A Feasible Production Strategy for Large Scale Cryogenic Readout Electronics in Giant LArTPCs

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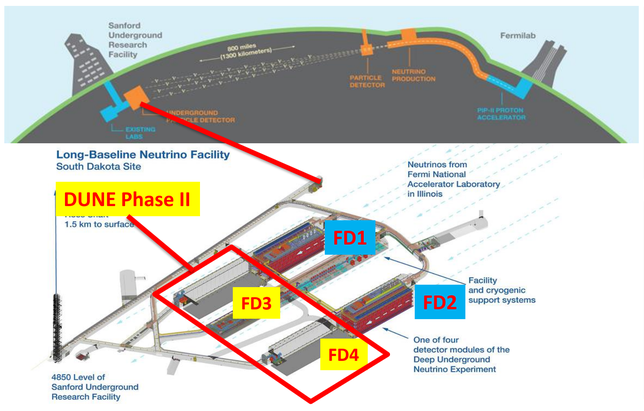
Introduction

- Deep Underground Neutrino Experiment (DUNE) experiment aims to answer several fundamental questions about the universe such as why matter dominates antimatter and whether protons can decay.
- The Phase I+II combined provide ultimate measurement of 3ν oscillation parameters (Δm^2_{32}, θ_{13}, θ_{23}, and δ_{CP}) and the FD3 & FD4 modules remain open in DUNE phase II for next generation LArTPC detectors.
- Perforated PCB-based Charge Readout Planes (CRPs) and Cold Electronics (CE) remains as highly competitive options for charge measurement. The expected number of TPC channels could reach up to 1 million in DUNE Phase II.
- Consequently, thousands of CE boards, submerged in liquid argon, must meet strict requirements to operate flawlessly for 20 to 30 years without maintenance.
- This paper presents a feasible production strategy developed for cryogenic readout electronics in Far Detector (FD) modules based on the production need of readout electronics in DUNE phase II.



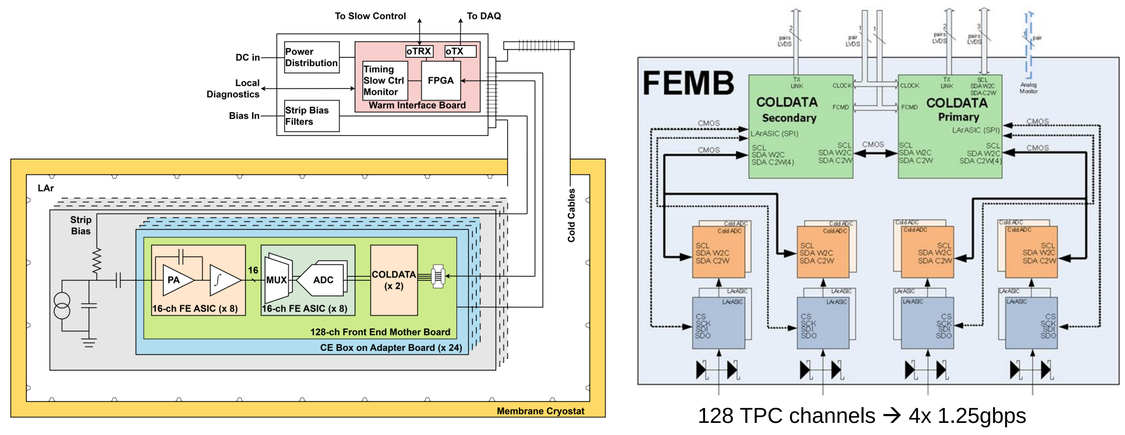
Phase I
- **FD: 2 x 17 kt LArTPC modules**
- **ND: ND-LAr + TMS (with PRISM) + SAND**
- **Beam: 1.2 MW beam line (PIP-II)**

Phase II
- **FD: 2 additional modules (total: 4 x 17 kt LAr-equivalent)**
- **MCND: ND-LAr + ND-Gar (with PRISM) +SAND**
- **Beam: > 2 MW beam line (ACE Upgrades)**

DUNE Phase I & II Far Detectors

Cryogenic Readout Electronics

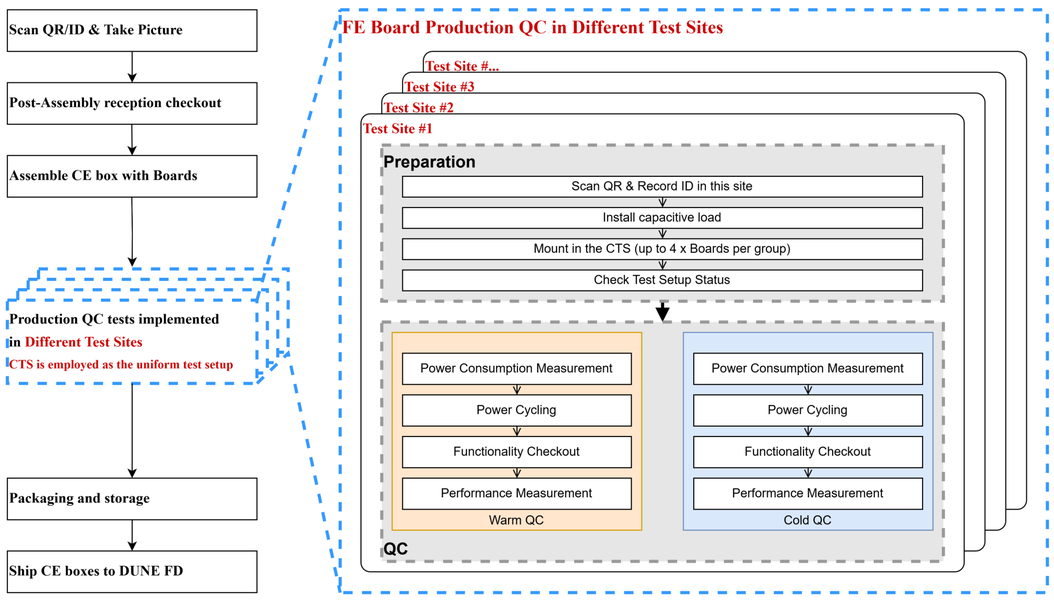
- The Equivalent Noise Charge (ENC) of DUNE single phase far detector is required to be smaller than 1000 e- and this noise level can only be achieved by cold electronics.
- This Front-End (FE) readout electronics could be placed close to the detector electrodes inside the cryostat to get rid of signal cables and yield the best Signal-to-Noise Ratio (SNR)
- Signal digitization and multiplexing to high-speed links inside the cryostat result in large reduction in the quantity of cables and in the number of cryostat feed-through penetrations, giving the designers of both the TPC and the cryostat the freedom to choose optimal configurations.
- High-channel density, low power, low noise to be placed close to electrodes for charge amplification, shaping, digitization and multiplexing to a few high-speed data links via copper cables (1.25 Gbps/link) or even cryogenic fiber transmission (10 Gbps/link or higher) once the technology becomes available.



The Front-end Readout Electronics for DUNE

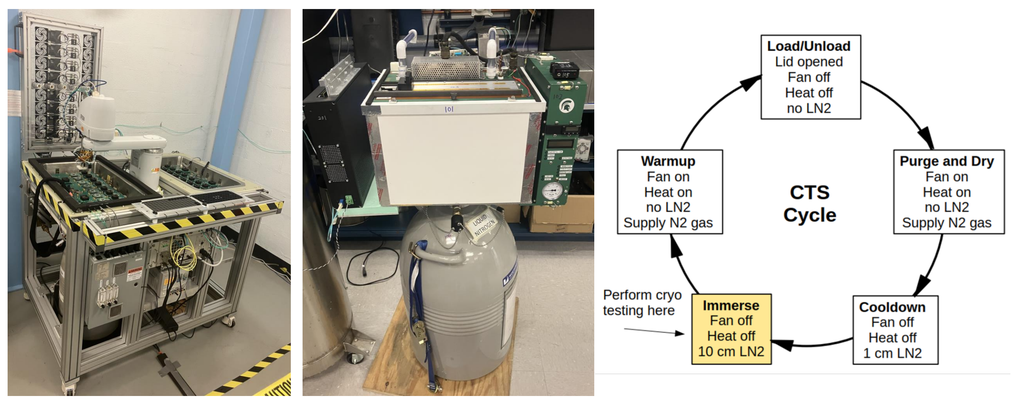
Production Strategy for Large Scale Cryogenic Readout Electronics

- Based on the experience of DUNE Phase I, a production Quality Control (QC) strategy is studied to maximize the large number of functioning readout channels in the giant LArTPC detector that achieve the consistent high-performance specifications, particularly on noise
- QC is plan to include 4 phases, preparation, warm QC, cold QC, and post-QC reception.
- Each readout electronics should be characterized by power consumption, functionality, and performance.
- Criteria of acceptance to be setup to assure the readout uniformity.



Production Strategy for Large Scale Cryogenic Readout Electronics

- Building on DUNE Phase I, the cryogenic testing stands, RTS and CTS, have been well developed. These test stands can be utilized for DUNE Phase II, enabling cryogenic qualification testing across multiple institutions in the US.
- RTS: Robotic Testing Station. It performs batch cryogenic qualification testing with high efficiency while minimizing human intervention. 6 RTS stations are being setup for the coming 100,000 ASIC cryo-QC task required by DUNE FD1&FD2.
- CTS: Cryogenic Testing Stand. The Cryogenic Testing Stand (CTS), featuring a chamber volume of 10 × 13.5 × 10 inches, is designed for board-level cryo-testing. Five CTS stations are being established to handle the Cryo-QC tasks for the 5,000 CE boards required for DUNE FD1 and FD2.
- "The Five S's" Data Management Strategy
  - **Sampling**: Software to perform the basic test data acquisition.
  - **Store**: How we store and organize the acquired data.
  - **Summarize**: Extract important values from all samples into unified representation.
  - **Sync**: Copy samples and summaries to a central location.
  - **Serve**: Distribute and display summaries, statistics, inform hardware selections.



Robotic Testing Station and Cryogenic Testing Stand

Discussion & Conclusions

- A Feasible production strategy methodology has been developed for the Large-scale cryogenics charge readout electronics in DUNE FD1 and FD2 modules.
- Analyze the capability of the existing cryogenic quality control test stands, discuss the lessons learned, and explore their potential capabilities to fulfill the production need of readout electronics in DUNE phase II
- The goal is to deliver cryogenic-qualified productions to maximize functional readout channels (>99%) and ensure stable performance for 20~30 years without repair and maintenance.

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