Status of ProtoDUNE Dual Phase

Jaime Dawson, on behalf of the DUNE collaboration

APC, Université Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs de Paris, USPC, Paris 75205, France.

E-mail: jdawson@in2p3.fr

Abstract. The Deep Underground Neutrino Experiment (DUNE) will use a large liquid argon (LAr) detector consisting of four modules each with a fiducial mass of 10 ktons of LAr. One of the technology options for the far detector modules is a liquid-argon Time Projection Chamber (TPC) working in Dual Phase mode. A large demonstrator, called ProtoDUNE Dual-Phase, with a $6 \times 6 \times 6 \text{m}^3$ (300t) active volume, is currently under-construction at the CERN neutrino platform. As well as being the engineering prototype of a Far Detector module, it will also demonstrate the concept of a very large Dual-Phase LAr TPC. The design of the TPC including the fabrication, testing, installation and commissioning of the various detector components is outlined.

1. Introduction

The Deep Underground Neutrino Experiment (DUNE) is a next generation neutrino oscillation experiment [1]. A high power wide-band beam operating in neutrino (anti-neutrino) mode will be produced at Fermilab, the flux and flavour composition will be characterised with the Near Detector. At a baseline of 1,300 km, deep underground at the Sanford Underground Research Facility (SURF, South Dakota), four gigantic Far Detector modules will measure $\nu_\mu$ ($\bar{\nu}_\mu$) disappearance, $\nu_e$ ($\bar{\nu}_e$) and $\nu_\tau$ ($\bar{\nu}_\tau$) appearance with the goals of:

- determining the Neutrino Mass Ordering (at more than 5 sigmas)
- measure the CP Violating phase over a wide range of values
- measuring precisely the oscillation parameters
- testing the 3-flavour paradigm

The DUNE Far Detector modules will be liquid argon TPCs (LArTPC), each holding a fiducial mass of 10 ktons [2]. With huge detectors deep underground, DUNE will also search for Nucleon Decay and the astrophysical observations of Galactic Supernovae.

Two different charge read-out strategies are proposed for the DUNE Far Detector TPCs. Single-Phase, in which charge signals are formed from three wire planes; two induction and one collection. Here the drift length of the detector is limited to 3 to 4 metres, such that a DUNE module comprises several TPCs within the liquid argon volume. An alternative approach which is being explored is Dual-Phase.

2. Dual Phase

The Dual Phase mode of operation uses a liquid argon target covered with a shallow layer of gaseous argon under an applied electric field, as shown in figure 1. Interacting particles in the
Interacting charged particles form ionisation tracks in the liquid argon. Scintillation is detected by photomultipliers at the bottom, and the charge tracks are imaged at the top by the LEM/Anode structure. Liquid argon target excite and ionise the argon molecules. Recombination is suppressed by the applied drift field of 0.5 kV/cm. De-excitation and recombination produce excimers resulting in the emission of UV light (128 nm) which is detected by PMTs with wavelength shifting coating. The scintillation light gives the T0 of each event. The drift field causes ionisation electrons to drift upwards towards the liquid surface. With a 6m depth of liquid argon, drift times can be as long as 3 ms, setting stringent requirements on the liquid argon purity. The electrons are extracted in to the gas phase by the Extraction field (2kV/cm) as shown in figure 2. As the electrons pass through the high electric field of the Large Electron Multiplier (LEM) avalanches occur, in pure Argon gas, multiplying the number of electrons. The multiplied electrons are collected on strips of 2 interleaved anodes. The interleaved structure ensures that the electrons are equally distributed on both anodes, resulting in two symmetric collection views (Views 0, 1). Each strip is 3m long and has a pitch of 3.125 mm. The Z co-ordinate, or the depth of the interaction, is given by the time interval between the arrivals of the charge and scintillation signals (T0).

Dual-Phase operation offers a high Signal/Noise (larger than 10 for a minimumionising particle), with a tunable gain. The density of the LEM and the design of the collection anodes will allow fine grained tracking (3 mm). The result is two collection views each with good Signal/Noise, with a minimum number of read-out channels.
The world's first large Dual-Phase demonstrator is the $3 \times 1 \times 1$ m$^3$ 4 tonne demonstrator [3] which was constructed at CERN, and took 500k cosmic ray muon events during the summer-autumn of 2017. Many of the necessary systems and engineering solutions for ProtoDUNE Dual-Phase have already been successfully trialled on this demonstrator. Whilst this detector has technical problems with the extraction grid and LEM high voltage, and so could not demonstrate the gain required for the DUNE Far Detector module, it successfully showed:

- Liquid argon level stability over time
- Stable drift field for the entire operation
- Equal charge splitting at the anode
- Purity compatible with a 4ms electron lifetime

3. ProtoDune Dual-Phase
The ProtoDUNEs, one Single-Phase and one Dual-Phase, are a necessary R&D step towards the construction of the DUNE Far Detectors. With them all the engineering solutions and installation procedures will be tested. Full-size components identical to those proposed for the Far Detector will be used. The prototypes are the largest liquid argon TPCs ever constructed, holding several hundreds of tonnes of liquid argon. With these large detectors, the long term performance and stability will be demonstrated.

Construction of the Single Phase ProtoDUNE was completed during 2018, and it successfully took data with a charged particle beam. This test beam data will allow characterisation of the detector response over the energy range of interest for DUNE ($\sim 0.5$ to $8$ GeV). ProtoDUNE Dual-Phase [4], is currently under construction, and should begin operation by summer-fall of 2019. It will be characterised using cosmic ray muons.

The detector design is shown in figure 3 and image of the interior in figure 4.

Drift Field The drift field is ensured by a hanging field cage and cathode. The cathode is modular ($3m \times 3m$), and should provide a 60% optical transparency. The objective is to achieve a drift field of 0.5 kV/cm, to do so requires applying -300 kV on the cathode. The maximum local field requirement is $< 30$ kV/cm. The High Voltage (HV) feedthrough used is the same for both ProtoDUNEes and is based on the ICARUS design. HV is fed
from above, and an HV extender-degrader delivers voltage to the field rings and cathode. Construction of the field cage was completed in April 2018, and tested in air, achieving 0.5 kV/cm.

**Charge Readout** The detector uses four $3 \times 3$ m$^2$ Charge Readout Planes (CRP). Each CRP comprises one extraction grid (3m×3m), 36 LEMs (0.5cm×0.5cm) and 36 interleaved anodes. Only half of the detector will be fully instrumented, such that two instrumented CRPs and two dummy CRPs have been installed. The LEMs are critical to success of the Dual-Phase detector. They are tested in gaseous argon before installation. The LEM design has evolved, modifications to the clearance, spacers and ground rings has resulted in a LEM design which suffers no trips (over periods longer than 64 hours), no sparks and with an effective gain > 20. The active area of the LEMs used is ~ 86%. Further optimisation of the active area is envisaged. The first CRP assembly was completed in June 2018. The CRPs are tested in a dedicated cold-box, under voltage, before installation. All four CRPS were installed in February 2019 (see figure 4).

**Charge Readout Electronics** The signals from the CRP strips are amplified by cryogenic 16-channel ASIC amplifiers situated inside the signal chimneys. The cold electronics are therefore accessible from the outside and optimum for the signal (short cables to reduce capacitance and low temperature to reduce noise). A 64-channel Advanced Mezzanine Board (AMC) digitizes the signals with a 12-bit 2.5 MHz ADC(AD9257). Twelve $\mu$TCA crates, seated on the top deck, each containing 10 AMC cards, treat the 7680 charge signals channels. The Charge Readout Electronics successfully ran on the 4 tonne demonstrator.

**Light Readout** The scintillation light is observed by 36 TPB-coated PMTs (Hamamatsu R5912-02mod) which line the bottom of the detector (underneath the cathode). The photomultipliers are currently at CERN, and will be tested before installation. An optical fibre calibration system will be used to calibrate the PMTs during operation at the single photoelectron level.

**Light ReadOut Electronics** A 16-channel $\mu$TCA Light ReadOut digitisation board is being developed, dedicated to the treatment of the PMT signals.

**DAQ** The White Rabbit Time and Trigger distribution network is used with slave nodes in each $\mu$TCA crate. Data will be taken using only lossless compression. The DAQ has been designed to support ~100 Hz of externals triggers with ~150 MB/event resulting in ~20GB/second of data.

4. Conclusion
ProtoDune DP will begin operation in mid-2019. This project is a crucial milestone providing feedback for the long baseline neutrino DUNE program. The prototype will test all major engineering solutions, in particular: the LNG Cryostat, Hanging Field Cage, feedthroughs and the proposed underground construction sequence. The prototype will also test on a large-scale, all proposed components for the Dual Phase DUNE module [5].

**References**
[1] Acciarri R et al. (DUNE) 2016 (Preprint 1601.05471)
[2] Acciarri R, Acero M A, Adamowski M, Adams C, Adamson P, Adhikari S, Ahmad Z, Albright C H, Alion T, Amador E and et al 2016 ArXiv e-prints (Preprint 1601.02984)
[3] Aimard B et al. 2018 JINST 13 P11003 (Preprint 1806.03317)
[4] De Bonis I et al. 2014 (Preprint 1409.4405)
[5] Abi B et al. (DUNE) 2018 (Preprint 1807.10340)