Risultati di fisica del run di PDS ProtoDUNE-HD

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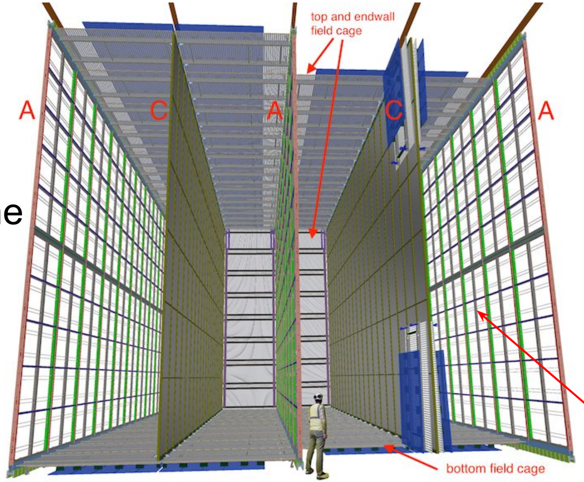
Università degli Studi di Padova

CONTENTS

- Protodune HD and Photon Detection System (PDS)
- PDS Analysis
- Conclusion

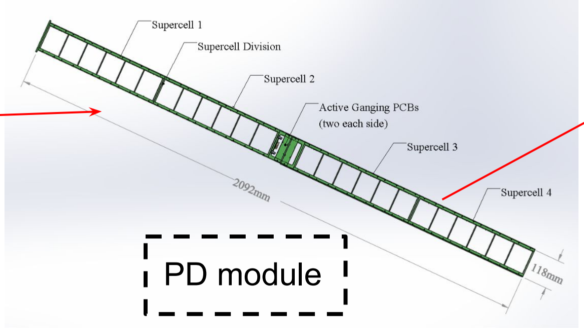
DUNE FAR DETECTOR HORIZONTAL DRIFT MODULE

- 4 Drift Volume (3.6 m x 58 m x 12 m)
- 3 Anodes and 2 cathodes
  - Cathode → 2 CPA array → each 150 (6x25) **C**athode **P**lane **A**ssembly (**CPA**) at: -180kV
  - 3 Anode Plane → each 50 (2x25) **A**node **P**lane **A**ssembly (**APA**) at ground potential
    → 4 wire planes: 1 Collection (X), 2 Induction (U,V) and 1 Grid (G)



- 10 PD modules for APA → 1500 in total
- 1 PD module → 4 super cell X-ARAPUCA (49 cm x 10 cm)
- Inside the APA: not decrease the active volume

Supercell



PD module

APA

SUPER CELL:
→ WLS Light Bar (487 mm × 93 mm × 3.5 mm)
→ 48 SiPMS per SUPERCELL → 192 per PD module

ProtoDUNE-HD @CERN

→ Perform **Validation** and **commissioning** of the the choices made for DUNE FD-HD

→770 tons of LAr

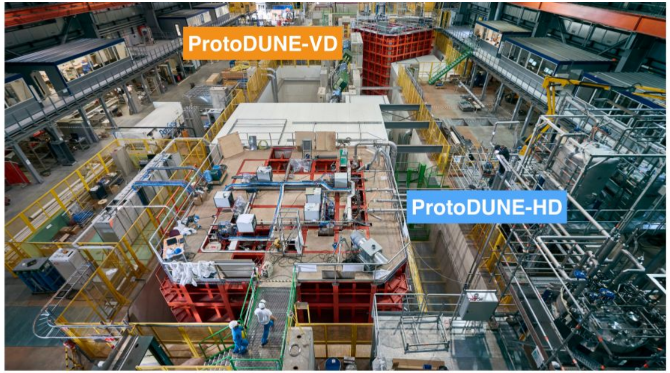
→ 4.6 m x 6.1 m x 7.2 m

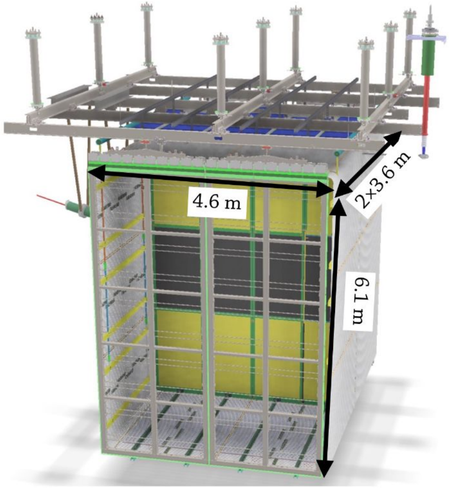
→ 4 APAs and two drift regions

→ Collected cosmics + beam data from **May up to September of 2024**

→ Beam: e, μ, p, π , K with momentum between 0.5 and 7 GeV/c

For ProtoDUNE-VD see F. Alemanno presentation





PDS ProtoDUNE-HD Configurations

→ 160 X-Arapuca used in total

SiPMs: Hammatsu (HPK) or Fundazione Bruno Kessler(FBK)
Light Guide: Eljen (EJ) or Glass to Power (G2P)

4 configuration at total

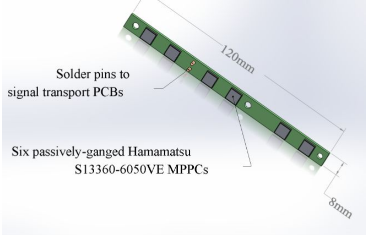
APA 1 - Full streaming → ~5.5 ms
APA 2 to 4 – self trigger → ~16 us

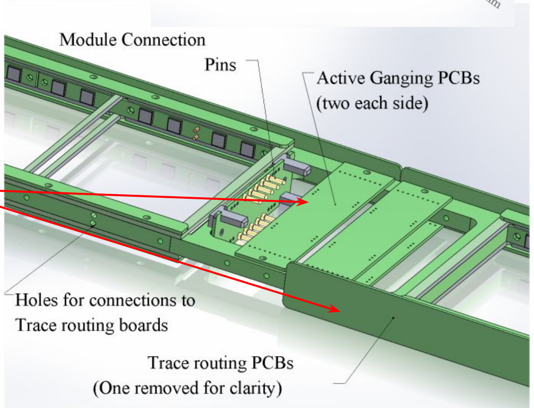
2 trigger configurations

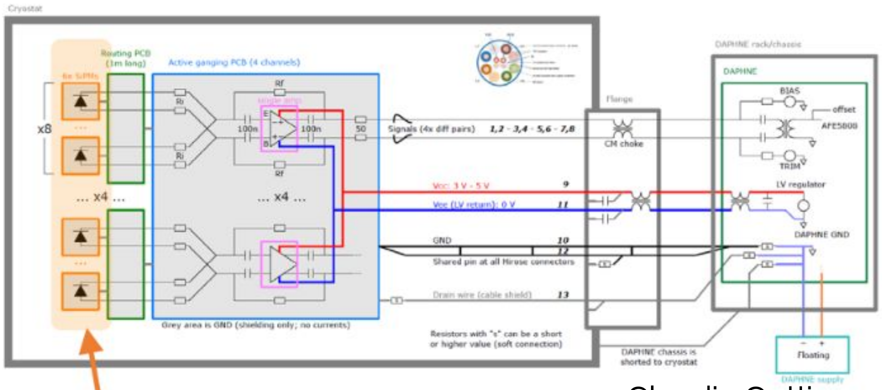
Channels and electronics

1 channel = 1 SuperCell (48 SiPMs)
→Bias and signal → same line

- Passive ganging: 6 SiPM from mounting board
- Active ganging: 8 SiPM mounting board
  Cold amplifier → Differential Signal
- Warm electronics: **DAPHNE** (**D**etector electronics from **A**cquiring **PH**otons from **NE**utrinos): Amplification, digitalization, sending to DAQ, and more
  based on **mu2e** cosmic ray veto







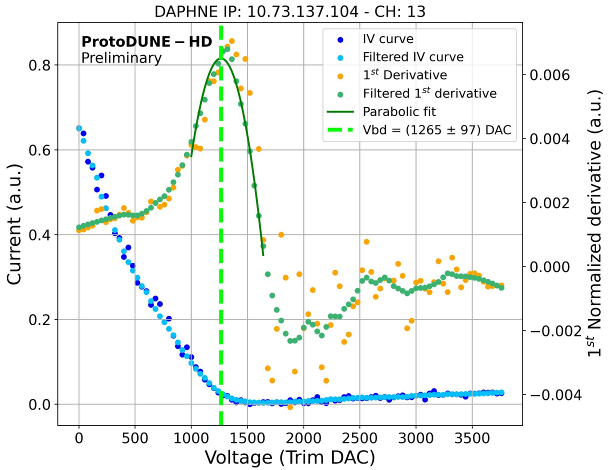
Claudio Gotti

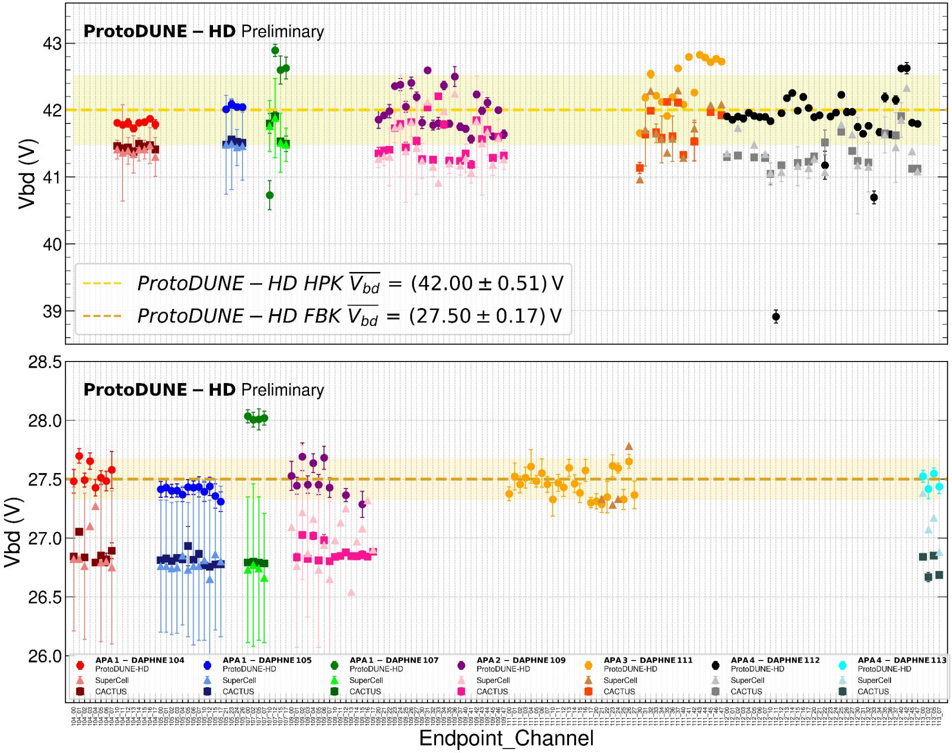
Breakdown Voltage Determination

Anna Balboni

→ The gain of SiPM is direct proportional to the overvoltage above the breakdown voltage:
$G = C_J \times (V - V_{BR}) / e^-$
→ The breakdown voltage depends of the temperature: T↓ → V_{BR}↓
→Ensure same gain to all channels
→Ensure stability over time

→ Voltage scan to determine I x V curves (48 SiPMs) → Parabolic fit at the first derivative



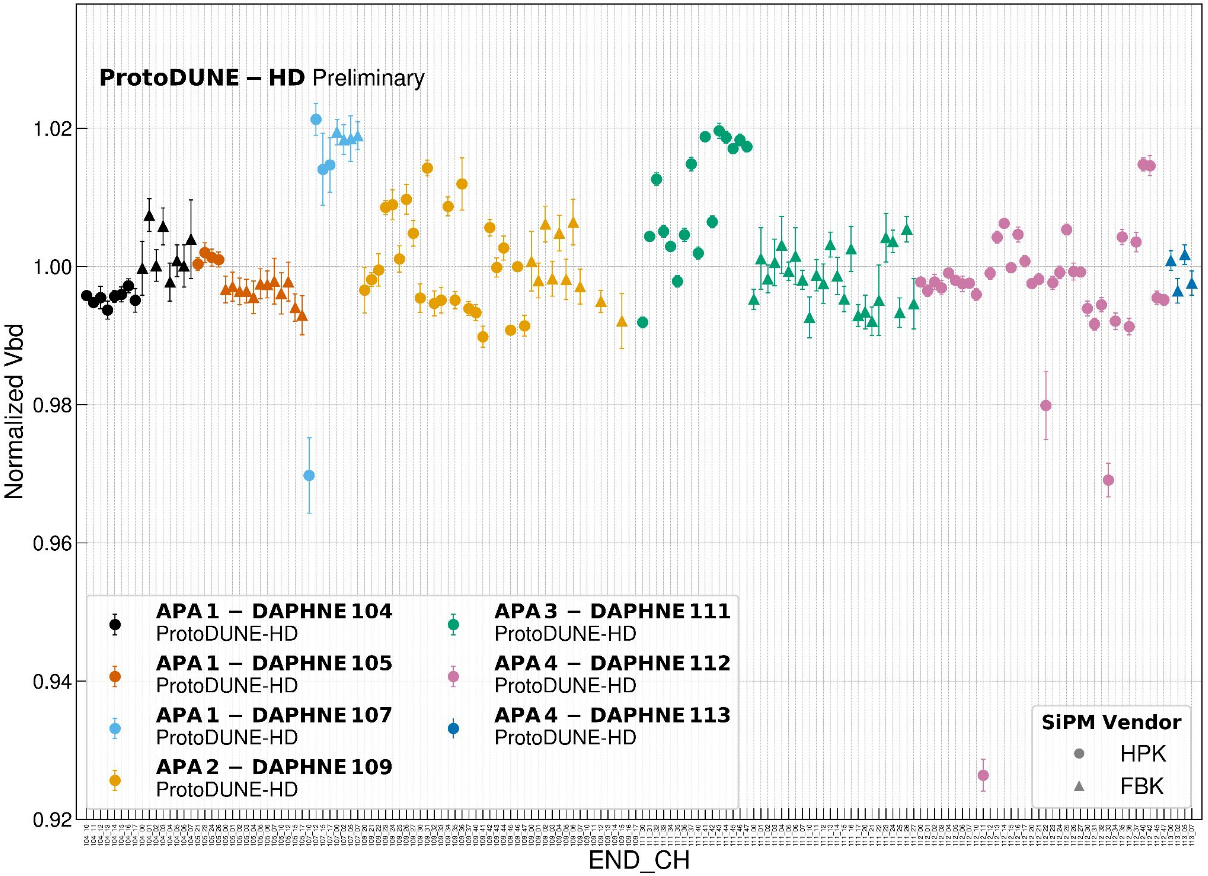


- *CACTUS data* → each SiPM was individually characterized;
- *SuperCell test* → the whole SuperCell was characterized.

Breakdown Voltage Stability

Anna Balboni

- The plot shows the average Vbd of each channel, normalized to the average Vbd of all FBK or HPK sensors.
- Error bars estimate the time Vbd variation of each module.
- A period of 4 months was considered.
- Vbd variations in time for all channels are below 2%.



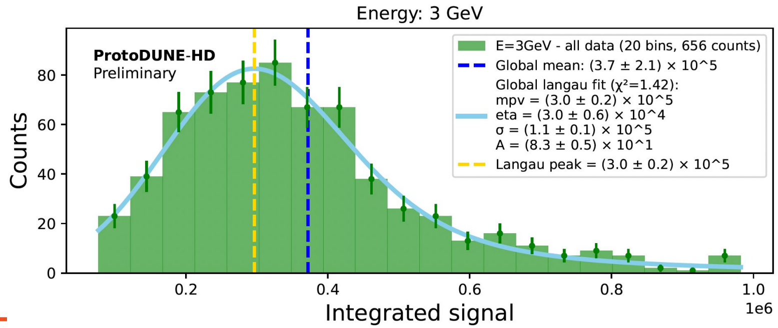
Calorimetry linearity

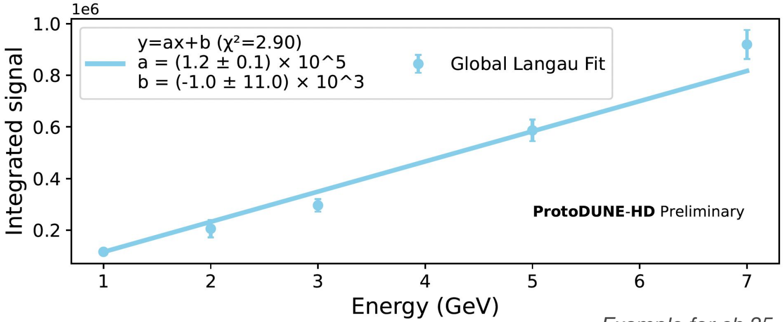
Anna Balboni

- The amount of scintillation photons produced by a ionizing particle is proportional to the deposited energy, so PDS can independently contribute to the **calorimetric reconstruction**.
- To a first approximation, the average light response is a linear function of the particle energy over the entire range of tested beam energies, between 1 and 7 GeV.

It is very preliminary, and the analysis is being redone using new data to allow the selection of light particles.

- The ongoing analysis includes:
  - Selection of waveforms associated to beam events, for which the charge integral is computed.
  - Study of the charge distribution, with a *langau* fit (convolution of a *gaussian* and a *landau*);
  - Study of the dependence of the integrated PDS signal with beam energy, showing good linearity.





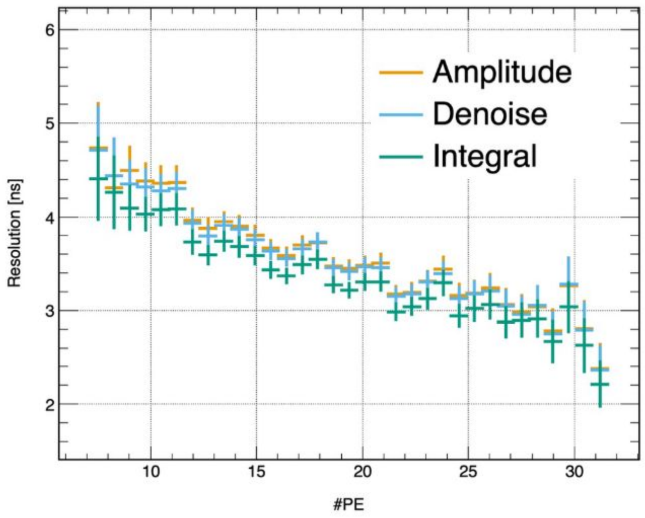
Example for ch 35 APA 2

Time Resolution and Time Alignment

Federico Galizzi

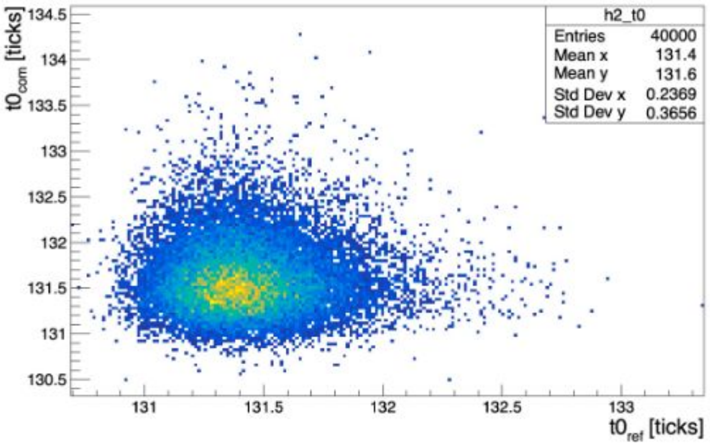
Find start of the waveform calculating where the pulse crosses half of its amplitude.
→ 1 tick = 16 ns
→Use data from runs where a single LED diffuser was employed to assume a point-like source
→Corrected by TOF

Single Channel analysis:



→ DUNE requires 100ns

Multi Channel analysis:



→Time-difference are small but not explainable as TOF effects

Self trigger studies

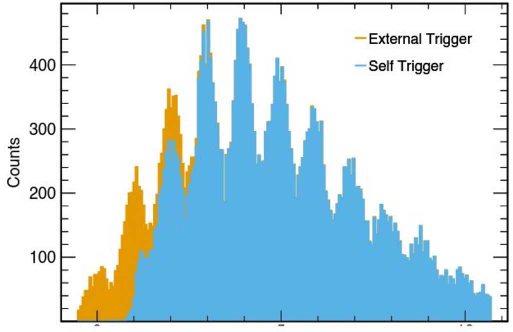
Results @ 1.5 PE threshold

Federico Galizzi

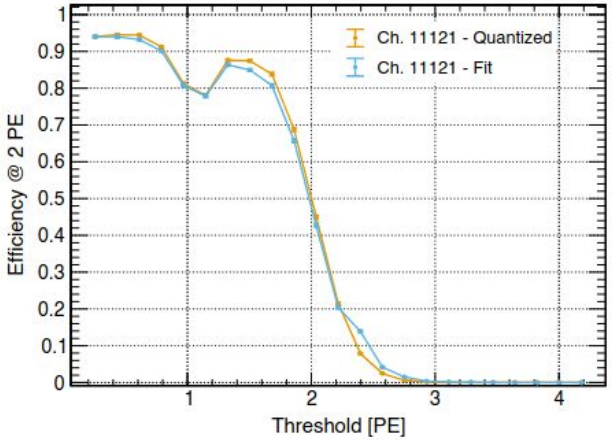
Use a matching filter to identify SiPM signals

Plot of the calibration histogram and the histogram of the selected waveforms

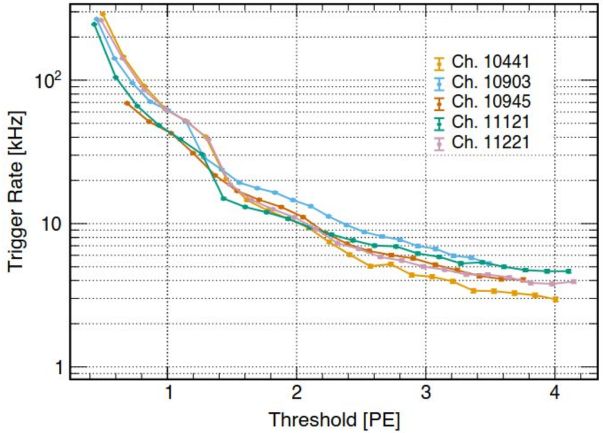
Channel	Eff. @ 2 PE [%]	Eff. @ 3 PE [%]
10441	83	96
10903	82	90
10945	83	95
11121	87	93
11221	85	96



Integral



Trigger Rate as function of threshold for different channels



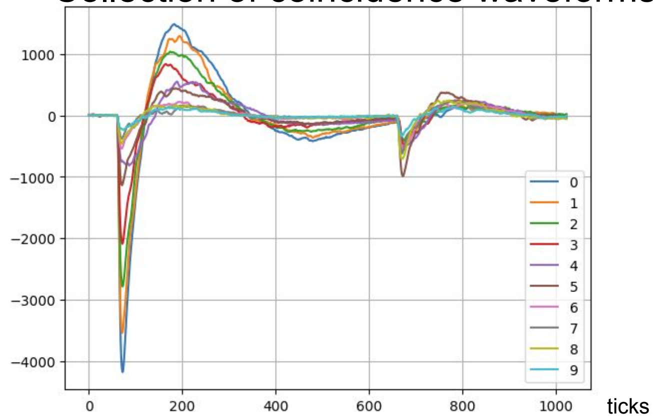
Light Yield vs Electric Field

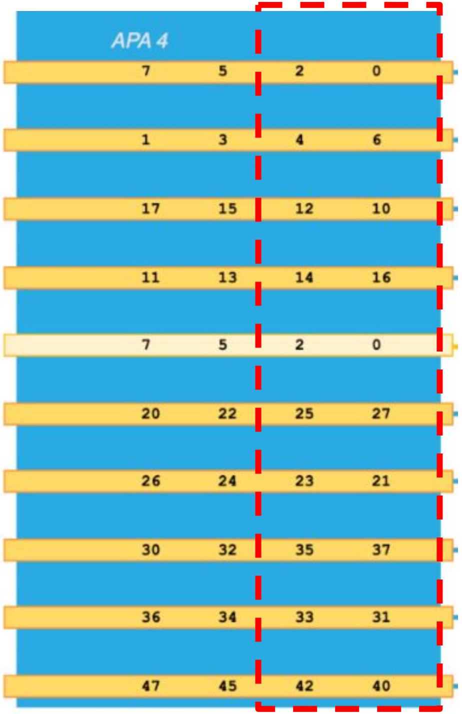
Gabriel Botogoske

Due to increase of electric field the recombination of ionization electrons decreases, decreasing also the light yield.
The ramp up goes from 0 kV to 180 kV
→ Electric field from 0 kV/cm to 0.5 kV/cm (10 points with 0.05 kV/cm step)

Selection of flashes:
→Selection of events recorded in 20 channels in a window of 5 units of timestamp
NOTE:(the trigger is counted in the UNIX time with a unit of 16 ns)

Collection of coincidence waveforms



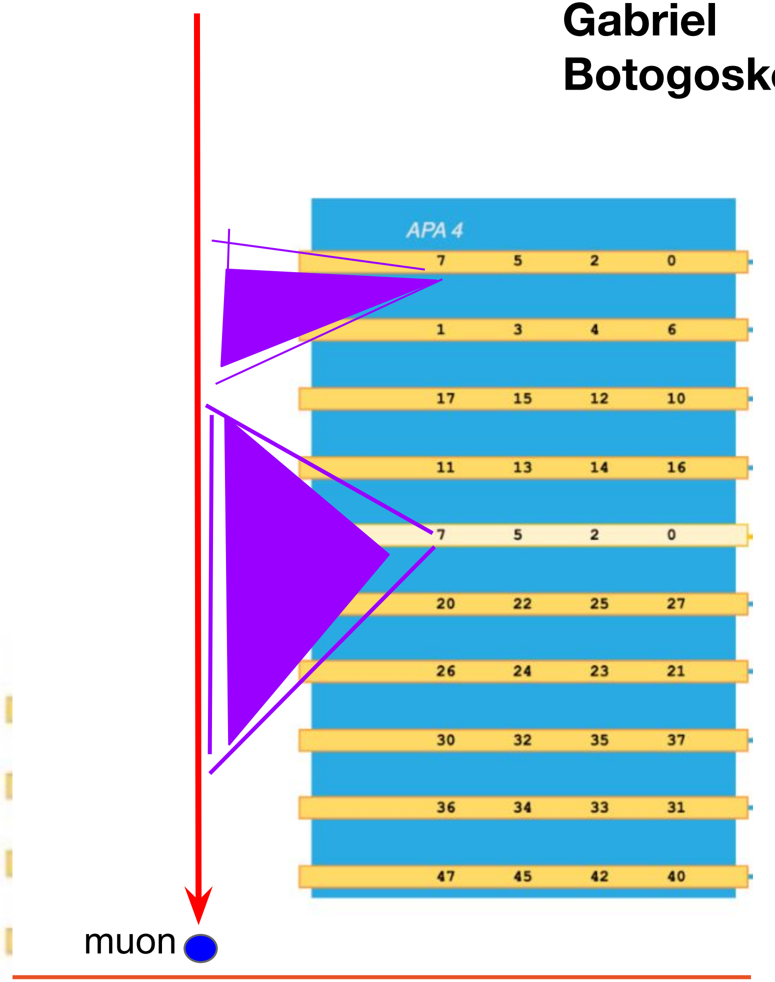


Light Yield vs Electric Field

Gabriel Botogoske

→Select muons that crosses the detector
Expect more light on the middle channels in relation to the top bottoms channels
→ Similar Behaviour on neighbour channels

	Cut name	Selection	# events
0	No cut		18007325
1	Synchronization between all 20 channels	$\Delta T_{\text{all}} \leq 5$	1295380
2	Synchronization between channels at same height and time direction	$\Delta T_{\text{left-right}} \leq 2$ and $\Delta T_{i+1,i} \geq 2$	408300
3	Channels with maximum amplitude at center and with minimum amplitude top and bottom		370740



DUNE

VALIDATING WITH WIRE DATA

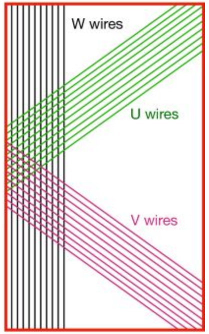
Gabriel
Botogoske

During HV scan the PDS was not triggering the charge data

Only external temporized trigger to the APA

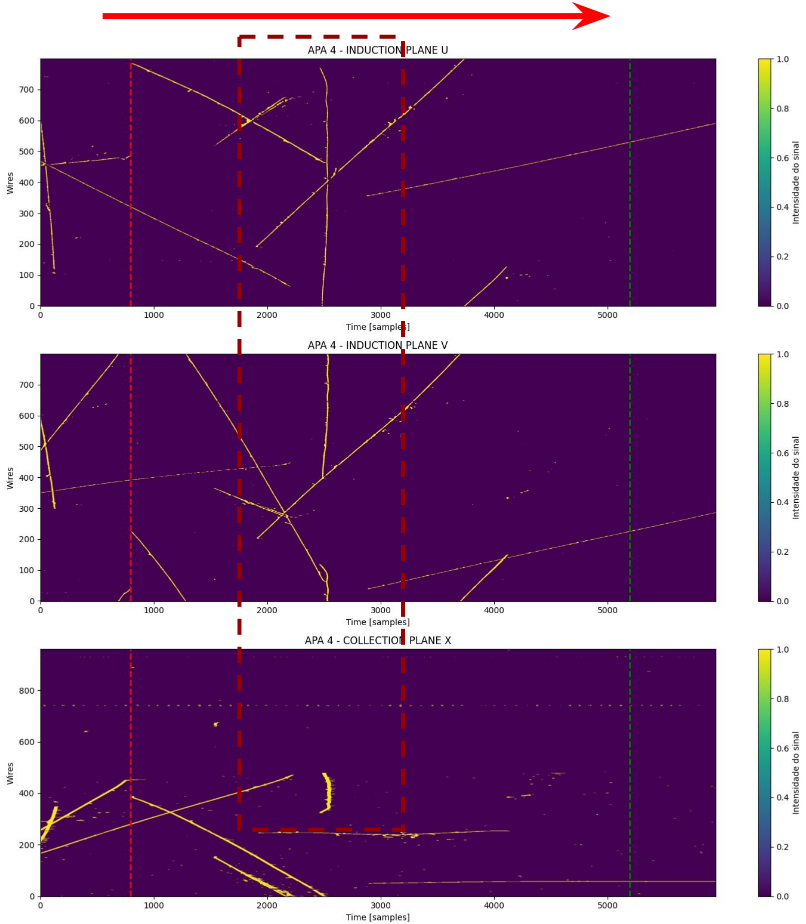
<u>But we can still give a look:</u>

Selected Event from my cut:
Red :PDS Trigger
Green: Max allowed time for a event, assuming drift speed of electron is 1.6mm/us



→ In the induction planes:
expect big tracks **"stopped"** in time

→ Collection plane: Small tracks, since the wires are vertical



Simulation Validation

APPLYING THE SAME CUTS (as in data analysis)

Gabriel Botogoske

Using LArSoft –> Generated 110 files with 10 events (windows of tpc)

Without the cuts:

Total flashes: 126195

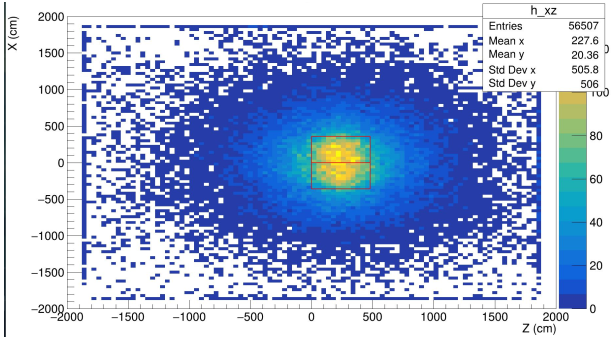
Flashes with mu+ or mu-: 64209

Fraction of flashes with mu+ or mu- : ~ 0.51

Flashes with no associated particle: 54821

Flashes with associated particles that are not muons: 7165

π^-, e^-, e^+, π^+,K, p,n, H, He, Ar,..



With the cuts:

Total flashes: 876

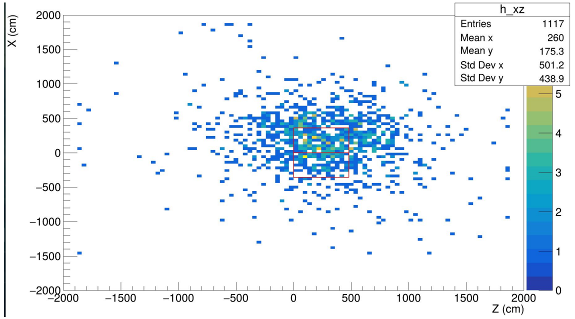
Flashes with mu+ or mu-: 875

Fraction of flashes with mu+ or mu- : ~ 0.999

Flashes with no associated particle: 0

Flashes with associated particles that are not muons: 1

Assuming a DAQ rate of 20Hz →
876x20/(10x110) ~ 16 events/s
–> Data is ~13 events/s(consistent)



Light Yield vs Electric Field

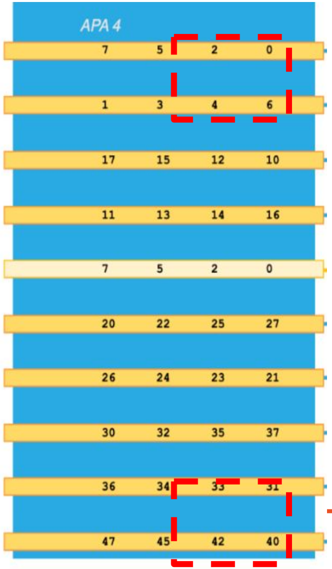
Gabriel Botogoske

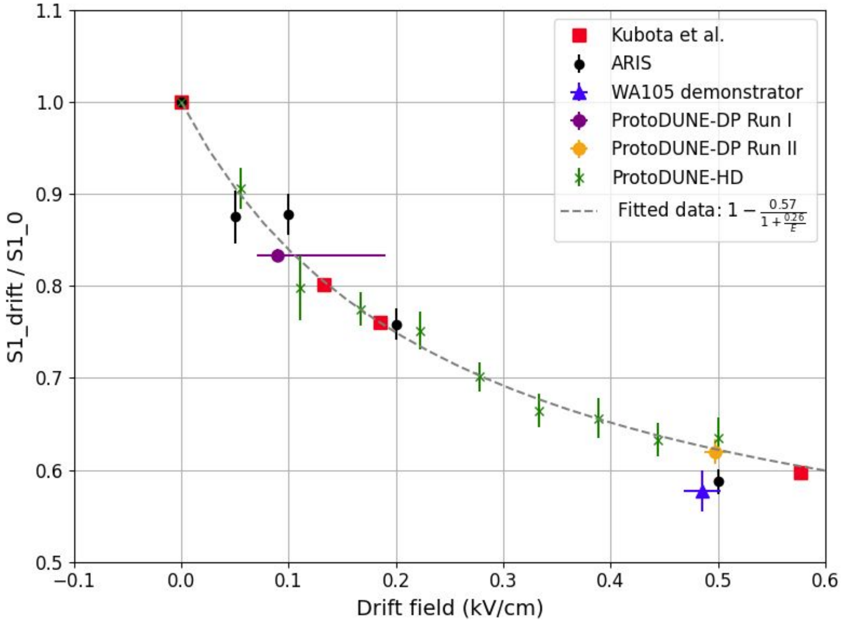
Birks Law:

$$\frac{S}{S_o} = 1 - \frac{B}{1 + \frac{\kappa}{|E_D|}}$$

Steps:

1) Determine the avg signal per channel and per High Voltage
2) Deconvolution of the waveform
3) Integral of the deconvolved waveform
4) Plot the normalized integral as function of drift field
5) Do the avg of bottom and top channels, since they don't show saturation, after the selection criteria



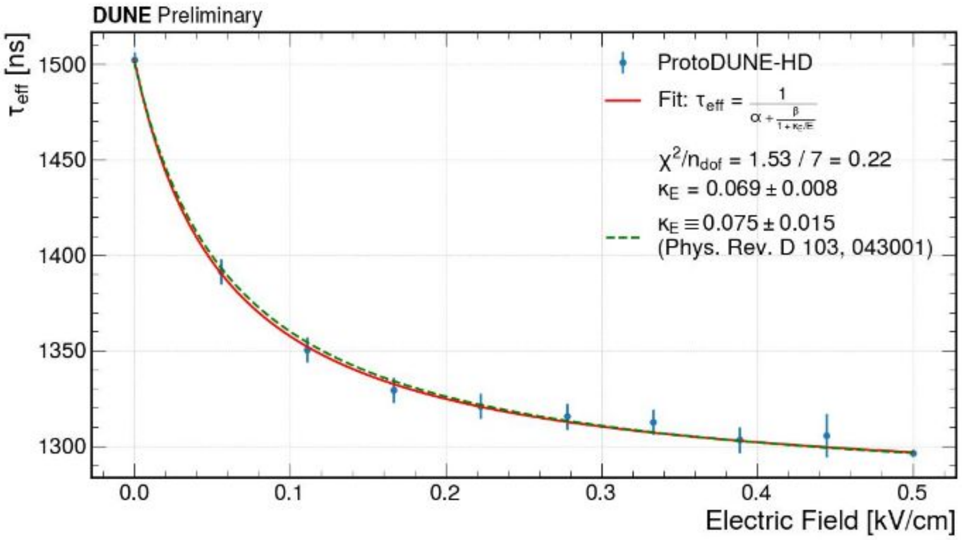


Tau Slow Studies

Henrique Souza

→ Studies show a strong dependence on the τ_{slow} with the electric field applied
→ The behaviour is also seen at ProtoDUNE-HD

$$L(t) = A_{slow}\exp(-t/\tau_{slow}) + A_{fast}\exp(-t/\tau_{fast})$$



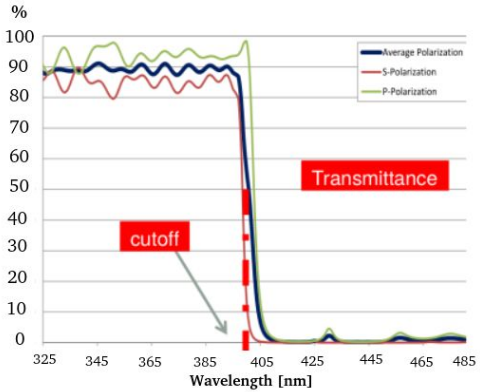
https://doi.org/10.1103/PhysRevD.103.043001 **E. Segreto, Properties of liquid argon scintillation light emission**

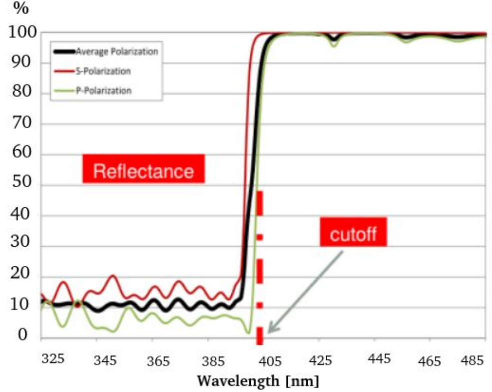
Conclusion

- PROTODUNE-HD validate the operations of FD-HD Photon Detection System
- Capabilities of measure Breakdown Voltage, light yield at different Voltages,, …
- A lot was learned for ProtoDUNE-VD
- A publication about the ProtoDUNE-HD PDS is now in progress and will be finalized by end of year

BACK-UP

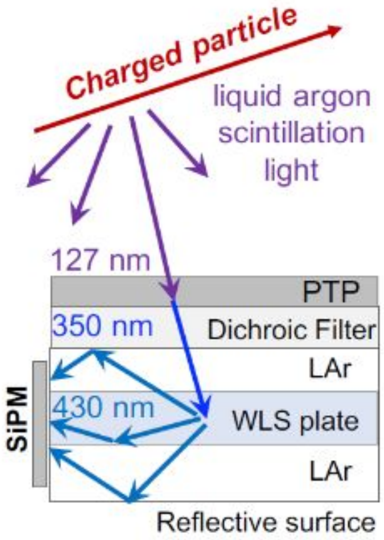
X-ARAPUCA



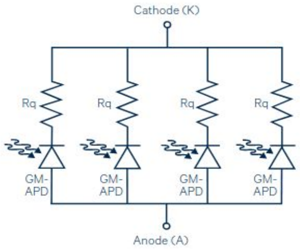


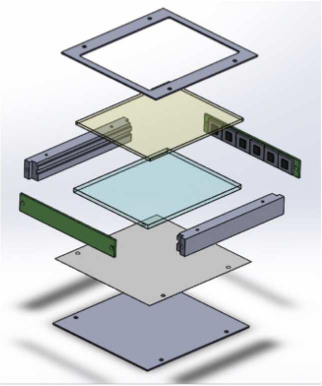
ARAPUCAs are light-collecting devices;

They are composed of:



- Mechanical structure
- p-Terphenyl (pTP) layer
- Dichroic filter*
- Light guide bar
- Reflective foil (Vikuiti)
- Silicon Photomultiplier (SiPMs)





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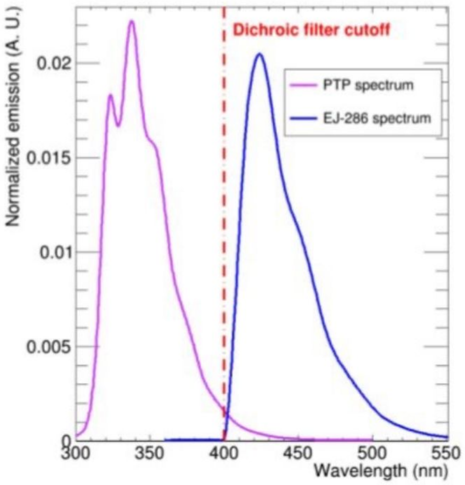


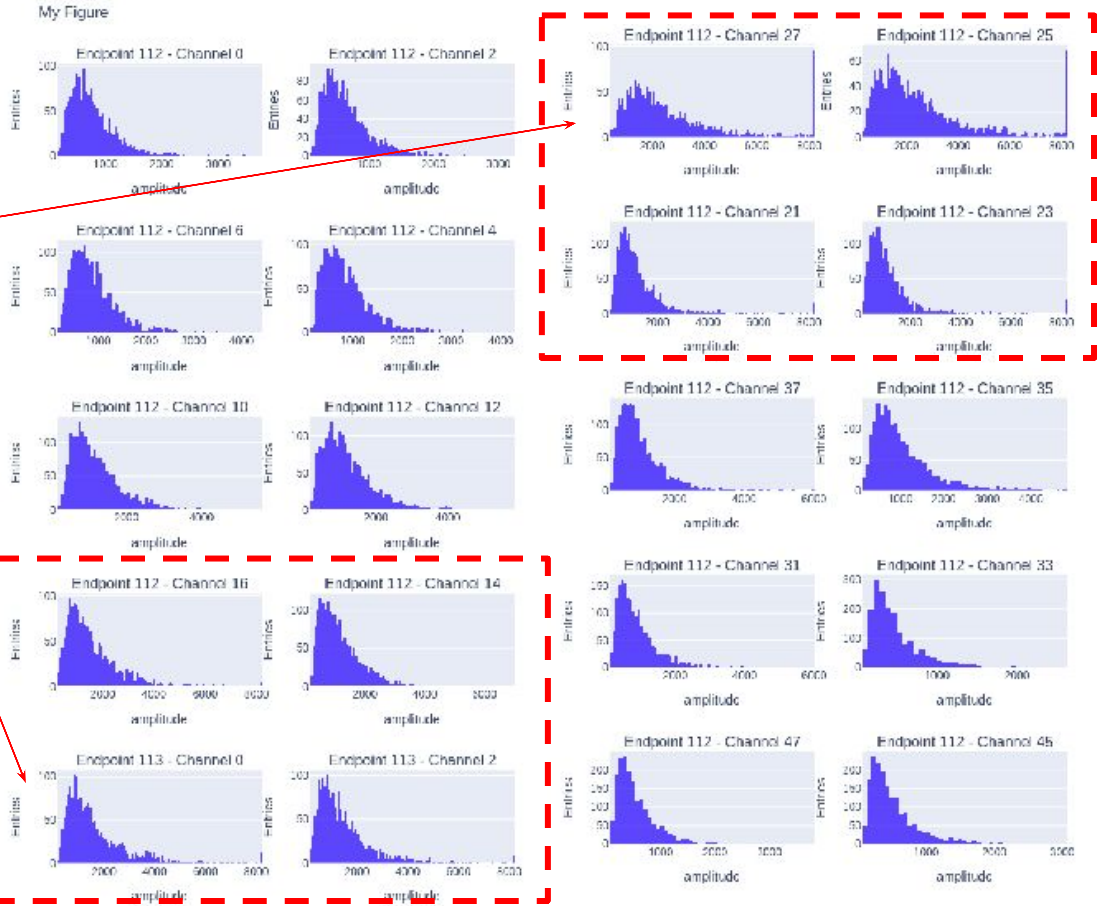
https://www.sciencedirect.com/science/article/abs/pii/S0168900220310457

Multi Channel analysis Time resolution:

Ep	DaphneCh	OfflineCh	APA	LED distance [cm]	Δ Distance [cm]	Δt0 [ns]	TOF correction [ns]
112	21	36	4	370.39			
111	46	44	3	360.42	-9.97	-5.68	0.43
111	47	48	3	417.05	46.65	-19.14	-2.03
111	44	54	3	368.58	-1.81	3.94	0.08
112	23	26	4	378.41	8.02	-2.83	-0.35
112	31	38	4	417.09	46.70	-13.00	-2.03
112	47	39	4	451.03	80.63	-22.27	-3.51

Amplitude histogram

Due to the selection method, the central channels exhibit significant saturation. However, this approach allows us to retain a large number of unsaturated channels. An additional advantage is that we avoid applying any cuts based on charge (integral) or amplitude, which would otherwise introduce a bias in the selection across different cathode voltages.



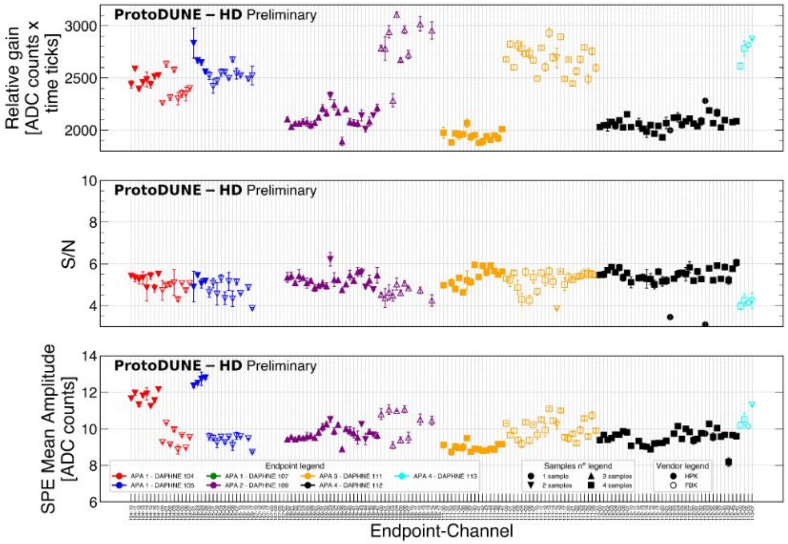
More Analysis

Gain / SNR calibrations

Julio Ureña

Preliminary

- From July 9th to September 25th (2024), several LED runs were taken - the aim is to have a reference calibration for other studies and to test the calibration stability on a channel basis
- The main goal of the calibration is the gain and the signal-to-noise ratio (SNR), although it can also provide cross-talk probabilities, amplitudes, SPE templates and an alternative way to compute the Vbd
- To calibrate the whole PDS, several runs using different LED configurations (mask, pulse width and intensity) must be acquired, so that for every channel a proper illumination is achieved for one run at least.
- The calibration is repeated for different bias voltages, matching SiPMs PDE of 40, 45 and 50%
- The analysis includes a mild cut to prevent integrating outlier waveforms, an algorithm for integration-window estimation on a channel basis and fitting of the charge histogram (typically including ~3k samples) to a sum of gaussians
- Gain and SNR computed from the fit parameters.



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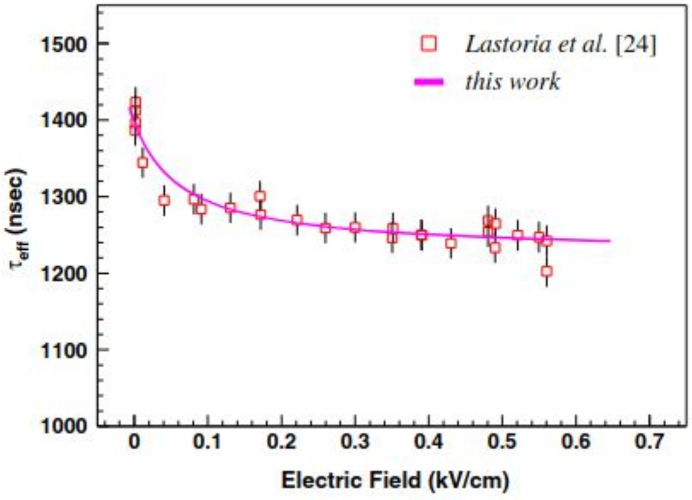
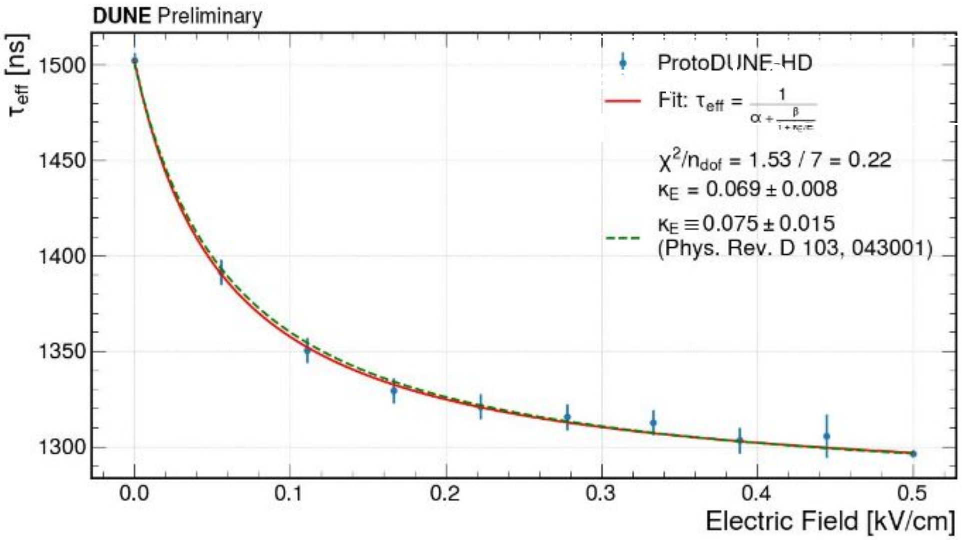




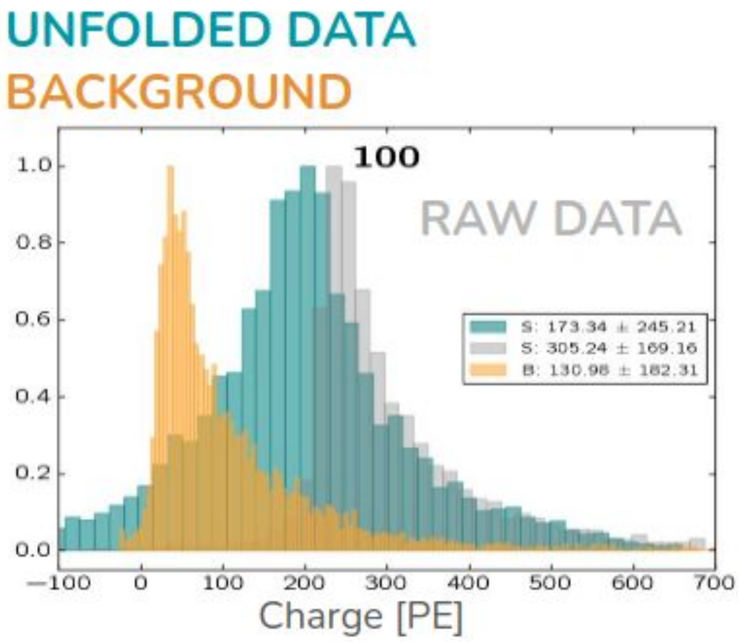
https://doi.org/10.1103/PhysRevD.103.043001

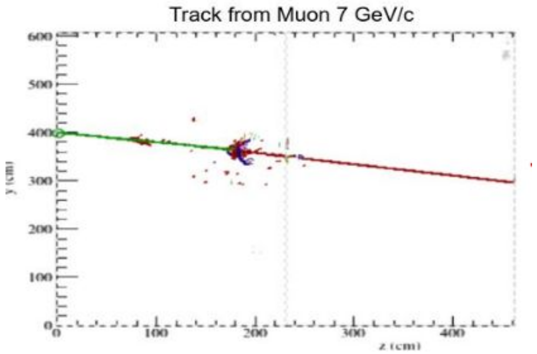
Photon Detection Efficiency Studies

Laura Pérez-Molina

→ Using muons and pions from the beam with 3 ,5 and 7 GeV
→ 2.5 V and 4.5V OV for HBK and FPK, respectively
→ Comparision with a MC data generated with LArSOFT

Expected PDE measured in lab ~ 2%
https://doi.org/10.1140/epjc/s10052-024-13393-2





→ Analysis in progress, preliminary results confirm expected efficiency

Michel electrons studies

Shuaixiang Zhang

→ Using PANDORA, select cosmic muon that crosses both side of detector with t0 reconstructed and match with the t0 from PDS.
→ Muon must stop inside the detector