Results from the Fermilab Materials Test Stand and Status of the Liquid Argon Purity Demonstrator

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Abstract. The Fermilab Materials Test Stand was developed to test the suitability of materials for use in large liquid argon time projection chambers (TPCs). In addition to determining which materials are viable for use in TPCs, the test stand has also shown that water is especially detrimental to maintaining long electron lifetimes. The Liquid Argon Purity Demonstrator is currently under construction at Fermilab. Its goal is to show that long electron lifetimes can be achieved without evacuation of the cryostat, which is of particular interest in designing large liquid argon TPCs.

1. Introduction
Liquid argon time projection chambers (LArTPCs) offer the possibility of imaging charged particle interactions with incredible spatial resolution. A charged particle passing through liquid argon will ionize the argon liberating \(\approx 55,000\) electrons per centimeter. The ionization electrons are drifted through an electric field towards readout wires where they produce current that is digitized by the readout electronics. A primary concern in the operation of an LArTPC is the ability of the electrons to reach the readout wires without being captured by electronegative contaminants. The large LArTPCs that are planned for future high energy physics experiments will require the electrons to be able to drift over distances of 2.5 m or more. The corresponding level of contamination in the liquid argon is at the level of 0.05 parts per billion (ppb) oxygen equivalent or less.

Two test stands at Fermilab are investigating aspects of LArTPC operation that relate directly to electronegative contamination in the liquid argon. The primary goal of the Materials Test Stand (MTS) is to qualify materials for use within LArTPCs and show that they do not increase the contamination in the liquid argon beyond acceptable levels. The primary goal of the Liquid Argon Purity Demonstrator (LAPD) is to show that the required level of purity can be achieved in a large volume of liquid argon without first evacuating the vessel containing the liquid and LArTPC. This test is motivated by the desire to save the costs associated with the construction of an evacuable cryostat for future multi-kiloton detectors.

2. The Materials Test Stand
The MTS is shown in Fig. 1 and is described in detail in [1]. The supply argon is sent through a molecular sieve to remove water and then through activated copper to remove oxygen before entering the evacuated cryostat. The cryostat has a capacity of 250 L and is vacuum insulated.
Figure 1. Photograph of the MTS at Fermilab showing the liquid argon supply, filters and cryostat.

Figure 2 shows a schematic of the cryostat and its instrumentation. The heart of the MTS is the airlock-sample cage assembly located in the center of the schematic. The airlock allows materials to be introduced into the cryostat without first having to empty it of liquid argon. The sample cage can be positioned anywhere between the airlock and the bottom of the cryostat to understand the temperature dependence of the impurities introduced by different materials.

In addition to the airlock, the cryostat also contains an ICARUS style purity monitor [2] to determine the electron lifetime and an internal filter to remove impurities introduced by the materials placed into the cryostat. The cryostat can be operated as a closed system when the liquid nitrogen cooled condenser is in operation. The argon gas that passes into the condenser is liquified and returned into the bulk liquid.

The condenser caused consternation in the performance of the MTS as the electron lifetime would rapidly decrease to zero whenever the condenser was used. The initial design of the condenser returned the liquid argon directly into the bulk liquid, and the method of return was hypothesized to cause the decrease in electron lifetime. Several new return paths were created in order to test the veracity of this hypothesis and it was found that increasing the surface area of cold metal encountered by the liquid before returning it to the bulk improved the electron lifetime. This result indicated that some impurity desorbed from warm surfaces, mixed with the gas and was then incorporated back into the liquid in the condenser. Further, that impurity absorbed to cold metal and could be removed from the liquid with an appropriate return path.

Water was a clear suspect for the impurity as it remains on surfaces in vacuum and has an affinity for cold surfaces. A moisture analyzer with 2 ppb detection capability was used to monitor the water concentration in the cryostat. Figure 3, taken from [1], shows the water concentration inside the cryostat as a material sample is placed at various depths in the cryostat.
The sample temperature and electron lifetime are also shown. As seen in the figure, the water concentration increases as the sample temperature increases, and the electron lifetime decreases. This figure demonstrates two major findings from the MTS. First, there is a direct relationship between electron lifetime and water concentration. Second, the water concentration does not change when materials are submerged in the liquid, but it does increase when materials are in the vapor space.

3. The Liquid Argon Purity Demonstrator

Currently operating LArTPC systems all rely on evacuation as the first step in obtaining a system capable of supporting long electron lifetimes. While that approach works well for small
Figure 3. Material sample temperature, water concentration inside the cryostat, and electron lifetime as a function of time.

systems, it is not an ideal solution for large systems where the mass of the liquid argon is on the scale of kilotons. The cost of an evacuable cryostat necessary to contain that mass of liquid argon is at least a factor of two larger than a comparable non-evacuable vessel.

The LAPD is designed to test whether a large mass of liquid argon can be purified to the necessary level to allow for electron lifetimes on the order of several milliseconds without evacuating the vessel first. This test will be done with nothing in the vessel except for the liquid argon and monitoring devices. The LAPD vessel is shown in Fig. 4; it is 3 m in diameter and 4.6 m tall. The vessel will be filled with 30 tons of liquid argon. The LAPD relies heavily on the experience from the MTS in its design and operation plan. The purity monitors to be used are copies of the MTS monitors as is the data acquisition system.

In addition to showing that evacuation is not necessary for achieving long electron lifetimes, the LAPD will also monitor temperature gradients in the bulk liquid and concentrations of water and oxygen in order to check our models for the behavior of the liquid. After achieving the long electron lifetimes the LAPD will be emptied and typical materials used in an LArTPC will be placed in the volume and the process will be repeated to show that the technique works in the presence of material as well.

The purification of the volume will proceed in two stages. The first stage will purge the vessel with argon gas. It has been shown that the concentration of oxygen in a vessel purged with gaseous argon can be reduced to 100 parts per million (ppm) after 2.6 volume exchanges [3]. After the initial volume exchange, the gas will be heated slightly to help dry the surfaces of the vessel and monitors. Once the water and oxygen concentrations inside the vessel are at the level of ppm, the gas will be circulated through filter vessels similar to those used in the MTS. The liquid will be introduced into the vessel after a concentration less than 1 ppm has been achieved. The liquid will be continuously circulated through the filter vessels in order to achieve concentrations of water and oxygen on the order of 0.1 ppb.

The components of the cryogenic system for LAPD had to be redesigned from their counterparts in the MTS to account for the much larger size of the system. New filter vessels
Figure 4. The vessel for the LAPD. It is 3 m in diameter and 4.6 m tall.

were designed to accommodate the larger volumes of liquid argon as well as making significant investment in new high purity cryogenic valves. The condenser and phase separator to be used in LAPD were also designed specifically for the system. Attention was given to how one would scale the system for kiloton scale masses of liquid argon and the potential scaling of the cost for such large systems. Initial estimates indicate that the cost of larger systems does not scale linearly with volume.

The LAPD is an ideal system in which to study the operation of kiloton scale LArTPCs. To that end, it will perform several tests. The first is to understand the number of liquid argon volume exchanges in order to achieve drift distances on the scale of 2.5 m. Additionally the filter capacity as a function of flow rate will be closely monitored. After achieving the required lifetime, a known contamination will be introduced into the system to see how quickly it can recover the electron lifetime.

The LAPD is intended to provide information for the design of the LArTPC detector proposed for the Long Baseline Neutrino Experiment. As such, it must operate before decisions of whether to make the cryostat evacuable are made. Several components of the system have already been constructed, including the purity monitors, cryogenic pump and condenser. The cryogenic valves and filter vessels are currently under construction. The LAPD is expected to begin operations in September, 2010.

4. Conclusions
The MTS has demonstrated several aspects of purifying volumes of liquid argon to achieve long electron lifetimes, including the negative impact of water. The LAPD is building on the experience of the MTS and will begin operation in the fall of 2010. Its first results will provide key input to the design of the LArTPC detector proposed for the Long Baseline Neutrino Experiment.
5. References
[1] Andrews, R. et al. 2009 Nucl. Instrum. Meth. A608 251
[2] G. Carugno et al. 1990 Nucl. Instr. Meth. A292 580
[3] Jaskierny, W. et al. 2006 FERMILAB-TM-2384-E