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Cold Electronics Readout System for ProtoDUNE-SP LAr-TPC

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Abstract

The Single Phase (SP) TPC readout electronics are referred to as the Cold Electronics (CE) because they will operate in LAr, to minimize channel capacitance and noise by keeping the length of the connection between the anode wires and its corresponding electronics input to an absolute minimum. In this paper, the CE system and preliminary results from the CE testing at warm and cold conditions after their installation on the protoDUNE-SP detector are presented.

Keywords: Front end, Trigger, DAQ and data management

1. Introduction

The Deep Underground Neutrino Experiment (DUNE) is an international long-baseline neutrino experiment that will build an intense neutrino beam from Fermi National Accelerator Laboratory in Batavia (Illinois) to a far detector, consisting of four Liquid Argon Time Projection Chambers (LAr-TPC) holding in total around 80 ktons, at the Sanford Underground Research Laboratory in South Dakota at 1300 kilometers downstream of the source [1]. The availability of two variants of the LAr-TPC technology, Single-Phase and Dual-Phase, for the DUNE far detector has led to an extensive prototype program (ProtoDUNE) development at the European Research Center (CERN) Neutrino Platform facility. The aim of the ProtoDUNE program is to better define the production and installation procedures for DUNE FD as well as accumulate test-beam data at CERN in order to calibrate the response of the detector to different particles species.

2. ProtoDUNE Single Phase

The ProtoDUNE SP detector is located in an extension to the EHN1 hall at CERN and it's going to take its first beam-data from the $+80 Gev/c$ H4 Secondary Beam Line before the LHC long shutdown at the end of 2018 [2]. The SP Time Projection Chamber (TPC) detector consists of 6 full-size Anode Plane Assemblies (APAs) for a total of 15,360 TPC sense wire and electronics channels. The electric field is produced by the 3 Cathode Plane Assemblies (CPA) installed in the inner part of the TPC for a total of 2x3.6 m of drift regions (Figure 1).
According to physics simulations, the Equivalent Noise Charge (ENC) of DUNE SP far detector should be less than 1/9 of the expected worse case (instantaneous charge arriving at the APA from a MIP) which requires ENC for induction wires to be less than 1000 e^-. To this purpose, a readout electronics integrated with detector electrodes has been developed for cryogenic temperatures ($77-89\ K$). In this configuration, the noise is independent to the fiducial volume and much lower than with readout electronics at room temperature [3].

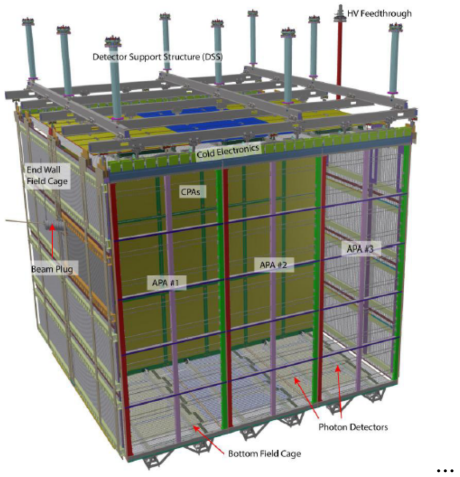

Figure 1: ProtoDUNE SP LAr-TPC schematic design.

2.1. The Readout Electronics Design

The readout electronics developed for ProtoDUNE SP is shown in Figure 2. It consists of 20 Front-End Mother Board (FEMB) installed close to the wire electrodes on top of each APA (120 FEMB in total). The FEMB purpose is to amplify, shape, digitize and transmit 15,360 TPC channels to the warm interface electronics through cold data cables. The warm electronics is the interface between the cold electronics and DAQ system. It is housed in the Warm Interface Electronics Crates (WIECs) attached directly to the signal feed-through flanges. Each WIEC has one Power and Timing Card (PTC), five Warm

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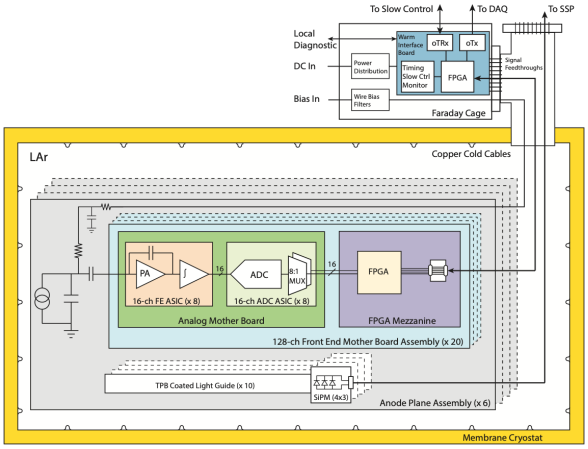

Figure 2: The CE Architecture designed for ProtoDUNE SP.

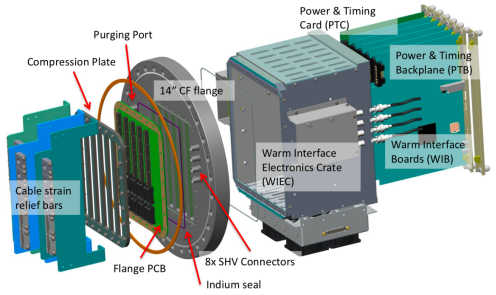

Figure 3: Schematic design of the Warm Interface Electronics Crates (WIEC) and components of the Warm Interface Electronics.

Interface Boards (WIBs) and a passive Power and Timing Backplane (PTB) inside the crate (Figure 3). The PTC provides a bidirectional fiber optical link to the timing system. It is used to fan out clock and control signals to WIBs through the PTB. A WIB, which hosts 4 FEMBs, forwards system timing signals to FEMBs and receives the high-speed data from FEMBs simultaneously. WIBs also reorganizes and transmits the data to the DAQ system over fiber optical links. The cold electronics performance can be studied using the integrated local diagnostic on WIB without DAQ system, which was a crucial tool during the cold electronics installation and checkout tests.

3. ProtoDUNE-SP Electronics Installation at CERN

All components of the electronics have been assembled at BNL and shipped to CERN after a comprehensive set of QA/QC tests. Additionally, an integration test has been performed at BNL by a small APA having the surface area of $\sim$ 40% of DUNE full-size APA. A noise performance test has been carried out at cryogenics temperature by submerging the APA in liquid nitrogen and reading out its 1024 sense wires by 8 FEMBs. Based on test results, a noise projection allowed

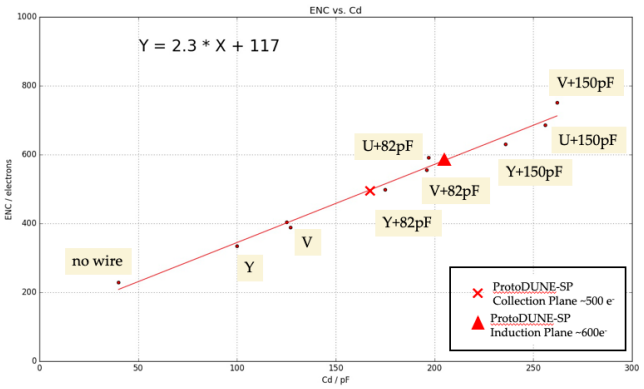

Figure 4: ENC projection for ProtoDUNE-SP based on 40% APA test results.

to predict the noise performance of ProtoDUNE-SP, that is expected to be $\sim 600e^-$ for the induction planes and $\sim 500e^-$ for the collection plane, which meets the detector design requirements (Figure 4).
Once delivered at Cern, the readout electronics has been assembled on the detector as described in the previous section. After the installation on APA, the pulse response of each FEMB has been checked by injecting bipolar test pulses from the FEMB electronics calibration circuit. Through averaging calibration response, functionality of all readout channels has been verified before starting the integration test.

4. The Cold Box test facility

In order to evaluate full-size APA performance at cryogenic temperature, a cold box was built for integration test at CERN. The integration test included a full-size signal feed-through assembly and used cables and readout electronics identical to the production system. This allows vertical slice test of APA wires, electronics and photon detectors on production APA frames.
The cold box facility Incorporates a full scale warm feed-through and use cables and readout identical to the production CE system. The FEMB readout through optical links from WIB on top of the signal feed-through allows a real time study of the detector performance in cold box tests.
Seven temperature sensors installed on one side of the APA allows to continuously monitor the temperature inside the cold box and the temperature gradient between the bottom and the top of the APA where all the CE is installed.

5. Noise Analysis during Cold Test

The APAs have been cooled down to $\sim$ 150 K by injecting cold nitrogen gas from the top of the cold box. The electronics noise performance has been evaluated first at warm temperature and during all the cold test stages (cool down, stable cold temperature and warm up).
In Figure 5, the noise performance of the induction planes (blue and red) and collection plane (green) are showed as a function of the temperature values corresponding to the several temperature sensors (orange) installed on the APA. At warm tem-

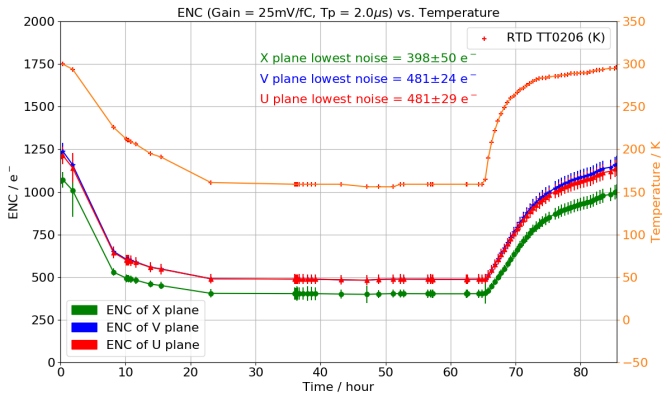

Figure 5: Noise performance of the electronics during the cold test as a function of the temperature measured on one side of the APA.

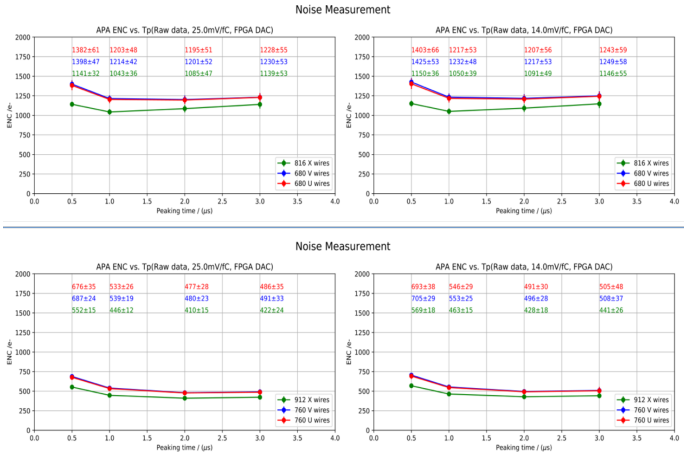

Figure 6: Comparison between ENC at warm (*up*) and cold (*down*) temperature for two different gain values (25 mV/fC *left*, 14 mV/fC *right*).

perature, the ENC is around 1200 e^- for the induction planes and 1100 e^- for the collection plane, namely around a factor 10 lower than the expected noise with the front-end electronics at room temperature. Additionally, due to the CMOS static characteristic at cryogenic temperature [4], the ENC decreases with the temperature. At the lowest temperature achievable by the cold box facility, the ENC reaches its minimum value at $\sim$ 500 e^- for the induction planes and $\sim$ 400 e^- for the collection plane, according to the noise projection and detector requirements discussed in the previous section.
In Figure 6 a more detailed comparison between the ENC at warm and cold temperature is showed for two different gain values as a function of the peaking time, confirming once more the advantages of the CMOS technology at cryogenic temperatures.

6. Conclusion

ProtoDUNE-SP project at the CERN Neutrino Platform facility will provide validation of LAr-TPC technology, detector response and long-term stability for DUNE FD optimization.

Readout electronics developed at BNL for low temperatures (77K-89K) has been installed on the ProtoDUNE-SP detector and an integration test has been performed at warm and cryogenic temperature. Promising results of the integration tests demonstrate again that the BNL readout electronics is an enabling technology for noble liquid detectors for neutrino experiments The Proto-DUNE TPC installation was completed on Apr 2018 and activities on the purity monitor, temperature gradient monitors, HV feedthrough and Cosmic Rays Trackers (CRT) are now ongoing in order to have the detector ready for the beam test planned to start on August 2018.

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