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OVERVIEW OF THE LIQUID ARGON CRYOGENICS FOR THE SHORT BASELINE NEUTRINO PROGRAM (SBN) AT FERMILAB

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ABSTRACT

The Short-Baseline Neutrino (SBN) physics program will involve three LAr-TPC detectors located along the Booster Neutrino Beam (BNB) at Fermilab. This new SBN Program will deliver a rich and compelling physics opportunity, including the ability to resolve a class of experimental anomalies in neutrino physics and to perform the most sensitive search to date for sterile neutrinos at the eV mass-scale through both appearance and disappearance oscillation channels.

The Program will be composed of an existing and operational detector known as Micro Boone (170 ton LAr mass) plus two new experiments known as the SBN Near Detector (SBND, ~ 260 ton) and the SBN Far Detector (SBN-FD, ~ 600 tons). Fermilab is now building two new facilities to house the experiments and incorporate all cryogenic and process systems to operate these detectors beginning in the 2018-2019 time frame.

The SBN cryogenics are a collaborative effort between Fermilab and CERN. The SBN cryogenic systems for both detectors are composed of several sub-systems: External/Infrastructure (or LN_2), Proximity (or LAr), and internal cryogenics. For each detector the External/Infrastructure cryogenics includes the equipment used to store and the cryogenic fluids needed for the operation of the Proximity cryogenics, including the LN_2 and LAr storage facilities. The Proximity cryogenics consists of all the systems that take the cryogenic fluids from the external/infrastructure cryogenics and deliver them to the internal at the required pressure, temperature, purity and mass flow rate. It includes the condensers, the LAr and GAr purification systems, the LN_2 and LAr phase separators, and the interconnecting piping. The Internal cryogenics is comprised of all the cryogenic equipment located within the cryostats themselves, including the GAr and LAr distribution piping and the piping required to cool down the cryostats and the detectors.

These cryogenic systems will be engineered, manufactured, commissioned, and qualified by an international engineering team. This contribution presents the performance, the functional requirements and the modes of operation of the SBN cryogenics, and details the current status of the design, present and future needs.

1. INTRODUCTION

In January 2015, an official proposal for a three detector program was presented at Fermilab. This proposal has led to the Short Baseline Program (SBN) with detectors known as MicroBooNe, SBN Near Detector (SBND and then known as LAr1-ND) and SBN Far Detector (SBN-FD) being accepted as part of a program involving liquid argon based Time Projection Chamber neutrino detectors. AS stated in that 2015 proposal:

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"The SBN program brings together three LAr-TPC detectors built and operated by leading teams of scientists and engineers from Europe and the U.S. The ICARUS-T600 detector is the first successful large-scale LAr-TPC to be exposed to a neutrino beam and to this point the largest LAr-TPC for neutrino physics. The MicroBooNE detector is the largest LAr-TPC built in the U.S. and will have been operational for several years at the start of the three detector program. The new near detector, LAr1-ND, is being developed by an international team with experience from ArgoNeuT, MicroBooNE and LBNE prototypes. The combination of these three detectors and associated collaborations represents a tremendous R&D opportunity toward the future LBN program".

MicroBooNe is a 170 ton liquid argon detector that has been in operation since the Spring of 2015. The cryostat is an ASME code vessel while the associated cryogenic systems were designed, fabricated and installed by Fermilab personnel. LAr and LN2 storage vessels are used to hour the cryogens which are delivered to the vessel or used in re-condensing of the gas boiloff of the detector.

The SBN Near Detector (SBND) includes one cryostat – using memberane cryostat technology develoed in the LNG business - measuring …..and associated cryogenics systems necessary to receive, transfer, store and purify the necessary liquid argon (LAr) required by the 260 kton experiment. Liquid nitrogen (LN2) is used to re-condense the gaseous argon (GAr) which boils of the detector mass.

The SBN Far Detector includes two cryostats contained within a single warm vessel and passive insulation (polyurethane foam). The cryogenic systems infrastructure also includes all systems to to receive, transfer, store and purify the necessary liquid argon (LAr) required by the 700 kton experiment.

Fermilab and CERN are collaborating to share the cryogenic systems development and installation for SBND and SBN-FD. MicroBooNE was developed at Fermilab and is fully operational sinc summer of 2015.

2. THE FIRST SBN DETECTOR: MICROBOONE

The MicroBooNE experiment and its Liquid Argon (LAr) Time Projection Chamber (TPC) detector technology is designed to collect neutrino interactions using the Booster Neutrino Beam at Fermilab and produce the first neutrino cross section measurements on argon in the 1 GeV energy range. The MicroBooNE cryogenic system is designed, similar to Fermilab's LAPD and 35T argon experiments, to provide continuous filtration of the liquid argon to remove oxygen and water impurities to the parts-per-trillion level. The physics operations commenced in summer 2015 and the cryogenic system has been successful in both reliability and argon purity requirements, to provide experimenters with the electron drift lifetime well above design requirement of 3 milliseconds. Electron lifetime is inversely proportional to the contamination amounts of electro-negative contaminants such as water and oxygen. Parameter specifications for purity can be found in Table 1.

Figure 1 gives a graphical representation for the initial fill of the cryostat over the month of June in 2015. As the cryostat was filled liquid argon recirculation pumps were turned on, removing the LAr at a rate of one full cryostat volume per day. This recirculated liquid is filtered through mol sieve and copper filtration beds to remove any oxygen and/or water content. This continuous recirculation allows the experiment to reach low purity and high electron drift times.

Table 1.

Parameter	Value	Motivation
Argon purity	<100 ppt O_2	MIP identification at longest drift
Argon purity	<2 ppm N_2	Scintillation light output
LAr Temperature gradient	<0.1 K	Drift-velocity uniformity
LAr recirculation rate	1 volume change/day	Maintain purity
Cryostat heat load	<15 W/m^2	Minimize convection currents and bubbles
Cryogenic capacity	10 kW	Capacity to deal with expected heat load
Cryostat maximum pressure	2.1 bar	Determines relief sizing

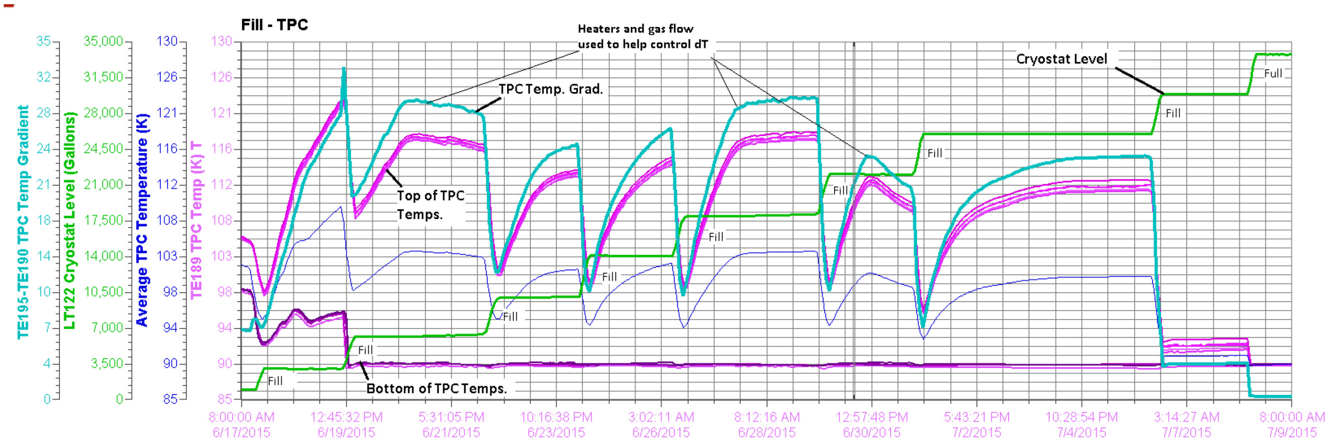

Figure 1. Graphical Representation of MicroBooNe Fill

3. DESCRIPTION OF THE SBN CRYOGENICS (SBND and SBN-FD)

3.1 Generalities of Both Systems

The near and far detector cryogenic designs are being developed With a focus on commonalities which can be used across the near and far detectors and also as a stepping stone for LBNF collaborative efforts. These systems will be modular in design and constructed on skids that can be tested separately prior to delivery to Fermilab for installation. Each experiment will rely on LN2 tankers for regular deliveries to local dewar storage. Storage dewars will be sized to provide several days of cooling capacity in event of a delivery Interruption. The lower estimated heat leak of the newly designed vessels allows for use of an open loop system typical of other LAr TPC vessels operated at Fermilab (see MicroBooNE).

The existing cryogenic system on the ICARUS T600 detector is meant to be kept as is, apart from the implementation of the open-loop LN2 delivery system. Figure 9 shows a schematic diagram of the T600 argon system including the existing LN2 refrigerators. These refrigerators would be replaced by a system like that shown in Figure 7 (bottom).
Preliminary discussions on the requirements and development of the T600 cryogenic system are ongoing. These discussions include the purification system, best re-condensation strategy,

and ullage conditions. It is not expected that these aspects will change significantly from previous experience where the systems performed well enabling the experiment to achieve very high levels of Argon purity with electron lifetime exceeding 15 ms. A description of the existing T600 cryogenic and purification systems can be found in 1 and the latest results on Argon punty are detailed in ….

3.2 Definition of Cryogenic Sub-systems

As FNAL and CERWN are engaging in a partnership which involves projects outside of the SBN Program (LBNF and ProtoDUNE), a common system and agreement for naming cryogenic subsystems has been defined. (See contribution 33 for example). The SBN detectors are being built with the following definitions.

External Cryogenics. It includes the equipment used to store the cryogenic fluids needed for the operation of the Proximity Cryogenics. LN2 is used as cryogen to heat exchange with gaseous argon for re-condensing as well as for thermal shields in the SBN-FD design. LAr is stored in a local dewar apart of the external cryogenic system and is delivered by transfer line to the detector.

Proximity Cryogenics. Consists of all the systems that take the cryogenic fluids from the External Cryogenics and delivers them to the Internal Cryogenics (I.e. detector cryostat) at the required pressure, temperature, purity, quality and mass flow rate. It includes the purification systems for the liquid (mole sieve filters and liquid pumps) and gaseous argon as well as the equipment for condensing argon (condensers, nitrogen and argon phase separators, and interconnecting piping).

Internal Cryogenics. Consists any cryogenic equipment located within the cryostats themselves, including the liquid and gaseous argon distribution piping and the piping to cool down the cryostats in the case of the SBND and simple fill lines for the SBN-FD.

Process Flow Diagrams (PFD) are shown in Figures 2 and 3 which show the equipment in basic form that is captured in each of the three subsystems. CERN has responsibsility for Proximity cryogenics for both detectors while Fermilab has responsibility for External cryogeninics for both, Internal for cryogeninics for the SBND. INFN is responsible for SBN-FD Internal as well as defining cooldown and fill procedures. FNAL has resposnibilities for process control hardware and software implementation in all cryogenic processes

3.3 Operational Modes and PFD

Each detector has developed a different approach to pre-cooldown as well as the approach to filling. The steps for each detector are described here.

3.3.1 SBND

- Gaseous argon purge. This is the initial phase during which the contaminants are removed from the cryostat (which starts filled with air) by means of a slow gaseous argon flow that pushes the impurities from the vessels bottom to the top and out. During the first part, when the cryostat is full of air, argon flow is established in open loop and vented. Once the contaminants (primarily oxygen,water and nitrogen) reach the parts per million (ppm) level, the argon is circulated in closed loop and sent to the gas purification system before being re-injected at the bottom of the cryostat. When the concentration of contaminants reaches the sub-ppm level, the cool-down can commence.
- Cool-down. Purified liquid argon is mixed with gaseous argon and distributed in dedicated sprayers

near the bottom of the cryostat to cool down the cryostat and the detector to their operating temperature
in a controlled way. Additional sprayers provide momentum to move the mist of liquid and gas uniformly inside. The cooling power is provided by the vaporization of liquid nitrogen from the refrigeration system.

- Filling. Once the cryostat and the TPCs are cold from cooldown method above then, then liquid argon is added directly from storage dewar.
- Steady state operations. During this phase the liquid argon contained inside each cryostat is continuously recirculated thought the liquid filtration system by means of an external pump. The boil-off gaseous argon is re-condensed in the condensers and purified through the liquid filtration system.

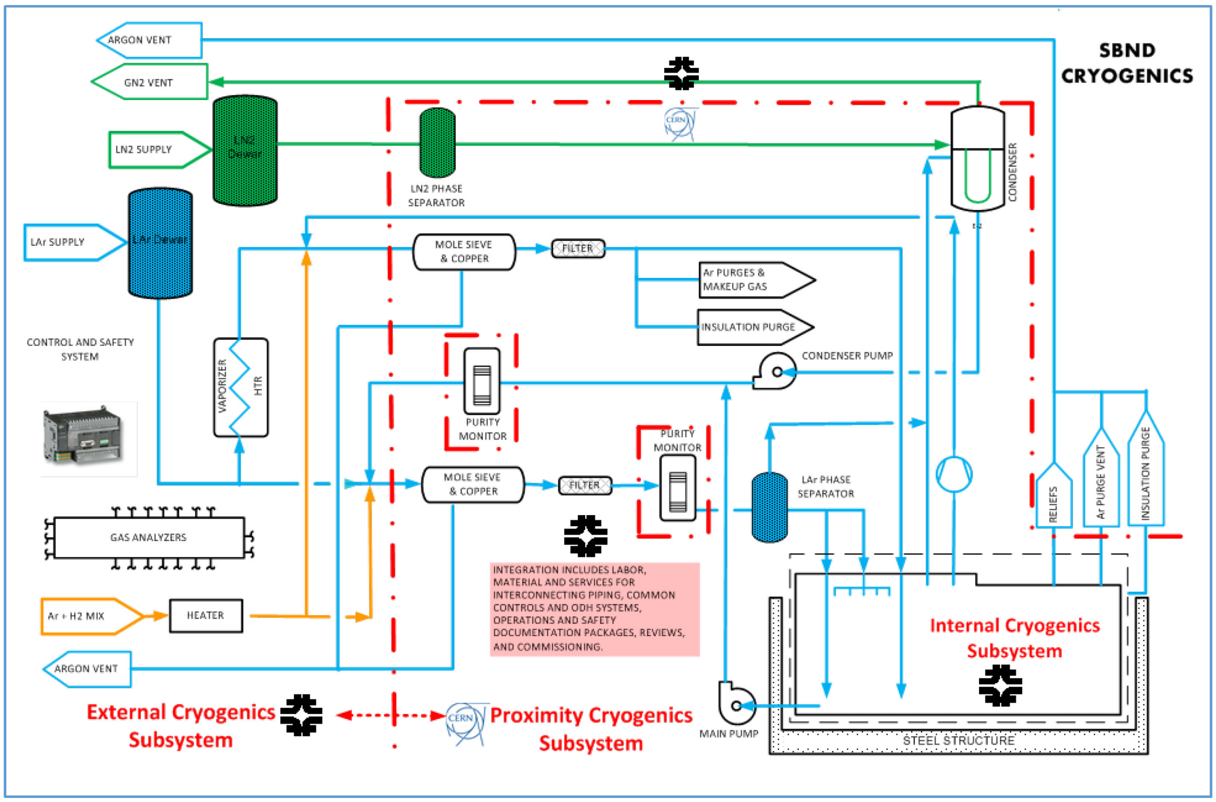

Figure 2. Process Flow Diagram for SBN Near Detector (SBND)

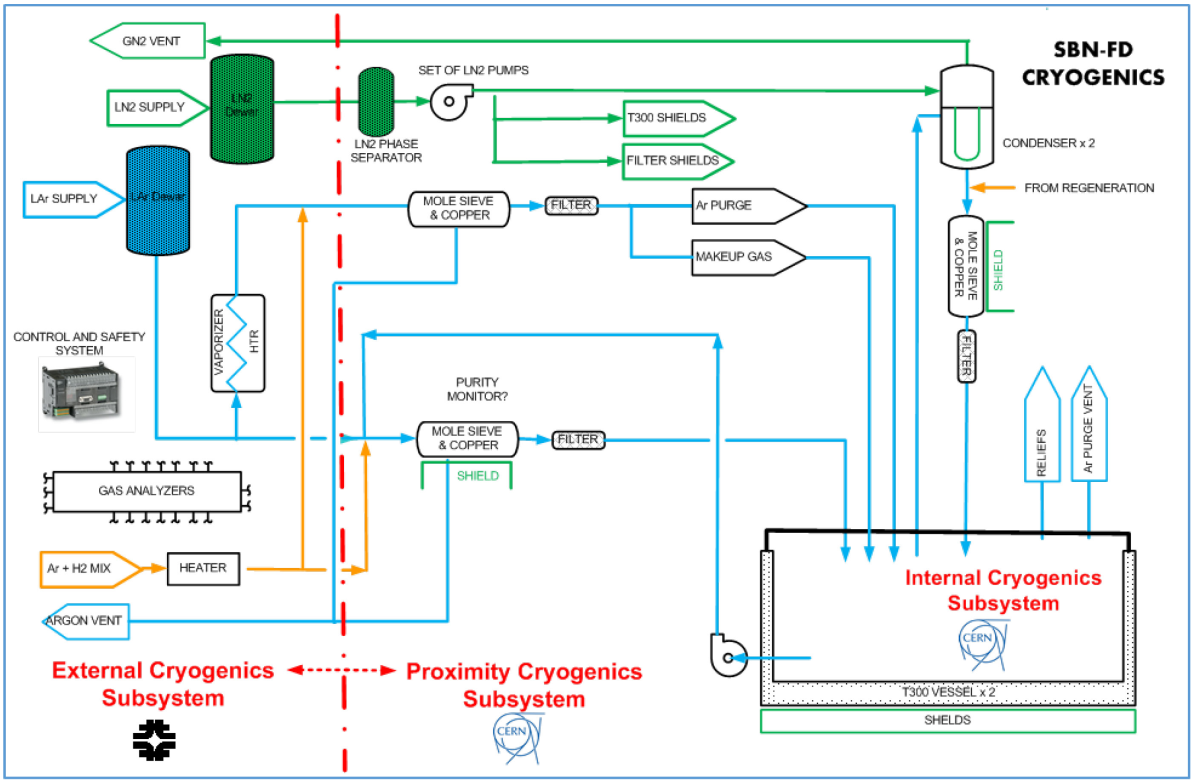

Figure 2. Process Flow Diagram for SBN Far Detector (SBN-FD)

SUMMARY AND NEXT STEPS

Fermilab and CERN are working together in the area of cryogenics to add two new neutrino detectors to the Neutrino Campus and Neutrino program based at Fermilab. Each laboratory has responsibilities and deliverables to bring systems online in 2018 for SBN-FD and 2019 for SBND. Each laboratory is in the design and fabrication mode at the time of this paper's writing. Equipment for External cryogenics is beginning to populate the two new buildings constructed for these detectors. In Europe the Proximity cryogenics is being designed and fabricated by a commercial vendor under CERN engineering guidance.

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REFERENCES

A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam, January 2015.