Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the 2023 Particle Physics Project Prioritization Panel

Conclusions and Impact of the P5 Report

US Future Circular Collider Workshop 2024

Karsten Heeger
P5 Deputy Chair,
On behalf of P5 Committee

2023p5report.org


P5 Panel
Smash Particles

P5 Panel

Exploring the Quantum Universe

Shoji Asai (University of Tokyo)
Amalia Ballarino (CERN)
Tulika Bose (Wisconsin–Madison)
Kyle Cranmer (Wisconsin–Madison)
Francis-Yan Cyr-Racine (New Mexico)
Sarah Demers (Yale)
Cameron Geddes (LBNL)
Yuri Gershtein (Rutgers)
Karsten Heeger (Yale) - *Deputy Chair*
Beate Heinemann (DESY)
JoAnne Hewett (SLAC) - HEPAP chair, ex officio until May 2023
Patrick Huber (Virginia Tech)
Kendall Mahn (Michigan State)
Rachel Mandelbaum (Carnegie Mellon)
Jelena Maricic (Hawaii)
Petra Merkel (Fermilab)
Christopher Monahan (William & Mary)
Hitoshi Murayama (Berkeley) - *Chair*
Peter Onyisi (Texas Austin)
Mark Palmer (BNL)
Tor Raubenheimer (SLAC/Stanford)
Mayly Sanchez (Florida State)
Richard Schnee (South Dakota School of Mines & Technology)
Sally Seidel (New Mexico) – interim HEPAP chair, ex officio since June 2023
Seon-Hee Seo (IBS Center for Underground Physics until Sep, Fermilab since Sep)
Jesse Thaler (MIT)
Christos Touramanis (Liverpool)
Abigail Vieregg (Chicago)
Amanda Weinstein (Iowa State)
Lindley Winslow (MIT)
Tien-Tien Yu (Oregon)
Robert Zwaska (Fermilab)

Blue: international members

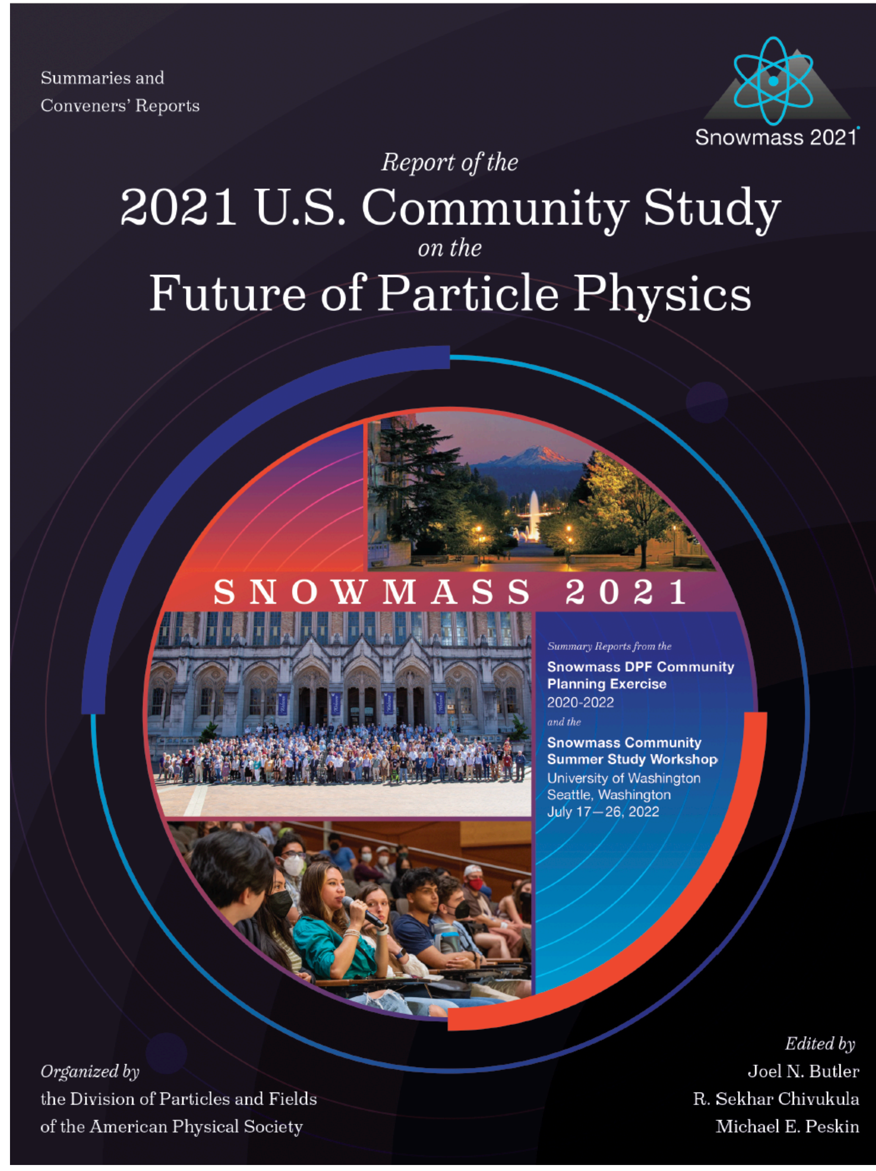
Charge to the 2023 P5 Subcommittee

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)

Final workshop of Snowmass 2021 Community Study (~2 years)
University of Washington, July 2022

Community Vision from Snowmass 2021



Summary of the 2021-2022 US HEP Community Planning Exercise

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

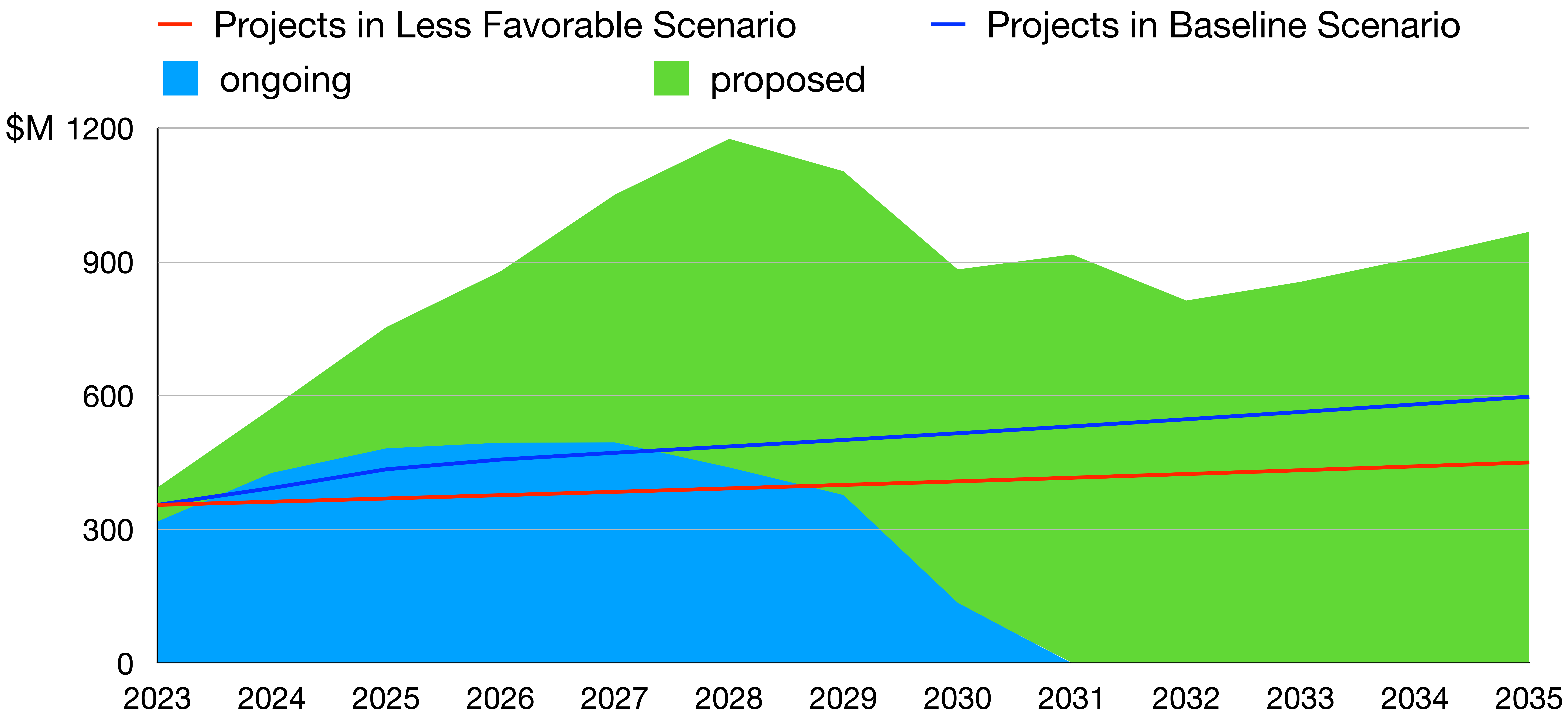
Higgs factory summary table

- Main parameters of the submitted Higgs factory proposals.
- The cost range is for the single listed energy.
- The superscripts next to the name of the proposal in the first column indicate:
  - (1) Facility is optimized for 2 IPs. Total peak luminosity for multiple IPs is given in parenthesis;
  - (2) Energy calibration possible to 100 keV accuracy for MZ and 300 keV for MW ;
  - (3) Collisions with longitudinally polarized lepton beams have substantially higher effective cross sections for certain processes

Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} cm^{-2}s^{-1}]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
FCC-ee[1,2]	0.24 (0.09-0.37)	7.7 (28.9)	0-2	13-18	12-18	290
CEPC[1,2]	0.24 (0.09-0.37)	8.3 (16.6)	0-2	13-18	12-18	340
ILC[3] - Higgs factory	0.25 (0.09-1)	2.7	0-2	<12	7-12	140
CLIC[3] - Higgs factory	0.38 (0.09-1)	2.3	0-2	13-18	7-12	110
CCC[3] (Cool Copper Collider)	0.25 (0.25-0.55)	1.3	3-5	13-18	7-12	150
CERC[3] (Circular ERL Collider)	0.24 (0.09-0.6)	78	5-10	19-24	12-30	90
ReLiC[1,3] (Recycling Linear Collider)	0.24 (0.25-1)	165 (330)	5-10	>25	7-18	315
ERLC[3] (ERL linear collider)	0.24 (0.25-0.5)	90	5-10	>25	12-18	250
XCC (FEL-based $\gamma\gamma$ collider)	0.125 (0.125-0.14)	0.1	5-10	19-24	4-7	90
Muon Collider Higgs Factory[3]	0.13	0.01	>10	19-24	4-7	200

Implementation Task Force, Thomas Roser

Budget Scenarios and Projects



not including on-shore Higgs factory

DOE only

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8.2 Hard Choices

- On-shore Higgs factory. We could not identify room in the budget executable in the next twenty years for an on-shore Higgs factory unless the overall budget is increased by more than a factor of a few. On the other hand, there is an ongoing process in Europe to see if FCC-ee is feasible. The Japanese HEP community has been making an effort to realize ILC as a global project hosted in Japan. We therefore recommend exploring off-shore options and vigorously pursuing international collaborations so the US can play a major role when one of those projects becomes reality. If FCC-ee and ILC are judged to be not feasible, a new panel should revisit the possibility of bidding to host a Higgs factory potentially as a global project and including advanced technology options.

Subcommittee on Costs/Risks/Schedule

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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

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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**

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1.1 Overview and Vision

We envision a new era of scientific leadership, centered on decoding the quantum realm, unveiling the hidden universe, and exploring novel paradigms. Balancing current and future large- and mid-scale projects with the agility of small projects is crucial to our vision. We emphasize the importance of investing in a highly skilled scientific workforce and enhancing computational and technological infrastructure. Acknowledging the global nature of particle physics, we recognize the importance of international cooperation and sustainability in project planning. We seek to open pathways to innovation and discovery that offer new insights into the mysteries of the quantum universe.

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Not Rank-Ordered

Recommendation 1

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).

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).

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).

US leadership in key areas of particle physics

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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

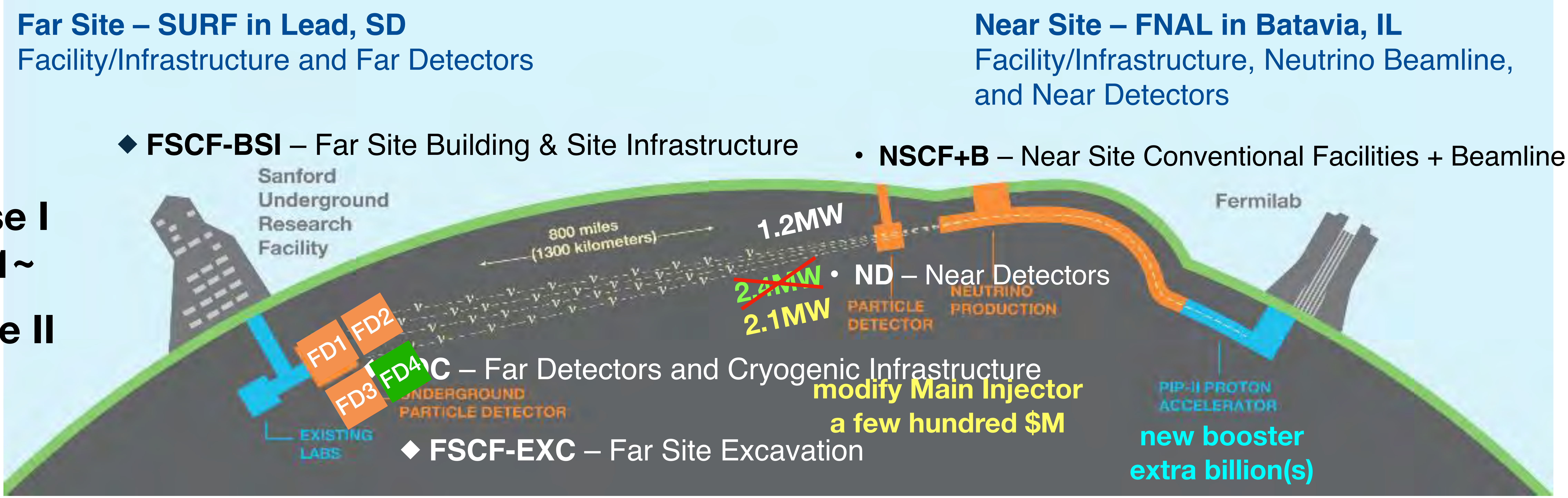
Major New Initiative: CMB-S4

Constrain the energy scale of inflation, determine the abundance of light relic particles in the early universe, measure the sum of neutrino masses, and probe the physics of dark matter and dark energy…

Site in Chile

Site at the South Pole

Long baseline neutrino facility (LBNF) and Deep Underground Neutrino Experiment (DUNE)



Phase I
2031~
Phase II

◆ DUNE is an international science collaboration of more than 1300 scientists from 35 countries plus CERN

- 50 – 50 split between U.S. and non- U.S. collaborators

3.1.4 – Future Opportunities: DUNE FD4, the Module of Opportunity

An upgraded detector module will provide excellent prospects for underground physics, including direct dark matter detection, exotic dark matter searches, and expanded sensitivity to solar neutrinos. R&D for advanced detector concepts should be supported.

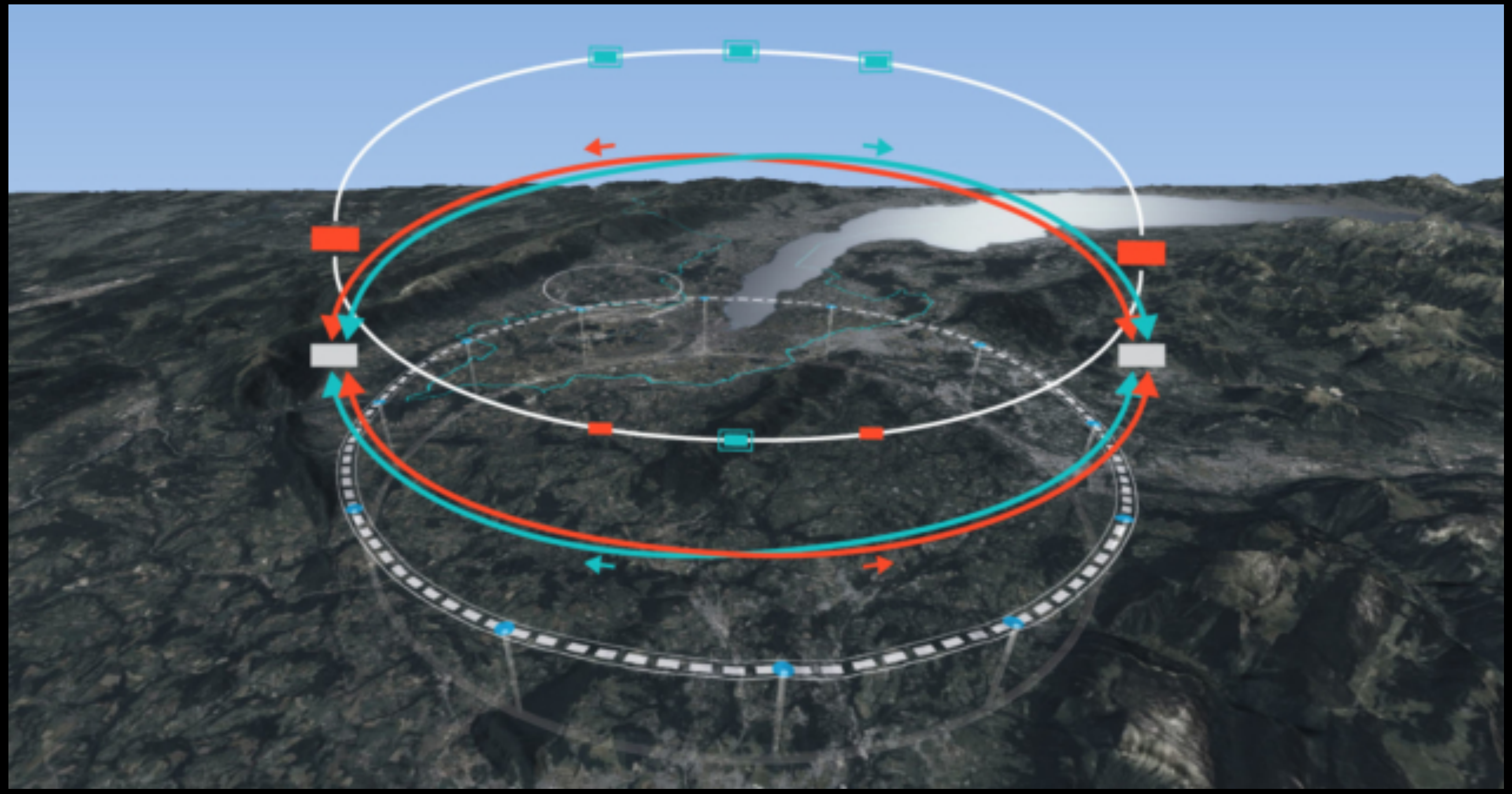
ffice of Science (TPC = $3.2B)
al particle physics mega-project

An Offshore Higgs Factory

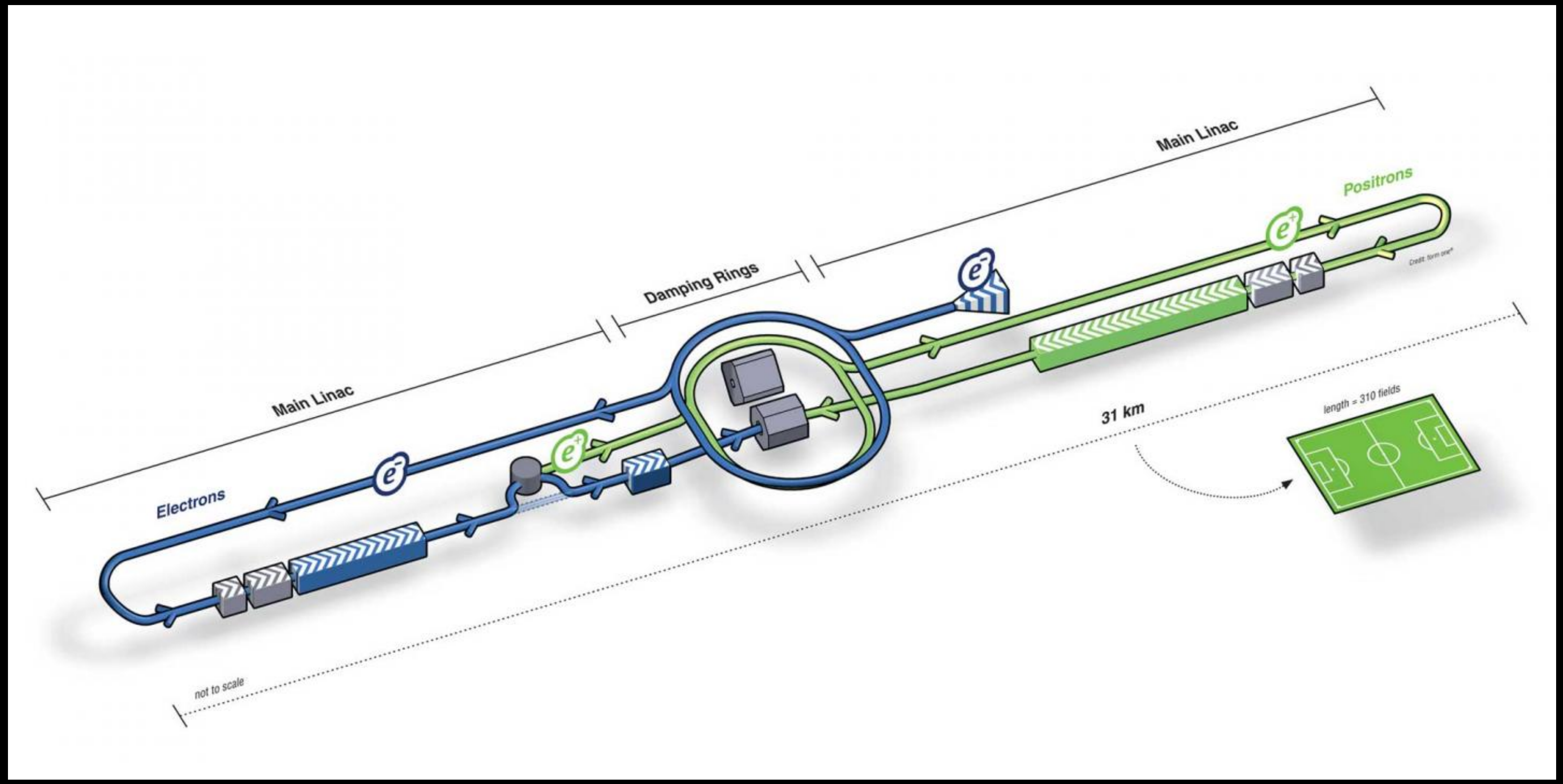
An electron-positron collider covering center-of-momentum energy range 90 - 350 GeV

- Precision measurements of couplings and some production modes
- Order of magnitude improved access to Higgs → invisible decays
- EW sector consistency checks, testing through quantum loops that relate W & Z bosons, the top quark, and the Higgs
- Improve knowledge of coupling to charm quark, potentially provide access to coupling to strange quark

FCC ee



ILC



G3 Dark Matter experiments

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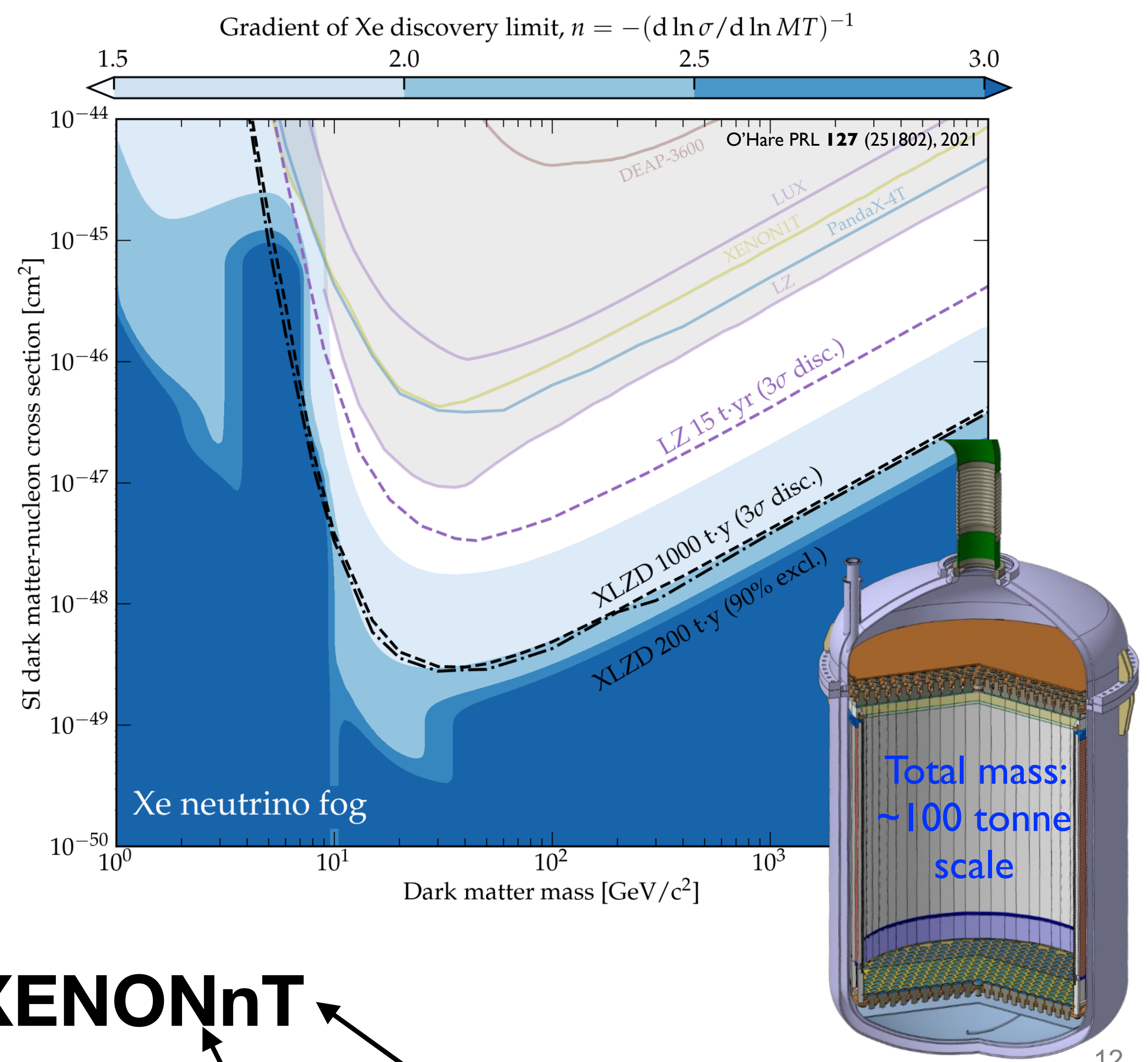
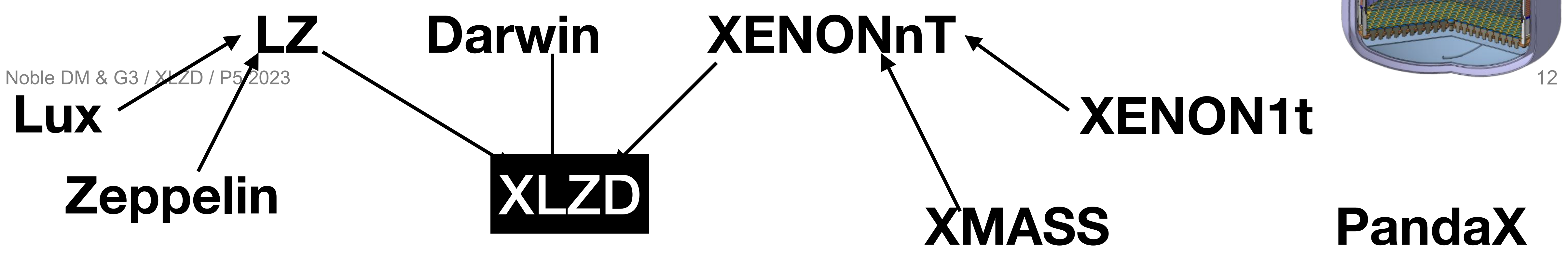
XLZD: definitive search for high mass WIMPs

- Searching for WIMPs into the "fog"
  - Nearly indistinguishable background from astrophysical neutrinos
  - Sensitivity rapidly falls - 20% flux uncertainty
  - Systematic limit (1000 tonne-year exposure) = practical limit of ~100-tonne detector
  - 3-sigma discovery at 3x10^{-49} at 40 GeV
- Combine best of LZ and XENONnT
  - 10x mass: 63-tonne fiducial of 70 active
  - Double TPC linear dimensions
  - Compact geometry: readout, underground transport & fit





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
(Can be hosted in the cavern made available through the SURF expansion)

If extra funds or NSF involvement:
Initiate construction of **a second G3 dark matter experiment** to maximize discovery potential when combined with the first one.

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Difficult Choices

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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: Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
>$3B										
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		

Science Drivers: Neutrinos, Higgs Boson, Dark Matter, Cosmic Evolution, Direct Evidence, Quantum Imprints, Astronomy & Astrophysics

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Not Rank-Ordered

Recommendation 4

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).

c. Expand the **General Accelerator R&D (GARD)** program within HEP, including stewardship (section 6.4).

d. Invest in R&D in **instrumentation** to develop innovative scientific tools (section 6.3).

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).

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.

5.2.4 – Major Initiative: Higgs Factory

One of our recommendations for major initiatives is the US involvement in a Higgs factory. The main purpose of the factory is to reveal the secrets of the Higgs boson (section 3.2). However, the Higgs boson is also a sensitive probe of the quantum imprints of new phenomena.

…

The Higgs factory we recommend can be run at the Z pole. Its high luminosity could produce of the order of 10^9–10^{12} Z bosons and a large sample of WW events. These abilities would enable an exceptional program of precision studies of electroweak interactions,

…

the Z bosons would then produce large samples of bottom and charm hadrons, and tau leptons in their decays, and at the 10^{12} Z boson scale will become extremely useful in that regard. For example, the FCC-ee circular collider is expected to produce a sample of bottom mesons twenty times larger than that of Belle II, enabling a strong indirect search program which will complement its Higgs boson and electroweak parameter measurements.

…

Comparing the direct measurements of the top quark and Higgs boson masses at a Higgs factory to the precision measurements of Z and W boson properties can reveal hidden quantum imprints of new particles and phenomena at 10 TeV energy scale

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Recommendation 6

Decisions without waiting for the next P5 in 10 years

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.

2.5 International and Inter-Agency Partnerships

In the case of the Higgs factory, crucial decisions must be made in consultation with potential international partners. The FCC-ee feasibility study is expected to be completed by 2025 and will be followed by a European Strategy Group update and a CERN council decision on the 2028 timescale. The ILC design is technically ready and awaiting a formulation as a global project. **A dedicated panel should review the plan for a specific Higgs factory once it is deemed feasible and well-defined;** evaluate the schedule, budget and risks of US participation; and give recommendations to the US funding agencies later this decade (Recommendation 6). When a clear choice for a specific Higgs factory emerges, US efforts will focus on that project, and R&D related to other Higgs factory projects would ramp down.

Parallel to the R&D for a Higgs factory, **the US R&D effort should develop a 10 TeV pCM collider (design and technology)**, such as a muon collider, a proton collider, or possibly an electron-positron collider based on wakefield technology. The US should participate in the International Muon Collider Collaboration (IMCC) and take a leading role in defining a reference design. We note that there are many synergies between muon and proton colliders, especially in the area of development of high-field magnets. R&D efforts in the next 5-year timescale will define the scope of test facilities for later in the decade, paving the way for initiating **demonstrator facilities within a 10-year timescale** (Recommendation 6).

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Area Recommendations

Collider R&D

10. To enable targeted R&D before specific collider projects are established in the US, an investment in **collider detector R&D funding at the level of $20M per year** and **collider accelerator R&D at the level of $35M per year** in 2023 dollars is warranted.

6.5 Collider R&D

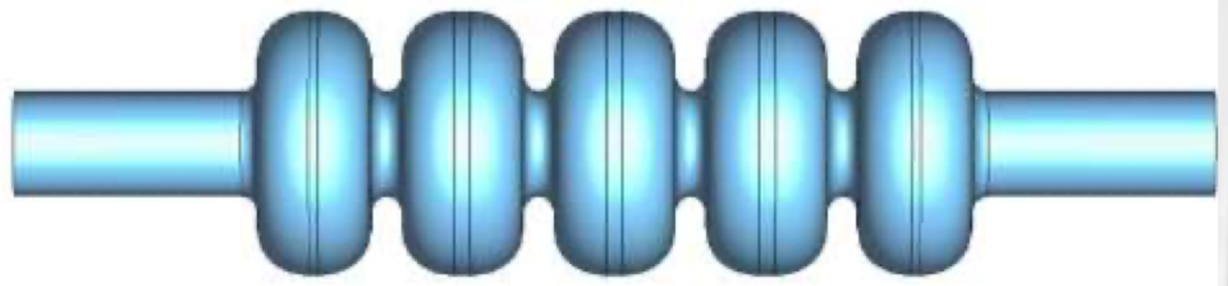
The decisions related to construction of an off-shore Higgs factory are anticipated to be made later this decade. The current designs of both FCC-ee and the ILC satisfy our scientific requirements. To secure a prominent role in a future Higgs factory project, the US should actively engage in feasibility and design studies (Recommendation 2c). Engagement with FCC-ee specifically should include design and modeling to advance the feasibility study, as well as R&D on superconducting radio frequency cavities designed for the ring and superconducting magnets designed for the interaction region. These efforts benefit from synergies in workforce development through participation in SuperKEKB and the Electron-Ion Collider.

Maintaining engagement with ILC accelerators through the ILC Technology Network can include design updates and cryomodule construction. These will support significant US contributions to potential projects. A global framework for future collider development, such as the ILC International Development Team as implemented by ICFA for the ILC, is relevant for all future colliders.

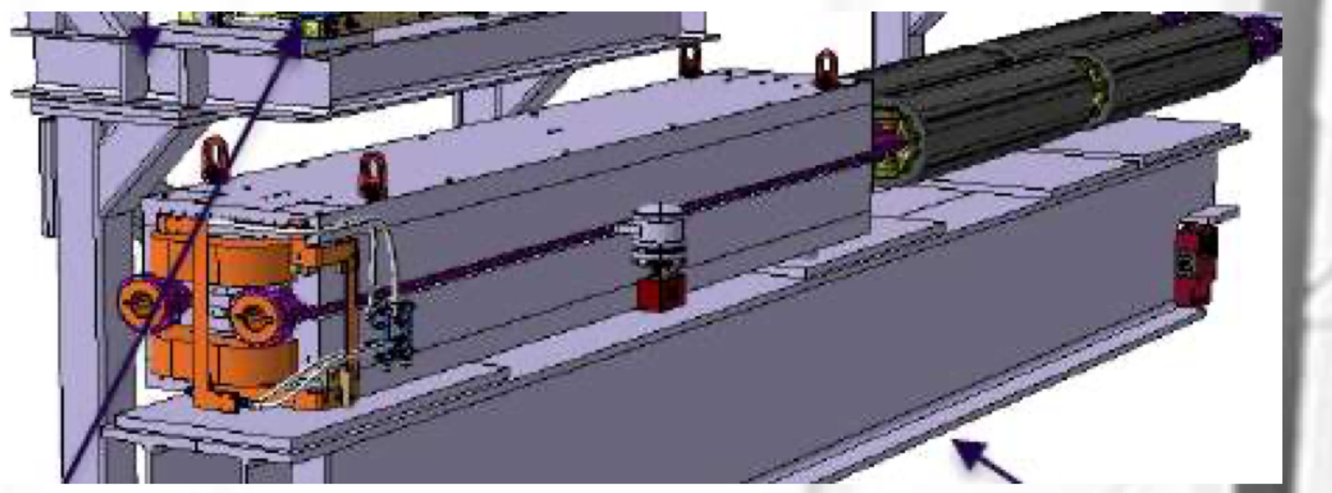
For Higgs factory detectors, a concerted effort of targeted R&D synchronized with the targeted accelerator R&D program is needed. The US should participate in international design efforts for specific collider detectors. To achieve the scientific goals, several common requirements apply to the detectors of the various collider options, including vertexing, tracking, timing, particle identification, calorimetry, muon detection, and triggering. Central coordination of these requirements is crucial. The US should engage in this coordination while taking leading roles in some of the design efforts.

Major international decisions on the route to a Higgs factory are anticipated later this decade. Supported by ICFA, the Japanese HEP community remains committed to hosting the ILC in Japan as a global project. The FCC-ee feasibility study is scheduled for completion by 2025, followed by an update by the European Strategy Group and a decision by the CERN Council. Once a specific project is deemed feasible and well-defined, the US should focus efforts towards that technology. A separate panel should determine the level and nature of US contribution while maintaining a healthy US on-shore program in particle physics (recommendation 6). In the scenario where a global consensus to move forward with the Higgs factory is not reached, the next P5 should reevaluate.

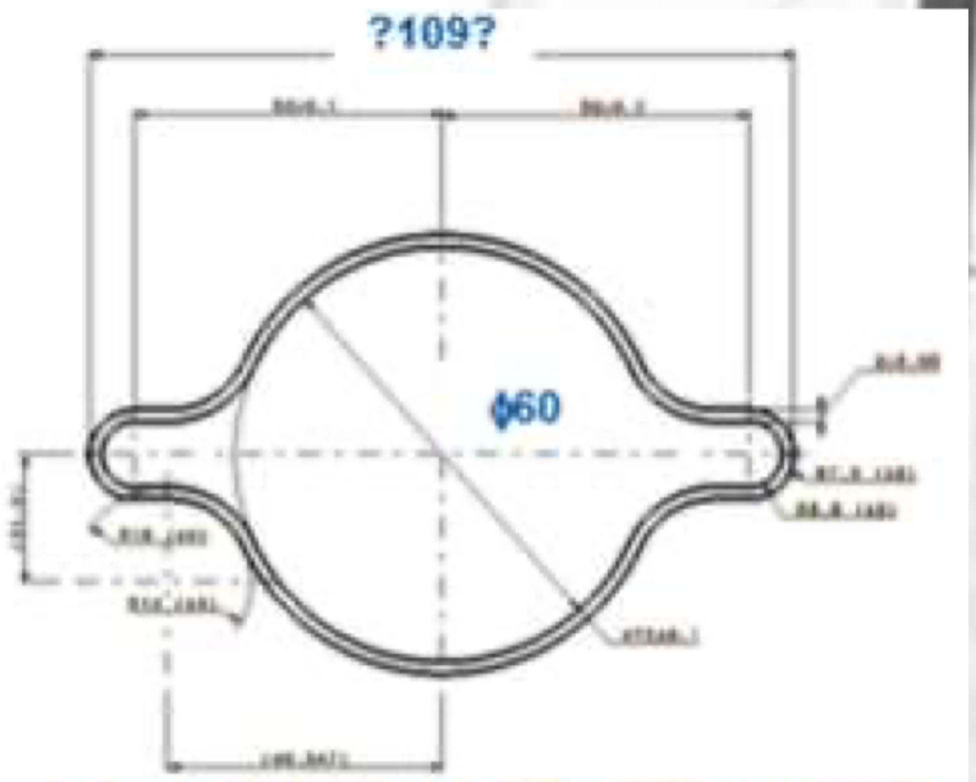
Possible Fabrication Elements - for Consideration (the US contribution TBD)



1) 2.1 GV 800 MHz SRF for Higgs, 28 CMs *O*(0.2B$)
2) 18.4 GV of 800 MHz SRF for *ttbar*, 244 CMs *O*(1.7B$)
3) 6-20 GeV S-band C^3 type linac *O*(0.25B$)



4) IR magnets for 4 IPs *O*(0.6B$)
5) Magnets for the collider and booster rings *O*(1B$)
6) 270 km of vacuum beam pipes (collider, booster) *O*(0.3B$)
7) Several km RF bypass beamline (switch btw tt and ZH) - TBD
8) Beam instrumentation/polarization *O*(0.15B$)
   - Collimation, halo monitors | Polarization wigglers, meters, sources | TMCI feedback



Vacuum chamber prototype cross-section

9) Technical Infrastructure contributions - TBD
   - Alignment | Radiation protection | Safety systems | Power converters

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Not Rank-Ordered

Recommendation 5

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 expectations for professional conduct and establish mechanisms for **transparent reporting, response, and training**. These mechanisms should be supported by laboratory and funding agency infrastructure. The efficacy and coverage of this infrastructure should be reviewed by a HEPAP subpanel.

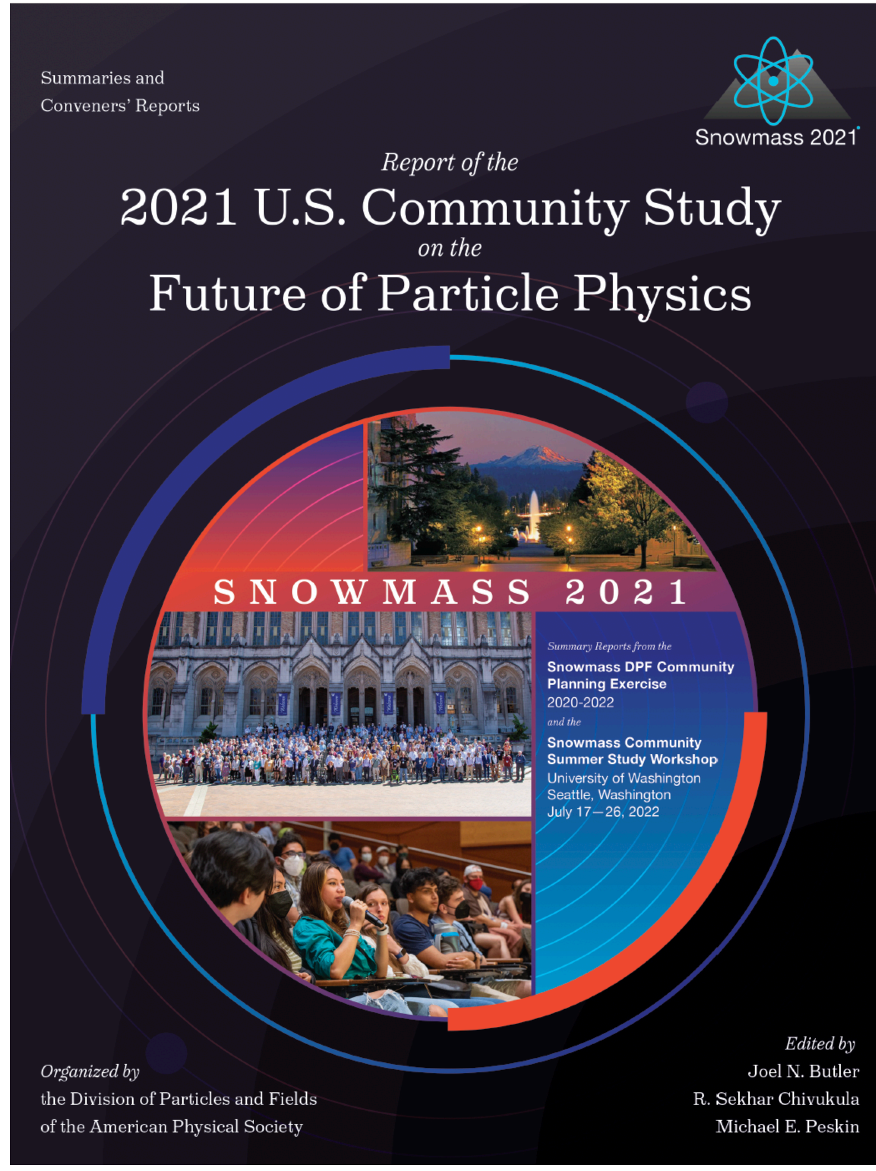
b. Funding agencies should continue to support programs that **broaden engagement** in particle physics, including strategic academic partnership programs, **traineeship programs, and programs in support of dependent care and accessibility**. A systematic review of these programs should be used to identify and **remove barriers**.

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 investigations to ensure that the unique experiences of individuals engaged in smaller collaborations and university settings are effectively captured.

d. Funding agencies should strategically increase support for **research scientists, research hardware and software engineers, technicians, and other professionals** at universities.

e. A plan for **dissemination of scientific results to the public** should be included in the proposed 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.

Community Vision from Snowmass 2021



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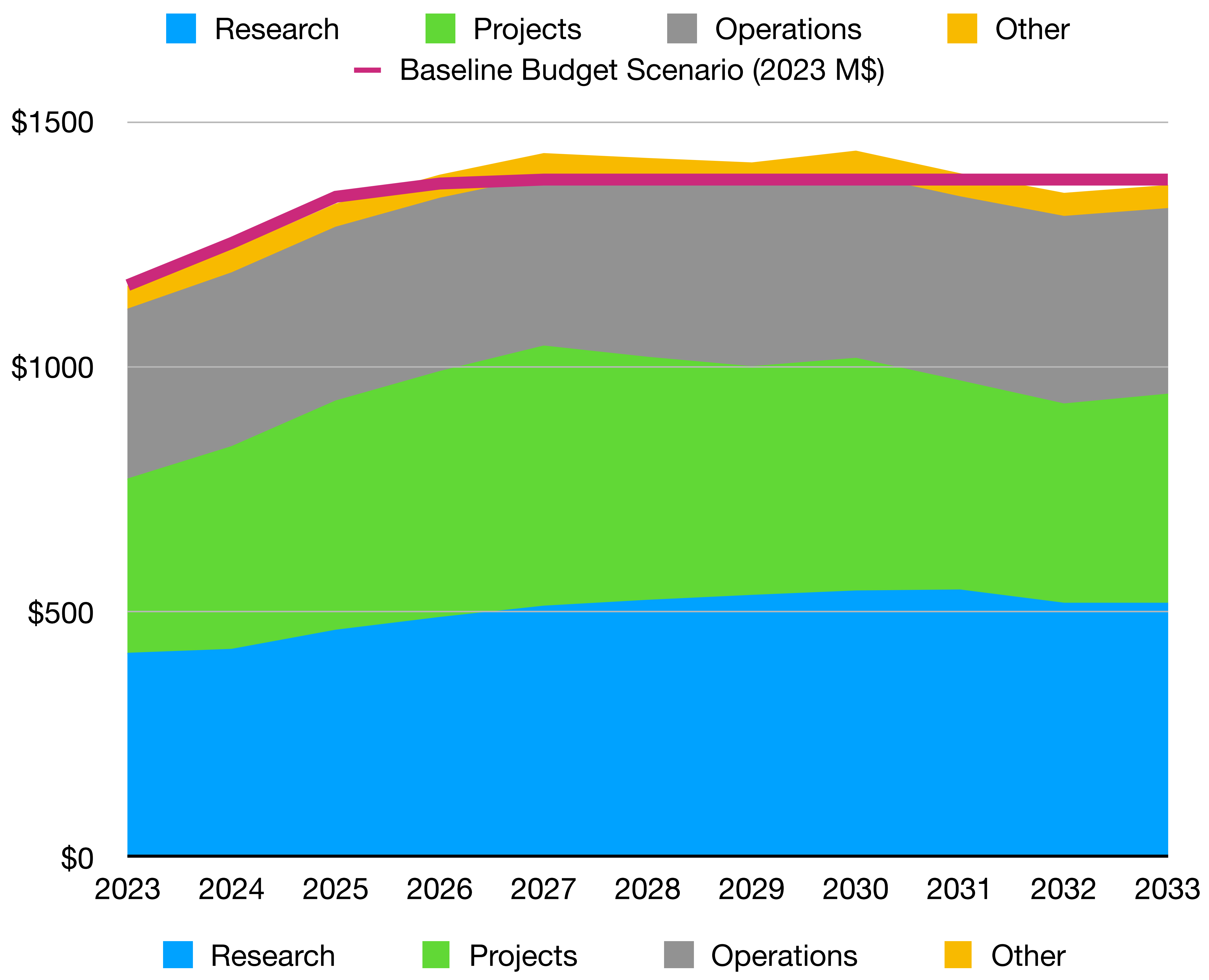
		✓ Higgs Factory
Neutrino Frontier	✓ LBNF/DUNE Phase I & PIP- II	✓ DUNE Phase II (incl. proton injector)
Cosmic Frontier	✓ Cosmic Microwave Background - S4	Next Gen. Grav. Wave Observatory*
	✓ Spectroscopic Survey - S5*	✓ Line Intensity Mapping*
	✓ Multi-Scale Dark Matter Program (incl. Gen-3 WIMP searches)	
Rare Process Frontier		✓ Advanced Muon Facility

The particle physics case for studying gravitational waves at all frequencies should be explored by expanded theory support.

✓ **Recommended**
✓ **R&D**

Budget Scenarios



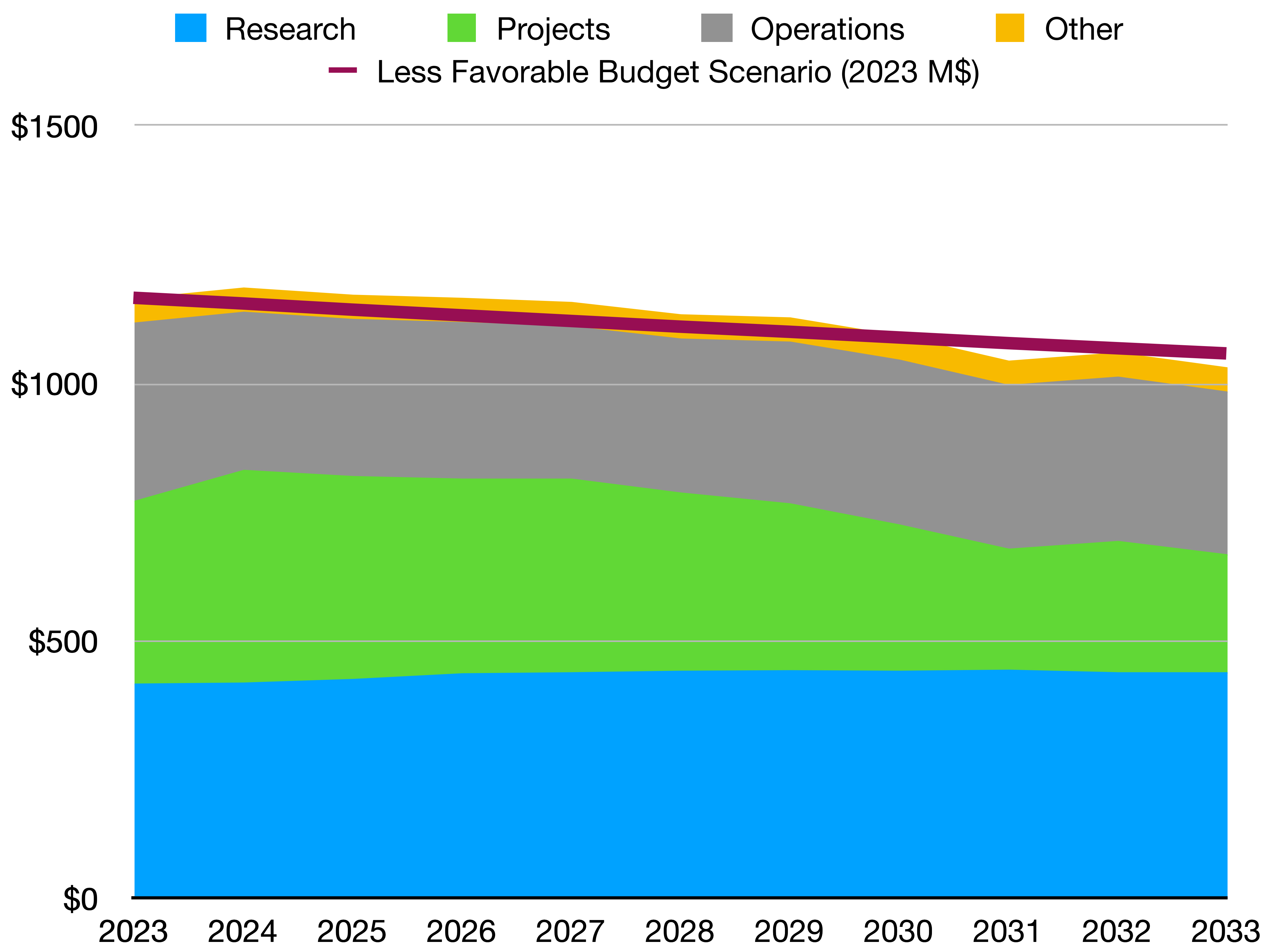


Fig. 2 Evolution of DOE budgets in Research, Projects, Operations, and Other in our budget exercise for the two budget scenarios given in the charge in 2023 dollars assuming 3% annual inflation.

Not in the Report

Broad and Diverse Program

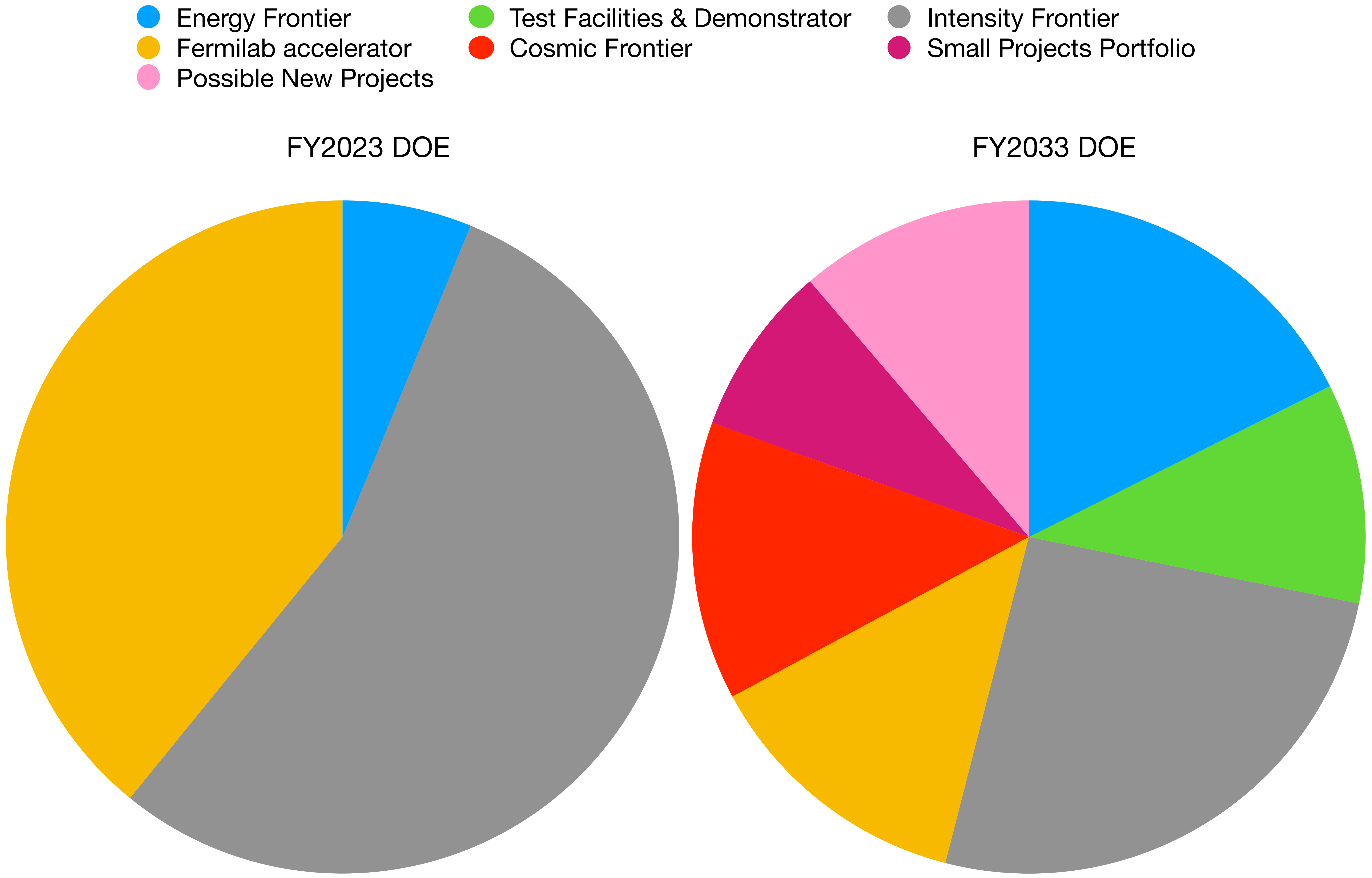


Fig. 3 Composition of DOE Projects in FY2023 (enacted) and FY2033 (recommended) in in our budget exercise. Demonstrator and Small Projects Portfolio are regarded as Projects for this pie chart.

Not in the Report

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.

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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

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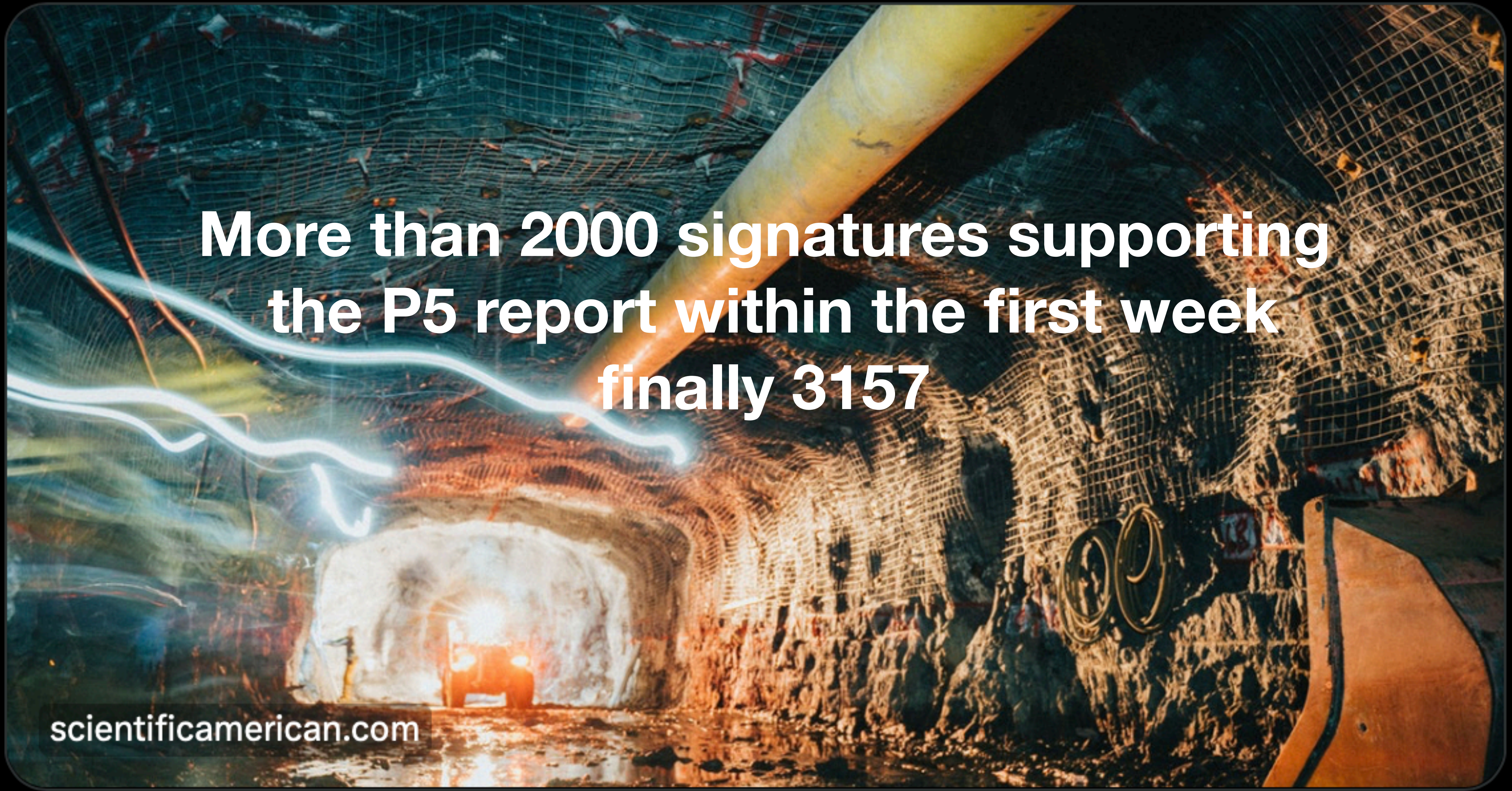
Dan Garisto
@dangaristo

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:



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