Introduction to cryogenics and argon instrumentation for protoDUNE-single phase

The organization of the cryogenics and argon instrumentation starts from an agreement that

"The responsibility for the system is split between ProtoDUNE-SP and CERN:

The ProtoDUNE-SP collaboration is responsible for all devices that will be installed and cabled inside the cryostat, the sensors needed to monitor the cryostat and its content, and the specifications for the system.

CERN is responsible for the implementation of the control system elements outside the cryostat (hardware, firmware and software), including the high-voltage and low-voltage power supplies necessary for the detector operation. "

As stated in the Technical Design Report [1]: "The protoDUNE-SP apparatus includes instrumentation beyond the TPC and the photon detectors to ensure that the condition of the liquid argon is adequate for operation of the TPC. This instrumentation includes gas analyzers to monitor the purge of the cryostat and ensure that any remaining atmospheric contamination is sufficiently low, thermometry to monitor the cryostat cool-down and filling, purity monitors to provide a rapid assessment of the electron drift-lifetime independent of the TPCs, and a system of internal cameras to help locate any sparks due to high voltage breakdown in the cryostat.

In addition, two sets of precision temperature sensors are being deployed to measure the temperature gradients inside the protoDUNE cryostat. These temperature measurements exploit the opportunity protoDUNE-SP provides to check the predictions of the Computational Fluid Dynamics models being used to design the argon flow in the (much larger) DUNE cryostat.

The CERN Neutrino platform is providing the essential measurements of the cryostat pressure and external environmental conditions."

The Neutrino Platform (NP) is also providing a differential pressure gauge which will measure the liquid argon level and a general weather station that will report ambient humidity, temperature and barometric pressure.

Table 1 lists the people and institutions involved at present (4-2017).

Function	People
Co-ordinators	A. Cervera, (IFIC, Spain) & S. Pordes (Fermilab, USA)
Temperature sensors	Jelena Maricic (Hawaii, USA) & A. Cervera
Cameras	M. Kordosky (William & Mary, USA)
Purity Monitors	J. Bian (UC Irvine, USA) & A. Renshaw (Houston, USA)
Gas Analyzers	S. Pordes
Controls System Interface	Flor Blaszczyk (Boston U., USA)
Measurements co-ordination	A. Hahn (Fermilab, USA)

Table 1: Roles.

In practice the effort is aimed at

1. providing rapid feedback on the condition of the argon and the cryostat during the purge, gas recirculation, cooldown, filling, and data-taking phases of the project
2. providing visual diagnostics to help identify the source(s) of problems particularly high voltage problems
3. providing a set of data for the checking and validation of the fluid dynamics models being used in the design of the cryogenic systems for DUNE.

The first two items are quite traditional. The deployment of purity monitors in the cryostat is designed to give a rapid indication of the quality of the argon in the cryostat. The monitors will be able to follow the electron drift-lifetime as it improves from the 100 us level to the ms region - and further in case the TPC reconstruction is not immediately available to do so. The purity monitor at the output of the purification system is uniquely able to assure the quality of the argon before it enters the cryostat. The camera system is designed to provide eyes into the cryostat.

The third item is less conventional and is a consequence of two circumstances. One circumstance was the result of an unfortunate design of the cryogenic system for the 35 ton tests, a design which resulted in a significant vertical dependence of the electron drift-lifetime, see [2]. This brought a renewed/widened sensitivity to the importance of the cryogenic fluid-flow design. The second circumstance is the important role that calculations of fluid dynamics (CFD = computational fluid dynamics) are playing in the design of DUNE itself.

As an example of the latter, the question was raised as to whether given the length of the DUNE cryostats it was necessary to have pumps at both ends - which would have required extending the cavern. Several configurations with pumps at one end only were studied and it was found that a distributed inlet manifold would produce an acceptably uniform impurity distribution. Figure 1 shows the dramatic difference achieved keeping the pumps at one end but distributing the argon inlets in a manifold along the length of the cryostat.

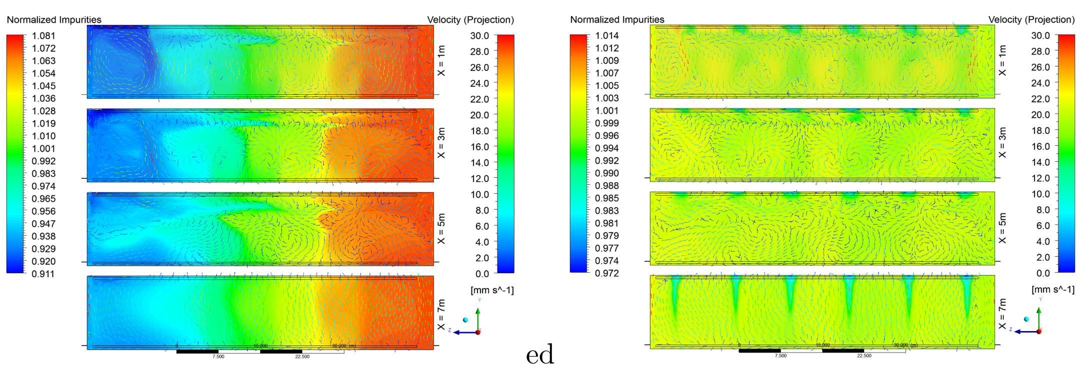

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Figure 1: Impurity distributions - left single entry point, right manifold of entry points along cryostat

Given the absence of an abundant flux of cosmic rays to measure the impurity distribution in DUNE itself, it seems prudent to exploit the protoDUNE cryostat system to check the validity of the calculations being used for DUNE to the extent possible.

In contrast to DUNE, the protoDUNEs will indeed experience a significant cosmic ray flux which may eventually allow a fine-grain measurement of the impurity distribution. Cross checking this distribution with the temperature measurements and protoDUNE simulations may also be quite fruitful.

General response to Charge questions

1. *Does the Cryogenic Instrumentation design meet the requirements? Are the requirements/justifications sufficiently complete and clear?* We believe that the planned instrumentation meets the requirements for successful operation of protoDUNE-SP. It is a considerable expansion on what was originally considered.

2. *Does the design represent a good development path towards DUNE?* Developing systems with purity monitors and temperature sensors that operate successfully in the 7 m deep environment of protoDUNE is a significant evolution towards a technology for DUNE, also given that the people involved are new to the technology. Developing a camera system that works well may also pay significant dividends for DUNE - if one can do anything to mitigate any problems such a system might catch in DUNE. We believe that investment in the extensive set of temperature measurements in protoDUNE-SP and the R & D invested in learning how to measure temperature gradients with high precision will provide important cross checks of the fluid dynamic calculations used for the design of DUNE and will also help in the operation of DUNE to measure its actual temperature situation.

3. *Does the design lead to a reasonable production schedule, including QA/QC, transport, installation and commissioning?* The design of part of the system is relatively advanced and part is clearly at a preliminary stage. There is not, however, a large amount of production involved. Transportation is not expected to be a schedule challenge. QA/QC is very much part of the actual production process. The time-critical elements are presently the temperature sensors to be installed on the cryogenic piping and the membrane floor. The temperature and mechanical requirements on the membrane sensors are quite standard and the installation should be straightforward now that a routing technique for the readout cabling inside the cryostat has been agreed with the NP. The temperature sensors themselves are commercial devices. The ones that attach to the argon piping will be calibrated over the next few months and should then be ready for installation.

4.*Is the installation plan sufficiently far advanced to assure that the detector can be installed as designed?* At this time, ports have been identified for all the components except the camera system whose definition is beginning. Both temperature monitors have been designed to ensure that the components can be installed within the existing height and lateral constraints. The vessel for the inline purity monitor needs to be defined but space is considered to be available.

5. *Are all internal interfaces between components (cryostat, cryogenics, TPC) documented, clearly identified and complete?* The process of developing the interfaces with other mechanical components is beginning now that the interfaces are identified - this has been largely a question of what structures could accept the temperature sensors. The major interactions involve the sensors on the cryogenic system already mentioned (interface with cryogenics/NP), a set of temperature sensors that will attach to the top ground planes (in-

terface with the TPC), the cameras which will also probably attach to the upper ground plane (interface with TPC), and the purity monitor that is installed just downstream of the purification systems (interface with cryogenics/NP). The gas analyzer system has some interface with the Cryogenics system as well. Space for and cable routing for equipment on top of the cryostat is also now under discussion. The need for and availability of equipment such as meters, oscilloscopes and leak-checkers is being investigated.

6. *Are the interfaces with the slow control system well defined and understood?* The interfaces with the detector controls system (dcs) are also being developed - these discussions cover location of systems and cabling on the cryostat as well as readout. For the temperature sensors, there is already close involvement with the dcs including feedthrough design. The gas analyzers use standard readouts, 4-20 mA, RS232 and ethernet. For the purity monitors, discussion of how to partition the system physically and logically is ongoing. For the purity monitors in the cryostat, the flash-lamp and amplifiers will be located near the feed-through. Experience at the 35t suggests that the digitizing electronics can be up to 30 m away. If this proves not to be the case, the digitizers will need to be near the amplifiers. It is proposed that a logically stand-alone system under the control of the run control system perform the tasks required to take purity-monitor data (set voltages, turn on the flash-lamp, read the digitizers, perform the analysis) and report the lifetime and other parameters to the dcs. See the response to charge question 8.

7. *Is the grounding and shielding of the Cryogenics Instrumentation understood and adequate?* The exchange of information on grounding and shielding has started.

8.*Are operation conditions (when will/can instrumentation be turned on) listed, understood and comprehensive?* It is recognized that there are at least three proposed activities of the cryogenic instrumentation that are likely to affect operation of the rest of the protoDUNE apparatus and need to be co-ordinated.

- The flash-lamp of the purity monitor typically produces a major amount of electrical noise and its light may also affect the photo-detectors. Taking purity-monitor data will clearly need to be under the auspices of the detector run control system. To set a scale for the amount of dead-time involved, a purity monitor run may take a few minutes. When the cryostat is first filled, one may wish to take a run every few hours given the circulation time of 5 days. Under stable operations with a working TPC, the monitors may be exercised one to a few times a day. The monitor by the purification system may be exercised hourly if it does not cause any interference to allow prompt warning of any problems.

- The motor that moves the Hawaii temperature profile monitor can be a source of electrical noise. This activity will need to be under the auspices of the run control system. The motor will be part of the electrical review and we will try to mitigate its effects as much as we can. The motion is used to allow in-situ cross calibration of the temperature sensors and finer spatial resolution temperature measurements, particularly at the bottom of the cryostat. We do not expect to do this frequently although at the beginning (probably before the argon is TPC quality) we will want to perform the cross calibration daily.

- The third aspect of the cryogenic instrumentation that could affect detector operation is the lighting that will accompany the camera system. Effective use of the cameras requires the ability to identify the sources of light and a system that illuminates the detector is helpful/essential to correlate the source of a spark (seen in the darkness) with a physical object in the detector. Such a lighting system may need to be interlocked with the photon-detectors.

We mention that the temperature sensor readout is a 4-wire constant current resistance measurement and is not expected to produce interference with detector operation.

9. *Are the analyses of the Cryogenics Instrumentation components sufficiently comprehensive for safe handling, installation and operation at the CERN Neutrino Platform?* This applies mainly to the installation of the temperature profile devices and the purity monitor system. The designs for these systems are at different stages of realization. Once the design for each of these devices is at a sufficiently mature stage, we expect to request appropriate reviews for local handling, installation, and commissioning.

10.*Is the Cryogenics Instrumentation quality assurance, quality control and test plan adequate? Have applicable lessons-learned from previous LArTPC devices been implemented into the device testing and into the system design?* Extensive testing during the assembly process is planned for the large-scale devices before installation.Sets of individual sensors will be tested as they are installed. Feed-throughs will be leak-checked, purity monitors tested in clean argon and vacuum, motorized operations performed outside the cryostat, and a full readout of temperature profilers performed.

References

[1] `http://docs.dunescience.org:8080/cgi-bin/ShowDocument?docid=1794`

[2] A. Hahn, RTD Spoolers and "precision" temperature measurements, `http://docs.dunescience.org:8080/cgi-bin/ShowDocument?docid=2317`