DUNE – ND Phase II Workshop

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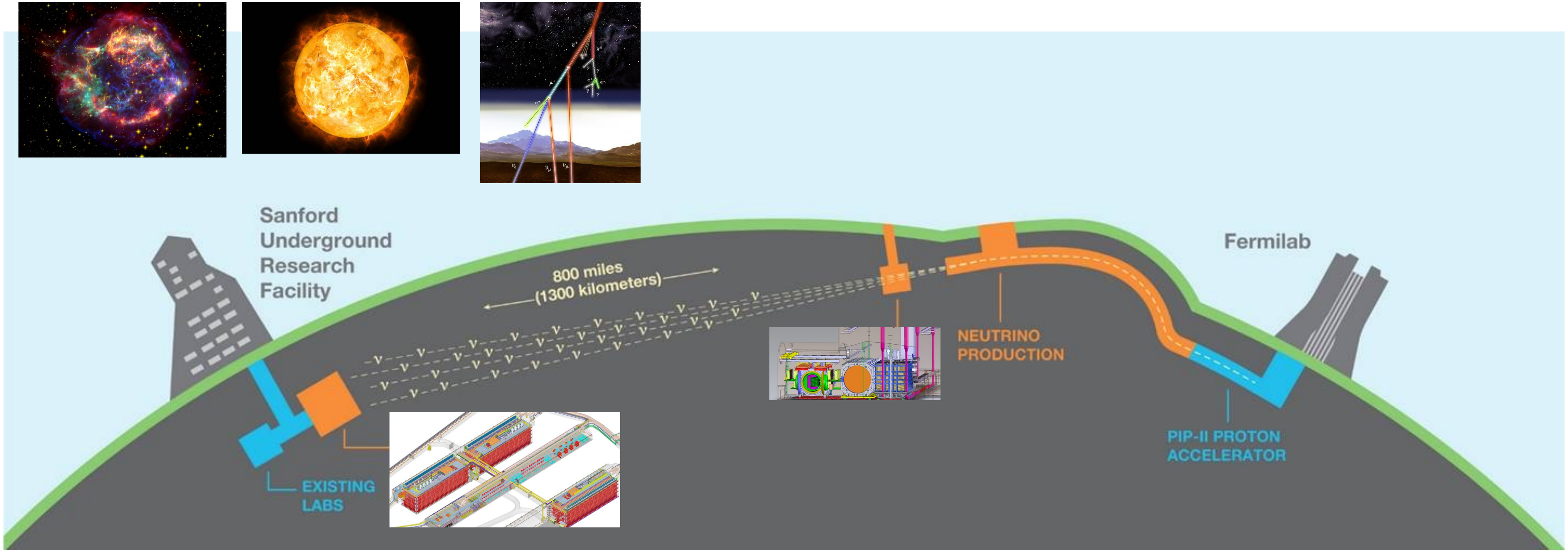
DUNE ND Phase II Workshop

Imperial College

21 June 2023

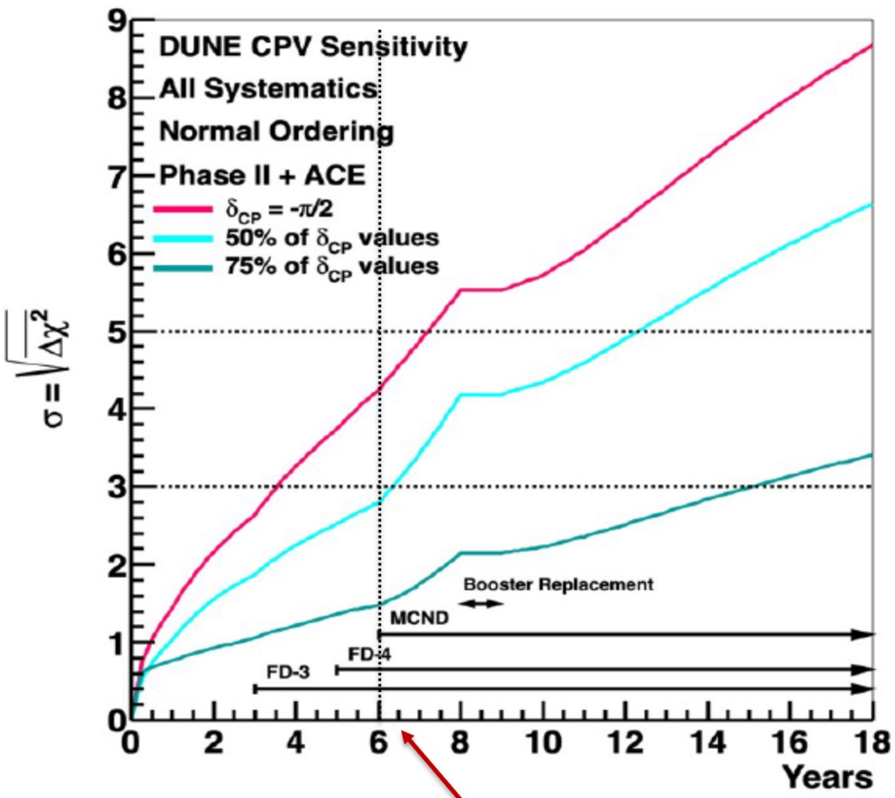
Full DUNE scope



- The <u>complete</u> DUNE detector
  - <u>Four Far Detector TPC modules </u>with up to 70 kt of liquid-argon.
  - A <u>Near Detector </u>which includes a liquid-argon TPC.
  - A 1.2 MW beam <u>upgradeable to 2.4 MW</u>.

Mary Bishai, Chris Marshall

DUNE Phase II = ultimate CPV reach



- If $\delta_{CP} = \pm 90°$, DUNE reaches 3σ CPV in 3.5 years, 5σ in 7 years
  - Hyper-K will likely get there first, if/when the mass ordering is known
- If $\delta_{CP} = \pm 23°$, it is extremely challenging to establish CP violation at 3σ → DUNE and Hyper-K are competitive and complementary

Improved systematics constraints from “More Capable” ND necessary to reach osc. physics goals

Primary Role of the DUNE ND

"The Near Detector complex at Fermilab must provide unprecedented control of systematic uncertainties through partial cancellation of systematic uncertainties **using argon as target nucleus and LArTPC detector technology**."

Requirements…

Hiro Tanaka

ND-GAR AND ITS REQUIREMENTS:

ND-M2 *Measure outgoing particles in ν-Ar interactions with uniform acceptance, lower thresholds than a LArTPC, and with minimal secondary interactions* *ND-GAr*

↓

ND-C3.2 ND-GAr shall detect protons with KE >10 (5 MeV goal)

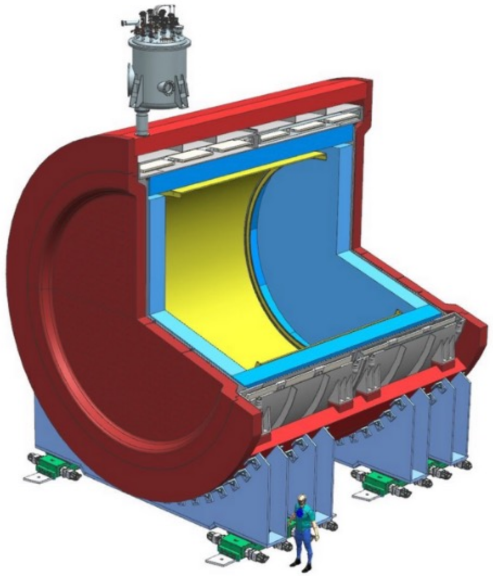
ND-C3.3 ND-GAr shall detect charged pions with KE >20 (5 MeV goal)

ND-C3.4 ND-GAr shall reconstruct charged tracks with a momentum resolution better than TBD

ND-C3.5 ND-GAr shall identify charged particle types with better than TBD separation

ND-C3.6 ND-GAr shall identify and reconstruct photons with energy greater than TBD with angular resolution better than tbd and energy resolution better than TBD

ND-C3.7 ND-GAr's calorimeter shall measure the timing for at least one charge track in TBD fraction of neutrino interactions with TBD timing resolution



- 0.5 Tesla superconducting solenoid with "partial yolk"
- 10 B high pressure gas argon TPC (HPgTPC)
  - 5 m ø x 5 m length,
  - O(1 ton) of Ar target
  - Refurbished ALICE chambers
- CALICE-inspired tile calorimetry system
- Instrumented yolk for muon detection

Requirements were motivated by:

- Studies showing the inability to fully characterize the pion final state of ν-Ar interactions in a LArTPC may result in large bias in δ
- ND-GAr should aim to make ν-Ar measurements with:
  - Low tracking thresholds, sign selection, with particle identification
  - Electromagnetic calorimetry for photon (neutron) reconstruction
  - 4π acceptance

SLAC NATIONAL ACCELERATOR LABORATORY Stanford University U.S. DEPARTMENT OF ENERGY LBNF/DUNE

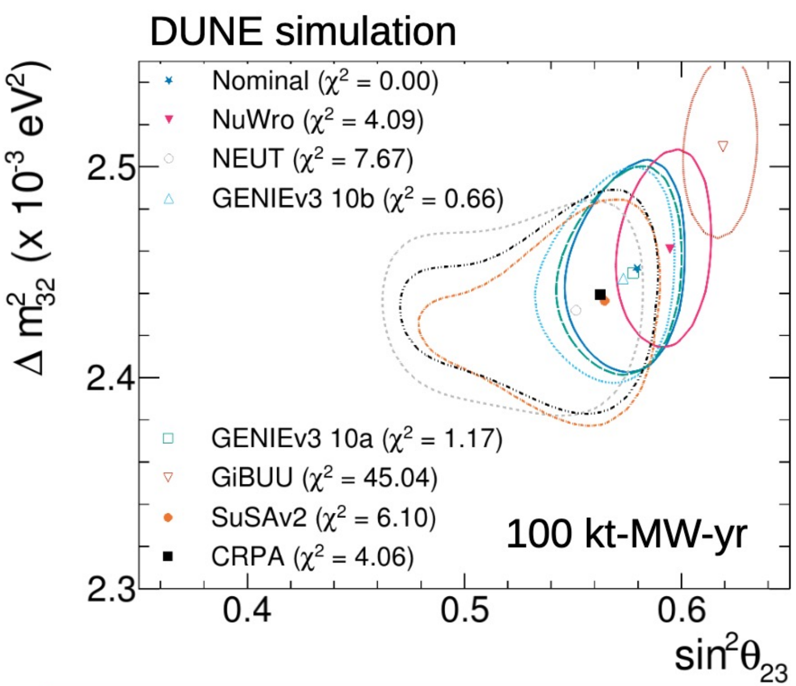
…need to be revisited

Motivation 1:

Callum Wilkinson, Luis Alvarez-Ruso

Bias studies: cross-section mismodeling

- Many theoretical/phenomenological models for neutrino interactions on the market → further potential for bias
- ND finds okay™ agreement by pulling parameters of nominal model → leads to biases in osc. parameters

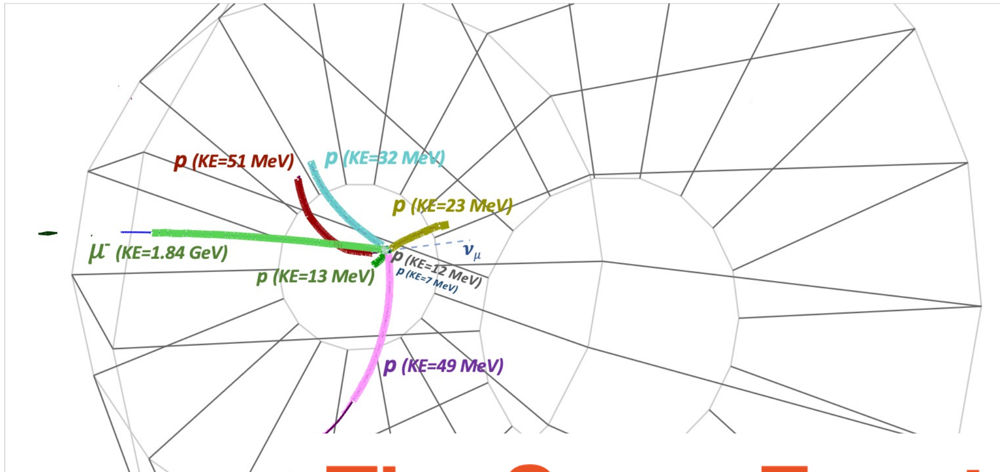


- **Φ** x **σ** degeneracies, limited by **ε**, are responsible
- Avoiding **degenerate solutions** will be an experimental and theoretical challenge
- Precision (phase-II) DUNE measurements may be limited by these issues

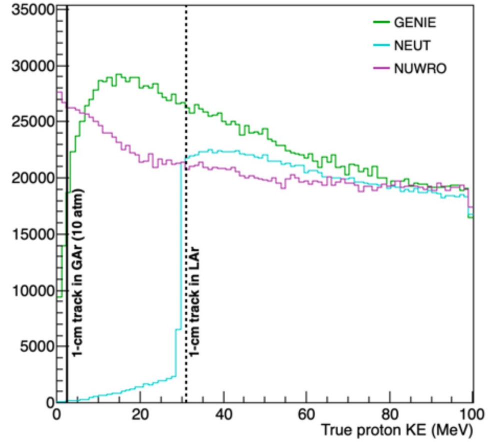
Motivation 1 (elevator pitch):

Tom Junk

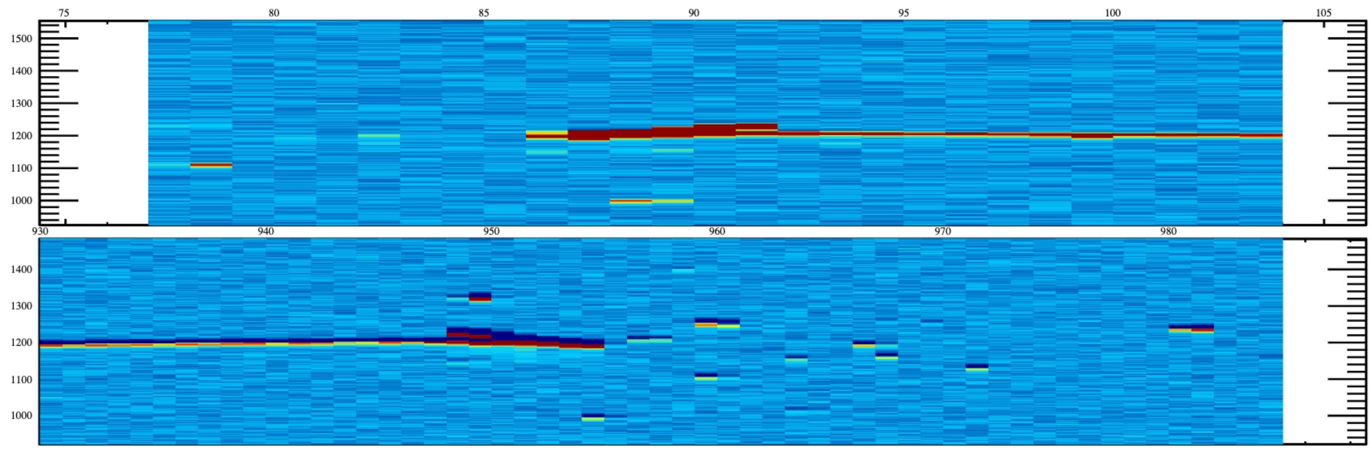
An Event with Seven Protons and Muon



Low-Energy Protons in Neutrino Scatters



The Same Event in LAr

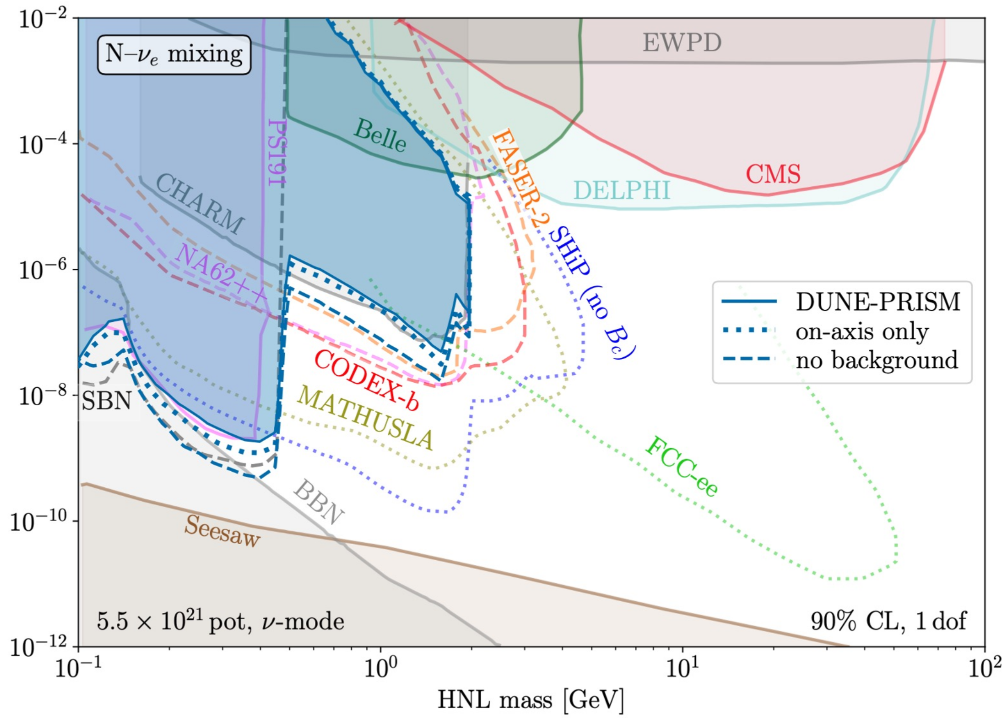


Silvia Pascoli, Kevin Kelly, Frank Deppisch

BSM Physics with Phase 2 ND

BSM searches enabled by Phase 2 ND will include:

- Neutrino Tridents
- Heavy Neutral Leptons
- Light Dark Matter
- Heavy Axions
- Tau Neutrinos



Going low in energy: Dark sectors

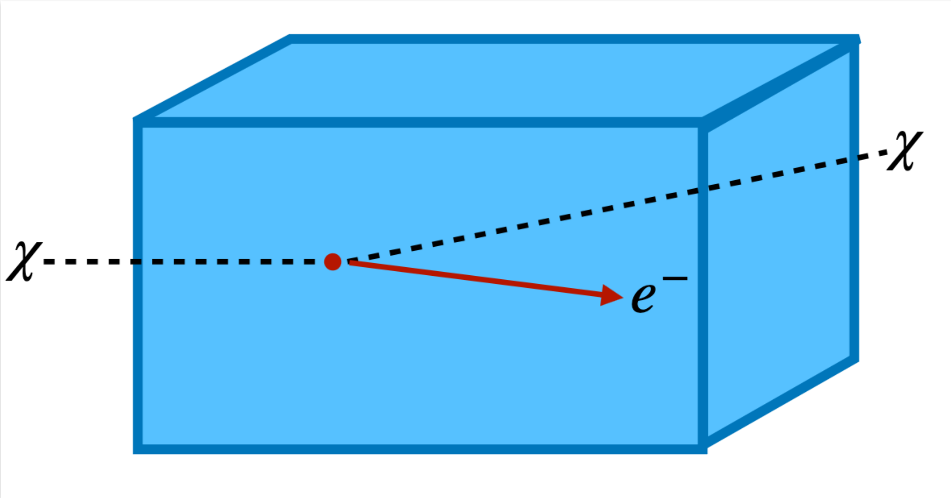
A change of paradigm might be needed: new physics may be light but hidden because too weakly interacting (dark or hidden sectors).

Not the only show in town: e.g. FASER..

Motivation 2 (elevator pitch):

Complementarity of Neutrino Detectors

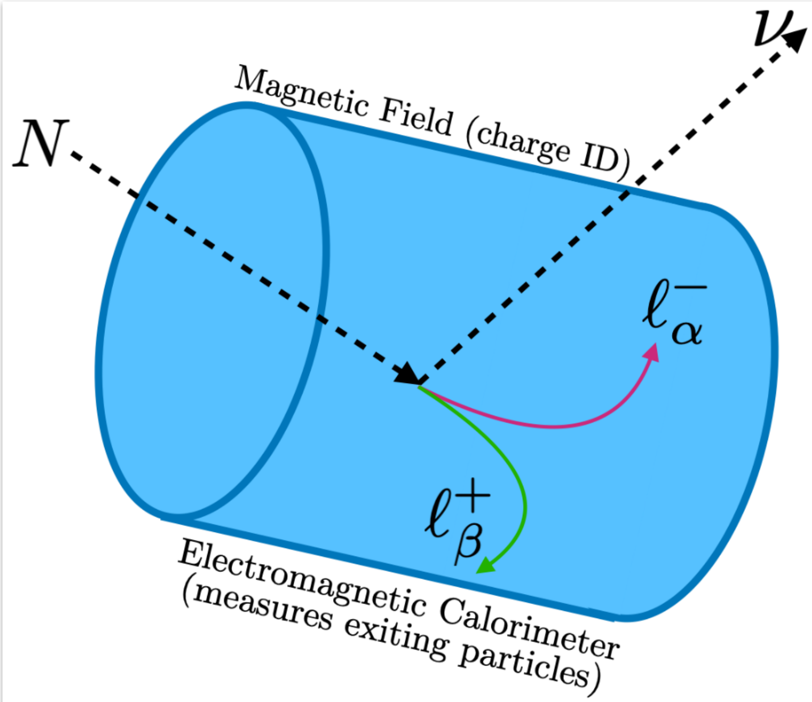
Liquid Detectors (SBND, ICARUS, etc.)



Large mass for rare-particle scattering

Excellent particle ID, energy resolution, etc.

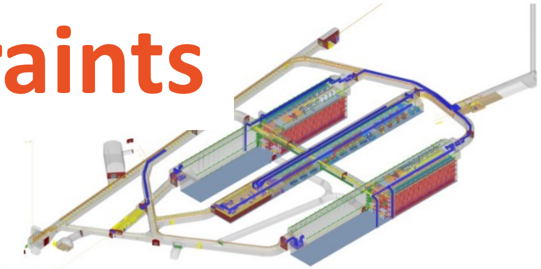
Gaseous Detectors (DUNE NDGAr)



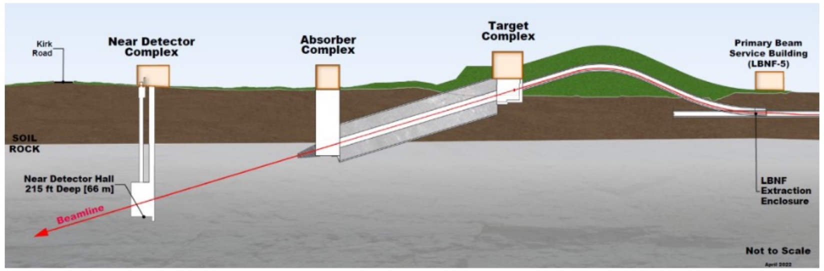
Decay Signal ∝ Volume

Neutrino Scattering Backgrounds ∝ Mass

Facility Constraints



Far Site



Near Site

LBNF/DUNE-US Project Scope

	Component	DOE Project Scope (meets 2014 P5 minimum to proceed – Phase I)	Phase II Requirements (meets 2014 P5 goal)
Near Site	Conventional Facilities	• Constructed to support 2.4MW primary and neutrino beamline • Constructed to support underground Ph I & II Near Detector	• None
	Neutrino Beamline	• Wide-band output neutrino beam, 1.2MW initially, designed to be upgradeable to 2.4MW	• 2.4MW capable target and new horns • New decay pipe window • Some additional cooling and instrumentation
	Near Detector	• US contribution to the DUNE Near Detector (Ph I)	• US contribution to more capable Near Detector (Ph II)
Far Site	Conventional Facilities	• Surface and underground facilities & infrastructure for 4 detector modules	• None
	Cryostats	• For 2 detector modules (CERN)	• For 2 detector modules
	Cryogenics	• 3 x nitrogen units; 35 kton liquid argon for detector modules	• 1 x nitrogen unit; 35 kton liquid argon for detector modules
	Far Detector	• US contributions to 2 x DUNE LAr TPC modules	• US contributions to 2 x DUNE LAr TPC modules

Project scope is unchanged since inception of LBNF and DUNE in 2015
Facility scope supports Phase II

The DOE-LBNF project provides the constraint for the ND facility

Joaquim Prats
John Back

ND-GAr Technology Choices

- Gas mixture choice: is there consensus for Ar – CF_4 (1%)?
- Amplification stage choices: wires, GEMs, or Micromegas?
- Readout choices: wires, pads, strips, LAPPDs or CCDs (if light readout)?
- Digitiser ASIC options for charge readout: LArPix, SAMPA, or HGROC?
- ECAL – need optimized design
- Magnet: MgB_2 ?

Technology choices need to be driven by (physics) requirements and an optimisation of performance vs availability of resources.

Making the physics case

- We need to strengthen link between physics goals and detector requirements.
- Need a hierarchy of requirements that take into account LBL physics (primary) but also SM (cross sections…) and BSM physics (FIPs…).
- Take into account all ND components (SAND, ND-GAr, ND-LAr, PRISM) for physics sensitivities.
- Need close collaboration between DUNE Physics Groups and the Phase II effort (formalize links..?).
- One goal would be a more flexible software framework for easily incorporating multiple ND data samples and neutrino interaction models in LBL analysis, to come up with better defined requirements.
- Similarly need a consistent approach and common simulation framework to study BSM sensitivities.

ND-LAr and SAND

- ND-LAr upgrades for Phase II: many possibilities exist, ranging from no upgrade to 'disruptive' upgrades (e.g., magnetised ND-LAr). We again need to sharpen Phase II ND requirements before deciding.
- SAND for Phase II: Options for additional nuclear targets, tracking improvements, GRAIN.
- In both cases operational experience may be needed for a decision.
- Beam power not a critical driver for possible upgrades.
- Incremental improvements might not need to be formally part of Phase II (e.g. in the form of a CD process).

Phase II Organization

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- As part of the Phase II re-organization, the Gas-Argon TPC group will move to the Phase II organisation with Patrick Dunne (Imperial) and Alysia Marino (Colorado) as joint conveners.
- Other ND Phase II options are invited to form similar working groups – but need critical mass.

White Paper/CDR-light/Workshop Report

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- Current plan is to write a joint FD/ND “white paper” which is based on the conclusions of the Valencia and Imperial Workshops.
- The paper will present ND Phase II technology options but should clearly motivate them in terms of the physics.
- Plans for this report – to be discussed here and now!