PROCEEDINGS OF SCIENCE

The DUNE Near Detector

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DUNE is a next-generation experiment aiming to provide precision measurements of neutrino oscillation parameters. It will detect neutrinos produced in the Long-Baseline Neutrino Facility beamline at Fermilab, using a Near Detector situated near the beam target where the neutrinos originate and a Far Detector located 1300 km away in South Dakota. A comparison of the spectra of neutrinos measured at the Far and the Near Detector will allow for the extraction of oscillation probabilities from which the oscillation parameters can be inferred. The specific role of the Near Detector is to serve as the experiment's control: it will establish the no oscillation null hypothesis, measure and monitor the beam, constrain systematic uncertainties, and provide essential measurements of the neutrino interactions to improve models. The Near Detector complex will include three primary detector components: a liquid argon time projection chamber, a high-pressure gas time projection chamber and an on-axis beam monitor. The three detectors will serve important individual and overlapping functions, with two of them being also able to move transverse to the beam's axis via the DUNE-PRISM program. The overall mission of the Near Detector, as well as the three sub-detectors' unique capabilities and physics programs will be discussed in these proceedings.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

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PoS(ICHEP2022)615

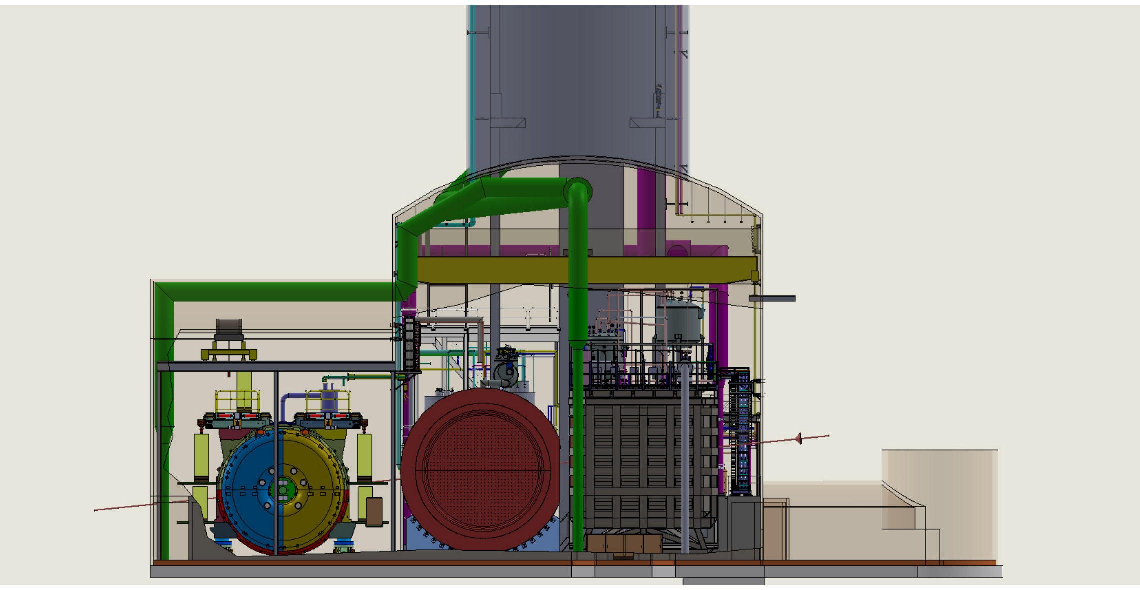
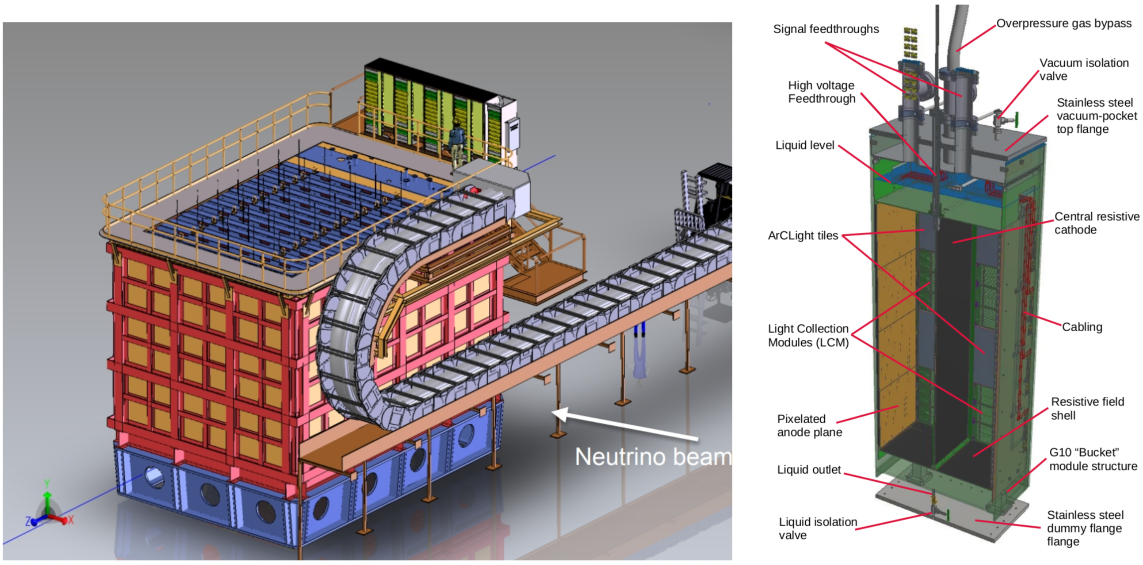


Figure 1: Schematic side-view of DUNE's ND-HAll. The neutrino beam direction is given roughly by the red arrow and from right to left the detectors ND-LAr, ND-GAr and SAND are shown.

1. DUNE and the role of the Near Detector

The Deep Underground neutrino experiment (DUNE) is a next generation long baseline neutrino oscillation experiment [1]. The experiment's main goal is to perform a precise and complete determination of the factors regulating neutrino oscillation probabilities, using both appearance and disappearance measurements in neutrino and antineutrino beams. These factors include δ_{CP}, which regulates the CP violation component in neutrino oscillations and is still undetermined, Δm_{32} or the neutrino mass ordering and the mixing angles. The experiment has three main components: a wide band 2.4 MW neutrino beam situated at Fermilab, capable of producing either a muon or anti-muon neutrino beam, a Far Detector (FD) [2] situated in South Dakota at a baseline of 1300Km, composed of a set of large-scale Liquid Argon Time Projection Chambers (LArTPC's) and a Near Detector (ND) [3] situated at just 600m from the neutrino source.
In order to make oscillation measurements possible, DUNE will have to make a prediction for the expected signal and background at the Far Detector as a function of the oscillation parameters, and then compare with the measured flavour-tagged neutrino spectra. In order to produce this prediction one must be able to determine the neutrino flux at production, the neutrino interaction cross sections and the response of the detector: all of these factors are affected by systematic uncertainties that need to be constrained. The Near Detector has been designed to specifically address each element necessary for the prediction: it will measure the un-oscillated neutrino beam flux on-axis and at different off-axis angles; it will help improve the current models of neurino interactions though measurements of cross-sections and final state topologies and it will model detector responses as a function of neutrino energy. The near detector has also been designed to operate in a high event rate environment, which in turn will provide the high statistics necessary to cover the full phase-space.
In order to fulfill its full set of requirements the Near Detector will be composed of three detectors with complementary designs: ND-LAr, which is a LArTPC similar in design to the Far Detector



(a) **(b)**

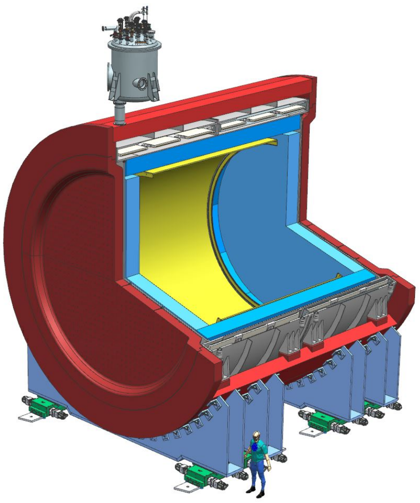
Figure 2: (a) Schematic view of the external components of ND-LAr, including the cryostat and the system for the DUNE-PRISM movement (b) Schematic drawing of a single ND-LAr module with its major components individually highlighted.

modules, ND-GAr which is a gaseous Argon TPC detector and SAND which is be a magnetized beam monitor. ND-LAr and ND-GAr will be movable off-axis and will participate in the DUNE-PRISM program, while SAND will remain fixed on-axis. A schematic view of the Near Detector with the full set of detectors is shown in Figure 1.

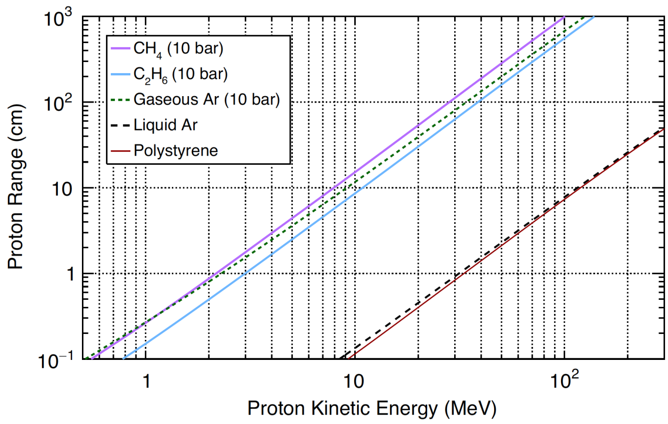
2. ND-LAr

ND-LAr is a liquid argon time projection chamber designed to operate in a high-rate environment (see Figure 2a for a schematic of the full detector). ND-LAr uses the same Argon target and a similar LArTPC detector technology as the Far detector modules, providing essential information in the modelling of the detector response as well as the neutrino interaction cross sections liquid Argon. In contrast to a classic LArTPC which usually contains a single time projection chamber, ND-LAr is constructed as a collection of 35 individual TPC modules, as originally designed for the ArgonCube prototype [4]. The modular design of ND-LAr will be essential in dealing with the high event rate in the detector, as it will allow for a smaller drift region, better light separation and a higher level of sensor pixelation. Each module will include two optically separated TPC's equipped with a LArPix [5] based pixelated charge readout system, a light readout providing fast timing information from the prompt scintillation light and a field structure offering very-low field non-uniformity in the entirety of the active volume (see Figure 2b).

Due to the relatively small dimensions of its active volume, ND-LAr won't be able to fully contain most of the muons produced in ν_μ Charged Current (CC) interactions in the liquid Argon. In order to precisely reconstruct the momentum of this muon sample, an external spectrometer component is needed: this role is fulfilled by ND-GAr.



(a)



(b)

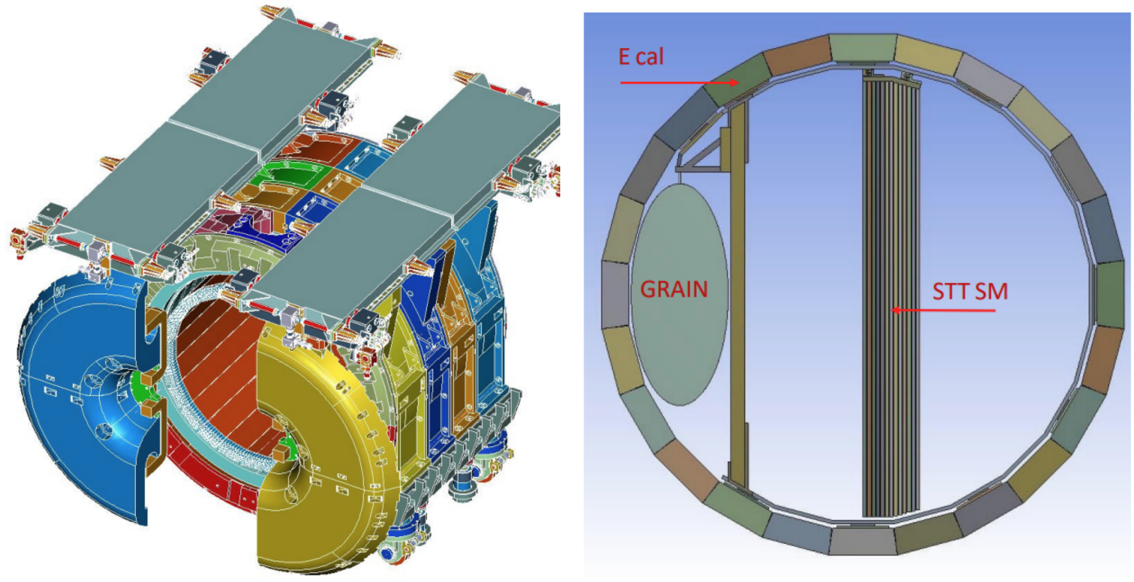
Figure 3: (a) Schematic view of the external components of ND-GAr with a cutaway showing the magnet, electro-magnetic calorimeter and the internal TPC (b) Plot showing proton range in cm as a function of Kinetic Energy in MeV in double logarithmic scale. The different curves show the range dependency in different gaseous, liquid or solid media [8].

3. ND-GAr

The Gaseous Argon Near Detector (ND-GAr) is envisioned to contain a high pressure gas TPC containing an Argon based gas mixture at 10 atmospheres of pressure, an electromagnetic calorimeter and a 0.5T super-conducting magnet (Figure 3a). The design of the central TPC component is based on the ALICE experiment at CERN [6] and the detector will reuse ALICE's readout chambers as part of its own set.

ND-GAr's main role in the Near Detector will be to act as a laboratory for the study of $\nu-$Argon interactions. The medium density in ND-GAr's TPC will be much lower than the one found in ND-LAr or the far detectors, which reduces the particle tracking thresholds and minimize multiple scattering and re-interactions of final state particles. This can be easily understood through the graph in Figure 3b [8], which shows the range of protons as the function of their kinetic energy in different media: the range is consistently higher in a gaseous medium, compared to a liquid or solid medium, making lower energies accessible for reconstruction. The lower tracking thresholds achievable in ND-GAr will be essential in the study of nuclear effects (i.e. Fermi Motion, Final State Interactions,2p2h etc.), which are currently poorly understood in neutrino on Argon interactions and limit the quality of the available models.

As ND-GAr is placed immediately downstream from ND-LAr, it also fulfills the role of a muon spectrometer for muons produced in ν_μCC interactions in the LArTPC, providing curvature-based measurements of the particles' momentum and charge.



(a) **(b)**

Figure 4: (a) Schematic view of the external components of SAND, including its cryostat and its solenoid magnet (b) Side view of the internal components of SAND, including its active liquid Argon target called GRAIN, one of the straw tube tracker modules and the electro-magnetic calorimeter.

4. DUNE-PRISM

ND-LAr and ND-GAr will be capable of moving up to 30 m transverse to the neutrino beam axis, spanning angles from 0° to 3°: this capability is referred to as DUNE-PRISM. As the off-axis angles increases, the neutrino flux's mean energy decreases and its energy spread gets narrower. The Near Detector will thus effectively have access to a variety of different un-oscillated neutrino fluxes which can be then combined to produce a prediction of the oscillated flux at the far detector. This is a data-driven approach that will reduce model dependence.
Another important aspect of the DUNE-PRISM program is that, since the different off-axis fluxes will have different mean energies and spreads, they will be dominated by different interaction types (quasi-elastic, resonant etc.), making it possible to better disentangle cross-section effects, to the benefit of the modeling of flux and interactions.

5. SAND

The System for On-Axis Neutrino Detection (SAND) will provide constant on-axis monitoring of the neutrino beam. This will be essential for the DUNE-PRISM program as it will ensure that the differences in the flux measured by ND-LAr and ND-GAr are due to their off-axis position rather than to anomalies in the beam production.
The main structural components of SAND, as well as its solenoid magnet, cryostat and electro-magnetic calorimeter will be repurposed from the KLOE experiment [7] (Figure 4). SAND's internal tracker design has been recently finalized and it will consist of a Straw Tube Tracker (STT), composed of modules which will include a series of tunable passive slabs, interleaved with tracking

layers of 5mm diameter tubes. The different targets provided by SAND, which will include materials such as CH_2 and C are potentially extremely useful in the study of neutrino interactions, as they will provide a clean sample of neutrino on hydrogen interactions by "subtraction", which are devoid of nuclear effects. SAND will also include its own active target of liquid Argon called GRAIN whose design is currently being finalized.

6. Conclusions

The DUNE Near Detector will be composed of three robust and complete detector systems all capable and necessary to achieve DUNE's physics goals. The detector roster will include ND-LAr, a modular LArTPC similar in design to the FD modules, ND-GAr, a pressurized gaseous Argon TPC and SAND, a magnetized on-axis beam monitor. Each of the detector designs is complementary and motivated by the needs of the DUNE experiment as a whole.

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