P5 Report Draft and DUNE Phase II

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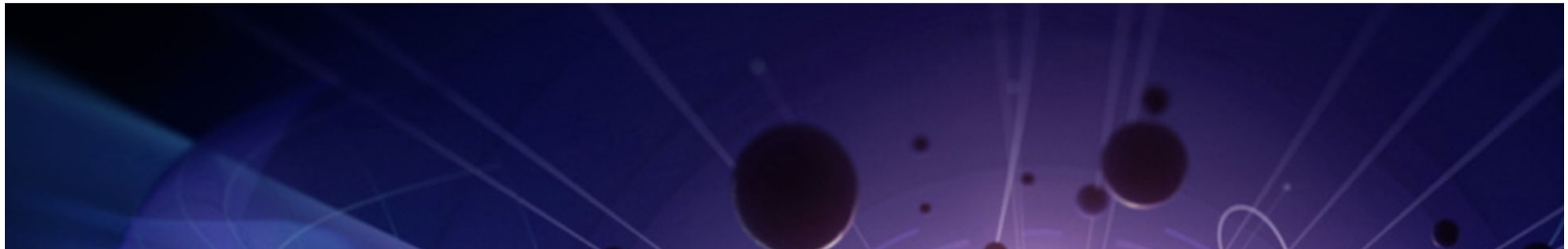
P5 Report

Draft of full report available at https://www.usparticlephysics.org/2023-p5-report/

Slides presented to HEPAP on December 7th and slides are available at https://science.osti.gov/-/media/hep/hepap/pdf/Meetings/2023/P5-HEPAPv2.pdf

Exploring the Quantum Universe

Draft
Pathways to Innovation and Discovery in Particle Physics
Report of the 2023 Particle Physics Project Prioritization Panel



From Slides

Exploring the Quantum Universe

Rank-Ordered

Recommendation 2

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).

Section 3.1.3 of Report

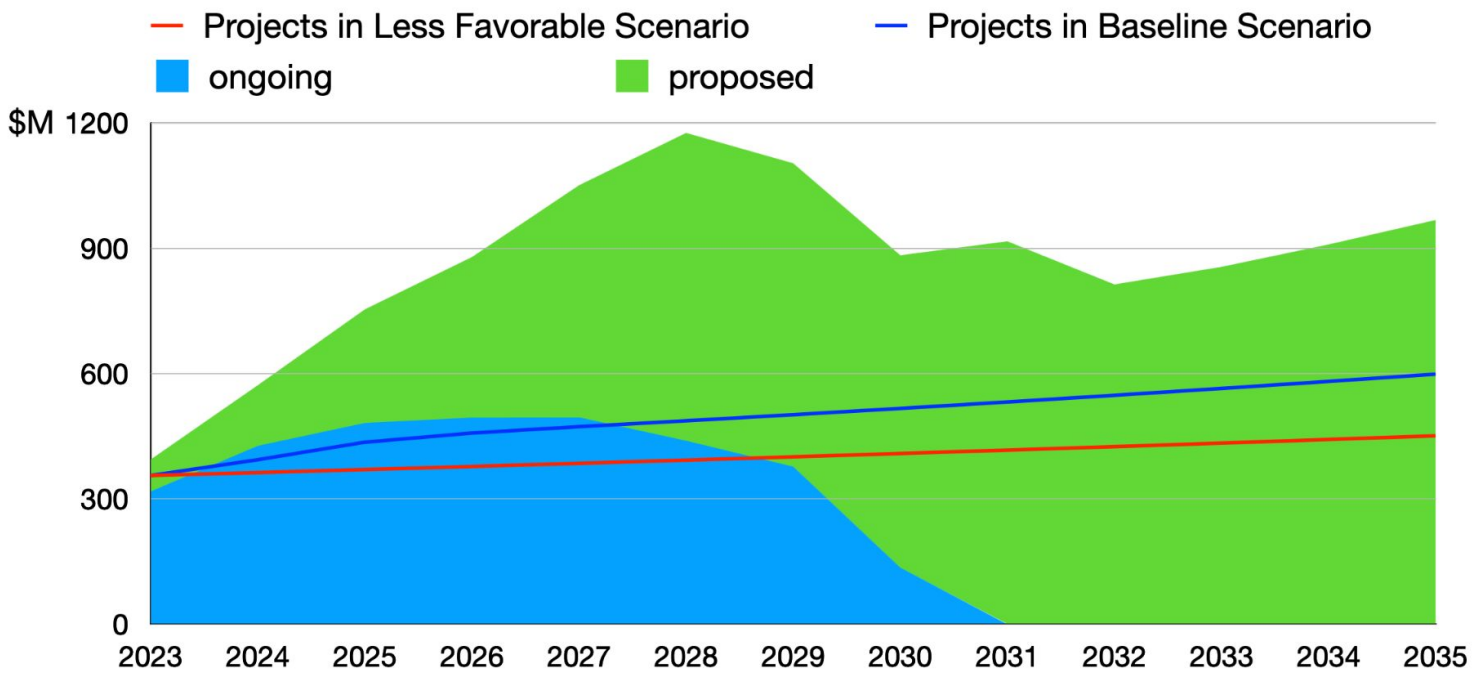
This is very strong support for the specific detector technology we are building

Together these upgrades more than quadruple the DUNE Phase I exposure to achieve 600 kt*MW*yr by the mid-2040s, the originally envisioned timescale. At this integrated exposure we expect statistical and systematic uncertainties to be roughly balanced, giving DUNE significant and unique discovery potential across the neutrino mixing landscape.

With higher statistics, control of systematic uncertainties (such as those arising from the interaction of neutrinos and nuclei) becomes increasingly crucial. A more capable near detector (MCND), a gas target combined with a magnetic field and electromagnetic calorimeter, is indispensable for this purpose. In addition, by being exposed to the world's most intense neutrino beam, it will create a unique laboratory for the discovery of novel particles and interactions, many of which could shed light on the nature of dark matter and possible hidden sectors.

From slides

Budget Scenarios and Projects



not including on-shore Higgs factory

DOE only

Timeline in Baseline Scenario

Construction in early 2030s.

This is soon! We are working with phase II leadership to work out a design report timeline

Would have liked an S in Dark Matter column, but point clearly supported in text

FD Module 4 construction begins around 2035

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

Science Experiments			Science Drivers						
Timeline	2024	2034	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 §		DEMONSTRATOR		P	P		P	S	
LIM			S		P	P			P

From slides

Exploring the Quantum Universe

Less Favorable Budget Scenario

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In this scenario, we would aim for a program that covers most areas of particle physics for the next 10 years, maintaining continuity and exploiting the ongoing projects in Recommendation 1 as our highest priority. The agencies should launch the same major initiatives as outlined in Recommendation 2, some of them with significantly reduced scope:

a. **CMB-S4** without reduction in scope.
b. **DUNE Third Far Detector (FD3)**, but **defer ACE-MIRT** and the More Capable Near Detector (**MCND**).
c. Contribution to an **off-shore Higgs factory** delayed and at **a reduced level**.
d. Reduced participation in an **off-shore G3 dark matter experiment** and **no SURF expansion**.
e. **IceCube-Gen2** without reduction in scope.

Less Favorable Budget Scenario, Section 8.3

MCND need tied strongly by report to ACE-MIRT

Spokes and physics co-ordination think phase II generally tricky in less favourable scenario so we push for baseline for DUNE

Difficult Choices for Less Favorable Budget Scenario

The less favorable budget scenario assumes a 2% increase in budget per year, which does not keep pace with the assumed 3% annual inflation. Actual inflation may be even higher. In this scenario, we had to make even harder choices than those made for the baseline budget scenario. We can maintain a minimum portfolio to continue some scientific progress, although US leadership will begin to erode in much of the field, jeopardizing our twenty-year vision for the US particle physics program. Impacts on some of the major projects are described below:

Reduced Contribution to an off-shore Higgs factory. The US contribution will be reduced and the US cannot play a commensurate role as an international partner in the project.

DUNE FD3 with deferred ACE-MIRT. This scenario explicitly forces a delay in DUNE Phase 2 timeline of execution, making the project less competitive and hurting the US reputation as a host for large international projects. In a technically limited schedule the order of phase II elements is ACE-MIRT, FD3 and MCND. There is a compelling science case for these three components and hence when budgets allow this would be the preferred order of construction. If, on the other hand, budgets are more constrained trade offs also have to consider the science lost. In the long run the same statistics for the beam physics would be obtained by the addition of either ACE-MIRT or FD3. However, FD3 offers a broader set of science topics related to non-beam physics like supernovae and also has a better potential of attracting international support than ACE-MIRT. Therefore, in a budget constrained scenario FD3 is prioritized over ACE-MIRT. MCND requires the combined statistics of FD3 and ACE-MIRT to accomplish its main goals and hence in all scenarios is the third priority. This is also based on the understanding that ACE-MIRT and MCND can be added at any time to the program should additional funds become available. In all scenarios we preserve long-lead time ACE-MIRT elements to enable staging of the beam.

Timeline in Various Budget Scenarios

Excerpt from table here. Full table on P5 website

Not recommended in less favorable scenario. Slides said “deferred” but this table has an N and doesn’t indicate starting R&D.

Indispensable detector that US can’t fund is however a great opportunity for international partners

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: Secc
Delayed: Recommend construction but delayed to the next decade
Can be considered as part of ASTAE with reduced scope

US Construction Cost >$3B				Science Drivers					
				Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints
Scenarios	Less	Baseline	More						
on-shore Higgs factory	N	N	N		P	S		P	P
$100–400M									
IceCube-Gen2	Y	Y	Y	P		S			
G3 Dark Matter 1	Y	Y	Y	S		P			
DUNE FD3	Y	Y	Y	P				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
$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	

Main takeaways

- This is at the better end of how P5 could have turned out for DUNE
- DUNE Phase I is strongly supported in all funding scenarios.
- P5 describe a magnetized gaseous near detector as indispensible to better control systematic uncertainties for DUNE in Phase II.
- Something like ND-GAr is recommended in 2 out of 3 budget scenarios, including the baseline scenario.
- Focus of this group should be supporting push for baseline and getting detector designed promptly
- 2030s are not very far away for starting construction!

More DUNE P5 discussion planned for DUNE collaboration call this Friday. See Mary's email.