Fermilab

Final Term Review

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DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Supervisors:

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- Alexander Kish

Neutrino oscillations

The primary objective of DUNE is to study lon-baseline neutrino oscillations

Origin of Matter

Could neutrinos be the reason that the universe is made of matter rather than antimatter? By exploring the phenomenon of neutrino oscillations, DUNE seeks to revolutionize our understanding of neutrinos and their role in the universe.

Unification of Forces

With the world's largest cryogenic particle detector located deep underground, DUNE can search for signs of proton decay. This could reveal a relation between the stability of matter and the Grand Unification of forces, moving us closer to realizing Einstein's dream.

Black Hole Formation

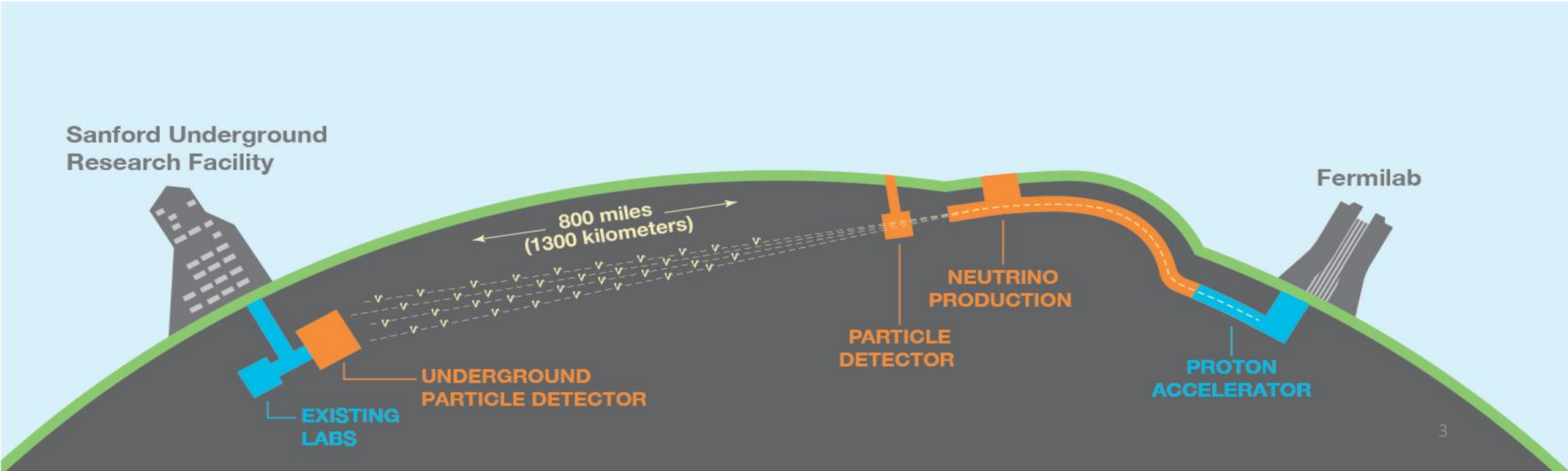
DUNE's observation of thousands of neutrinos from a core-collapse supernova in the Milky Way would allow us to peer inside a newly-formed neutron star and potentially witness the birth of a black hole.

A neutrino beam will be generated using the proton accelerator complex at Fermilab. The location in deep underground would allow detection of neutrinos of astrophysical origin (and possibly other rare underground phenomena) in a lower energy range (10-100 MeV) compared to beam neutrinos (1-10 GeV)

The **Near Detector (ND):** located at Fermilab, characterizes and monitors the beam
The **Far detector (FD)**: the largest and most technologically advanced liquid-argon neutrino detector
An underground cavern is currently under construction, to contain **4 detector modules**. At least two of these will use **Liquid Argon Time Projection Chambers (LArTPC)**

(FD-1) will be a **Horizontal Drift (HD)** LArTPC

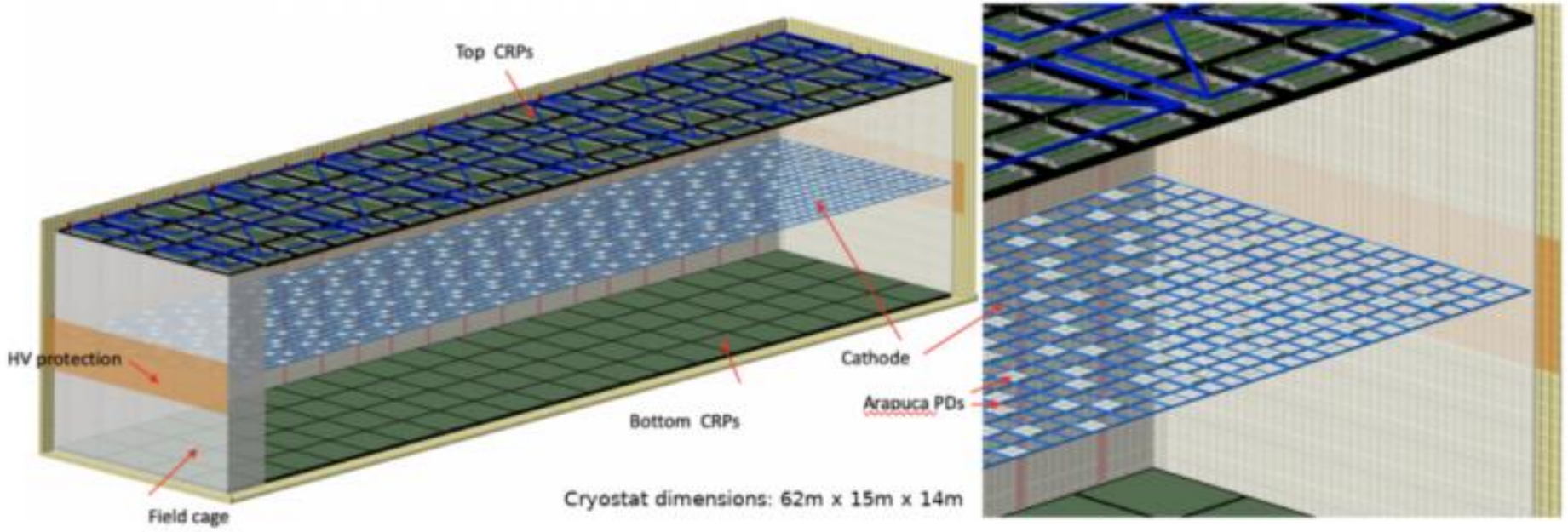
(FD-2) will be a **Vertical Drift (VD)** LArTPC



VD-LArTPC

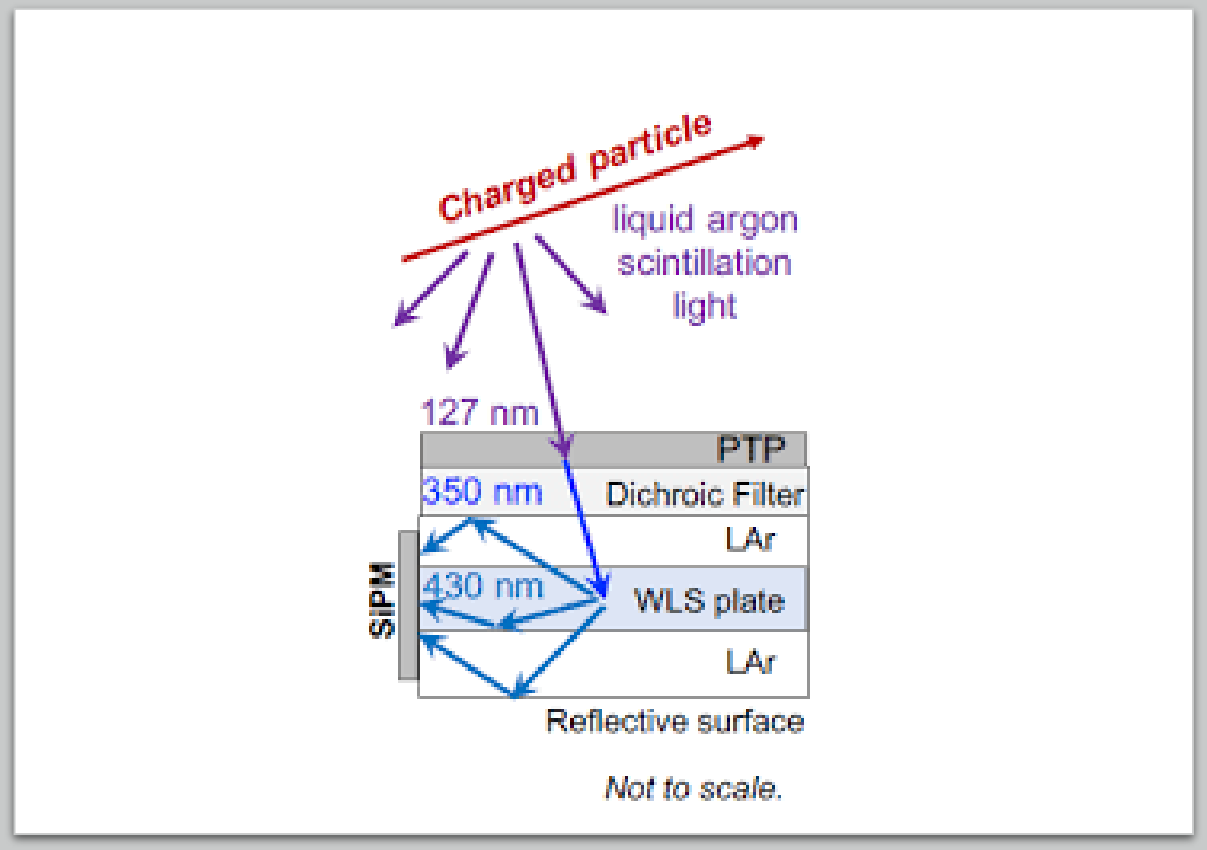
Charge generated by **ionization** is drifted towards a set of grids which allows the reconstruction of particles' trajectories inside the chamber. Argon **scintillation light** is also collected providing **fast timing** information used in event time reconstruction, precise calorimetric energy reconstruction and efficient triggering capability, and to reduce energy threshold and study low-energy neutrino interactions (e.g. SuperNova neutrinos)

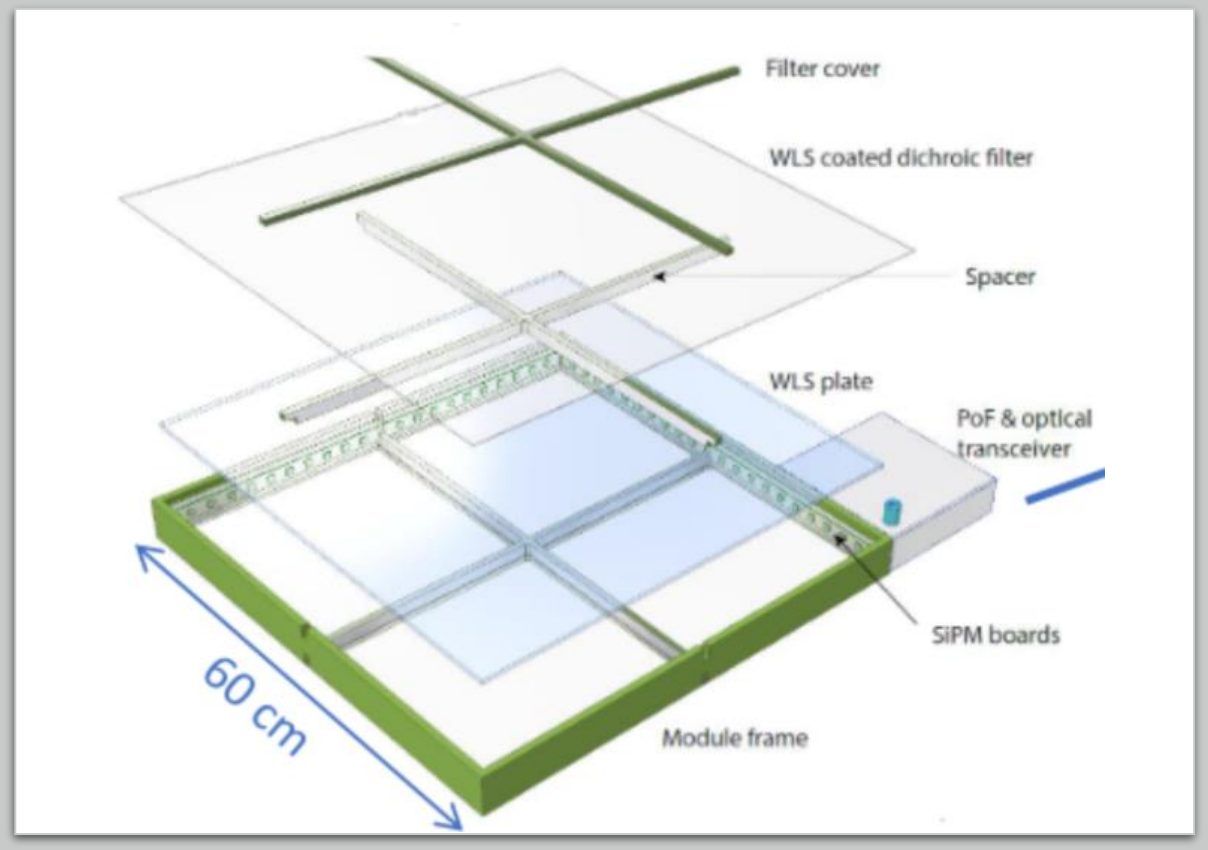
Divided into two volumes by a central horizontal cathode, each volume will have its own anode plane, parallel to the cathode, where electrons will be collected by **Charge Readout Planes**.



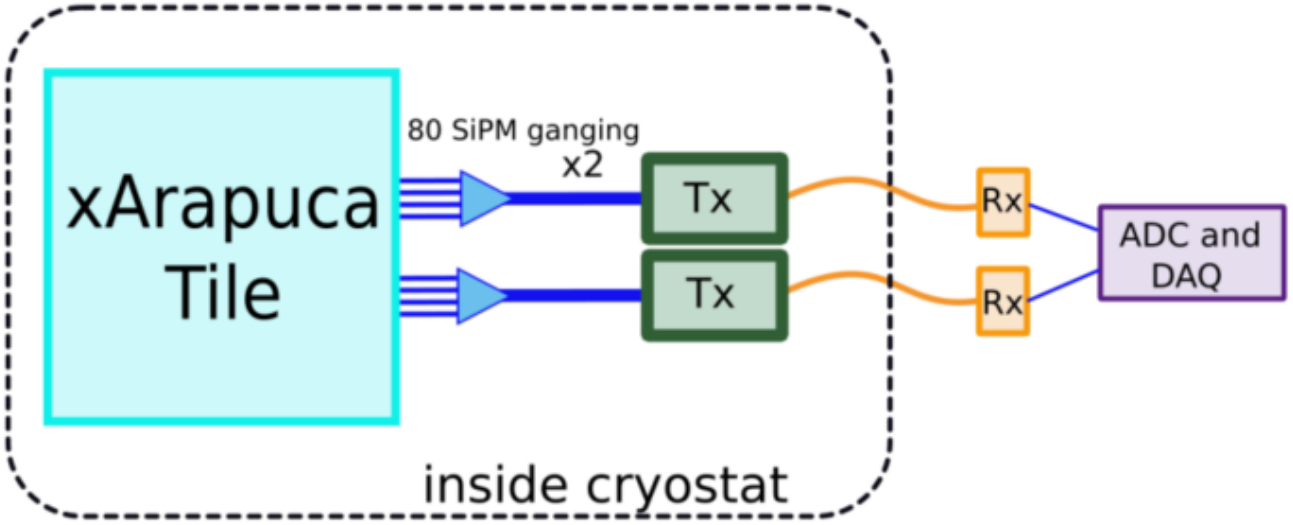
PDs

- This **Photon Detection System (PDS)** will use large 60 x 60 cm2 **X-Arapucas,** a box with highly reflective internal walls and with a set of wavelength shifters and a dichroic filter designed to trap photons on the inside of the device so they can be detected by silicon photomultipliers (SiPM)





PoF & SoF



Analog Optical Transmitter inside the cryostat to bring the signal produced by PDs to a **Receiver** and **Digitizer**, both placed in warm

Power will be supplied **over fiber**. The light of a high-power laser will be transmitted using multi-mode fibers to a photovoltaic power converter placed inside the cryostat and close to the photo-sensors.

Fermilab is leading the development of the **Power Delivery Over Fiber** (**PoF**) and front-end electronics for **Analog** and **Digital Optical Signal Transmission** (**SoF**).
Dedicated R&D and test facility is in operation at the FNAL Proton Assembly Building (PAB)

Main Aim

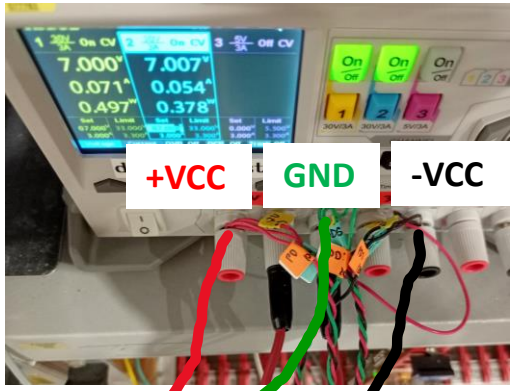
Testing and characterization of silicon photomultipliers (SiPMs) and their aggregated read-out, optimization of the analog optical readout electronics (SoF)

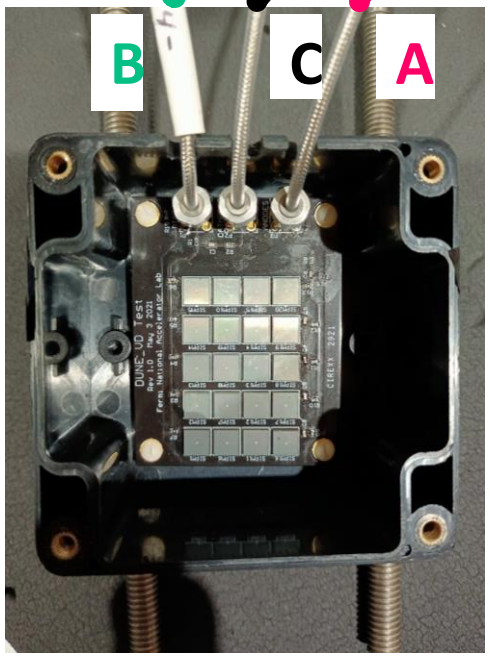
Experimental Setup 1

Test schematic

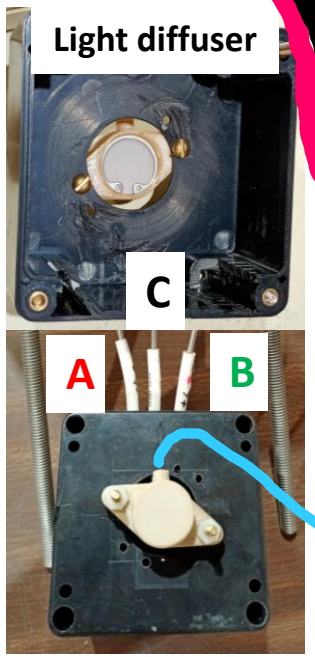
Single Mode OF
$(9\mu m)$

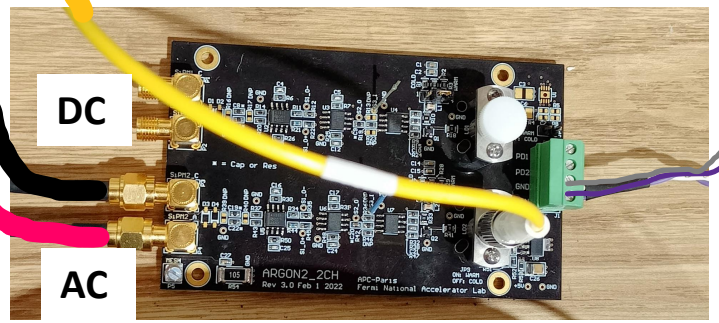
Analog Optical Transmission
(Argon2x2)

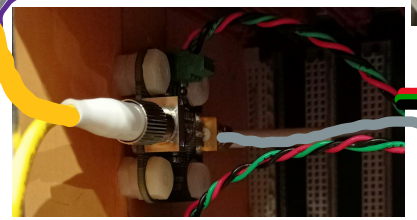




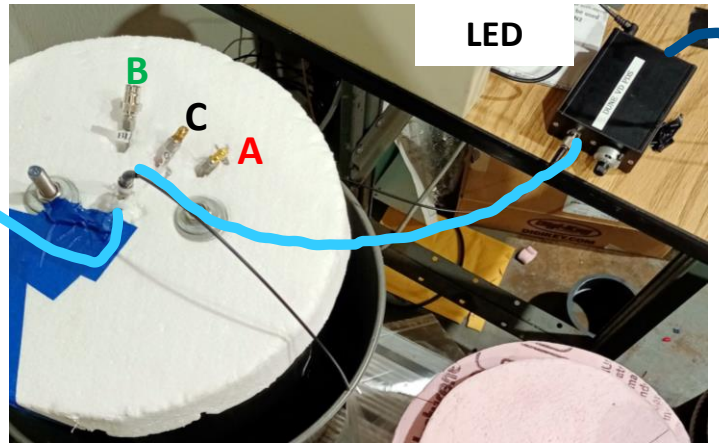
20 SiPM test card







Optical Receiver
(Koheron PD100)



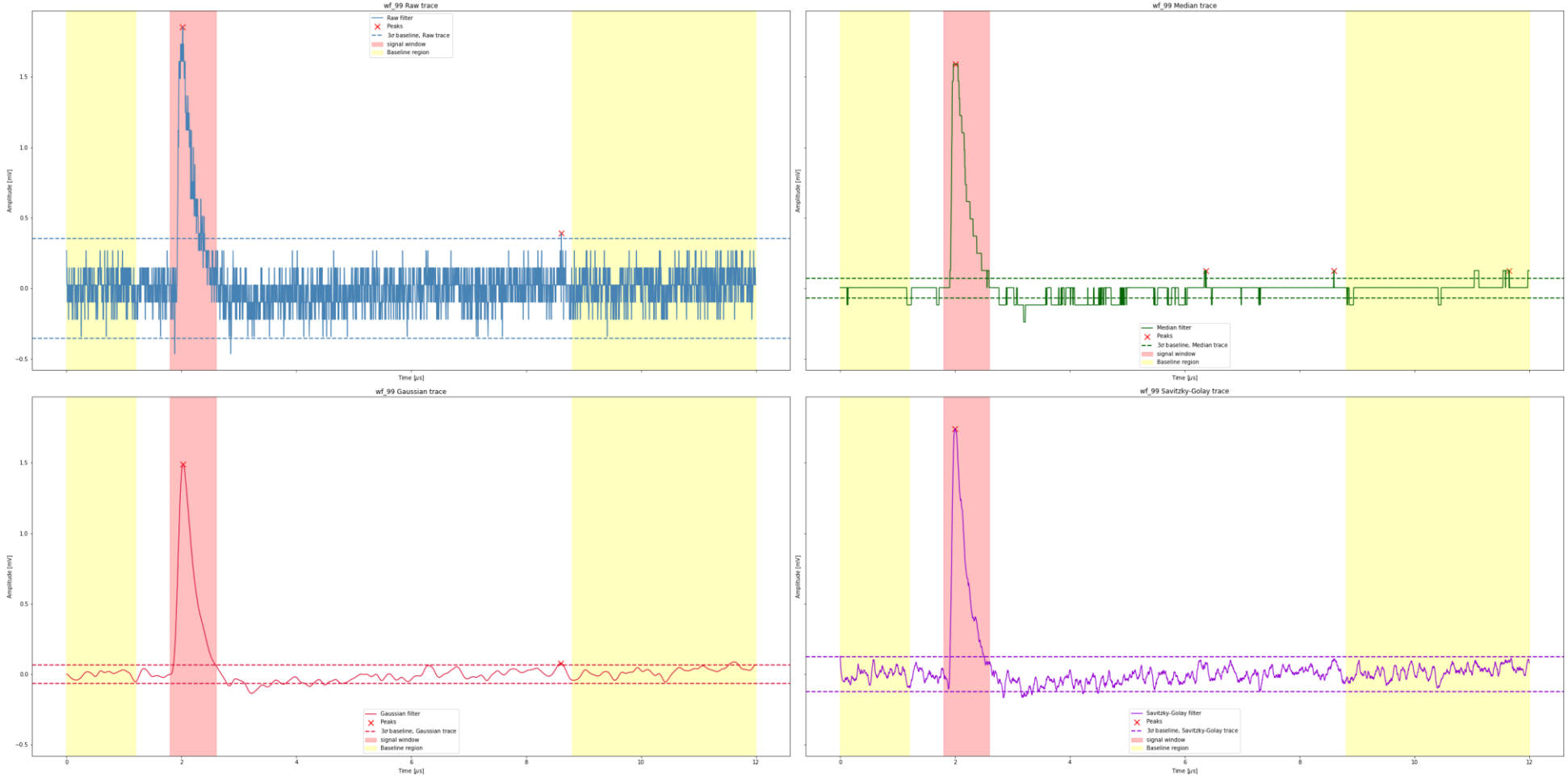
LED used as Trigger

Digitizer (CAEN, TTL)

Data taken on: 01 September 2022

Example of waveform (mean bsl subtracted)

The signals in this test were by LED flashes (with the SiPM board in liquid Argon bath)



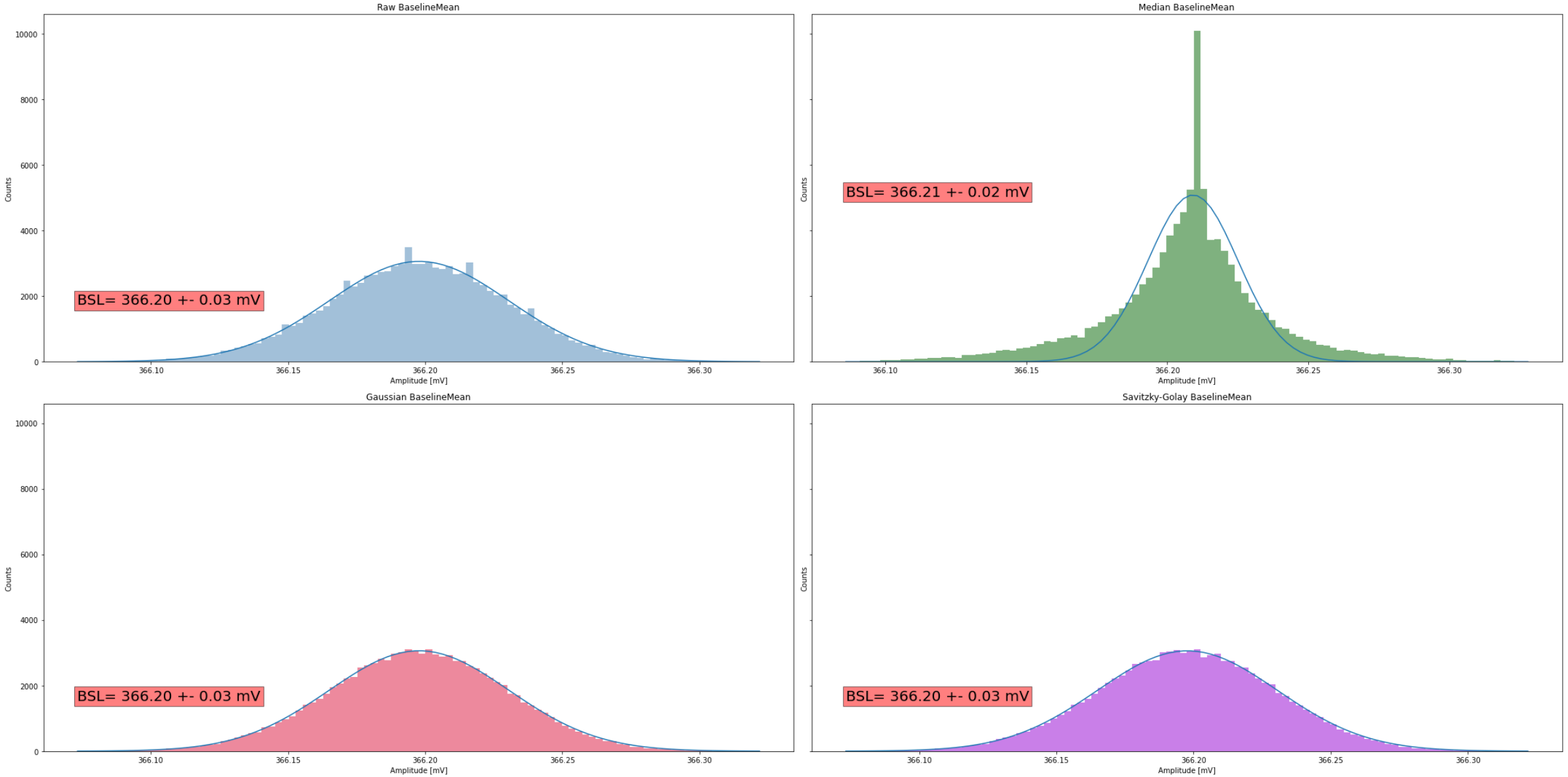
3 high frequency digital filters:

- **Median**
- **Gaussian**
- **Savitzky-Golay**

Algorithm to find peaks (calibration with low intensity laser, sensitive to single p.e.)

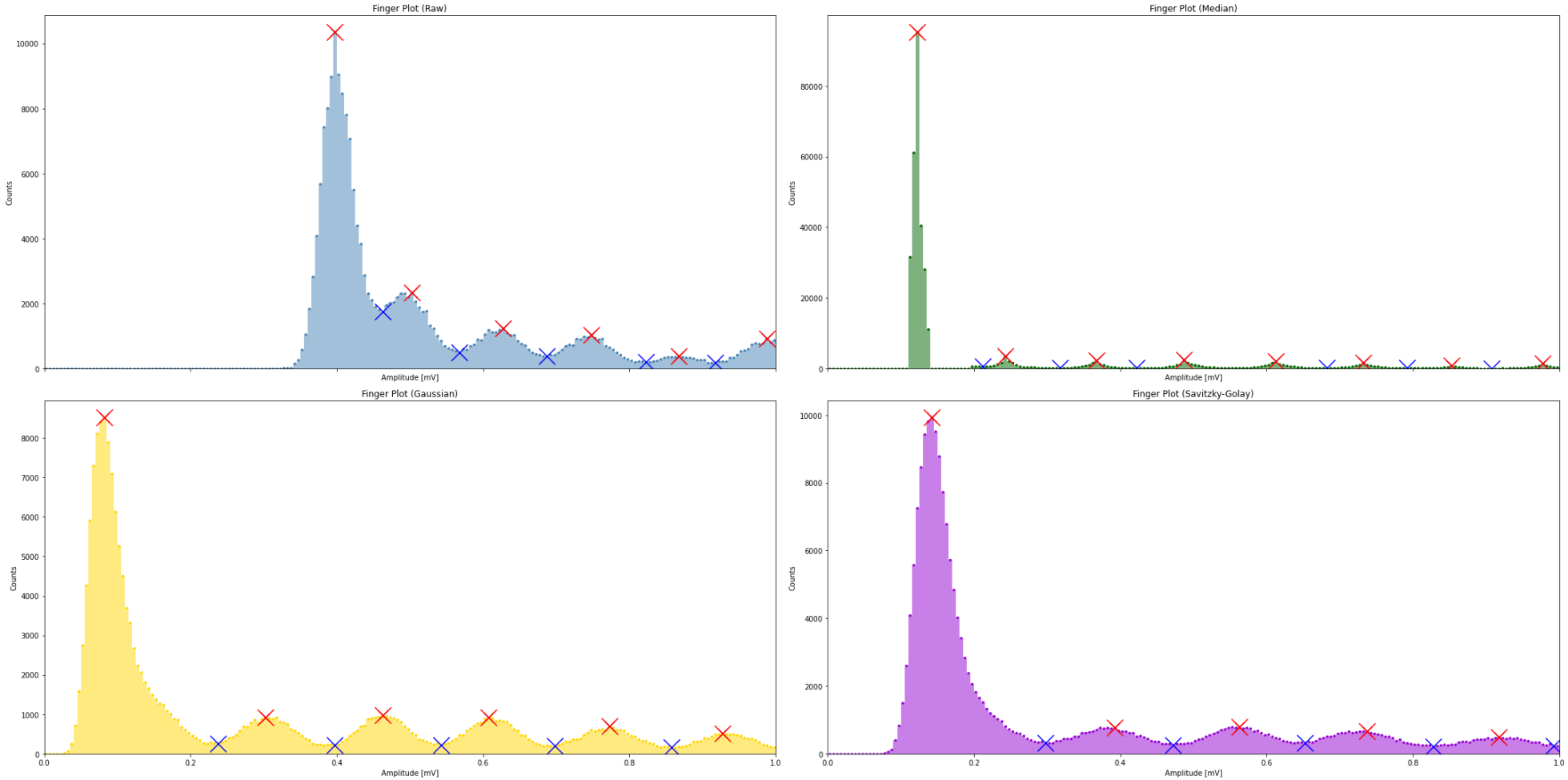
Already scaled down by baseline value (mean in first 300 samples)

Mean Baseline distribution



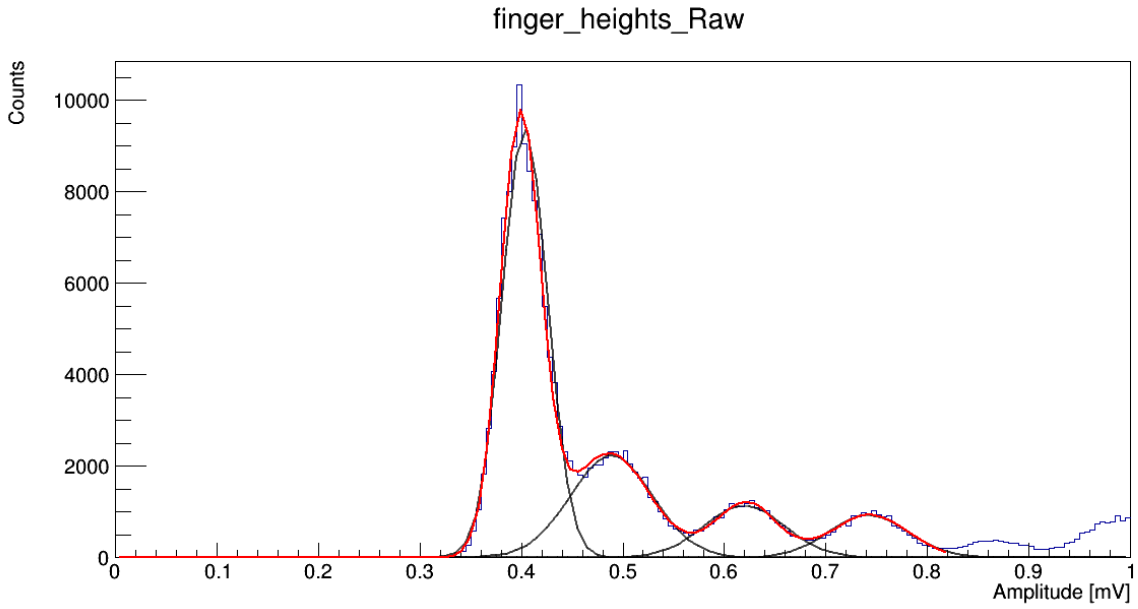
Finger Plot (peaks amplitudes)

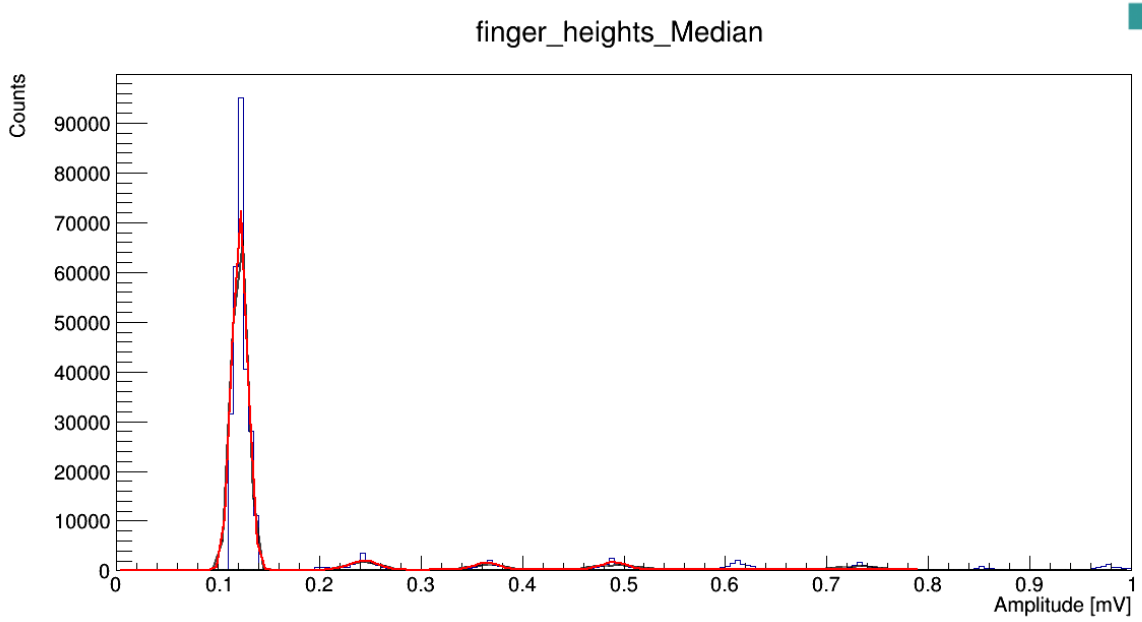
For each event (waveform) we consider the amplitudes of all peaks found, and make an histogram across all the events, obtaining the so called «**Finger Plot**»

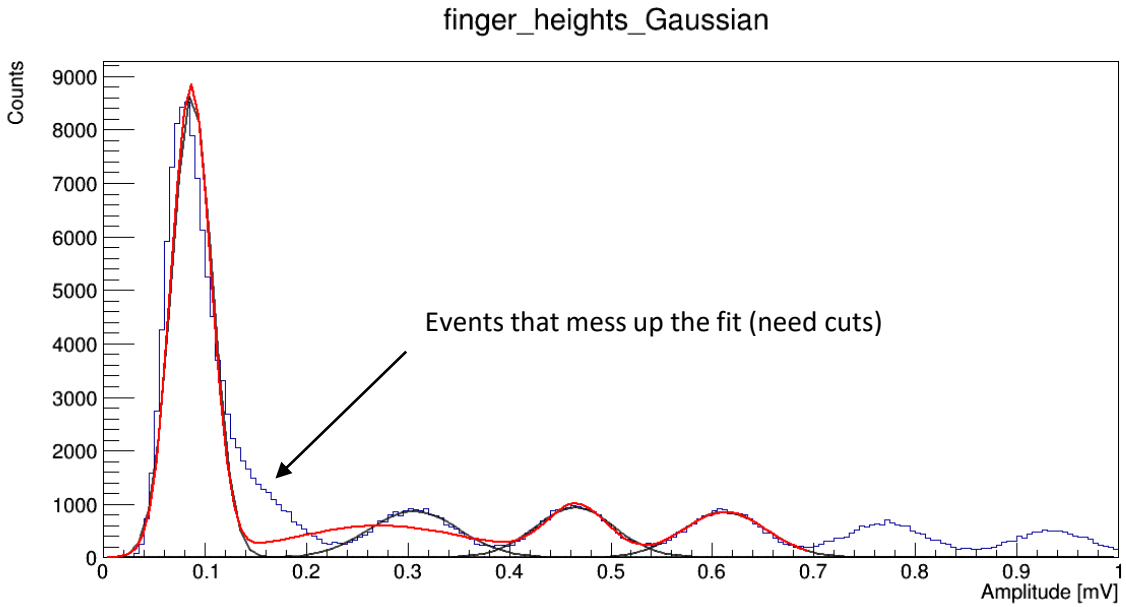


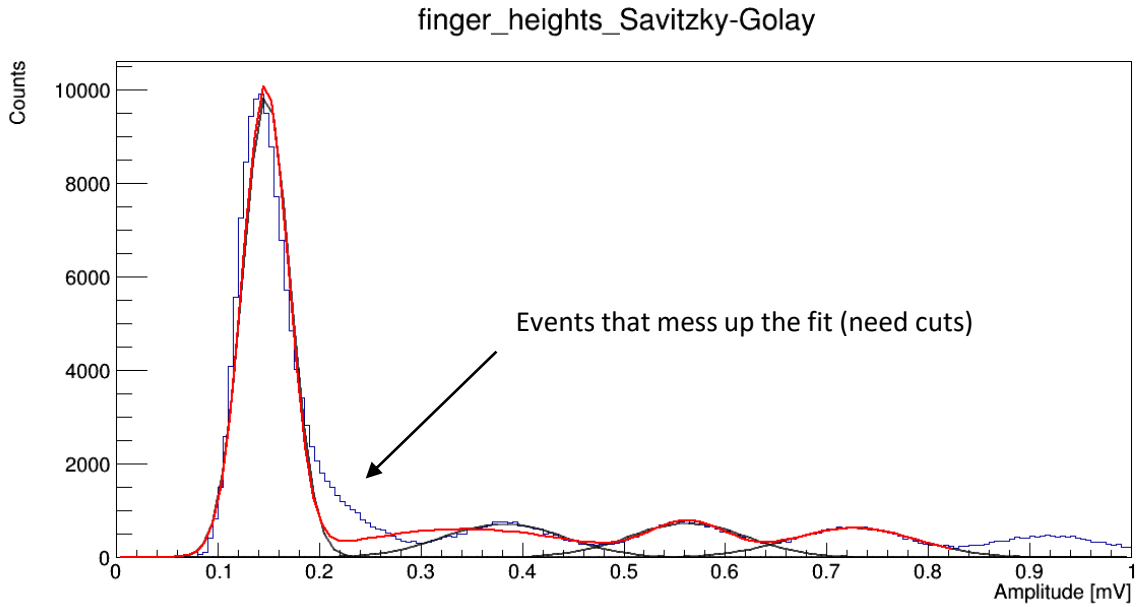
- Why Raw data starts with higher amplitudes?
- One can notice that filters generally lower the amplitude of a peak.

Finger Plot (peaks amplitudes)

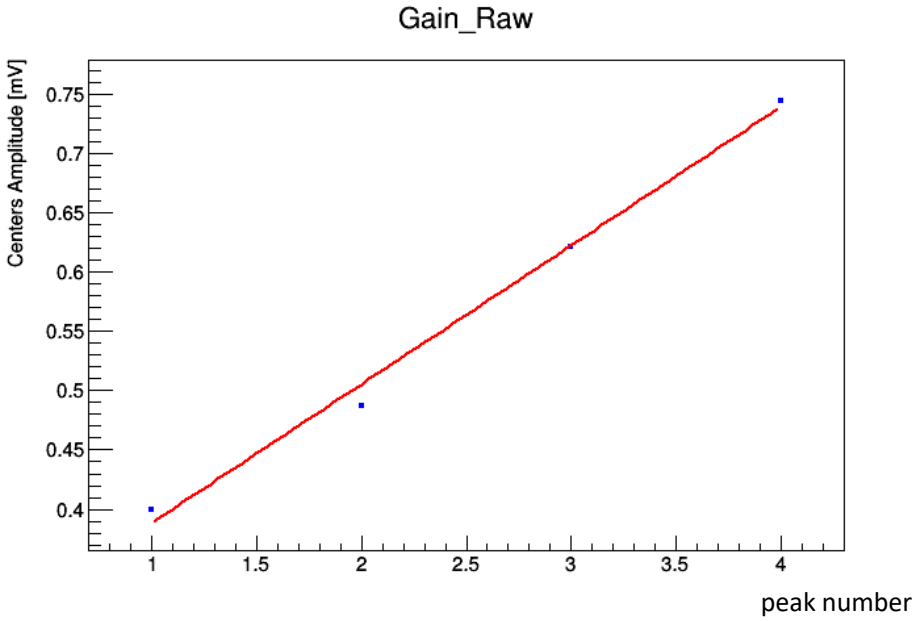


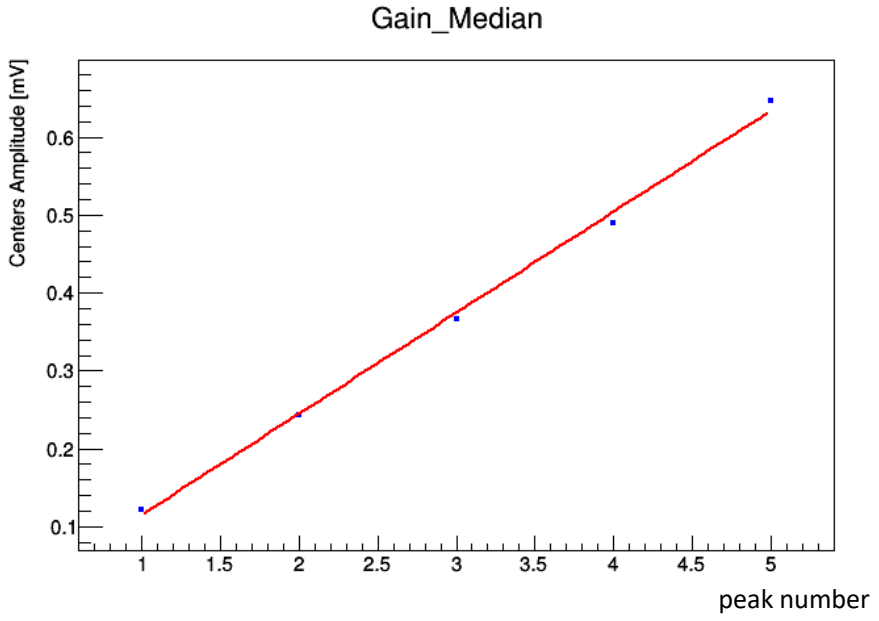


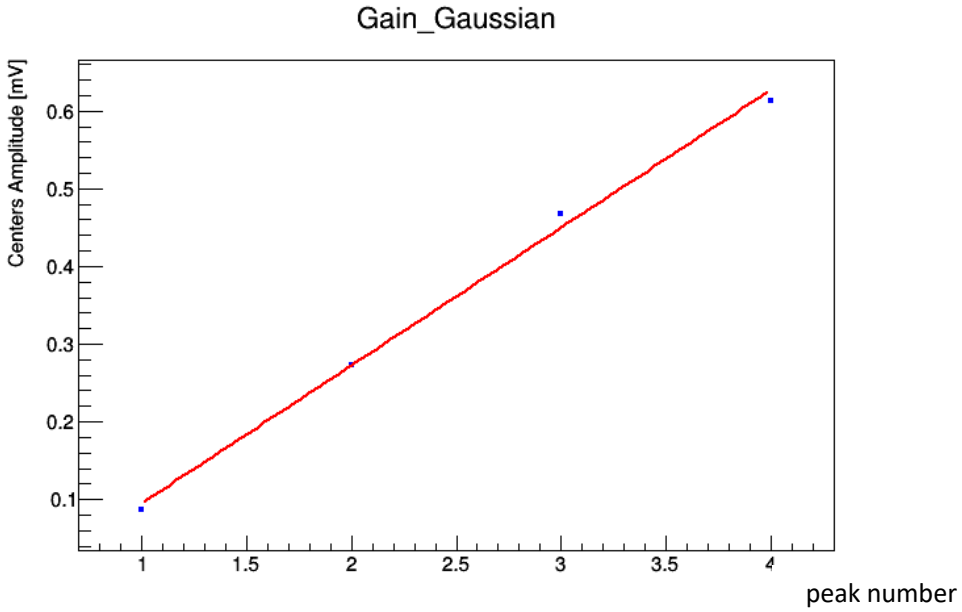


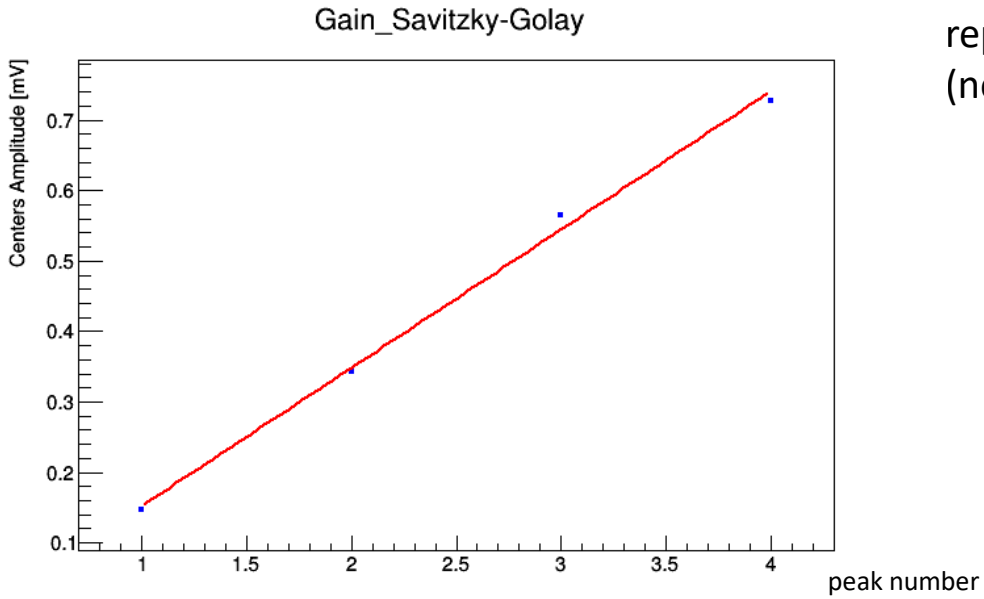


Gain (amplitudes)







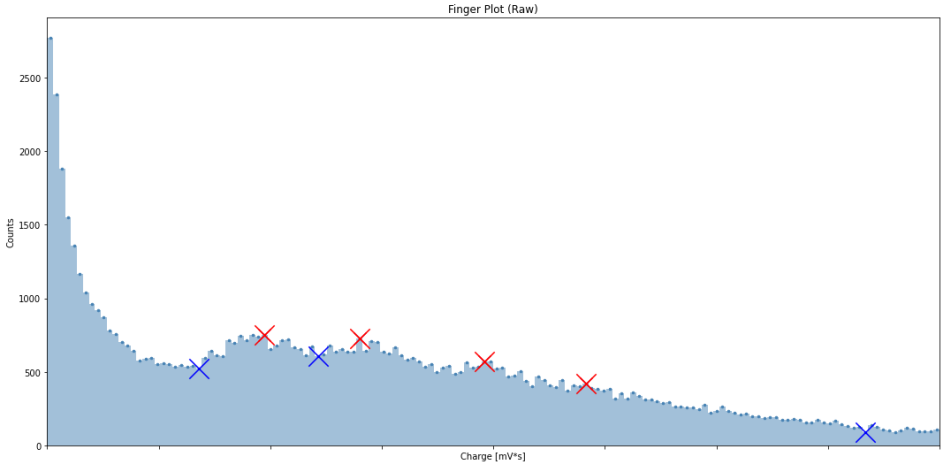


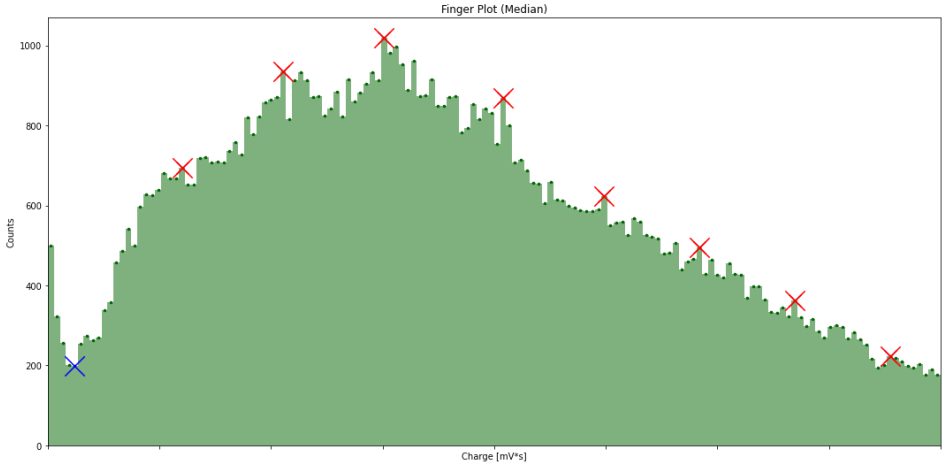
- Expected linear behaviour

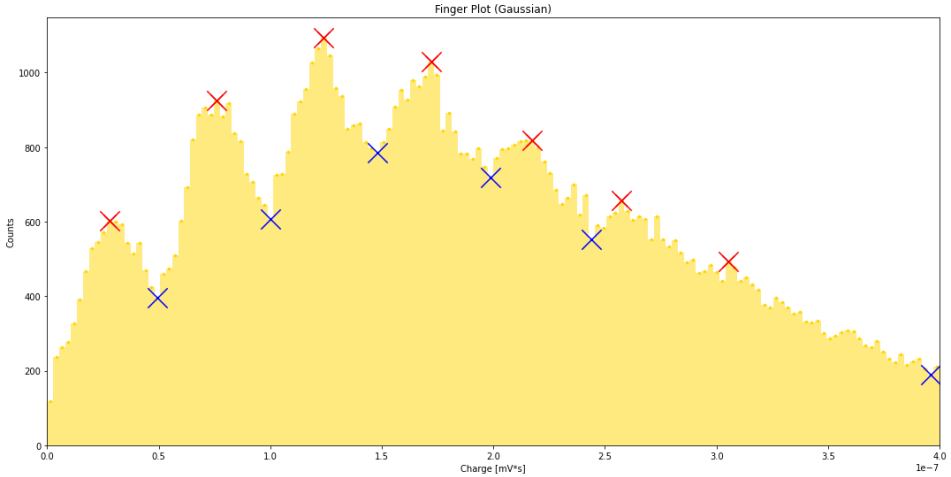
- Can’t validate data, since it is still not possible to determine if the first peak representes the «Pedestal» (noise) or 1 or more p.e.

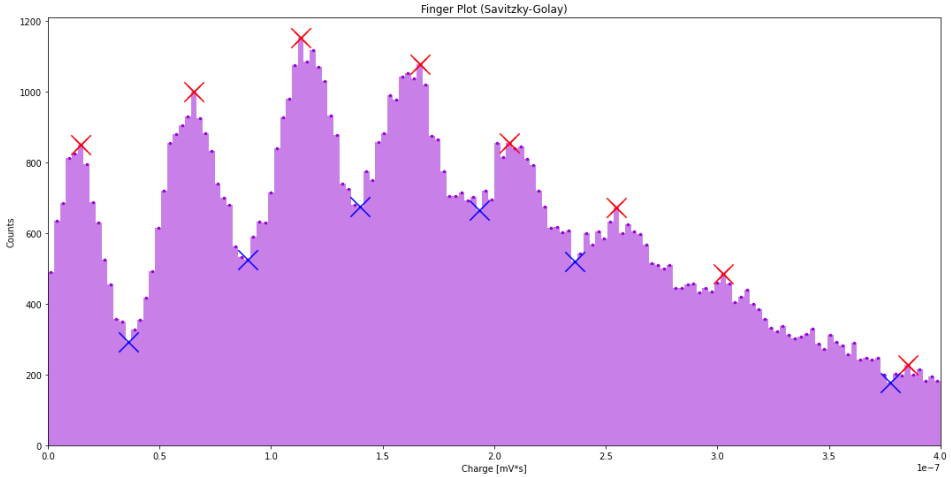
Finger Plot (peaks charges)

Developed an algorithm able to find peaks and minima, to autoset the range of fitting (simple for the moment but I'm willing to improve it)







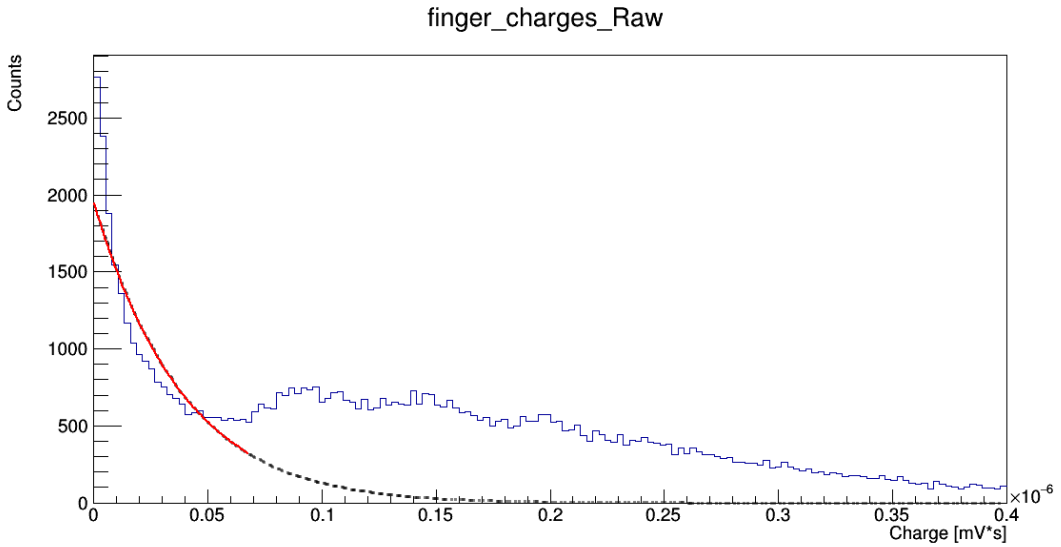


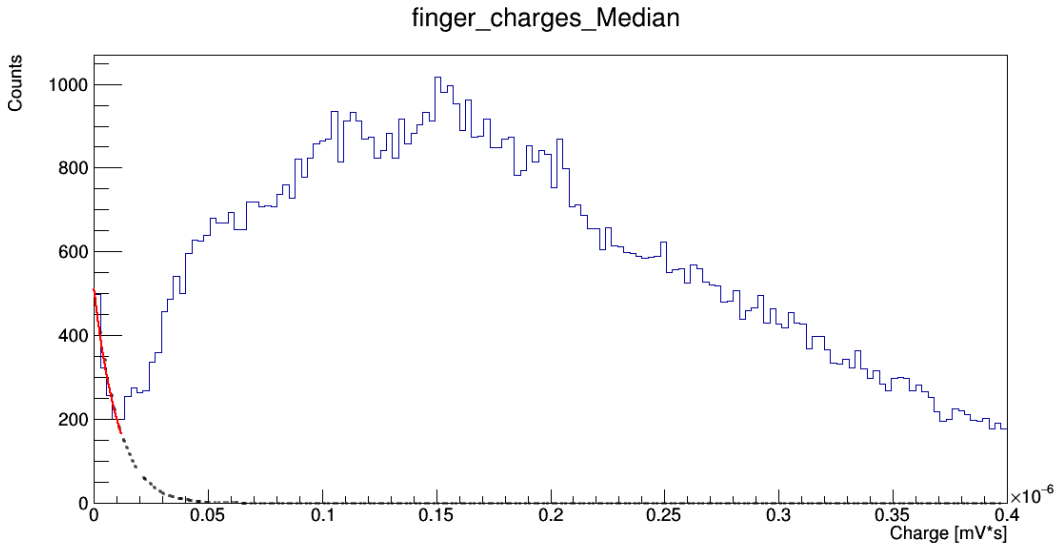
- Can't get any peak with Raw data or Median filter

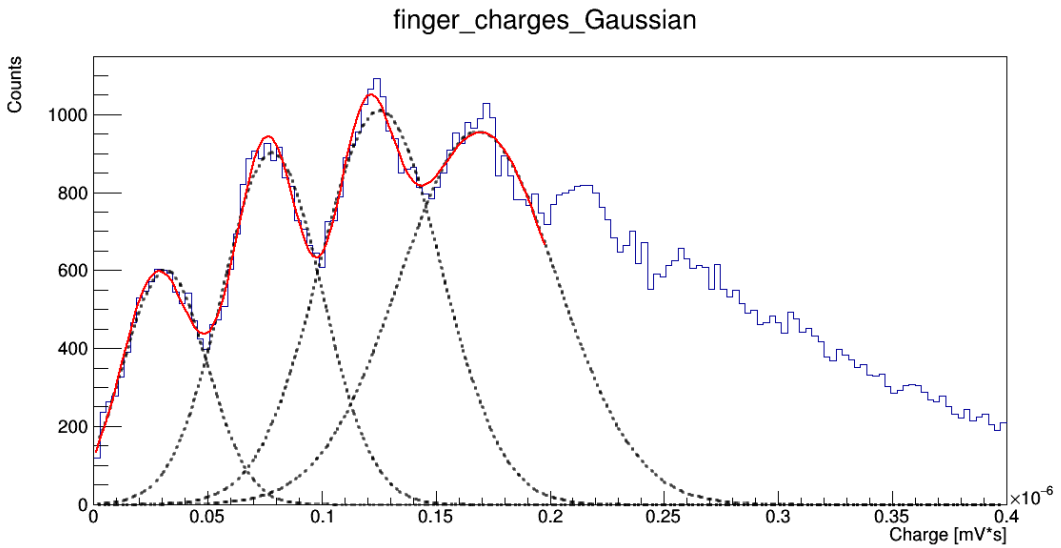
- Peaks come out with Gaussian and Savitzky-Golay filters

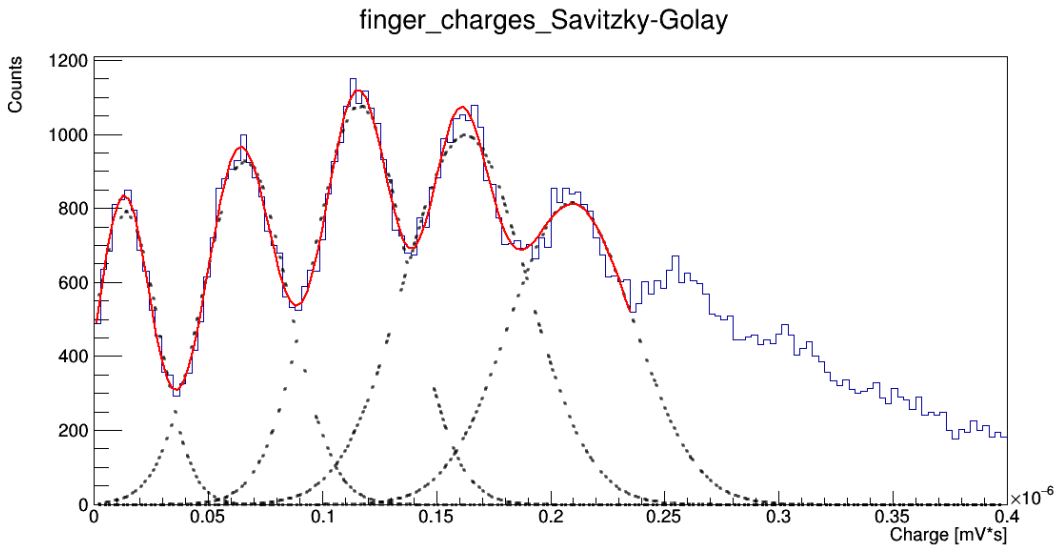
Finger Plot (peaks charges)

Fit single peaks ⟶ Total fit (sum of gaussians)

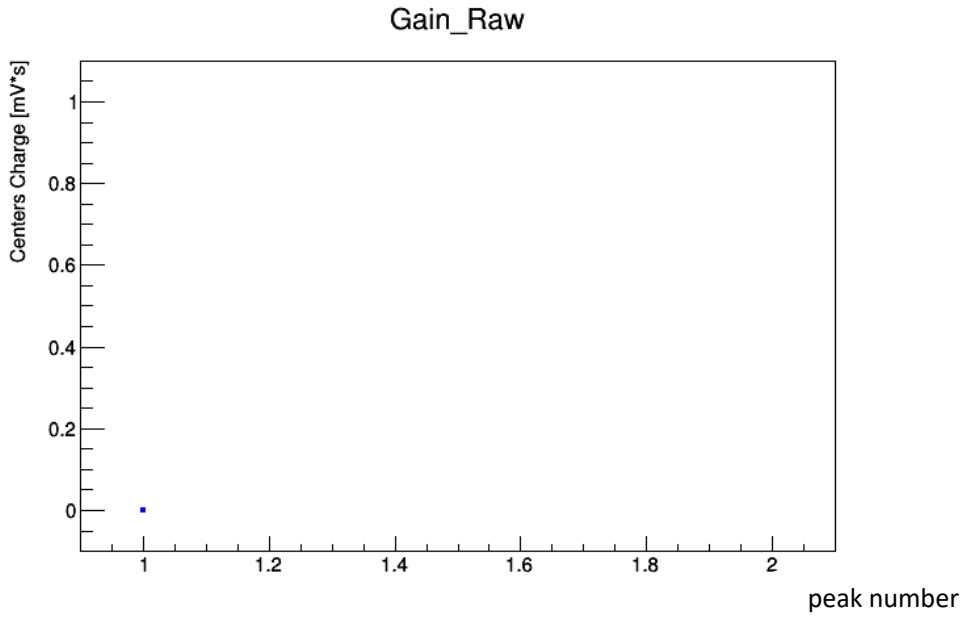


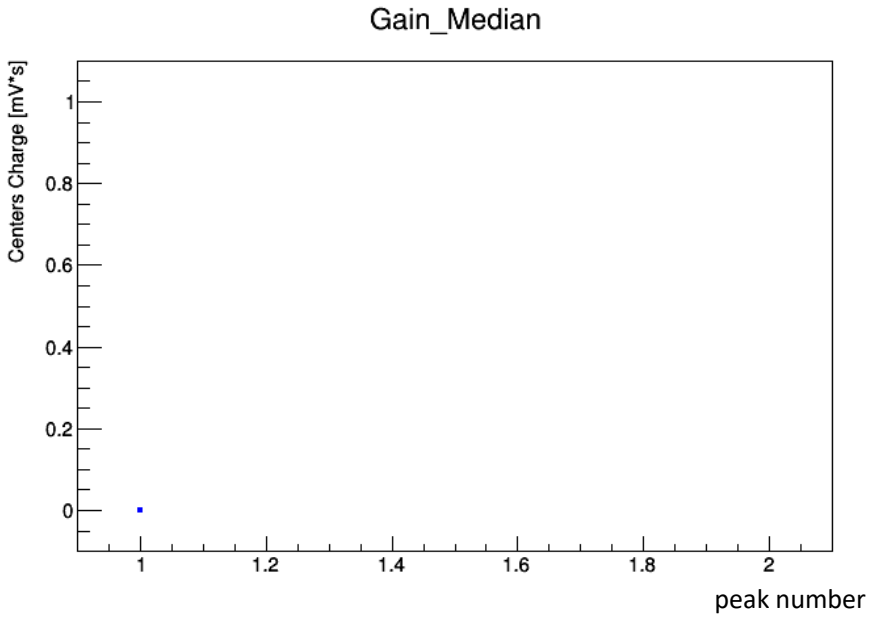


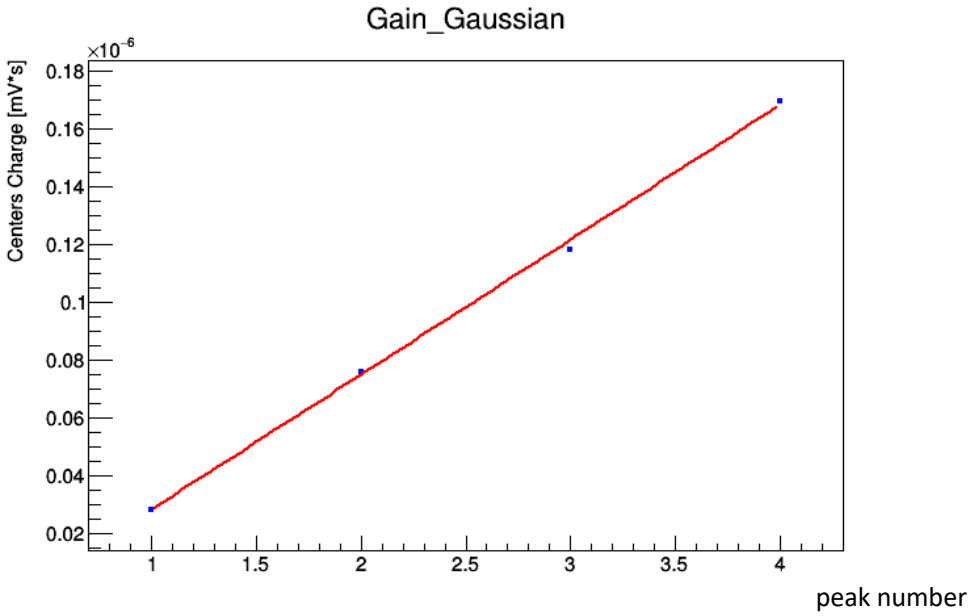


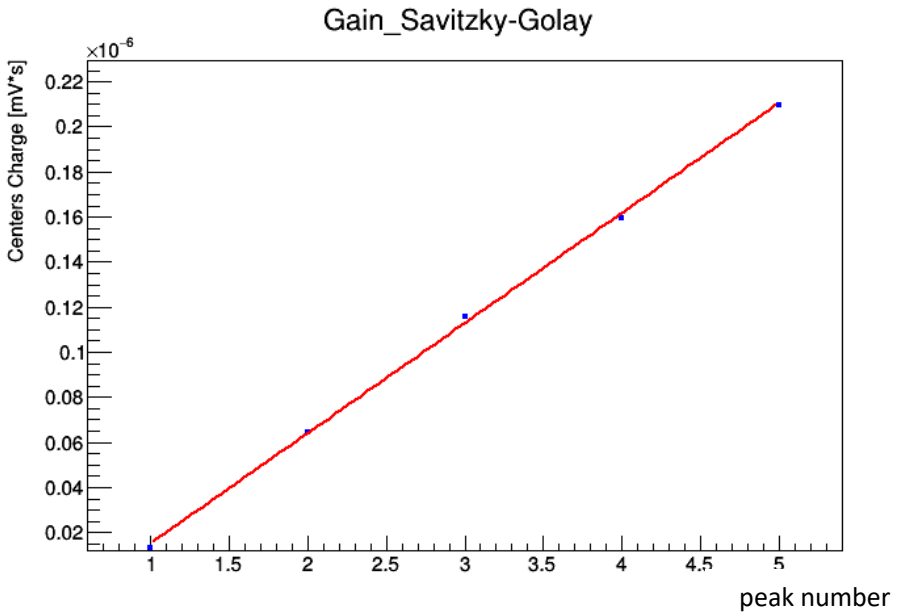


Gain (charges)









- Expected linear behaviour

- We were not able to convalidate data, so we have not stated if the first peak is the Pedestal or 1p.e.

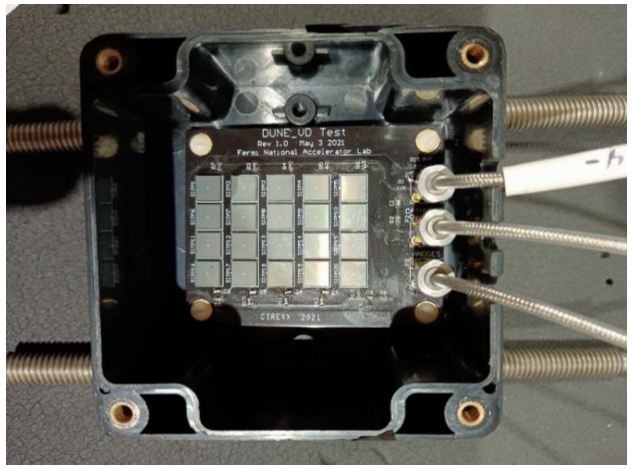
Experimental Setup 2

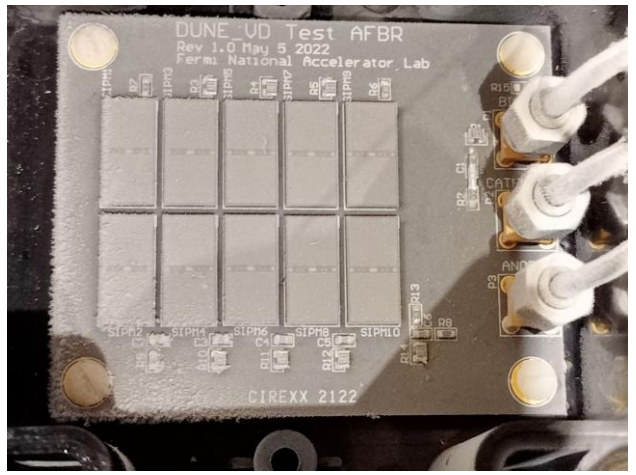
What changed

Setup 1

Setup 2

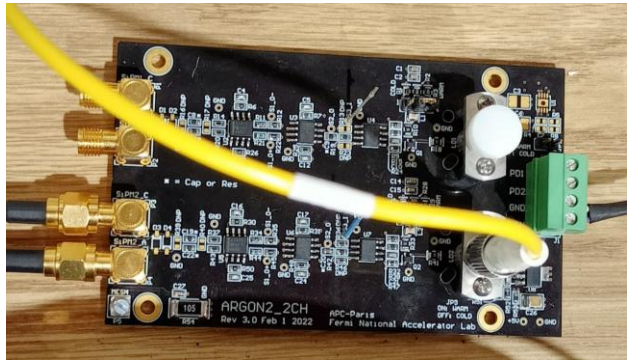
- **Producer**: Hamamatsu
- **Breakdown voltage in LAr**: 32V
- **# SiPMs**: 20 (sum)

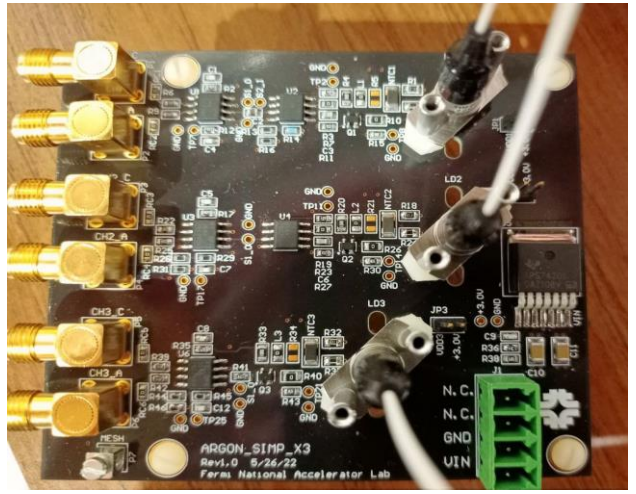




- **Producer**: Broadcom
- **Breakdown voltage in LAr**: 28V
- **# SiPMs**: 10 (each made by 2 in parallel, so have a greater capacitance)

- **Model**: Argon2x2 Board
- **# channels**: 2
- **Voltage needed**: 5V



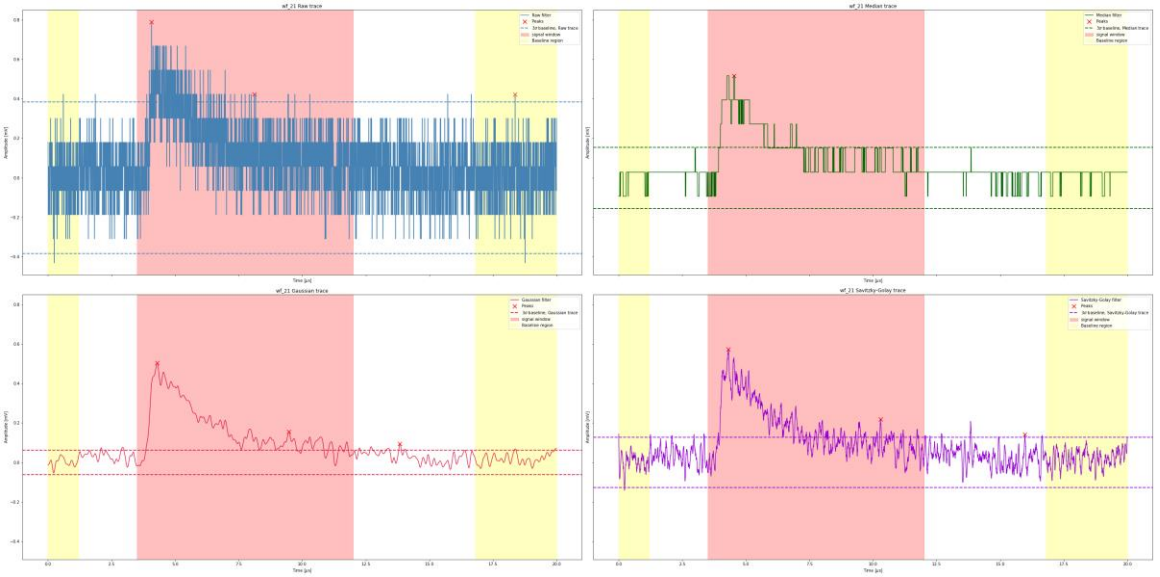


- **Model**: Argon_SIMP_X3
- **# channels**: 3
- **Voltage needed**: 3V

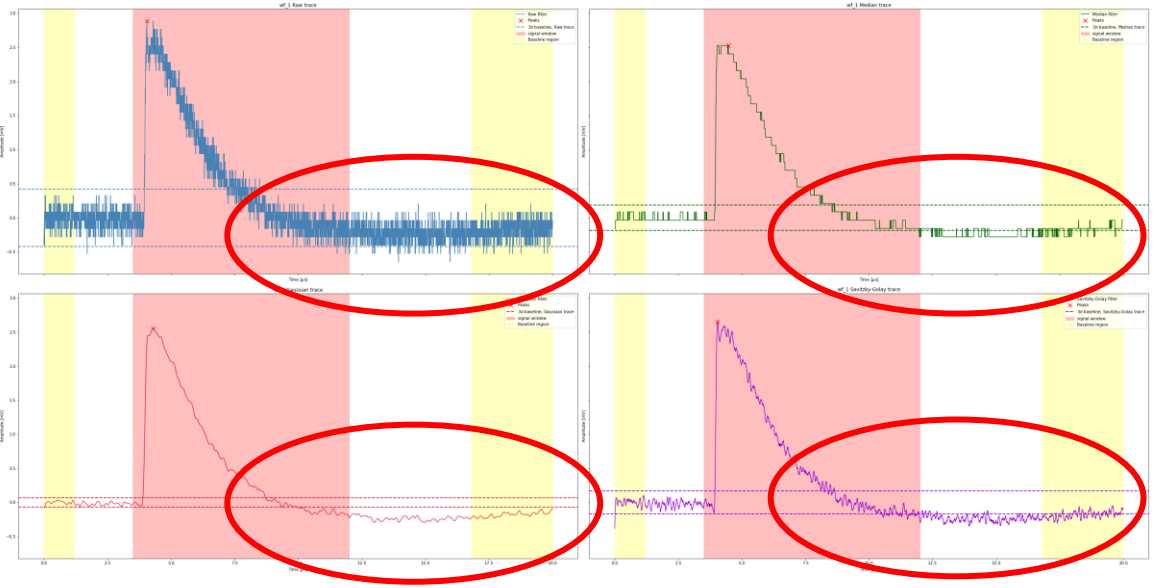
Data taken on: 20 September 2022

Example of waveforms

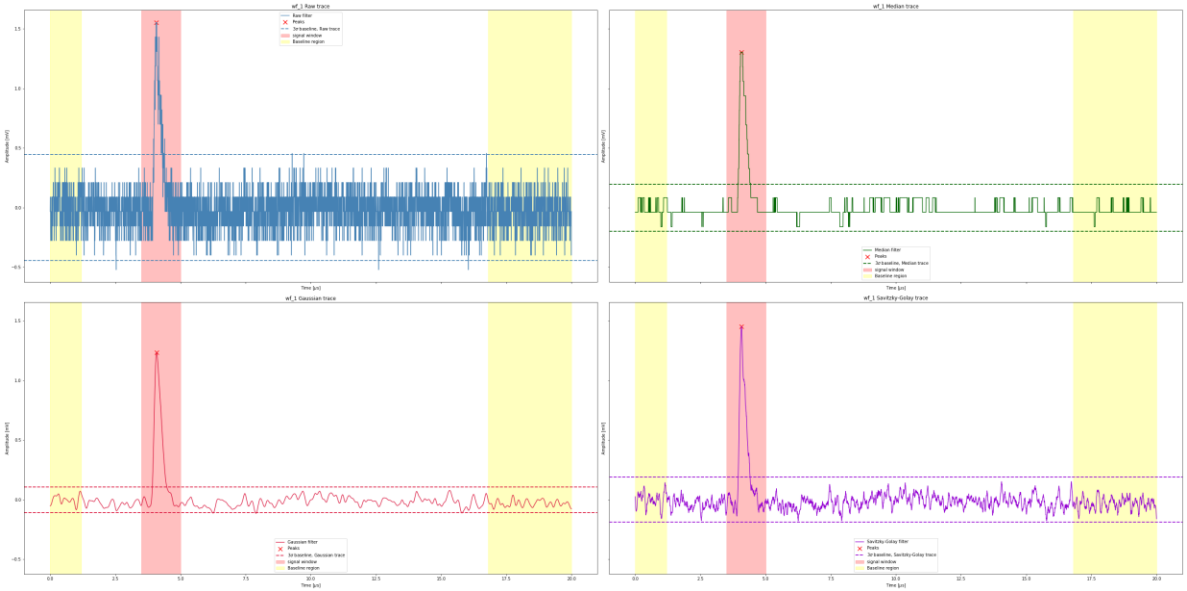
Broadcom, 7.0, 40V (run 1608)



Broadcom, 10.0, 40V (run 1553)

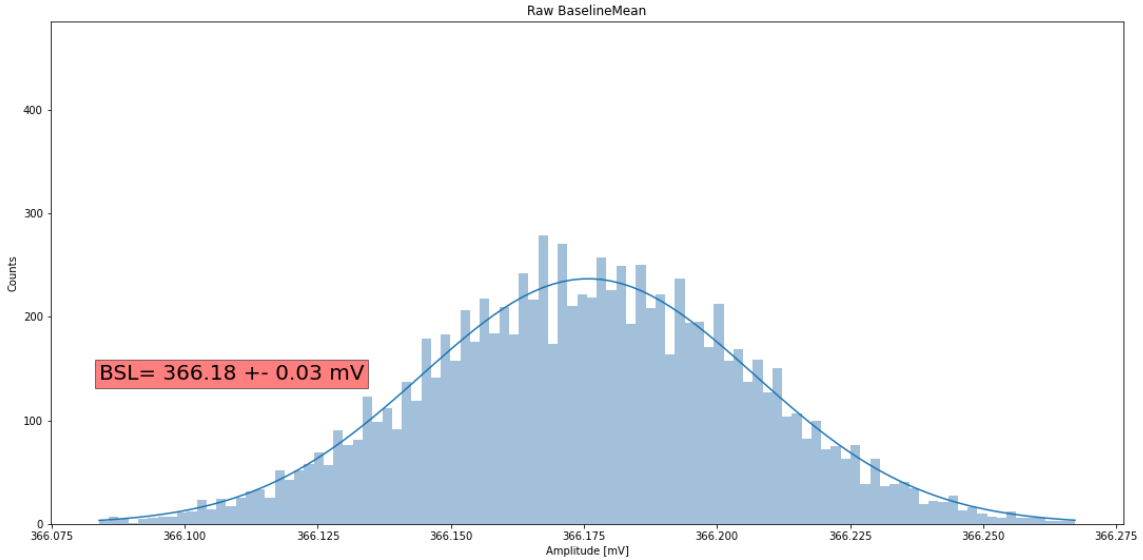


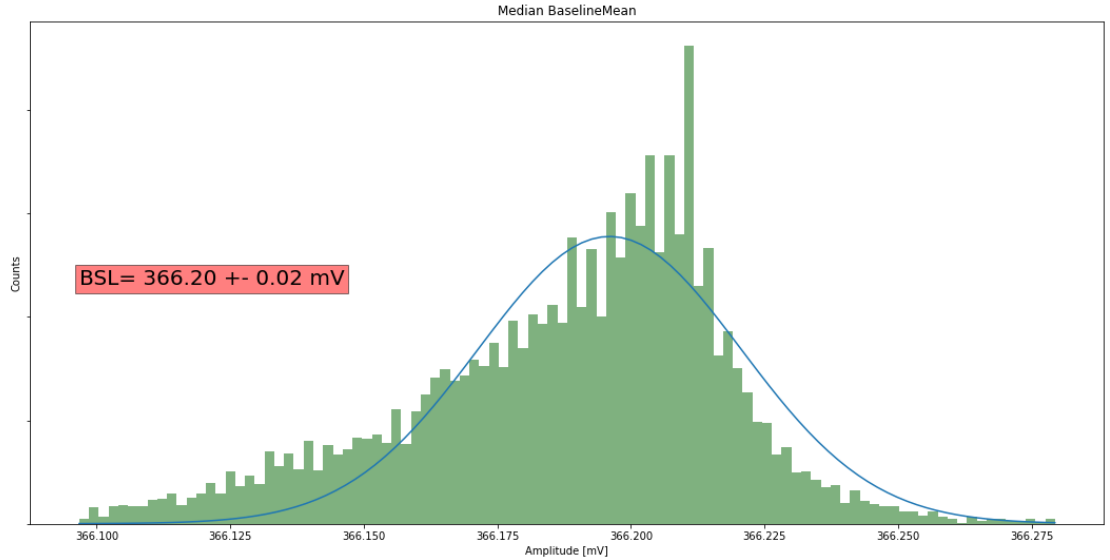
Hamamatsu, 6.4, 38V (run 1638)

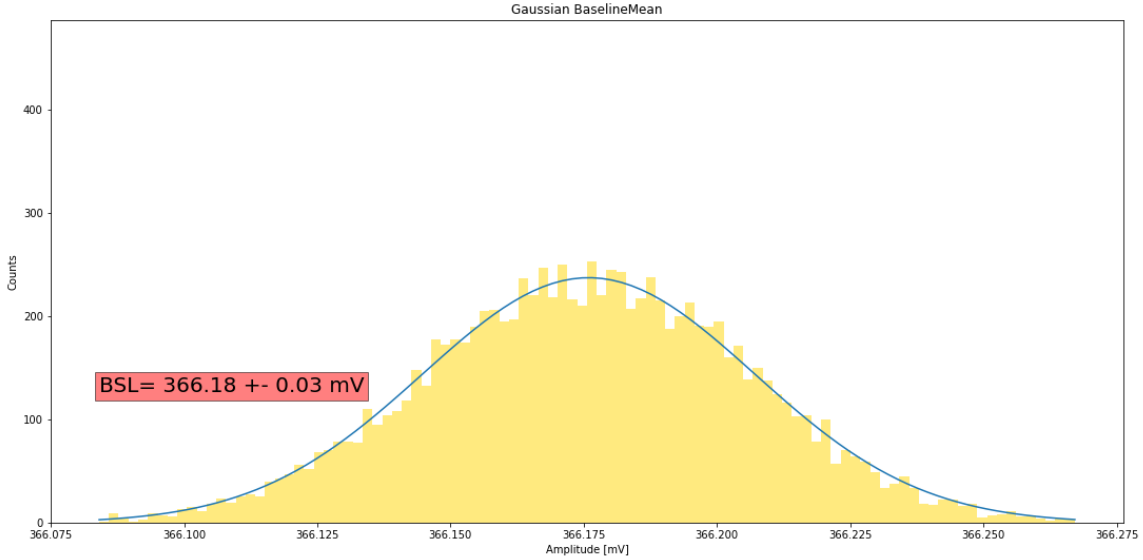


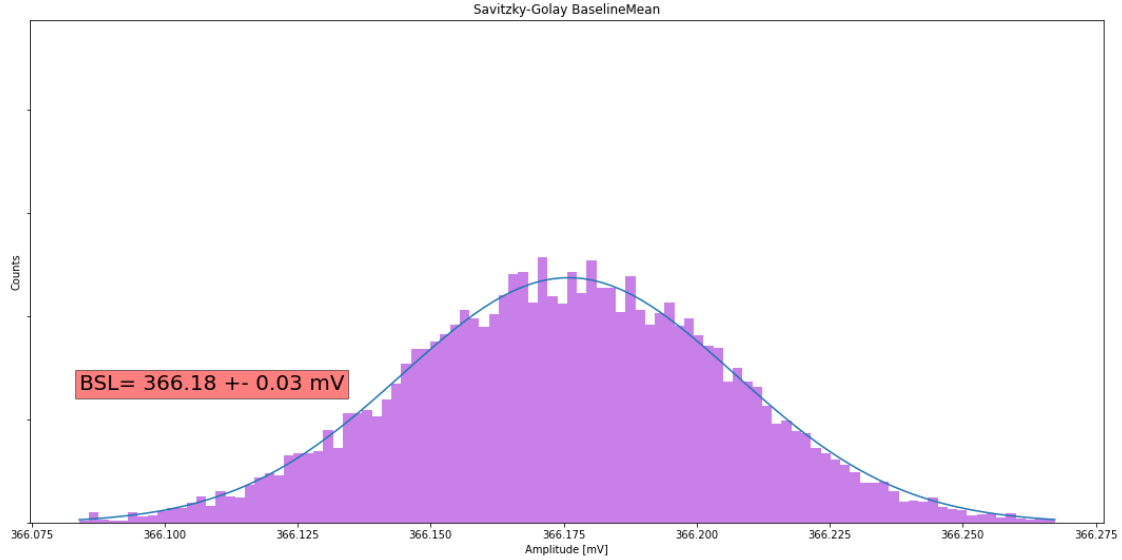
Broadcom has **longer pulses** and **higher undershoot** with respect to Hamamatsu

Mean Baseline distribution





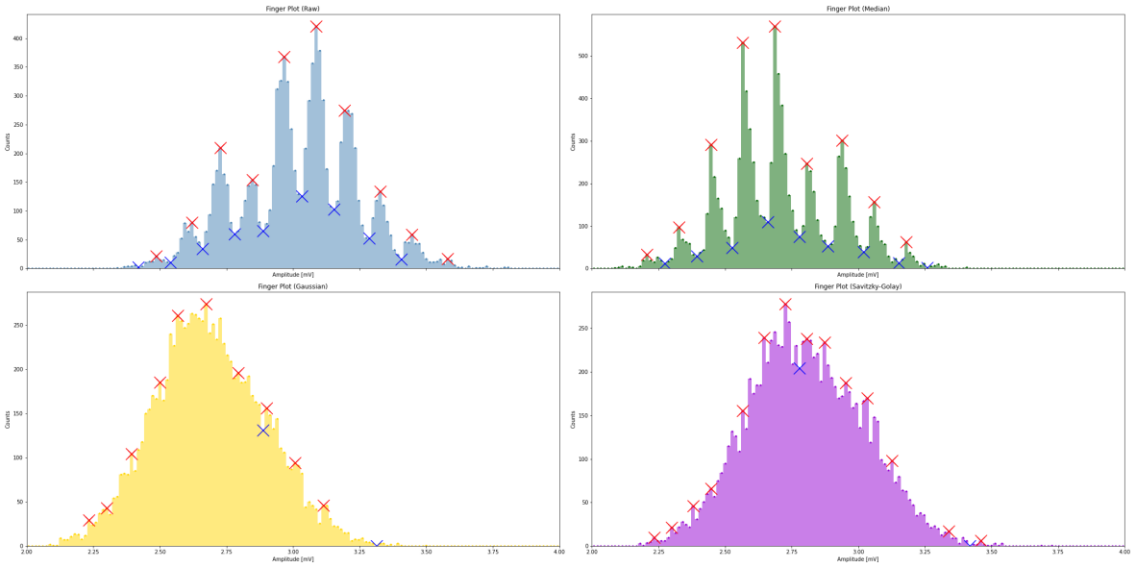


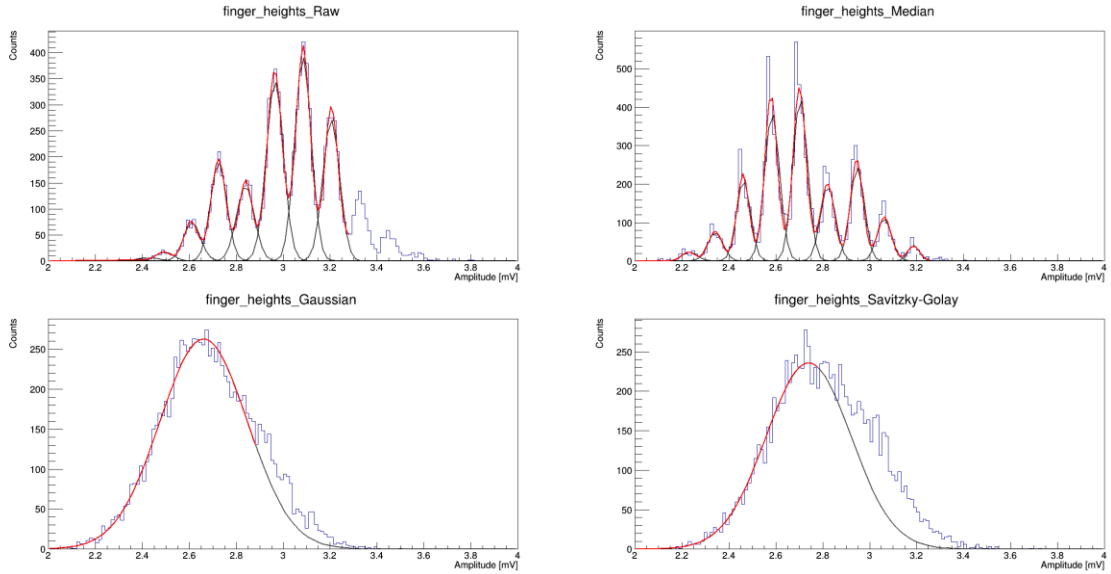


Finger Plot (peaks amplitudes)

Run 1553

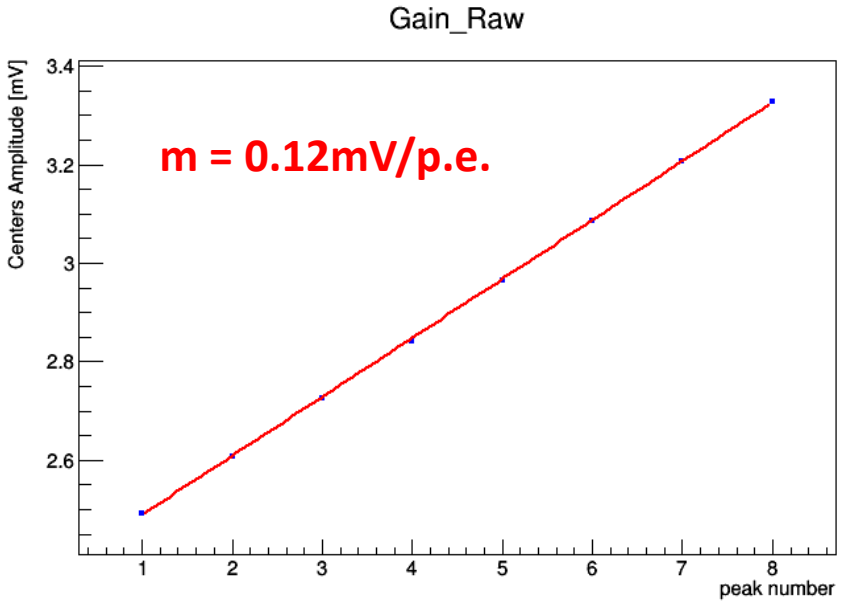
Due to LED high intensity, the amplitudes start with high values (can't see SPE)

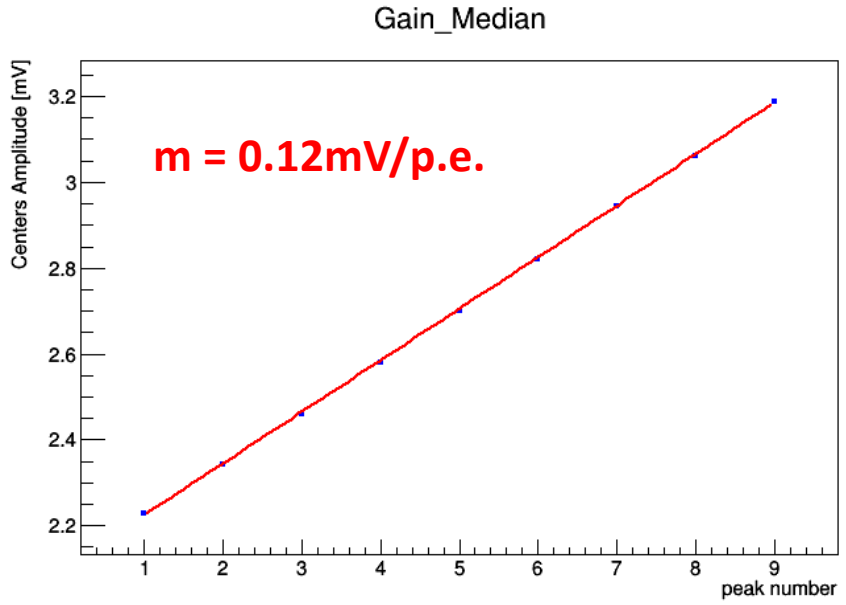


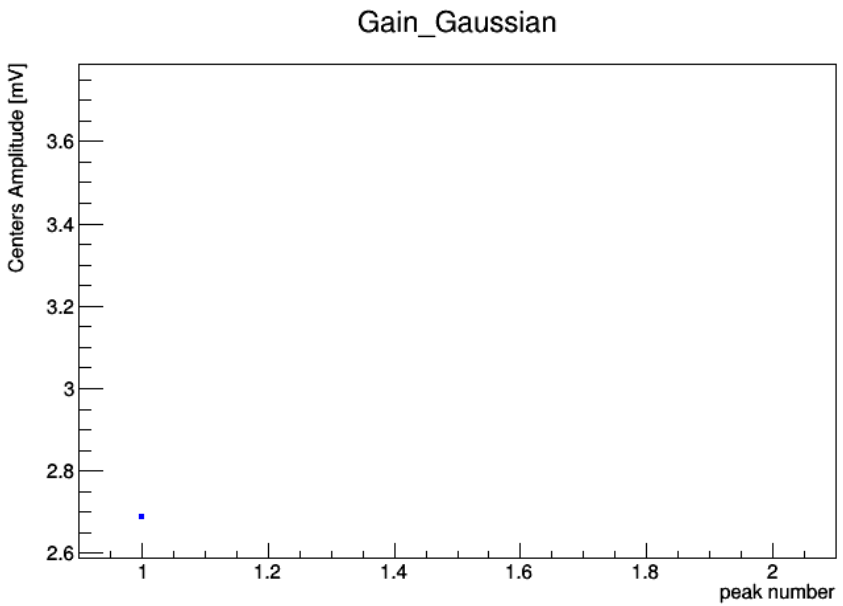


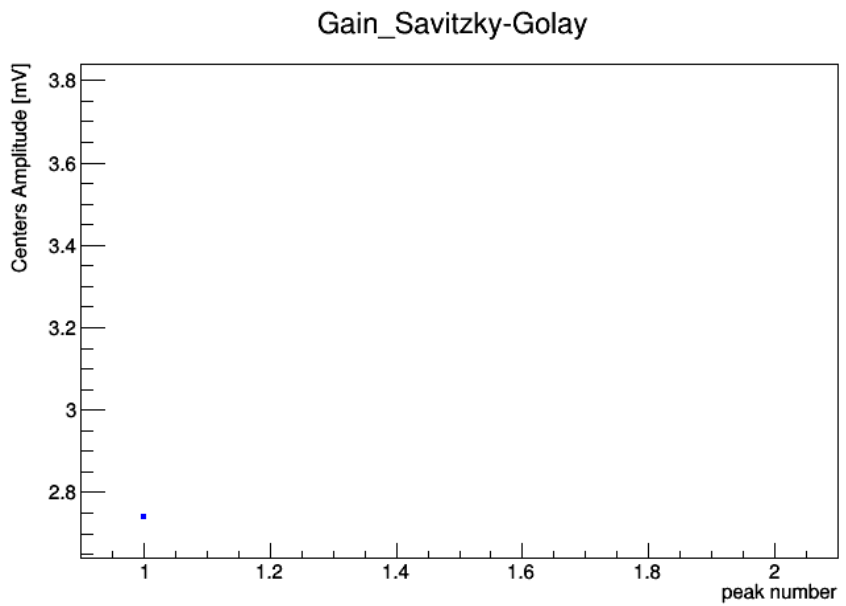
With Gaussian and Savitzky-Golay filters there is no resolution

Gain (amplitudes)









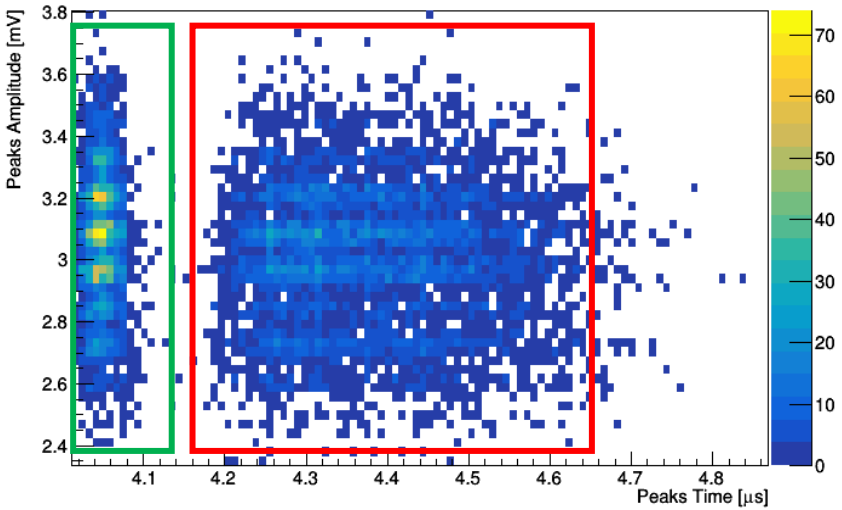
- Expected linear behaviour
- It does not start with 1p.e., we can determine it from the slope
- Using amplitudes, it should be possible to see SPE with Raw data or Median filter

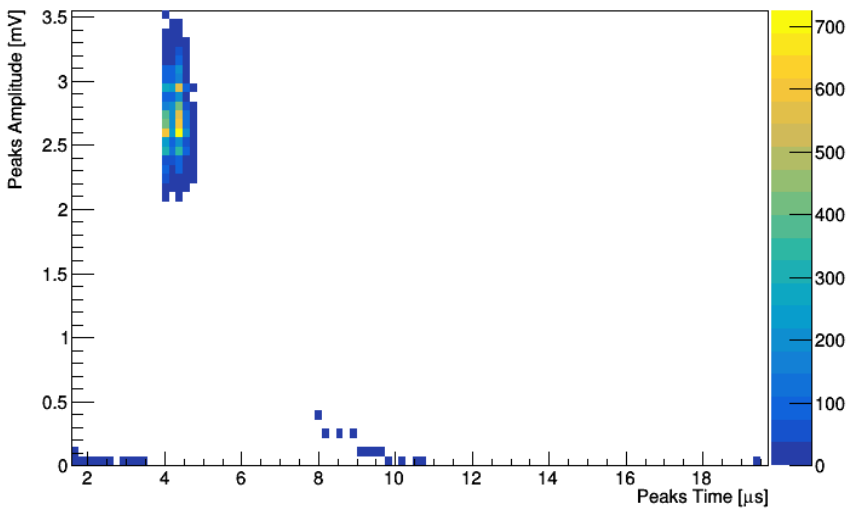
Amplitudes vs time of the peaks

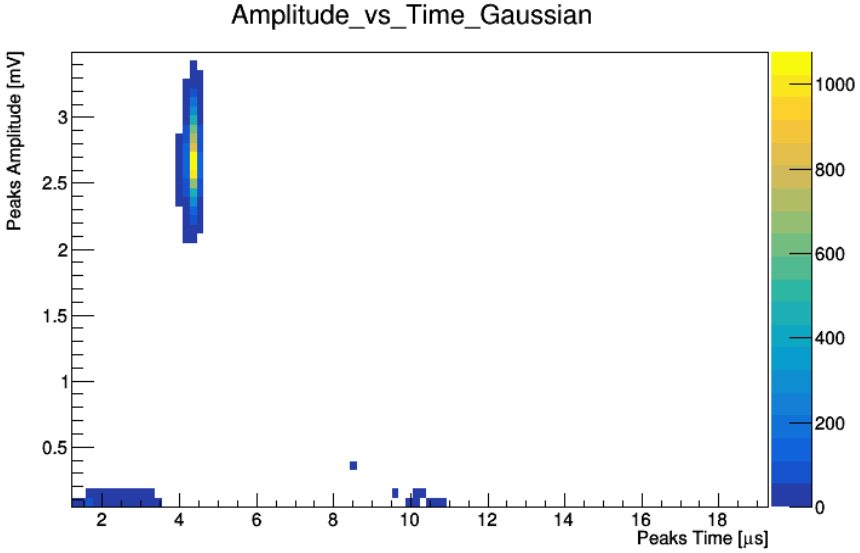
We see probably a signal region and a noise region, but further analysis are required to convalidate

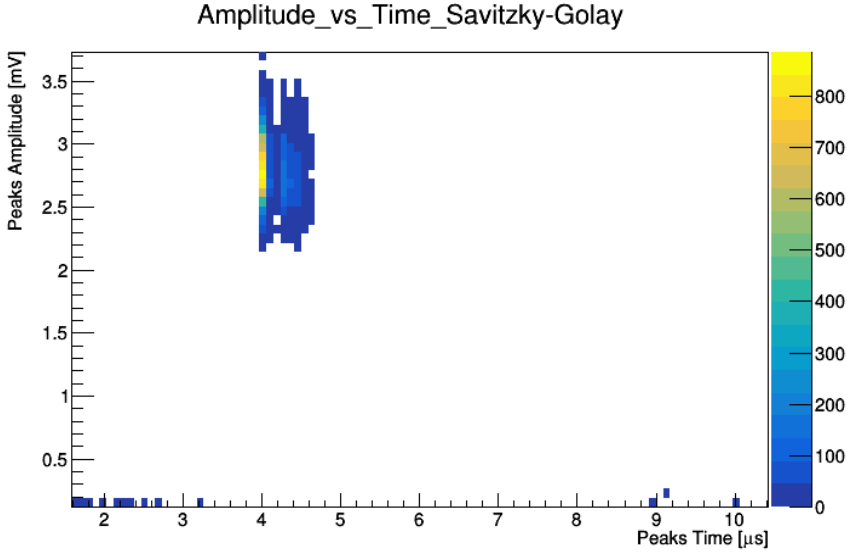
Signal

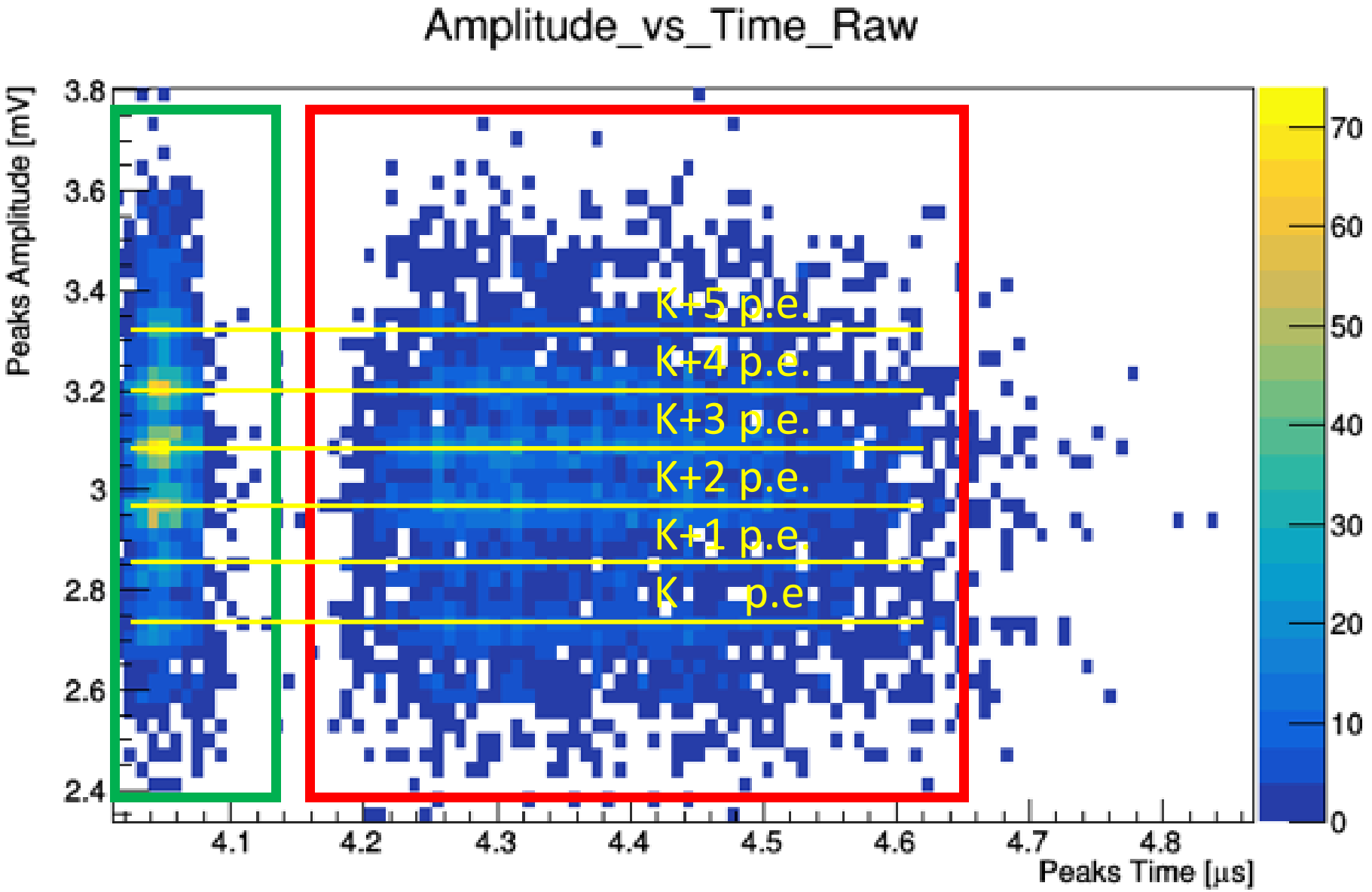
Noise





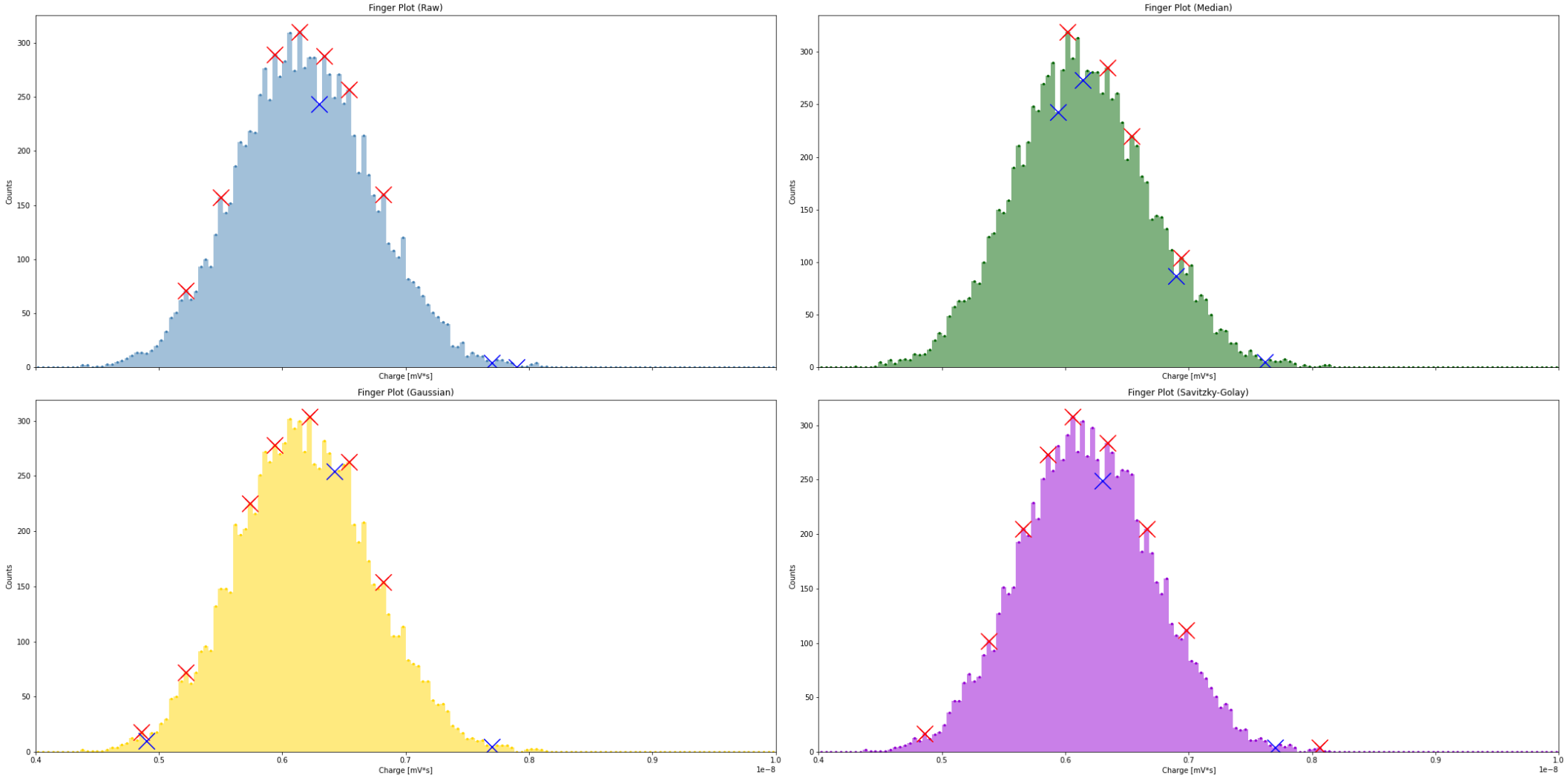





Amplitude_vs_Time_Raw
Peaks Amplitude [mV]
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
Peaks Time [µs]
70
60
50
40
30
20
10
0
K+5 p.e.
K+4 p.e.
K+3 p.e.
K+2 p.e.
K+1 p.e.
K p.e.

Finger Plot (peaks charges)

Found that we have no resolution on charge (probably due to the change of the Analog to Optical converter, since we have the same problem for Hamamatsu SiPM which have been already tested and functioning), but still do not know why



Summary

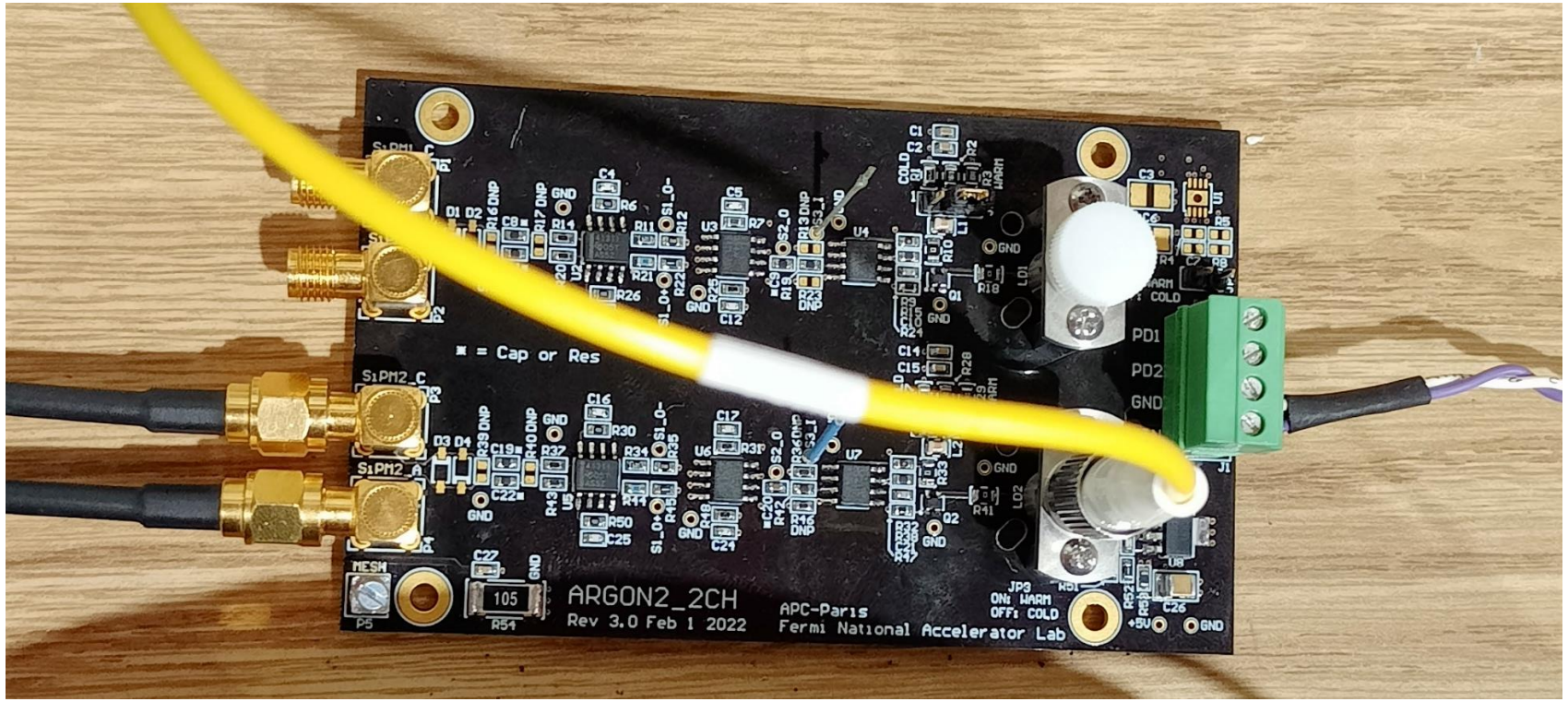
1. Prepared the experimental setup shown;
2. Tested all the electrical and optical components;
3. Acquired several sets of data, changing SiPMs board and Analog to Optical Converter;
4. Data analysis:
    - write a first prototype of code which is able to read all events (waveforms), plot them and apply 3 digital filters (high-frequency noise), calculate and subtract baseline;
    - first simple algorithm able to find peaks, integrate them in a fixed or moving window and save their main properties (amplitude, sample, time, charge)
    - plot and fit Finger Plot (using both amplitudes and charges)
    - calculate gain (using both amplitudes and charges)

Future Plan

1. Take data which are usable to calculate:
   - **SNR** (Signal to Noise Ratio) as: $\frac{\mu_{SPE}}{\sigma_{BSL}}$;
   - **Resolution** to SPE as: $\frac{\sigma_{SPE}}{\mu_{SPE}}$;
2. Compare several types of SiPMs, coming from different vendors;
3. Analog readout boards in different configurations;
4. Further improve algorithm to find peaks and integrate Finger Plots.

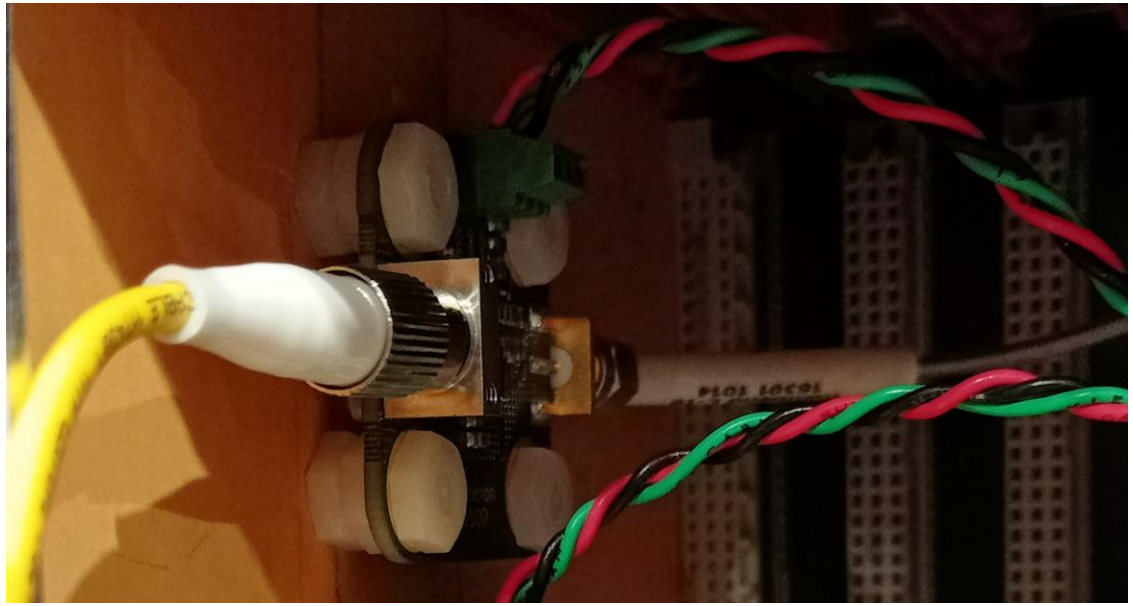
Thanks for the attention

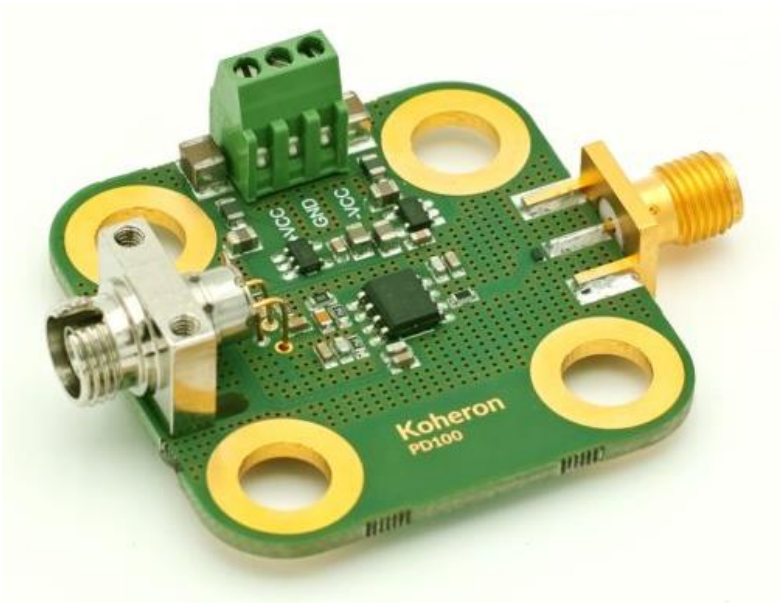
Analog Optical Transmission



It amplifies and converts an analog signal (in this case coming from the SIPM board) into a light signal, that goes throguh the (yellow) fiber

Optical Receiver (Koheron PD100)





It receives the optical signal coming from the **Analog Optical Transmission (Argon2x2)** and converting it into an analog electrical signal, ready to be acquired by an ADC