PROCEEDINGS OF SCIENCE

DUNE Status and Science

Laura Pérez–Molina* **on behalf of the DUNE Collaboration**

CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
Av. Complutense 40, E-28040 Madrid, Spain

E-mail: laura.perez@ciemat.es

The Deep Underground Neutrino Experiment (DUNE) is a next–generation, long–baseline and dual–site neutrino experiment. It will be composed of the most powerful muon–neutrino beam and two detectors: a near detector (ND) located at Fermilab, where the neutrinos are produced, and a far detector (FD) 1300 km apart at the Sanford Underground Research Facility (SURF). The chosen baseline and a 40–kt fiducial liquid argon mass will ensure high sensitivity measurements of the oscillation parameters. Moreover, proton decay and supernova neutrino burst searches could be performed. DUNE will resolve the neutrino mass ordering with 5σ precision, for all δ_{CP} values, after 2 years of running with the nominal detector design and beam configuration. It also holds the potential to detect charge–parity violation in the neutrino sector with 3σ (5σ) precision after 5 (10) years, for 50% of all δ_{CP} values. The current status and timeline of the project will also be discussed.

The European Physical Society Conference on High Energy Physics (EPS-HEP2025)
7-11 July 2025
Marseille, France

*Speaker

PoS(EPS-HEP2025)180

1. Introduction

The Deep Underground Neutrino Experiment (DUNE) is a next–generation long–baseline (1300 km) neutrino experiment [1]. DUNE main physics goals are to unveil the neutrino mass ordering, to search for leptonic charge–parity (CP) violation and the θ_{23} octant [2]. This will be possible thanks to the wideband beam and its long baseline [3]. Moreover, it has a broad non–beam physics program that includes searches beyond the Standard Model (proton decay) and astrophysical neutrinos (supernova neutrino burst, solar and atmospheric neutrinos). DUNE design has been conceived to make these very precise measurements, and it will consist of a near detector (ND) complex located at Fermilab, 574 m from the neutrino source, and a far detector (FD) located at the Sanford Underground Research Facility (SURF) in South Dakota, 1300 km away from the ND. In Figure 1 we show a schematic with the positions for its different components.

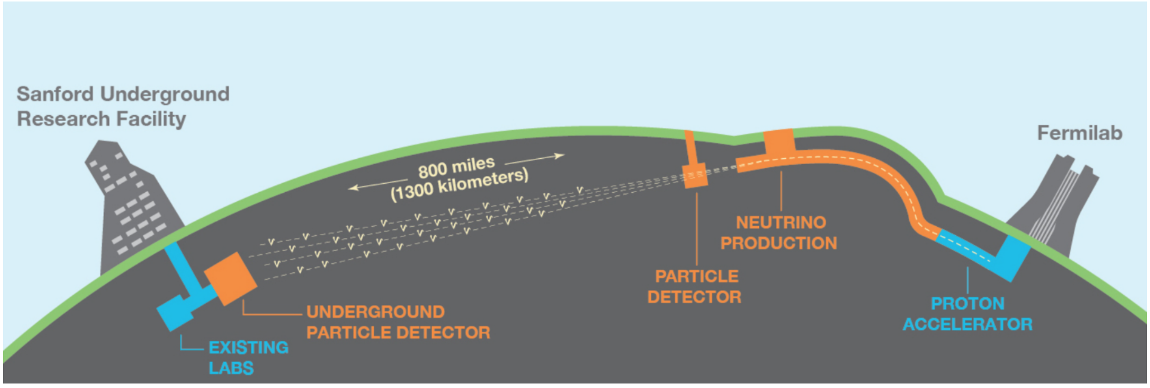


Figure 1: Schematic of the DUNE experiment. The neutrino beam is produced at Fermilab, with the near detector complex located at the surface and the far detector situated deep underground at SURF [1].

DUNE is being deployed in two phases. Phase I includes the full near and far site facilities, featuring a 1.2 MW upgradable neutrino beamline, two Liquid Argon Time Projection Chamber (LArTPC) modules (17 kt each) for the FD, and three detectors for the near detector, which includes a LArTPC and a temporary muon spectrometer. In Phase II [4], the beamline will be upgraded to over 2 MW, and two additional far detector modules will be added, bringing the total to four modules for a combined active volume of 40 kt, along with a more capable near detector.

2. DUNE Detectors

2.1 Near Detector

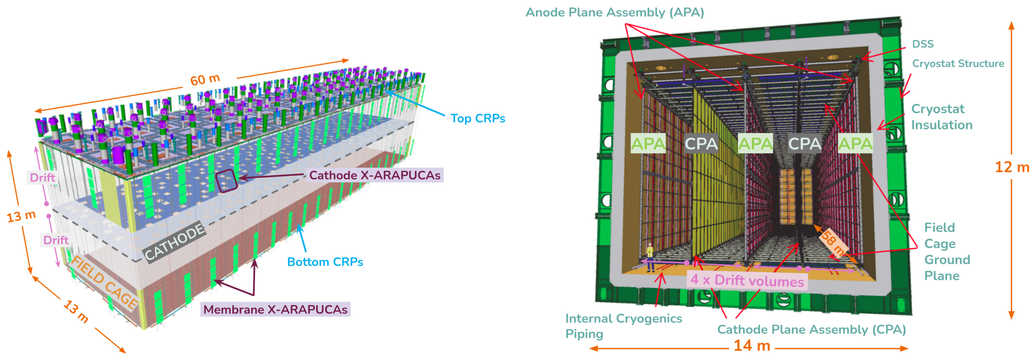
The DUNE near detector complex is located at Fermilab [5]. It is designed to provide crucial measurements of the neutrino flux and energy spectrum before oscillation, which are essential for interpreting the data from the far detector. The near detector complex consists of three main components: a movable Liquid Argon Time Projection Chamber (NDLAr), the muon spectrometer (TMS), and an on–axis detector (SAND).

2.2 Far Detector

The DUNE far detector [6] is located at the Sanford Underground Research Facility (SURF) in South Dakota, approximately 1300 km from the neutrino source at Fermilab. The far detector will consist of four modules, each with a fiducial mass of 17 kt, for a total of 40 kt of active volume. The far detector modules are designed to be deep underground, which helps shield them from cosmic rays and other background radiation, allowing for high–precision measurements of neutrino interactions.

The phase approach allows considering different technologies for the fourth module and all the improvements from first phase can be applied to the second. The first two modules will have the LArTPC technology, which enables precise imaging through drifted ionization electrons and accurate event timing via VUV scintillation photons. These two signals are crucial for understanding particle interactions, and are recorded by the charge collecting system and a photon detection system respectively.

The first far detector module will have two drift volumes separated by a cathode. A drift field of 450 V/cm will allow to drift the electrons for 6.5 m. It will only count with two anode planes and the charge readout will be based on PCB strips [7]. The second module will have four horizontal drift modules of 3.5 m each and the charge is measured with wire planes [8]. In both cases the photon detection system will be based on X–ARAPUCAs. In Figure 2 we show the schemes for both modules with their respective components.



(a) (b)

Figure 2: DUNE far detector modules: (a) vertical [7] and (b) horizontal drift modules [8].

2.3 CERN Prototypes

The DUNE collaboration has been actively working on prototypes at CERN to test and validate the technologies that will be used in the far detector. These prototypes are essential for ensuring that the final design meets the stringent requirements for precision and reliability. As 60% of interaction at DUNE energy will have pions in their final state, these prototypes are crucial to measure and constrain the interaction models. Not only that but it has been validated the excelent e/μ and e/γ separation together with the precise hadron reconstruction. Summarizing, a very high particle ID, energy reconstruction and spatial resolution (~mm) has been achieved [9]. The prototypes have been tested with cosmic rays and particle beams, providing valuable data that will inform the design of the final far detector modules.

3. Physics Program

Although the neutrino oscillation phenomena within the three neutrino families is constrained by current experimental data, there are still crucial open questions. Starting with the mass ordering, the value of δ_{CP} or the θ_{23} octant. DUNE main goals is to precisely determine these parameters [2].

To address these questions DUNE can look to the oscillation channel $\nu_\mu \rightarrow \nu_e$ ($\overline{\nu}_\mu \rightarrow \overline{\nu}_e$) and study the energy dependence of the ν_e ($\overline{\nu}_e$) appearance probability. In Figure 3 we show the unoscillated flux at the near detector, as well as the oscillation probabilities for muon neutrinos to electron neutrinos and muon anti–neutrinos to electron anti–neutrinos.

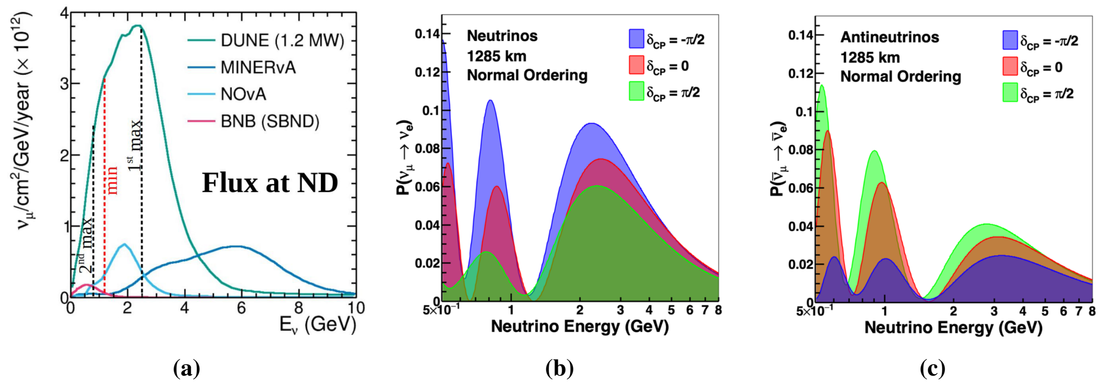
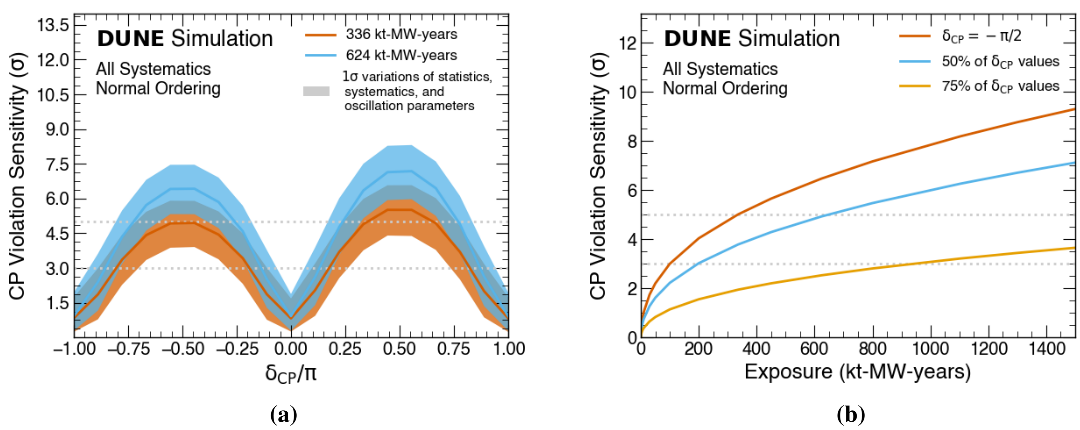
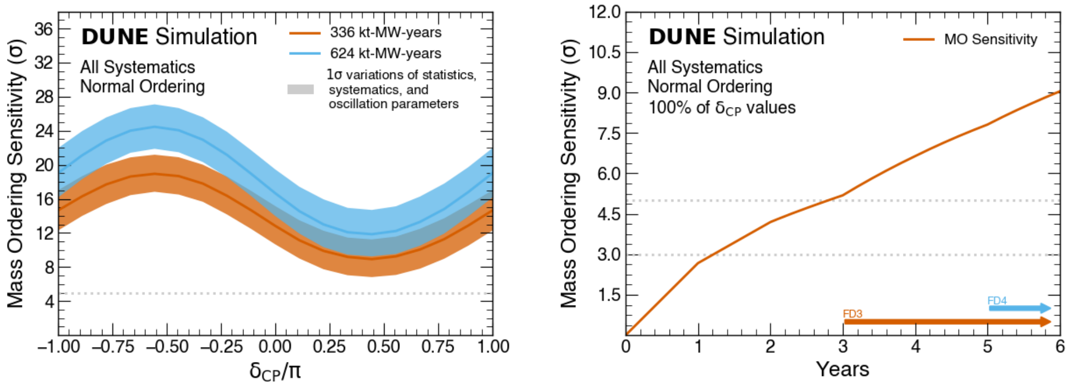


Figure 3: DUNE neutrino beam. (a) Unoscillated flux at the near detector, (b) muon neutrino to electron neutrino oscillation, and (c) muon anti–neutrino to electron anti–neutrino oscillation. Figures from [10].

Neutrino and anti–neutrino beams are crucial to measure δ_{CP} (see Figures 3b and 3c), which combined with the long–baseline allows determining the neutrino mass ordering. DUNE will allow us to measure the first two oscillation maxima which is unprecedented among other long–baseline experiments. In Figure 4a we show the sensitivity to CP violation as a function of δ_{CP} after 7 (orange) and 10 (blue) years of running. Maximal sensitivity is found at $\delta_{CP} = (\pm)\pi/2$ and decreases around CP–conserving values. In Figure 4b we show the sensitivity to CP violation as a function of the exposure for three different scenarios for δ_{CP}.





(c) **(d)**

Figure 4: DUNE sensitivities to: CP violation with respect to (a) δ_{CP} values and orange and blue regions representing 7 and 10 years of exposure respectively and (b) the exposure where the orange, blue and yellow curves show the different situations depending on the true value of δ_{CP}; Mass Ordering with respect to (c) δ_{CP} values (orange and blue regions represent 7 and 10 years of exposure respectively) and (d) the exposure where 100% of the δ_{CP} values are considered and the inclusion of the two last far detectors are also shown. Figures from [10].

The mass ordering sensitivity is shown in Figure 4c as a function of δ_{CP} after 7 (orange) and 10 (blue) years of running. Note that 5σ could be achieved during the first years of running independently of the value of δ_{CP}. In Figure 4d we show the sensitivity to the mass ordering as a function of the exposure, considering all possible values of δ_{CP}. The inclusion of the two last far detectors is also shown, improving the sensitivity.

DUNE also aims to detect neutrinos originated in supernovae explosions, in what is called a supernova neutrino burst (SNB). These neutrinos carry with them information about the core–collapse process, from the progenitor to the explosion and the remnant; but also may have information about new exotic physics. Although these are quite rare, as the expected supernovae explosion events are about one every few decades for our galaxy and Andromeda, the long lifetime of the experiment makes it reasonable to expect some.

4. Conclusions

Currently, the construction site and infrastructure are complete, and the installation of the cryostat has commenced. This installation is anticipated to be finished by mid–2027, when the installation of the far detectors will begin. By 2029, data collection from solar and atmospheric sources could commence. Finally, the first neutrino beam data expected by 2030.

In conclusion, the DUNE experiment represents a significant advancement in the field of neutrino physics, focusing on long–baseline oscillation studies and the exploration of mass ordering and CP violation. The collaboration is actively engaged in a successful prototyping program, with ongoing construction efforts aimed at commencing scientific operations by the end of this decade.

References

[1] DUNE Collaboration: B. Abi et. al., *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I: Introduction to DUNE*, 2020, [2002.02967, physics.ins-det].

[2] DUNE Collaboration: B. Abi et. al., *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics*, 2020, [2002.03005, hep-ex].

[3] DUNE Collaboration: R. Acciarri, et. al., *Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE): Conceptual Design Report, Volume 4 The DUNE Detectors at LBNF*, [1601.02984].

[4] DUNE Collaboration: A. Abed Abud et. al., *DUNE Phase II: scientific opportunities, detector concepts, technological solutions*, *JINST* **19** (2024) P12005 [2408.12725].

[5] DUNE Collaboration: A. Abed Abud et. al., *Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report*, 2021, [2103.13910, physics.ins-det].

[6] DUNE Collaboration: B. Abi et. al., *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume III: DUNE Far Detector Technical Coordination*, 2020, [2002.03008, hep-ex].

[7] DUNE Collaboration: A. Abed Abud et. al., *The DUNE Far Detector Vertical Drift Technology, Technical Design Report*, 2023, [2312.03130, hep-ex].

[8] DUNE Collaboration: B. Abi et. al., *Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology*, 2020, [2002.03010, physics.ins-det].

[9] DUNE Collaboration: B. Abi et. al., *First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform*, *JINST* **15** (2020) P12004.

[10] DUNE Collaboration: B. Abi et. al., *Long-baseline neutrino oscillation physics potential of the DUNE experiment.*, *Eur. Phys. J. C 80, 978 (2020)* **80** (2020) 978.