P5 report: PAC

Bonnie Fleming
January 11th, 2024

Overall: Excellent report!

- Well balanced, hard choices
- Endorsement of DUNE Phase 1 and 2
- Ambitious future on Energy Frontier (Muon shot…)
    - modernization of FNAL accelerator complex, critical for next generation machine and for physics along the way
    - Investment in R&D
- Workforce and Climate
- Working to develop a plan for FNAL response…

Many thanks to the PAC for your review of our presentations/plan to P5 last year!

Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

Report of the 2023 Particle Physics Project Prioritization Panel

Fermilab Town Hall
11 December 2023

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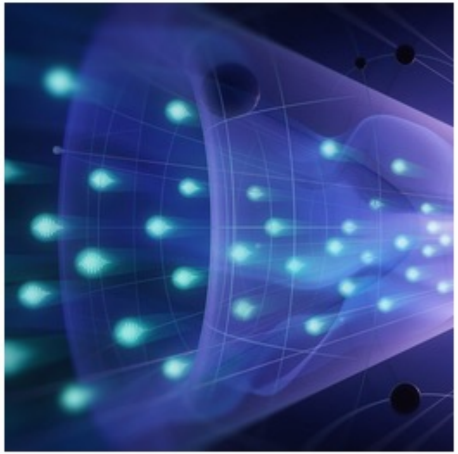
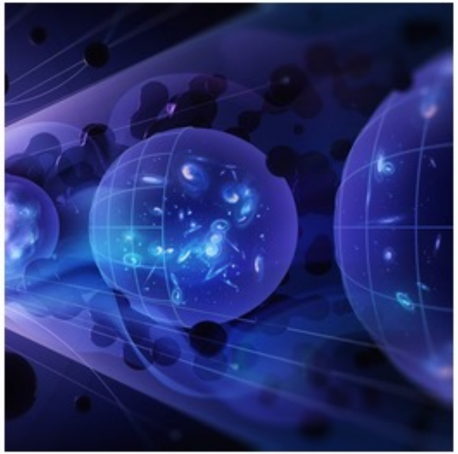
2023p5report.org

U.S. DEPARTMENT OF ENERGY

NSF





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

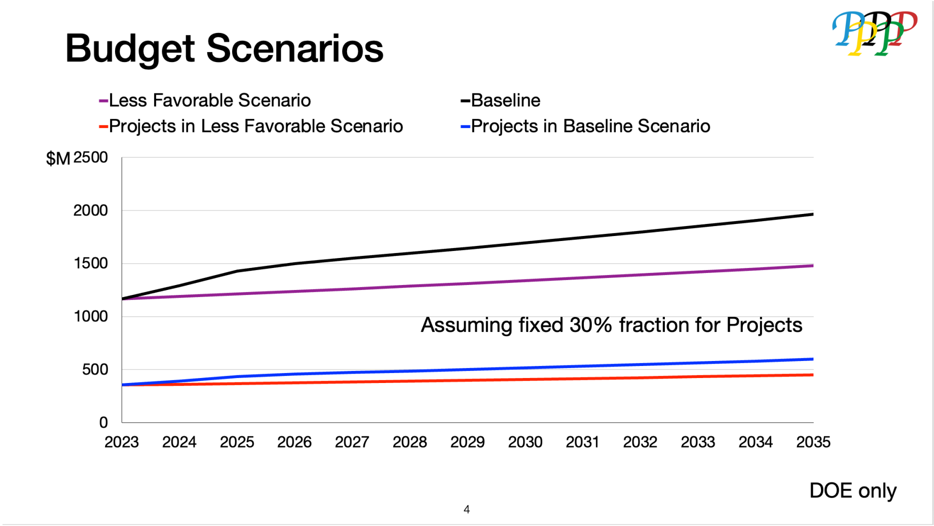
Illuminate the Invisible Universe

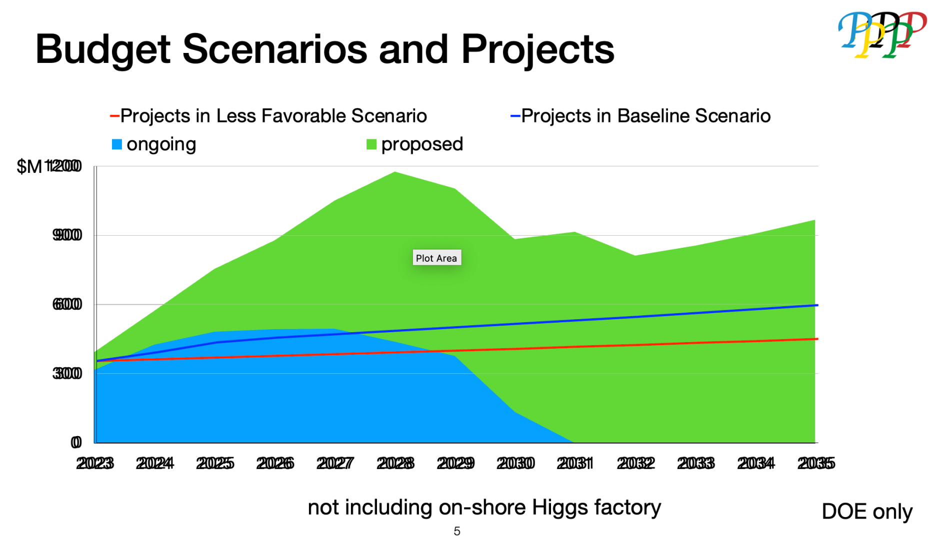
Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

Link to full report

Budget Scenarios





P5 also proposed a "More" favorable budget scenario

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Recommendation 1

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:

Not rank ordered

a. **HL-LHC**
b. **The first phase of DUNE and PIP-II**
c. **The Vera C. Rubin Observatory**

Continued support for medium scale ongoing experiments including completion of construction, operations, and research:

d. **NOvA**, **SBN**, **T2K**, and **IceCube**
e. **DarkSide-20k**, **LZ**, **SuperCDMS**, and **XENONnT**
f. **DESI**
g. **Belle II**, **LHCb**, and **Mu2e**

Current program

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Recommendation 2

Major Projects

Construct a portfolio of major projects that collectively study nearly all fundamental constituents of our universe and their interactions, as well as how those interactions determine both the cosmic past and future.

These projects have the potential to transcend and transform our current paradigms. They inspire collaboration and international cooperation in advancing the frontiers of human knowledge. Plan and start the following major initiatives **in order of priority from highest to lowest**:

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Recommendation 2

Major Projects

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).

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).

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).

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).

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).

Rank ordered

In the Baseline scenario:

- DUNE FD3
- MCND (near detector for Phase 2)
- ACE-MIRT (upgrades to complex to support early implementation of 2.1 MW beam

Above as proposed to P5

DUNE FD4 R&D over the next decade to 2034

→ As proposed, FD4 TPC construction start in 2033 with operations in 2036

Science Enablers

- LBNF/PIP-II
- ACE-MIRT
- SURF Expansion
- ACE-BR §, AMF

Figure 1 – Program and Timeline in Baseline Scenario (B)

Index: Operation, Construction, R&D, Research; P: Primary; S: Secondary

§ Possible acceleration/expansion for more favorable budget situations

Timeline: 2024 – 2034

Science Experiments	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
LHC		P	P		P	P	
LZ, XENONnT			P				
NOvA/T2K	P				S		
SBN	P				S		
DESI/DESI-II	S		S	P			P
Belle II			S		S	P	
SuperCDMS			P				
Rubin/LSST & DESC	S		S	P			P
Mu2e						P	
DarkSide-20k			P				
HL-LHC		P	P		P	P	
DUNE Phase I	P				S	S	S
CMB-S4	S		S	P			P
CTA			S				P
G3 Dark Matter §	S		P				
IceCube-Gen2	P		S				P
DUNE FD3	P				S	S	S
DUNE MCND	P				S	S	
Higgs factory §		P	S		P	P	
DUNE FD4 §	P				S	S	S
Spec-S5 §	S		S	P			P
Mu2e-II						P	
Multi-TeV §		P	P		P	S	
LIM	S		P	P			P

In the “Less” scenario: R&D only for ACE-MIRT and no MCND

In the “More” scenario: FD4 is brought back in as a ”Y”

Figure 2 – Construction in Various Budget Scenarios

Index: N: No Y: Yes R&D: Recommend R&D but no funding for project C: Conditional yes based on review P: Primary S: Secondary
Delayed: Recommend construction but delayed to the next decade
Can be considered as part of ASTAE with reduced scope

Scenarios	Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
				Science Drivers						
US Construction Cost >$3B										
on-shore Higgs factory	N	N	N		P	S		P	P	
$1–3B										
off-shore 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	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 #	N	N	N	P		P		P		

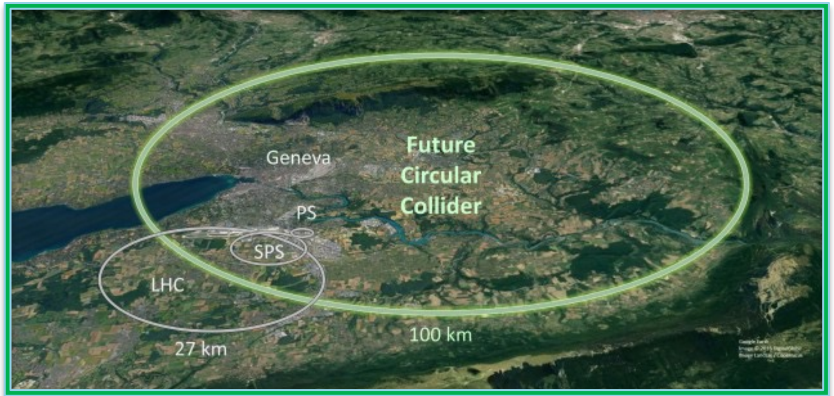
The Energy Frontier
Beyond the LHC and HL-LHC

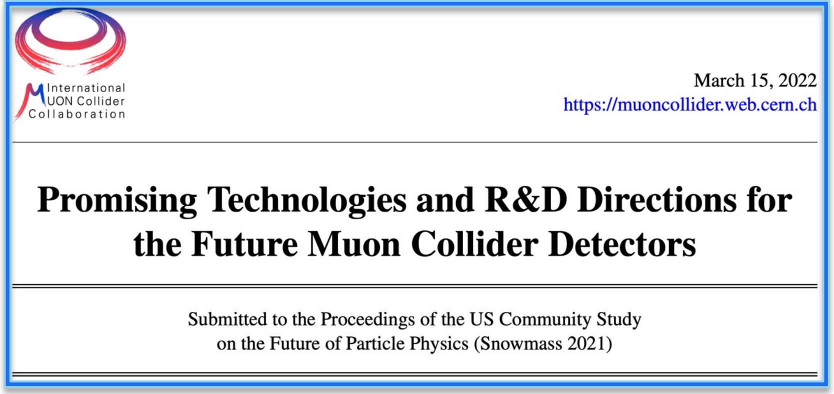
Reminder: FNAL presentation to P5

Precision measurements of the Higgs boson and EW sector and BSM searches at future colliders will shed light on key open questions in particle physics.

- This exploration will require an investment in accelerator technology research to
  - Contribute to the international effort to build a Higgs factory at CERN
  - Revitalize accelerator and detector R&D towards a next-generation multi-TeV energy frontier machine
- *Fermilab is poised to host a next generation multi-TeV energy frontier collider, as a global endeavor, following the completion of the full DUNE program*
- In order to make realistic progress, a substantial investment **in targeted accelerator research** as well as **associated detector research** will be required

These efforts should be organized through **national integrated accelerator R&D and detector R&D programs** that are aligned and coordinated with our international partners




International MUON Collider Collaboration

March 15, 2022
https://muoncollider.web.cern.ch

Promising Technologies and R&D Directions for the Future Muon Collider Detectors

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

2.3 The Path to a 10 TeV pCM

Realization of a future collider will require resources at a global scale and will be built through a world-wide collaborative effort where decisions will be taken collectively from the outset by the partners. This differs from current and past international projects in particle physics, where individual laboratories started projects that were later joined by other laboratories. The proposed program aligns with the long-term ambition of hosting a major international collider facility in the US, leading the global effort to understand the fundamental nature of the universe.

…

In particular, a muon collider presents an attractive option both for technological innovation and for bringing energy frontier colliders back to the US. The footprint of **a 10 TeV pCM muon collider is almost exactly the size of the Fermilab campus**. A muon collider would rely on a powerful multi-megawatt proton driver delivering very intense and short beam pulses to a target, resulting in the production of pions, which in turn decay into muons. This cloud of muons needs to be captured and cooled before the bulk of the muons have decayed. Once cooled into a beam, fast acceleration is required to further suppress decay losses.

…

Although we do not know if a muon collider is ultimately feasible, **the road toward it leads from current Fermilab strengths and capabilities to a series of proton beam improvements and neutrino beam facilities, each producing world-class science while performing critical R&D towards a muon collider. At the end of the path is an unparalleled global facility on US soil. This is our Muon Shot.**

Recommendation 4

Invest in Future

Support a comprehensive effort to develop the resources—theoretical, computational, and technological—essential to our 20-year vision for the field. This includes an aggressive R&D program that, while technologically challenging, could yield revolutionary accelerator designs that chart a realistic path to a 10 TeV pCM collider.

Investing in the future of the field to fulfill this vision requires the following:

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Recommendation 4

Invest in 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).

Not rank ordered

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Recommendation 6

Mid-decade Panel

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.

Area Recommendations

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FNAL Accelerator Complex

Facilities and Infrastructure

11. Form a dedicated task force, to be led by Fermilab with broad community membership. This task force is to be charged with **defining a roadmap for upgrade efforts and delivering a strategic 20-year plan for the Fermilab accelerator complex** within the next five years for consideration (Recommendation 6). Direct task force funding of up to $10M should be provided.

11. Assess the **Booster synchrotron and related systems for reliability risks** through the first decade of DUNE operation, and take measures to **preemptively address these risks**.

Area Recommendations

Facilities and Infrastructure cont.

11. To successfully deliver major initiatives and leading global projects, we recommend that:

   a. National Laboratories and facilities should work with funding agencies to establish and maintain streamlined access policies enabling **efficient remote and on-site collaboration** by international and domestic partners.

   b. National Laboratories should prioritize the **facilitation of procurement processes** and ensure **robust technical support** for experimenters.

   c. National Laboratories and facilities should prioritize the creation and maintenance of a **supportive, inclusive, and welcoming culture**.

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Area Recommendations

Invest in Future: R&D

Instrumentation

6. **Increase the annual budget for generic Detector R&D by at least $20 million** in 2023 dollars. This should be supplemented by additional funds for the collider R&D program
7. The detector R&D program should continue to leverage national initiatives such as QIS, microelectronics, and AI/ML.

General Accelerator R&D

8. **Increase annual funding to the General Accelerator R&D program by $10M per year** in 2023 dollars to ensure US leadership in key areas.
9. Support generic accelerator R&D with the construction of small scale test facilities. Initiate construction of larger test facilities based on project review, and informed by the collider R&D program.

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.

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Recommendation 3

Balanced program

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.

Not rank ordered

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Recommendation 5

Workforce

Invest in initiatives aimed at developing the workforce, broadening engagement, and supporting ethical conduct in the field. This commitment nurtures an advanced technological workforce not only for particle physics, but for the nation as a whole.

Recommendation 5

Workforce

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.

Not rank ordered

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Area Recommendations

16. Resources for national initiatives in **AI/ML, quantum computing, and microprocessors** should be leveraged and incorporated into research and R&D efforts to maximize the physics reach of the program.
17. Add support for a sustained R&D effort at the level of **$9M per year in 2023 dollars to adapt software and computing systems to emerging hardware,** incorporate other advances in computing technologies, and fund directed efforts to transition those developments into systems used for operations of experiments and facilities.
18. Through targeted investments at the level of **$8M per year in 2023 dollars**, ensure sustained support for key **cyberinfrastructure** components. This includes widely-used software packages, simulation tools, information resources such as the Particle Data Group and INSPIRE, as well as the shared infrastructure for preservation, dissemination, and analysis of the unique data collected by various experiments and surveys in order to realize their full scientific impact.
19. **Research software engineers and other professionals at universities and labs** are key to realizing the vision of the field and are critical for maintaining a technologically advanced workforce. We recommend that the funding agencies embrace these roles as a critical component of the workforce when investing in software, computing, and cyberinfrastructure.

Sustainability

20. HEPAP, potentially in collaboration with international partners, should conduct a dedicated study aiming at **developing a sustainability strategy for particle physics.**

Excellent report!

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- Ambitious future on Energy Frontier (Muon shot…)
  - modernization of FNAL accelerator complex, critical for next generation machine and for physics along the way
  - Investment in R&D
- Workforce and Climate
- Working to develop a plan for FNAL response…

Backup

Area Recommendations

Theory

1. **Increase DOE HEP-funded university-based theory research by $15 million per year in 2023 dollars (or about 30% of the theory program)**, to propel innovation and ensure international competitiveness. Such an increase would bring theory support back to 2010 levels. Maintain DOE lab-based theory groups as an essential component of the theory community.

ASTAE

2. For the ASTAE program to be agile, we recommend a **broad, predictable, and recurring (preferably annual) call for proposals.** This ensures the flexibility to target emerging opportunities and fields. A program on the scale of **$35 million per year in 2023 dollars** is needed to ensure a healthy pipeline of projects.
3. To preserve the agility of the ASTAE program, **project management** requirements should be outlined for the portfolio and should be adjusted to be commensurate with the scale of the experiment.
4. A successful ASTAE experiment involves 3 phases: **design, construction, and operations.** A design phase proposal should precede a construction proposal, and construction proposals are considered from projects within the group that have successfully completed their design phase.
5. **The DMNI projects** that have successfully completed their design phase and are ready to be reviewed for construction, **should form the first set of construction proposals for ASTAE.** The corresponding design phase call would be **open to proposals from all areas of particle physics.**