

The WA105-3x1x1 m³ dual phase LAr-TPC demonstrator

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The dual phase Liquid Argon Time Projection Chamber (LAr TPC) is the state-of-art technology for neutrino detection thanks to its superb 3D tracking and calorimetry performance. Its main feature is the charge amplification in gas argon which provides excellent signal-to-noise ratio. Electrons produced in the liquid argon are extracted in the gas phase. Here, a readout plane based on Large Electron Multiplier detectors provides amplification of the charges before its collection onto an anode with strip readout. The charge amplification enables constructing fully homogeneous giant LAr-TPCs with tuneable gain, excellent charge imaging performance and increased sensitivity to low energy events. Following a staged approach the WA105 collaboration is constructing a dual phase LAr-TPC with an active volume of $3 \times 1 \times 1 \text{ m}^3$ that will soon be tested with cosmic rays. Its construction and operation aims to test scalable solutions for the crucial aspects of this technology: ultra high argon purity in non-evacuatable tank, large area dual phase charge readout system in several square meter scale, and accessible cold front-end electronics. A milestone was achieved last year in the completion of the 24 m^3 cryostat that hosts the TPC. This is the first cryostat based on membrane technology to be constructed at CERN and is therefore also an important step towards the realisation of the upcoming protoDUNE detectors. The $3 \times 1 \times 1 \text{ m}^3$ dual phase LAr-TPC will be described in and we will report on the latest construction progress.

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1. Introduction

Giant Liquid Argon Time Projection Chambers (LAr TPCs), at the 10 kton level, are at the design and prototyping stage in the context of the Deep Underground Neutrino Experiment (DUNE) [1]. Liquid Argon TPCs, provide a complete 3 dimensional image of the neutrino interaction final state particles over a wide range of energies, allowing for efficient background rejection and good energy reconstruction. The double (or dual) phase liquid Argon TPC [2, 3, 4] represents a novel concept for liquid argon detectors. Compared to the single-phase, the dual-phase design will provide a fully active volume without dead material, a smaller number of readout channels, a finer readout pitch, a more robust signal-to-noise ratio with tunable gain, a lower detection energy threshold, and a better pattern reconstruction of the events avoiding induction views. These will allow to best exploit the “bubble chamber”-like features of the liquid argon TPC at the 10-kt scale. The aim of the WA105 experiment at the CERN Neutrino Platform is to fully demonstrate the dual phase technology at the scales of the DUNE Far Detector, by constructing and testing full-scale detector components, assessing their installation procedures in a 300 ton protoDUNE dual phase demonstrator and to measure the detector performance in a charged particle test beam [5]. Following a staged approach, the WA105 collaboration has already constructed a smaller dual phase $3 \times 1 \times 1$ m³ prototype that is about to be commissioned and will start data taking with cosmic rays in the coming months. This prototype is the largest dual phase LAr TPC ever to be built and is the concrete result of many years of R&D on smaller detectors.

2. Overview of the $3 \times 1 \times 1$ m³ detector

The WA105- $3 \times 1 \times 1$ m³ dual phase TPC is illustrated in Figure 1. It consists of a one meter high field cage made by 20 field shapers placed at a constant spacing of 50 mm and a metallic grid cathode.

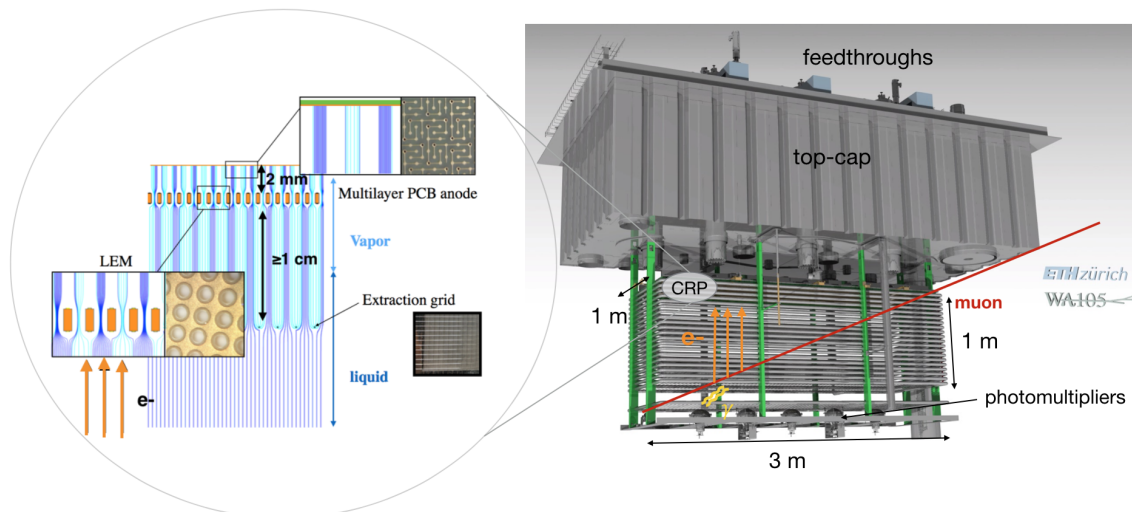


Figure 1: Drawing of the WA105- $3 \times 1 \times 1$ m³ dual phase LAr TPC. The zoom provides an illustration of the charge amplification region near the surface of the liquid argon

A uniform drift field is provided by a resistor divider chain situated between the cathode and the top field shaper. At the top the drifting charges are extracted to the gas phase where they are amplified and readout by a $3 \times 1 \text{ m}^2$ charge readout plane (CRP). Five photomultiplier tubes (PMTs) coated with the wavelength shifter, TPB, are fixed under the cathode. They are sensitive to the 128 nm scintillation light from the argon scintillation and provide the reference time for the drift as well as the trigger. The entire detector is hung under a 1.2 m thick insulating top cap. The field cage is fixed by eight FR4 bars and the CRP is suspended by means of three adjustable cables inserted in dedicated suspension feedthroughs. The top cap is part of the cryostat structure providing the functionality of reducing heat input and minimizing the liquid and gas Argon convection. The thermal insulation of both top-cap and cryostat is based on GRPF (glass reinforced polyurethane foam) layers, interspersed with pressure distributing layers of plywood. Its thickness and composition is such to reach a residual heat input of 5 W/m^2 in cold operation. The inside of the cryostat is covered with 1.2 mm thick corrugated steel panels that are precisely shaped to absorb the thermal contractions.

2.1 The Charge Readout Plane

The key concept of the dual phase LAr-TPC, relies on extracting the ionisation charge to the Argon gas phase where it can be amplified by Large Electron Multipliers (LEMs) [6]. The LEMs function by triggering Townsend multiplication in the high electric field regions inside their holes. The principle is illustrated in the zoom of Figure 1, the electrons are efficiently extracted from the liquid with an electric field of around 2 kV/cm and amplified with a field of about 30 kV/cm applied across both electrodes of the LEM. The electric field to extract the charges is provided by

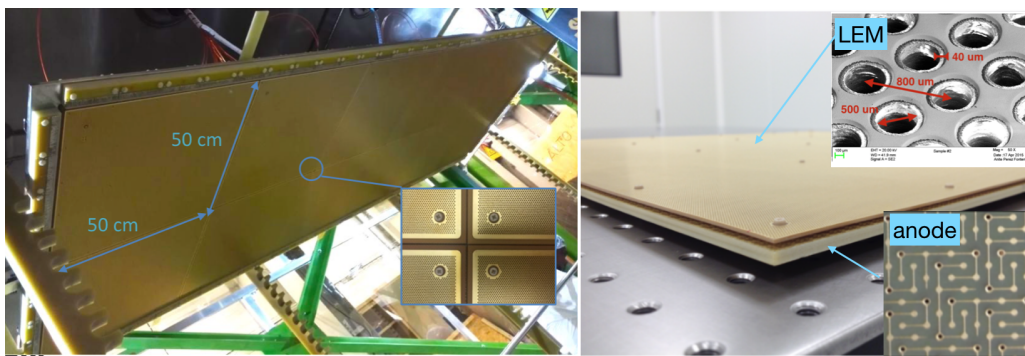


Figure 2: Bottom view of the Charge Readout Plane showing the fully active $3 \times 1 \text{ m}^2$ amplification area. An individual LEM and anode sandwich with zooms on their surfaces is shown on the right.

an extraction grid placed 5 mm below the LAr surface. Once amplified in the LEM the electrons are then collected and recorded on a two-dimensional and segmented anode. The anode consists of a set of strips (views) that provide the 2D x and y coordinates of the event with a 3 mm pitch. Both the anodes and LEMs are rather standard printed circuit boards (PCBs) that can easily be mass-produced in the industry at affordable costs. In the design concept of the $3 \times 1 \times 1 \text{ m}^3$, all those stages (extraction grid, LEM and anode) are assembled in a single Charge Readout Plane (CRP). The CRP therefore consists of the 2D anodes, the LEMs and the extraction grid assembled as a multi-layered “sandwich” unit with precisely defined inter-stage distances and inter-alignment.

A picture of the CRP during detector assembly is shown in Figure 2. The extraction grid is made from 100 micron diameter wires matching the readout pitch of 3 mm and tensed across the $3 \times 1 \text{ m}^2$ area of the CRP. The anodes and LEMs on the other hand come in individual units of $50 \times 50 \text{ cm}^2$ PCBs. Twelve of each are precisely positioned on the frame to provide a fully active amplification and readout area. One of the technological deliverables of the $3 \times 1 \times 1 \text{ m}^3$ is to demonstrate a uniform gain and detector response on readouts at the multi-square meter scale. In this respect the design as well as the quality control of the LEMs, anodes and extraction grid are all crucial aspects. All designs have matured following many years of prototyping on smaller scale LAr detectors. For instance the pattern on the anode was optimised to ensure exact 50:50 charge sharing between both views and the best resolution on the particle energy loss per unit length [7]. LEMs of varying hole sizes, hole pitch, rim sizes or thicknesses have been operated to verify the geometry that provides the best and most stable gain in dual phase conditions [8]. We are therefore confident that the components of the WA105 CRP match our criteria in terms of stability and charge uniformity. The CRP frame itself was also dipped multiple times in open liquid Nitrogen baths and precise survey methods such as photogrammetry were employed to verify the mechanical tolerances in cryogenic conditions.

2.2 Feedthroughs and flanges

The Feedthroughs are crucial components that serve as interface for signal, high voltage and slow control sensors between the inside of the detector and the experimental acquisition. They are all situated on the top cap and have to at least penetrate the 1.2 meter insulation thickness to reach the various parts of the detector (see Figure 1). Almost all the feedthroughs installed in the $3 \times 1 \times 1 \text{ m}^3$ are based on innovative concepts, they will be tested during the operation and their design will either be copied or scaled up for future detectors. Since the requirements on vacuum tightness, high voltage breakdown limits, cryogenic compatibility, are stringent most of them had to be custom designed in close collaboration with industry. As example we show in Figure 3 a picture of the high voltage feedthrough and of one of the signal feedthroughs.

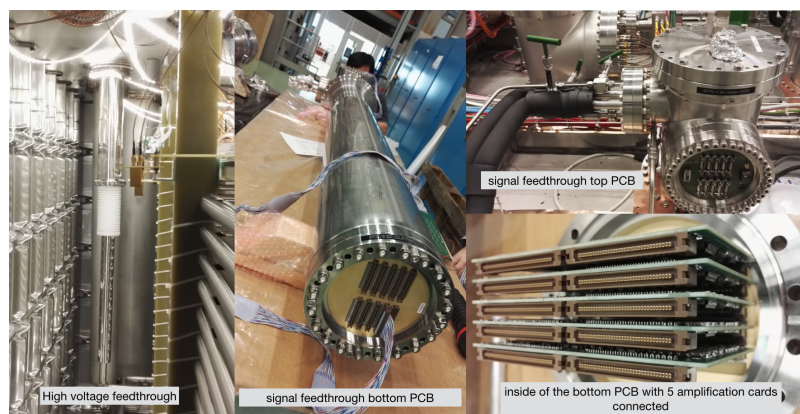


Figure 3: The 300 kV high voltage feedthrough connected to the cathode of the detector inside the cryostat (left). A complete view of a signal feedthrough (middle) and close up pictures showing the top part of the feedthrough as well as the inside of the bottom PCB with the preamplifier boards connected.

The role of the high voltage feedthrough is to safely guide the high voltage from the power supply cable to the cathode of the detector. It requires a very careful design and precise manufacturing to minimise all local electric fields in argon and to keep its heat input to a minimum to avoid formation of bubbles. The prototype that is installed in the $3 \times 1 \times 1 \text{ m}^3$ was manufactured by the company CINEL Strumenti Scientifici s.r.l. It has been successfully tested up to -300 kV in pure argon in a dedicated setup [9]. The ability to withstand a voltage of 300 kV was guided by the requirements of being able to provide a feedthrough for 6 meters drift in the upcoming WA105- $6 \times 6 \times 6 \text{ m}^3$ detector. For the $3 \times 1 \times 1 \text{ m}^3$ the feedthrough will be operated at about 50 kV and will provide feedback on its long term stability.

An excellent signal-to-noise-ratio is crucial to reach the required physics performances, especially for the low energy neutrino physics. In this context an innovative design of signal feedthroughs will be tested. They allow to place the amplification stage close to the anodes, thereby also profiting from the cold environment, while still being able to extract the boards for maintenance without accessing the main vessel. Each feedthrough reads out 320 channels and consists of a ~ 2 meter long stainless steel "chimney" sealed on both ends by circular multilayer printed circuit boards (PCBs) with connectors welded on both sides. The PCBs are carefully designed to provide ultra-high vacuum leak-tightness. The bottom PCB serves as interface between the connection to the anode and the five amplifier boards located inside the chimney. Each board is guided from the top thanks to specially designed FR4 blades. A complete insertion of the blade guarantees that the amplifier board is electrically connected to the bottom PCB. The top PCB then serves as interface between the amplified signals and the digital electronics located on top of the cryostat.

2.3 Slow control sensors

The slow control system for WA105 is part of a continued progressive prototyping effort aiming at developing a system dedicated to multi-ton liquid argon double phase detectors. It provides precise monitoring of temperatures, pressures, high voltages and liquid argon level. Innovative developments include the construction of very precise level meters, a motorised suspension system capable of adjusting the CRP frame with a sub mm precision, special thermometers to measure temperature gradient in the gas phase, and custom made cryogenic cameras. The cryogenic cam-

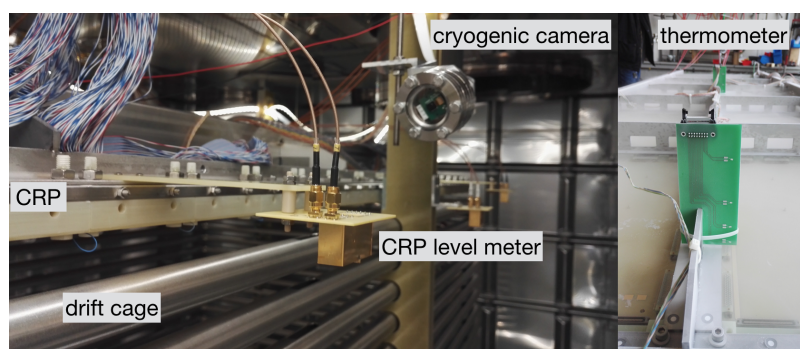


Figure 4: Left: picture of the top of the $3 \times 1 \times 1 \text{ m}^3$ detector inside the cryostat. The CRP and part of the drift-cage along with some slow control sensors are clearly visible. Right: picture of a thermometer during an open cryogenic bath test of the CRP-frame

eras are essential parts as they provide a direct view during operations and are useful for instance

to monitor the level and stability of the liquid Argon level. A picture of some of the sensors installed in the $3 \times 1 \times 1 \text{ m}^3$ is shown in Figure 4. The monitoring system has been developed in close collaboration with CERN, a reliable and cost effective solution has been found by using National Instruments modules mounted in standard experimental racks. This system is fully scalable to meet the needs of future larger detectors.

3. Conclusion

After more than a decade of R&D on small scale prototypes, a first $3 \times 1 \times 1 \text{ m}^3$ large dual phase liquid argon TPC has been constructed at CERN. The entire assembly sequence has proven to be straightforward and rather simple thanks to the attractive design of having a fully homogenous volume with a minimal number of readout channels. Its upcoming operation will mark a decisive milestone for the upcoming US Department of Energy CD-2 in 2019. It is also a first step towards the realisation of much larger neutrino detectors capable of unprecedented imaging and compelling physics discoveries such as leptonic CP violation, the neutrino mass ordering or proton decay.

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