

An Overview of the DUNE Far Detectors



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1 The DUNE Physics Program

The Deep Underground Neutrino Experiment (DUNE) is a long-baseline neutrino oscillation experiment aiming at observing the transition from muon (anti)-neutrinos to electron and tau (anti)-neutrinos [1]. A $\bar{\nu}_\mu^{(-)}$ broadband beam peaking at 2.5 GeV will be created in Fermilab PIP-II accelerator and sent towards the far detector complex, located 1300 km away in the Sanford Underground Research Facility (SURF). The far detector complex will hold four ~ 20 -kton far detectors (FDs) based on liquid-argon technology in order to observe oscillation towards $\bar{\nu}_e^{(-)}$ and $\bar{\nu}_\tau^{(-)}$ flavours. In Phase I of the experiment, the complex will hold two detectors (FD1 and FD2), as well as a moveable liquid argon near detector located downstream the Fermilab beam dump in order to characterise the neutrino flux. In Phase II, two detectors (FD3 and FD4) will be added in the far detector complex, and an improved near detector complex will provide better measurements of the unoscillated neutrino flux.

The physics objectives of DUNE are the measurement of charge-parity (CP) violation in the leptonic sector, with the ability to reach a 5σ precision over 50% of the CP-violating phase δ_{CP} values [2]. Using the difference of scattering in ν_e and $\bar{\nu}_e$ along the long beamline, DUNE also has the capacity to measure the ordering of neutrino mass eigenstates at 5σ as shown on Fig. 1. Concerning the oscillation

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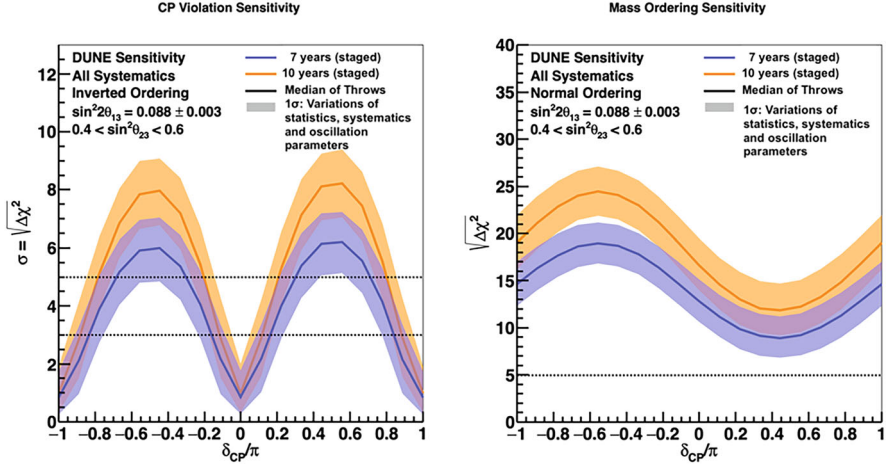


Fig. 1 DUNE sensitivity to CP violation (left) and neutrino mass ordering (right) as a function of the CP-violating phase δ_{CP} , assuming the normal ordering of neutrino masses. Reprinted under CC-BY-4.0 from [2]. © 2024, The Author(s)

matrix angle, DUNE can resolve the θ_{23} octant in case of non-maximal mixing and provide an independent measurement of θ_{13} with a resolution comparable to reactor experiments at high exposure. In addition to beam neutrinos, DUNE can also observe neutrinos at lower energies originating from the Sun or supernovae, and neutrinos at higher energies created during the collision of cosmic rays with the Earth atmosphere. Besides its precision neutrino oscillation physics measurements program, DUNE will be able to probe a large range of beyond-Standard Model phenomena, from nucleon decay to spacetime symmetry breaking and new particles and interactions [3].

2 The DUNE Far Detector Complex

The scientific program described above requires a large number of neutrino observations, a known challenge considering the very low cross-section of those particles. For this aim, in Phase I, the DUNE far detector complex will include two far detectors placed in $66 \times 19 \times 18 \text{ m}^3$ cryostats in order to observe $\mathcal{O}(10^3)$ neutrino interactions over the experiment timeline. The cryostats are subdivided in modules filled with liquid argon at a temperature of 88 K ($-185 \text{ }^\circ\text{C}$) in order to detect the charged particles created by neutrino interactions in the 10-kton fiducial volume. At DUNE energies, neutrinos interact with argon atoms predominantly through charge-current resonant, quasi-elastic and deep inelastic interactions creating charged particles. In 79% of the cases, the argon atom is ionised and the created electrons are drifted towards an anode acting a signal collector by a 500-kV electric field. In 21% of the cases, the atom is excited and form an excimer state with another

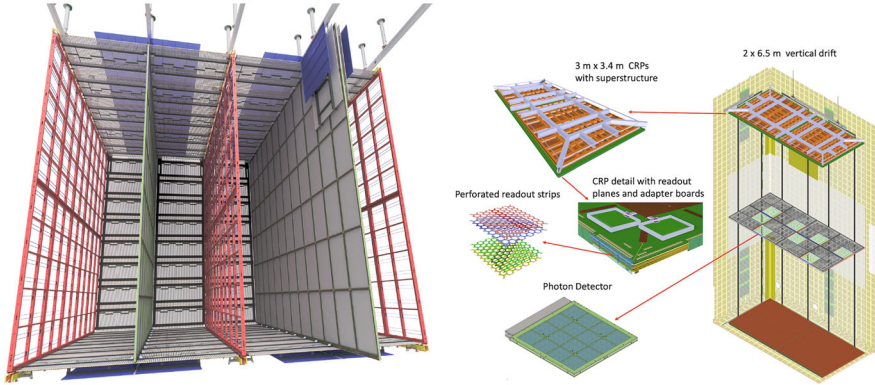


Fig. 2 Left: schematics of a FD1 (horizontal drift) module, where the red planes are the wire plane anodes and the grey planes the cathodes (from [4]). Right: schematics of a FD2 (vertical drift) module, where the top and bottom planes are the CRP anodes, and the middle plane is the cathode. Reprinted under CC-BY-4.0 from [5]. © 2024, The Author(s)

atom, releasing the extra energy through ultra-violet photons collected by an X-ARAPUCA light trap made of wavelength shifting, dichroic filter and silicon photomultiplier.

While both FD1 and FD2 rely on similar detection principle, they present small variations in their design. The FD1 modules contain 3 anodes and 2 cathodes placed vertically, creating four drift volumes of 3.6 m length as shown on Fig. 2 left. The charge signal is collected at the anode plane assembly, consisting of 3 layers of wire planes, each plane holding 2560 wires with a 4.7 mm pitch [4]. Each anode plane contains 10 light traps, and the read-out is performed by cryogenic electronics located inside the cryostat. The FD2 modules contain 2 anodes and 1 cathode placed horizontally, creating a vertical electric field with 6.5 m drift length as shown on Fig. 2 right. The ionisation electrons are collected at the anode consisting of 160 charge readout planes across the detector [5]. Each plane is made of 3 layers of circuit board printed with linear copper strips and drilled with holes to enable the circulation of charges, with a total of 3072 strips per plane with a pitch from 5 to 7.65 mm. The bottom electronics is similar to FD1, while the top electronic is divided between the amplification stage inside the cryostat and the digitisation stage located outside for better accessibility and longevity. The light collection is assured by 352 X-ARAPUCA located on the cathods and in the field cage.

3 Current Status and Future Prospects

The DUNE collaboration carried a large R&D program over the last years. Small prototypes have been extensively used to test the design of the FD1 and FD2

cathodes and anodes. A first module of the FD1, labelled ProtoDUNE-SP, of volume $7 \times 6 \times 7.2$ m, have been assembled and put to test in the CERN Neutrino platform between 2018 and 2020 [6]. Using cosmic rays and the H4 beamline delivering charged pions, kaons, protons, muons and electrons with momenta in the range 0.3–7 GeV/c, the detector performance has been validated within design specifications, and exceeding them in several cases [7]. The large set of measurements performed includes the energy loss for charged particle, the drift electron lifetime, the electronic gain and noise, as well as the light detectors characteristics. The identification and reconstruction of particles going through liquid argon is performed using the LArSoft toolkit developed and maintained for the ArgoNeuT, DUNE, LArIAT, MicroBooNE, and SBND experiments¹ [8], and furthermore calibrated using ProtoDUNE data to achieve the required sub-centimeter resolution. ProtoDUNE-SP, relabelled ProtoDUNE-HD, will take more data in Summer 2024. A first module of the FD2, ProtoDUNE-VD, is currently being assembled and will take data in 2025. The far detectors are planned to be installed and start taking by the end of the 2020s.

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References

1. B. Abi et al. (DUNE Collaboration), Deep Underground Neutrino Experiment (DUNE), far detector technical design report, volume I: introduction to DUNE. *J. Instrum.* **15**, T08008 (2020). <https://doi.org/10.1088/1748-0221/15/08/T08008>. [arXiv:2002.02967 [physics.ins-det]]
2. B. Abi et al. (DUNE Collaboration), Long-baseline neutrino oscillation physics potential of the DUNE experiment. *Eur. Phys. J. C* **80**, 978 (2020). <https://doi.org/10.1140/epjc/s10052-020-08456-z>. [arXiv:2006.16043 [hep-ex]]
3. B. Abi et al. (DUNE Collaboration), Prospects for beyond the standard model physics searches at the deep underground neutrino experiment. *Eur. Phys. J. C* **81**, 322 (2021). <https://doi.org/10.1140/epjc/s10052-021-09007-w>. [arXiv:2008.12769 [hep-ex]]
4. B. Abi et al. (DUNE Collaboration), Deep Underground Neutrino Experiment (DUNE), far detector technical design report, volume IV: far detector single-phase technology. *J. Instrum.* **15**, T08010 (2020). <https://doi.org/10.1088/1748-0221/15/08/T08010>. [arXiv:2002.03010 [physics.ins-det]]

¹ <https://larsoft.org/>

5. A. Abed Abud et al. (DUNE Collaboration), The DUNE far detector vertical drift technology, Technical Design Report. [arXiv:2312.03130 [hep-ex]]
6. A.A. Abud, et al. (DUNE Collaboration), Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC. *J. Instrum.* **17**, P01005 (2022). <https://doi.org/10.1088/1748-0221/17/01/P01005>. [arXiv:2108.01902 [physics.ins-det]]
7. B. Abi et al. (DUNE Collaboration), First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform. *J. Instrum.* **15**, P12004 (2020). <https://doi.org/10.1088/1748-0221/15/12/P12004>. [arXiv:2007.06722 [physics.ins-det]]
8. E.L. Snider, G. Petrillo, LArSoft: toolkit for simulation, reconstruction and analysis of liquid argon TPC neutrino detectors. *J. Phys. Conf. Ser.* **898**, 042057 (2017). <https://doi.org/10.1088/1742-6596/898/4/042057>

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