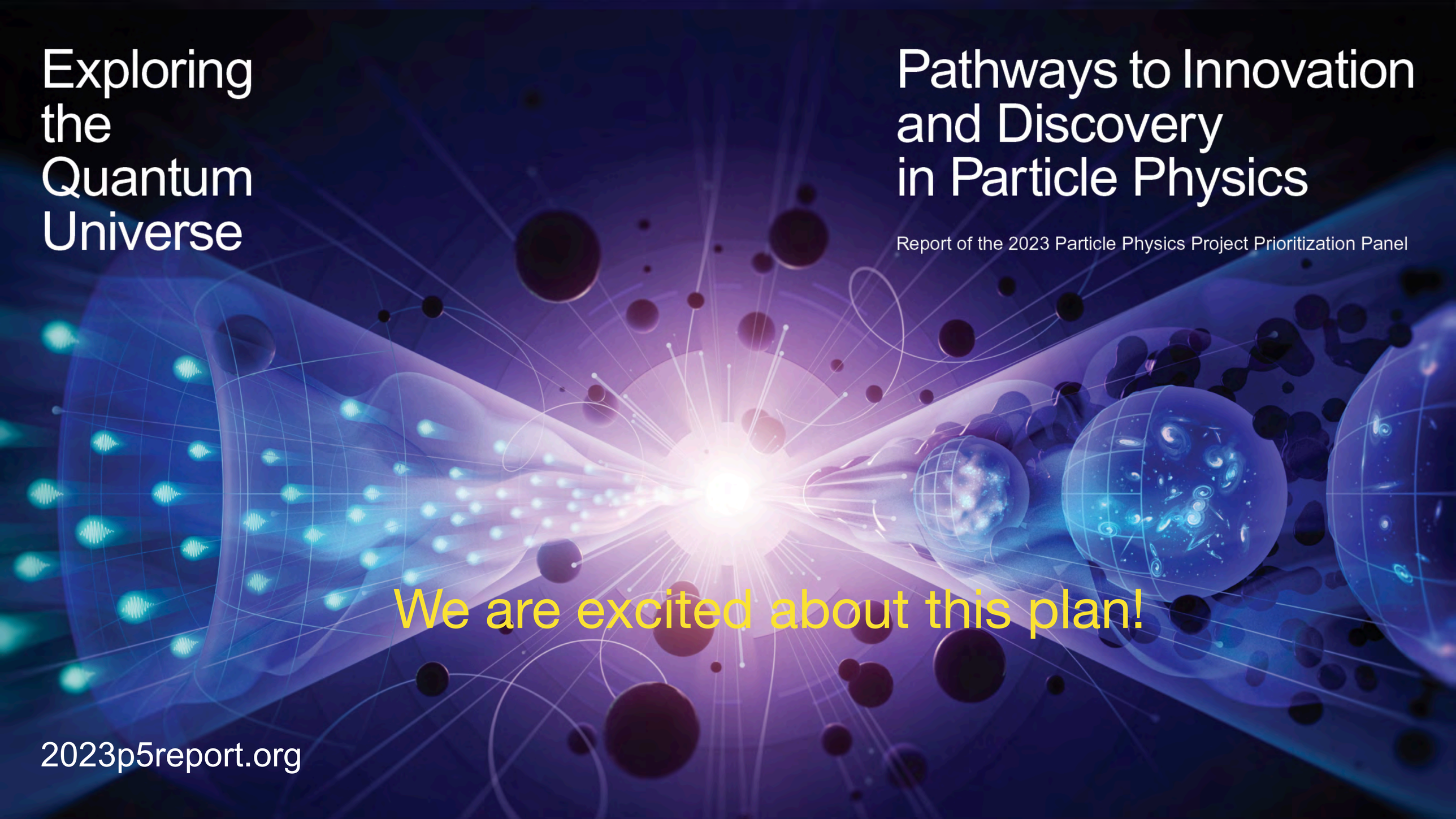
ARRA Funding	
FY	$M
2008	0.0
2009	236.5
2010	0.0

IRA Funding	
FY	$M
2021	0.0
2022	303.6
2023	0.0

Students at **public 4-year institutions** paid **$5,423** in tuition & fees, room & board in 1990-91 (**$13,643** [or x2.52] in Dec 2022 adjusted dollars). By 2020-21, the cost has risen to **$21,337** [or x3.93].

Some Lessons and Observations from P5

- HEP is a global enterprise, international collaborations are key, need to work with and understand international partners.
- Understanding costs is important for P5 planning. Subcommittee on costs, schedules, and risks provided important input.
- Early career researchers have an important voice in the field.
- Lead with the science, it inspires and unites people.
- A prioritized, strategic plan is basis for success. Rollout and briefings for P5 are substantial effort.
- Implementation is key to the success of the field.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Looking forward to its implementation.
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