Snowmass2021 - Letter of Interest

Investigations of Fundamental Parameters of Liquid Argon for Particle Detection

Thematic Areas:

■ (IF8) Noble Elements
■ (IF9) Cross Cutting and Systems Integration

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Abstract: We propose a long term facility for investigations of liquid argon properties to aid in its application for particle detection. Such a cryogenic facility needs to have sufficiently large size to accommodate detector structures, ultra-high purity, excellent control over cryogenic conditions such as temperature and circulation rate, and operational flexibility. Operational flexibility implies the ability to stage detectors, or change measurement conditions in the cryostat and be able to start operations without a large overhead in time to get to high purity conditions. In this letter we briefly describe our design of such a system which is under construction. In the second part of the letter we describe two measurements that will be made with this system: first, the time projection chamber field response which is essential to reconstruct the 3D image of drifting ionization charge, and second, a model for impurities in liquid argon detectors. The impurity model has been verified with previous measurements using a smaller system with 20 liter volume; we intend to further explore this model and its parameters with the new system that is built with the specific purpose of being high purity and flexible. Furthermore, with the establishment of the facility, we can provide a general purpose test platform for the community with quick turn around time.

Motivations: The Liquid Argon Time Projection Chamber (LArTPC) is an exciting detector technology that is undergoing rapid development. LArTPCs have been constructed and operated in several neutrino and dark matter experiments, ranging in size from hundreds of liters to hundreds of cubic meters. Moreover, the Deep Underground Neutrino Experiment (DUNE) is proposing $\sim$10,000 m^3 LAr detector modules[1] to answer important remaining questions in the neutrino physics[2]. LAr is chosen because it has ideal physical properties for a detector medium: it is dense and commercially available in large quantities at relatively low cost. A thorough understanding of LAr properties and optimization of detector designs is crucial to the success of future LAr experiments. In this letter, we propose a long term facility for investigation of LAr properties to aid in its application for particle detection.

Facility Description: As a general purpose LAr test platform, the cryogenic facility needs to have sufficiently large size to accommodate detector structures, ultra-high purity, excellent control over cryogenic conditions such as temperature and circulation rate, and operational flexibility. Operational flexibility implies the ability to stage detectors, or change measurement conditions in the cryostat and be able to start operations without a large overhead in time to get to high purity conditions. Currently, a 260-liter LAr test facility is being constructed at the Brookhaven National Laboratory for this purpose. It is an upgrade of an existing 20-liter LAr test stand, where the idea of passive argon circulation with gas purification has been demonstrated to be effective in achieving the required purity level for LArTPC operation[3]. The schematic diagram and a photo of the system under construction are shown in Fig. 1 and 2. The key parameters for the designed LAr test facility are listed in Table 1. The 260-liter main cryostat allows to host a fully functional TPC to test various TPC and electronic readout designs. The top flange is designed to have sufficient ports for necessary feedthroughs and accommodate future upgrades and applications. An inline liquid argon filter is added to the filling line to achieve parts per billion impurity in terms of oxygen and water upon initial filling, while the gas circulation, purification, and condensing further improves the purity to below 1 ppb within 1–2 days.

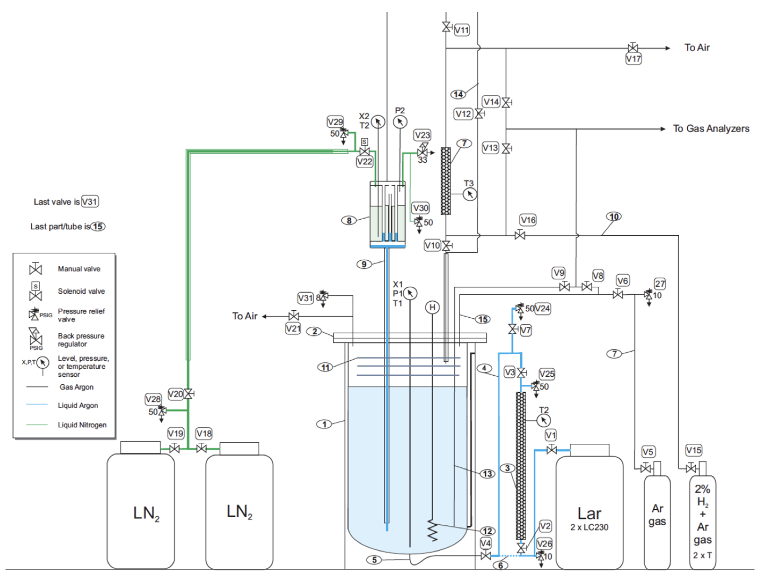

Figure 1: The schematic diagram of the 260-liter LAr test facility.

Figure 2: A photo showing the cryogenic system under construction.

Current Applications: Two experiments are being designed and constructed to make use of the 260-liter LAr test facility. They are planned to be carried out in the next two to three years.

The first application is the LArTPC field response calibration system (LArFCS). Recent development in

Table 1: Key parameters of the LAr test facility. The turnaround time is the time needed for LAr to reach sub-ppb purity after initial filling, plus the time to warm-up and recover from the previous experiment.

Total Volume	Inner Diameter	Inner depth	Heat load	Turnaround time
260 liters	22 inches	47.5 inches	150 W	1 week

LArTPC signal processing[4;5] has shown that an accurate prediction of the position and time dependent impulse field response function is the key to robustly extract the ionization charge from the induced electronic signals. Experimental data have indicated that typical 2D electrostatic simulation software (e.g. GARFIELD) may not be accurate enough to account for the long range of the induction signals and the 3D layout of the electrodes, leading to distortions in the deconvoluted signal. Therefore, LArFCS is proposed to directly measure the field response function versus the transverse distance to the starting electron location with high precision. The key components of LArFCS include a small-scale TPC inside the cryostat with an electron source from a Au-photocathode illuminated by a pulsed UV laser. The laser provides a precise control of the positions of photo-electrons through an optical arrangement of mirrors and mobile optical stages. The TPC provides the uniform electric field for electron drift and the collection of the signals on the wire planes, and is designed to allow easy modification and upgrade with different configurations of wire geometries. This measurement will provide crucial input to benchmark the software simulation and to study the various systematic effects that could alter the field response, such as electric field strengths, bias voltage, wire patterns, edge effects, broken wires, and so on.

The second application is the testing of impurity modeling in LAr detectors. Impurities in LAr (e.g. oxygen, water, and nitrogen) can significantly attenuate the charge or light signals, resulting in a decrease in detection efficiency and energy resolution. Therefore, it is essential not only to establish an ultra high purity in the cryogenic system, where considerable care must be taken to purify the Ar and to minimize the introduction of impurities through leakage and surface desorption from materials inside the detector, but also to have a verified realistic engineering model of the introduction, transport, and removal of possible impurities as the liquid and gas are being continuously circulated in the system. Such a model can help understand the contamination and purification systems, which can further lead to significant cost reduction in the construction and operation of large LAr detectors. An analytical impurity model has been developed by the BNL group and verified with previous measurements using a smaller system with 20 liter volume[6]. We intend to further explore this model and its parameters with the new system that is built with the specific purpose of being high purity and flexible. In particular, a precise measurement of Henry's constant for water in LAr is planned to aid the interpretation of experimental data regarding water impurities.

Future Opportunities: The establishment of the LAr test facility will provide a general purpose test platform for the community with quick turn around time. Small-scale experiments can be performed without a huge overhead to set up. There will be many opportunities to use this facility. Examples include but not limited to: measurement of fundamental LAr properties, such as the transverse diffusion coefficient, in an external electric field, measurement of light and charge yield at different stopping powers, testing of new TPC designs and cold electronics readout, testing of new photocathode materials and electron sources, etc. We believe such a long term LAr test facility will integrate well and be beneficial to the future LAr detector R&D programs.

References

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