Science Priorities Working Group Neutrino Town Hall

Matt Toups, on behalf of the Science Priorities Working Group Neutrino Subgroup*

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Context

Science Priorities Working Group set up by Lia to prepare Fermilab's input to P5, chaired by Jim Amundson

- "In advance of the P5 meeting later this year, we are asking that you chair a Fermilab working group to help prepare the laboratory's input to the panel. Your deliverable should be a prioritized set of recommendations for the U.S. particle physics program and Fermilab's role over the next decade to be presented to the P5. The recommendations should integrate the broader community's scientific aspirations set in a global context."

Neutrino Subgroup provides input (the raw material) for this presentation on topics related to neutrino physics

These slides are a draft of the input we plan to provide the Science Priorities Working Group

Note that Fermilab's input to the last P5 consisted of a 14-slide presentation by Gina Rameika

- Ultimately, the final prioritized set of recommendations will require synthesizing the message in these slides with the messages from all the other subgroups as well

Starting Point: Snowmass Neutrino Frontier Report

Executive summary makes 5 recommendations

- Maintain balanced program across (time, size, cost) scales with opportunities to resolve neutrino-related anomalies
- Complete existing ν program and execute DUNE in its full scope
- Fund directed R&D to capitalize on DUNE Phase II opportunities
- Support robust theory effort
- Lead HEP-wide plan to address diversity, equity, and inclusion (DEI) and community engagement needs

Implications of these for Fermilab's science priorities are clear: execution of the full scope of DUNE (Phase I and Phase II) should be the lab's highest priority

- In this case, we see our role as reaffirming the compelling science case laid out at Snowmass

Our Message

Build DUNE Phase I with all haste and commit to DUNE Phase II

- DUNE is a best-in-class neutrino experiment with a rich portfolio of compelling science
- DUNE is the culmination of a multi-decade, global program to develop the modern, LArTPC ν detector

Evolve Fermilab's program of short-baseline, accelerator ν experiments in light of upcoming results

- SBN results will inform the future direction of the field, including the DUNE physics program
- Decay-at-rest ν experiments are a complementary probe of new physics at short baselines
- Smaller experiments provide a pipeline of talent trained in all experiment stages: design, execution, analysis

Establish funding mechanism for directed R&D for DUNE Phase II detector upgrades

- R&D for technologies that will enable future physics programs beyond the next P5 should also be backed

Provide support for theory, including in ν interaction modeling, generator development, and pheno

Demand leadership in HEP-wide EDI efforts from Fermilab, as host of the international ν community

LBNF/DUNE Phases I and II

From the 2014 P5 Report

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

For a long-baseline oscillation experiment, based on the science Drivers and what is practically achievable in a major step forward, we set as the goal a mean sensitivity to CP violation[2] of better than 3σ (corresponding to 99.8% confidence level for a detected signal) over more than 75% of the range of possible values of the unknown CP-violating phase δ_{CP}. By current estimates, this goal corresponds to an exposure of 600 kt*MW*yr assuming systematic uncertainties of 1% and 5% for the signal and background, respectively. With a wideband neutrino beam produced by a proton beam with power of 1.2 MW, this exposure implies a far detector with fiducal mass of more than 40 kilotons (kt) of liquid argon (LAr) and a suitable near detector. **The minimum requirements to proceed are the identified capability to reach an exposure of at least 120 kt*MW*yr by the 2035 timeframe, the far detector situated underground with cavern space for expansion to at least 40 kt LAr fiducial volume, and 1.2 MW beam power upgradable to multi-megawatt power. The experiment should have the demonstrated capability to search for supernova (SN) bursts and for proton decay, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime.**

Phase II (future):

- Increased mass at Far Detector
- More Capable Near Detector (MCND)
- Increased beam power by Booster replacement

Phase I (current):

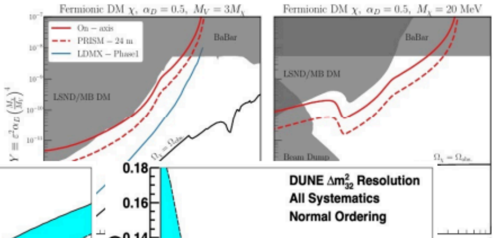
- Accomplished with PIP-II, LBNF/DUNE-US, and DUNE International Partners
- Meets P5 minimum requirements to proceed by 2035 timeframe
- Same project scope as proposed at CD-1R in July 2015

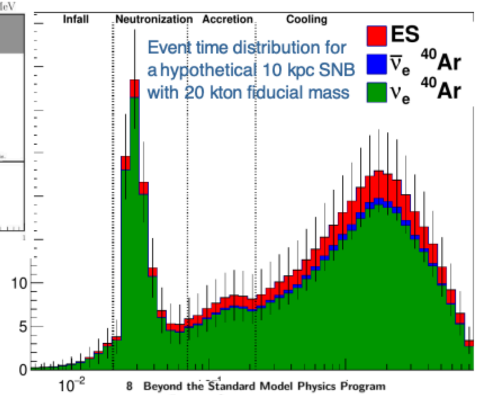
LBNF/DUNE-US Project + DUNE Int'l Project

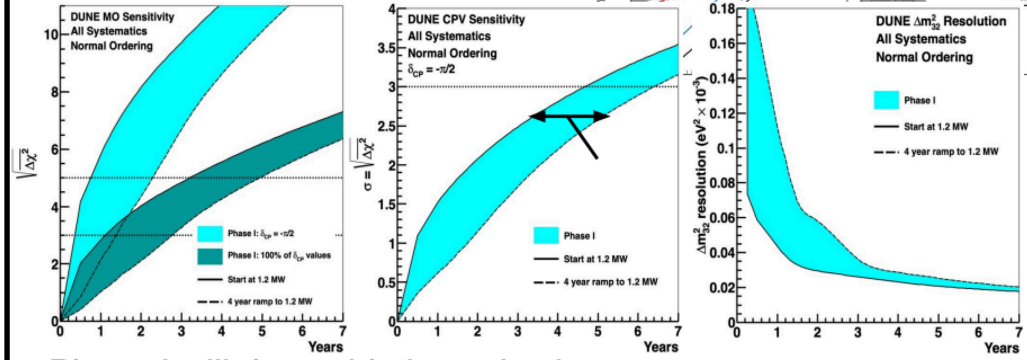
Capability Description	Phase I	Phase II
Beamline		
1.2MW (includes 2.4MW infrastructure)	X	
2.4MW		X[1]
Far Detectors		
FD1 – 17 kton	X	
FD2 – 17 kton	X	
FD3		X[2]
FD4		X[2]
Near Detectors		
ND LAr	X	
TMS	X	
SAND	X	
MCND (ND GAr)		X

Note 1: requires upgrades to LBNF neutrino target and upgrades to Fermilab accelerator complex. The LBNF facility is built to support 2.4MW in Phase I.
Note 2: Caverns and cryo-infrastructure built in Phase 1

DUNE Phase I Physics







Phase I will do world-class physics:

- Only experiment with 5σ mass ordering capability regardless of true parameters
- Discovery of CPV at 3σ if CP violation is large
- High precision disappearance parameters, (e.g. surpass current Δm^2_{32} error in ~2-3 years)
- DUNE is already very sensitive to a galactic supernova burst with Phase I
- DUNE is an excellent BSM physics experiment in Phase I
- Phase I Near Detector has world leading sensitivity to DM produced in beamline

8 Beyond the Standard Model Physics Program

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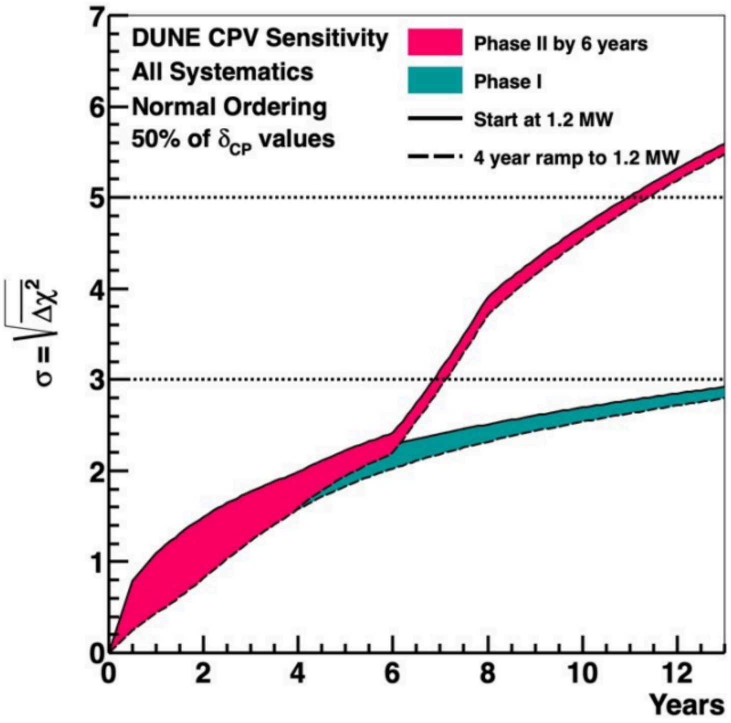
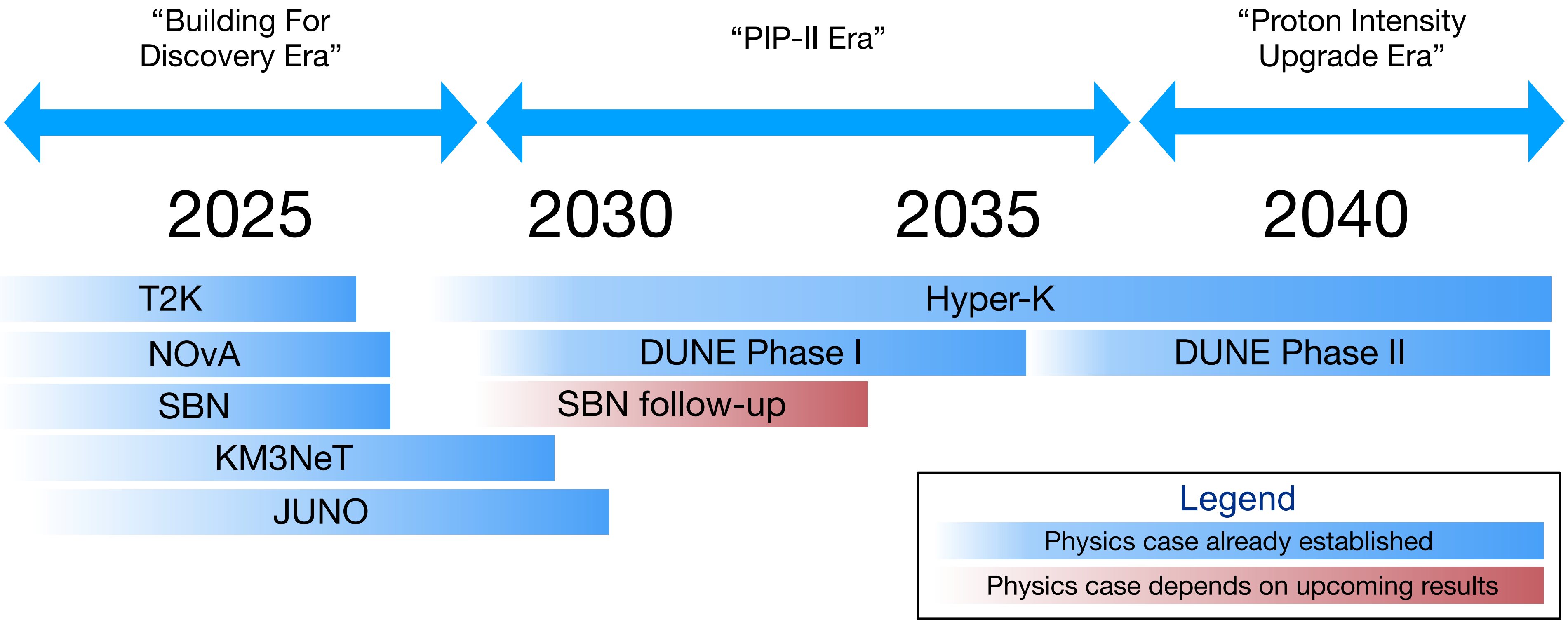
DUNE Phase II Physics



- DUNE needs full Phase II (FD3&4, 2,4MW, MCND) scope to achieve precision physics goals defined in P5 report.
- CPV sensitivity for 50%of δCP values shown
  - Precision measurements are similarly affected
- Timescale for precision physics is driven by achieving full scope on aggressive timescale, early ramp-up is not as relevant
- Many BSM searches at the Near Detector will benefit from the beam upgrade:
  - Neutrino tridents, Milicharged particles, Heavy neutral leptons, Light dark matter, Anomalous ν_τ appearance etc.

DUNE Timeline



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Global Landscape circa 2030

Neutrino mass ordering

- Unless nature chooses certain favorable parameters, planned future experiments will struggle to adequately address this question
- Combined fits of accelerator (NOvA, T2K), reactor (JUNO), and atmospheric (KM3NeT/ORCA) neutrino data will be required to make progress

Neutrino CP Violation (CPV)

- Hyper-K & T2K sensitivities highly dependent on the neutrino mass ordering
- Unambiguous discovery of CPV will require resolving this parameter degeneracy

DUNE/Hyper-K Complementarity

Experiment Parameters

	DUNE	Hyper-K
Distance	1300 km	295 km
Energy	Wide band beam	Narrow band beam
Matter effects	Large	Negligible
Target	Ar	H_2O
Detector	TPC	Cherenkov Ring

Physics Program

	DUNE	Hyper-K
Mass hierarchy	5σ	N/A
CP violation	Discovery and precision measurement	Discovery
Oscillation parameters	Comprehensive	Select few
Proton Decay	$p \rightarrow K^+\bar{\nu}$	$p \rightarrow e^+\pi^0$
Supernova ν	ν_e	$\bar{\nu}_e$
BSM searches	Extensive	Available

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DUNE Costs

DUNE is an international experiment

- FD I & II detector modules have ~50% contributions from non-DOE sources

Detector costs

- FD II detector: $50M (M&S with no contingency)
- FD II cryostat: IKC from CERN valued at $35M (European accounting)
- US DOE contribution to DUNE Phase I ND capped at $200M

Phase II upgrade

- Assume DOE burden for additional FD modules and more capable near detector no more the 50% of overall cost
- Costs significantly less than DUNE Phase I since it benefits from prior detector prototyping efforts as well as existing caverns and cryo-infrastructure at the far site

R&D

Detector upgrades for DUNE Phase II present an excellent opportunity to extend the physics reach of DUNE

Most R&D targeted to DUNE Phase II aims at extending the range of applications of existing noble element TPC detectors, for instance to reduce energy thresholds towards solar neutrino energy ranges or to improve energy resolution

- These include, for example, the optimization of LArTPC light and charge collection, the magnetization of LArTPCs, and various aspects of GAr TPC design and calibration
- R&D on horn and target design is also vital to go beyond 1.2 MW beam for DUNE

Funding mechanism for directed R&D for DUNE Phase II upgrades should be established, in analogy with the collider experiments

R&D for technologies that will enable future physics programs beyond the next P5 should also be supported

- The proposed noble liquid detector R&D consortium, in particular, has strong synergies with the Fermilab-based neutrino program

Accelerator R&D for a neutrino factory

- The discovery of θ_{13} in 2012 at the largest value experimentally allowed at the time opened up the possibility that conventional neutrino beam experiments could access a large fraction of leptonic CP-violating phase space
- Depending on results from DUNE, there may be reason to build a neutrino factory in the future

Neutrino Theory

In Jesse's Snowmass talk, theory is at the center of the P5 science drivers, binding everything together

- "Develop transformative concepts and technologies to enable future discoveries"

Credit: Jesse Thaler

Borrowing terminology from the SPWG theory subgroup: theory is the "glue" that connects everything we do

We echo the theory subgroup's call for robust theory support and emphasize that support for neutrino theory, including interaction modeling, generator development, and phenomenology is essential for neutrino discovery science

Equity, Diversity, and Inclusion

Jesse's talk also emphasized that science is not done in a vacuum, but rather within the context of a community

– "Cultivate a vibrant, inclusive, and supportive scientific community"

We support the EDI subgroup's statement that Fermilab, as a focal point of the US HEP community, must take responsibility for leading the HEP community in promoting EDI through specific actions

Neutrino physics is an area experiencing significant growth within HEP, which presents opportunities for individuals from historically underrepresented groups to participate and remain in the field

– Fermilab, as the host of the international neutrino community, should also take a leadership role within HEP in embracing these opportunities

Credit: Jesse Thaler

Fermilab's Short-baseline Neutrino (SBN) Program & Follow-ups

Suite of medium-scale neutrino experiments vital for the field

- Physics results inform future directions for the field
- Essential contributions to LArTPC technology development
- Training the next generation of scientists in all experiment stages: design, execution, and analysis

Possible discoveries at SBN that will demand follow-up

- Near-to-far detector appearance/disappearance effects pointing to oscillation physics
- Single detector excesses (e.g. in e^+e^- final states) pointing to other BSM physics
- Data from decay-at-rest beam dump experiments like $JSNS^2$ will also inform follow-ups to the SBN

Example SBN follow-ups:

- BNB upgrade with PIP-II to characterize signal with larger SBN stats (low-cost, continued running)
- CEvNS-based NC oscillation measurement at PIP-II beam dump (medium-cost, new experiment)
- DUNE ND will also have something to say

Thank you for your attention

Discussion/feedback