

Recent R&D results on LAr LEM TPC and plans for LBNO demonstrators

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2015 J. Phys.: Conf. Ser. 650 012011

(<http://iopscience.iop.org/1742-6596/650/1/012011>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 188.184.3.52

This content was downloaded on 20/11/2015 at 12:59

Please note that [terms and conditions apply](#).

Recent R&D results on LAr LEM TPC and plans for LBNO demonstrators

C. Cantini, L. Epprecht, A. Gendotti, S. Horikawa, S. Murphy,
G. Natterer, L. Periale, C. Regenfus, F. Resnati, A. Rubbia,
F. Sergiampietri, T. Viant and S. Wu
on behalf of the LAGUNA-LBNO and WA105 collaboration

ETH Zurich, Institute for Particle Physics, CH-8093 Zürich, Switzerland

E-mail: Shuoxing.Wu@cern.ch

Abstract. The double phase Liquid Argon (LAr) Time Projection Chamber (TPC) is the state-of-art technology for neutrino detection thanks to its superb 3 Dimensional (3D) tracking and calorimetry performance. Based on this technology, the Giant Liquid Argon Charge Imaging Experiment (GLACIER) is proposed to be the far detector for the Long Baseline Neutrino Oscillation (LBNO) experiment aiming at studying neutrinos 2300 km away from their production point. We report recent R&D results on the charge readout system for GLACIER and the plans to build the GLACIER demonstrators at CERN.

1. Introduction

With the last mixing angle θ_{13} measured [1, 2, 3], neutrino physics enters a new era. Thanks to the large θ_{13} value, determining the ordering of the 3 neutrino mass eigenstates (mass hierarchy) and measuring the charge parity violation (CPV) phase δ_{CP} of the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix become possible. The proposed LBNO [4] experiment will perform these measurements by studying the $\nu_{\mu} \rightarrow \nu_e$ and $\bar{\nu}_{\mu} \rightarrow \bar{\nu}_e$ oscillations. The LBNO experiment fully exploits the dependence of the oscillation probability as a function of L/E . The energy spectrum of the neutrino beam and the 2300 km baseline are chosen so that the $\nu_{\mu} \rightarrow \nu_e$ oscillation covers its first and second maxima. With its first 5 years running with GLACIER 20 kton as the far detector, LBNO could determine the mass hierarchy to 5σ confidence level (C.L.) over the full δ_{CP} range and provide evidence of CPV at 3σ C.L. [5]. With 10 years running with GLACIER 20 and 50 kton as the far detectors and a high power PS beam, LBNO could determine δ_{CP} at 5σ C.L. over 54% of the true δ_{CP} value [5]. Besides studying accelerator neutrinos, LBNO also has the unprecedented potential for detection of atmospheric and solar neutrino as well as proton decay searches.

The LAr TPC has the unique advantage of being both a 3D tracking detector and a calorimeter. The electron and muon created from ν_e and ν_{μ} interaction with argon nucleus have distinct behaviours when travelling in the LAr and are easily identified. Thanks to its fine granularity, the LAr TPC has a good separation power for electron from π^0 which is one of the largest backgrounds for ν_e appearance signal. The sub-mm transverse diffusion for drifting electrons over several meters enables building giant LAr TPCs without charge imaging



distortion. The 128 nm scintillation light provides a very precise event starting time for 3D track reconstruction.

Unlike traditional single phase LAr TPC using wire planes to readout the drifting electrons, GLACIER uses the micro-pattern gas detector technology [6] to provide charge amplification in the gas phase. The amplified charge is then collected on a novel 2 dimensional (view) anode. Unlike the bi-polar signals from the induction views of the single phase TPC, the two views of GLACIER both have the same unipolar signals which greatly facilitates the event reconstruction. Thanks to its adjustable gain, GLACIER lowers the detection threshold and covers a broad energy range from MeV to multi-GeV. This feature enables GLACIER to be also sensitive to solar and super-nova neutrinos. Despite the many appealing advantages, the technical challenges towards GLACIER need intensive R&D and prototyping efforts.

2. R&D results of the charge readout system

The charge readout system of GLACIER 20 and 50 kton detector is in a modularised configuration [7]: each modular is a $4 \times 4 \text{ m}^2$ charge readout plane (CRP) consisting of 64 $50 \times 50 \text{ cm}^2$ anodes and Large Electron Multiplier (LEM) panels respectively and one $4 \times 4 \text{ m}^2$ extraction grid. 4 anodes are bridged together to form a readout length of 2 m, and each LEM is functioning independently. Issues associate with the increased detector size appear and need to be addressed: 1. the increased inter-strip capacitance will bring significant noise to the front-end electronics; 2. the increased probability of badly drilled holes of the LEM will limit the maximal gain and might prevent the LEM from stable operation due to more frequent discharges; 3. the worsen matching between the extraction grid and the anode strips will degrade the charge collection uniformity. All these issues closely relate to the charge imaging performance of GLACIER thus need to be solved on smaller prototypes.

The R&D for the GLACIER charge readout system was carried out with the so called “3 liter” setup [8]. It is a double phase LAr LEM TPC with a readout area of $10 \times 10 \text{ cm}^2$ and a drift length of 21 cm. It’s a small setup and could be easily operated with a fast turn-around thus very useful to test new ideas. After being evacuated for several days, the chamber is filled with filtered liquid argon and then exposed to cosmic muons for several days data taking. The high quality muon samples with a known energy lose per unit length (dE/dx) are used to calibrate the chamber in terms of effective gain, charge sharing and long term stability. The recorded data was reconstructed using the software package QScan [9] which does hit finding, clustering, 2D and 3D tracking, etc.

2.1. The low capacitance anode

As reported in [8], we successfully developed the 2D readout anode consisting of two sets of orthogonal copper strips separated by a layer of Kapton (polyamide) with a typical thickness of $50 \mu\text{m}$. Though well functioning at a readout length of $\sim 10 \text{ cm}$, this technology is not suitable to scale up to meter level as required by the GLACIER. The difficulties come from: 1. due to the small gap thus a big capacitance ($\sim 600 \text{ pF/m}$ [10]) between the X and Y strips, the noise level of the pre-amplifier will increase dramatically; 2. since the X strips lay above the Y strips, the anode can not be produced from a standard PCB production procedure and etching the Kapton will bring extra complexity.

Figure 1 shows the novel anode layout and the schematic as the solution. The red pads and tracks denote the readout in one direction and the unfilled ones for the other direction. For both views, the pads and tracks are printed on the same layer and the connection is done through vias and tracks on the other layer. Due to the fully symmetric layout between the two views, the charge sharing asymmetry is kept within 1% as seen from Fig. 2 right. Thanks to the additional pads in between the readout pads and tracks, we are able to keep a uniform charge collection

between neighbouring strips within the same view. A direct result is the similar measured $\Delta Q/\Delta s$ for tracks with different azimuth angles as shown in Fig. 2 left and middle.

The capacitance of this novel anode is measured to be ~ 150 pF/m, which is a factor of 4 reduction compared with the Kapton type anode. Thanks to its integration of two views on the same layer, the anode could be produced by PCB industry using standard copper etching technique. As reported in [10], we also tried other geometry layout and the one showed in this paper gave the best results in terms of capacitance and resolution.

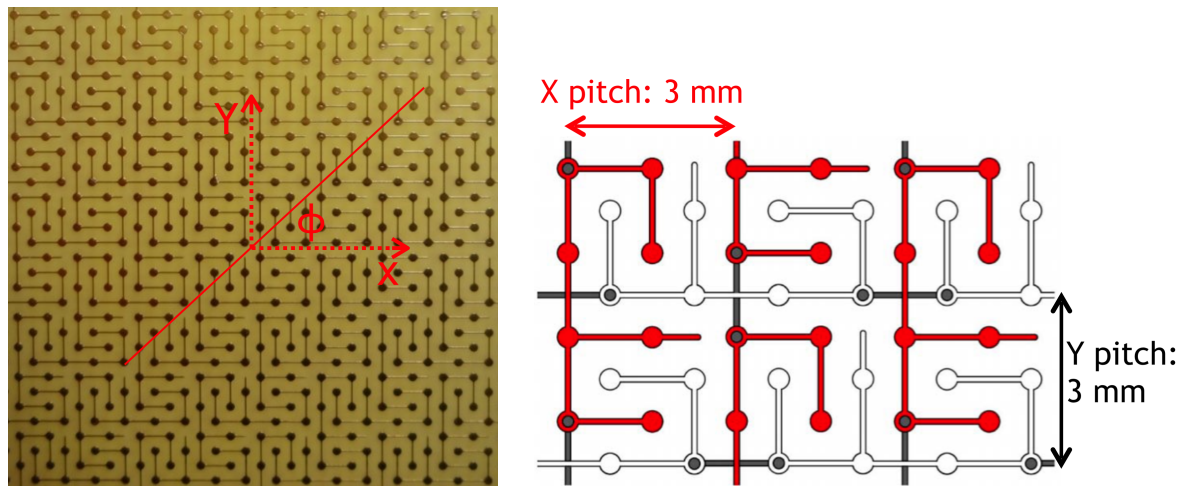


Figure 1. The novel 2D anode (left) and the schematic (right). The red pads and tracks denote one view and the white for the other view.

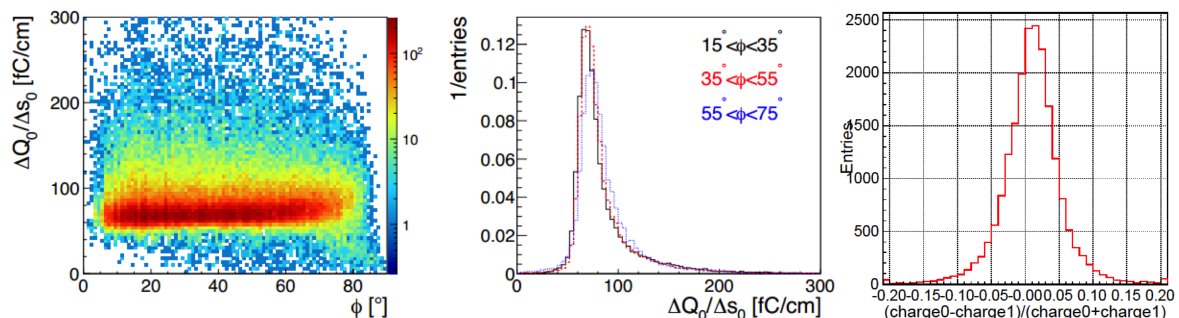


Figure 2. Performance of the novel anode. Left: the measured $\Delta Q_0/\Delta s_0$ vs. track azimuth angle; middle: distributions of $\Delta Q_0/\Delta s_0$ for three azimuth angle ranges; right: the distribution of the difference of charge collection between two views.

2.2. The LEM

The LEM or Thick GEM (THGEM) is the key apparatus of the double phase LAr TPC. Its function is to amplify the electrons produced in the LAr medium in the gas phase before being collected on the anode. Holes at a constant pitch are mechanically drilled through a copper-clad FR4, and rims are later etched around the holes to prevent discharges occurring between the top and bottom electrodes. A high electrical potential over 3 kV is applied across the two electrodes resulting in an electric field high enough to trigger the Townsend avalanche for the entering electrons. The holes absorb the UV photons produced in the avalanche process and

thus act as the mechanical quencher to prevent the photon feedback phenomenon. This property makes the LEM suitable to operate in ultra pure argon gas in the absence of quenching gas.

The design parameters of the LEM include the FR4 thickness, the hole diameter, the arrangement of the holes, and the size of the rim. These parameters affect both the gain at a certain potential difference and the maximal achievable gain. The effective gain is defined as the sum of $\Delta Q/\Delta s$ of both views divided by that of the muon. The effective gain takes account of the transparencies of the extraction grid-LEM, LEM itself, LEM-anode and the gain of the LEM. Thus, it could be described by $G_{eff}(E, p, T) = \mathcal{T} \times e^{x \cdot \alpha(p, T, E)}$ with first term the transparency, second term the gain of the LEM. x denotes the amplification length, α is the first Townsend coefficient with the form of $\alpha(p, T, E) = \frac{Ap}{T} e^{-\frac{Bp}{E}}$, where A and B are parameters depending on the gas. Fits to the gain curves as shown in Fig. 3 give trend both in the transparency and amplification length consistent with expectation from electrostatic simulations [11]. In terms of maximal achievable gain, the one with 1mm thick FR4, 500 μm hole in diameter, hexagonal hole layout and 40 μm rim gives the best result of a gain over 160.

As described in [10], we observed the behaviour of the initial decreasing and final stabilisation of the gain which is concluded to be the charging-up of the FR4 dielectric surface. In this study, we found both the charging-up time and the ratio between the final and initial gain depend on the geometry parameters. For a detailed discussion, please refer to [11]. Though charged up, the LEMs could still be operated at a stable gain over 20, which fully meets the requirement for GLACIER. One notable observation is that the LEMs have very few or no discharges over an operation of several days. This “discharge-free” behaviour promises us to step forward to the $50 \times 50 \text{ cm}^2$ LEM as proposed for the GLACIER.

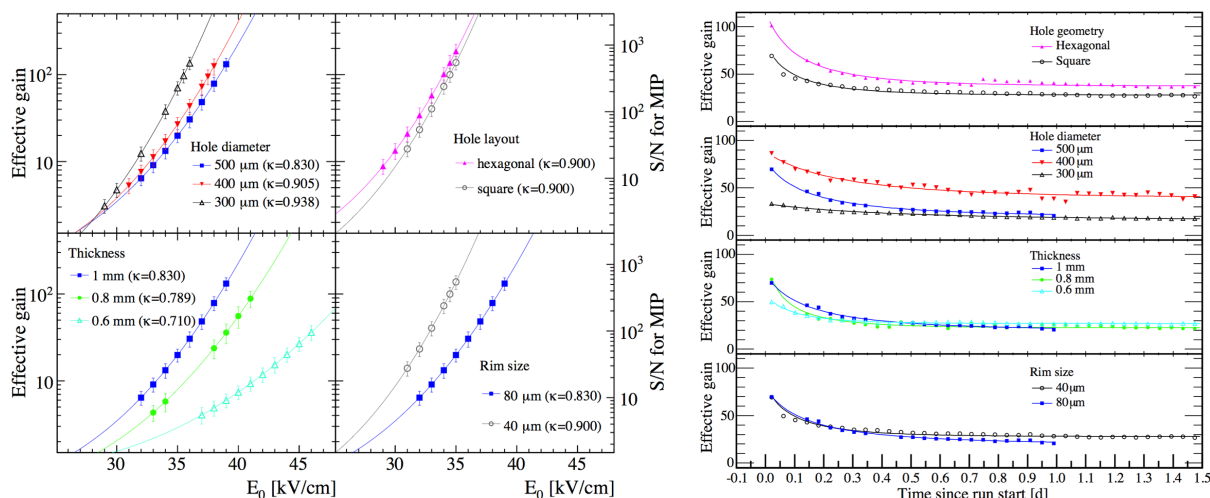


Figure 3. Performance of the LEMs with different geometry parameters. Left: effective gain vs. LEM electric field; right: the stabilisations of the effective gain over time.

2.3. The extraction grid

In the initial stage of the “3 liter” setup, there were two extraction grids placed in both liquid and gas phase [8]. Though being able to keep the charge image distortion minimised, it requires more high voltage channels and additional alignment between the two grids. As reported in [10], we successfully extracted electrons and kept the charge image undistorted by means of a single extraction grid placed in the liquid phase. By precisely aligning the stainless steel wires with

respect to the anode strips, we are able to maintain a good gain uniformity to the level of $\pm 10\%$ as seen from Fig. 4.

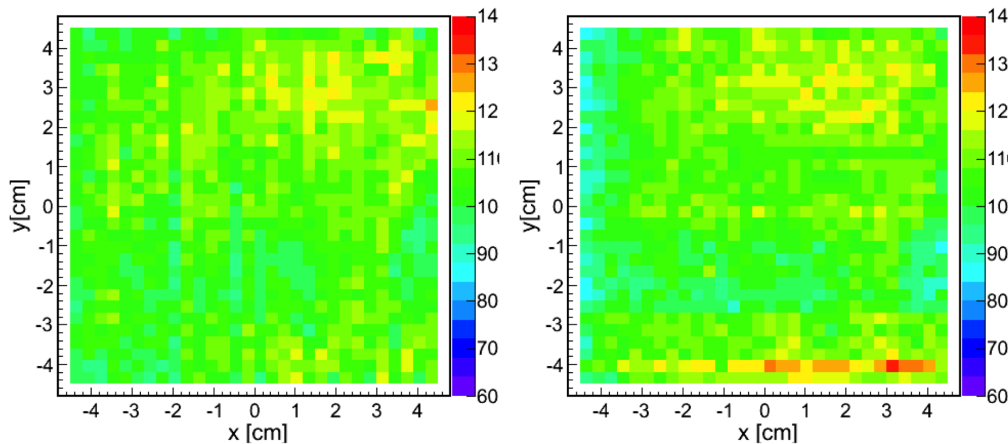


Figure 4. $\Delta Q/\Delta S$ normalised to 100 fQ/cm as a function of X and Y for view0 (left) and view1 (right).

3. Plan for the GLACIER demonstrators

With good performance achieved by the small prototypes, it's of fundamental importance to demonstrate that we could build and operate larger LAr LEM TPCs before going to the GLACIER scale. Thus, two demonstrators are proposed to demonstrate the feasibilities of the LAr LEM TPC technology in the multi-ton and multi-hundred-ton scales respectively.

3.1. The $3 \times 1 \times 1 \text{ m}^3$ demonstrator

The $3 \times 1 \times 1 \text{ m}^3$ demonstrator has a fiducial volume of $3 \times 1 \times 1 \text{ m}^3$ corresponding to a 4.2 ton fiducial mass. The charge readout system covers an area of $3 \times 1 \text{ m}^2$ and the drift length is 1 m. The TPC is hanging from the so called "top cap" and contained inside a membrane tank with a dimension of $7.3 \times 4.9 \times 4.7 \text{ m}^3$ as shown in Fig.5. The total liquid argon mass will be 20 ton. The $3 \times 1 \times 1 \text{ m}^3$ demonstrator is being built and will be tested with cosmic muons at building 182 of CERN beginning of 2016. As a purely technical demonstrator, the $3 \times 1 \times 1 \text{ m}^3$ will give vital feedback on the following aspects:

- (i) *Purity in non-evacuated membrane tank.*
 As required by GLACIER to drift the electrons over 20 m, the oxygen equivalent impurity should be kept within 100 ppt level. This is challenging since the membrane tank could not be evacuated since it does not sustain vacuum inside. Alternatively, by means of argon gas "piston-purge" we should be able to remove the air and achieve the required purity following continuously purifying both the gas and liquid. The $3 \times 1 \times 1 \text{ m}^3$ will be used to test this principle.
- (ii) *The large area charge readout system.*
 The $3 \times 1 \times 1 \text{ m}^3$ TPC will be implemented with 12 $50 \times 50 \text{ cm}^2$ anode and LEM panels respectively. It will give information on the gain, charge sharing uniformity, signal to noise ratio and so on for such a large area readout system.
- (iii) *Accessible cold front-end electronics.*
 The $3 \times 1 \times 1 \text{ m}^3$ TPC will be implemented with 1920 readout channels. These front-end cards will be placed near the argon vapour phase in order to reduce the noise. Furthermore, these cards could be accessed and replaced without polluting the argon in the tank.

(iii) *Cryogenic and purification system.*

For the membrane tank, the rated pressure is very small. Thus the cryogenic system needs to be designed to safely compensate the boiling-off gas without reaching the rating pressure. A scalable boiling-off compensation principle and sub-immersed liquid argon recirculation system will be tested.

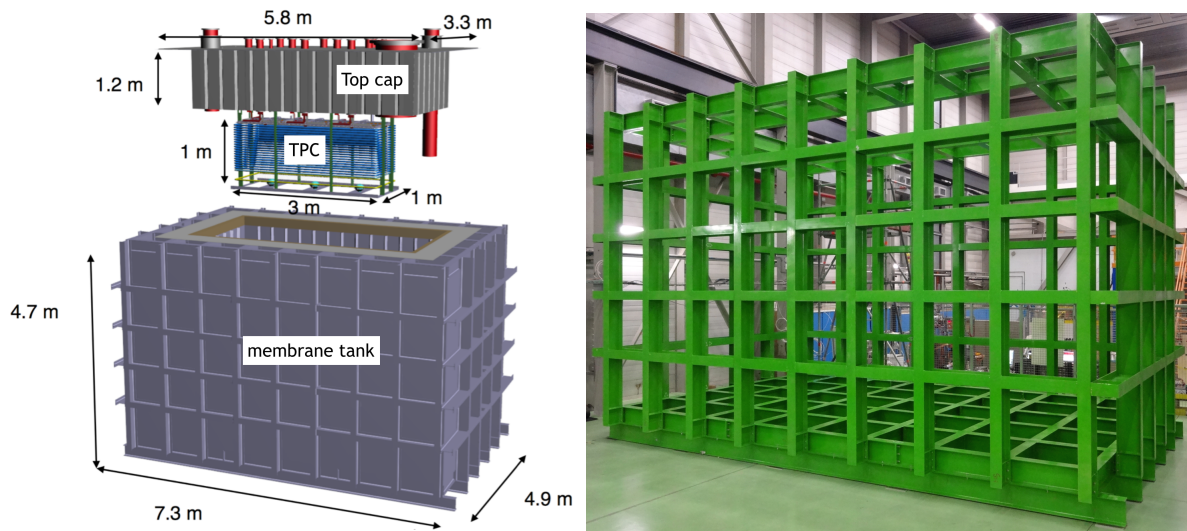


Figure 5. Left: 3D drawings of the $3 \times 1 \times 1 \text{ m}^3$ TPC, the top cap and the membrane tank; right: the completed outer structure to host the membrane inner tank and the insulation panels.

3.2. The $6 \times 6 \times 6 \text{ m}^3$ demonstrator

In the mean time of building and testing the $3 \times 1 \times 1 \text{ m}^3$ prototype, the $6 \times 6 \times 6 \text{ m}^3$ LAr LEM TPC will be built and tested in a beam at the CERN north area. It has a LAr fiducial mass around 300 ton and a total mass around 700 ton. As a technical demonstrator, it will further prove the feasibilities as listed for the $3 \times 1 \times 1 \text{ m}^3$. Moreover, with a drift length of 6 m, it'll be able to test the image distortion over such a long drift together with the high voltage generation and feedthrough. With a typical drift field of 1 kV/cm, it requires a negative potential of 600 kV at the cathode. How to generate and feed in such a high voltage without discharging against the membrane tank is not clear and thus needs further R&D. This is the way towards GLACIER, since the cathode voltage will be as high as 2 mega-volts for a drift length of 20 m.

Besides the technical goals, the $6 \times 6 \times 6 \text{ m}^3$ TPC programme also has rich physics topics. It'll be the first double phase LAr TPC in a test beam. Its fiducial mass is big enough to fully contain the hadronic shower from the multi-GeV pion interactions. This allows us to precisely calibrate the energy resolution of liquid argon in an energy range of 0-10 GeV as proposed by LBNO. With a large data set collected, we'll be able to develop and improve the existing particle tracking and identification algorithms. Due to the similarity in the event topology between a neutrino and pion interaction, the data will be used to develop the automatic neutrino event reconstruction algorithm.

The activities of the $6 \times 6 \times 6 \text{ m}^3$ go in parallel with the $3 \times 1 \times 1 \text{ m}^3$. A detailed technical design report was drafted [12], and it is approved by CERN with an official experiment name of WA105 [13]. Within an affordable timescale, we are able to build and operate this device before the long shutdown of the LHC in 2018.

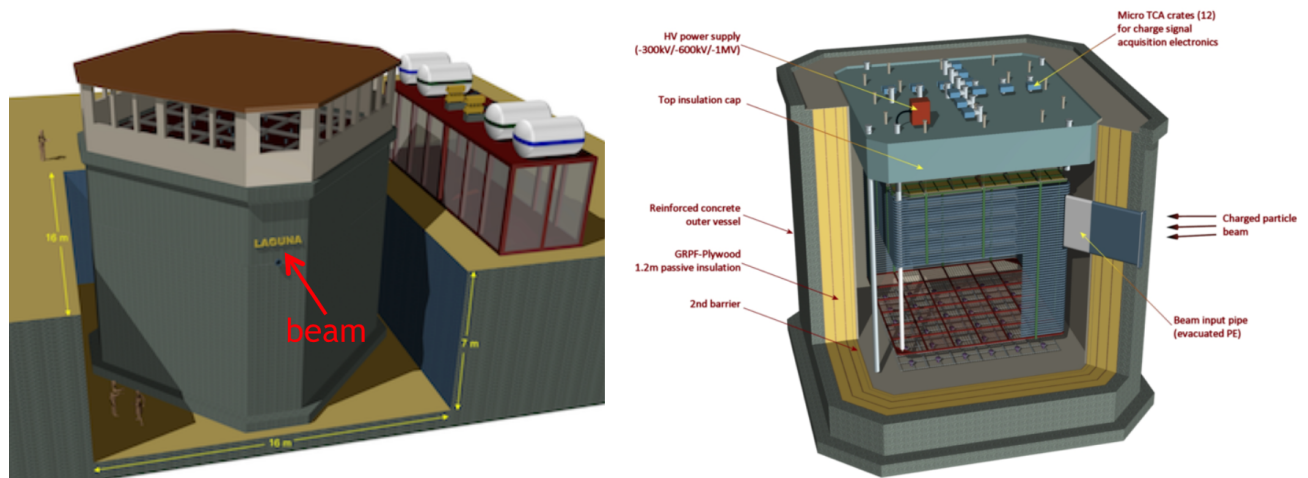


Figure 6. The $6 \times 6 \times 6 \text{ m}^3$ LAr LEM TPC to be put in a test beam at the CERN north area.

4. Conclusions

The LAr LEM TPC is the state-of-art technology for neutrino detection thanks to its superb tracking and calorimetry performance. The LBNO experiment is competitive in its physics potential to discover the neutrino mass hierarchy and measure the δ_{CP} within an affordable timescale. Good R&D on the charge readout system have been performed in the sense of reducing the anode capacitance, optimising the LEM geometry for a higher gain, simplify the extraction grid and improve the gain uniformity. Having achieved the desired performance, we're moving forward for the $3 \times 1 \times 1 \text{ m}^3$ and $6 \times 6 \times 6 \text{ m}^3$ demonstrators to prove the feasibility of the LAr LEM TPC technology to extend to the multi-ton and multi-hundred-ton scales. These demonstrators will bring vital input for the design and operation of the GLACIER 20 and 50 kton for LBNO.

5. Reference

- [1] F. P. An *et al.*, "Observation of Electron-Antineutrino Disappearance at Daya Bay" *Phys. Rev. Lett.* **108**, 171803 (2012).
- [2] J. K. Ahn *et al.*, "Observation of Reactor Electron Antineutrinos Disappearance in the RENO Experiment" *Phys. Rev. Lett.* **108**, 191802 (2012).
- [3] K. Abe *et al.*, "Observation of Electron Neutrino Appearance in a Muon Neutrino Beam" *Phys. Rev. Lett.* **112**, 061802 (2014).
- [4] Stahl, A *et al.*, "Expression of interest for a very long baseline neutrino oscillation experiment (LBNO)" SPSC-EOI-007; <http://cds.cern.ch/record/1457543?ln=en>
- [5] S. K. Agarwalla *et al.*, "The mass-hierarchy and CP-violation discovery reach of the LBNO long-baseline neutrino experiment" *J. High Energy Phys.* **05** (2014) 094 [arXiv:1312.6520]
- [6] RD51 collaboration, <http://rd51-public.web.cern.ch/RD51-Public/>
- [7] <http://laguna.ethz.ch:8080/Plone/deliverables/laguna-lbno-284518-deliverables>
- [8] A. Badertscher *et al.*, "First operation of a double phase LAr Large Electron Multiplier Time Projection Chamber with a 2D projective readout anode" *Nucl. Instrum. Meth.* **A641**, 48-57 (2011).
- [9] J. Rico, "First study of the stopping Muon sample with the ICARUS T600 detector" Ph.D. Dissertation, ETH 14906 (2002).
- [10] C. Cantini *et al.*, "Long-term operation of a double phase LAr LEM Time Projection Chamber with a simplified anode and extraction-grid design" *JINST* **9**, P03017 (2014) [arXiv:1312.6487 [physics.ins-det]].
- [11] C. Cantini *et al.*, "Performance study of the effective gain of Large Electron Multipliers in LAr-LEM TPCs" [arXiv:1412:4402 [physics.ins-det]].
- [12] L. Agostino *et al.*, "LBNO-DEMO: Large-scale neutrino detector demonstrators for phased performance assessment in view of a long-baseline oscillation experiment" [arXiv:1409.4405]
- [13] <http://wa105.web.cern.ch/wa105/>