From April 22 to June 27, 2025

Measurement of the efficiency for the DUNE photodetection system

Under the direction of Inés Gil Botella

By Laurine CASSAGNE

Plan

- Introduction
- The Deep Underground Neutrino Experiment (DUNE)
- The Photon Detection System
- Cryogenic Setup for the measurement of the efficiency
- My analysis
- Conclusion

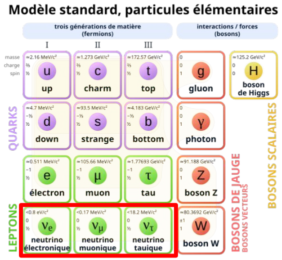
Introduction

- Internship in the Neutrino team at CIEMAT, Madrid. (April 22 - June 27)
- Used data from lab measurements taken at CIEMAT for upcoming publications.
- Using a python environment created by PhD students of the CIEMAT to analyze data.
- Objective : analyze data from lab experiments and extract the Photon Detection Efficiency of DUNE photodetectors.

*CIEMAT : Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

The Deep Underground Neutrino Experiment (DUNE)

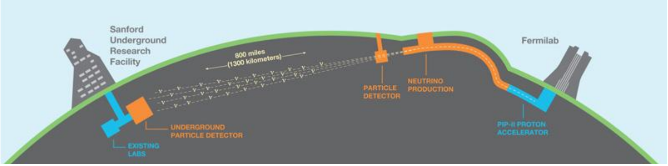
Neutrino particles



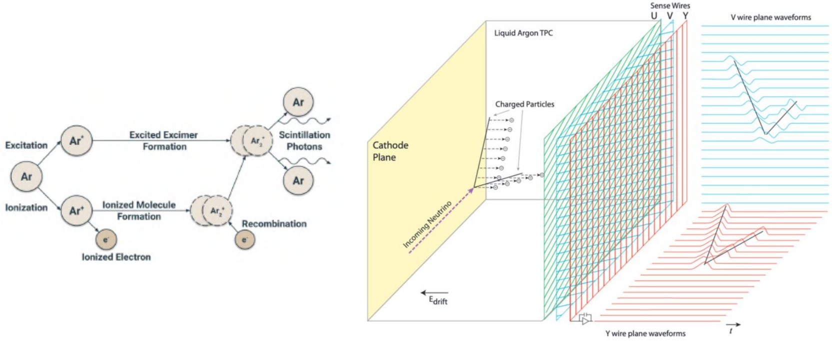
- Neutral elementary particle of the Standard Model with 3 distinct flavors.
- Very weak interaction with matter.

DUNE's aim goals

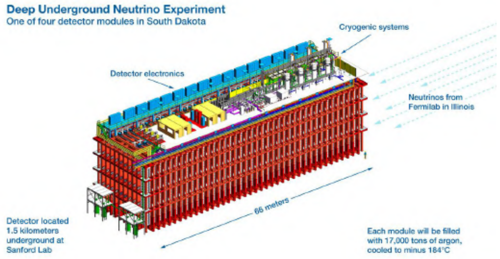
- Observe neutrino oscillation by measuring flavors appearance and disappearance.
- Observe CP violation in the lepton sector in order to learn more about the matter-antimatter asymmetry.
- Detect astrophysical neutrinos (Sun and supernovae) and search for physics beyond the Standard Model.



Liquid Argon Time-Projection Chamber (LArTPC)



Far Detector



- 4 LArTPC modules filled with 17 000 tons of LAr.

The Photon Detection System

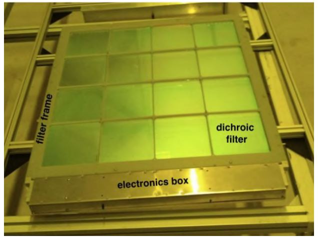
Objectives of the Photon Detection System

- Determine the interaction time (t_0).
- Recover particles energy by calorimetric measurement.

Particularities of the scintillation light

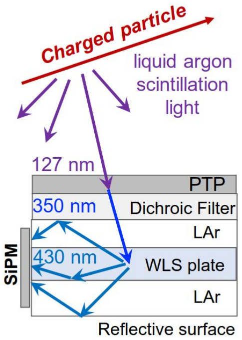
- Charged particles creating scintillation light after energy deposit.
- Scintillation photons wavelength in LAr : 127 nm (VUV).

Needs of DUNE photodetectors



- Converting VUV scintillation light into visible light to be detectable by SiPMs.
- Covering a very large area while optimizing costs.
- Resisting to cryogenic temperatures.

X-ARAPUCA photodetector principle



Not to scale.

- pTP: converts VUV light into 350 nm light.
- Dichroic filter: cutoff at 400 nm.
- Wavelength Shifting (WLS): converts 350 nm photons to 430 nm photons blocked by the dichroic filter.
- Reflective surface: maximize light trapping.

*pTP : p-terphenyl

Cryogenic Setup for the measurement of the efficiency

Installations of the CIEMAT for measurement in LAr and acquisition

Electronic modules

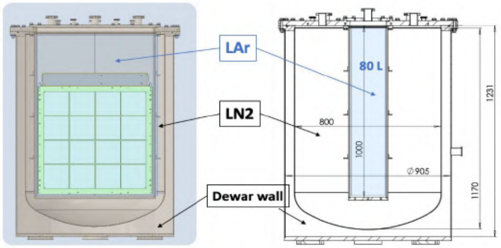
Vessel with
cryogenic conditions

Data monitoring

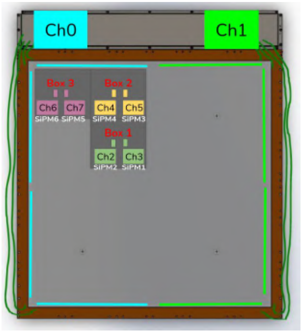
Cryogenic Setup for the measurement of the efficiency

<u>Efficiency</u> : Detector's ability to record the events emitted by a source. $\epsilon = \frac{\#PE \text{ detected}}{\#\gamma \text{ incident}}$

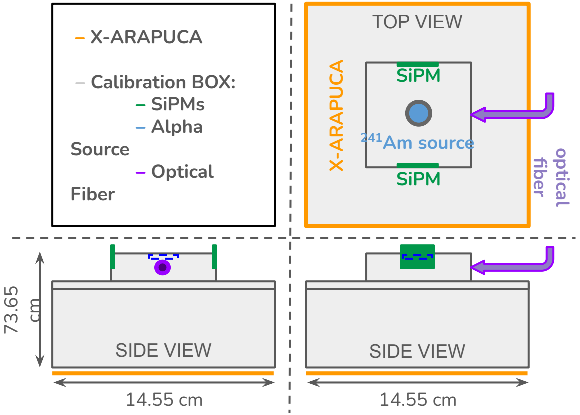
T ≈ -186°C

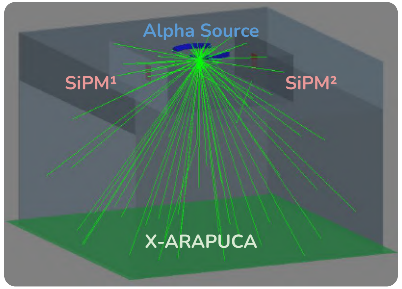


*GAr (99.9999% purity) is liquified with LN_2 at 2.7 bar



- 1 X-ARAPUCA -> 2 channels
- 6 ref SiPMs -> 6 channels
- 3 boxes -> 2 SiPMs per box



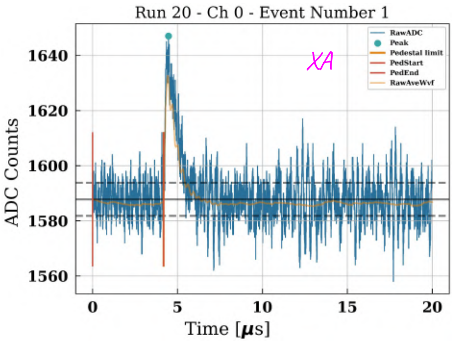


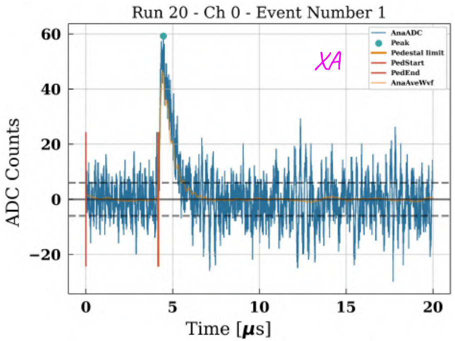
- One ^{241}Am source per box
- <u>Source activity</u>:
  1354.53 ± 0.82 Bq
- <u>α particles energy</u>:
  5.485 MeV (84.45%)
  5.443 MeV (13.23%)

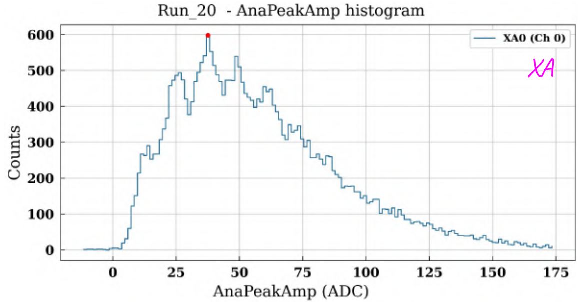
My analysis

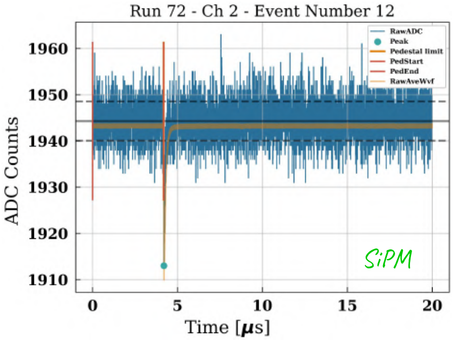
Laser runs : Baseline and Peak Amplitude definitions

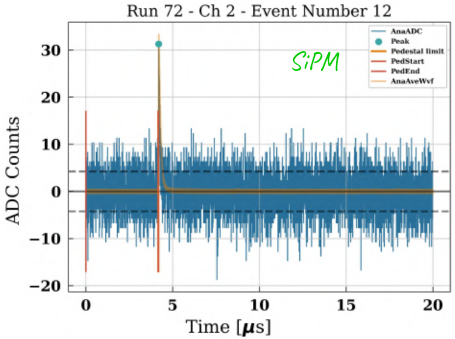
Before baseline subtraction	*After baseline subtraction*	Peak Amplitude histograms examples

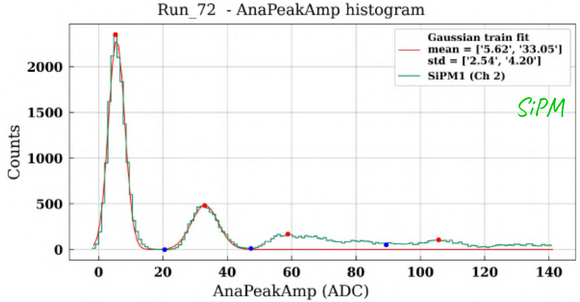






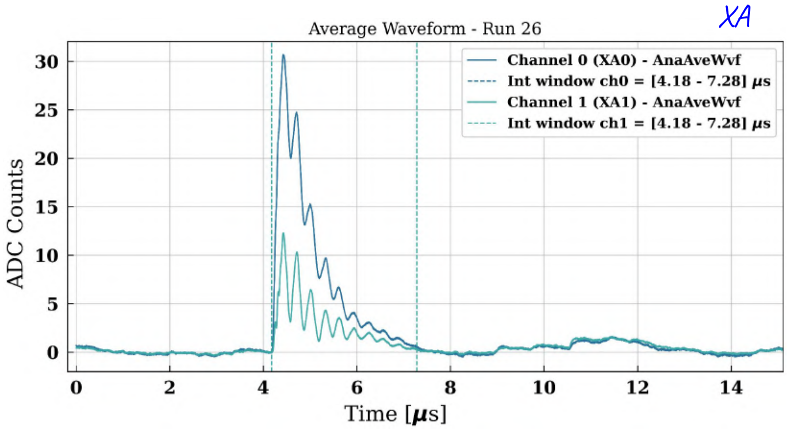


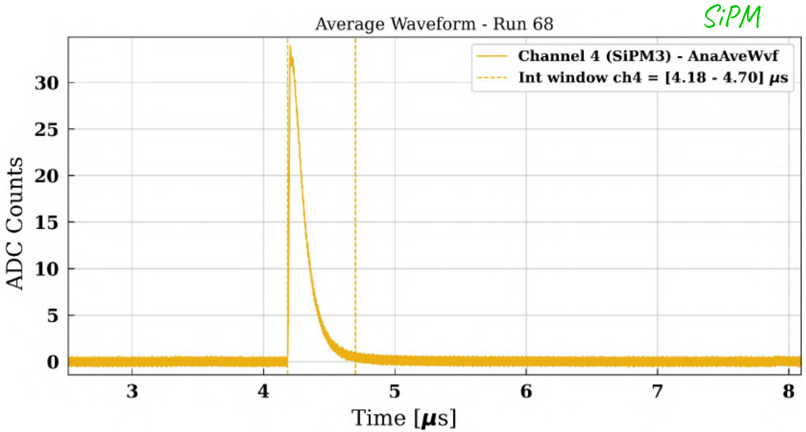




My analysis

Selection of the integration window





- Baseline noisier than for SiPM channels.

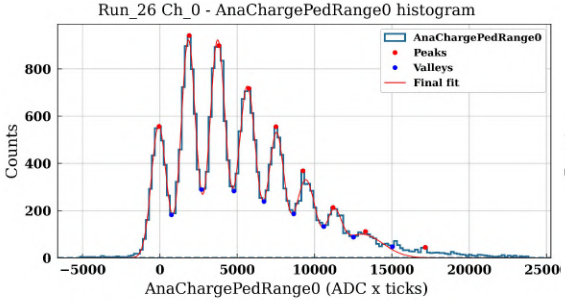
- Integration time window fixed :
  - from the time where the signal starts to increase significantly
  - to a time around where the signal is falling to zero

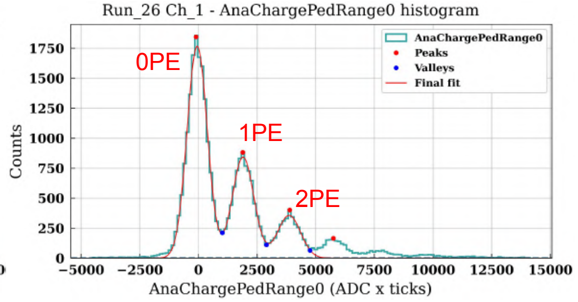
- Integration time window defined according to the average waveform :
  - from the time where the signal starts move away from zero
  - to the first time where the signal falls below zero

My analysis

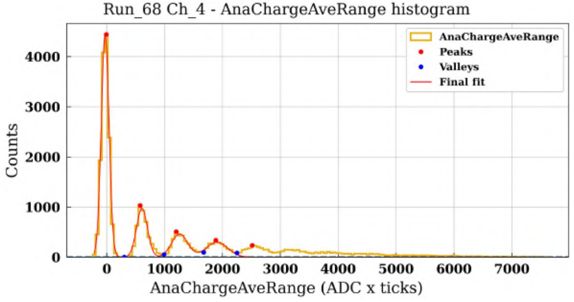
Calibration charge histograms

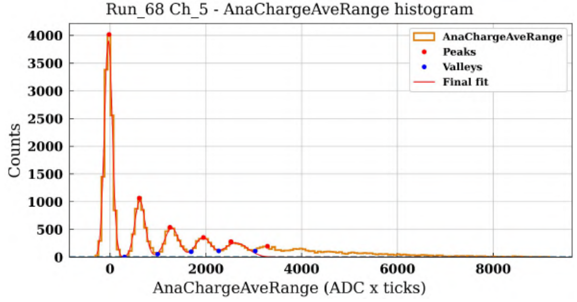
XA - 5.5 OV





Box 2 - 4 OV





Definitions and formulas :

- Gain : Represents the amount of charge produced by one detected PE.
- Signal to noise ratio : Ratio of the amount of counts between the detected signal and the noise.

$$Gain_i = \mu_{i+1} - \mu_i$$

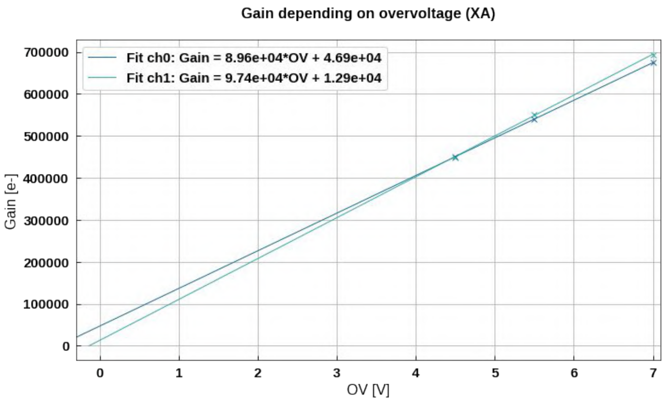
$$SN_i = (\mu_{i+1} - \mu_i) / \sigma_i$$

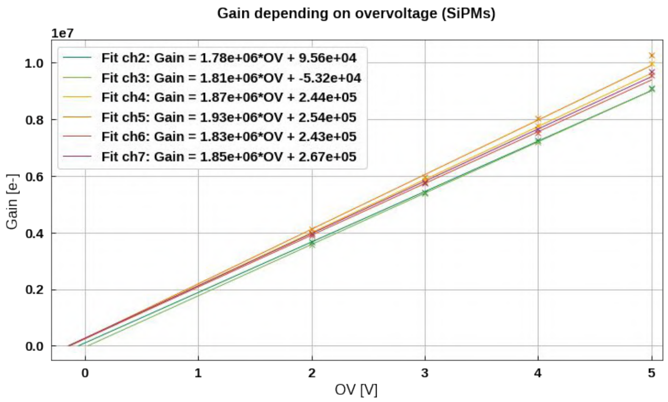
i : Fitted peak number (number of PE)
μ_i : Gaussian fit center corresponding to "i" PE
σ_i : Gaussian fit std corresponding to "i" PE

My analysis

Gain and Overvoltage

<u>Overvoltage</u> : Amount of additional voltage added to the photodetector breakdown voltage.





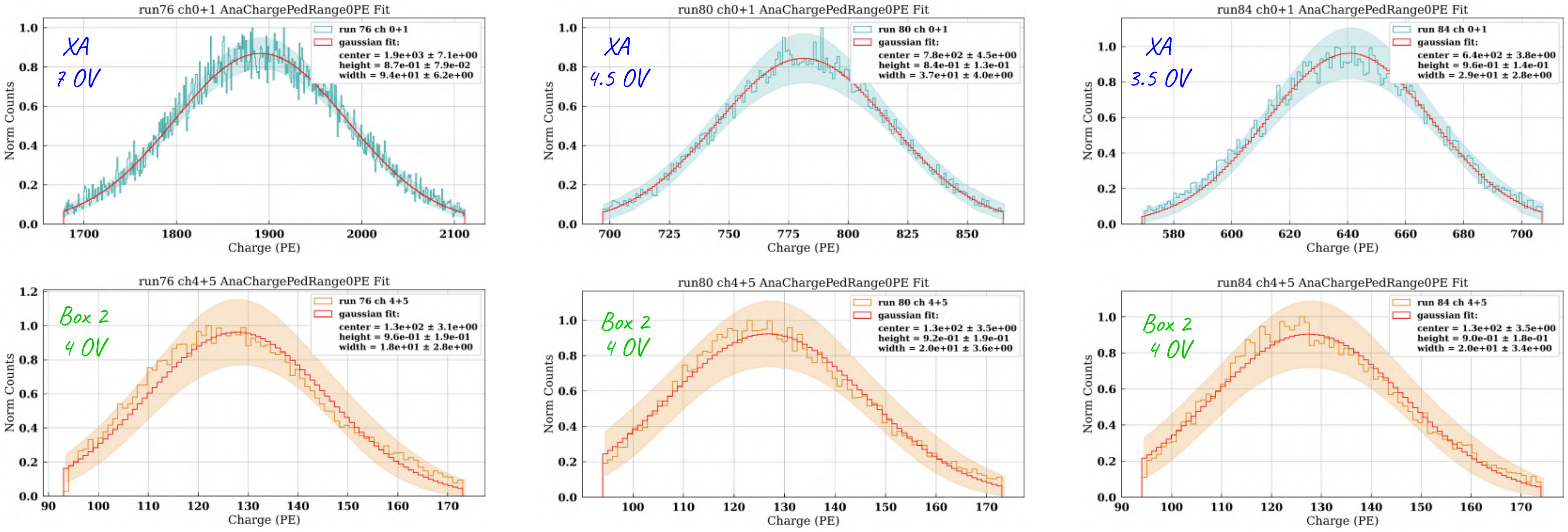
Gain values examples

OV	Gain ch4 (SiPM3)
5	$9.10^6 \pm 1.10^4$
4	$7.10^6 \pm 6.10^3$
3	$5.10^6 \pm 4.10^3$
2	$4.10^6 \pm 2.10^3$

➡ **Linear law between gain and overvoltage**

My analysis

Scintillation light detection: charge collected by each sensor



- Charge histogram are addition of the amount of charge detected between both SiPM in each box and between both channels of the X-ARAPUCA.
- Charge divided by gain before plotting in order to obtain the amount of PE.

My analysis

Efficiency

<u>Formulas used</u>

$$\epsilon_{XA} = \frac{\#PE_{XA}}{\#PE_{SiPM}} \cdot \epsilon_{refSiPM} \cdot f_{corr}$$

$$f_{corr} = \frac{f_{X\text{-}talk}(XA)}{f_{X\text{-}talk}(SiPM)} \cdot f_{geom}$$

$$f_{X\text{-}talk} = 1 - P_{XT}$$

- $f_{X\text{-talk}}$: Correction factor due to parasite signals detected by a SiPM cell from signals detected by neighbor cells.
- f_{geom} = 4.7 ± 0.1 % : Geometric correction factor due to setup disposition.
- $\epsilon_{refSiPM}$ = 12.1 ± 1.1 % : Efficiency of the reference SiPM.

Efficiency requirement by DUNE Collaboration: **ϵ > 2.6 %**

OV	Absolute Efficiency of the X-ARAPUCA
7	5.0 ± 0.5 %
4.5	3.9 ± 0.4 %
3.5	3.3 ± 0.4 %

Relative error : ~ 10 %

<u>Remark</u> : Reference SiPM efficiency uncertainty dominates in the XA efficiency.

Conclusion

- Results of the efficiency comparable with results from other analysis and meeting expectation of DUNE Collaboration.
- What I concretely did during my internship :
  - 2 weeks of documentation
  - 1 week starting to familiarize with the Python environment
  - 3 weeks learning how to perform calibration
  - 3 weeks to make a complete analysis in order to obtain an efficiency result
- New experience acquired in particle physics research, particle detectors, data analysis and teamwork.
- Additional international experience by working in a foreign country.
- One more month to analyze new data and work in the lab with students, technicians and researchers to test new X-ARAPUCA configurations.

THANK YOU FOR LISTENING !