Photo-detector readout of the DUNE FD2 in a cryogenic and high-voltage environment

LABORATOIRE ASTROPARTICULE & COSMOLOGIE

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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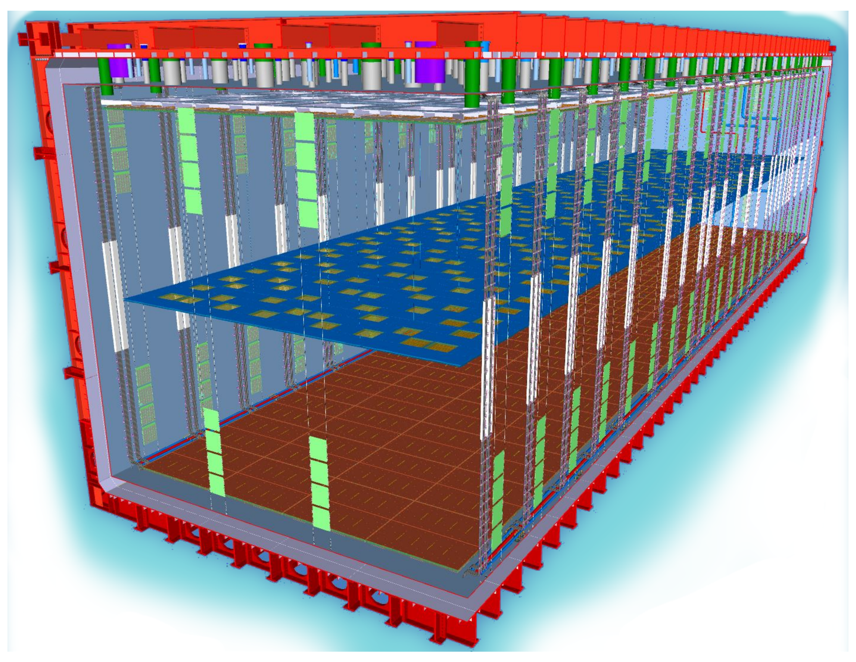
The Vertical Drift Photo-Detection System Readout

The second DUNE Far Detector will be instrumented with a Vertical Drift Liquid Argon Time Projection Chamber (VD-LArTPC)[1] and a **Photo-Detection System (PDS)**.

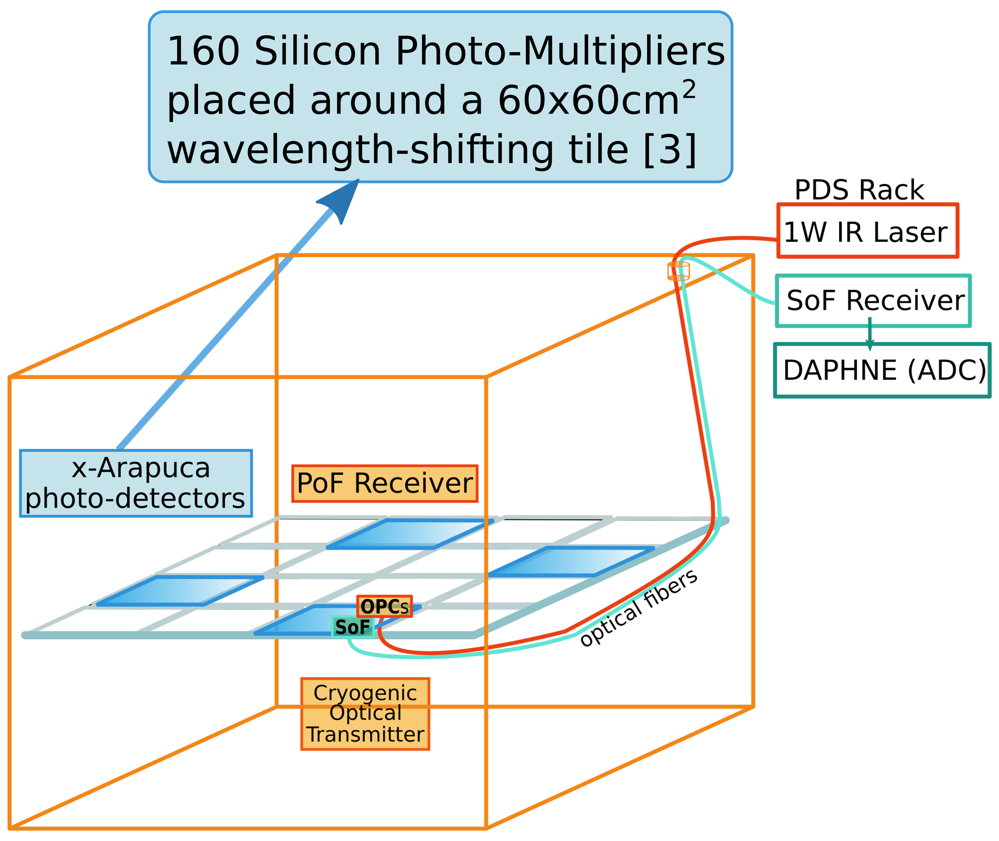
The PDS provides a **time-stamp and a trigger for neutrino events** by detecting the scintillation light emitted by the argon in the detector, at 127 nm wavelength.

In order to improve the light-yield of the PDS, **half of the photo-detectors will be embedded in the TPC cathode, at -300 kV**.

Therefore, both the **signal readout and powering must be done through non-conducting materials**.



Drawing of the DUNE FD2 cryostat containing the VD-LArTPC. The xArapucas are represented in green on the walls of the cryostat and on the cathode surface.



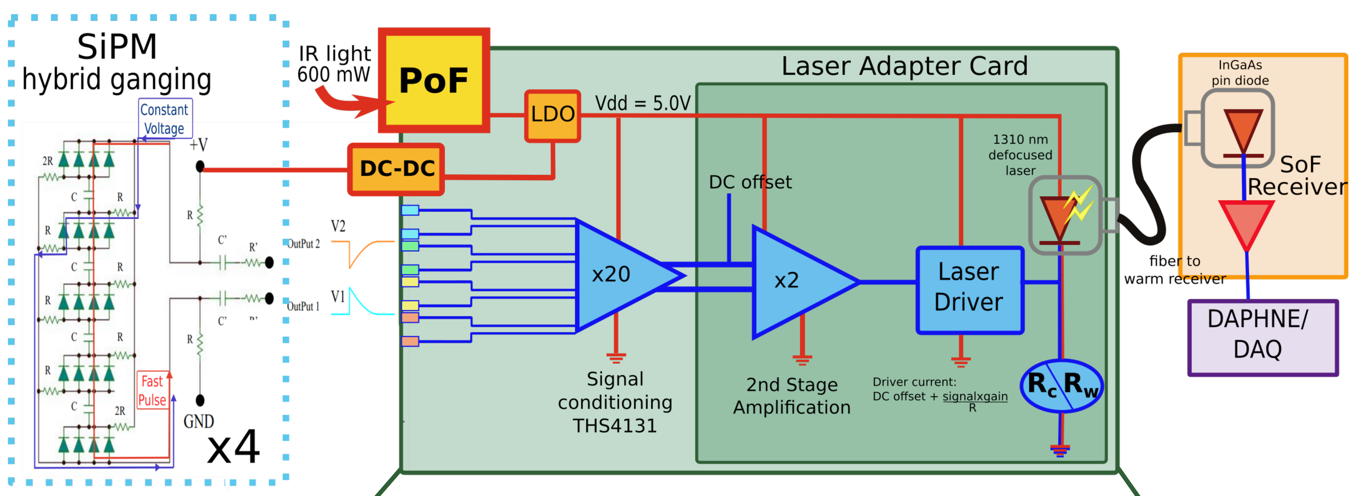
Power-over-Fiber

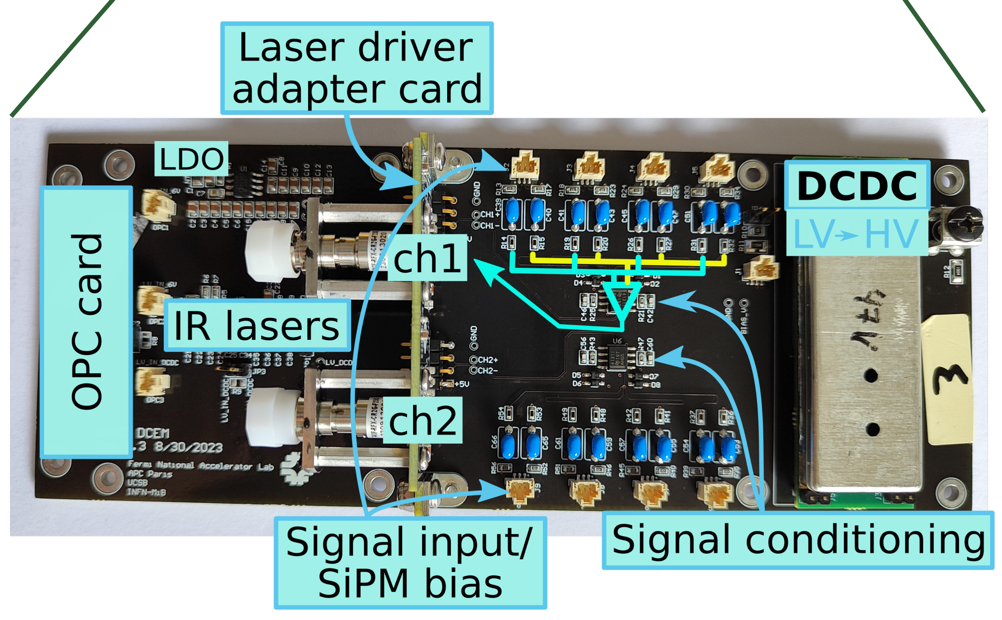
The light of a high power IR laser is transmitted through multi-mode optical fibers towards the optical-power converters (OPCs) embedded in the readout electronics [2]. A "DCDC" does the low- to high-voltage conversion to bias the SiPMs.

Signal-over-Fiber

The SiPM signal is conditioned, amplified, and used to drive an IR laser. The analog signal is thus transmitted using multi-mode optical fibers. An analog optical receiver outside the cryostat's interfaces to the digital electronics.

Schematic drawing of the SoF electronics



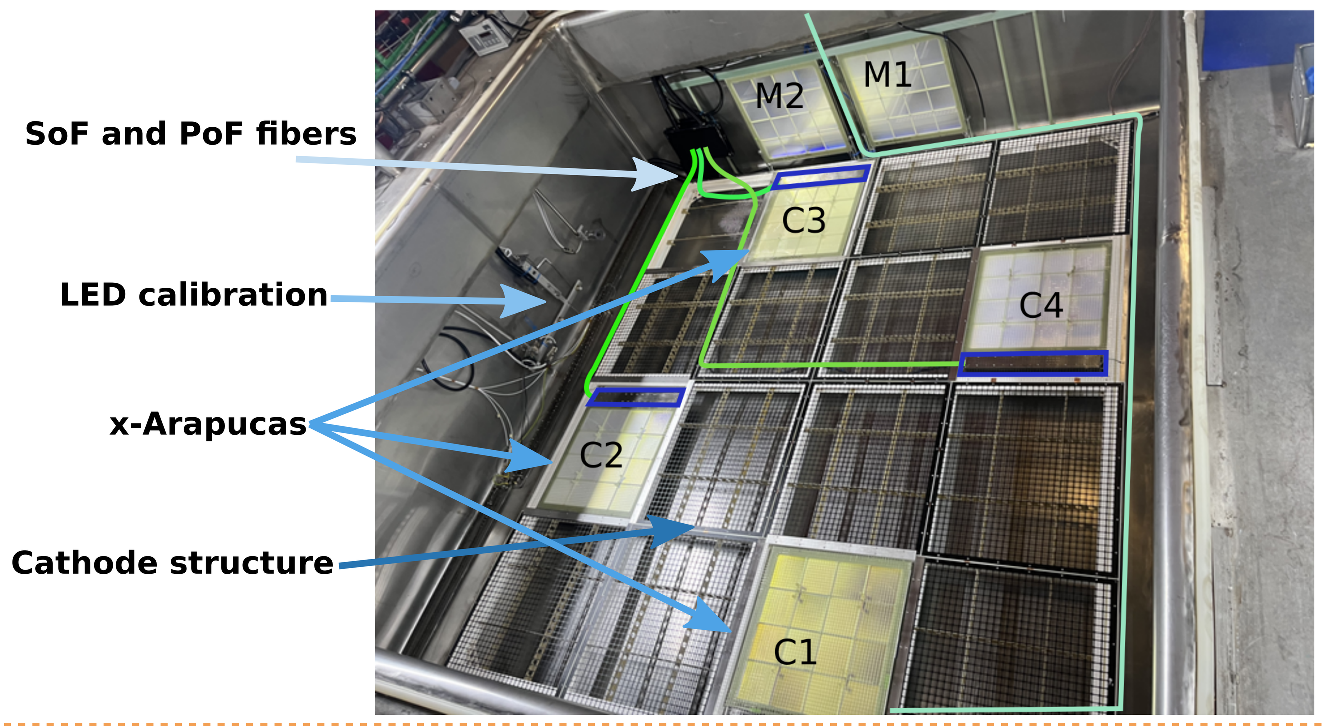


Prototyping campaigns at the CERN Neutrino Platform

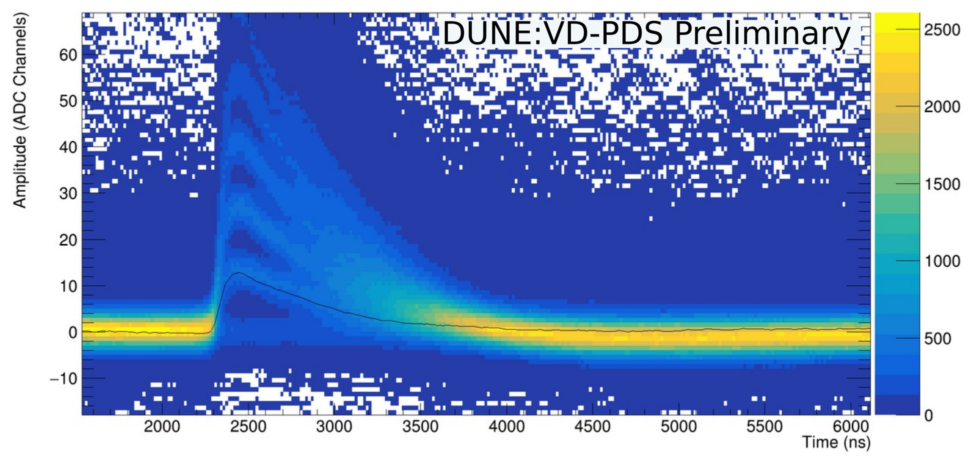
A 3x3x1 m³ cryostat has been in use since late 2021 to test the VD prototypes.

In 2024 the VD-PDS group installed four x-Arapuca detectors in the cathode operated in this cryostat. They were read out through SoF electronics and powered with PoF.

Baseline DUNE FD components were used except where a technology decision was pending or the installation circumstances required adaptations.



Persistence plots showing the single photo-electron (SPE) signal (black line), and up to 4-5 PE signals.



An LED calibration system is used to illuminate the modules with increasing amounts of light. The 275 nm LED light allows us to increase the size of the signals detected in a controlled way in order to study the performance of the modules.

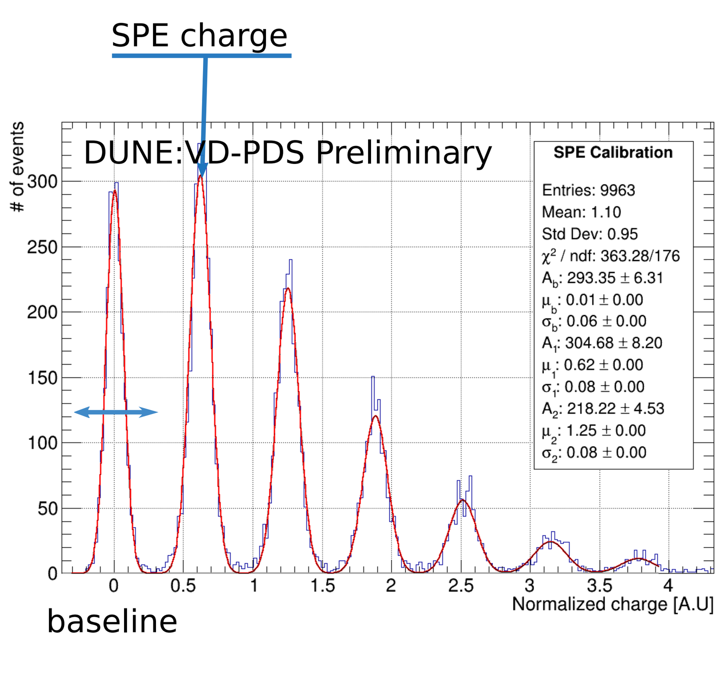
The PDS test stand at CERN

The multiple prototyping campaigns served to develop an assembly and testing protocol.

Valuable experience was acquired to determine the QA/QC procedures to follow during the upcoming detector construction and installation.

Performance of the PDS cathode readout

Single photo-electron sensitivity



Signal-to-Noise Ratio:

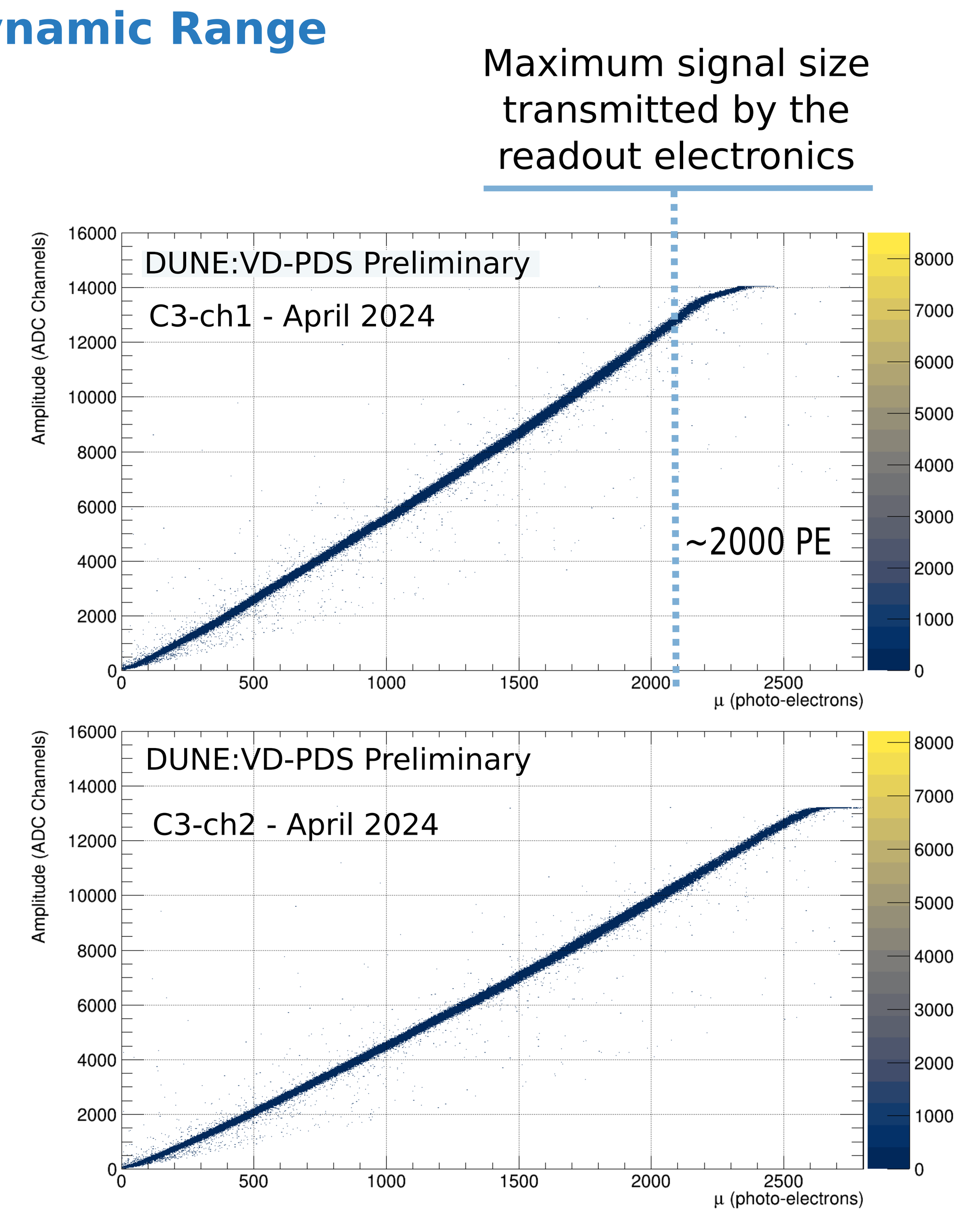
$$\mathrm{SNR} = \frac{\text{SPE average charge}}{\text{baseline RMS}}$$

Prototype run results April 2024

		SPE amplitude (ADC)	Baseline RMS (ADC)	SNR
C1	ch1	7	4	8.8
	ch2	6.3	3.9	7.9
C2	ch1	6.3	4.5	6
	ch2	5.1	4	6.2
C3	ch1	6.1	3.7	10.1
	ch2	5.4	4.9	6.1
C4	ch1	4.1	3.7	5.9
	ch2	6.4	5.3	5.3

Summary of results obtained in the last prototype run using SoF electronics. Four modules were evaluated, with two readout channels each.

Dynamic Range



Results from the interplay between:

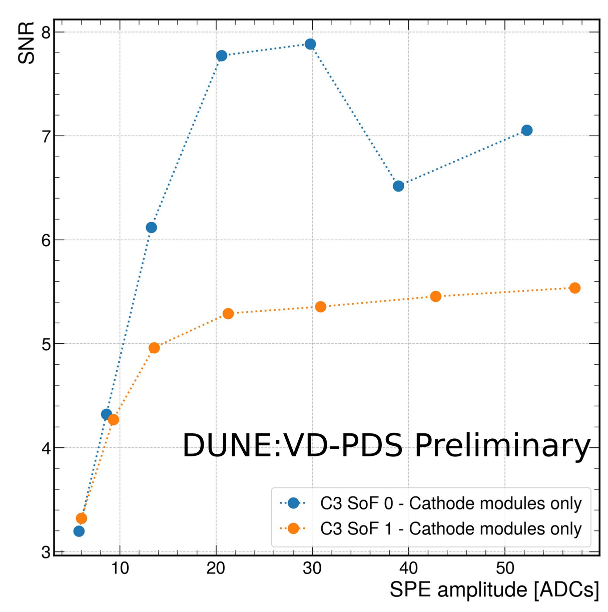
- the SiPM signal size at the output of the x-Arapuca
- the cold transmitter's maximum signal output
- the warm receiver's maximum input
- the ADC's range

The SoF cold electronics evaluated in the prototype run of April 2024 demonstrated a dynamic range between 1600 and 2000 PE.

Warm Receiver and Digitization

- Analog optical receiver: converts light signal to voltage
- DAPHNE: analog amplification and digitization

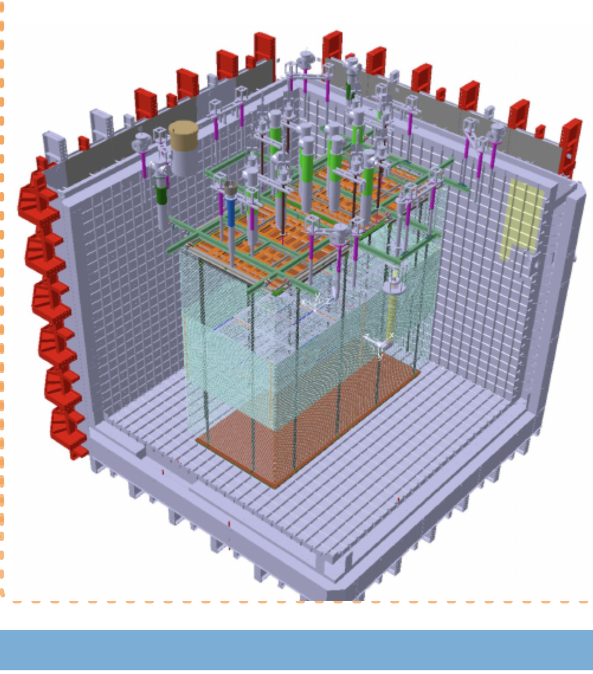
The gain of the receiver and the amplification in DAPHNE need to be coherently chosen to optimize the performance at digitization.



The first tests of the full readout were performed in April 2024.

The performance was studied as a function of the gain, that modifies the SPE amplitude.

Upcoming Developments



ProtoDUNE-VD is a kiloton-scale prototype installed at the CERN Neutrino Platform.

A full PDS system has been installed alongside the TPC.

The detector is expected to run before the end of 2024.

[1] The DUNE Far Detector Vertical Drift Technology TDR arxiv:2312.03130
[2]Characterization and Novel Application of Power Over Fiber (...) arxiv:2405.16816
[3] The X-ARAPUCA: an improvement of the ARAPUCA device arxiv:1804.01407