ProtoDUNE-VD Photon Detection System

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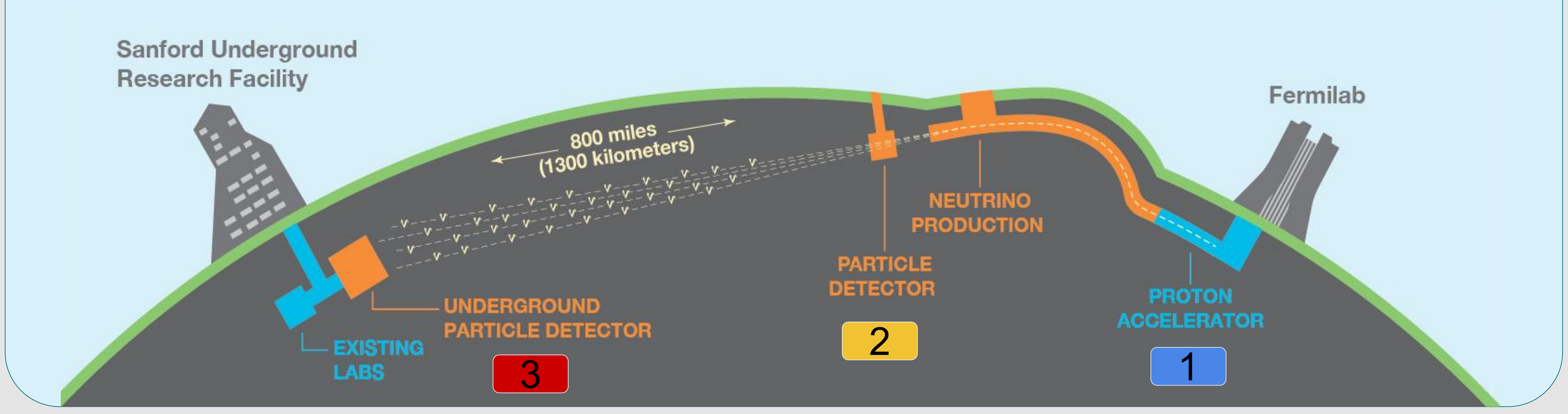
DEEP UNDERGROUND NEUTRINO EXPERIMENT

The DUNE Experiment

DUNE is a **next-generation long-baseline neutrino experiment** using a 1.2 MW beam produced at Fermilab (Illinois, USA). The beam will be characterized at a **Near Detector complex** located at Fermilab and observed 1300 km away by a large-scale **Far Detector** consisting of 17 kt **liquid argon modules** located at SURF (South Dakota, USA).



Key Objectives

- Measure neutrino oscillations parameters with high precision (mass ordering, CP violation).
- Beyond Standard Model searches.
- Study neutrinos from astrophysical sources (e.g. supernovae, solar).

Key Components

- 1 Neutrino beam: Proton accelerator
- 2 Near Detector (ND) at Fermilab
- 3 Far Detector (FD) at SURF

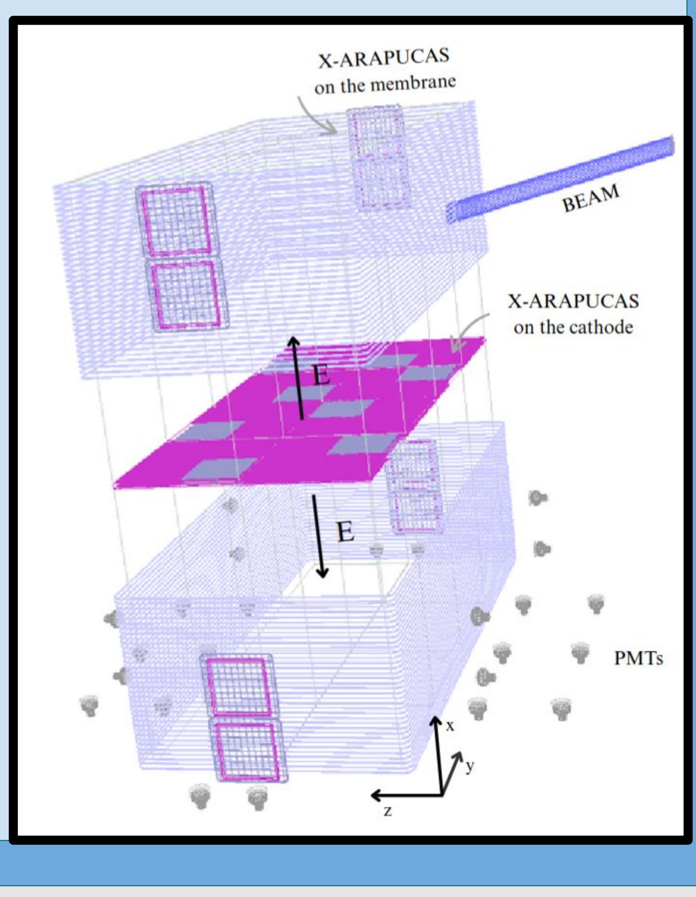
ProtoDUNE-VD: A prototype of the DUNE Far Detector

ProtoDUNE at CERN

- The ProtoDUNE program, at CERN Neutrino Platform, is the large-scale test bed for the technologies that will be used in the DUNE Far Detector.
- ProtoDUNE-VD is a prototype of the DUNE Far Detector VD module, designed to validate detector performance, commissioning procedures, and long-term operation before the construction of the final underground detectors.

Vertical Drift LArTPC Technology

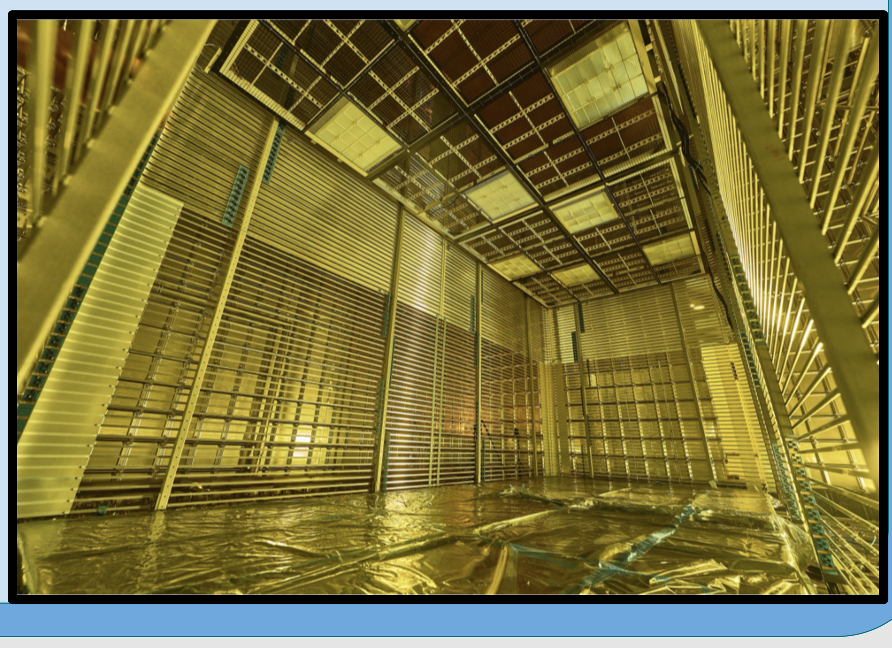
- The novel Vertical Drift (VD) liquid argon time projection chamber (LArTPC) design employs a vertical electric-field configuration, with a central cathode positioned between two anode planes.
- This configuration creates two fiducial volumes (top and bottom).
- The VD concept simplifies detector construction.
- Liquid argon doped with xenon to increase light yield.



ProtoDUNE-VD Overview

ProtoDUNE-VD represents the first large-scale implementation of the VD LArTPC technology and is currently taking data since Summer 2025. Key technical parameters include:

- Total cryogenic volume: ~0.77 kt LAr
- Two symmetric drift regions (~3 m each).
- Central cathode plane.
- Anode plane assemblies at the top and bottom.
- Photon detection system with X-ARAPUCAS on the cathode and cryostat walls.



The Photon Detection System (PDS) in ProtoDUNE-VD

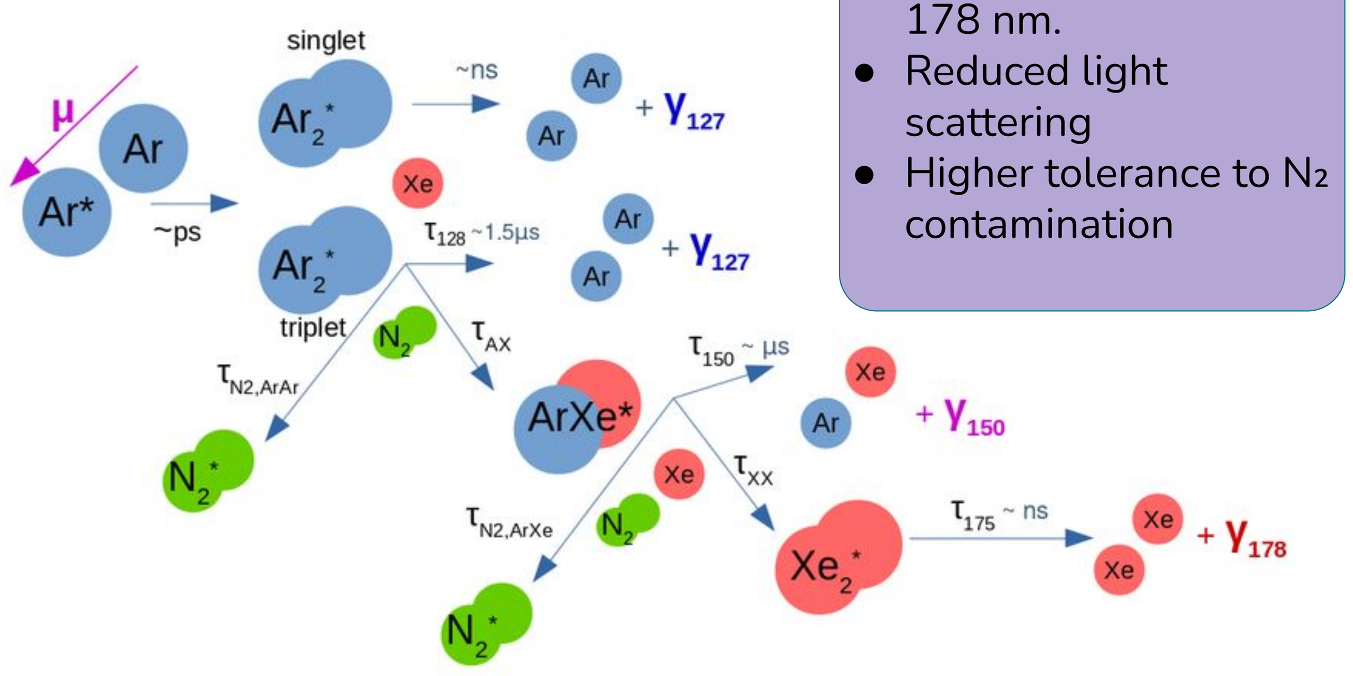
The PDS detects scintillation light produced in liquid argon when a charged particle deposits energy. This light provides essential timing information for triggering the detector and for event reconstruction

Light production in liquid argon

- Charged particle → excitation and ionization of Ar.
- Formation of Ar_2^* excimers.
- De-excitation → emission of VUV photons (127 nm).
- Two temporal components:
  - Fast: ~6 ns (singlet).
  - Slow: ~1.6 μs (triplet).

Xe doping

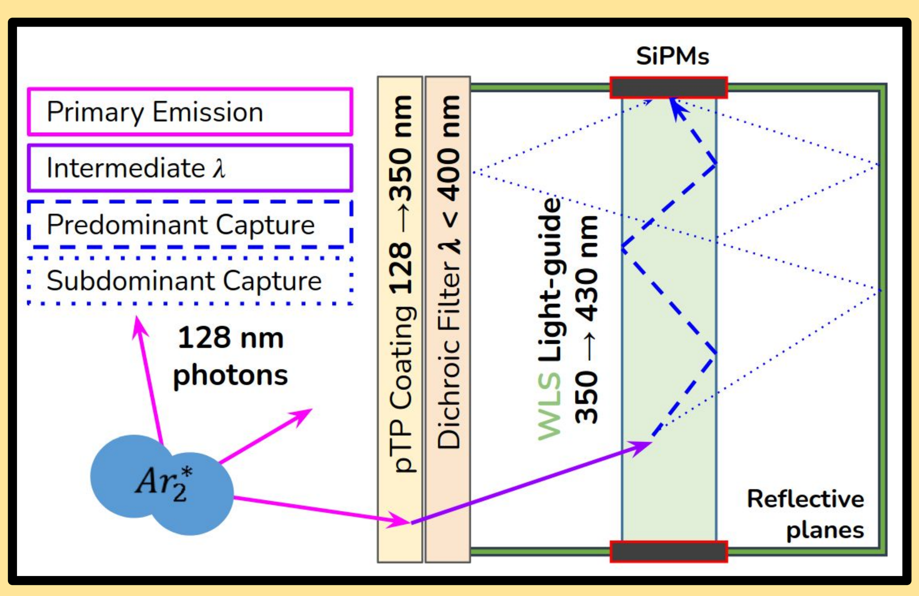
- Energy transfer: $Ar_2^* \rightarrow Xe_2^*$
- Emission shifted to 178 nm.
- Reduced light scattering
- Higher tolerance to N_2 contamination



Light detection: Two complementary technologies

X-ARAPUCAs

X-ARAPUCA: A novel design combining a reflective light trap and a wavelength-shifting light guide, where photons are confined by total internal reflection and collected by SiPMs. The design has been optimized to improve light detection efficiency using measurements performed at CIEMAT (1).



Photomultiplier Tubes (PMTs)

Complementary PDS to study LAr scintillation light, leveraging the successful performance of PMTs in ProtoDUNE-DP (2).

Different WLS configurations to caracterise xenon-doped LAr scintillation light:

- **TPB** (Tetraphenyl Butadiene) evaporated on PMT surface: Sensitive to λ >128 nm
- **PEN** (Polyethylene Naphthalate) sheets: λ >128 nm
- **Quartz window:** λ >170 nm (Xe)
- **Clear PMT:** λ >300 nm (visible)

(1) G. Botogoske et al. submitted to EPJC, arXiv:2511.12328 (2025).
(2) DUNE Collaboration, EPJC 82 618 (2022).

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