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The ProtoDUNE large demonstrator of the Liquid Argon double phase TPC program at CERN

Jaime Dawson, for the DUNE collaboration.

Laboratoire Astroparticule et Cosmologie, 10 rue Alice Domon et Léonie Duquet, 75205 Paris, France

E-mail: jdawson@in2p3.fr

Abstract. The Deep Underground Neutrino Experiment (DUNE) will use a large liquid argon detector consisting of four modules each with a fiducial mass of 10 kt. A liquid-argon TPC working in double phase mode has been proposed as one of the first modules. The protoDUNE DP is a large demonstrator of the double phase liquid argon TPC with a $6 \times 6 \times 6$ m³ (300t) active volume. ProtoDUNE DP is under construction at CERN and will be exposed to a charged particle beam (0.5-20 GeV/c) in 2018.

1. Introduction

The Deep Underground Neutrino Experiment will use a huge liquid argon detector, consisting of four modules each with a fiducial mass of 10 ktons, deep underground, studying appearance and disappearance from a wide-band beam with the goals:

- CPV measurement over a wide range of values
- Neutrino Mass Hierarchy discrimination at more than 5 sigmas
- Precise Oscillation Parameters
- Testing the 3-flavour paradigm

This ambitious program also includes the search for Nucleon Decay and the astrophysical observations of Galactic Supernovae.

A liquid argon TPC working in dual phase mode has been proposed as one of the first DUNE modules [1]. This detector will have excellent tracking and calorimetric capabilities, and a totally homogenous response. The detector concept was first proposed by GLACIER[2].

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 liquid argon target excite and ionise the argon molecules. Recombination is suppressed by the applied Drift field (0.5-1kV/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 (0.5-1 kV/cm) 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

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Figure 1. 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.



Figure 2. Cut open view of the structure of the $6 \times 6 \times 6m^3$ prototype, showing major exteriour parts.

electrons are extracted in to the gas phase by the Extraction field (2kV/cm). 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, ie 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 (for m.i.p >100), with a tunable gain (~ 20 - 100). 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, no induction views and no ambiguities, with a minimum number of read-out channels. Tests of small prototypes ranging in size from 3 to 250 litres of liquid argon have already been made, showing successful operation [3].

3. ProtoDune Dual-Phase

The $6 \times 6 \times 6$ m³ Dual-Phase detector is under construction at CERN [4]. It will test all necessary systems for the final DUNE module. The detector design is shown in Figure 2. It consists of an LNG membrane tank containing 300 tons of liquid argon. The Drift Field is ensured by a hanging field cage and a transparent cathode.

Charge Readout The detector uses four $3x3 \text{ m}^2$ Charge Readout Planes (CRP) which consist of LEMs and interleaved anodes.

Charge Readout Electronics The signals from the CRPs 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 μ TCA crates, seated on the top deck, each containing 10 AMC cards, treat the 7680 charge signals channels.

Light Readout The scintillation light is observed by 36 TPB-coated PMTs (Hamamatsu R5912-02mod) which line the bottom of the detector.

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Light ReadOut Electronics A 16-channel μ TCA Light ReadOut digitisation board has been developed, dedicated to the treatment of the PMT signals. The LRO has two acquisition modes:

(i) **External beam trigger** – a waveform of ±4ms around the spill, coursely sampled at 2.5 MHz, is provided by 14-bit 40 MHz ADC (AD9279).

(ii) Internal trigger from ParisROC2 ASIC [5] (giving timestamp and charge) for off-beam events. DAQ The White Rabbit Time and Trigger distribution network is used with slave nodes in each μ TCA crate. Some ~100M beam triggers will be acquired in 2018. Data will be taken using only lossless compression. The DAQ has been designed to support ~100 Hz of beam triggers with ~150 MB/event resulting in ~20GB/second of data.

4. Beam Test

ProtoDUNE DP will be situated in the CERN North Area EHN1 Extension. It will be exposed to a charged particle beam (0.5 -20 GeV/c) in 2018. Incoming particles of known energy are necessary to calibrate the response of the detector. We use the fact that the secondary particles produced, for example, by 5 GeV π - and ν_{μ} , have similar characteristics, to assess the performance of the detector to neutrinos and test the energy reconstruction algorithms.

Due to the large size of the detector, hadronic showers will be fully contained. Liquid argon is non-compensating so electromagnetic and hadronic showers require different calibrations. Electron showers are well understood, however, predictions for hadronic showers vary greatly. The understanding of calorimetry is a fundamental milestone to achieve the required level of precision in the reconstruction of the neutrino energy.

5. Conclusion

ProtoDune DP will begin operation in 2018. 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, the proposed components for the DUNE module: Charge ReadOut Plane, LightReadOut and Data AcQuisition.

The charge particle beam test has three major physics goals. Firstly to acheive high accuracy in hadronic shower reconstruction to validate simulations. Secondly to test energy reconstruction algorithms and to determine the achievable resolution. Thirdly, to make cross-section measurements of charged hadron interactions (π +, π -, k, p) on Ar nuclei.

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