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

A. name1[1], B. name2[2], and C. name3[3]

[1]Department of X1, University Y1
[2]Department of X2, University Y2
[3]Department of X3, University YY3

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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.

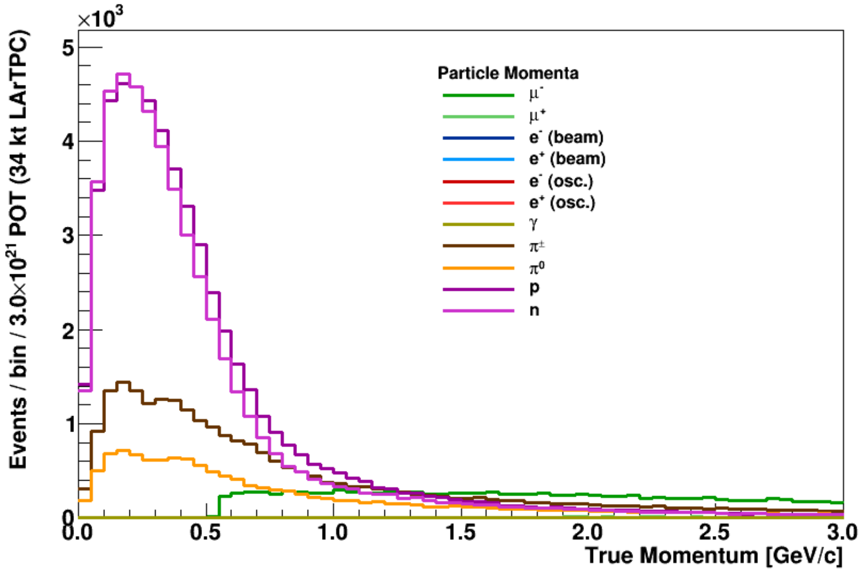

Figure 2: Particle momenta distributions for particles coming from all fluxes (ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$) at both near and far detector locations.

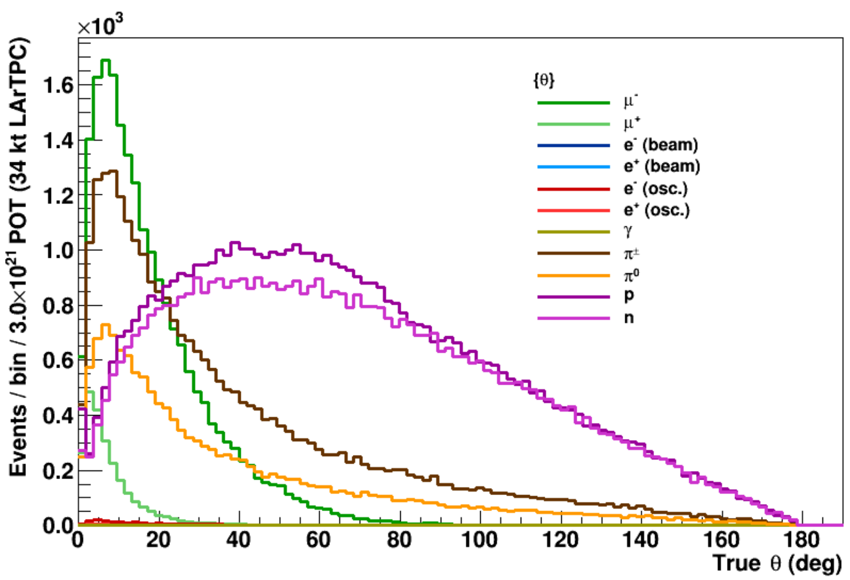

Figure 3: Particle angle wrt to the beam axis distributions for particles coming from all fluxes (ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$) at both near and far detector locations.

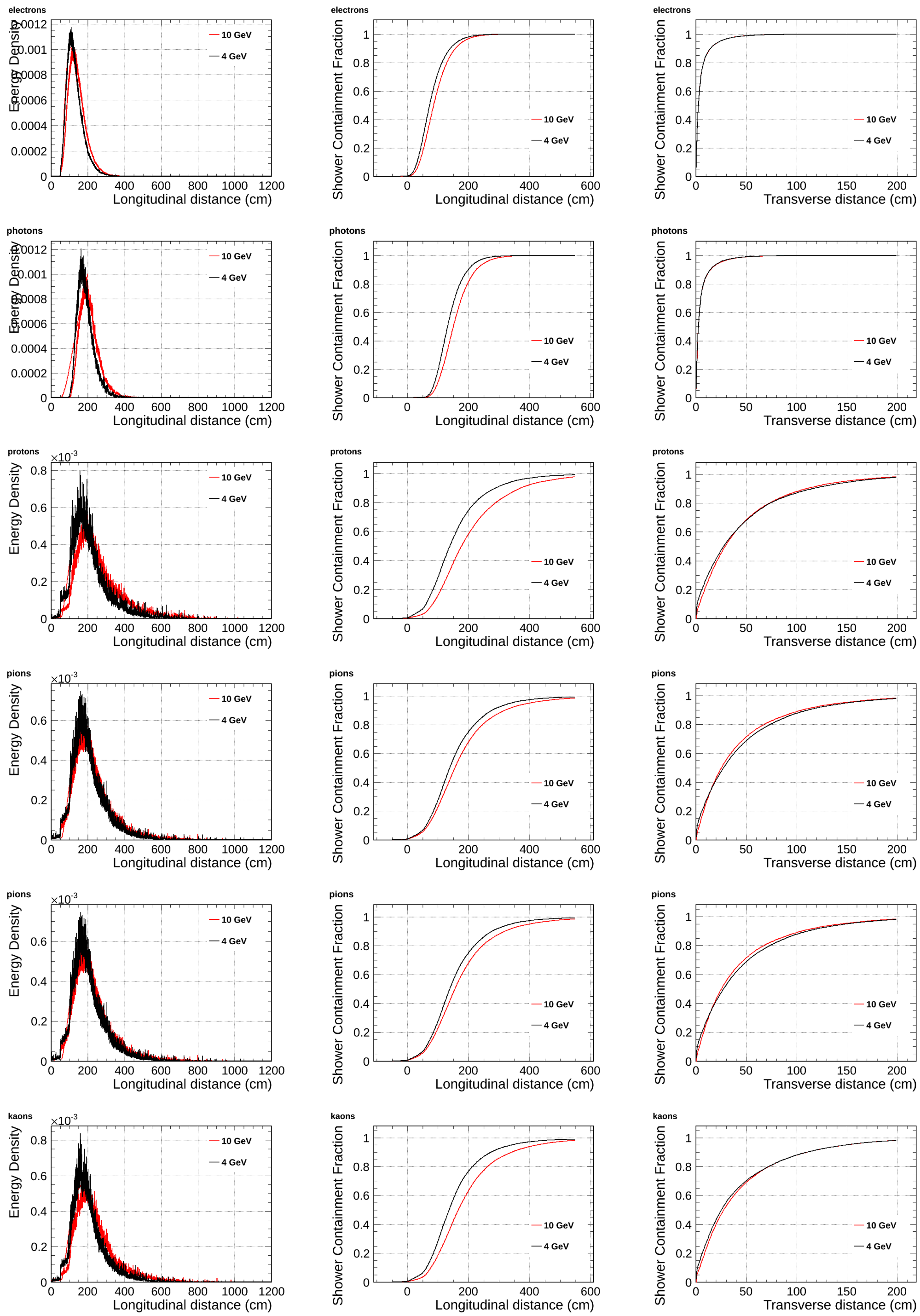

Figure 4: Particle containment plots.

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 $K^0 \rightarrow K^+$)

3 Single Phase LAr Detector [~10 pages; J. Stewart et al.]

3.1 LBNF detector

The far detector for the ELBNF collaboration will be a series of four xx kt (10 kt) active (fiducial) volume liquid argon time projection chambers instrumented with photon detection. It is planned that the first 10 kt detector will be ready for commissioning in 2021. One option for the TPC design is a wire plane based TPC with cold electronics readout. Designs of this style are are referred to as single-phase detectors as the charge generation, drift, and detection all occurs in the argon liquid phase. This style TPC has the advantage that there is no charge amplification before collection making a very precise charge measurement possible. To achieve ELBNF's goals, a detector much larger than ICARUS, the largest LAr TPC detector built to date, is needed. ELBNE is developing a scalable far detector design shown in Figure 5 that would scale-up LAr TPC technology by roughly a factor of 50 compared to the ICARUS T600 detector. To achieve this scale-up, a number of novel design elements need to be employed. A membrane cryostat typical for the liquefied natural gas industry will be used instead of a conventional evacuated cryostat. The wire planes or anode plane assemblies (APAs) will be factory-built as planar modules that are then installed into the cryostat. The modular nature of the APAs allow the size of the detector to be scaled up to at least 40 kt fiducial mass. Both the analog and digital electronics will be mounted on the wire planes inside the cryostat in order to reduce the electronic noise, to avoid transporting analog signals large distances, and to reduce the number of cables that penetrate the cryostat. The scintillation photon detectors will employ light collection paddles to reduce the required photo-cathode area. Many of the aspects of the design will be tested in a small scale prototype at Fermilab but given the very large scale of the detector elements a full-scale test is highly desirable.

The goals of the LBNE detector test can be broken into four categories: argon contamination mitigation verification, TPC mechanical verification, TPC electrical verification, and photon detection light yield verification. Research at Fermilab utilizing the Materials Test Stand has shown that electronegative contamination to the ultra-pure

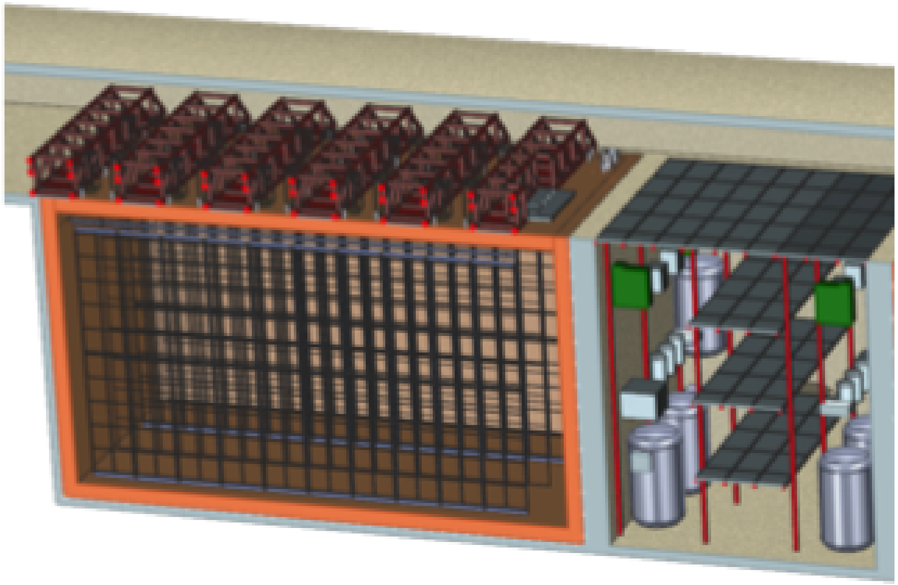

Figure 5: 3D model of one design of the ELBNF single-phase detector. Shown is 5kt fiducial volume detector which would need to be lengthened for the 10 kt design. The present ELBNF plan calls for the construction of 4 10 kt detectors of similar design.

argon from all materials tested is negligible if the material is under the liquid argon. This implies that the dominant source of contamination originates from the gas ullage region and in the room temperature connections to the detector. Careful design of the ullage region to insure that all surfaces and feedthroughs are cold is expected to greatly reduce the sources of contamination over what exists in present detectors. Other concepts attempt to eliminate the gas ullage completely. The goals related to mechanical testing are to test the integrity of the detector. In the current design, each APA measures 2.3 m by 6.0 m and includes 2560 wires and associated readout channels. Given the complexity of these assemblies, a test where the detector can be thermally cycled and tested under operating conditions is highly advised prior to mass production. The mechanical support of the APAs can be tested to verify that the mechanical design is reliable and will accommodate any necessary motion between the large wire planes. The impact of vibration isolation between the cryostat roof and the detector can also be tested. Finally a potential improvement in the cryostat design is the possibility to move the pumps external to the main cryostat. This will reduce any mechanical coupling to the detector and also greatly improve both reliability and ease of repair. The electrical testing goals are to insure that the high voltage design is robust and that the required low electronic noise level can be achieved. As the detector scale increases so does the capacitance and the stored energy in the device. The design of the field cage and high voltage cathode planes needs to be such that HV discharge is unlikely and that if the event occurs no damage to the detector or cryostat results. The grounding and shielding of large detectors is also critical for low noise operation. By testing the full scale elements one insures that the grounding plan is fully developed and functional. Large scale tests of the resulting design will verify the electrical model of the detector.

3.2 CERN prototype detector

3.2.1 Overview of the CERN test Detector

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

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.

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

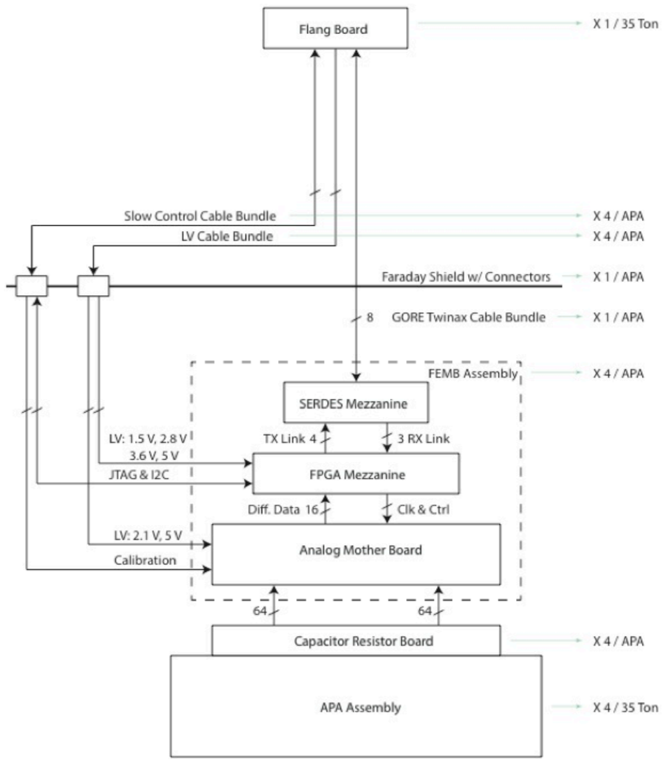

Figure 6: Schematic for the TPC cold FE electronics. ***MG*** Not sure if this is high enough quality. ***Ask Chen for source and fix numbers.

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?

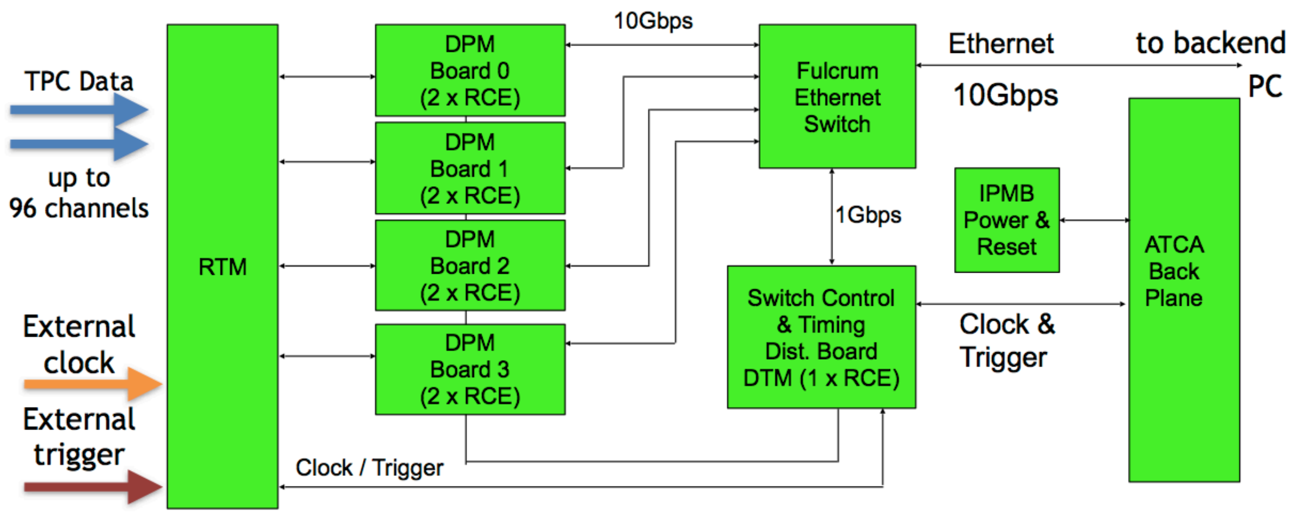

Figure 7: Schematic for the TPC DAQ system.

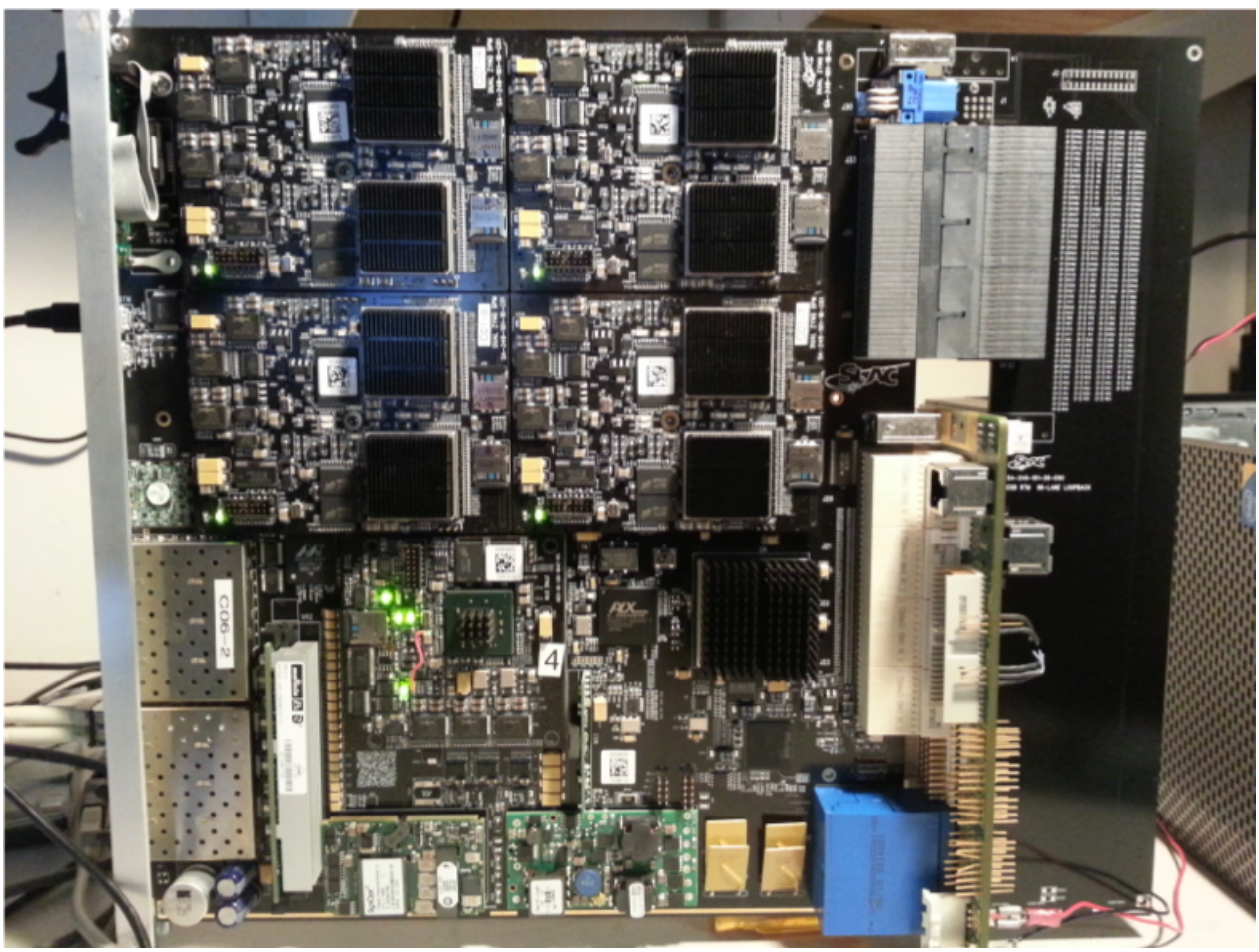

Figure 8: The COB (left of the large connectors) and RTM (right).

- 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

4.2 CERN prototype detector

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 [$\sim$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 [~2 pages; Thomas/Greg]

this is the summary section

$\rightarrow$ total estimated page count: ~60 pages