DEEP UNDERGROUND NEUTRINO EXPERIMENT

Towards first NP04 PDS article

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Motivation

- ProtoDUNE-HD (or NP04) operation is coming to an end in 40 days
- In two months from now we will be overwhelmed with ProtoDUNE-VD (NP02) preparation, commissioning and operation
- We think it is time to collect all existing studies and write a first publication
  - We aim at having a well advance draft by Christmas
- We assume this will be a DUNE publication (not PDS only)
- JINST is the current baseline, other ideas ?

Scope

- This will be the first NP04 PDS publication, but not the last
- We think a good criterium to establish the scope is: *include only analyses without charge-light matching*
  - Standard PDS performance: V_{bd}, S/N, gain, dynamic range, noisy/dead channels, time resolution, PDE
  - Self-trigger: algorithms, efficiency and prospects for trigger activities and candidates
  - Simple physics applications: tau slow, calorimetry, s.p.e. rate, …
- We would use however beam particle identification, needed for some studies

Outline

Performance and physics applications of the photon detection system of the ProtoDUNE-HD detector at CERN

Abstract

Keywords: Detectors, Liquid Argon, Cryogenics, Photon detection, Optics

1. Introduction

Overall description of DUNE and its physics goals. Remark importance of PDS. Explain how the NP04 experience will be extrapolated to FD-HD

2. The ProtoDUNE-HD detector and its photon detection system

2.1. Overall description of ProtoDUNE-HD

Mention evolution from ProtoDUNE-SP

2.2. The Photon Detection System

Mention evolution from ProtoDUNE-SP

2.2.1. X-ARAPUCA photon collectors
2.2.2. Readout electronics
2.2.3. The LED calibration system
2.2.4. Detector simulation
2.3. Beamline and data taking

Beamline, beam detectors, DAQ, timing interface, data collected, data quality monitoring

3. Photon detection system calibration and performance

3.1. SiPM breakdown voltage

Explain the IV method, Vbd map and time evolution. Comparison with lab measurements

3.2. Single photo-electron calibration

Explain is about the LED calibration. Scans over LED configurations and OV. Explain the method, S/N and gain maps, time evolution. It does not include readout optimization

3.3. Problematic channels

Small discussion about problematic channels (IV curves, noisy, dead) and debugging

3.4. Time alignment and resolution ← **Mandatory**

Offset introduce by cable lengths, time resolution studies, ...

3.5. X-arapuca efficiency

Measurement of the arapuca efficiency using MC to understand the light yield at each arapuca

4. Readout optimization

Interplay between signal to noise and dynamic range. Vgain and OV scans, integrators on/off, equalisation, saturated channels, ...

5. Using light for triggering

5.1. Self-trigger algorithms and their efficiency

Description of the algorithms, efficiency of the different algorithms estimated in the lab, and efficiency of the integrated algorithm in NP04

5.2. Light topologies in ProtoDUNE-HD

Spatial/time distribution of light for different types of events

5.3. Prospects for trigger activities

How to use light topologies for building trigger activities

6. Physics applications

6.1. LAr scintillation time profile

Tau slow analysis

6.2. Particle discrimination
6.3. Rayleigh scattering length (out of scope ?) ←
6.4. Light based calorimetry
6.4.1. Light yield vs drift field
6.4.2. Light yield vs beam energy
6.4.3. Energy resolution
6.4.4. Prospects for light yield map measurements
6.5. Single photo-electron rate ← **Easy**

DCR, Ar39, photons from the tail of the muon signals, ion recombination.

6.6. Identification of low energy physics processes ← **??**

Bi source and Ar39 identification

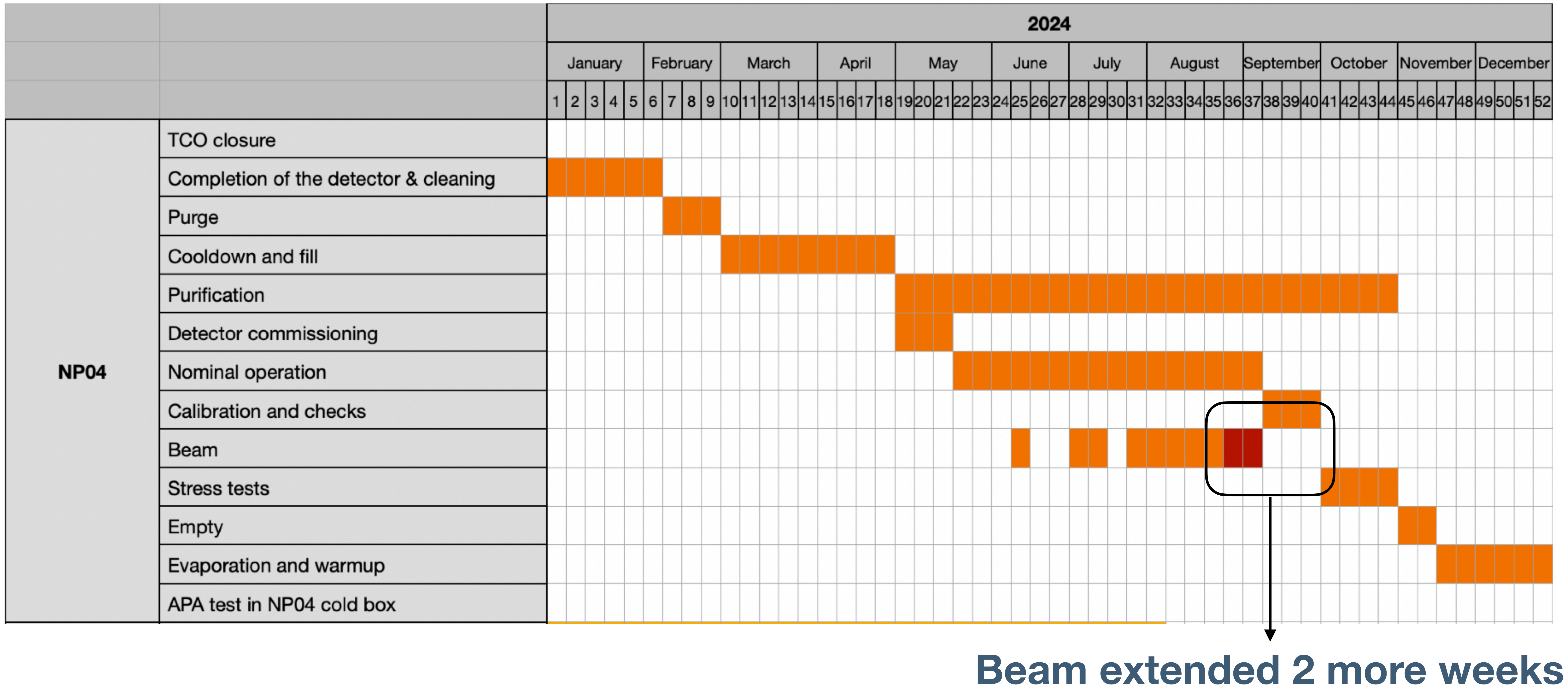
6.7. Cosmic muon rate (out of scope ?) ←

7. Conclusions

Backup

Introduction

- Most results shown in this talk will be presented on Thursday at 8 am in the PDS analysis session
- Continuous beam since August 1st until September 18th
- Liquid will be transferred to NP02 in November
- Lots of calibration and physics data to analyse



Overview of PDS in NP04

- 160 channels, with 4 channels per PDS module. One channel is one X-ARAPUCA
- 7 DAPHNE boards with 40 channels each
- APA1 in full streaming mode (3 daphnes) and the rest in self-trigger (~1 daphne/APA)
- Two different SiPM vendors, Hamamatsu (orange) and FBK (light yellow)

Calibrations

Laura Pérez, Manuel Arroyave

- Crucial to benchmark the detector performance and to produce physics results

	methode	frequency	Last time
Breakdown voltage	DAPHNE current monitor	biweekly	21/08
s.p.e. amplitude	LED	biweekly	28/08
tau slow	Cosmics + noise	Not regular	10/07

Breakdown voltage

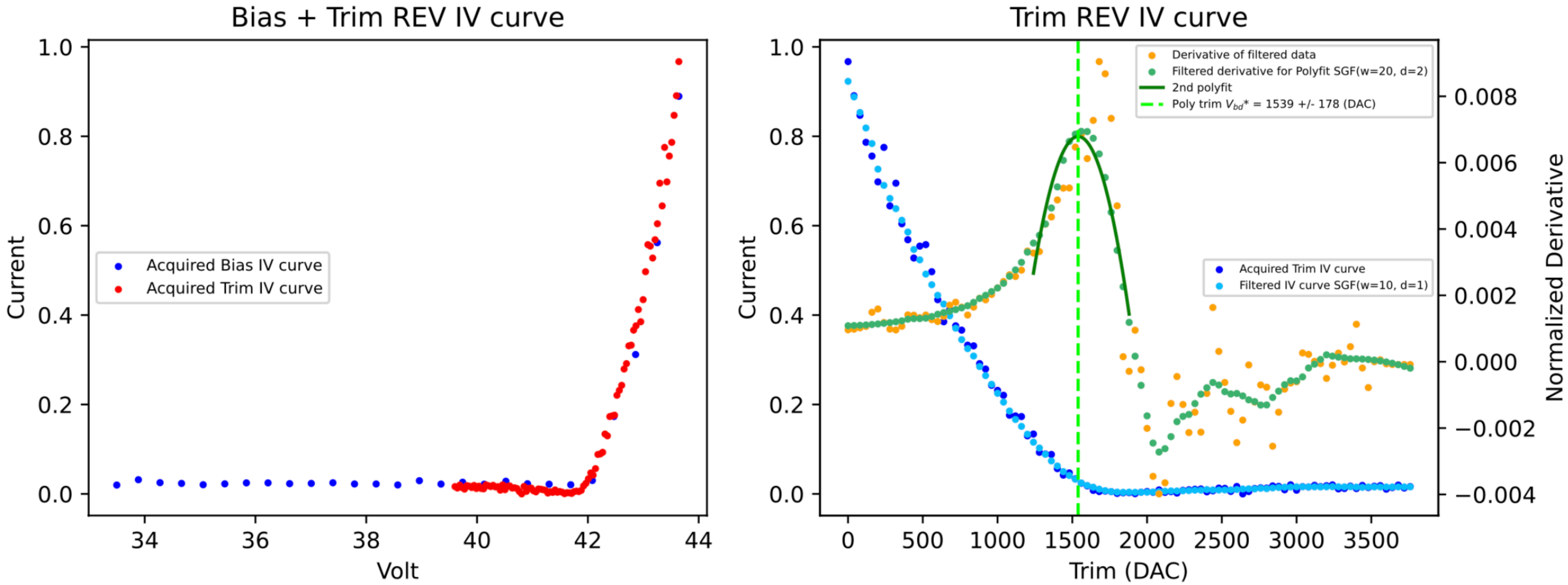
Anna Balbonni

- Needs to be computed for each X-ARAPUCA since the operation voltage (V_{OP}) must be set accordingly

$$V_{op} = V_{bd} + OV$$

	Hamamatsu	FBK
Overvoltage (OV)	**+2.5**	**+4.5**

- Studied feeding a variable voltage into each X-ARAPUCA and monitoring its current (IV curve)



Breakdown voltage

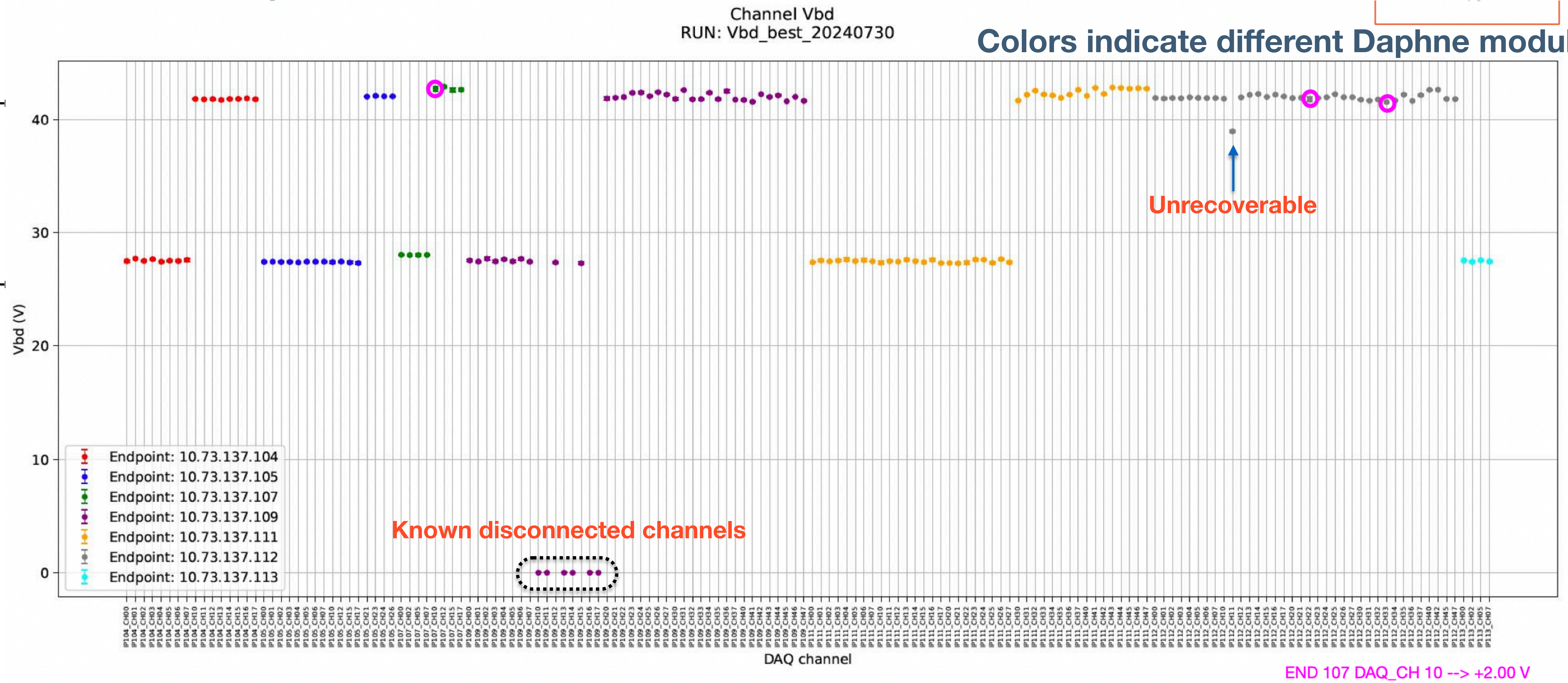
Anna Balbonni

- 4% dead channels (known since installation). Only one unrecoverable noisy channel
- This plot is redone every two weeks. Results so far are stable

Colors indicate different Daphne modules

Hamamatsu

FBK



END 107 DAQ_CH 10 --> +2.00 V
END 112 DAQ_CH 22 --> +0.60 V
END 112 DAQ_CH 33 --> +0.86 V

These are the current Vbd values used

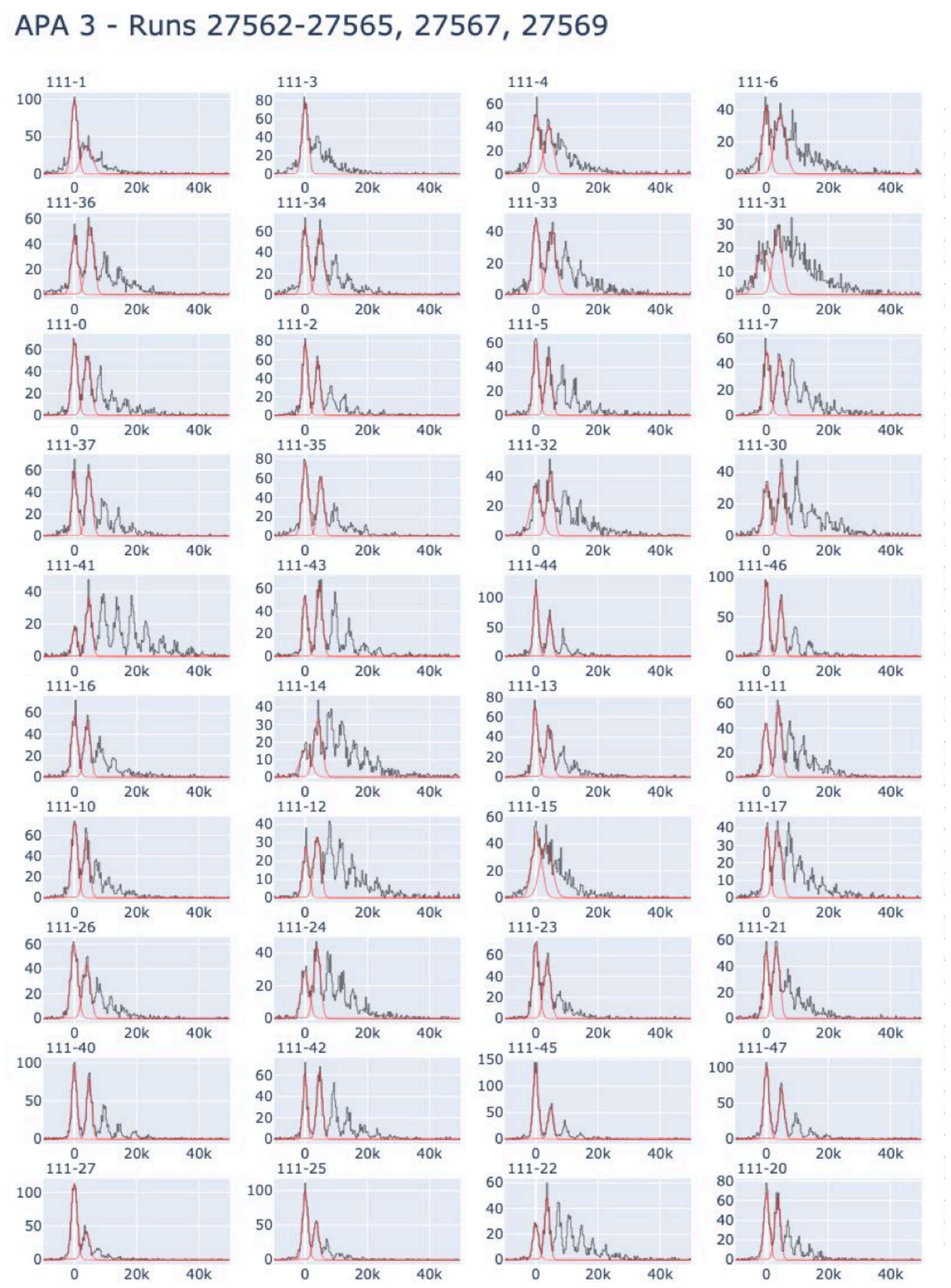
Single p.e. calibration

Julio Ureña

- The PDS is able to detect single photons
- The charge detected by the SiPMs needs to be calibrated
- A 270 nm LED calibration system sends pulsed light to 5 diffusers in each side of the cathode
- Sweet spots for each X-ARAPUCA have been found varying the LED intensity, pulse width and fibers being fired

	Run Time	Intensity	Pulse width	Fiber mask
APA1	4 mins	1400-2800	20	50
APA2	3 mins	1400-4000	20	50
APA3,4	3 mins	1400-2200	1	1,12

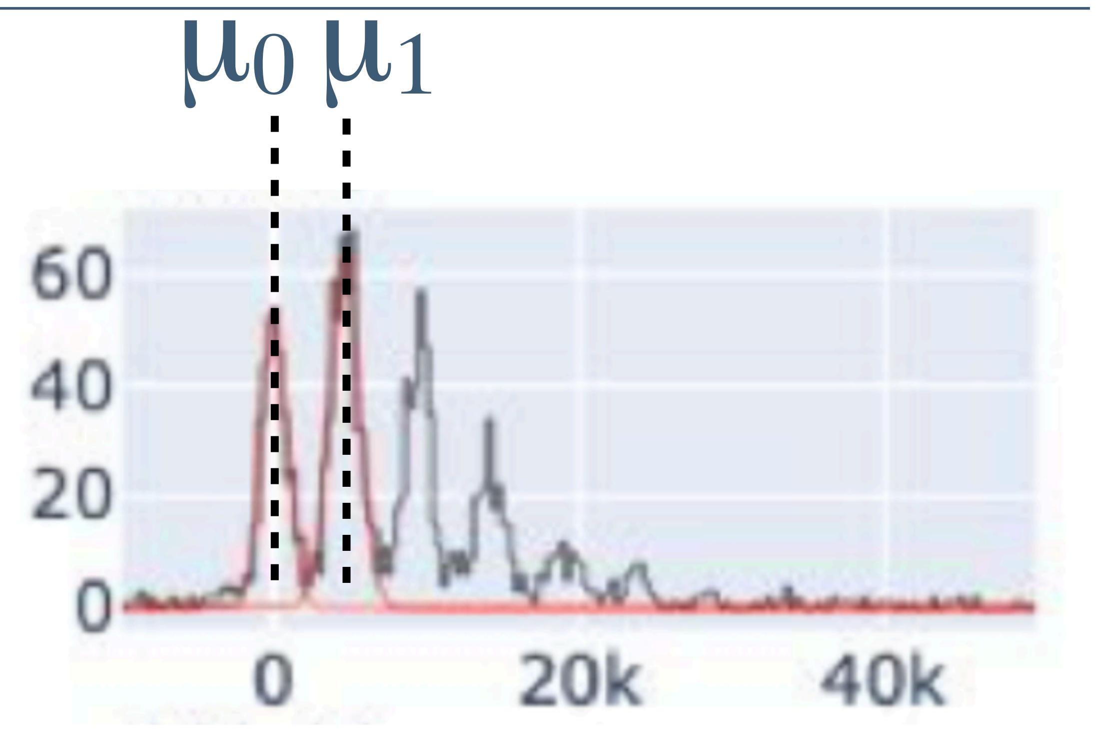
- Each calibration campaign takes about 2 hours



Gain studies

Julio Ureña

- The gain can be computed for each X-ARAPUCA
- It depends on the OV. A scan was done to characterise that dependency

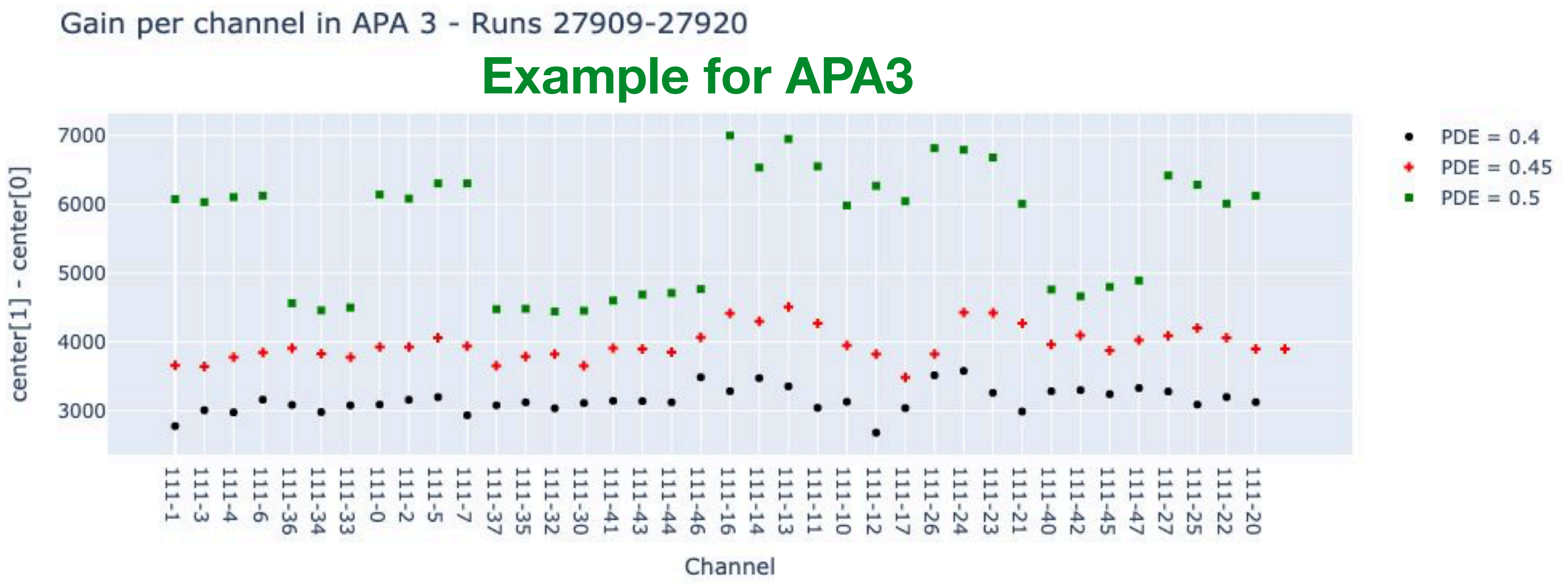


$$\text{Gain} = \mu_1 - \mu_0$$

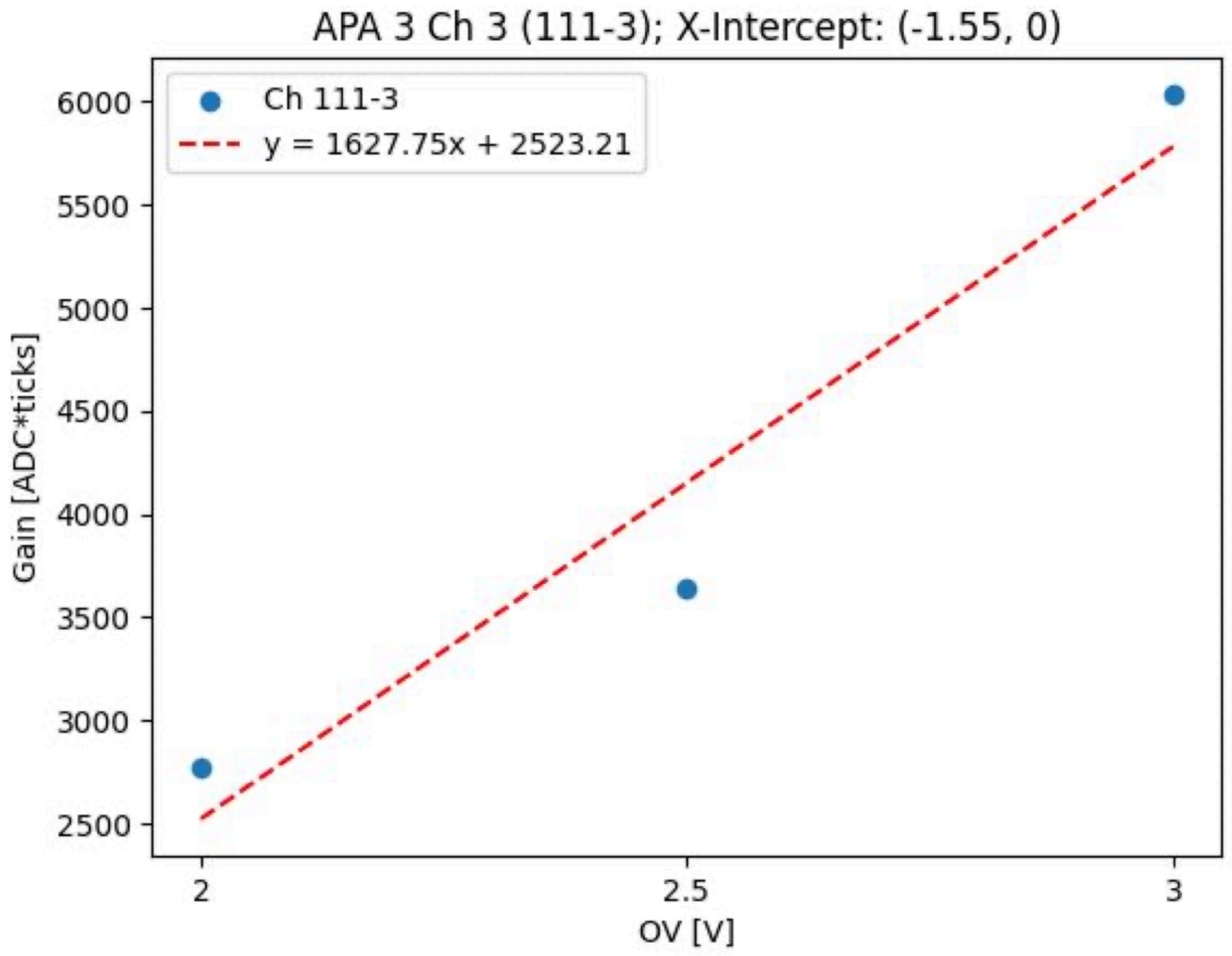
OV for each Photon Detection Efficiency (PDE)

	40% PDE	45% PDE	50% PDE
Hamamatsu	2	+2.5	3
FBK	+3.5	+4.5	7

Example for APA3



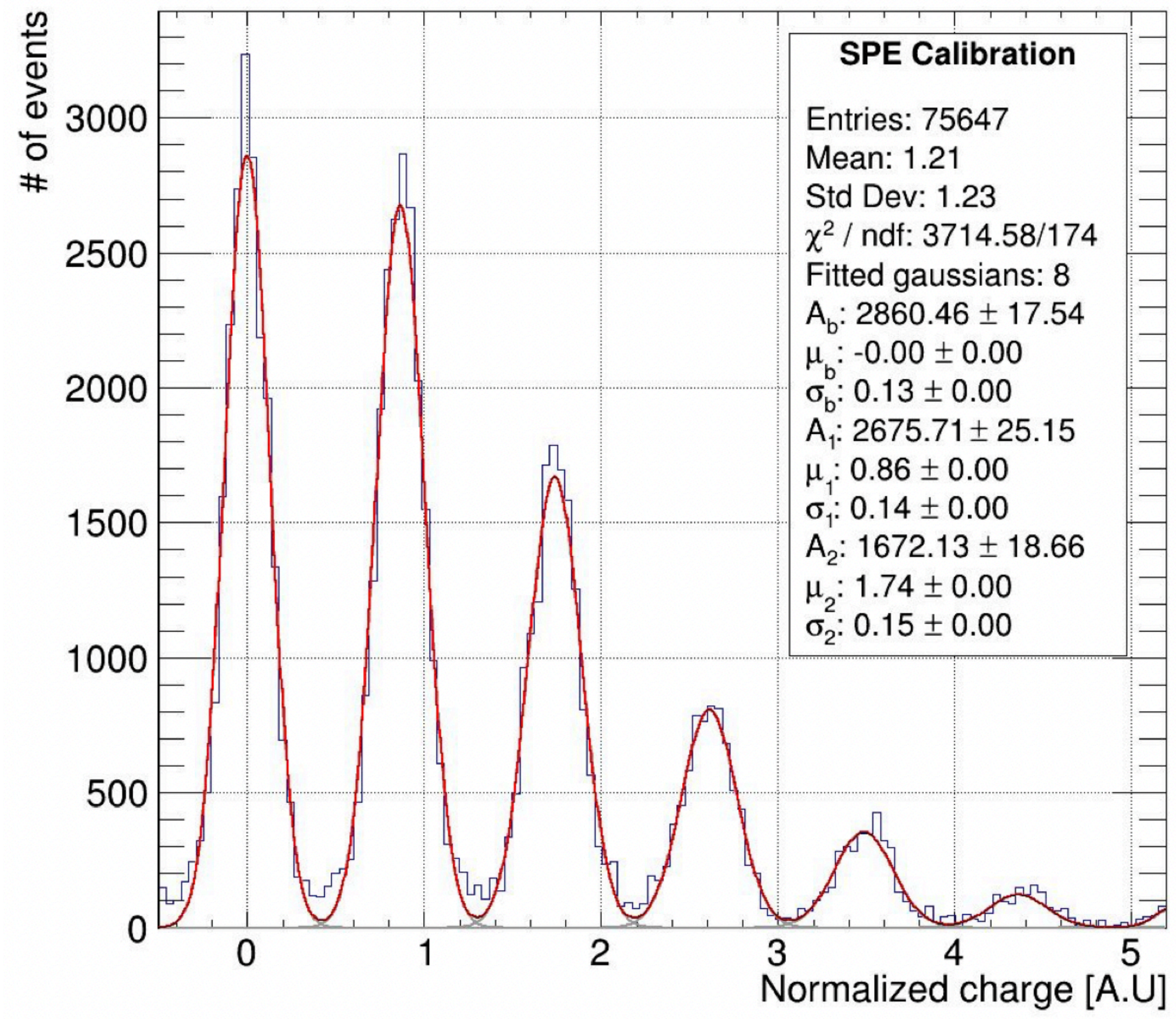
Example of one channel in APA3

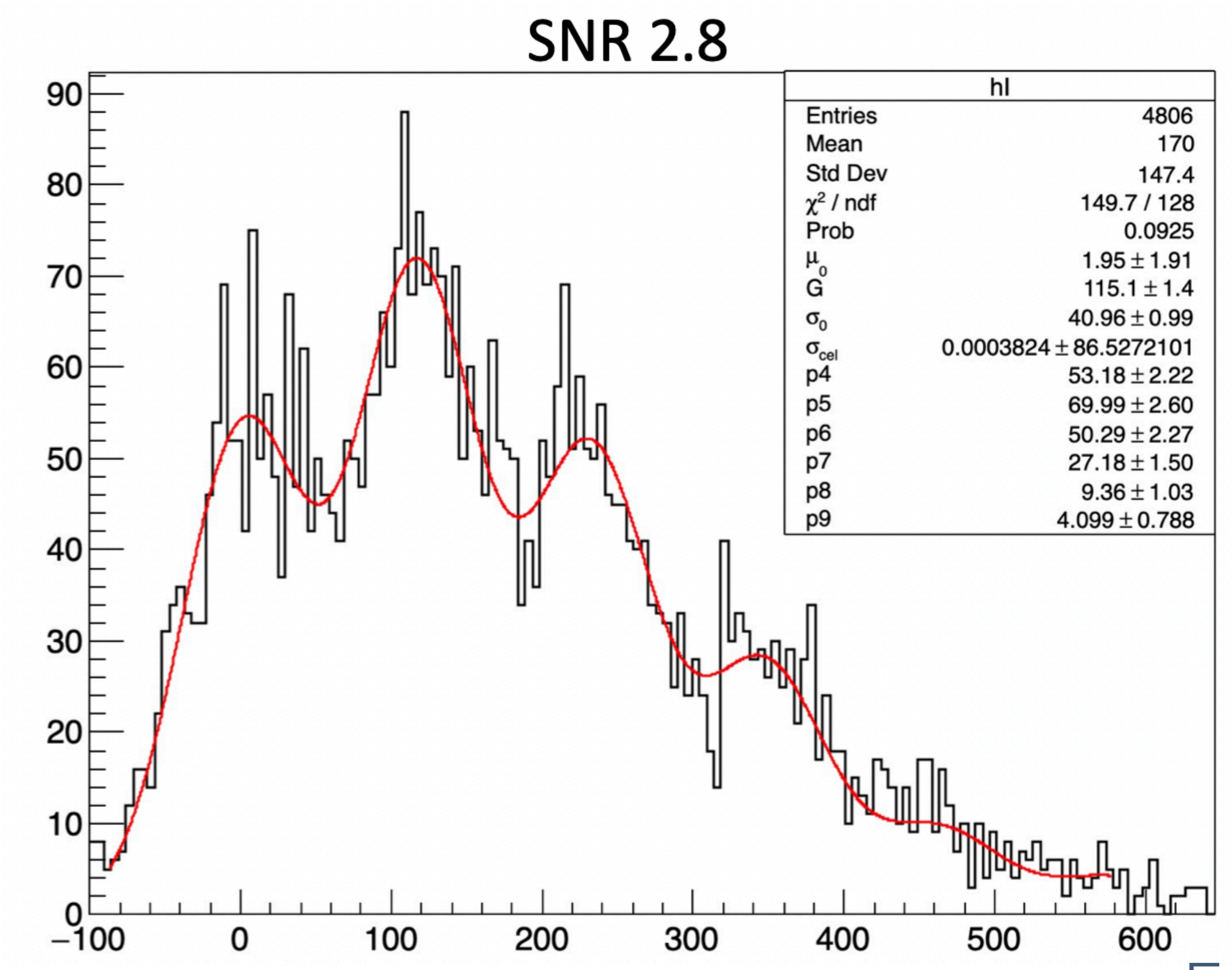


Signal to noise

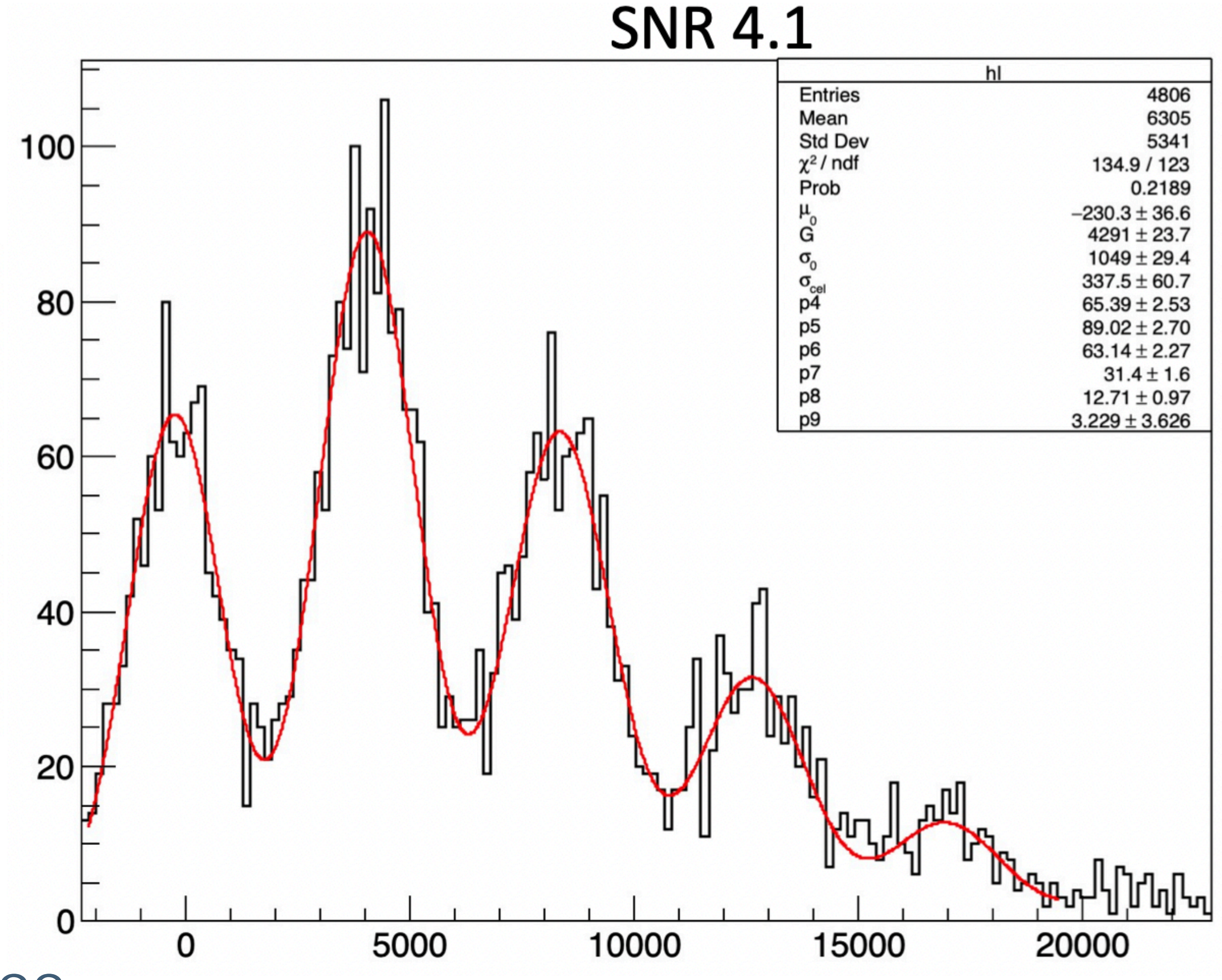
Federico Galizzi, Julio Ureña, Henrique Souza

- The requirement is S/N > 4. Preliminary analysis reveals that most channels fulfil this condition
- There are few channels with lower S/N. The matched filter can be used to improve that





Matched filter:
Auto-correlation of the wavwforms with the spe template

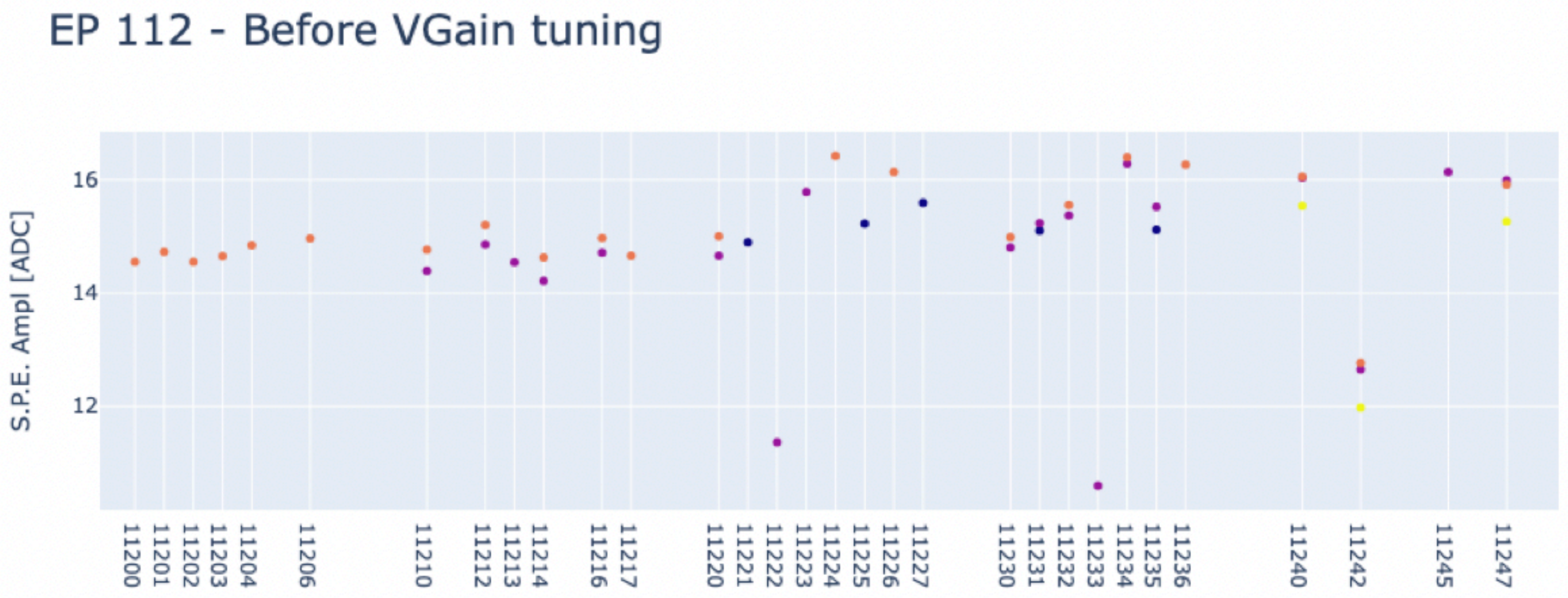


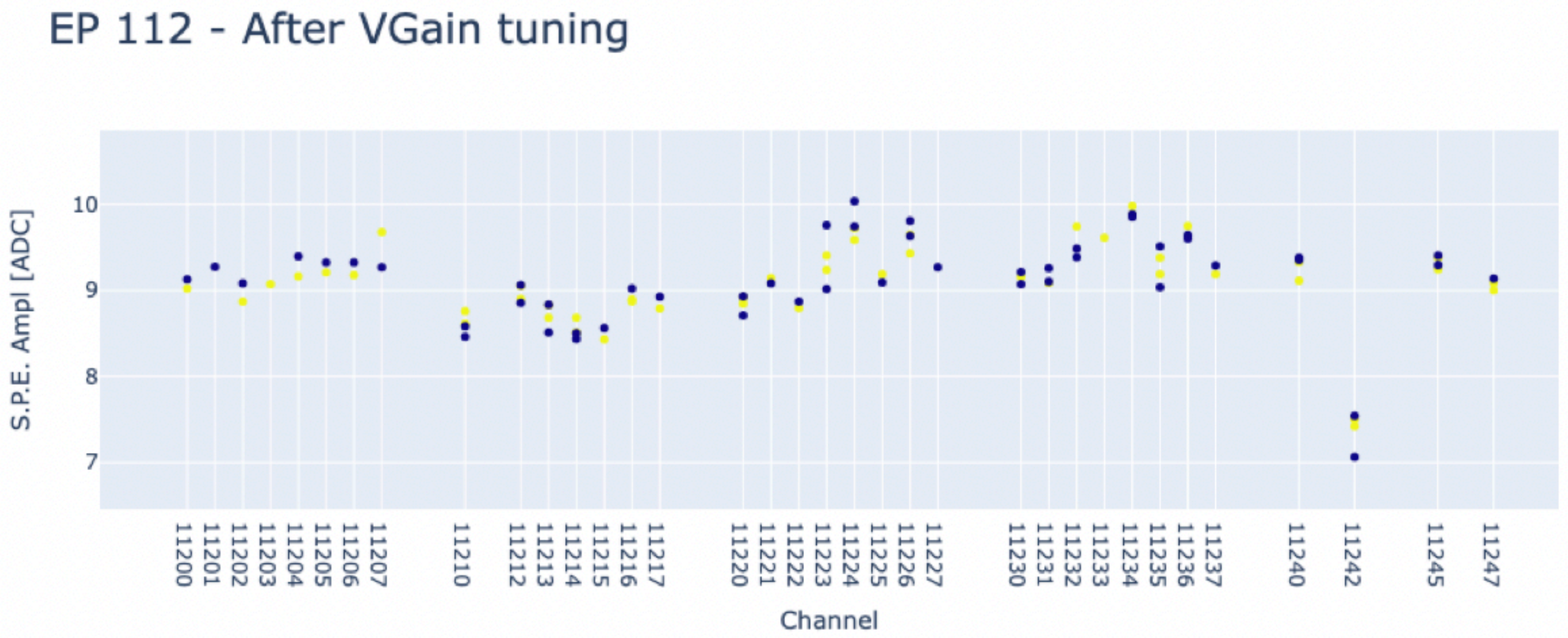
Example: run 27918 – channel 112-22

Equalizing s.p.e amplitude

Federico Galizzi

- DAPHNE's AFEs have two amplification stages and an attenuator → We can tune the attenuation level AFE by AFE (2 PD modules – 8 channels). Note that this changes both the signal and the noise levels!

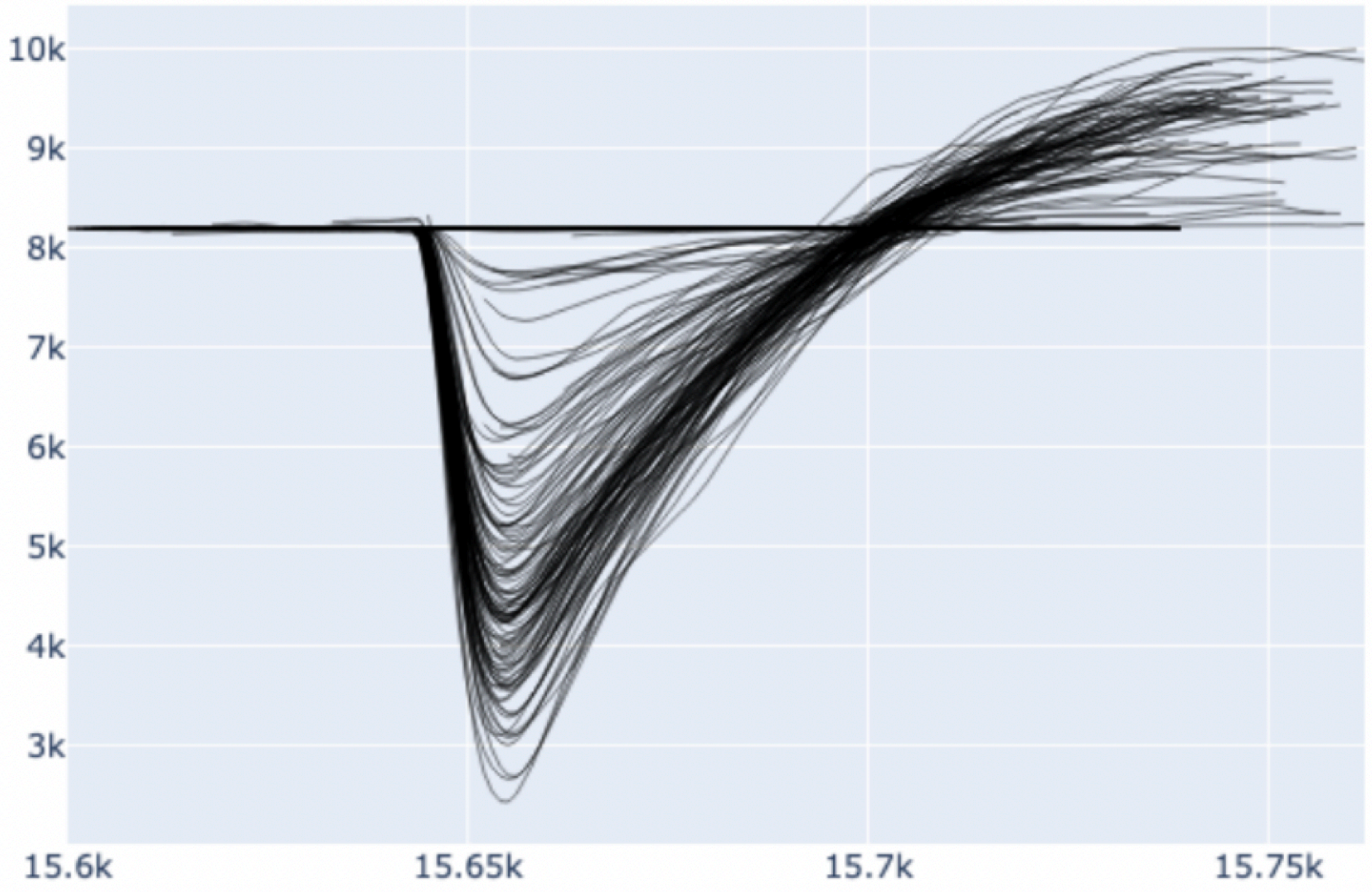




Dynamic range

- Initially the baseline was set at ~11000 adcs (to record undershoot), which assuming a s.p.e. amplitude of 8 adcs results in a dynamic range of 1400
- It was decided to use DAPHNE integrators for the beam run, to reduce the noise, but this resulted in a baseline of ~8000 adcs and a dynamic range of about 800 with s.p.e. amplitude of 10 adcs
- However, we don’t see saturation for 7 GeV beam data
- In any case we plan to do dedicated dynamic range studies after the beam run, varying several parameters:
  - Baseline, Vgain, integrators on/off, etc
  - Aim at finding the right balance between S/N and dynamic range, keeping a equalised s.p.e. amplitude

7 GeV beam data —> no saturation



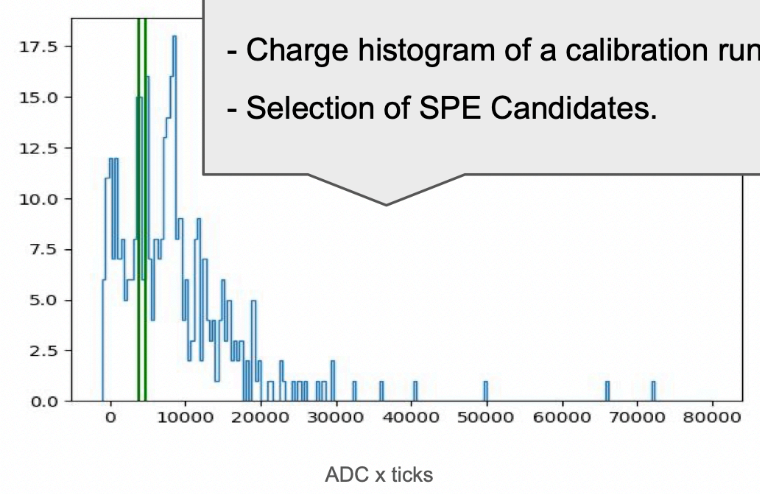
SPE templates & Deconvolution

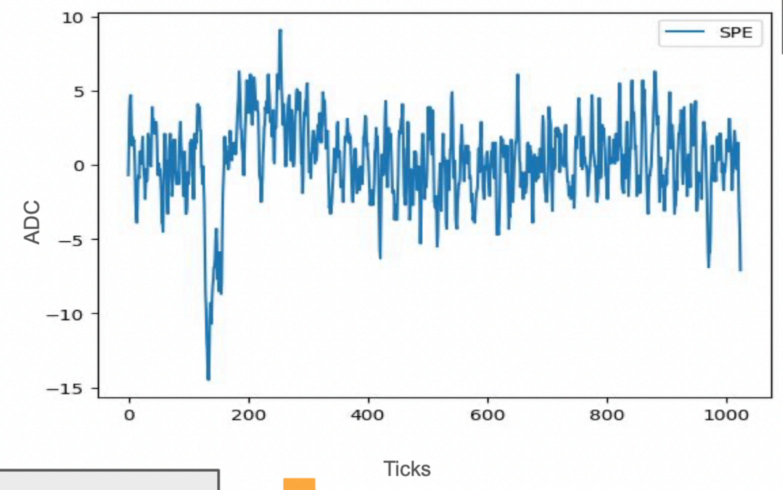
Renan de Aguiar,
Michaela Zabloudil, Maritza Delgado

SPE templates

1st step:

- Charge histogram of a calibration run ;
- Selection of SPE Candidates.



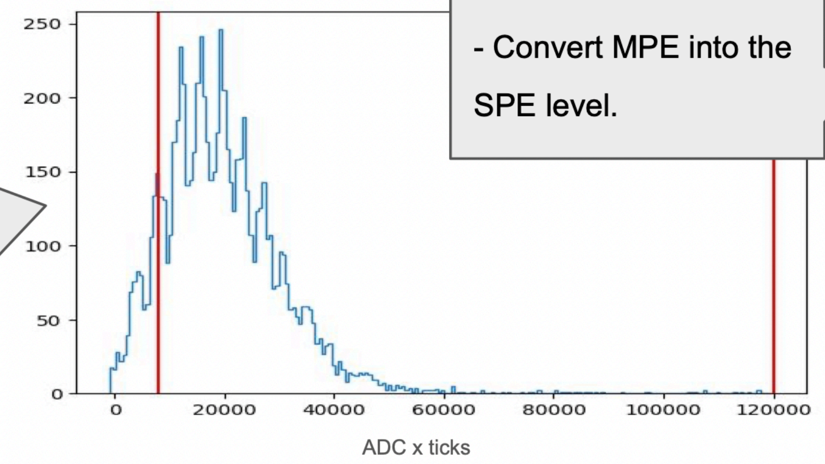


2nd step:

- Computing the average waveform of a SPE.

3rd step:

- Charge histogram of a calibration run ;
- Selection of MPE

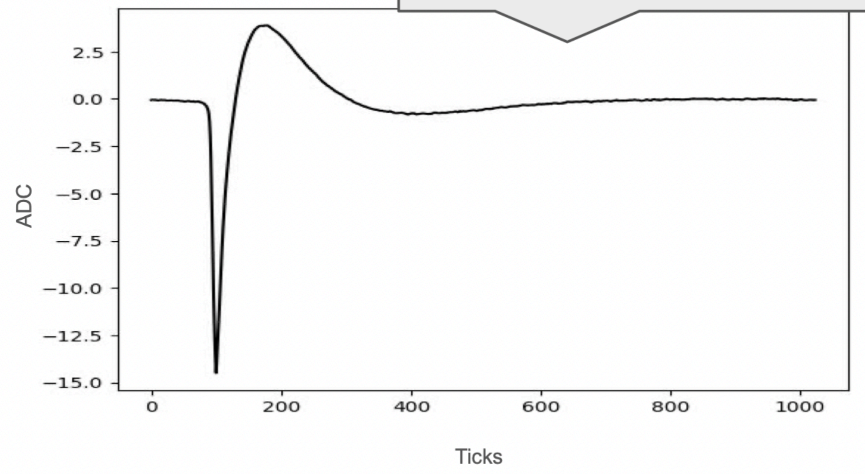


4th step:

- Convert MPE into the SPE level.

Final step:

- Calculate the SPE template by the average of the waveforms.



*Thanks: M.Zabloudil & M. Delgado

Deconvolution

1. With Signal + SPE Template compute:

$$S = \left[\frac{fft(signal)}{fft(template)}\right]$$

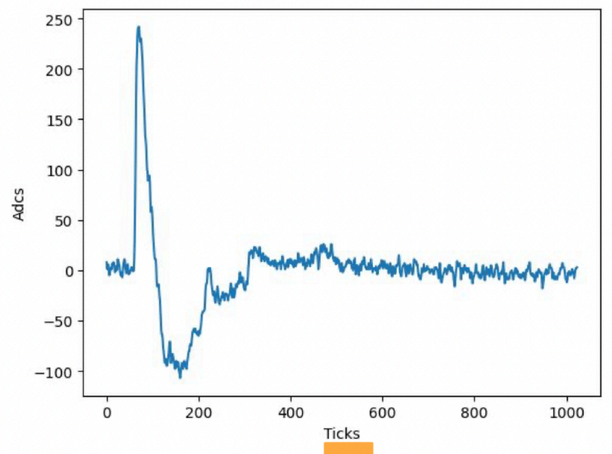
2. *Optional*: Filter application (Wiener or Gauss)
3. Compute the inverse fourier transformation
4. *Optional*: Apply a second filter on the deconvolved signal
5. Fit:

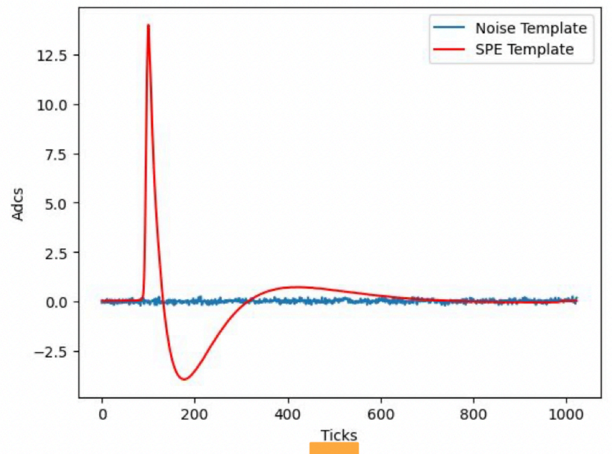
-> Try:

$$fit = \frac{A_S}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_S}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_S}\right) e^{\frac{t-t_0}{\tau_S}} + \frac{A_F}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_F}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_F}\right) e^{\frac{t-t_0}{\tau_F}}$$

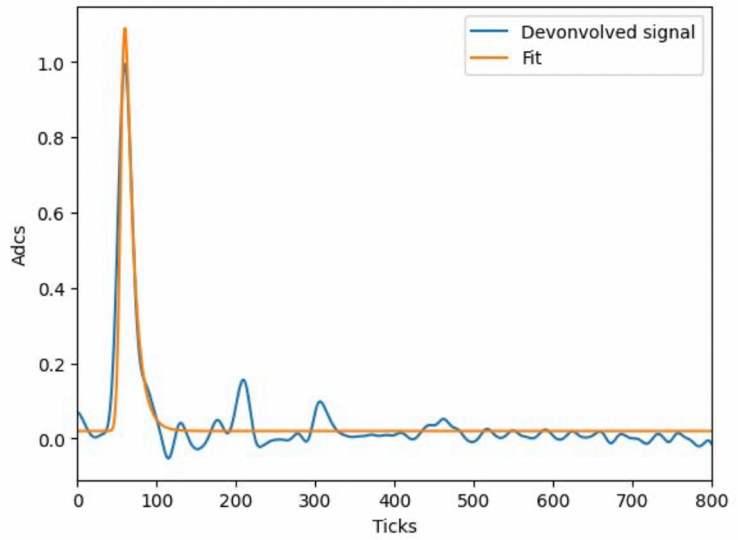
-> Except:

$$fit = \frac{A_S}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_S}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_S}\right) e^{\frac{t-t_0}{\tau_S}} + \frac{A_I}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_I}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_I}\right) e^{\frac{t-t_0}{\tau_I}} + \frac{A_F}{\sqrt{2}} e^{\frac{\sigma^2}{2\tau_F}} \text{Erfc}\left(\frac{t-t_0}{\sigma} + \frac{\sigma}{\tau_F}\right) e^{\frac{t-t_0}{\tau_F}}$$





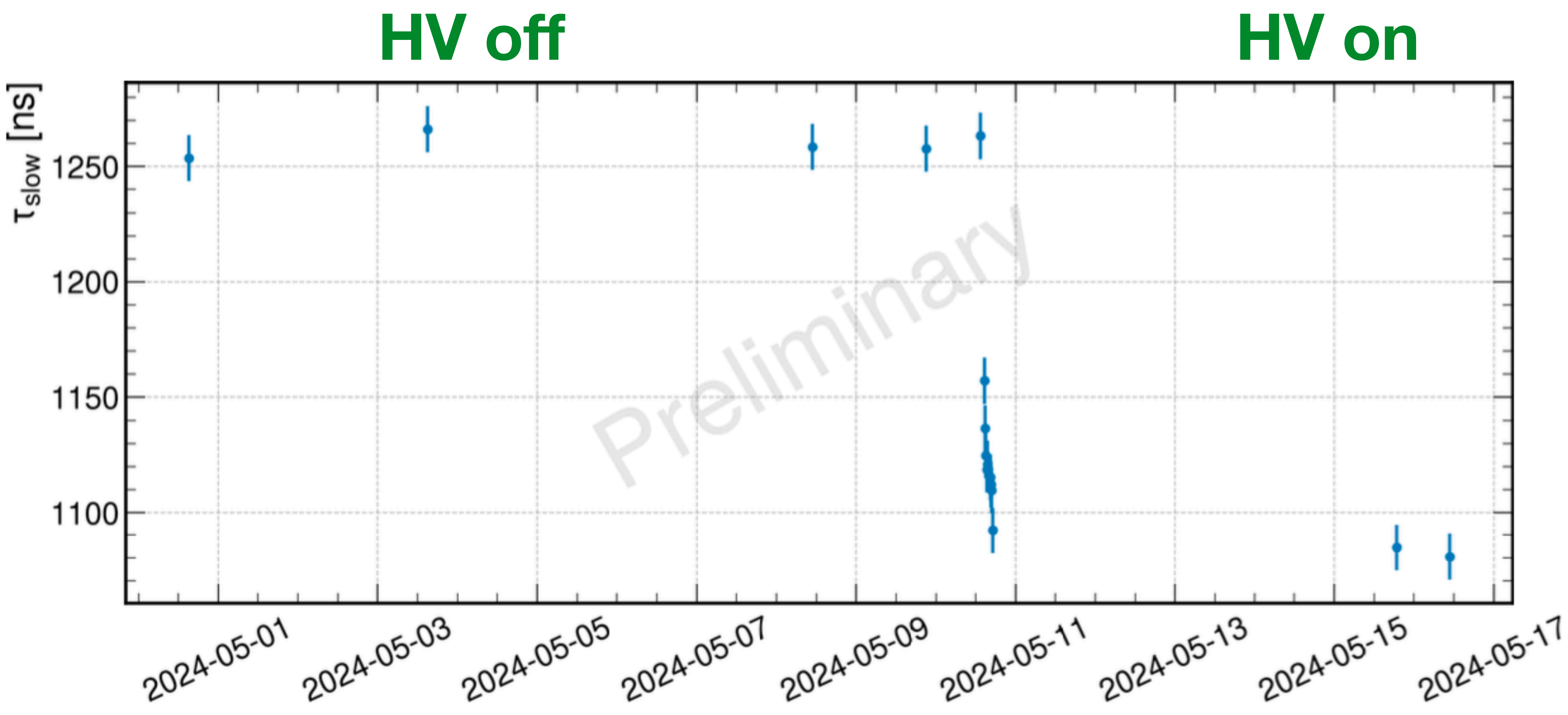
Tau_Slow (ns) = 1437.9662761898703 +- 1.2916885792227093e-12
Tau_Fast (ns) = 9.024910321608596 +- 3.2664985155885656e-15
Tau_Intermediary (ns) = 167.6622543045856 +- 9.189659883283042



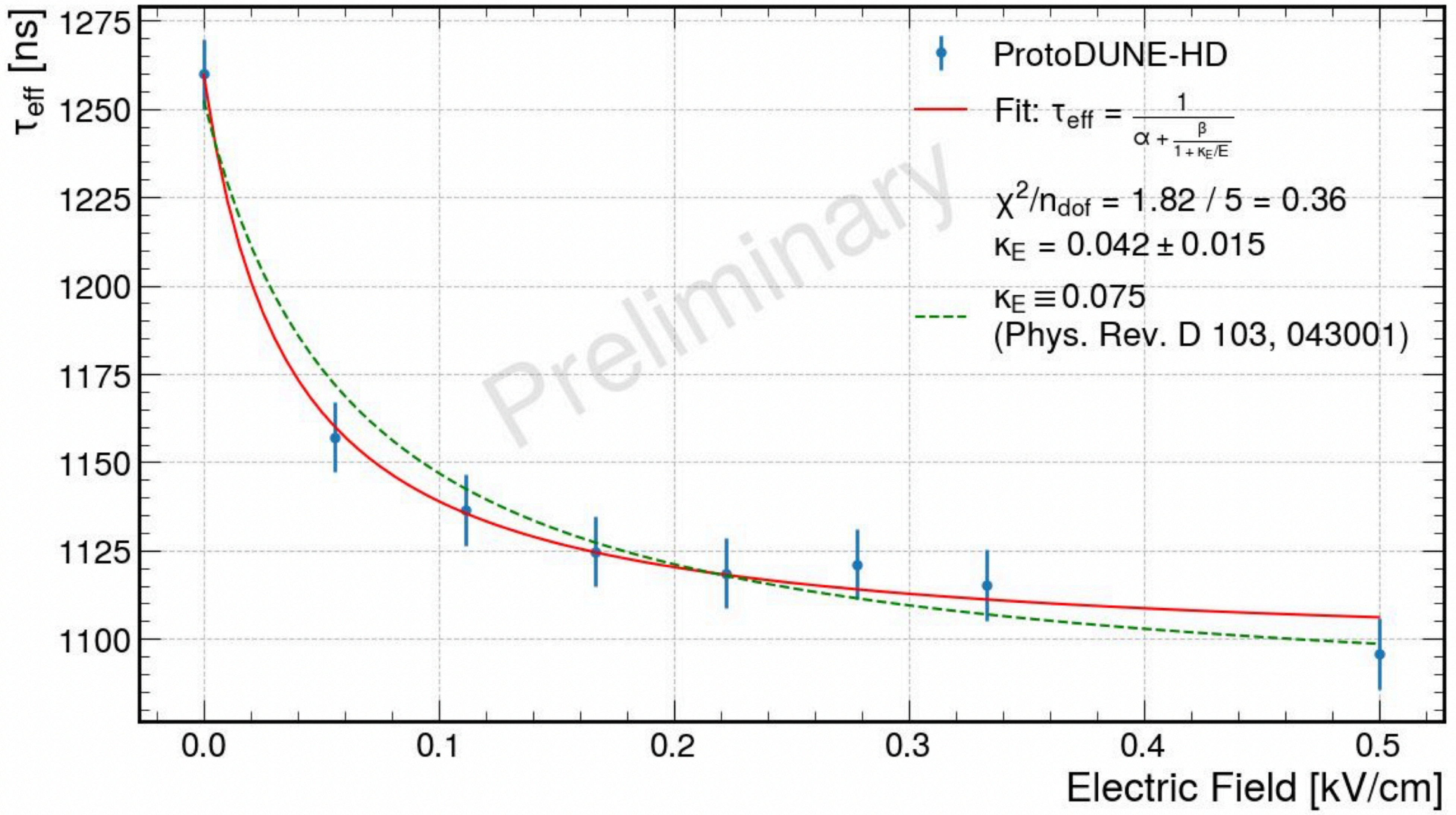
Tau slow

Henrique Souza

- The decay time of the slow component of the scintillation light (τ_{slow}) has important information about nitrogen contamination and particle ID
- A HV scan with dedicated τ_{slow} PDS runs (cosmics, LED, noise) was carried out on May 10th
- We have more recent τ_{slow} PDS runs but haven't been analysed yet



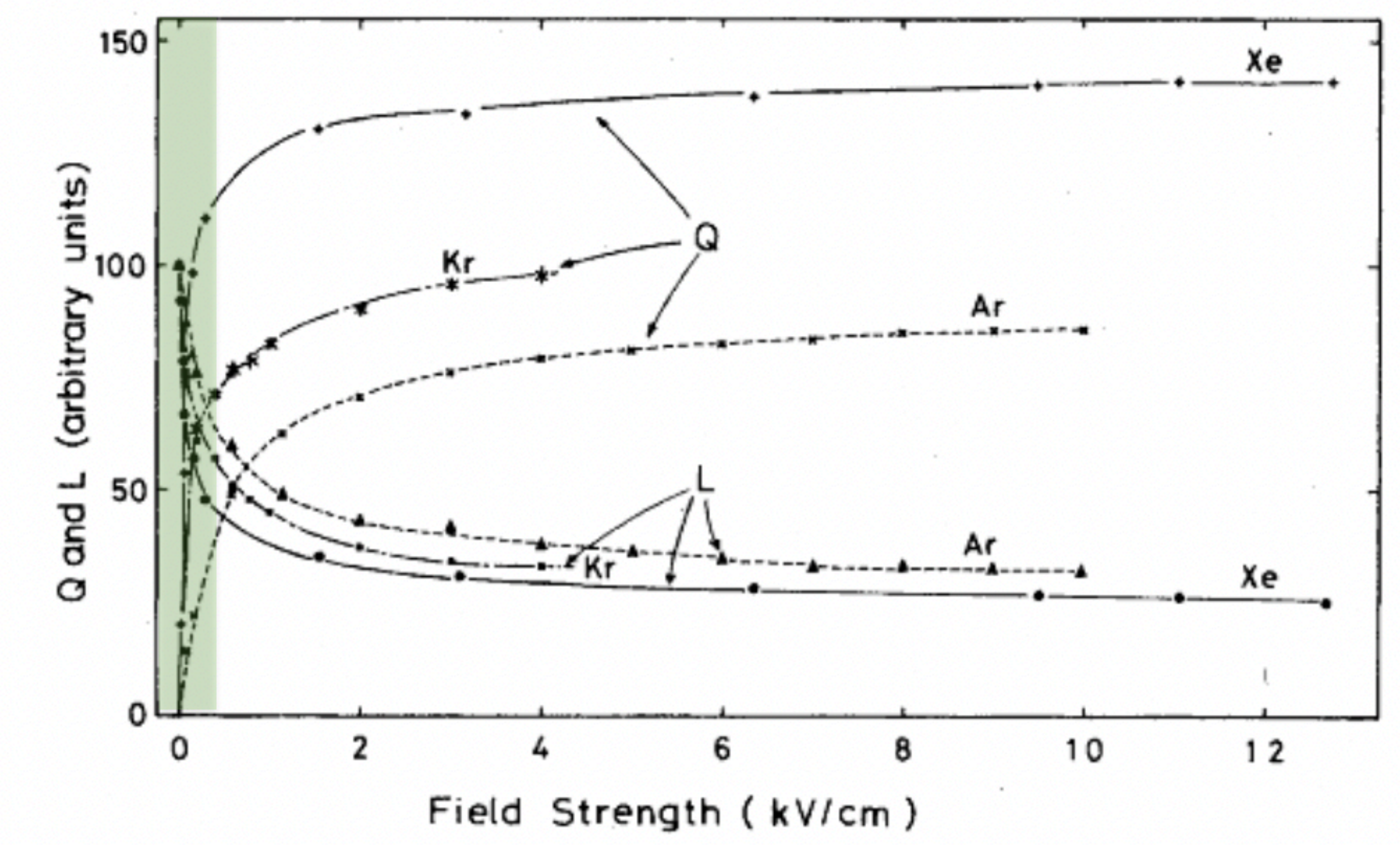
τ_{slow} vs drift field



Light yield vs drift field

Gabriel Botogoske

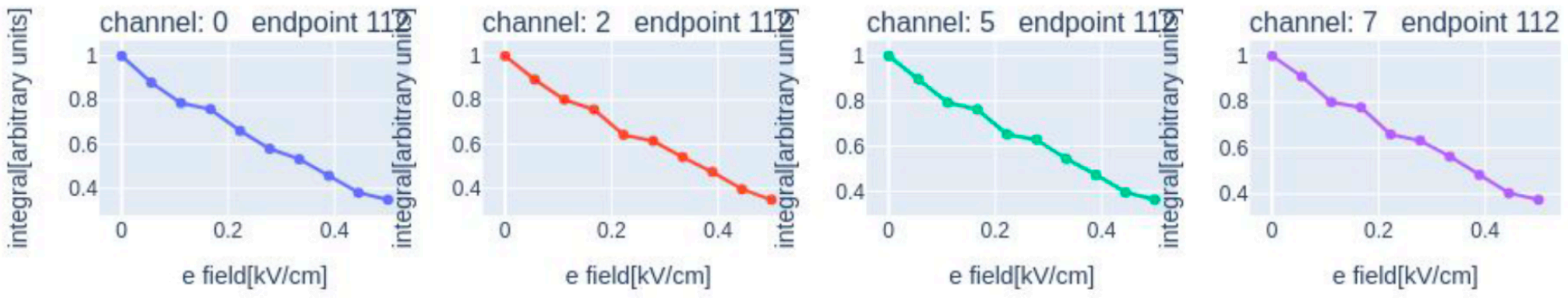
- The light yield is expected to decrease with the drift field

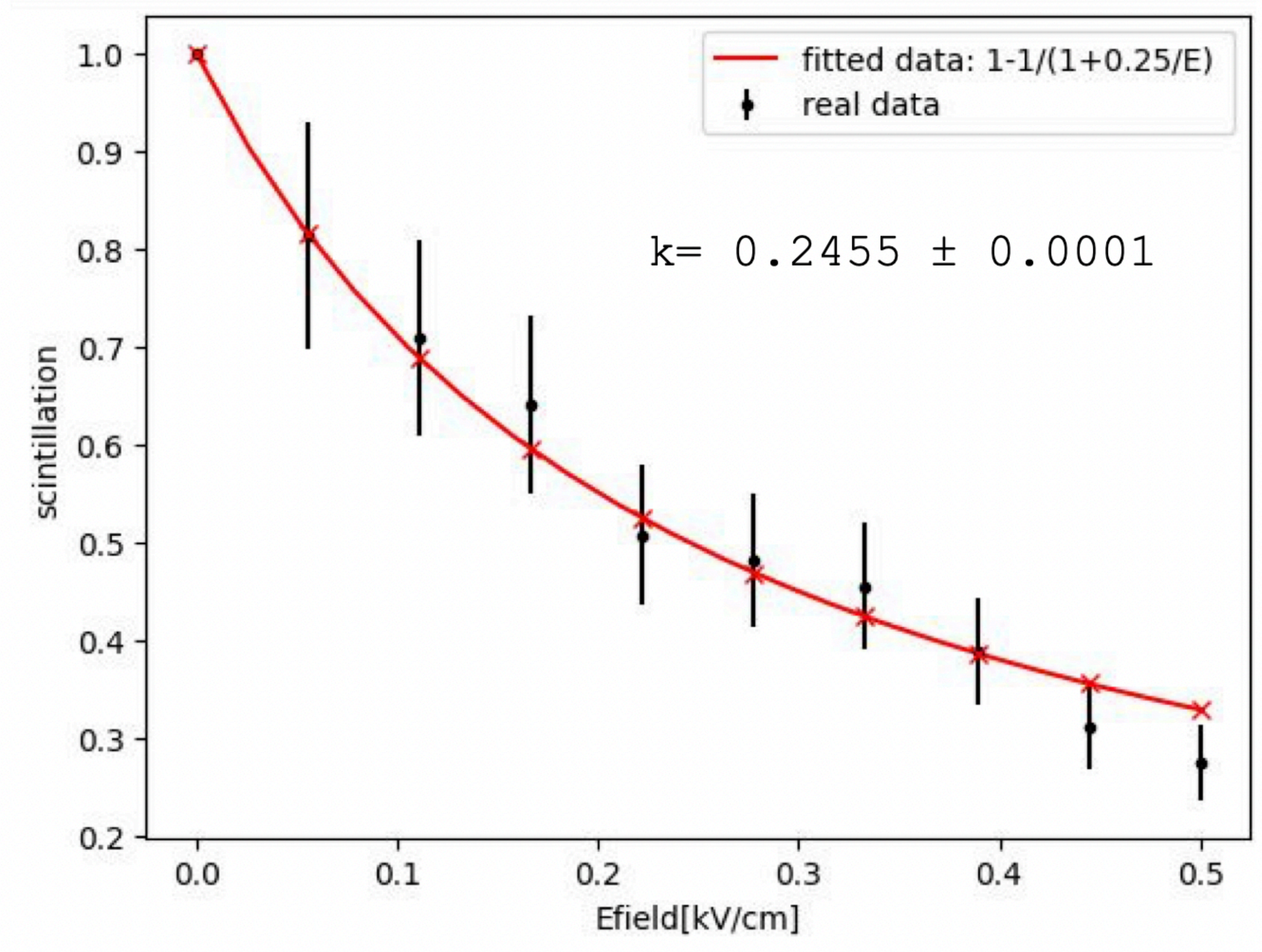


Anti-correlation with charge (Birk's law)

$$S = 1 - \frac{1}{1 + k/E}$$

- Results using the May HV scan. Pending analysis of August HV scan

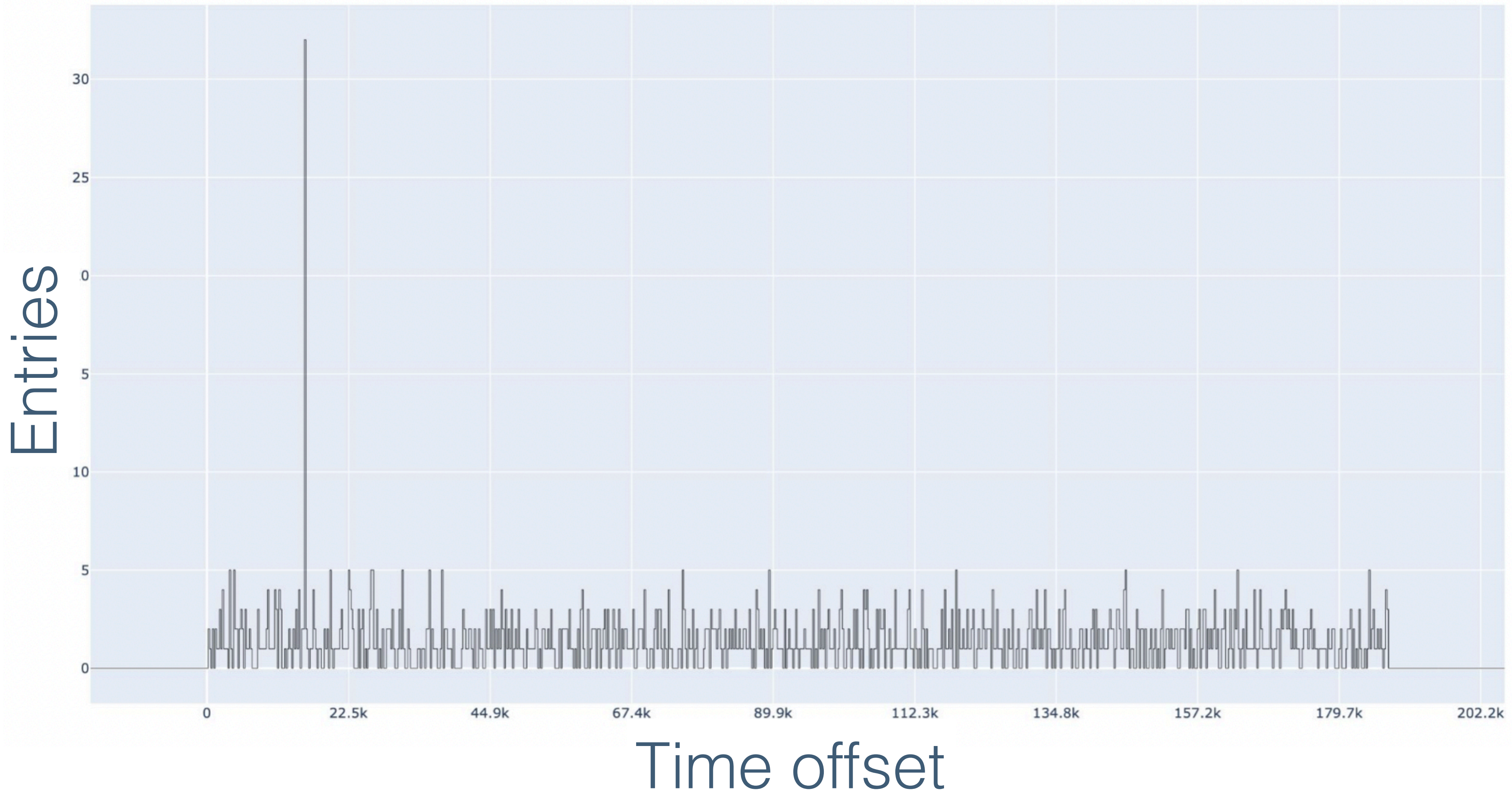




Light yield vs beam energy

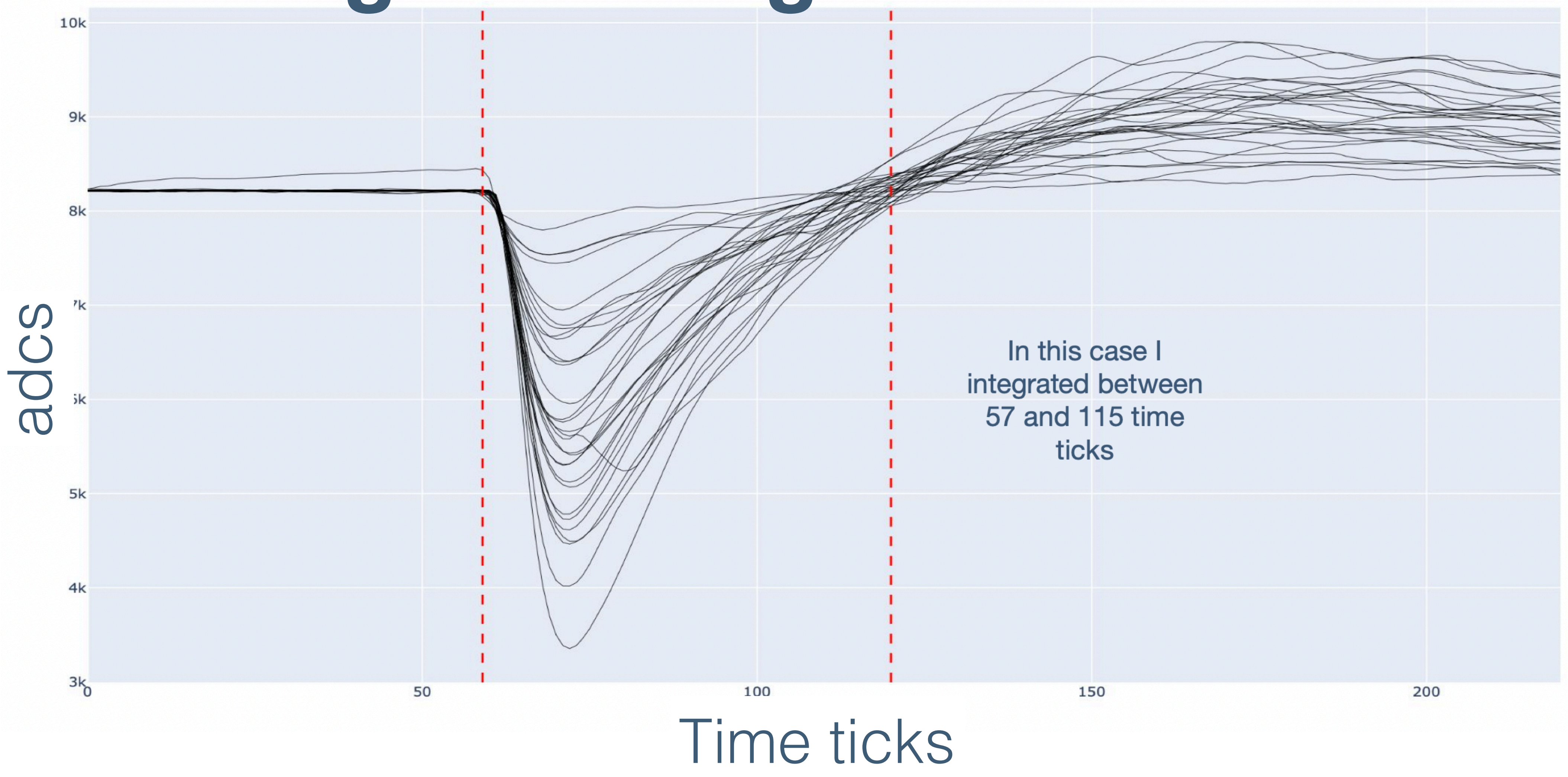
Anna Balbonni

1. Select beam waveforms

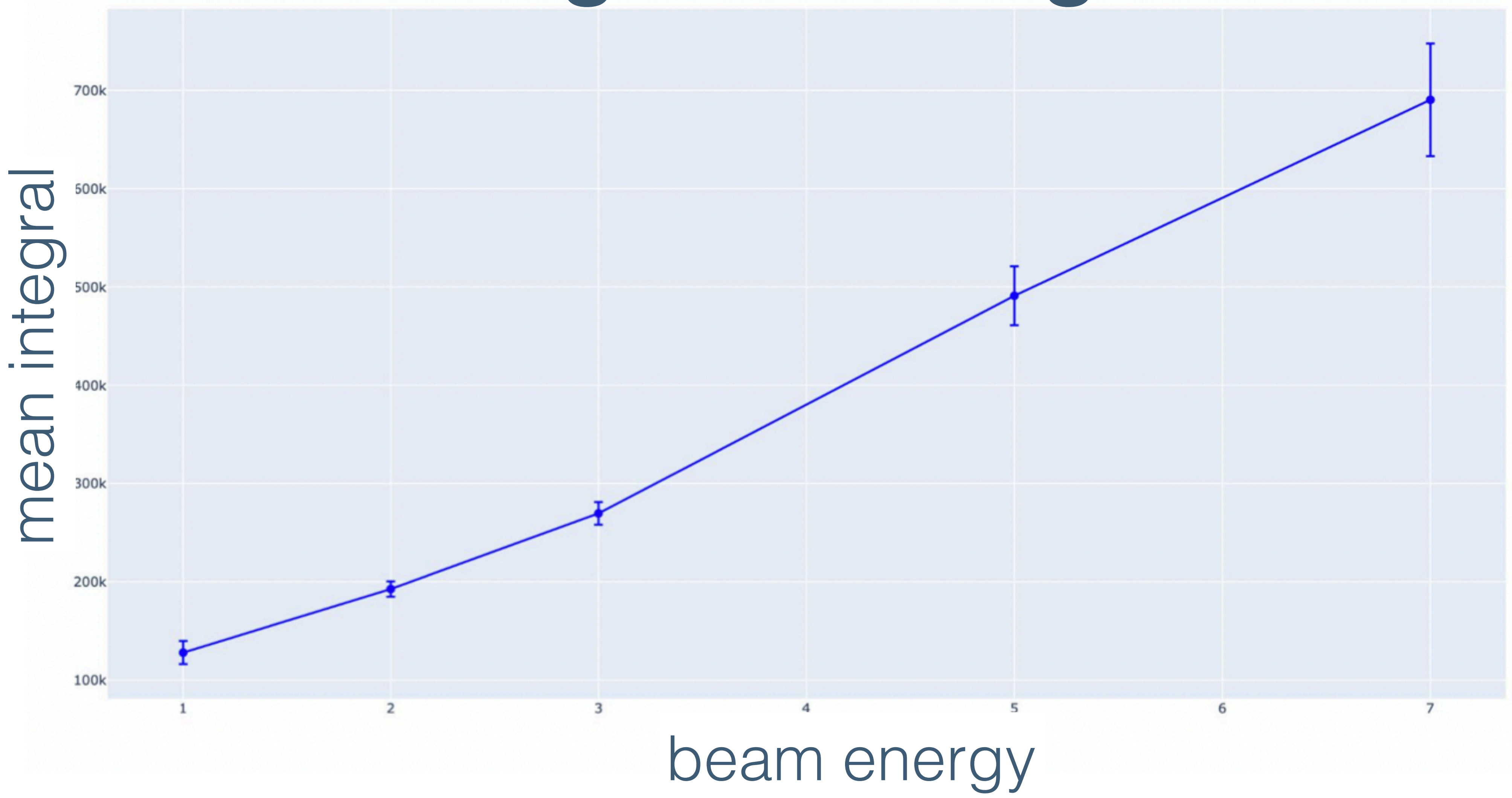


- For the moment no particle ID
  - Ideally we should select e+/e-
- Done for self-trigger and full streaming
- Here shown for self-trigger

2. Integrate charge



3. Plot integrated charge vs beam energy



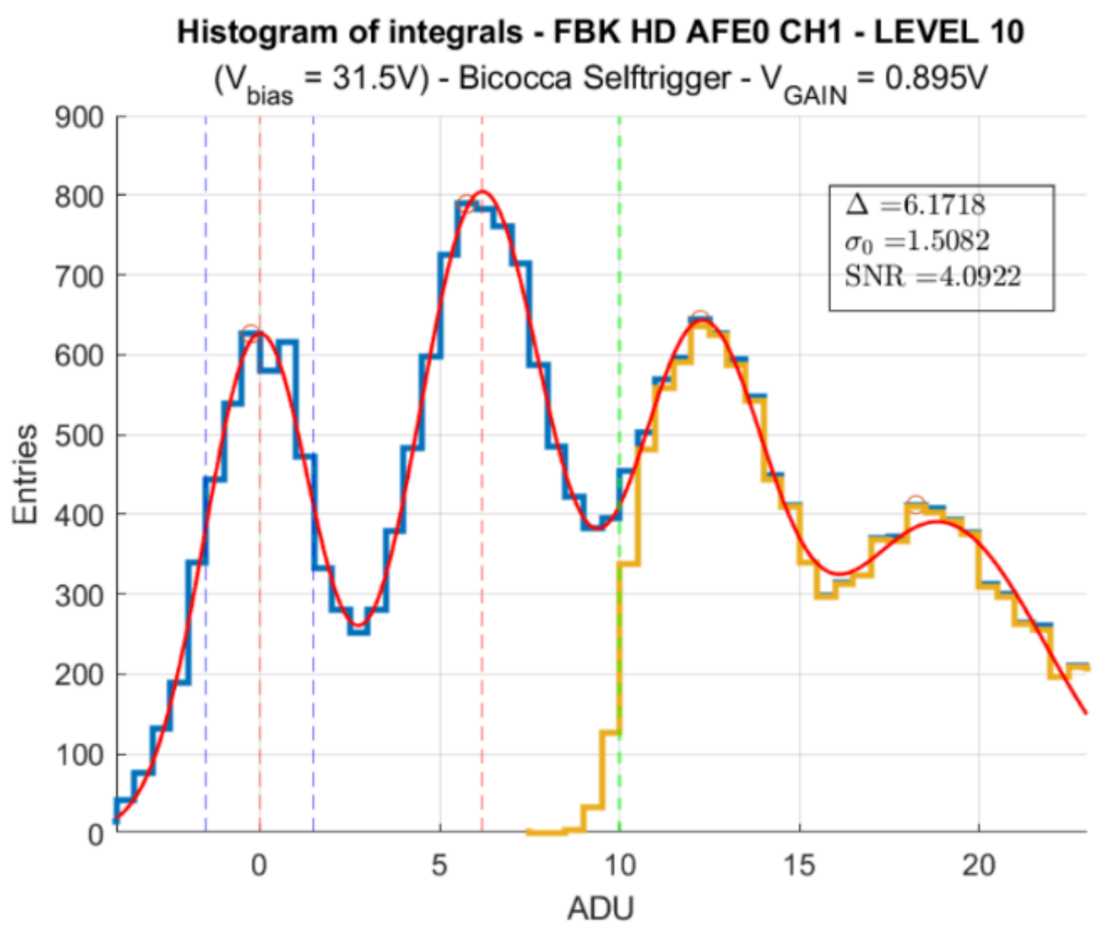
Self-trigger algorithms

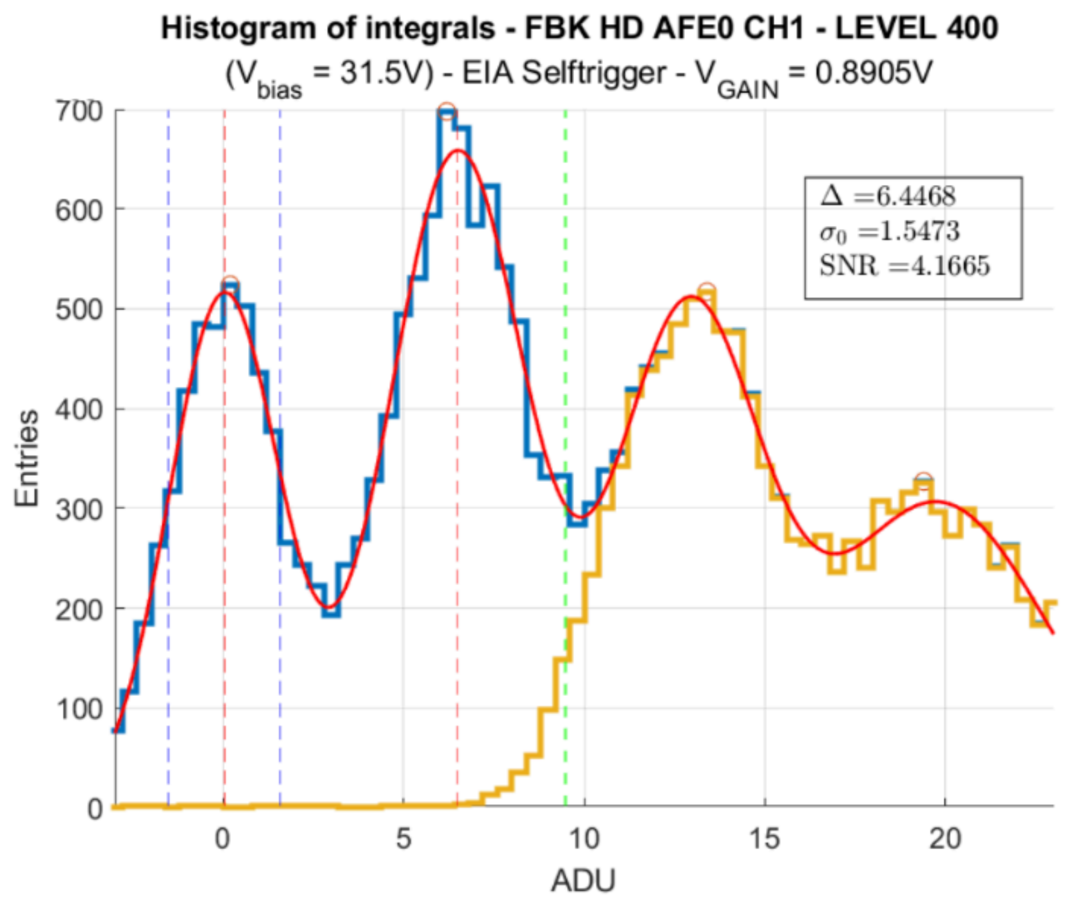
Esteban Cristaldo, Federico Galizzi, Carlos Benítez
Manuel Arroyave, Ignacio López, Daniel Ávila, Antonio Verdugo

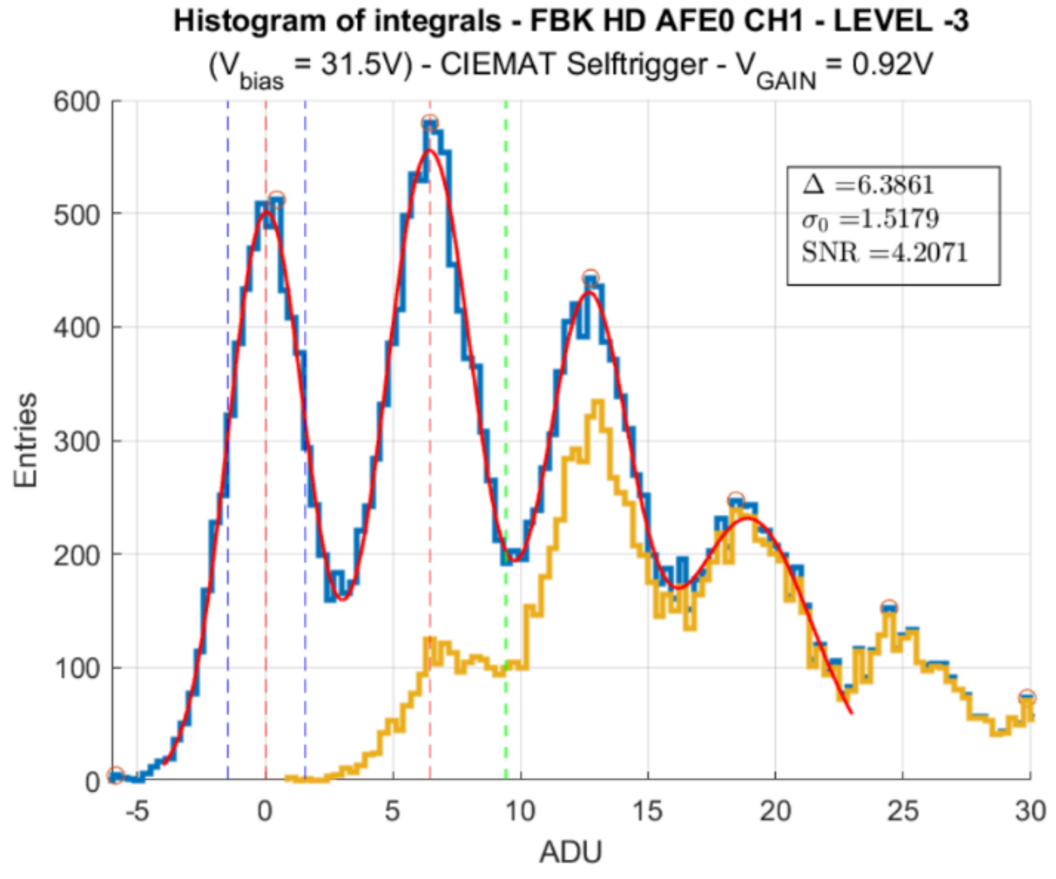
- Currently running with a very simple self-trigger algorithm (a threshold)
- Three more sophisticated algorithms being developed
- Two independent efficiency tests:
  - Standalone test bench in MiB laboratory with LED pulser (shown in the plots)
  - NP04 studies with LED calibration system. Preliminary tests in June. We will continue after beam run

Blue: LED trigger
Orange: self-trigger

Threshold at 1.5 p.e.
~100% efficiency above 2 p.e.

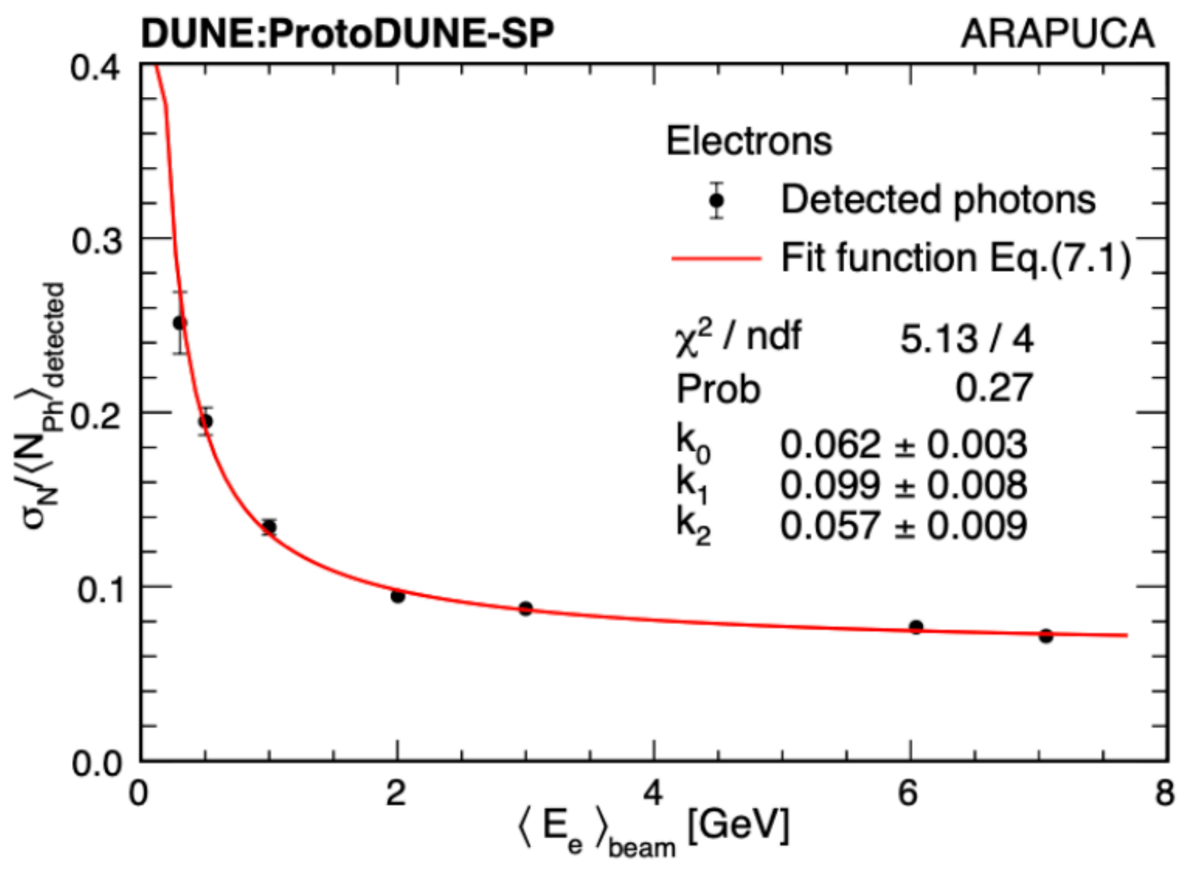




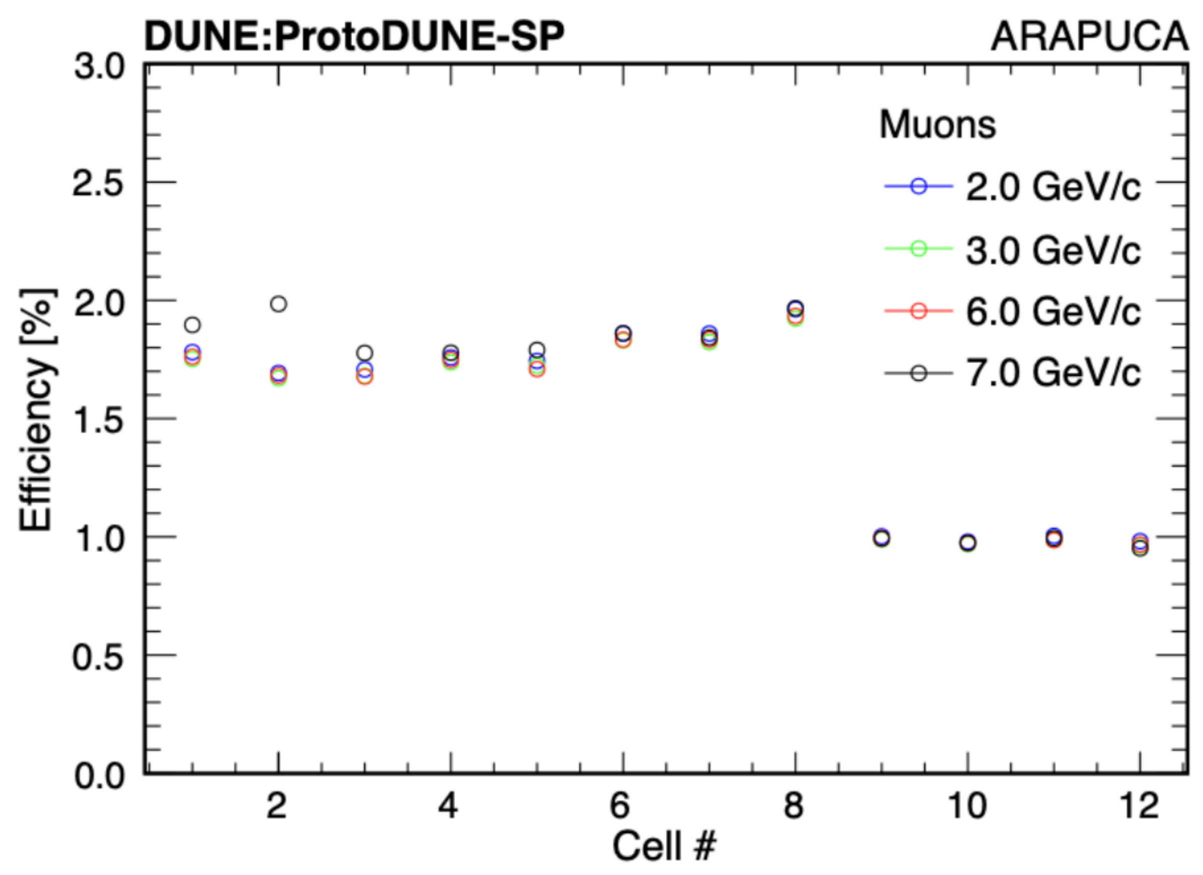


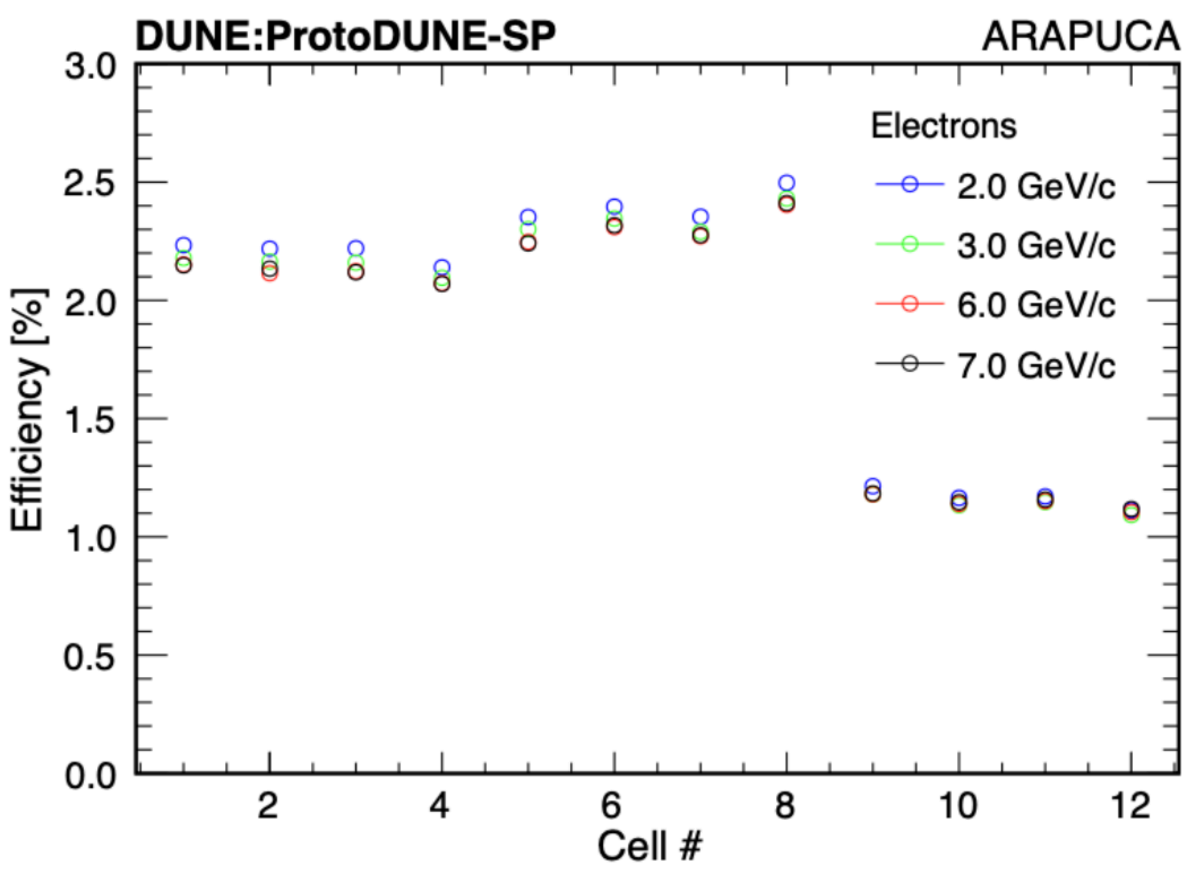
Other ongoing studies (plots from PD-1)

- Energy resolution



- X-ARAPUCA efficiency (requires MC)



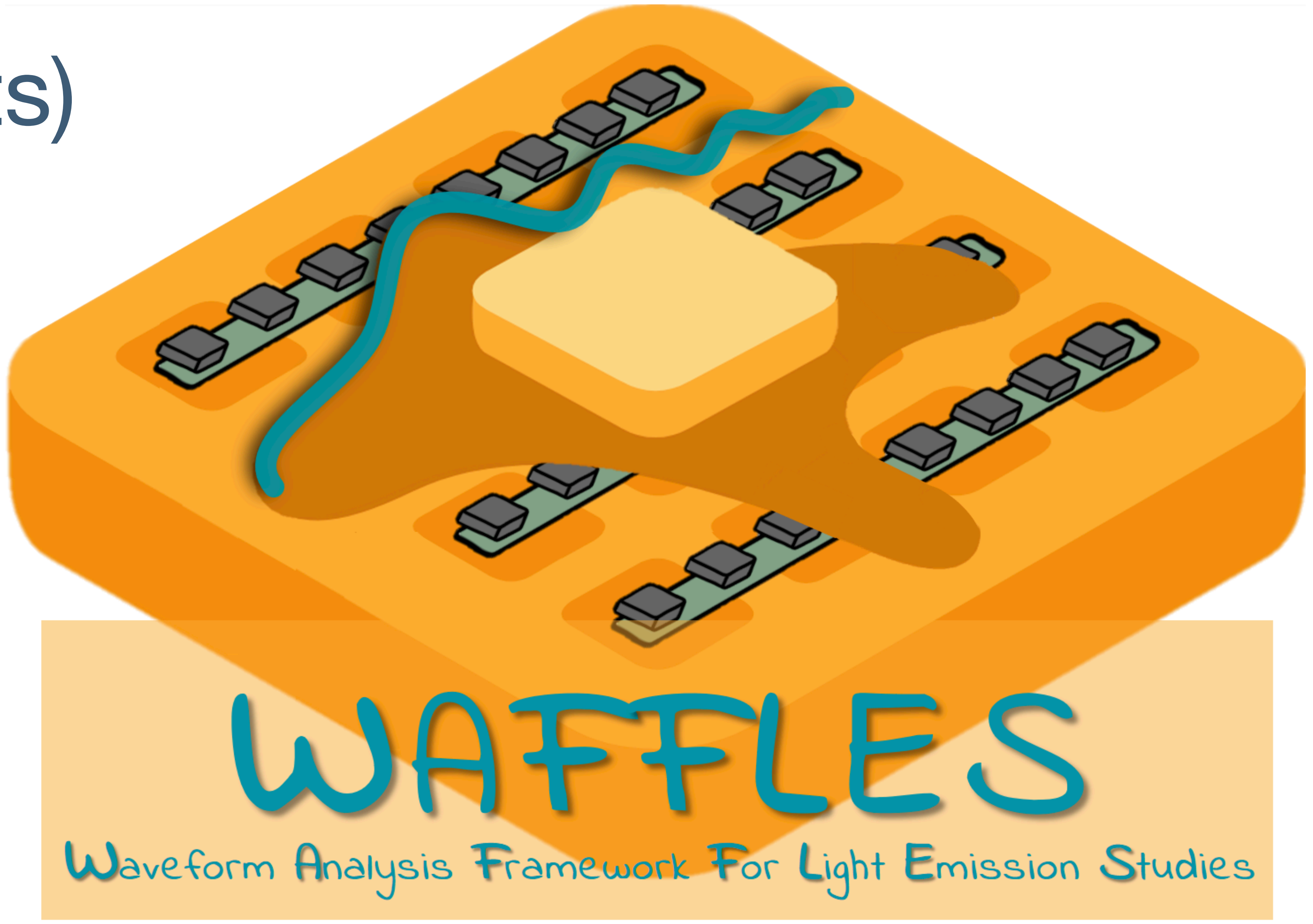


- Particle ID using slow/fast components ratio
- PDS timing resolution
- Clustering and PDS topologies

- We will need to present a plan for the use of TPs within the DAQ system. A signature for events from scintillation light has to be well described and hopefully supported by data and simulations.

The common analysis framework (WAFFLES)

- We realised soon in May of the need of a common way of analysing the data:
  - To speed up performance and physics studies
  - To easily integrate new analysers (mainly students)
  - To export know how to NP02 and later to FDs
- This common analysis framework is called WAFFLES
  - Written in python with a modular structure
  - Specific analyses are part of the framework and can be shared



- We are building a team of about 10 people, able to use waffles and produce results

Plans for tests after beam run

- Deployment of the new firmware with a more sophisticated self-trigger algorithm
  - Esteban has prepared new versions of the firmware, integrating trigger primitive calculation, self-trigger, and counters
- Self-trigger efficiency studies in NP04
- Dynamic range studies