LAr Purity Monitor System Report for the

ProtoDUNE-SP Cryogenics Instrumentation Review

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I. LAr Purity Monitor System Motivation

Purification is essential for successful operation of a liquid argon time projection chamber (LAr TPC), the requirement of which is determined by the maximum ionization electron drift length. While the TPC itself can measure the purity of the LAr based on the drift electron lifetime, this can only be done once a certain level of purity has been achieved, and until that point is reached it may be unclear what the level of purity is and if conditions in the detector are becoming better or worse. The 35-ton prototype detector at Fermilab was instrumented with four purity monitors. The data taken with them during the first part of the second phase is shown in Figure 1 and clearly shows the ability to measure the electron lifetime between 100 us and 3.5 ms. Additionally, because of the large scale of the ProtoDUNE detector (and especially the DUNE far detectors), sudden changes in the purity of the LAr being injected back into the cryostat may go unnoticed, and if this were to occur for too long it would cause irreversible contamination to the LAr ending data taking for the main physics goals. Having purity monitors continuously monitoring the detector, placed in strategic places and then used as an interlock, it could be possible to salvage the overall purity of the detector and continue running with the ability to take usable data. An irreversible contamination cannot be tolerated in ProtoDUNE and the DUNE far detectors and so strategically placed purity monitors should be implemented to further mitigate this risk. Additionally, ProtoDUNE offers the last opportunity to deploy purity monitors inside a functioning large-scale single phase (SP) LAr TPC before moving to the DUNE far detectors, and so this final chance should be taken advantage of to optimize the performance of such purity monitors. Finally, this gives a perfect opportunity to set in place the proper strategy for using these purity monitors as a means for monitoring the environment within the LAr TPC on a much more continuous basis.

Because it is necessary to strategically monitor the purity of the LAr inside ProtoDUNE, University of California, Irvine and University of Houston plan to produce, install, and operate throughout the lifetime of the experiment a set of purity monitors based on the design of those currently installed inside the 35-ton prototype detector. Three purity monitors are to be installed inside the cryostat and one to be installed within the LAr cryogenics line (outside the cryostat) after the argon purification unit. Additionally, an upgrade is being proposed that aims to further improve the already very successful design of the purity monitors by replacing the external xenon flash lamp light source with an LED light source deployable inside the cryostat. This upgrades would serve to increase the lifetime of the purity monitors, reduce noise generated by the light sources making operations easier and more continuous, and decrease the cost per purity monitor.

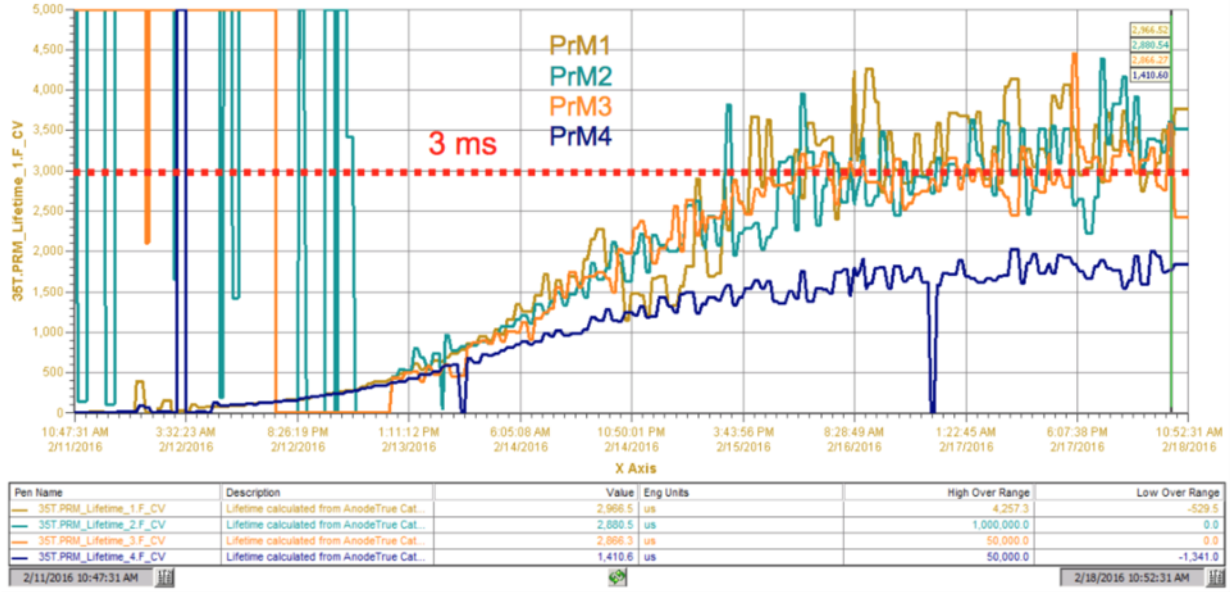

Figure 1: The electron lifetime measured by the four purity monitors as a function of time for the first part of the second 35-ton run. Notice the stratification that is present, this should be further investigated in ProtoDUNE.

II: Technical Description

The purity monitors will have a common baseline design, with the option available to develop an upgraded design for increased precision on the lifetime measurement. The three locations inside the cryostat will be near the LAr TPC, located at the detector end close to one of the APA planes. One purity monitor would be placed near the bottom of the APA plane, one near the center and one at the top, allowing for different depths inside the cryostat to be measured and compared to the contaminant distribution simulations which have been run. This will also allow for the study of the stratification of the LAr within the cryostat, something that has been observed in the 35-ton prototype and should be further understood. Optimization of the purity monitor positions with respect to the current cryostat and LAr TPC design will be done and interfaced through the cryostat and APA WGs. Details about the purity monitors placed inline of the cryogenics system and exterior to the cryostat will be interfaced with the cryogenics WG. Final decision of whether or not there will be an inline monitor should be made very soon and work will proceed based on this decision. The decision is in the hands of the project management and the Cryogenics WG, since it is based on available budget.

The basic purity monitor is a double gridded ion chamber immersed in the LAr volume. It measures the electron drift lifetime between its anode and cathode to determine the purity of LAr. The electrons are generated by the purity monitor's UV-illuminated gold photocathode. The electron lifetime in LAr is inversely proportional to the electronegative impurity concentration. The fraction of electrons generated at the cathode that arrive at the anode (Q_A/Q_C) after the electron drift time, t, is a measure of the electron lifetime, τ: $Q_A/Q_C = e^{-t/\tau}$.

The design of the purity monitor is based on those used at ICARUS, LAPD and the 35-ton

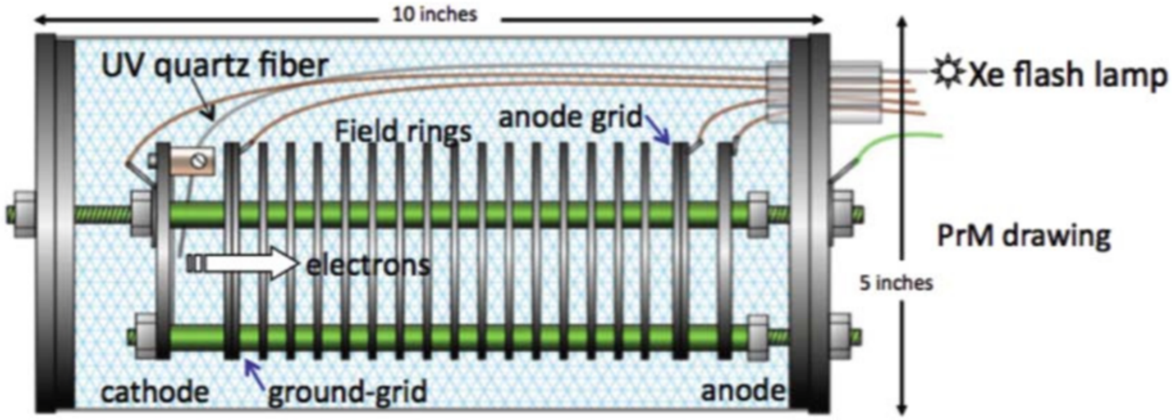

Figure 2: Drawing of the purity monitor design.

prototype. The purity monitor consists of four parallel, circular electrodes: a disk holding a photocathode, two grid rings (anode and cathode), and an anode disk. The region between the anode grid and cathode grid contains a series of field-shaping stainless steel rings that are electrically connected by resistors. A stainless mesh cylinder is used as a Faraday cage to isolate the purity monitor from electrostatic backgrounds. A drawing of the purity monitor is shown in Figure 2.

The cathode grid is at ground potential. The cathode, anode grid, and anode are electrically accessible via modified vacuum grade high voltage feedthroughs. The anode grid and the field shaping rings are connected to the cathode grid by an internal chain of 50 MΩ resistors to ensure the uniformity of the electric fields in the drift regions.

The photocathode that produces the photoelectrons is an aluminum plate coated with 50 Å of titanium and 1000 Å of gold and attached to the cathode disk. A xenon flash lamp is used as the light source in the baseline design, although this should be replaced by a more reliable and possibly submersible light source in the future. The UV output of the lamp is quite good around $\lambda = 225$ nm, which is close to the work function of gold. 1-3 UV quartz fibers are used to carry the Xe UV light into the cryostat to illuminate the gold photocathode. Another quartz fiber is used to deliver the light into a properly biased photodiode outside of the cryostat to provide the trigger signal when the lamp flashes.

Currently the electrons which are utilized to measure the drift electron lifetime in the LAr are generated by illuminating a photocathode, consisting of titanium and gold deposited onto a thin aluminum sheet, with a high intensity pulse from a xenon flash lamp. The source provides the 200-250 nm UV light necessary for producing electrons at the photocathode surface. However, these sources can be expensive while the lifetime can be quite limited. For this reason, continuous monitoring of the LAr is often abandoned and periodic monitoring taken as the common mode of operation, with monitoring sometimes occurring on hour time scales. Having much more continuous monitoring is something that is a must for a purity monitor which could detect sudden changes in the purity of the argon being injected into the detector and act as a first warning of any problems with the argon filtration system. The same type of photocathode as used in previous purity monitors was directly illuminated with a 245 nm LED purchased from

Sensor Electronic Technology, Inc. while in vacuum, and the generated electrons drifted to an anode 2 cm away from the photocathode. The resulting electric current through the photocathode as a function of the voltage across the LED is shown in Figure 3. The LED could be coupled into the fiber currently used for the flash lamp, enabling LEDs to replace the traditional sources allowing for more continuous monitoring of the liquid argon.

However, the objective of this work is to build an enclosure capable of allowing the LED to be immersed into the LAr, thus eliminating the need for the exterior light source and the optical fiber which needs to be fed-through into the cryostat. In this configuration, a low voltage electrical feedthrough would replace the fiber optic feedthrough and would provide the signal to allow the LED to be pulsed at will, with an expected lifetime at least ten times longer than the traditional sources. Degradation of the optical fiber has also been suspected to happen over time, and so eliminating the need for these could also increase the longevity of the performance of the purity monitors. Successful implementation of this configuration would pave the way for using LEDs as the light source in the DUNE far detectors, allowing for much more continuous monitoring of detector purity and a reduction in the cost per purity monitor (this is especially beneficial when many of these purity monitors should be built for the DUNE far detectors).

The cathode and anode signals are fed into two charge amplifiers contained within the purity monitor electronics module. This electronics module includes a filter circuit and an amplifier circuit that are shielded by copper plates, so the signal and high voltage can be carried on the same cable and decoupled inside the purity monitor electronics module. The amplified outputs of the anode and cathode will be measured with a digitizer that interfaces with either a DAQ PC or directly with the DAQ system for the LAr TPC APA wire readout.

We plan to deploy four almost identical purity monitors. Each purity monitor with its Faraday cage is 25 cm in length and 12 cm in diameter. Each purity monitor needs a 2−3/4 Conflat flange (CF) half nipple with a 3-pin HV feedthrough for the power supply and signal read out. The three purity monitors inside the cryostat can share a 2−3/4 CF half nipple with an 9-channel optic fiber feedthrough for the light supply. Therefore, in total ~6 2−3/4 CF flanges are needed (the exact number will be optimized by sharing flanges among purity monitors when possible). Since the inner height of ProtoDUNE is about 8 m, proper engineering design for the mounting system is necessary and will be optimized with the help of the project mechanical engineers.

III: Schedule for Construction and Testing

There are already four purity monitors that have been delivered to UCI and University of Houston. We will refurbish these four purity monitors to start and makes test for this task. Currently, one monitor has been completely refurbished at UCI, then shipped to FNAL and installed in the Tallbo cryostat. This refurbished purity monitor successfully measured the electron lifetime in Tallbo during the week of 04/13/17. This proves that the old purity monitor hardware from ICARUS can be refurbished and deployed at a distant location. The next step is to finish refurbishment of the monitor at UH, which will then be taken to UCI during the summer of 2017 for vacuum testing, along with the other two monitors which will be refurbished during the summer and already housed at UCI. R&D for the LED light source is ongoing, but is expected to conclude by mid-summer 2017, at which point a final decision will be made of whether to deploy an LED light source into ProtoDUNE. Additionally, during summer of 2017 the remainder of the components required for the system will be procured and testing will happen as they are received. The final system individual component testing will be completed at UCI by the end of 2017, allowing for the full system to be assembled at the beginning of 2018. Table 1 shows the expected schedule for the purity monitor system, with the expected installation date schedule for the end of April or the beginning of May in 2018.

Table 1: Schedule of tasks for Purity Monitor System.

Milestone	Description	Expected Date of Completion	Date Completed
Proposal	Proposal submitted to the ProtoDUNE management from UCI, UH and UM for the PrMon system for ProtoDUNE. The proposal stated that three monitors would be placed into the cryostat at three different heights, plus an option to place a PrMon inline of the cryogenics system after the LAr filtration unit.	9/30/16	9/30/16
Initial Refurbishment	Refurbish 1 PrMon at UCI and 1 at UH.	11/30/16	11/30/16
Test First Monitor	Test the first refurbished PrMon at UCI.	12/31/16	12/31/16
LED Test	Test LED light source option at UH using the refurbished monitor.	6/1/17	
PrMon Test	Test 1 or 2 PrMons at Fermilab using one of the larger cryostats there (BLANCHE, LAPD, 35-ton).	4/13/17	4/13/17
Installation 1	Install the base that will be used to secure the bottom PrMon to the floor of the cryostat, this need to be done before access to this area is blocked. This is also a good time to make sure the reserved space for the PrMon electronics is appropriate and everything will fit.	9/30/17	
Interfaces	Finalize interfaces with slow controls, cryostat, and electrical system.	9/30/17	
Refurbishment and Testing	Procure all parts and equipment and refurbish all 3 PrMons that will be used in ProtoDUNE, build light sources, mounting system and electronics for the 3 PrMs. Would also do the same for a fourth PrMon if it is decided that an inline monitor will be required.	12/31/17	
System Assembly and Test	Assemble the full system and make all required tests before shipment to CERN.	2/28/18	
Shipment	Ship the assembled and tested system to CERN for installation in ProtoDUNE.	3/15/18	
Installation 2	Install the electrnics equipment, install the PrMons into the cryostat, make final connections and test the system.	4/31/2018	

IV: Schedule for Resolving Interface Issues

There is one existing electronics module that can be used for readout for testing the purity monitors at UCI, this will continue to be used through the summer. We are now coordinating with the DAQ and slow controls WGs to make the final equipment selections for the power supplies and electronics that will be used for the system. A baseline design has now been put into place, in which the purity monitor system will be integrated with the CERN DCS. A NIM crate containing the purity monitor front-end will be placed as close to the purity monitor cryostat port as possible, as well as the xenon light source. The front-end will then connect to the purity monitor digitizers, which can be away from the cryostat and readout via the slow control computer running the custom purity monitor software that is developed in LabVIEW. Long coaxial cables that follow CERN regulations will connect the purity monitor front end electronics modules to the power supplies and digitizers. Development of the software will occur during the summer of 2017, and so it is expected that the interfacing of the purity monitor system with the CERN DCS will truly be finalized towards the end of summer. However, discussions of how to best fill the needs of both the CERN DCS and the purity monitor system are ongoing even now and will continue throughout the summer of 2017.

Interfacing with the cryogenics WG will be had to determine the exact placement of the inline purity monitor (should funding permit) and to make sure all aspects of the installation and operations have been accounted for. The port on the cryostat has already been decided as Port 4.1, as shown in Figure 3. Flanges for the system have already been defined and follow-up will be had to make sure this is still on track. During the next month, we will interface with the Cryostat and Installation WGs to define the placement of the bottom purity monitor in the cryostat and plan a trip to CERN at the end of summer to possibly mount the plate which would secure the bottom purity monitor to the floor of the cryostat. It has already been confirmed with the Cryostat WG that a stainless steel plate can be epoxied to the floor and used as a base to hold down the purity monitor. Installation of the purity monitor system is set for the end of April of the beginning of May of 2018 as one of the last items to be installed. Since the purity monitor system is one of the last thing to be installed in the cryostat, and it will be done from the top of the cryostat (aside from the bottom purity monitor plate placement done during the summer of 2017) and so will not interfere with other installations procedures. Initial discussion have begun to incorporate the current grounding scheme of the purity monitor system, which allows for the low noise readout required for the precision measurement to be made, with the requirements of the grounding scheme for the cryostat and TPC detector. It is expected that a detailed scheme will be in place by the end of summer 2017, in plenty of time to be implemented within the purity monitor system.

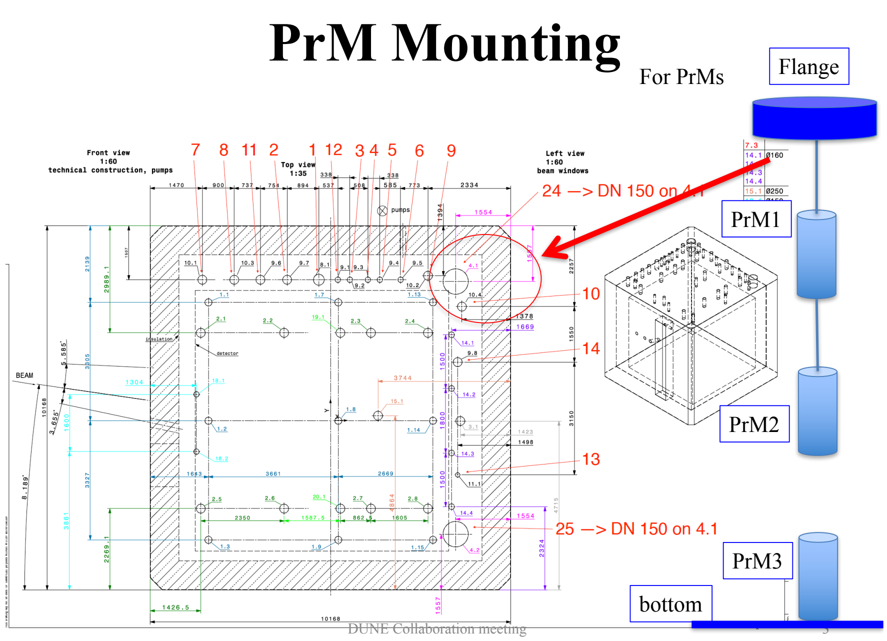

Figure 3: Purity monitor system port placement on ProtoDUNE cryostat.