PROCEEDINGS OF SCIENCE

LBNO-DEMO (WA105): a large demonstrator of the Liquid Argon double phase TPC

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LBNO-DEMO (WA105) is a large demonstrator of the double phase liquid argon TPC intended to develop and test the main elements of the GLACIER-based design for the purpose of scaling it up to the 10–50 kton size needed for Long Baseline Neutrino Oscillation studies. The crucial components of the design are: ultra-high argon purity in non-evacuable tank, long drifts, very high drift voltages, large area Micro Pattern Gas Detectors, and cold preamplifiers. The active volume of the demonstrator is $6 \times 6 \times 6$ m^3 (approximately 300t). WA105 is under construction at CERN and will be exposed to charged particle beams (0.5-20 GeV/c) in the North Area in 2018. The data will provide the necessary calibration of the detector performance and benchmark reconstruction algorithms. This project is a crucial milestone for the long baseline neutrino program, including projects like LBNO and DUNE.

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1. Introduction

Determination of the neutrino Mass Hierarchy (MH), and the phase of CP violation (CPV) in the leptonic sector are among the main physics goals for the next decade. While there are several ways of achieving these goals, there is a broad consensus that only a Long Baseline Neutrino Oscillation experiment (LBNO) would yield unambiguous results (at least 5 sigma effect) over a realistic measurement time [1]. LBNO approach requires a powerful proton accelerator to generate the desired neutrino beams and a detector, at a distance of at least 1300 km, to register neutrinos and measure their energy and flavor. A giant (10-50 kt) Liquid Argon Time Projection Chamber (LAr TPC) has been proposed for that purpose. It would have excellent tracking, timing, and calorimetric capabilities and, due to the high density of the LAr, it would be relatively compact. It would also have very good sensitivity for the study of proton decay and would be available for a wide range of astrophysical measurements. To reduce the flux of particles from cosmic showers, such a detector should be located deep underground.

2. Detector concept

When a charged particle traverses a volume of LAr it ionizes Ar atoms along the track. In the presence of a strong electric field a fraction of the electron-ion pairs do not recombine but drift apart along the field lines. In favorable conditions (very pure LAr, very strong and uniform electric field, etc.) the charge may travel over a distance of up to 20 m and reach the electrode without significant spatial distortion. In other words, the LAr TPC concept is similar to a bubble chamber but instead of taking photographs of the tracks, their 3D position and density is extracted from the digitized charge collected by an XY position-sensitive electrode as a function of the drift time (Z coordinate). As the mobility of electrons is much higher than that of Ar ions, the relevant charge signal is collected from the anode.

There are two ways of collecting charge from a LAr TPC. In a single phase system the anode is immersed in the liquid and the charge is collected without additional amplification. The best known and the largest so far (2 x 300 ton modules) detector of this type is ICARUS [2]. The second approach is to place the anode in the gas phase, just above the liquid level. By doing so one may utilize charge amplification in the gas leading to improved performance [3]. The largest built double-phase LAr TPC is the ArDM detector [4]. It has cylindrical active volume with a diameter of 80 cm and 120 cm drift length yielding the target mass of 850 kg. The goal of WA105 [5] is to build a large-scale demonstrator of a double-phase LAr TPC (see Fig. 1) with the fiducial size of $6 \times 6 \times 6$ m^3, and to check its performance with charged particle beams from the CERN SPS. This data will also yield valuable topology information for the reactions on Ar atoms that is needed to reduce systematic errors for measurements with LAr detectors. Ultimately, the WA105 collaboration aims to demonstrate that the double phase LAr TPC is scalable up to at least 10 kton. This is the module size proposed for the DUNE experiment [6].

3. Phased approach

The time schedule approved by the SPS Committee for WA105 is very tight. Due to the major upgrade of the entire accelerator complex at CERN in 2019–2020 (Long Shutdown 2), all data

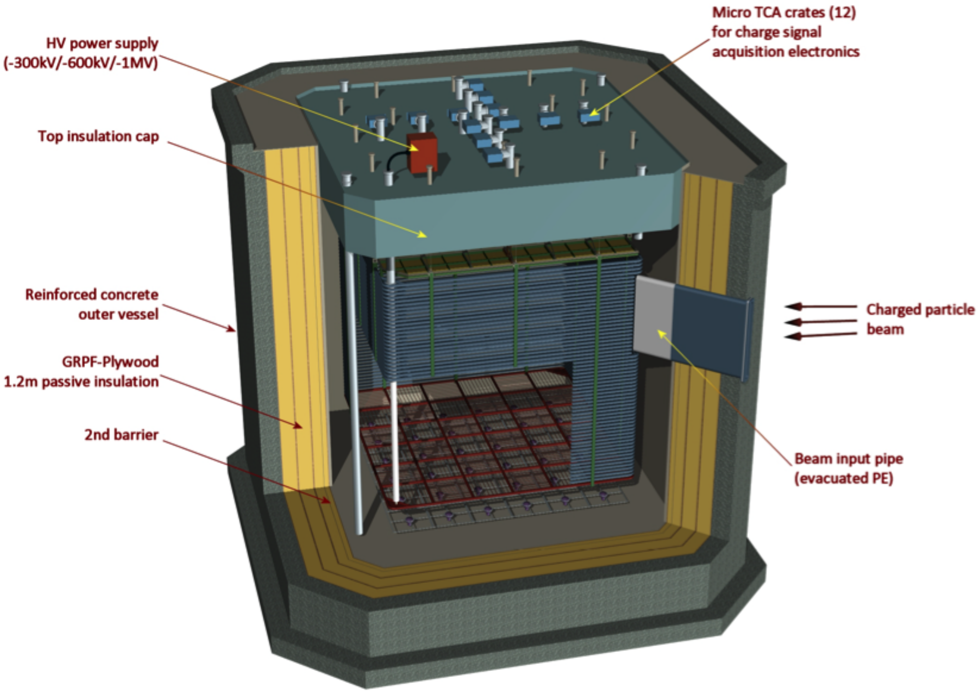

Figure 1: Conceptual design of the $6 \times 6 \times 6$ m^3 inner detector inside the cryostat.

taking with the $6 \times 6 \times 6$ m^3 detector must be realized during 2018. Before that the extension of the CERN EHN1 (building 887) must be completed (around the first quarter [1Q] of 2016), the cryogenic vessel constructed and commissioned (around 4Q of 2016), and the inner detector installed and tested. To accelerate R&D on the inner detector and to test the cryogenic components before the new building is ready, WA105 has chosen a phased approach by starting with a $3 \times 1 \times 1$ m^3 prototype (Fig. 2). Currently (October 2015) the vessel is completed and the first data from the prototype is expected during 1Q of 2016.

4. Detector components

The detailed description of the detector is provided in [5]. The main elements of the $6 \times 6 \times 6$ m^3 demonstrator are the cryogenic vessel containing ultra-pure liquid argon, the top deck, and the inner detector. The base and the sidewalls of the outer structure of the vessel will be made of a 50 cm thick reinforced concrete. The inner side will be then lined with 1.2 m of passive insulation and encased with a thin corrugated steel layer. This membrane tank technology has been developed for the storage and transportation of the Liquid Natural Gas. The dimensions of the inner vessel will be $8.3 \times 8.3 \times 8.1$ m^3 containing 700 t of liquid argon. To achieve the lifetime of ionization electrons of the order of 3–10 ms needed to drift the charges all the way to the anodes suspended from the top deck, the purity requirements for LAr are very stringent: on the level of 100 ppt of O_2 equivalent. The top deck, in addition to the thermal insulation and mechanical support for the inner

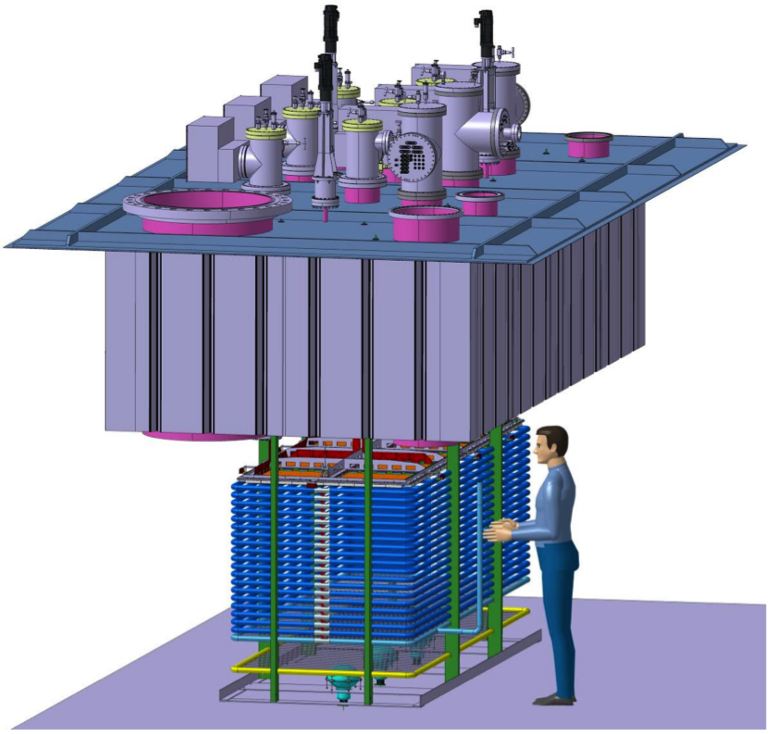

Figure 2: Conceptual design of the upper deck and the inner detector of the $3 \times 1 \times 1$ m^3 prototype.

detector, has to provide multiple chimneys with feed-through connectors for data, HV, monitoring, etc.

The inner detector is the most complicated part of the setup. All the instrumentation is located on the outer perimeters keeping the central active volume of ~ 216 m^3, containing ~ 302 tons of liquid argon, free for undisturbed charge drift. To avoid the distortion of track topology, the electrostatic field in the detector volume should be uniform and provide adequate charge drift velocity. For the best extraction efficiency, electric field of at least 2.5 kV/ cm is required. The uniformity of the field is maintained by a drift-cage made of equally spaced field shapers made of round pipes forming rectangular loops with rounded corners, shown both on the Fig. 1 (for the $6 \times 6 \times 6$ m^3 demonstrator) and Fig. 2 (for the $3 \times 1 \times 1$ m^3 proto). The voltage along the field cage changes linearly from the grounded anode on the top to the cathode on the bottom of the$6 \times 6 \times 6$ m^3 demonstrator operated at operated at 300–600 kV.

Minimum Ionizing Particles (MIP) moving in LAr (1.4 g/cm^3) have an average energy loss dE/dx of 2.12 MeV/cm. Since the mean excitation energy is 19.5 eV and the mean ionization energy is 23.6 eV, LAr TPCs have very good energy and spatial resolution also for low energy particles provided the anode has sufficient granularity for the charge readout. Both the $3 \times 1 \times 1$ m^3 prototype and the $6 \times 6 \times 6$ m^3 demonstrator will utilize the same modular elements to instrument the Charge Readout Plane (CRP) over the entire top surface of the active volume. CRP will have two functional layers: a charge amplification stage based on LEM technology (Large Electron Multiplier) and a 2D anode. LEMs will consist of a 1 mm thick FR4 plate cladded on both sides

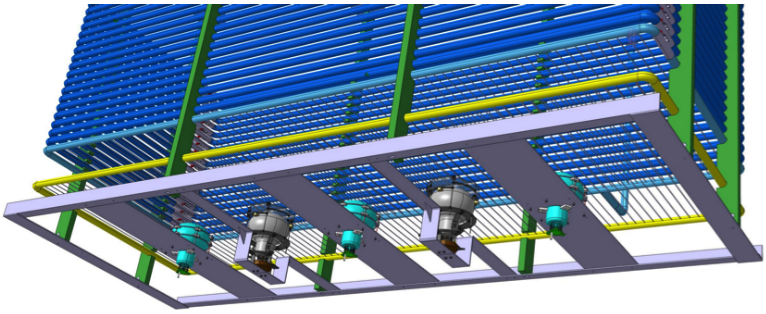

Figure 3: Scheme of the light readout in the $3 \times 1 \times 1$ m^3 prototype with five TPB coated Hamamatsu 8" R5912-02MOD PMTs. The desired sensor density is 1 PMT/m^2. Two of the five PMTs (the second and the fourth from the left) are redundant for the purpose of light collection and serve as a test bench for the $6 \times 6 \times 6$ m^3 detector.

with passivated copper and perforated with 500 μm diameter holes drilled on an 800 μm pitch (center-to-center). The operating voltage between the front and the back surface of the LEM will be 3.5 kV generating the field of 35 kV/cm inside the holes – sufficient to trigger electron avalanche in the gas to multiply the charge. The 2D anode will have two perpendicular sets of electrode strips picking-up the charge along the X and Y coordinates. The electrodes will be separated by a thin, transparent insulating layer.

5. Light detection

In addition to ionization, interaction of charged particles with argon may result in excitation of Ar atoms and subsequent emission of the scintillation light. Typical light yield is of the order of a few tenths of thousands of photoelectrons per MeV. The wavelength of emission peaks at 128 nm. Ultra-pure argon is highly transparent also at this wavelength. The scintillation light has two characteristic time constants: the 6 ns fast component, and the 1500 ns slow component.

The main purpose for the detection of the scintillation light is to provide a time reference for the registered tracks and a trigger signal for events induced by cosmic rays. Both in the $3 \times 1 \times 1$ m^3 prototype and in the $6 \times 6 \times 6$ m^3 demonstrator the scintillation light will be detected by photosensors located under a girded cathode (Fig. 3). Due to the large expected light yield, one 8" PMT per square meter will be sufficient. Currently the default sensor is Hamamatsu R5912-02MOD. To match the emission wavelength with the photocathode sensitivity the surface of the PMTs will be coated with a wavelength-shifter (WLS); most likely with the Tetraphenyl-butadiene(1,1,4,4-tetraphenyl-1,3-butadiene or TPB). The proposed system should be able to detect not only the primary scintillation induced by charged particles in the active volume but also the secondary scintillation light produced in the gas phase of the detector by the drift electrons extracted from the liquid and accelerated in the strong electric field in the vicinity of the LEMs.

6. Outlook

WA105 is expected to make a significant progress in the development of the new generation of neutrino detectors utilizing LAr TPC and gas amplification of the collected charge. This project is a crucial milestone for the long baseline neutrino program. The data collected by WA105 using charged particle beams (0.5-20 GeV/c) in the North Area at CERN will provide the necessary calibration of the detector performance, and benchmark reconstruction algorithms. The ultimate goal is to provide the technology for one or several 10 kton-sized modules to be installed in the Homestake Mine, South Dakota as part of the DUNE experiment.

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