The PDS @ ProtoDUNE-HD: IV curves and first beam results

Anna Balboni, on behalf of the PDS team

Meeting Annuale della Collaborazione Nazionale DUNE ITALIA

30/10/2024

INFN FERRARA
Istituto Nazionale di Fisica Nucleare
Sezione di Ferrara

Università degli Studi di Ferrara

DUNE

Content

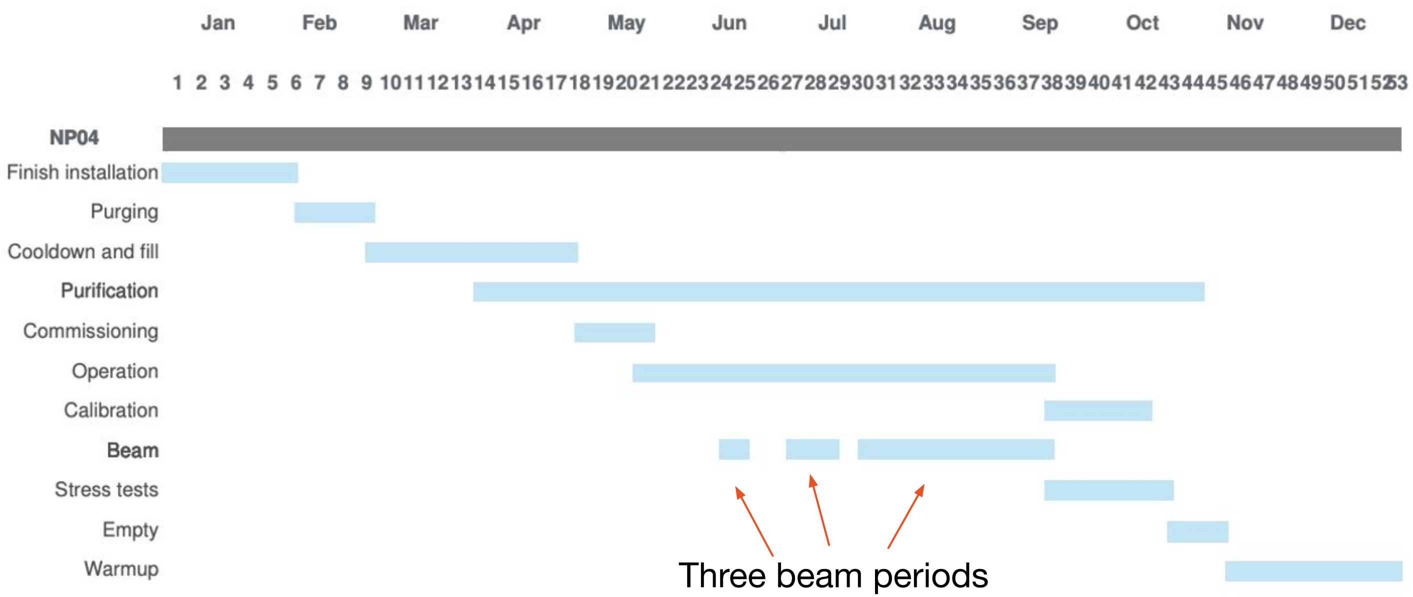
- ProtoDUNE-HD run overview;
- IV curves and Breakdown voltage;
- Light yield vs Energy beam;
- Channel saturation.

1. ProtoDUNE-HD run

Overview

- **ProtoDUNE-HD** is the prototype of the LArTPC with Horizontal Drift technology that will be used for the first module of the DUNE Far Detector, incorporating full-size components and an active volume of 7×6×7.2 m^3.

- It operated during summer 2024 at CERN North Area and was exposed to $e^{\pm}$, $\mu^{\pm}$, p and $K^{\pm}$ beams with energy of 1, 2, 3, 5 and 7 GeV, collecting about 30M events.



Italian group contribution

- Selection, production and tests of SiPMs.
- Assembly and testing of ~50% of the PDS modules.
- PDS module tests at CERN cold box.
- Cryogenic electronics development and validation of the DAPHNE analogue component.
- Firmware modification for the implementation of filters and trigger algorithms.
- Installation, commissioning and data taking.
- Data analysis.

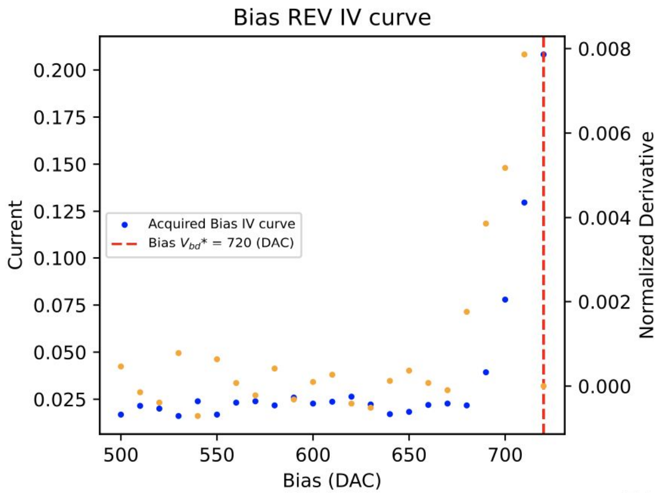
2. IV curves and Breakdown voltage

Overview

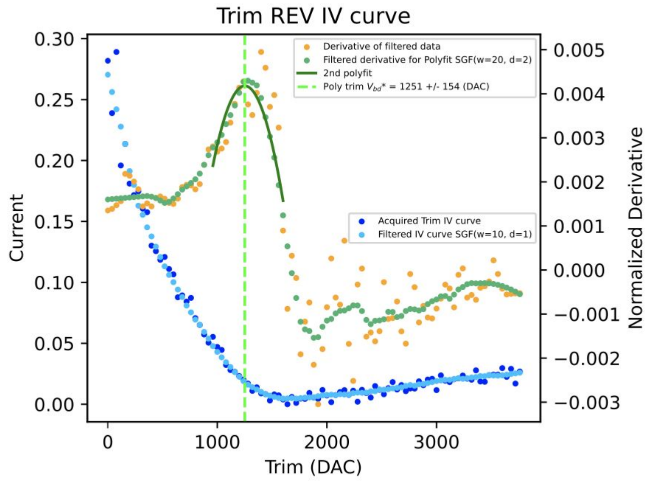
- To monitor the ProtoDUNE-HD PDS performances during its operation, the main parameters are periodically measured in appropriated calibration runs and compared with results previously obtained in laboratory.
- Reverse IV curves are acquired to compute the **Breakdown voltage**.
- Each IV curve is related to a DAPHNE channel, i.e a X-ARAPUCA module (48 SiPMs).
- The operation voltage is then adjusted to ensure a uniform PDE across all channels.
- Tools for the IV curves analysis and results are in the PDS git repository.
- The analysis is organized in different steps:
  1. Vbd determination;
  2. Vbd quality check;
  3. Vop determination.

Vbd determination

- DAPHNE front-end boards allow to perform IV scans. The voltage is supplied in two stages:
  1. Bias, in steps of ~0.7 V
  2. Trim, in negative steps of ~1 mV.



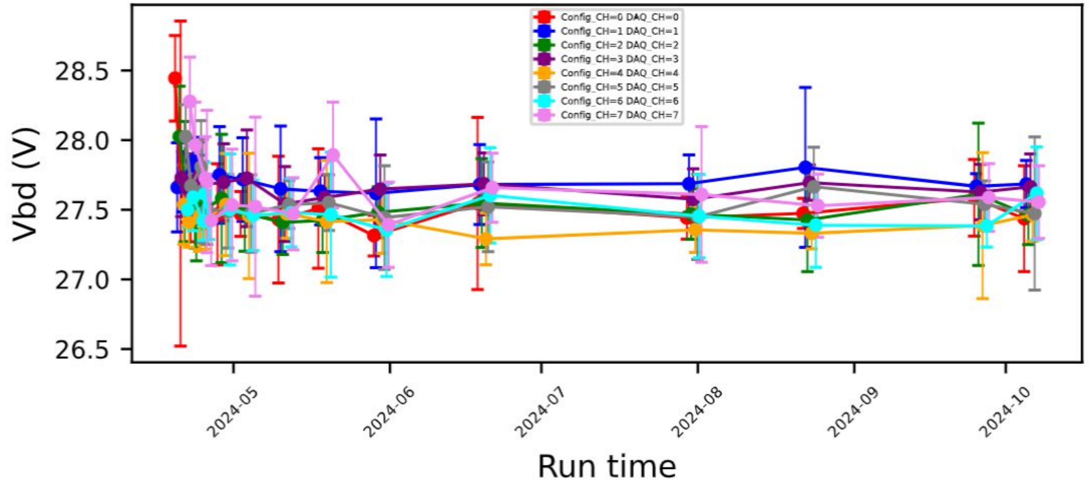
- The procedure is the following:
  1. A <u>bias scan</u> up to a fixed voltage limit is performed. The last bias point is taken as *Vbd_bias_component* and starting point for trim scan.
  2. A <u>trim scan</u> is performed, between 0 and 4000 DAC with fixed bias. The trim IV curve is analyzed and a parabolic fit of the trim first normalized derivative is done, to obtain *Vbd_trim_component*.
  3. By combining bias and trim info, the channel **Vbd** value is obtained.



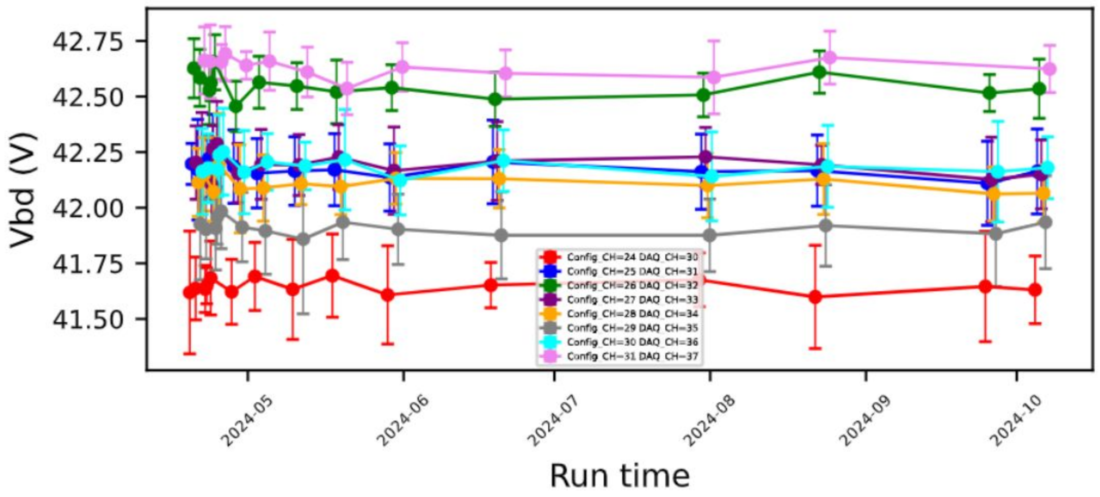
Vbd quality check

- IV curve and Vbd results are checked manually and anomalies are noted in this file.
- The Vbd distribution of all channels is studied and Vbd values are compared with previous results.
- The **Vbd evolution** in time is checked.

ENDPOINT 104 - AFE 0



ENDPOINT 111 - AFE 3



Constant Vbd evolution in time for all channels

Vop determination

- The Vbd mean value of each channel is computed, by using only good run data, and it is taken as best estimation of the breakdown voltage.
- The operation voltage is estimated by adding a given overvoltage to the Vbd mean value and specific **json maps** for DAPHNE configuration are produced.

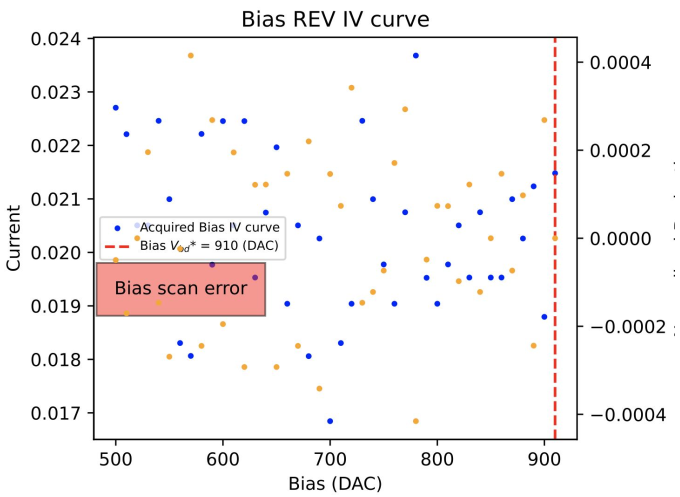

```
{
  "10.73.137.104": {
    "id": 4,
    "apa": "1",
    "ch": [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15],
    "bias": [783, 1135, 0, 0, 0],
    "trim": [256, 56, 246, 97, 307, 228, 254, 166, 124, 154, 126, 204, 124, 116, 70, 146, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
    "ov": {"fbk": 4.5, "hpk": 3.0},
    "run": "Vbd_best_20240730"  },

  "10.73.137.105": {
    "id": 5,
    "apa": "1",
    "ch": [0, 1, 2, 3, 4, 5, 6, 7, 8, 10, 13, 15, 17, 19, 20, 22],
    "bias": [809, 806, 1156, 0, 0],
    "trim": [67, 53, 79, 76, 109, 50, 53, 48, 110, 0, 68, 0, 0, 144, 0, 189, 0, 116, 0, 46, 84, 0, 86, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
    "ov": {"fbk": 4.5, "hpk": 3.0},
    "run": "Vbd_best_20240730"  },
  …
}
```


Bias fixed per AFE (8 ch)

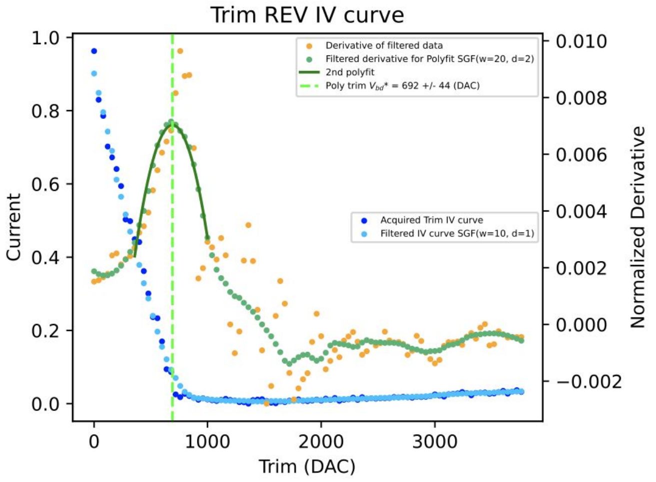
Trim fixed per CH

Vbd anomalies

- 6 disconnected channels in endpoint 109:
  - DAQ_ch 11, 13, 14, 16 → missing file
  - DAQ_ch 10, 17 → only noise

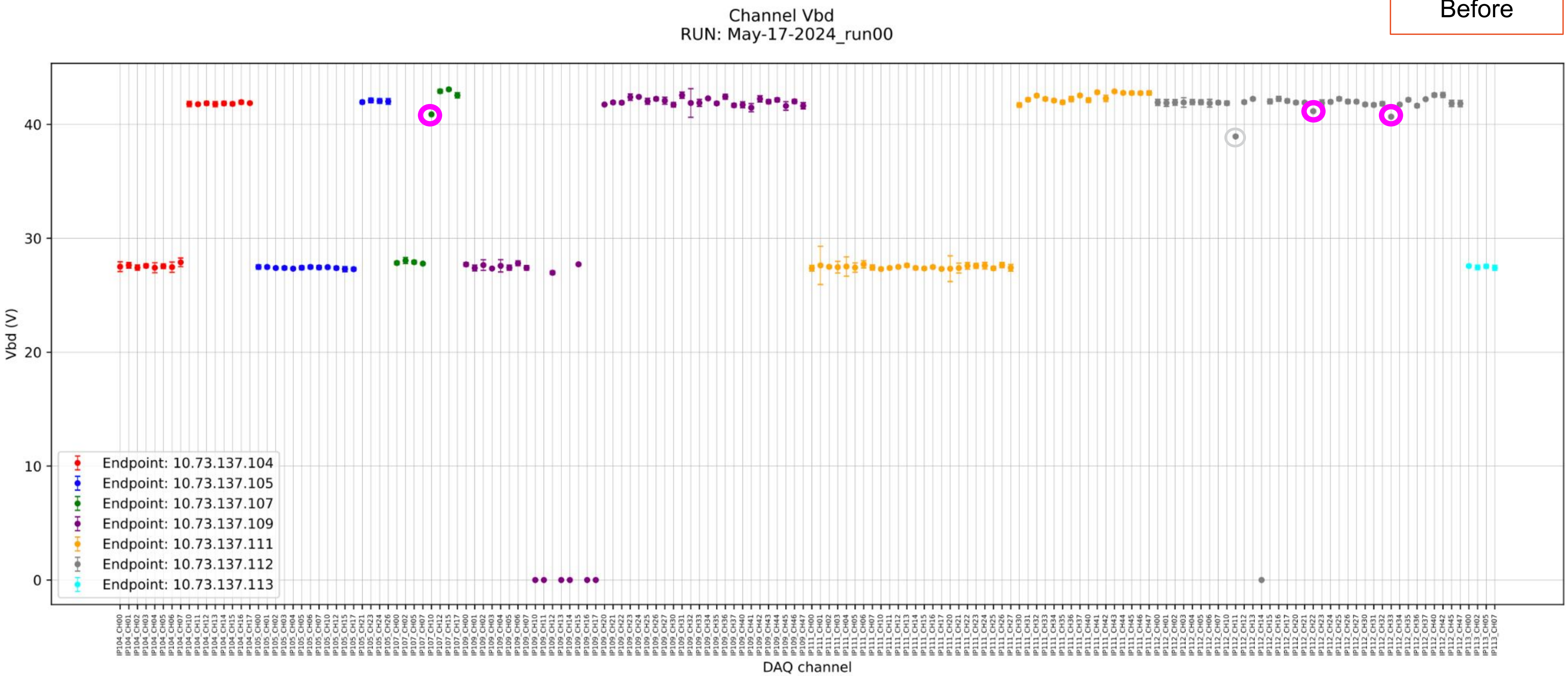


- 4 channels with *steep* IV curve, resulting in a low Vbd:
  - DAQ_ch 10 in endpoint 107
  - DAQ_ch 11, 22, 33 in endpoint 112



Three channels with *steep IV curve* were recovered, by adding an additional overgoltage.

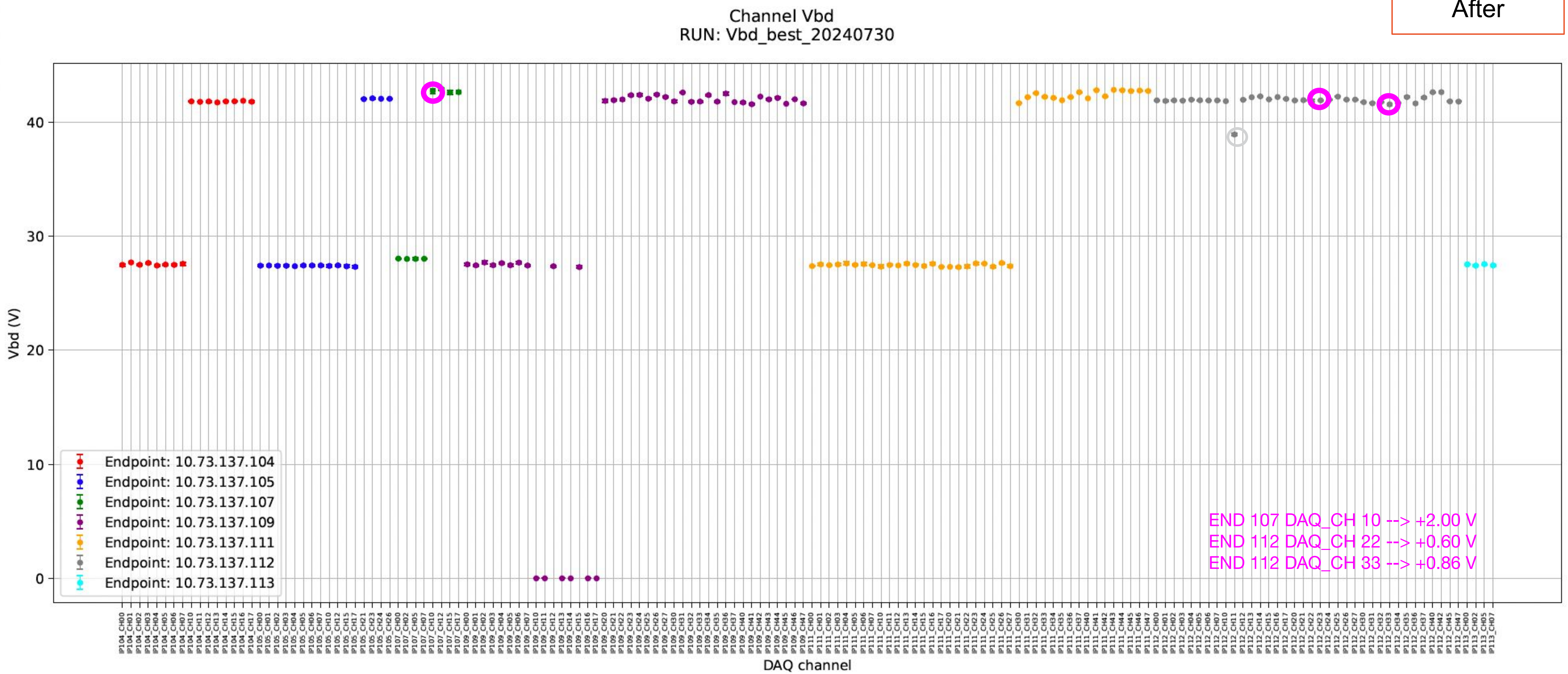
Before



DAQ_ch 11 in endpoint 112 can't be recovered

These are the Vbd values used from the beginning of August.

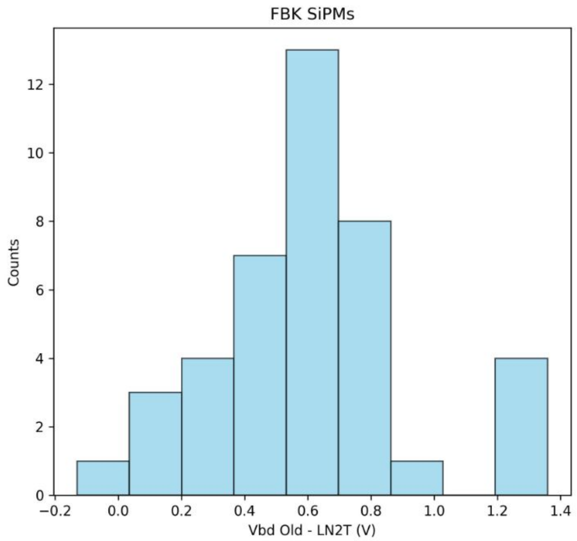
After

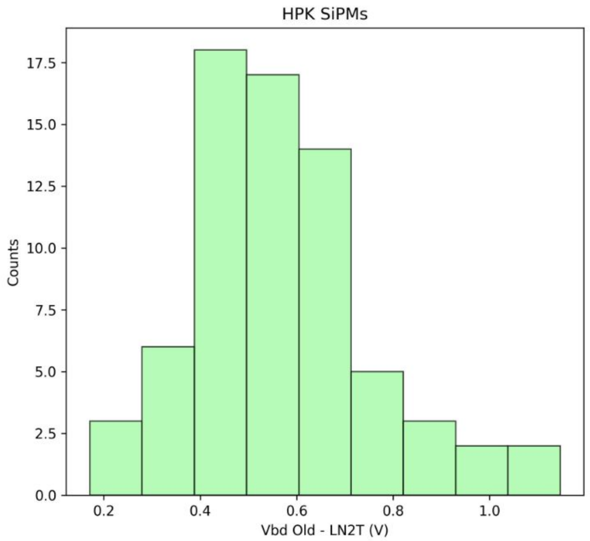


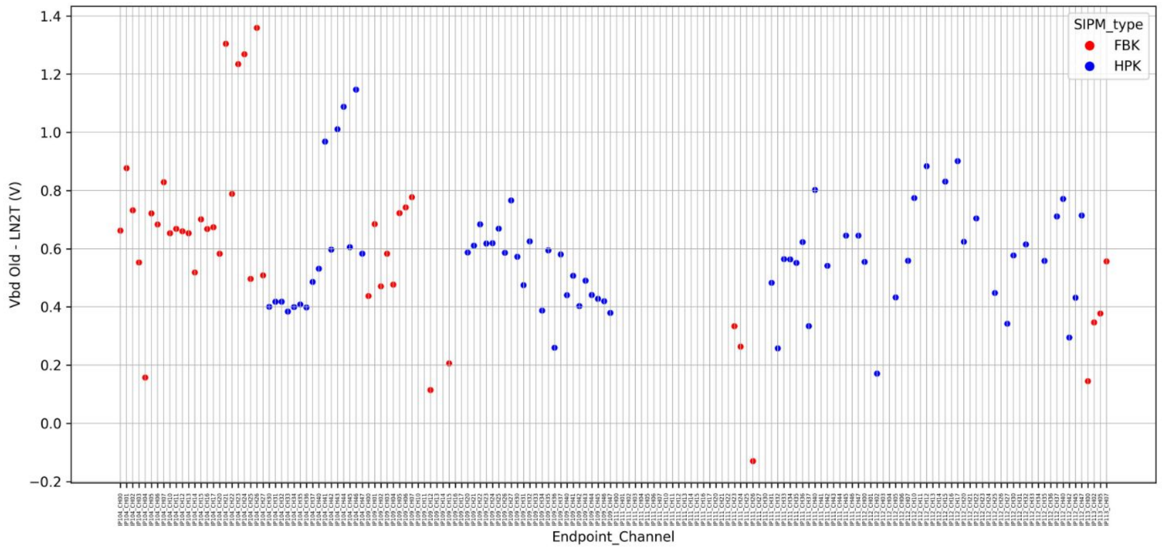
DAQ_ch 11 in endpoint 112 can't be recovered

ProtoDUNE-HD and LAr Vbd comparison

- Comparison between:
  - Vbd measured in LAr inside ProtoDUNE-HD using DAPHNE, by studying IV curves;
  - Vbd measured during LN2 tests before supercells assembling.

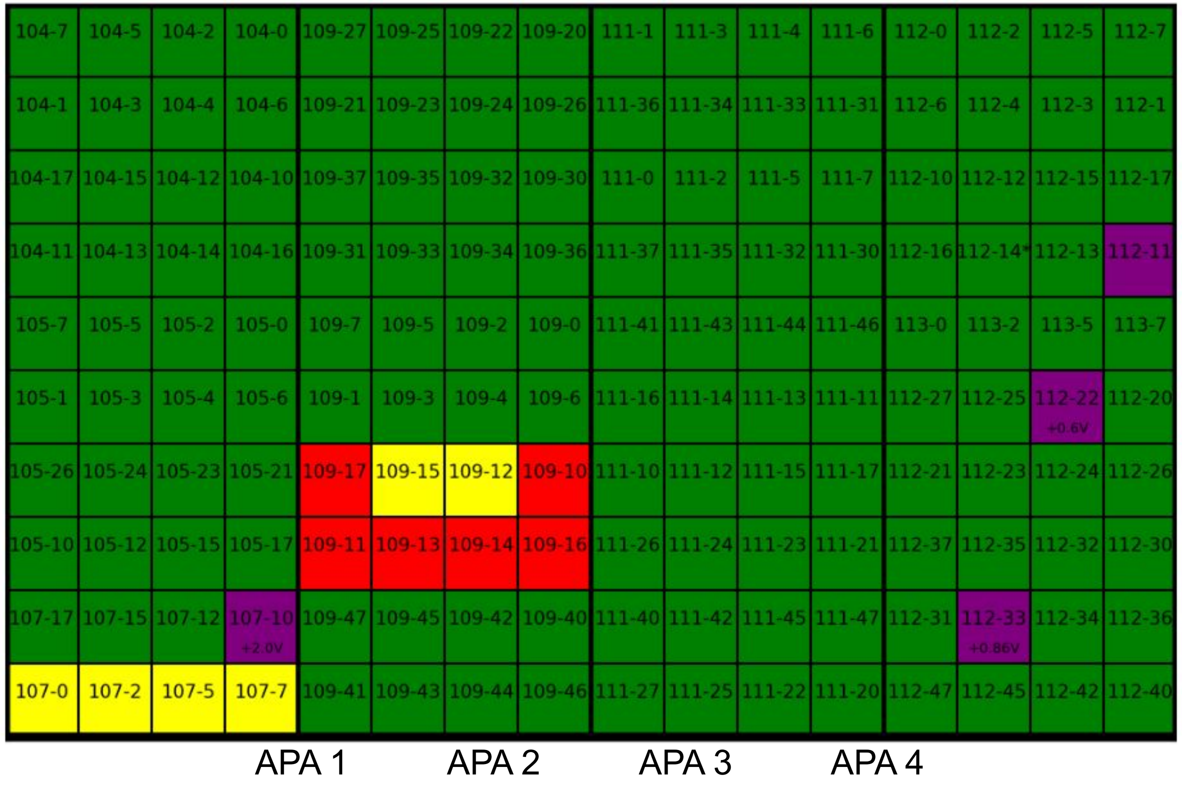






- A LAr - LN2 Vbd difference is expected due to the different temperatures:
  - Mean FBK ΔV_{bd}= 0.61 V
  - Mean HPK ΔV_{bd}= 0.57 V

Summary



IV curve status

before 24th September

- 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).

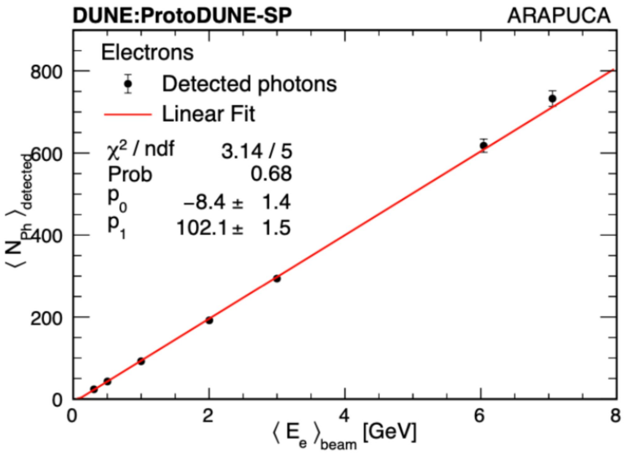
Important: on 24th September, channels of endpoint **104**, **105** and **107** were all moved to the same daphne, identified with ip **104** (see the updated configuration, updated iv map and new-old comparison plots)

3. Light yield vs Energy beam

Overview

- The goal of this analysis is to study the **light yield** (LY) as a function of **beam energy** (E) and obtain results comparable to ProtoDUNE-SP.

- To compute LY, the amount of light produced after a beam event occurred must be estimated. This can be done by looking at the **charge** of a **beam signal** and then, thanks to calibration runs, switch to the number of photoelectrons.



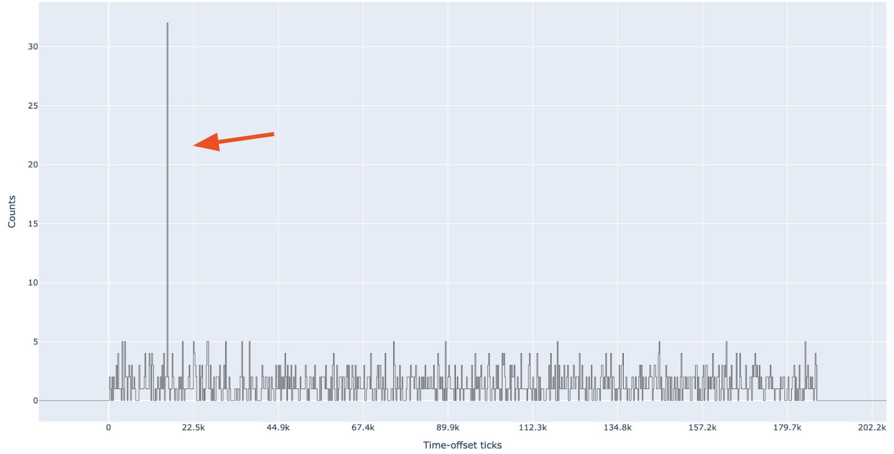
- Now, the analysis is organized in different steps:
  1. Select waveforms associated to beam events;
  2. Compute the charge, as signal integral in an appropriate range;
  3. Study the charge distribution and evaluate the mean value;
  4. Study the integral charge value as a function of the beam energy.

- The self-trigger and the full-streaming procedure for beam even selection is a bit different.

Beam event selection

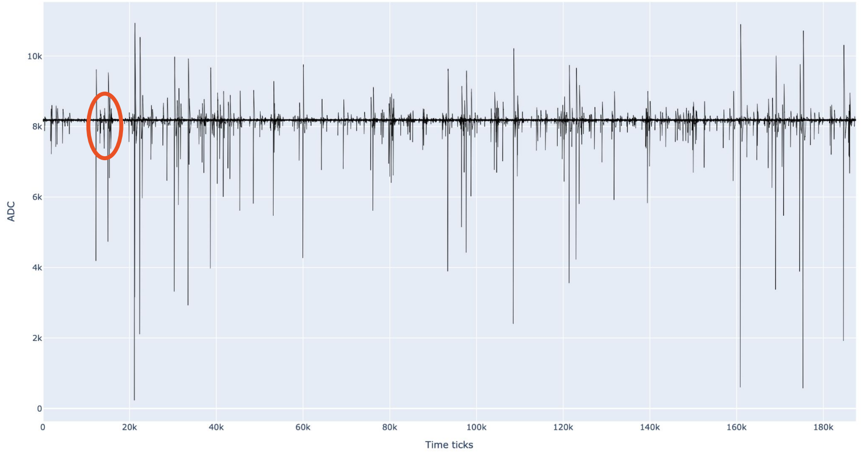
Self-trigger channels

1. The **time-offset** of each waveform is computed, i.e. the difference between the DAQ and the PDS window timestamps.
2. The time-offset distribution is studied, searching for a peak, due to beam interaction.
3. Only waveforms associated to a time-offset in a small range around that peak are selected.



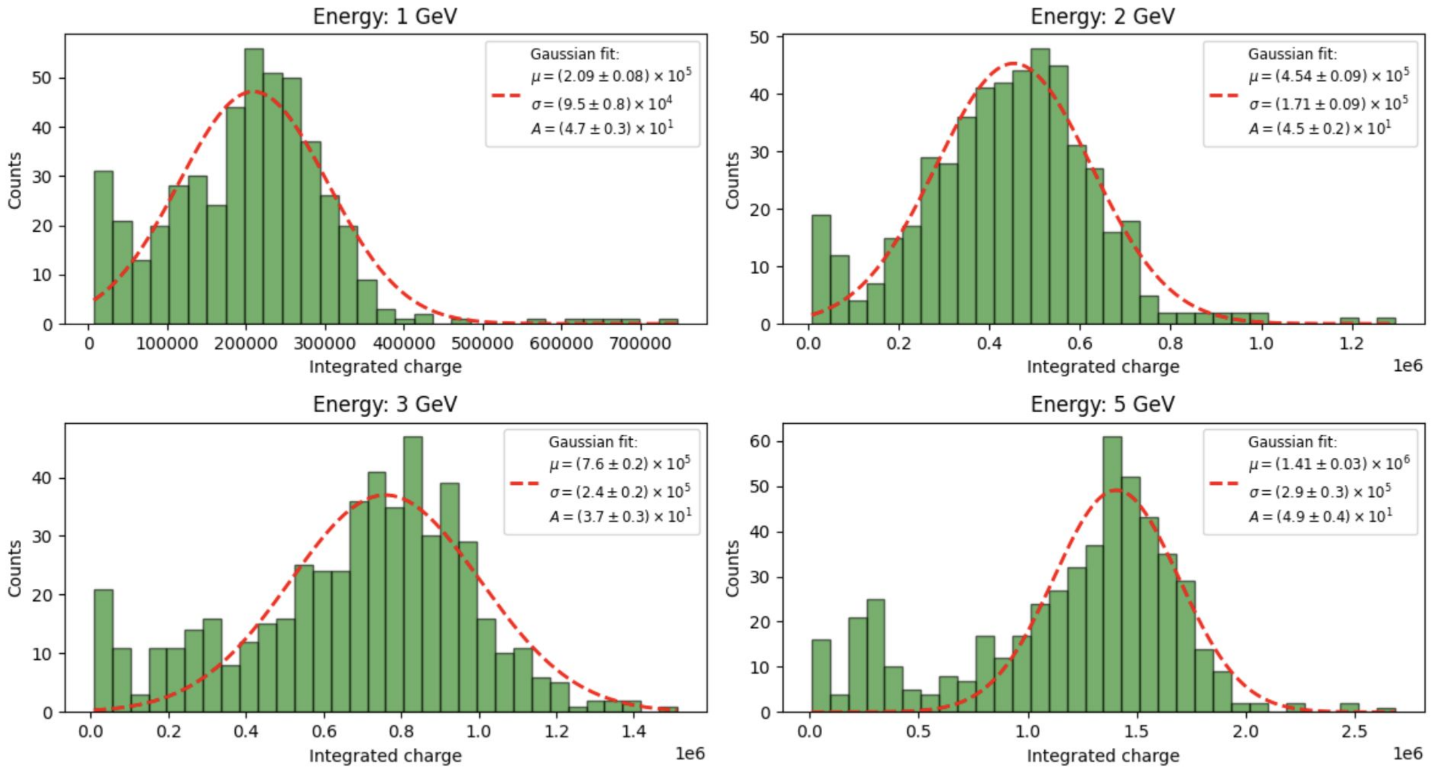
Full-streaming channels

1. The whole PDS window (~3 ms) is studied, plotting many waveforms on the same diagram and looking for a darker region, where there should be a concentration of events due to the beam interaction.
2. Only waveforms within the identified timestamp region are studied.



Charge distribution

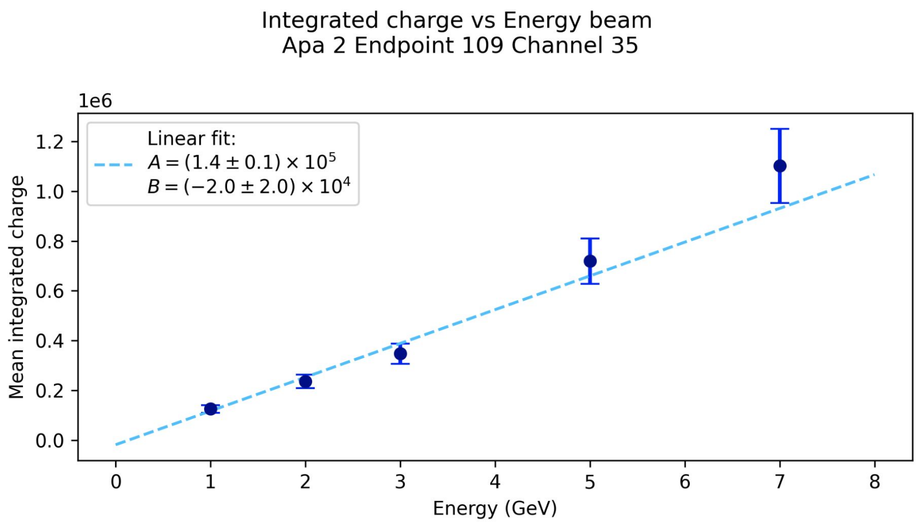
- The charge of the beam waveform is computed as the integral in a given integration range.
- The change distribution is studied and its mean value is obtained from the gaussian fit.

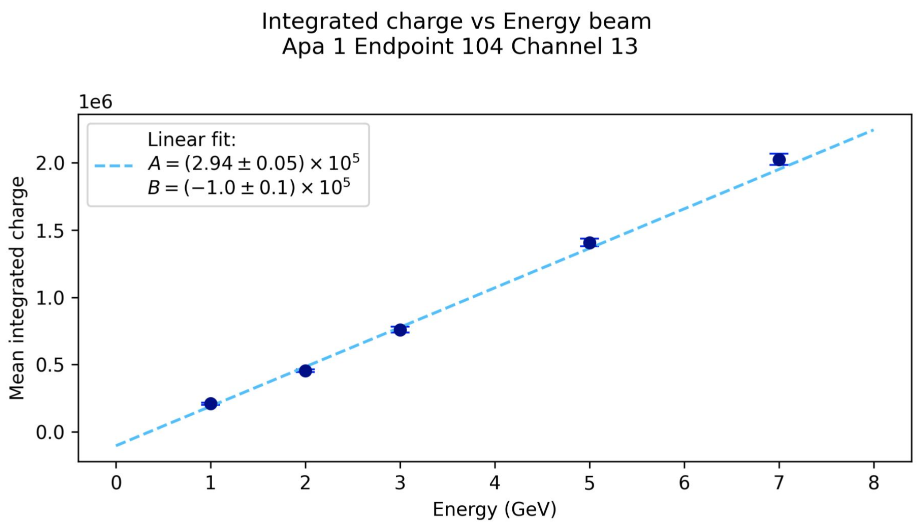


Example
End 104 - Ch 13 (APA 1)
Collimator position: 20mm

First results and next steps

- I started to analyze five runs of June, with collimator at 20 mm, no selection on Cherenkov detectors and Energy at +1 (27338), +2 (27355), +3 (27361), +5 (27367) and +7(27374) GeV.





- Next steps are:
  - Increase statistics, in particular for self-trigger channels.
  - From the integrated charge, compute the number of photoelectrons.
  - Obtain beam information and look at runs with specific charge particles.

4. Channel saturation

First results and next steps

- It's important to check if some channels saturate due to beam events, by looking at the ADC amplitude of the waveforms signals.

- From a first analysis of **APA 1** (full-streaming), looking at run 27374 of the June beam period, with energy = +7 GeV and collimator position = 20 mm:
  - END 105, CH 12 shows 8% of saturated beam events;
  - END 105, CH 4 shows 1.2 % of saturated beam events:
  - END 104, CH 10 12 16 and END 105, CH2 3 6 21 23 24 shows 0.5% of saturated beam events.

  Some saturated events could be connected to cosmic ray interaction, during the beam window.
  These channels are currently under investigation.

- A first rough analysis (with few statistics) of self-trigger channels was performed, and no anomalies were noticed in this run.

- Self-trigger channels and other runs analysis is ongoing.

Thank you for the attention!