DEEP UNDERGROUND NEUTRINO EXPERIMENT

The new Photon Detection System for DUNE Vertical Drift FD#2

DUNE Collaboration Meeting

Jan. 28, 2022

Flavio Cavanna *on behalf of the VD R&D team in the PD Consortium*

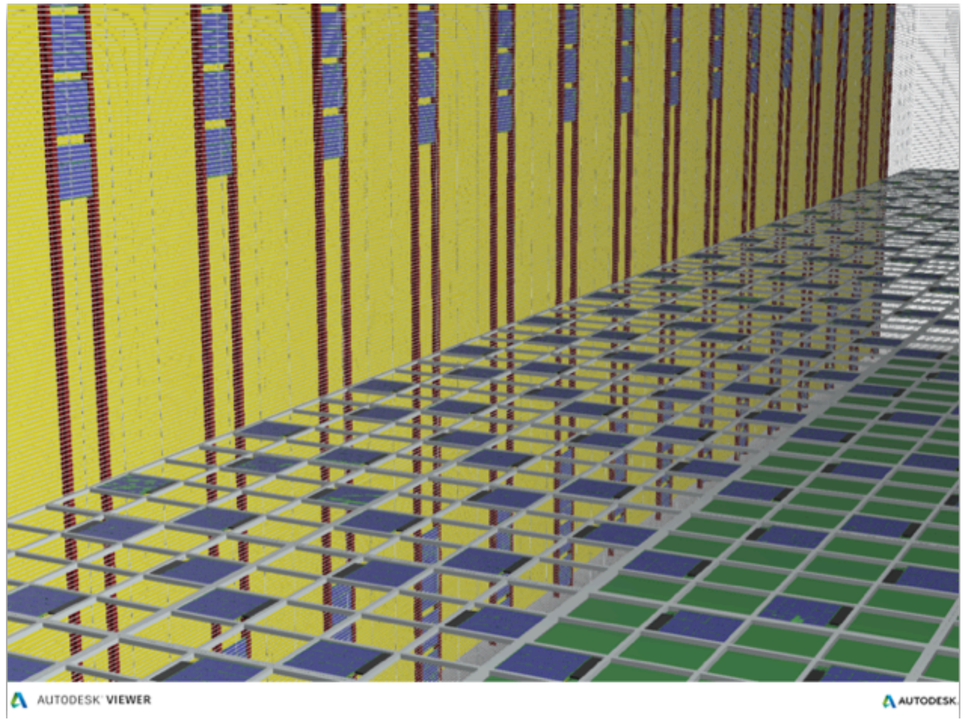
Fermilab

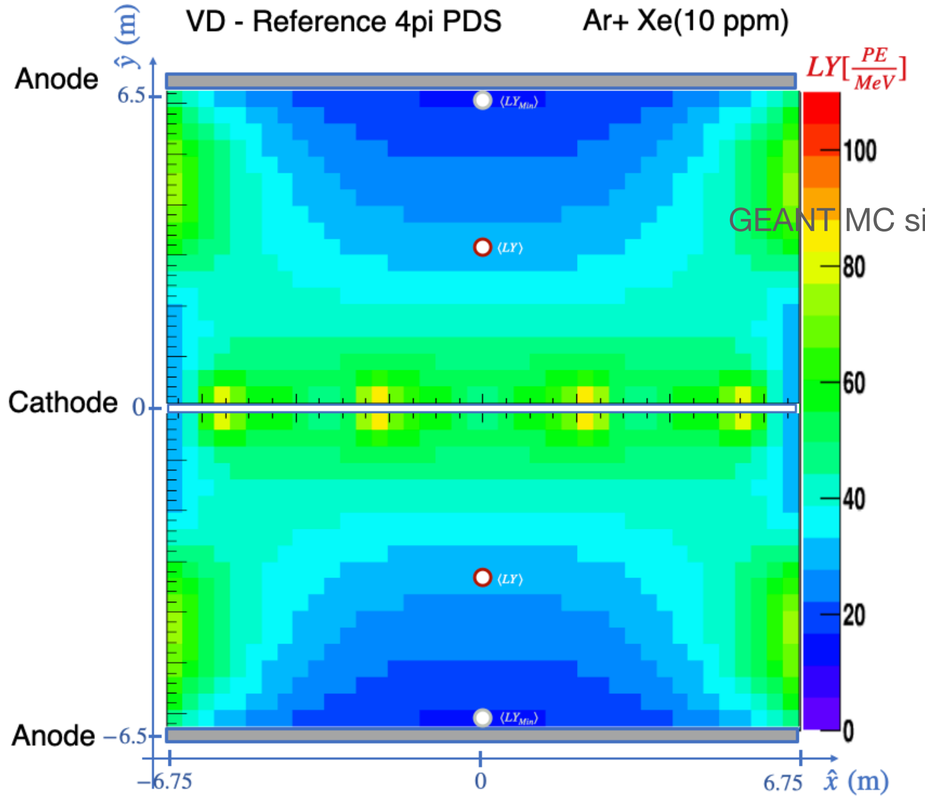
In the FD#2-VD module the LAr target is segmented in two LArTPC active volumes, either side of central cathode.
Wrt FD#1-HD, dimensions of the the LAr active volumes are bigger with longer light source-detector distances, but also opportunities are offered for a more even photo-sensitive area coverage around these volumes.

By distributing large area photon detectors over the sides of the active LArTPC volume one can obtain a ~uniform LY throughout the volume and high on average, so as to be able to perform high resolution calorimetry and position reconstruction (and therefore also trigger with max efficiency) for neutrino events down to low threshold.

In the Reference Design of the VD PD System the active optical coverage is distributed onto the 3 larger sides of the LAr Volume (Cathode side and the two long FC sides with augmented transparency - 70% T), a passive optical coverage (by reflectivity) is provided at the Anode side and Xe doping is adopted to minimize Rayleigh scatter for light at far distance.

LY is uniform, high on average ~44 PE/MeV and a min LY ~ 22 PE/MeV in small dimmer regions near the anodes





GEANT MC simulations

Operating PD on HV surface (Cathode) requires

electrically floating *Photo-sensors* and *r/o Electronics*

⇒ **Power (IN) and Signal (OUT) transmitted via non-conductive cables (e.g. optical Fibers)**

Existing PoF and SoF *(optolinks)* **technologies are commonly employed for voltage isolation between source/receiver and embedded electronics in high voltage or high noise environments.**

⇒ **however - none of the commercially available technologies are rated to operate in Cold (at LAr Temperature)**

A highly specialized R&D has been launched (mid Mar '21)

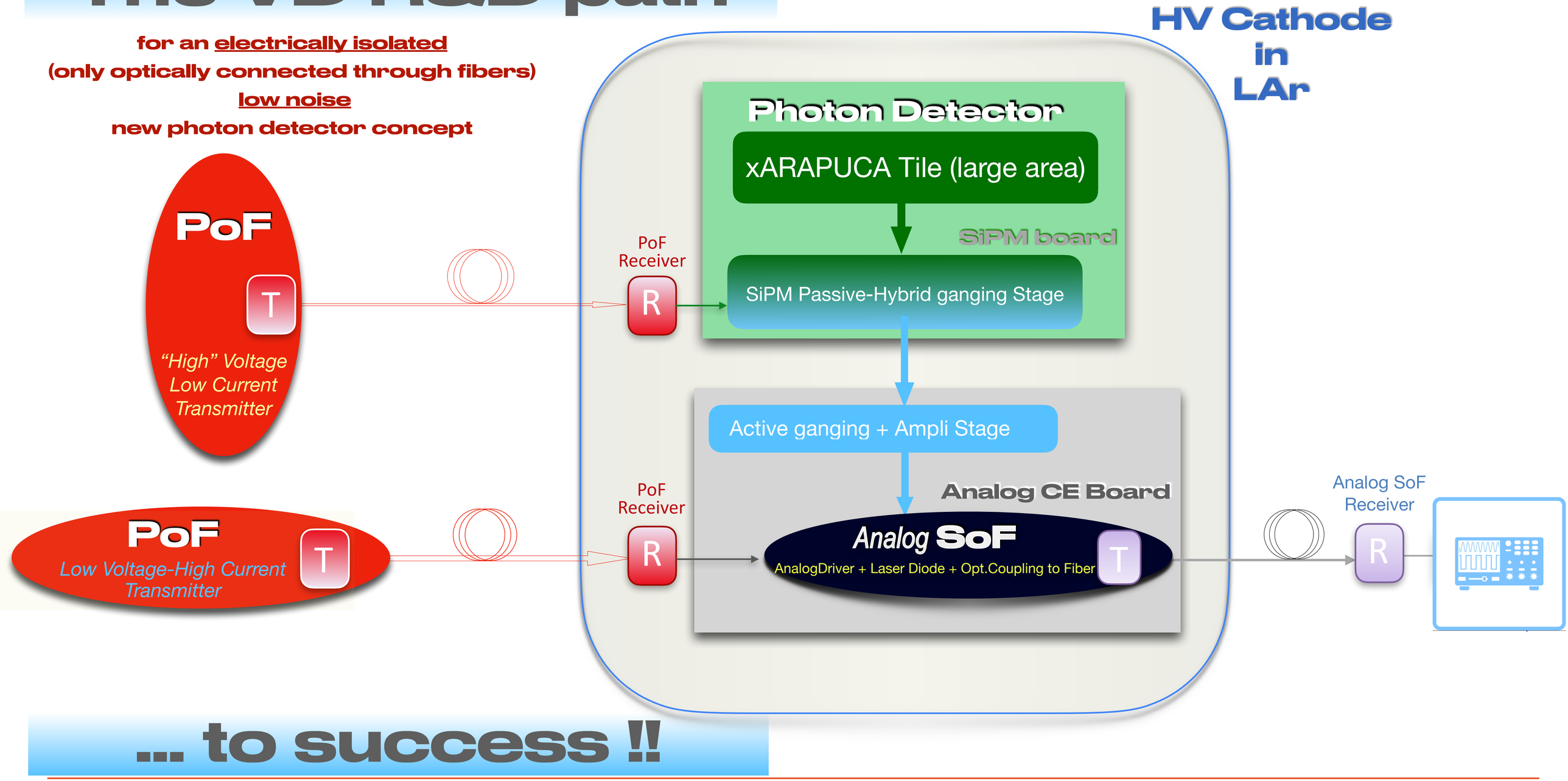
to customize PoF and SoF technology for Cold applications

or

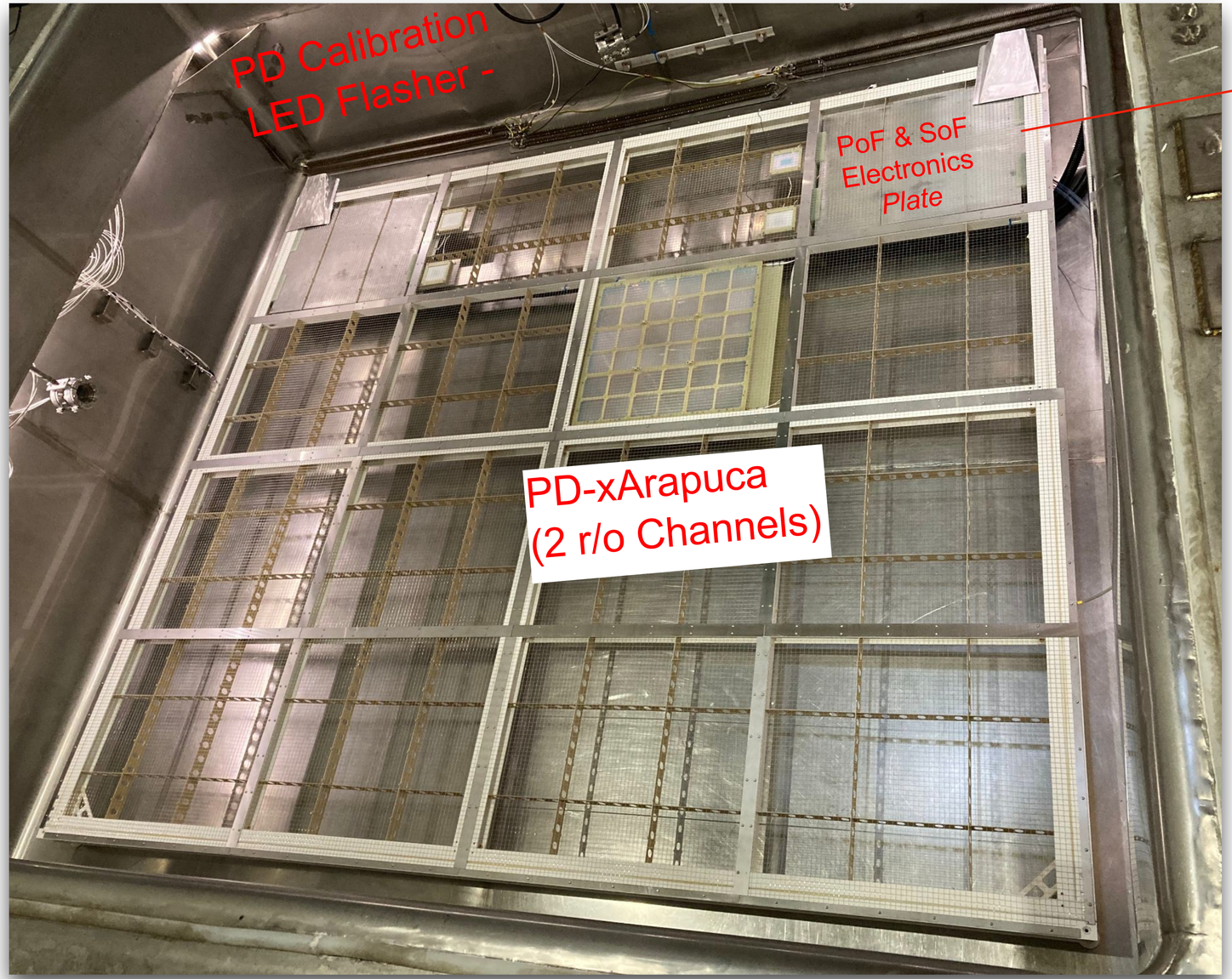
to thermally isolate from Cold environment and operate COTS technology in Warm

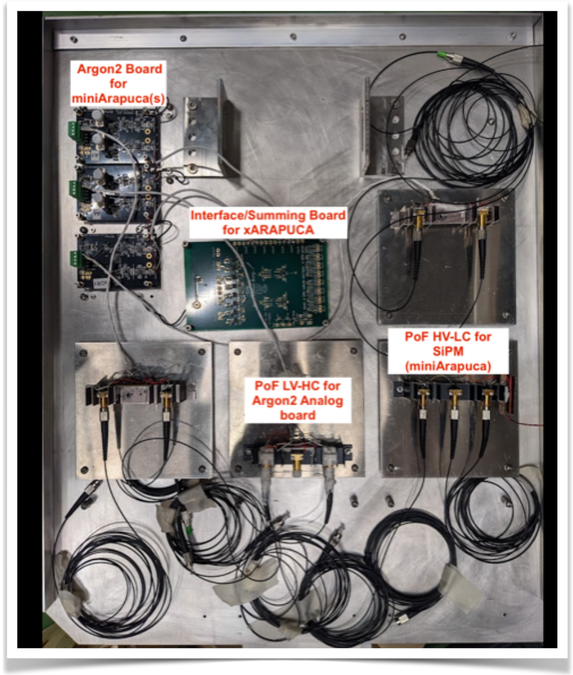
The VD R&D path

for an <u>electrically isolated</u>
(only optically connected through fibers)
<u>low noise</u>
new photon detector concept



... to success !!



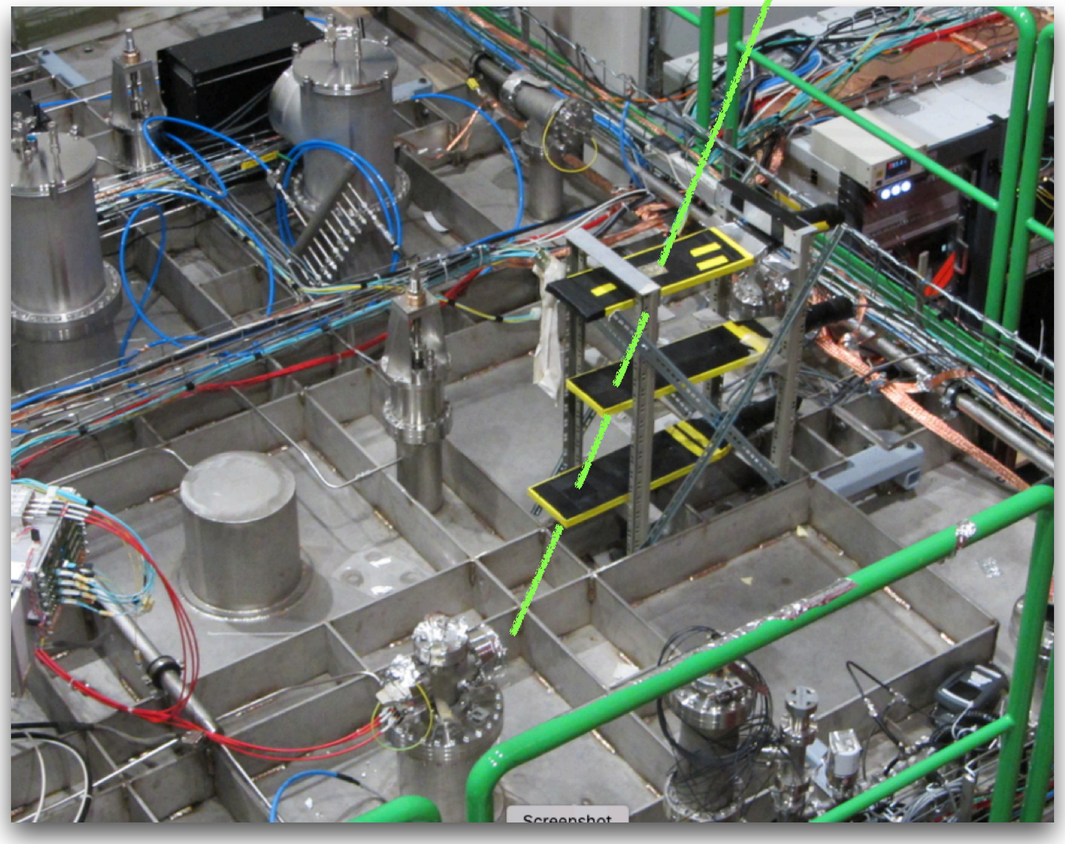


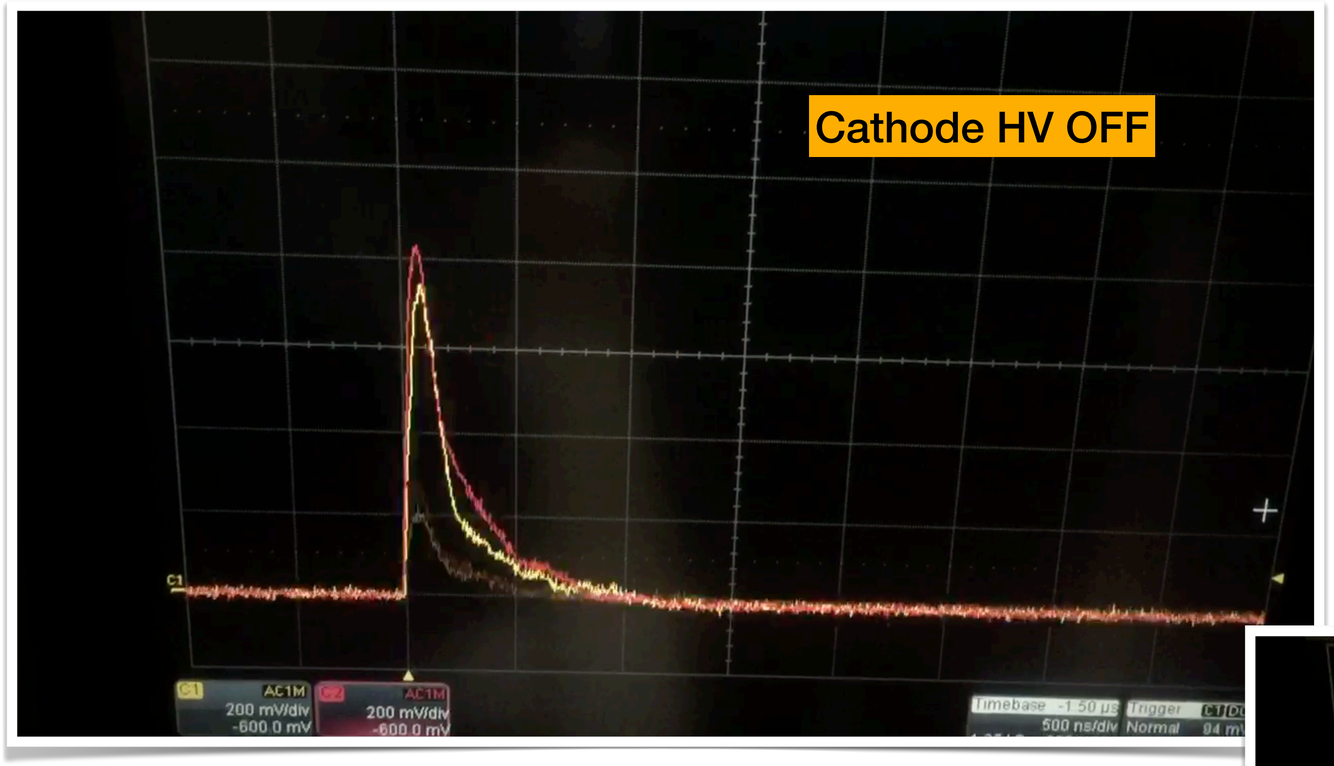
On Dec. 13
PDS on the Cathode + LED Calibration system installed in ColdBox at CERN Neutrino Platform

Another PD prototype with a thermally isolated version of the R/O electronics ["CryoSub" R&D option] was also installed and successfully operated - not reported here [see D. Cussans talk on Dec 27 PDS parallel Session]

Cosmic Muon

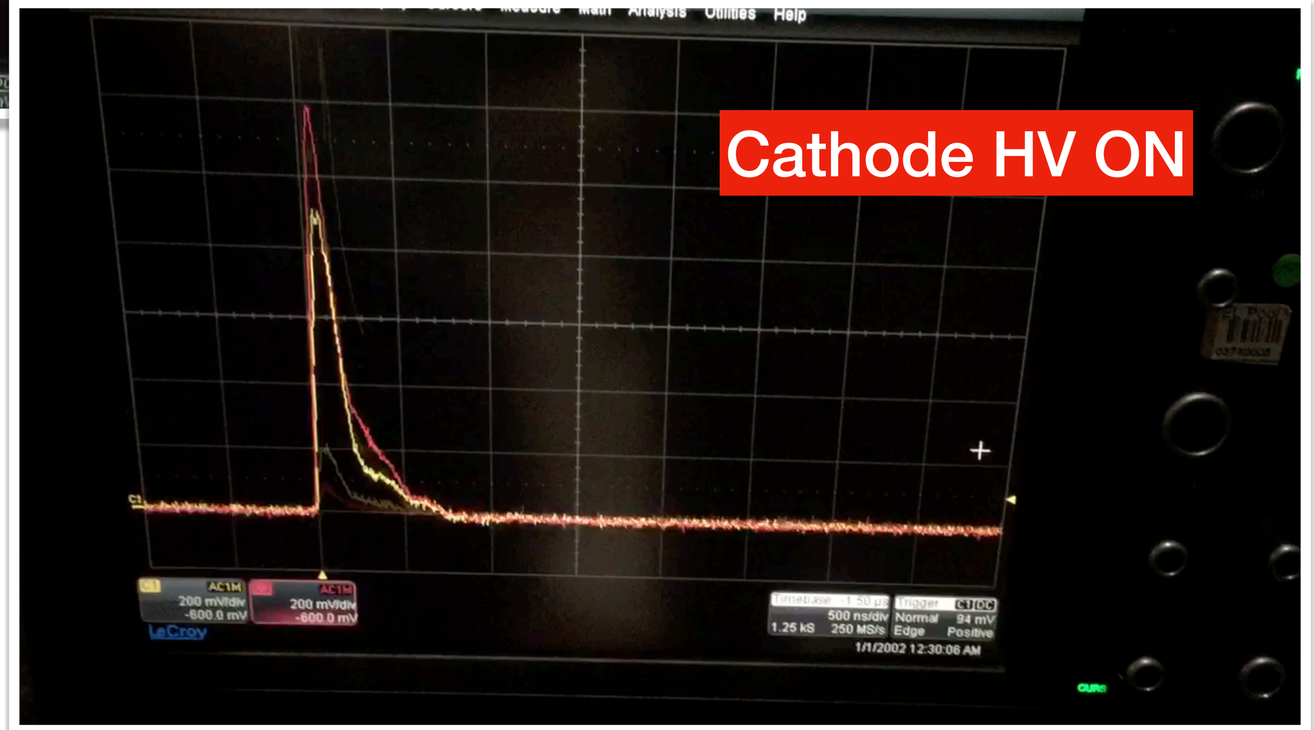
External Muon Telescope on the CB top





Milestone #1:

record VD PDS signals with HV on Cathode in LAr

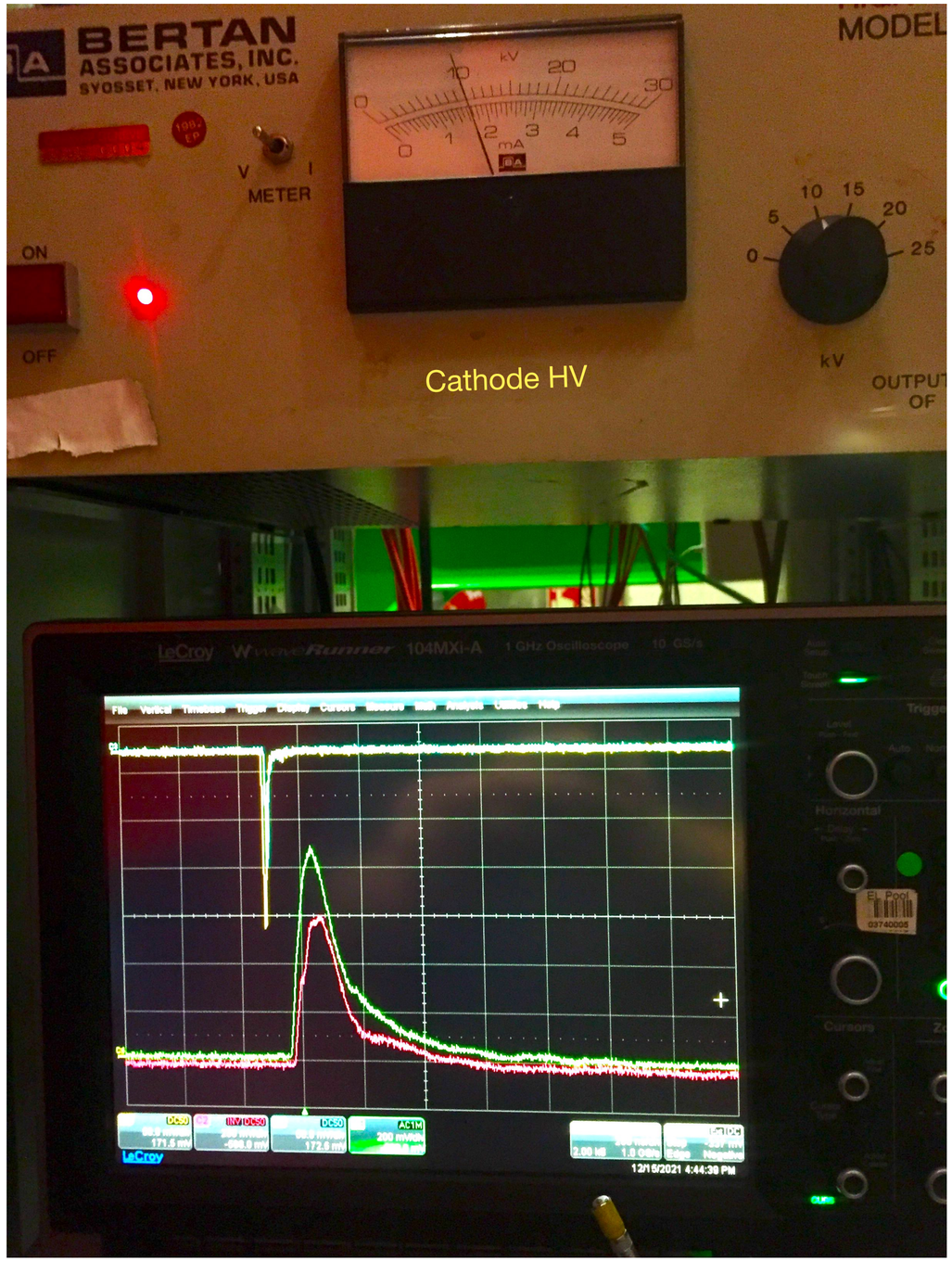


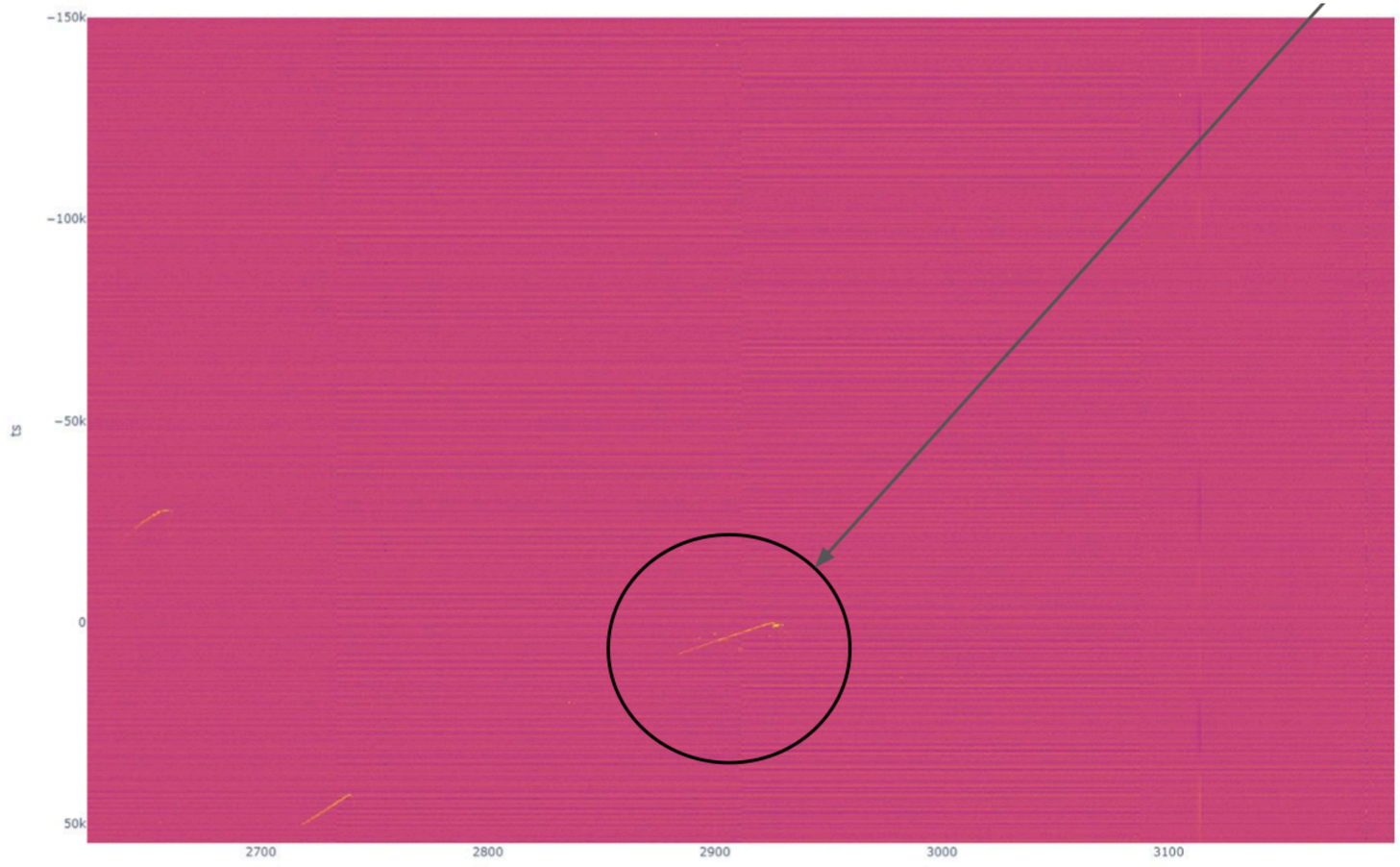
PoF is turned ON on Dec. 15 - clean signals immediately seen on scope

No visible difference
(no noise increase or signal distortion)
when HV ON

Milestone #2:

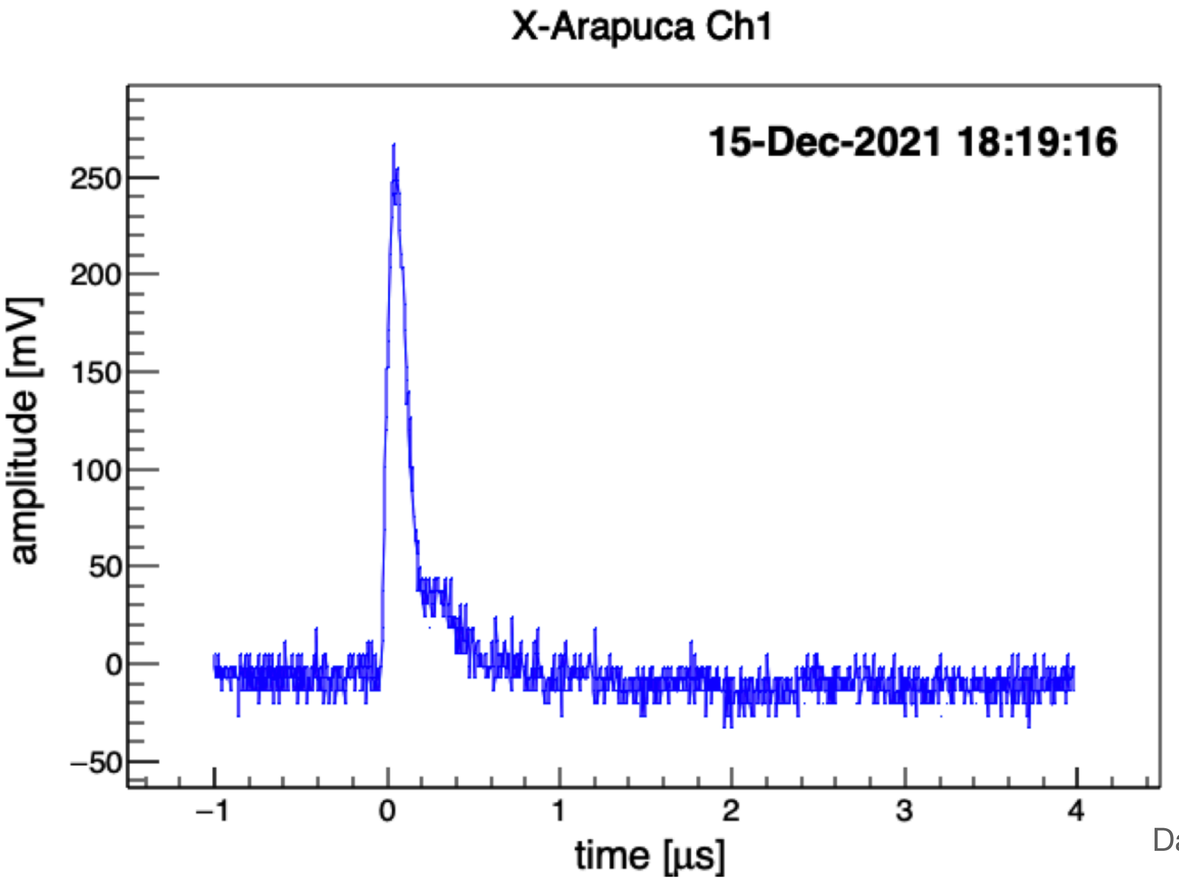
xARAPUCA on Cathode
provide trigger to TPC DAQ and
detect tracks in coincidence with Light Flash

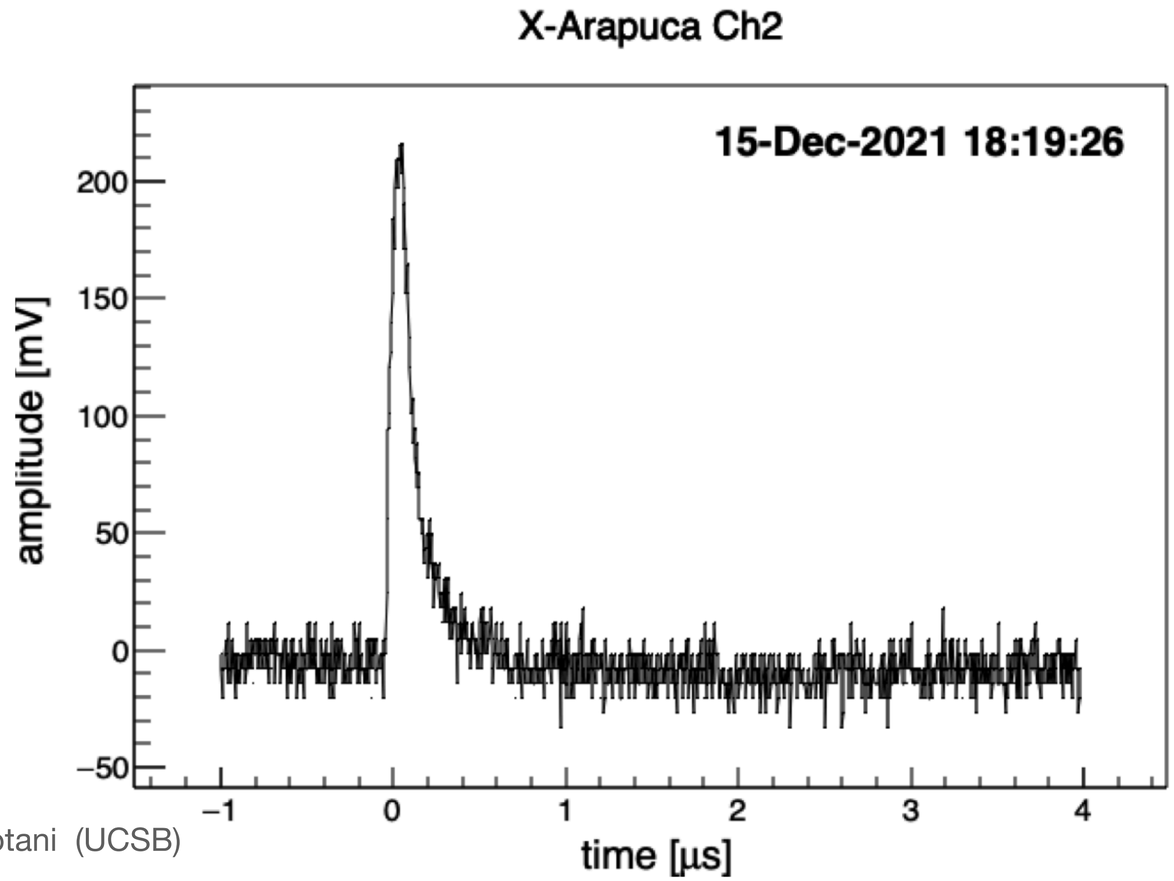




Cosmics Run

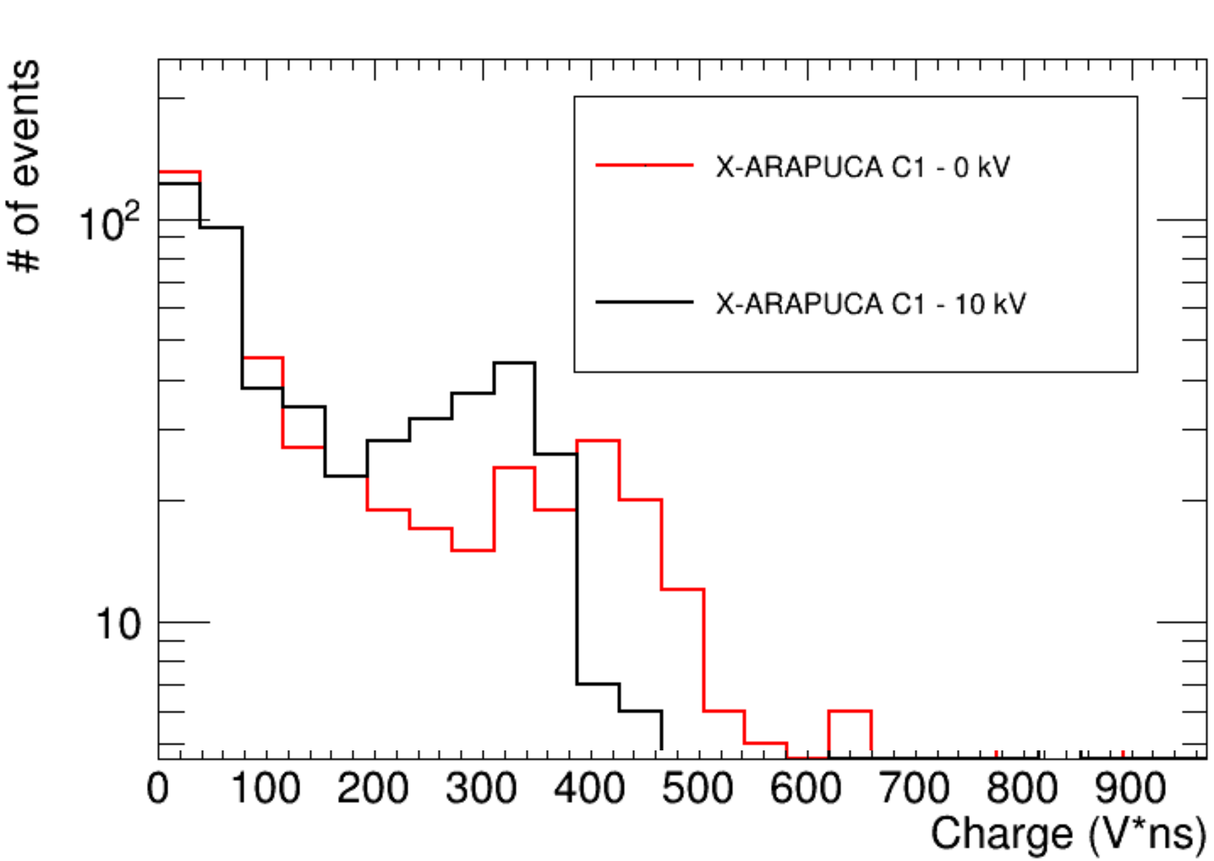
Example of signals triggered on CRT + X-Arapuca

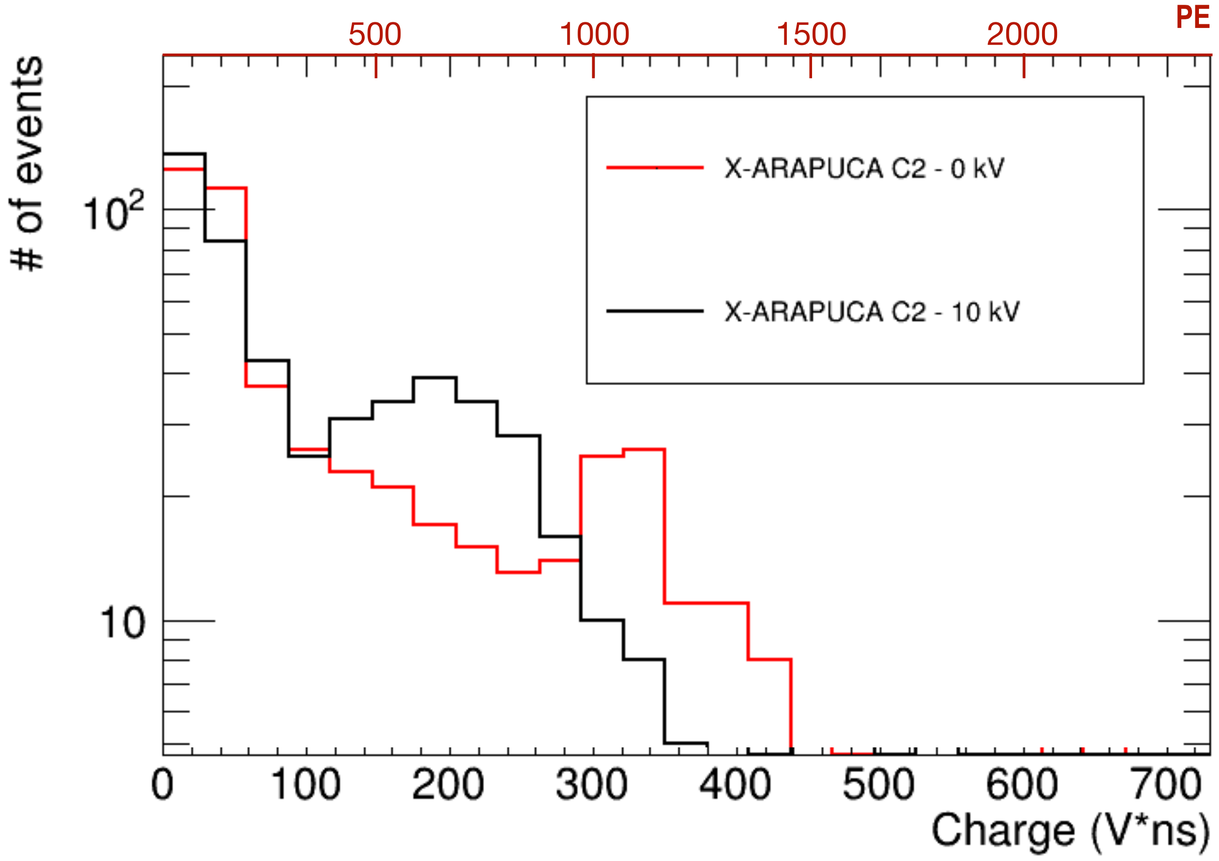




Dante Totani (UCSB)

Light Signals from Cosmic Tracks (external CR Telescope trigger)





1 PE ≃ 0.3 V*ns
(see next slides)

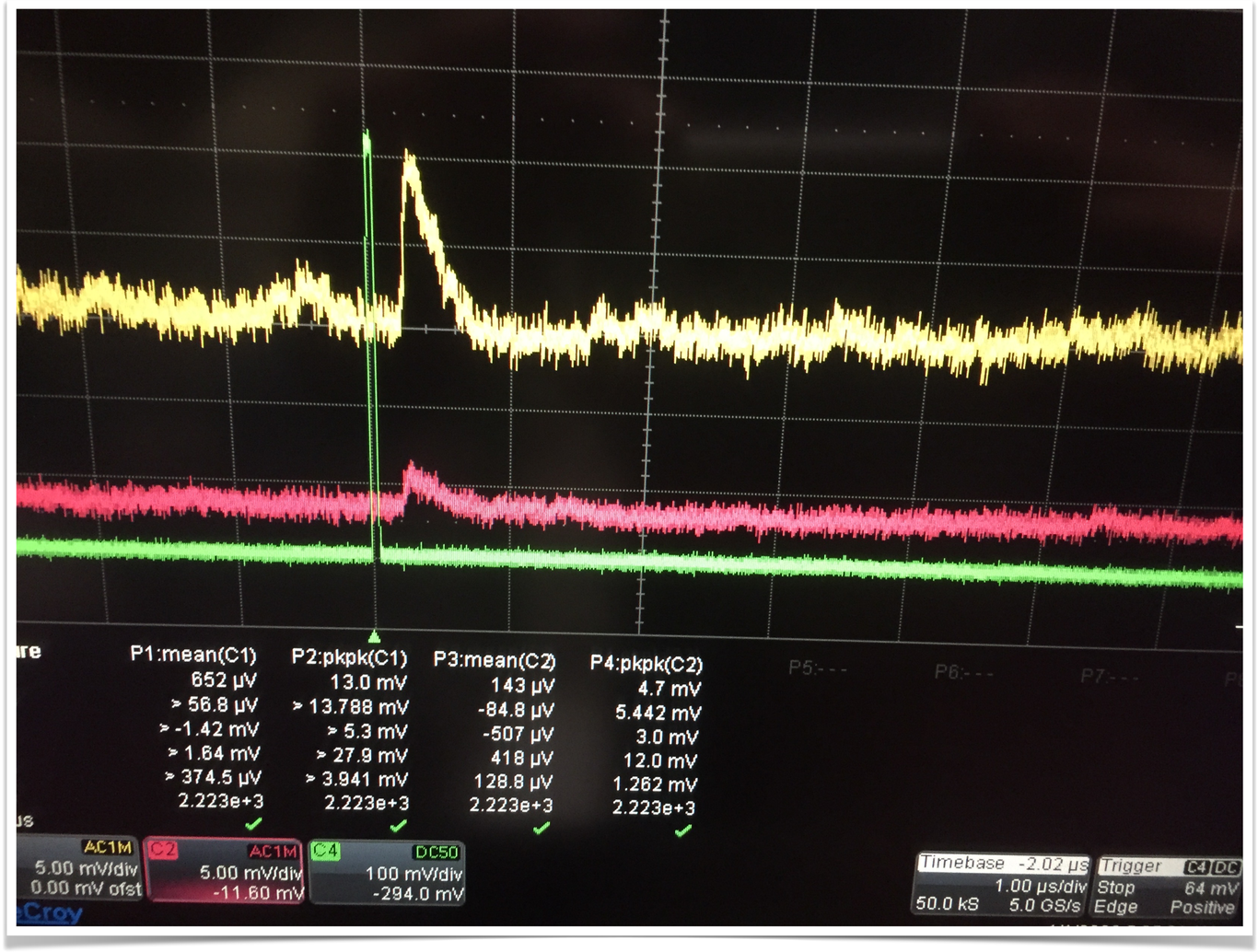
EF-ON vs EF-OFF: light spectra change due to recombination

Henrique Souza (APC)
Sabrina Sacerdoti (APC)

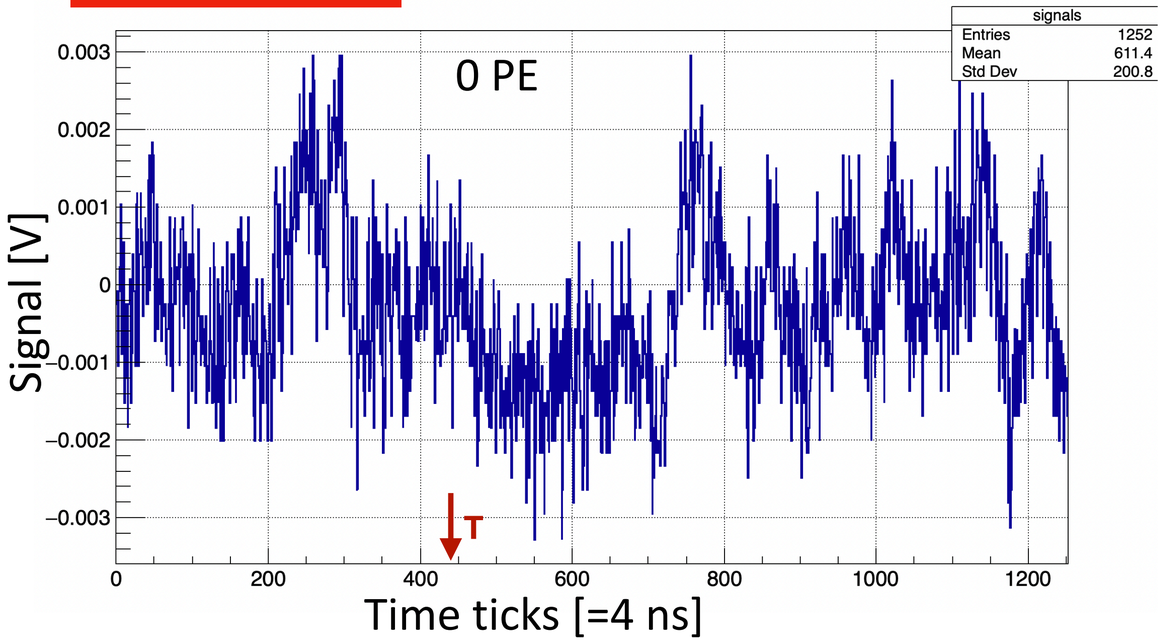
First look to detector response characterization with SMALL STAT Calibration Data with LED flasher

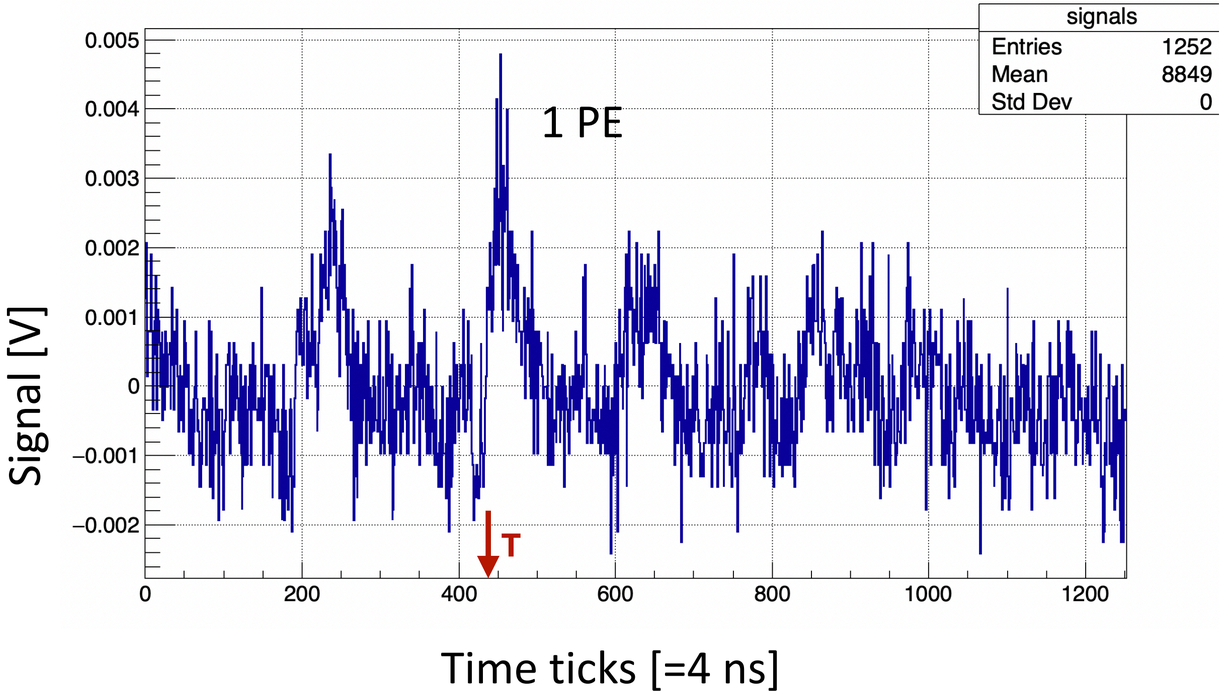
Analysis is in progress and results here are PRELIMINARY

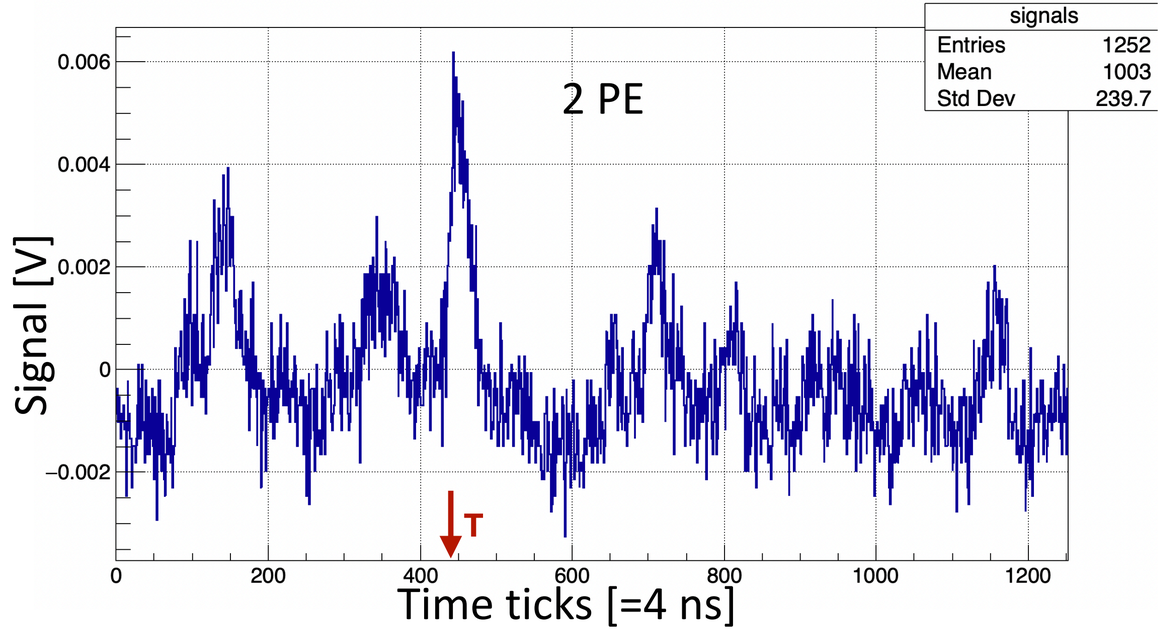
Calibration Run



Calibration Run







File used:
C1XArapuca_Efield_0kV_CRPon_A1ch1_250MHz_LEDwith20ns ampl5V00000.txt **[500 waveforms]**

Noise (baseline fluctuations) shows unexpectedly large low frequency components (studies are under way to identify the sources of this noise)

Calibration Run

X Arapuca Channel 1:

Scanned	Prediction from Poisson statistics
Total events = 500	----------
Noise events = 327	$\lambda_P = 0.425$
Single PE=130	138.8
2 PE = 36	29.5
3 PE = 5	4.1

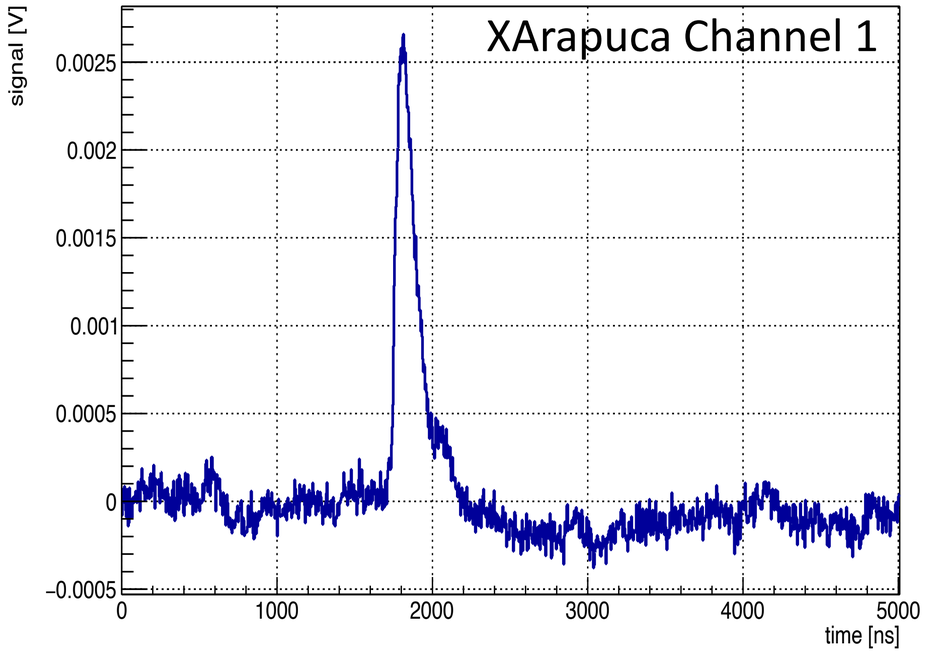
Note: some after-pulse and X-talk contribution to 1-2-3..-PE counts is expected - probably a number of SPE are in the noise (0-PE sample)

X Arapuca Channel 2:

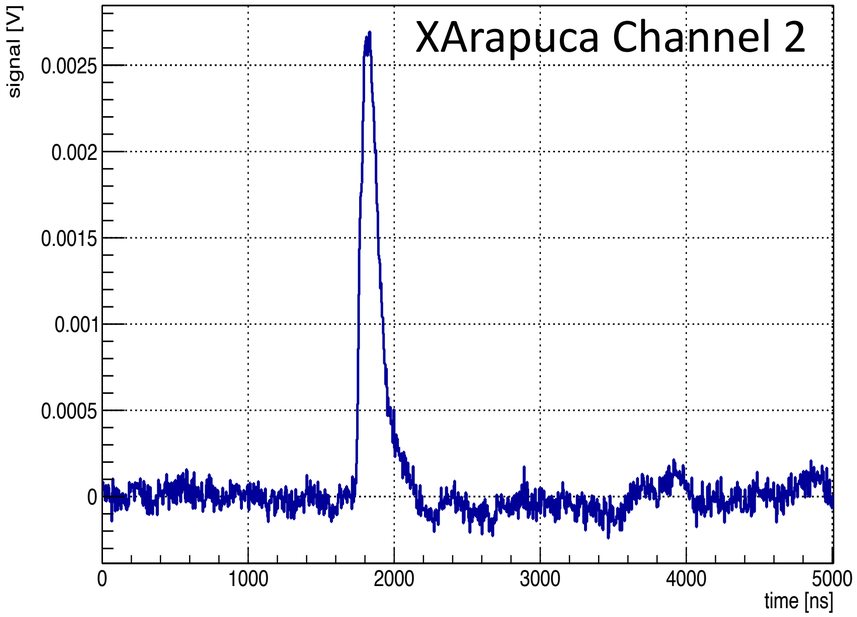
Scanned	Prediction from Poisson statistics
Total events = 500	----------
Noise events = 325	$\lambda_P = 0.424$
Single PE=143	140.0
2 PE = 26	30.1
3 PE = 5	4.3

Analysis is in progress - with more extended statistics

Average SPE waveform

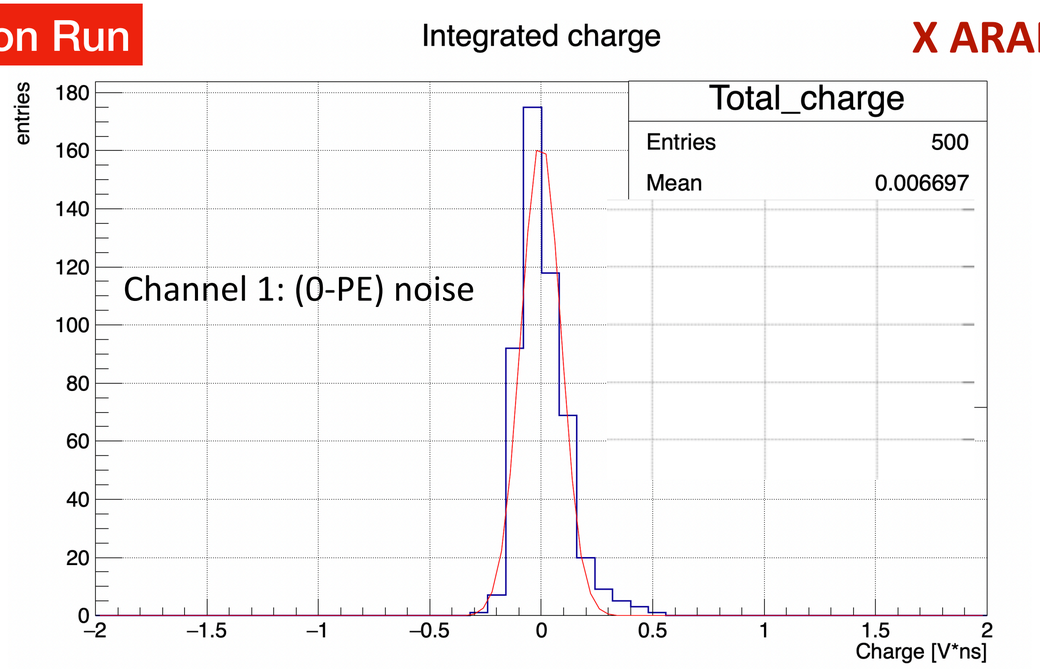


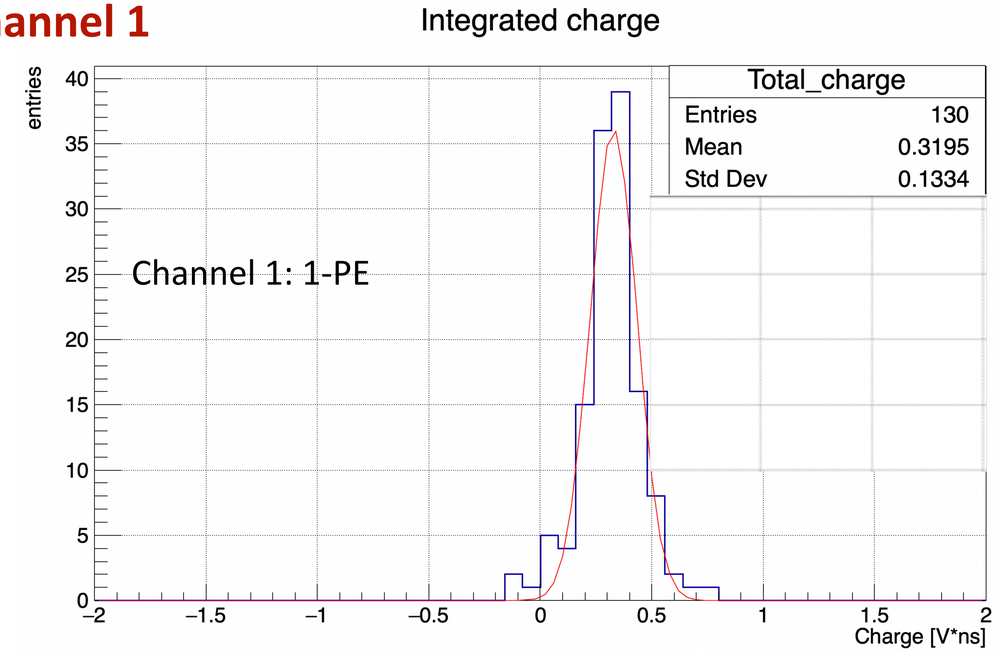
Average SPE waveform



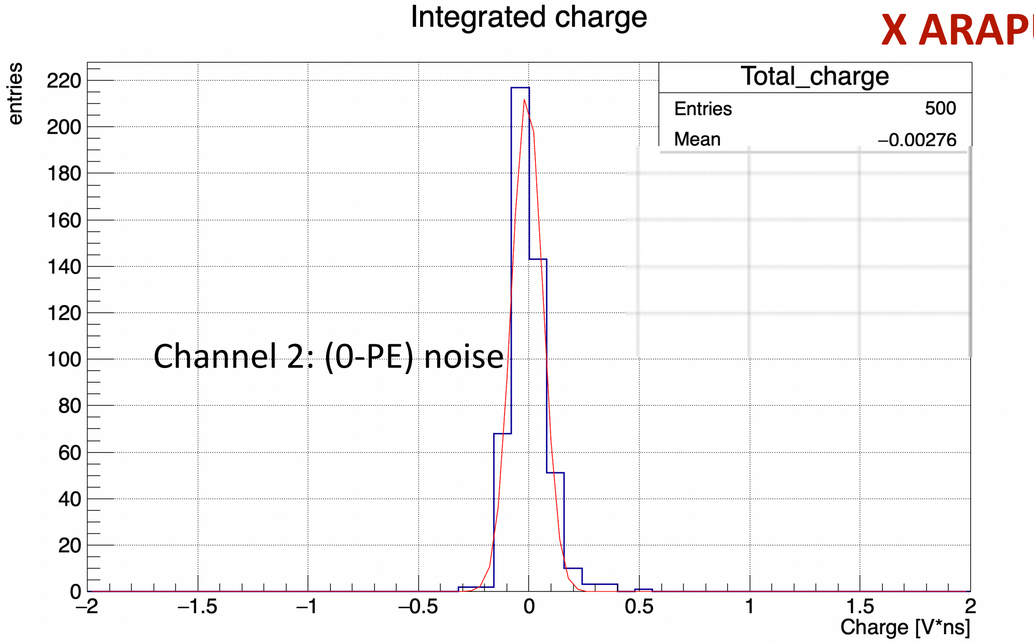
Calibration Run

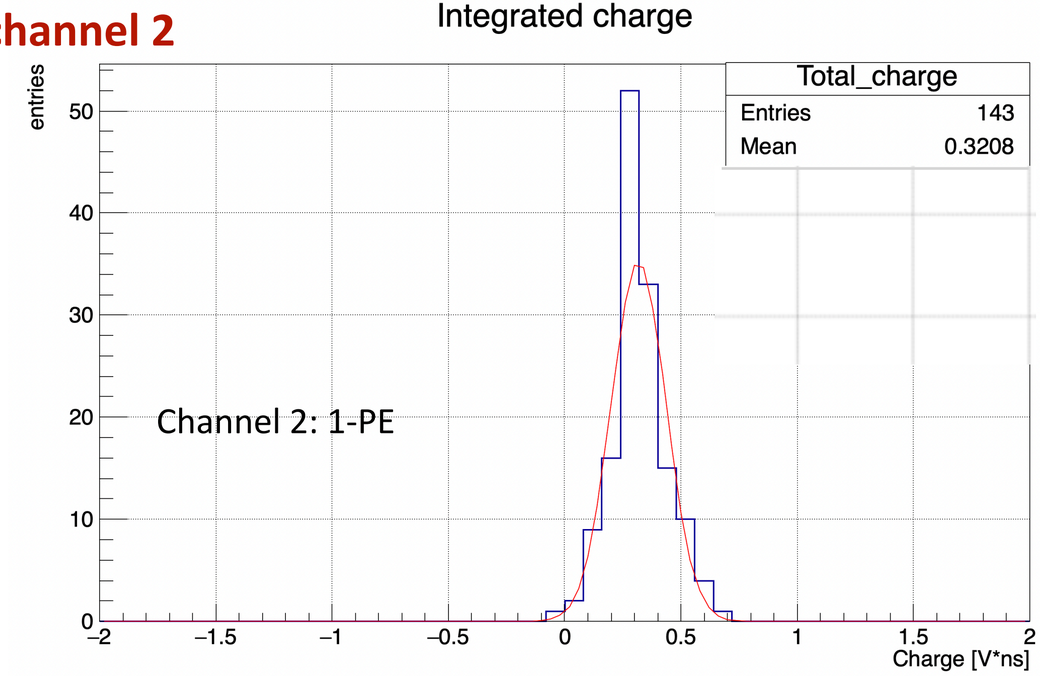
X ARAPUCA channel 1



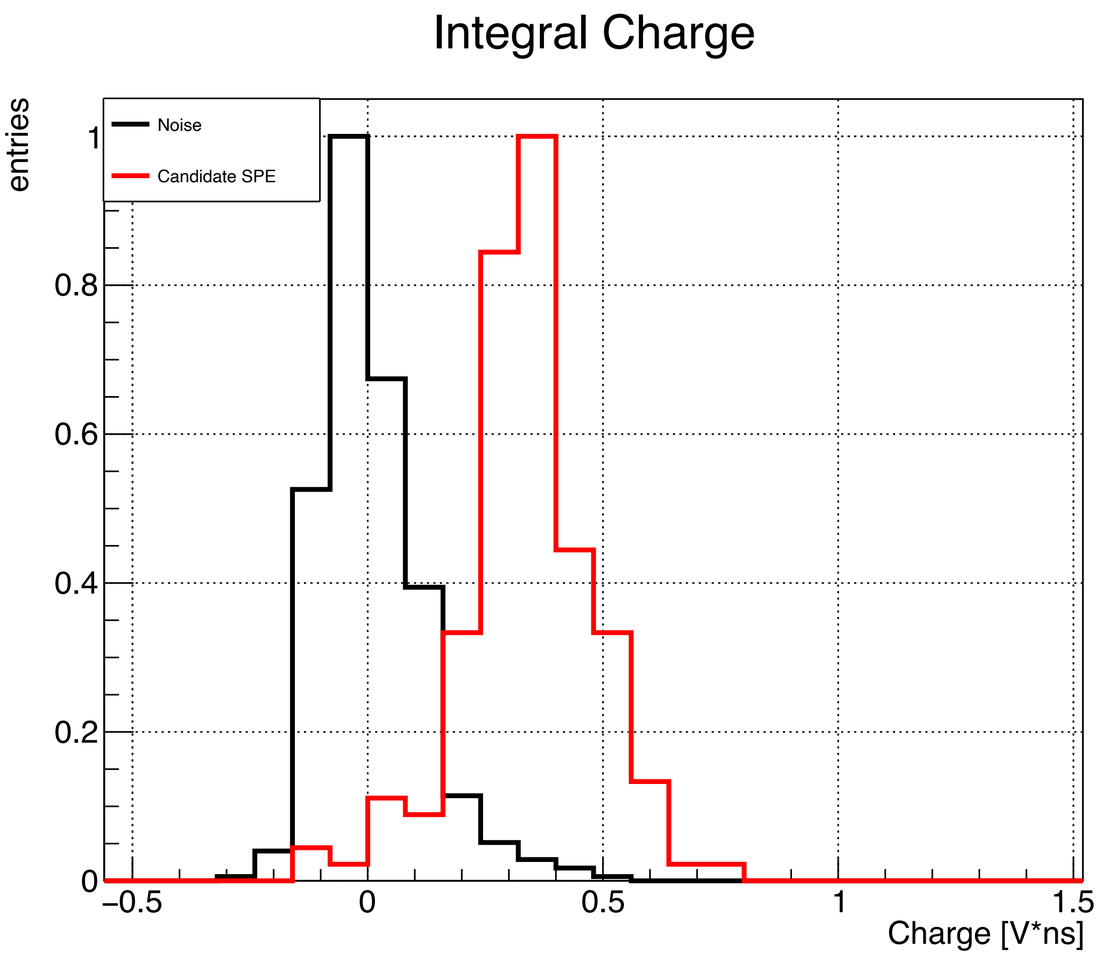


X ARAPUCA channel 2

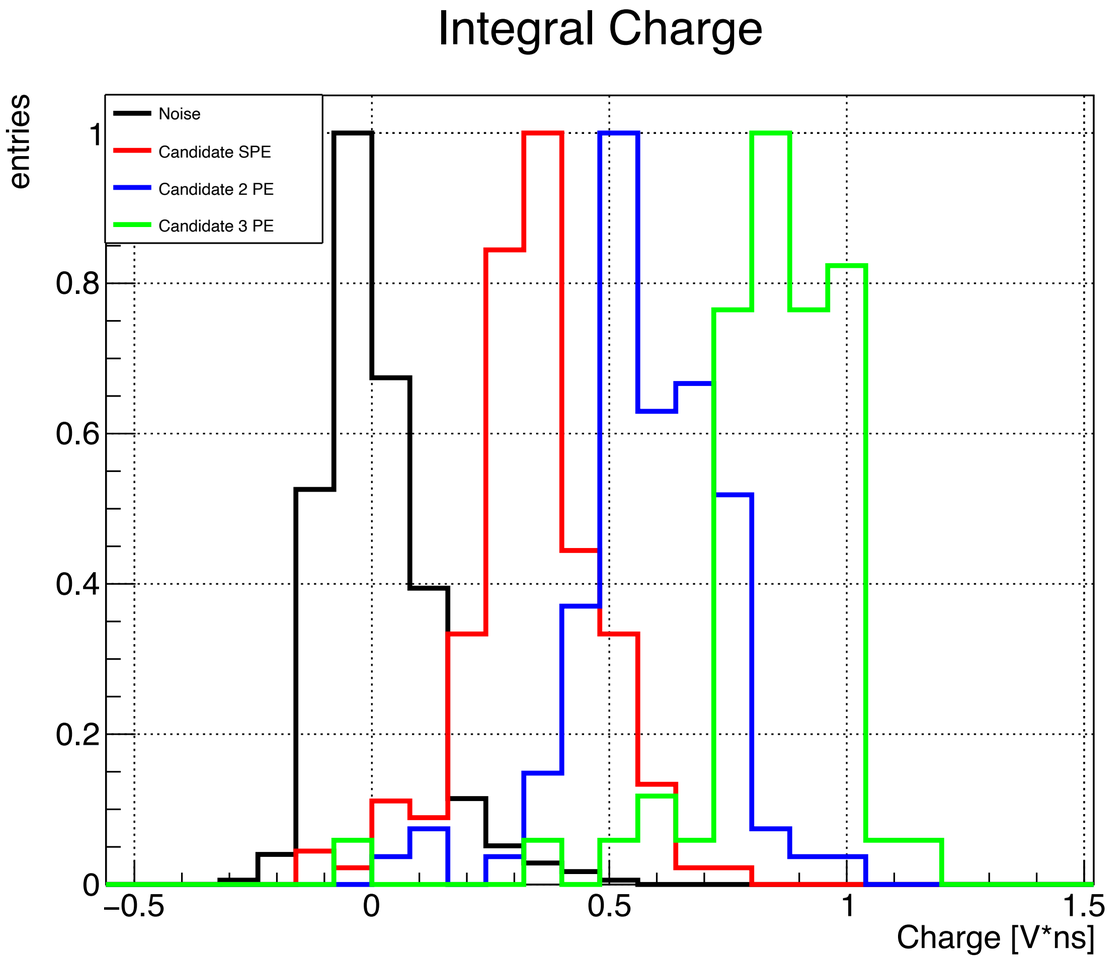




Calibration Run



Noise (0-PE) and 1-PE Charge distributions (normalized)



and here adding 2-PE and 3-PE Charge distributions (normalized)

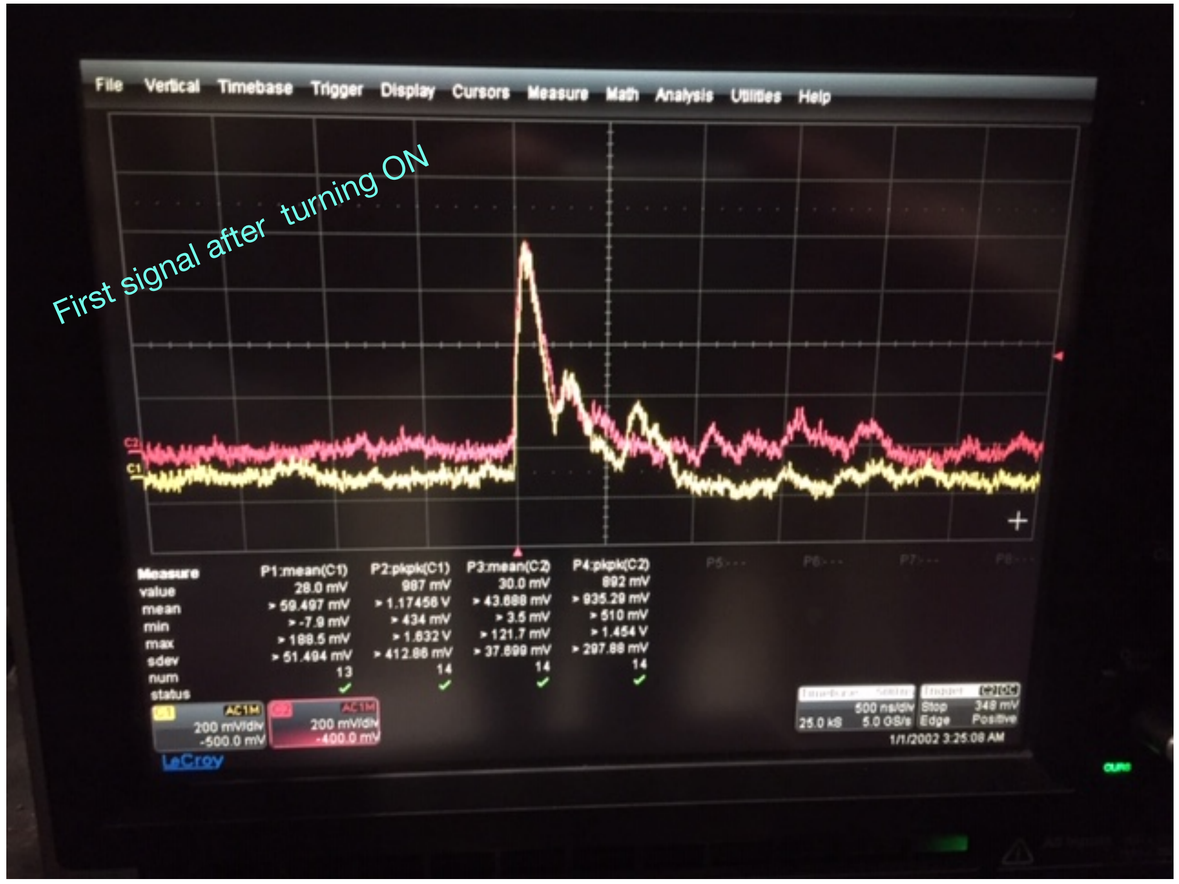
Summary

- A first PDS prototype for VD FD#2 was conceived, built, installed and tested at the CERN-NP CB test facility (a very fast development from ~8 months intense activity from the great VD team in the PD Consortium)
- Test was completely successful, all milestones achieved:
  - *PD detector operates in LAr on Cathode at HV (without signal distortion or noise increase)*
  - *PD on the Cathode provide flash/trigger for TPC track matching*
- Small data statistics for off-line analysis and calibration collected in the few days left before shutdown [Dec15 to Dec 17]
- An innovative detector technology has been validated:
  - ***PoF*** *successfully operated and delivering LOW NOISE, clean isolated Power to PDS*
  - ***Analog SoF*** *successfully demonstrated for linear transmission of signals from Single PE to 1000 PE signals*
  - *Extension to Very Large Area detector (with large n. of SiPM in new ganging scheme) shows to be attainable - another step in versatile ARAPUCA technology -*
- *Development will continue in 2022 for Optimization of the Detector technology and full characterization of performance*

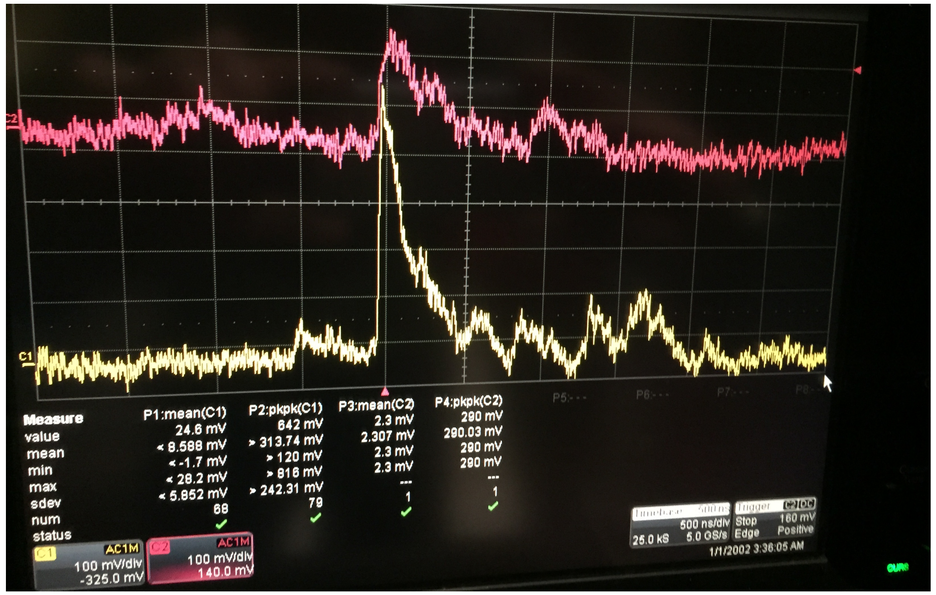
Milestone #1:

detect light signals with PoF and SoF from xARAPUCA large size tile

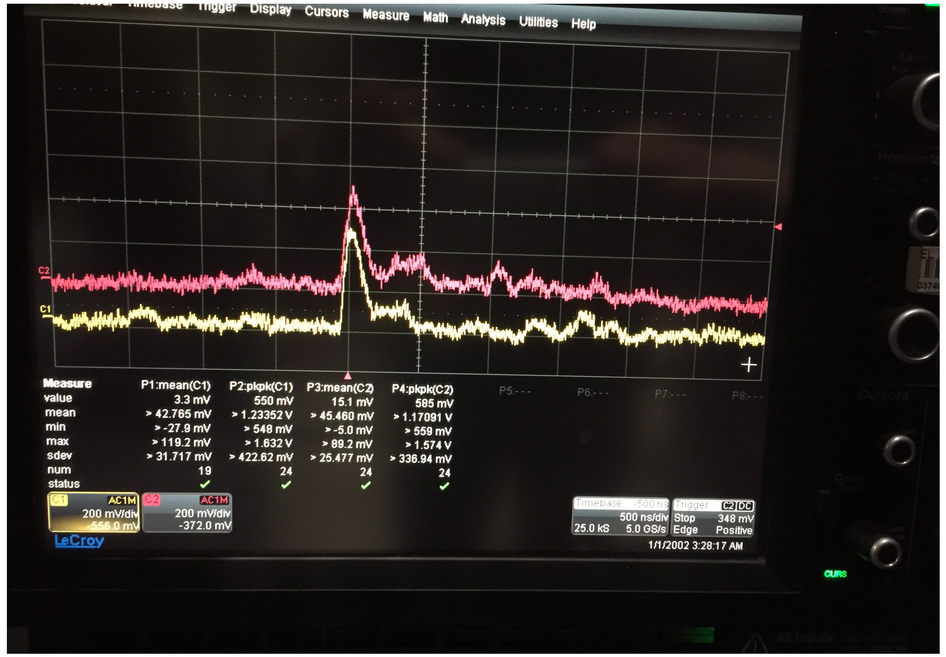
Cathode still in cold GAr (while filling) HV OFF



xARAPUCA Tile
2 channels - 80 SiPMs each
(hybrid passive & active ganging)

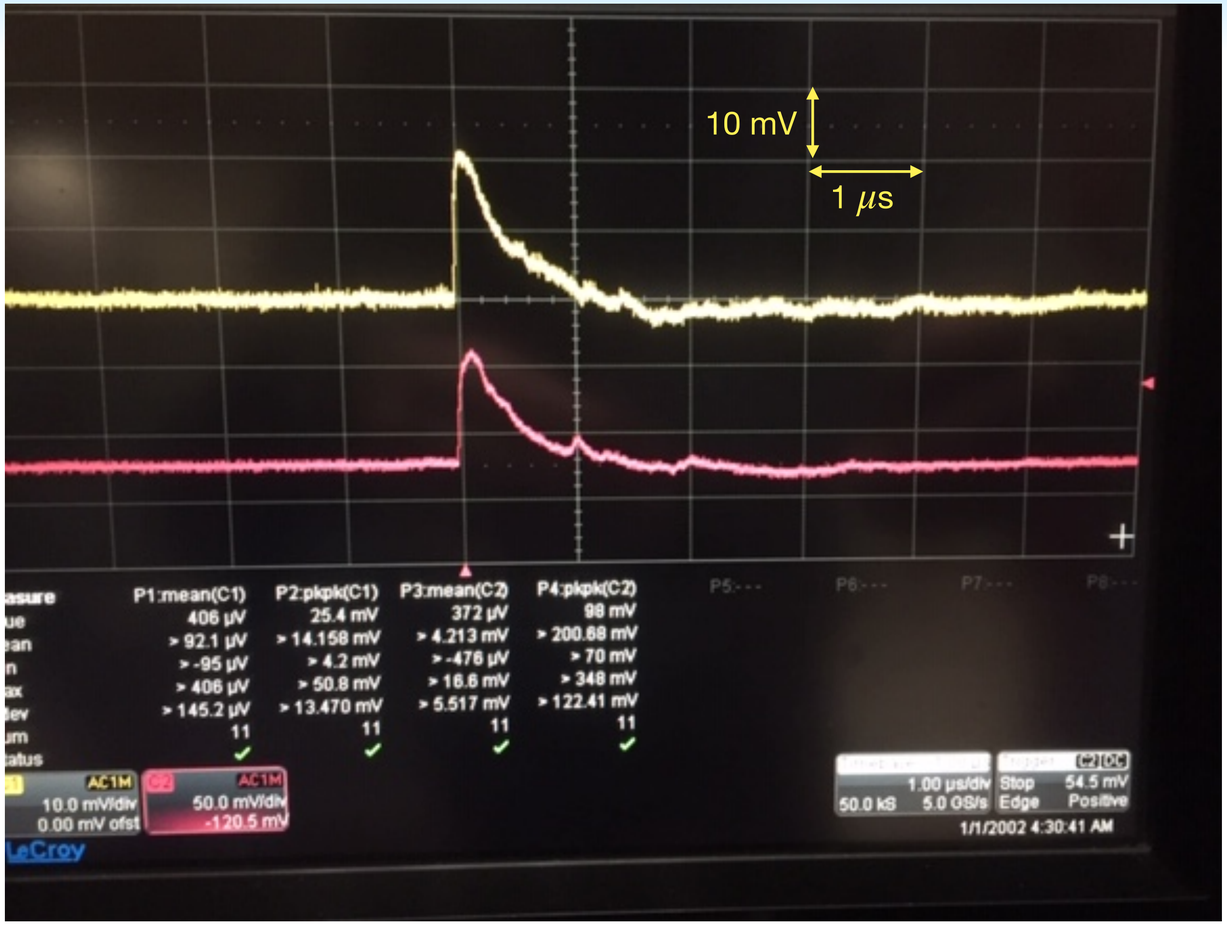


2 mini-ARAPUCA
Plate B
(20 SiPM - hybrid passive ganging)



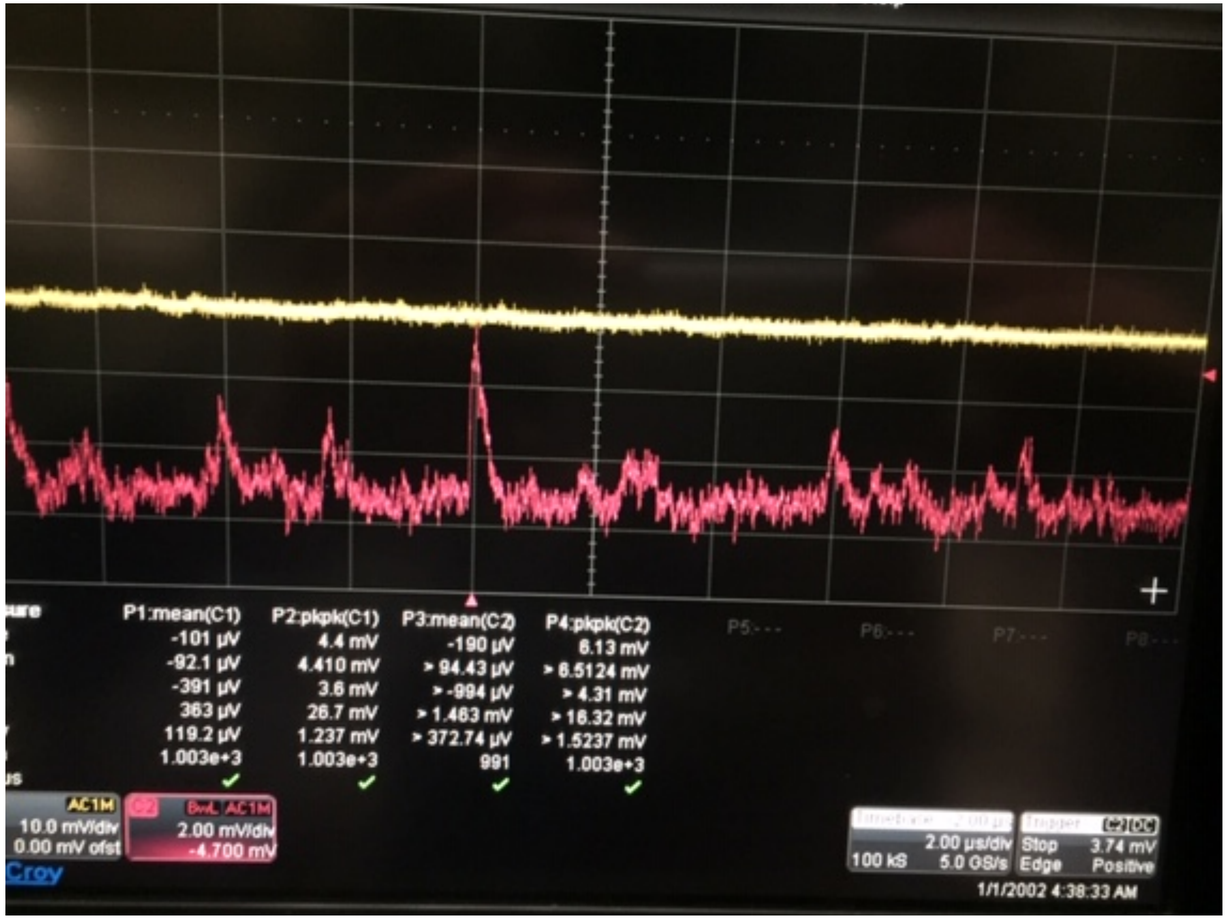
2 mini-ARAPUCA
Plate C
(20 SiPM - hybrid passive ganging)

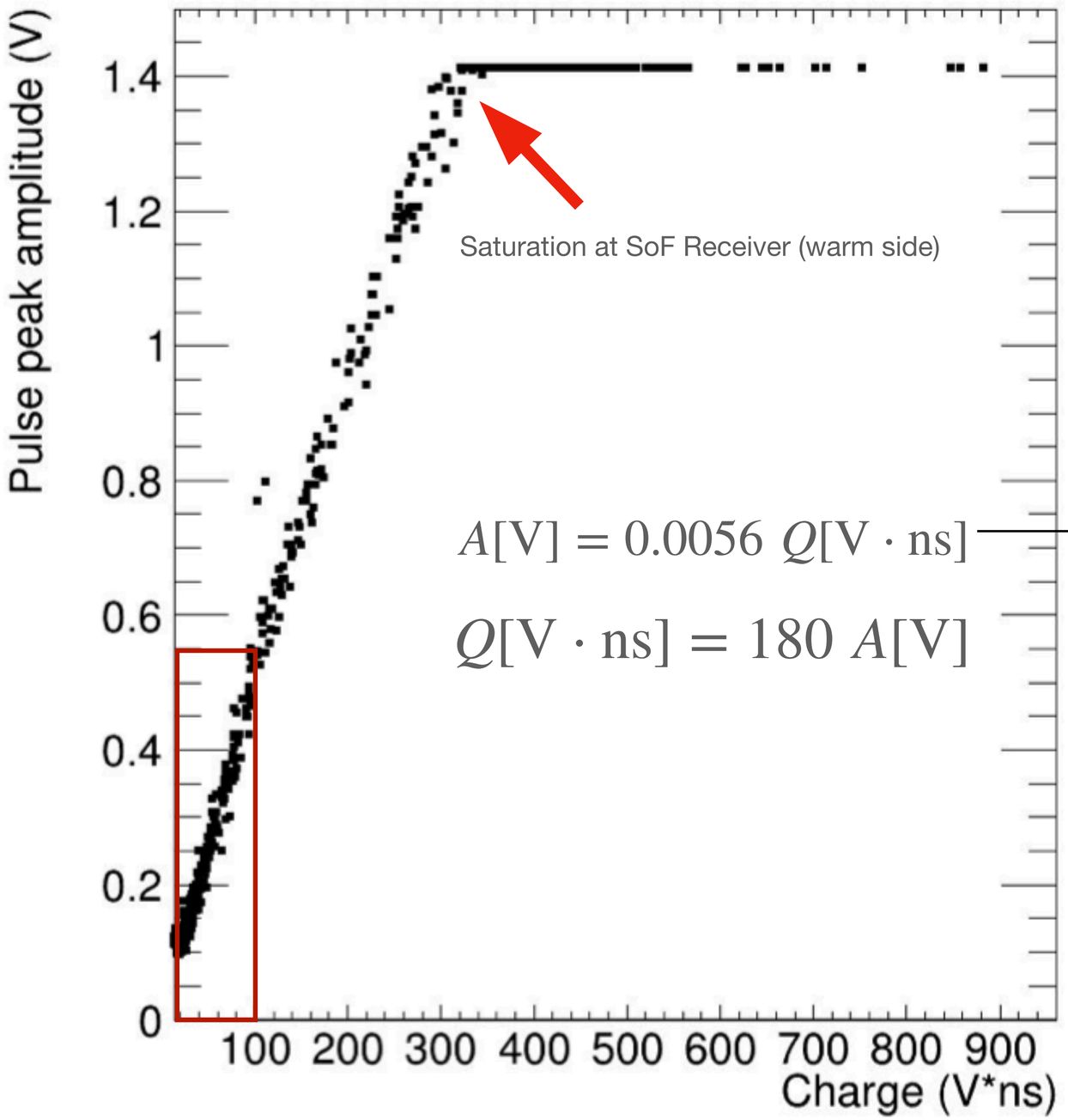
record VD PDS signals with HV on Cathode in LAr



xARAPUCA Tile
2 channels - 80 SiPMs each
(hybrid passive & active ganging)

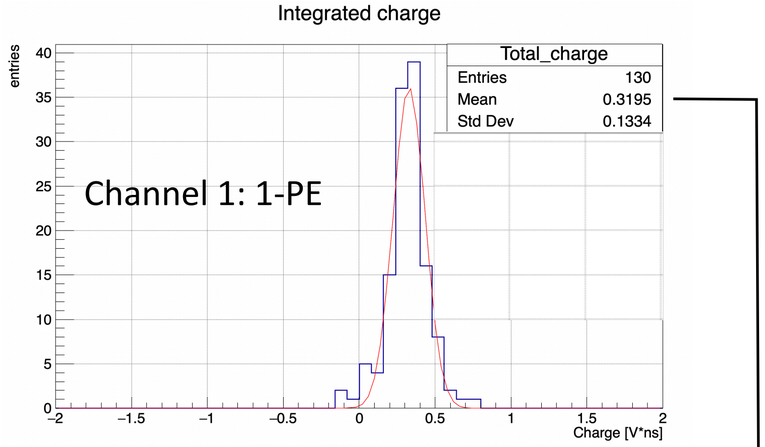
xARAPUCA Tile (red trace -1 channel)
sequence of SPEs and fewPEs



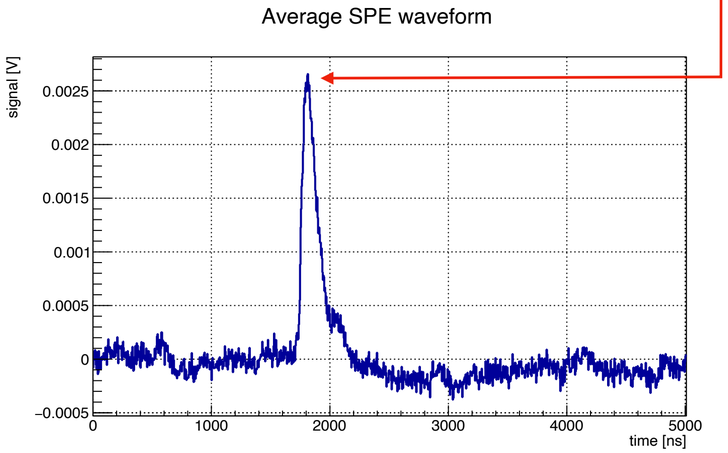


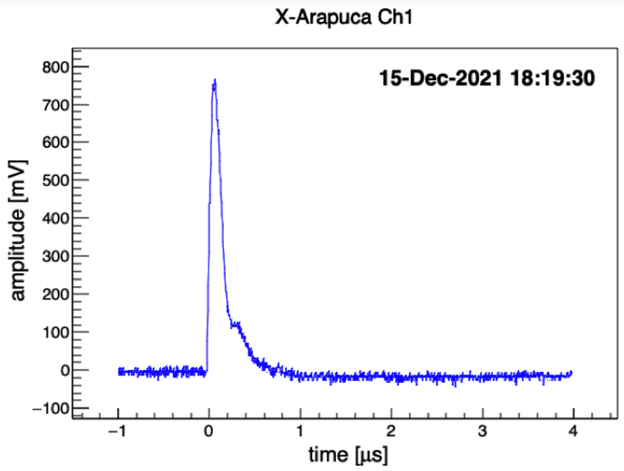
$$A[\mathrm{V}] = 0.0056\ Q[\mathrm{V}\cdot\mathrm{ns}]$$

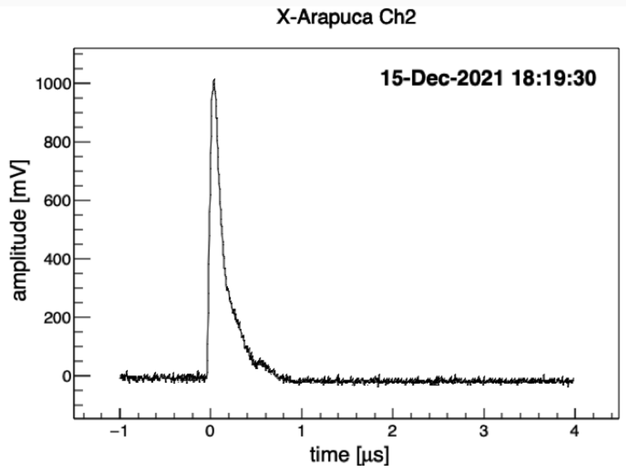
$$Q[\mathrm{V}\cdot\mathrm{ns}] = 180\ A[\mathrm{V}]$$



$$\langle A_{SPE} \rangle = C\ \langle Q_{SPE} \rangle = 0.0056 * 0.3195\ \mathrm{V} \simeq 0.0020\ \mathrm{V}$$







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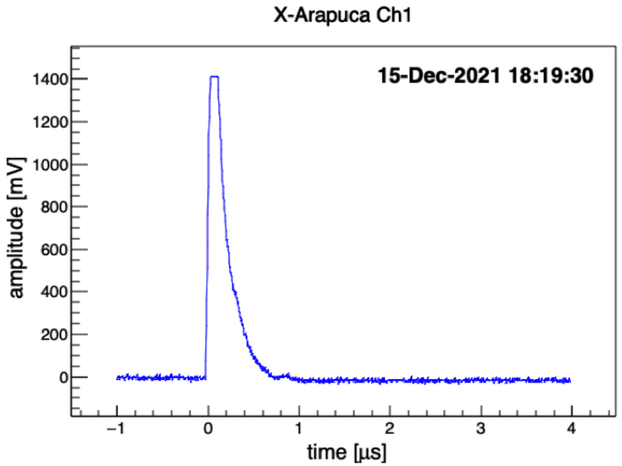
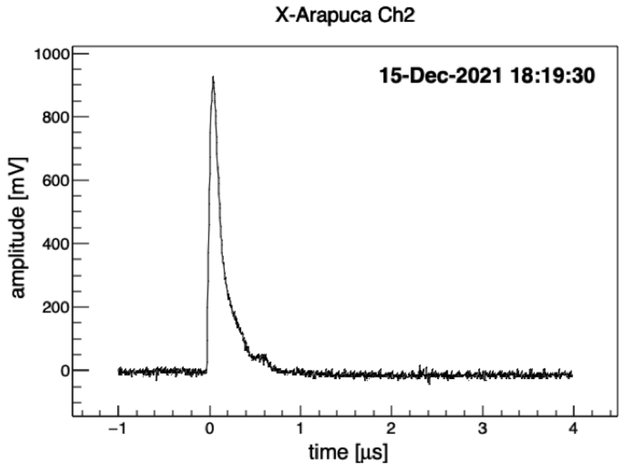
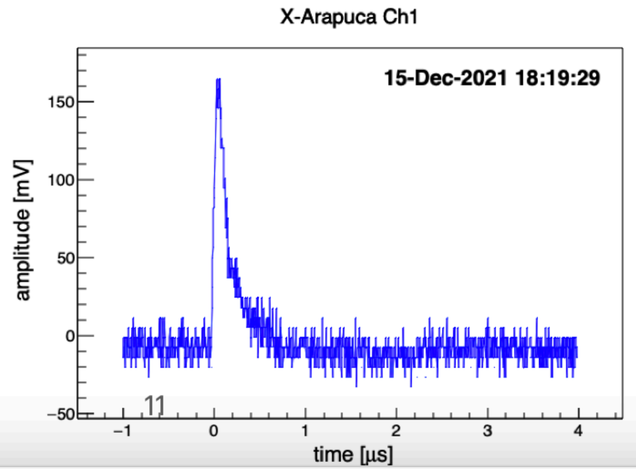
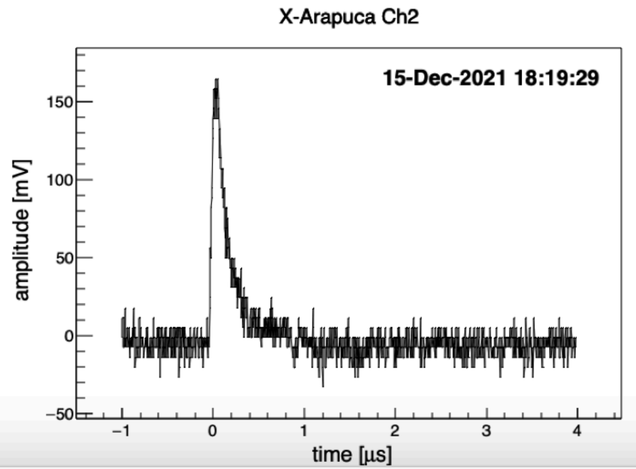
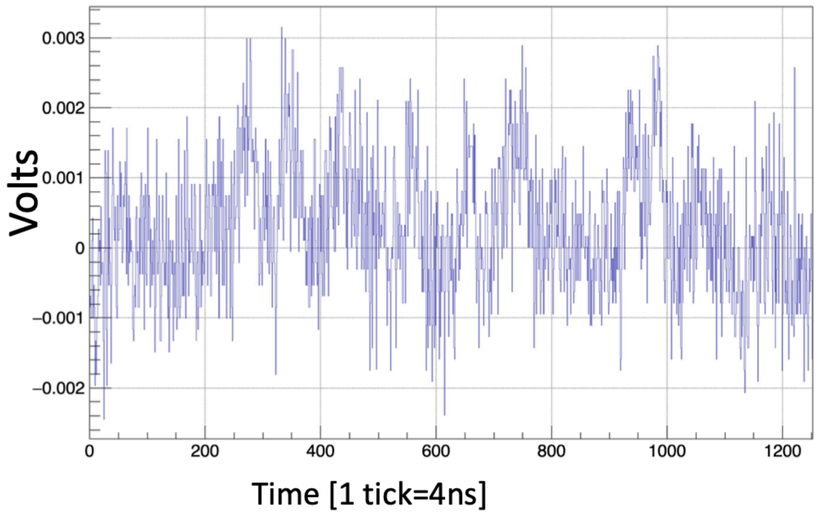


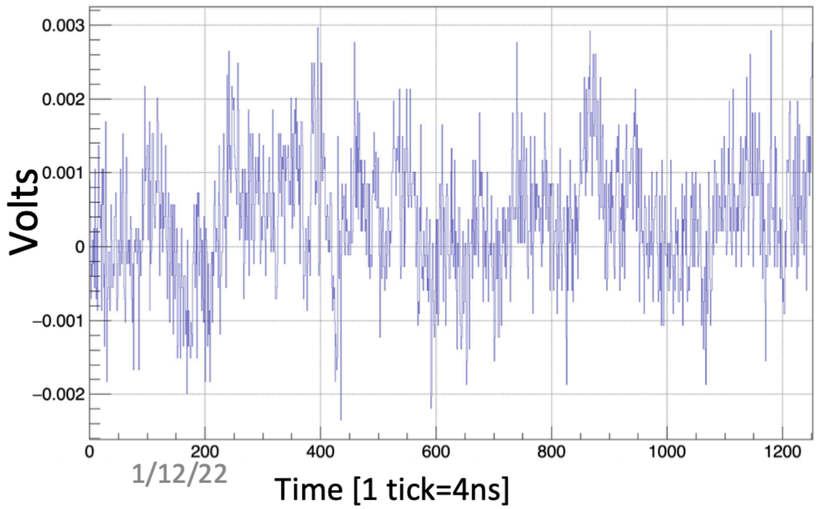


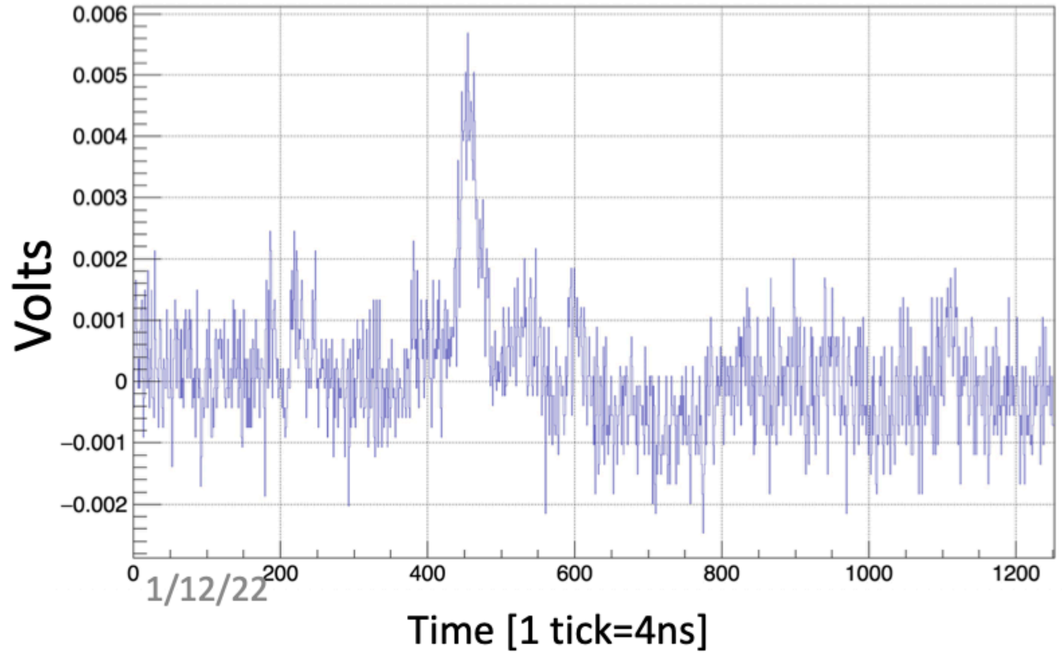


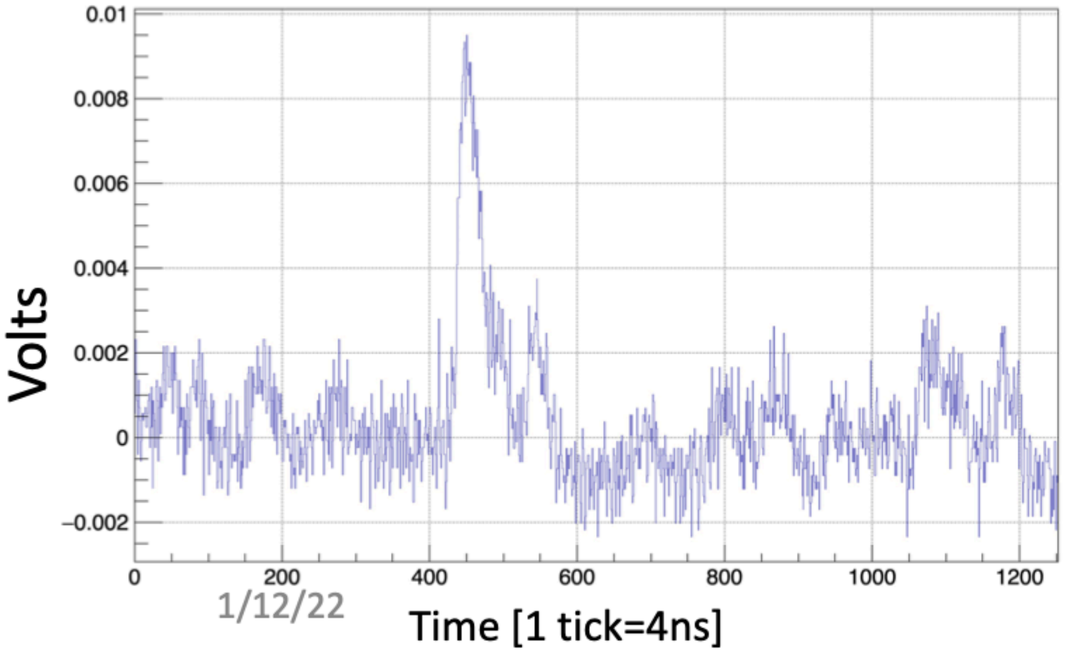


Candidate no signal events [noise]:









verify linear response of the SiPMs (xARAPUCA Ch.#1)
to calibration LED signal of increasing amplitude