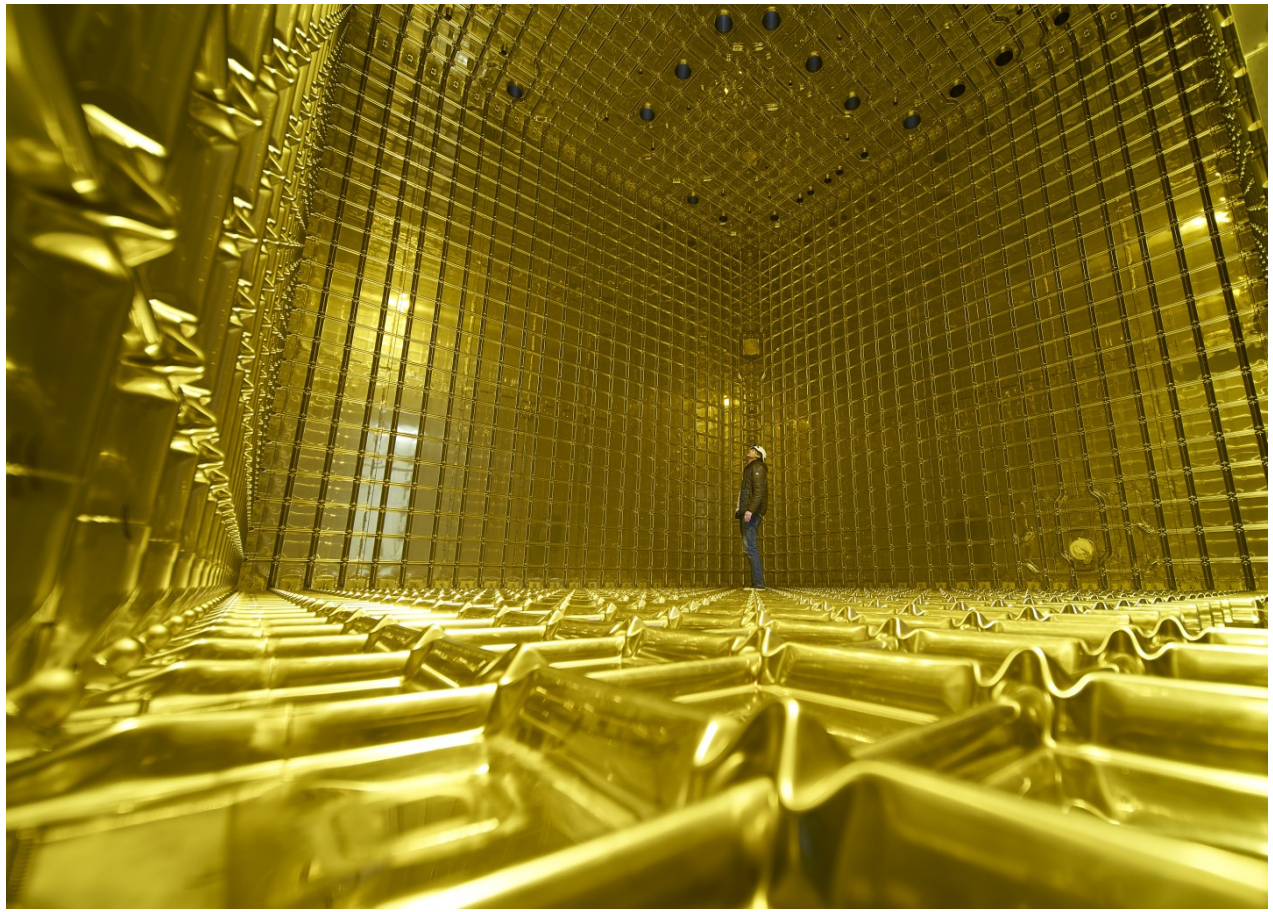
The Photon Detection System of the DUNE Far Detector



Francesca Alemanno - INFN Lecce
for the DUNE PDS Group

Incontri di Fisica delle Alte Energie (IFAE 2025)
9-11 Aprile 2025, Cagliari

INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI LECCE

DUNE

Overview

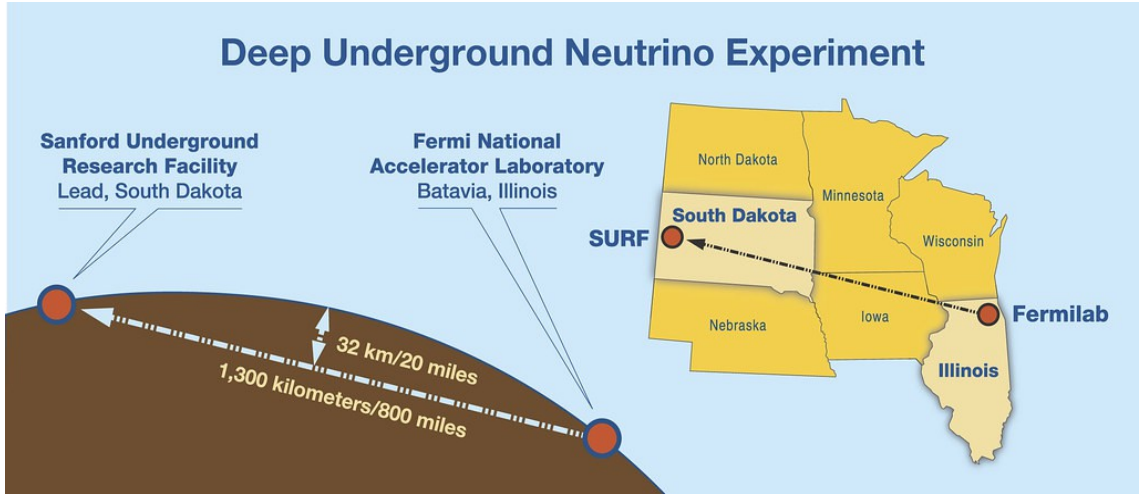
The DUNE experiment

- Overview and scientific goals
- DUNE Far Detector
- **Photon Detection System (PDS)**

Far Detector prototypes at CERN

- ProtoDUNE at CERN: the first two FD prototypes
- **PDS in protoDUNE**

Summary and future prespectives

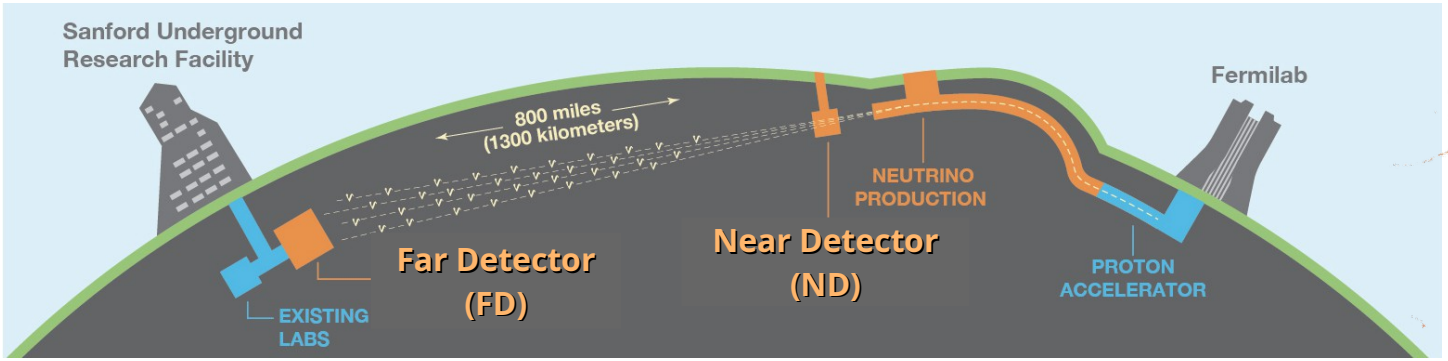


The DUNE experiment

The Deep Underground Neutrino Experiment (DUNE) is a new generation long-baseline neutrino oscillation experiment

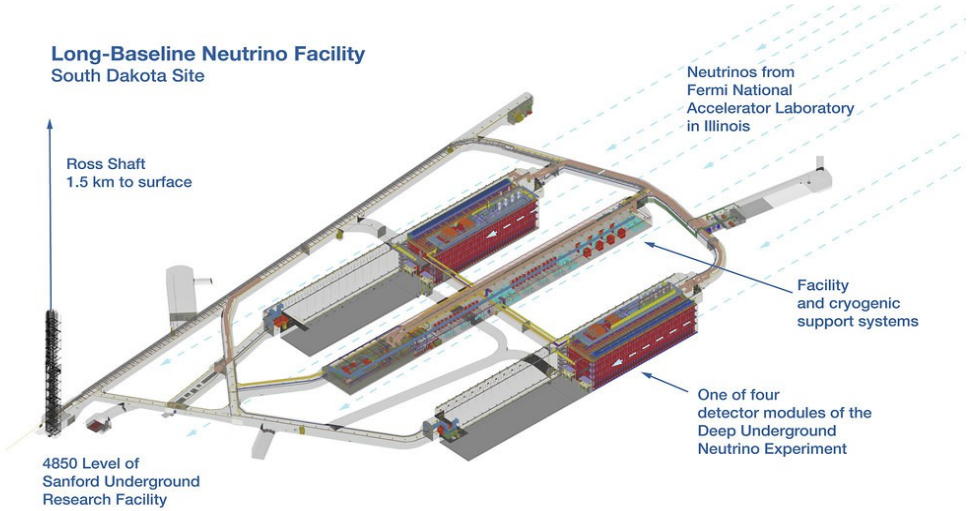
Main goals:

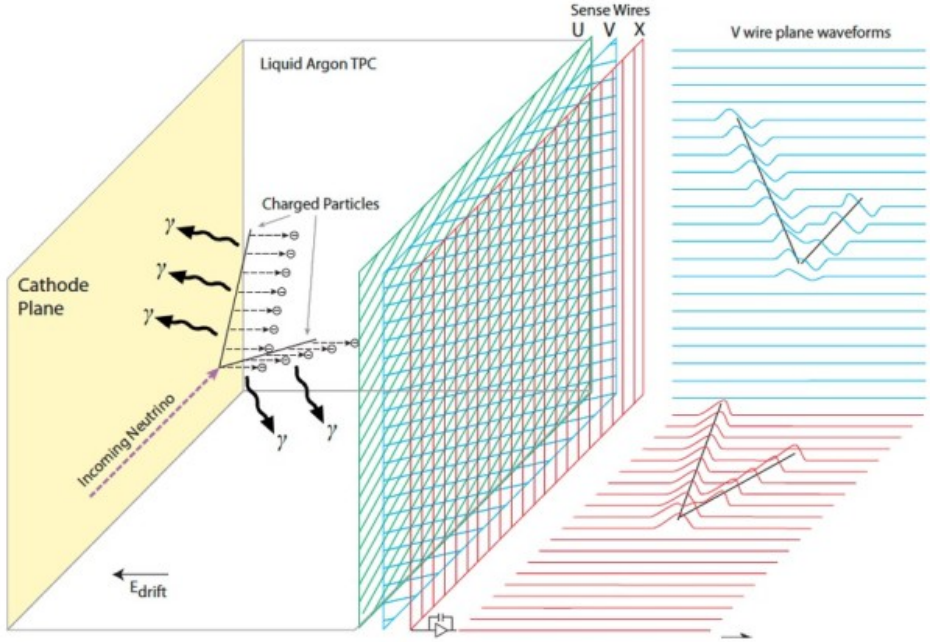
- High precision measurement of the neutrino oscillation parameters
- Supernova and solar neutrinos detection
- Beyond the Standard Model Searches

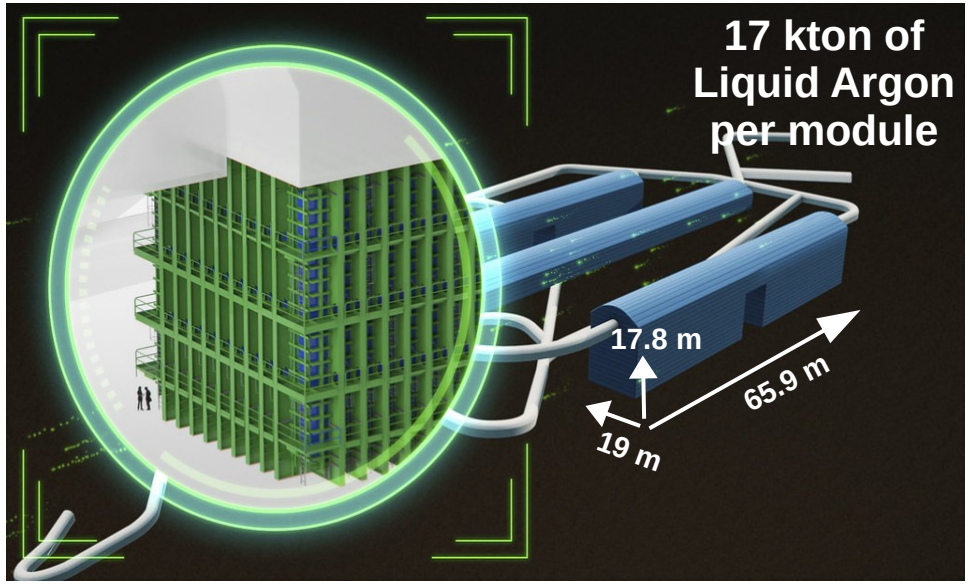


- High-power proton beam of 1.2 MW upgradable to 2.4 MW
- High-power, wide-band neutrino beam (~GeV energy range)
- Near detector at 575 m from the ν source
- Far detector in South Dakota (~1300 km) and 1.5 km deep underground

DUNE Far Detector







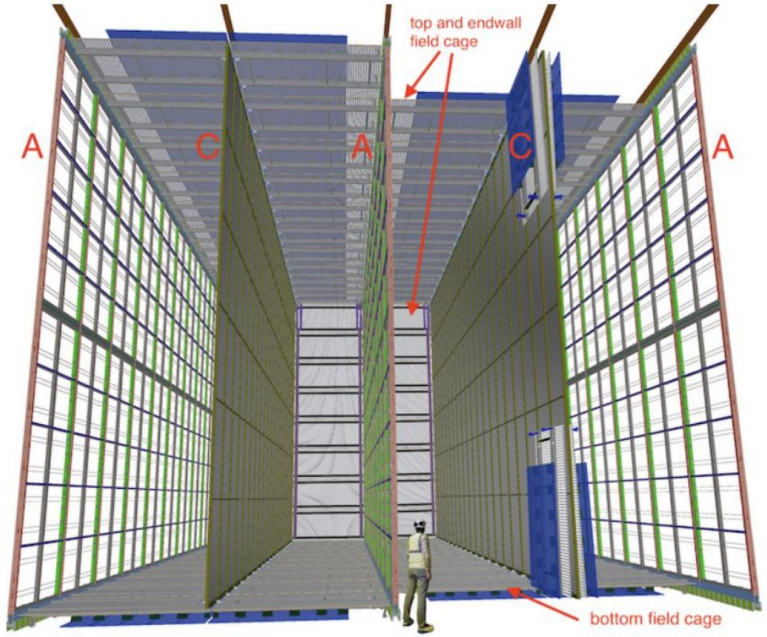
Charged particles in LAr produce free **ionization electrons** and **scintillation light** (128 nm) → **DOUBLE READOUT:**

- **Time Projection Chamber (TPC)** for charge
- **Photon Detection System (PDS)** for light

Advantages of a double readout:

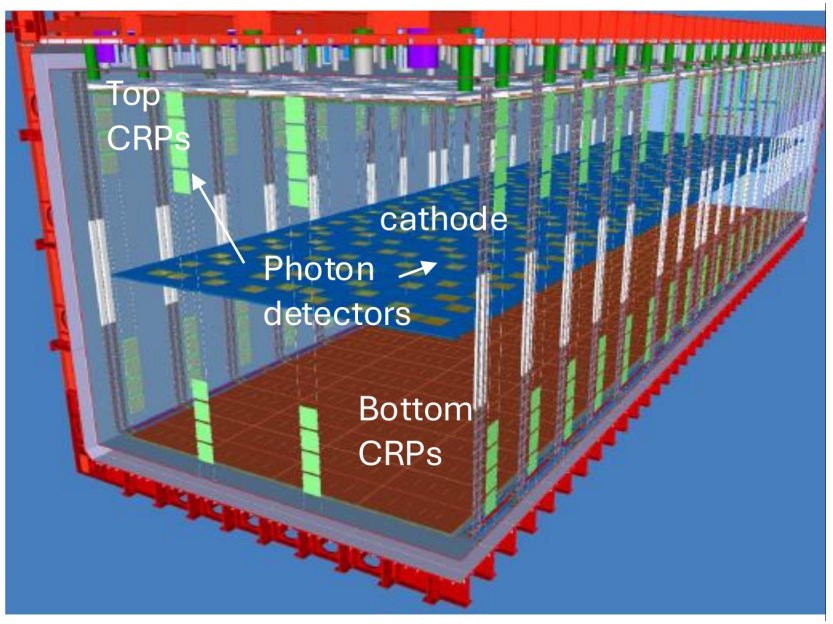
- **Neutrino interaction vertex reconstruction**
- **Combined calorimetry**
- **Prompt signal** (Trigger for non-beam events)

Far Detector modules



First two modules:

- **Horizontal Drift (HD)**
- **Vertical Drift (VD)**



Horizontal Drift

- Four 3.6 m x 12 m x 58 m drift regions
- 3 anodes and 2 cathodes
- Anode Plane Assemblies (APAs): wire chamber technology
- Photon detectors in the APAs

Vertical Drift

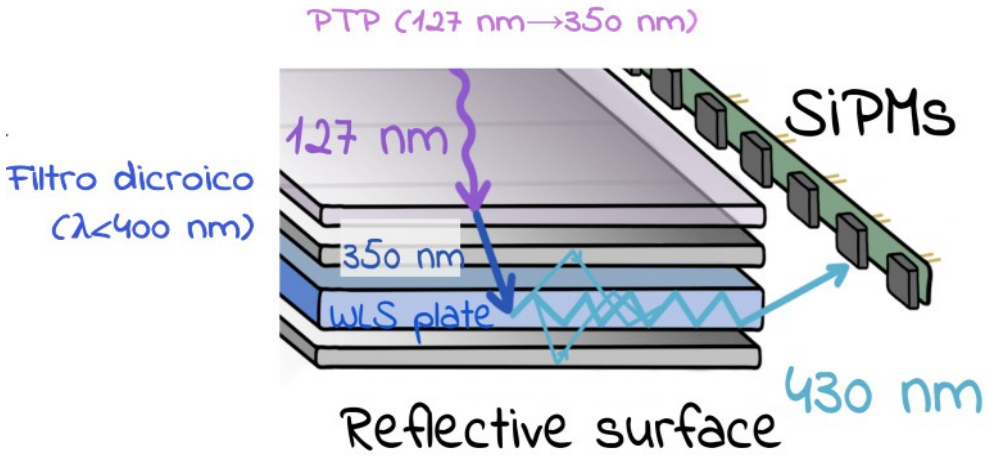
- First module to be delivered
- Two drift volumes of 13.5 m x 60 m x 6.5 m drift
- 2 anodes and 1 cathode
- Charge Readout Planes (CRPs): perforated PCB technology
- Photon detectors in cathode and walls

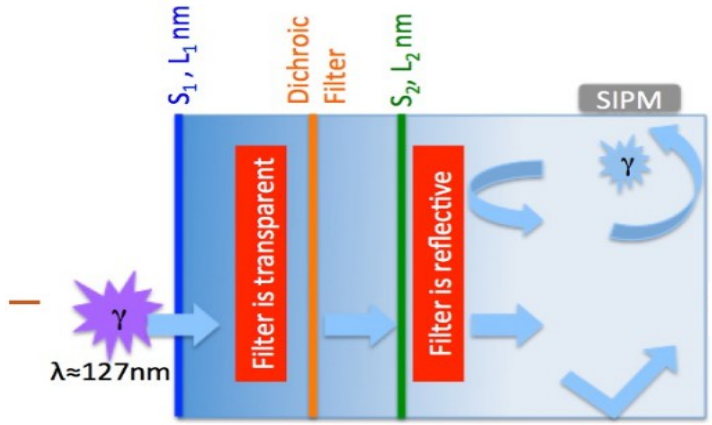
Far Detector Photon Detection System
X-Arapuca

Arapuca = trap in Portuguese

The X-Arapuca is a trap for photons

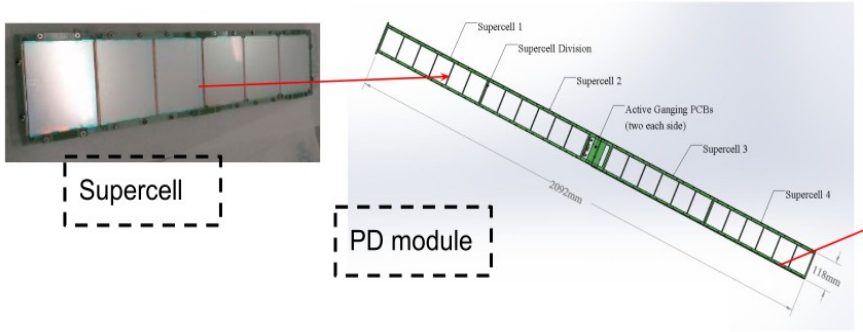
- **PTP (P-terphenyl layer)**
  - Converts the LAr scintillation light
  - λ=128 nm → λ=350 nm
- **Dichroic filter**
  - **Transparent** to light with **λ < 400 nm**
    - → the PTP converted light can enter
  - **Reflective** for **λ > 400 nm**
- **Wavelength shifter bar (WLS bar)**
  - Converts the incoming light to **λ = 430 nm**
    - → **the light is trapped**
- **Silicon PhotoMultipliers (SiPM)**
  - Light detection

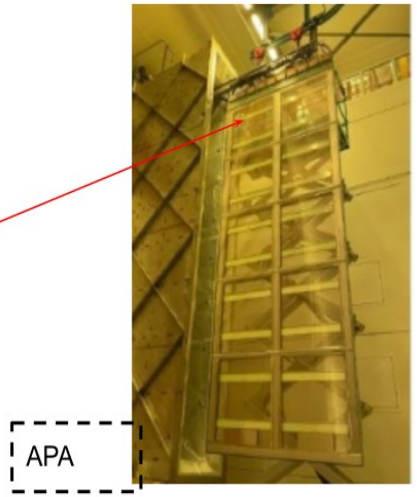




FD1 and FD2 Photon Detection System

HD

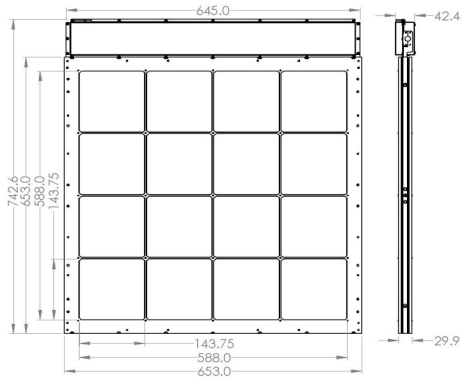




- 4 **Supercell** X-ARAPUCA (49 cm x 10 cm) per PD module
- 48 **SiPMs** per Supercell
- One channel: bias and signal on the same line

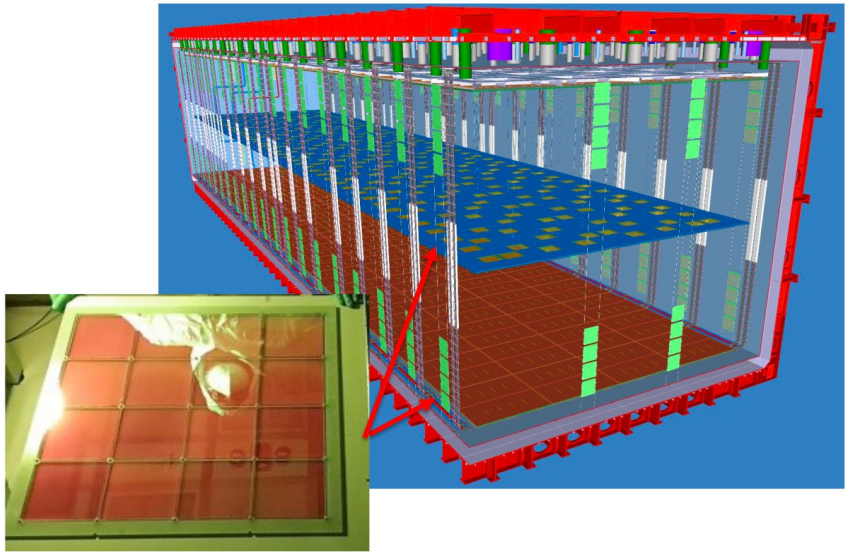
- **Installed inside the APA → does not decrease the active volume**
- 10 PD modules for APA
- **1500 modules in total:**
  - 500 dual-face in the middle
  - 1000 single-face in the edges

VD

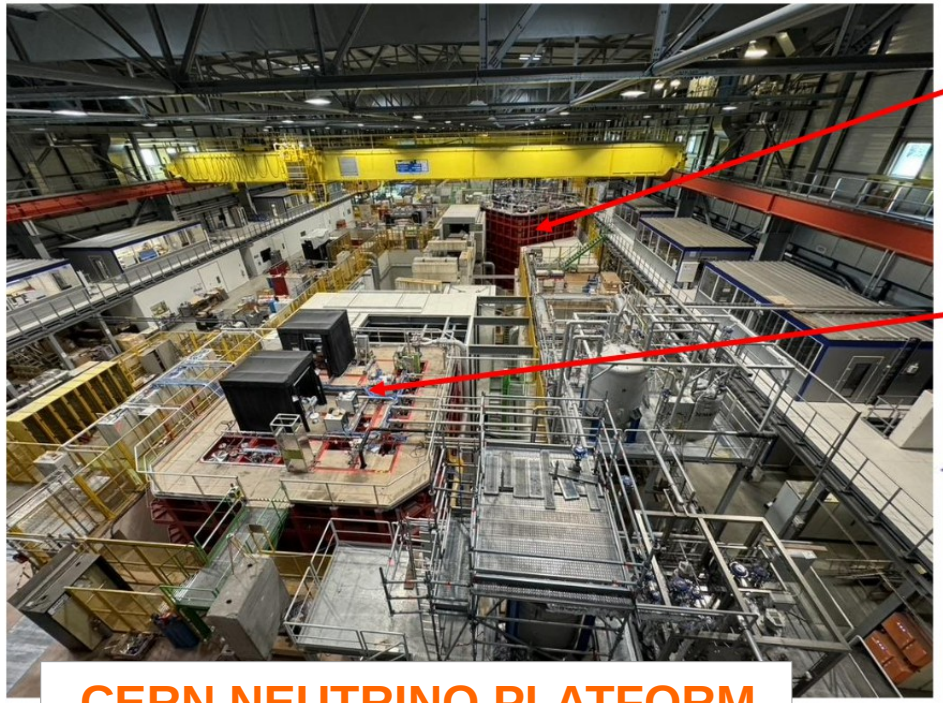


- **Megacell** X-ARAPUCA (65 cm x 65 cm)
- 160 **SiPMs** (40 per side)
- Two channels: 80 SiPMs per channel

- **Cathode (300 kV)**
  - 80 cathode modules
  - 4 X-ARAPUCA Megacell double-faced per cathode module
  - **320 double-face X-ARAPUCAs in total**
- **Walls**
  - Behind the transparent (70%) field cage
  - 320 at long walls
  - 32 short walls
  - **352 single-face X-ARAPUCAs**

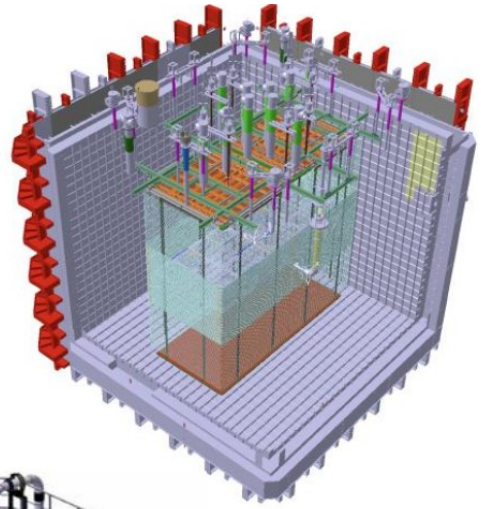


ProtoDUNE @ CERN

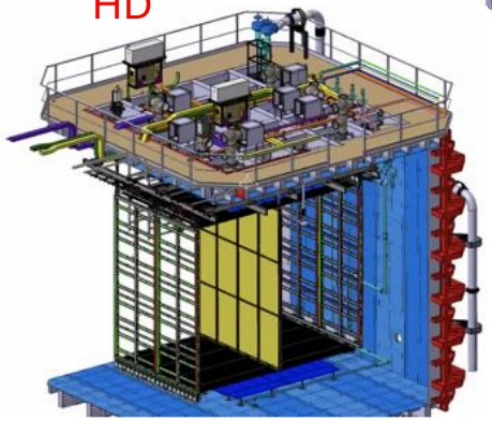


CERN NEUTRINO PLATFORM
@ EHN1

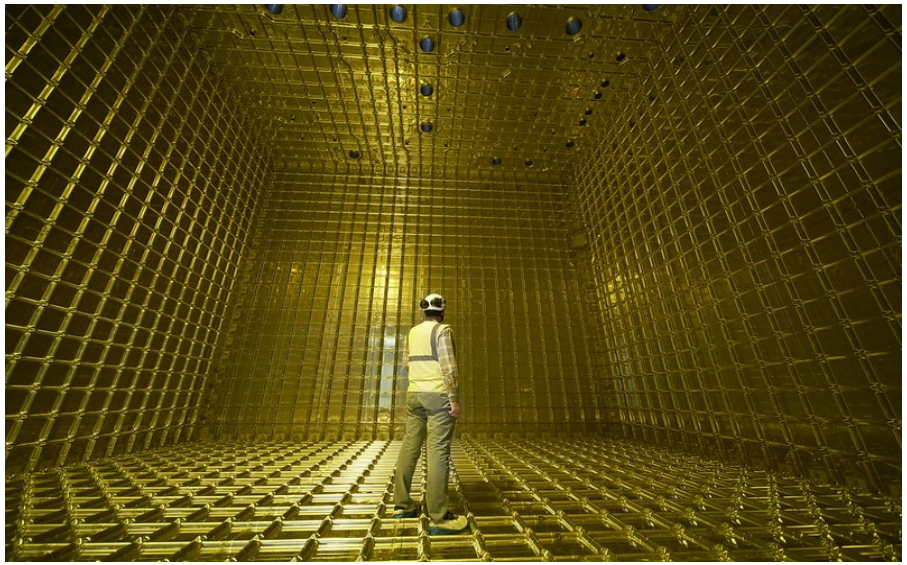
NP02
VD



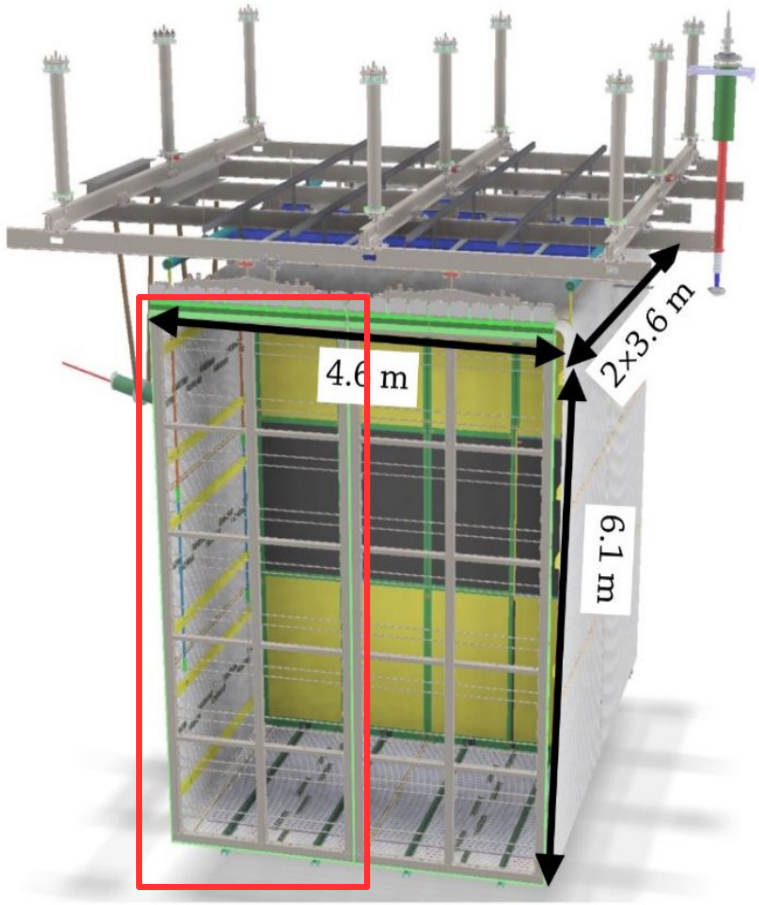
NP04
HD



- **2 prototypes (~ 8 x 8 x 8 m^3)**
- **760 ton of LAr**
- **Time Projection Chamber (TPC)**
- **Photon Detector System (PDS)**
- **Cosmic-Ray Tagger**



ProtoDUNE Horizontal Drift

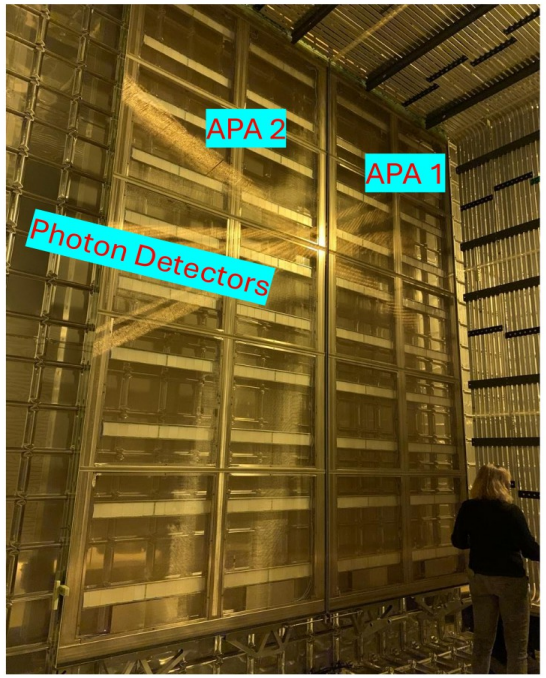


APA

2 APAs per side
Cathode in the middle

FIRST PROTOTYPE

- 0.28 kton fiducial volume
- Electric field 500 V/cm
- Drift length 3.6 m
- Anode: 3 layers of wire planes
- 4 APAs



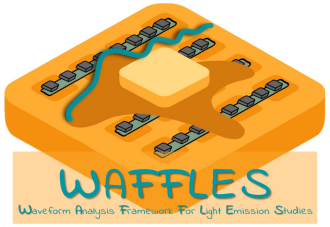
PDS integrated in the APAs

- 10 PDS modules per APA, between the wire layers → 40 X-Arapuca modules in total
- X-Arapuca absolute efficiency ~2-3%
- 48 SiPMs 6 x 6 mm^2 per X-Arapuca
- 2 different SiPMs: Hamamatsu and FBK

ProtoDUNE HD operations started in May 2024 and ended in December 2024

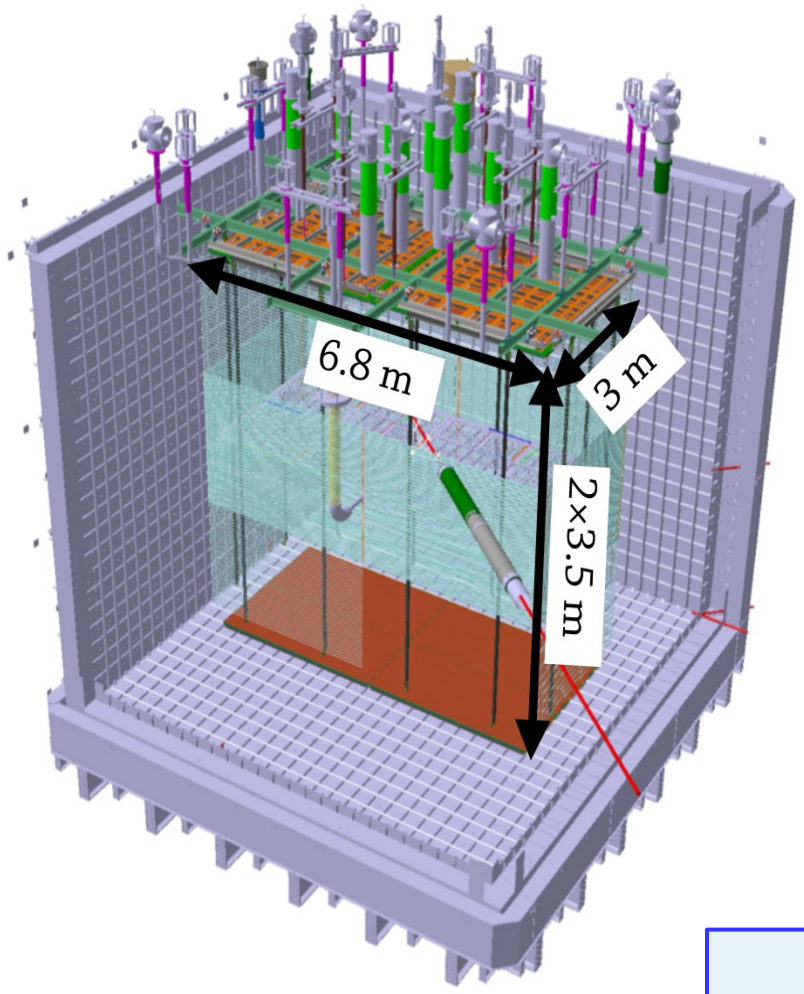
Development of analysis tools for the PDS

Data analysis ongoing



Poster from Anna Balboni
ProtoDUNE-HD Photon Detection System performance

ProtoDUNE Vertical Drift



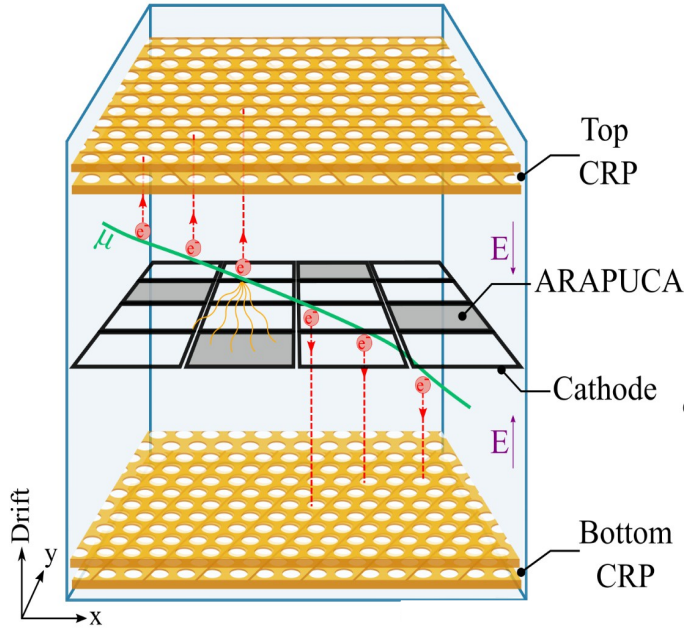
SECOND PROTOTYPE

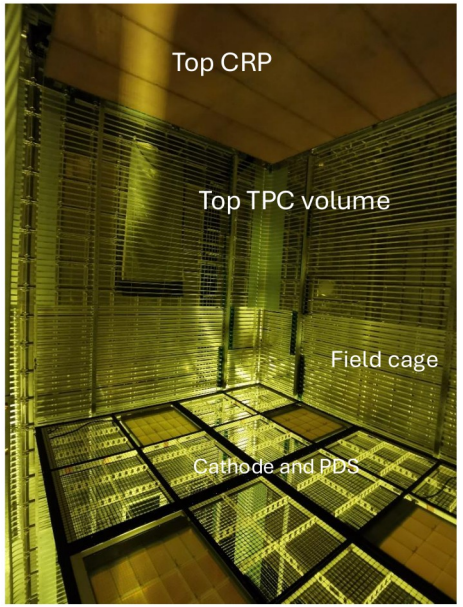
- 3.5 m vertical drift
- 4 Horizontal Charge Readout Planes (CRPs) → 2 at the top and 2 at the bottom
- Horizontal cathode in the middle

PHOTON DETECTORS

- 16 Megacell X-ARAPUCAs (60 x 60 cm^2)
- 8 on the cathode → innovative Power Over Fiber and Signal Over Fiber technology *
- 8 behind the field cage
- 20 PMTs installed outside the active volume
- 160 SiPMs (40 per side)
- 2 different SiPMs: Hamamatsu and FBK

ProtoDUNE VD ready and filled with LAr
Operation in Spring/Summer 2025





Poster from Valeria Trabattoni

Utilizzo di un Convertitore DC-DC a controllo remoto per la polarizzazione di fotomoltiplicatori al silicio per l'esperimento DUNE

** M.A. Arroyave et al 2024 JINST 19 P10019*

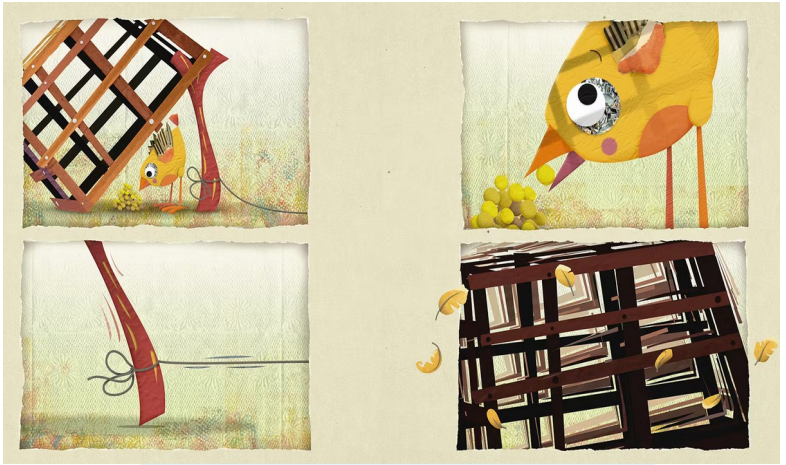
Summary and future perspectives

The Deep Underground Neutrino Experiment is a
future long-baseline neutrino oscillation experiment

- 4 Far Detectors of 17-kton of LAr each
- **First two Far Detectors** already designed: Horizontal Drift (HD) and Vertical Drift (VD)
- Double readout of charge and light

- Innovative **Photon Detection System** based on the **X-ARAPUCA** detectors
- Different design for HD and VD X-ARAPUCAs
- First **successful tests at CERN in protoDUNE-HD** – data analysis in progress
- ProtoDUNE-VD technology succesfully tested
- Operation of the **protoDUNE-VD starting soon** at CERN

Stay tuned!



Arapuca for birds

Thank you for your attention