GRAN SASSO hands-on 2025
PhD school on experimental astroparticle physics
September 8th - 15th, 2025

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

SFB 1258 Neutrinos Dark Matter Messengers

DSFC Dipartimento di Scienze Fisiche e Chimiche

GSSI GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN Istituto Nazionale di Fisica Nucleare

Characterization and Integration of Large Area SiPM Arrays at the NOA Facility

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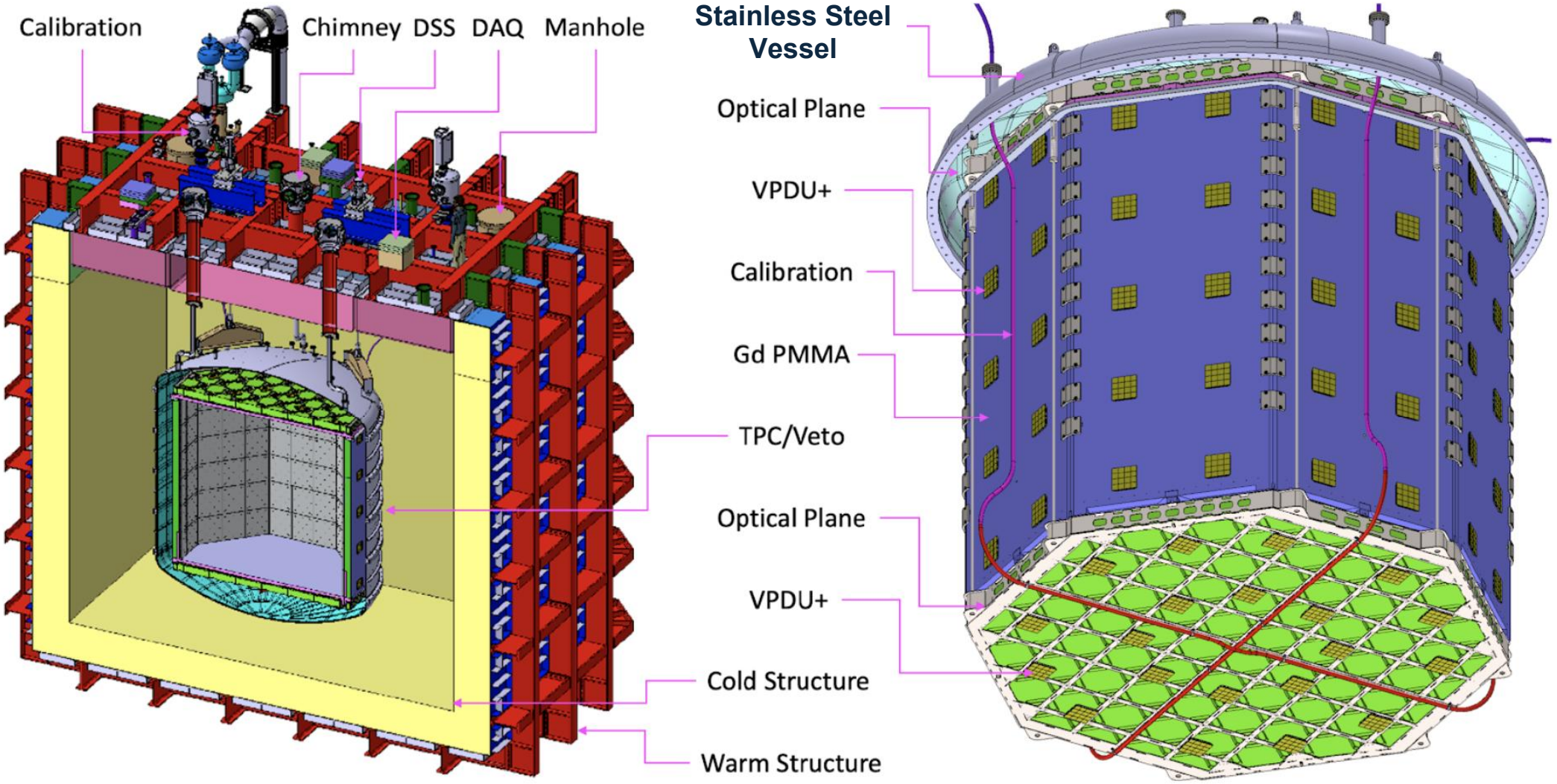
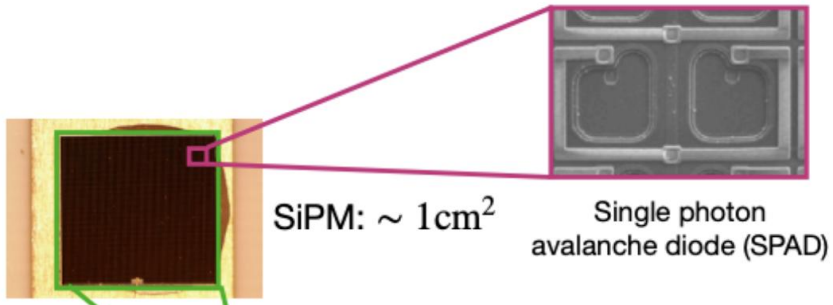
ASTROCENT

CAPA Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

DarkSide-20k experiment

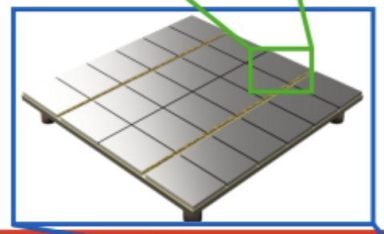


Optical planes

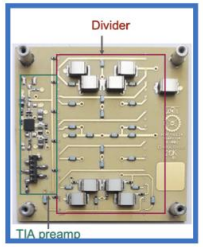


SiPM: $\sim 1\text{cm}^2$

Single photon avalanche diode (SPAD)



Tile: 24 SiPMs



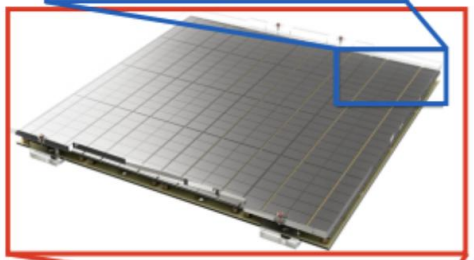
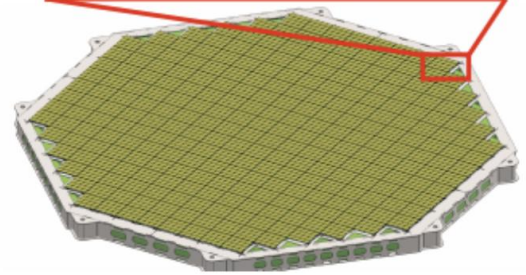


Photo-detection unit (PDU): 16 tiles arranged in 4 readout channels



TPC optical plane: 525 PDUs $\sim 21\text{m}^2$

+120 PDUs for the Veto system

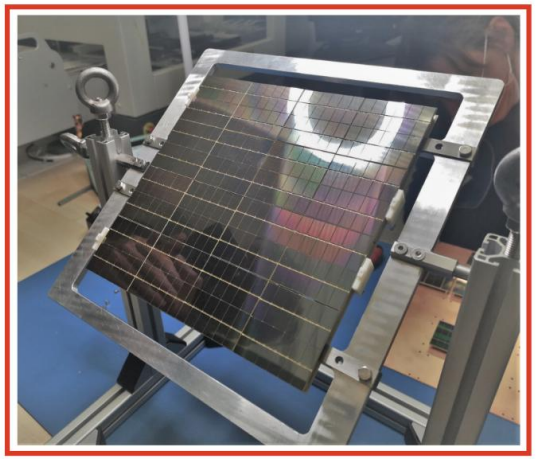
Collaboration with FBK for SPAD design

2019: 24 SiPM tile frozen

2022: refinement of the electronics

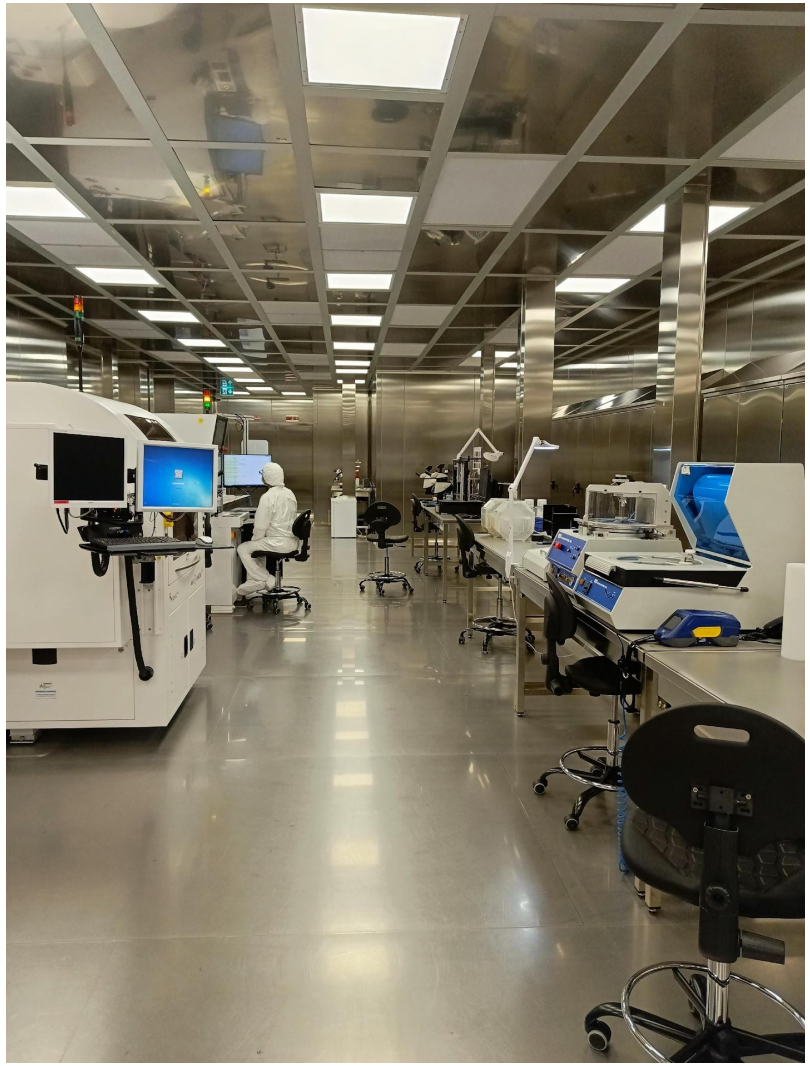
2022: full PDU!

Late 2022 until present: mass production and assembly at NOA



First 2 fullv assembled devices are curr
in N

The NOA facility

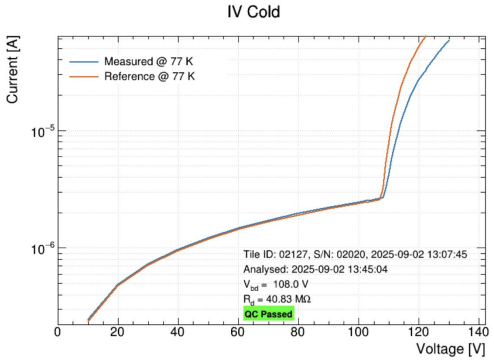


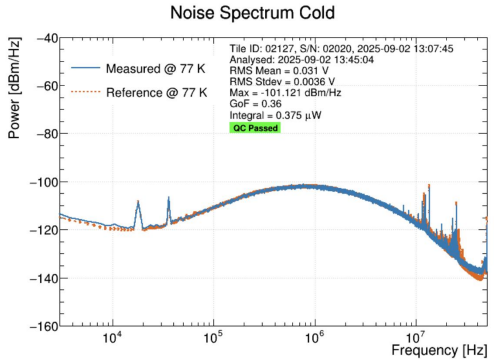
NOA is a clean room of ISO6 standard
It became operational on February 2023
NOA has two main areas:

- CR3 (350 m^2) is devoted to the assembly of SiPMs, tiles, PDUs and respective tests
- CR2 (70 m^2) devoted to integration of the optical planes

Summarized pipeline

Production: wire bonding done, optical inspection…





Tiles to be tested:

- CMOS imaging
- *DCR* (Dark Count Rate)
- *PCR* (Pulse Count Rate)
- IV curve
- Noise Spectrum
- Pulse counting
- Average single photoelectron

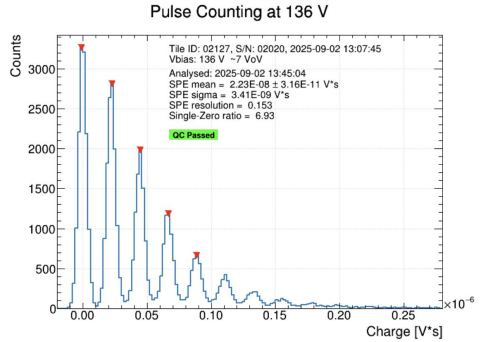
Test failed: check condition

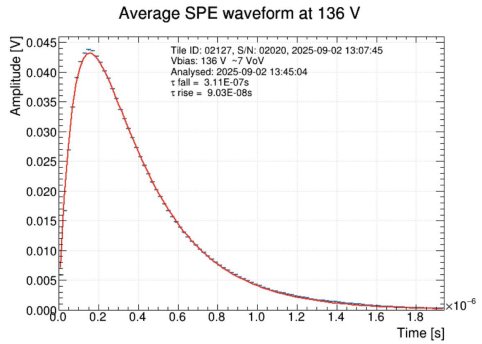
→ Re-work

→ **Bad for sure**

Test passed:

Waiting for PDU assembly





The NOA facility

Waveform-level analysis: high-PCR tiles

PCR events:

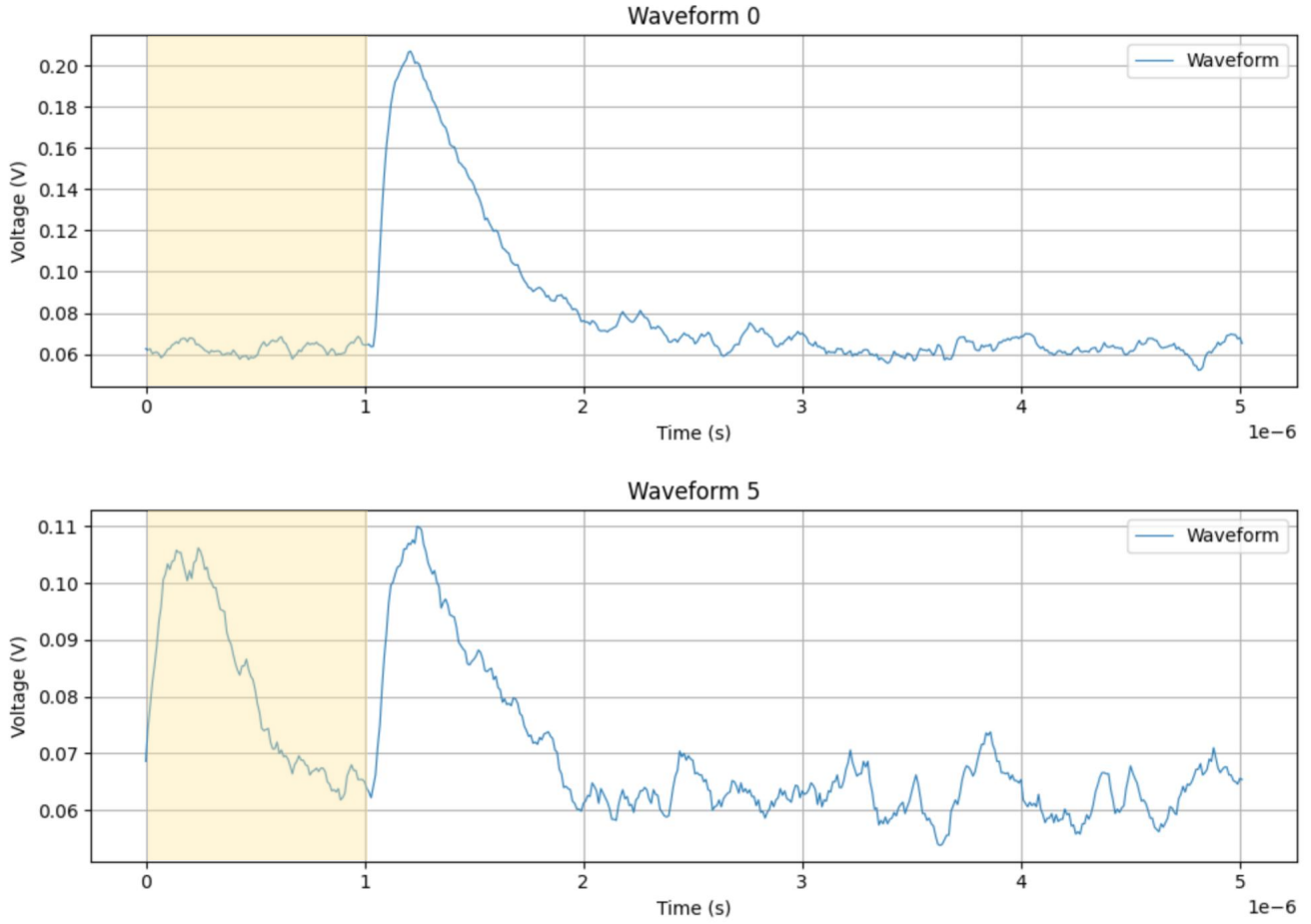
Photoelectrons in the pretrigger region (external trigger)

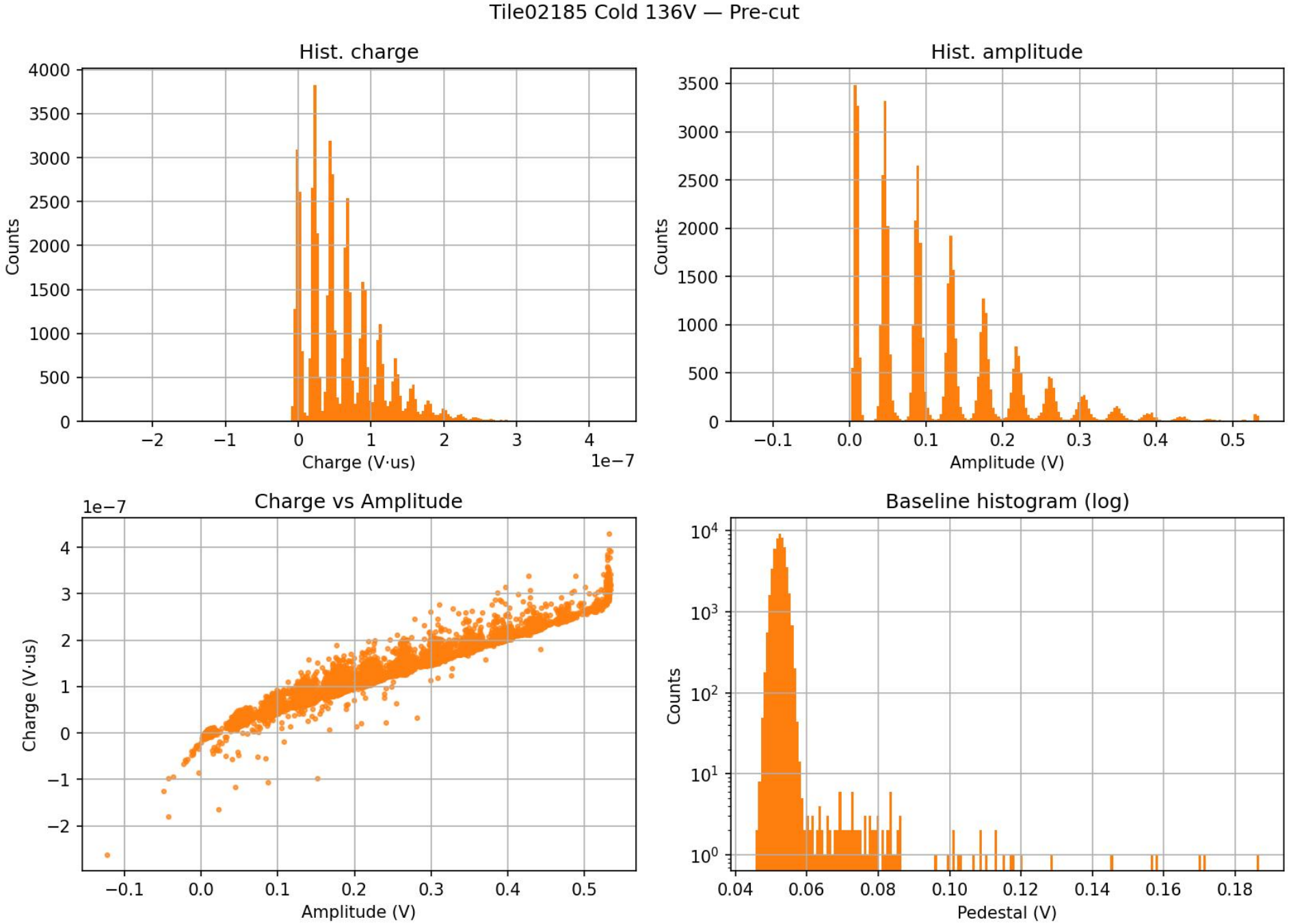
→ Baseline overestimated

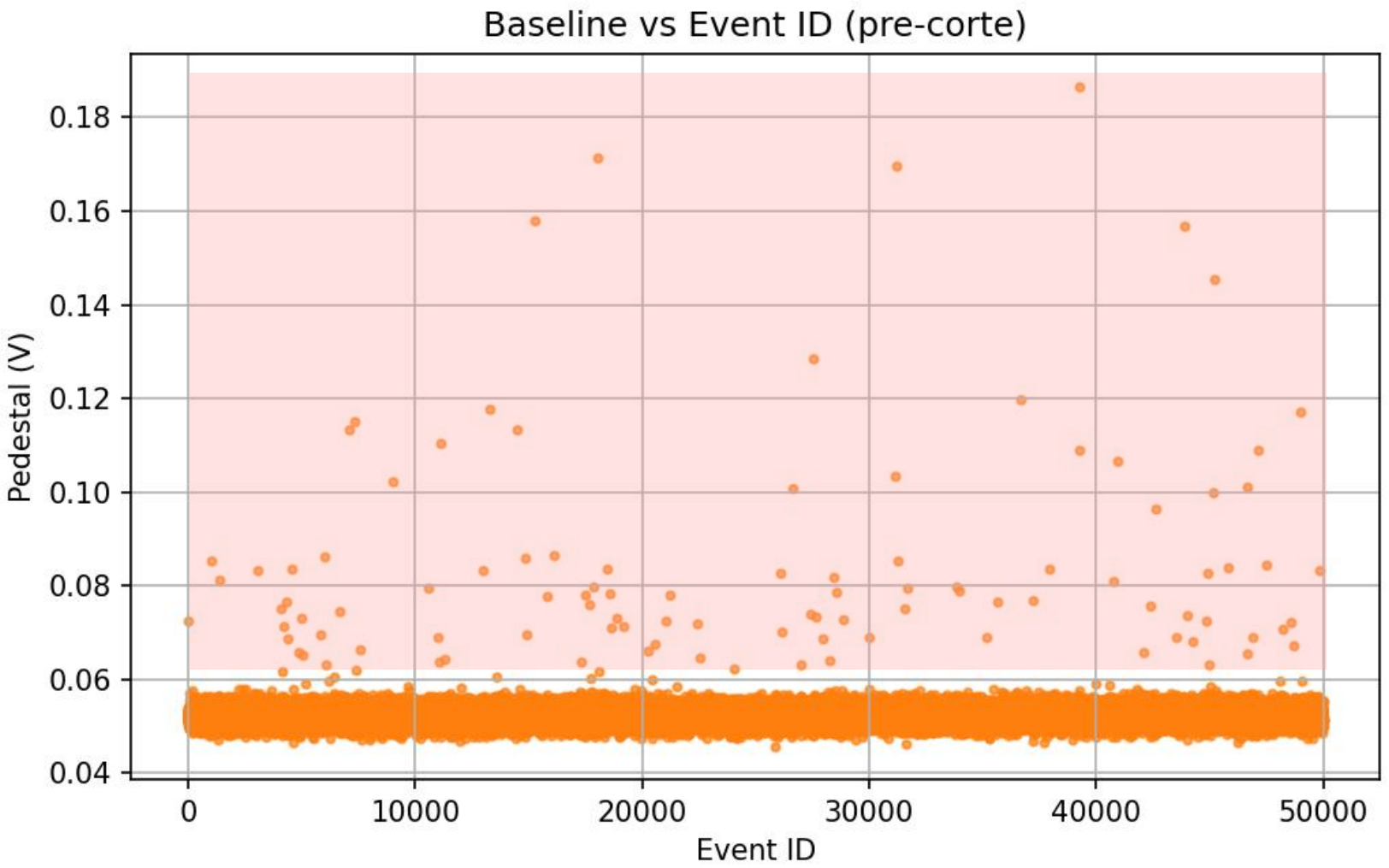
→ Integrated charge underestimated

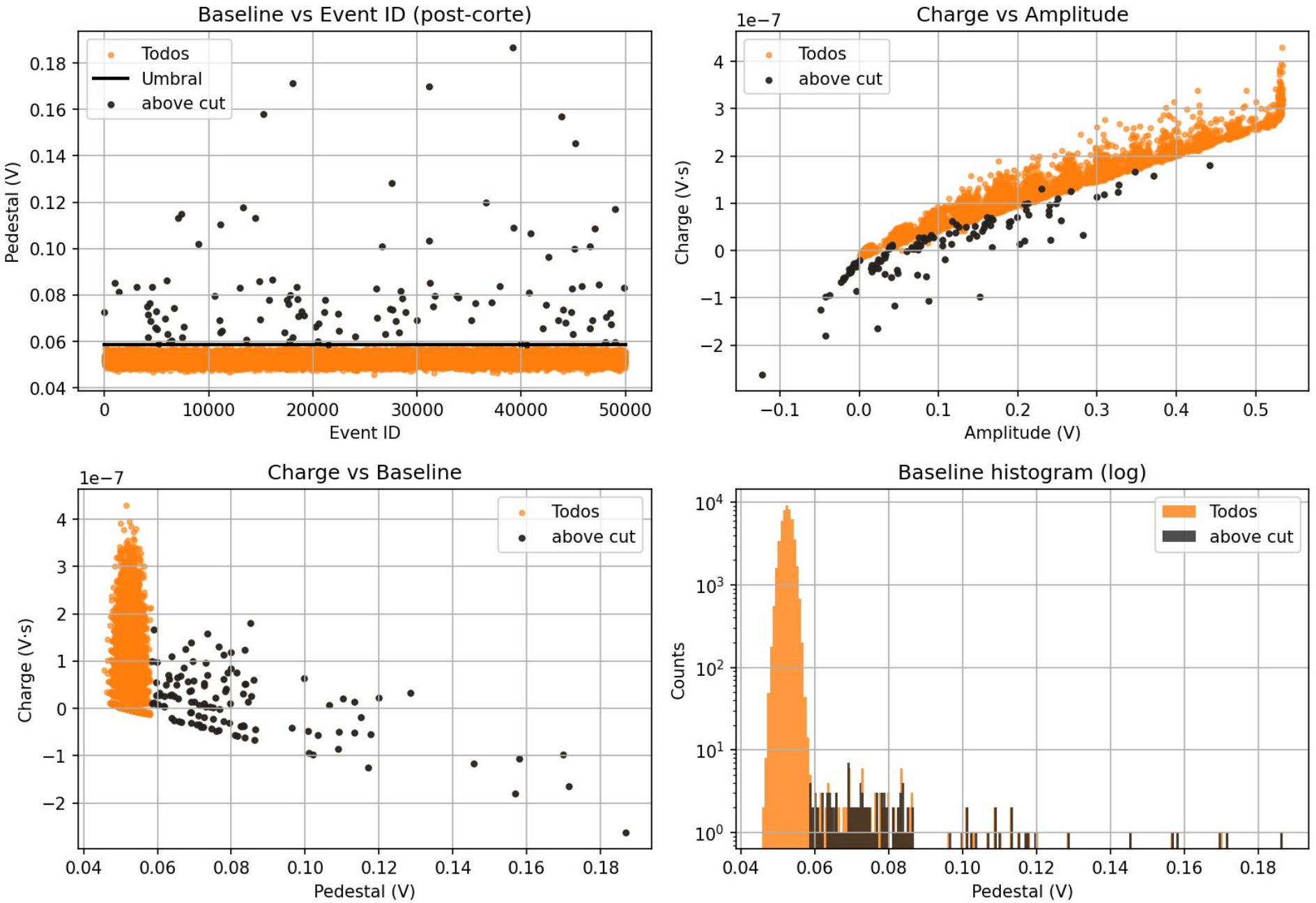
Correlation with DCR (if DCR is high, we expect PCR high too), but what about the opposite?

Python analysis to identify these events from the waveform level...

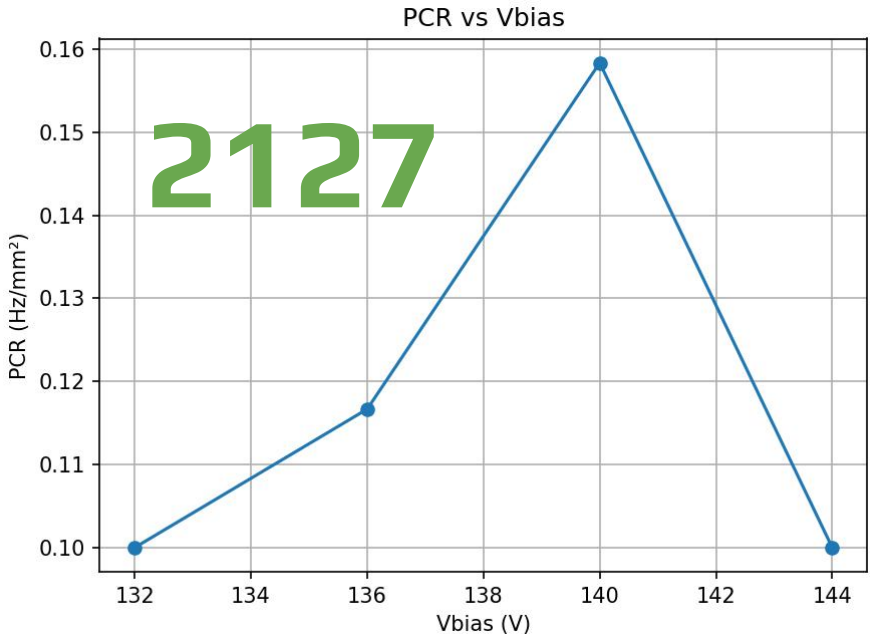


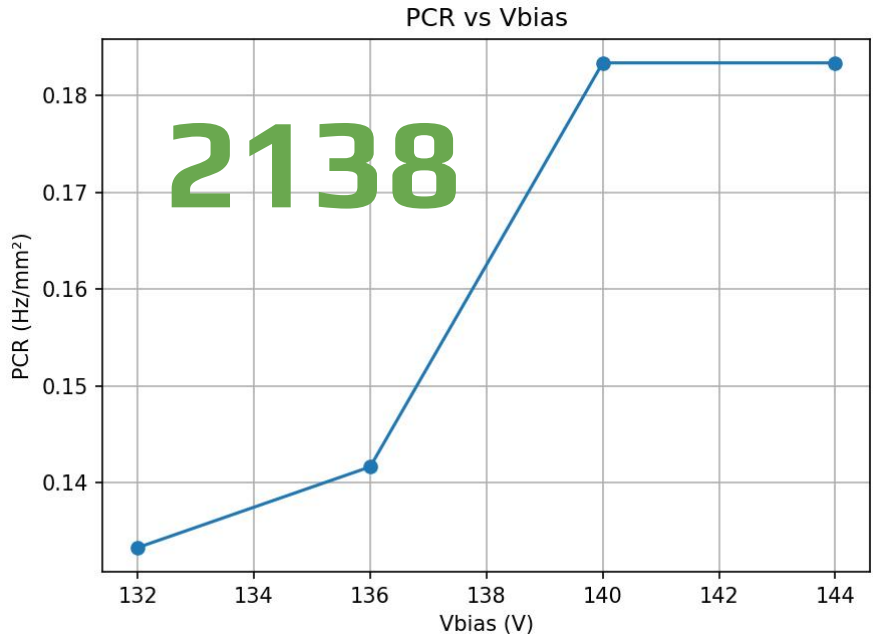

Tile02185 Cold 136V — Pre-cut
Hist. charge
Counts
Charge (V·us)
1e−7
Hist. amplitude
Counts
Amplitude (V)
Charge vs Amplitude
1e−7
Charge (V·us)
Amplitude (V)
Baseline histogram (log)
Counts
Pedestal (V)

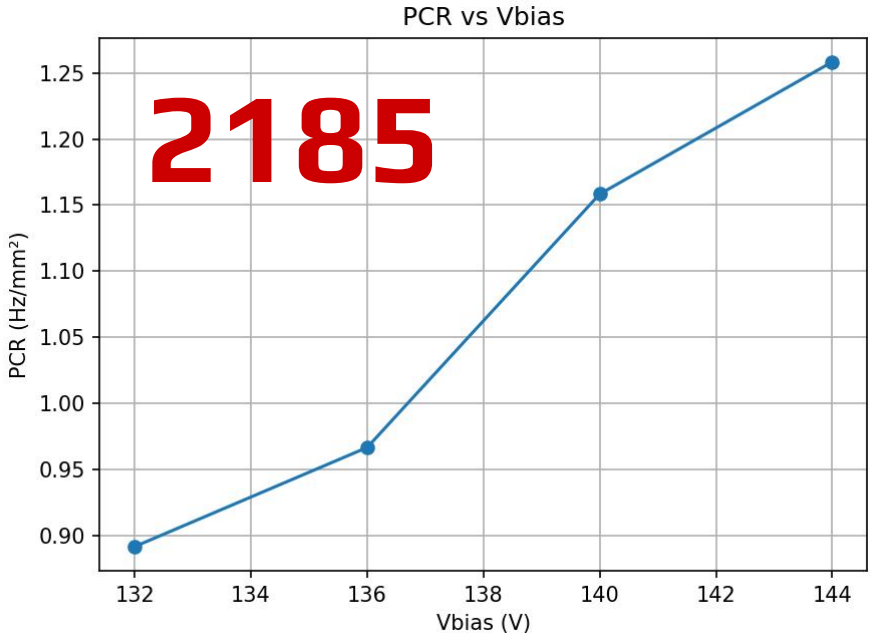

Baseline vs Event ID (pre-corte)
Pedestal (V)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0
10000
20000
30000
40000
50000
Event ID

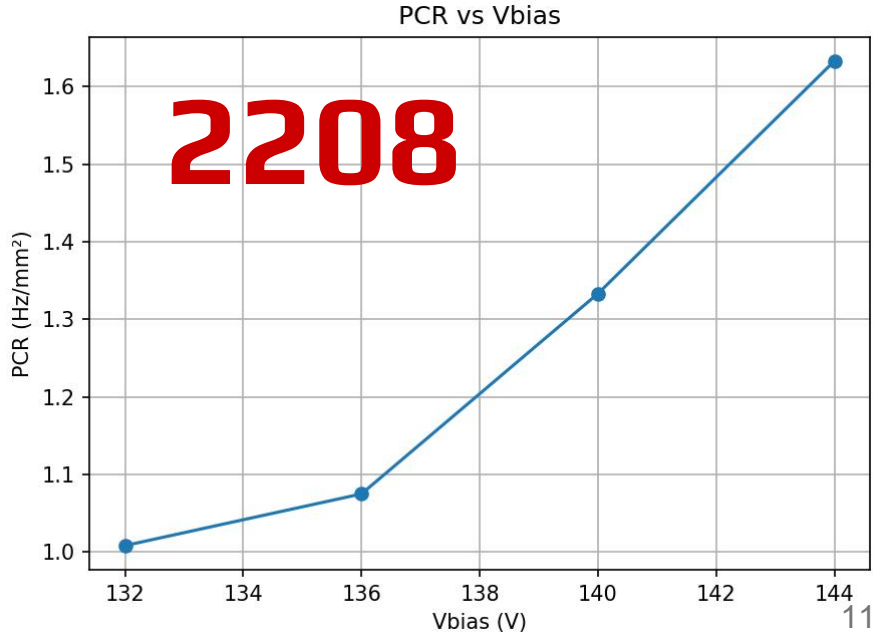

Tile02185 Cold 136V — Post-cut (k=4)
Baseline vs Event ID (post-corte)
Todos
Umbral
above cut
Pedestal (V)
Event ID
Charge vs Amplitude
1e−7
Todos
above cut
Charge (V·s)
Amplitude (V)
Charge vs Baseline
1e−7
Todos
above cut
Charge (V·s)
Pedestal (V)
Baseline histogram (log)
Todos
above cut
Counts
Pedestal (V)

PCR results

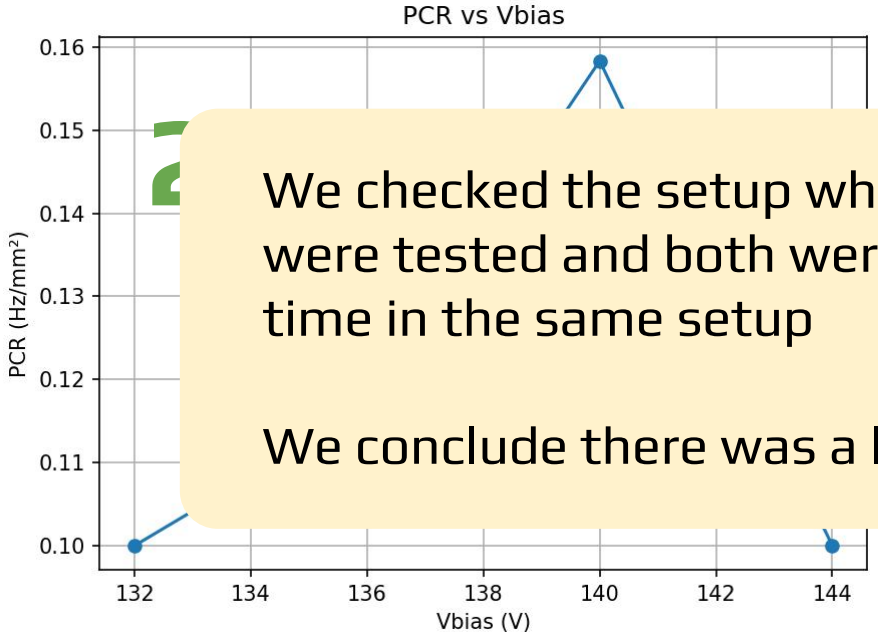

PCR vs Vbias
2127
PCR (Hz/mm²)
Vbias (V)
0.16
0.15
0.14
0.13
0.12
0.11
0.10
132
134
136
138
140
142
144

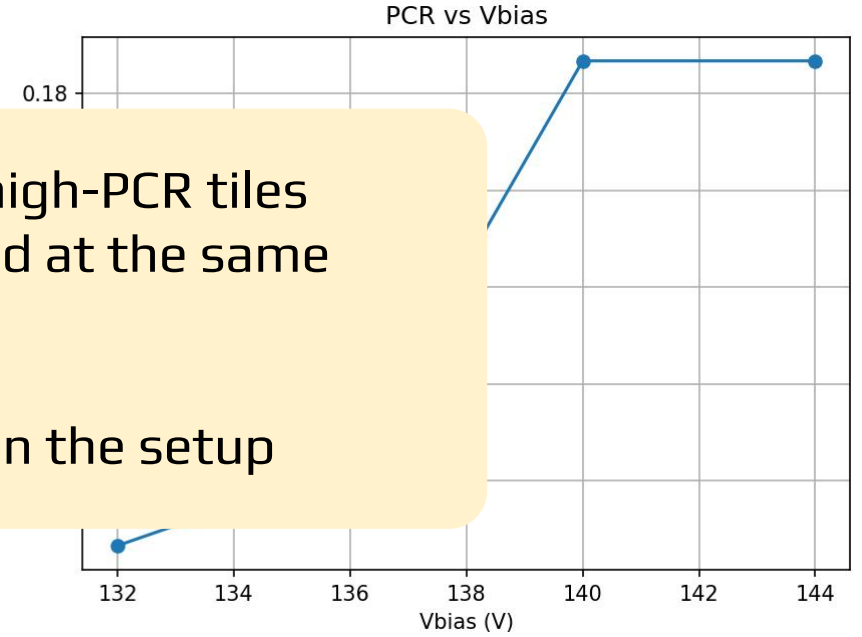

PCR vs Vbias
2138
PCR (Hz/mm²)
Vbias (V)
0.18
0.17
0.16
0.15
0.14
132
134
136
138
140
142
144


PCR vs Vbias
2185
PCR (Hz/mm²)
Vbias (V)
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
132
134
136
138
140
142
144


PCR vs Vbias
2208
PCR (Hz/mm²)
Vbias (V)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
132
134
136
138
140
142
144

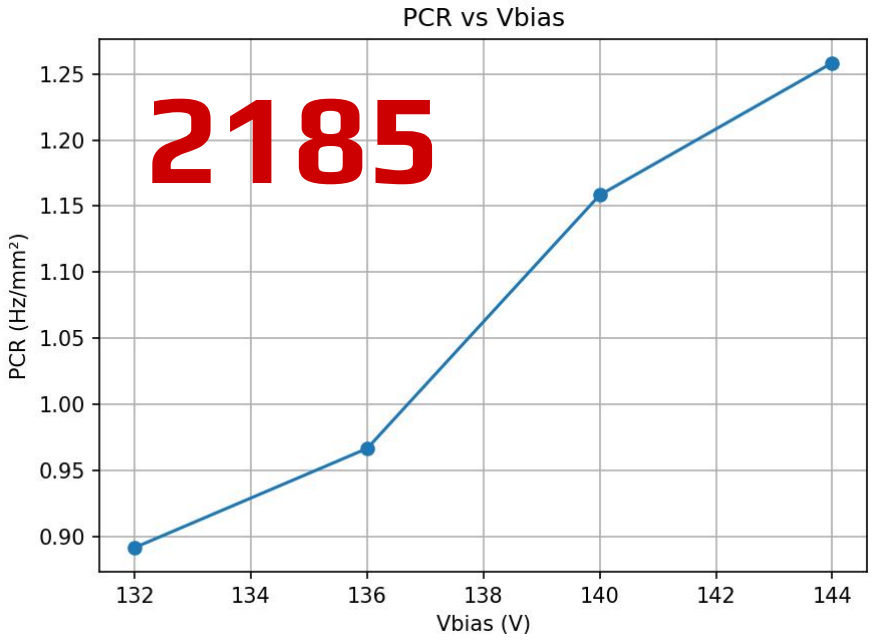
PCR results

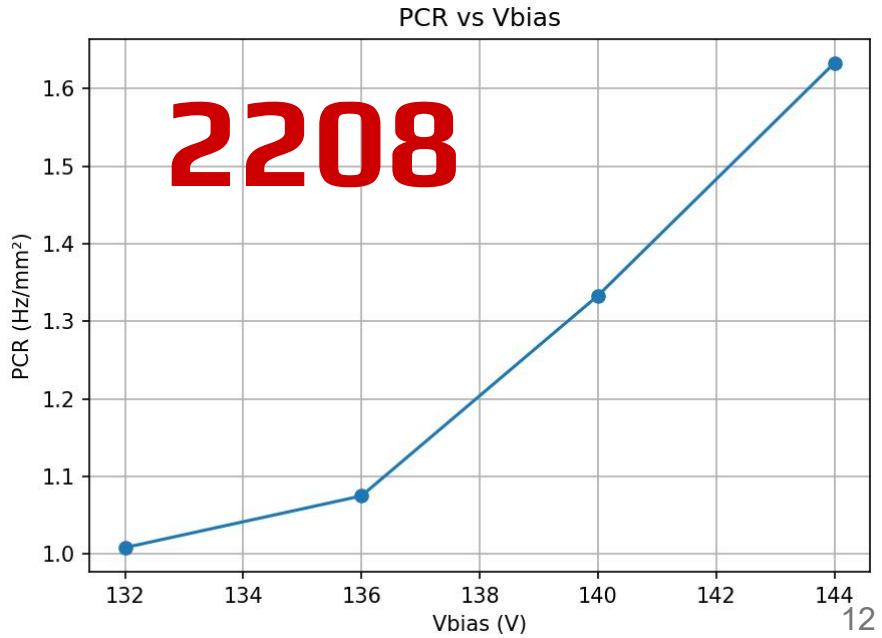




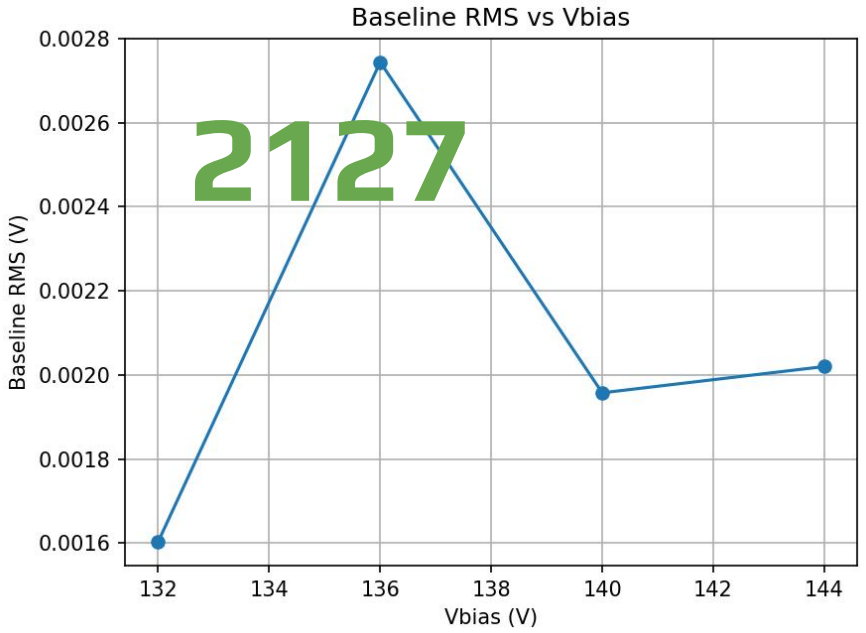
We checked the setup where the 2 high-PCR tiles were tested and both were measured at the same time in the same setup

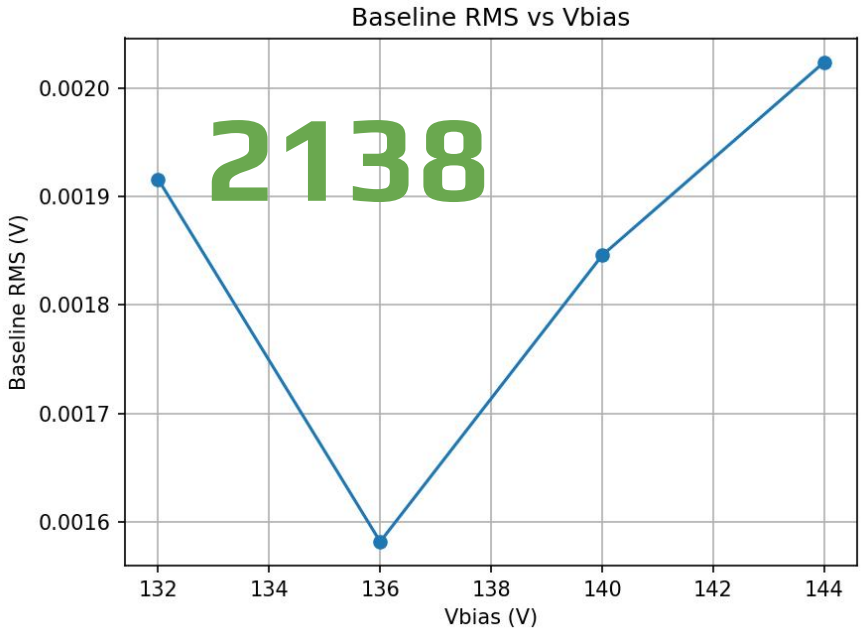
We conclude there was a **light leak** in the setup

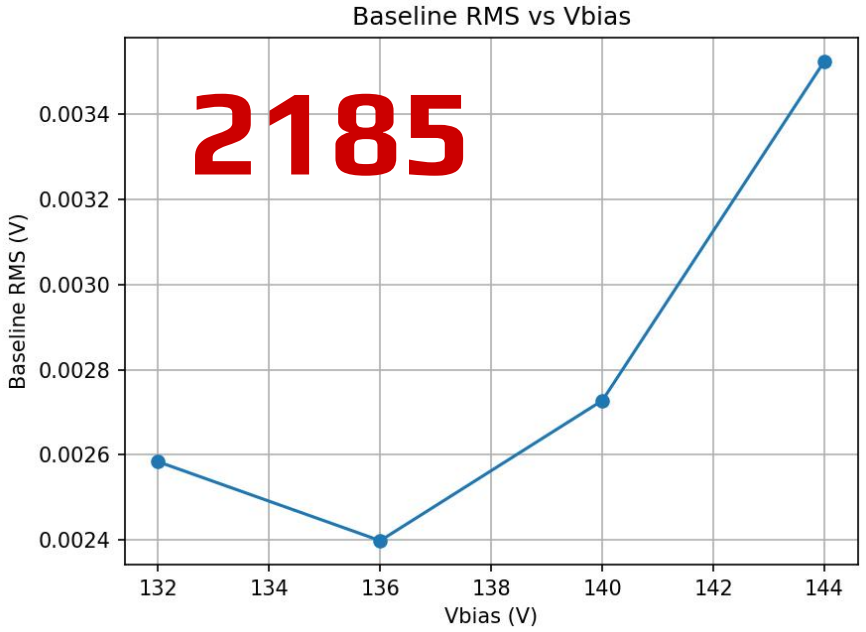


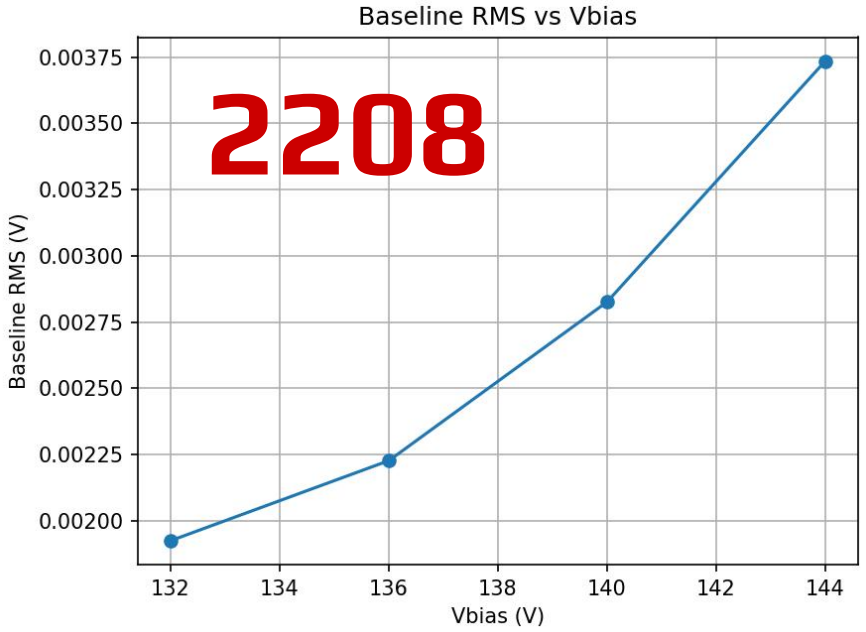


Baseline RMS as a light leak estimator?

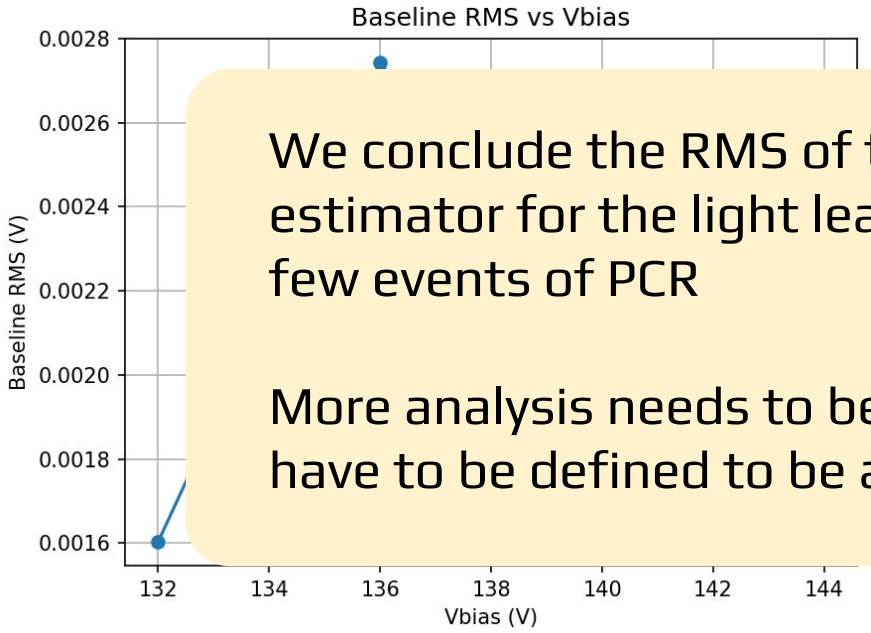


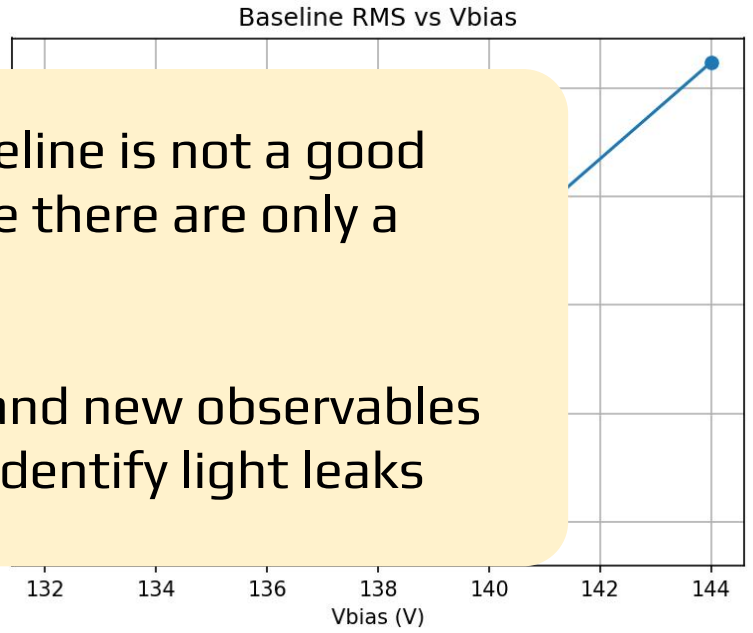






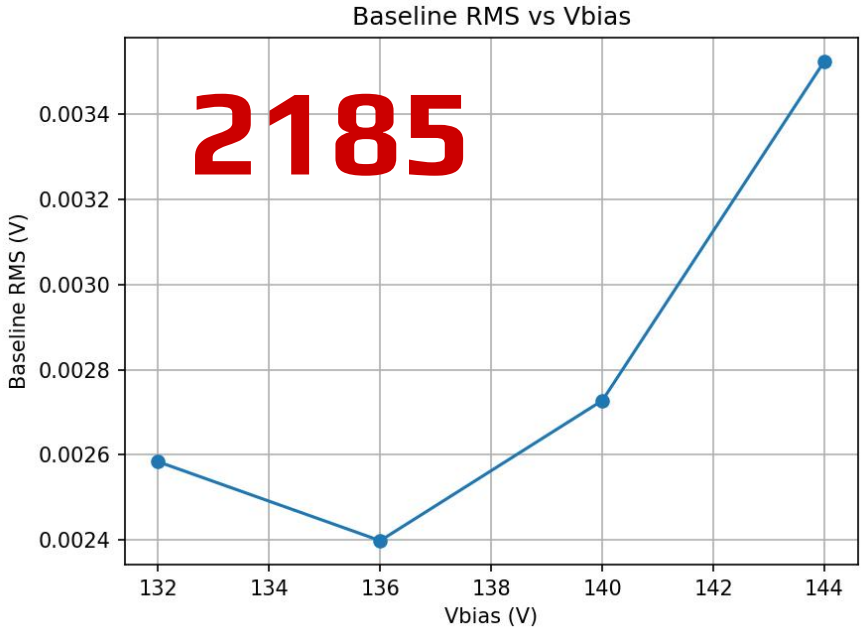
Baseline RMS as a light leak estimator?

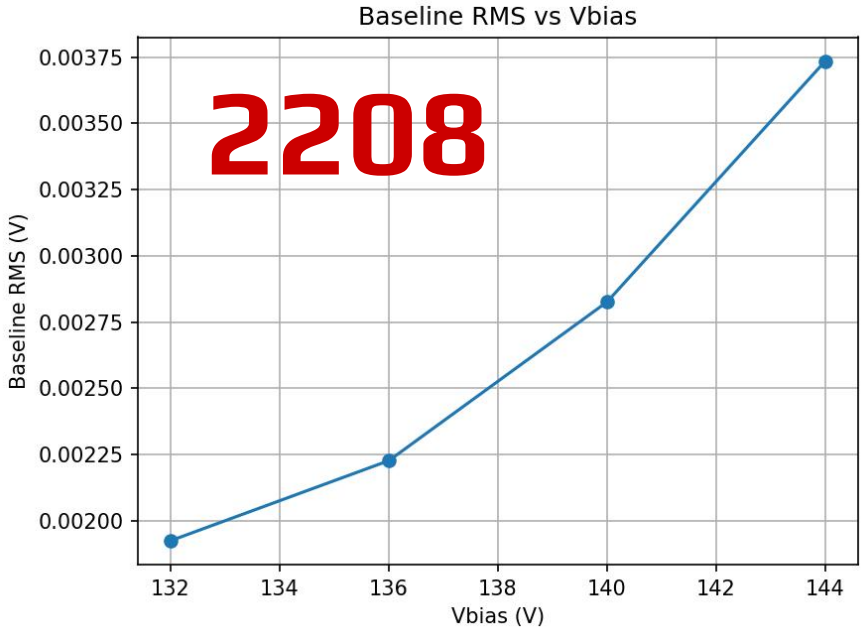




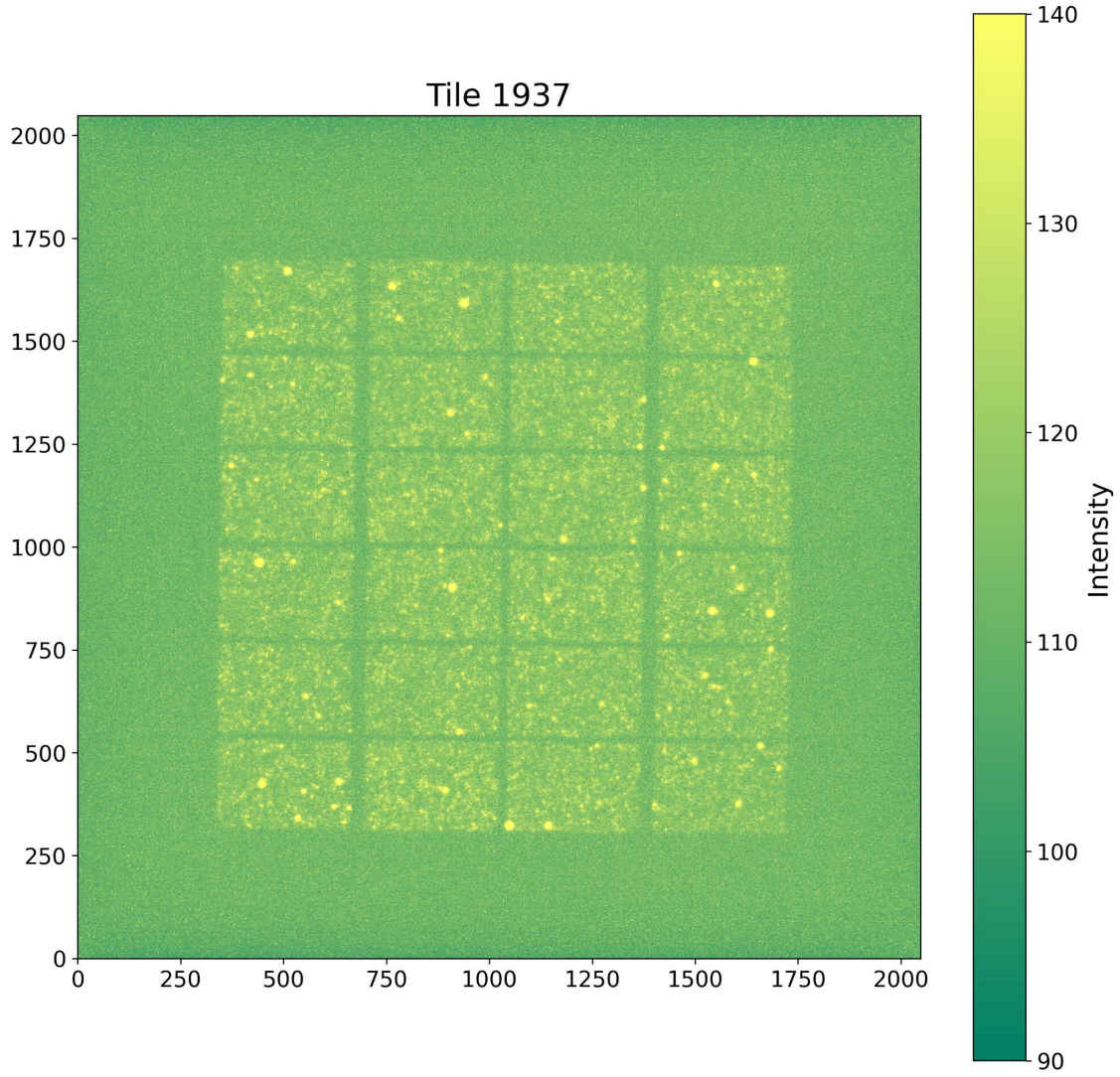
We conclude the RMS of the baseline is not a good estimator for the light leaks since there are only a few events of PCR

More analysis needs to be done and new observables have to be defined to be able to identify light leaks





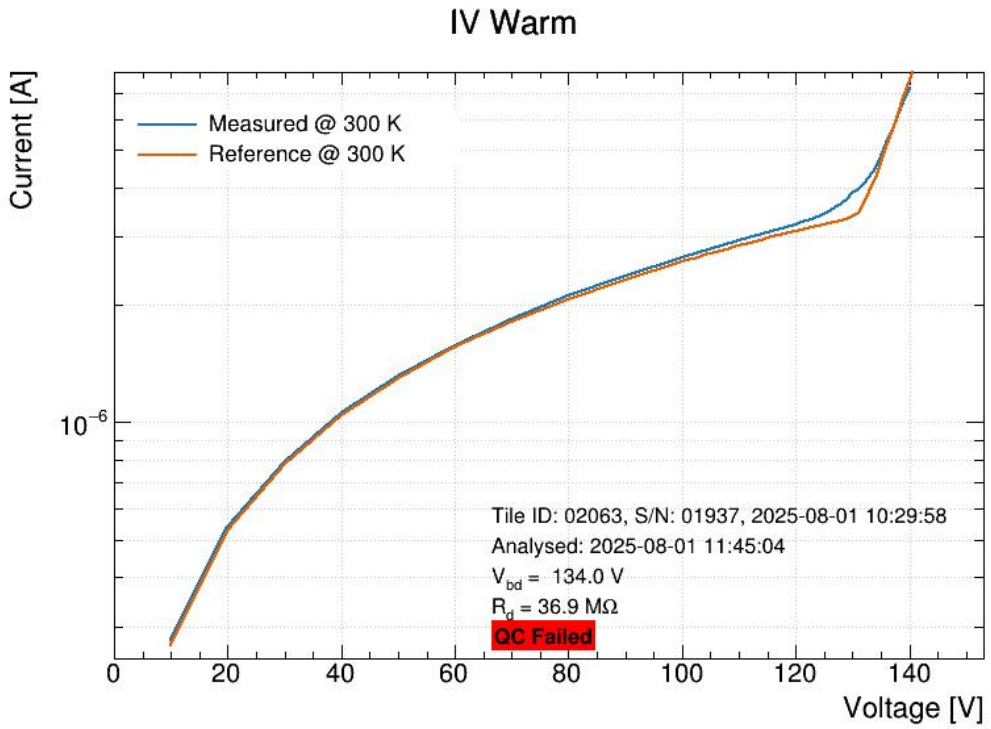
Tile testing



Tile #1937

- CMOS image doesn’t show any damaged SiPM
- You can recognise bad SiPMs because they appear darker

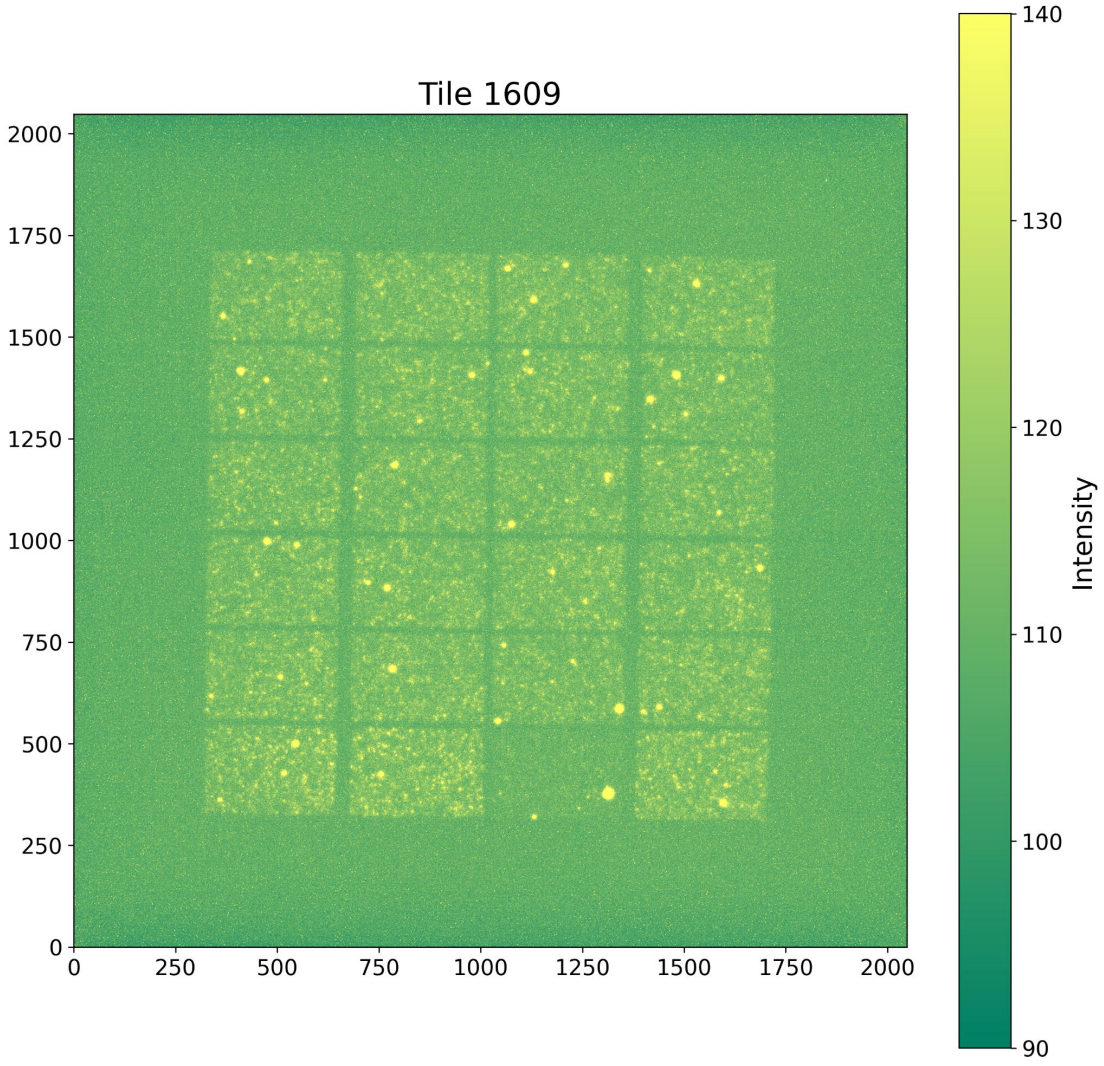
Tile testing



Even though from the CMOS image it seems that no SiPM is damaged, the IV Warm test failed because the measured breakdown voltage (blue line) is lower than the theoretical value (orange line, 132 V)

The other plots such as Noise Spectrum, Pulse Counting at 144V and 136V, and PCR curve are good.

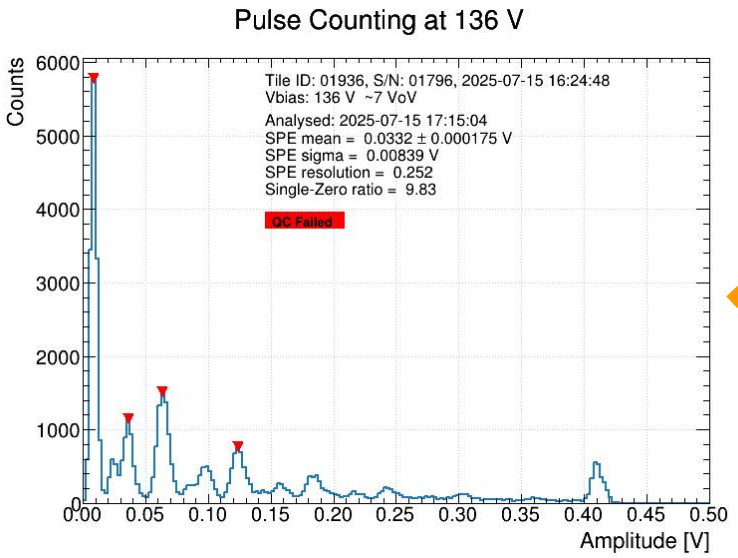
Tile testing



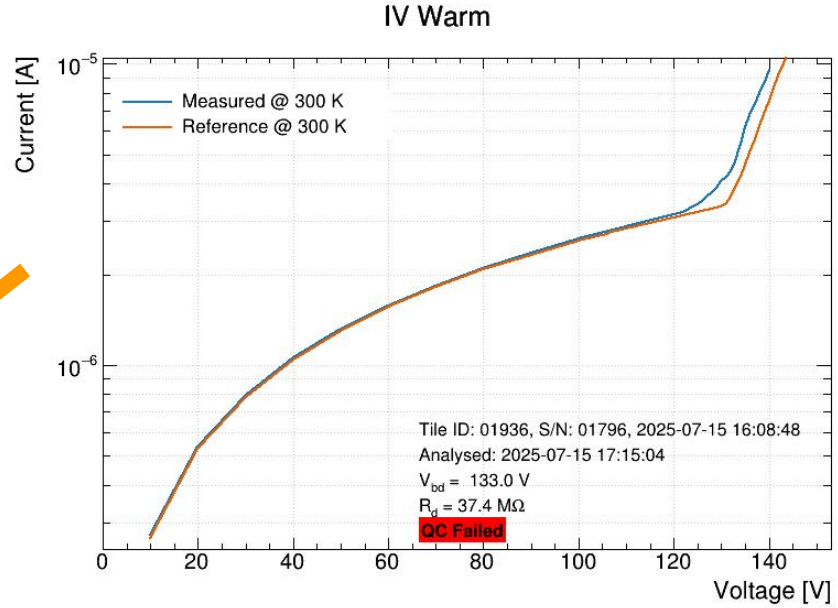
Tile #1609

- The 3rd SiPM of the last raw is darker so it is damaged

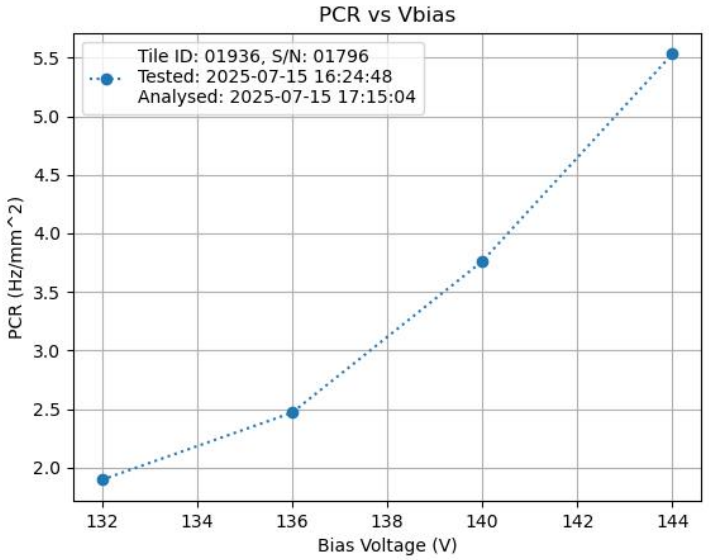
Tile testing



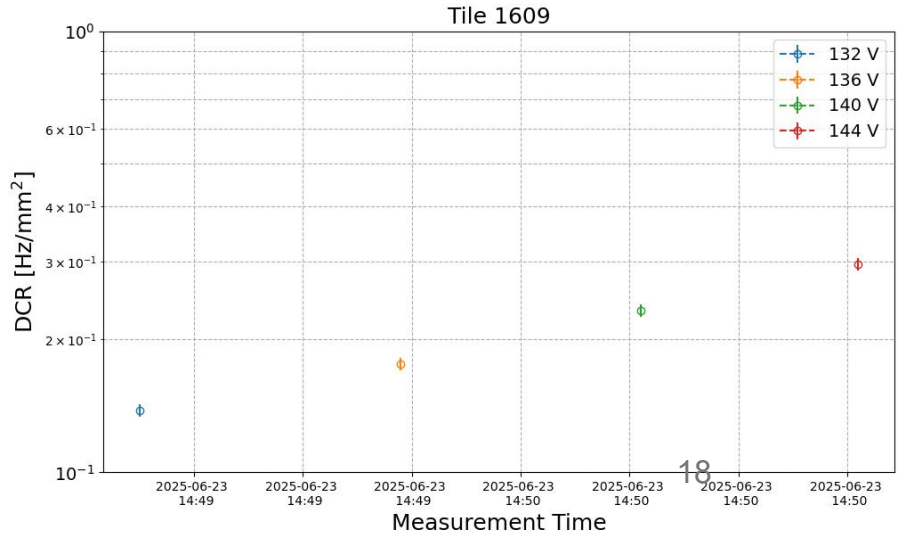
The Pulse Counting test failed because, as you can see, this is not a proper finger plot.



Regarding the IV Warm test, the measured breakdown voltage is lower than the theoretical value.

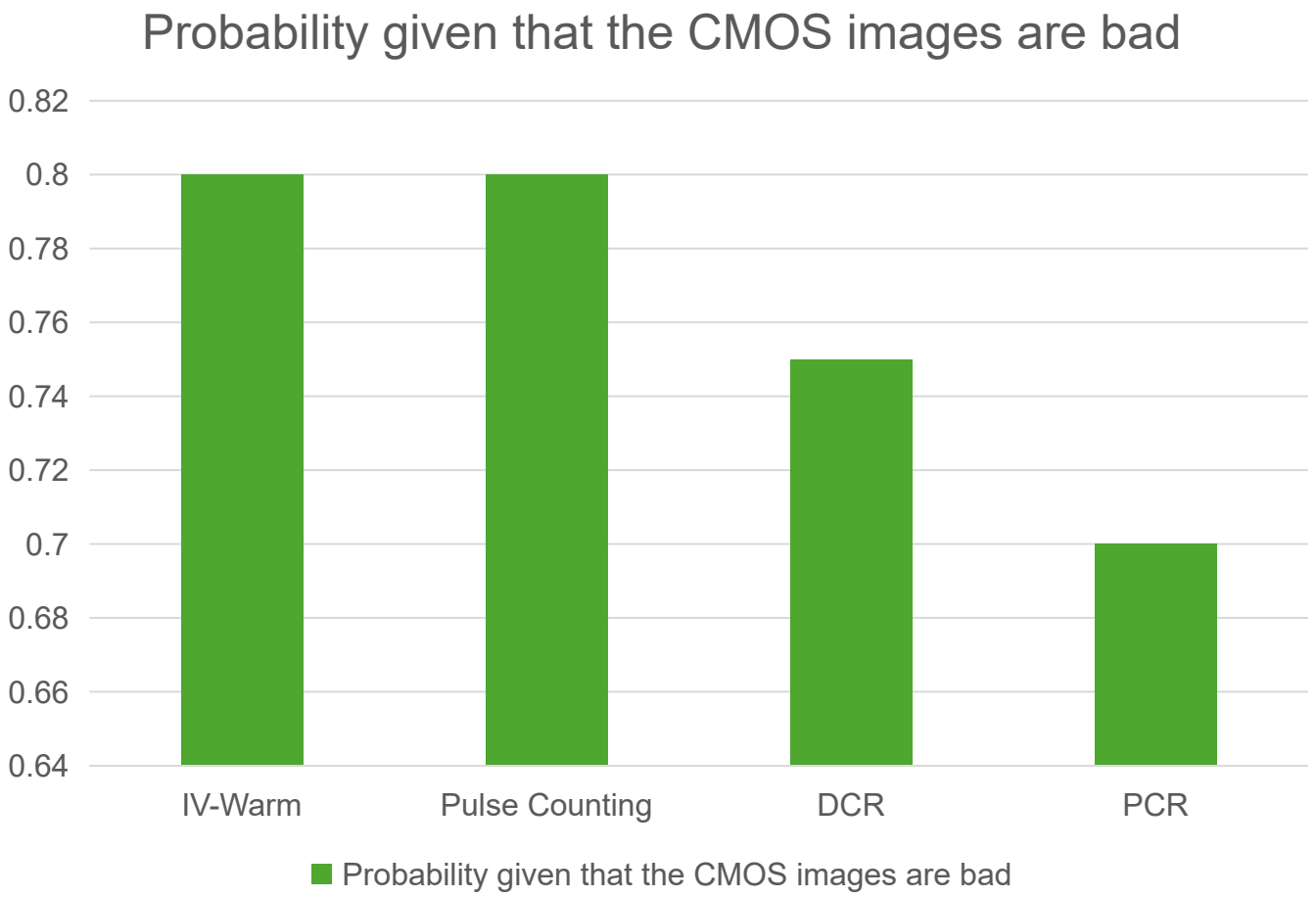


The maximum PCR value at 136V must be 0.3 while in our case it is 2.5



The maximum DCR value at 136V must be 0.1 while in our case it is 0.18

What we observed



What we found out

- Bad CMOS result is correlated with IV test failure, Pulse Counting test failure, high DCR and PCR values but this correlation is not conclusive, meaning we cannot tell which specific test failure will happen if the CMOS images show damaged SiPMs but we know that there will be at least a failure.

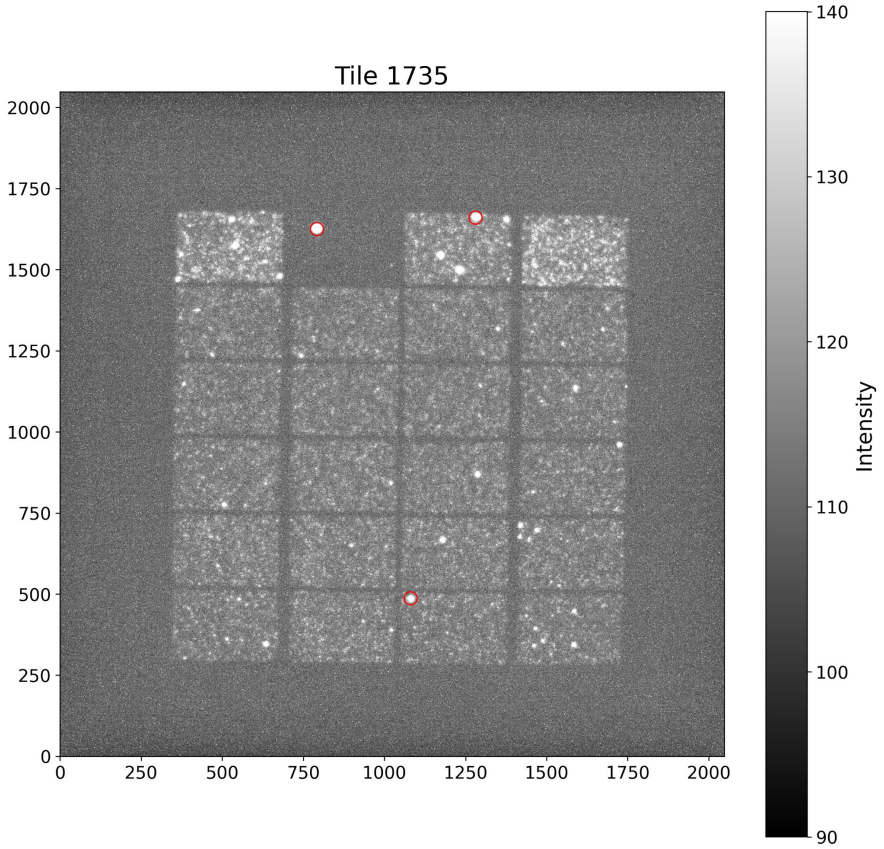
- In most cases the Noise Spectrum was good. Any problem with this kind of test is usually correlated to electronics.

- It is important to keep in mind that our sample space had few data points (particularly for the DCR values) so this results are not too conclusive.

- Additionally, as we observed for the tile #1937, sometimes the CMOS images are fine but the DCR and PCR values are too high or too low and the IV and Pulse Counting tests fail so we can conclude that CMOS images are not a reliable indicators of any bad results.

CMOS pictures analysis

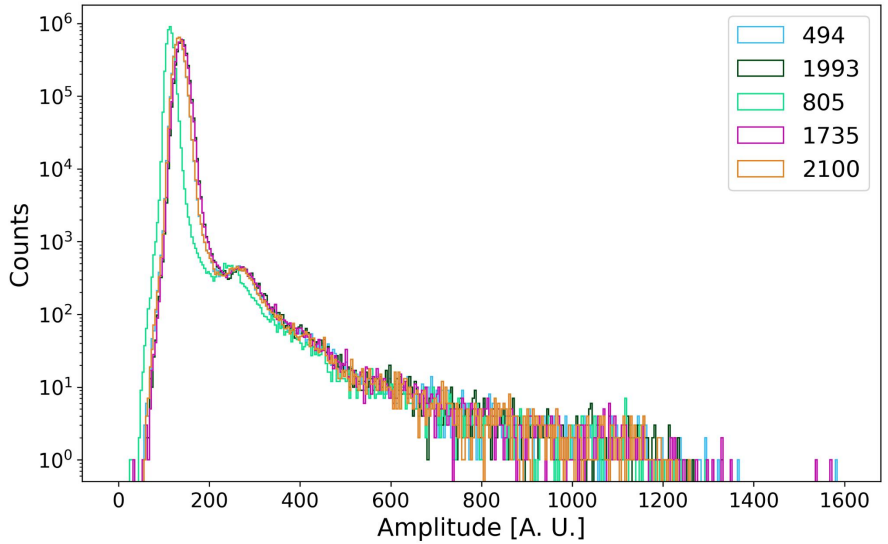
We also investigated the possibility of a more quantitative and systematic approach, analysing the pixel matrix of the CMOS images.



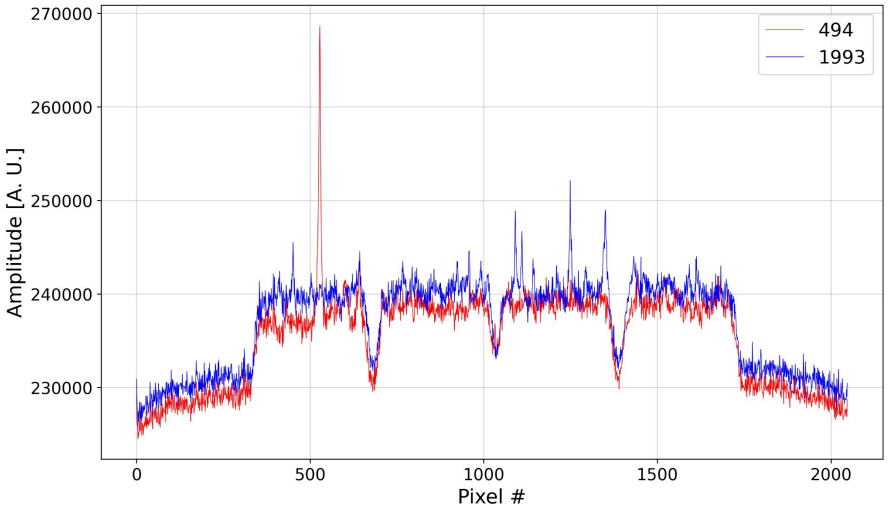
Example of peak finding algorithm applied on a damaged tile:

- a precise tuning would be required to obtain a reliable technique
- from rough analysis no dependence of DCR with respect to number and intensity of peaks has been found
- ML techniques could help, but training data would be required

CMOS pictures analysis



Amplitude distributions do not provide any separation

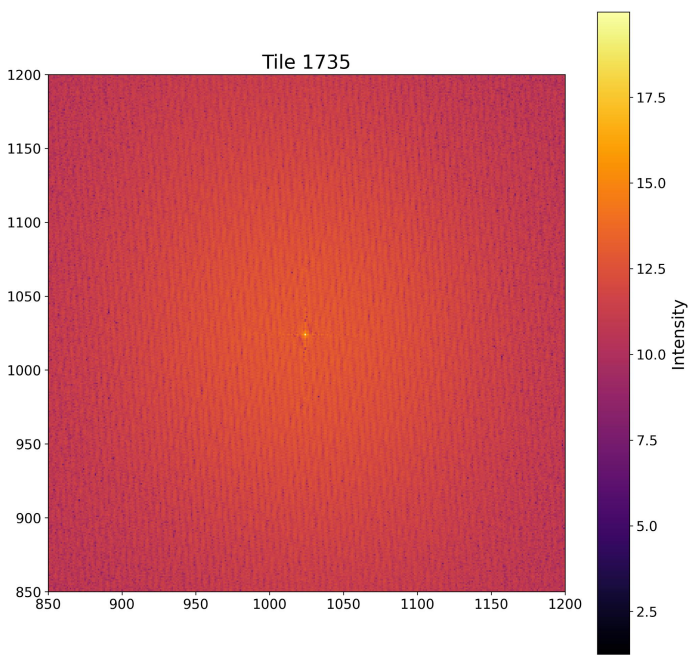


1D projections sometimes spot hidden spikes but they are not predictive on the DCR:

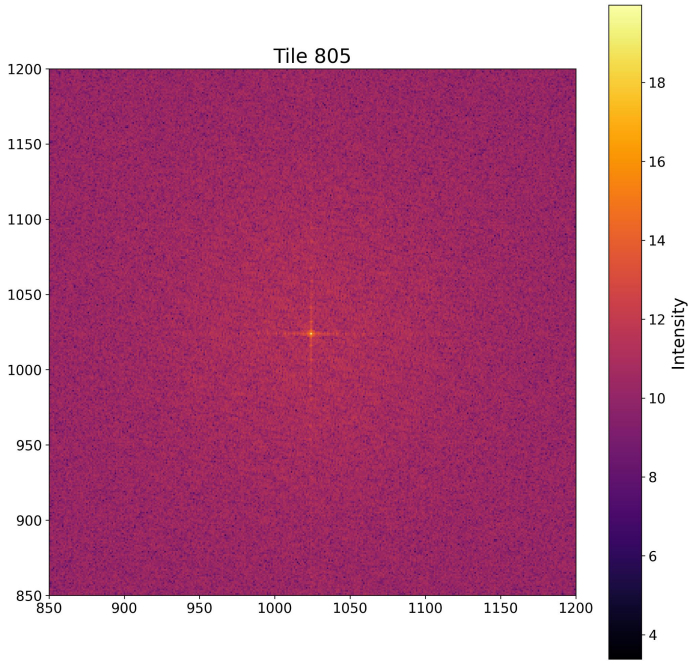
- 494 has low DCR
- 1993 has high DCR

CMOS pictures analysis

A spatial Fourier analysis has also been attempted



low DCR tile



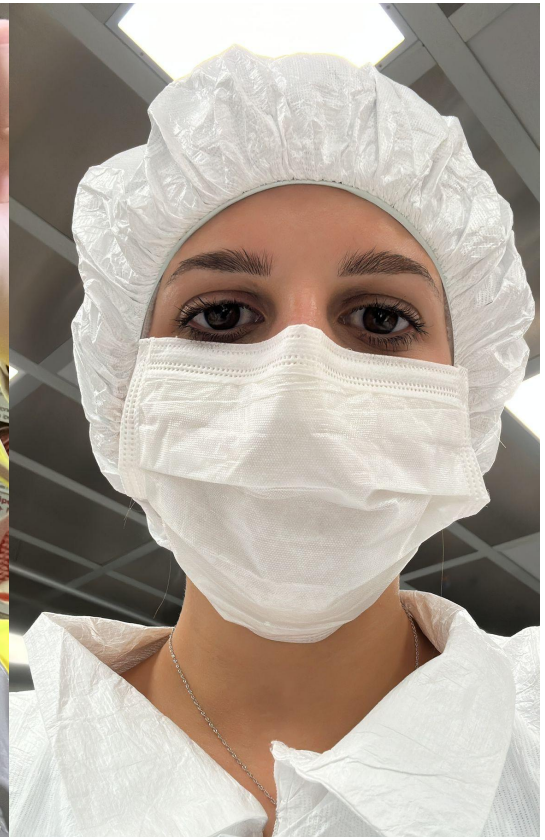
high DCR tile

- Some differences are visible in Fourier space
- Whether this can have an application is an open question

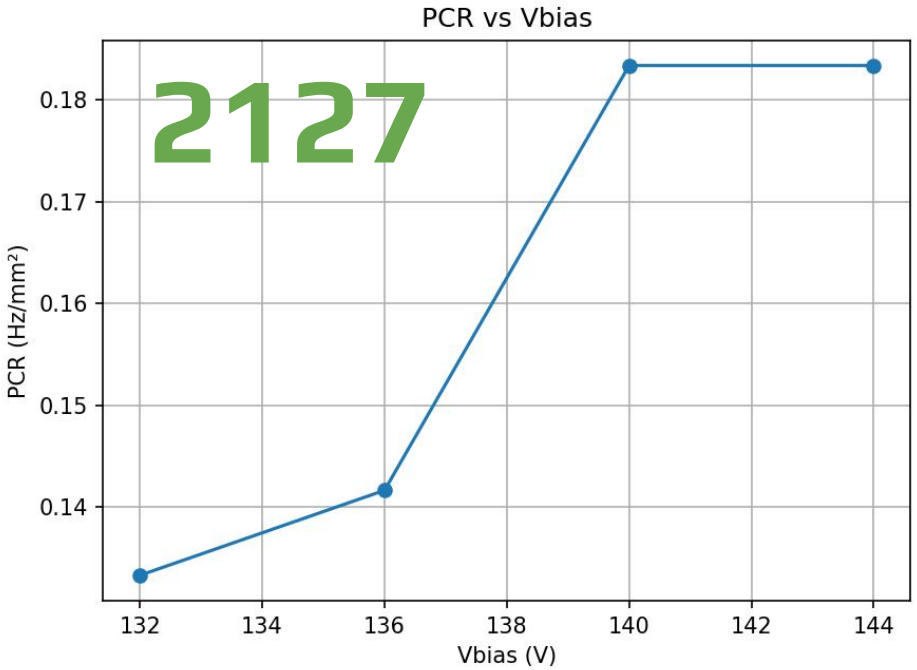
Conclusions: What we have done

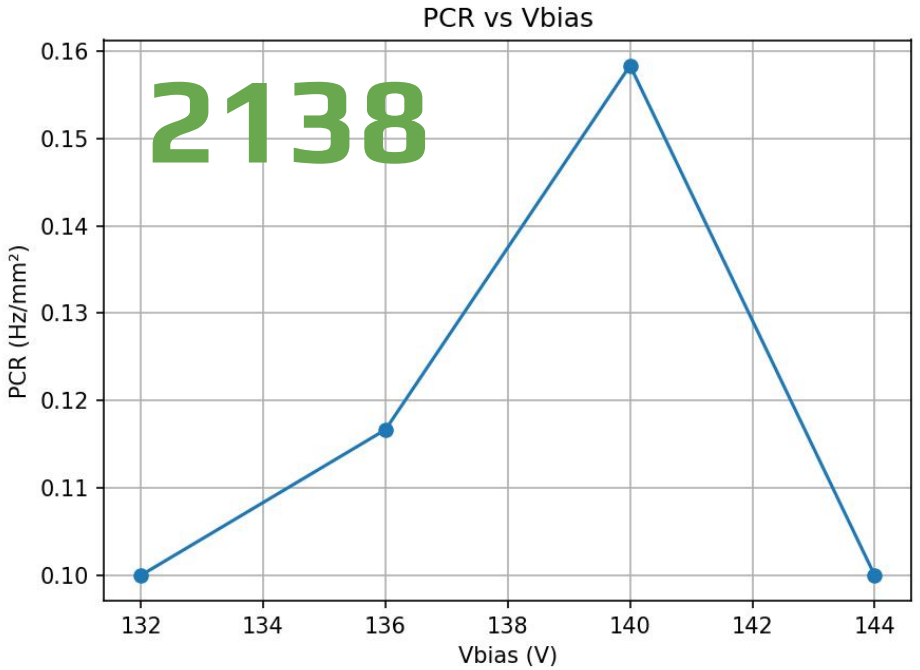
- Familiarize ourselves with procedures of tile quality testing.
- Develop a waveform-level analysis to estimate the PCR and checked different observables to identify light leaks.
- Discover if a correlation between CMOS results and other tests exists.
- Be able to predict which specific type of failure will happen based on the CMOS images.
- Find a more quantitative way to study CMOS results.

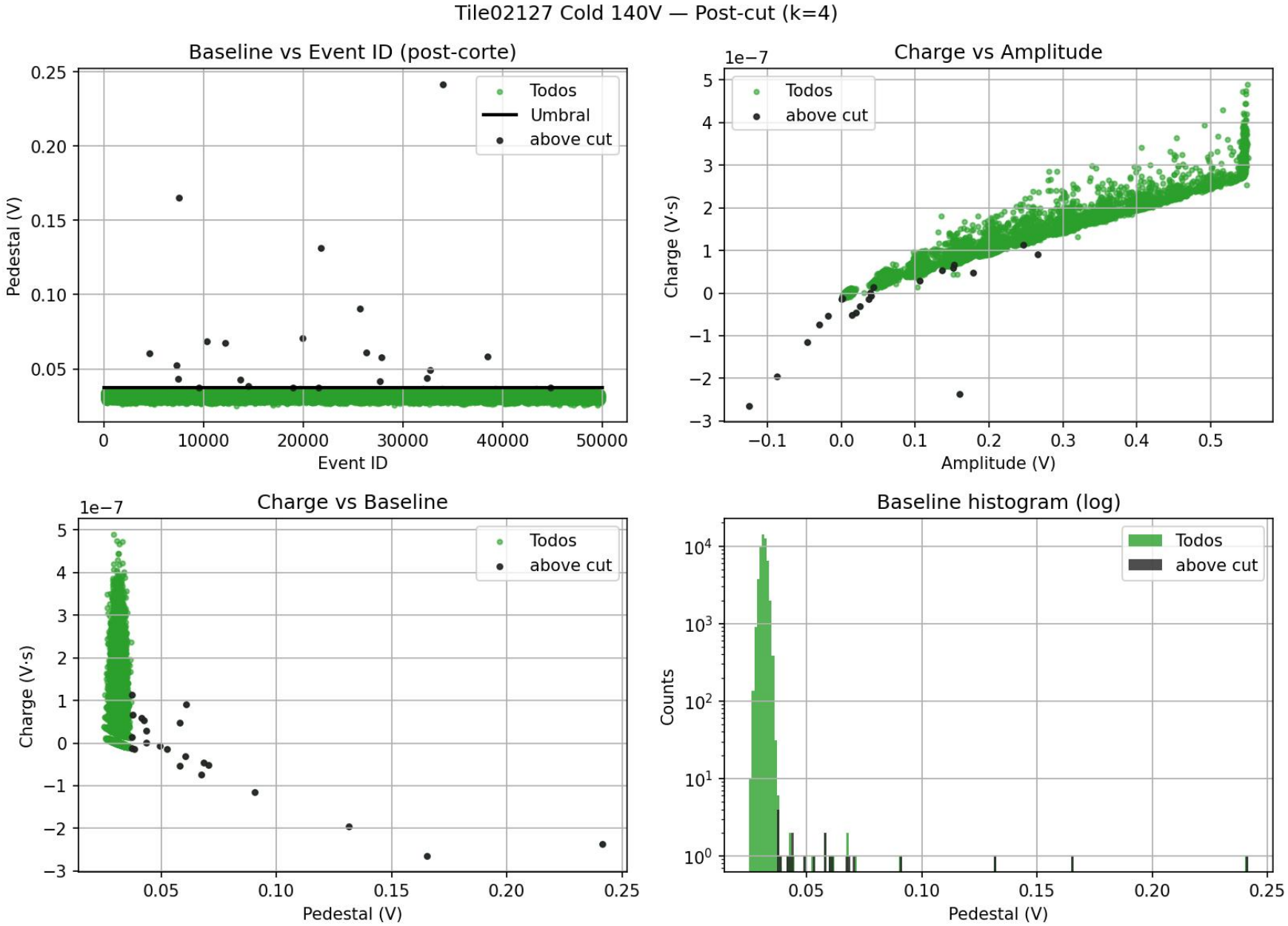
Thanks for listening!

Good PCR tiles show values <0.3 Hz/mm^2






Tile02127 Cold 140V — Post-cut (k=4)
Baseline vs Event ID (post-corte)
Pedestal (V)
Event ID
Todos
Umbral
above cut
Charge vs Amplitude
1e−7
Charge (V·s)
Amplitude (V)
Todos
above cut
Charge vs Baseline
1e−7
Charge (V·s)
Pedestal (V)
Todos
above cut
Baseline histogram (log)
Counts
Pedestal (V)
Todos
above cut