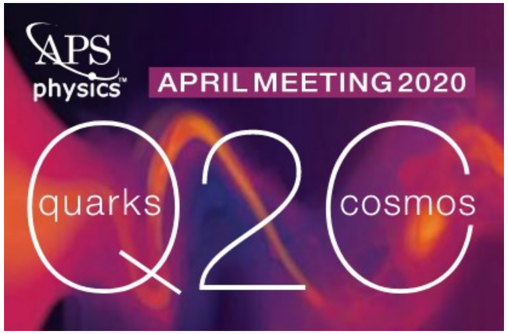


Light detection results from ProtoDUNE Dual-Phase

Jose Soto-Oton on behalf of the DUNE Collaboration

APS April Meeting 2020

18th April 2020

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
DUNE

Deep Underground Neutrino Experiment

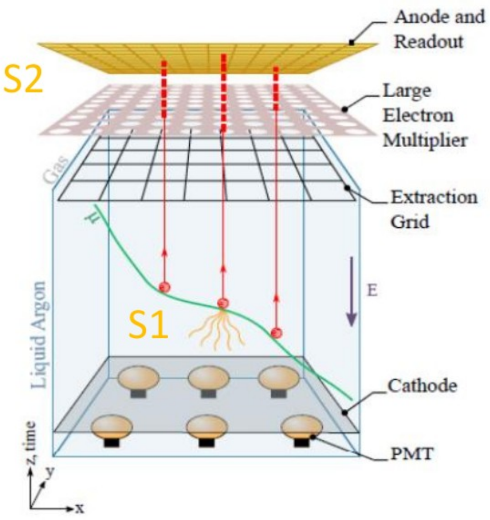
DUNE is a long-baseline neutrino oscillation experiment. It will detect a beam of neutrinos produced 1,300 km away.

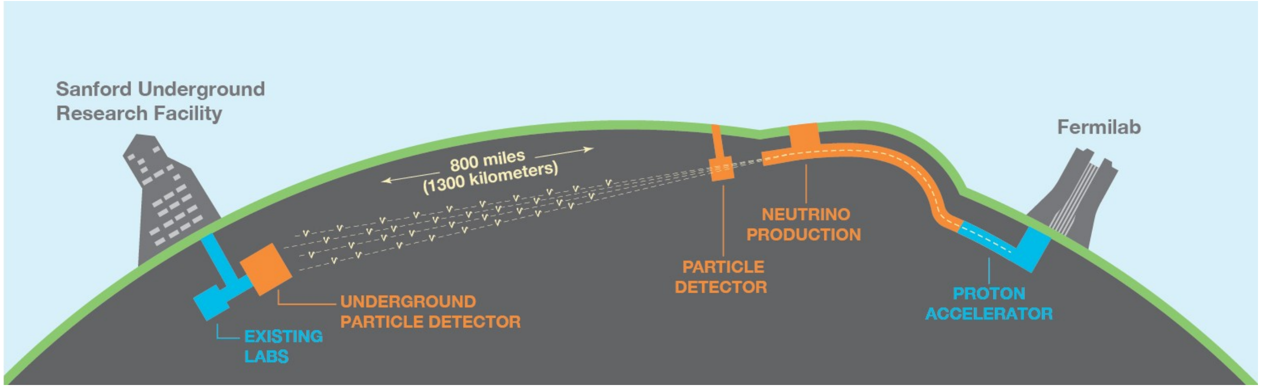
It has a rich physics program:

- **CP violation** and **neutrino mass** ordering using neutrino oscillations.

- **Proton decay** searches, **neutrino astrophysics** and physics **Beyond Standard Model** searches.

4 x LArTPCs of 12x12x60 m^3 10kton fiducial mass each.



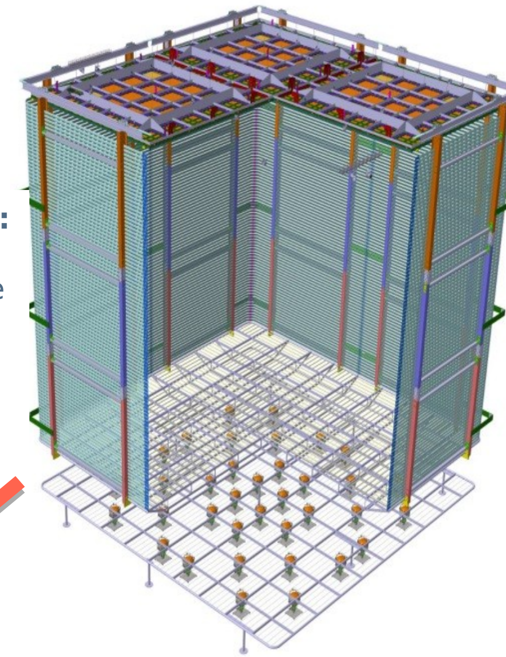


Dual-Phase module:

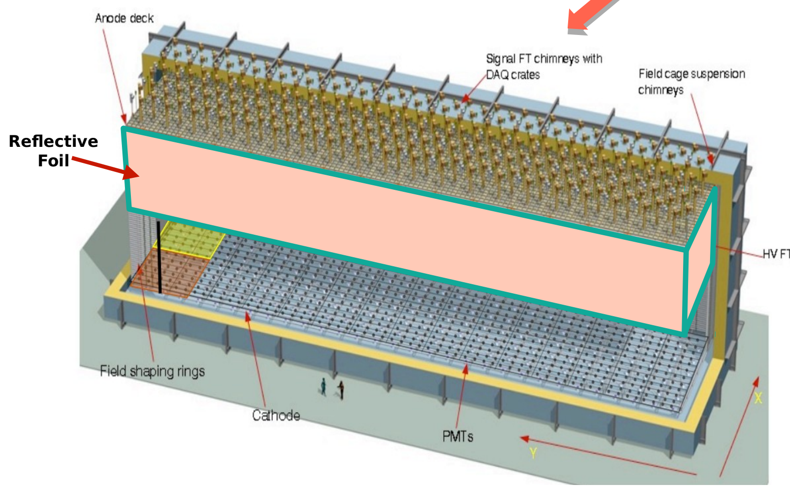
- 12m drift distance.
- Argon gas layer in the top where the charge signal is extracted, amplified and collected.

Towards a 10kton Dual-Phase TPC

WA105 3x1x1 m3 (CERN):
2014-2017.
5 ton LAr.
1m drift.
[JINST 13 (2018) P11003]

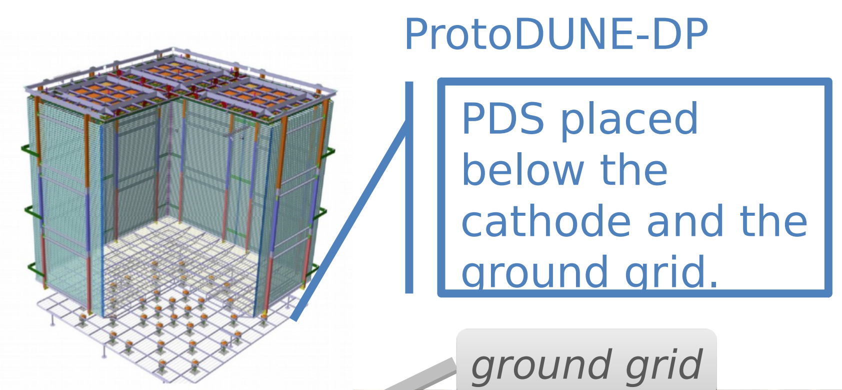


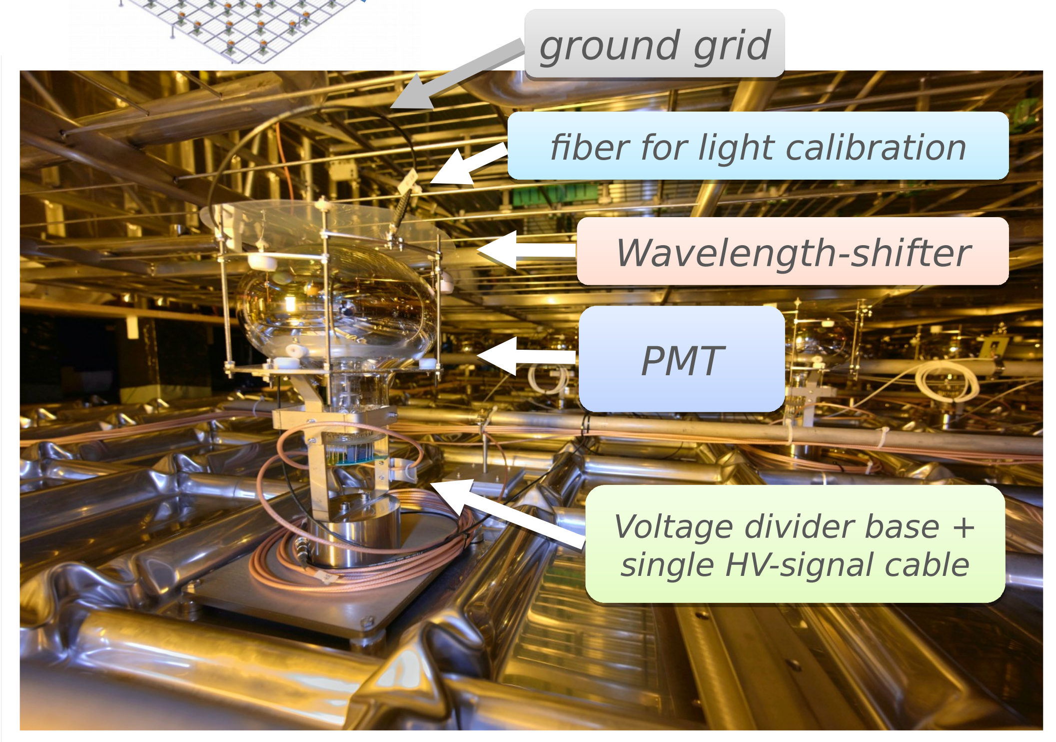
ProtoDUNE DP (CERN):
2018-Present
6x6x6 m3 Active Volume
300 ton LAr
6m drift
[arxiv:1409.4405]



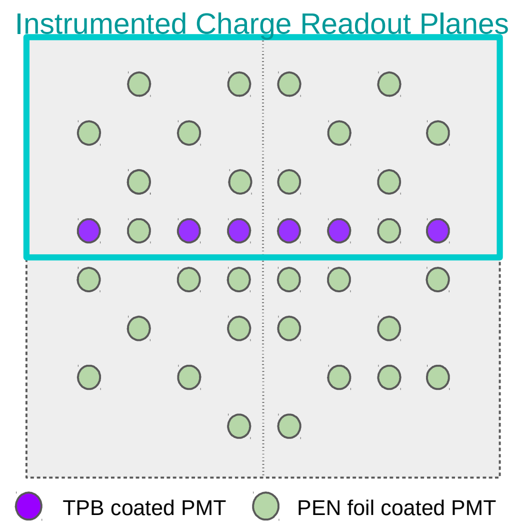
DUNE Dual-Phase Far detector (SURF):
Operation expected in 2026.
4 LAr TPCs.
60x12x12 m3 Active Volume.
10kton of LAr each.
12 m drift
[arXiv:1807.10340]

ProtoDUNE Dual-Phase Photon Detection System





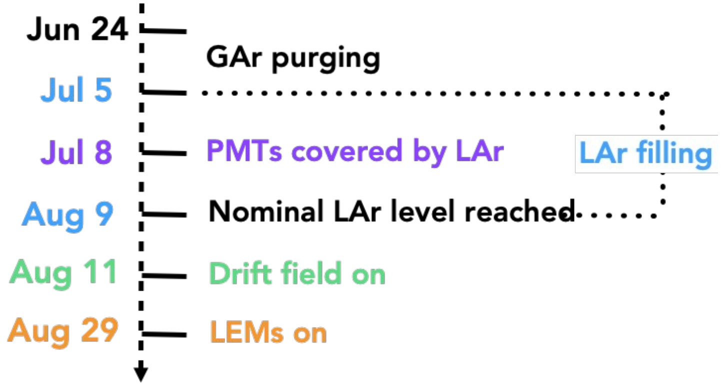
- The light detections system provides the event time, needed to have 3D reconstruction.
- **It consist on 36 8'' cryogenic PMTs** fully characterized at room and cryogenic temperature JINST 13 (2018) T10006
- **Wavelength-shifter**: Scintillation light is shifted to visible light to be detected more efficiently. A combination of PMTs covered with polyethylene naphthalate (PEN) sheets and PMT coated with Tetraphenyl butadiene (TPB) is used.
- Dedicated **light calibration system** (LCS): LED & fiber based JINST 14 (2019) T04001

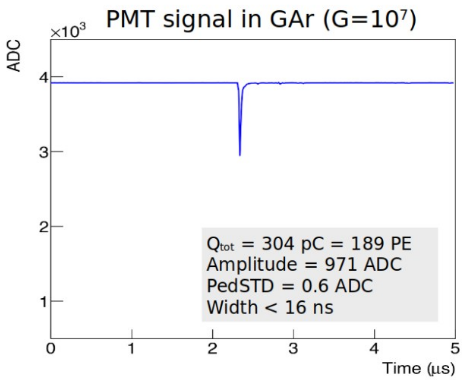


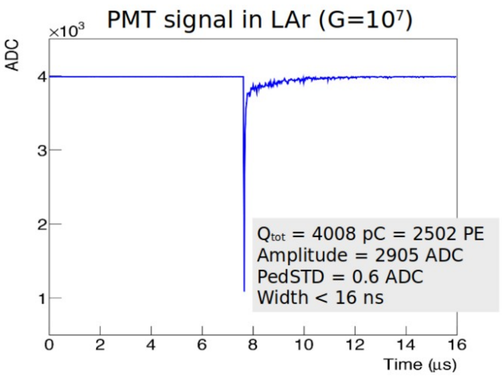
Summary of collected data

- Data taken almost every day since June 2019
- All 36 PMTs are working well with very low noise (see typical waveforms below).
- This represents >360 hours of data (86M events).
- Different trigger conditions:
  - Calibration runs.
  - Random trigger runs.
  - Cosmic Ray Taggers (CRT) runs.
- We expect to continue takind data during this year.

Trigger	# of runs	# of events	time (h)
CRT Panels	40	319k	260
Random trigger	101	12M	11
Calibration runs	690	15M	8
PMT trigger runs	572	58M	83
Random trigger in coincidence with charge DAQ	10	144k	4
Total	**1413**	**86M**	**366**



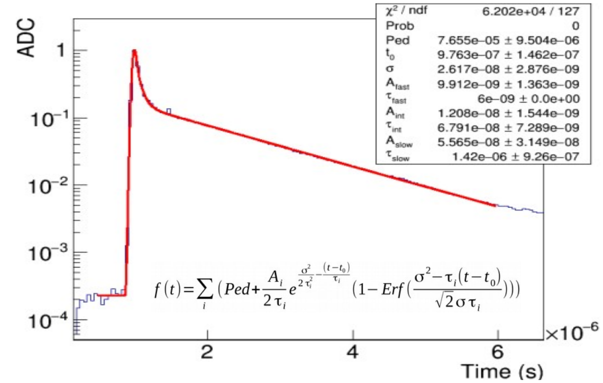


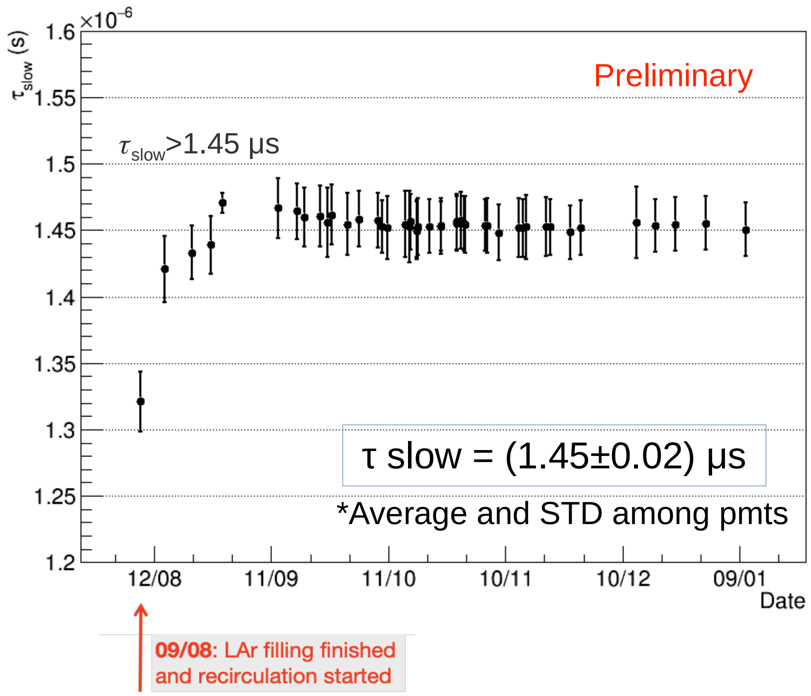


Study of the scintillation light
Tau slow monitoring

- **LAr purity is critical in a LAr TPC**: Impurities trap the ionization electrons, reducing the readout charge, and blinding the detector.
- **LAr purity can be monitor using the scintillation light** produced by cosmic muons.
- The time profile of the scintillation light can be described as the sum of two exponential: A fast one (with decay constant of τ_{fast} ~6ns), and a slow one (τ_{slow} ~1.5us).
- τ_{slow} **component is an indicator of LAr purity.**
- We can measure τ_{slow} from our data by averaging waveforms. Then the scintillation profile is fitted to a convolution of 1 gaussian with 3 exponentials (2 decay parameters + 1 for the WLS).
- If purity is affected at a ppm level, we would measure a decrease in the τ_{slow}.
- Purity has remained in the ppb level since September 2019 as we don't see variations on the tau slow. This is in agreement with the Purity Monitors.

Example of average waveform & fit

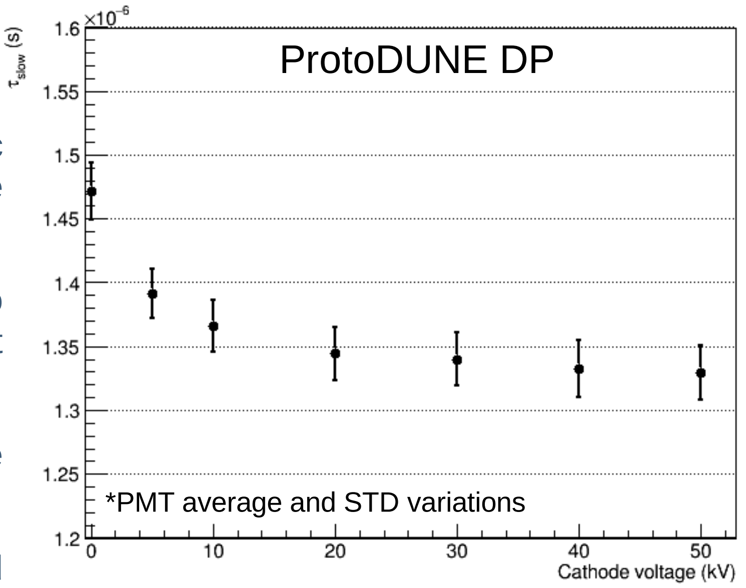


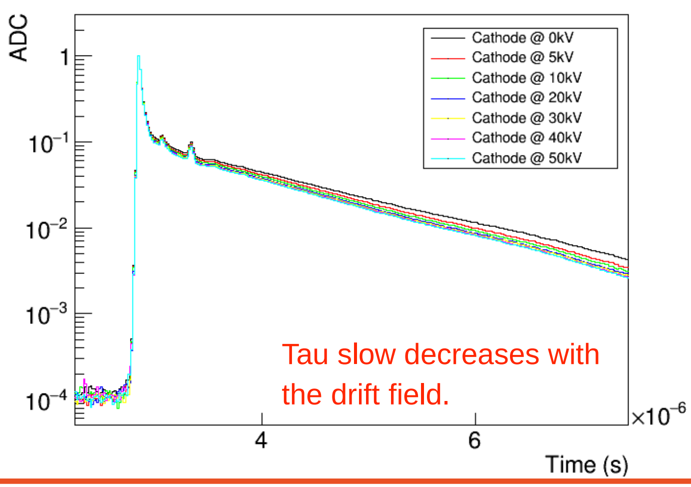


Study of the scintillation light

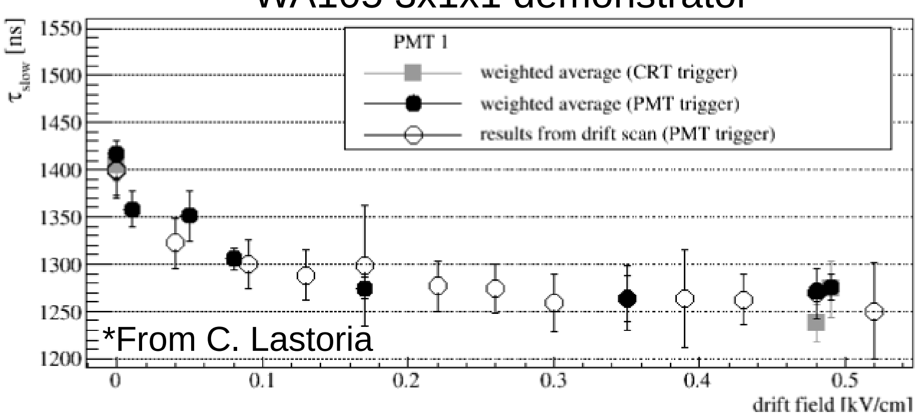
Tau slow variation with drift field

- **LAr scintillation light depends on the drift field**: An electric field reduces the amount of Ar excimers produced by the recombination of Ar^{+} with electrons, and thus, the light yield.
- A dedicated scan on the cathode voltage was performed to study the dependence of the scintillation profile with the drift field.
- One run per cathode voltage was taken and triggering on one PMT placed on the center.
- τ_{slow} **component shows a dependence in with the drift field** (top right), as it was observed In the 3x1x1 data (bottom right).





WA105 3x1x1 demonstrator



Study of the scintillation light

Muon rate estimation

Every MIP crossing the detector provides an S1 signal.

By counting the number of S1 signals, we can estimate the rate of muons inside our detector.

- **Muon identification:**

  - Any signal with an amplitude above 20ADC (~3PE) at G=1.e7

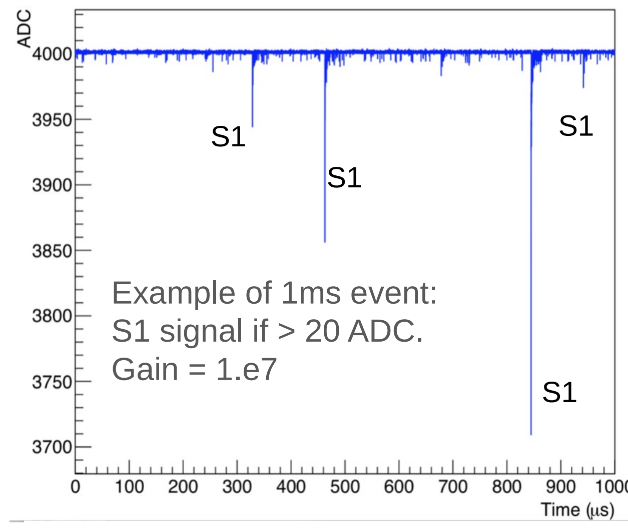
  - No new S1 signal considered during tau slow. A window proportional to the amplitud is rejected after each S1..

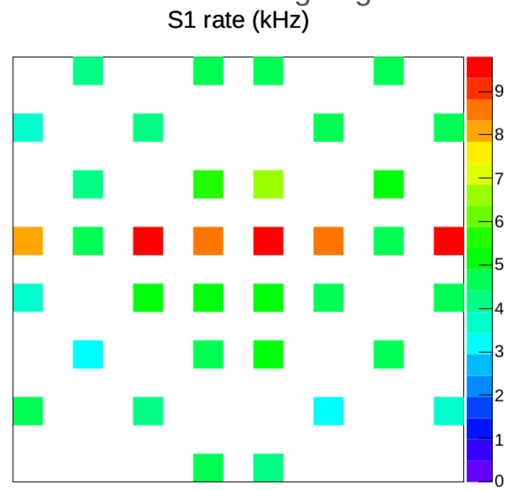
- **Muon rate**

  - Random trigger
  - No fields
  - G = 1.e7

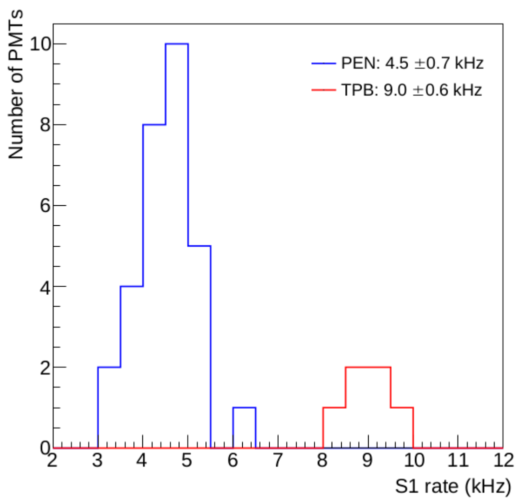
Average S1 rate:
- TPB PMTs: ~9.0Hz
- PEN PMTs: ~4.5Hz

A comparison with Monte Carlo simulation is ongoing.



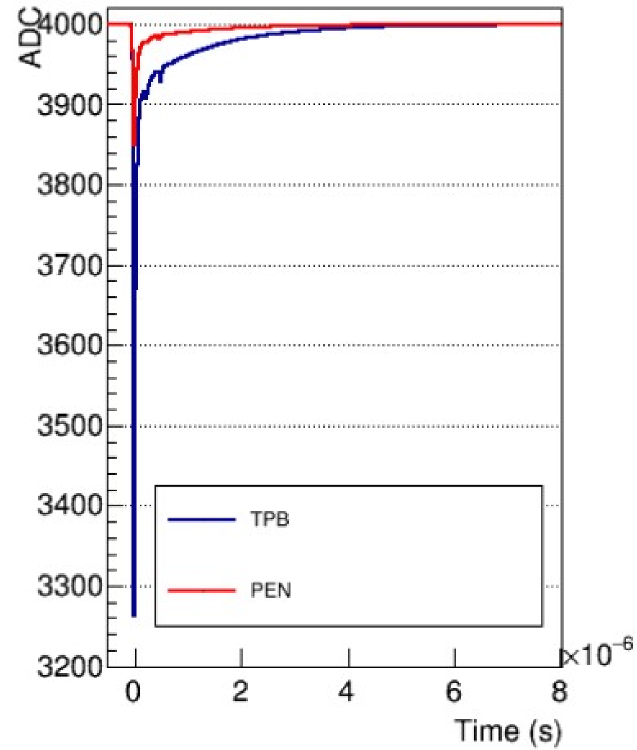


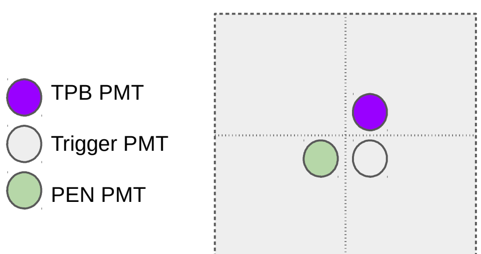
*Top view, each bin represents a PMT at its position in the detector.

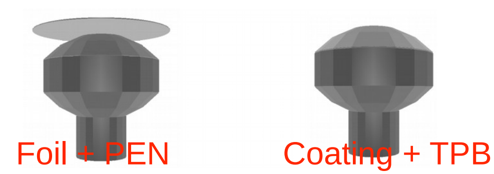


PEN/TPB performance studies

- Scintillation light in LAr is produced in the VUV range, where most photosensors are not sensitive. To solve this a **wavelenght shifter** is introduced to improve detection efficiency.
- Polyethylene naphthalate (**PEN)** is a novel and promising material easy to scale to large detectors, versus the more conventional TetraPhenyl Butadiene (**TPB)**.
- We can compare the performance of both systems in protoDUNE Dual-Phase: We study the S1 amplitude of PEN & TPB PMTs symmetrically placed within the detector and w.r.t to the triggering PMT.
- The average S1 amplitude ratio: PEN/TPB = ~20%
- Considering the geometrical differences, the PEN efficiency is ~30-40% wrt TPB.
- A more complete analysis on going.







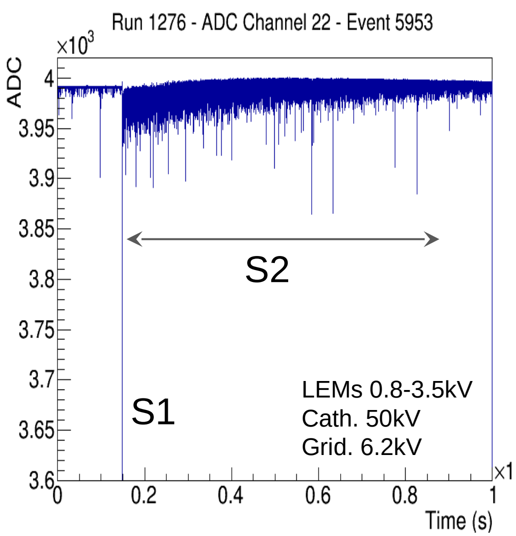
The TPB-coated PMT photocathode receives ~35% more photons due to the geometrical differences of the two systems

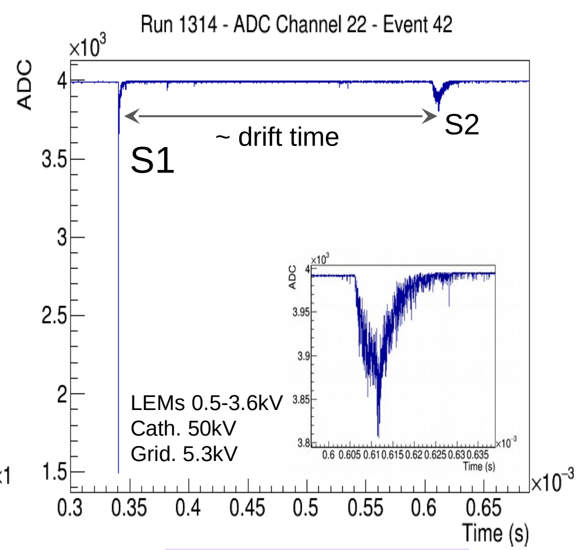
Secondary scintillation light

We are able to detect light produced by the electrons extracted and amplified in the gas phase in all PMTs (>6 meters away).

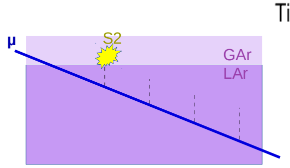
S2 has a different time profile depending on the track geometry:

- **1)** A lower continuum background of S2 after an S1 for tracks starting in the interphase GAr-LAr.
- **2)** All S2 light in a shorter time for horizontal tracks: S1 and S2 are clearly separated by the drift time (the vertical coordinate).

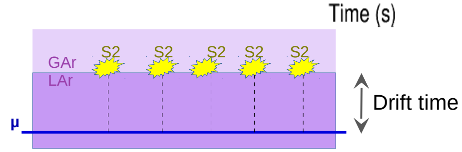




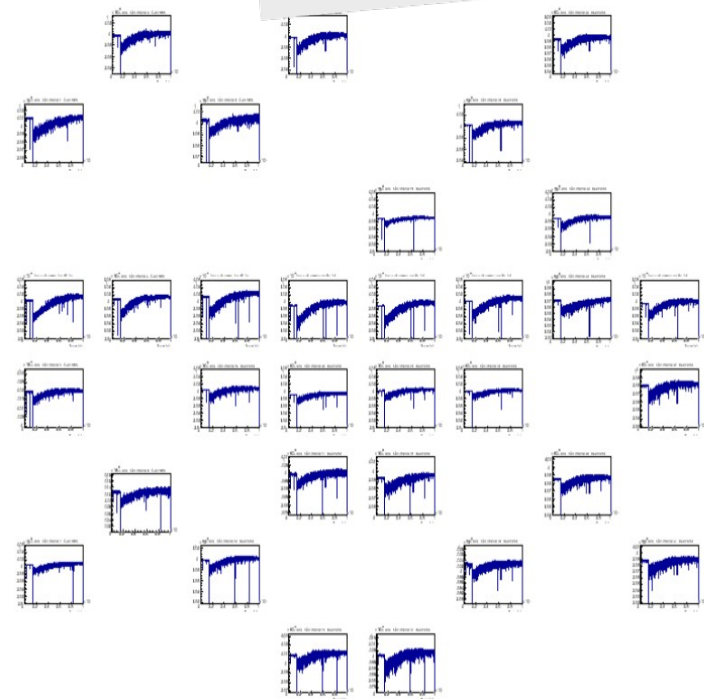
1)



2)



The 36 PMTs see S2 signals from the gas phase!



*Not at the same scale: Larger zoom in PEN PMTs to appreciate S2

Cosmic Ray Tagger data

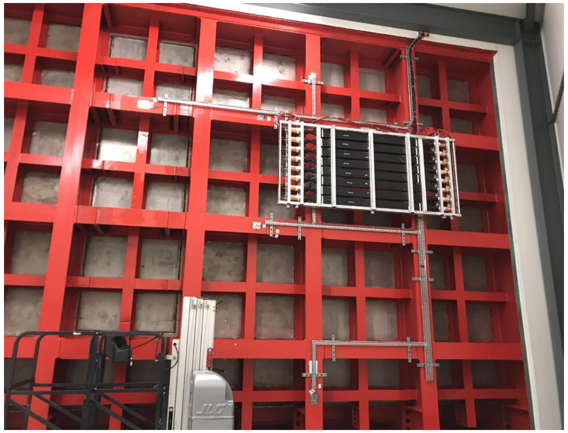
- Two **Cosmic Ray Taggers** placed in two walls of the cryostat provide a **trigger** for diagonal crossing muons (see drawing below).

- Both systems (CRTs and PMTs) timestamps its data using a central clock (White Rabbit), this allows to do an **offline matching** of the information provided by the two systems.

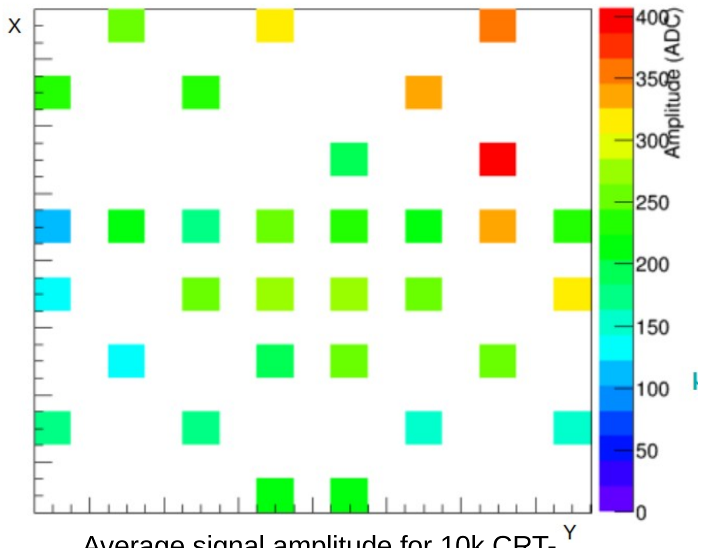
- Crossing muons can be selected offline using a **time-of-flight** based cut provided by the CRTs.

- Average signal amplitude is shown below for ~10k crossing muons. We observe a larger signal for PMT placed closer to the track, as expected.

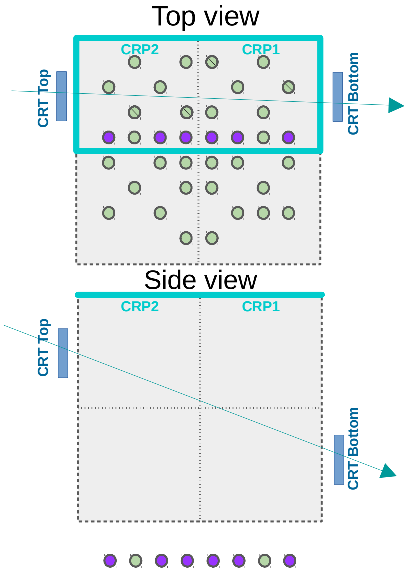
The CRTs also provide a track recontruction, more analysis are ongoing using CRT+PMT combined information and Monte Carlo simulations.



Top view



Average signal amplitude for 10k CRT-triggered muons.



*Not to scale

Summary

- ProtoDUNE Dual-Phase is a prototype of the forthcoming Dual-Phase Far Detector of DUNE constructed and being operated at CERN Neutrino Platform.
- ProtoDUNE Dual-Phase Photon Detection System has been taking data in stable conditions since summer 2019.
- The data adquired will help us to validate the design the Photon Detection System of the Dual-Phase Far Detector of DUNE.
- First light analysis results have been shown.

  - Scintillation light monitoring (purity).

  - Scintillation light dependence with fields (tau slow).

  - Preliminary PEN/TPB performance comparison.

  - Cosmic Ray Tagger data.

- Many other analysis are ongoing:

  - Monte Carlo simulations, Charge/Light/CRT combined analysis, study of the electroluminescence light.