NuFact 2024

Argonne NATIONAL LABORATORY

ProtoDUNE Photon Detection System

NUFACT 2024

J. Soto-Oton on behalf of the DUNE collaboration

Lemont (Illinois, US), September 20th 2024

IFIC INSTITUT DE FÍSICA CORPUSCULAR

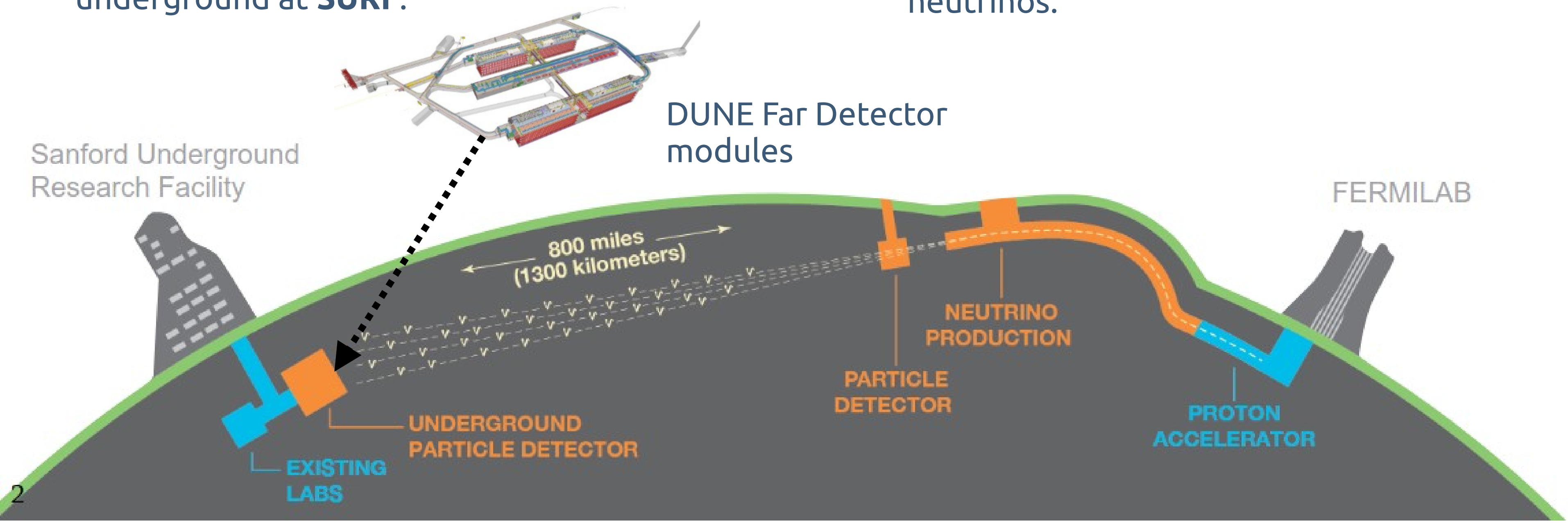
DUNE

The Deep Underground Neutrino Experiment

- Next generation **neutrino oscillation experiment**.
- High-intensity neutrino **beam** and **near detector** complex at **Fermilab**.
- 4 **massive (17kton)** liquid argon Time Projection Chambers (**LAr-TPC**) Far Detector modules 1.5km underground at **SURF**.

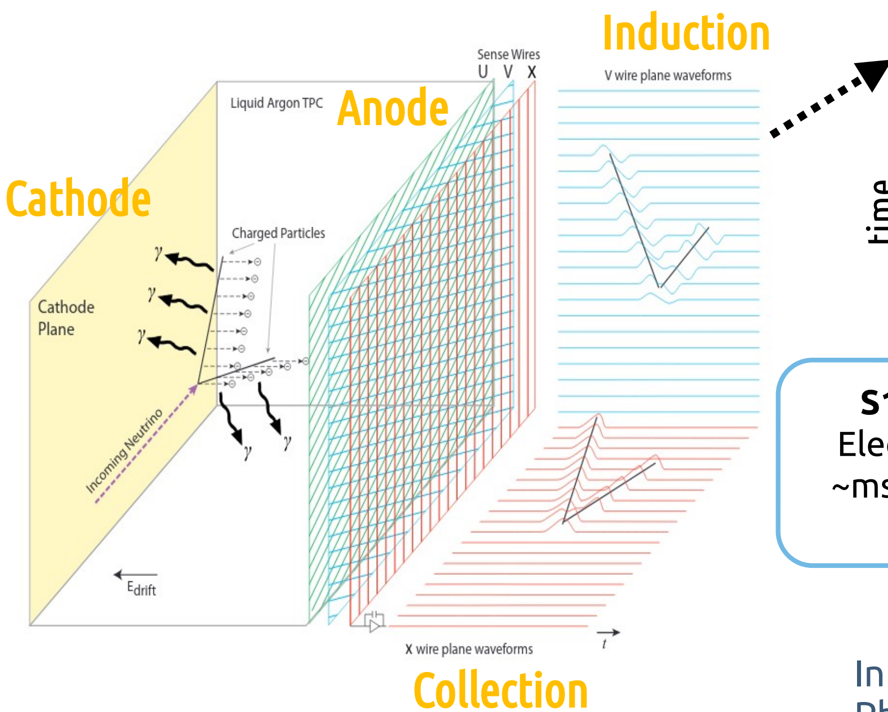
Measurement of ν_μ/ν_e dis-/appearance*:
- Neutrino mass ordering.
- CP violation.
- Precision on mixing parameters.
- BSM searches.

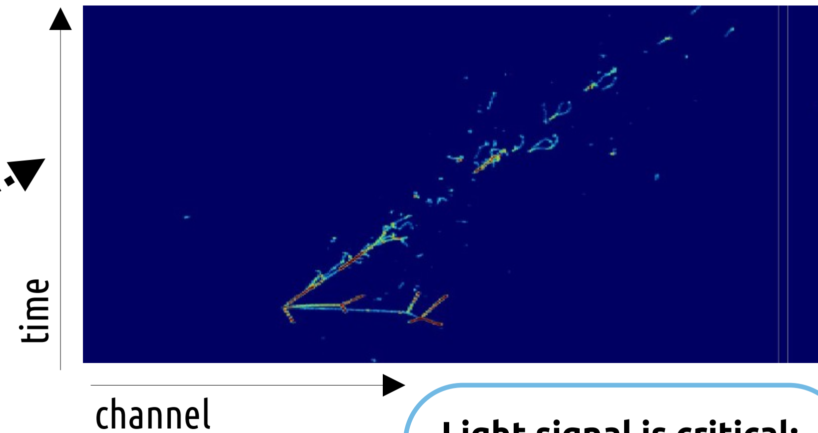
Plus supernova, atmospheric and solar neutrinos.



The LAr-TPC operating principle

- DUNE will bring the LAr-TPC technology to a massive scale.
- Charged particles crossing liquid argon produce ionization **electrons** and scintillation **photons** (S1 signal).
- Electrons are **drifted** by an uniform electric field and **read out** by a segmented anode. This allows the reconstruction of the track.



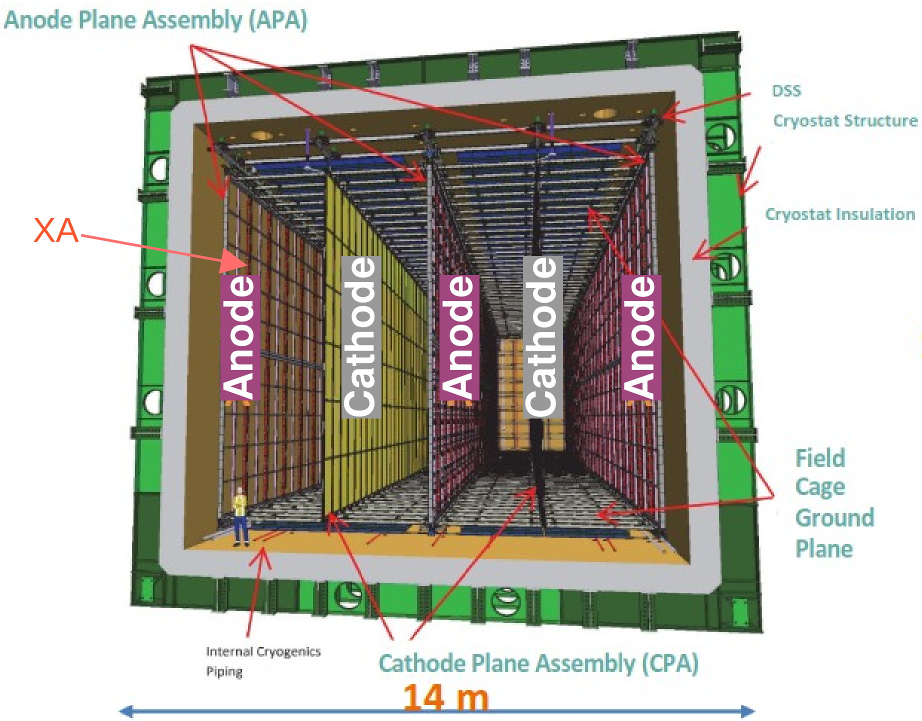


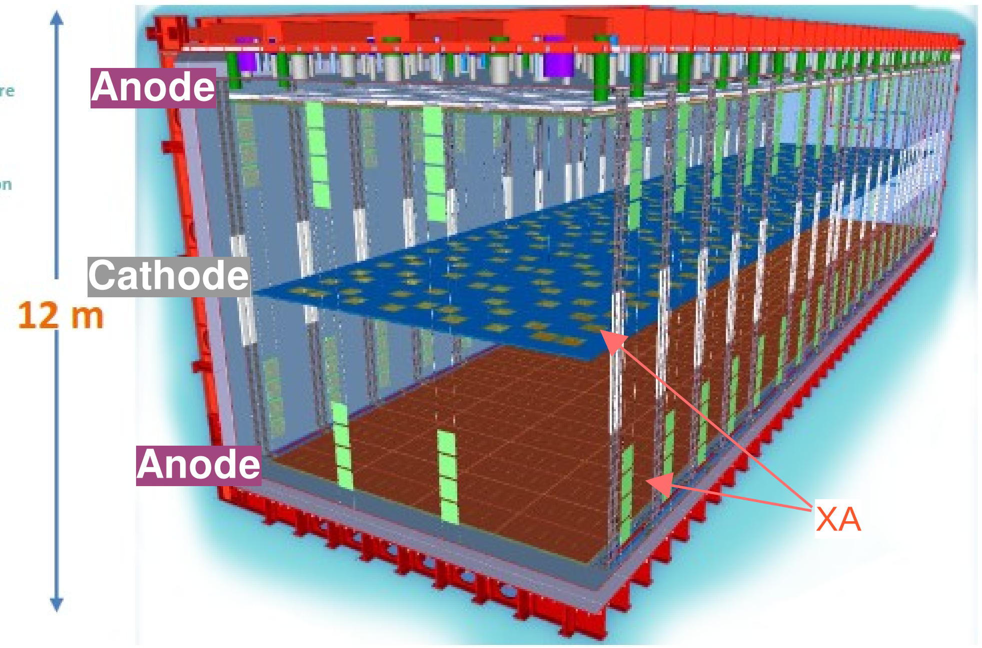
S1 is a fast signal: Electrons drift time is ~ms, while just ~ns for photons.

Light signal is critical:
- Trigger.
- Event time (needed for 3D reco.).
- Energy reconstruction.
- PID, etc.

In DUNE, the S1 light signal is detected by the Photon Detection System (PDS), based on the **Xarapuca-concept (XA)**.

Two FD designs





FD Horizontal Drift

- Four drift volumes of 3.6-m drift.
- Wired-based anode.
- 6000 XArapuca devices (48 x 10 cm^2) on the anode.
- 48 SiPM (6 x 6 mm^2) ganged per XArapuca.

FD Vertical Drift

- Two drift volumes of 6.5-m drift.
- Perforated-PCB anode.
- 320 XArapuca on the cathode (PoF for bias and readout)
- 352 XArapuca on the cryostat walls.
- 80 SiPM (6 x 6 mm^2) ganged per XArapuca.
- It will use Xe doped LAr.

ProtoDUNE programme at CERN Neutrino Platform

PDS requirements

- Av. Light yield > 20 PE/MeV
- Min Light yield 0.5 PE/MeV
- Time resolution <100ns.
- Dark noise < 1kHz Calibration.
- Dynamic range (saturation <20%)

ProtoDUNE-SP

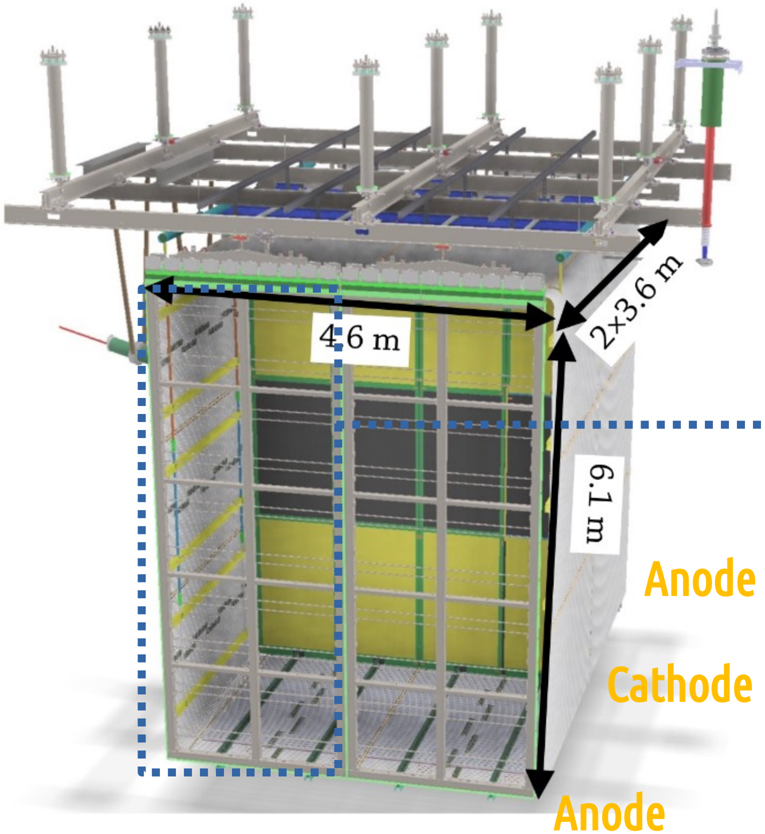
ProtoDUNE-DP

ProtoDUNE-HD

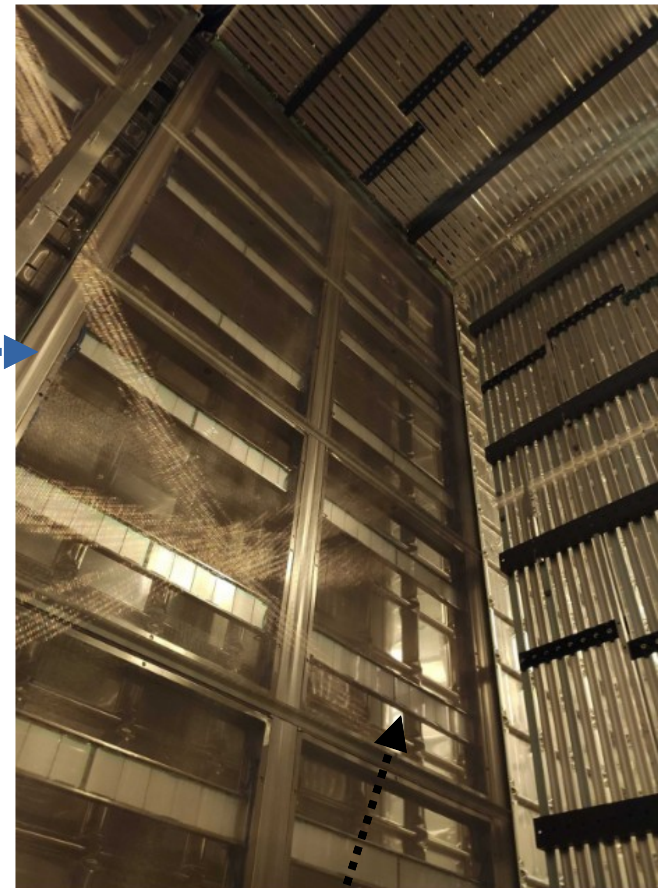
ProtoDUNE-VD

2018 2019 2020 2022 May 2024 November 2024

ProtoDUNE-HD design and operation



View of an APA



- ProtoDUNE-HD test the FD components at real scale.
- 3.6-m of drift.
- 4 wire-based Anode Planes Assemblies (APAs).
- 40 XArapuca per APA (160 in total)
- Filled started in March 2024, operation started in May 2024.
- Exposed to a ($e^{\pm}$, $\mu^{\pm}$, p and $K^{\pm}$) beam. 10 weeks from June to September 2024
- It has collected about 30M events

ProtoDUNE-HD Photon Detection System

- Scintillation light is produced at the VUV range.
- The XArapuca **shifts** the photons wavelength towards the visible range and **redirect** them towards a SiPMs.

Main elements of the XArapuca Supercell (1 readout channel):

- **PTP-coated dichroic filters** with 400 nm cutoff
- **WLS plate** with an emission wavelength higher than the filter transmission threshold
- 48 electrically ganged **SiPMs** 6x6 mm2

Different configuration are tested:

- FBK SiPM + Eljen WLS plate.
- FBK SiPMs + Glass-to-Power WLS plate.
- Hamamatsu SiPMs + Eljen WLS plate.
- Hamamatsu SiPMs + Glass-to-Power WLS plate.

Dedicated PDE measurements at the lab (CIEMAT & MiB):

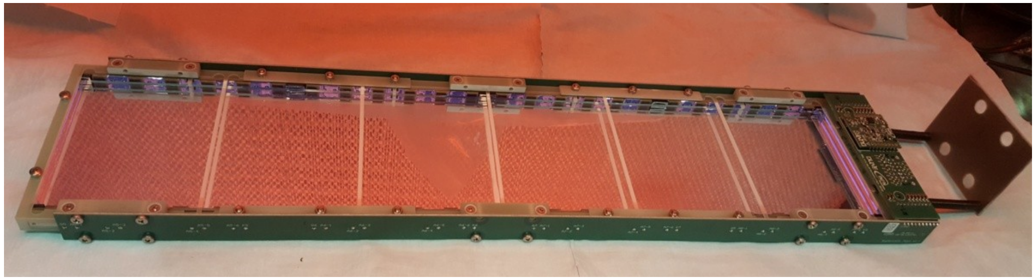
- PDE 1.5-2.5%
- Slightly higher for HPK SiPMs.
- G2P 20% better than Eljen

arXiv:2405.12014

SiPM were characterized at CT

- VBR, Gain, noise studies.

2024 JINST 19 T01007

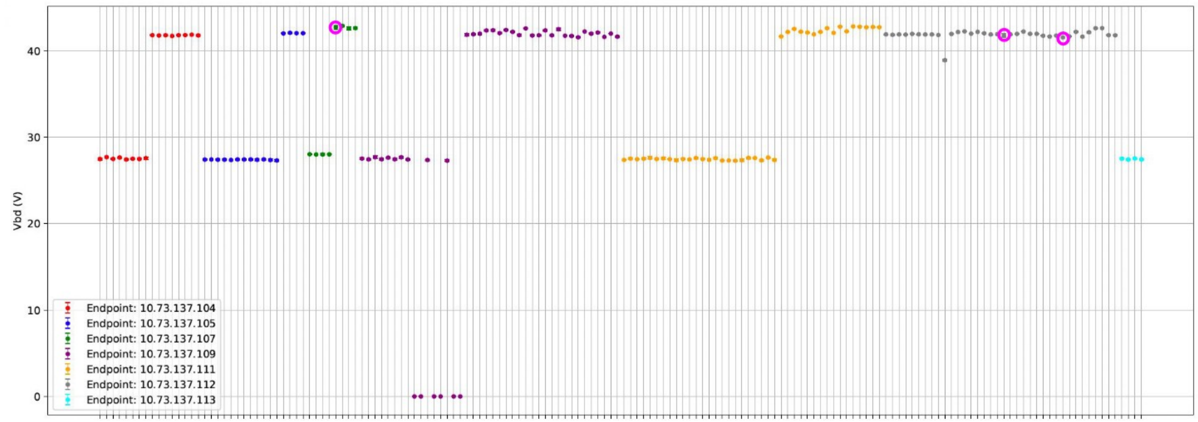


X-Arapuca supercell

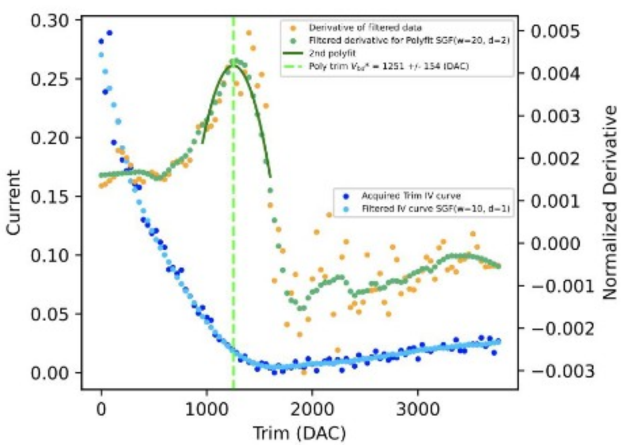
ProtoDUNE-HD SiPM IV curves

- 4% of dead channels.
- The FE system allows to perform dedicated IV scans to compute the VBR.
- The VBR is measured weekly and the operation voltage adjusted to ensure a uniform PDE across all channels. VBR is stable.

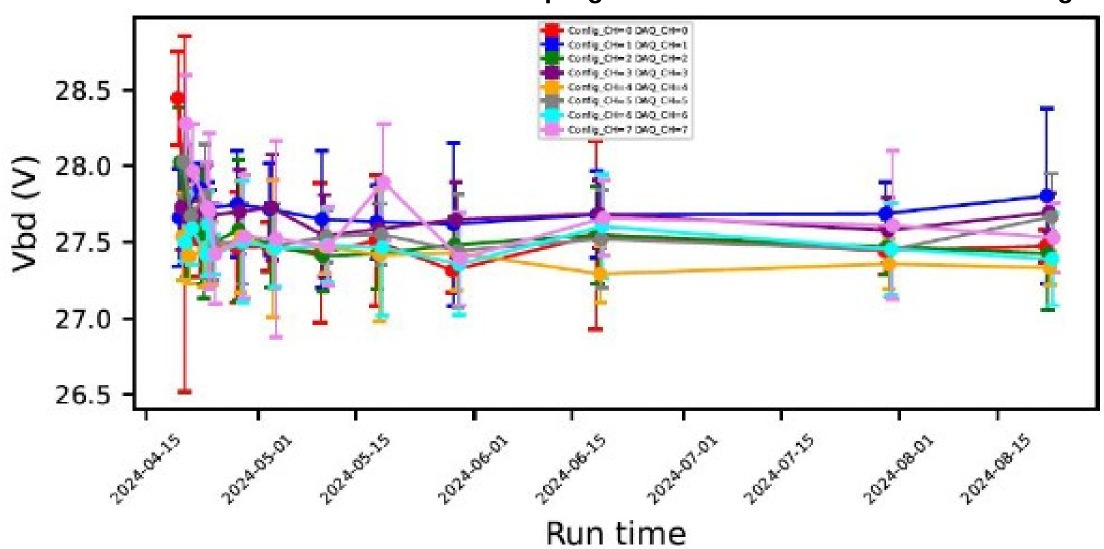
DUNE: ProtoDUNE-HD Work in progress **VBR across all channels**



DUNE: ProtoDUNE-HD Work in progress
VBR calculation

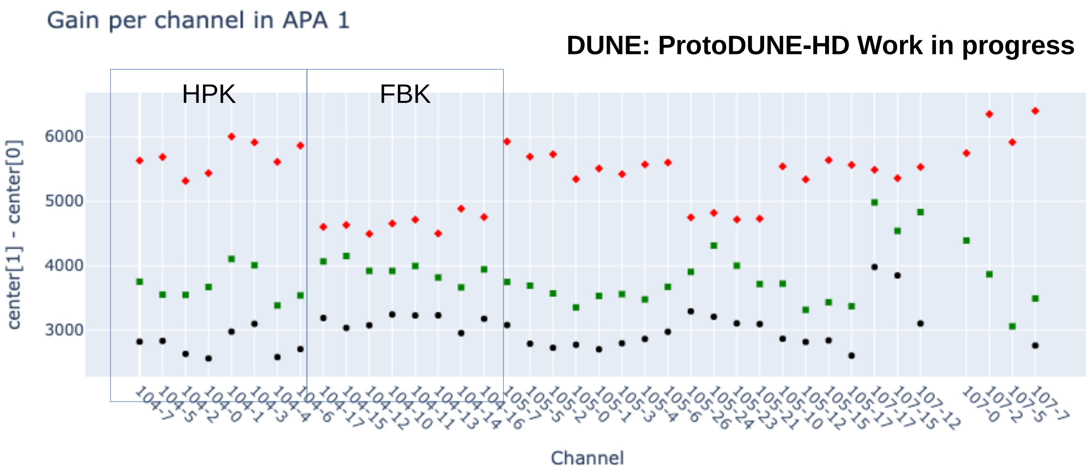


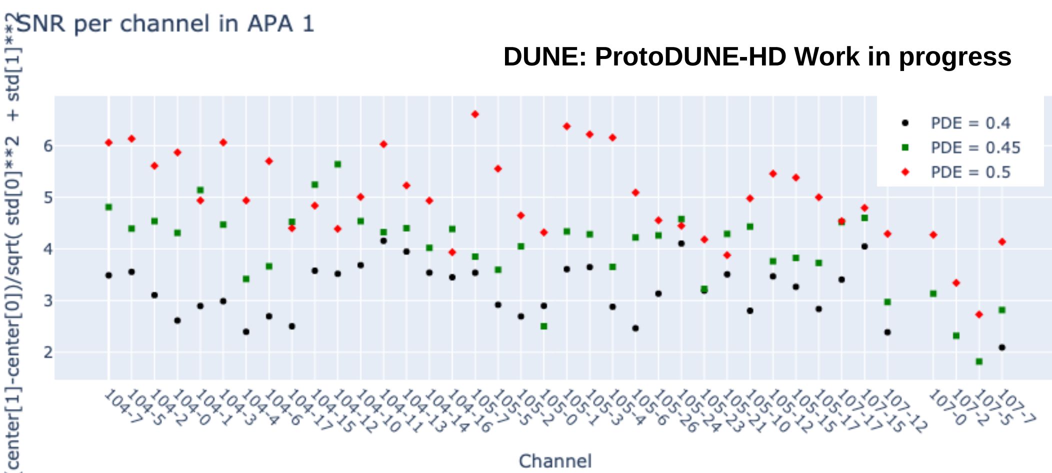
DUNE: ProtoDUNE-HD Work in progress **VBR monitoring**



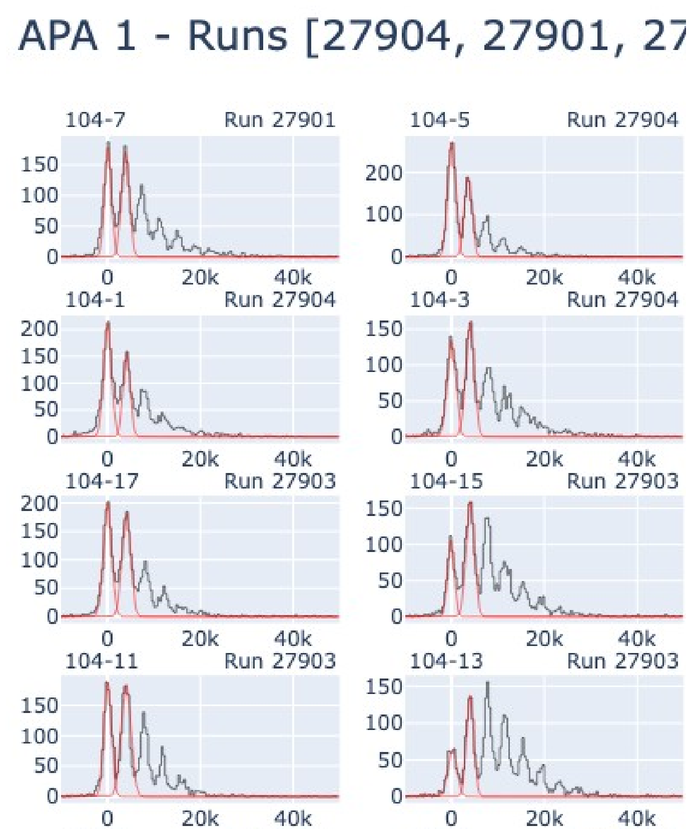
ProtoDUNE-HD PDS gain calibration

- A dedicated LED-based calibration system is used to calibrate and monitor the gain and Signal-To-Noise ratio of all SiPMs.
- The FE amplifier can be tuned to equalize the response (on going).
- An average SNR between 3 and 6 is obtained depending on the OV.



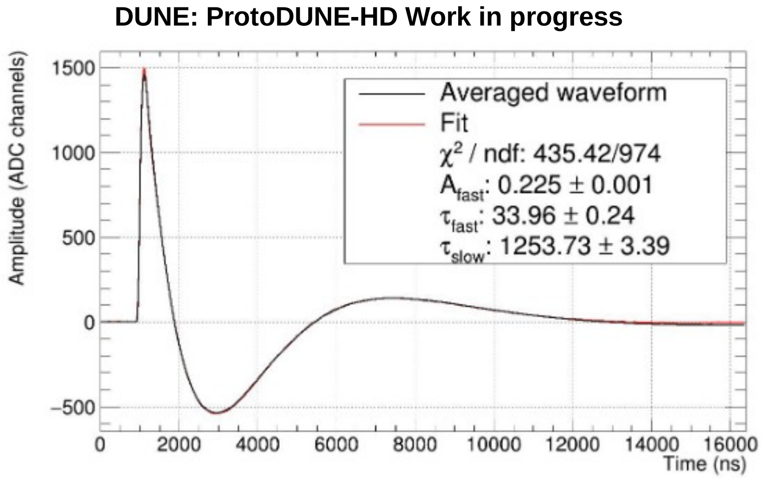


DUNE: ProtoDUNE-HD Work in progress



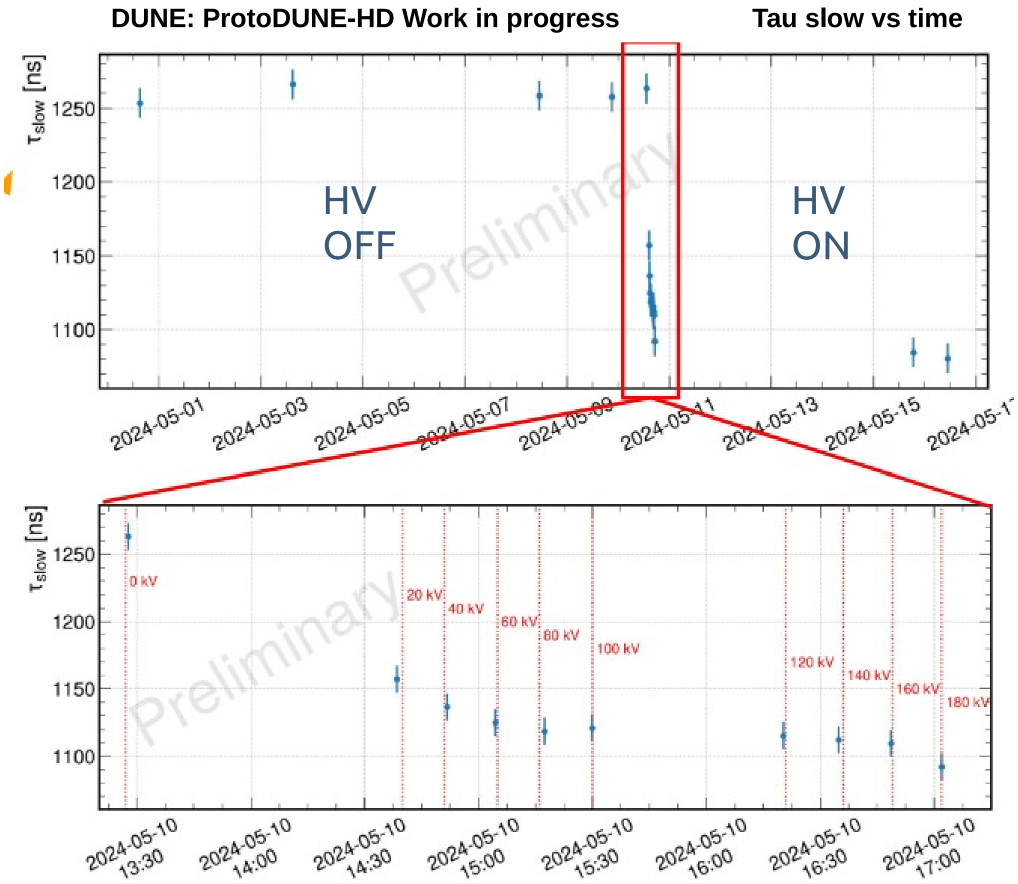
Tau slow monitoring

- Scintillation light is produced by the Ar^{*}_{2} excimer decay with two times: Fast (singlet, ns) and Slow (triplet, μs).
- The scintillation time profile (average waveform) can be fitted to extract this two values.
- A value of the tau slow of ~1.3μs is obtained at 0kV (1.1μs at 0.5kV/cm).



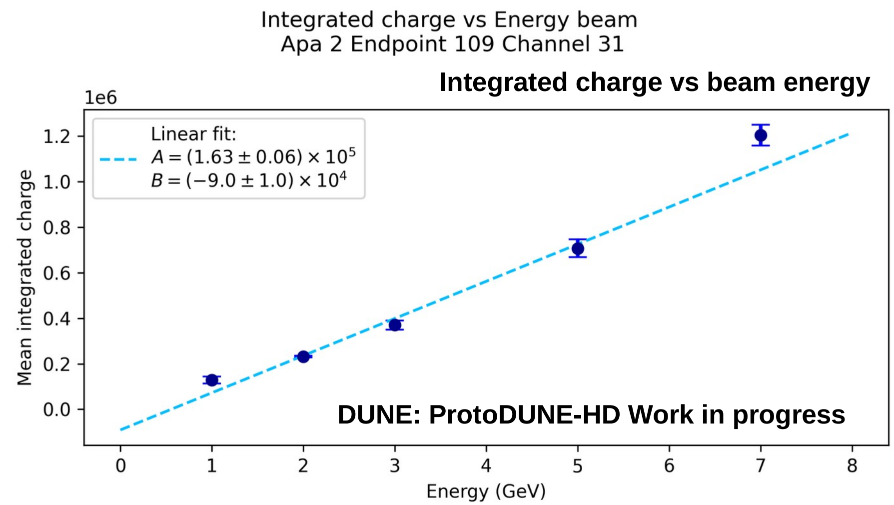
$$L(t) = \frac{A_f}{\tau_f} \times e^{-t/\tau_f} + \frac{1-A_f}{\tau_s} \times e^{-t/\tau_s}$$

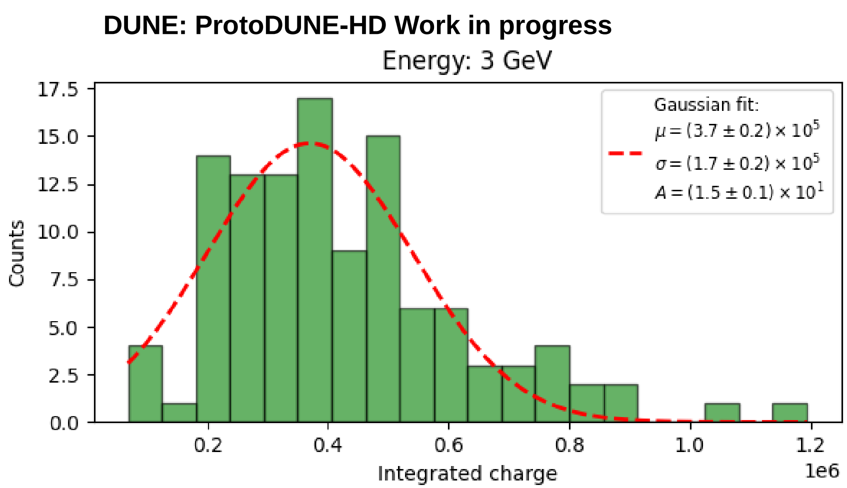
$$R(t) = SPE(t) \circledast L(t)$$

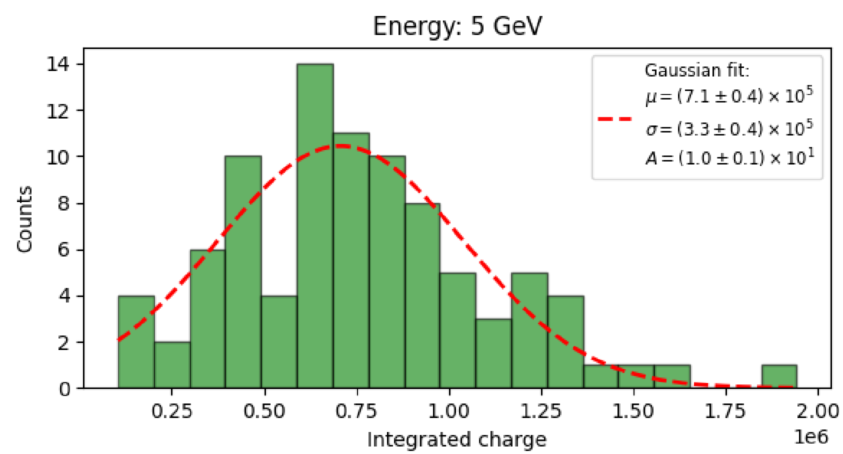


Light yield vs beam energy

- Beam content: e-, protons, pions, K and mu with momenta between **0.5 GeV/c and 7 GeV/c**.
- Since the amount of photons produced is proportional to the deposited energy, the PDS can provide an independent energy measurement.
- Beam data can be used to test the linearity of the system to provide an energy measurement.
- The PDS show a good linearity (work still ongoing).



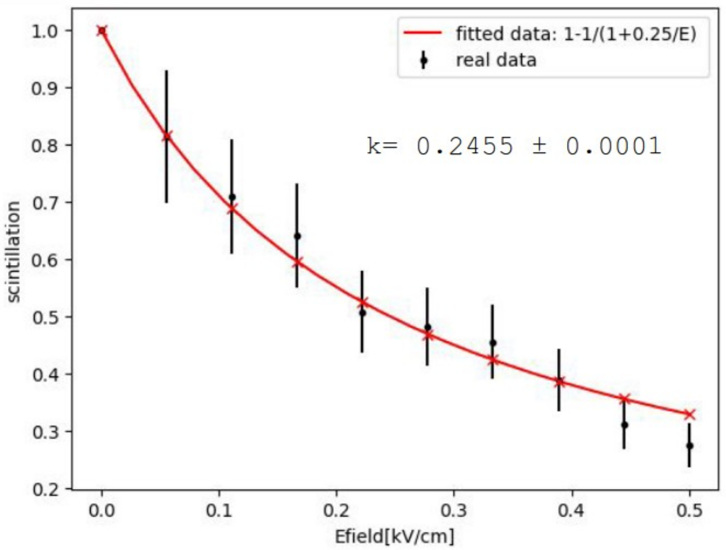




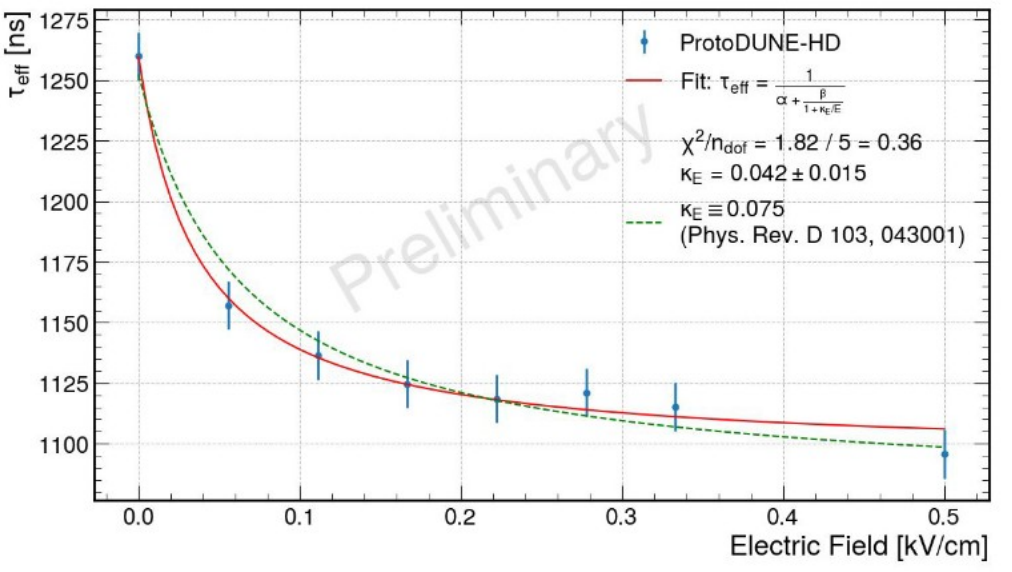
Drift field studies

- An attenuation of the light yield with the drift field is expected/observed due to the lower recombination.
- The time profile also depends on the drift field: τ_{slow} is reduced with the drift field (in agreement with previous observations).

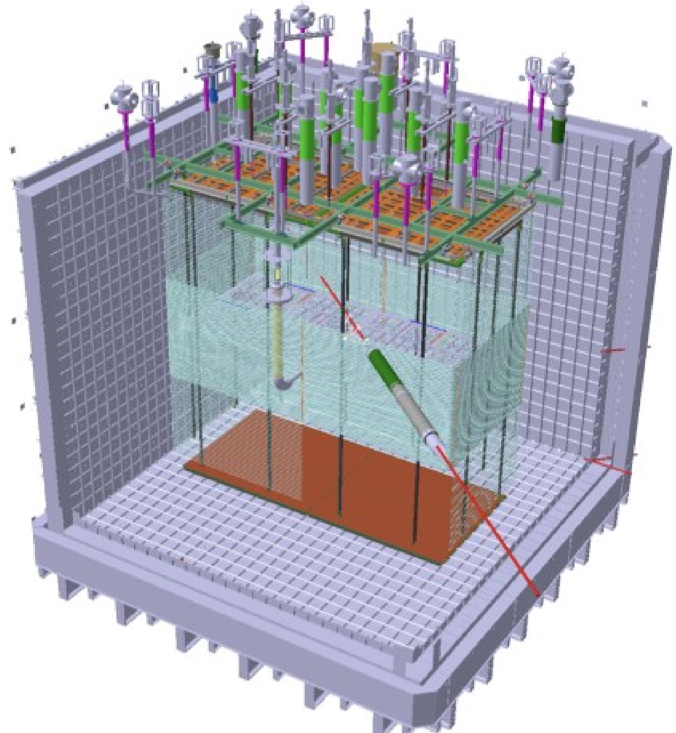
DUNE: ProtoDUNE-HD Work in progress
Light yield vs drift field



DUNE: ProtoDUNE-HD Work in progress
τ_{slow} vs drift field



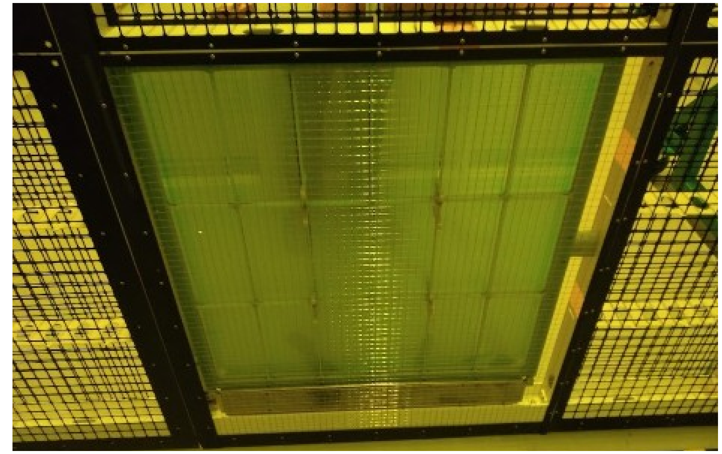
ProtoDUNE-VD PDS design

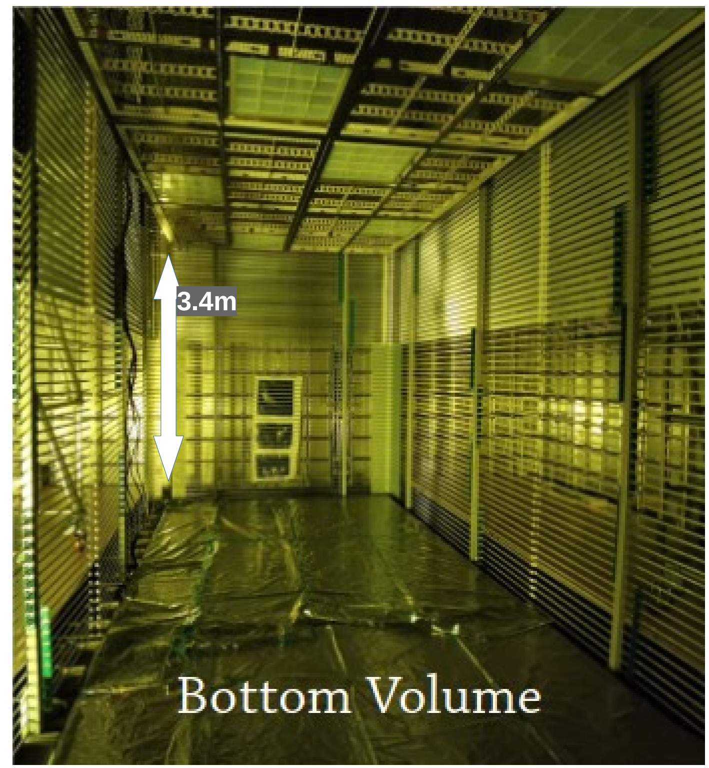


- 16 XArapuca tiles (~ 60 x 60 cm²)
  - 8 Double side for cathode (PoF* & SoF*)
  - 8 Single side for membrane wall.

  20 PMTs will be also installed outside.
- It will use both pure LAr (first) and Xe-doped LAr (later).
- It will be start operation November 2024, re-using argon from ProtoDUNE-HD (very soon!)

*see talks by S. Sacerdoti and D. Leon.





Conclusions

- DUNE will be a high-precision long-baseline neutrino oscillation experiment that will resolve the neutrino mass ordering and measure the CPV phase in the leptonic sector among others goals.

- The DUNE Far Detector will be 4 massive liquid argon TPCs (17kton each).

- The photon detection system is a critical system in a LAr-TPC (trigger, event time, 3D reconstruction, energy measurement).

- The DUNE FD PDS is based in the XArapuca technology, which is being validated at 1:1 scale in the DUNE prototypes at CERN (protoDUNEs).

- ProtoDUNE-HD is taking data now, the PDS is performing well and several studies are ongoing to demonstrate that the PDS design meets the DUNE requirements.

- ProtoDUNE-VD will be filled in November 2024, to validate the technology for the second FD.

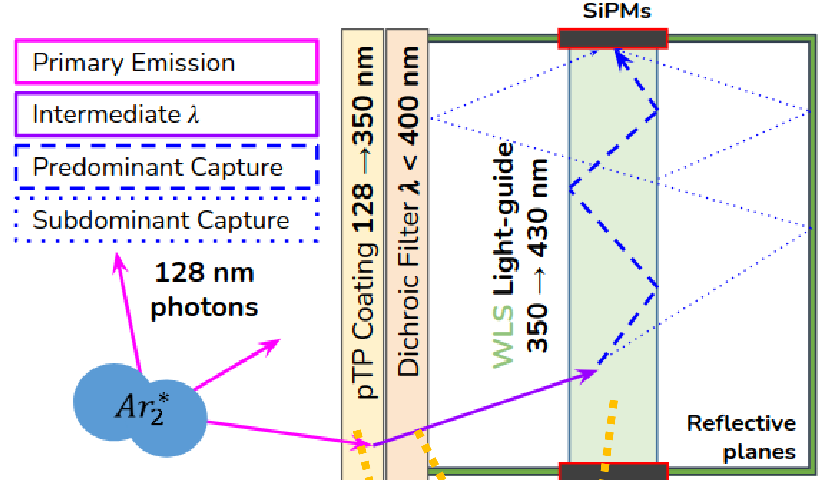
Backup

ProtoDUNE-HD XArapuca

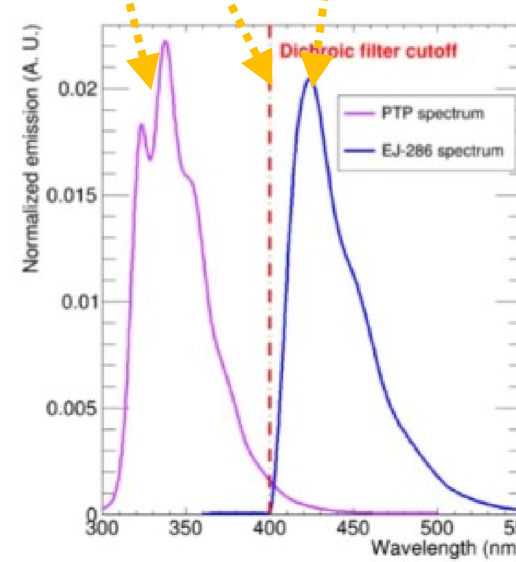
- Scintillation light is produced at the VUV range.
- The XArapuca **shifts** the photons wavelength towards the visible range and **redirect** them towards a SiPMs.

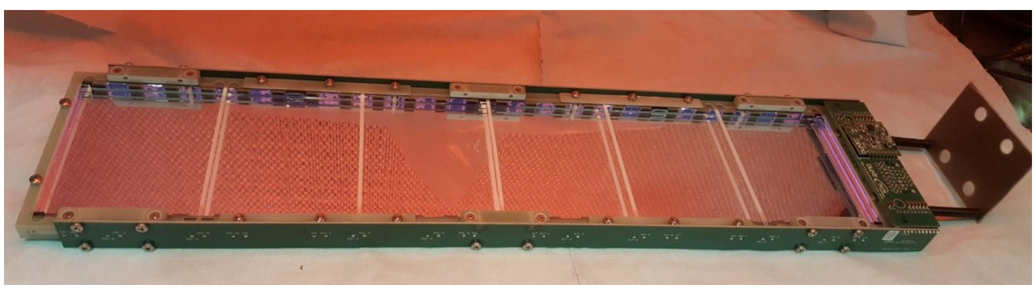
Main elements of the XArapuca Supercell (1 readout channel):

- **PTP-coated dichroic filters** with 400 nm cutoff
- **WLS plate** with an emission wavelength higher than the filter transmission threshold
- 48 electrically ganged **SiPMs** 6x6 mm2



[A.A. Machado et al 2018 JINST 13 C04026]

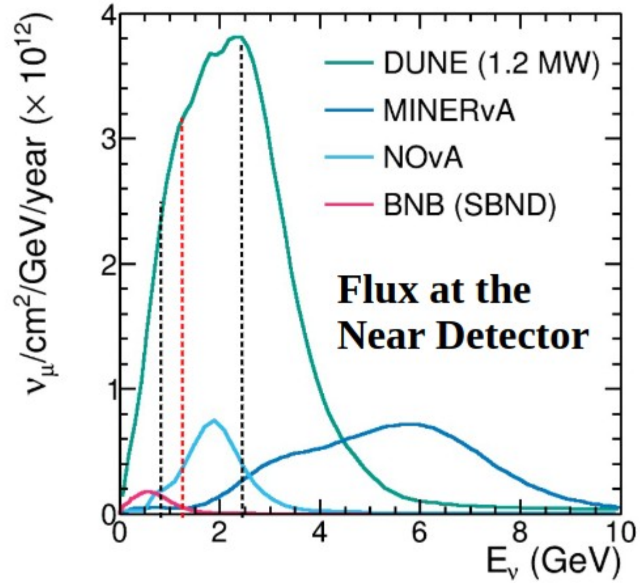


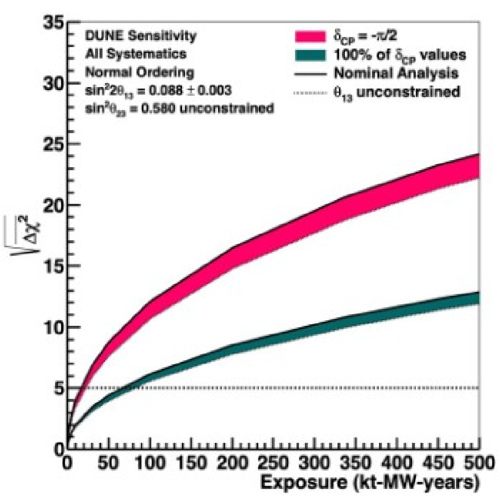


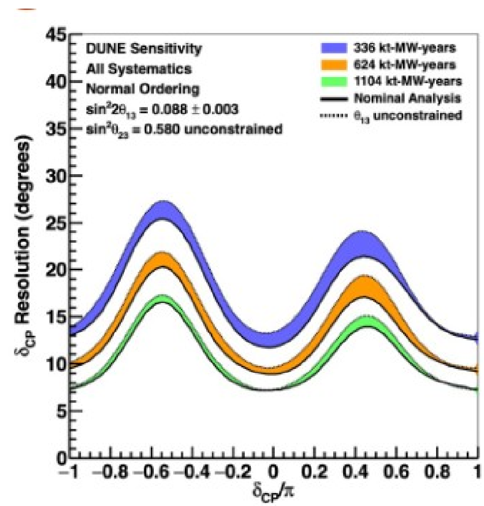
X-Arapuca supercell

The Deep Underground Neutrino Experiment

- Wide-band energy beam (100MeV – 10GeV).
- First 1.2MW then upgraded to 2.4MW.
- Large flux between the first and second oscillation maxima.







- >5σ mass ordering significance in two years.
- Resolution to δCP is ~6-16° depending on true value

ProtoDUNE-HD PDS PDE measurements

Photon Detection Efficiency (PDE) measurements in dedicated test-stands at CIEMAT and Milano Bicocca using **alpha sources**:

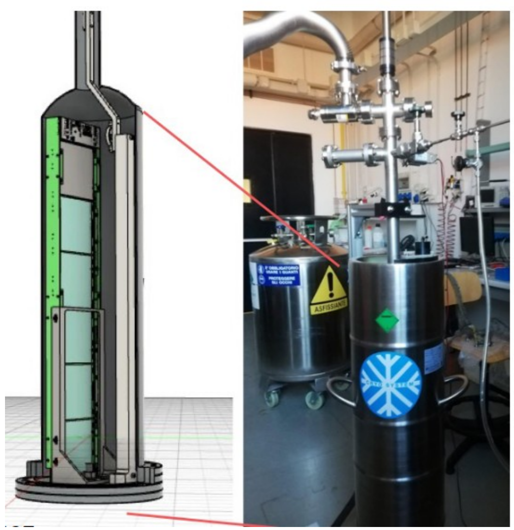
- Method A: Relative measurement w.r.t a calibrated sensor.
- Method B: Considering the light yield in Ar.

All three measurements lead to compatible results within errors:

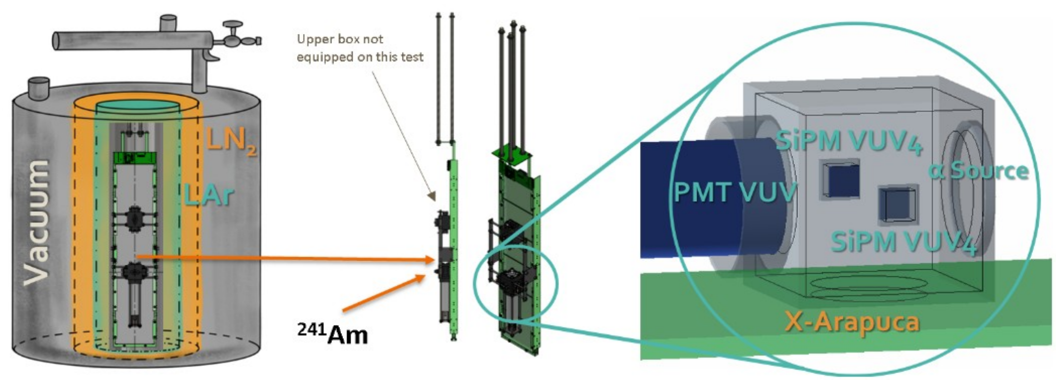
- Slightly higher for HPK SiPMs.
- G2P 20% better than Eljen.

	FBK + EJ	FBK + G2P	HPK + EJ	HPK + G2P
ϵ_{MAD}	1.34 ± 0.24	-	1.59 ± 0.29	2.13 ± 0.38
ϵ'_{MAD}	1.61 ± 0.12	-	1.86 ± 0.15	2.50 ± 0.21
ϵ_{MIB}	1.80 ± 0.15	2.22 ± 0.19	-	2.40 ± 0.20

arXiv:2405.12014



MiB setup

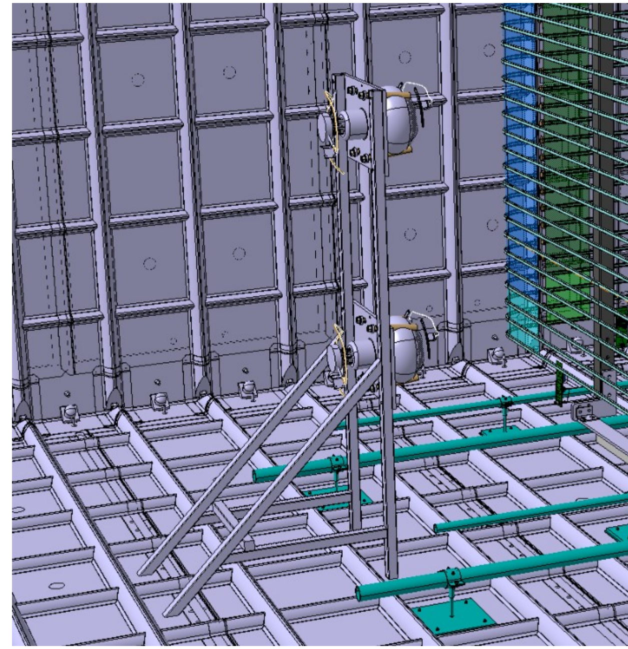


CIEMAT setup

ProtoDUNE-VD PDS design

- 20 PMTs will be also installed around the active volume (TPB-coated/PEN foil), succesfully operated during ProtoDUNE-DP, and with a very well-understood behaviour.
- Quartz filters will be placed in some PMTs and XAs to separate xenon and argon light (argon acts as a wavelength-shifter).

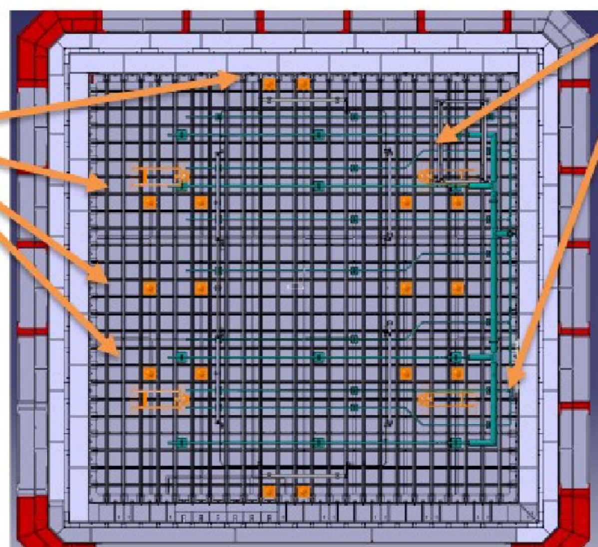
PMT support structure



PMT layout in ProtoDUNE-VD

Layout:

16 PMTs with PEN to study light propagation in 6 m.



8 PMTs looking towards the field cage at the same distance than the X-ARAPUCAs and at the same height for the PDE measurement (6 TPB + 2 PEN PMTs).

PEN PMT