Cold Electronics system for ProtoDUNE-SP LAr-TPC

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on behalf of ProtoDUNE-SP collaboration

14th Pisa Meeting on Advanced Detectors – May - June 2018
Deep Underground Neutrino Experiment (DUNE)

Over 1000 collaborators from 175 institutions in 30 countries

Far Detector at 1.5km underground: 4x10 kton Liquid Argon Time Projection Chambers (TPCs)

Two TPC concepts:
- Single Phase (LAr)
- Dual Phase (Ar gas+LAr)

The first 10 kton TPC will be Single Phase (LAr)

New megawatt-power beam at Fermilab

Near Detector at Fermilab
ProtoDUNE ~1% of DUNE

~ 400 tons LAr (Fiducial mass)  ~4x10 kton LAr

- Single-Phase LAr TPC prototype:
  - 6 full-size (6x2.5 m²) Anode Plane Assemblies (APAs)
  - 3 Cathode Plane Assemblies (CPA)
    - 2 x 3.6m drift regions
    - Total of 15,360 TPC sense wires and electronic channels
- Key test of design concepts and construction:
  - TPC sense wire planes
  - Cold electronics integral to wire planes
  - Cryostat feedthroughs to integral warm interface (WIEC)
  - Scintillator SiPM Photon Detectors (PD)
  - HV system, field cage and cathode, for long drift (3.6m)

R. Acciarri - ProtoDUNE: prototyping the ultimate medium – high energy range (MeV - GeV) neutrino detector
protoDUNE-SP Goals

- Prototyping production and installation procedures for DUNE far Detector Design [*task of the ongoing effort*]
- Validate design from perspective of basic detector performance
- Accumulate test-beam data to understand/calibrate response of detector to different ptcl. species
- Demonstrate long term operational stability of the detector
Project approved December 2015, TPC installation completed on Apr 2018, data taking End Summer-Fall 2018 → results available before the 2019 DUNE FD Technical Design Review
Each APA is isolated inside the cryostat and only connected to the cryostat through the CE at its own CE flange.

Warm Interface Electronics: from CE to DAQ with shielding and local real-time diagnostics.
Noise (ENC) vs TPC Sense Wire and Signal Cable Length for CMOS at 300K and 89K

MIP Signal for 3x3 and 5x5 mm Sense Wire Spacing

DUNE with warm electronics (300K)
ENC ~ $6 \times 10^3$ e

MicroBooNE
ENC~400 e

CMOS at 77K: ENC< $10^3$ e

Signal for (1/e drift) $10^4$e
3x3 5x5
Cold vs. Warm CMOS: static characteristics vs. T

At 77-89K, charge carrier mobility in silicon increases, thermal fluctuations decrease with $kT/e$, resulting in a higher gain, higher $g_m/I$, higher speed and lower noise.
ProtoDUNE-SP Cold Electronics

Warm electronics
Local diagnostics
Warm Interface Electronics Crate (6)
Warm Interface Board (30)
Power and Timing Card (6)
Power and Timing Backplane (6)

CE flange
Flange assembly with cable strain relief and flange PCB for cable/WIB connection (6)

Signal feed-through
Tee pipe with 14” Conflat flanges and crossing tube cable (CTC) support (6)

Cold cable
LV and data cable (120+120) to FEMB and APA wire-bias SHV cable (48)

Front End Motherboard
(FEMB) 128 channels of digitized wire readout enclosed in CE Box (120)
CE boxes were assembled at Brookhaven National Laboratory (BNL) and shipped to CERN after a comprehensive set of QA/QC tests.

Integration tests in LN2 were performed at BNL by a 40% of DUNE APA (2.8 m x 1.0 m) in a smaller cold box.
CE installation on Anode Plane Assembly (APA)

CE boxes installation on APA

Cabling on cable tray

Installed CE boxes

Cable hook up to feedthrough

CE boxes test after installation on APA
A Cold Box for testing APAs

Cold box allows integral test of electronics and photodetectors on production APAs

• Follows the same power and grounding rules for the detector electronics
• Incorporates a full scale warm feed-through and use cables and readout identical to the production system

FEMB readout through optical links from WIB on top of the signal feed-through allows a real time study of detector performance in cold box tests and during installation of APAs.
APA Test in cold Nitrogen gas

- TT0907 sensor at top of cold box
- Internal FE ASIC temperature sensor is readout through a scope

APA being moved into Cold Box

Temperature monitoring

1 Jun 2018
Noise vs Temperature – Cold Box Cooldown

APA2 (2018-01)

ENC (Gain = 25mW/ke, Tp = 2.0μs) vs. Temperature

Lowest temperature reached
TT0907 ~ 159K

ENC at 159K:
U-plane: 481 e⁻
V-plane: 481 e⁻
X-plane: 398 e⁻

1. Uniform gain (77 e⁻/bin) is applied for calculating noise of all channels
2. Bias voltages were off

1 Jun 2018

M. Spanu - PM 2018
Overall ENC Performance - Warm vs. Cold

APA4 (2018-03)

Done by local diagnostic function (every channel uses its own gain calibrated by FPGA-DAC)

Warm, 25mV/fC

Cold, 25mV/fC

Warm, 14mV/fC

Cold, 14mV/fC

1 Jun 2018
After the cold test, all 6 APAs and 3 CPAs have been installed into the ProtoDUNE-SP cryostat

- Electronics and photodetectors have been tested before and after the installation on APAs
- All CE and PD cables are routed through the chimney out of the cryostat and connected to the corresponding crate

What’s next?
The detector is assembled, so now let’s make it work!

- Installation CRT, purity monitors, temperature gradient monitors, HV feedthrough (ongoing now)
- Purge, cooldown, fill the detector (July – August)
- Turn on the detector and make it work stably, smoothly, and noise free (end of August)
- Beam Run (August 29th → November 11th)
- ...

1 Jun 2018
Summary

- **Readout electronics** developed at BNL for low temperatures (77K-89K) is an **enabling** technology for noble liquid detectors for neutrino experiments.

- **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. The TPC **installation** was completed on Apr 2018.

- Different expert teams are now at work on the activation procedures of the different TPC components.

- We’re almost ready for the **beam run**… Looking forward to see the results!
References


Thank you for your attention!
APA, CPA & front end cold electronics system for single phase DUNE far detector

DUNE 10 kt Far Detector
- **384,000 channels**
- 24,000 FE ASICs/24,000 ADC ASICs
- 6,000 COLDATA ASICs
- 3,000 Front End Mother Board assemblies
ProtoDUNE SP facility – EHN1 at CERN

Clean Room  Cryostat  Detector Control System (DCS) room  Grounding Status Monitor

Cold Box (inside)  N2 dewar

Cooling System

1 Jun 2018
H4 VLE Beam line

- 400 GeV/c P beam from SPS
- 80 GeV/c secondary $^+$ beam
- $\sim 0.5 – 7$ GeV/c tertiary $e^-, p, \mu^+, \mu^-$ beam

- +80 GeV/c @ H4, -80 @ H2 simultaneously
- NP04 (secondary) target
- ProtoDUNE-SP cryostat
- ProtoDUNE-DP cryostat

H4 VLE beam line under construction
CMOS Cold ASICs Upgrades Implemented

- FE ASIC
  - Built-in 6-bit DAC for calibration pulse generation
  - Built-in analog monitoring output for debug
  - Address pole-zero cancellation and drive capability in buffer-off mode
  - Add higher bias current (1nA and 5nA) options and smart reset
  - Revise BGR start-up circuit and increase ESD protection on I/O
    - **Will be used to instrument SBND and ProtoDUNE-SP**
  - **Will be used to instrument SBND and ProtoDUNE-SP**

- ADC ASIC
  - Implement COLDATA (DUNE baseline design by FNAL, *prototype expected in FY19*) compatible interface and FE ASIC compatible configuration
  - Address the early saturation and roll-back
  - Implement power-on default configuration and extend soft-control functions
  - Revise BGR start-up circuit and increase ESD protection on I/O
  - Improve ADC INL/DNL → not completely resolved
    - **Will be used to instrument ProtoDUNE-SP**
  - **SBND is exploring COTS ADC option**
  - Cold ADC ASIC development is very challenging given the amplified mismatch error and inaccurate simulation model in cryogenic temperature

**CMOS Cold ASICs Upgrades Implemented**

![Image of CMOS ASICs](image-url)
APA1 - Pulse response

Inject bipolar pulses from electronics calibration circuit on FEMB

Temperature ~ 173K

Overlap 1600 induction FE channels

Overlap 960 collection FE channels
1. Uniform gain (80 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off

Measured by FE ASIC

RTD: TT0907

ENC at 173K:
- U-plane: 528 e-
- V-plane: 526 e-
- X-plane: 436 e-

Lowest temperature reached
TT0907 ~ 173K  FEASICs ~ 183K

Data acquisition is done by local diagnostic
1. Uniform gain (77 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off
Noise vs Temperature – Cold Box Cooldown

1. Uniform gain (77 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off
3. WIB2FEMB1 was inactive before cooldown

ENC at 160K:
- U-plane: 488 e⁻
- V-plane: 488 e⁻
- X-plane: 406 e⁻

APA4 (2018-03)

Lowest temperature reached
TT0907 ~ 160K

1 Jun 2018
Diagnostics on Abnormal Channels (18 Out of 15360)

APA2 (2018-01)

Test started at: 2018-01-17 15:48:55
Inactive FEMBs: WIB3FEMB2,
25mV/fC, 1.0us, 2432 channels

ADC stuck code
A V wire (V14) with high noise (792e⁻)

Missing wire connections
ENC ~280e⁻ → consistent with the FEMB seeing the additional capacitance from the CR board

Missing wire connections
ENC ~220e⁻ → consistent with the FEMB when it sees nothing
MicroBooNE long term stability of average MIP response, incl. argon purity variations

FE ASICs in LAr: (gain) variations <0.2% over >2years

MicroBooNE-NOTE-1013-INT