Proposal for a Full-Scale Detector Engineering Test and Test Beam Calibration of a Single-Phase LAr TPC

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Abstract

insert abstract here

Contents

1 Introduction [$\sim$5 pages; Thomas/Greg/Bob Wilson]

Describe LBNF science and need to prototype and test detector performance

- short description of physics measurements of ELBNF
- point to uncertainties in present knowledge of input parameters for sensitivity studies, lack of MC validation
- validation of full scale detector components

2 CERN prototype detector and charged particle beam test [$\sim$10 pages; Donna/Jarek]

describe and motivate proposed detector and beam test requirements

2.1 Requirements for the detector, beam and commissioning

The Single-Phase Cern Prototype detector is intended to provide necessary information to reduce systematic uncertainties for the oscillation measurements in the US-based long base-line neutrino experiment. The LAr TPC technology is not new but wasn't extensively used in the 1-10 GeV neutrino energy range. The main source of uncertainties due to detector with the current values are shown in table 1

Table 1: Current known sources of detector uncertainties for liquid argon or TPC.

source of uncertainty	**value**	**reference**
e/γ separation		
e-m shower calibration		
hadronic shower calibration		
low energy acceptance electron identification		
.....		

Table 2: Current known sources of uncertainties due to interaction of charged particle with argon.

source of uncertainty	**value**	**reference**
pion(Kaon) absorbtion		
pion(Kaon) charge exchange		
pion (Kaon) production in secondary interactions		
muon capture		Phys. Rev. C 35, 2212
energy scale		
Michel electron tagging		
.....		

With current detector uncertainties from table 1 the sensitivities for the CP violation phase measurement is shown in Fig. 2.1 **Task: make this plot** . The proposed test beam detector will reduce uncertainties to XX

Figure 1: Sensitivites for the δ_{CP} measurement for using current knowledge of the single-phase LAr-TPC detector technology and for reduced detector uncertainties from SPCP beamtest data. The plots prepared for 40 kton fiducial mass and $xx \times 10^{21}$POT.

2.1.1 Particles energy and direction

Plans for running beam for the the ELBNF include both neutrino and anti-neutrino configurations. These beams will be composed mainly of muon neutrinos (anti-neutrinos) as well as electron neutrinos (anti-neutrinos). In figures 2.1.1 and 2.1.1 the distributions on momenta and angles of particles created in neutrino interaction are shown.

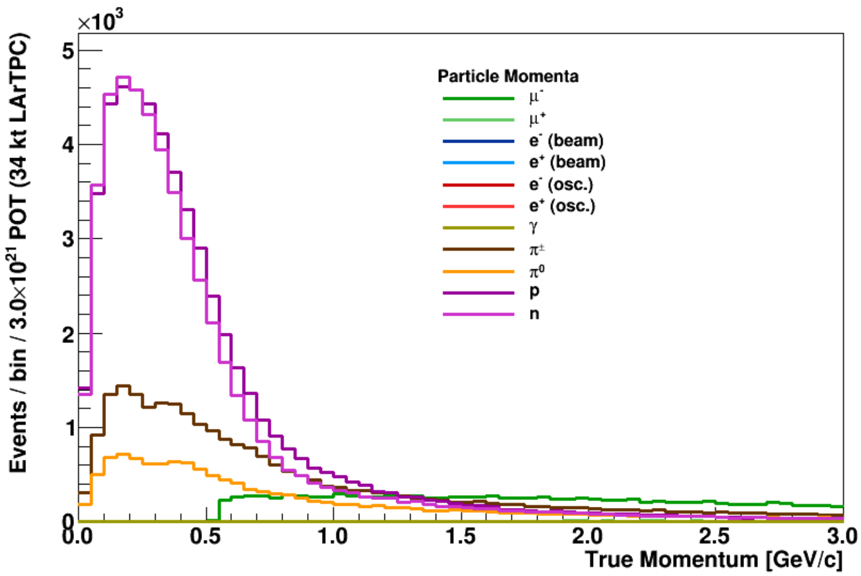

Figure 2: Particle momenta distributions for particles coming from all fluxes (ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$) at both near and far detector locations.

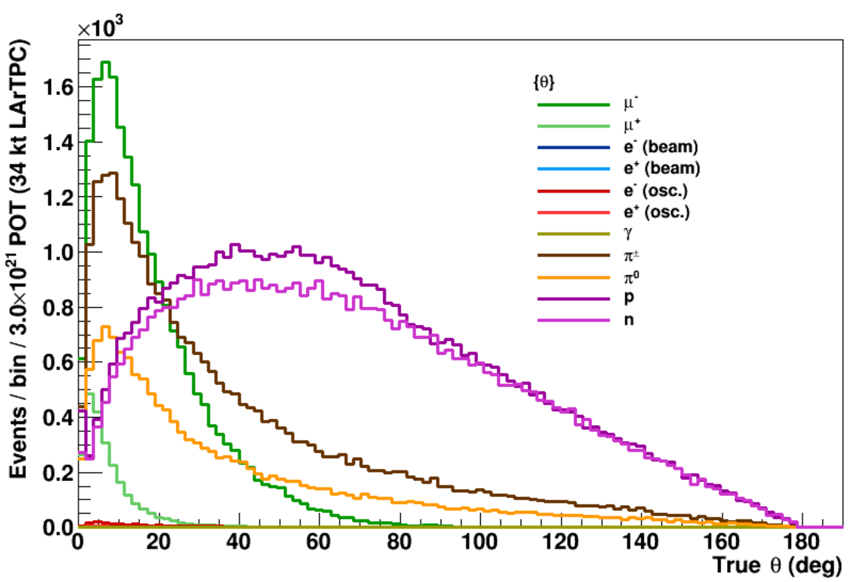

Figure 3: Particle angle wrt to the beam axis distributions for particles coming from all fluxes (ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$) at both near and far detector locations.

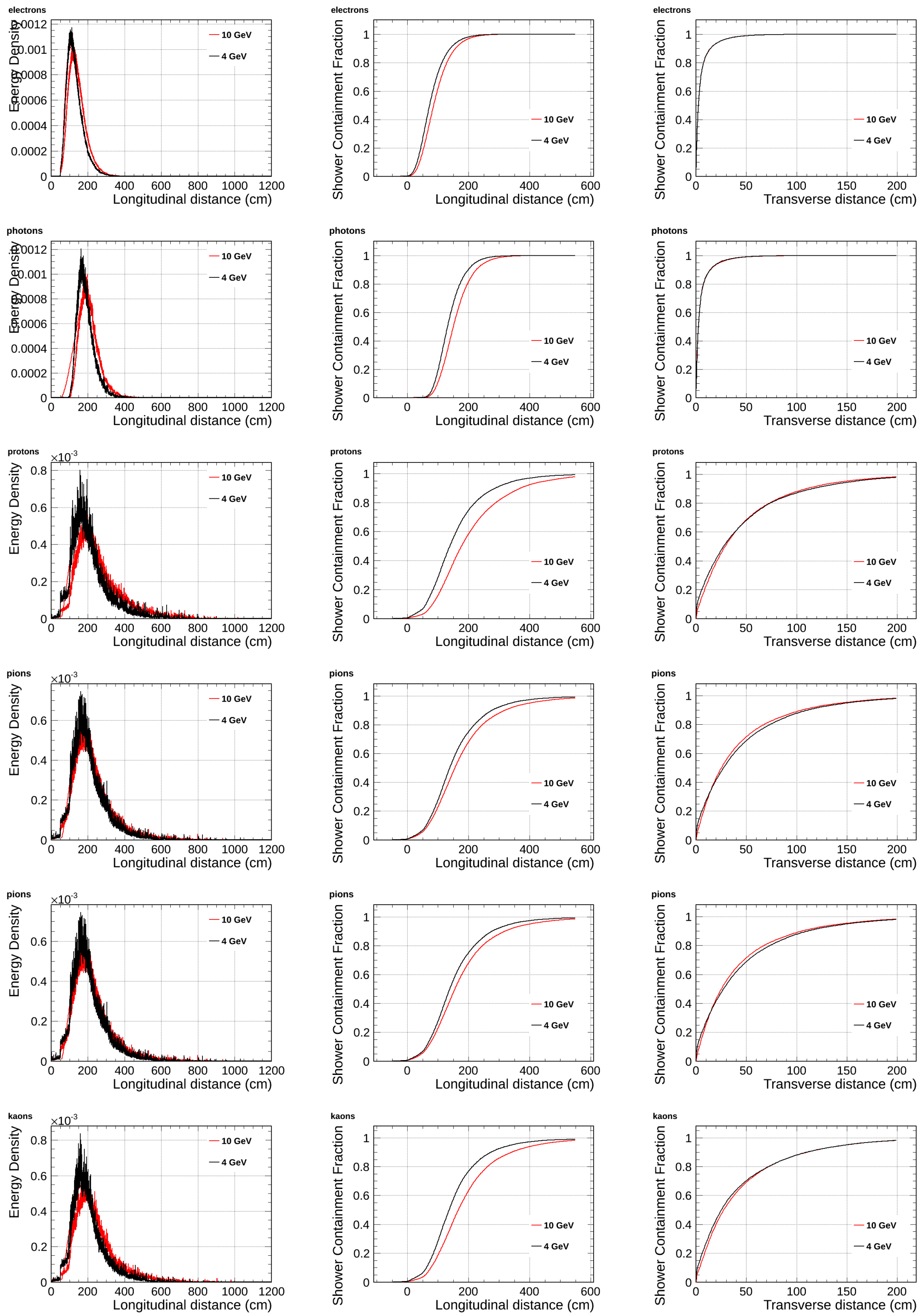

Figure 4: Particle containment plots.

2.1.2 Particle rates

Estimation of beam particles rates necessary to collect high enough statistics in a reasonable time to obtain goals of of the measurements.

2.1.3 Run plan

Based of the rates from the beam and required rates from the physics considerations.

2.2 Detector performance tests

2.2.1 Bethe-Bloch parametrisation of charged particles

The SPCP will allow to study the detector response to charge particles from the test beam and will serve as a calibration detector. The measured energy deposition for various particles and its dependence on the direction of the particle will feed into our Monte Carlo generator and allow more precise reconstruction of neutrino energy and interactions topologies with good particle identifications.

How we compare with Lariat? Multiple scattering

The set of single-phase prototype detector helped to understand the detector response to cosmic muons. But there is still lots to learn with additional studies. The charge particle identification efficiencies has been mapped for only limited range of the particle energies.

2.2.2 e/γ separation

The separation of the electrons from photons is the most important feature of the LAr TPC detectors for the search of the CP violation phase where we look for appearance of the ν_e in the ν_μ beam. Showers from electrons are part of the signal whilst the single photons might contribute to the background sample. The photons can undergo two process: pair production and Compton scattering. The dominant process for photons with energies of several hundreds MeV is the e^+ e^- pair production, but Compton scattering also occur at this energies. For pair production the e/γ separation is achieved by looking at the beginning of the electromagnetic shower, where for election we see energy deposition typical for single MIP and for photon we see energy deposition consisted with two MIP. The separation of e/γ has been measured in the ArgoNEUT experiment using neutrino scattering data with low statistics. Currently the separation efficiency is estimated to be at the level of of 94 % (? cite and check the number). In case of the Compton scattering the off atomic electron the signal is much more difficult to distinguish from the electron from the CC ν_e scattering.

The separation of the e/γ measured by ArgoNEUT is not sufficient for the ELBNF experiment. Here we propose a measurement of the separation efficiency as the function of energy and angle. **we need someone to look into this**

2.2.3 Reconstruction efficiencies and particle identification

The reconstruction of events in the LAr TPC is still a challenge but rapid progress has been achieved in recent years (cite pandora and other reconstruction algorithms). Despite the progress reconstruction algorithms have to rely Monte Carlo predictions which don't simulate liquid argon detectors responses correctly. Reconstruction algorithms will benefit greatly from test beam data particularly from the full scale prototype. The reconstruction algorithms will be trained to correctly reconstruct track, electromagnetic and hadronic showers.

The data of tracks and showers can be used to create a library which can be used for matching with he neutrino data, similar to the LEM (library event matching).

Main issues for the reconstruction algorithms:

- The reconstruction algorithms try to use all three planes on the signal readout. if the orientation of the track/shower is such that it is aligned with wires on one of the plans it significantly reduces quality of reconstructed objects.
- Calorimetry with collection and induction planes. In the ICARUS experiment the deposited energy was reconstructed from the signal on the collection plane. The induction planes bipolar signal wasn't "stable" enough to use it for calorimetric measurement. In the ELBNF design there is additional shielding wire plane which will improve the quality of the bipolar signal and the test beam experiment will help with its calibration.
- Vertexing.
- Reconstruction efficiency for low energy particles. The reconstruction algorithm suffer from the lose of fefficiency for low energy particle or particles which leave less than 200-300 hits. Training the algorithms on a low energy particles from the test beam will improve the quality and efficiency of the reconstructed objects.

2.2.4 Cross section measurements

Precise measurement of the absorption and charge exchange of pions and kaons. Pion absorption is a large part of the pion nucleon cross section from 50 MeV to 500MeV with no data above about 1GeV pion kinetic energy. **Add plots and values for known cross sections wit errors**

- pion absorption on argon - Kotlinski, EPJ 9, 537 (2000)
- pion cross section as a function of A - Gianelli PRC 61, 054615 (2000)

There is not currently a satisfactory theory describing absorption. The Valencia group (Vicente-Vacus NPA 568, 855 (1994)) developed model of the pion-nucleus reaction with fairly good agreement, although not in detail. The actual mechanism of multi-nucleon absorption is not well understood.

2.2.5 Charge sign determination

It is not possible to determine charge of the particle on the event by event basis with non-magnetised LAr TPC detectors. However, the statistical analyst will be possible. We will fit the muon's half time which is different for muons and antimony due to different muon capture cross sections. For the μ^+ for argon we expect about xx% to be captured and for μ^- about yy%.

2.2.6 Single track calibration

2.2.7 Shower calibration

Reconstruction of neutrino energy depends of a quality of reconstruction of both electromagnetic and hadronic showers.

- **features of Hadronic shower in LAr TPC** - **features of electromagnetic shower in LAr TPC** - Missing energy from neutral (Neutrons scattering)

2.3 Other measurements

2.3.1 Anti-proton annihilation

2.3.2 Proton decay background (cosmogenic $K^0 \to K^+$)

3 Single Phase LAr Detector [$\sim$10 pages; J. Stewart et al.]

3.1 LBNF detector

Description of LBNF far detector components

- Overview of the far detector option
  - List major components
- Dimensions
- Need for Modularity
- Scaling from previous detectors
- Possible development paths
- Parameter summary

3.2 CERN prototype detector

Detailed description of CERN prototype detector components

3.2.1 TPC description and size (from Jack Fowler)

The TPC will be assembled from elements that are of the same size as those planned for the single phase far detector. The overall size of the TPC will be derived by the size and number of anode planes (APA). It has been determined in order to perform the required physics, the TPC will consist of three APAs. The APAs will have an active area 2.29 m wide and 6.0 m high. These active area dimensions result in an APA that is 2.32 m wide and 6.29 m high. The combination of the three APAs will determine the overall length of the TPC. This is 7.2 m. There will be a cathode plane (CPA) on either side of the APAs. The size of the CPAs is determined by the active area of the three APAs.

The active area of the three APAs is approximately 7.2 m wide by 6.2 m high. The drift distance between the CPAs and row of APAs will be 2.5 m. The overall width of the TPC will be determined by a combination of the drift distances along with the thickness of the APA, which is constructed of 3" x 4" stainless steel (SS) structural tubing. The overall width of the TPC is 5.2 m. Like the length of the TPC, the overall height will be determined by the height of the APA. The overall height of the TPC will be 6.3 m. The TPC dimensions will be 7.2 m long x 5.2 m wide x 6.3 m high.

Along with the APAs and CPAs, the TPC will include a field cage that surrounds the entire assembly. It will be designed similarly to the field cage in phase 2 of the 35t experiment at FNAL. This is a series of protruded fiberglass I beams for the structural elements. These I-beams will be tiled with large copper sided FR4 panels to create the field cage. Each panel will be connected with a series of resistors. The field cage will be connected to the CPAs through a capacitor assembly.

All of this will be supported by rows of I-beams supported from a mechanical structure above the cryostat. The hangers for these I-beams will pass through the insulated top cap. There will be a series of feed thru flanges in the top cap of the cryostat to bring in and take out services for the TPC. There will be a HV feed thru for each of the CPAs and one signal feed thru for each of the APAs

3.2.2 Parameters table

3.2.3 Requirements (data rate, dimensions, gap to wall, ?)

3.2.4 Installation

Installation Plans for the TPC into the Cryostat (from Jack Fowler)

The interior of the cryostat will be prepared prior to the installation of the TPC. A series of support rails will be suspended below the top surface of the cryostat membrane. These will be structurally supported by a truss structure above the cryostat. These supports will pass through the top of the cryostat. They need to be designed to minimize the heat gain into the cryogenic volume. For the CPAs, the rails need to be electrically isolated due to high voltage concerns. To preserve the ability to reverse the order of the TPC components, all of the support rails will be designed to the same set of requirements regarding loads and attachment points.

There will be a series of feed thru flanges located along each of the support rails. These will be cryogenic flanges where the services for the TPC components can pass through the top of the cryostat. It is foreseen that each CPA will require one feed thru for the high voltage probe to bring in the drift voltage. The drift voltage is 500 V/cm. For a drift distance of 2.5 m, the probe voltage will be 125 kV. There will be one service feed thru for each of the APAs. These feed thrus will include high speed data, bias voltages for the wire planes, control and power for the cold electronics.

The main TPC components will be installed through a large hatch in the top of the cryostat. This is similar to the installation method intended for the detector at the far site. This hatch will have an aperture approximately 2.0 m wide and 3.5 m long. Each APA and CPA panel will be carefully tested after transport into the clean area and before installation into one of the cryostats. Immediately after a panel is installed it will be rechecked. The serial installation of the APAs along the rails means that removing and replacing one of the early panels in the row after others are installed would be very costly in effort and time. Therefore, to minimize the risk of damage, as much work around already installed panels as possible will be completed before proceeding with further panels. The installation sequence is planned to proceed as follows:

1. Install the monorail or crane in the staging area outside the cryostat, near the equipment hatch.
2. Install the relay racks on the top of the cryostat and load with the DAQ and power supply crates.
3. Dress cables from the DAQ on the top of the cryostat to remote racks.
4. Construct the clean-room enclosure outside the cryostat hatch.
5. Install the raised-panel floor inside the cryostat.
6. Insert and assemble the stair tower and scaffolding in the cryostat.
7. Install the staging platform at the hatch entrance into the cryostat.
8. Install protection on (or remove) existing cryogenics instrumentation in the cryostat.
9. Install the cryostat feedthroughs and dress cables inside the cryostat along the support beams.
10. Install TPC panels:
    (a) Install both CPA panels. These will be installed from the floor of the cryostat. Access to the top edge will be required by scaffolding.
    (b) Install and connect HV probe for each of the CPAs.
    (c) Perform electrical tests on the connectivity of the probe to the CPAs.
    (d) Install first end wall of vertical field cage at the non-access end of the cryostat. These will be installed from the floor of the cryostat. Scaffolding will be needed to install the supporting structure and then attach the panels to the structure.
    (e) Test the inner connections of the field cage panels.
    (f) Install the first APA and connect to the far end field cage support.
    (g) Connect power and signal cables. This will require scaffolding to access the top edge of the APA.
    (h) Test each APA wire for expected electronics noise. Spot-check electronics noise while cryogenics equipment is operating.
    (i) Install the upper field cage panels for the first APA between the APA and CPAs This will require scaffolding to access the upper edge of the APA, CPA and field cage structure.

(j) Perform electrical tests on upper field cage panels.

(k) Repeat steps (f) through (j) for the next two APAs.

(l) Install the lower field cage panels between the APAs and CPAs. Start at the far end away from the access hatch and work towards the hatch.

(m) Perform electrical test on lower field cage panels and the entire loop around the TPC.

(n) Remove temporary floor sections as the TPC installation progresses.

(o) Install sections of argon-distribution piping as the TPC installation progresses.

(p) Install the final end wall of vertical field cage at the access end of the cryostat. These will be installed from the floor of the cryostat. Scaffolding will be needed to install the supporting structure and then attach the panels to the structure.

11. Remove movable scaffold and stair towers.

12. Temporarily seal the cryostat and test all channels for expected electronics noise.

13. Seal the access hatch.

14. Perform final test of all channels for expected electronics noise.

In general, APA panels will be installed in order starting with the panel furthest from the hatch side of the cryostat and progressing back towards the hatch. The upper field cage will be installed in stages as the installation of APA and CPAs progresses. After the APAs are attached to the support rods the electrical connections will be made to electrical cables that were already dressed to the support beams and electrical testing will begin. Periodic electrical testing will continue to assure that nothing gets damaged during the additional work around the installed APAs.

The TPC installation will be performed in three stages, each in a separate location; the locations, or zones, are shown in Figure x-xx (this illustration was made for a 34-kton, in-line underground detector, but the work zones are also applicable for the 10-kton surface siting). First, in the clean room vestibule, a crew will move the APA and CPA panels from storage racks, rotate to the vertical position and move them into the cryostat. Secondly, in the panel-staging area immediately below the equipment hatch of the cryostat, a second crew will transfer the lower panels from the crane to the staging platform, connect the upper and lower panels together, route cables to the top of stacked panels and f inally transfer the stacked panels on to the monorail trolley that moves within the cryostat. A third crew will reposition the movable scaffolding and use the scaffold to make the mechanical and electrical connections at the top for each APA and CPA as they are moved into position. The monorails inside and outside the cryostat will each have two motorized trolleys so that work can be conducted by all three crews in parallel. The steady-state rate for installation, given this work plan and a single-shift schedule, is estimated to be two stacked panels per day.

The requirements for alignment and survey of the TPC are under development. Since there will be plenty of cosmic rays in the surface detector and beam events, significant corrections can be made for any misalignment of the TPC. The current plan includes using a laser guide or optical transit and the adjustment features of the support rods for the TPC to align the top edges of the APAs in the TPC to be straight, level and parallel within a few mm. The alignment of the TPC in other dimensions will depend on the internal connecting features of the TPC. The timing of the survey will depend on understanding when during the installation process the hanging TPC elements are in a dimensionally stable state. The required accuracy of the survey is not expected to be finer than a few mm.

3.2.5 APA

- General description of the APA
- Justification for the basic design (Dimensions, wire Wrapping, wire pitch and angle, hung nature)
- Description of construction technique

3.2.6 CPA and Field Cage

- General description of the CPA - material, HV coupling, Stored energy, ...
- Description of construction and installation
- General description of the field cage
- Description of design alternatives and engineering plan
- Overview of design and installation plan

3.2.7 TPC Readout

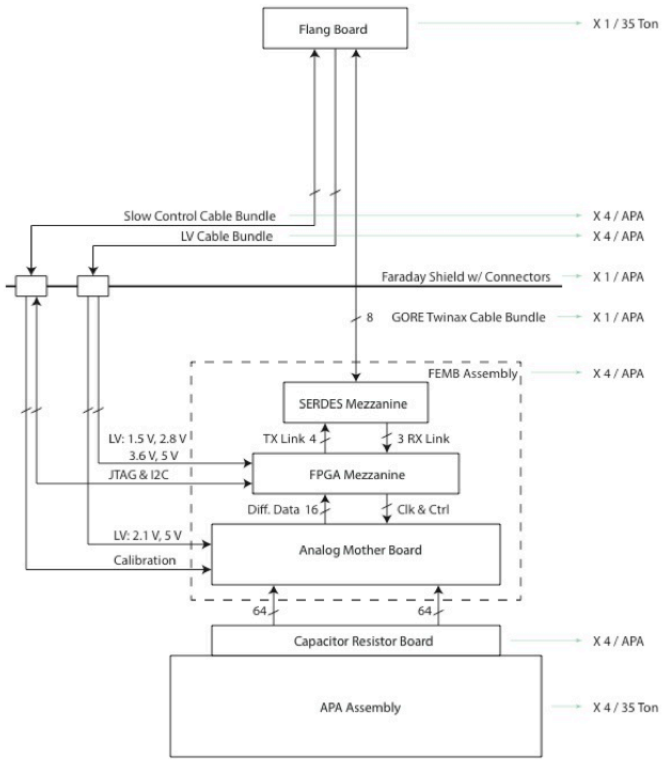

Figure 5: Schematic for the TPC cold FE electronics. ***MG*** Not sure if this is high enough quality. ***Ask Chen for source and fix numbers.

The TPC front-end (FE) electronics operate at cryogenic temperatures. The system provides amplification, shaping, digitization, buffering and multiplexing of the signals. The FE electronics consist of three boards stacked on top of one another: the Analog Mother Board, the FPGA Mezzanine Board, and the SERDES Mezzanine Board. Figure 3.2.7 shows a schematic of the cold FE electronics.

The Analog Mother Board contains the front-end ASIC chips which perform the analog readout of the TPC wires. The FE ASIC chip is implemented as a mixed-signal ASIC providing amplification, shaping, digitization, buffering, a 16:2 multiplexing stage, a driver and voltage regulators. The analog-to-digital converter on the ASIC samples each TPC wire at 2 MHz. Eight such chips are mounted on a single readout board, instrumenting 128 adjacent wires in one plane.

The two (multiplexed) signals from each FE ASIC are fed into the FPGA Mezzanine Board. The cold FPGA aggregates the TPC data and also supplies the control and clock to the FE ASICs. The FPGA on the mezzanine board receives the data and packages the 128 channels together, one 2 MHz clock tick at a time. This is then sent to the SERDES board for serialization and sent to the cryostat flange board over high-speed (1 Gbps) serial links and finally to the DAQ system.

Besides the high-speed signal cable, which is a twin-axial cable bundle manufactured by GORE, there are cable bundles for low-voltage power, wire-bias voltages, and various slow controls and monitoring. Redundant cables will be provided for many of these functions. The cable bundles will be connected through a feedthrough on the roof of the cryostat.

parameter	value
ADC Sampling Rate	2 MHz
More stuff	
Cluster-on-Boards (COB)	3
Data-Processing-Modules (DPM)	12
ATCA Shelves	1 (6-slot)
TPC Readout Compute Nodes	3

The primary interface between the TPC front-end electronics (FE) and the DAQ subsystem consists of an ATCA-based system of RCEs (Reconfigurable Cluster Elements). The RCE system receives the serialized raw data for the FE, performs zero-suppression on it, and packetizes and transmits the resulting sparsified data to a back-end data farm for event building and further processing. Additionally, the RCE system transmits timing and control signals to the FE as well as forwarding configuration data to them at start-up.

The RCE system consists the following components: a commercial ATCA shelf (2-, 6-, or 14-slot), a Cluster-On-Board (COB) which is the "front board" in ATCA terms, and a Rear-Transition-Module (RTM) which is the "rear board". A schematic of the system is shown in Figure 3.2.7. The COB is a custom board, developed by SLAC, which holds the processing power of the system. The COB (see Figure **??**) consists of 5 bays for holding daughter boards, an onboard 10-GbE switch, and both 10- and 1-Gb ethernet connections for communications with the back-end system. Four of the daughter-board bays are for Data Processing Modules (DPM), each of which can hold up to two RCEs. The RCE is the core procession unit of the system; it is made up of a modern SoC (currently, the Xilinx Zynq-7045) with multiple high-speed I/O ports (up to 10-Gbps each) and external DRAM and flash memory controllers. The other bay on the COB contains the Data Transmission Module (DTM) which is responsible for distributing timing and trigger information to and between the DPMs.

While the COB hardware is application agnostic, the RTM is application specific. The RTM provides the mechanical interface between the front-end (or, in our case, the flange electronics) and the back-end, as well as other external sources such as the timing or trigger systems. In this case we will use fiber optic connections between the flange and the TPC DAQ using 8 12-channel (full duplex) CXP connectors on the RTM.

With the assumption that each cold FE board multiplexes it's 128 wire channels to 4 outputs at 1-Gbps each, the non-zero suppressed data for 1 APA can be fed into a single COB (containing 8 RCEs). Each RCE would receive data from 2 FE boards, perform zero-suppression, and send the result to the back-end.

MG***data rates?

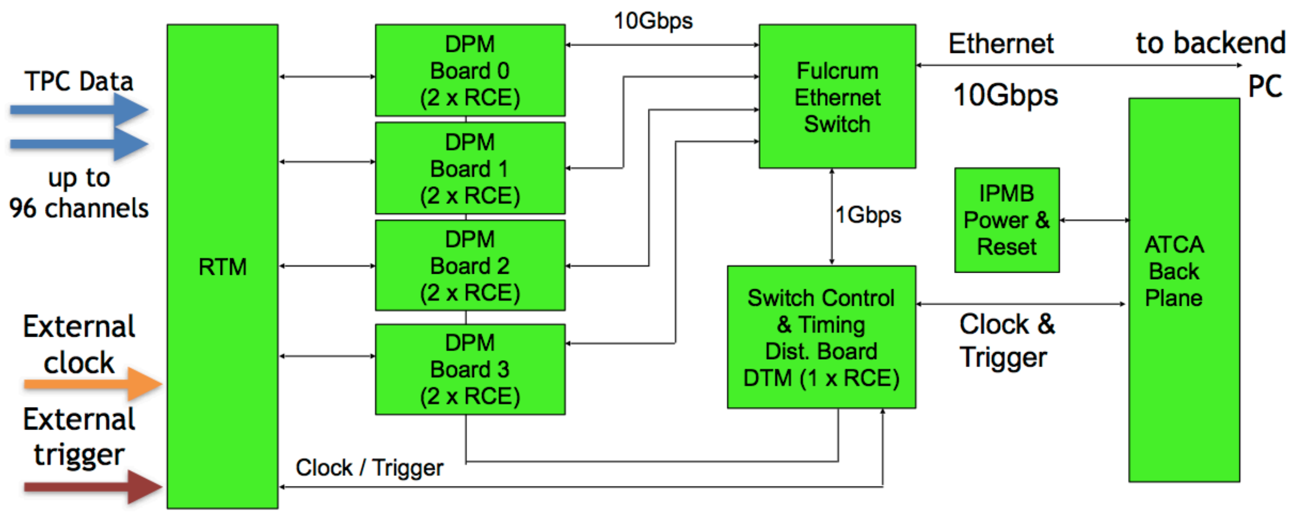

Figure 6: Schematic for the TPC DAQ system.

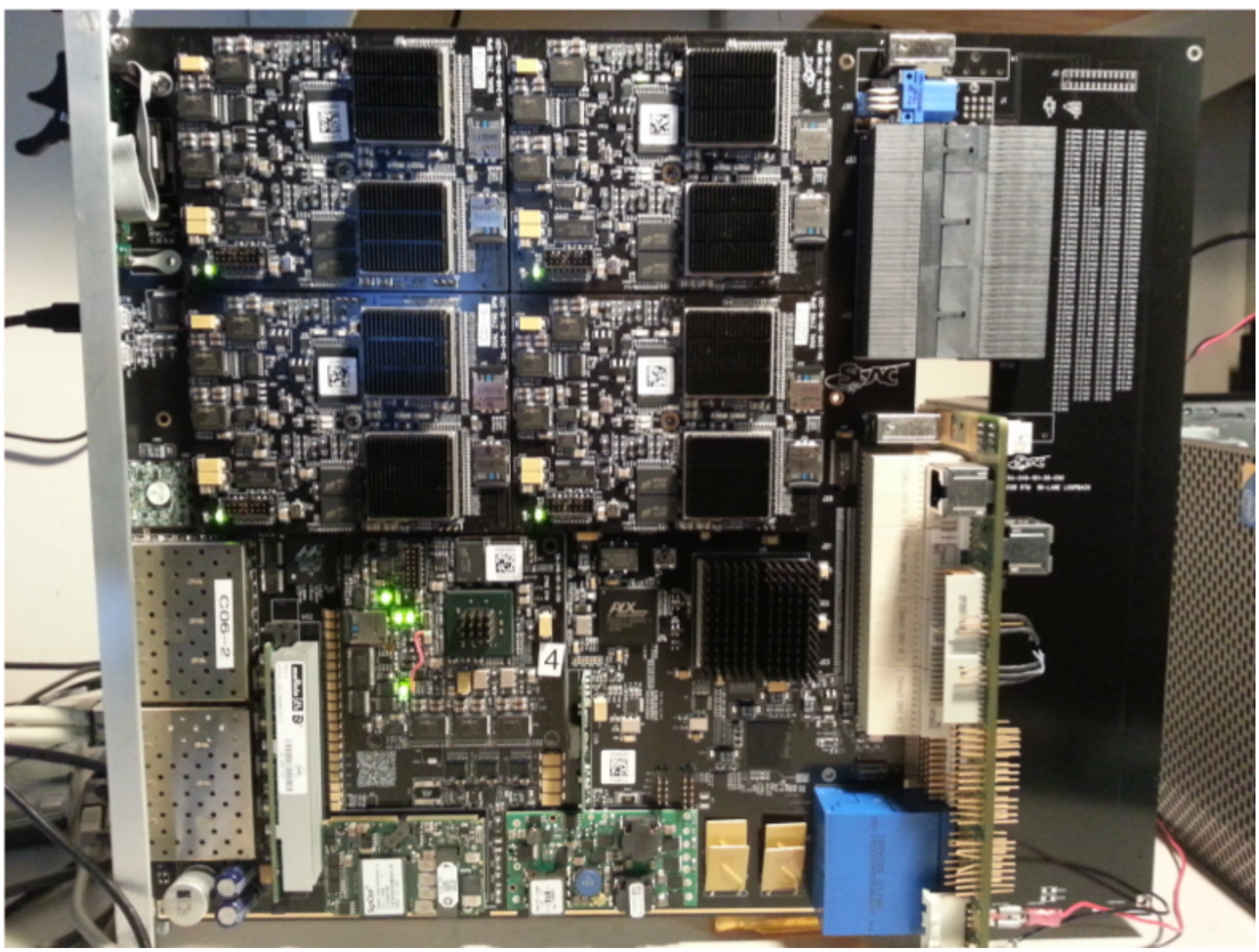

Figure 7: The COB (left of the large connectors) and RTM (right).

- Overview of the TPC readout chain (include main parameters)
- Overview of the cold electronics
- Overview of the RCE and interface to the DAQ
- Discussion of sparsification and triggering

3.2.8 Photon Detection System

- General description of the photon system including requirements
- Overview of the photon system alternatives and selection process
- Description of the readout and development plans

3.2.9 DAQ, Slow control and monitoring

The DAQ will merge data to form events from the LArTPC, photon detector and beam detector readouts using the artDAQ data acquisition toolkit using a farm of commercial computers connected with an Ethernet switch. ArtDAQ is in use on several experiments at Fermilab. We are using it on the 35t prototype, so we will have considerable experience by the time of the CERN test.

The data collection for the CERN test will operate in a mode similar to that forseen for the underground detectors. In order to collect data from non-beam interactions such as proton decay candidates or atmospheric neutrinos, data will be continuously read in to the artDAQ data receiver nodes and processed through the artDAQ system in quanta corresponding to time intervals fixed from the time of the beginning of the run. These are then transferred through the switch to a set of event building nodes which work in parallel, each node receiving all the data from all the detectors for the time intervals it is responsible for processing. There will be 32 parallel incoming data streams from the LArTPCs and 16 streams from the photon detectors. There will be an additional stream from the trigger board (the same board as built by Penn for the 35t test will be used) which will receive input of the spill gate, warning of extraction, and pattern-unit bits from trigger counters and other beamline instrumentation such as Cerenkov counters [Which section are these described in?, should we refer to them from here?].

Synchronisation across all the input sources is essential in order that artDAQ can bring together the data from the input streams correctly for processing by the event building nodes. The data receiver nodes will provide overlap by repeating the data at the boundaries of the time intervals so that a particle whose data spans two time intervals can be collected. The time synchronisation is provided to the RTM back-module on the LArTPC readout crates, to the SSP photon detector readout and to the trigger board from a GPS based time synchrononisation distribution system originally designed for the NOvA experiment. This system includes functionality to calibrate and correct for the cable delays, and to send synchronisation control signals to the readout at predetermined times.

The event building nodes will select time regions of interest within the time intervals they are processing and form these into events to be written to disk. The algorithms to select the events may be as simple as looking for a trigger bit in the trigger board data stream, or may involve looking for self-triggered events in the LArTPC data. An aggregation task, which is part of artDAQ will handle the parallelized event building processes by merging the output events into a single stream and writing them to disk. To avoid oversized output data files, when a predetrmined file size is reached, the aggregator will switch to writing to a new file. The collaboraion requests to CERN, data links of sufficient bandwidth to transfer these files from the CENF to the CERN data center, and from there to locations worldwide for analysis.

Improved versions of the software systems which are being prototyped at the 35t test will available for the CERN test including (a) Run control which controls and monitors the DAQ processes and allows run starts and stops to be performed by the operator (b) online monitoring (c) slow control of voltages and temperatures being used by the electronics (this may not be comprehensive by the time of the CERN protoype, but we plan on prototyping the readout of some of the quantities). The trigger board includes facilities for generating calibration pulses and for identifying the event times of the calibration events.

- General description of the DAQ system
- Plans and status for the 35t and next steps
- Needs for a slow control system

3.2.10 Offline requirements and software

4 Cryostat and cryogenics system [∼5 pages; David/Barry/Jack

Describe requirements to meet detector goals

4.1 LBNF detector

This section to provide context and illustrate which aspects need testing at the CERN prototype

(Probably can take text from CDR once it's more developed)

4.2 CERN prototype detector

4.2.1 Cryostat from David Montanari

The Single Phase TPC test at CERN will use a membrane tank technology to contain the base design of 725 tons of LAr equivalent to about $520m^3$. The design is based on a scaled up version of the LBNE 35 Ton Prototype and the Fermilab Short Baseline Near Detector. We propose that the cryostat be housed in the extension of the EHN1 Bat 887 at CERN, where the cryogenic system components will also be located. The cryostat will use a steel outer supporting structure with a metal liner inside to isolate the insulation volume, similar to the one of the dual phase detector prototype WA105 $1 \times 1 \times 3$ and to the Fermilab Short Baseline Near Detector. The support structure will rest on I-beams to allow for air circulation underneath to maintain the temperature within the allowable limits. The scope of the EHN1 cryostat subsystem includes the design, procurement, fabrication, testing, delivery and oversight of a cryostat to contain the liquid argon and the TPC. This section describes a reference design, whose scope encompasses the following components:

- steel outer supporting structure,
- main body of the membrane cryostat (sides and floor),
- top cap of the membrane cryostat.

A membrane cryostat design commonly used for liquefied natural gas (LNG) storage and transportation will be used. In this vessel a stainless steel membrane contains the liquid cryogen. The pressure loading of the liquid cryogen is transmitted through rigid foam insulation to the surrounding outer support structure, which provides external support. The membrane is corrugated to provide strain relief resulting from temperature related expansion and contraction. The vessel is completed with a top cap that uses the

Figure 8: Exploded view of the membrane cryostat technology

Figure 9: Side (left) and end (right) views of cryostat

same technology. Two membrane cryostat vendors are known: GTT (Gaztransport & Technigaz) from France and IHI (Ishikawajima-Harima Heavy Industries) from Japan. Each one is technically capable of delivering a membrane cryostat that meets the design requirements for this detector. To provide clarity, only one vendor is represented in this document, GTT; this is for informational purposes only. Figure 1 shows a 3D model of the GTT membrane and insulation design.

The conceptual reference design for the Single Phase Test at CERN cryostat is a rectangular vessel measuring 9.5 m in length (parallel to the beam direction), 7.3 m in width, and 8.40 m in height; containing a total mass of 725 tons of liquid argon. Figure 10 shows side and end views of the cryostat respectively. Figure 3 shows a 3D view. To minimize the contamination from warm surfaces, during operation the temperature of all surfaces in the ullage shall be lower than 100 K. The top plate will contain two hatches to install the TPCs and enter the tank, a manhole and several penetrations for the cryogenic system and the detector.

Design Parameters

This design is meant to test technical solutions that may be of interest for future needs of the Long Baseline Neutrino program. The use of a cold ullage (¡ 100 K) to lower the impurities in the gas region, and of a LAr pump outside the cryostat to minimize the effect of noise, vibration and microphonics to the TPC inside the LAr are Value Engineering studies for the Long Baseline program. The design parameters for the TPC Test at CERN cryostat are listed in Table I.

Insulation system and secondary membrane

The membrane cryostat requires insulation applied to all internal surfaces of the outer support structure and roof in order to control the heat ingress and hence required refrigeration heat load. The maximum required static heat leak is $15W/m^2$ for the floor and the sides and $20W/m^2$ for the roof. Preliminary calculations show that it can be obtained using 0.8 m thick insulation panels. Given an average thermal conductivity coefficient for the insulation material of 0.0283 W/(m·K), the heat input from the surrounding steel is expected to be about 3.7 kW total. It assumes that the hatches are foam insulated as well. This is shown in Table II. The insulation material is a solid reinforced polyurethane foam manufactured as composite panels. The panels get laid out in a grid with 3 cm gaps between them (that will be filled with fiberglass) and fixed onto

Figure 10: Isometric view of the membrane cryostat

Table 3: Design requirements for the cryogenic system (put in right values)

Design Parameter	Value
Location	Preferably not in front of the cryostat (on t
Cooling Power	TBD based on the heat leak of the cryostat
Liquid argon purity in cryostat Gaseous argon piston purge rate of rise	10 ms electron lifetime (30 ppt O2 equivale 1.2 m/hr
Membrane cool-down rate	From manufacturer
TPCs cool-down rate	¡40 K/hr,¡10 K/m (vertically)
Mechanical load on TPC	The LAr or the gas pressure shall not apply
Nominal LAr purification flow rate (filling/ops)	5.5 day/volume change
Temperature of all surfaces in the ullage during operations Gaseous argon purge within insulation	¡100 K 1 volume change /day of the open space be
Lifetime of the cryogenic system	Consistent with the LAr program. TBD.

anchor bolts anchored to the support structure. The composite panels contain the two layers of insulation with the secondary barrier in between. After positioning adjacent composite panels and filling the 3 cm gap, the secondary membrane is spliced together by epoxying an additional overlapping layer of secondary membrane over the joint. All seams are covered so that the secondary membrane is a continuous liner.

The secondary membrane is comprised of a thin aluminum sheet and fiberglass cloth. The fiberglass-aluminum-fiberglass composite is very durable and flexible with an overall thickness of about 1 mm. The secondary membrane is placed within the insulation space. It surrounds the bottom and sides. In the unlikely event of an internal leak from the primary membrane of the cryostat into the insulation space, it will prevent the liquid cryogen from migrating all the way through to the steel support structure where it would degrade the insulation thermal performance and could possibly cause excessive thermal stress in the support structure. The liquid cryogen, in case of leakage through the inner (primary) membrane will escape to the insulation volume, which is purged with GAr at the rate of one volume exchange per day.

Table 4: Heat load calculation for the membrane cryostat (insulation thickness = 0.8 m). (put in right values)

Design Parameter	Value
Location	Preferably not in front of the cryostat (on the beam)
Cooling Power	TBD
Liquid argon purity in cryostat Gaseous argon piston purge rate of rise	10 ms electron lifetime (30 ppt O2 equivalent) 1.2 m/hr
Membrane cool-down rate	From manufacturer
TPCs cool-down rate	¡40 K/hr,¡10 K/m (vertically)

Cryostat Configuration

This section describes the configuration of the cryostat only. The TPC is described in Section xxx. With the intent to minimize the contamination in the gas region, the ullage will be kept cold (¡ 100 K). A possible way to achieve this requirement is to spray a mist of clean liquid and gaseous argon to the metal surfaces in the ullage and keep them cold, similar to the strategy that was developed for the cool down of the LBNE 35 Ton prototype.

Outer Support Structure

The reference design is a steel support structure with a metal liner on the inside to isolate the insulation region and keep the moisture out. This choice allows natural and forced ventilation to maintain the temperature of the steel within acceptable limits, without the need of heating elements and temperature sensors. It reduces the time needed for the construction: the structure will be prefabricated in pieces of dimensions appropriate for transportation, shipped to the destination and only assembled in place. Fabrication will take place at the vendor's facility for the most part. This shortens the construction of the outer structure on the detector site, leaving more time for completion of the building infrastructure. If properly designed, a steel structure may allow the cryostat to be moved, should that be desired later in the future.

Main body of the membrane cryostat

The sides and bottom of the vessel constitute the main body of the membrane cryostat. They consist of several layers. From the inside to the outside the layers are stainless steel primary membrane, insulation, thin aluminum secondary membrane, more insulation, and steel outer support structure with meal panels acting as vapor barier. The secondary membrane contains the LAr in case of any primary membrane leaks and the vapor barrier prevents water ingress into the insulation. The main body does not have side openings for construction. The access is only from the top. There is a side penetration for the liquid argon pump for the purification of the cryogen.

Top cap

Several steel reinforced plates welded together constitute the top cap. The stainless steel primary membrane, intermediate insulation layers and vapor barrier continue across the top of the detector, providing a leak tight seal. The secondary barrier is not used nor required at the top. The cryostat roof is a removable steel truss structure that bridges the detector. Stiffened steel plates are welded to the underside of the truss to form a flat vapor barrier surface onto which the roof insulation attaches directly. The penetrations will be clustered in the back region, as far away from the beam as possible. The top cap will have a large opening for TPC installation, a secondary smaller opening for personnel access and a manhole. The truss structure rests on the top of the supporting structure where a positive structural connection between the two is made to resist the upward force caused by the slightly pressurized argon in the ullage space. The hydrostatic load of the LAr in the cryostat is carried by the floor and the sidewalls. Everything else within the cryostat (TPC planes, electronics, sensors, cryogenic and gas plumbing connections) is supported by the steel plates under the truss structure. All piping and electrical penetration into the interior of the cryostat are made through this top plate, primarily in the region of the penetrations to minimize the potential for leaks. Studs are welded to the underside of the top plate to bolt the insulation panels. Insulation plugs are inserted into the bolt-access holes after panels are mounted. The primary membrane panels are first tack-welded then fully welded to complete the inner cryostat volume.

Cryostat grounding and isolation requirements

The cryostat has to be grounded and electrically isolated from the building. Table IV presents the list of the current grounding and isolation requirements for the cryostat.

Table 5: Design parameters for the cryostat top (put in right values)

Design Parameter	Value
Location	Preferably not in front of the cryostat (on the beam)
Cooling Power	TBD
Liquid argon purity in cryostat	10 ms electron lifetime (30 ppt O2 equivalent)
Gaseous argon piston purge rate of rise	1.2 m/hr
Membrane cool-down rate	From manufacturer
TPCs cool-down rate	¡40 K/hr,¡10 K/m (vertically)

Figure 11: Top plate grounding layout

Figure 4 shows the layout of the top plate grounding.

Table 6: Cryostat grounding and isolation requirements (put in right values)

Design Parameter	Value
Location	Preferably not in front of the cryostat (on the beam)
Cooling Power	TBD
Liquid argon purity in cryostat	10 ms electron lifetime (30 ppt O2 equivalent)
Gaseous argon piston purge rate of rise	1.2 m/hr
Membrane cool-down rate	From manufacturer
TPCs cool-down rate	¡40 K/hr,¡10 K/m (vertically)

Leak prevention

The primary membrane will be subjected to several leak tests and weld remediation, as necessary. All (100%) of the welds will be tested by an Ammonia colorimetric leak test (ASTM E1066-95) in which welds are painted with a reactive yellow paint before injecting a Nitrogen-Ammonia mixture into the insulation space of the tank. Wherever the paint turns purple or blue, a leak is present. The developer is removed, the weld fixed and the test is performed another time. Any and all leaks will be repaired. The test lasts a minimum of 20 hours and is sensitive enough to detect defects down to 0.003 mm in size and to a $10^{-7} std - cm^3/s$ leak rate (equivalent leak rate at standard pressure and temperature, 1 bar and 273 K). To prevent infiltration of water vapor or oxygen through microscopic membrane leaks (below detection level) the insulation spaces will be continuously purged with gaseous argon to provide one volume exchange per day. The insulation space will be maintained at 30 mbar, slightly above atmospheric pressure. This space will be monitored for changes that might indicate a leak from the primary membrane. Pressure control devices and safety relief valves will be installed on the insulation space to ensure that the pressure does not exceed the operating pressure inside the tank. The purge gas will be recirculated by a blower, purified, and reused as purge gas. The purge system is not safety- critical; an outage of the purge blower would have negligible impact on LAr purity.

Cryostat size from TPC dimensions (from Jack Fowler)

The minimum internal size of the cryostat is determined from size of the TPC. At the bottom of the cryostat there needs to be a minimum of 0.3 m between the frame of the CPA and closest point on the SS membrane. This is to prevent high voltage discharge between the CPA and the electrically grounded membrane. It is foreseen that there would be some cryogenic piping and instrumentation under the TPC. There is a height allowance of 0.1 m for this. There will be access and egress space around the outside of the TPC and the membrane walls. On three sides, 1.0 m of space is reserved for this. The final side of the TPC will have piping and instrumentation for the cryogenic system. There will be 1.3 m of space reserved for this.

The support system for the TPC will be located at the top between the underside of the cryostat roof and the top of the TPC. The plan is to model this space similar to what is planned for the far site TPC. There will be 0.9 m of ullage space. In order to prevent high voltage discharge, the upper most part of the CPA needs to be submerged a minimum of 0.3 m below the liquid Argon surface. The top of the TPC will be separated from the membrane by a minimum of 1.2 m.

Adding all of these to the size of the TPC yields the minimum inner dimensions of the cryostat. A minimally sized cryostat would be 9.5 m long, 7.3 m wide and 8.4 m high. This assumes the TPC will be positioned inside the cryostat with the CPAs and end field cages parallel to the walls of the cryostat. Also there is no space allotted for a beam window to enter the cryostat. Clearance would need to be added if it violates any of the current boundaries listed above. These dimensions also preserve the ability to reverse the order of the APAs and CPAs inside the TPC. The current plan is to have the APAs located in the center of the cryostat with a CPA on each side. Reversing this to have the CPA in the center and APAs on each side may be required to achieve some of the proposed physics. The orientation of the TPC components will be finalized after various scenarios have been sufficiently simulated.

4.3 Cryogenic System (from David Montanari)

The cryogenic system is being developed as part of the international engineering team set up between Fermilab and CERN to design, fabricate and install cryogenic systems of similar requirements and increased size for Short and Long Baseline at Fermilab, and WA105s at CERN. The goal is to develop a single model and adapt if for all future generation detectors, with the necessary scaling up in size and adjustments for eventual different needs of the different detectors. Table 7 presents the list of requirements for the cryogenic system for the Single Phase TPC test at CERN detector.

Figure 1 outlines the basic scheme of the LN2 supply system, which was proposed by CERN for the Short Baseline Program and agreed as an appropriate solution for this detector as well. The experiment will rely on LN2 tankers for regular deliveries to a local dewar storage, which will be sized to provide several days of cooling capacity in the event of a delivery interruption. From the dewar storage the LN2 is then transferred to a distribution facility located in the experimental hall. It includes a small buffer volume and an LN2 pumping station that transfers the LN2 to the argon condenser and other services as needed. The low estimated heat leak of the vessel (3.5 kW) and the location inside an above ground building allow for use of an open loop system typical of other installations operated at Fermilab (LAPD, LBNE 35 ton prototype, MicroBooNE) and at CERN (???). Main goal of the LN2 system is to provide cooling power for the argon condenser, the initial cool down of the vessel and the detector, and all other services as needed.

Figure 2 shows a schematic diagram of the proposed liquid argon system. It is based on the design of the LBNE 35 ton prototype, the MicroBooNE detector systems and the current plans for the Long Baseline Far Detector.

Main goal of the LAr system is to purge the tank prior to the start of the operations (with GAr in open and closed loop), cool down the tank and fill it with LAr. Then continuously purify the LAr and the boil off GAr to maintain the required purity (electron lifetime measured by the detector).

The LAr receiving facility includes a storage dewar and an ambient vaporizer do deliver LAr and GAr to the cryostat. The LAr goes through the liquid argon handling and purification system, whereas the Gar through the gaseous argon purification before entering the vessel. The LAr purification system is currently equipped with a filter containing mol sieve and copper beds, and a regeneration loop to regenerate the filter itself. The filter medium may change following the ongoing developments on filtration schemes, but the concept remains the same.

During operation, an external LAr pump circulates the bulk of the cryogen through the LAr purification system. The boil off gas is first re-condensed and then is sent to the LAr purification system before re- entering the vessel.

Table 7: Design requirements for the cryogenic system

Parameter	
Location	Pre
Cooling Power	TBD based on the heat leak of the cryostat
Liquid argon purity in cryostat	
Gaseous argon piston purge rate of rise	
Membrane cool-down rate	
TPCs cool-down rate	
Mechanical load on TPC	The LAr or the gas pressur
Nominal LAr purification flow rate (filling/ops)	
Temperature of all surfaces in the ullage during operations	
Gaseous argon purge within insulation	1 volume c
Lifetime of the cryogenic system	

(figures)

5 Charged Particle Test Beam Requirements [∼10 pages; Cheng-Ju]

5.1 Particle Beam Characteristics

5.2 EHN1 H4ext Beam Line

5.2.1 Beam Optics

5.2.2 Expected Rates and Purity

5.3 Beam Instrumentation

5.3.1 Beam Position Detector

5.3.2 Time-of-Flight Detector

5.3.3 Threshold Cherenkov Counter

5.4 Muon Veto

5.4.1 Muon Halo

5.4.2 Cosmic-Ray Muon

5.5 Beam Window on LAr Cryostat

This section could be absorbed into the cryostat chapter.

6 Computing requirements, data handling and software [∼3 pages; Maxim/Graig]

computing, data handling and software requirements go here

7 CERN neutrino platform test environment [5 pages; David/Jack/Cheng-Ju/Thomas]

Description of Requirements, layout and constraints

- short description of location and orientation of cryostat + cryogenics system in EHN1 (David)
- description of beam line layout (Cheng-Ju)
- space for staging, control room, electronics racks, clean room, scaffolding, etc. (Jack)
- power requirements and cooling (Jack ?)
- ...

8 Organization, schedule and cost estimate [$\sim$5 pages; Thomas/Greg]

insert organization, schedule and cost estimates here

- schedule
- working group structure and distributions of tasks/responsibilities
-
- list detector components covered by LBNX project
- describe sharing of cryostat responsibilities (engineering, contracting); what is expected
- beam line expected to be set up by CERN
- beam line monitoring
- plans for data analysis and publications
- describe overlap/commonalities with WA105 data analysis

9 Summary [$\sim$2 pages; Thomas/Greg]

this is the summary section
$\rightarrow$ total estimated page count: $\sim$60 pages