The LAr1-ND Experiment

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Abstract.
LAr1-ND is a Liquid Argon Time Projection Chamber (LArTPC) based experiment which will operate in the Booster Neutrino Beam (BNB) at Fermilab, at a distance of 110m from the target. The 112 t active volume detector will make precision measurements of the neutrino interaction cross section in argon, as well as forming the near detector for the short-baseline neutrino (SBN) programme at Fermilab. The 4 m × 4 m × 5 m TPC consists of 2 anode planes, each composed of 3 wire planes, with a central cathode. In combination with the MicroBooNE and ICARUS-T600 detectors, this experiment provides a powerful opportunity to understand observed neutrino anomalies, and has the potential to make precision measurements of oscillations to sterile states.

In addition to the physics goals, the detector technology developed and used in this experiment will form an important step towards the future detectors for long-baseline neutrino experiments. The detector design will be discussed in the context of its physics potential, and contribution to future technologies.

1. Introduction
The Fermilab Short Baseline Neutrino (SBN) program includes the construction of a Liquid Argon Near Detector, LAr1-ND [1] in the Booster Neutrino Beam (BNB), in a new enclosure at 110m from the source. LAr1-ND will form the near detector of a three detector system, with MicroBooNE [2] and ICARUS-T600 [3] as the intermediate and far detectors, as illustrated by figure 1. This system of LArTPCs forms an experiment capable of definitively addressing existing anomalies in neutrino physics and making precision measurements of high-∆m² neutrino oscillations through both appearance and disappearance searches.

Leveraging the advanced design work performed for LBNE and the very recent experience of the MicroBooNE detector construction, the LAr1-ND project has the potential to move forward quickly.

Due to the high event rate of neutrino interactions at the near location, significant physics output can be achieved with a relatively short run of the LAr1-ND experiment. In addition to the SBN physics program, LAr1-ND will have a development program serving as an engineering prototype for LArTPCs for long-baseline CP-violation searches in the future.

2. The LAr1-ND Measurement programme
While LAr1-ND, in conjunction with MicroBooNE and the ICARUS-T600, is a critical part of the oscillation physics program, the detector allows a large number of relevant physics results as a stand alone experiment. This section briefly discusses a selection of these measurements.
2.1. The MiniBooNE Low Energy Excess
The MiniBooNE experiment [4] has observed an excess in low energy electron neutrino events, the nature of which has yet to be characterised. The main physics goal of MicroBooNE is to do so. Observation of a low energy excess signal by MicroBooNE in the years leading up to the beginning of LAr1-ND data taking would immediately lead to the question of whether that excess is intrinsic to the beam or appears over the 470 m distance between source and detector. LAr1-ND, at 110 m from the BNB target, can search for the same excess in a relatively short time.

It has been estimated [5] that for an exposure of $2.2 \times 10^{20}$ protons on target (POT) a MiniBooNE-like excess would result in 803 excess $\nu_e$ charged current (CC) events, compared to a background of 3,177 events expected in the 200 - 650 MeV lepton energy range. Considering the statistical and systematic uncertainties, this is a $5.4 \sigma$ signal.

2.2. Neutrino Interaction Cross-section Measurements
Neutrino-nucleus interactions are critical to understand in neutrino oscillation experiments, including the future liquid argon long-baseline program. LAr1-ND provides an ideal venue to conduct precision cross section measurements in the GeV energy range. The experiment will collect enormous neutrino event samples and, continuing the studies done by MicroBooNE and ICARUS, will make the world’s highest statistics cross section measurements for many $\nu$-Ar scattering processes.

In LAr1-ND more than 2 million neutrino interactions will be collected per year in the full active volume (assuming $2.2 \times 10^{20}$ POT), with 1.5 million $\nu_\mu$ and 12,000 $\nu_e$ charged current events, 250,000 neutral current events identifiable by a single nucleon recoil track, and a few hundred elastic scattering events. One year exposure of LAr1-ND will provide an event sample 6-7 times larger than will be available in the full MicroBooNE Phase I run.

In addition to the above measurements, we will be able to directly compare neutrino cross sections off carbon (A=12) and argon (A=40) targets to search for a nuclear dependence in cross section, since LAr1-ND will use the same neutrino beam used by the MiniBooNE experiment.

3. The LAr1-ND Detector
3.1. The Cryostat and Infrastructure
The LAr1-ND detector will make use of membrane cryostat technology as demonstrated by the 35t LBNE prototype [6]. The LAr1-ND cryostat will use the same commercial technology, using

![Figure 1. 3-detector system of the Short Baseline Neutrino programme at Fermilab.](image-url)
passive foam insulation, but with several key differences. The LAr pump will be located outside of the cryostat, allowing easier access. It is also planned to have a much smaller warm ullage than has been thus far demonstrated, which creates a less contaminated volume of gas, and hence a smaller scale purification system.

The detector system will be housed in a new building, located adjacent to the existing SciBooNE hall, as shown in figure 1.

3.2. TPC design
The TPC baseline design is a $5 \times 4 \times 4$ m active volume, with two 2 m drift regions. The charge is drifted from a central cathode, to wire readout planes at either end of the detector. Both consist of multiple anode plane assemblies and cathode plane assemblies (APA and CPA respectively), as shown in figure 2.

Each APA has dimensions $2.5 \times 4 \times 4$ m, and consists of three wire planes; a vertical collection plane (Y), and two induction planes (U,V) at $\pm 60^\circ$ angles to the vertical, as illustrated in figure 3. The wire pitch is 3 mm, which is identical to that used in the T600 and MicroBooNE. This enables electron / photon separation with very similar efficiencies. Bias voltages of approximately -200 V, 0 V, and +500 V will be applied to the (U,V,Y) wire planes, respectively, to provide the 100% transparency condition necessary to allow all electrons to pass through the U and V planes and be collected by the Y plane.

All wires in the APAs are bonded mechanically with epoxy and terminated electrically with solder onto bonding boards made out of G10, which also provide connection to the readout electronics. The APA uses a similar wire bonding method to the one developed for the LBNF APAs, but without the continuous helical wrapping.

In order to minimize the cost of the readout electronics, each APA has cold readout electronics on two edges only. The U wires of each APA are electrically connected via flexible jumper connections at the adjoining edges, as shown in figure 3. The V wires are similarly connected.

In this design there is a gap of 15 mm between the two active apertures of the APAs which creates a dead readout region. To overcome this issue there is an option to insert a printed circuit board in the gap between the two APAs, with biased electrodes, such that the incoming electrons are deflected towards the active region of the wire frame, as shown in figure 4. This will eliminate electron loss, at the expense of distorted electric fields. The track reconstruction due
Figure 3. A schematic of the bridged APA concept.

Figure 4. a) A schematic showing the biased-electrode inserted between the two APA frames, to divert electrons to the nearby active regions. b) The distortion on the reconstructed electron tracks. c) A Garfield simulation of the electron drift lines in a two strip configuration.

to the electric field distortions can be mapped out, and corrected at the reconstruction stage. This field shaping concept will be implemented at one section of the LBNE 35 ton TPC and evaluated during Phase II operation.

LAr1-ND aims to provide a verified alternative to the wrapped APA design, with a cost and space efficient design. This method of tiling the APAs and minimising dead space is extremely relevant R&D as we look at moving towards larger volume LAr TPCs.

The key design parameters of the LAr1-ND TPC are summarised in table 1.
Table 1. LAr1-ND TPC key design parameters

| TPC parameter                          | Value                                      |
|----------------------------------------|--------------------------------------------|
| TPC active volume                     | 112 metric ton                             |
| TPC dimensions                        | 5 m (L) × 4 m (H) × 4 m (W)                |
| Maximum drift time                    | 1.28 ms, 2 m max. drift length             |
| Anode Plane Assembly dimensions       | 2.5 m × 4 m                                |
| Wire Properties                       | 150 µm diameter, CuBe                      |
| Wire planes                           | 3 per APA, U and V at ±60° to vertical (Y) |
| Cathode bias                          | -100 kV at 500 V/cm drift field           |
| Number of Wires                       | 2816 channels/APA, 11264 wires total in TPC|
| Wire tension                          | 0.5 kg at room temperature                 |

Figure 5. A wavelength shifting light guide bar, read out by SiPMs.

Figure 6. Two light collection system designs for the LAr1-ND TPC. Left: The light guide bar design. Right: TPB-coated reflector tile system.

3.3. Photon readout

LAr1-ND provides an excellent test-bed for light collection systems in a LAr detector. There are two proposed light collection systems, an overview of each is presented here. The opportunity to test new approaches, possibly side-by-side is an important one for the goal of informing an optimized design for use in future LAr detectors for long-baseline neutrino physics.

One of the approaches is very similar to the current baseline design for LBNF. The light collection system consists of acrylic bars mounted behind the APA frame, as shown in figure 6. These acrylic bars are dip-coated in Tetraphenyl butadeine (TPB) wavelength shifter which converts the incident primary scintillation light with wavelength 128 nm to 430 nm light, which can be efficiently read out (see figure 5). Each bar is read out by 3 Silicon Photomultipliers (SiPM), giving position resolution of 2.5 cm in the vertical direction.

Another approach being considered is based on a concept adapted from liquid argon dark matter detectors. In this design, the inner surfaces of the detector volume are covered with TPB-coated reflector foils, in order to enhance light collection. The motivation behind this is to naturally enhance the light yield without need for additional readout channels. The reflector
The use of TPB-coated cryogenic PMTs is also being considered, analogous to the system implemented in the ICARUS and MicroBooNE detectors.

### 3.4. Detector drift field calibration system

The knowledge of the electric field inside the drift volume of a TPC is a key aspect for performing subsequent event reconstruction. Since distortions of particle tracks due to field non-uniformities are indistinguishable from particle multiple scattering, they affect the accuracy of the particle momentum reconstruction based on track scattering angles.

Deviations of the field map from perfect uniformity in a LArTPC may arise due to accumulation of positive argon ions in the drift volume. Since the LAr1-ND detector sits at the surface, there will be an estimated 2200 cosmic ray muons per second in the fiducial volume of the detector. This, in addition to the ions produced in neutrino interactions leads to space-charge; an accumulation of low mobility positive ions in the detector volume. This causes electric field non-uniformities, which change as a function of time.

In order to measure these electric field non-uniformities, a pulsed UV laser system will be implemented in the detector. This system, as described in [8] will produce straight ionisation tracks at defined locations in the liquid argon, using a $\lambda = 266$ nm source to produce ionisation via multi-photon absorption. The laser tracks are created one by one using pulsed laser beams and a steerable mirror, as shown in figure 7. The reconstructed position of the tracks can then be mapped to the known location of the ionisation deposition, and the curvature of the tracks used to map the distortions of the electric fields.

This system was developed in ARGONTUBE [9], and a similar system has been implemented in the MicroBooNE detector.

### 3.5. Electronics

The aim of the TPC readout is to digitize, compress losslessly and record the TPC signals upon the reception of a variety of triggers. The electronics readout of the 11,264 APA wire channels consists of three parts: cold electronics, warm interface electronics, and signal feedthrough. The system will be built upon the technology developed for use in both the MicroBooNE and
LBNE 35t prototype, however, the major difference is the intention to put all of the front-end electronics inside the cryostat, operating in the cold.

A block diagram showing the readout of a single APA channel is shown in figure 8. The signal from each wire is pre-amplified and shaped by a CMOS analog front end ASIC, then digitized by a CMOS ADC ASIC inside the cryostat. The digitized signal is sent to an FPGA, which aggregates data from multiple ADC chips and multiplexes it to high speed serial links. The serial data is then sent over cold cables through a feed-through to the warm interface board installed outside of the cryostat on top of the signal feed-through. The warm interface board receives the electrical serial data from the cold electronics and converts it to optical signals for transmission over a fiber optical link to the TPC readout module, housed in a crate. Once the signal arrives at the TPC readout module, it is processed in an FPGA for compression, reduction, and storage. Processed data is buffered on board temporarily and then transmitted to DAQ PCs through the crate backplane and optical links. Data received on PCs is then stored in hard drives for further analyses.

4. Summary and Timeline
LAr1-ND is the new LArTPC in the SBN program. It not only has an exciting physics program, but also provides a great opportunity for detector development towards future large liquid argon
detectors for long-baseline neutrino experiments.

Currently, there is a large amount of R&D activity towards realising the detector. The preliminary design is complete, with a conceptual design review (CDR) submitted in January 2015, and a technical design report to be submitted mid-2015. Ground breaking for the detector building is planned to take place in August 2015, with the cryostat installation in November 2016. The detector installation will take place in late 2017, with a view to a first cooldown in November 2017, and first beam data in April 2018.

The proposed schedule for the LAr1-ND experiment is a very aggressive one, with design, fabrication, assembly and installation of the detector before the end of 2017. Nevertheless, the collaboration is building on the experience of the design, construction, and operation of existing liquid argon TPCs, and this gives the project the potential to move forward quickly, attaining these goals.

5. References

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