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		
.....		

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

source of uncertainty	**value**	**reference**
pion absorbtion		
pion charge exchange		
muon capture		
.....		

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.

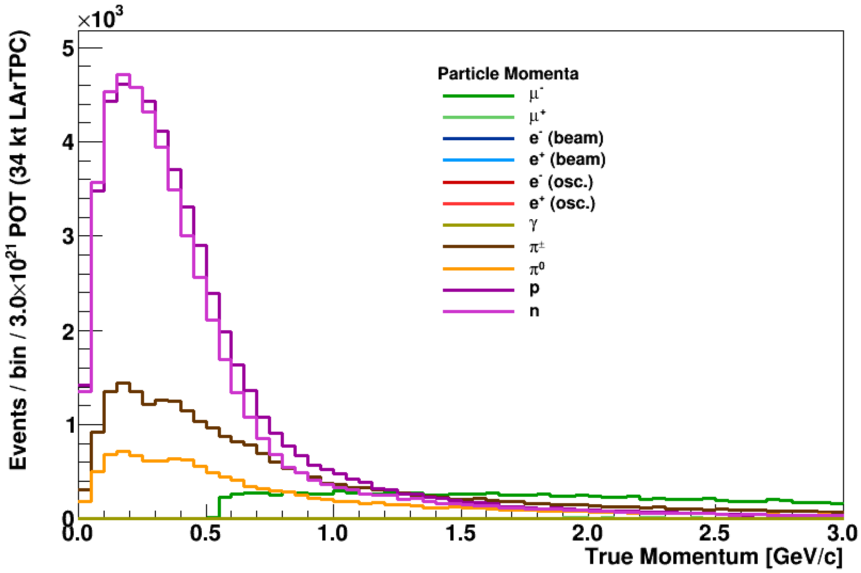

Figure 2: Particle momenta distributions for particles coming from all fluxes (ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$) at both near and far detector locations.

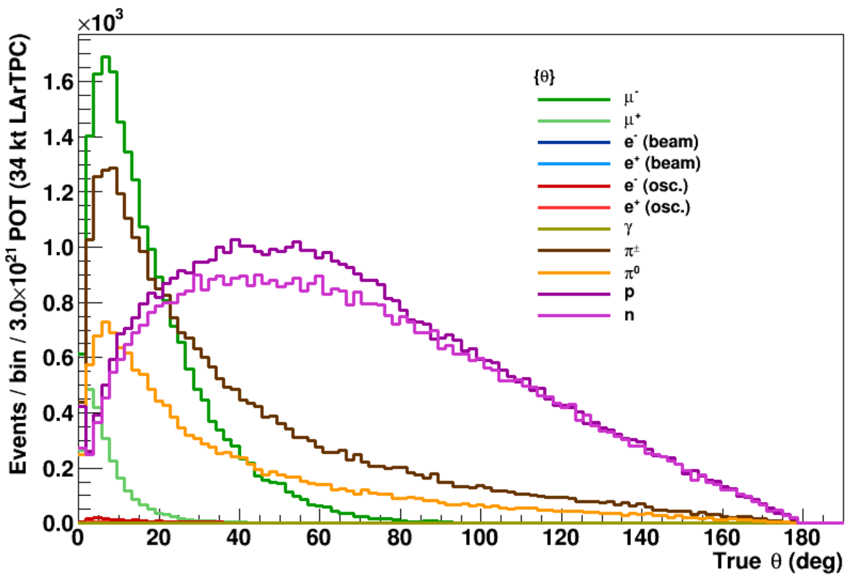

Figure 3: Particle angle wrt to the beam axis distributions for particles coming from all fluxes (ν_e, ν_μ, $\bar{\nu}_e$ and $\bar{\nu}_\mu$) at both near and far detector locations.

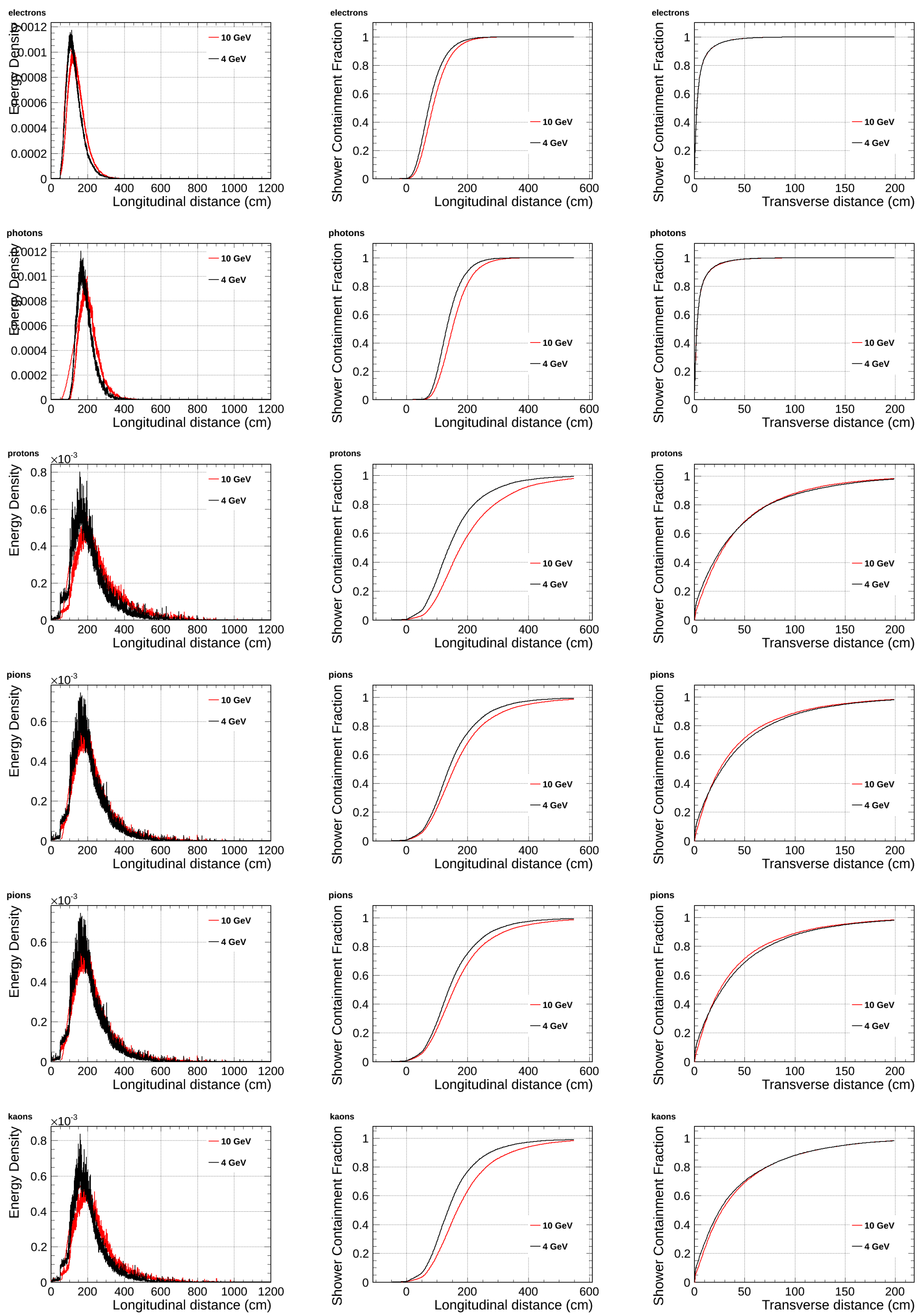

Figure 4: Particle containment plots.

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 [∼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

- Overview of the CERN test Detector
- Parameters table
- Requirements (data rate, dimensions, gap to wall, ?)
- Installation

3.2.1 APA

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

3.2.2 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

3.2.3 TPC Readout

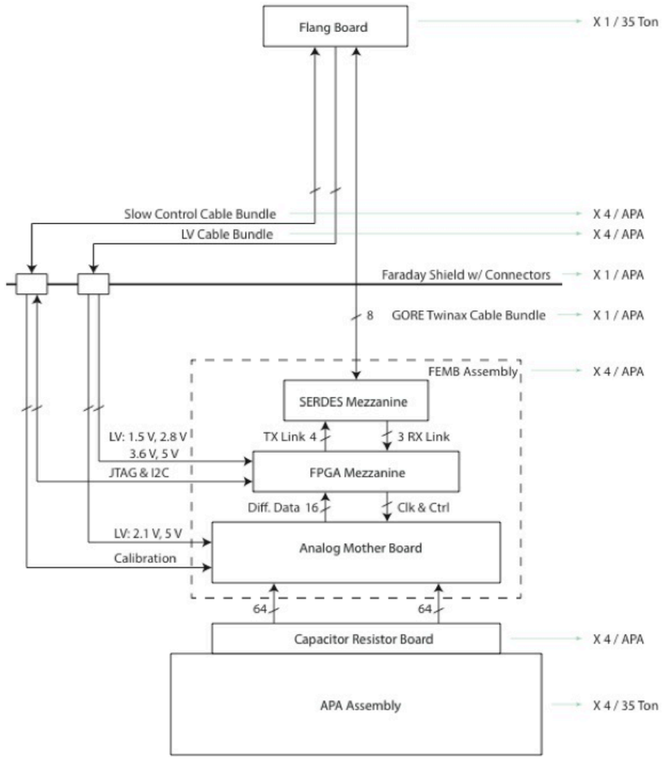

Figure 5: Schematic for the TPC cold FE electronics. ***MG*** Not sure if this is high enough quality. ***Ask Chen for source and fix numbers.

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 3.2.3 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". The COB is a custom board, developed by SLAC, which holds the processing power of the system. The COB (see Figure 7) 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 propose to use fiber optic connections between the flange and the TPC DAQ using QSFP+ connectors.

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.

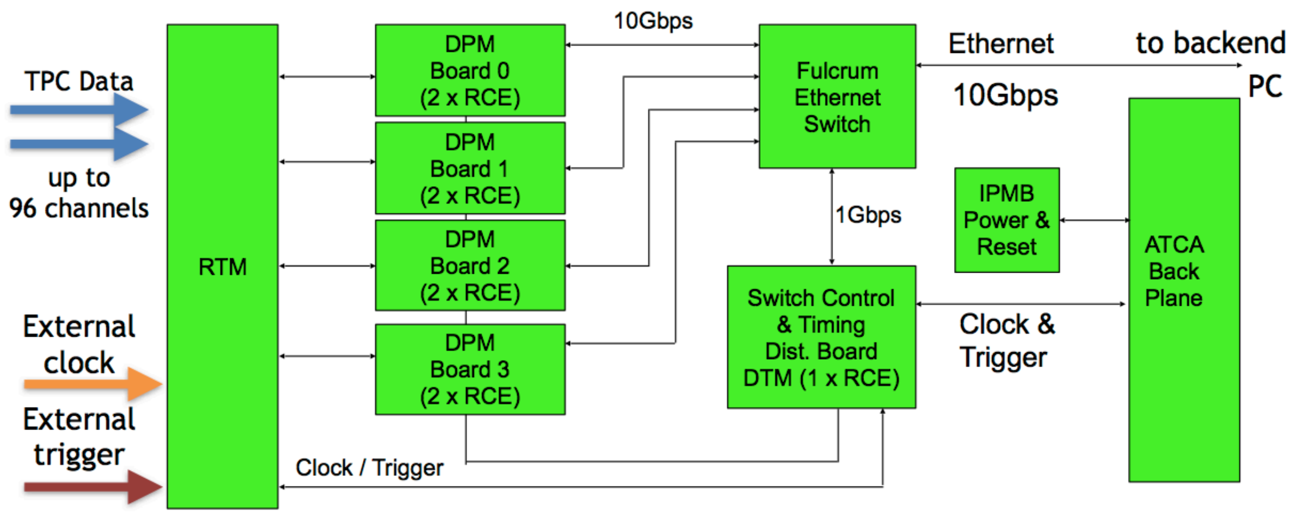

Figure 6: Schematic for the TPC DAQ system.

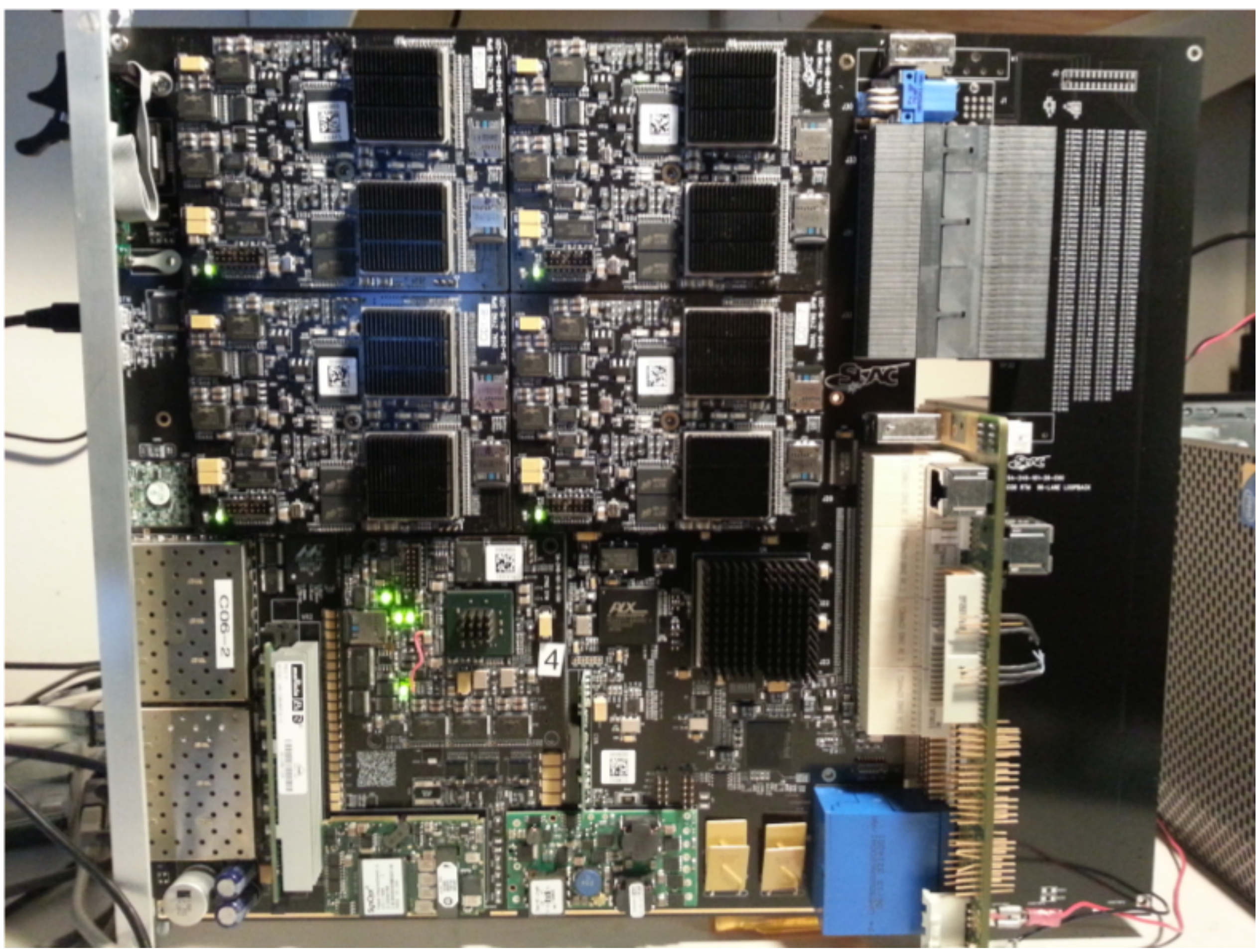

Figure 7: The COB (left) and RTM (right).

- 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

3.2.4 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

3.2.5 DAQ, Slow control and monitoring

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

3.2.6 Offline requirements and software

4 Cryostat and cryogenics system [$\sim$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 [∼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 [∼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
→ total estimated page count: ∼60 pages