Financiado por la Unión Europea NextGenerationEU
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GVANEXT
DEEP UNDERGROUND NEUTRINO EXPERIMENT

# ProtoDUNEs: Testing Technologies for the Deep Underground Neutrino Experiment

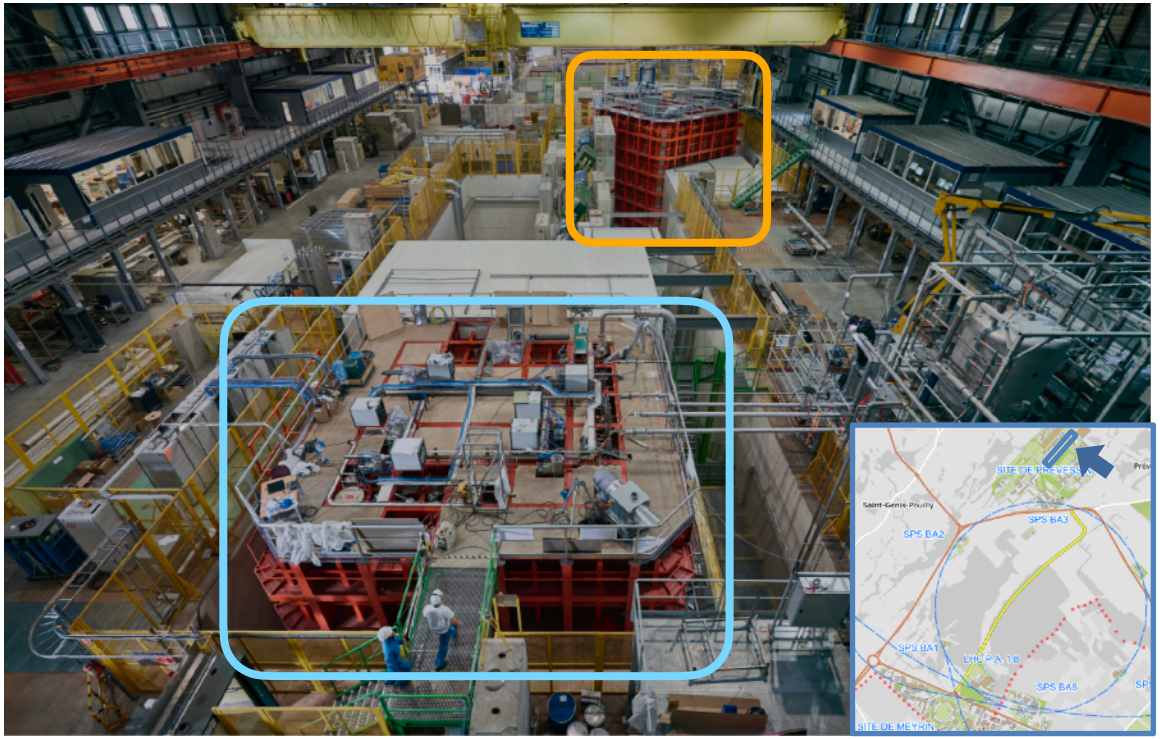
Andrea Roche Fernández

XVII CPAN days

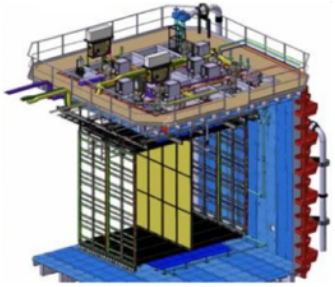
19th November 2025

CSIC Consejo Superior de Investigaciones Científicas
Universitat de València
IFIC Institut de Física Corpuscular
Excelencia Severo Ochoa
DUNE Deep Underground Neutrino Experiment

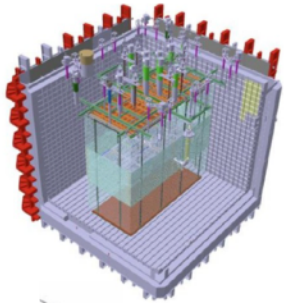
# ProtoDUNE overview

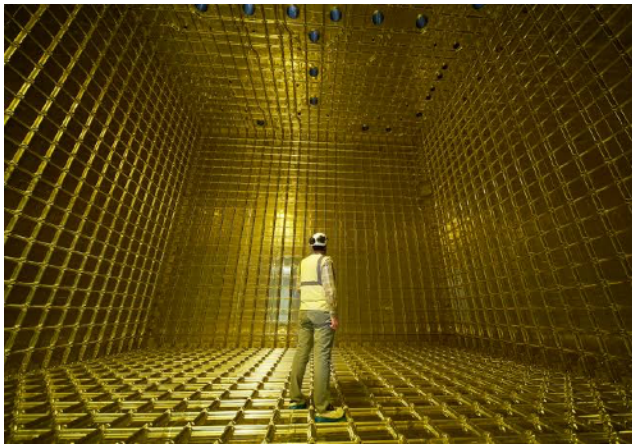



NP04



NP02





## ProtoDUNE stages

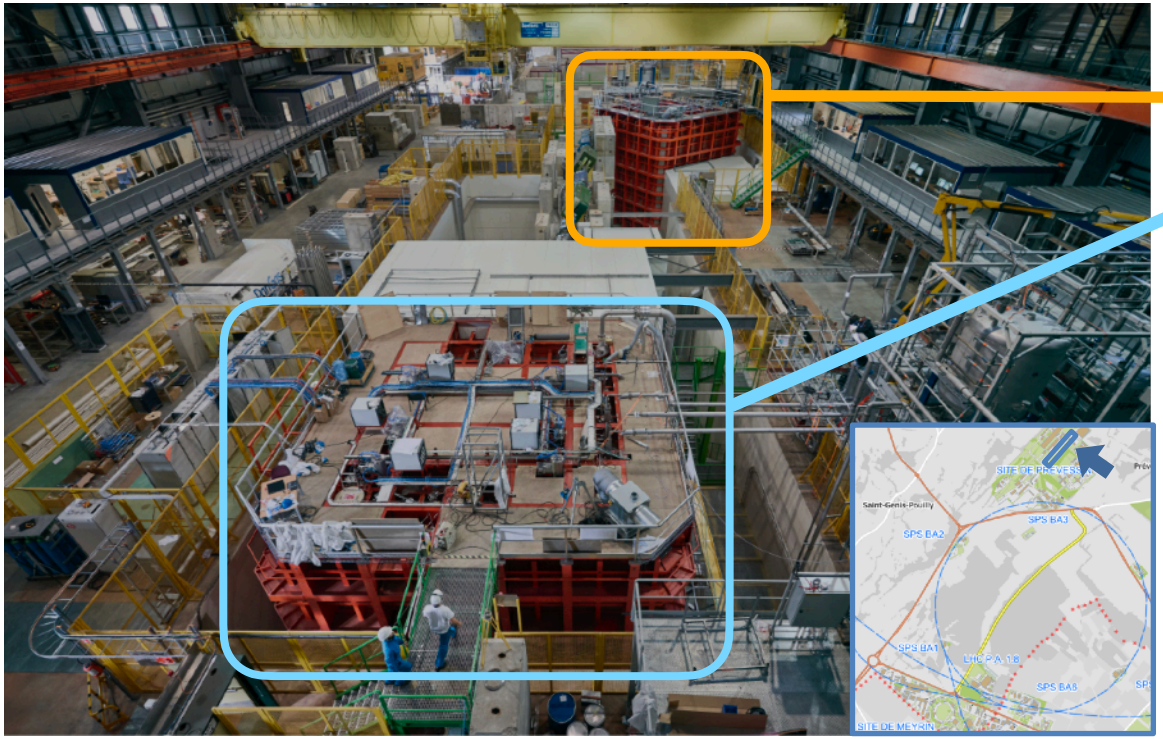
Two detectors (LArTPCs) built inside each cryostat at different times:

- ProtoDUNE-I (2018-2020)
  - ProtoDUNE-SP — NP04 — ProtoDUNE-HD (FD1)
  - ProtoDUNE-DP — NP02 — ProtoDUNE-VD (FD2)
- ProtoDUNE-II (2024-2026)

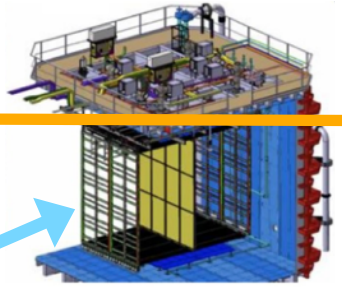
## ProtoDUNEs at CERN

- DUNE Far Detector (FD) prototypes located at CERN at (1:20) scale.
- 760t total mass of LAr.
- Test beam to validate performance.

# ProtoDUNE overview




NP04



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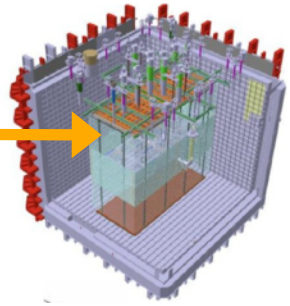

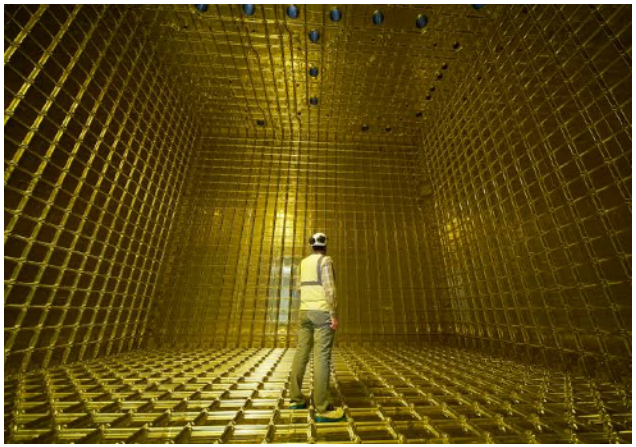

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## ProtoDUNEs at CERN

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# ProtoDUNE motivation

## Hardware

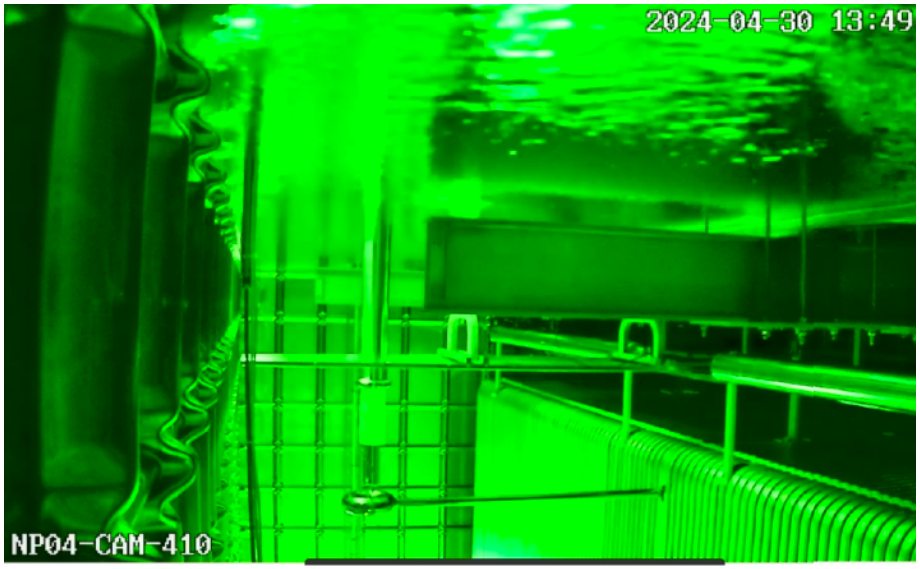
- Prototyping production and installation procedures
- Validating the design from basic detector performance
- Demonstrating long-term operational stability

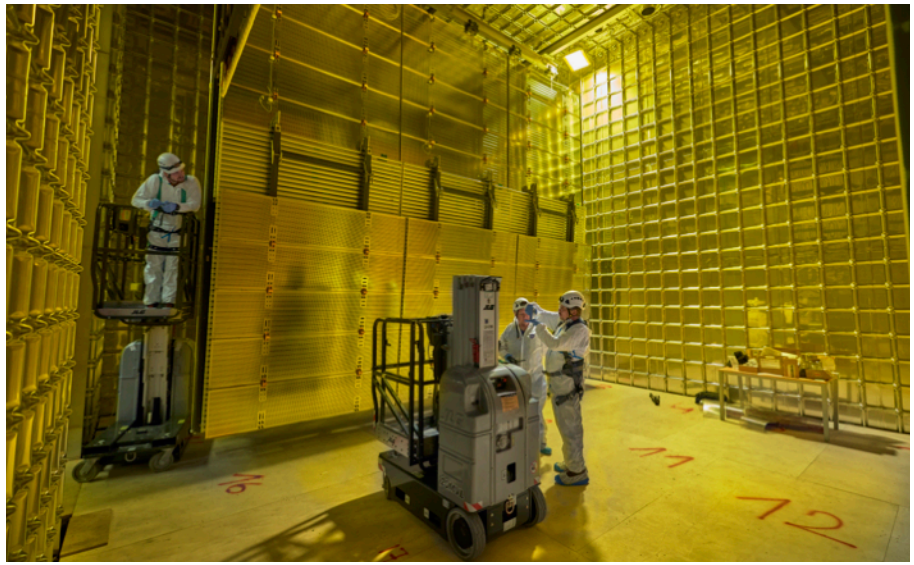
## Cosmics data

- 3D map of detector response: space charge and E field distortions
- Different settings: E-field, recirculation

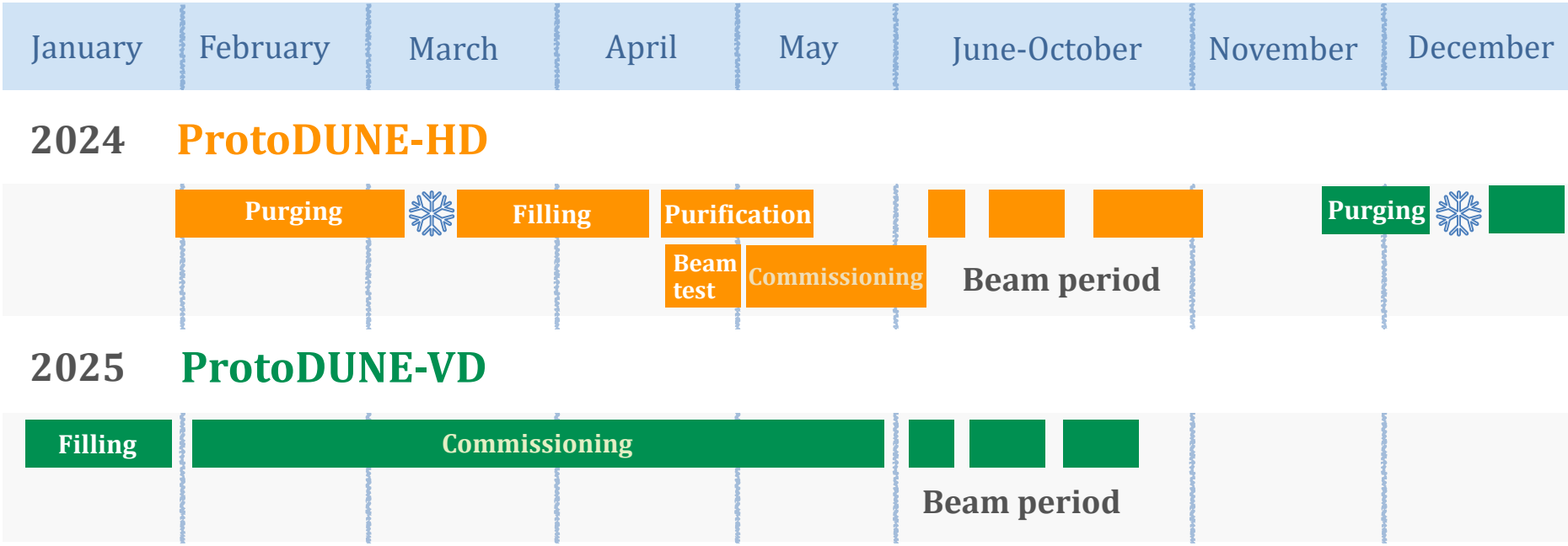
## Test beam data

- Detector response understanding, calibration, dE/dx, PID
- Perform cross section measurements of hadrons in Argon



# ProtoDUNE operation timeline





PDS office

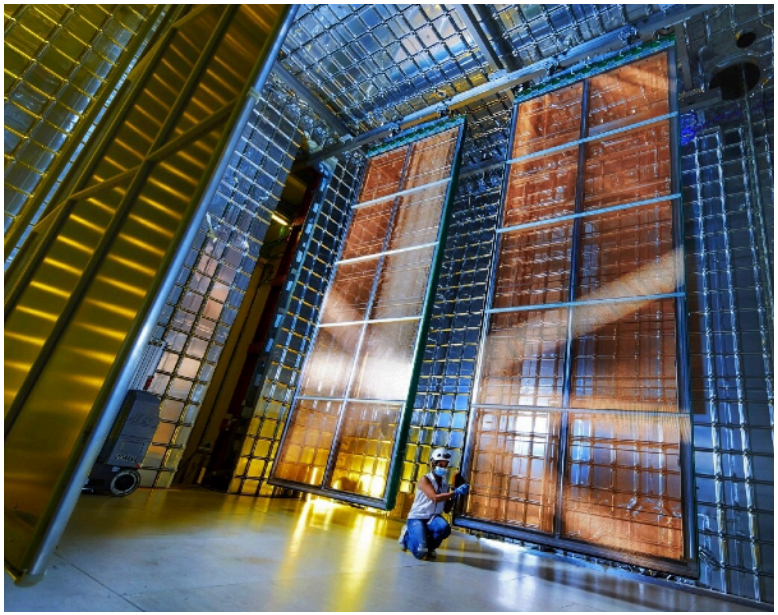

NP02 cryostat

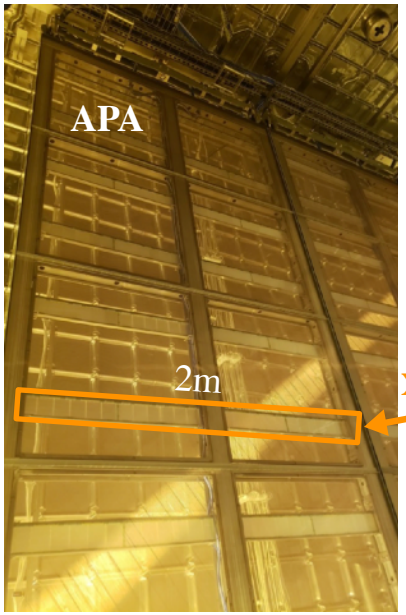

Control room at Neutrino Platform

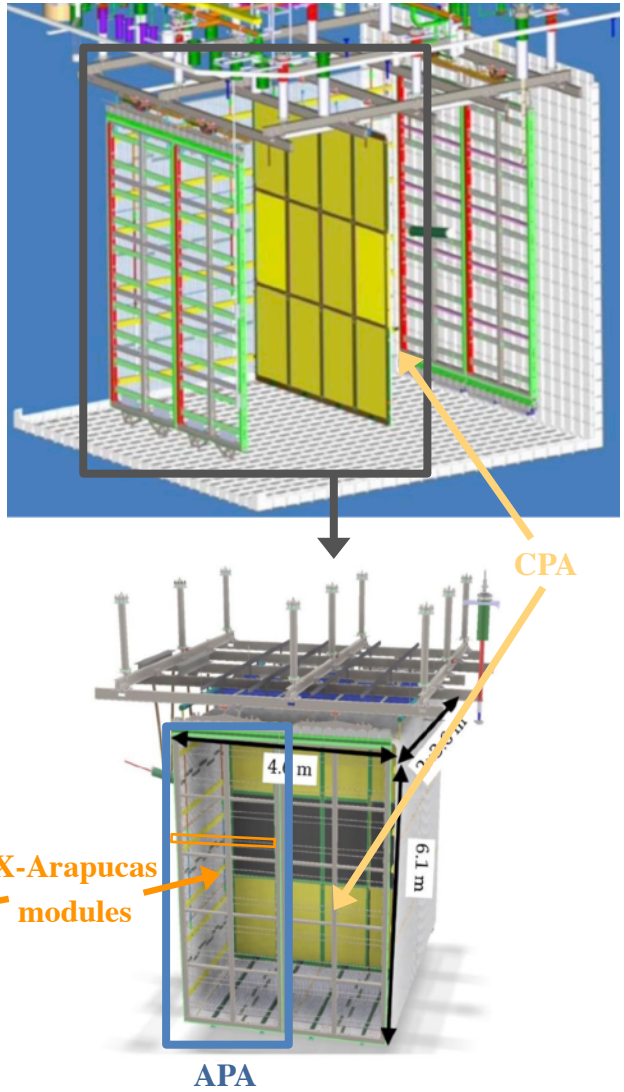
# ProtoDUNE Horizontal Drift (PD-HD)

## Characteristics

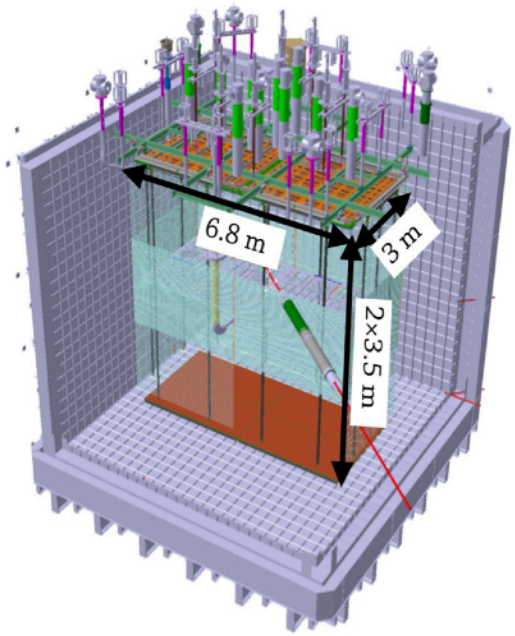
- 2 active volumes, with 3.6 m drift each, separated with a cathode
- 2 anode plane assemblies (APAs), facing the cathode plane assembly (CPA) on each side
- Photon Detection System (PDS) modules, integrated in the APAs:
  - 40 rectangular (2m length) X-Arapucas modules in total, with 4 channels each
  - 48 SiPMs (Hamamatsu or FBK) per channel

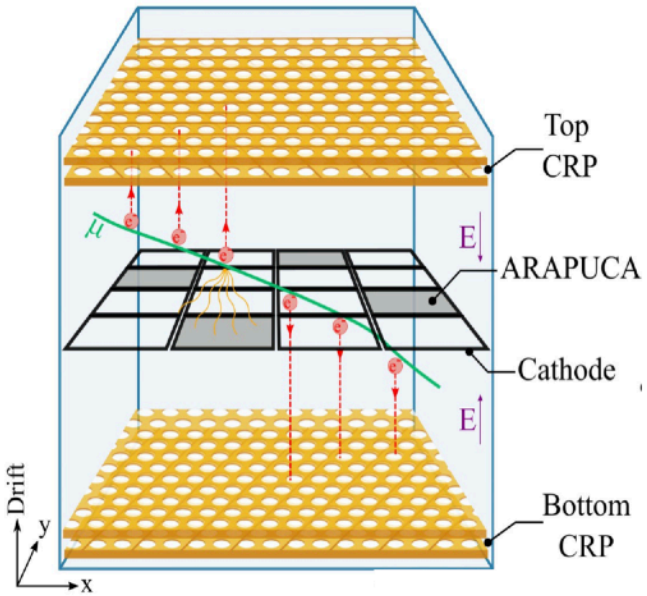


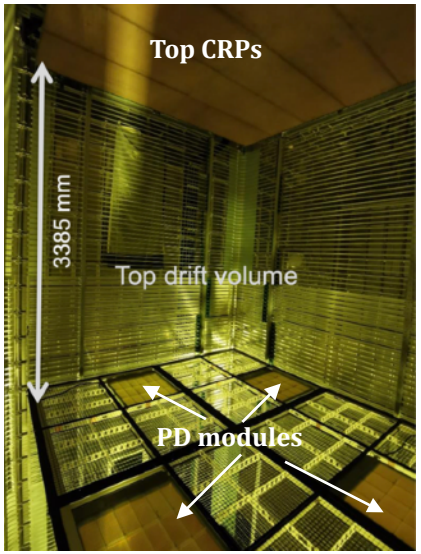


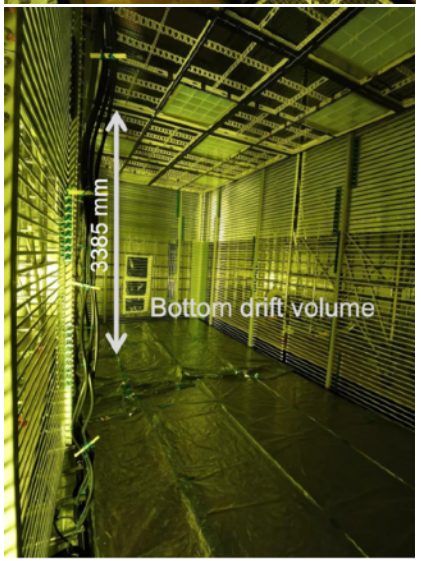



# ProtoDUNE Vertical Drift (PD-VD)




## Characteristics

- 2 active volumes, with 3.4 m drift each, separated by a cathode
- 2 Horizontal Charge Readout Planes (CRPs) facing the cathode on each side
- Photon Detection System (PDS):
  - 16 square (60x60cm$^2$) X-Arapucas modules in total, with 2 channels each: 8 on the cathode and 8 on the cryostat wall
  - 80 SiPMs (Hamamatsu or FBK) per channel

# Time Projection Chamber (TPC)

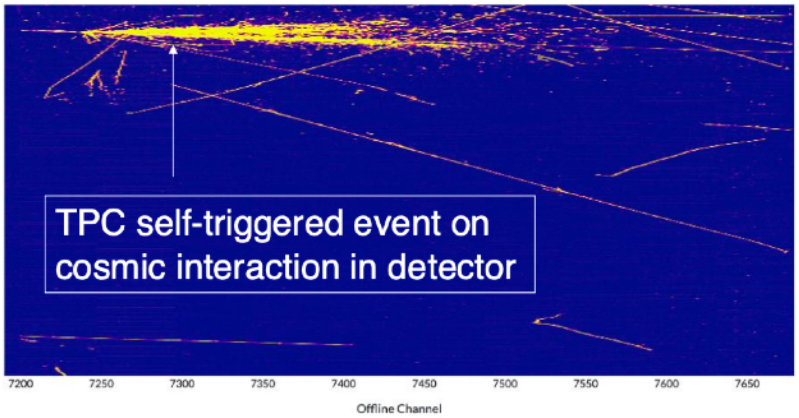
## Charged particles produce in LAr

- Ionization ➡ Charge pulse ➡ APAs or CRPs
- Excitation ➡ VUV light emission ➡ PDS

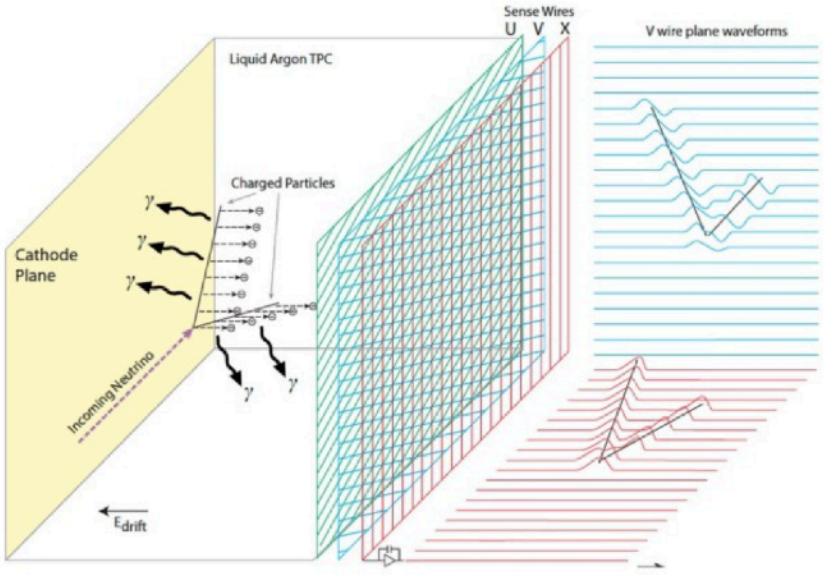
## Advantages of a double readout

- Track reconstruction
- Prompt signal
- Combined calorimetry

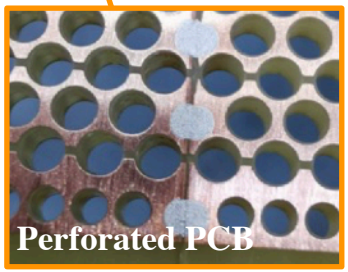
Cosmic interaction in PD-HD




Operation of a TPC in PD-HD





# Photon Detection System (PDS)

Spanish contribution

Paper in preparation

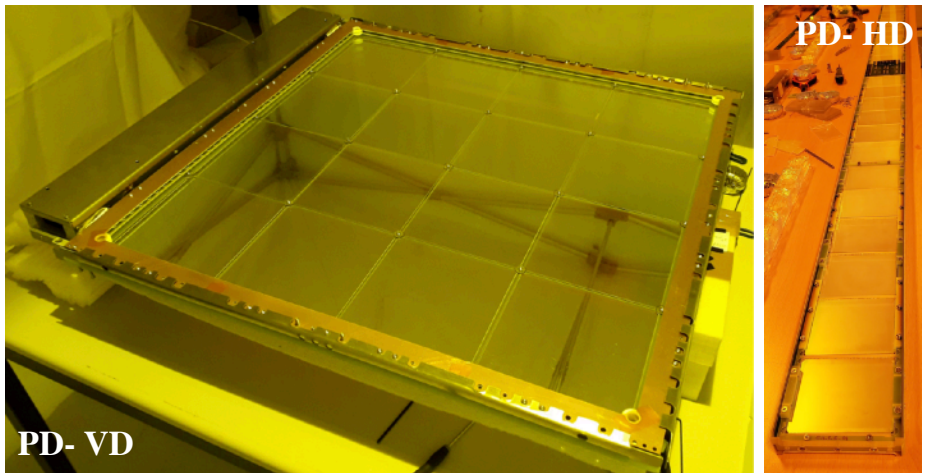
## X-ARAPUCA

- Technology for FD1 and FD2
- Photon trap
- Wavelength shifters + SiPMs

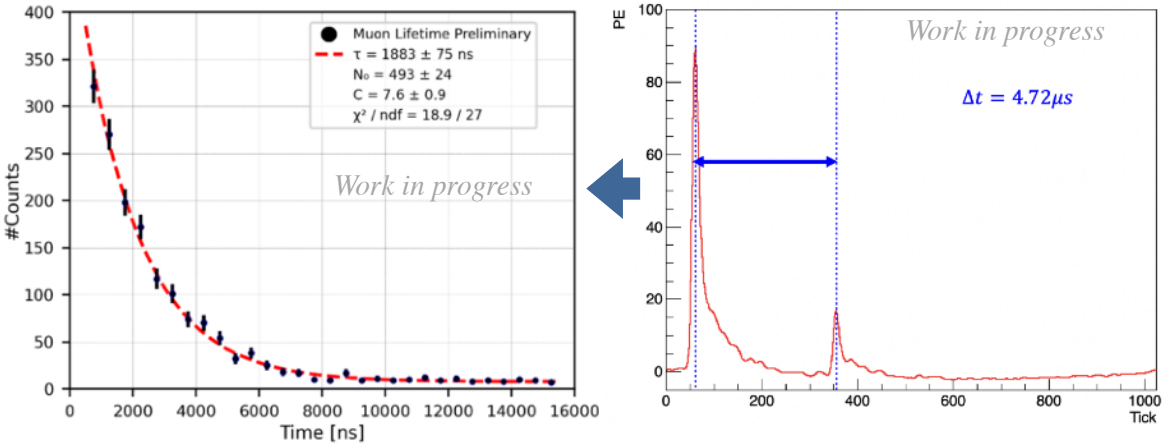
## Results in ProtoDUNE-HD

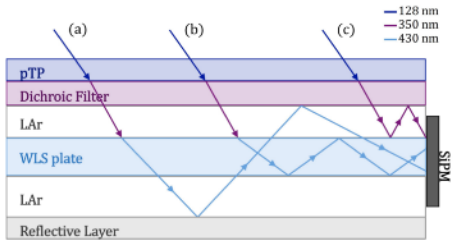
- Good timing resolution
- Excellent Single PhotoElectron resolution

**X-Arapuca modules in ProtoDUNE**

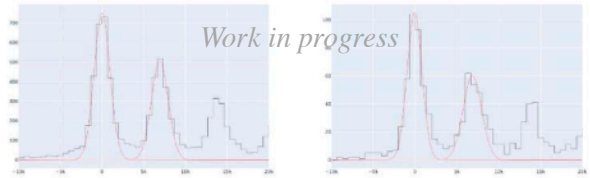



**Muon lifetime estimation in PD-HD to demonstrate good timing resolution**




X-Arapuca concept

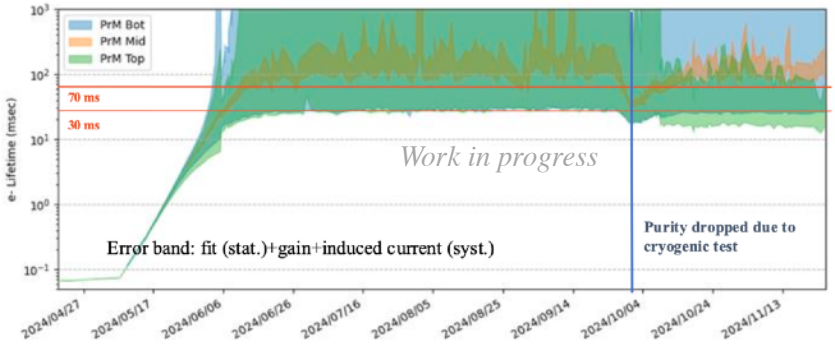



**LED calibration analysis from different channels in PH-HD**

# Cryogenic instrumentation

Papers in preparation

**Electron lifetime during the ProtoDUNE-HD run**




## Purity Monitors

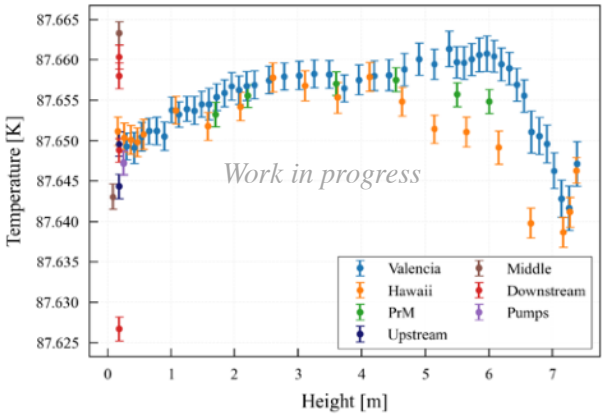
- Miniature TPC using artificial electron source to measure *e* lifetime in LAr
- Good stability and precision in NP04 and NP02

## Temperature Monitoring System

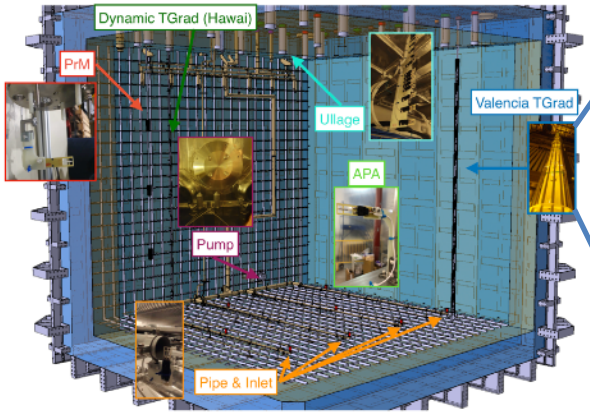
- 159 Resistance Temperature Detectors (RTD) in HD
- 4 fibers with 34 Fiber Bragg Gratings (FBG) in VD
- Measured T-profiles from different sub-systems reveal a coherent picture for all sensors

Spanish contribution

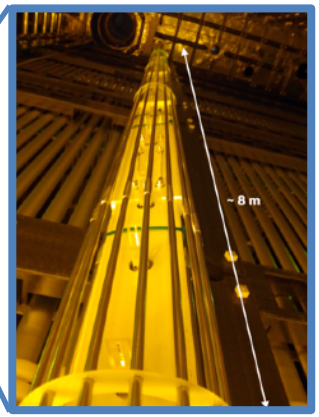
**T-profiles from different subsystems**




**Temperature Monitoring System**




**Valencia TGrad**



# ProtoDUNE analyses

Spanish contribution

Papers completed and in preparation

## ProtoDUNE-I

- Operation successfully completed
- Paper already published with first physics results on PD-SP

## ProtoDUNE-II

- Operation successfully completed
- Paper in preparation for PD-HD performance
- Physics analyses ongoing

Design and performance of the photon detection system of the ProtoDUNE-HD detector at CERN

**Abstract**

This article describes the design and performance of the Photon Detection System (PDS) of ProtoDUNE-HD, one of the DUNE far detector prototypes operated at CERN. The PDS is designed to complement the Time Projection Chamber – which provides precise tracking – by offering high-precision timing capabilities, essential to locate non-beam events, and enabling competitive event energy reconstruction. R&D on the various components of the PDS, which began in 2016, culminated in this prototype, operated during 2024 and exposed to a charged particle test beam. Design changes from previous versions are discussed, along with a detailed performance evaluation and some initial physics results. Lessons learned from this prototype that will inform and improve the final version to be installed in DUNE far detectors are also presented.

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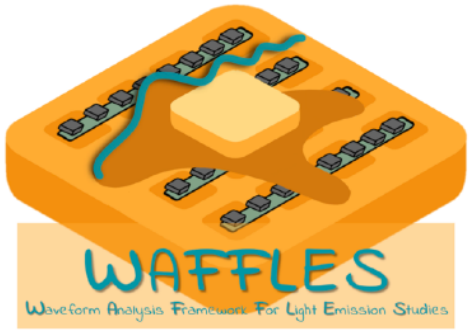
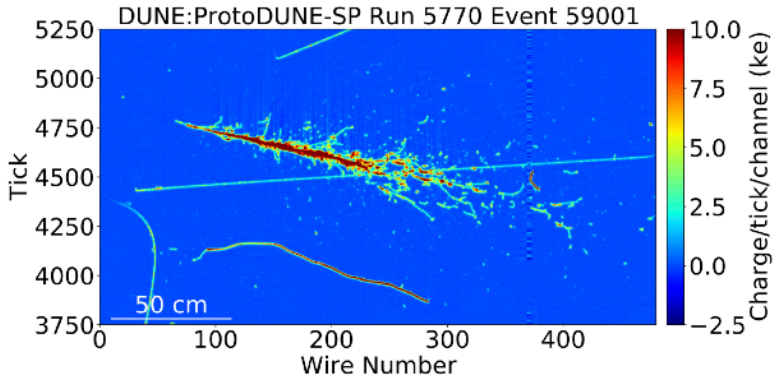
*Preprint submitted to Nuclear Instruments and Methods A* *November 10, 2025*

Paper of the PDS performance in PD-HD

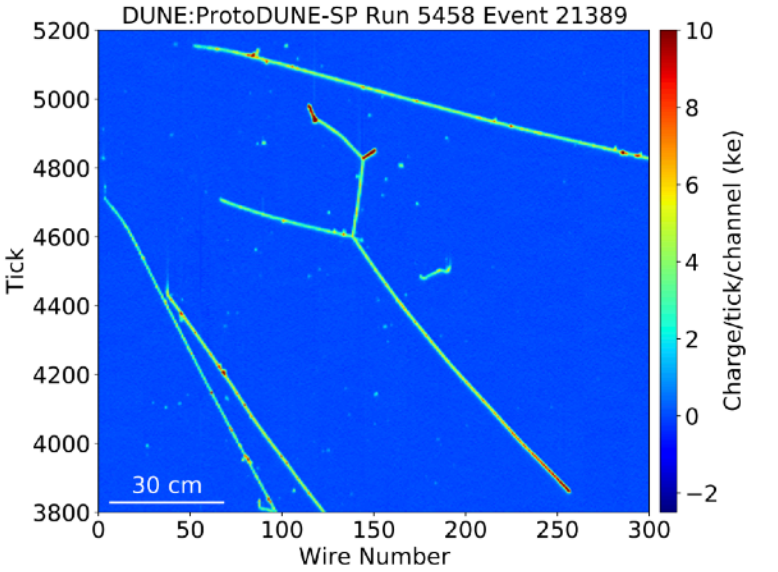



Software for PDS analyses

A 6 GeV/c electron candidate




A 1GeV/c pion candidate



# Next steps: Protodune-III

Spanish contribution

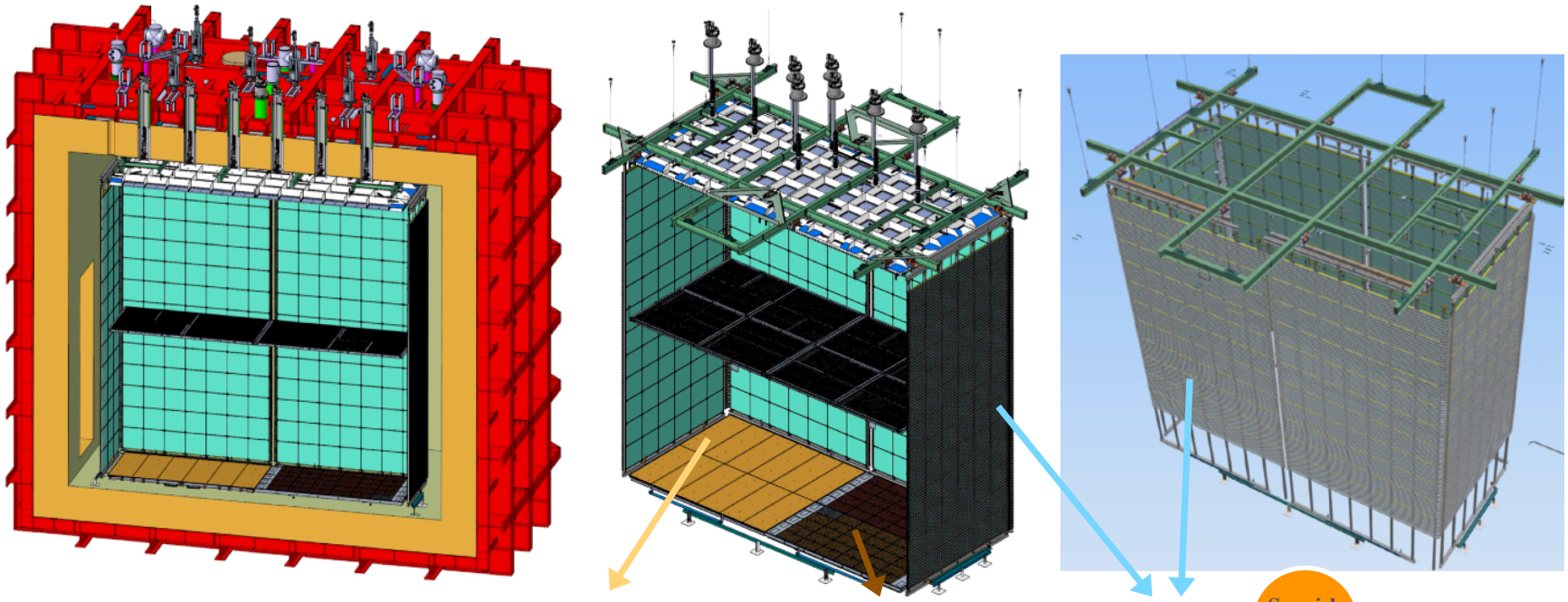
## Proposal

- ProtoDUNE-III at NP02 cryostat to test and demonstrate LArTPC technologies for FD3 and FD4
- First run during 2028-2029

## Main goals

- **Large-scale prototype** for integration of Phase II components at **full FD dimensions**
- Study the performance over several months

**3D model of the proposed detector configuration for ProtoDUNE-III**



# Conclusions

## ProtoDUNEs: Testing technologies for DUNE

- Many physics results from ProtoDUNE-I, some of them already published.
- Very successful operation and analyses ongoing in ProtoDUNE-II.
- Mature technologies extensively tested and ready for construction.
- Ongoing R&D for DUNE Phase-II Far Detector, to be proved in ProtoDUNE-III run in 2028.
- Strong Spanish contributions to cryogenic instrumentations and Photon Detection System.


September, 2025

Thank you!

DUNE Collaboration Meeting in Valencia