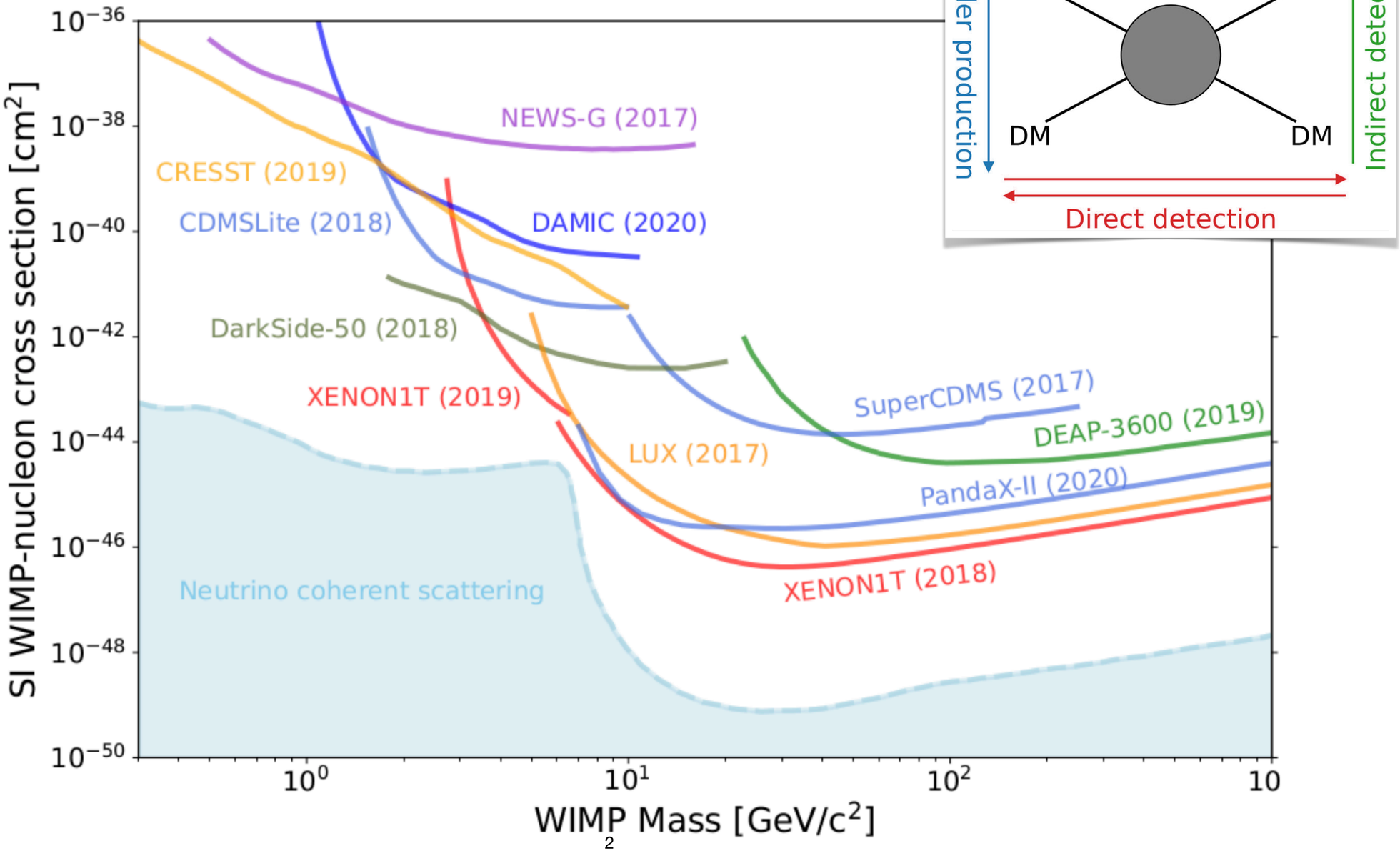
A study of prototype detectors, components and analysis strategies for DarkSide-20k

Camilla Salerno

Supervisors: Prof. Paolo Agnes, Prof.ssa Giuliana Fiorillo

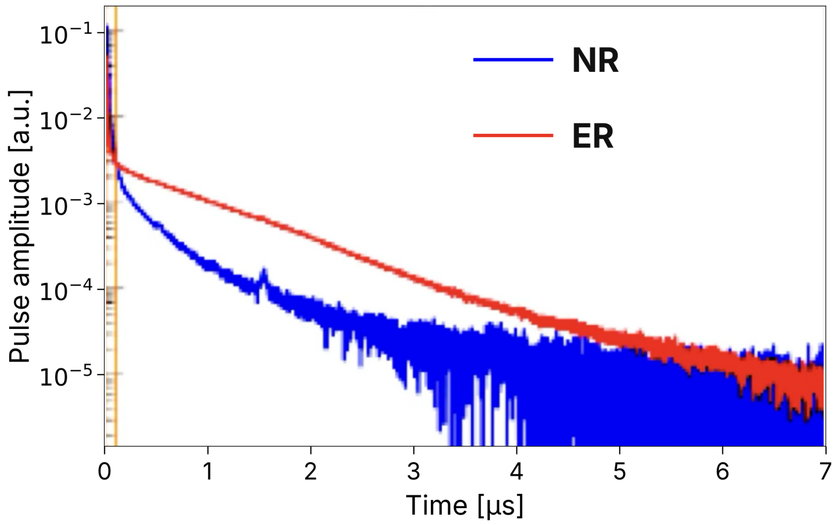
Passage to 3rd year 14/10/2026

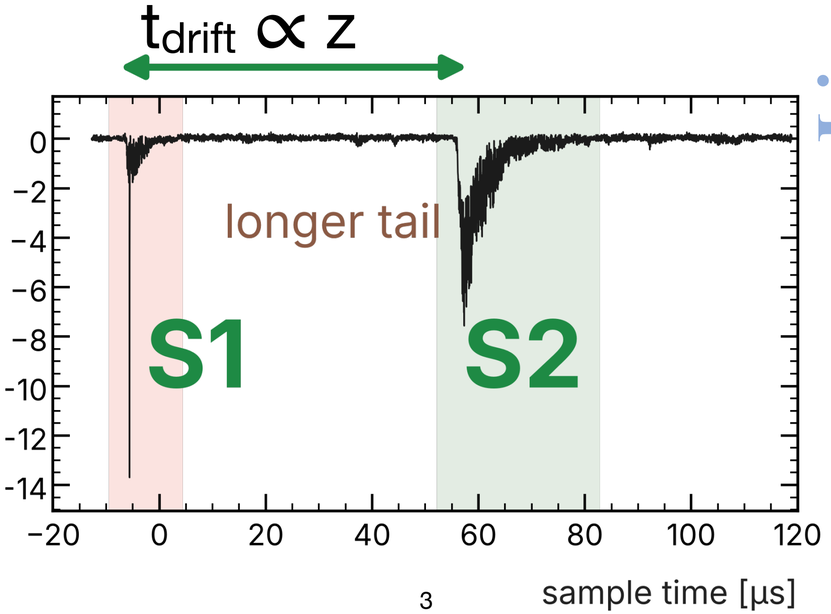
Dark Matter Direct Detection

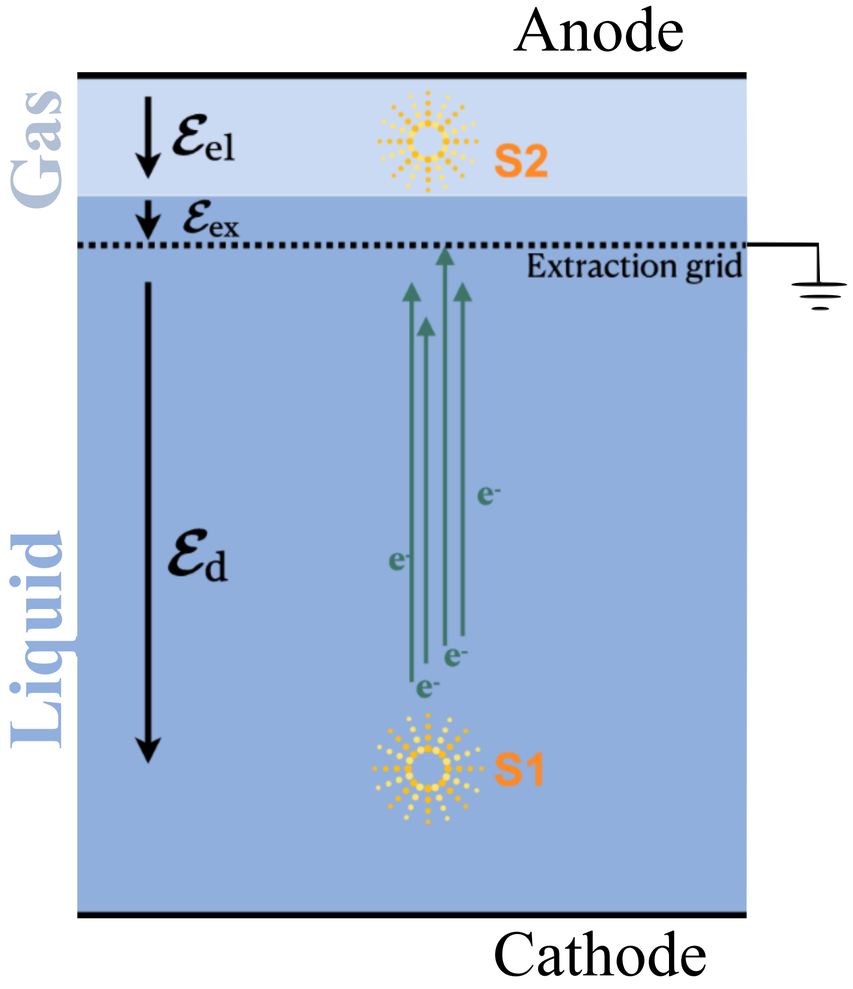


Double-phase Time Projection Chamber

- S1 prompt light from excitation of target atoms
- Three electric fields: $\boldsymbol{E_d}$ between cathode, $\boldsymbol{E_{ex}}$ between grid and Liquid-gas interface, $\boldsymbol{E_{el}}$ between Liquid-gas interface and anode
- S2 delayed amplified signal from ionization electrons of target atoms
- 3D position reconstruction from the combination of S1 and S2 signals
  ~ 1 cm in XY, ~1 mm in Z
- **Pulse Shape Discrimination** enables **10^9 rejection** of electron recoil backgrounds in LAr







Darkside-20k experiment

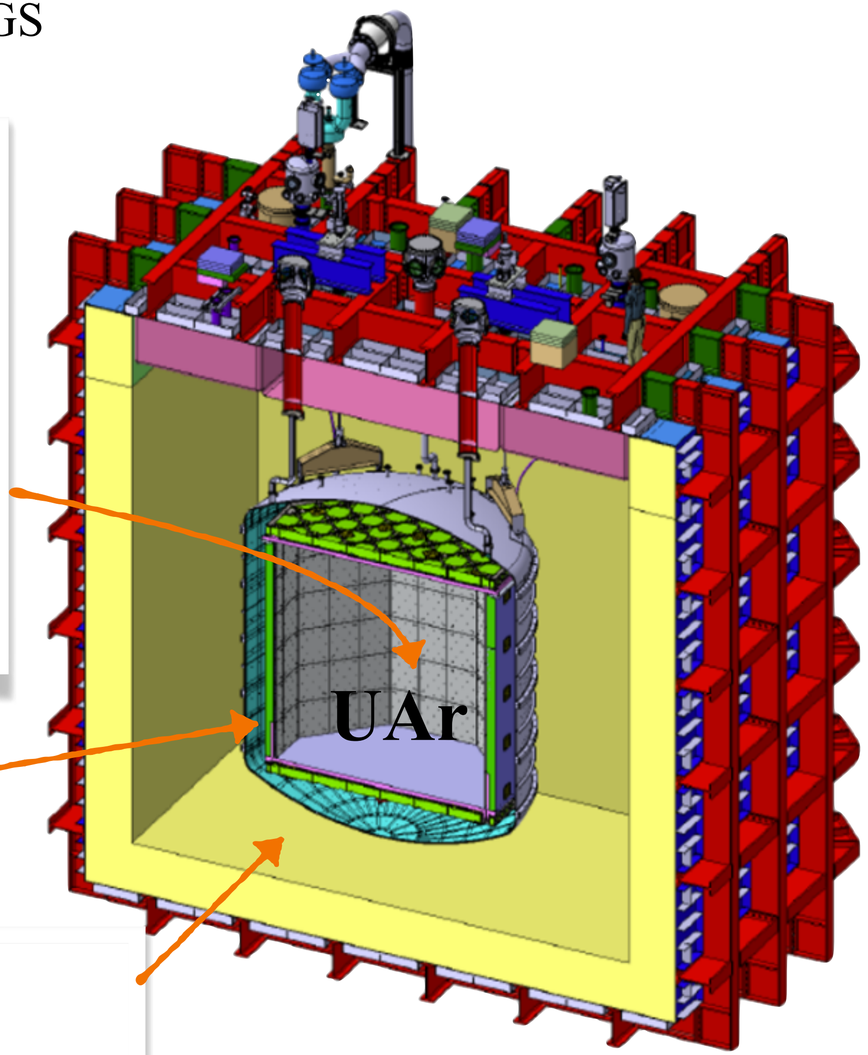
Double-phase TPC filled with LAr to search WIMPs under construction @ LNGS

TPC:

- filled with ~50 t of liquid underground argon (UAr), with ~20 t fiducial mass
- Acrylic vessel: ~3.5 m height × ~3.5 m diameter
- 7mm of Gas Pocket
- Clevios-coated walls, cathode and anode for field generation
- Readout: 21m² SiPMs + TPB wavelength shifter (128nm ->420nm)

Inner Veto:
Stainless steel vessel filled with ~36 t of UAr equipped with SiPMs

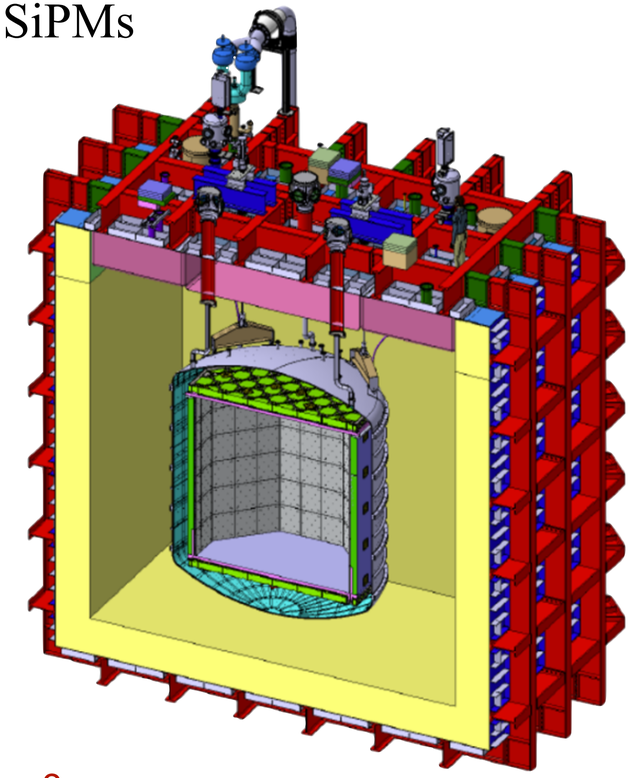
Outer Veto:
DUNE-like membrane cryostat filled with ~650 t of liquid atmospheric argon (AAr), equipped with SiPMs



Optical readout in DarkSide-20k

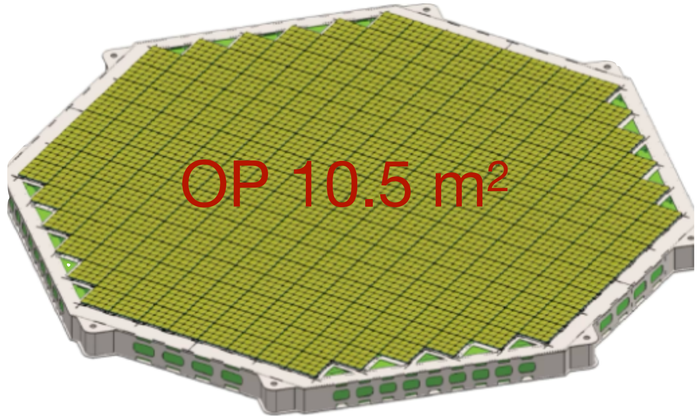
TPC:

- Two Optical planes (OP) for a total of 21m^2 of covered area, ~100% coverage of cryogenic SiPMs
- Each PDU made of 16 Tiles, each composed of 24 SiPMs
- 2112 readout channels (Quadrant), each made of 4 Tiles
- Photon Detection Efficiency of ~45% in LAr at 7V over breakdown voltage
- Dark Count Rate (DCR) ~0.01 Hz/mm^2 at 77K and 7 V over breakdown voltage

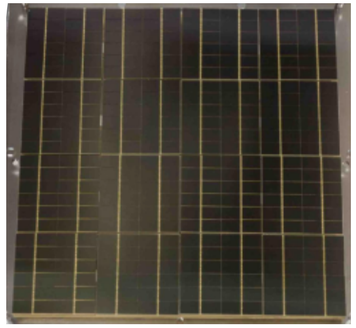


Veto:

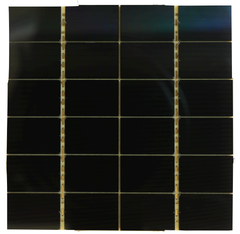
- Same SiPMs and same Tile to PDU arrangement but different electronics
- 480 IV channels (produced in UK) + 128 OV channels (from spare TPC PDU)



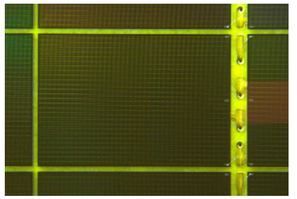
PDU ~20x20 cm^2



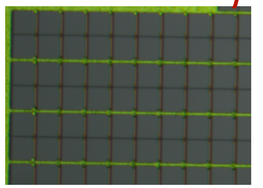
Tile ~5x5 cm^2



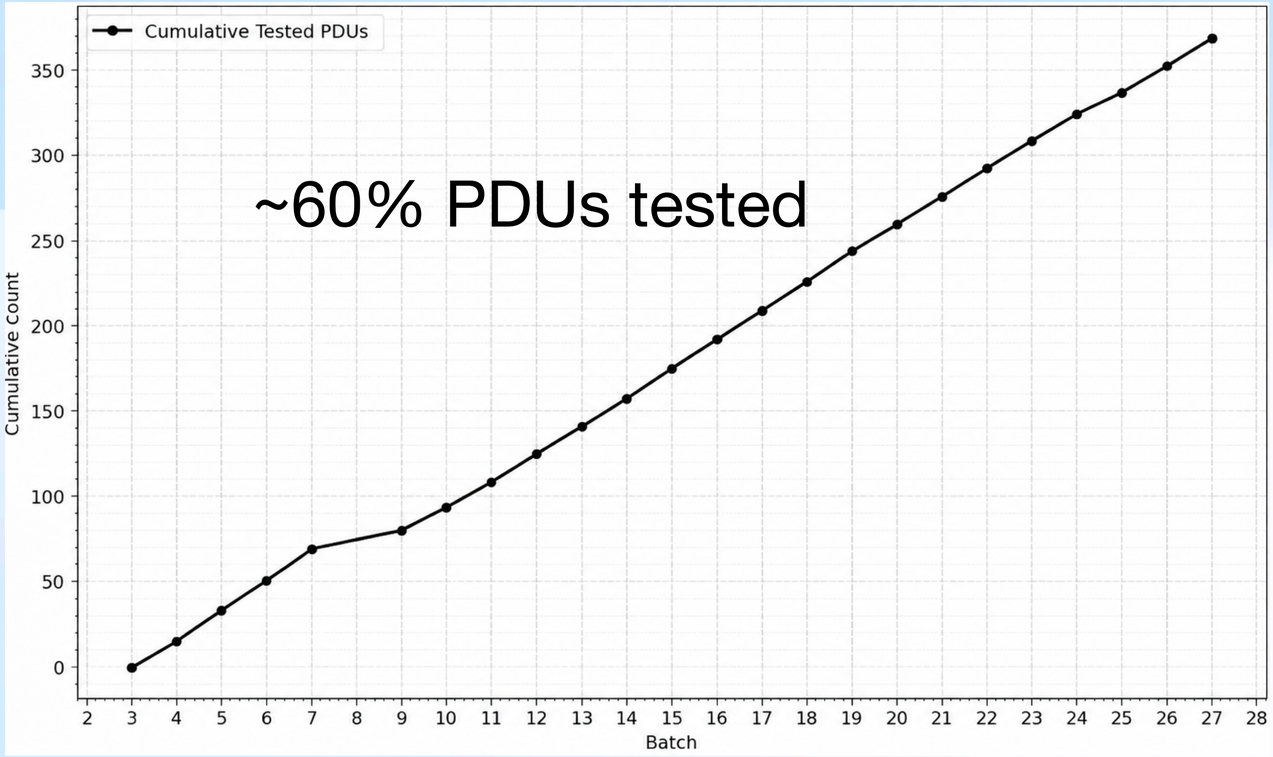
SiPM ~1 cm^2



Cell ~30x30 μm^2



PDU
Quality Assurance & Quality Control



We need **uniformity** (>2000 channels), **stability** (10 years), **low noise** and **high photo-detection efficiency** (> 45%), **10 ns timing resolution** (PSD) across the whole array of detectors to enable the physics potential of DarkSide-20k

==> **very stringent production and qualification protocols for detector-grade devices**

PDU production and testing

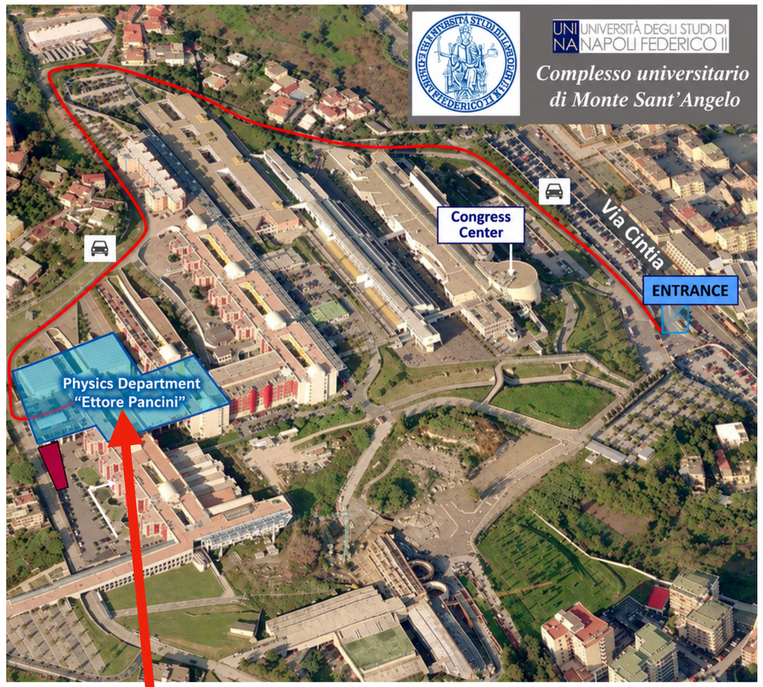
PDU assembly

~400m² ISO6



Nuova Officina Assergi (NOA)
LNGS

PDU long term stability cold (77K) test
ISO6



PDU testing facility (PTF)
Naples

PDU production and testing: NOA

SiPM wafers by L. Foundry

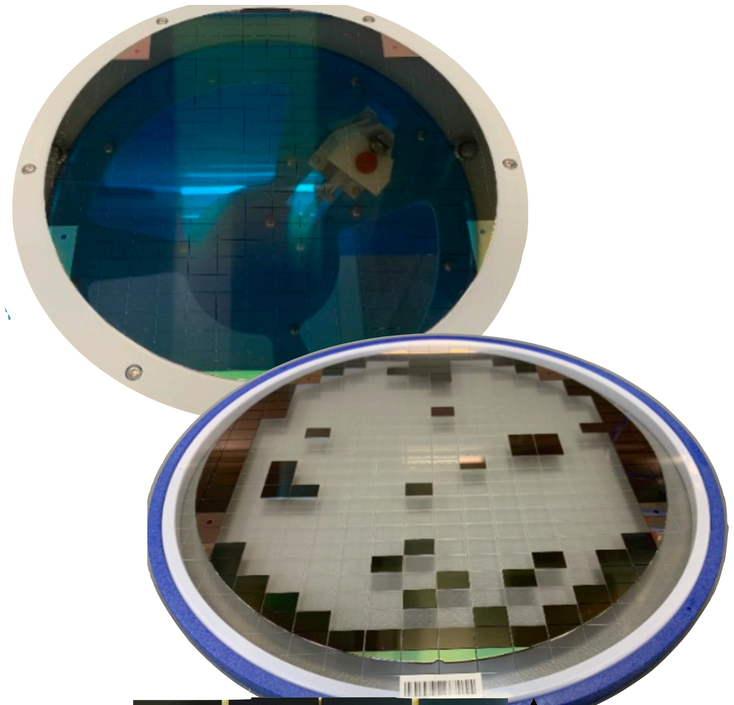
Wafer testing at 77K

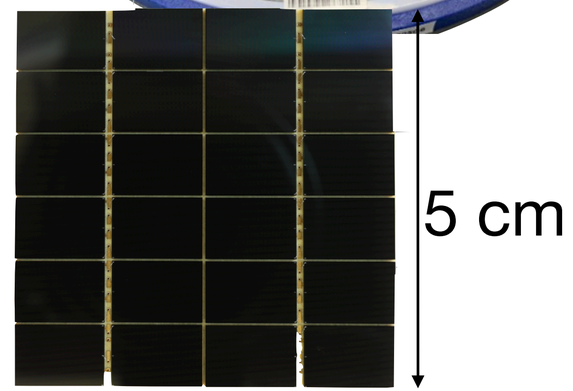
Dicing

SiPMs Bonding Onto the printed circuit board (PCB)

Wire bonding

Tile optical inspection





CMOS scanning

Tile warm test (295 K)

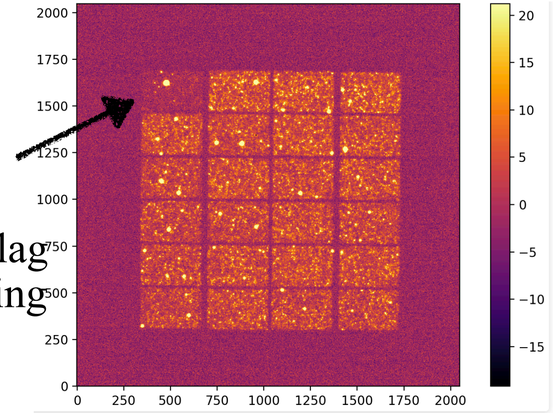
Tile cold test (77K)

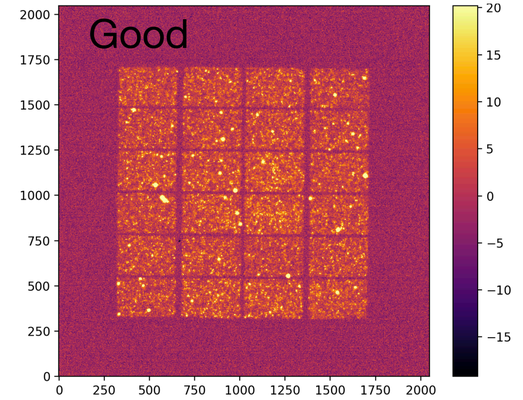
PDU assembly

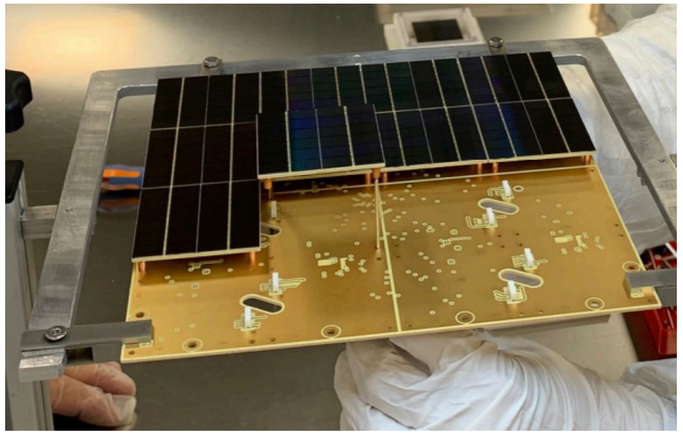
PDU warm test

PDU shipped to PDU testing facility (PTF) in Naples for cold test

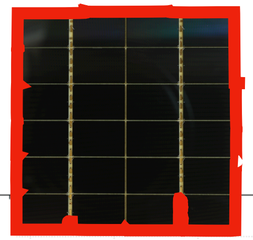
Possible to flag malfunctioning SiPMs





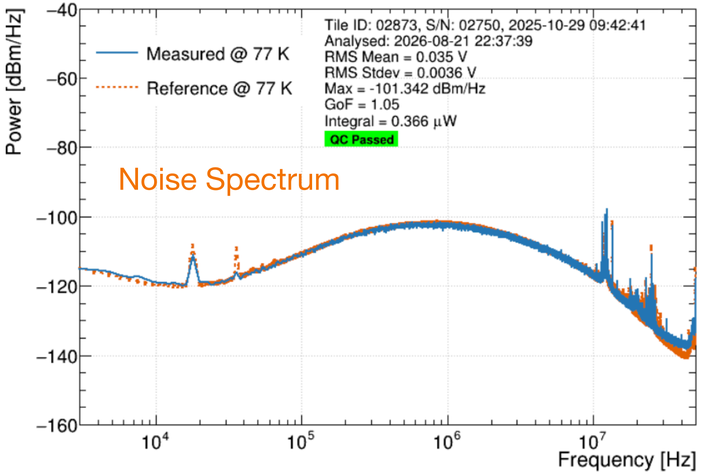


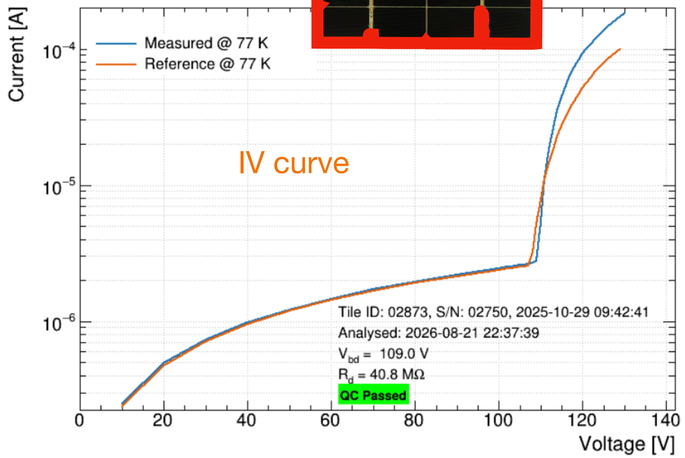
Quality Assurance & Quality Control: tiles

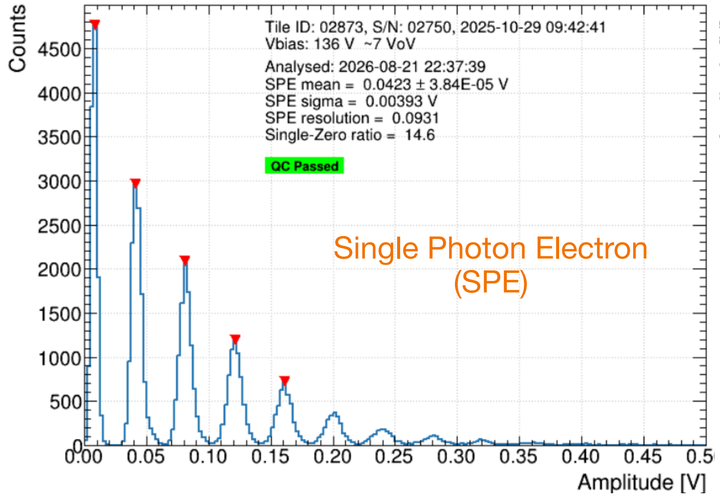


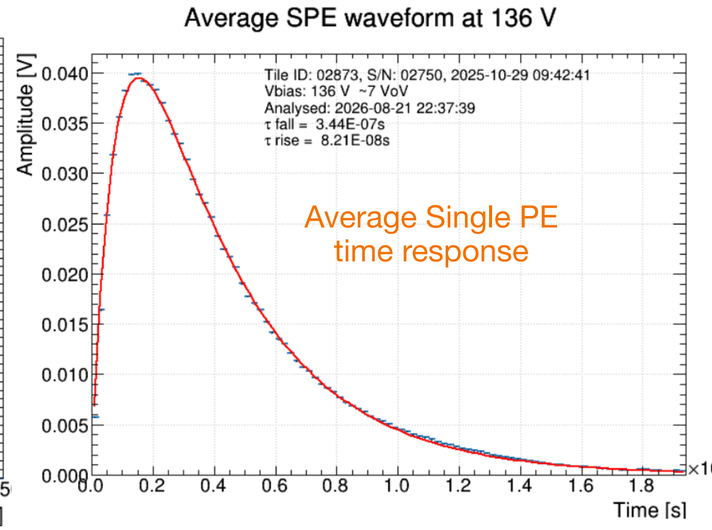
To ensure uniformity in the optical response across the OPs we measure for each tile:

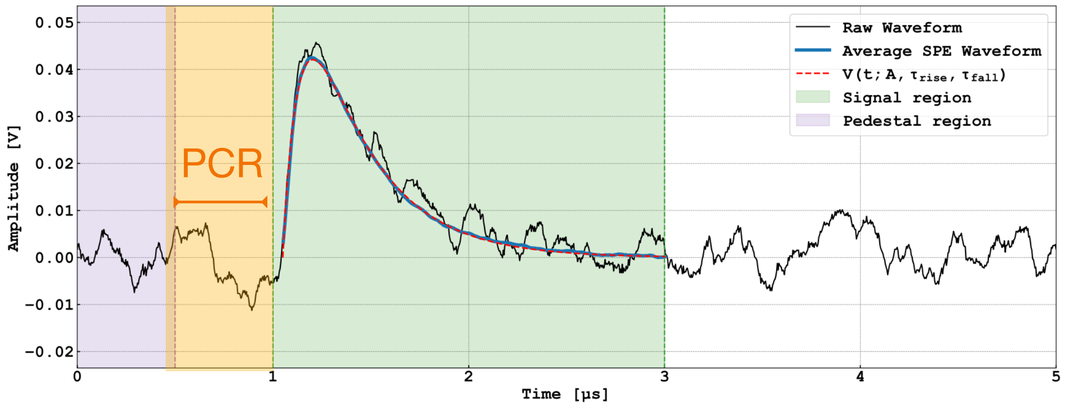
- **Noise Spectrum** below breakdown (40V) both at 295K and at 77K
- **IV curves** both at 295K and at 77K
- **Pulse analysis** at 77K: SPE charge and amplitude, SPE pulse shape, Pulse Count Rate (PCR)
- **Dark Count Rate (DCR)** setup for subsample, self trigger data tacking, very slow (several hours) for 4 tiles with good DCR levels (<0.1 Hz/mm² @7 V over voltage)





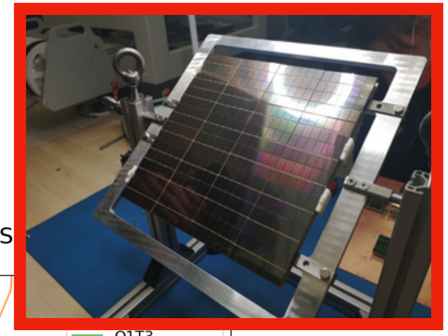


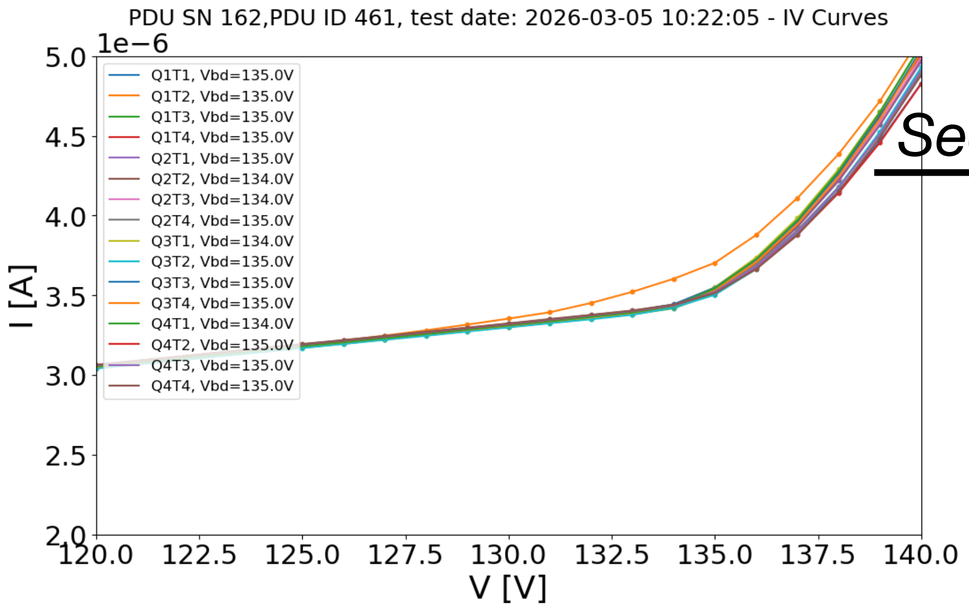




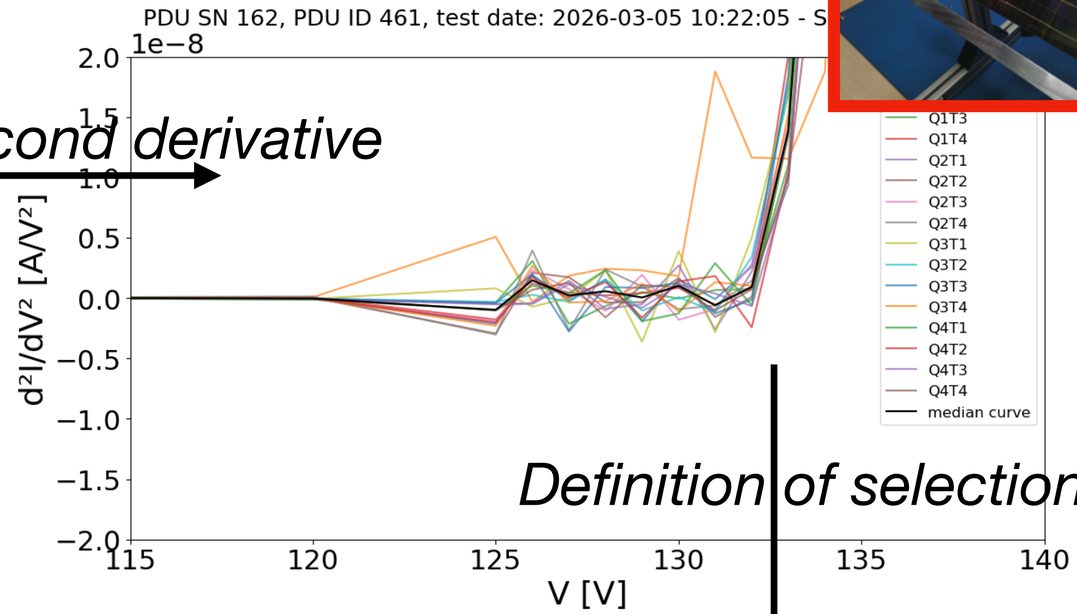
DarkSide-20k Collaboration. Production, quality assurance and quality control of the SiPM Tiles for the DarkSide-20k Time Projection Chamber. *Eur. Phys. J. C* **85**, 1334 (2025). https://doi.org/10.1140/epjc/s10052-025-14940-1

Quality Assurance & Quality Control: PDUs





Second derivative

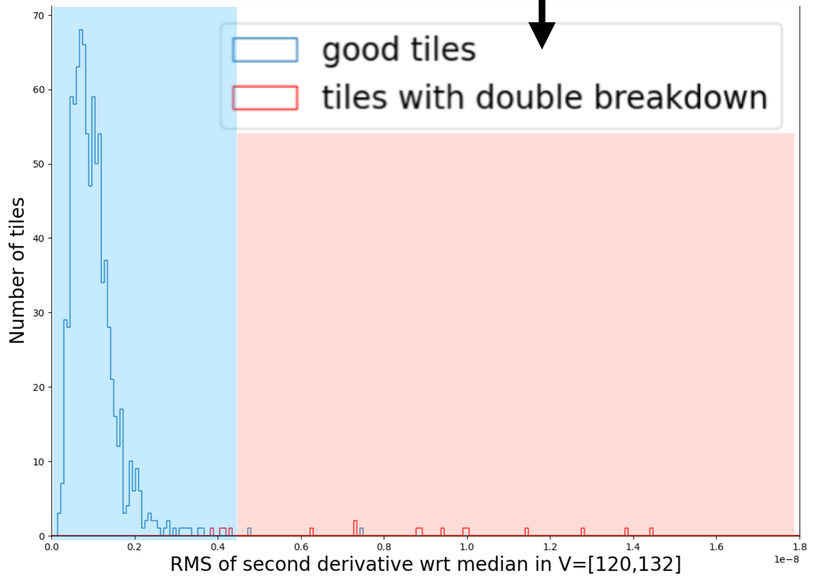


Definition of selection criteria

Probably caused by handling of sensors and damaging of Wire Bondings

The old analysis algorithms wasn't able to find these kind of problems

<u>No more downstream failures observed after this implementation</u>

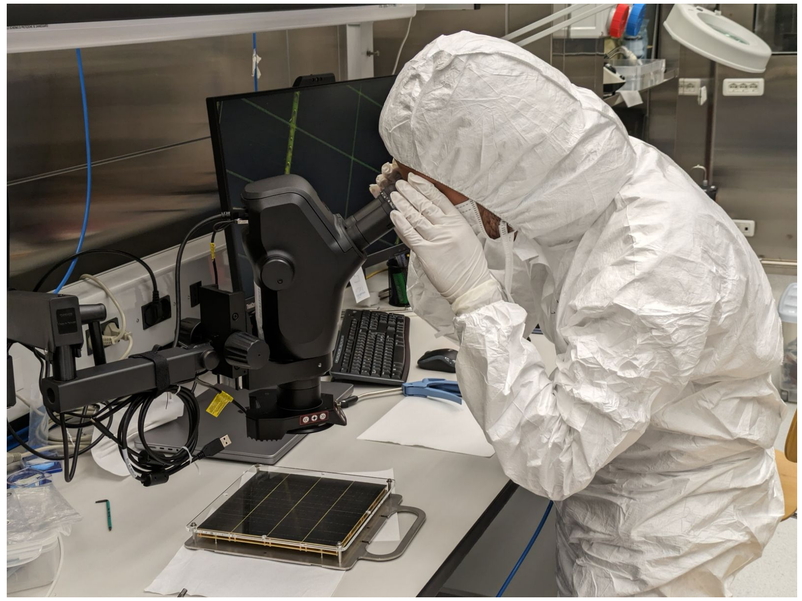


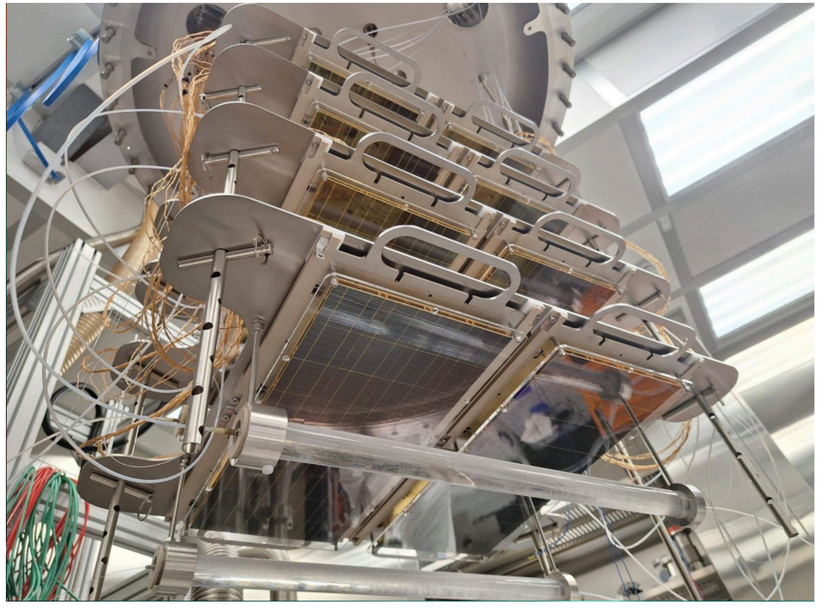
Quality Assurance & Quality Control: PDUs, long term

Batch of 16 PDUs arrival	PDUs unpacking and optical inspection	PDUs installation and warm tests	Cryostat closure and filling with LN	PDU cold tests (IV + Noise)	Laser calibration stability tests every 4h (automatic refilling)	LN drain and Warm up	After warm up IV + Noise	Cryostat opening Plus dismounting	PDUs shipped back to NOA for retest (and rework)

~2d ~8d ~2d

We install 16 PDUs for each test which in total lasts ~2 weeks, 4 PDUs for each floor.





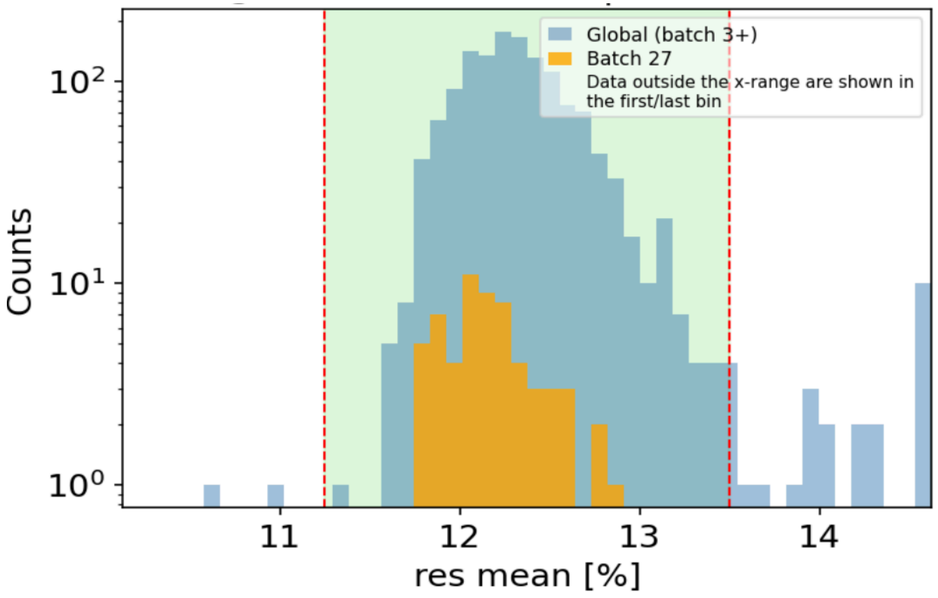


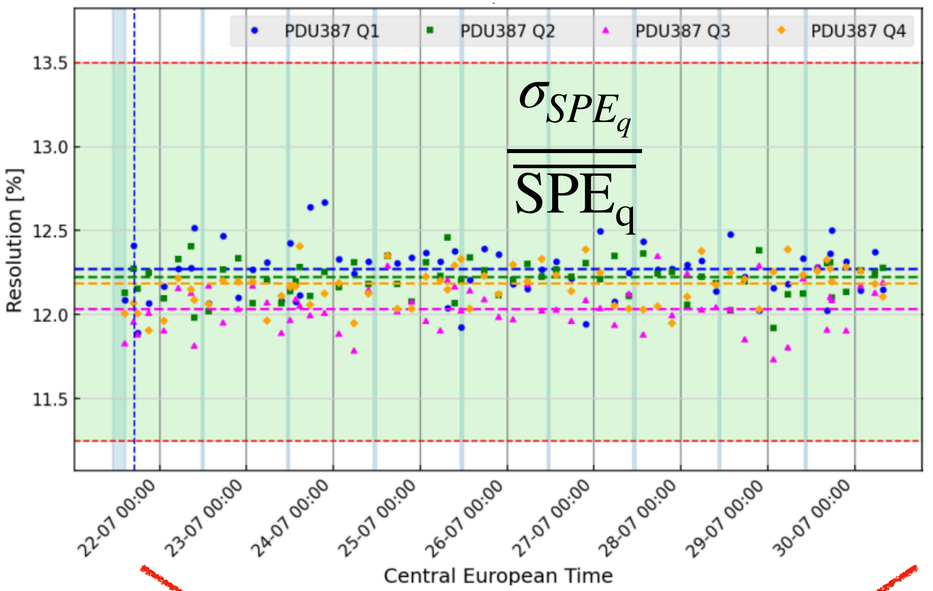
Quality Assurance & Quality Control: PDUs, long term

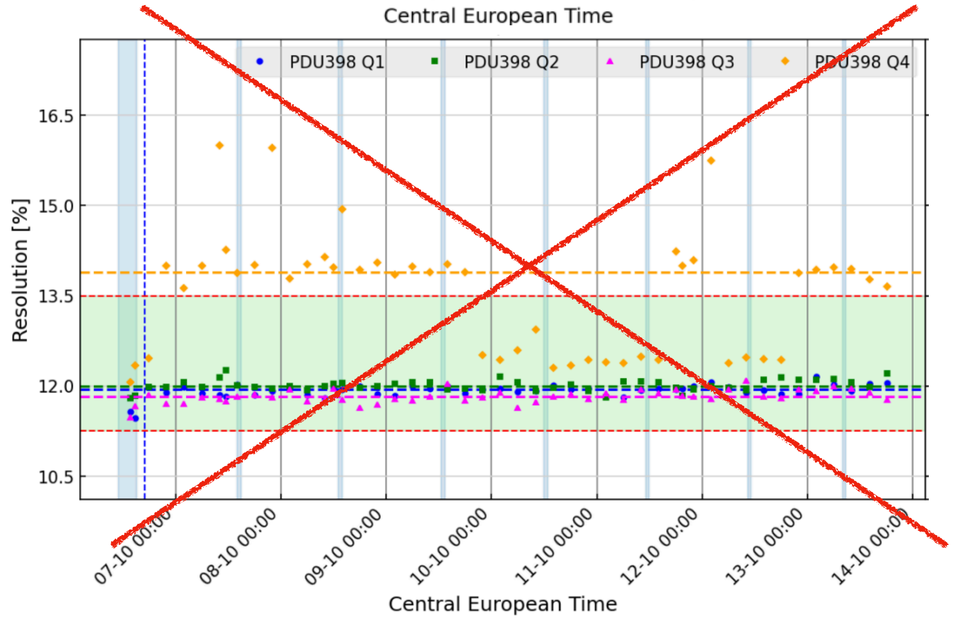
To check the proper functioning of PDUs at cold temperatures and uniformity in the optical response we monitor:

1. **IV curves** and **noise spectra**
2. **SPE charge** mean and σ
3. **SPE amplitude** mean and σ
4. **Resolution** mean and σ
5. **Signal To Noise ratio (SNR)** mean and σ
6. **PCR**

Build global distribution and define acceptance cuts







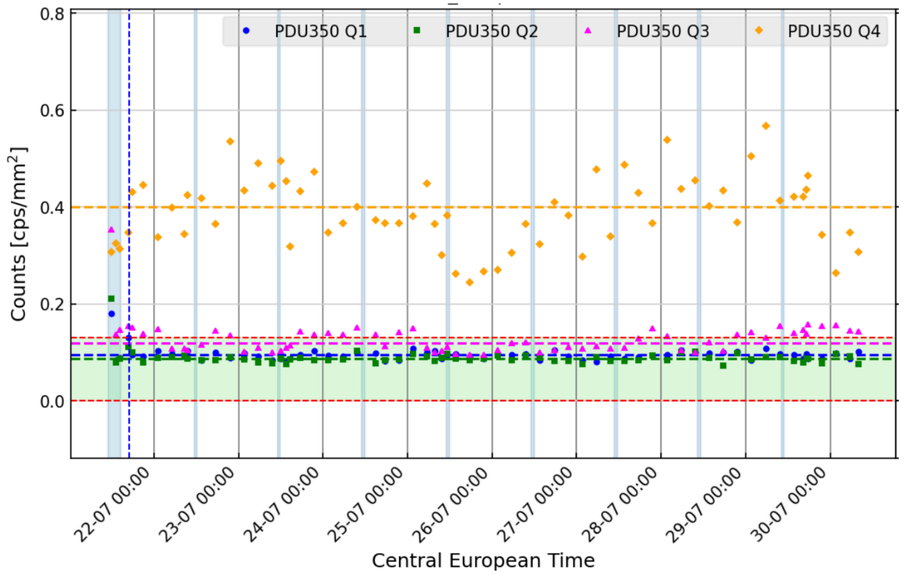
Quality Assurance & Quality Control: Pulse Count Rate

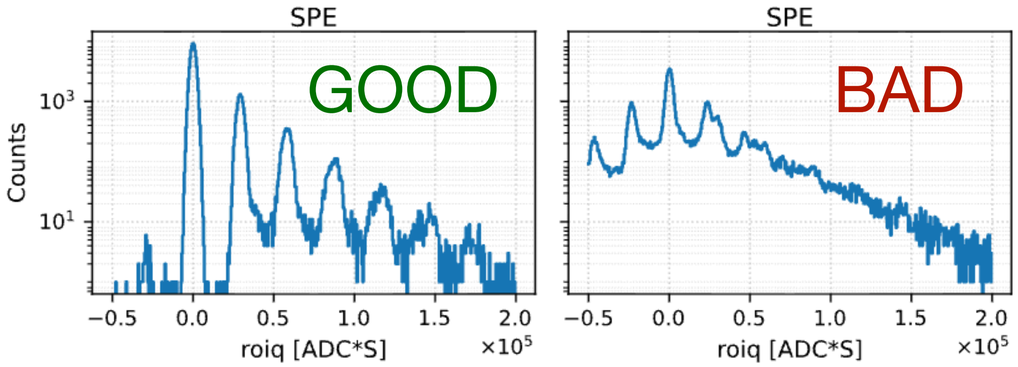
High PCR is a good proxy to High DCR

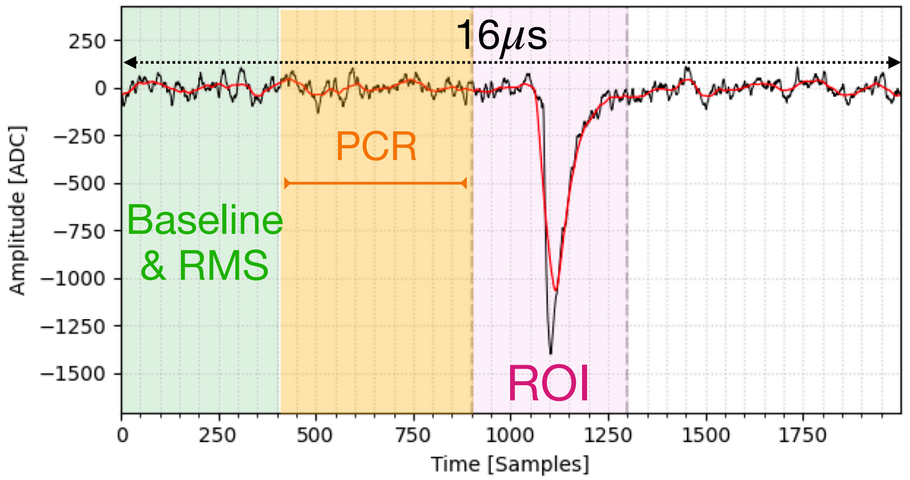
The problem is the appearance of SPE-like pulses noise:

1. Worse resolution ⟶ worse background discrimination
2. Impact at the Data Acquisition system
3. Difficult to reconstruct the finger plot in very severe cases (PCR >1Hz/mm^2), not possible to calibrate

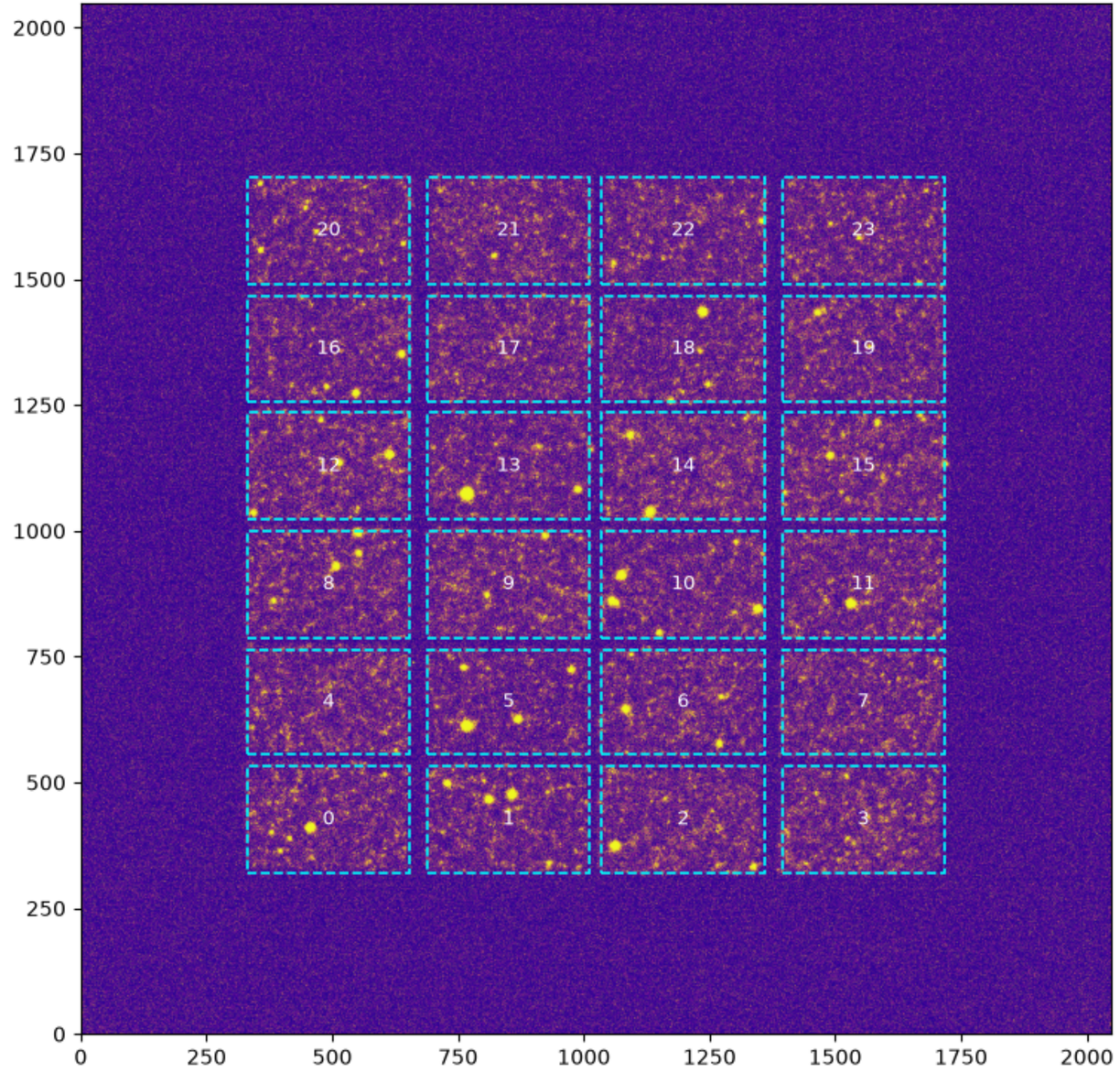
Biggest reason of failure (still only 2% of tiles have high PCR 😊)







Next Steps



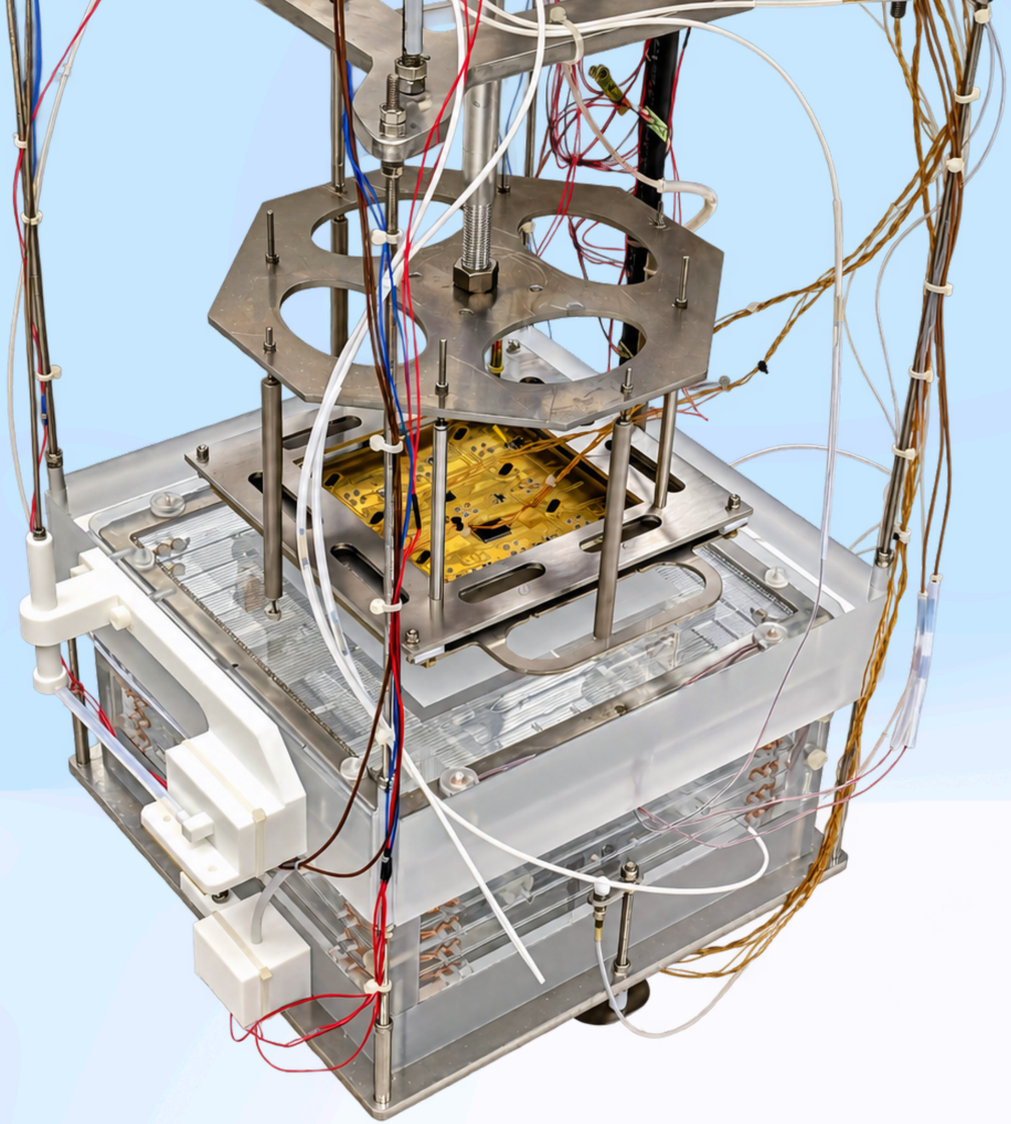
1) Machine Learning based analysis to be able to classify the tiles with high PCR from their CMOS image

We could spot a problematic device in a time scale of few minutes instead of ~weeks of testing !!!

2) DCR-PCR correlation to predict noise levels in DS20k

3) Improve the algorithm for stability analysis, include channel to channel correlation

4) Paper writing

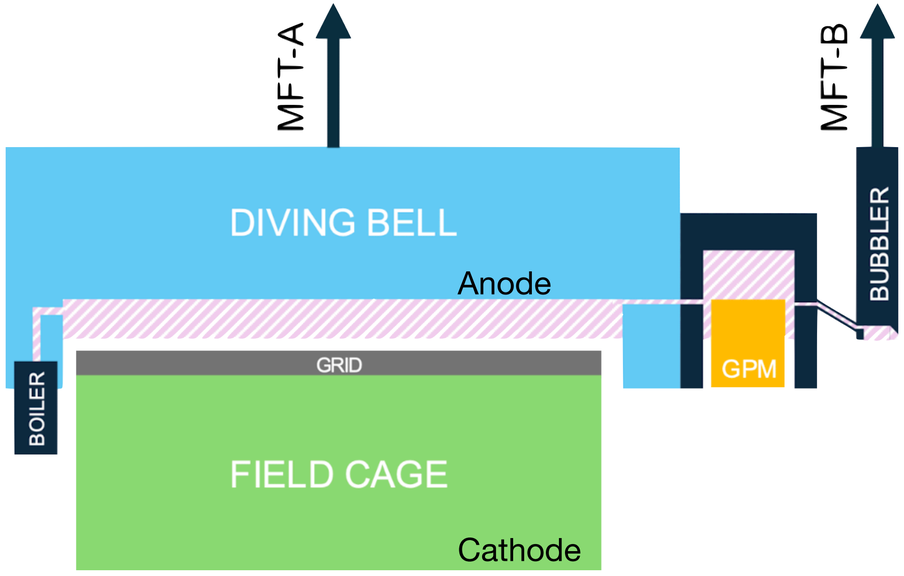


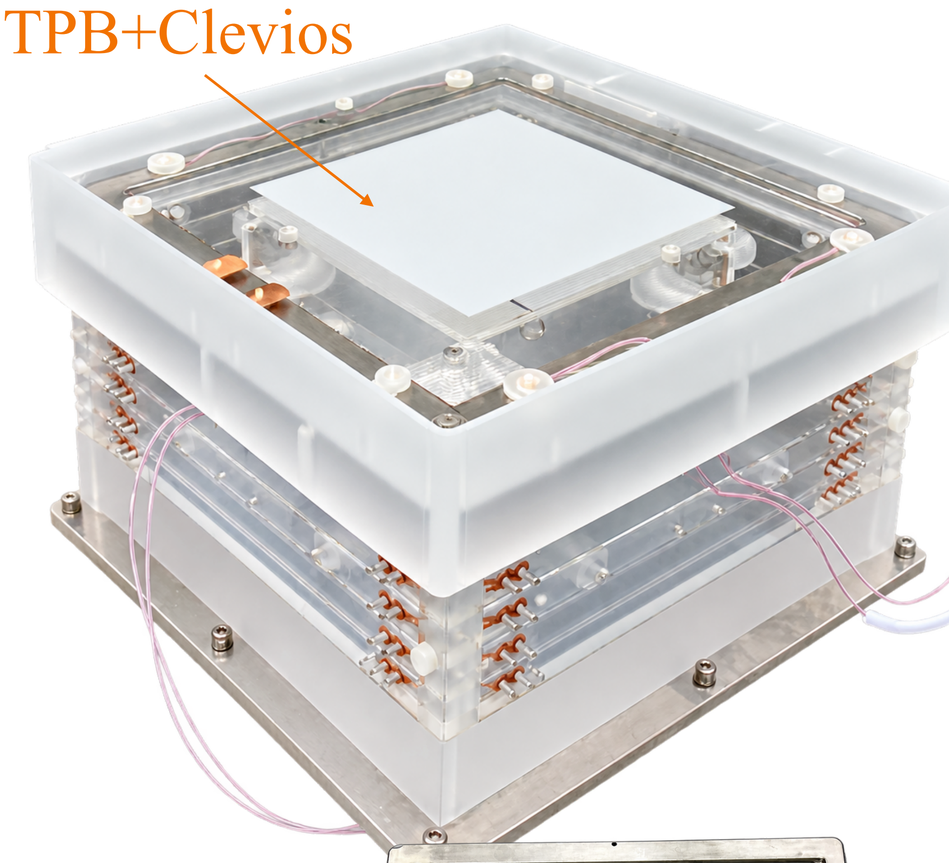
Proto-0



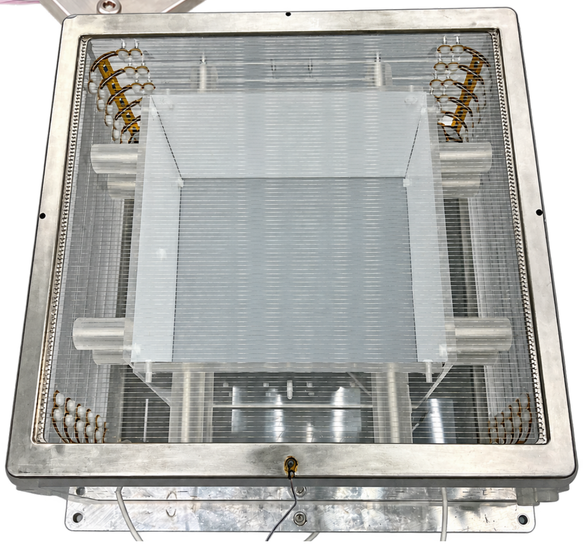
Proto-0 detector

- **First Double Phase LAr TPC running with our PDUs**, filled with 7 kg of Ar in the active volume
- Early identification of potential operational issues before DS-20k commissioning
- Located in ISO 6 Cleanroom of ‘CryoLab’ Laboratory at INFN Naples

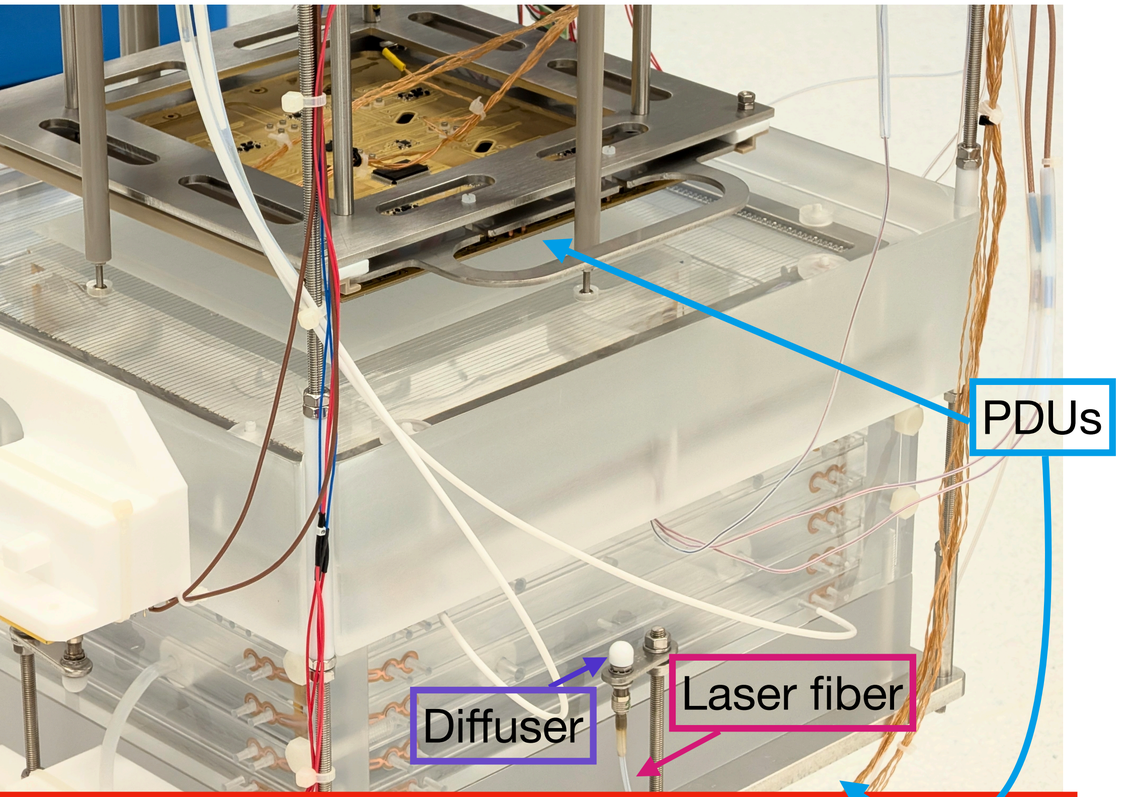


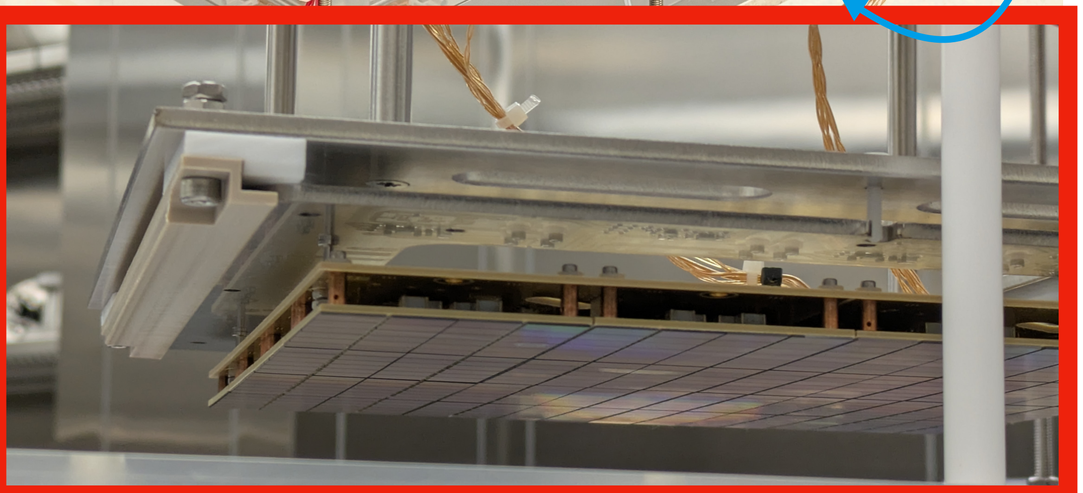


- Electric field generated with conductive polymer Clevios coating
- Adjustable liquid height and gas pocket thickness



Proto-0 detector: PDUs monitoring

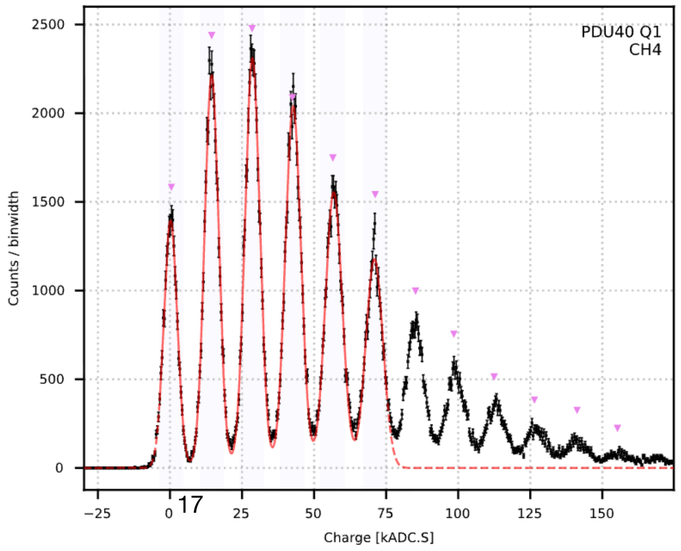


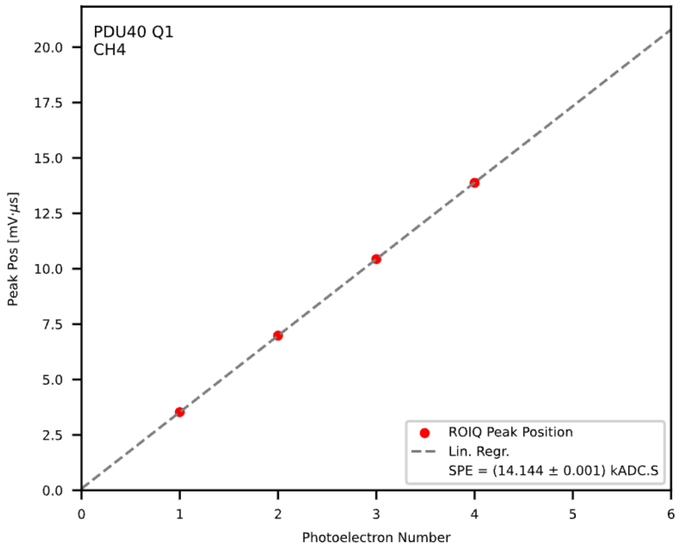


We calibrate the photosensors using light from an external pulsed delivered through cryogenic optical fibers.
We want to monitor in LAr:

1. The noise spectrum
2. The breakdown voltage
3. The SPE amplitude and charge

We will reach ~1y of PDU monitoring in LAr!



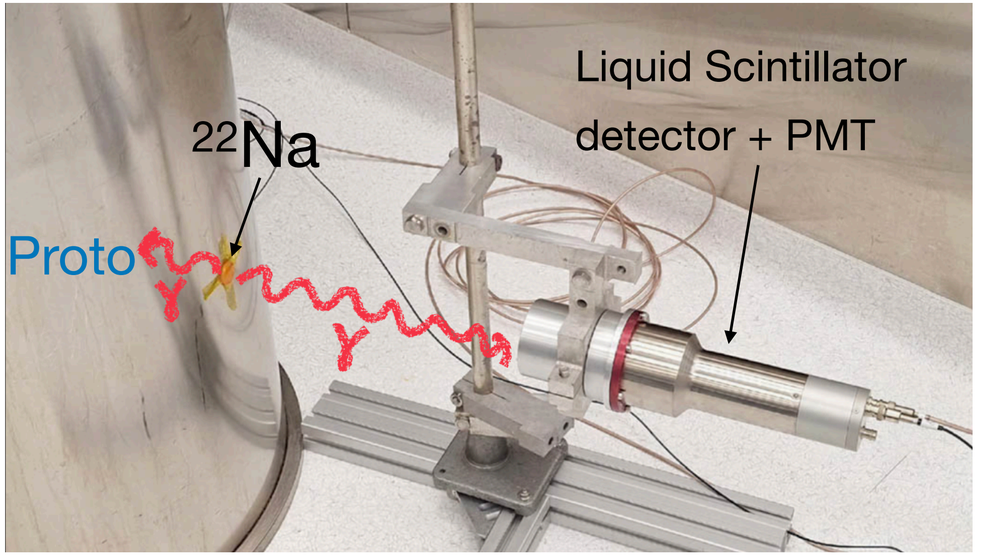


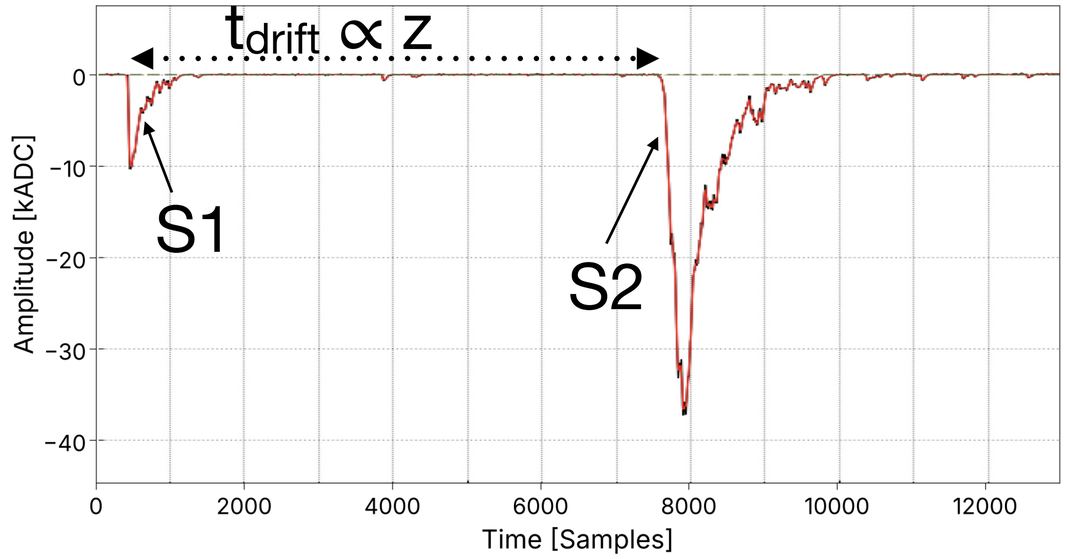
Proto-0 detector: physics data

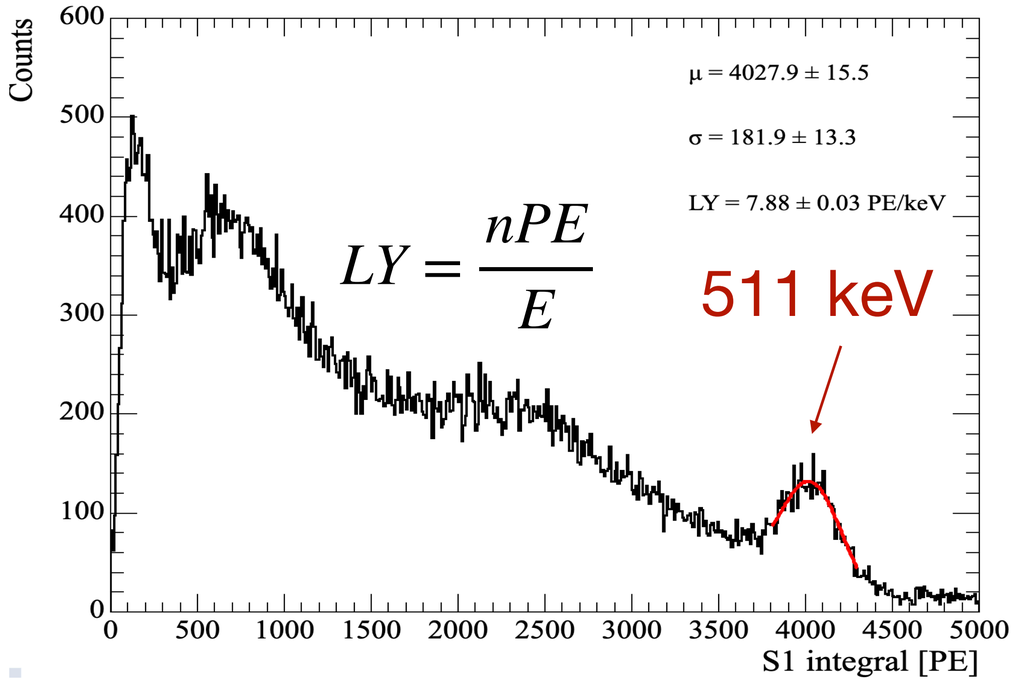
- To characterize the detector response we use a 16kBq ^{22}Na source and a low energy 50kBq ^{83m}Kr source (~41. keV)
- We can study the shape and the amplitude of the signal as a function of: E_d, E_{ex}, Gas pocket thickness, Liquid-Gas interface position, Bias of the PDUs

Current Campaign:

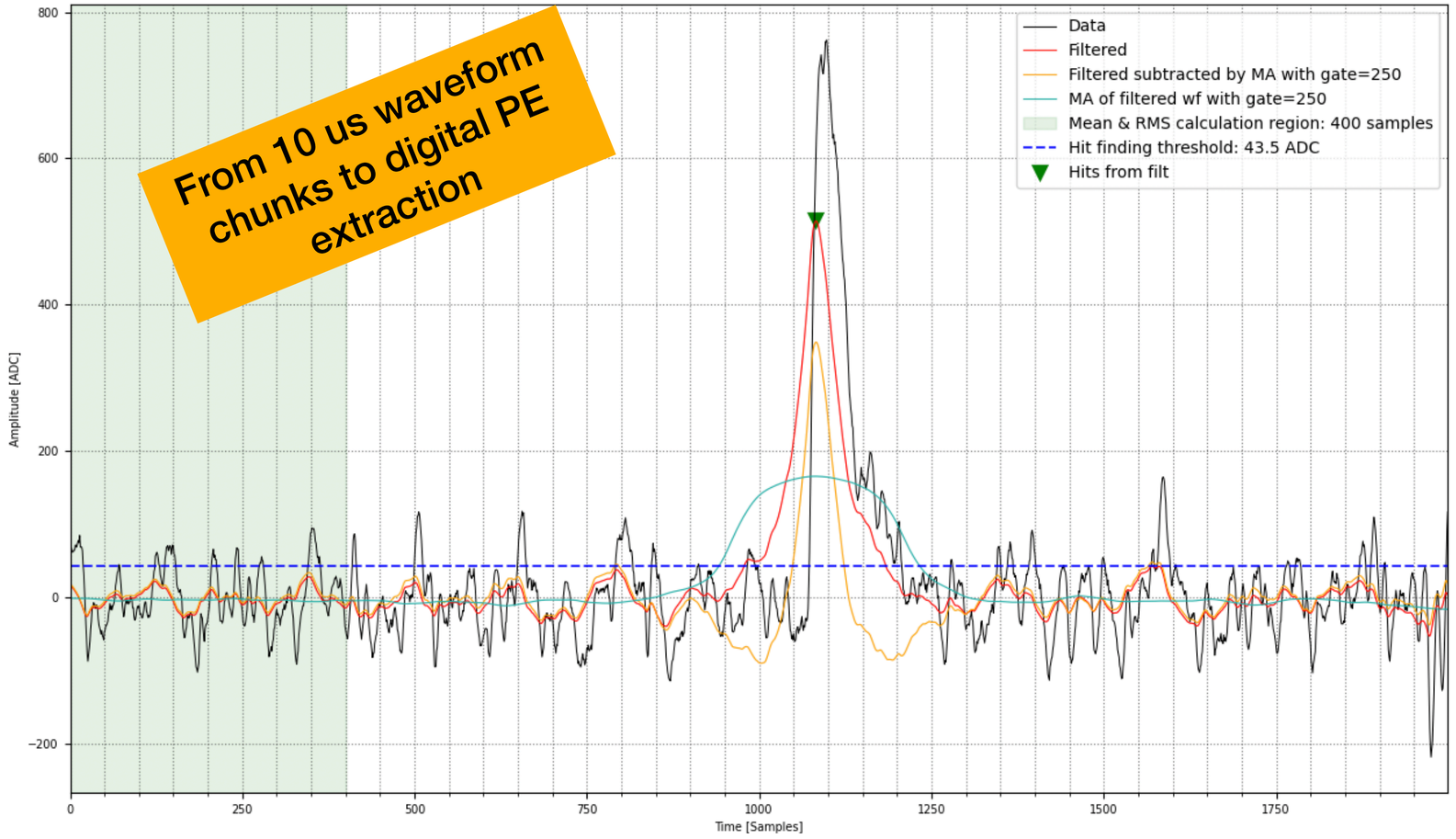
- 1kBq ^{241}Am (~59 keV γ) source attached to the drift volume walls







Proto-0 hit finder development



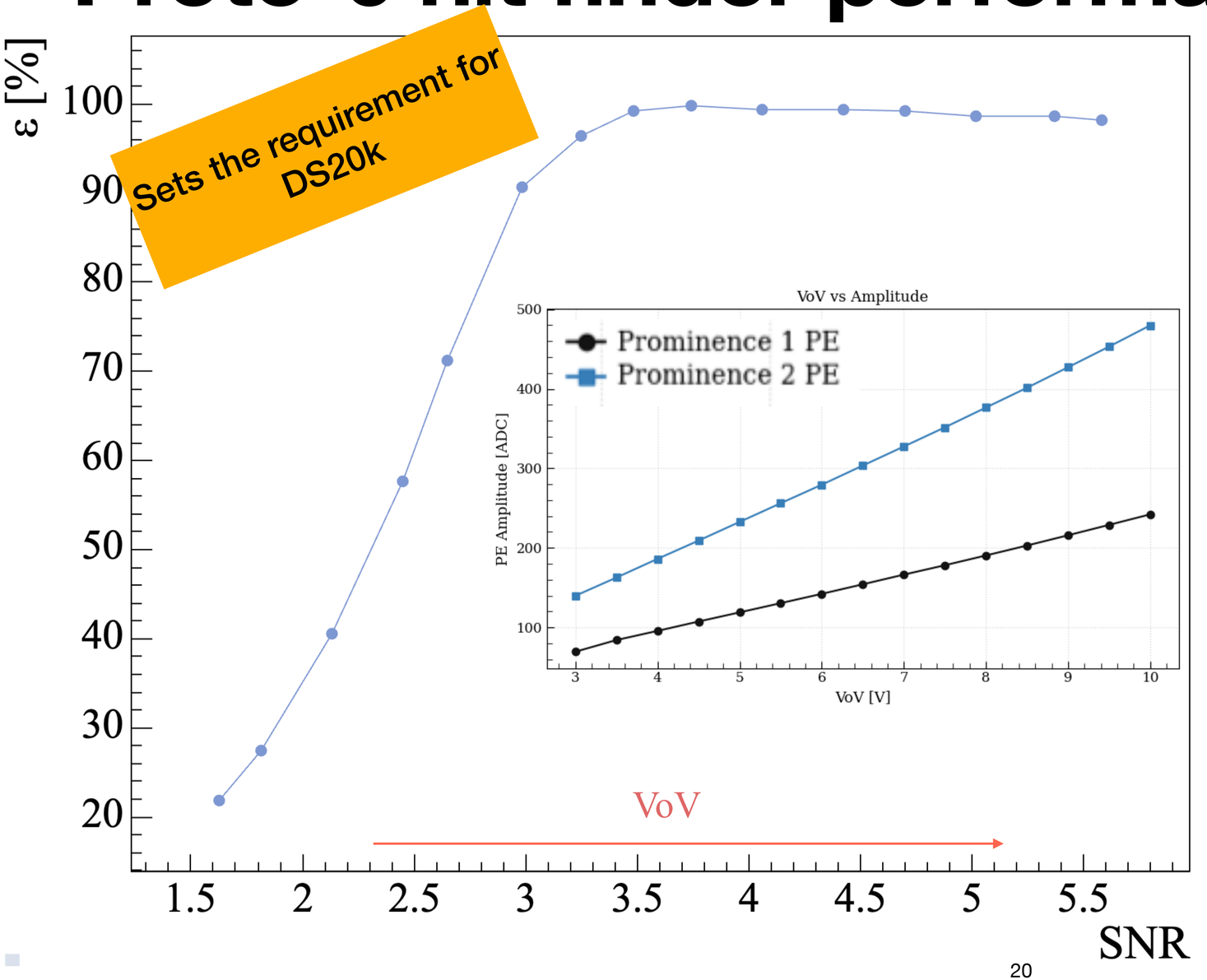
This are events of a laser run on which this analysis is based.

In red we have the filtered waveform while in light blue we have the moving average (MA) of the filtered waveform.

subtracted waveform = filtered - MA

In green we have the region where we compute the average and RMS of the subtracted waveform used to define the hit finder threshold. Hit finder has been fully optimized to maximize the efficiency

Proto-0 hit finder performance



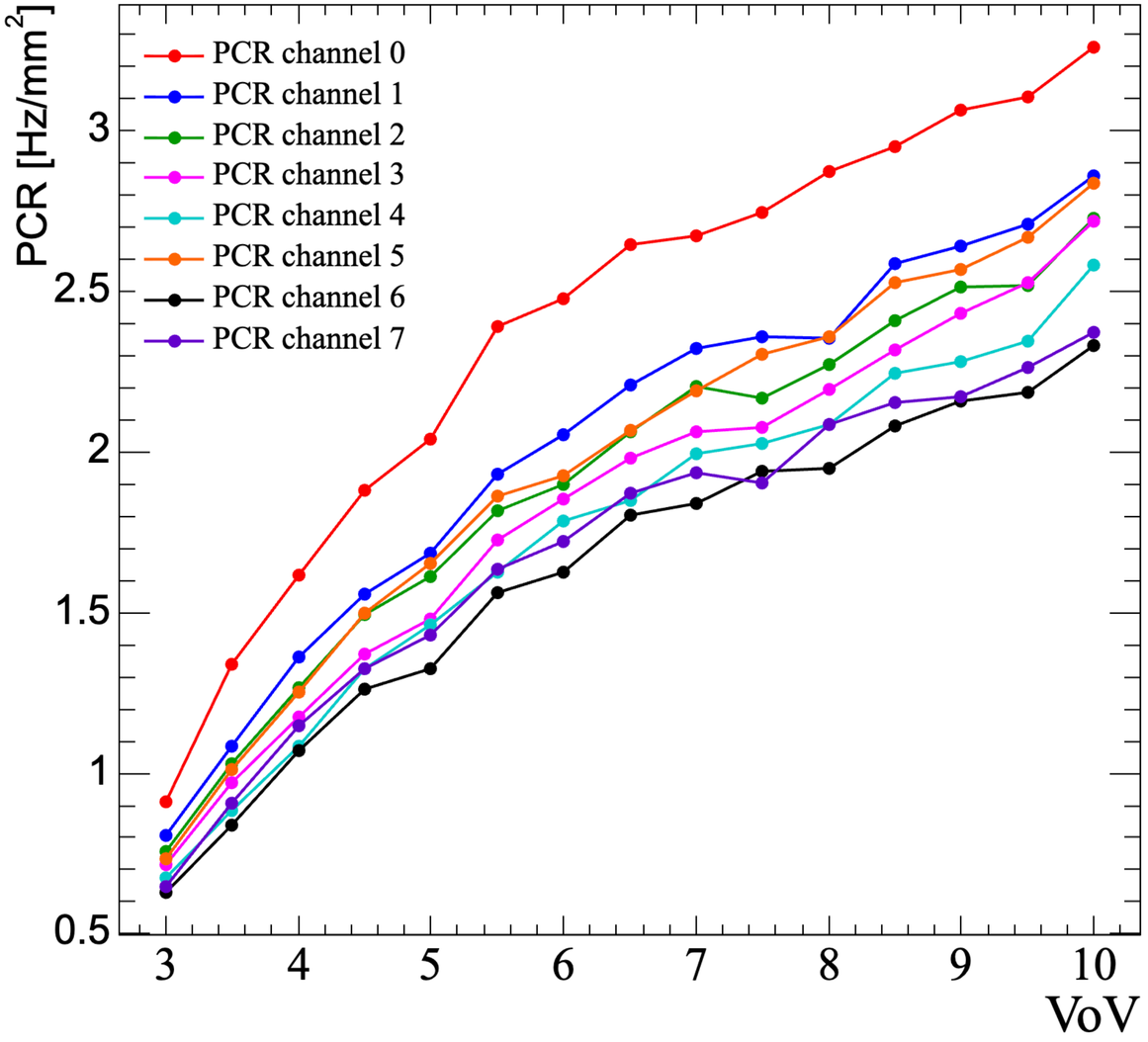
This efficiency is estimated looking at the waveform integral as the “truth”.

Finally we count how many time a waveform with 1PE integral corresponds to a 1PE hit reconstructed

$$SNR = \frac{2PE - 1PE}{noise}$$

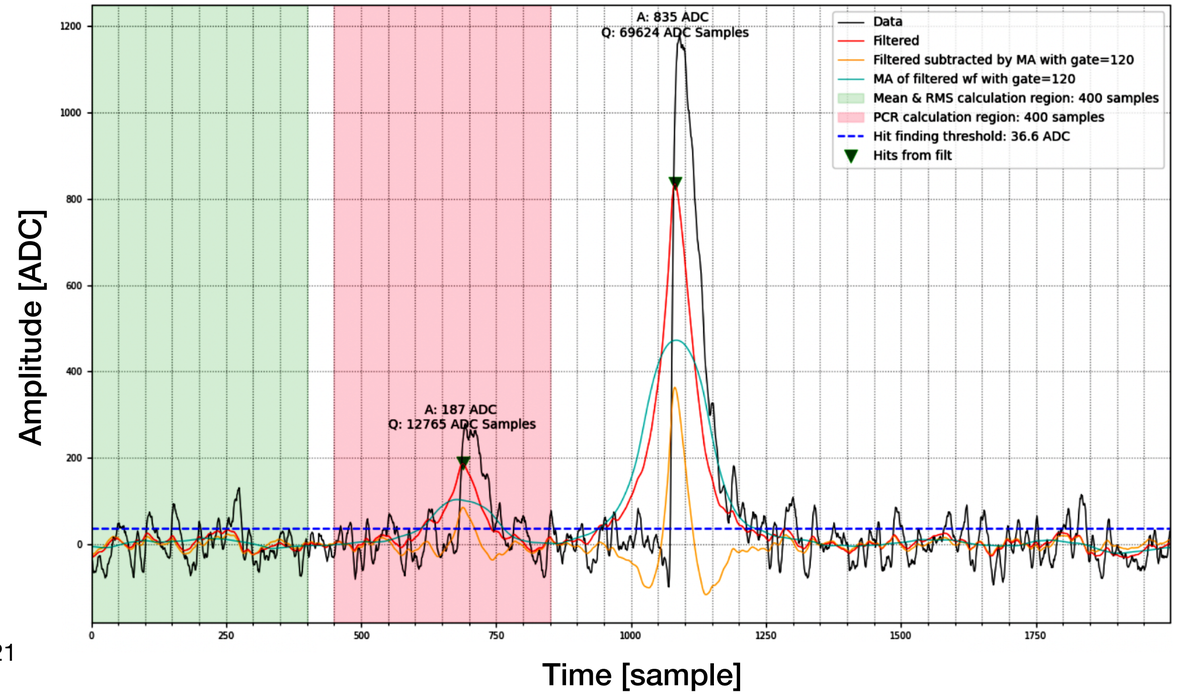
Proto-0 hit finder: results

PCR



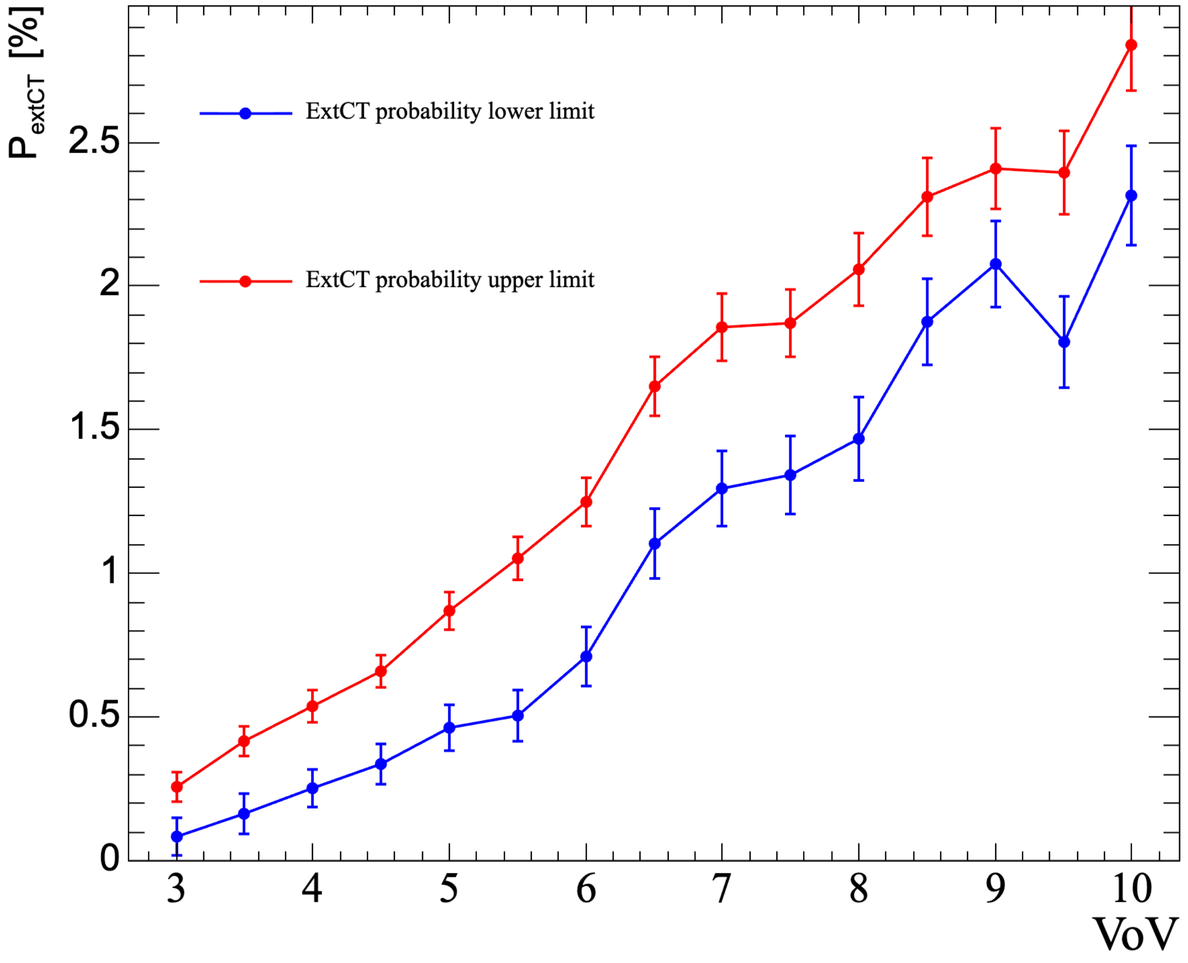
- Having the hit finder allows us to be able to measure the PCR.
- We can monitor PCR stability at time scale of 1y in LAr!

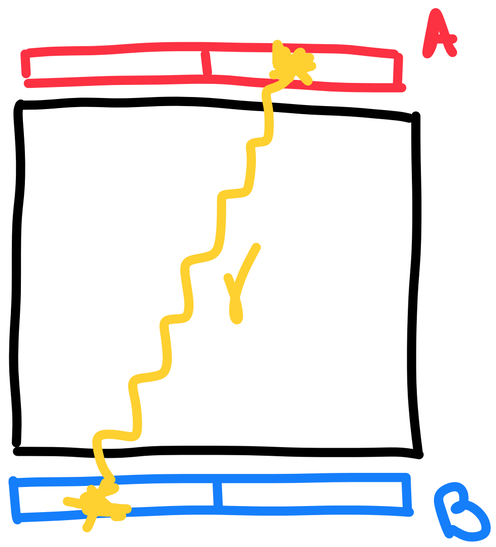
$$PCR = \frac{counts}{events * window * ChArea}$$

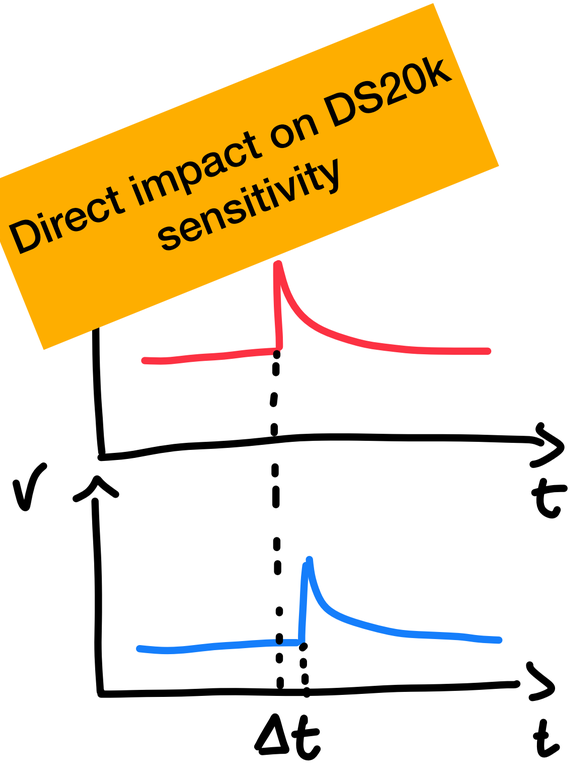


Proto-0 hit finder: results

External CrossTalk







ExCT probability > 5% can impact our Background rejection (PSD)

With Proto, having two PDUs facing each other, we can estimate it from a data

- Laser run tacking pre-trigger region
- Count how many coincidences we have between 2 differen channels

Conclusions

- My work in the QA/QC is playing a key role in ensuring high quality of the PDUs that will end up in the final experiment
- I led Proto-0 assembly during the current campaign, gaining hands-on experience in hardware integration and system validation (7 weeks in shift, run coordinator)
- My work on Proto-0 is actively contributing in the validation of the technologies that will end up in the final DarkSide-20k experiment

Papers in preparation for PDU production & testing and for Proto-0!

Conferences

- Sheffield, June 22 -26 2026, **PASCOS** 2026: the 31st International Symposium on Particles, Strings, and Cosmology , poster winning 3rd best poster
- Rome, September 7 -11 2026, **RICAP** 2026: Roma International Conference on AstroParticle physics, poster
- Amsterdam, October 6–9 2026, **LIDINE** 2026: LIght Detection In Noble Elements, talk

Publications

- The Darkside-20k Data Acquisition System DarkSide-20k Collaboration, Fabio Acerbi (Fond. Bruno Kessler, Trento) et al. e-Print: 2604.03059 [physics.ins-det]
  DOI: 10.1088/1748-0221/21/09/P09017
  Published in: JINST 21 (2026) 09, P09017
- Construction and characterisation of the DarkSide-20k veto silicon photo-multiplier tiles DarkSide-20k Collaboration, Fabio Acerbi (Fond. Bruno Kessler, Trento) et al. e-Print: 2604.02551 [physics.ins-det]
  DOI: 10.1140/epjc/s10052-026-16217-7
  Published in: Eur.Phys.J.C 86 (2026) 9, 1089
- Cryogenic characterisation of the FBK NUV-HD-cryo Silicon Photomultipliers for the DarkSide-20k dark matter experiment
  arXiv:2610.18223

Outreach

- Maker Fair - The European Edition is an annual public event dedicated to innovation, technology and creativity, Rome October 2025
- Maker Fair - The European Edition is an annual public event dedicated to innovation, technology and creativity, Rome October 2026

Backup

PDU production and testing: NOA

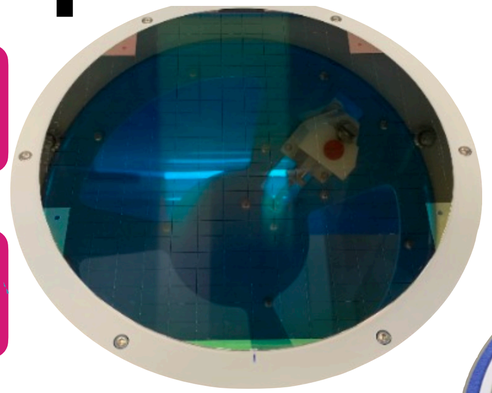
SiPM wafers by L. Foundry

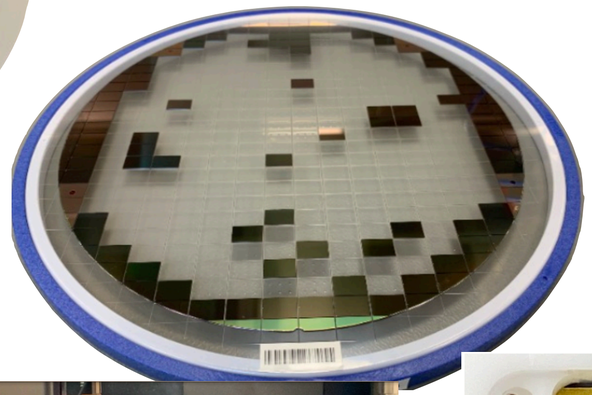
Wafer testing at 77K

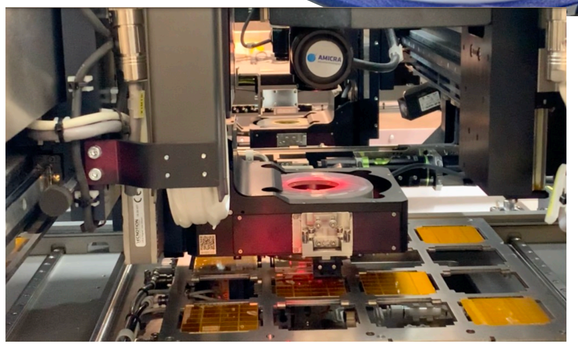
Dicing

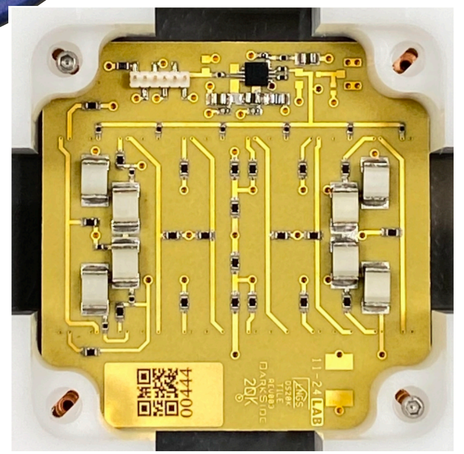
SiPMs Bonding Onto the qualified printed circuit board (PCB)

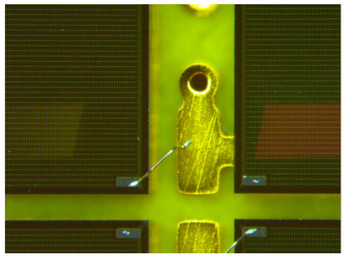
Wire bonding











Tile assembly area





Tile test area

PDU production and testing: NOA

SiPM wafers by L. Foundry

Wafer testing at 77K

Dicing

SiPMs Bonding Onto the printed circuit board (PCB)

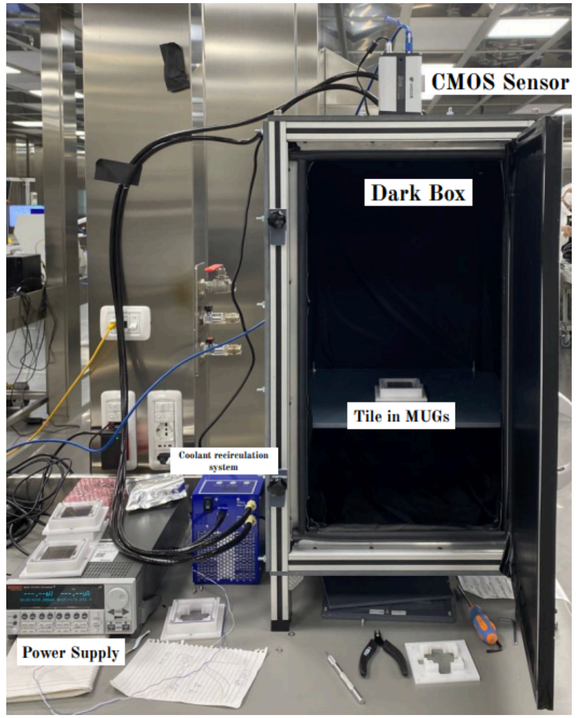
Wire bonding

Tile optical inspection

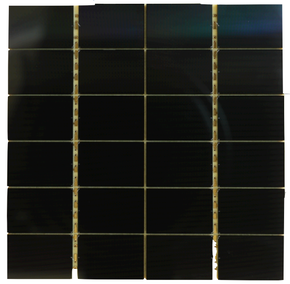
CMOS scanning

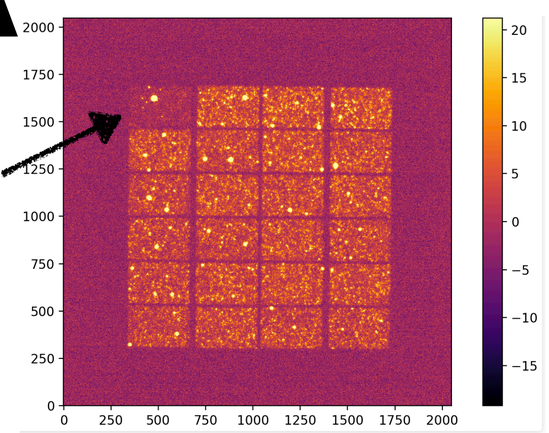
Complementary Metal-Oxide-Semiconductor (CMOS) sensor

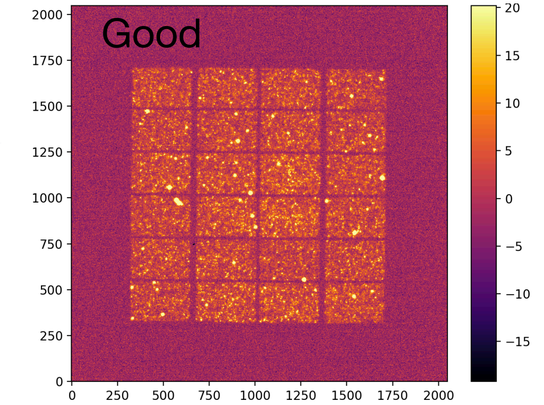
characterize SiPMs by detecting the Hot Carrier Luminescence (HCL) photons produced during their operation in Geiger mode



Possible to flag malfunctioning SiPMs







DarkSide-20k Collaboration. Production, quality assurance and quality control of the SiPM Tiles for the DarkSide-20k Time Projection Chamber. *Eur. Phys. J. C* **85**, 1334 (2025). https://doi.org/10.1140/epjc/s10052-025-14940-1

PDU production and testing: NOA

SiPM wafers by L. Foundry

Wafer testing at 77K

Dicing

SiPMs Bonding Onto the printed circuit board (PCB)

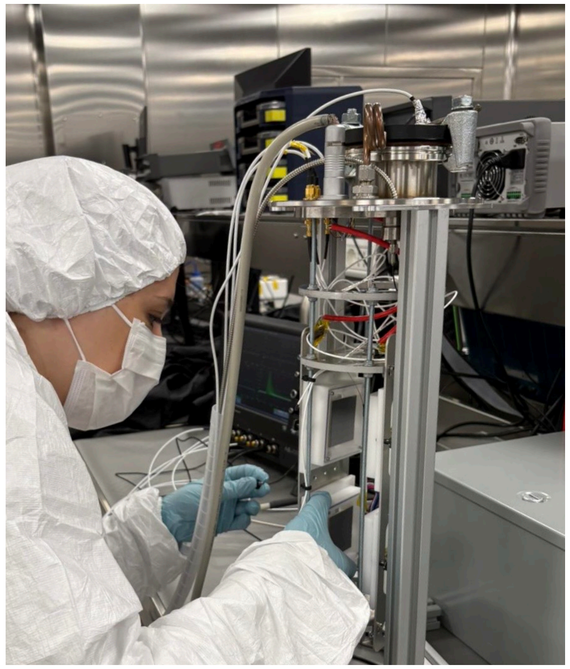
Wire bonding

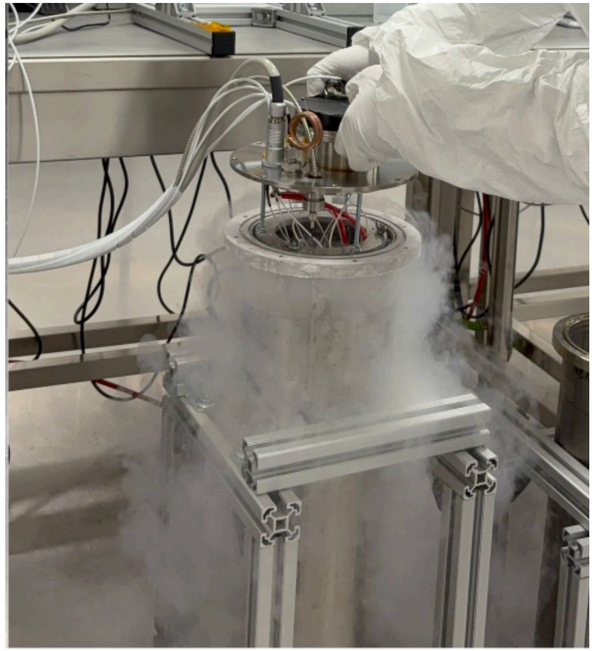
Tile optical inspection

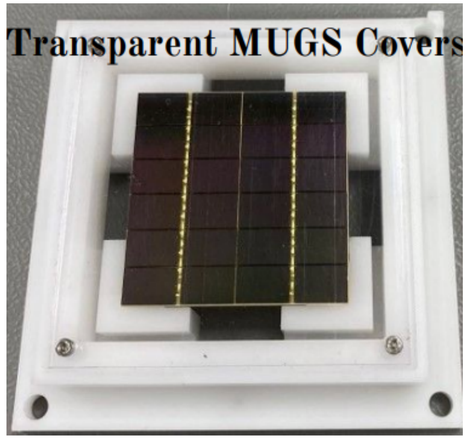
CMOS scanning

Tile warm test (295 K)

Tile cold test (77K)





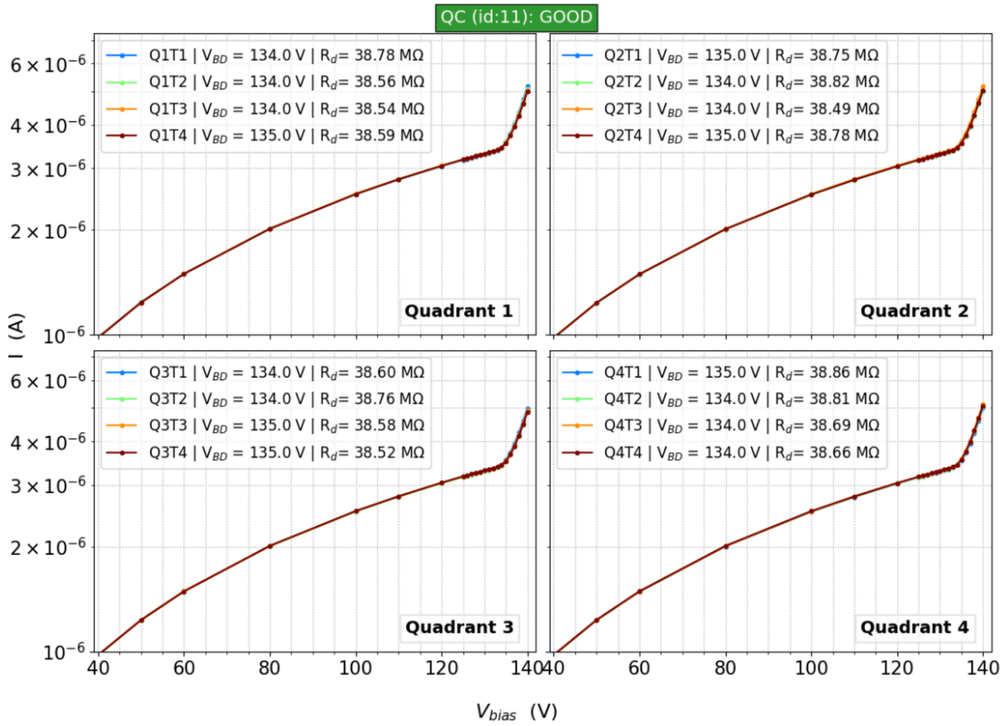


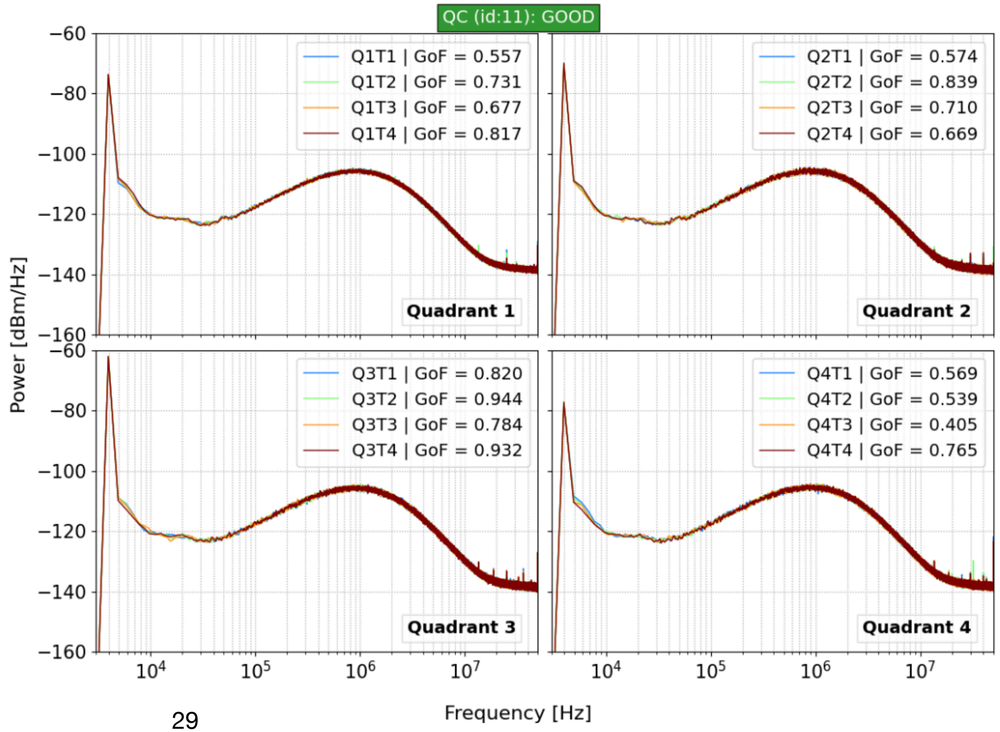
DarkSide-20k Collaboration. Production, quality assurance and quality control of the SiPM Tiles for the DarkSide-20k Time Projection Chamber. *Eur. Phys. J. C* **85**, 1334 (2025). https://doi.org/10.1140/epjc/s10052-025-14940-1

PDU warm test

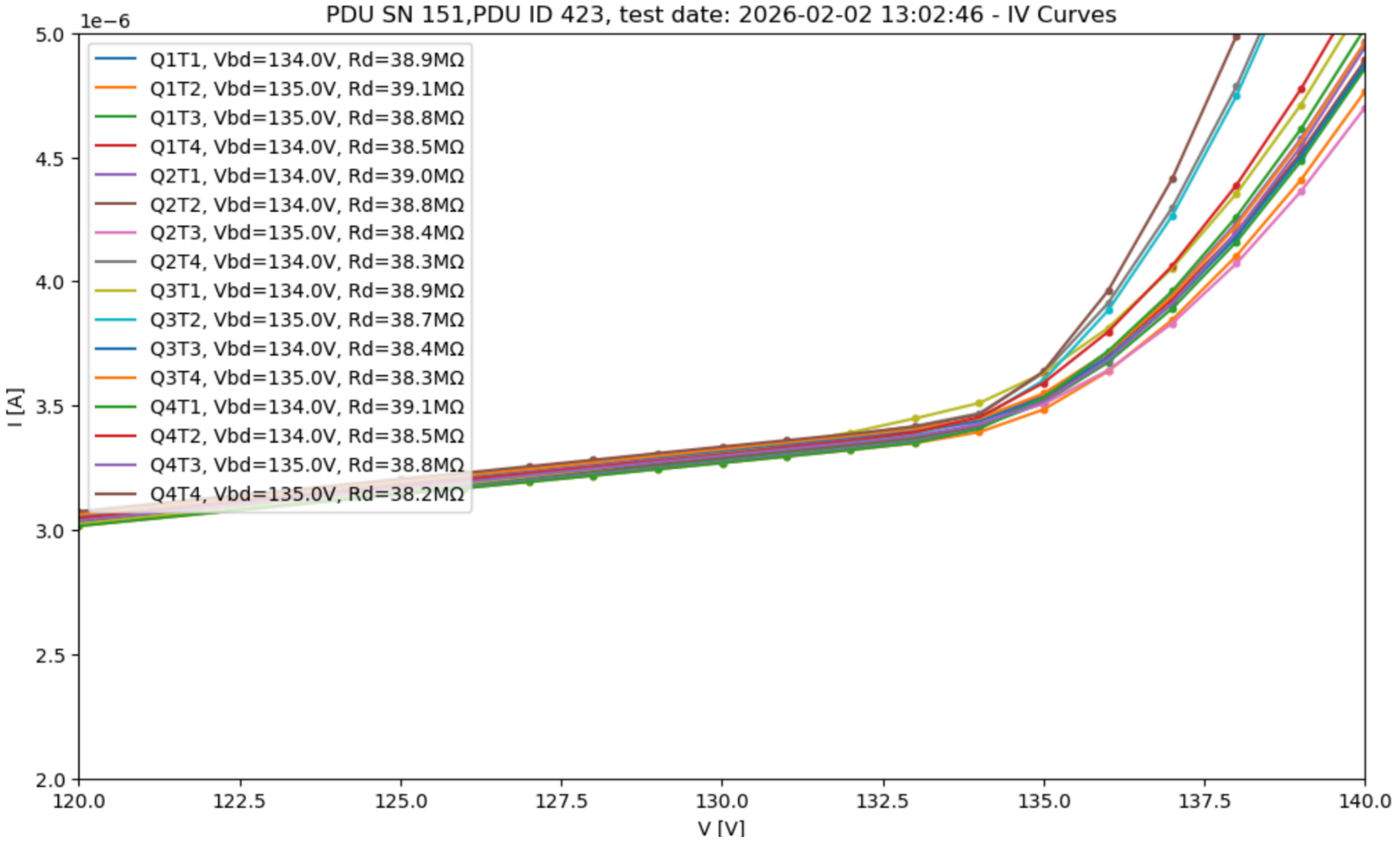
To check the proper functioning of PDUs before shipment to Naples we measure:

- Noise Spectrum below breakdown (40V) at 295K
- IV curves at 295K : RMS of second derivative to spot anomalous breakdown behaviors



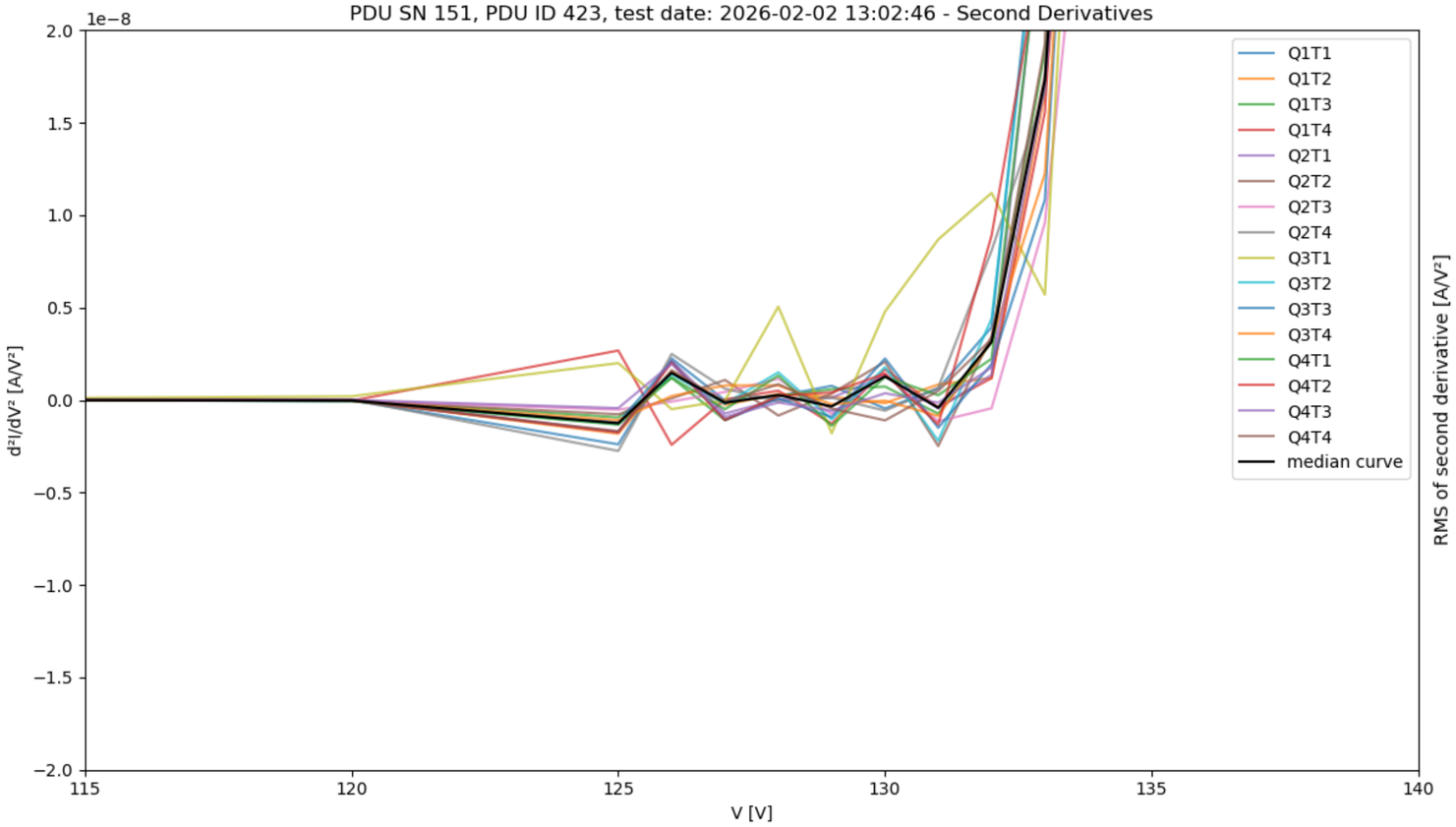


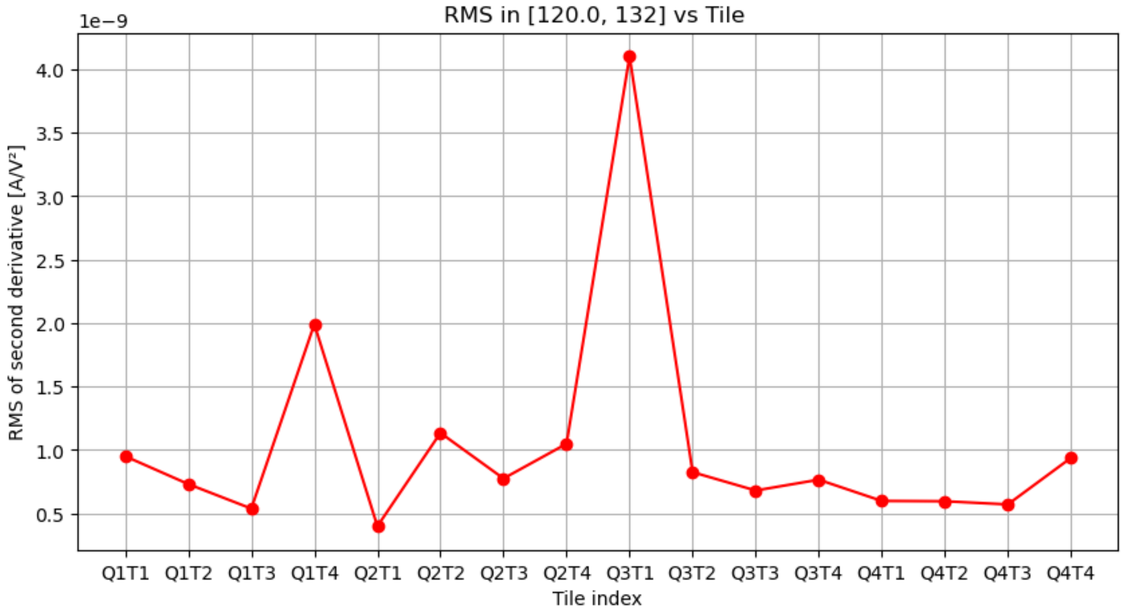
PDU warm test: double breakdown problem



Also works on much smaller effects

QA&QC: RMS algorithm



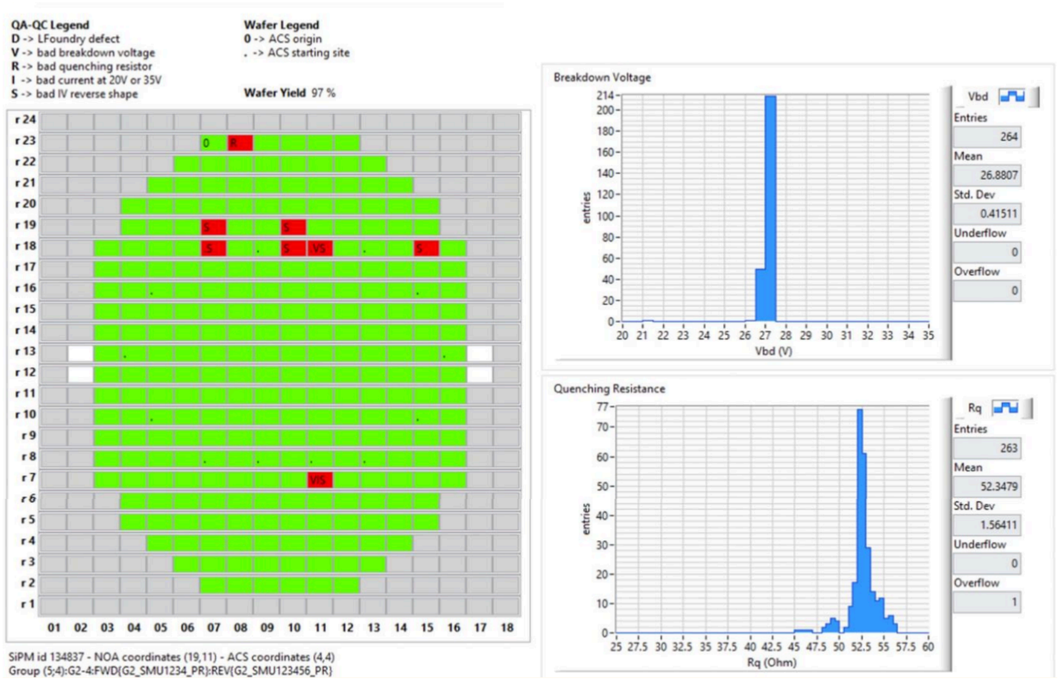


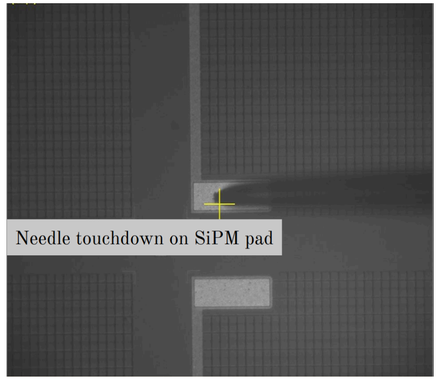
SiPM cryoprobe test

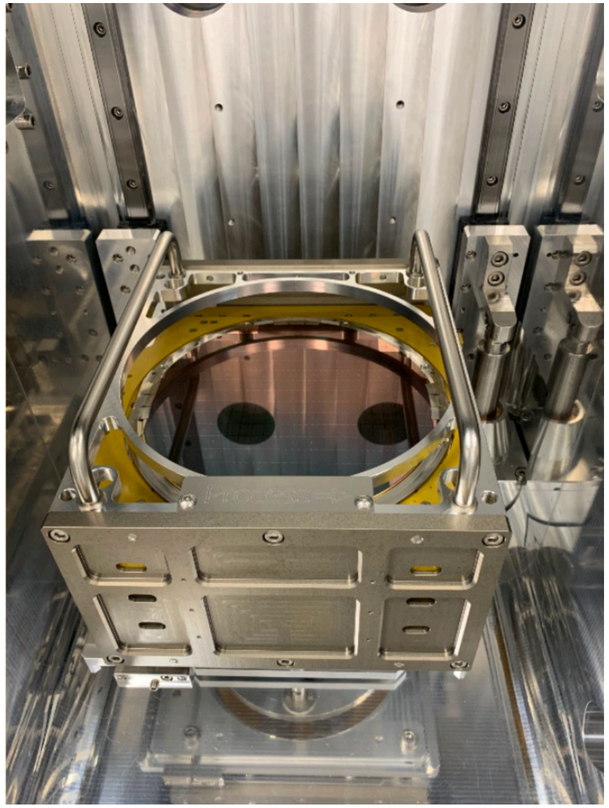
The SiPMs are received in form of wafers from L Foundry (LF). These wafers need to be probed @ 77 K using the PAC200 machine to ensure functional SiPMs for the detector.

The cryogenic characterisation of each SiPM includes measurements of the breakdown voltage, the quenching resistance, and the leakage current as a function of the bias voltage.

The output of these test gives a map of the wafer blighting the bad SiPMs

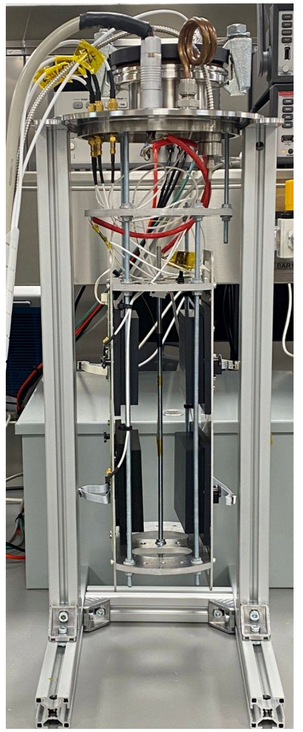


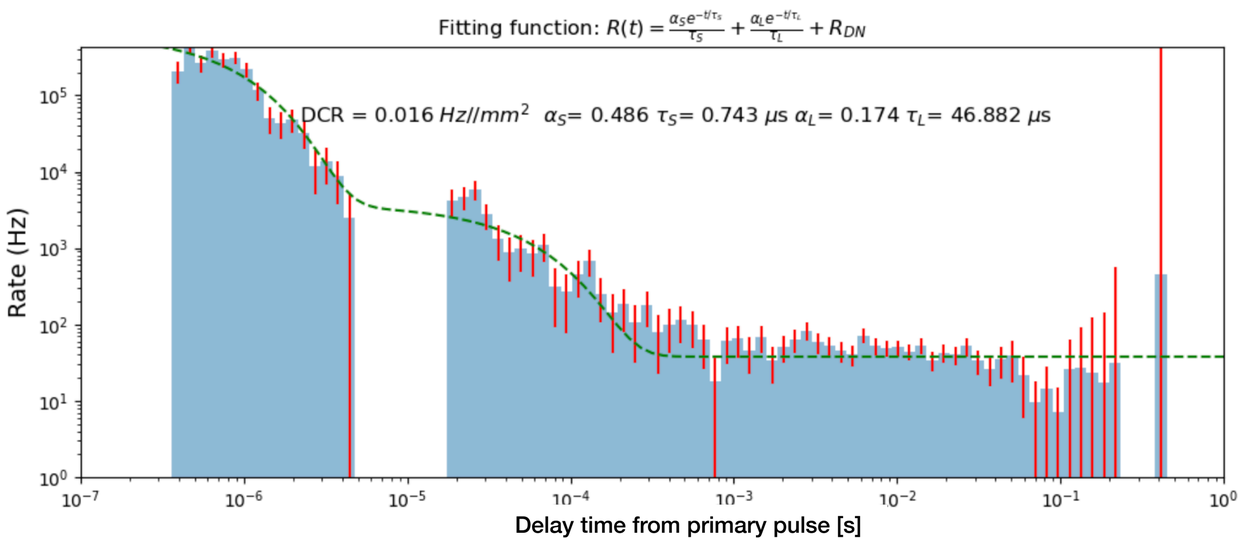


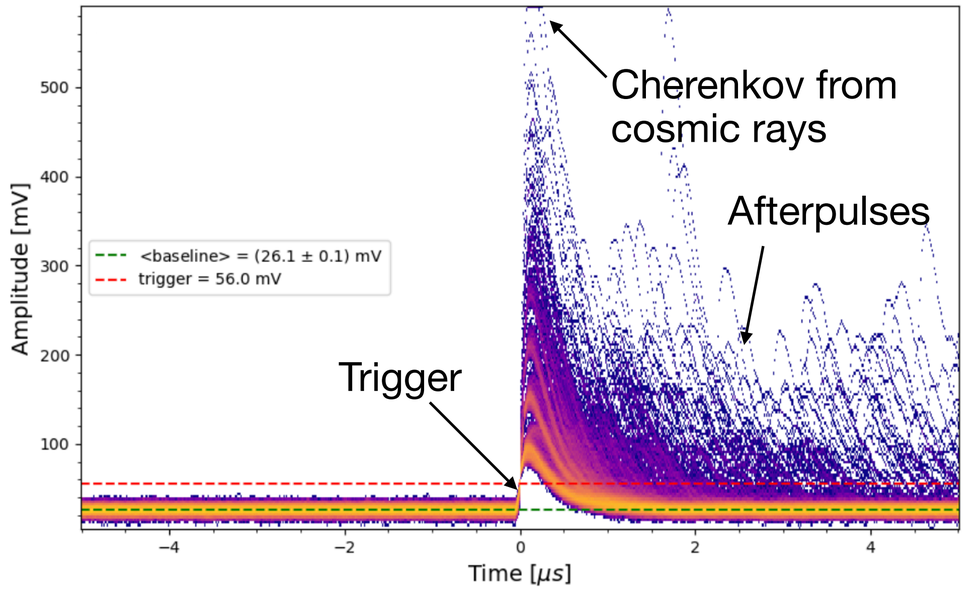


DCR measurement

- Black tile holders
- Self triggered data (20mV over baseline)
- DCR estimated as the time independent component of the distribution of the rate of pulses after a certain delay time from the trigger pulse





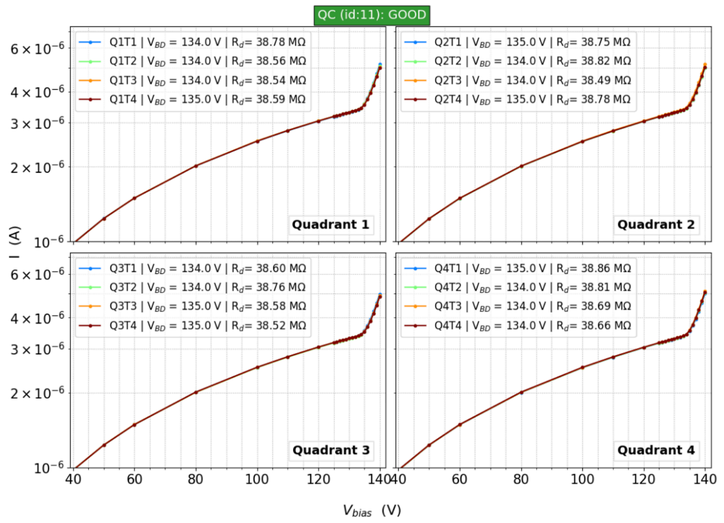


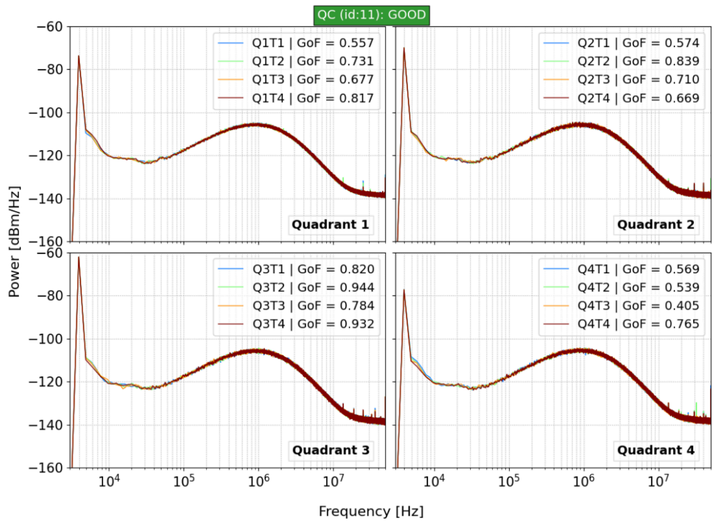
Quality Assurance & Quality Control

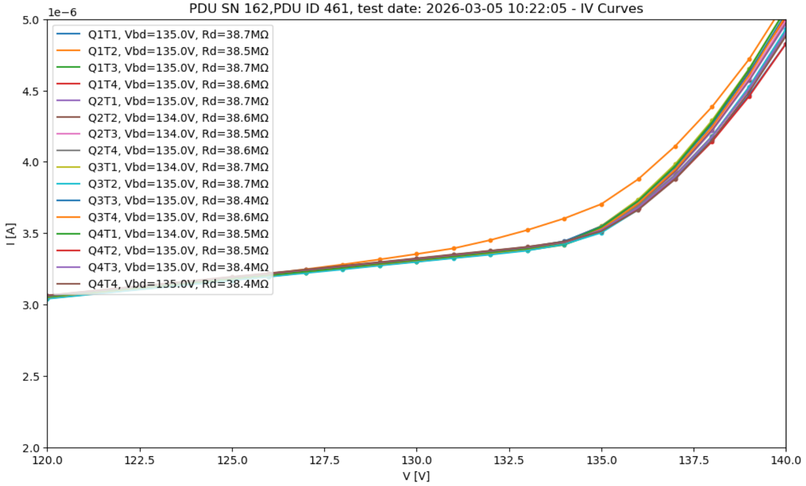
PDU warm test in NOA

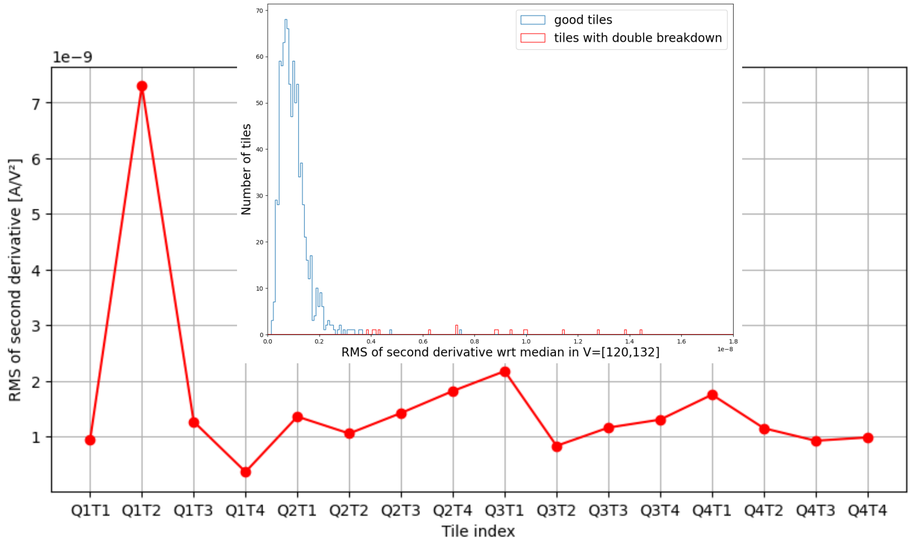
To check the proper functioning of PDUs before shipment to Naples we measure:

- Noise Spectrum below breakdown (40V) at 295K
- IV curves at 295K : RMS of second derivative to spot anomalous breakdown behaviors

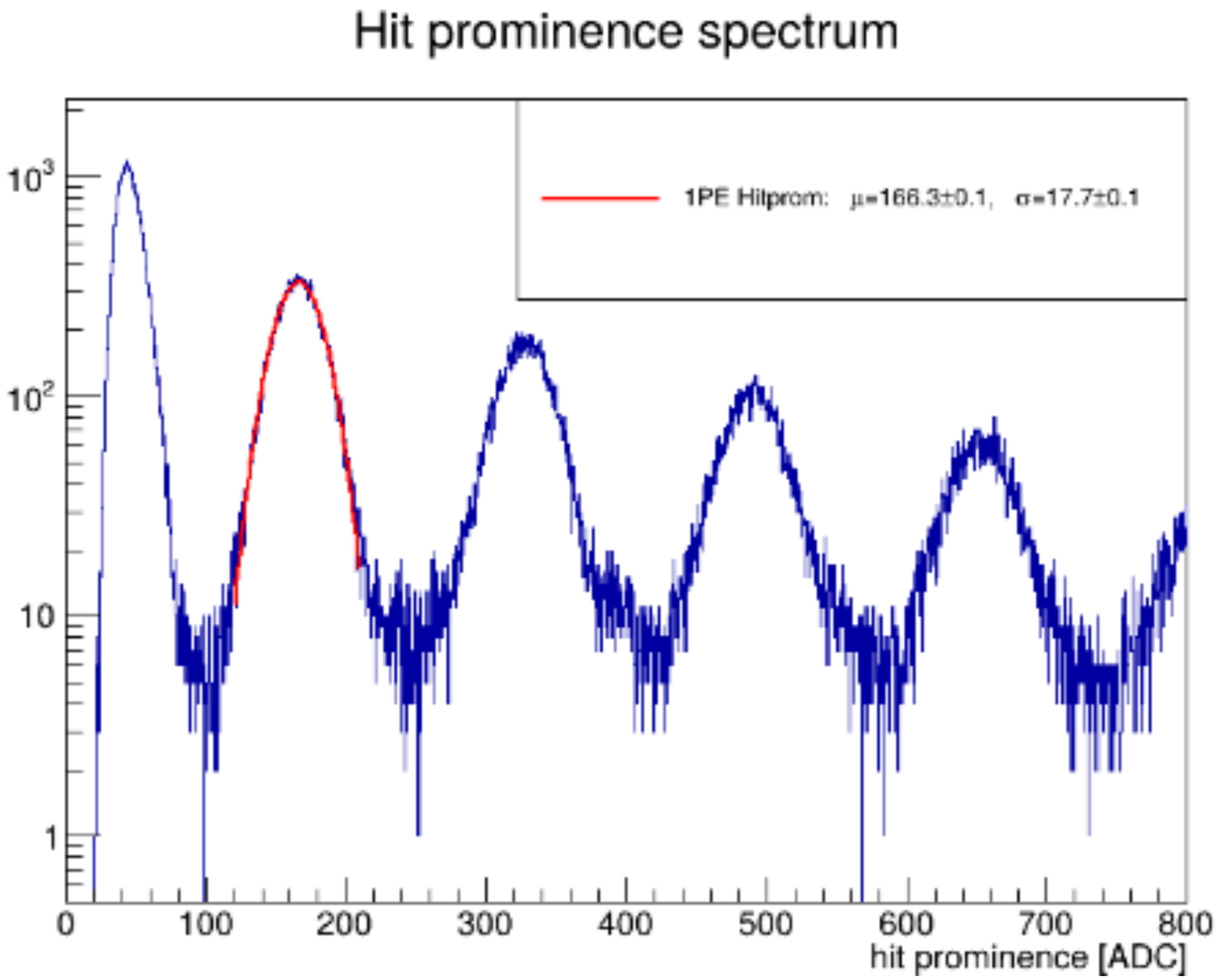






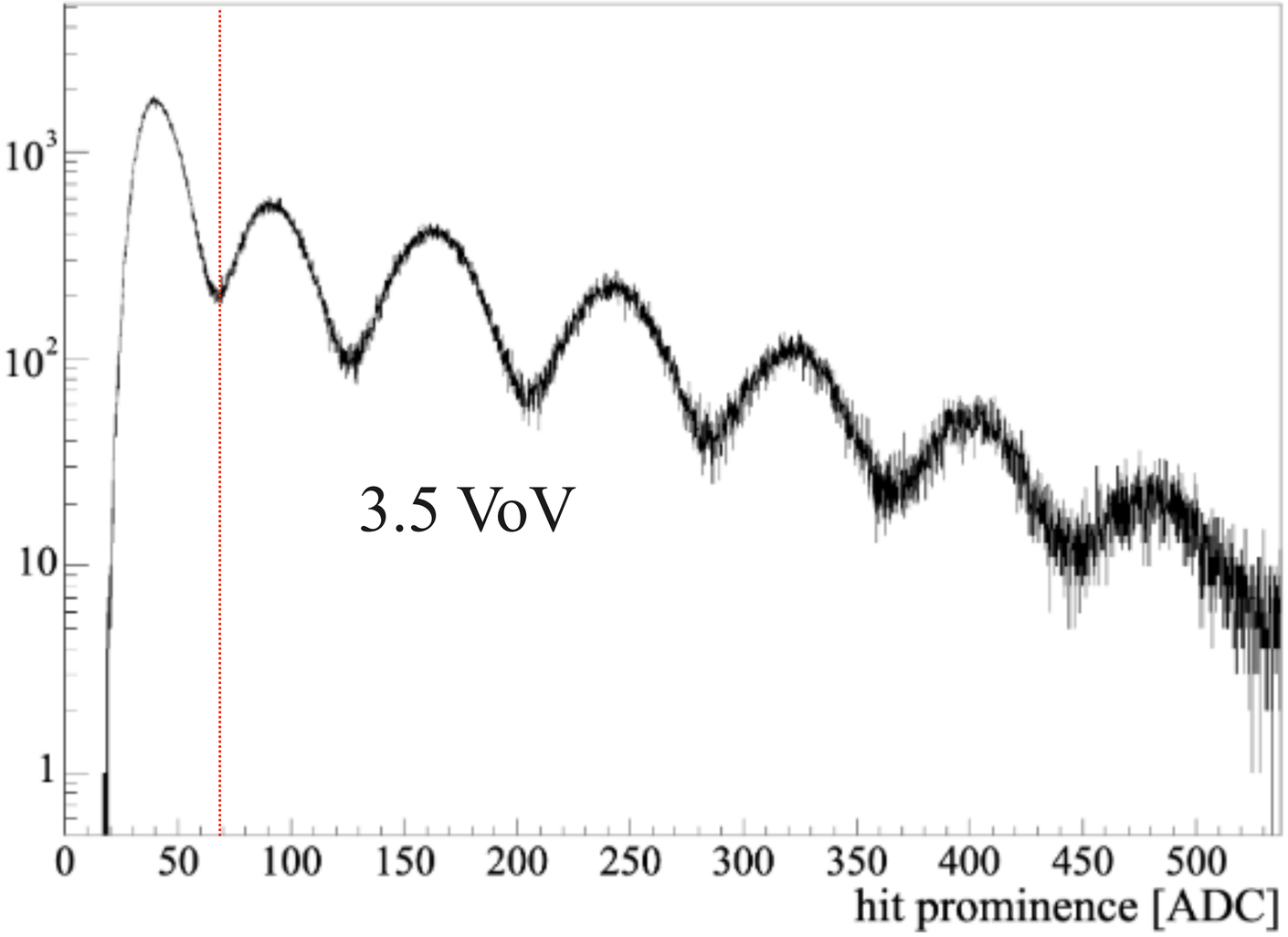


Hit finder efficiency



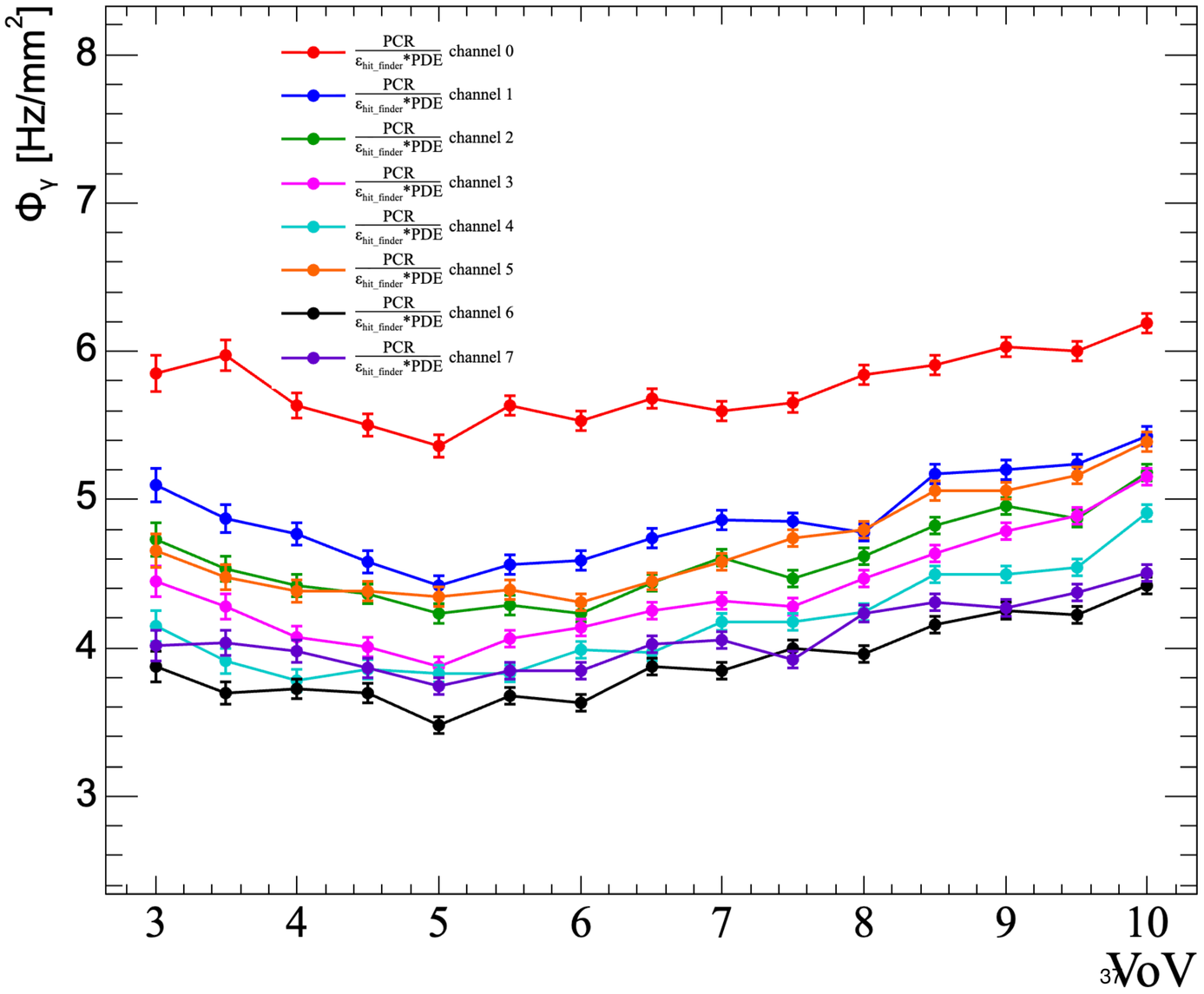
To compute the hit finder efficiency we select all the waveforms that have a charge integral corresponding to 1PE in the window (I chose 1μs to the right and 0.1 μs to the left) around the trigger sample.

Hit finder efficiency



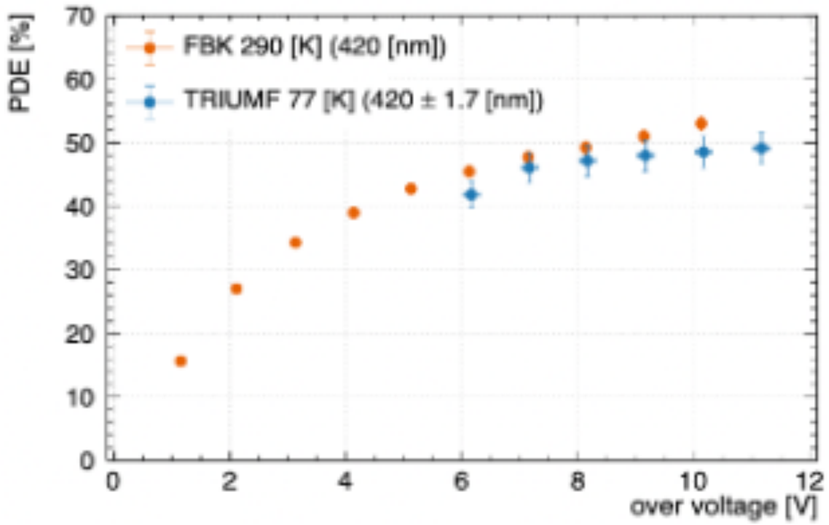
As we lower the bias of SiPMs the separation between nose and signal worsens as expected: In order to avoid considering 0PE hits in the efficiency study from 6.5VoV and below a forced cut is implemented in order to separate the 0PE peak and the 1PE peak.

PCR

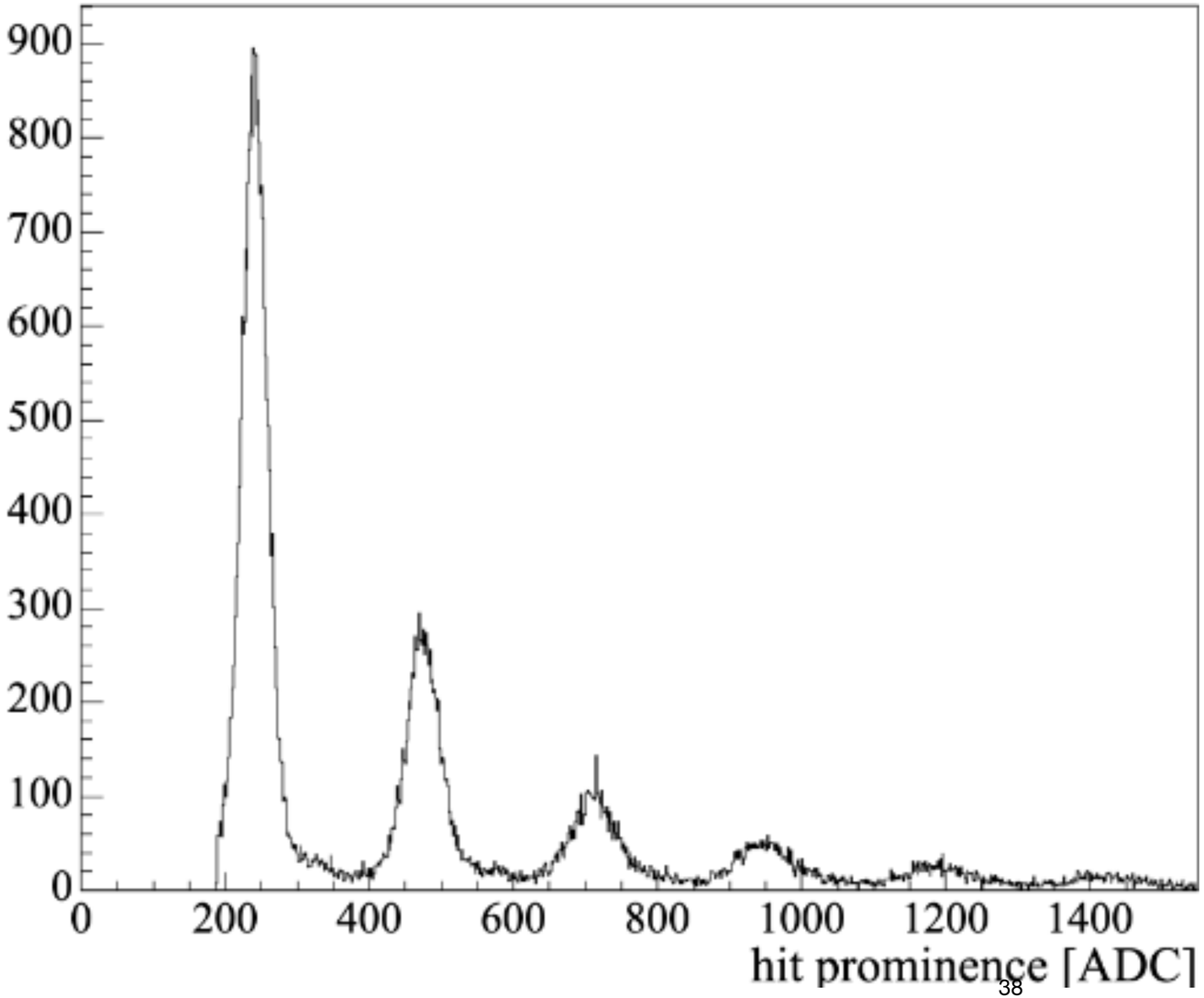


We can also correct the PCR with the PDE and the hit finder efficiency, obtaining the incoming photon flux.

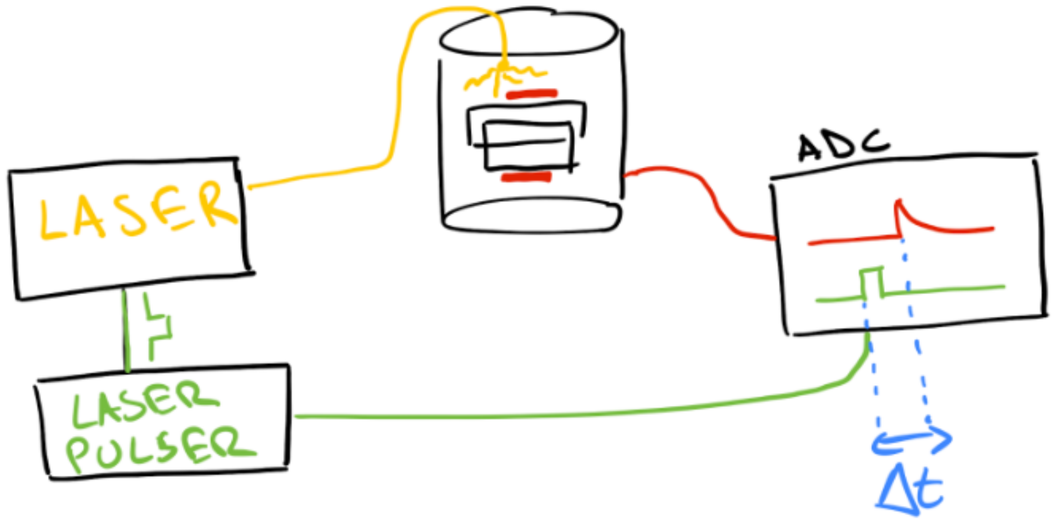
- The rising at lower VoVs is due to the underestimation of hit finder efficiency
- The rising at higher VoVs can be due to DCR + ExCT increasing with SiPMs bias



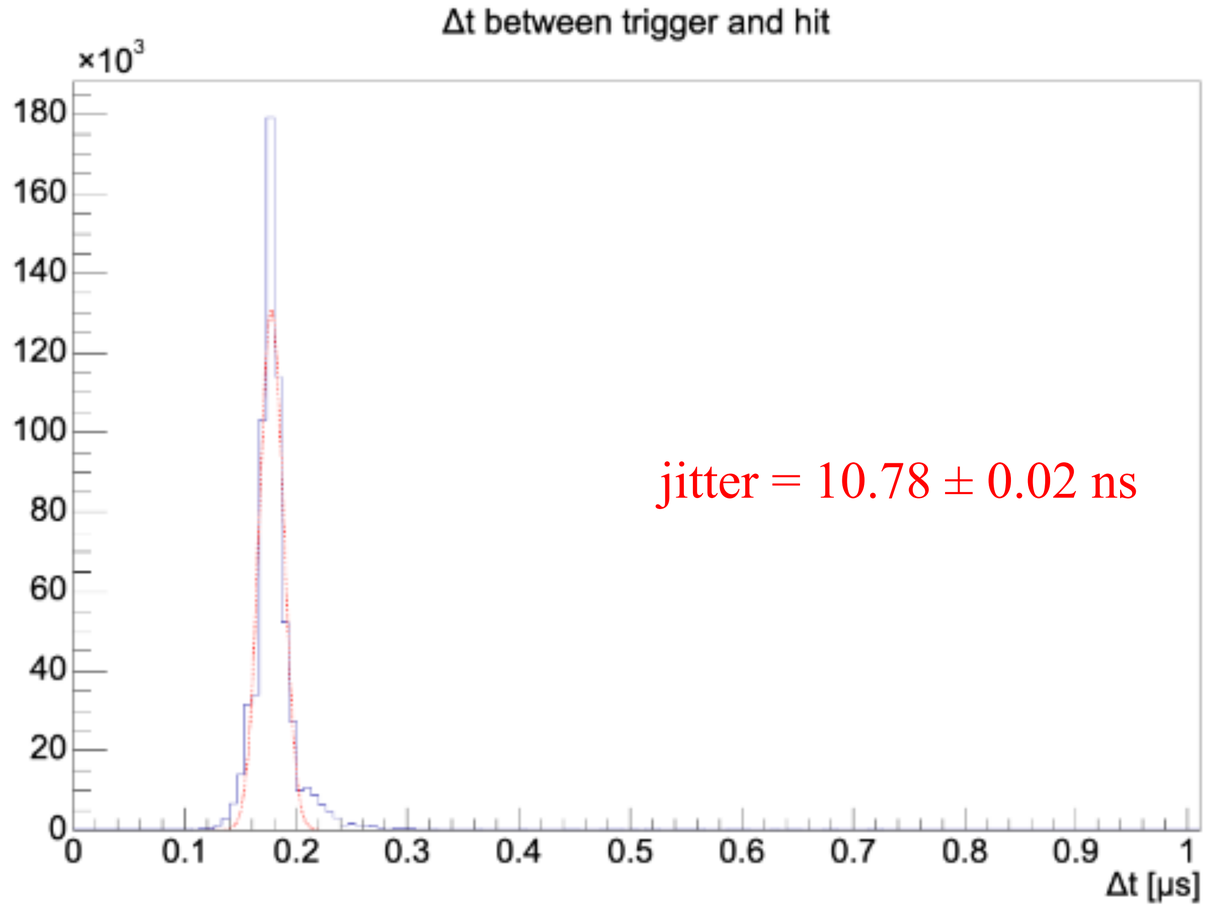
PCR


900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
hit prominence [ADC]

Jitter evaluation



This is obtained plotting the time difference Δt for every hit independently of the prominence or the channel, with respect the trigger. The jitter is obtained fitting the distribution cutting the tails.



jitter = 10.78 ± 0.02 ns