

WA105: a large-scale demonstrator of the Liquid Argon double phase TPC

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Abstract. The physics case for a large underground detector devoted to neutrino oscillation measurements, nucleon decay and astrophysics is compelling. A time projection chamber based on the dual-phase liquid Argon technique is an extremely attractive option, allowing for long drift distances, low energy threshold and high readout granularity. It has been extensively studied in the LAGUNA-LBNO Design Study and is one of the two designs foreseen for the modules of the DUNE detector in the US. The WA105 experiment envisages the construction of a large scale prototype at CERN, to validate technical solutions and perform physics studies with charged particle beams.

1. Introduction

A very large underground detector could measure precisely the oscillations of a neutrino beam over a long baseline, to access open questions in neutrino physics such as mass hierarchy and the existence of CP violation. It would also improve significantly the current sensitivity to nucleon decay and would detect neutrinos of astrophysical origin, notably from SuperNovae.

The liquid argon time projection chamber is the technology envisaged for the DUNE experiment, envisaging installation of four 10-kton detectors at the Homestake mine in South Dakota. A detailed description of the experiment and its goals is provided elsewhere in these proceedings [1].

At least one of the four detectors can exploit the dual-phase liquid Argon Time Projection Chamber (TPC) technique, described in section 2. This technique has already been developed on small detectors, however a large-scale prototype is needed to validate technical solutions and to perform studies on event reconstruction and particle identification capabilities, using charged particle beams: this is the goal of the WA105 experiment at CERN, that will be discussed in section 3.

2. The dual-phase liquid Argon TPC

Liquid Argon (LAr) is a dense medium, providing a good target for neutrino interaction. Its relatively low cost make it suitable for very large detectors, to the scale of several kilotonnes. The time projection technique allows for full three-dimensional reconstruction of events: the scintillation light provides the t_0 of the interaction, the ionization charge is then drifted, under the action of a uniform electric field, to one end of the detector, where the charge readout system



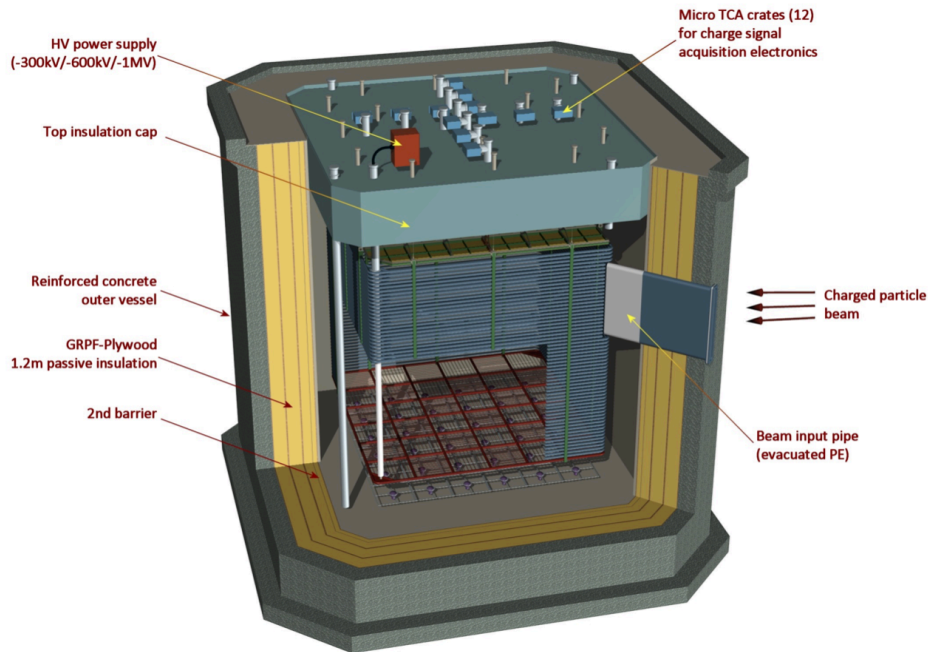


Figure 1. Schematic layout of the WA105 demonstrator at CERN.

measures the time of arrival, proportional to the distance along the drift coordinate, and the position in the two coordinates orthogonal to the drift.

The construction of large cryostats to host tens of kilotonnes of liquid Argon has been developed in the context of the LAGUNA-LBNO Design Study [2] based on solutions used by the LNG industry. This provides a fully active TPC volume.

In the dual-phase TPC, the ionization charge is extracted, after the drift, to a gaseous phase, where multiplication is provided by an intense electric field. Multiplication in the gaseous phase opens the possibility to use very large drift distances, up to tens of meters, with less stringent constraints on the liquid Argon purity, thus reducing the number of readout channels for large detectors. The charge is then collected on the readout anode with two orthogonal views, allowing for mm-level resolution on both views. The concept was proposed in [3] and several steps have been achieved since then with R&D mainly at CERN and ETH Zurich: from a $10 \times 10 \times 10 \text{ cm}^3$ (5 kg) prototype [4] to a $40 \times 76 \times 60 \text{ cm}^3$ (1 t) detector to a 1 m^3 mechanical mockup of the charge readout plane. The next stages envisage the construction of large-scale prototypes in the context of WA105.

3. The WA105 demonstrator at CERN

WA105 is one of the projects approved in the context of the CERN Neutrino Platform, providing support and infrastructure for neutrino detector and beam R&D.

Its main goal is the construction of a large-scale demonstrator of the dual-phase liquid Argon TPC, with a fiducial volume of $6 \times 6 \times 6 \text{ m}^3$ (300 t), shown schematically in Figure 1. It will test technical solutions for very large detectors with this technology and will perform physics studies with charged particle beams in 2018. A new extension of the EHN1 experimental area is being built for this purpose.

A pilot detector, with a fiducial volume of $3 \times 1 \times 1 \text{ m}^3$ (4 t), is at present being constructed at CERN and will operate with cosmic muons starting in 2016.

The WA105 Collaboration is composed of about 120 physicists and engineers from 22 institutes in 10 countries. The Technical Design Report was submitted to the CERN SPSC in 2014 [5].

3.1. WA105 scientific motivations

The main aim of WA105 is to test automated reconstruction and analysis algorithms in a dedicated test-beam programme. Samples of incoming μ^\pm , π^\pm and e with momenta from 0.5 to 20 GeV/c will be collected. The size of the detector has been chosen to allow for full containment of showers produced by incoming particles of few GeV, which look similar to those that will be induced by neutrino interactions in DUNE.

Automated algorithms will be developed and tested for the full reconstruction of showers from electrons, charged and neutral pions and tracks from muons, exploiting the unmatched performance for particle identification and reconstruction provided by the very fine sampling of the readout. Criteria to identify particles, in particular to distinguish electrons from neutral pions, will be developed.

An important item will be the study of calorimetry, to allow for full reconstruction of the incoming neutrino energy with the best resolution. The possibility to complement the charge readout with information from the light readout will be explored.

Hadronic secondary interactions, which play an important role in our knowledge of neutrino interactions, will be studied in detail.

Finally, precise measurements of the interaction cross-section of charged pions and protons on Argon nuclei will be performed.

The simulation and analysis software has been intensively developed in the past few months, notably to include the simulation and reconstruction of cosmic muons at large rate in surface operation, space charge effects, detailed description of light signal production and collection.

3.2. WA105 technical goals

WA105 is indispensable for the development and proof-check of industrial solutions, to validate technologies on a large scale. Technical issues to be addressed include

- very high liquid Argon purity (<100 ppm of O_2 are needed for an electron lifetime of about 10 ms),
- construction and operation of a large field cage,
- very high voltage generation,
- large area micro-pattern charge readout,
- cold front-end charge readout electronics,
- long-term wavelength shifter coating of the photomultipliers,
- integrated light readout electronics.

Some of these will be briefly detailed below.

Charge multiplication in the gaseous phase is achieved with the use of the Large Electron Multiplier (LEM), where a very intense electric field is produced inside small holes (typically with 50 μm diameter and 80 μm pitch). The charge is then collected on anodes manufactured from a single multi-layer printed circuit board, providing symmetric charge sharing between the two orthogonal views and a space resolution of 3 mm on each view. Charge resolutions close to 8% have been obtained on both views, with an effective LEM gain close to 30 [4].

A cost-effective solution for front-end electronics and data acquisition consists of analog preamplifiers implemented in CMOS ASIC circuits for high integration and large scale affordable production, connected to micro-TCA crates. The ASIC analog amplifiers can be integrated on a feed-through flange terminating the chimneys on the roof of the tank, under the insulation

layer, in order to be cooled to a temperature near that of liquid argon and thus exploit the reduction of electronics noise with temperature and with the reduced capacitance of cables for the analog signal, which are shorter than in the case of ASICs placed outside the cryostat. The micro-TCA crates for charge digitisation will be placed in the warm zone on top of the cryostat. The front-end electronics thus remains accessible during the whole duration of the experiment.

Scintillation light provides the t_0 for interactions as well as, in principle, complementary information for energy reconstruction and particle identification. The light readout system of WA105 will consist of 36 photomultipliers (8" Hamamatsu R519mod2), each assembled with a TPB-coated window for wavelength shifting. A front-end board for grouped readout has been developed, with the PARISROC2 ASIC [6] providing a time-stamp with precision up to 1 ns and an ADC (AD9249) reading up to 16 channels with 14 bits continuous digitization at a frequency of 40 MHz. Grouped readout will be indispensable to reduce cost and complexity in the DUNE detector. Its performance will be studied in WA105.

The construction of a very large size (10-100 kton) cryostat is out of reach with traditional construction methods. A new technology has been developed based on LNG industrial solutions. In this technology, the functions of structural support, insulation and liquid containment are realised by different components, namely an outer steel structure, specially designed insulating panels and a thin layer of steel plates. The so-called corrugate membrane panels technique (licensed by GTT, France) is an attractive solution for the latter component. The thermal insulation is passive, based on GRPF (glass reinforced polyurethane foam) layers, interspersed with pressure distributing layers of plywood. The first large-scale cryostat tank based on this technique has been constructed for the $3\times 1\times 1$ m³ pilot detector at CERN.

4. Conclusions

The dual-phase Liquid-Argon TPC is an attractive design for future large underground neutrino detectors. The WA105 prototype is being constructed at CERN, to validate technical solutions and to perform physics studies with charged particle beams.

References

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