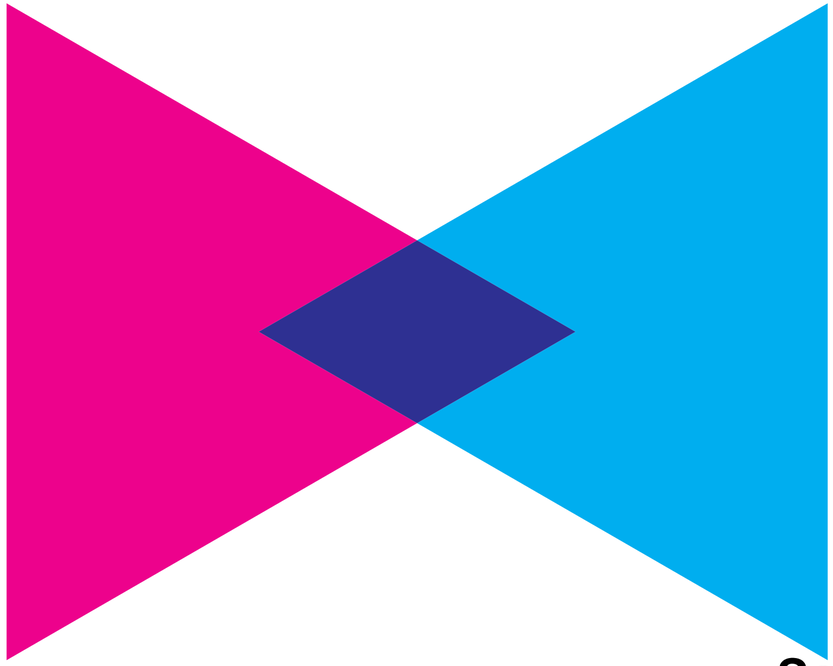
Exploring the Quantum Universe

Pathways to Innovation and Discovery in Particle Physics

DRAFT Report of the 2023 Particle Physics Project Prioritization Panel



Some Observations, Thoughts and Opinions on the P5 Report

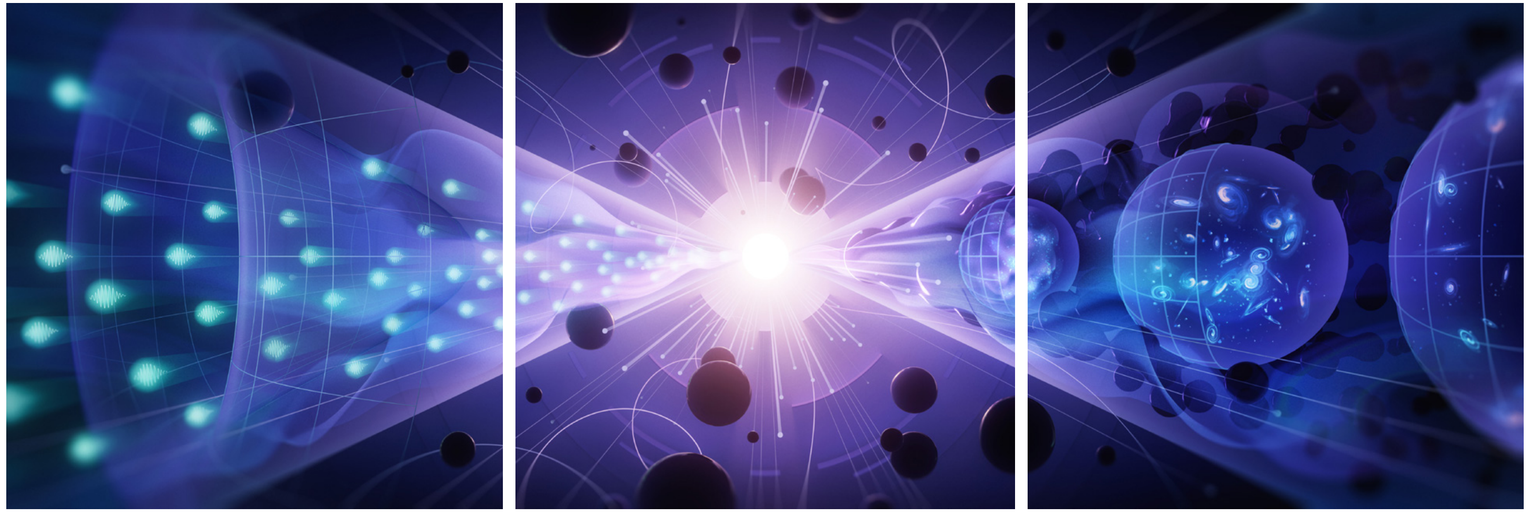
A strategic plan for the High Energy Physics Advisory Panel

Jonathan Paley
Fermilab

NuSTEC Board Meeting, December 2023

The P5 Report

- After a long and arduous Snowmass process, the US Particle Physics Project Prioritization Pannel P5 Report was released on Thursday, Dec. 7, 2023



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

Neutrinos in the P5 Report

- The report focuses on Projects (new facilities and experiments), not Research or Operations. Charged to consider two funding scenarios, a “baseline” (level w.r.t. funding) and a “less favorable” (an erosion of 1%/year). The committee also included an additional “more favorable” scenario.
- Neutrinos factor in heavily in the report. Not just about CP violation, but rather about “the mysteries” of the neutrino.
- Very strong support for completing DUNE Phase 1.
- Strong support for DUNE Phase 2.
- Reasonable support for the DUNE “More Capable Near Detector” (LArTPC —> HPGasTPC)

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.

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).

d. NOvA, SBN, and T2K (*elucidate the mysteries of neutrinos*, section 3.1).

Recommendation 2: 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.

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).

Recommendation 3: 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.

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.

A great opportunity for a small-to-mid scale neutrino scattering experiment that could tackle issues that the DUNE NearDet will not!

Recommendation 4: 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.

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).

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

Important for those working on theory and generators.

Recommendation 5: 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.

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.

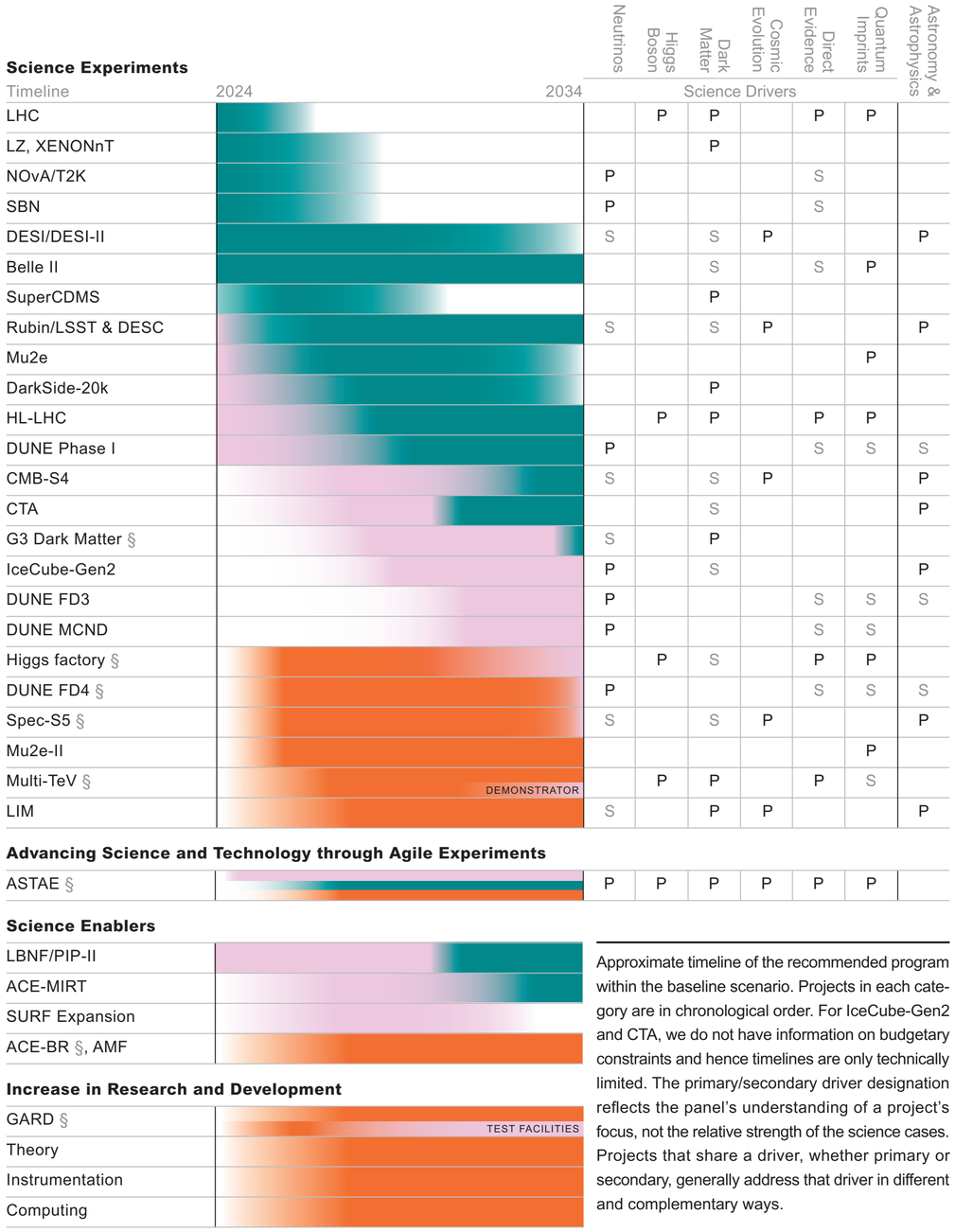
b. Funding agencies should continue to support programs that broaden engagement in particle physics, including strategic academic partnership programs, traineeship programs, and programs in support of dependent care and accessibility. A systematic review of these programs should be used to identify and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

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

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



Approximate timeline of the recommended program within the baseline scenario. Projects in each category are in chronological order. For IceCube-Gen2 and CTA, we do not have information on budgetary constraints and hence timelines are only technically limited. The primary/secondary driver designation reflects the panel's understanding of a project's focus, not the relative strength of the science cases. Projects that share a driver, whether primary or secondary, generally address that driver in different and complementary ways.

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

US Construction Cost >$3B Scenarios	Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
				Science Drivers						
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		

- DUNE FD3 is recommended at any funding level.
- BUT, ACE-MIRT and/or FD4 would not get full funding under the less favorable scenario. This will significantly delay reaching 600 kton*MW*yr exposure.
- The DUNE MCND, which would give us unprecedented capability in studying ν-Ar scattering, is not recommended in the less favorable scenario.

3.1.6 – New Initiative: A Portfolio of Agile Projects for Neutrinos

The ASTAE portfolio for neutrinos should encompass precise measurements of neutrino interactions, comprehensive neutrino flux assessments, and searches for neutrino BSM physics, coupled with development of cutting-edge technologies for future detectors (Recommendation 3a).

3.1.7 – 20-Year Vision

If there are hints of a need for heightened precision, muon-decay based neutrino beams emerge as the logical choice to enhance measurement accuracy. Depending on the nature of the departure from three-flavor oscillations, this could entail the deployment of a low-energy muon storage ring, as exemplified by the Neutrinos from Stored Muons (nuSTORM) experiment. This is certainly the case if novel neutrino types or interactions mediated by light new particles come into play. A facility like nuSTORM also has the potential to significantly refine our understanding of neutrino-nucleus interaction cross sections.

Area Recommendation 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.

Area Recommendation 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.

Area Recommendation 6: Increase the budget for generic Detector R&D by at least $20 million per year in 2023 dollars. This should be supplemented by additional funds for the collider R&D program.

Area Recommendation 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.

Area Recommendation 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.

Area Recommendation 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.

Area Recommendation 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.

Discussion