

Status and plans of ProtoDUNE - Horizontal Drift (NP04)

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153rd SPSC Meeting

7 May 2024

Outline

- Context and motivation for NP04 phase II.
- Data analysis and publications from NP04 phase I (ProtoDUNE-SP).
- Beam data and measurements plan for NP04 phase II (ProtoDUNE-HD).
- NP04 subsystems highlights since the last report.
- NP04 status, including the H4-VLE beamline.

NP04 – ProtoDUNE

- NP04 is the **1:25 prototype**, with **full scale components**, of the **DUNE** Far Detector 1 Single Phase LAr TPC with Horizontal Drift: **FD1-HD**.
- Phase I constructed in 2016-18 (cryostat and TPC), took data in 2018-20.
- Exceeded design specifications and DUNE requirements.
- Automatic offline reconstruction (pattern recognition, track/cluster ID, PID) and physics analysis demonstrated; physics results published.
- *Our success underpinned DUNE FD final designs, Reviews, CD2/3.*
- **NP04 phase II is FD1-HD module 0**: demonstration of final, production components and methods.
- Phase II beam data will allow to complete/improve hadron cross-section measurements on Argon, useful input to DUNE physics.

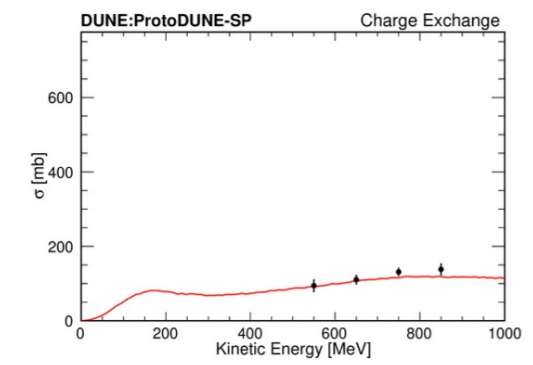
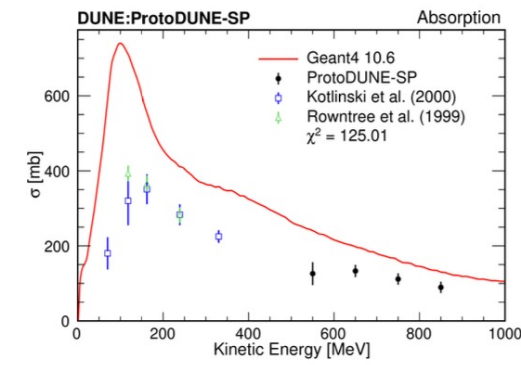
NP04 phase I data analysis and results

Publications since last report

1. Identification and reconstruction of low-energy electrons in the ProtoDUNE-SP detector. *Phys. Rev. D* 107 (2023) 092012
2. Reconstruction of interactions in the ProtoDUNE-SP detector with Pandora. *Eur. Phys. J. C* 83 (2023) 618
3. Doping Liquid Argon with Xenon in ProtoDUNE Single-Phase: Effects on Scintillation Light. Submitted to JINST. 2402.01568

Ongoing analyses

- Exclusive π^+ - Ar: aim to publish in 2024.
- Inclusive π^+ - Ar inelastic: good agreement with G4; DUNE review starting soon.
- Inclusive proton-Ar inelastic: good agreement within statistics with G4; DUNE review starting soon.
- Differential π - Ar charge exchange: internal note in preparation.
- Inclusive kaon - Ar inelastic: Analysis improved, measurements below MC. DUNE approved.
- Other interesting analyses in PhDs:
 - Secondary kaons
 - Seasonal variations of cosmic muons
 - others



(a)

(b)

Figure 2: Preliminary exclusive cross section results from likelihood-fit based analysis (black circles) compared to Geant4 v10.6 predictions (red curves) and a measurement of π^+ -Ar absorption by the LADS collaboration (blue open squares [26] and green open triangles [25]).

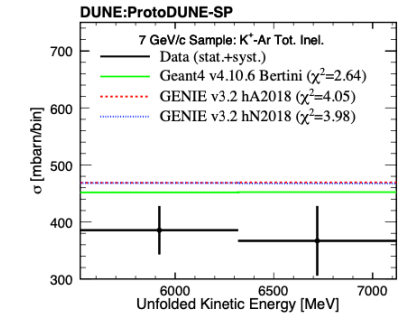
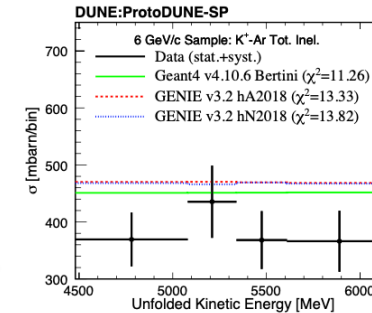
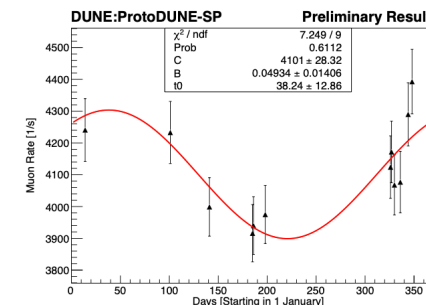


Figure 1: Total inelastic cross section measured from primary beam kaons with test beam data taken at the 6 GeV/c setting (left) and 7 GeV/c (right). Comparisons included on the measured cross section are to the simulations GENIE v3.2.0 and Geant4 [16–23].



Beam data and measurements plan for phase II

Beam data plan, phase II

- 7 weeks of beam approved.
- First week (wk25): momentum scan for both polarities. Electron/positron samples to measure energy resolution and linearity in TPC (charge) and PDS (scintillation).
- Six weeks (wk28-33):
 - **2 weeks +1 GeV/c**: inclusive and exclusive pion, proton cross-sections. Double phase I stats, cover the delta region (125 MeV pion k.e.). Improve current results which are very statistics limited. Improves detector response characterization.
 - **2 weeks -1 GeV/c**: no negative polarity taken in phase I. Perform x-section measurements as for (+), characterize detector response.
 - **2 weeks +/- 5-7 GeV/c**: increase statistics of current result for positive Kaons. Make unique measurements for negative kaons.

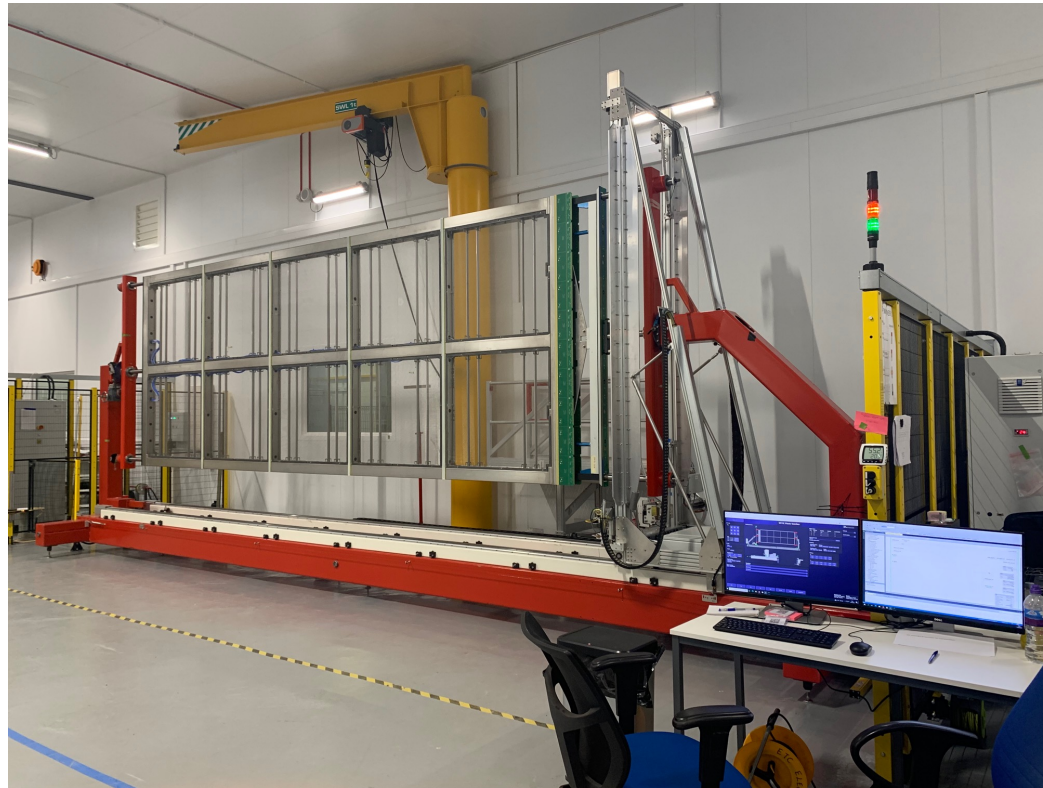
NP04 subsystems

Changes from phase I

2023 highlights

Aims for phase II

Anode Plane Assemblies

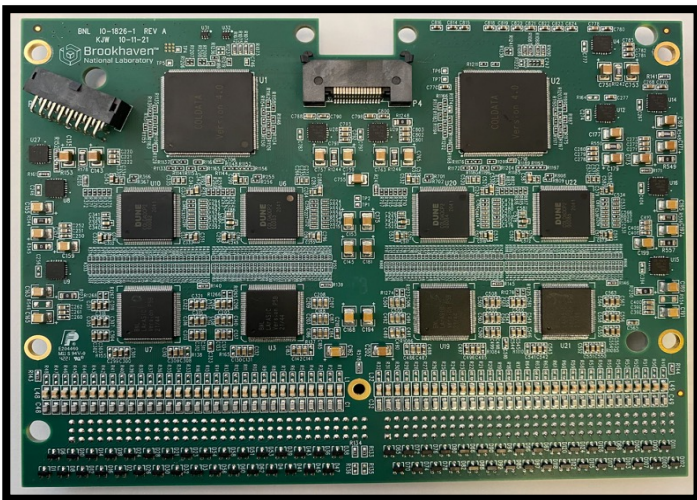


- **6m x 2.4m**, double-sided, 4-layer charge readout. **24km** of wire.
 - **150** APAs in DUNE FD1-HD;
 - **6** in NP04 phase I, **4** in phase II.
- Minor mechanical and electrical (boards) modifications from phase I, to meet DUNE FD integration requirements.

Phase II aims: Validate modifications and series production, mechanical stability, S/N performance with new CE.

TPC Readout Electronics (CE)

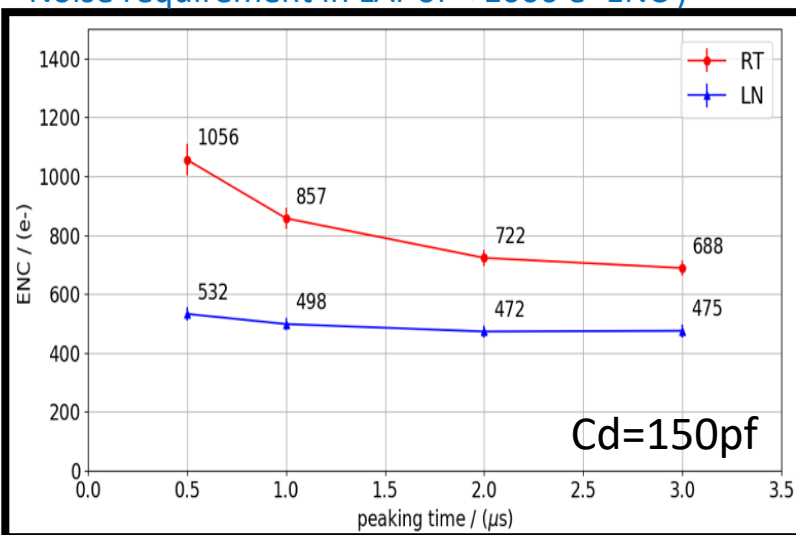
Front-end Mother Board for NP04 Phase-II



Changes based on lessons learned from NP04 phase I:

- Three new/revised custom ASICs for the Front-end Motherboards
- Upgraded FPGA on the Warm Interface Boards to a powerful Xilinx Zynq UltraScale+ FPGA
- Design changes to cable assembly, connectors, cable tray, etc. to improve long term reliability

Benchtop Electronics Noise Measurement (Exceed Noise requirement in LAr of $< 1000 e^- ENC$)

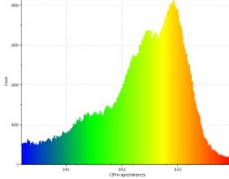
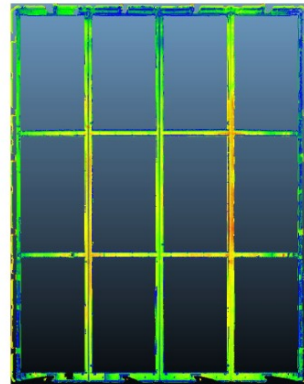
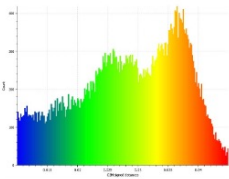
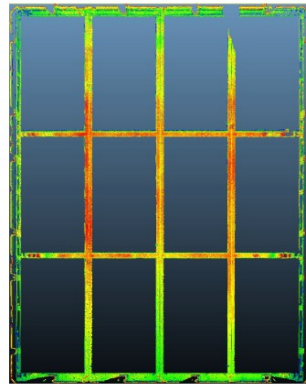


Key Goals for NP04 Phase-II:

- Validate the final design of the TPC electronics system
- Integration with other subsystems (APA, PDS, CALCI, and DAQ)

High Voltage System: CPA, Field Cage, Beam Plug

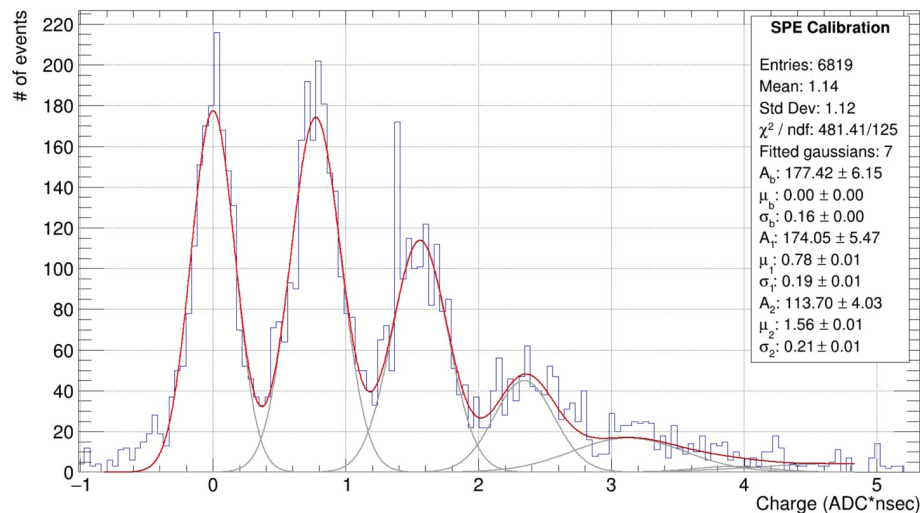
- Fully installed in 2022.
- 2023: CPA survey confirmed planarity to within ± 1 cm.
- 300 kV PS, cable and feedthrough tested and installed in 2023.
- The system has been stable in LAr at 40kV for weeks.



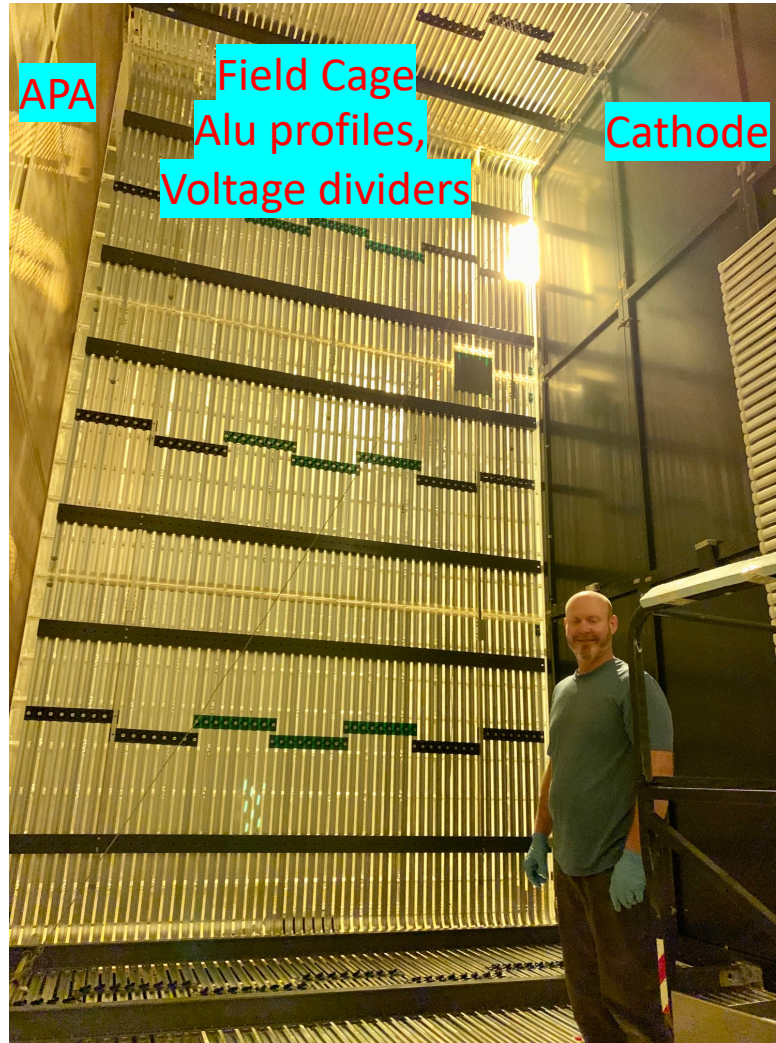
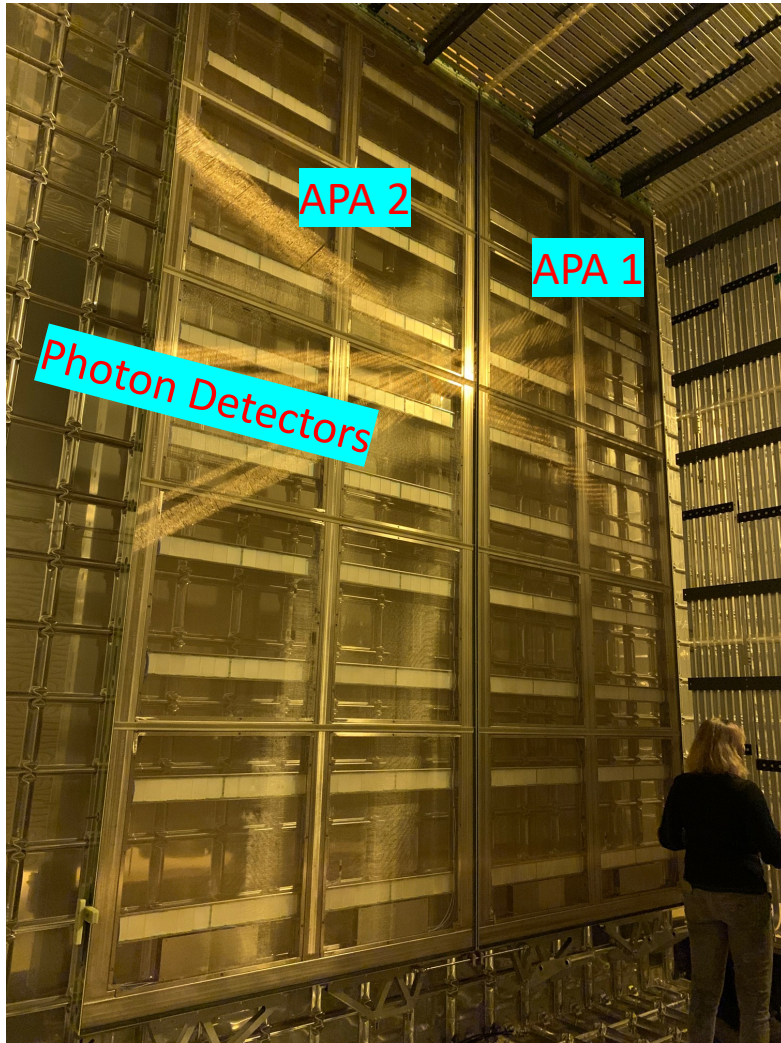
Photon Detection System

- **New** for ProtoDUNE II: **X-Arapuca** light trap.
- Wavelength shifting and dichroic mirrors.
- SiPMs, new R/O electronics (DAPHNE).
- 10 modules per APA.
- 2023: electronics, LED calibration system installed and integrated; self-triggering development.

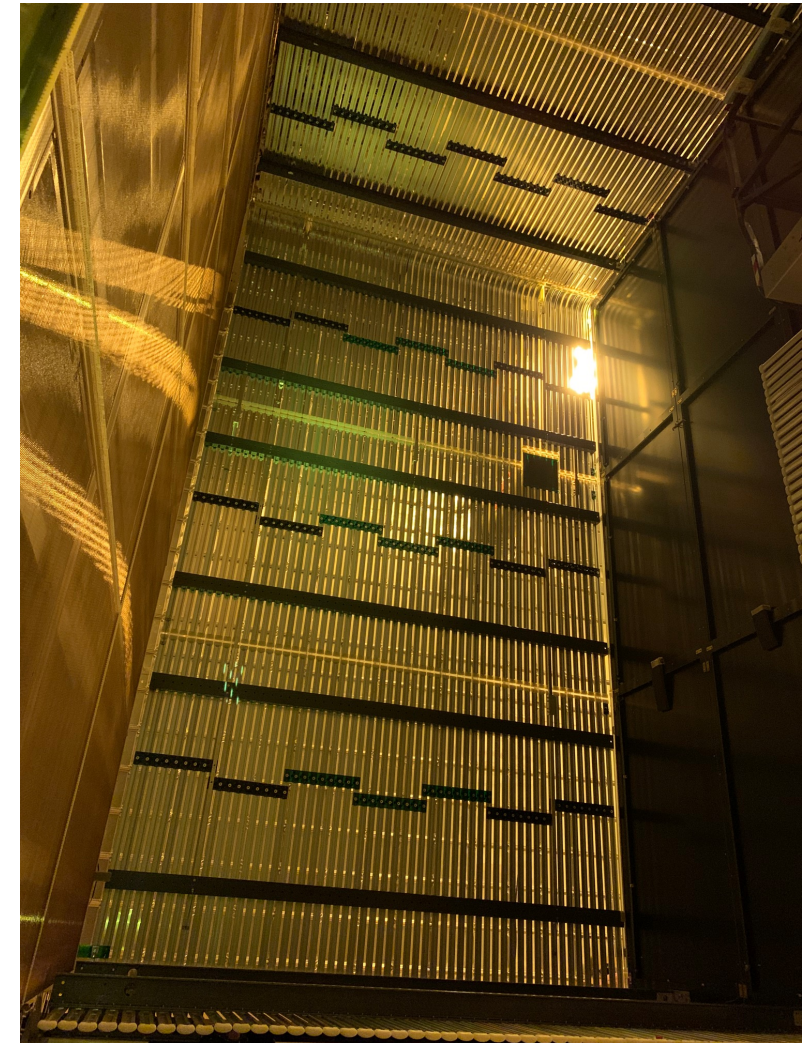
Single photoelectron spectrum from a channel in APA 2.



NP04 phase II TPC



Beam (Saleve) side TPC completed



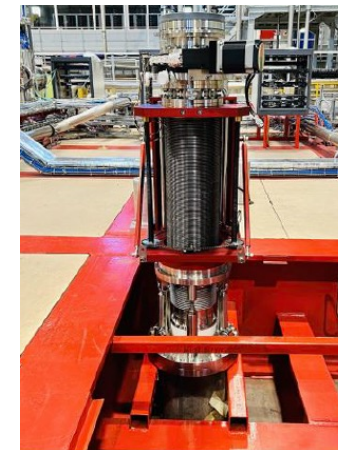
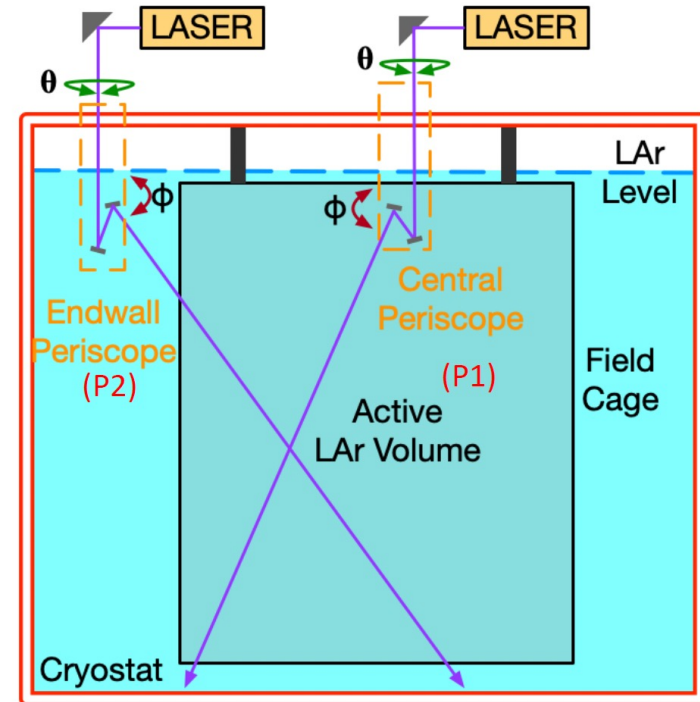
Calibration & Cryogenic Instrumentation

- **NEW** Ionization Laser system for spatial calibration (alignment, space-charge, electric field).

- 266 nm for direct Argon ionization,
- Retractable & rotational periscopes,
- Laser Beam Location System: pin diodes & mirrors.

- **NEW** Bi-207 sources installed near Anode and Cathode.

- **Pulsed Neutron Source**: brief test in phase I, new source implementation planned for phase II.
- **Temperature Monitoring System**: added 52 sensors for better data-CFD validation.
- **Purity Monitor System** (3 units) upgraded.



Trigger & DAQ

- Distributed, high-performance software system, based on COTS components with some elements of custom firmware and hardware.
- **New** in ProtoDUNE phase II: implementation of the full DUNE TDAQ system design.
- Substantial progress in integration of CE, PDS, Cosmic Ray Tagger, Laser systems.
- Phase II goals:
 - Validate & stress-test design and implementation in view of DUNE FD: throughput, long-term stability, reliability,
 - Assessment & key performance parameters measurement, including super-nova burst cycle.
 - Tests of trigger schemes, control and management etc.

Latest status

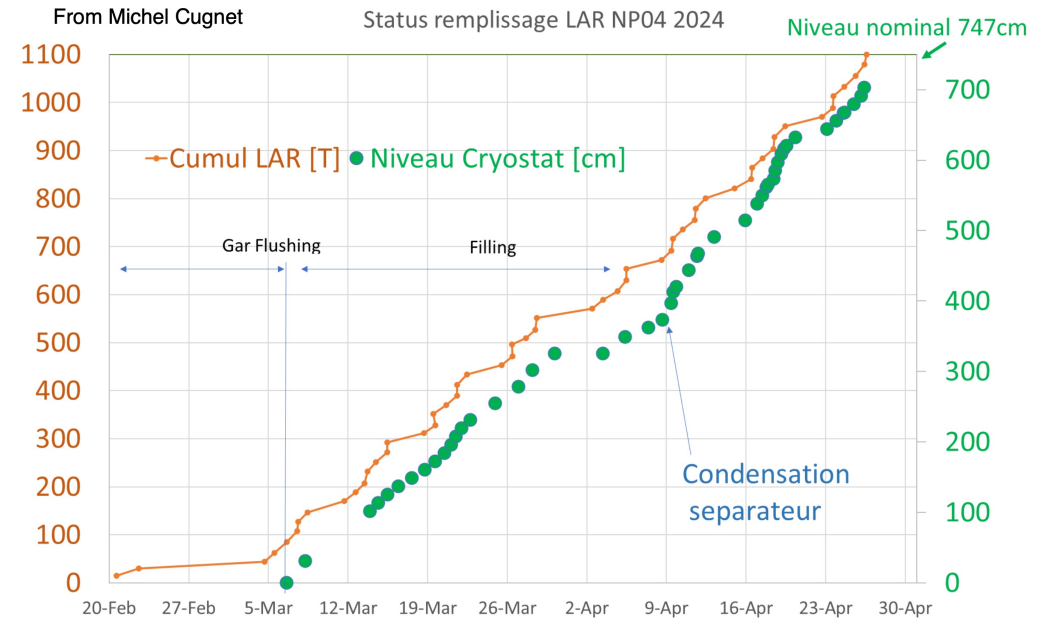
Argon fill completed

Many systems already checked out

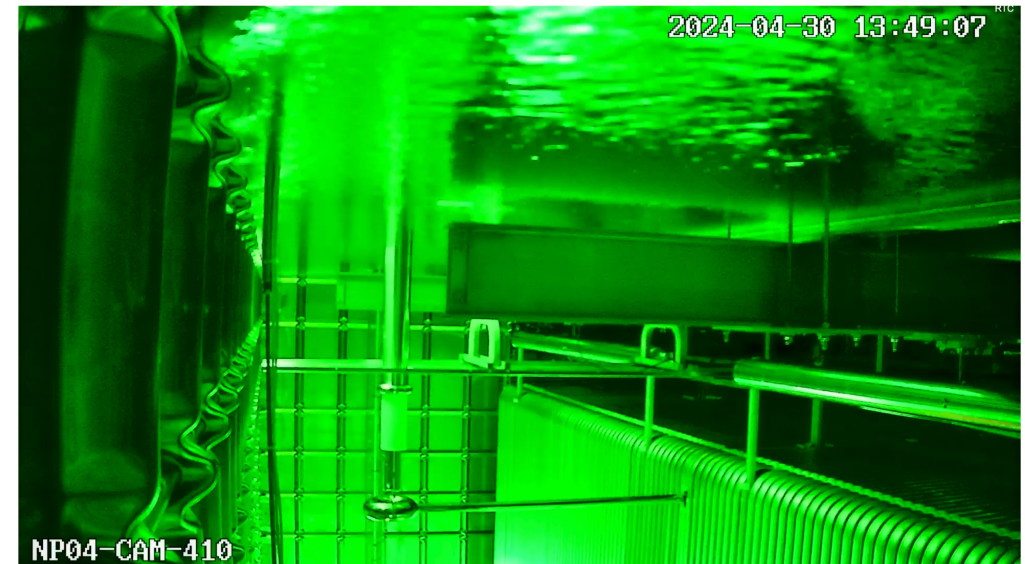
Beamline recommissioned

Argon fill

- TPC was assembled in 2022.
- Argon unavailability – high prices delayed fill.
- Tendering process started 10/23, contract 01/24.
- DUNE high-lever decision to fill NP04 first.
- **Detector full since 30 April.**
- Purity monitored through the fill, 30-60 μs .
- Low HV applied and monitored through the fill.
- **40 kV since full**, stability and no signs of any issue. All relevant currents monitored.
- Now in recirculation/purification stage while all detector systems being commissioned and tuned.



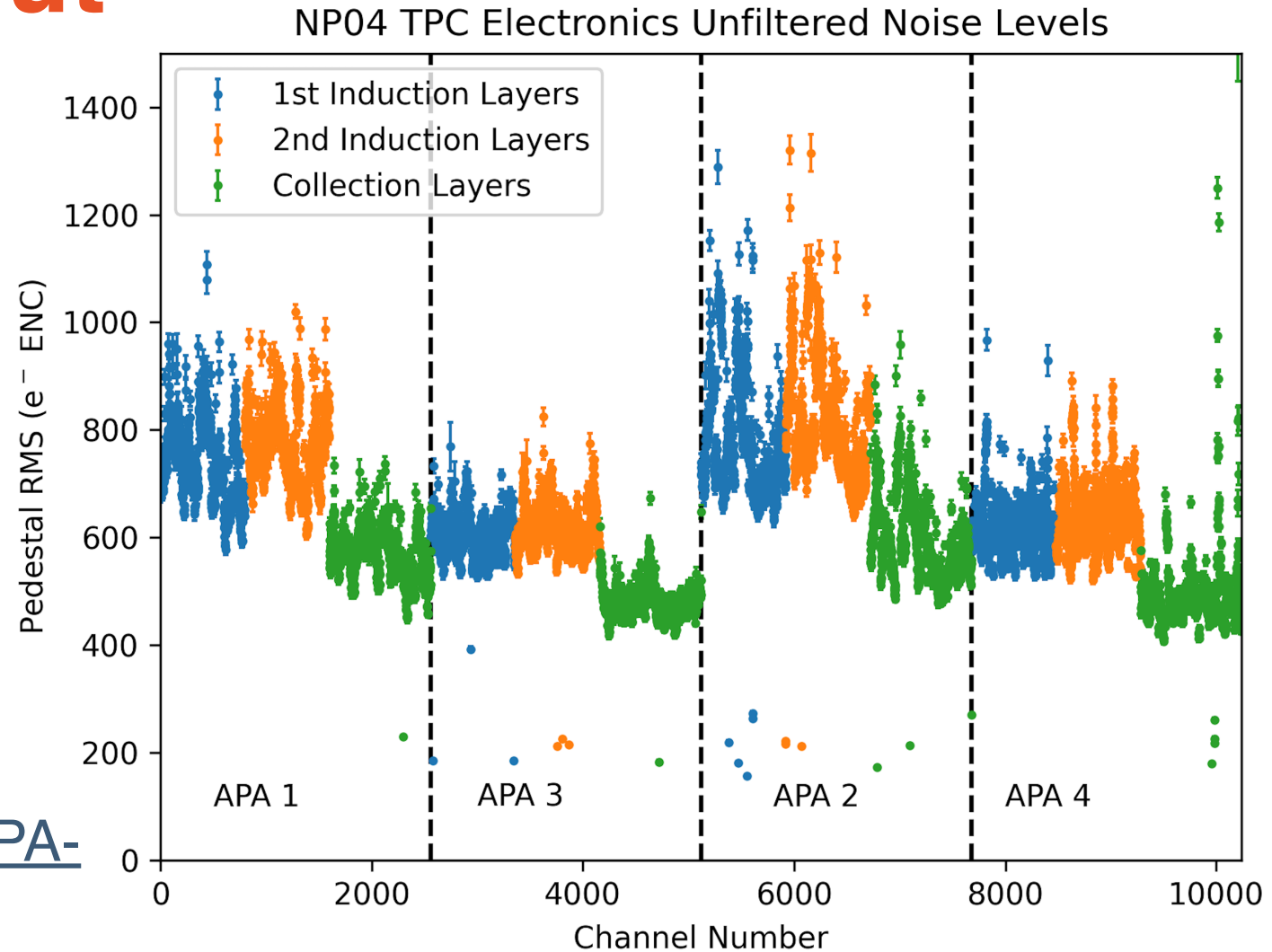
Filling stopped at 13:30 on the 30th of April



TPC charge readout

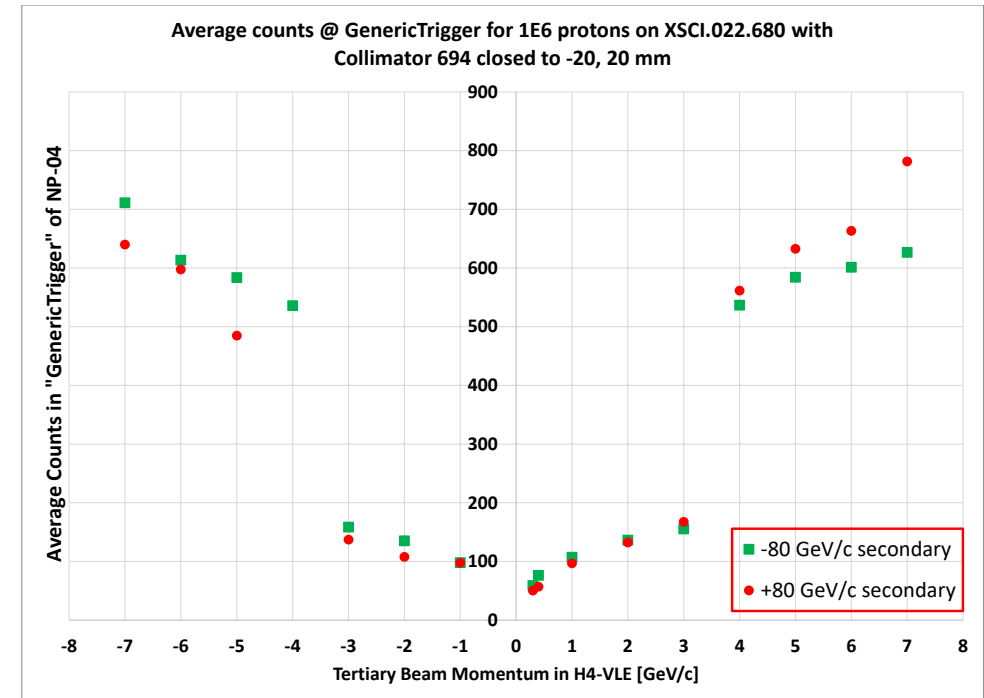
- DUNE requirements:
 - $< 1,000 e^- \text{ ENC}$
 - $< 1\%$ bad channels
- Measured on May 5th:
 - Noise level achieved even before coherent noise subtraction.
 - Bad channels 0.33%
 - Excluding APA 2: 0.18%

An excellent first checkout for the APA-CE charge readout system!



Beamline

- H4-VLE: extension of H4, double- bend achromat magnetic spectrometer.
- Delivers both polarities, mixed hadrons or electrons, 0.3 – 7 GeV/c.
- Beam **recommissioned in 2024** after 5.5 years of inactivity; working well (BE-EA).
- Beam counters also unchanged, work well, Čerenkovs to be tuned (SY-BI).
- **Beam rates measured** with collimators at half position – polarity independent of H2.



THANK YOU