FD HD technical board
14/08/2024

DEEP UNDERGROUND NEUTRINO EXPERIMENT

NP04 PDS Performance and Testing Plans

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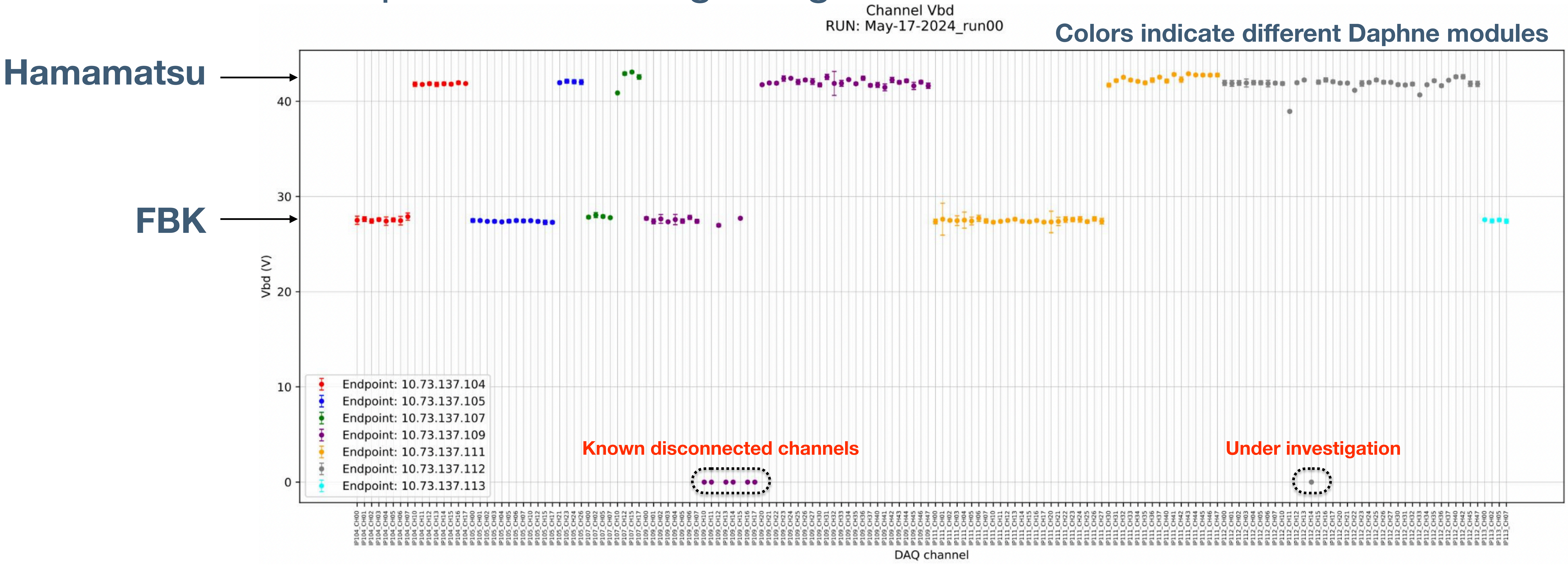
Of behalf of the PDS team

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)

160 channels

- 4% dead channels (known since installation). Few other channels under investigation
- All channels alive provide meaningful signals



Calibrations

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

	methode	frequency	Last time
Breakdown voltage	DAPHNE current monitor	biweekly	31/07
s.p.e. amplitude	LED	biweekly	12/08
tau slow	Cosmics + noise	Not regular	10/07

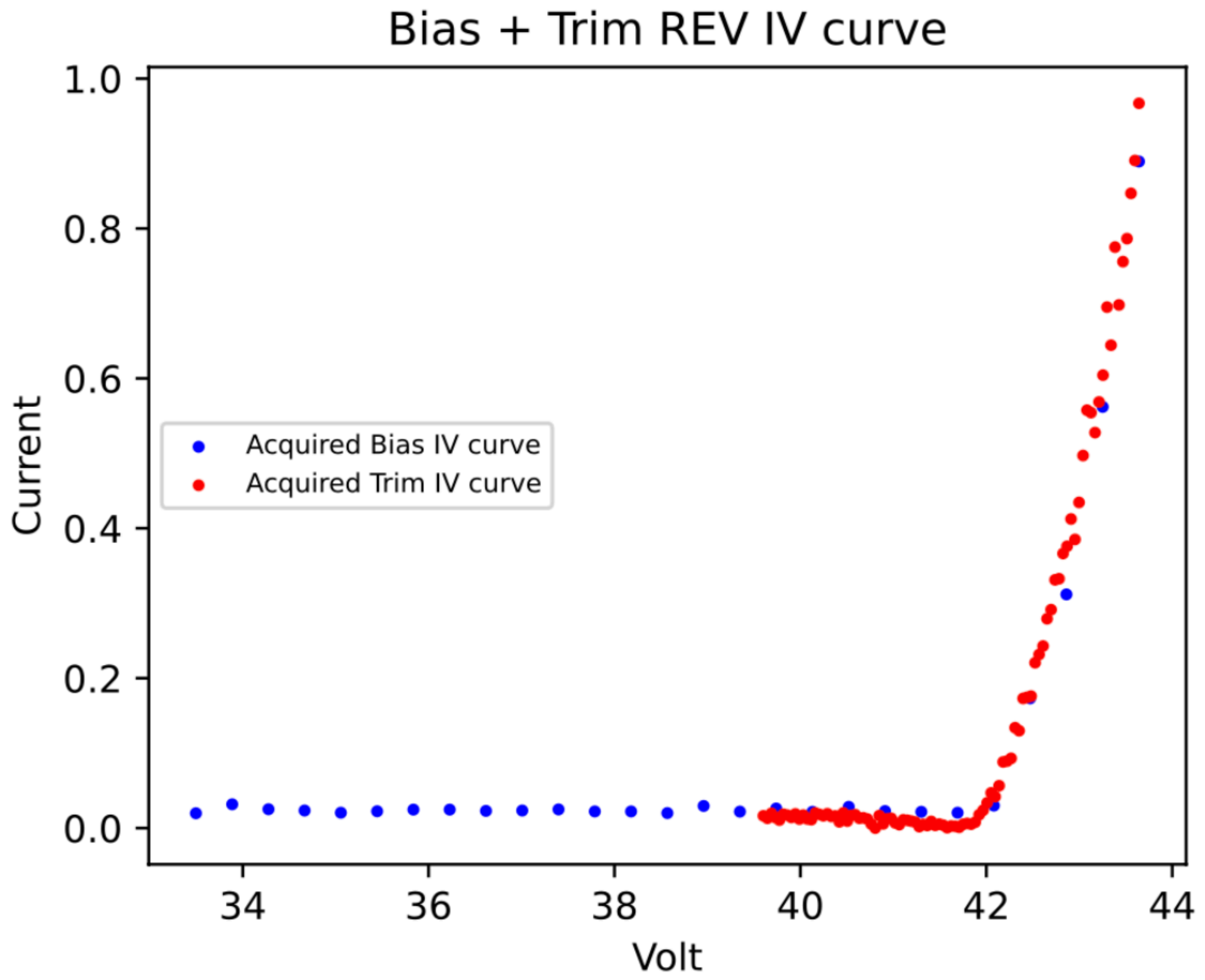
Breakdown voltage

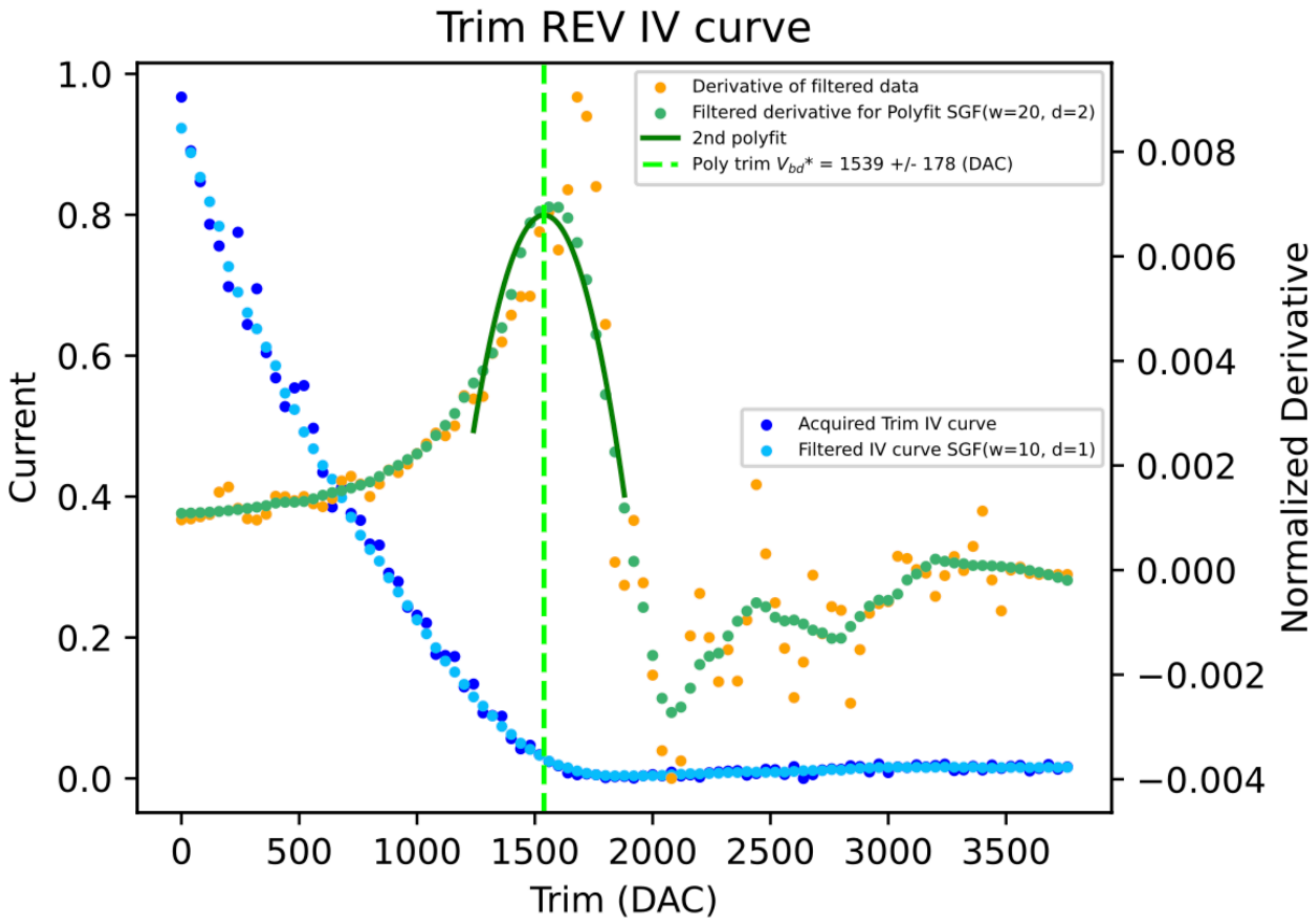
- Needs to be computed for each X-ARAPUCA since the operation voltage (V_{OP}) must be set accordingly

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

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

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



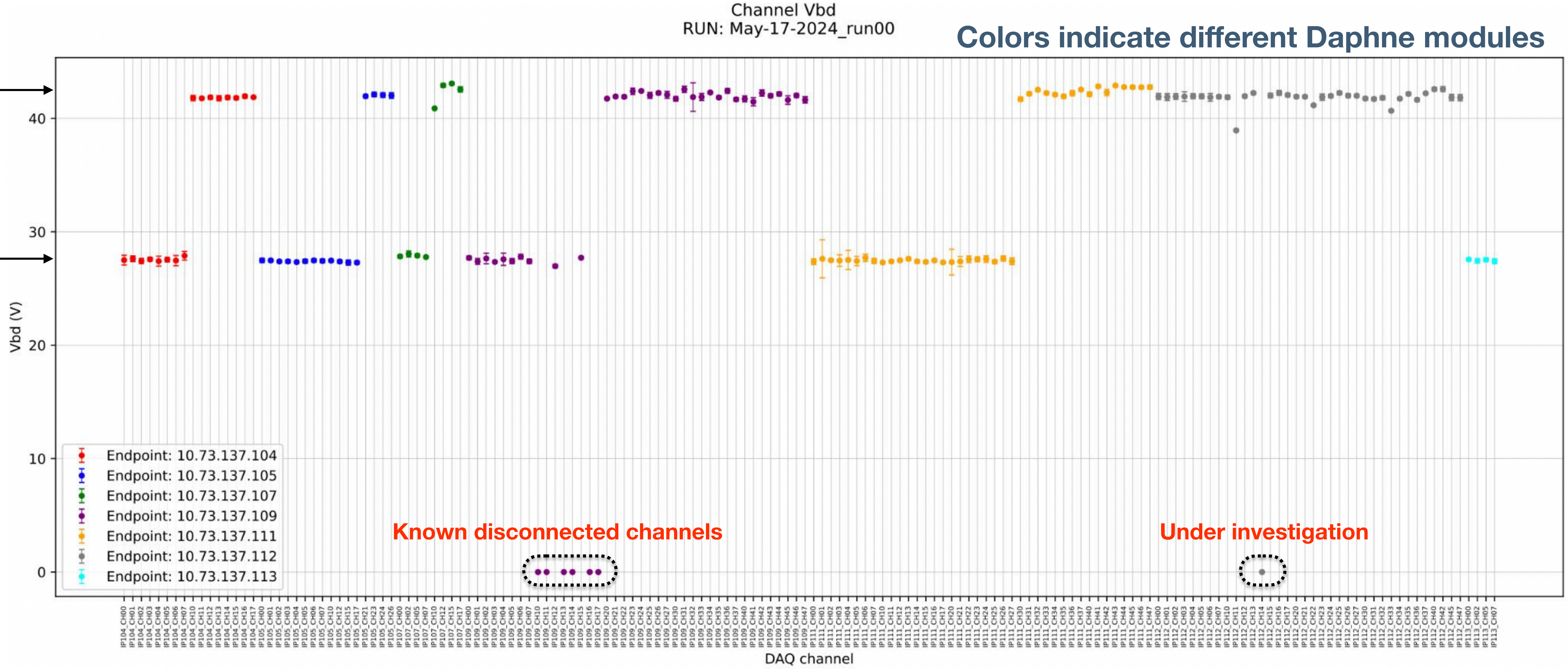


Breakdown voltage

- These plot is redone every two weeks. Results so far are stable

Hamamatsu →

FBK →

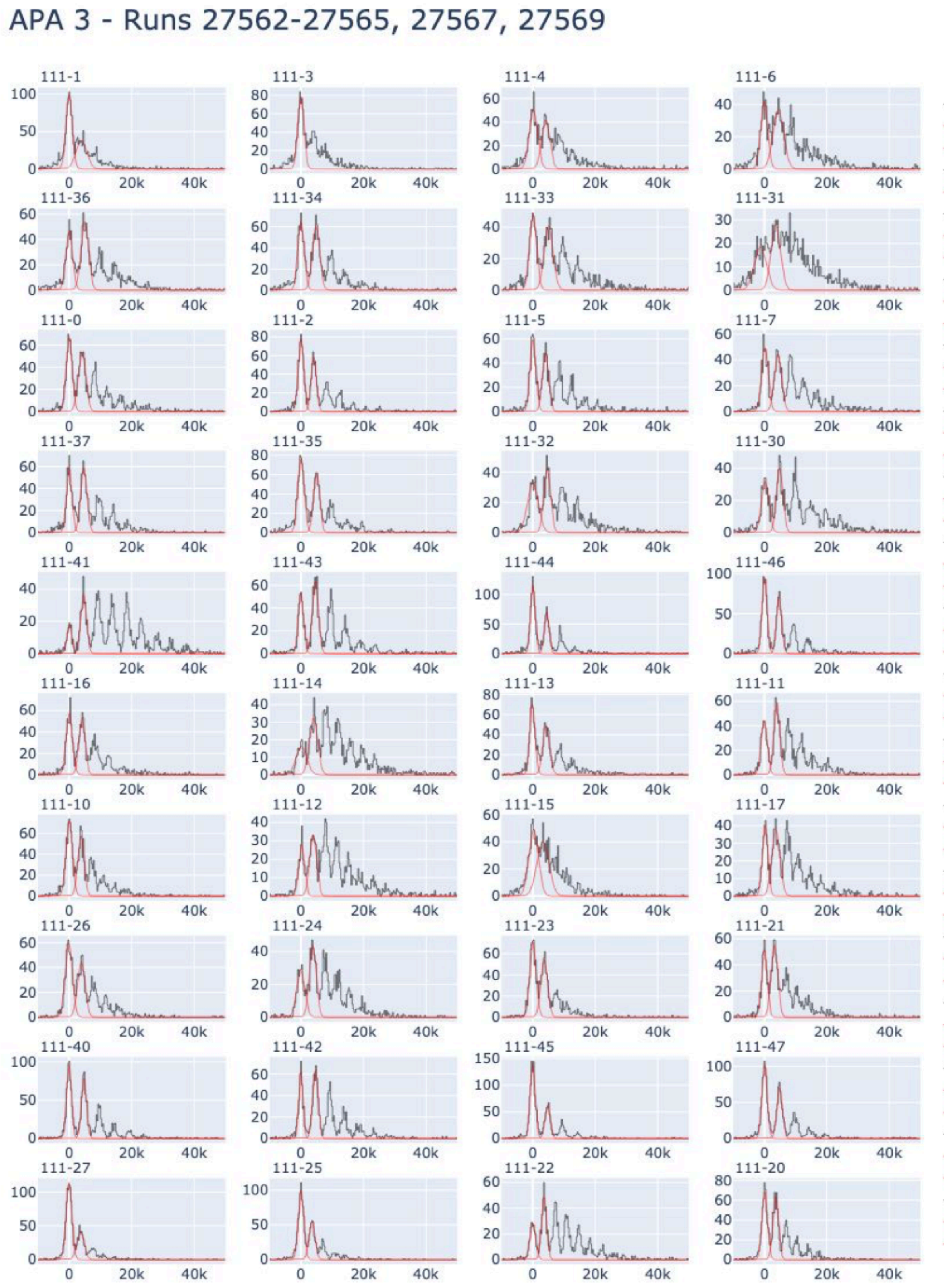


Single p.e. calibration

- 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

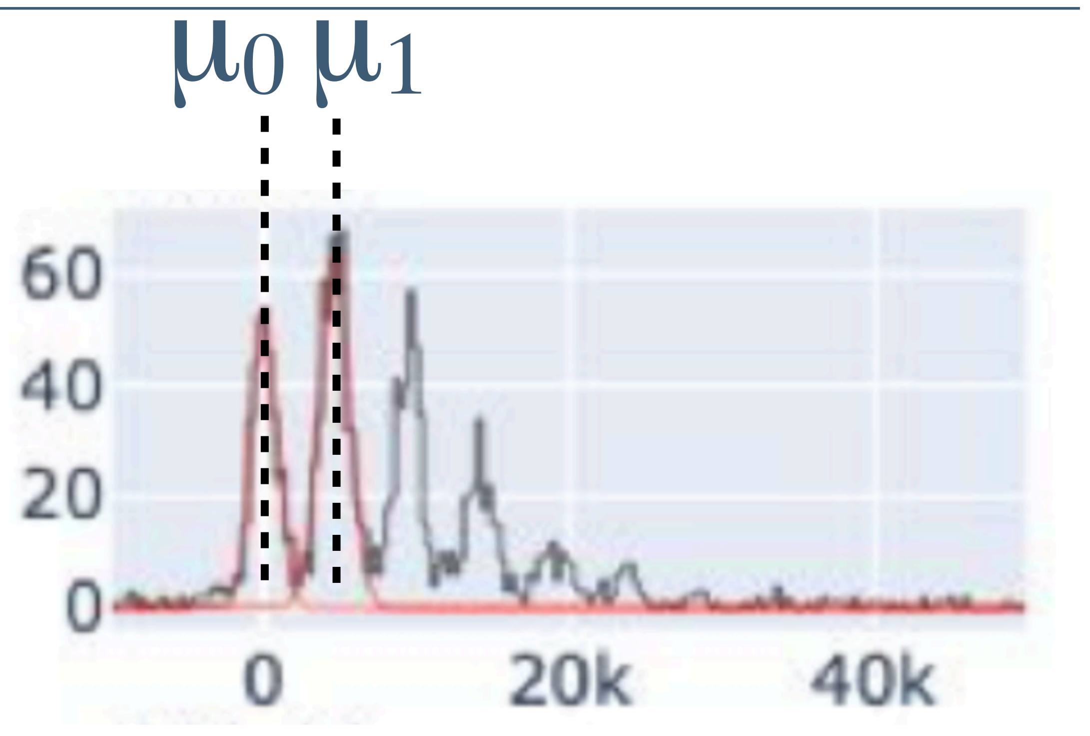
	Run Time	Intensity	Pulse with	Fiber mask
APA1	4 mins	1400-2800	20	50
APA2	3 mins	1400-4000	20	50
APA3,4	3 mins	1400-2200	1	1,12

- Each calibration campaign takes about 2 hours



Gain studies

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

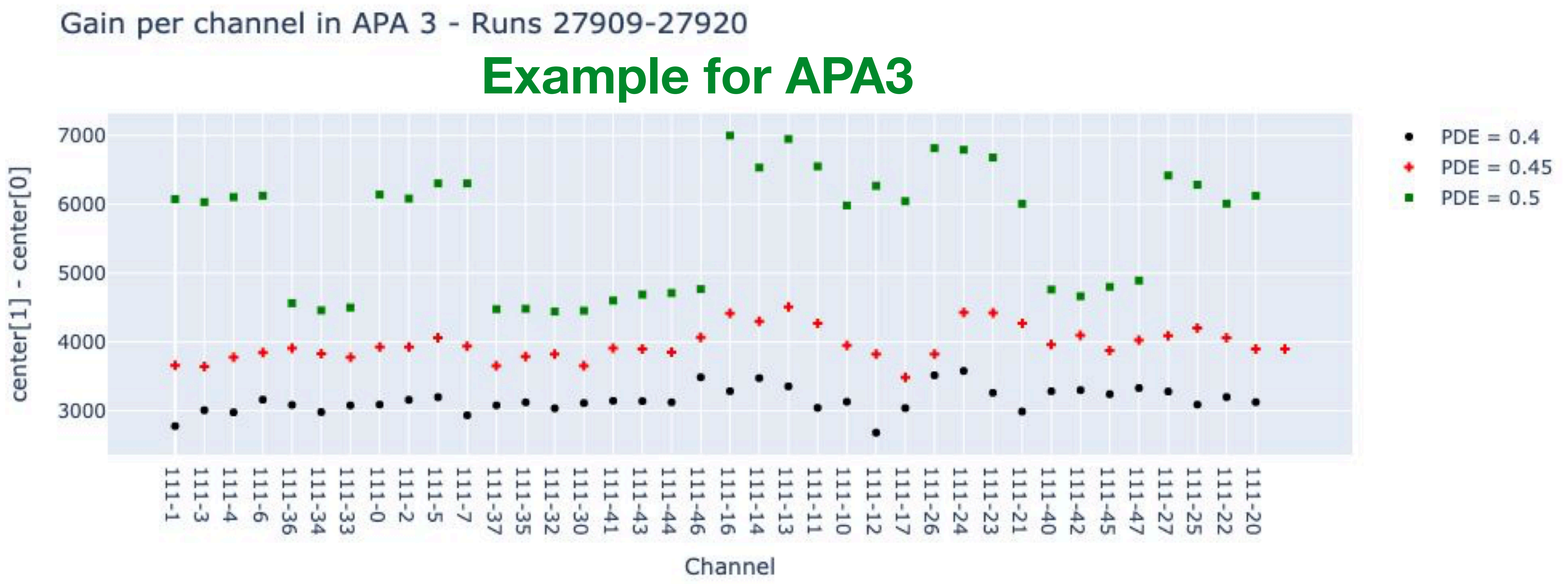


$$\text{Gain} = \mu_1 - \mu_0$$

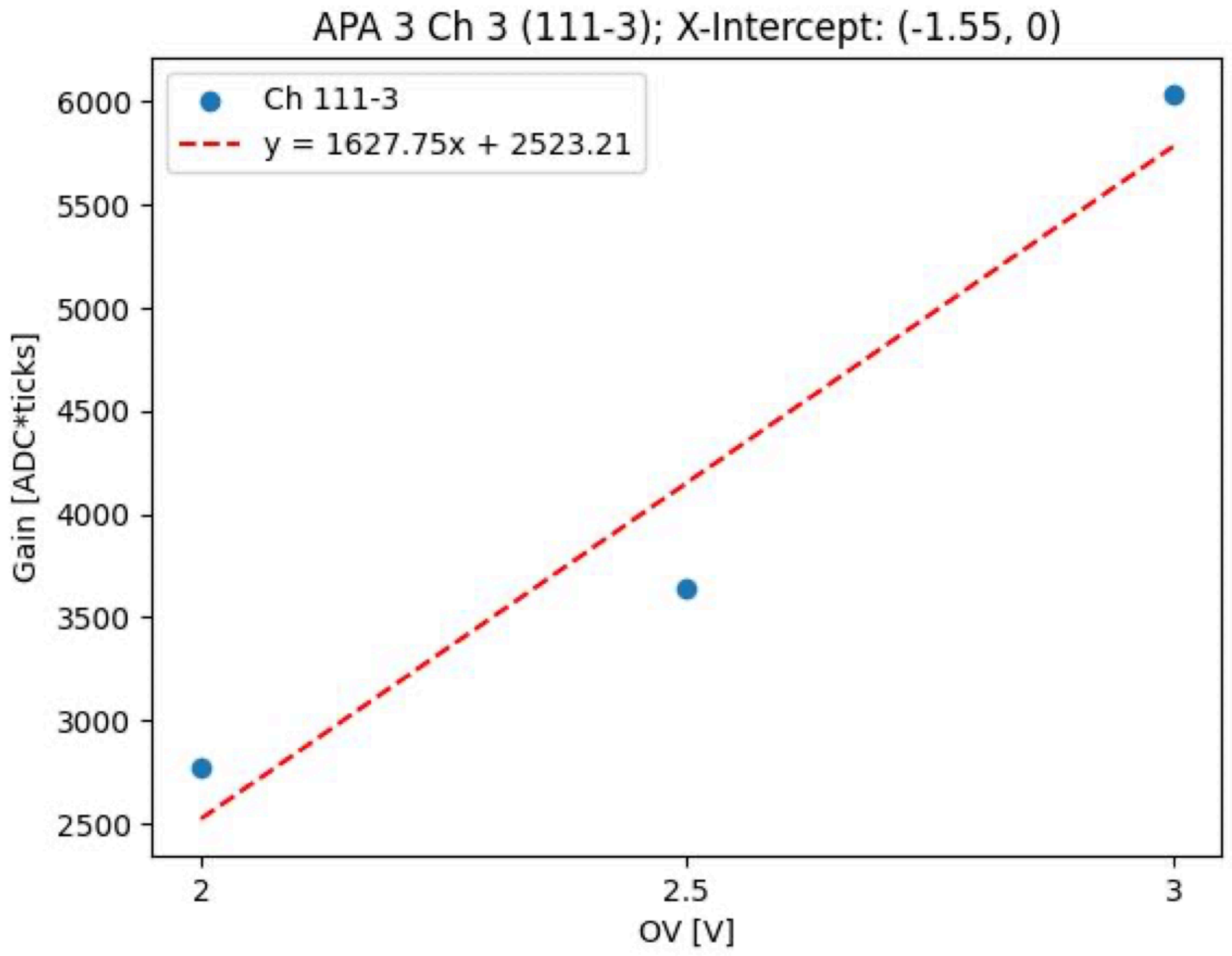
OV for each Photon Detection Efficiency (PDE)

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

Example for APA3

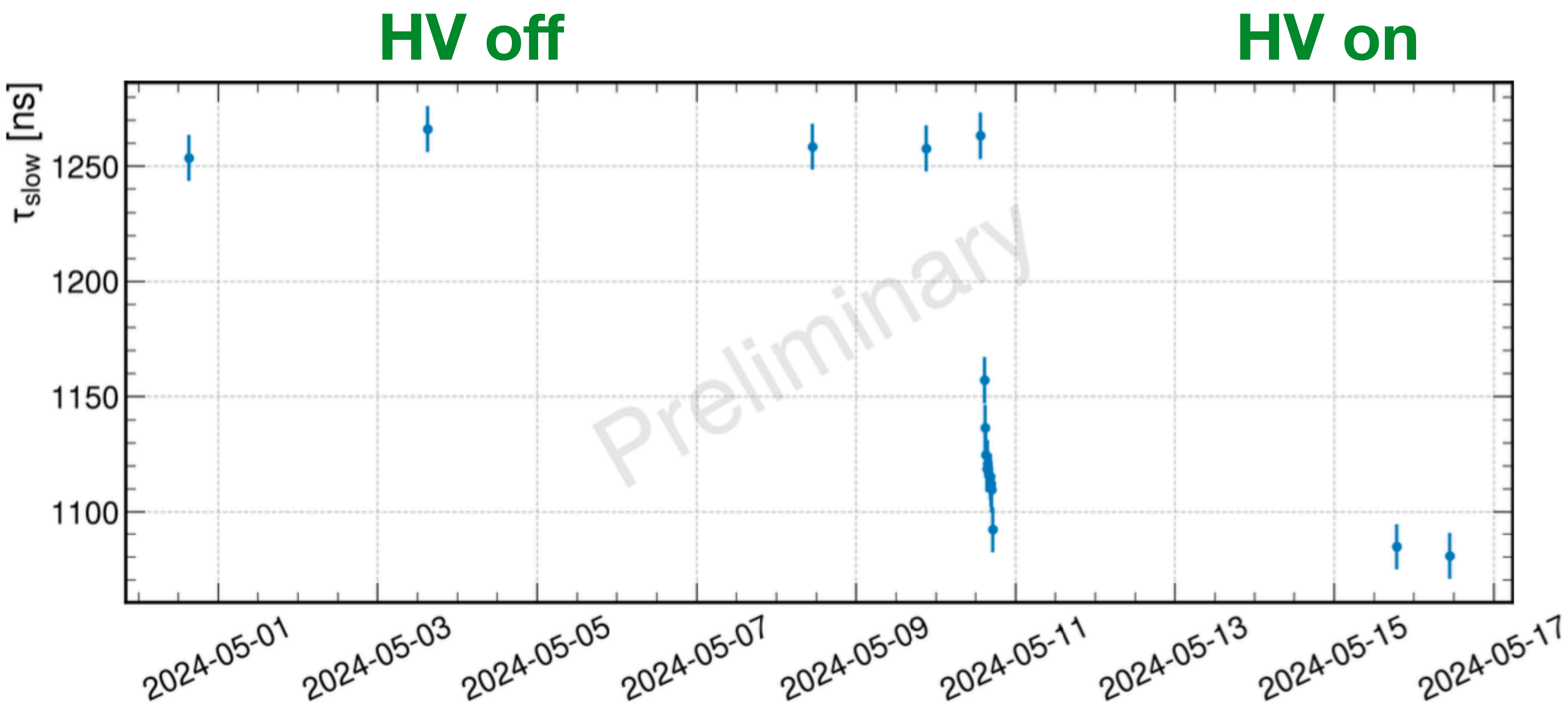


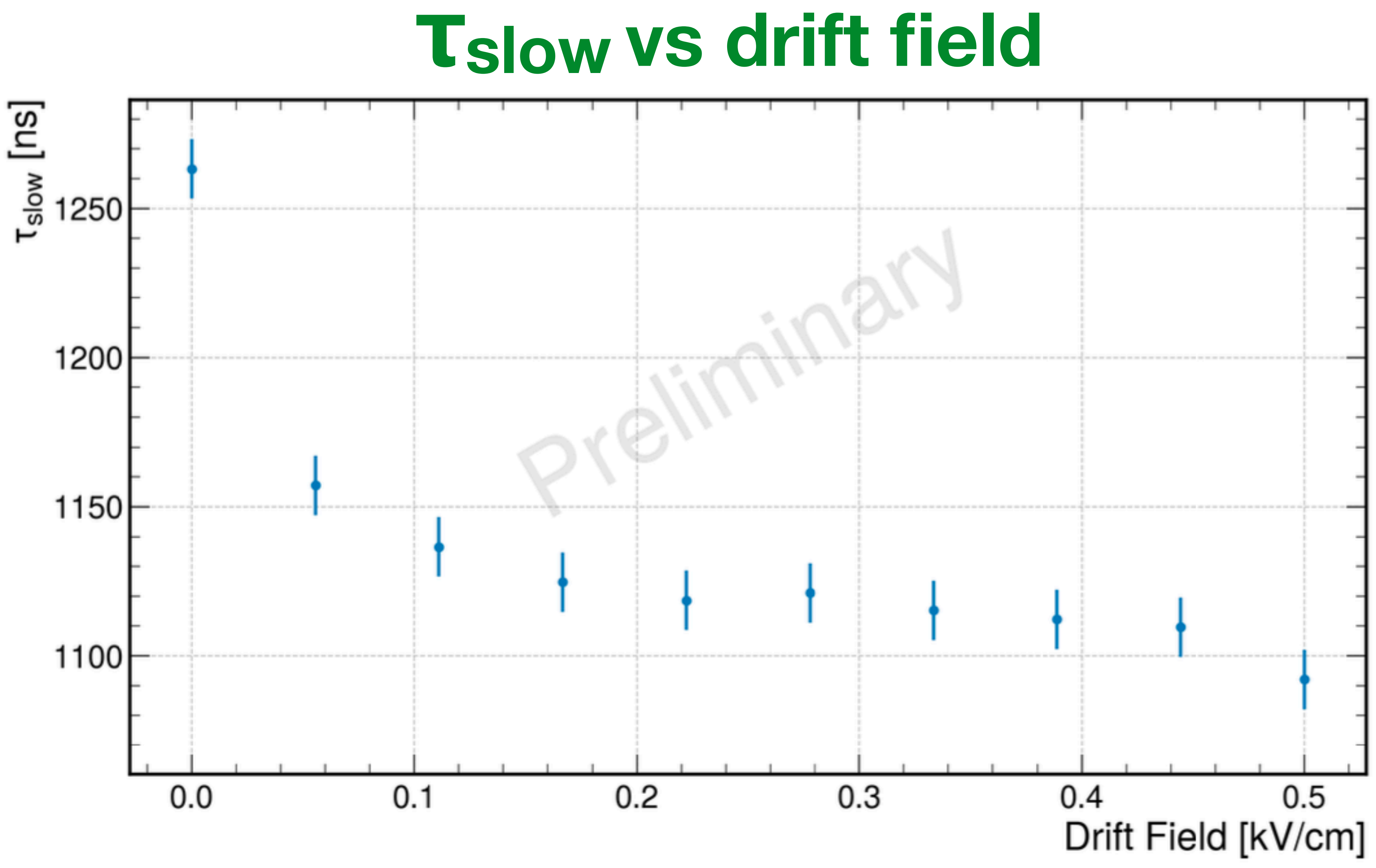
Example one channel in APA3



Tau slow

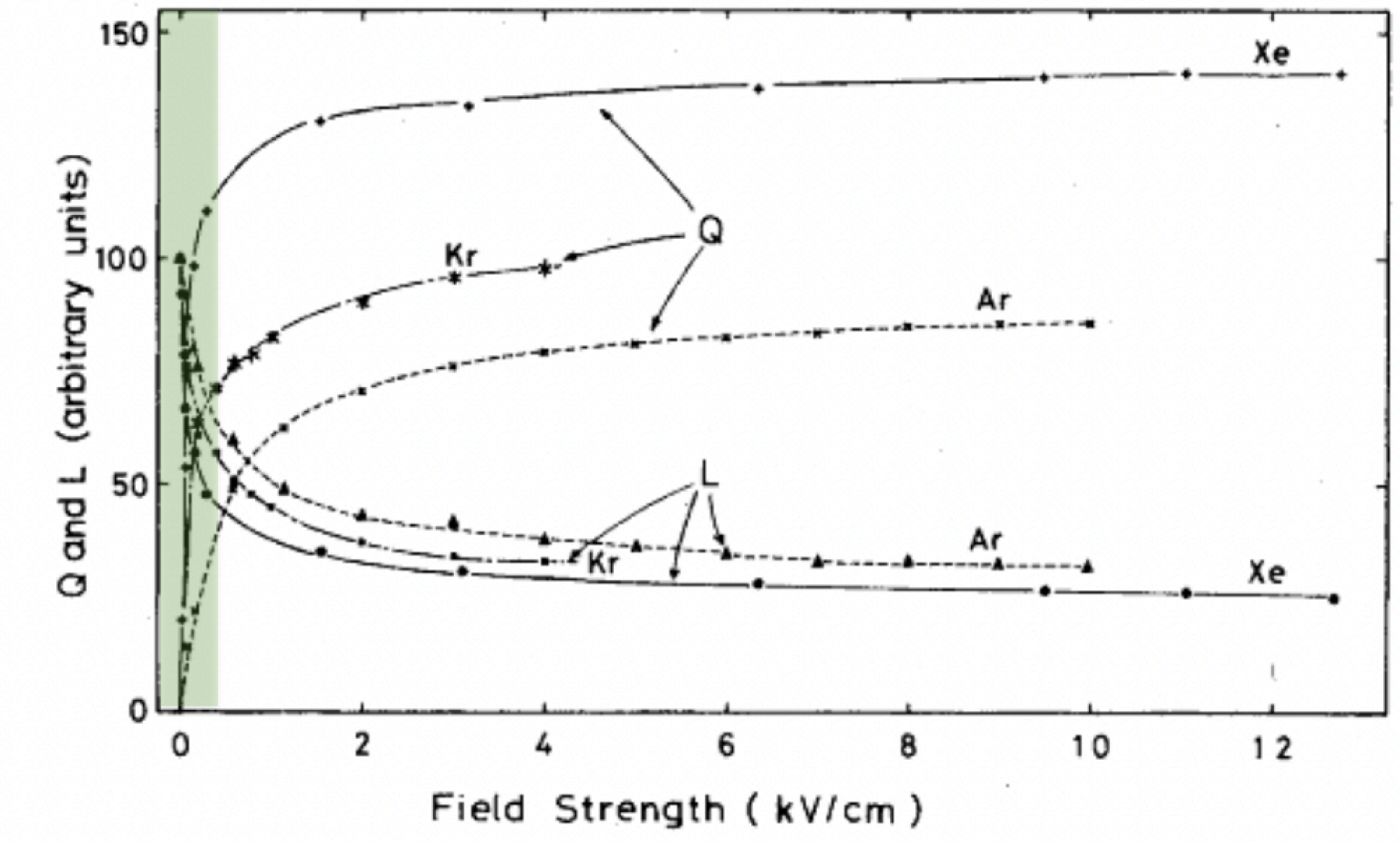
- The decay time of the slow component of the scintillation light (τ_{slow}) has important information about nitrogen contamination and particle ID
- A HV scan with dedicated τ_{slow} PDS runs (cosmics, LED, noise) was carried out on May 10th
- We have more recent τ_{slow} PDS runs but haven't been analysed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





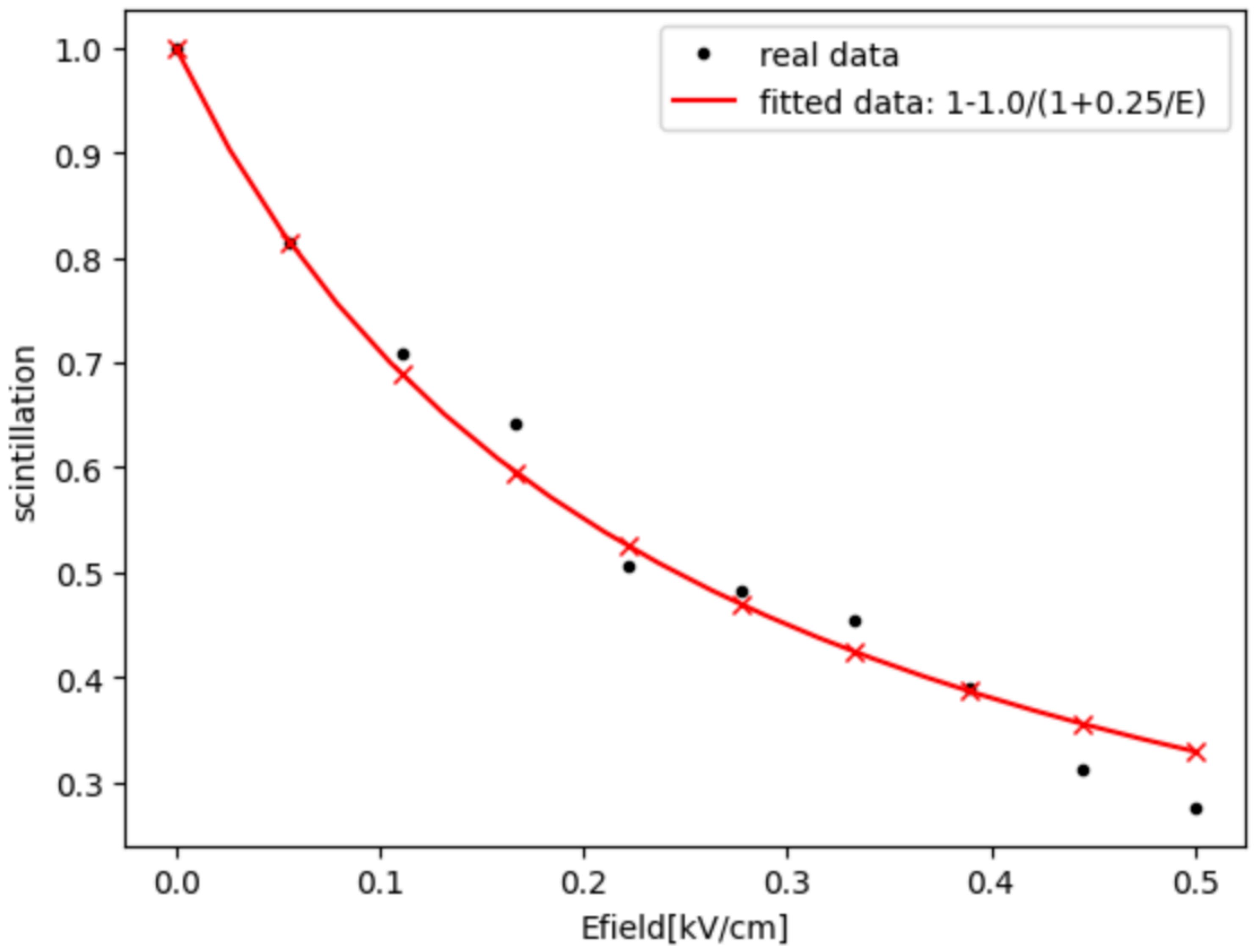
Light yield vs drifty field

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

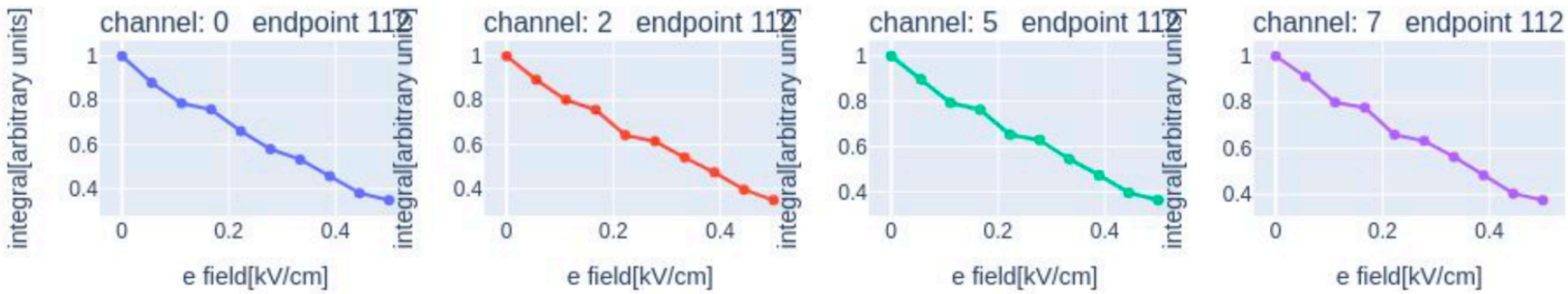


Anti-correlation with charge (Birk's law)

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



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

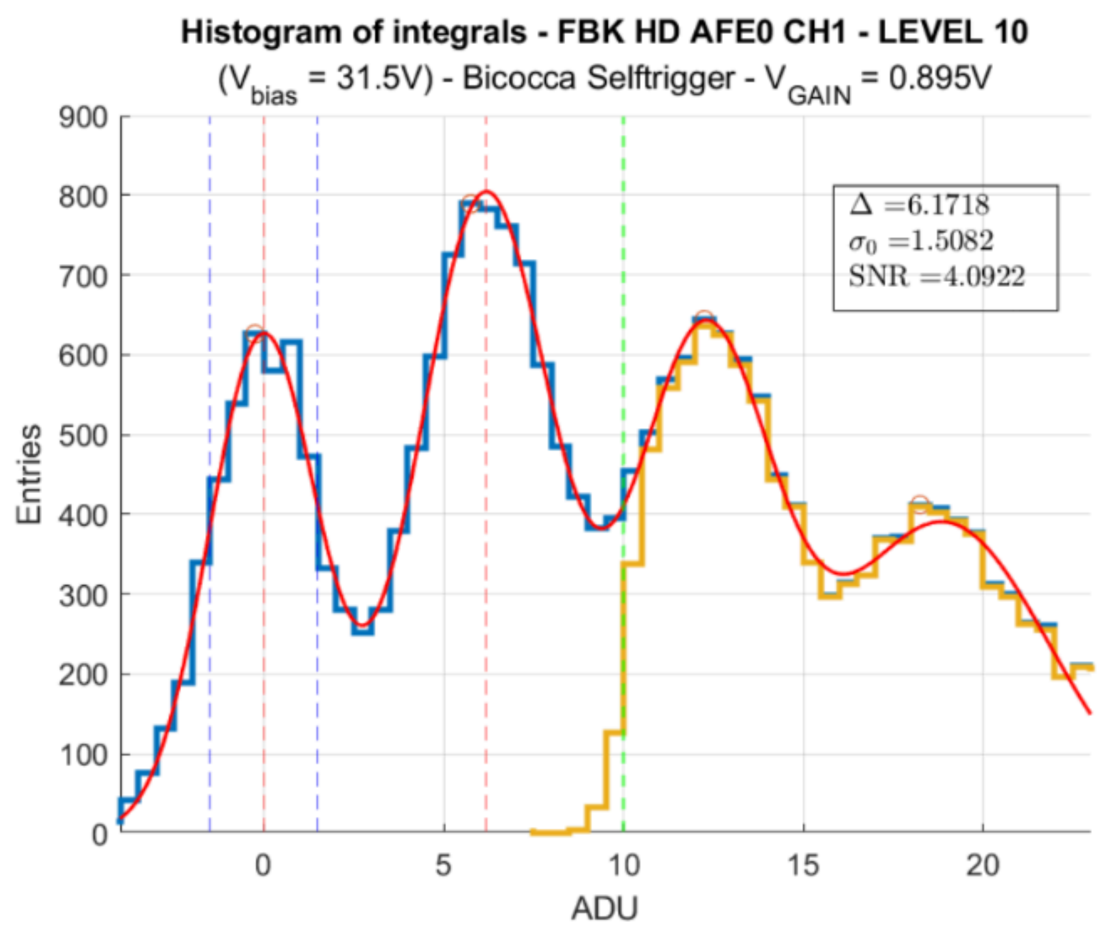


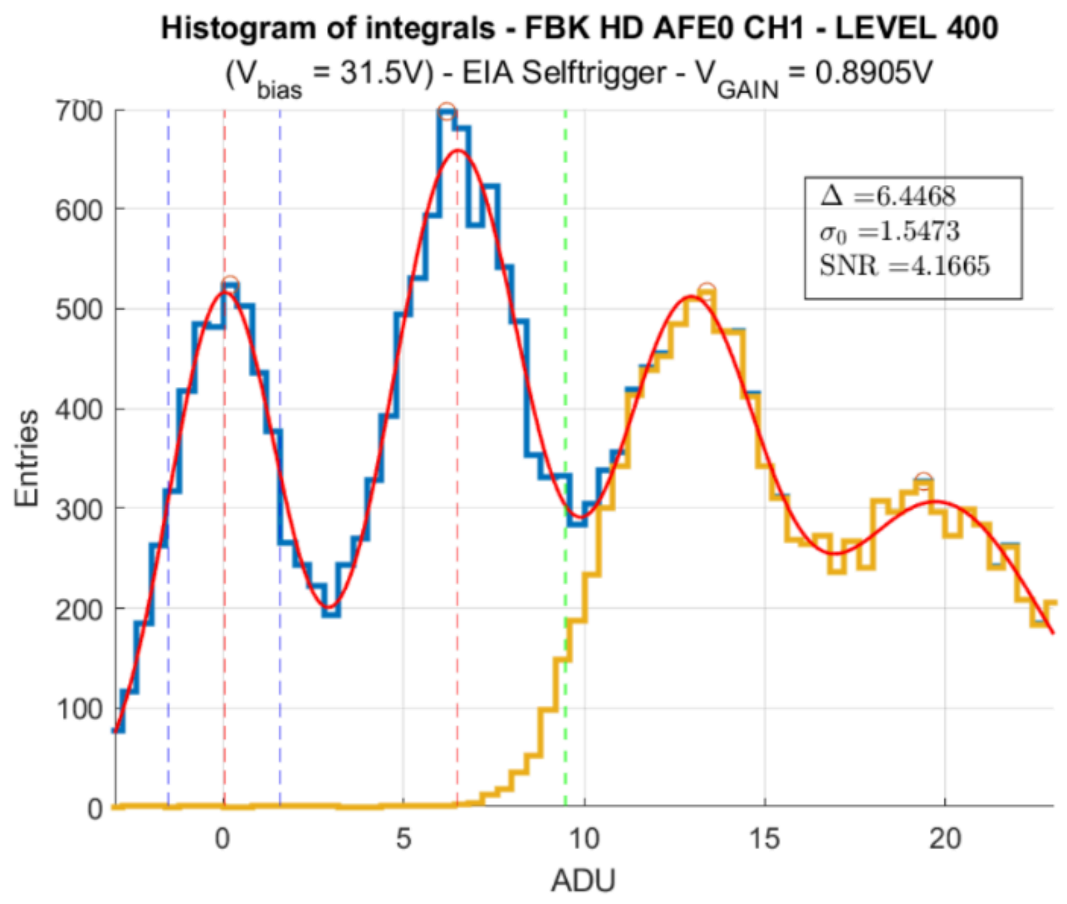
Self-trigger algorithms

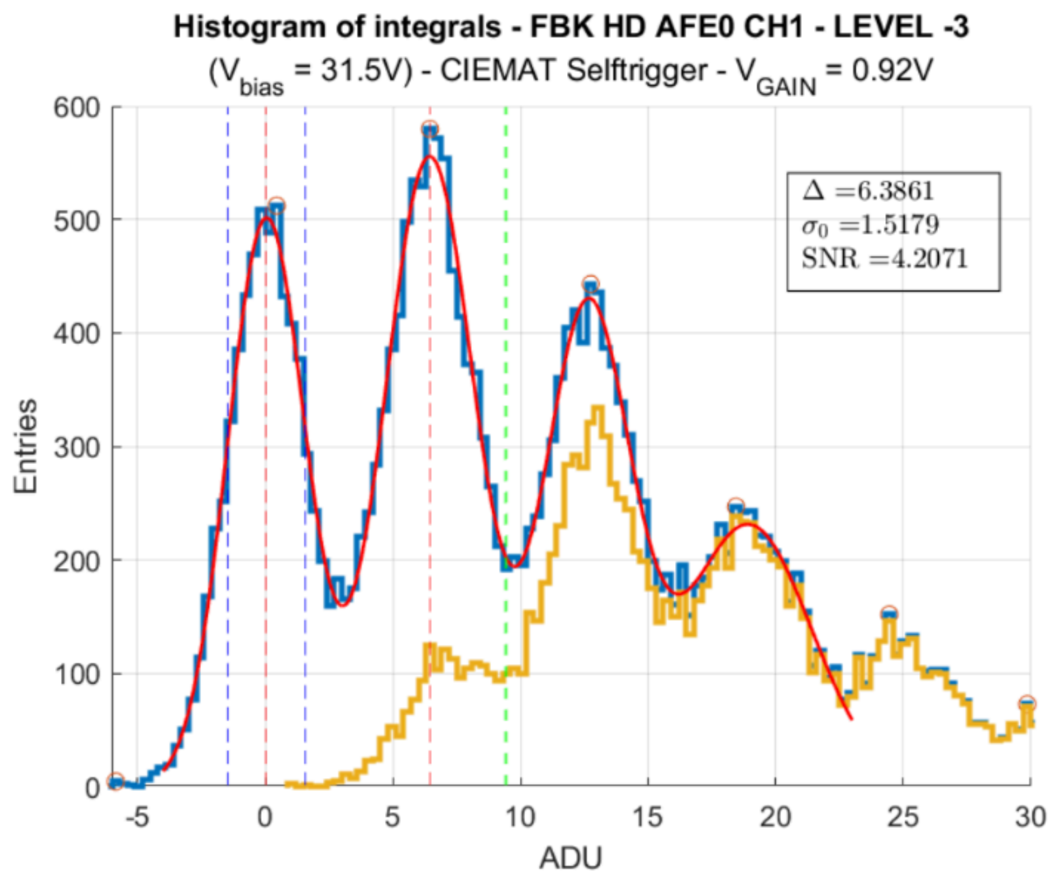
- Currently running with a very simple self-trigger algorithm (a threshold)
- Three more sophisticated algorithms being developed
- Two independent efficiency tests:
  - Standalone test bench in MiB laboratory with LED pulser (shown in the plots)
  - NP04 studies with LED calibration system. Preliminary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

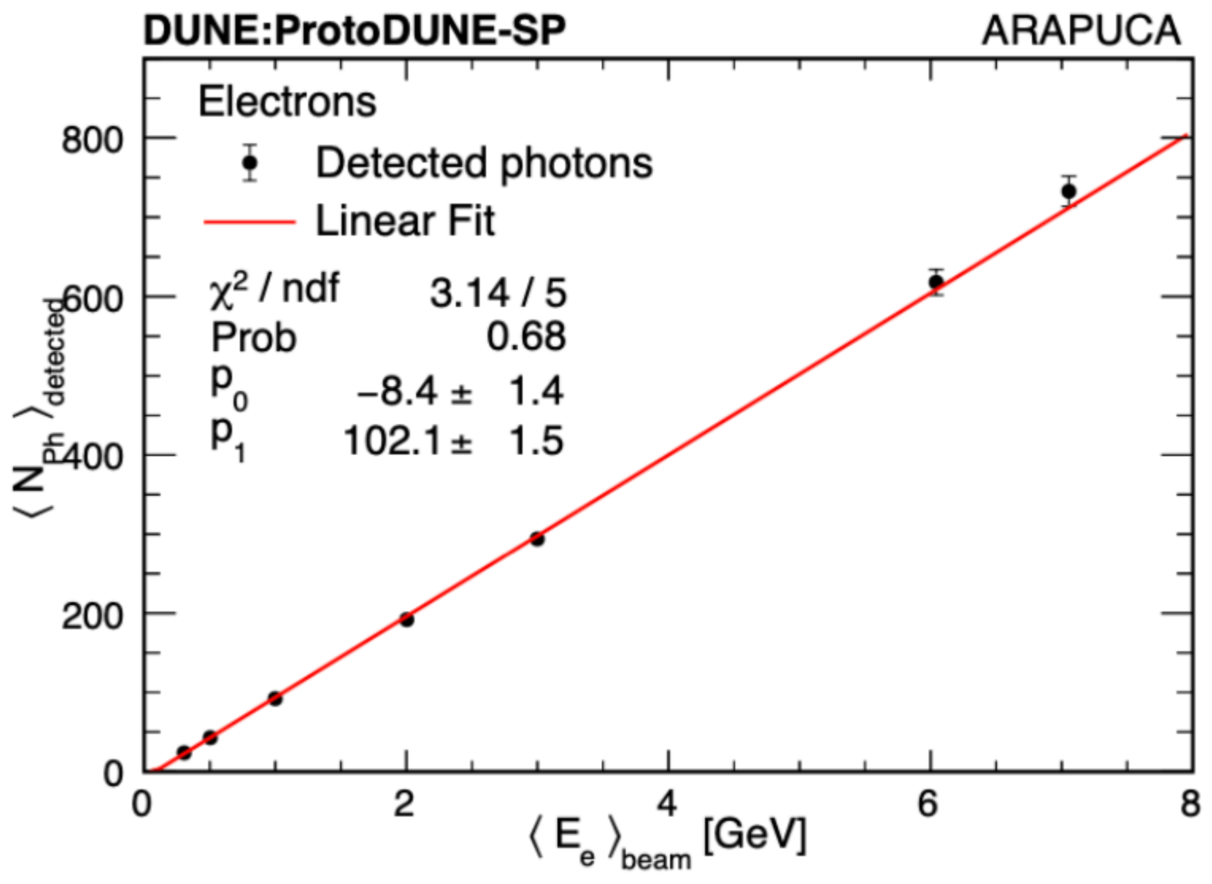


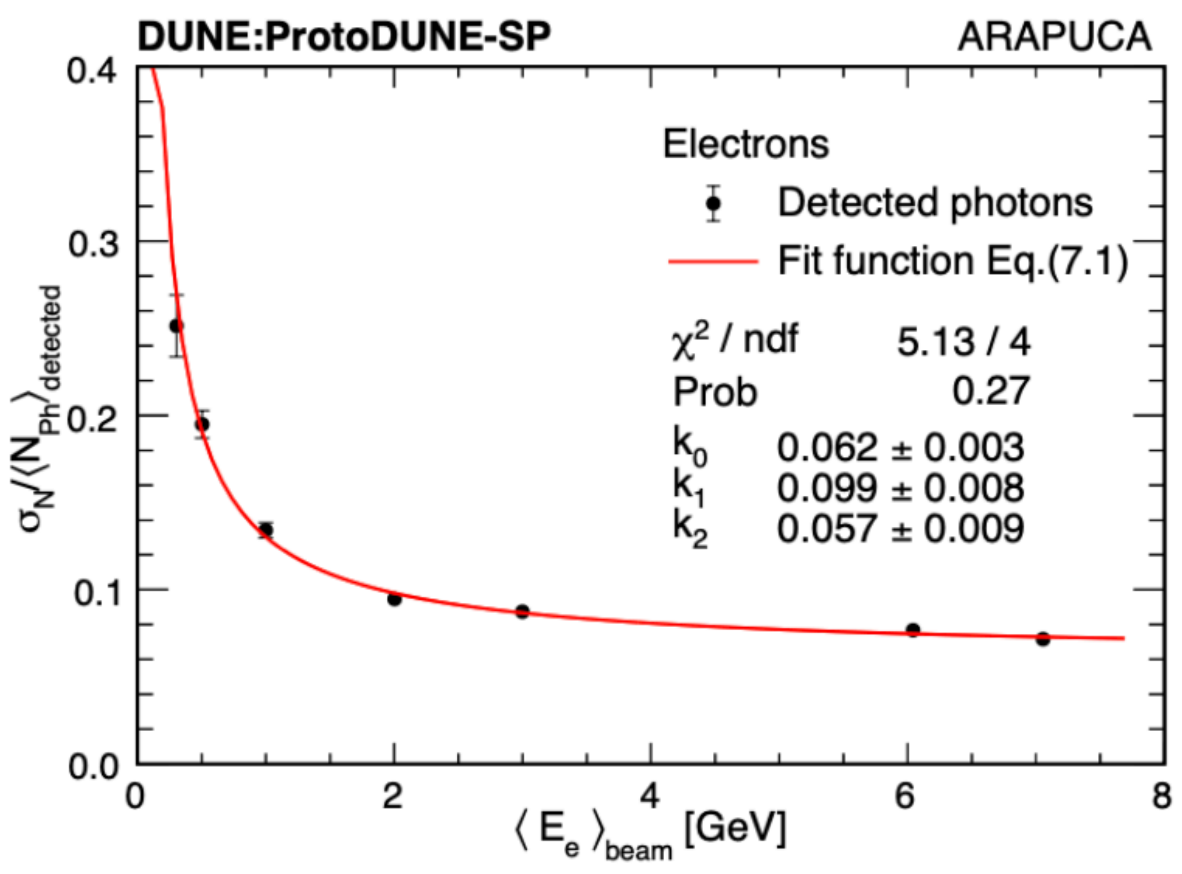




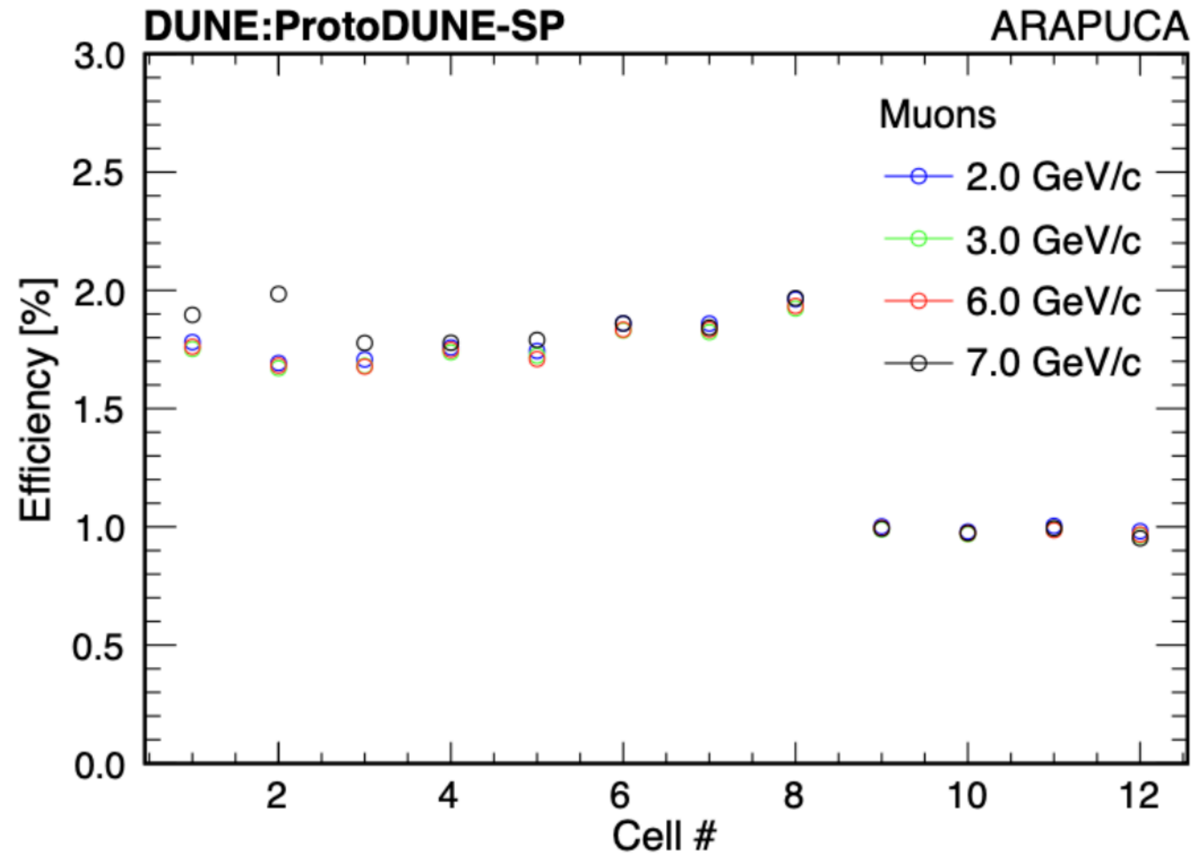
Other ongoing studies (plots from PD-1)

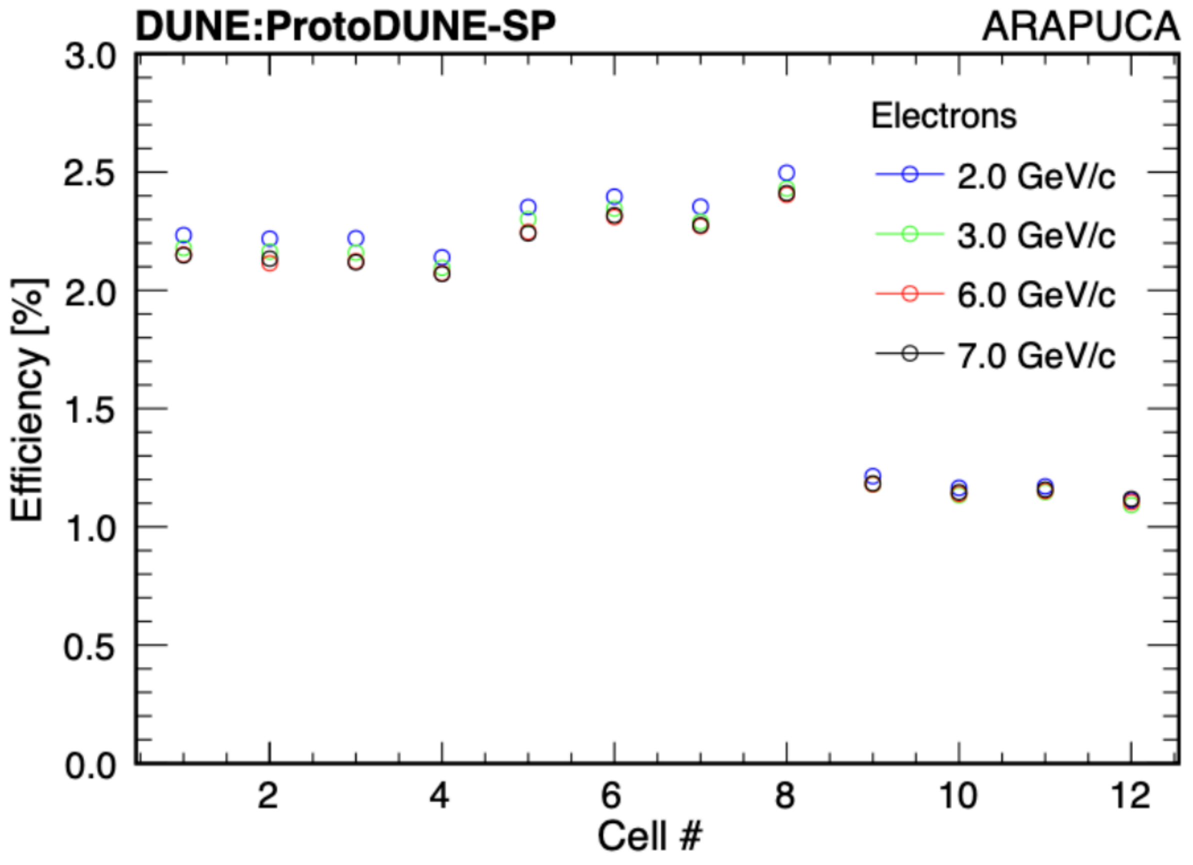
- Light yield vs beam energy and E resolution





- X-ARAPUCA efficiency (requires MC)





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

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 (Waveform Analysis Framework For Light Emission Studies)
  - 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 August and September

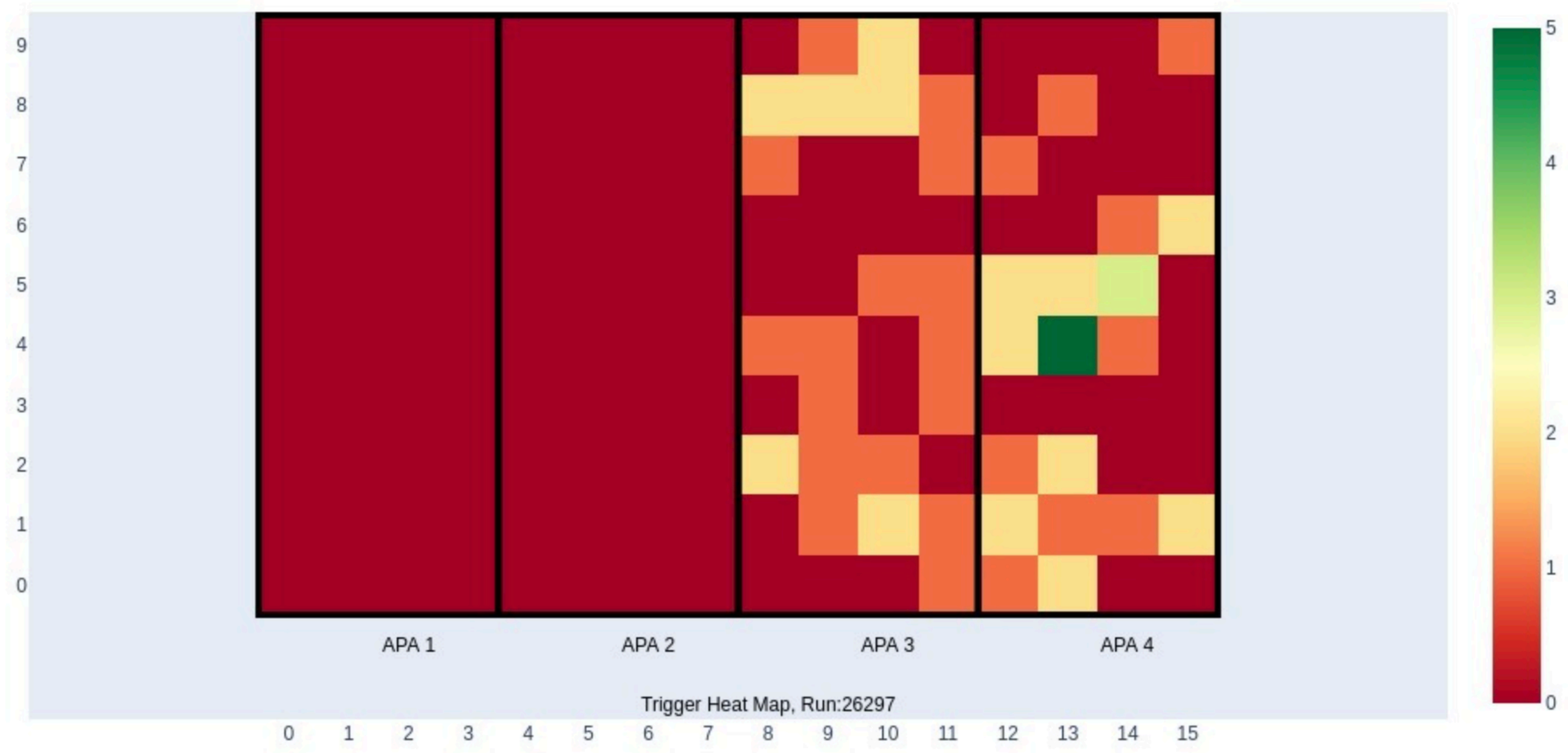
- During beam time PDS will request to be detached from the main run to perform few calibration runs:
  - Breakdown voltage calibration: 2 hours most likely tonight and in two weeks
  - s.p.e. LED calibration: 2 hours in 10 days from now
- Once the beam is over we will carry out self-trigger efficiency studies
- Lots of effort on the analysis side, but now partially in standby since many people is on vacation
  - The common analysis framework (WAFFLES) is being crucial, and will be very beneficial to export all lessons learned to the VD module (NP02) latest this year

Backup

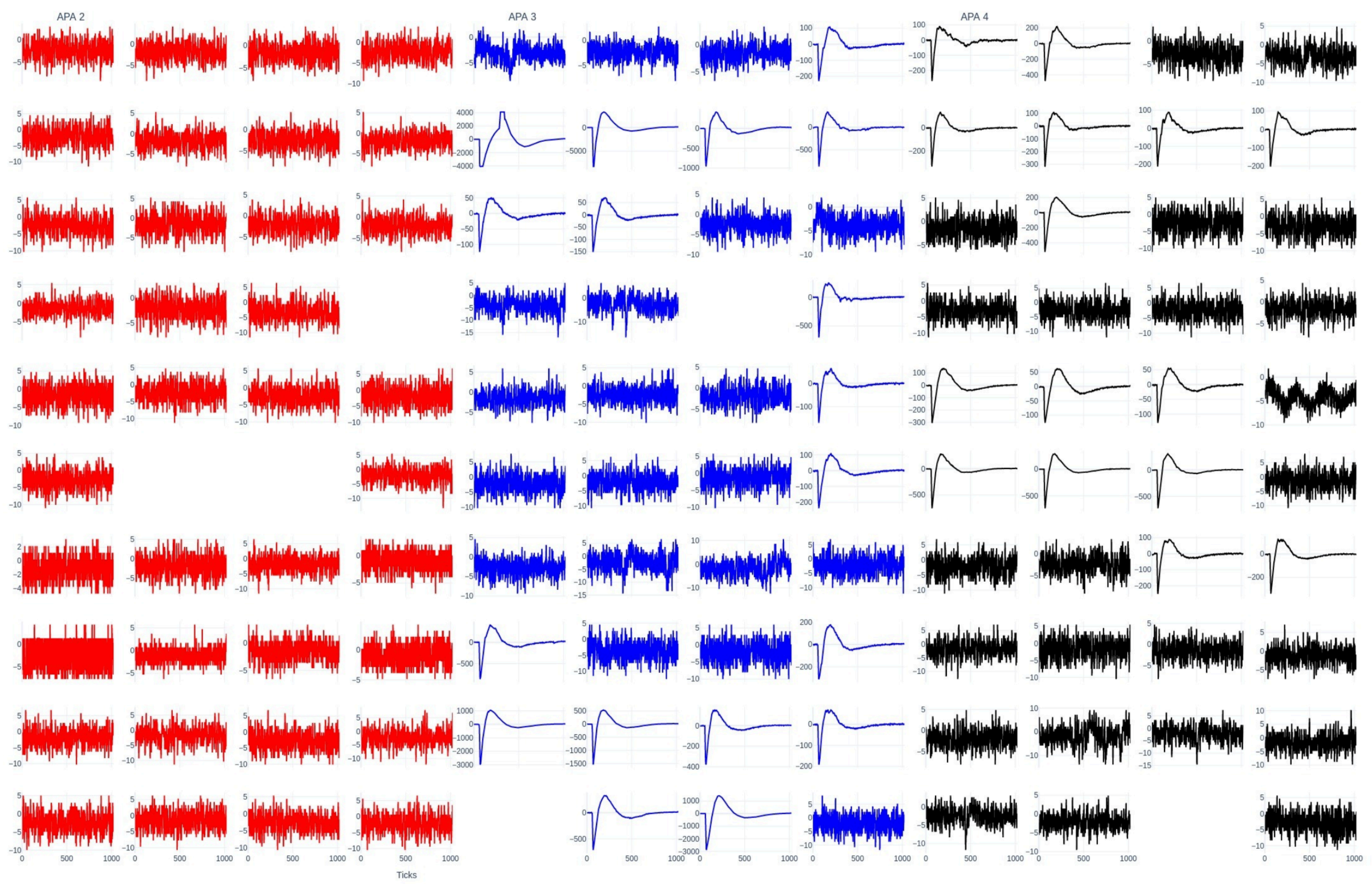
DQM plots for shifters

- Few **DQM** single record plots are ready through “official” DAQ dqmtools

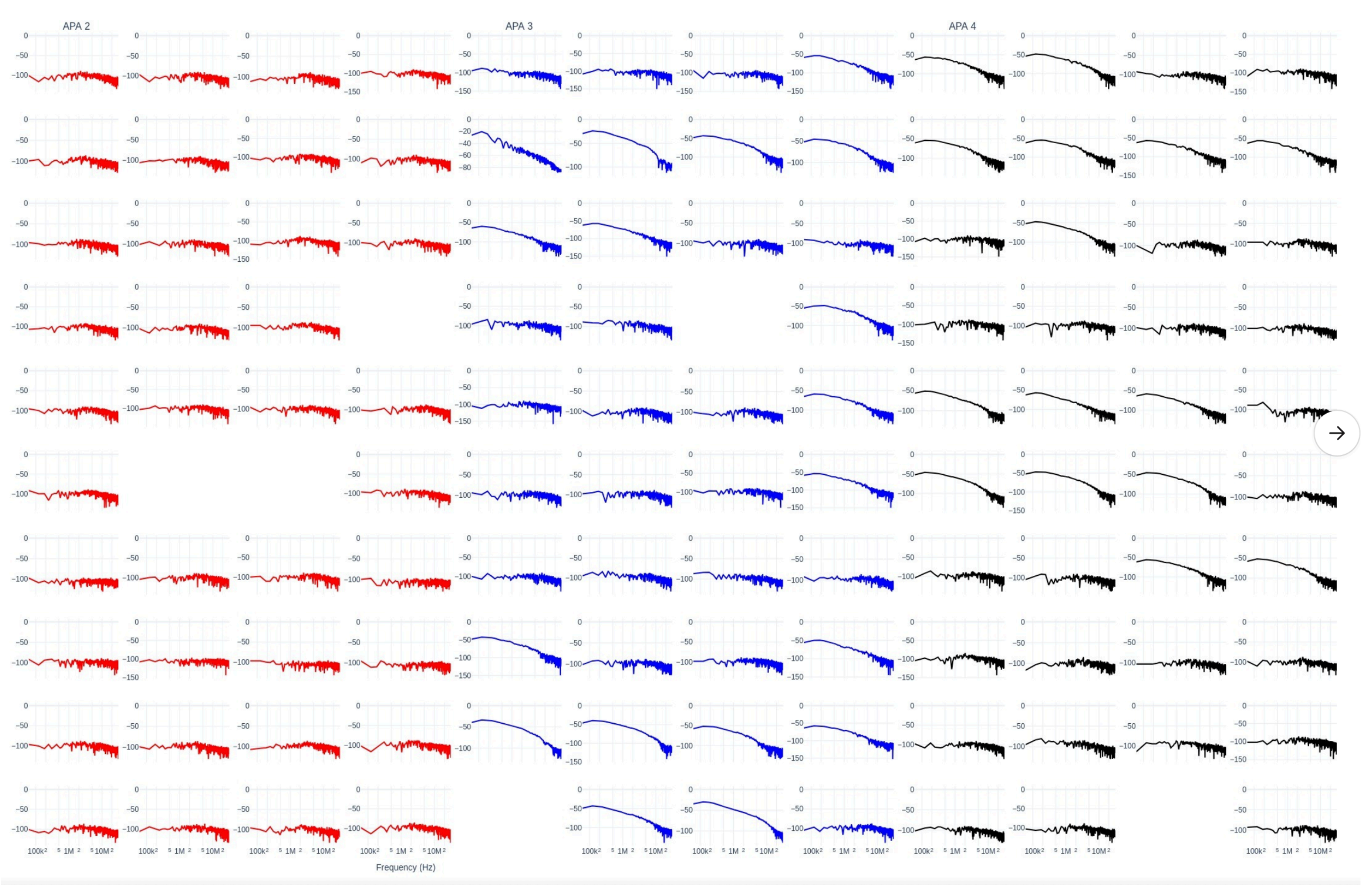
Trigger rate per channel



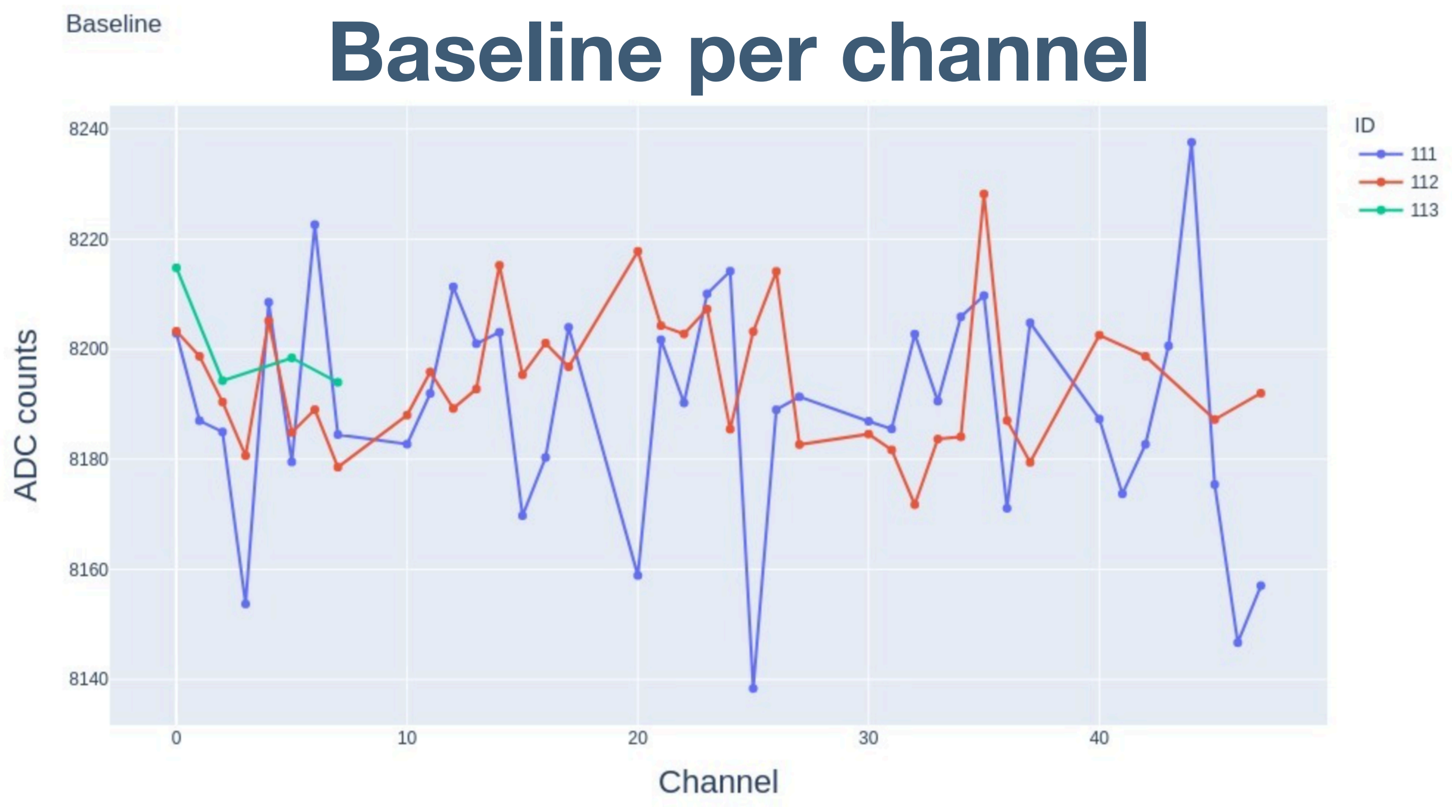
Average waveform per channel



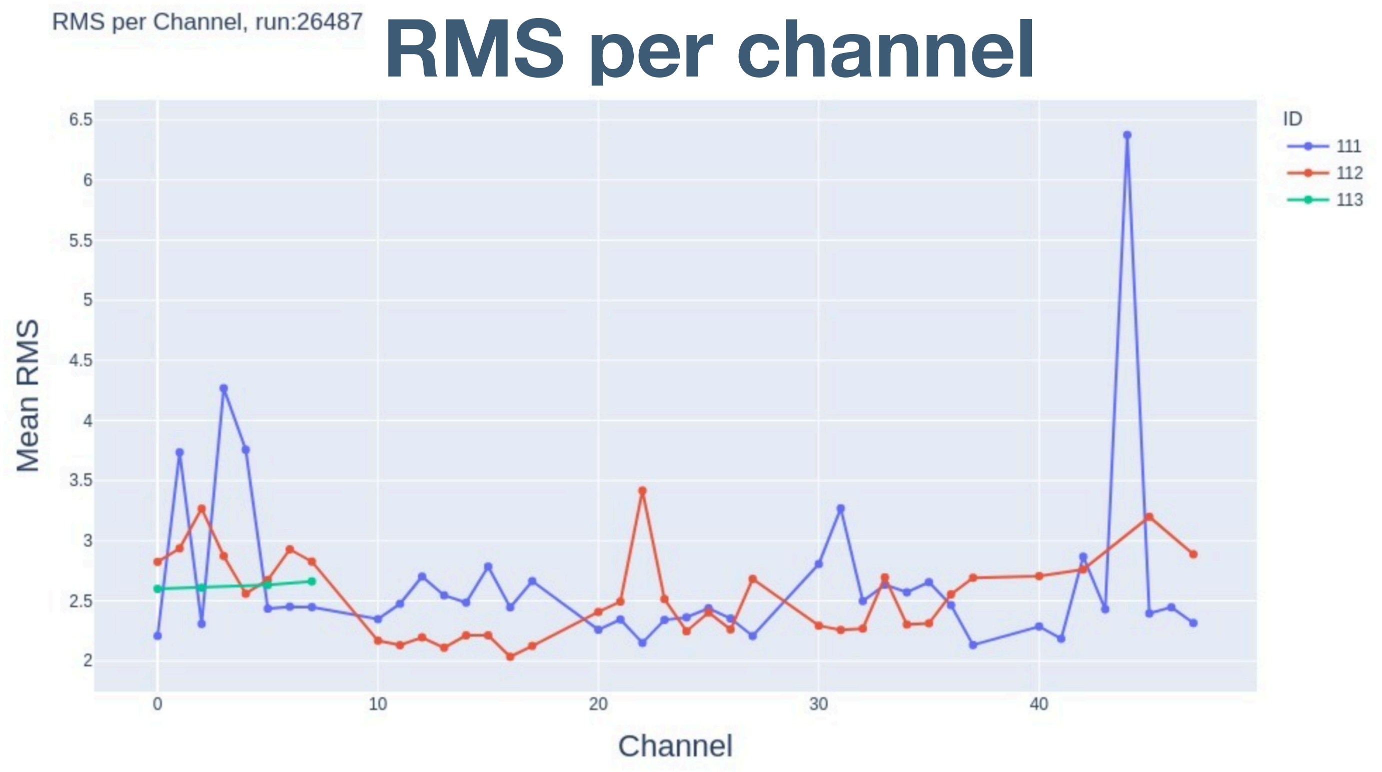
FFT per channel



Baseline per channel



RMS per channel



Increase bandwidth for self-trigger

- APA2-APA4 will operate in self-trigger mode
- Enabling proper reduction of the self-trigger threshold (to 1.5 p.e.) requires increasing the bandwidth
- We could use up to 4 FELIX links for each DAPHNE. This requires **new firmware** (almost ready) and **adding more fibers** to APA2-4 daphnes

Ongoing and planed analyses

- Compare PDS and beam timing. Study PDS timing resolution
- Light yield vs beam energy and particle type
- Light yield spatial and time distribution
- Light yield for various detector conditions (HV, XA OV, …) ?
- Self trigger-rate vs threshold
- X-ARAPUCA efficiency studies. Need MC. Maybe for later

PDS and beam timing

What do you need to do with the first beam and for how long

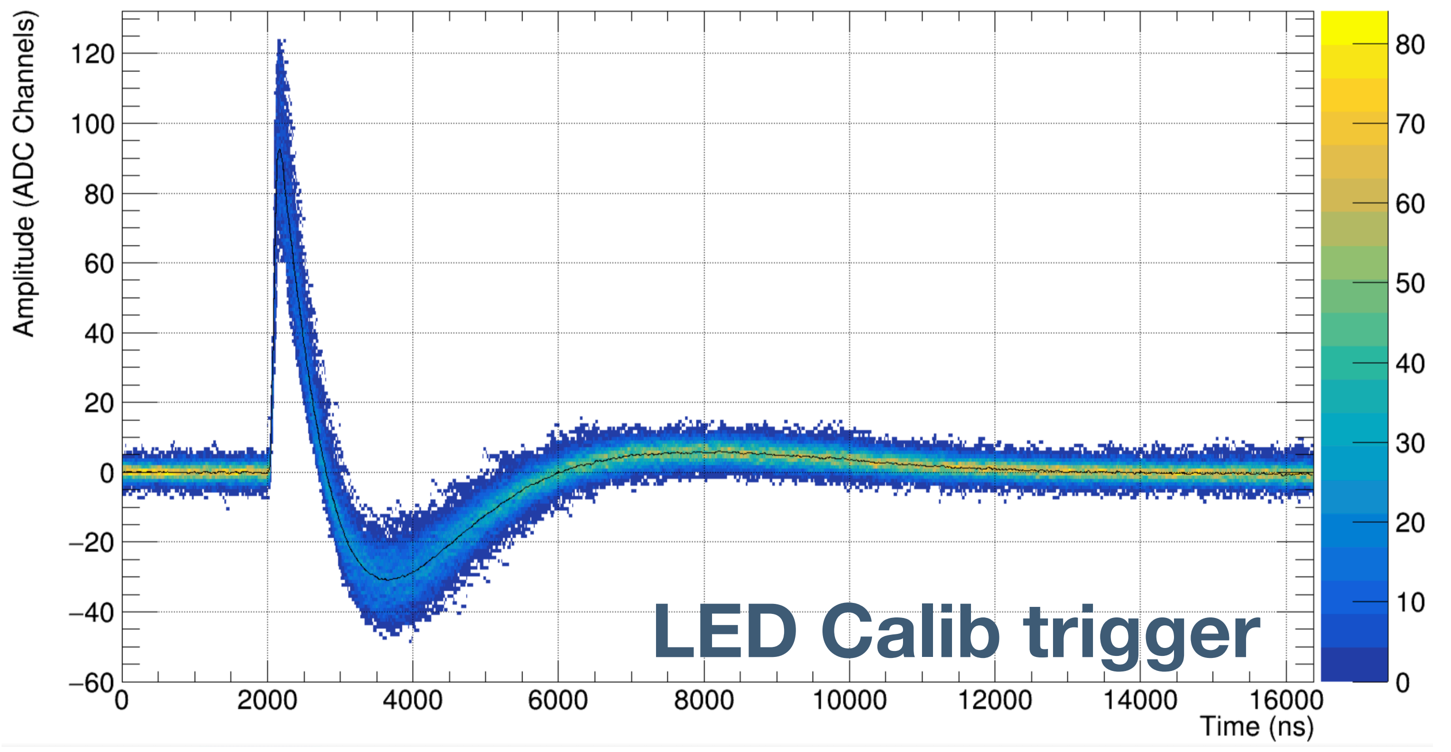
- In principle no calibrations during beam time:
  - IV curves and LED calibrations to be done immediately before
- Are there plans (is it possible?) to modify cathode HV during beam time ?
- It would be useful to have a random trigger (TI command probably) to monitor noise, FFTs, DCR, cosmic rate, …
- CRT trigger also useful to remove cosmic bkg
- Request to have regular tau slow calibration during beam time

		Momentum (GeV/c)			
		1	**2**	**3**	**6 - 7**
e	TOF (ns)	0, 105	0, 105	–	–
	XCET-L	1	1	1	1
	XCET-H	–	–	1	1
μ / π	TOF (ns)	0, 110	0, 103	–	–
	XCET-L	0	0	0	1
	XCET-H	–	–	1	1
K	TOF (ns)	–	–	–	–
	XCET-L	–	–	0	0
	XCET-H	–	–	0	1
p	TOF (ns)	110, 160	103, 160	–	–
	XCET-L	0	0	0	0
	XCET-H	–	–	0	0

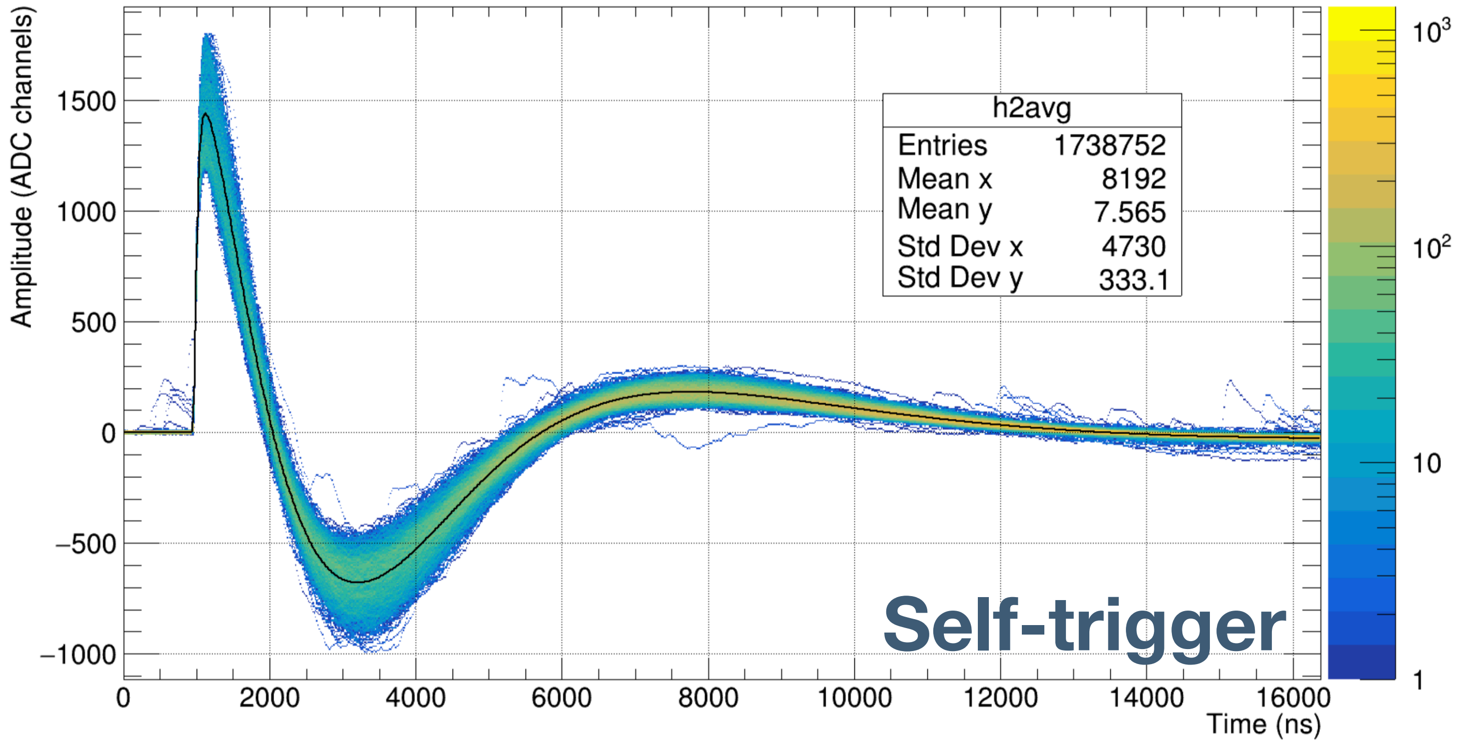
First *physics* result

- Measurement of the slow component of the liquid argon scintillation light
- Use LED pulses for deconvolution of detector effects and cosmic muons for the actual analysis

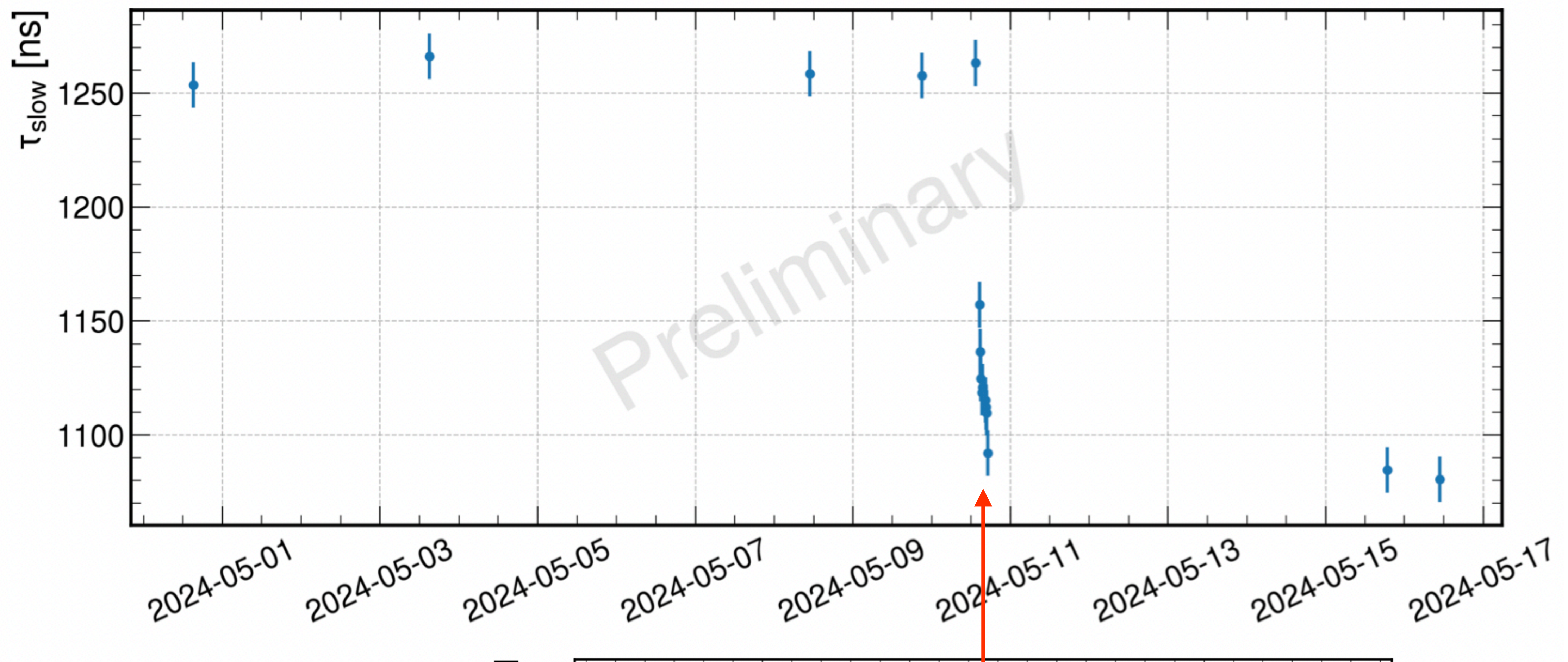
selected large intensity LED flashes

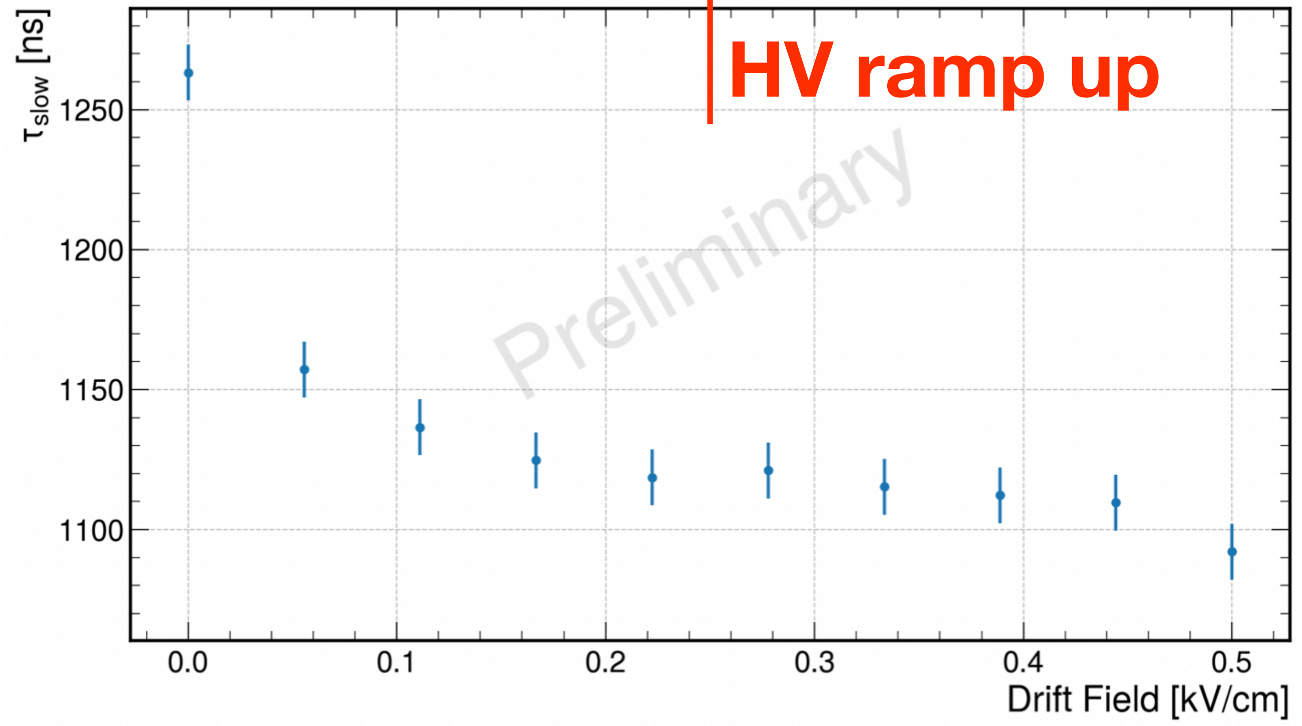


selected waveforms from muons



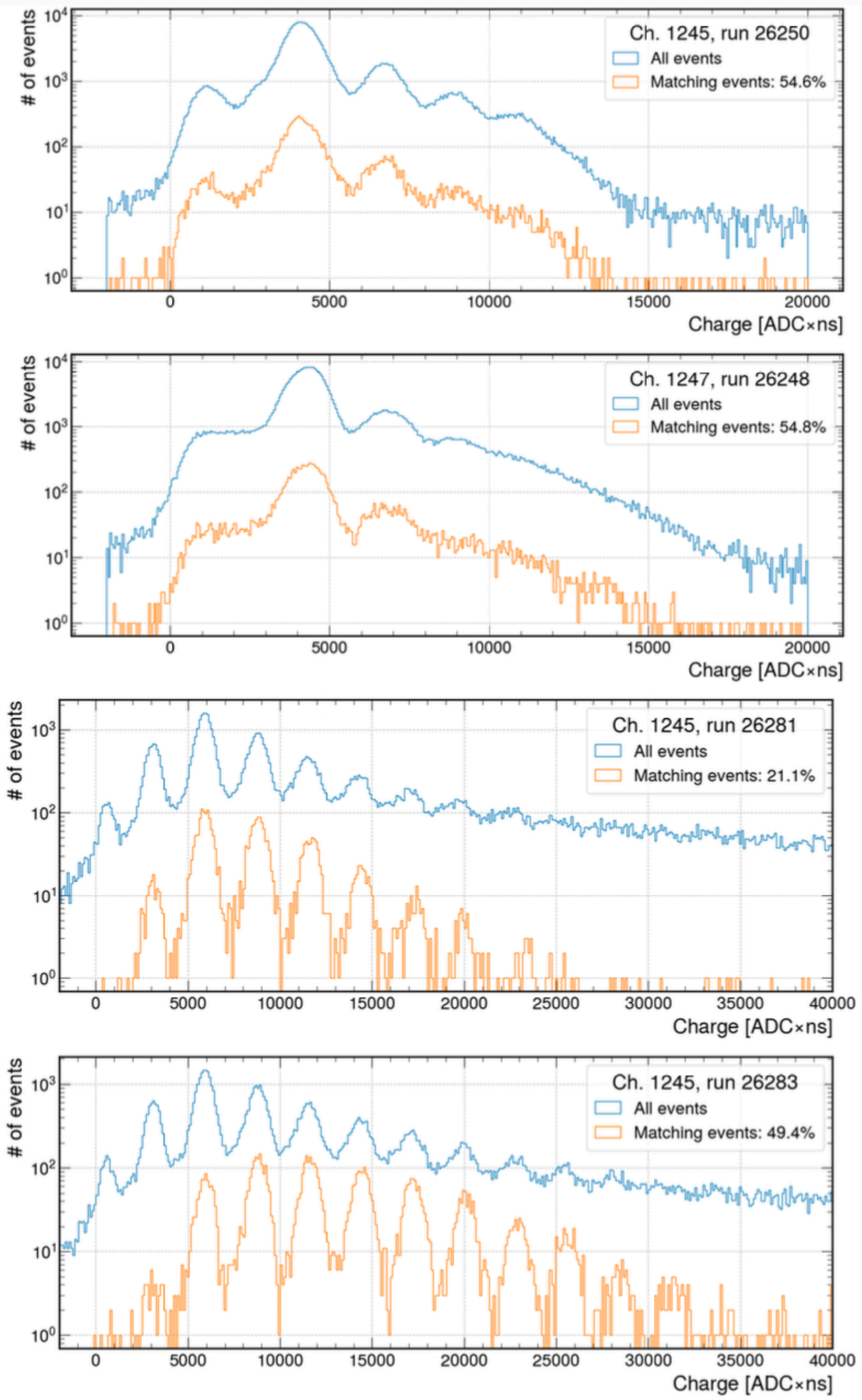
evolution with time of τ_{slow}





τ_{slow} vs drift field during HV ramp up

Self-trigger testing



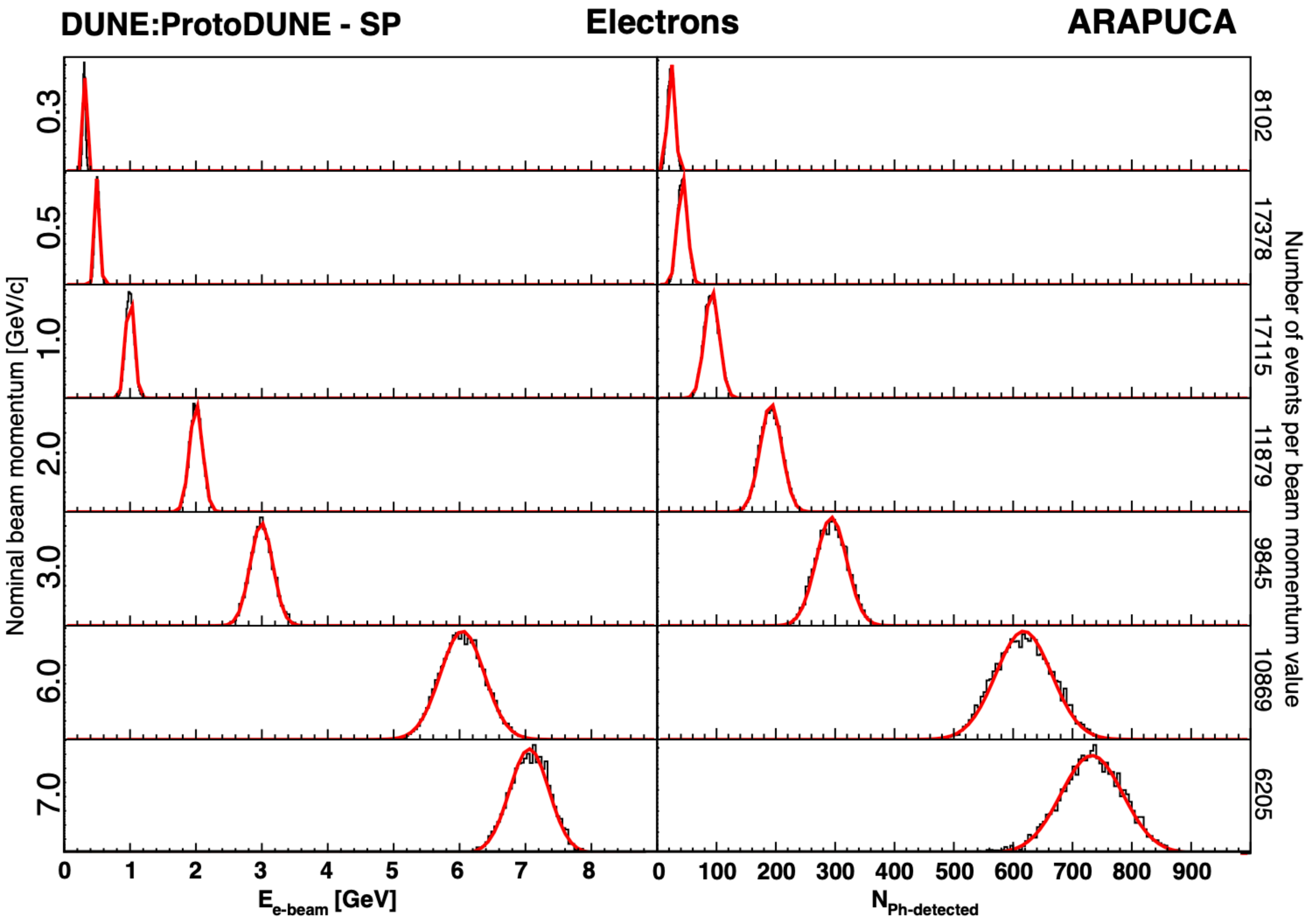
DEEP UNDERGROUND NEUTRINO EXPERIMENT

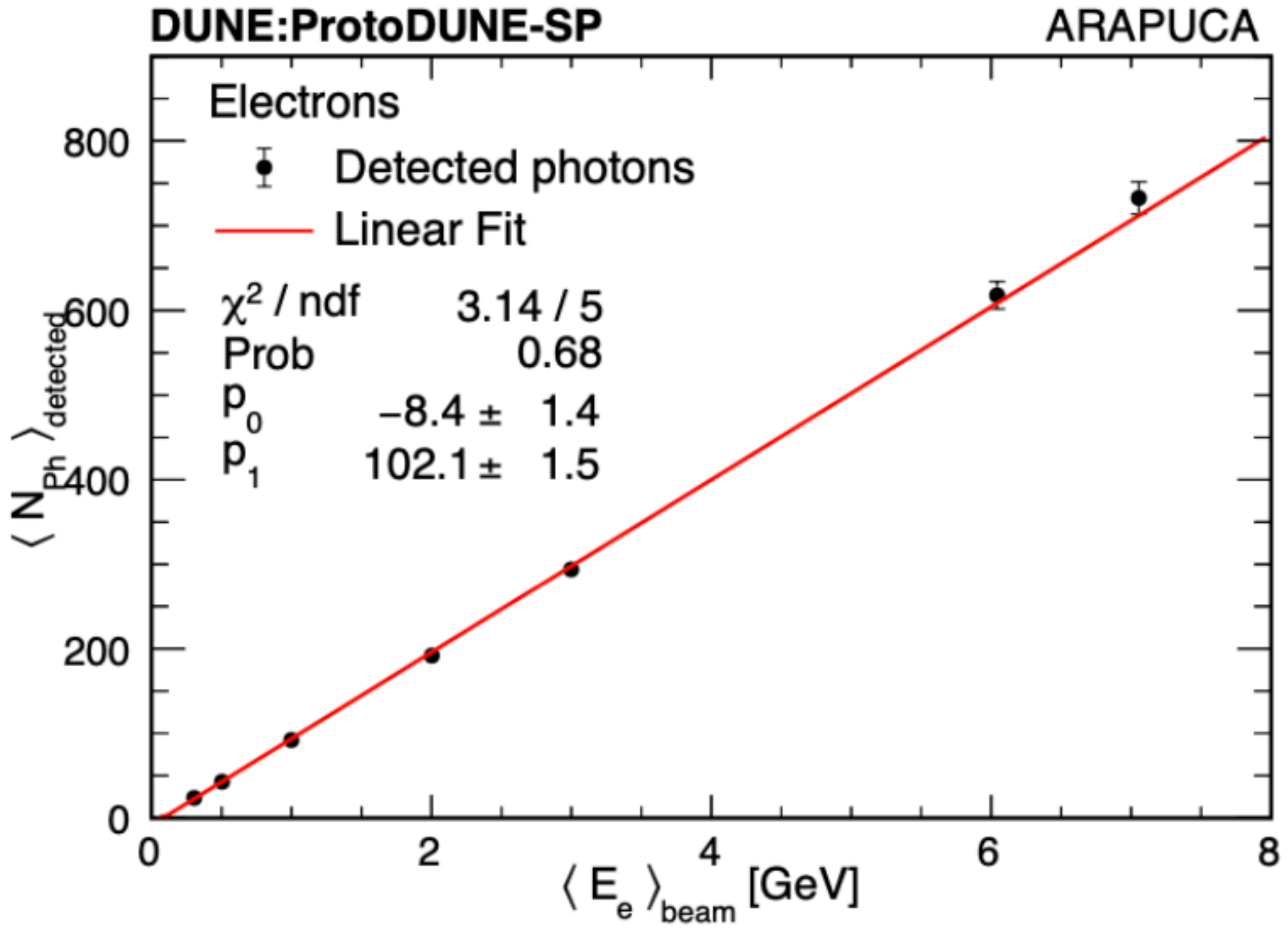
Self Trigger Algorithms Procedure / Conditions:

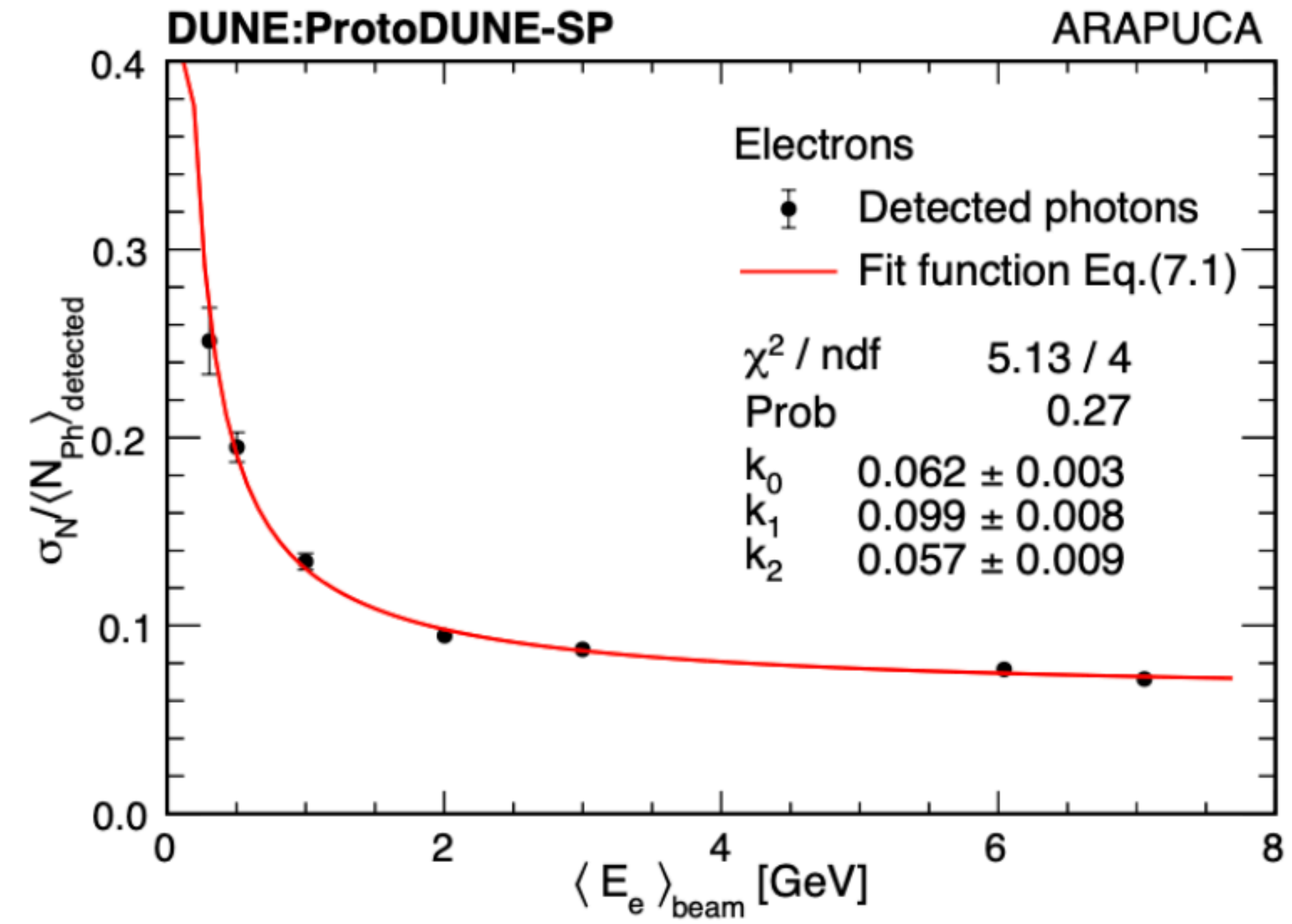
- We use LED signals and calibration for SPE as a reference.
- Using the same PD module we launch a run in self trigger mode still using the LED signal, and saving the Time Stamps.
- We remove data from LAr Scintillation.
- We represent efficiency as a ratio between both charge histograms.

D.Avila, I.López, E.Cristaldo, A.Verdugo, H.Souza, C.Benitez

Light yield vs beam energy







- Ideally, this study should be done for all other beam particle types

Studies requiring MC simulation

- X-ARAPUCA efficiency studies comparing number of detected photons (data) and number of incident photons (MC)