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2013 JINST 8 C09011

(http://iopscience.iop.org/1748-0221/8/09/C09011)

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PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *July 23, 2013*
ACCEPTED: *August 14, 2013*
PUBLISHED: *September 23, 2013*

LIGHT DETECTION IN NOBLE ELEMENTS (LIDINE 2013)
29th – 31st MAY 2013, FERMI NATIONAL ACCELERATOR LABORATORY
ILLINOIS, U.S.A.

The LArIAT light readout system

A.M. Szelc[1]

Yale University,
New Haven, CT 06520 U.S.A.

E-mail: andrzej.szelc@yale.edu

ABSTRACT: Most neutrino experiments using liquid argon as a detector medium focus on obtaining information about the interaction from ionization electrons and choose to use the scintillation light as a trigger or an indication of interaction time. On the other hand, experiments investigating lower energy ranges, i.e. Dark Matter searches have shown that there is a wealth of information in the scintillation light, which by itself allows calorimetric reconstruction and particle identification based on the shape of the light signal. LArIAT is a an experiment set to calibrate the LAr Time Projection Chamber technology by placing the detector on a beam of charged particles of known type and momentum. One of its goals is to test a Dark Matter search-like light collection system, which could supplement the calorimetric and particle identification capabilities of the LArTPC. The plans to implement this setup in the LArIAT detector will be presented together with the small set-up being constructed to test the components.

KEYWORDS: Noble liquid detectors (scintillation, ionization, double-phase); Photon detectors for UV, visible and IR photons (vacuum) (photomultipliers, HPDs, others); Time projection Chambers (TPC); Cryogenic detectors

[1]for the LArIAT Collaboration

doi:10.1088/1748-0221/8/09/C09011

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1 Introduction

Liquid Argon Time Projection Chambers (LArTPC) are becoming one of the most promising detector technologies for neutrino physics. This is a result of their superior precision in 3D reconstruction and the availability of calorimetric information combined with a relatively simple detector construction. The LArTPC is built around collecting the ionization electrons resulting from charged particles traversing the liquid argon volume. These energy depositions can also manifest themselves as scintillation light which can be collected in order to improve the precision of the detector.

1.1 Liquid Argon Time Projection Chamber

The Liquid Argon Time Projection Chamber (LArTPC), proposed by C. Rubbia [1] and pioneered by the ICARUS collaboration [2], aims to take advantage of the qualities of liquid argon as a detector medium. The principle of operation is shown in figure 1 — an energy deposition caused by a charged particle traversing the medium results in scintillation light and ionization electrons. In a LArTPC, the free electrons are drifted towards the anode in a uniform electric field where they are registered on wires in at least two planes, due to electromagnetic induction and collection of the electrons on the last plane of wires. Because the wires in different planes are at an angle with respect to each other, identifying the crossing channels registering the charge deposit gives the position reconstruction in the Y and Z coordinates. The time of drift provides the X coordinate completing the full 3D reconstruction of an event. Measuring the quantity of the deposited charge provides calorimetric information.

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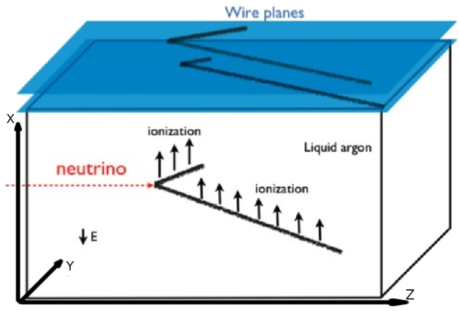

Figure 1. The principle of operation of the Liquid Argon Projection Chamber. Details in text.

1.2 The LArIAT light readout concept

Apart from the ionization electrons, the energy deposited in liquid argon also produces scintillation photons. Most LAr neutrino detectors are equipped with light detectors, however, they are primarily used as a trigger and to provide timing information for off-beam events [2, 3]. In LAr Dark Matter detectors the scintillation light plays a much more important role: it can be the only measurement of energy — [4] or acquired together with ionization in so called double phase detectors [5, 6]. The Dark Matter experiments have shown, that scintillation light can be used not only for calorimetric reconstruction but also to separate the signal, i.e. highly ionizing nuclear recoil events, from background, i.e. electron-recoil events.

One of the objectives of LArIAT is to see whether a Dark Matter-like scintillation light collection system can complement the LArTPC calorimetric reconstruction and particle ID methods. If it is successful, this could change the way neutrino detectors look at scintillation light in liquid argon.

2 The LArIAT program @ FNAL

2.1 LArTPC calibration

The LArTPC is a relatively new technology and some of its features and capabilities are still being studied. An important technical parameter is the electron recombination factor, which governs the amount of charge that can be collected per energy deposition depending on the density of ionization, often parametrized using the Birks method [7]. As far as capabilities are concerned, the most interesting are the electron/gamma separation and the negative muon capture rate as they will both have an important impact in future neutrino experiments. One should note that the above values are strongly dependent on the physics properties of argon itself, and therefore, once measured they will be translatable to all other LArTPC detectors. Their precise determination will allow future experiments to lower their systematic errors which may prove essential in precision physics down the road.

Interestingly, despite its growing use as a detector in neutrino physics in the past — [2, 8], near future — [3] and future — [9] experiments there has been relatively little dedicated effort to calibrate the LArTPC. Up to now, most of the parameters relevant to understanding the data coming from LAr have been measured using non-dedicated datasets [10, 11]. Such measurements will have an intrinsic systematic error due to the difficulty of controlling all of the measurement parameters.

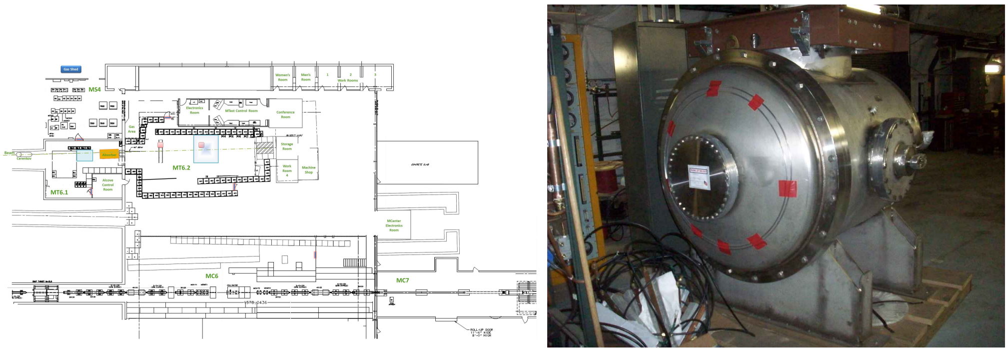

Figure 2. The layout of the FTBF at Fermilab (left) and the modified LArIAT cryostat, placed at MCenter/MC7. The front Flange which will host the beam window and the side port where the PMTs will be installed are visible. (right)

The LArIAT experiment [12] is being constructed to fill this gap in our knowledge by placing a LArTPC on a beam of charged particles of known momentum and type and measuring the effects of their interactions in liquid argon.

2.2 LArIAT at the Fermilab Test Beam Facility

The LArIAT program is a multistage approach that aims to set up a permanent test facility to calibrate and test LArTPCs and their components using a beam of charged particles at the Fermilab Test Beam Facility (FTBF). The ultimate goal will be a cryogenic/purification facility at FNAL designed to allow future tests of LAr detectors. For this reason the MCenter area of FTBF is being set up in a way that will allow longer term occupation, different from the standard, usually short term operations in the MTest area, see figure 2.

A tertiary beam (similar to the one used by the MINERvA beam test [13]) is being set up. Its configuration is being optimized in order to obtain a spectrum of charged particles closely resembling that of future neutrino experiments, e.g. [3, 9]. These particles will be directed at the detector with Time of Flight, Cherenkov and Wire Chamber detectors placed in the beam-line providing particle ID and momentum of the incoming particles.

Currently, two experimental stages are planned. The first phase will reuse the ArgoNeuT detector [8] with modifications to the cryostat and cryogenic system, see figure 2. The modifications were necessary to minimize the quantity of material on the path of incoming charged particles, and to allow the installation of the light readout system and a new cryogenic setup. However, since most of the components of the detector already exist, it can be ready for operation relatively quickly — the planned start of data taking is in the Spring of 2014.

The second stage of the program will involve a larger TPC, somewhat smaller than the MicroBooNE detector. It will be designed as a longer-term use facility to test new ideas and technologies.

2.3 LArIAT physics goals

LArIAT has a rich physics program that is aimed at measuring interactions of charged particles expected from neutrino events. The main goals of the first phase include measuring the dE/dx electron-gamma separation capability, which is an important factor in experiments looking for ν_e

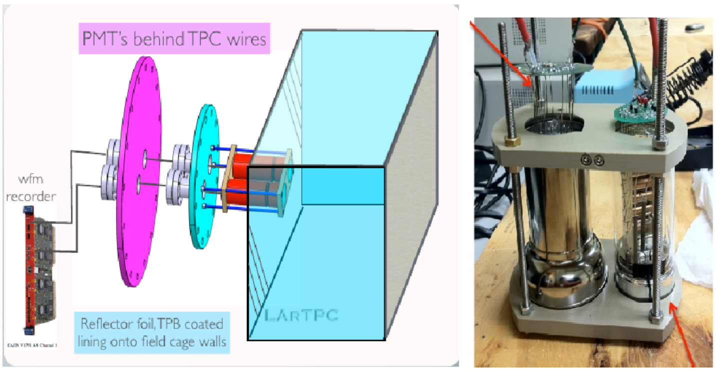

Figure 3. The scheme of the LArIAT light readout system (left) and the two PMTs in their PEEK holder (right).

appearance and measuring non-magnetic muon sign determination, which will be crucial, especially for future large, non-magnetized detectors looking at differences between neutrino and anti-neutrino interactions. In parallel, the recombination factors for different particles in the beam, like protons, kaons and pions will be measured, increasing the precision of calorimetric reconstruction and particle ID for all future LAr detectors.

The second phase will focus on measuring EM and hadronic shower containment and invisible energy ratios. And, last but not least, the LArIAT detectors will serve as a place to test new ideas and technologies in liquid argon.

3 The LArIAT light readout system

The LArIAT light detection system is an expansion of the planned design for ArgoNeuT Run II, which is a natural consequence of the fact that LArIAT is re-using the ArgoNeuT TPC and Cryostat. This enforces some constraints on the system, for example the PMTs must fit into the side flange of the Cryostat, which has been modified for this purpose.

The setup, see figure 3, will consist of 2 PMTs, one of them being a 3” Hamamatsu R-11065 [14], the other being a 2” ETL PMT which will be supplemented by the addition of 2 SiPM detectors all operating at cryogenic temperature. The light readout system will collect much more light than typical neutrino experiments — the current estimate from simulations points to $\simeq$ 50 phel/MeV (at zero field) — and digitize it fast enough to differentiate fast and slow light. To achieve this, large parts of the TPC frame construction will be covered with TPB, a wavelength shifter, evaporated on reflector foils (VIKUITY) to increase the uniformity of light collection.

The scintillation VUV photons, coming from charged particles traveling through the liquid argon, will be wavelength-shifted into visible photons when hitting the TPB and then reflected from the mirror surfaces beneath to be ultimately collected by the PMTs. The signals from the PMTs will be digitized using a fast ADC, CAEN model V1751 [15], and then stored in a PC. This design will allow in situ gain calibration using single photoelectrons from the tail of the signal while simultaneously allowing for event by event calorimetric reconstruction. This technique will be especially powerful for lower energy events that are usually close to the threshold for standard LArTPC detectors.

4 Testing the set-up

The components of the light readout system will be tested using a smaller chamber in a dedicated test-setup at the University of Chicago before they are inserted into the LArIAT cryostat. A small mock-"TPC" was built out of the same G10 material used to construct the actual ArgoNeuT/LArIAT TPC in order to recreate the optical properties found in the real detector. The tests will serve to make sure that the system is ready to be installed in M-Center and to constrain some of the parameters of our MC simulation.

Both the small system and the full detector light collection simulations are being developed in parallel in a standalone Geant4 simulation. The simulation parameters will be refined using the results from the test chamber, which in turn will allow improving the precision of the simulation of the full detector. Some parameters can be constrained earlier, an example being the reflectivity of G10 in blue light, which was unknown. We are investigating the possibility of measuring it using an integrating sphere. This relatively simple measurement will allow constraining the simulation parameters even further. First measurements have been performed and are being implemented in the simulation code.

The test set-up is being assembled and at the time of writing is close to the first filling.

5 Conclusions

The LArIAT detector will test the idea of implementing a "Dark Matter-like" light readout system in a neutrino detector. It will use the scintillation light coming from liquid argon for calorimetric reconstruction and particle identification. The expected light yield of 50 phel/MeV (@ zero field) should be sufficient to enhance our calorimetric reconstruction and examine the capabilities, using scintillation light for particle ID at beam neutrino energies. The system is composed of known components, which minimizes the risk of surprises. Tests with a small prototype will be performed to test the components and clarify the design and allow refining of our simulation for the full detector.

References

[1] C. Rubbia, *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, CERN-EP-77-08 (1977).

[2] ICARUS collaboration, S. Amerio et al., *Design, construction and tests of the ICARUS T600 detector*, *Nucl. Instrum. Meth.* **A 527** (2004) 329.

[3] MicroBooNE collaboration, H. Chen et al., *Proposal for a New Experiment Using the Booster and NuMI Neutrino Beamlines: MicroBooNE*, FERMILAB-PROPOSAL-0974.

[4] MINICLEAN collaboration, A. Hime, *The MiniCLEAN Dark Matter Experiment*, arXiv:1110.1005.

[5] P. Benetti et al., *First results from a Dark Matter search with liquid Argon at 87 K in the Gran Sasso Underground Laboratory*, *Astropart. Phys.* **28** (2008) 495 [astro-ph/0701286].

[6] DARKSIDE collaboration, D. Akimov et al., *Light Yield in DarkSide-10: a Prototype Two-phase Liquid Argon TPC for Dark Matter Searches*, arXiv:1204.6218.

[7] J. Birks, *Theory and Practice of Scintillation Counting*, Pergamon Press (1964).

[8] C. Anderson et al., *The ArgoNeuT Detector in the NuMI Low-Energy beam line at Fermilab*, 2012 *JINST* **7** P10019 [arXiv:1205.6747].

[9] LBNE collaboration, T. Akiri et al., *The 2010 Interim Report of the Long-Baseline Neutrino Experiment Collaboration Physics Working Groups*, arXiv:1110.6249.

[10] ICARUS collaboration, S. Amoruso et al., *Study of electron recombination in liquid argon with the ICARUS TPC*, *Nucl. Instrum. Meth.* **A 523** (2004) 275.

[11] ARGONEUT collaboration, R. Acciarri et al., *A study of electron recombination using highly ionizing particles in the ArgoNeuT Liquid Argon TPC*, 2013 *JINST* **8** P08005 [arXiv:1306.1712].

[12] P. Adamson et al., *LArIAT: Liquid Argon TPC in a Test Beam*, FERMILAB-PROPOSAL-1034.

[13] R. Gran et al., *Test Beam Calibration of the MINERvA Detector Components*, FERMILAB-PROPOSAL-0977.

[14] R. Acciarri et al., *Demonstration and Comparison of Operation of Photomultiplier Tubes at Liquid Argon Temperature*, 2012 *JINST* **7** P01016 [arXiv:1108.5584].

[15] R. Acciarri et al., *Tests of PMT Signal Read-out of Liquid Argon Scintillation with a New Fast Waveform Digitizer*, 2012 *JINST* **7** P07003 [arXiv:1203.1371].

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