ProtoDUNE-HD Photon Detection System: IV curve and Vbd determination

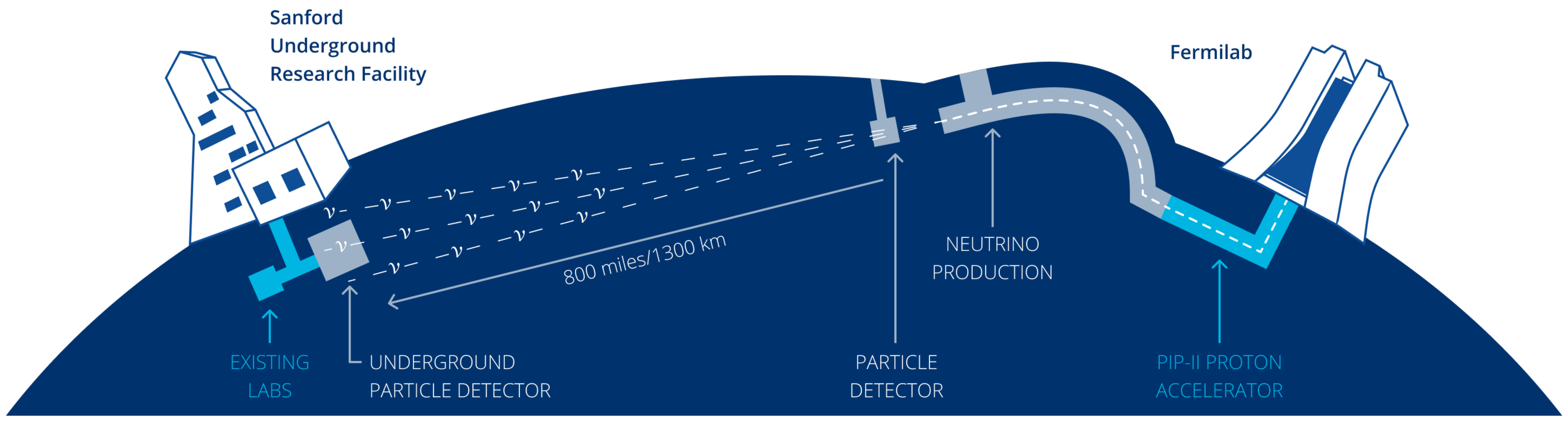
INFN FERRARA
Istituto Nazionale di Fisica Nucleare
Sezione di Ferrara

Anna Balboni for DUNE Collaboration
Università degli Studi di Ferrara, Italy
Istituto di Fisica Nucleare, sezione di Ferrara, Italy

FERRARIAE UNIVERSITAS 13 91 EX LABORE FRUCTUS

The Deep Underground Neutrino Experiment

DUNE is a *next-generation long-baseline experiment for neutrino physics* under construction in US, whose scientific program is expected to start around 2030.



It will consist of two detectors, exposed to an intense muonic neutrino beam, produced at FNAL (Illinois):

- The **Near Detector** (ND) will be located at FNAL;
- The **Far Detector** (FD) will be located at SURF (South Dakota), 1300 km away from ND and about 1.5 km underground.

DUNE will pursue a broad science program:

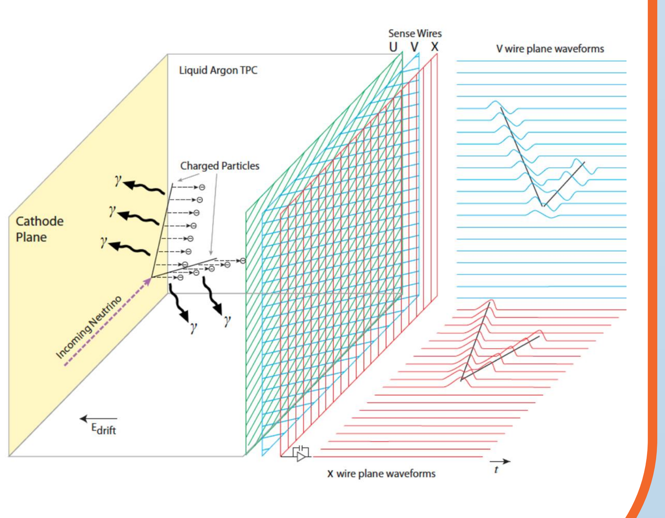
- Study **neutrino oscillations** by using ν_μ and $\overline{\nu_\mu}$ beams;
- Evaluate the **CP violation** in the leptonic sector;
- Determine the **neutrino mass ordering**;
- Search for **proton decay** (BSM physics);
- Detect **supernova neutrinos**.

DUNE Far Detector

It will consist of 4 Liquid Argon Time Projection Chambers (**LArTPCs**). Two single-phase technologies are currently developed: **horizontal drift** (HD) and **vertical drift** (VD), depending on the orientation of the electric field.

The topology of a *neutrino – LAr interaction* is reconstructed by looking at the tracks of secondary charged particles, which produce:

- **Ionization electrons**, which drift towards the anodic wire planes due to the electric field, providing two spatial coordinates;
- **Scintillation light**, detected by the Photon Detection System (PDS), providing the event start time for the 3rd spatial coordinate reconstruction.



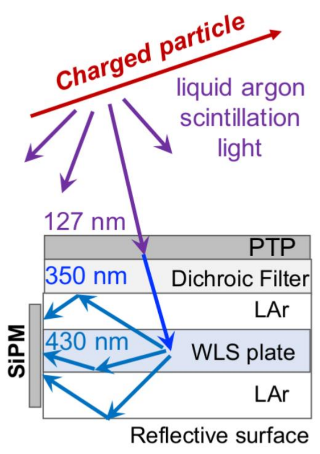
LArTPC-HD technology

FD-HD Photon Detection System

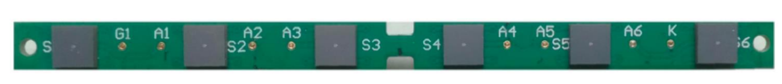
The **PDS** detects the VUV scintillation light produced by ionizing particles in LArTPC-HD. It is made by X-ARAPUCA modules, which consist of cells that act as light traps, by capturing photons inside a box where are detected by Silicon PhotoMultipliers (SiPMs).

X-ARAPUCAs are made by several layers:

- P-Terphenyl (PTP), to shift VUV photons to $\lambda = 350$ nm;
- Dichroic filter with $\lambda_{cut} = 400$ nm;
- Wavelength Shifter plate (WLS), with $\lambda_{emission} = 430$ nm;
- Reflective layer.



SiPMs are mounted in groups of six on Photosensor Mounting Boards (PMBs).



Each X-ARAPUCA contains 48 SiPMs electrically connected in parallel, whose output signals are collected by a front-end electronics (**DAPHNE** boards).

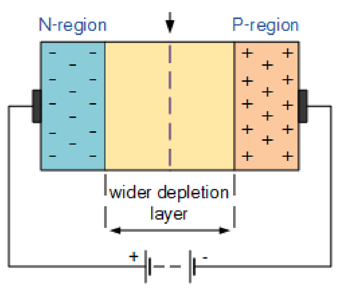
Each Photon Detection module consists of 4 X-ARAPUCA, $[209 \times 12 \times 2]$ cm^3.

Silicon PhotonMultiplier

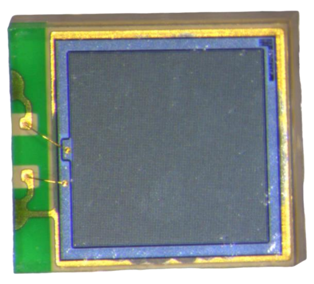
The **SiPM** is a 2-D array of SPADs, connected in parallel and joined together on a common silicon substrate. SPADs are **Avalanche photodiodes** working in Geiger mode, i.e. PN junctions polarized above the breakdown voltage.

Main SiPM parameters are:

- **Breakdown voltage** (V_{bd});
- Photon detection efficiency (*PDE*);
- Dark count rate (*DCR*).

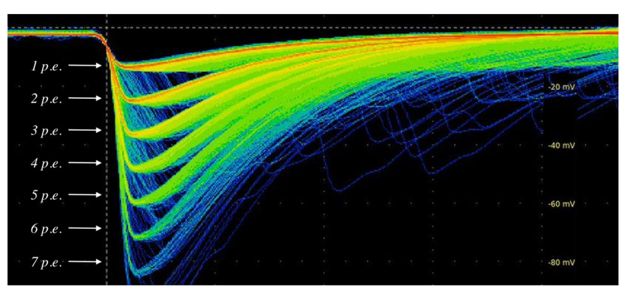


PN junction reverse biased



SiPM at microscope

When a photon hits a SPAD, a self-sustaining avalanche starts. It is then quenched by a quenching circuit, in series. The SiPM output signal is proportional to the number of fired SPADs.

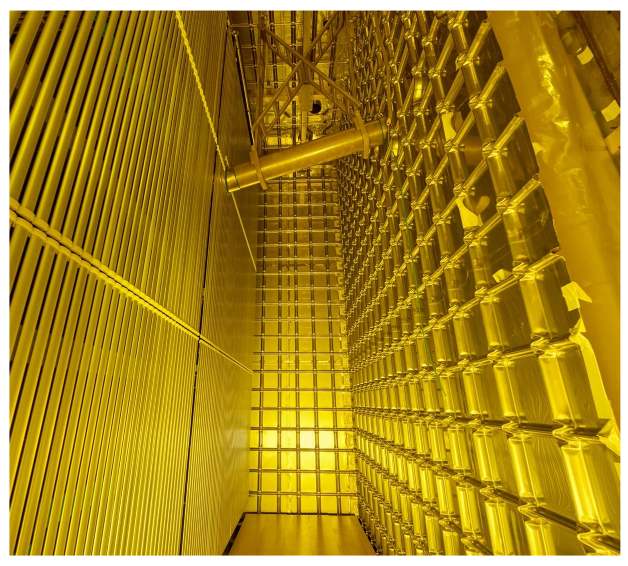


ProtoDUNE-HD

ProtoDUNE-HD tests the DUNE FD-HD components at real scale.
It was constructed and operated in the **CERN** North Area during summer **2024**.
It was exposed to e±, μ±, p and K± beams for 10 weeks, collecting about 30M events.

It consists of two drift volumes, separated by a planar cathode, with a drift distance of 3.6 m.

- The charge signals are readout by two anode plane assemblies (APAs) facing the cathode on each side.
- The scintillation light signals are detected using 160 X-ARAPUCAs. Different modules were tested, using FBK or HPK SiPMs and different WLS plates.

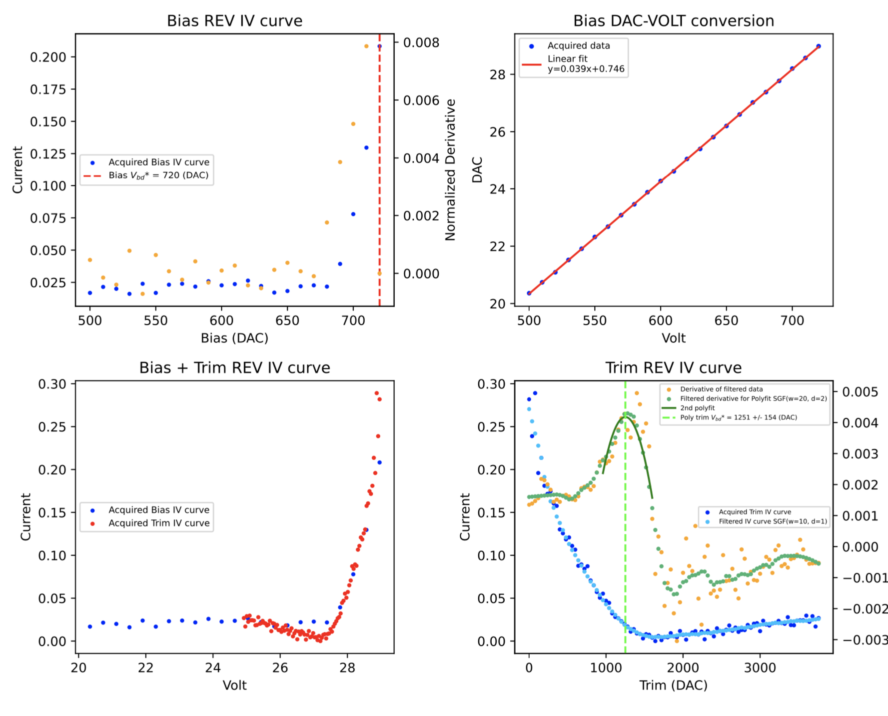


ProtoDUNE-HD SiPM IV curves

It is important to monitor the ProtoDUNE-HD PDS performances, during its operation. To do this, the main parameters are periodically measured and compared with results previously obtained in laboratory. The operation voltage is then adjusted to ensure a uniform PDE across all channels.

The DAPHNE boards allow to perform IV scans, in order to compute the SiPM V_{bd}. The voltage is supplied in two stages, *bias* (steps of ~ 0.7 V) and *trim* (negative steps of ~ 1 mV). The acquired **IV curve** is related to a daphne channel, i.e. an X-ARAPUCA module containing 48 SiPMs. The **breakdown voltage** can be computed as the maximum of the normalized first derivative of the reverse IV curve.

- A bias scan up to a fixed voltage limit is performed;
- The last bias point is taken as *V_{bd} bias component* and starting point for trim scan;
- The trim IV curve is analyzed and a parabolic fit of the trim first normalized derivative is done, to obtain *V_{bd} trim component*.
- By combing bias and trim info, the channel *V_{bd} value* is evaluated.

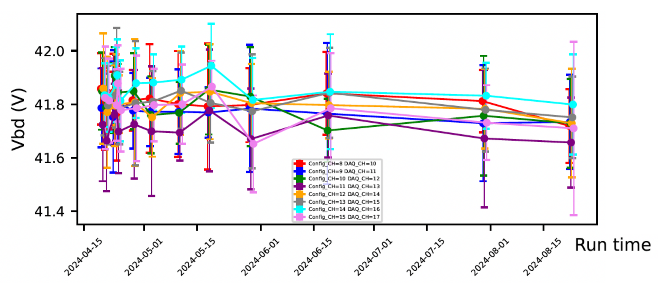


IV curve analysis: APA 2 - Endpoint 109 - Channel 6 - FBK

Vbd monitoring

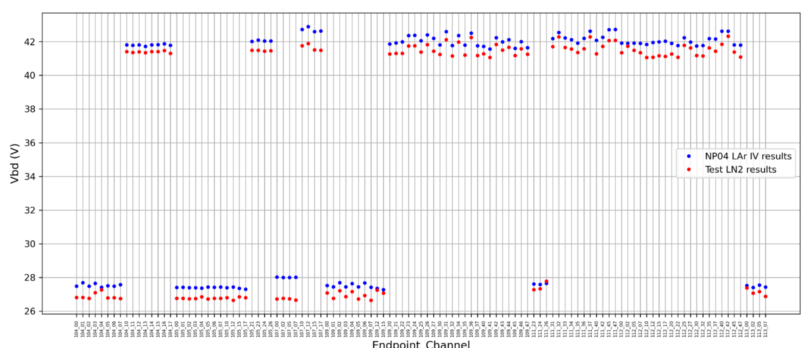
Breakdown voltage is constant in **time**:

- For FBK, $\overline{V_{bd}} = (27.5 \pm 0.2)$ V
- For HPK, $\overline{V_{bd}} = (42.1 \pm 0.3)$ V



APA 1 - Endpoint 104 - AFE 1- HPK

Measured V_{bd} are compared with LN_2 test results. A **LAr - LN_2 Vbd** difference is expected due to different temperatures.



ProtoDUNE-HD PDS IV status

- 144 channels with **good IV curve**;
- 6 channels with **noisy IV curve**, working well;
- 6 **dead channels**, disconnected from the beginning;
- 4 channels with ***steep* IV curve**, that results in improper V_{bd} estimation which leads to a channel underbiasing (3 channels were recovered through an additional overvoltage).