DUNE project input for UK drafting day (4 November 2024)

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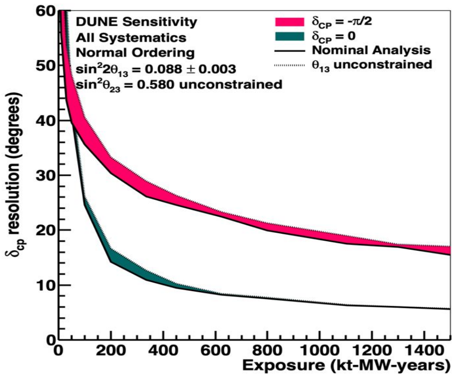
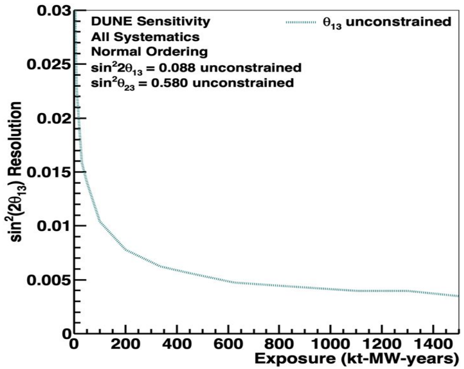
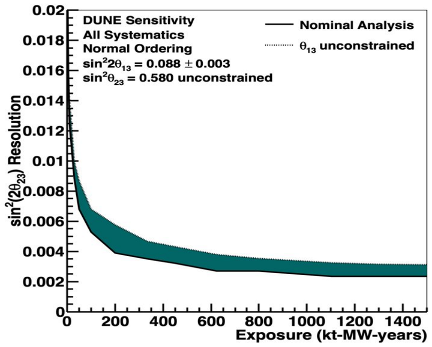
DUNE (Phase II) - Key Physics Deliverables

The goals of the oscillation physics programme of Phase II are:

- high-precision measurements of all four parameters: θ_{23}, θ_{13}, Δm^2_{32} and δ_{CP},
- to establish CPV at high significance over a broad range of possible values of δ_{CP}, and
- to test the three-flavor paradigm as a way to search for new physics in neutrino oscillations.

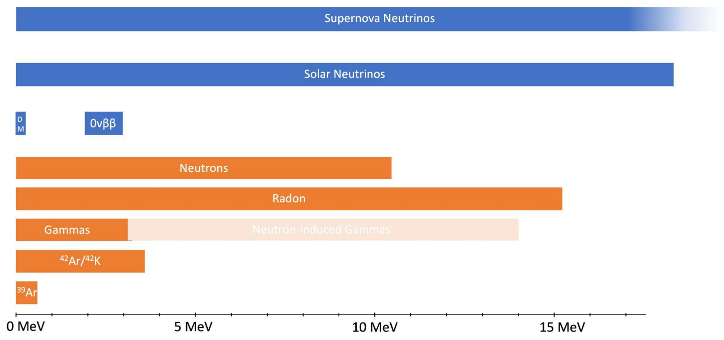


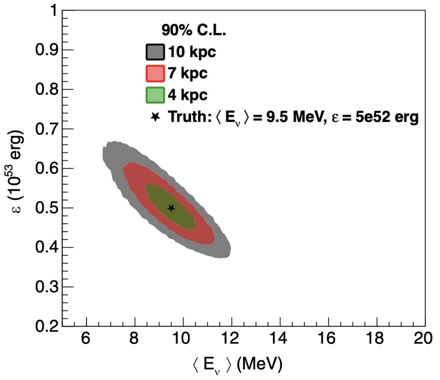




DUNE (Phase II) - Key Physics Deliverables

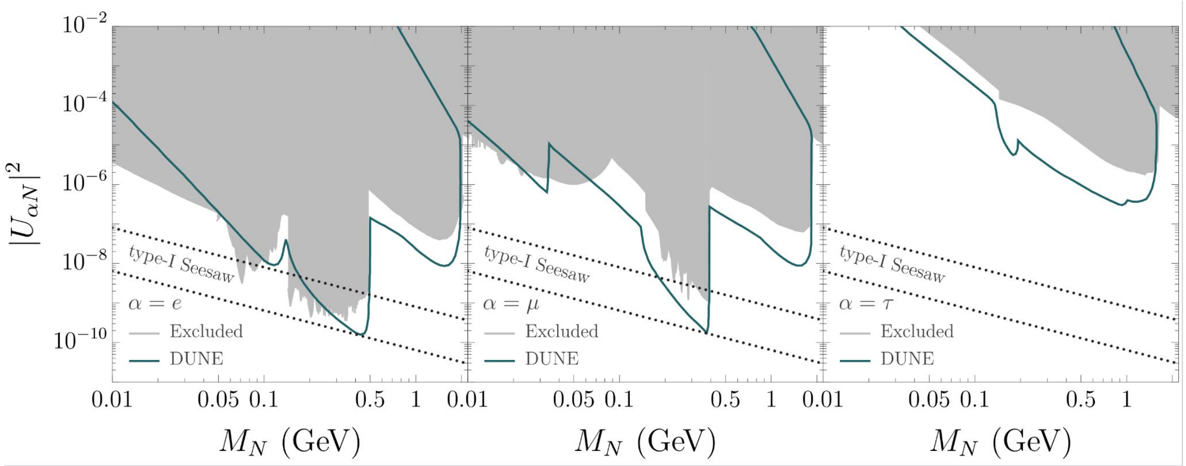
- DUNE will be part of a multi-messenger network of neutrino and optical telescopes studying the next galactic core-collapse supernova (CCSN) - see plot bottom right for sensitivity
- DUNE will be primarily sensitive to the astroparticle electron-neutrino flux for energies 5-100 MeV, complementary to other detection techniques (see plot bottom left)
- Lower thresholds would fundamentally expand the low-energy physics opportunities with DUNE Phase II, in addition to larger mass.
- DUNE can select a sample of ^{8}B solar neutrinos that would improve upon current solar measurements of Δm^2_{21} via the precise measurement of the day-night flux asymmetry.
- DUNE can also make the first observation at >5σ of the “hep” flux .
- DUNE Phase II could measure the energy dependence of the solar electron-neutrino survival probability, P_{ee}, and probe the upturn in P_{ee} due to the MSW effect in the Sun.





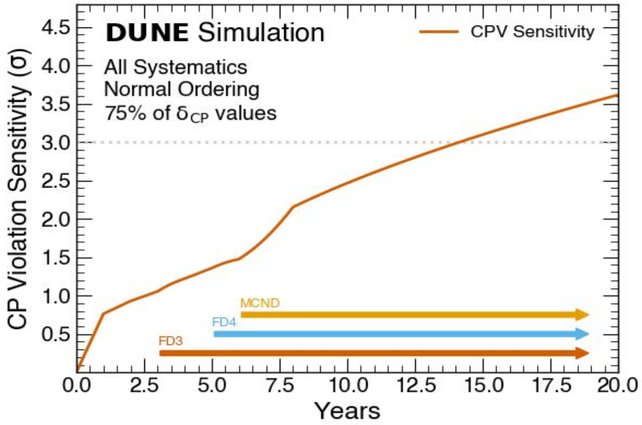
DUNE (Phase II) - Key Physics Deliverables

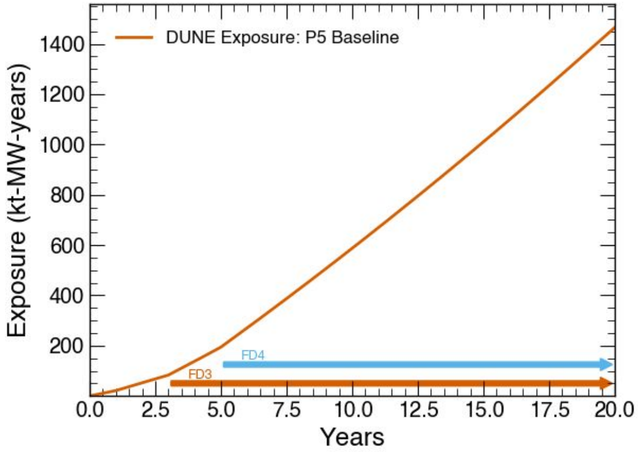
- The DUNE Near Detector (ND) can search for a wide variety of long-lived, exotic particles that are produced in the target and decay in the ND. Heavy neutral leptons (see plots below) and axion-like particles (ALPs) are examples of well motivated searches possible with DUNE.
- Other: rare event searches in Far Detector, non-standard oscillation phenomena



Datasets and running/exposure time required

- The oscillation key physics deliverables require 600 − 1000 kt·MW·yr of data statistics, depending on the measurement.
- This can be achieved by operating for 6 − 10 *additional* calendar years with a greater than 2 MW beam and a FD of 40 kt LAr equivalent fiducial mass. Without doubling the FD mass and the beam intensity, the additional time required would be 24 − 40 years
- Improvements of ND systematics due to NDGAr assumed starting in year 7.





Estimated Project Costs/Resources

- LBNF/DUNE (phase 1) is a ~$3B investment from the US DOE with ~$800M support from partners
- PIP-II accelerator upgrade represents a further ~$1B investment from US DOE with ~$300M support from partners
- The UK (construction) project is a £79.5M investment from BEIS(DSIT)/STFC and includes major contributions to PIP-II accelerating cavities, high power neutrino targets, LAr TPC detector elements, data acquisition, trigger, monitoring, reconstruction software and computing.
- DUNE operations phase supported by a common fund process starting from 2024
- The UK project consists of 18 institutes, including RAL and Daresbury, amounting to ~100 PhD full-member authors of the DUNE collaboration.
- Phase II R&D currently funded through non-project resources such as EU-AIDA, ERC, Advanced Fellowships etc.
- LBNF/DUNE (Phase 2) has a baseline cost of the US project of ~$500M with the expectation that a similar amount is contributed by partners, with cryostats provided by CERN.
- The success of the R&D programme strongly depends on the availability of the Neutrino Platform at CERN and its resources.

Dedicated submission(s) for the ESPPU:

- DUNE is preparing a dedicated submission to the ESPPU based on the DUNE Phase II White Paper.
- A separate DUNE-UK submission is under discussion.

DUNE Phase II:
Scientific Opportunities, Detector Concepts, Technological Solutions

The DUNE Collaboration*

August 26, 2024

DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Accepted by J. Instrum.

*Editors: Sowjanya Gollapinni, Anne Heavey, Stefan Söldner-Rembold, Michel Sorel

Non-collider projects specific input

Comparison of physics goals with the current state of the art in the area.

- The preponderance of matter over antimatter in the early universe, the dynamics of the supernova neutrino bursts (SNBs) that produced the heavy elements necessary for life, the nature of dark matter, and whether protons eventually decay – these mysteries at the forefront of particle physics and astrophysics are key to understanding the evolution of our universe.
- DUNE is the next-generation, state-of-the-art experiment that will provide a breakthrough from the precise measurement of the neutrino oscillation parameters, including the potential discovery of a non-zero CPV phase.
- DUNE will be measure, for the first time since 1987, a significant neutrino signal from a supernova, with many orders of magnitude high statistics.

The project's main advantages compared to competitor projects

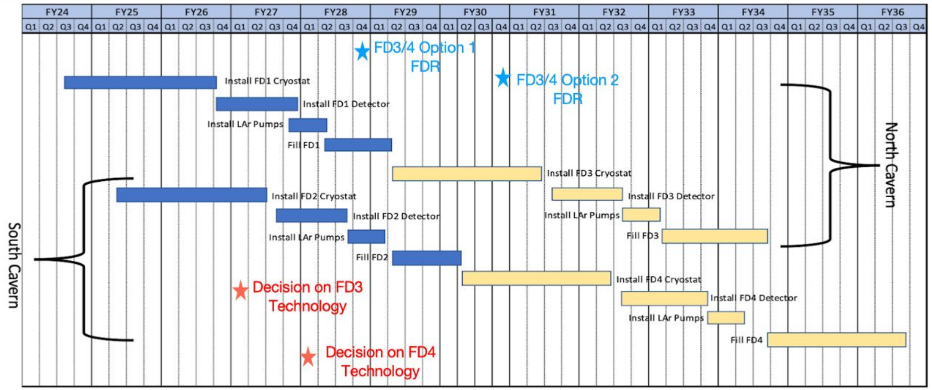
- A broad multi-decadal science programme covering accelerator-based neutrino physics and astroparticle physics.
- Ability to deliver both discovery and precision physics through the state-of-the-art liquid-argon TPC technology.
- Determination of mass ordering and CPV in a single experiment through precision spectrum measurements that resolve degeneracies.
- Pre-existing infrastructure (FD caverns, ND facility) for Phase II.

Preferred location for the project

- The Far Detector is located at the SURF Laboratory in South Dakota (USA)
- The Accelerator and the Near Detector are located at Fermilab (USA)
- Significant prototyping (including physics measurements) are performed on the Neutrino Platform at CERN.
- R&D and Prototyping is also planned as part of the SOLAIRE proposal in Boulby.

DUNE Timelines

- FD1/2 (Phase I): start of physics 2029
- FD3: R&D until 2031, construction 2032-2034, exploitation >2036
- FD4: R&D until 2034, construction 2035-2036, exploitation >2037
- ND-GAr: R&D until 2034, construction 2035-2036, exploitation >2037



Earliest installation start in 2029 with FD3 completed in Q4,2034 and FD4 in Q4,2036

DUNE specific input

Main risks/obstacles for realisation of physics goals (e.g. development of new technologies, construction of a new facility)

- Table shows main technology options and their key R&D goals.
- Facility already under construction.
- Require cryostats through CERN for FD3/4.

Anticipated area(s) of UK involvement

Currently (Phase I construction):

APAs construction, DAQ (FD/ND), reconstruction software, physics algorithms, computing software framework, target and PIP-II cavities

Future (Phase II R&D projects):

Advanced charge readout options (SOLAIRE, ARIADNE, Q-Pix)
Gas-argon TPC for Near Detector (NDGAr)

Technology	Prototyping Plans	Key R&D Goals
CRP (Sec. 3.3.2)	**2024:** Cold Box tests at CERN. **2025-2026:** ProtoDUNE-VD at CERN.	Port LArASIC to 65 nm process
APEX (Sec. 3.3.1)	**2024:** 50 L & 1-ton prototypes at CERN. **2024-2025:** $\mathcal{O}(100)$-channel demonstrator at Fermilab. **2025-2028:** ProtoDUNE-VD at CERN.	Mechanical integration of APEX PD in field cage
		Signal conditioning, digitization and multiplexing in cold
LArPix, LightPix (Secs. 3.3.3 and 3.3.5)	**2024:** 2x2 ND demonstrator at Fermilab. **2024-2025:** Cold Box tests at CERN. **2026-2028:** ProtoDUNE at CERN.	Micropower, cryo-compatible, detector-on-a-chip ASIC
		Scalable integrated 3D pixel anode tile
		Digital aggregator ASIC and PCB
Q-Pix, Q-Pix-LILAr (Secs. 3.3.3 and 3.3.5)	**2024:** Prototype chips in small-scale demonstrator. **2025-2026:** 16 channels/chip prototypes in ton-scale demonstrator at ORNL. **2026-2027:** Full 32-64 channel "physics chip".	Charge replenishment and measurement of reset time
		Power consumption
		R&D on aSe-based devices and other photoconductors
ARIADNE (Sec. 3.3.4)	**2024:** Glass THGEM production at Liverpool. **2025-2026:** ProtoDUNE-VD at CERN.	Custom optics for TPX3 camera
		Light Readout Plane design with glass-THGEMs
		Characterization of next-generation TPX4 camera
SoLAr (Sec. 3.3.5)	**2024:** Small-size prototypes at Bern. **2025-2028:** Mid-scale demonstrator at Boulby.	Development of VUV-sensitive SiPMs
		ASIC-based readout electronics