Cryogenic Readout Electronics for a MPPC Based Array Operating at Liquid Xenon Temperature

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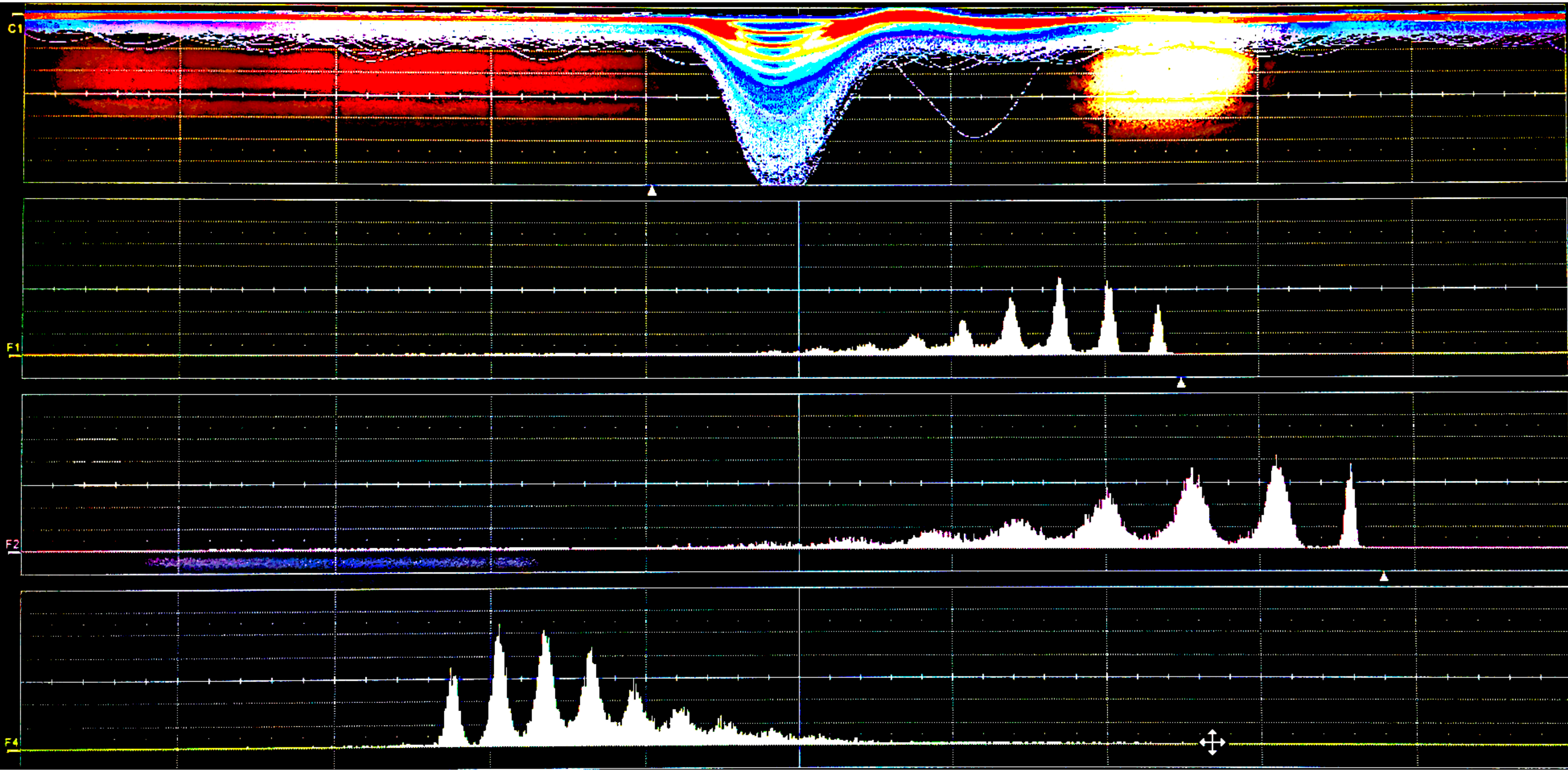
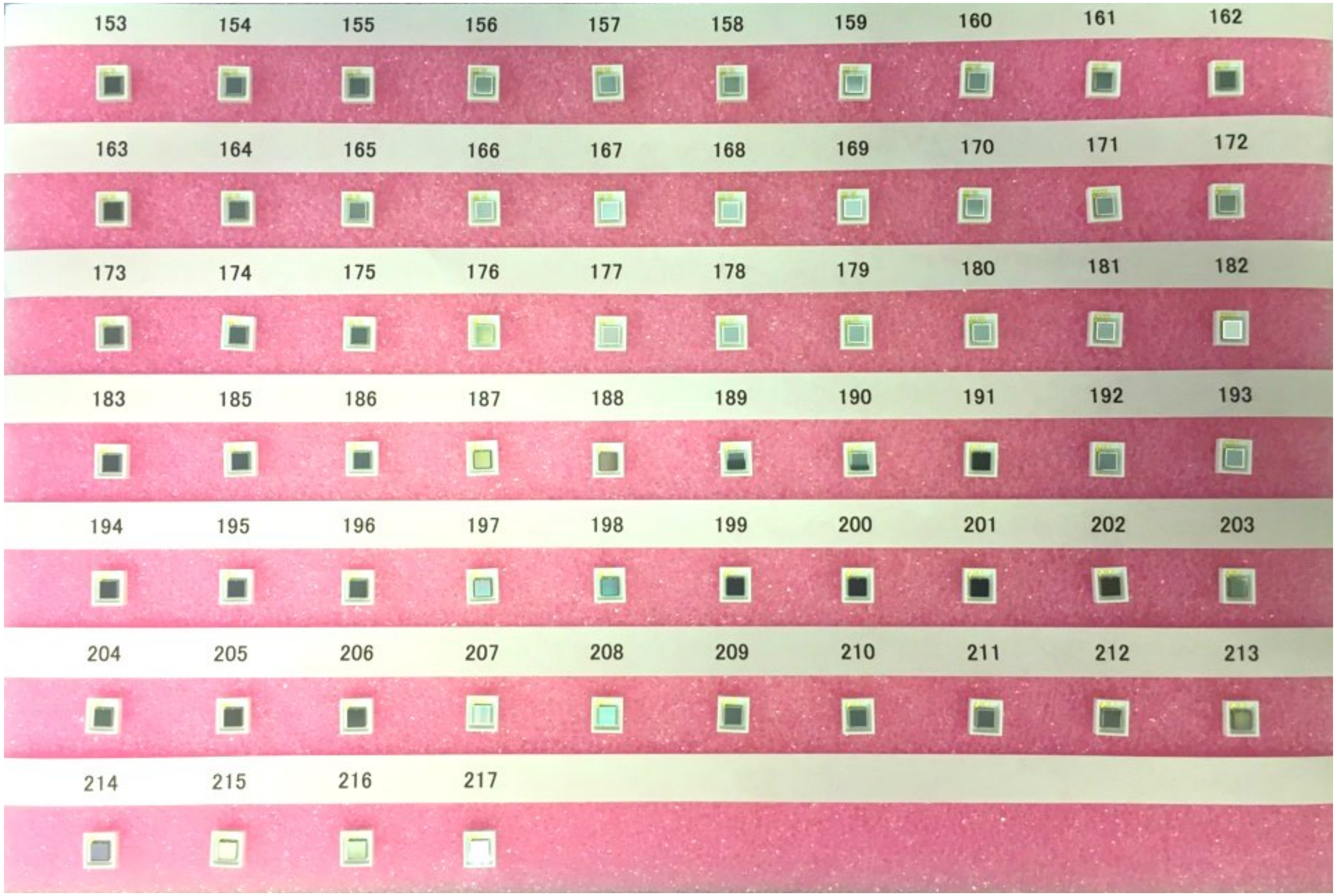


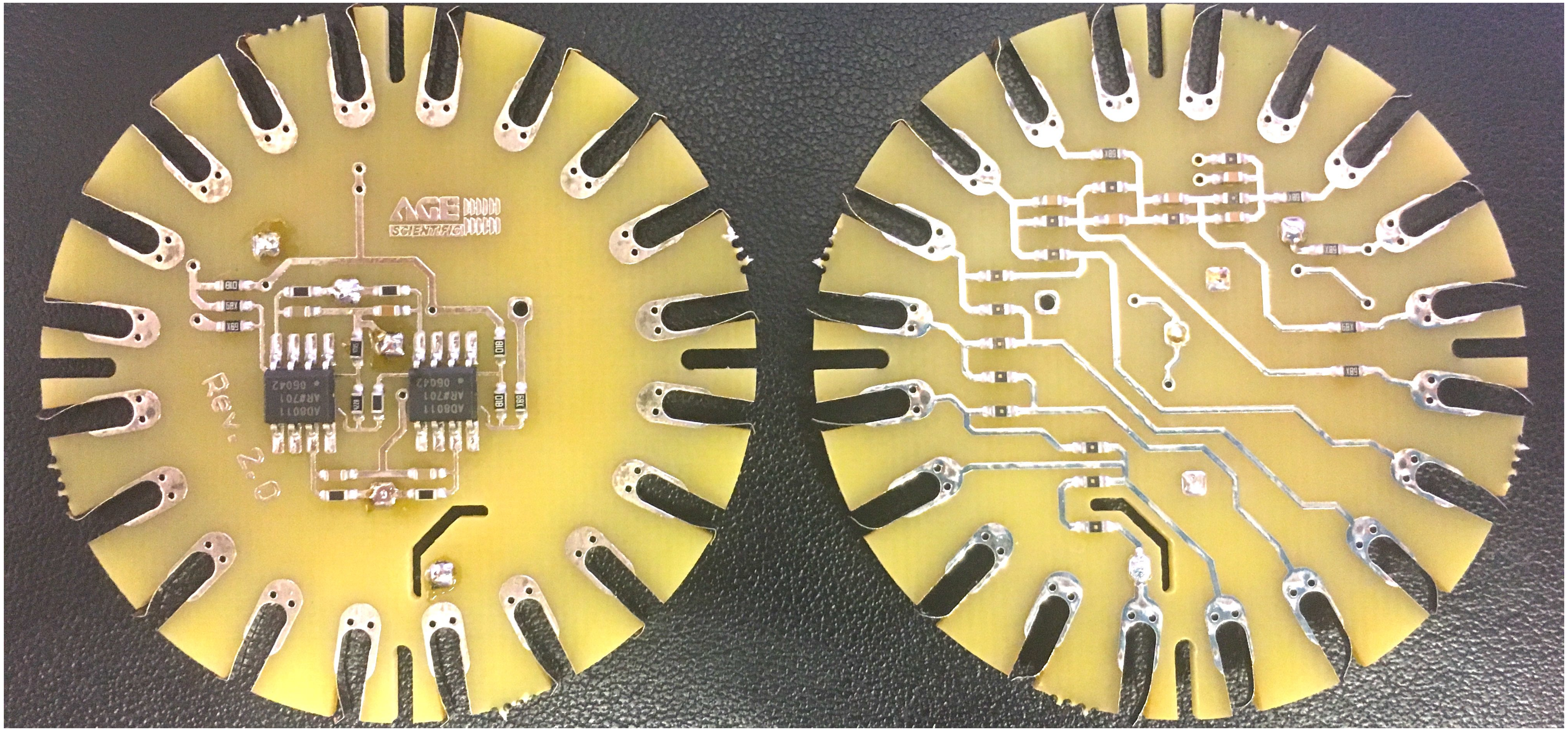
Adriano Di Giovanni, ICASiPM - June 11-15, 2018 - Schwetzingen, Germany

Goals



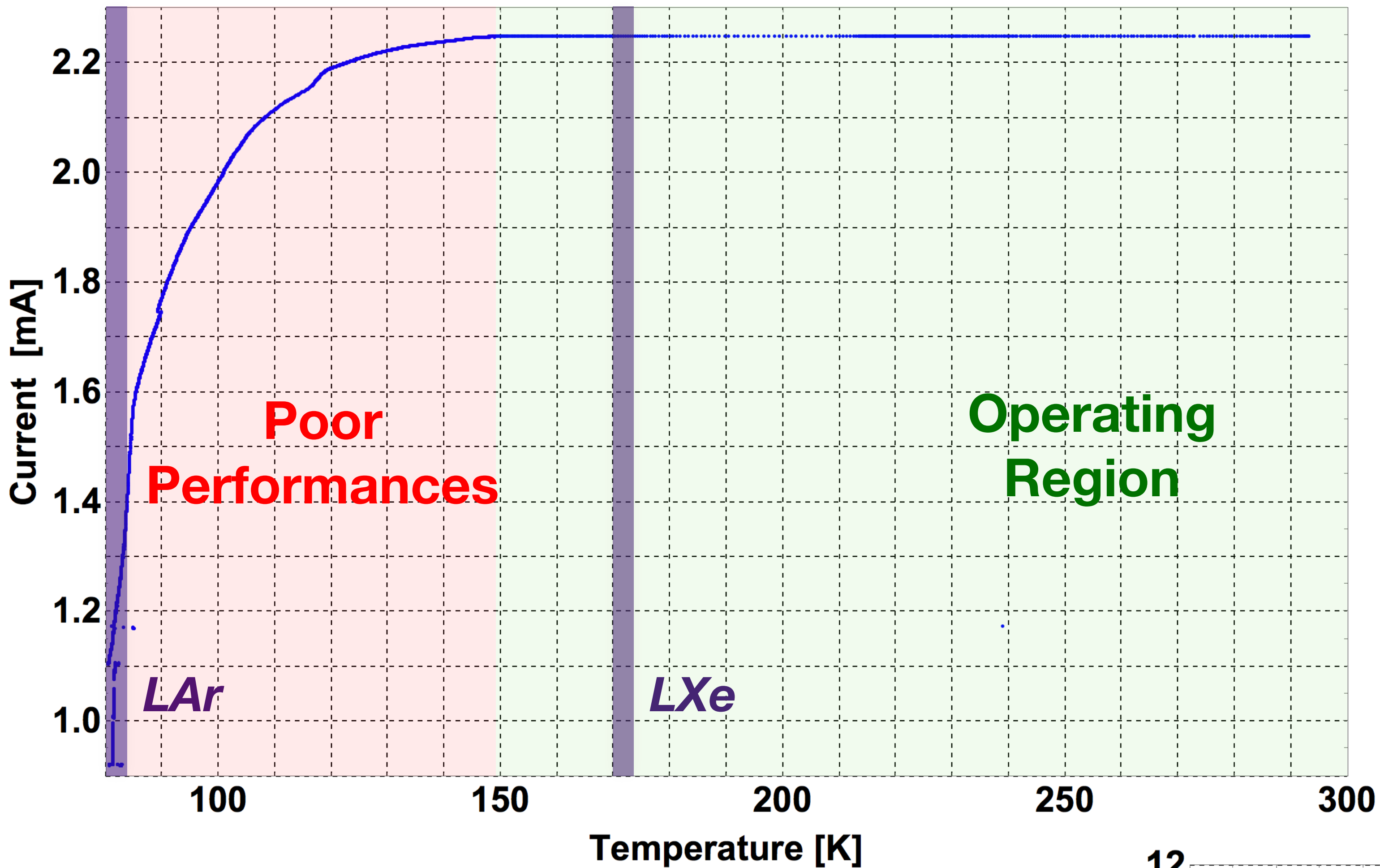
- Realization of a low power cryogenic electronics operable at 175 K for the readout of **VUV sensitive MPPCs** (S13370-3050CN, a.k.a. **VUV4**).
- Selection of a commercial operational amplifier working in cryo-environment.
- Optimize the maximum numbers of MPPCs that can be readout as a single channel.
- Provide a design allowing for gain equalization in real time.
- Dark Matter experiments look for **single photon detection capability.**
- **Background is a concern (mass, cables, components, materials)**

An amplifier for VUV Hamamatsu R11410 PMT operating in cryogenic environment



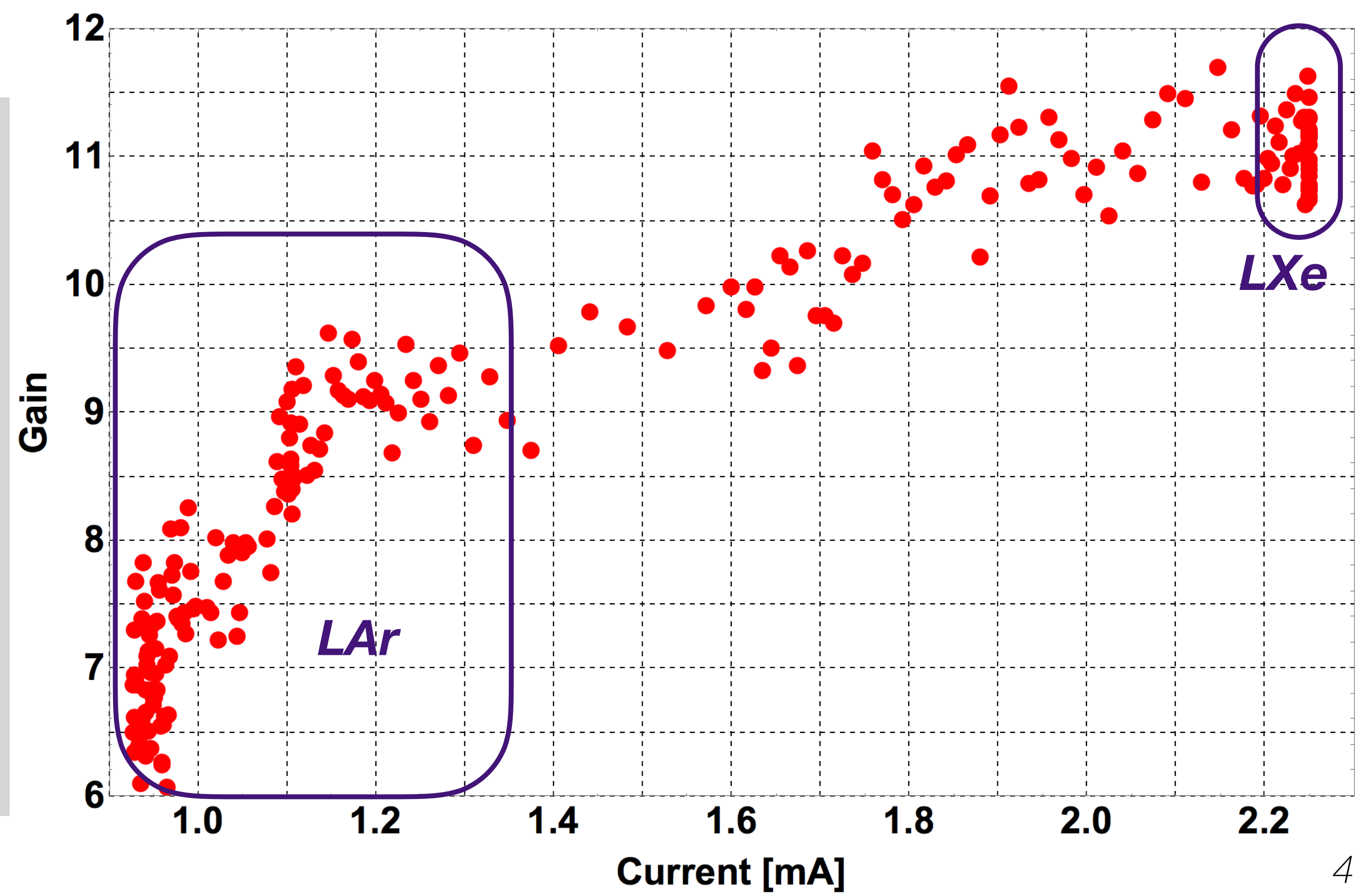
- ~ 80 MHz Bandwidth (Rise time: Input signal <4 ns, Output signal ~12 ns)
- IN/OUT impedance 50 Ohm
- 2X **AD8011** operational amplifiers (**± 5V, can be “unbalanced” to match the dynamics**)
- Low Noise (< **200 μV RMS @ 5X amplification**)
- Designed for **0.5 X & (5 X to 15 X)** dedicated outputs
- Power consumption: Min 6 mW, Max 20 mW (amplification unaffected, only dynamic range)
- **Background is a concern: radioactivity screening is required**

Performances of AD8011 in cold environments



The amplifier (along with the integrated voltage divider) was designed to operate with an Hamamatsu R11410 PMT.

- Below 150 K, the current drain starts dropping (figure above).
- For currents < ~2.0 mA (@ ±5 V) the gain is affected (figure on the right).
- The **AD8011** can be used **at liquid xenon temperature**, while **at liquid argon temperature** becomes inadequate due to gain decrease and instability.

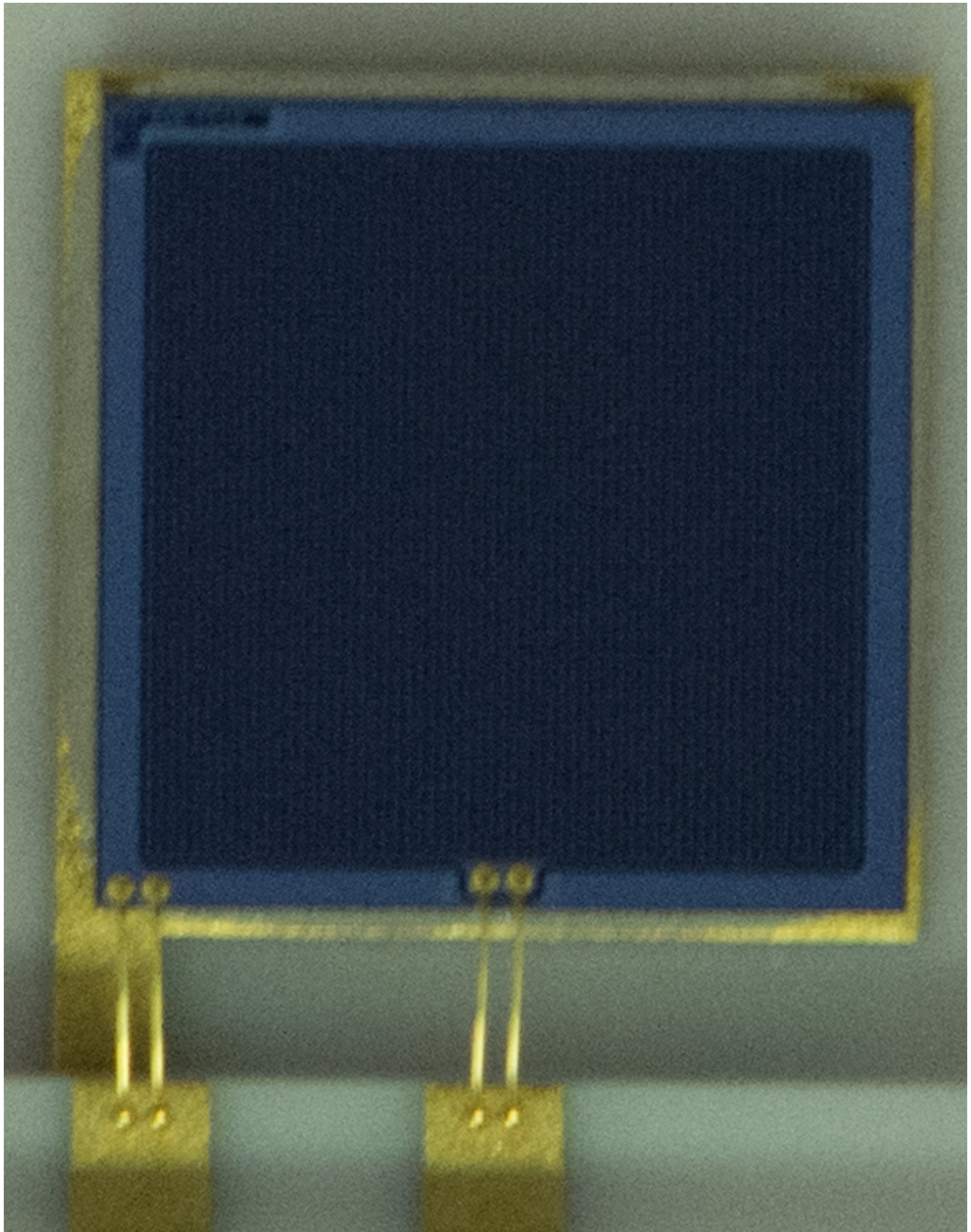


Radioactivity screening of AD8011

Radio Nuclide	Activity [mBq/kg]	Concentration [10^{-9}g/g]	Activity [µBq/pc]	Activity SMD* [mBq/kg]
Ra-228	<39	<9.6	< 2.9	280 ± 40
Th-228	(60 ± 20)	(15 ± 4)	(5 ± 1)	290 ± 30
Ra-226	(50 ± 20)	(4 ± 2)	(4 ± 1)	810 ± 40
Th-234	(1.0 ± 0.5)X10^3	(80 ± 40)	(70 ± 40)	(4.9 ± 0.7)X10^3
Pa-234m	<1,400	<110	< 100	(4.1 ±1.1)X10^4
U-235	<50	<88	< 3.7	240 ± 80
K-40	<700	<2.3 X 10^4	< 51	(1.2 ± 0.2)X10^3
Cs-137	<3.3	-	< 0.24	<7.4
Co-60	<3.4	-	< 2.5	<5.8

*SMD RESISTOR RMCF0805JT15M0

S13370-3050CN = VUV4 MPPC family by Hamamatsu



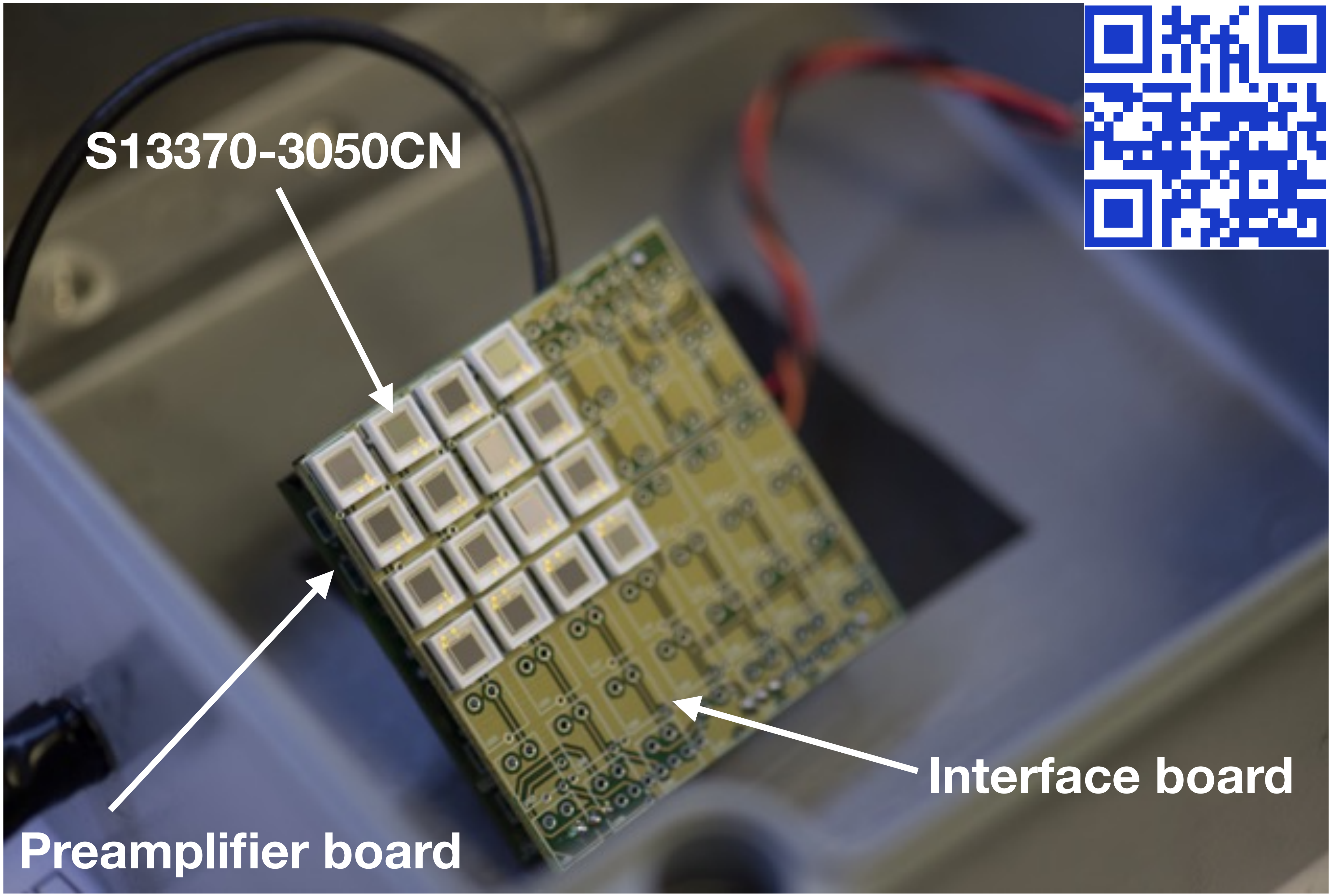
PROS:

- Sensitive to LXe-LAr scintillation light
- P.D.E. (@ 178 nm) ~ 25%
- Intrinsic Single Photon Detection capability
- “Cold proof”
- Low Voltage operation (~56 V @ 298 K)
- Gain ~ standard PMT
- Magnetic Field Insensitive

CONS:

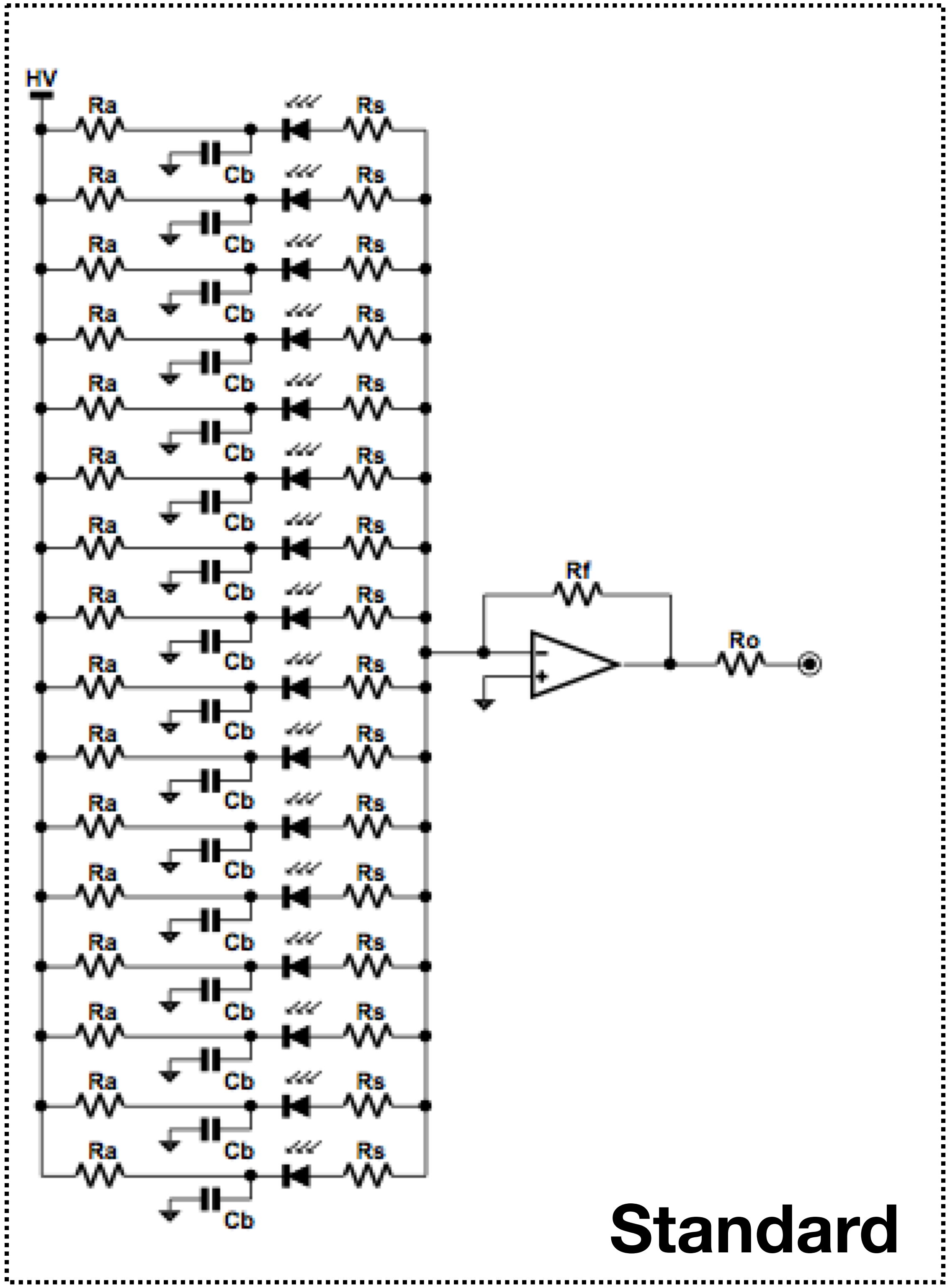
- Dark Counting Rate
- Cross Talk / Afterpulses
- Characteristics = f(Temperature)
- Size (usually < cm^2)
- “Large” Pixel Capacitance: fraction of pF
- ~ Naked: handle with care
- Grouping of many MPPCs is challenging
- Everything but cheap

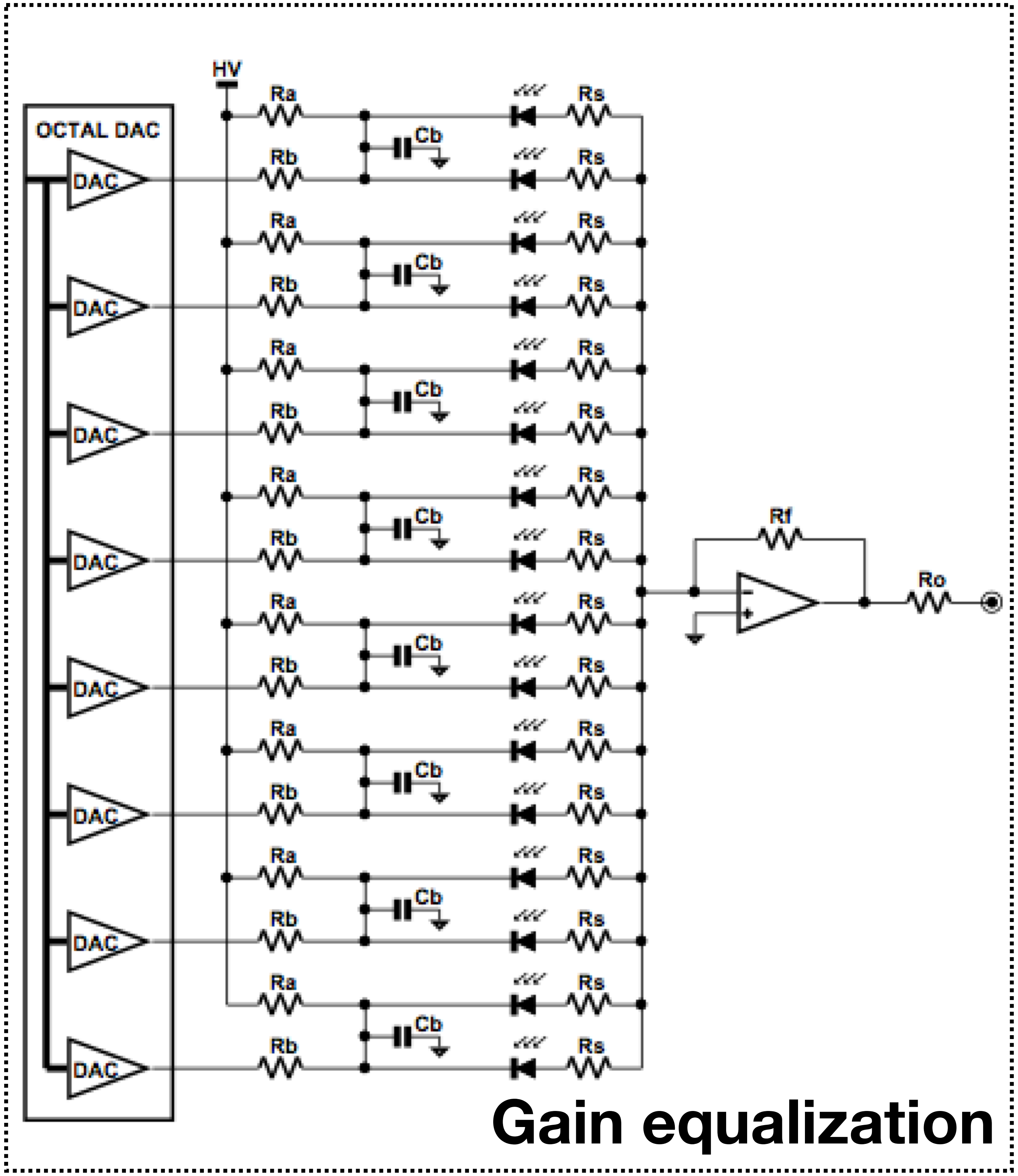
Adapting the AD8011 to a readout of a multiple MPPC array (16 devices reported here)



S13370-3050CN = VUV4 MPPC family manufactured by Hamamatsu

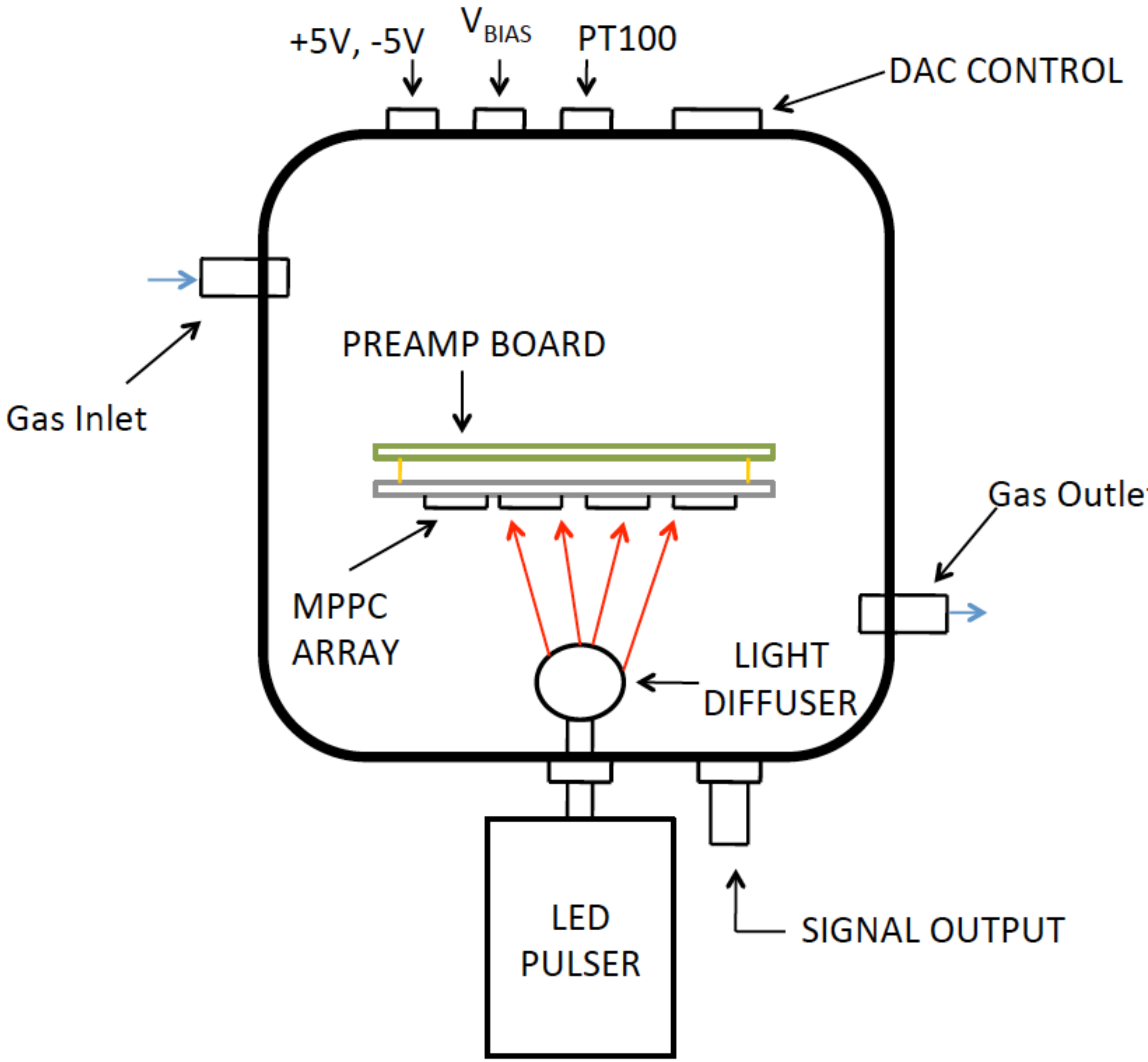
Schematics of 16-channels-electronics





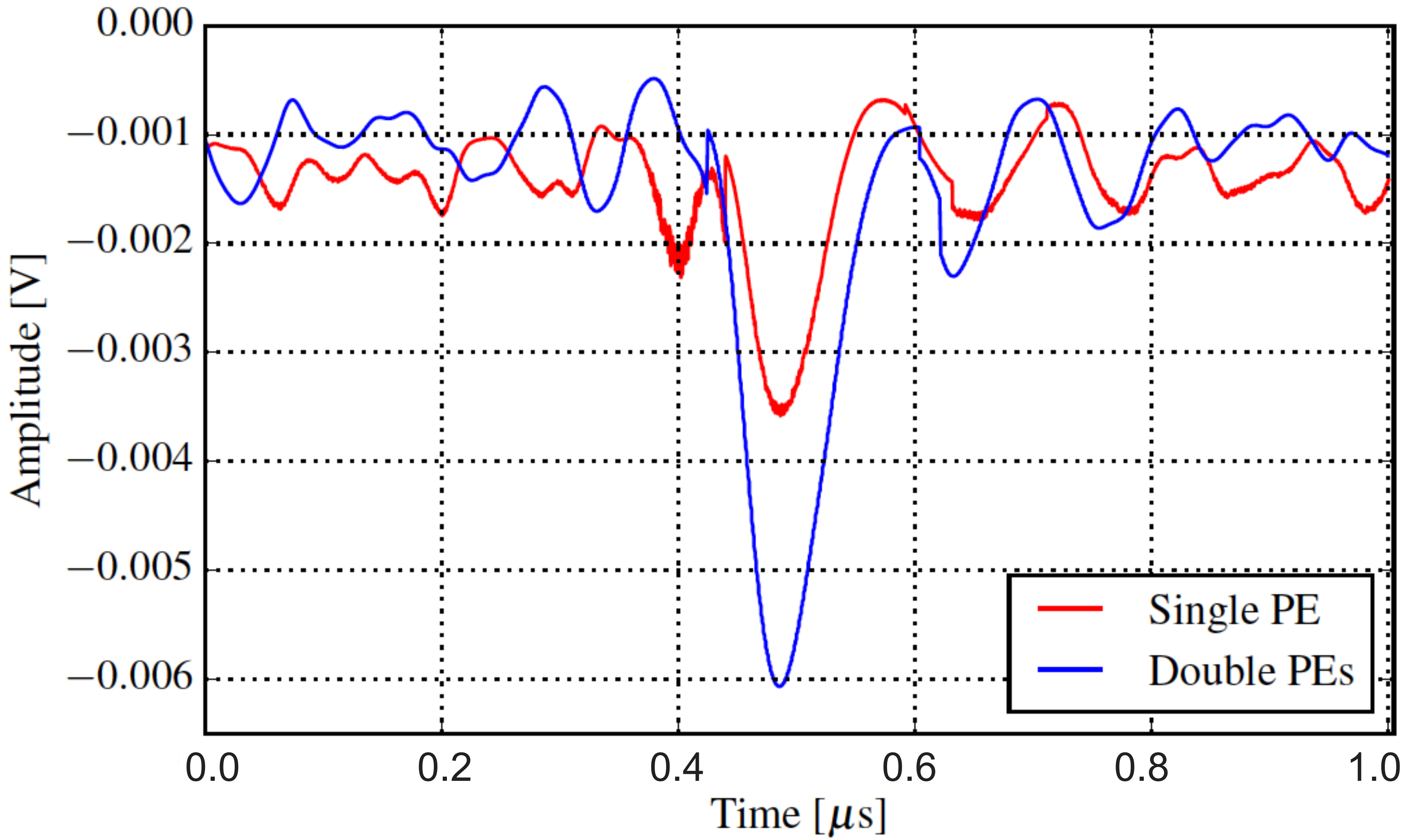
- This technique is effective only if the dark counting is small enough (~ sub-Hz)
- Noise contribution must be evaluated
- A similar "Standard" circuit was proposed by DarkSide: JINST 10 (2015) P08013

Experimental setup



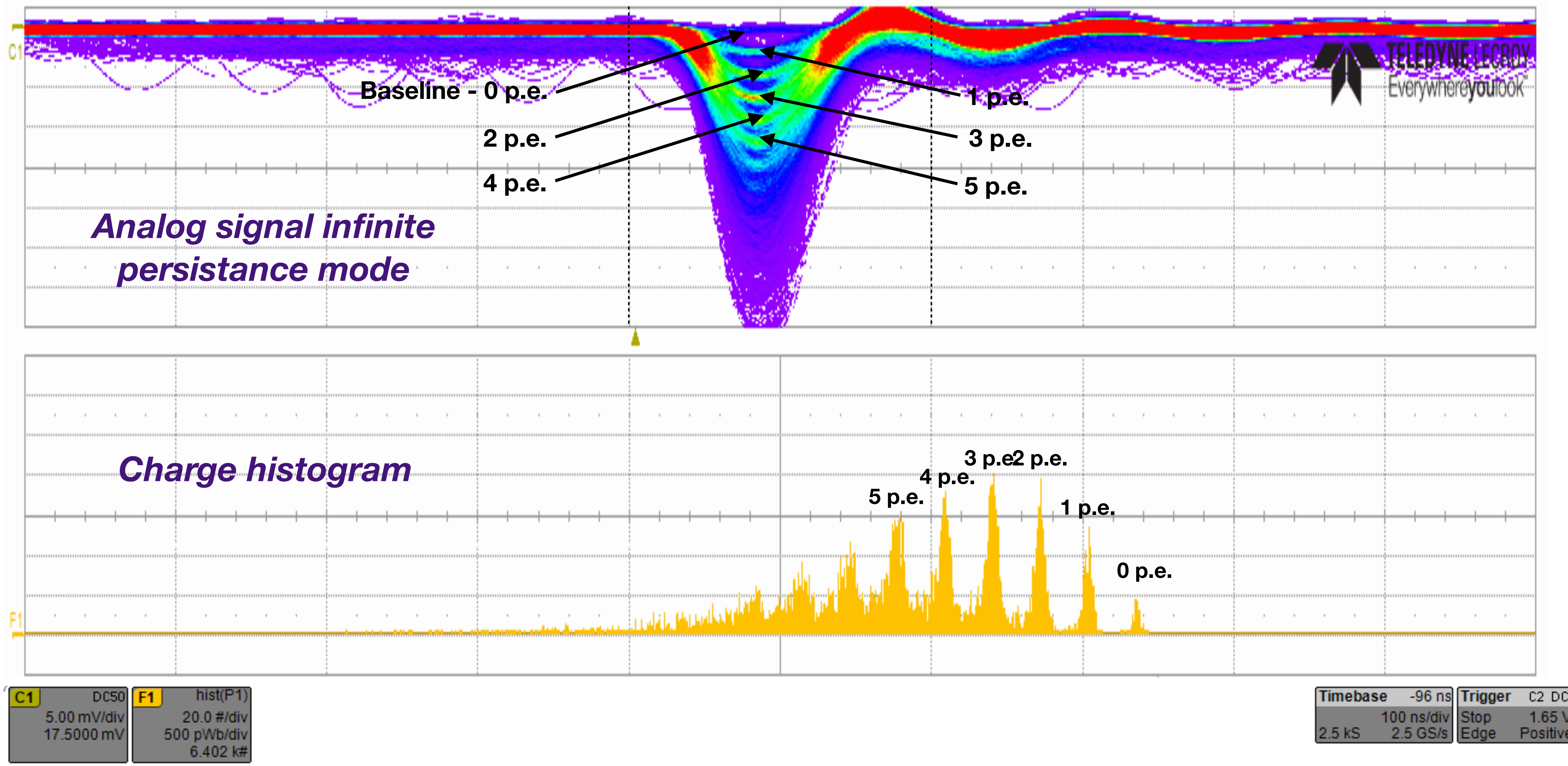
- Nitrogen in gas phase used to purge water vapor condensation at 175 K.
- The MPPC array has been operated at different over voltages and illuminated by a pulsed UV LED.

A glimpse to the waveforms



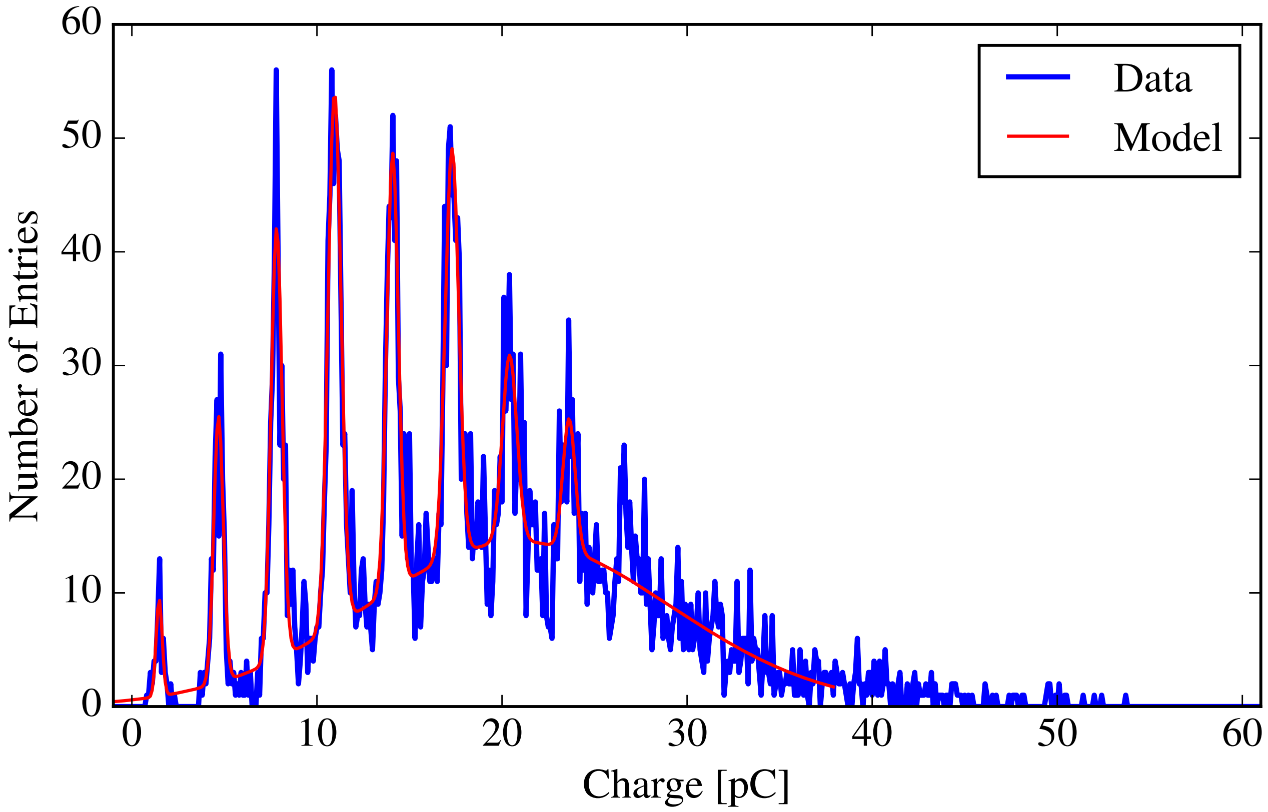
Typical waveforms corresponding to a single photon and to 2 photons taken at 175 K, 2 V of over-voltage (50 Ω termination).

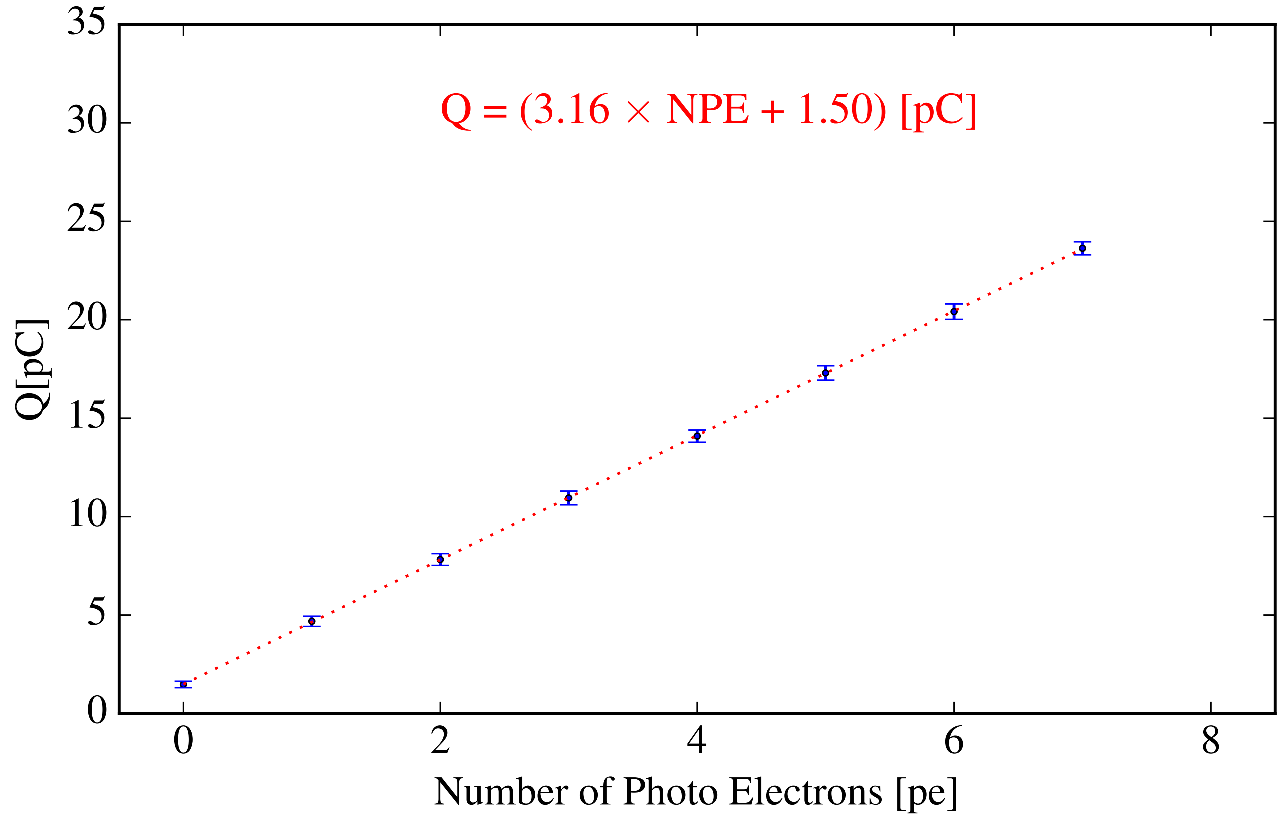
Single photon counting capability (“*low*” light intensity, @ 3 V of over voltage, 175 K)



- Data acquisition performed by Lecroy HDO6104.
- The DAC control for the biasing fine tuning not activated here.
- NO FILTER (hardware).
- No Y-axis increased resolution.
- NO offline FILTER (Optimum, Matched, …).
- Infinite persistance mode.

Single photon counting capability (“*low*” light intensity, @ 3 V of over voltage, 175 K)

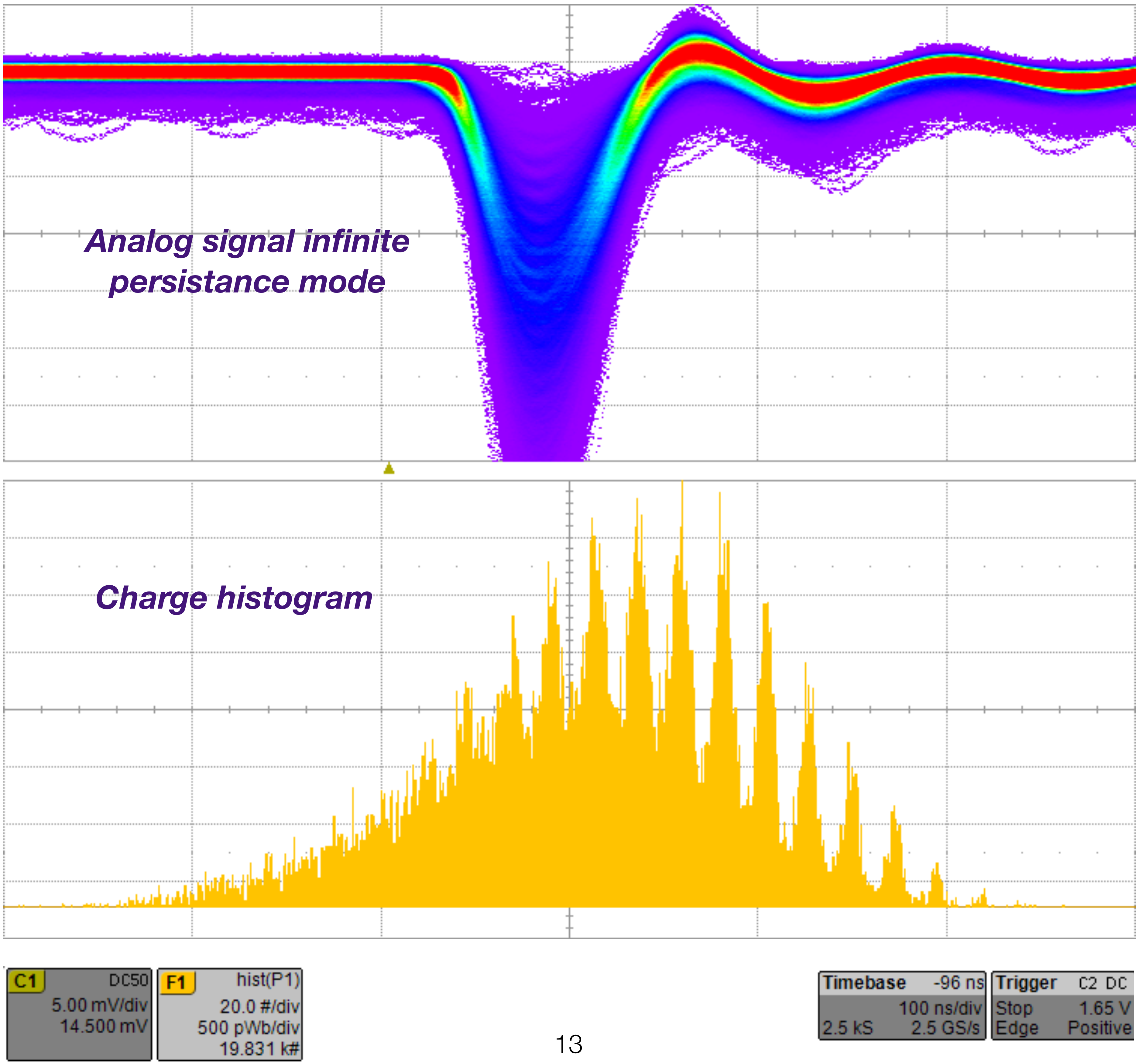




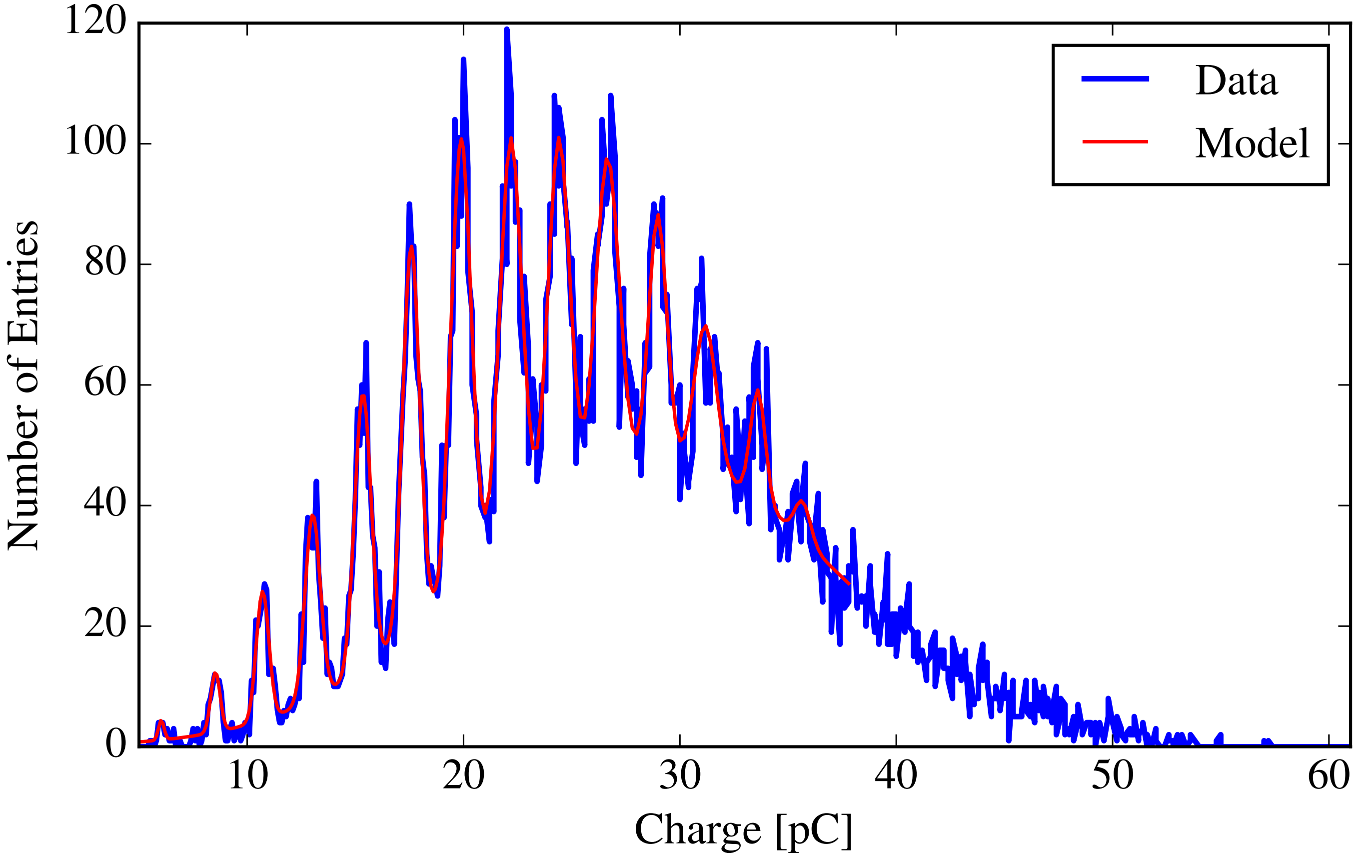
- 8 gaussian functions used to fit the charge distribution
- The gain of the array operating @ 3 V of over voltage, 175 K is ~ 2 x 10^7
- The charge of the 1 p.e. is (3.21 ± 0.26) pC
- The overall charge noise (pedestal) is (1.47 ± **0.16**) pC

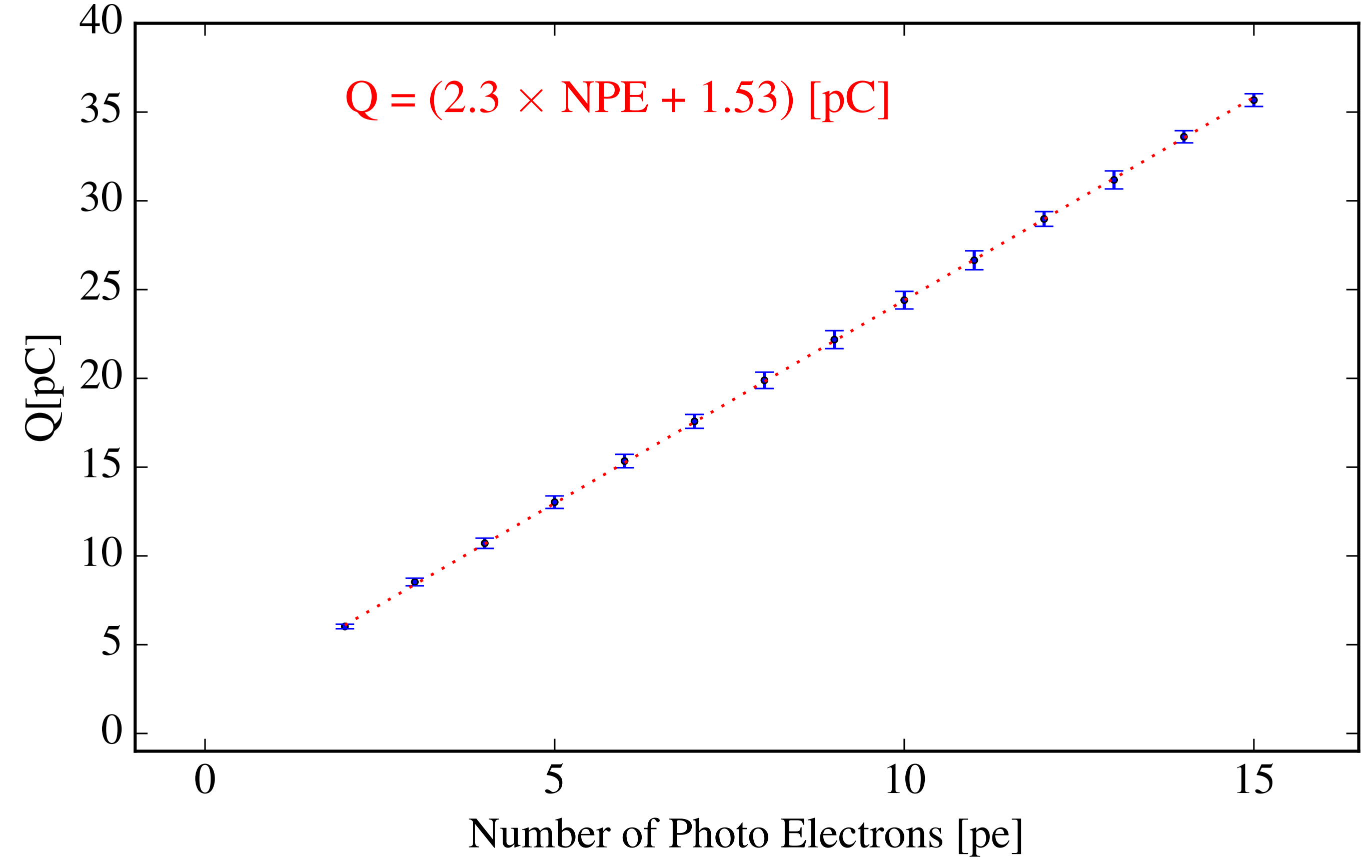
But still, more **MPPCs can be summed up preserving** the performance of the electronics

Single photon counting capability
(“*high*” light intensity, @ 2 V of over voltage, 175 K)



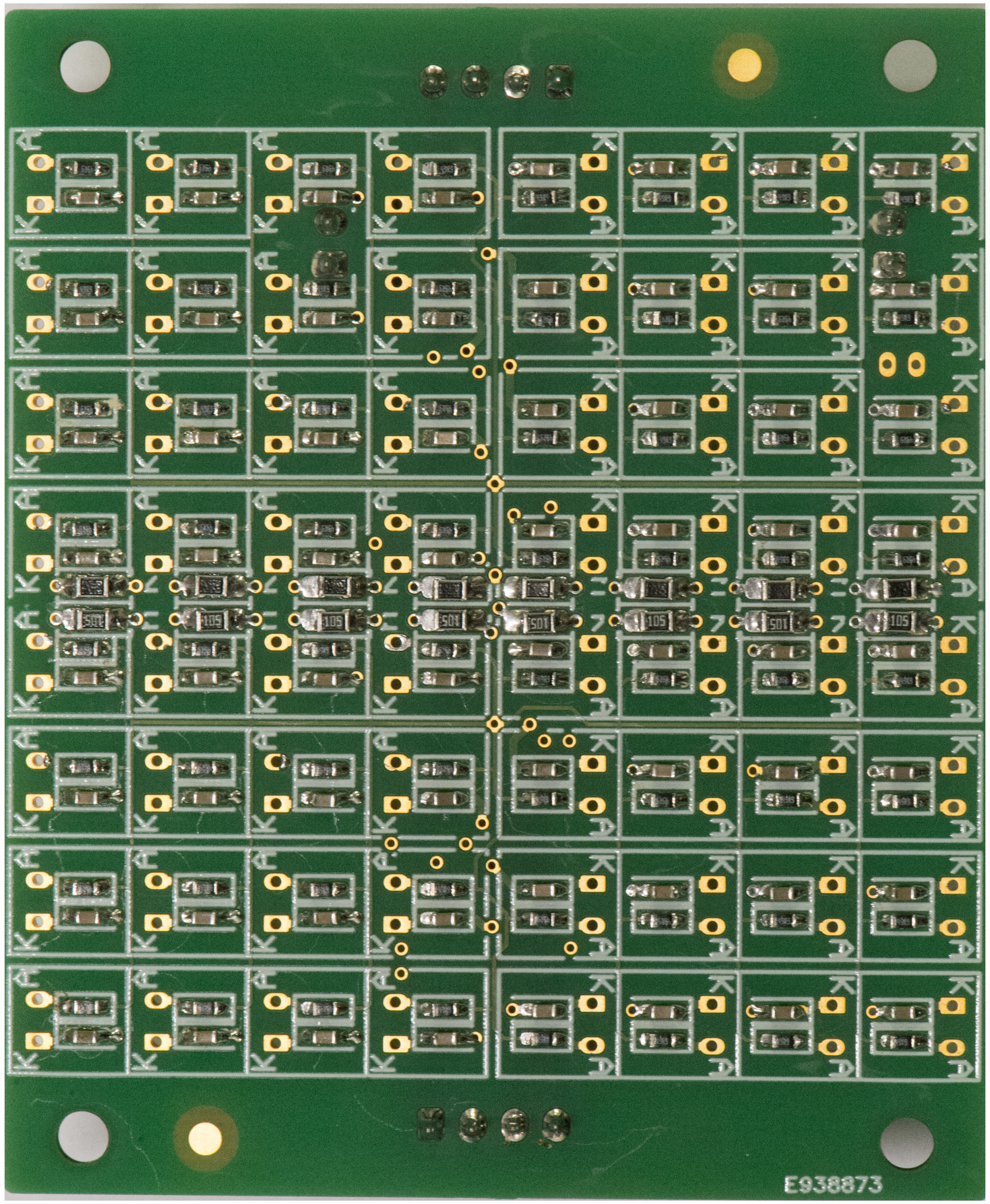
Single photon counting capability
("*high*" light intensity, @ 2 V of over voltage, 175 K)

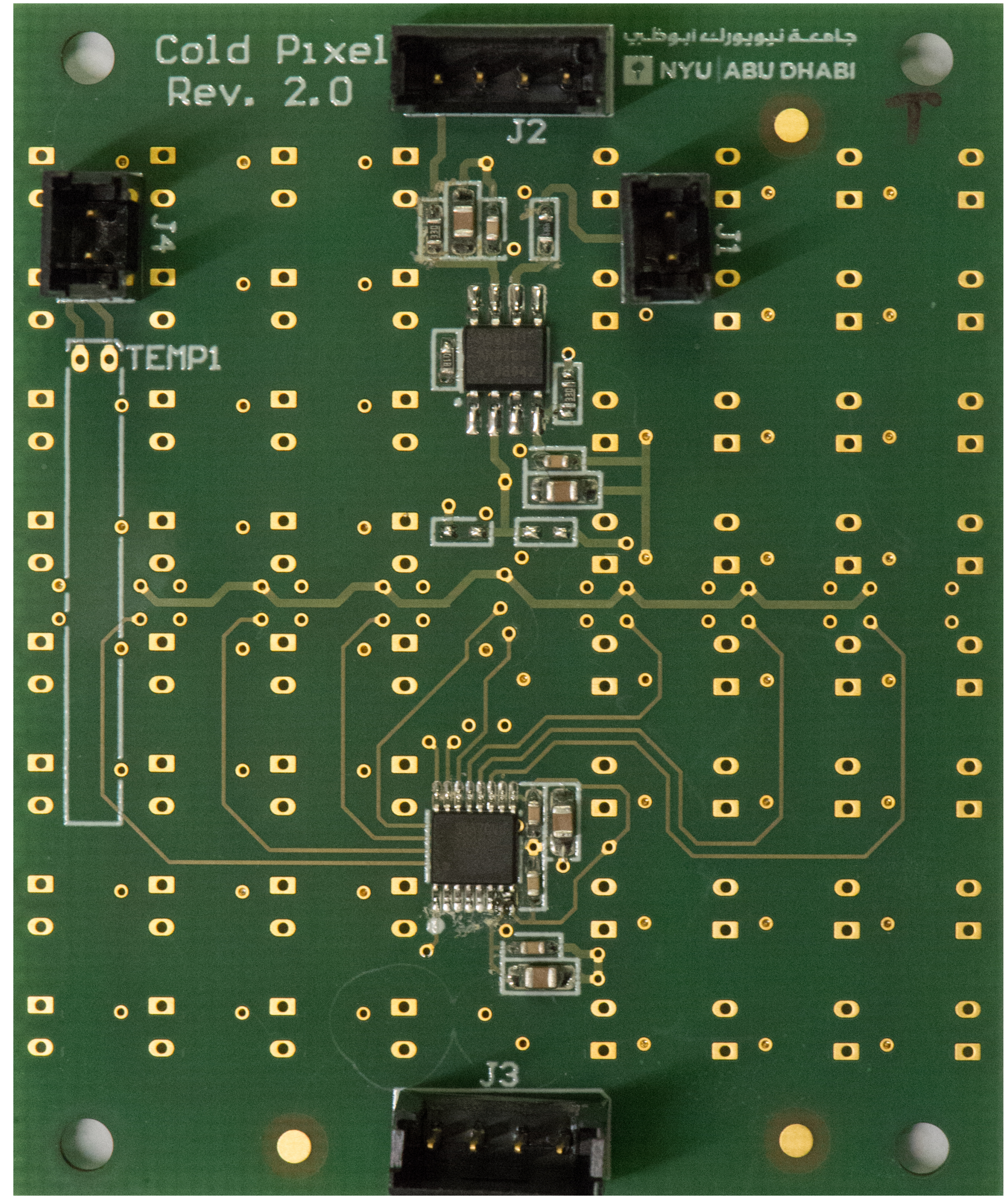




- 14 gaussian functions used to fit the charge distribution
- The gain of the array operating @ 2 V of over voltage, 175 K is ~1.4 x 10^7
- The charge separation between two consecutive photopeaks is ~2.3 pC
- Distinctive charge-photopeaks distribution is preserved at higher intensity

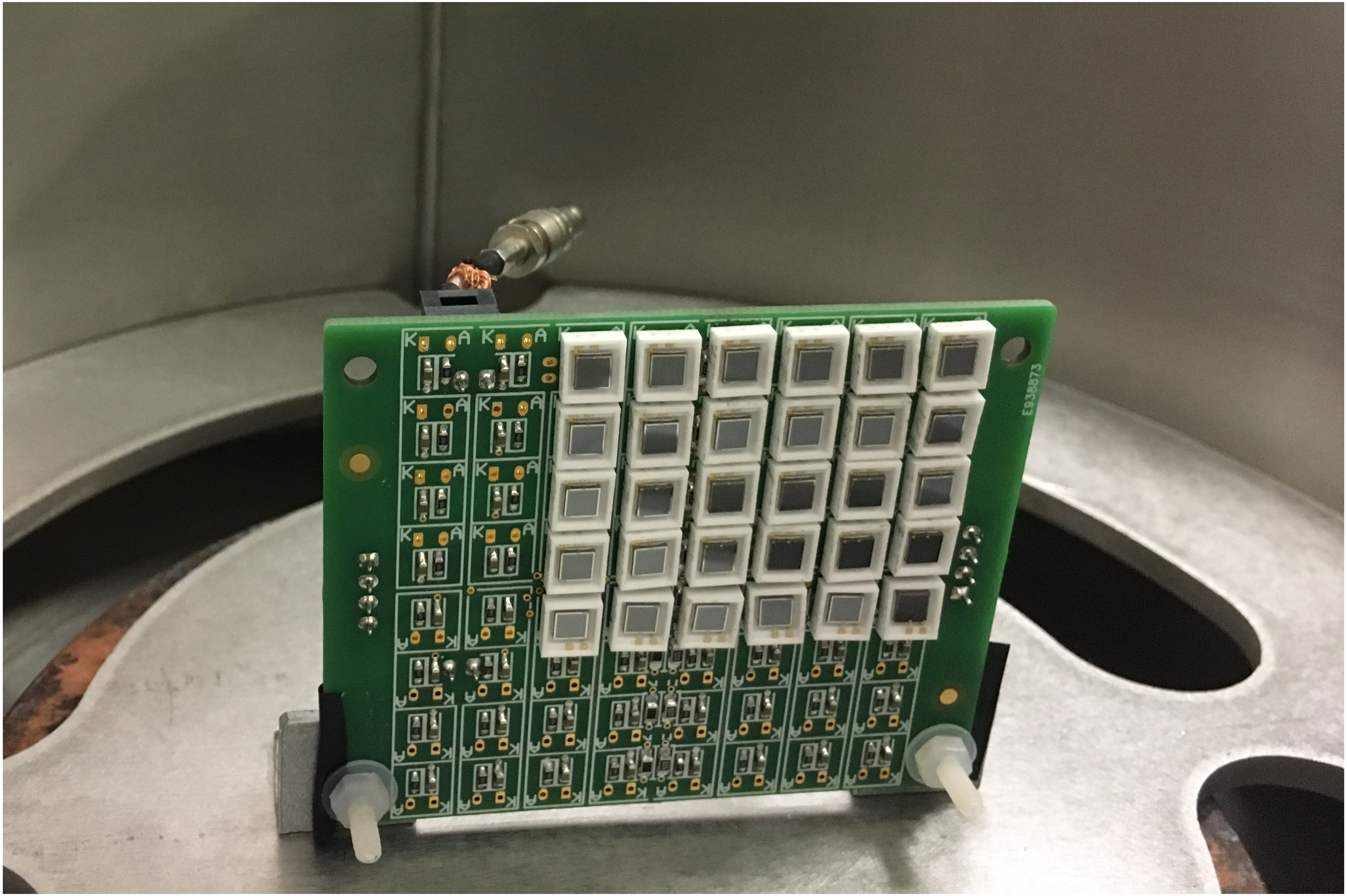
Rev. 2.0



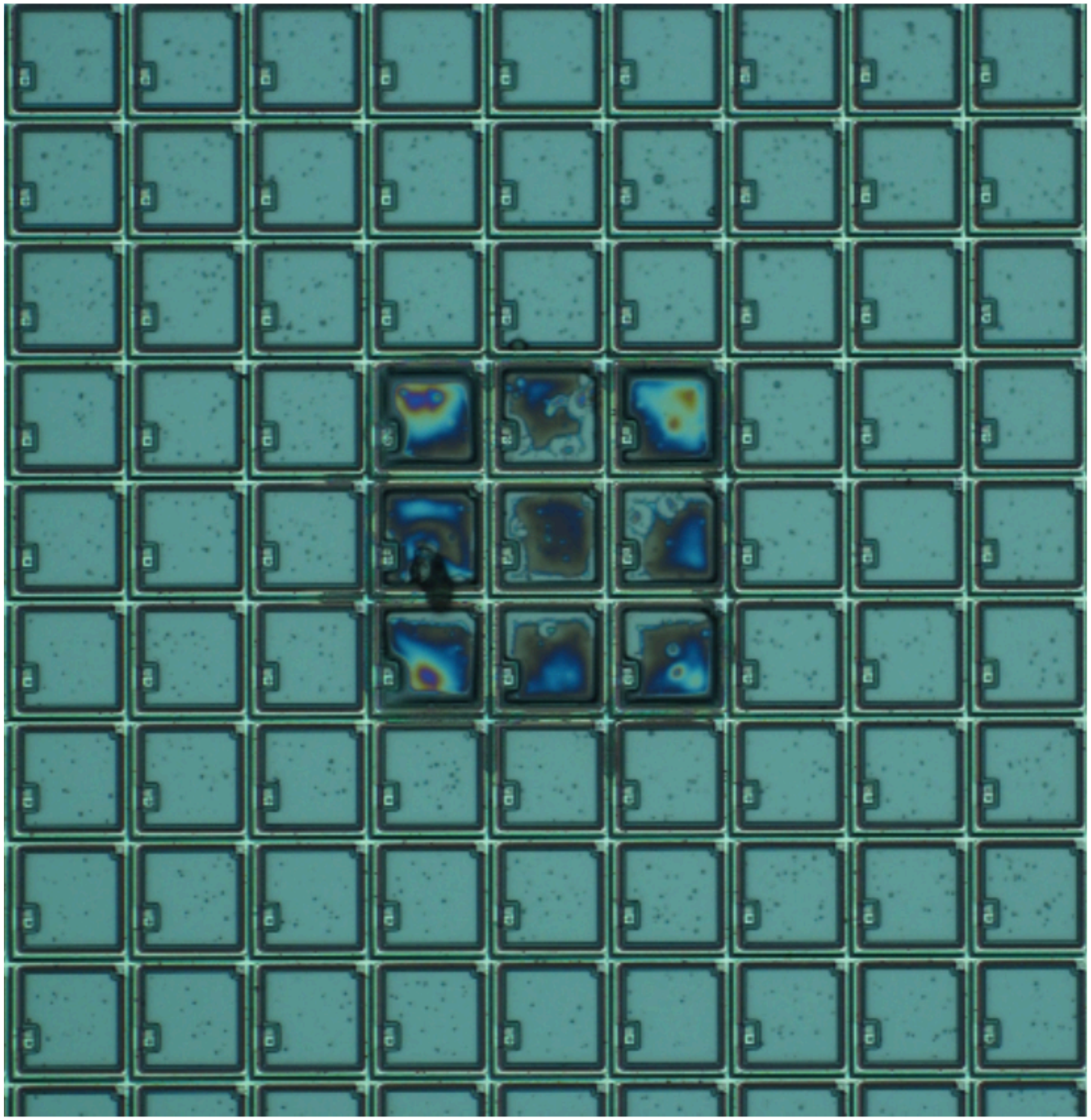


- More compact layout using two PCB sides. It can readout up to 64 VUV4-MPPCs.
- DAC biasing tool and temperature control implemented.

Rev. 2.0



Rev. 2.0 test postponed



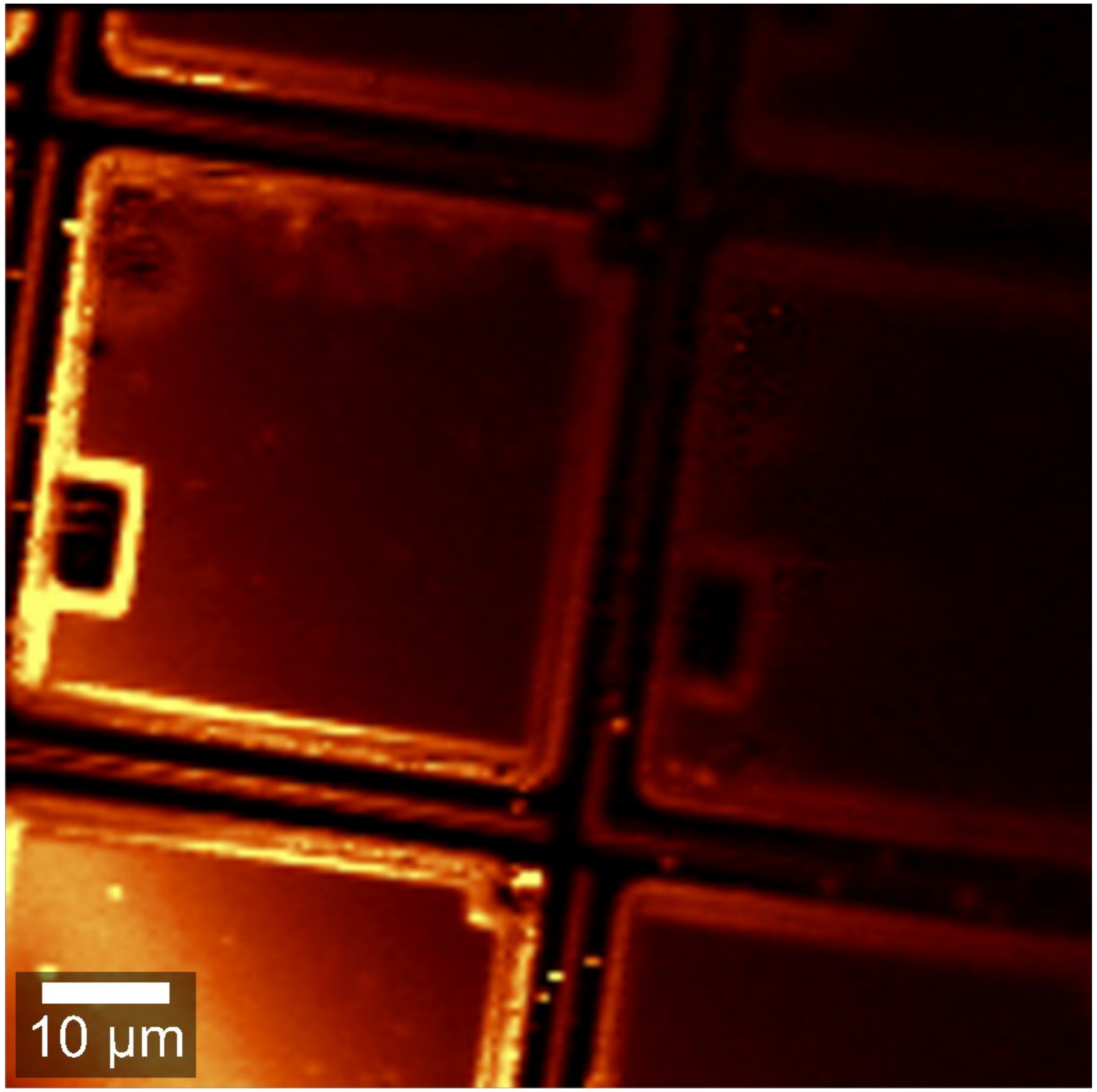
Optical Microscopy

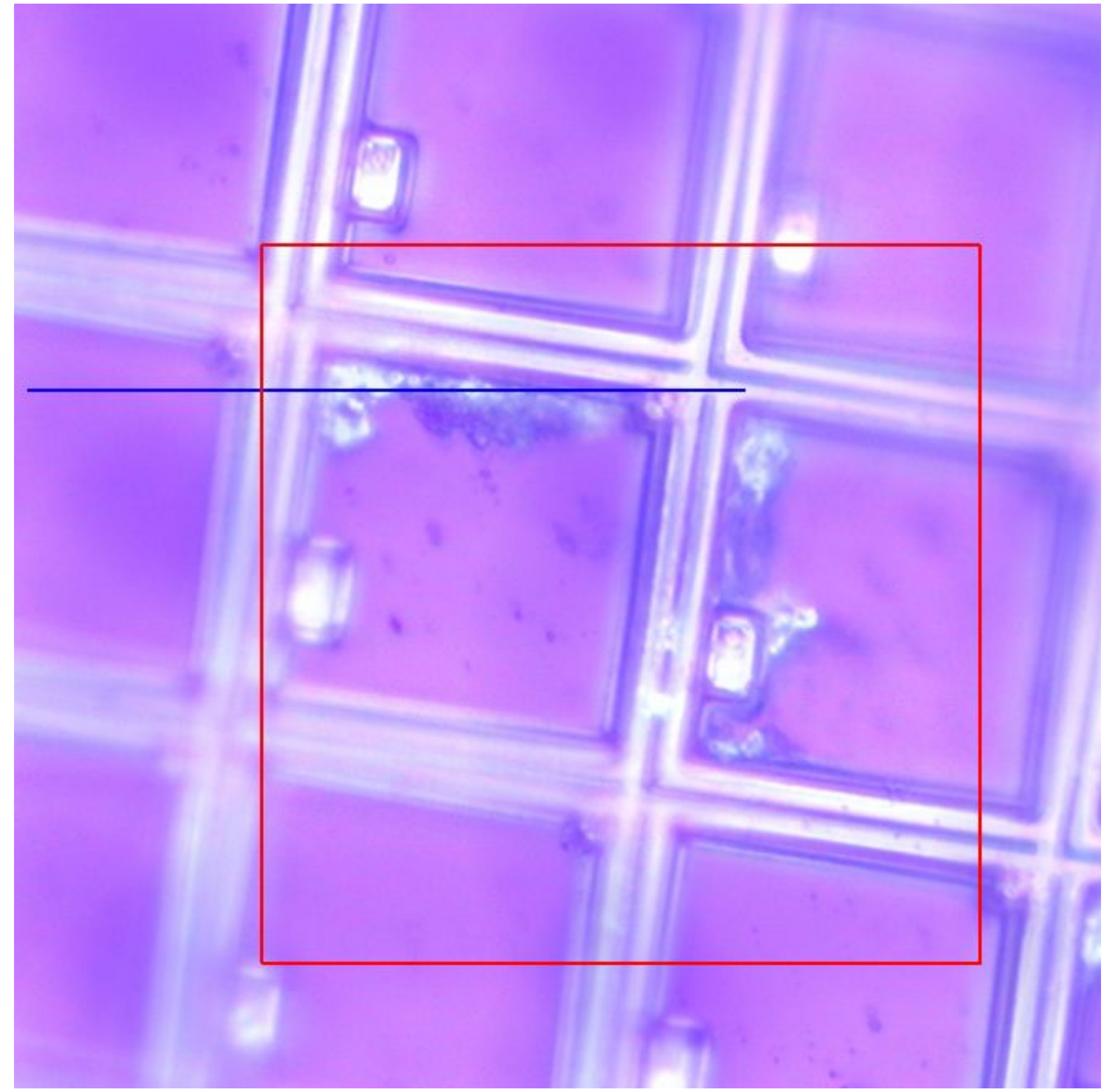
- We started observing weird signals during cold operations.
- We run several configurations with no positive outcome.
- microscopy on a sample of MPPCs.

- A large number of MPPCs compromised at pixel level.
- All MPPCs subjected to several cold cycles (in vacuum and N_2 atmosphere).
- Hamamatsu tends to favor the human mistake (mine).

Damage due to what?
- ESD (I don't think so)
- Large cooling down gradient (NO)
- Heat dissipation (not possible by design)
- Intense flash of light (I cannot exclude it)

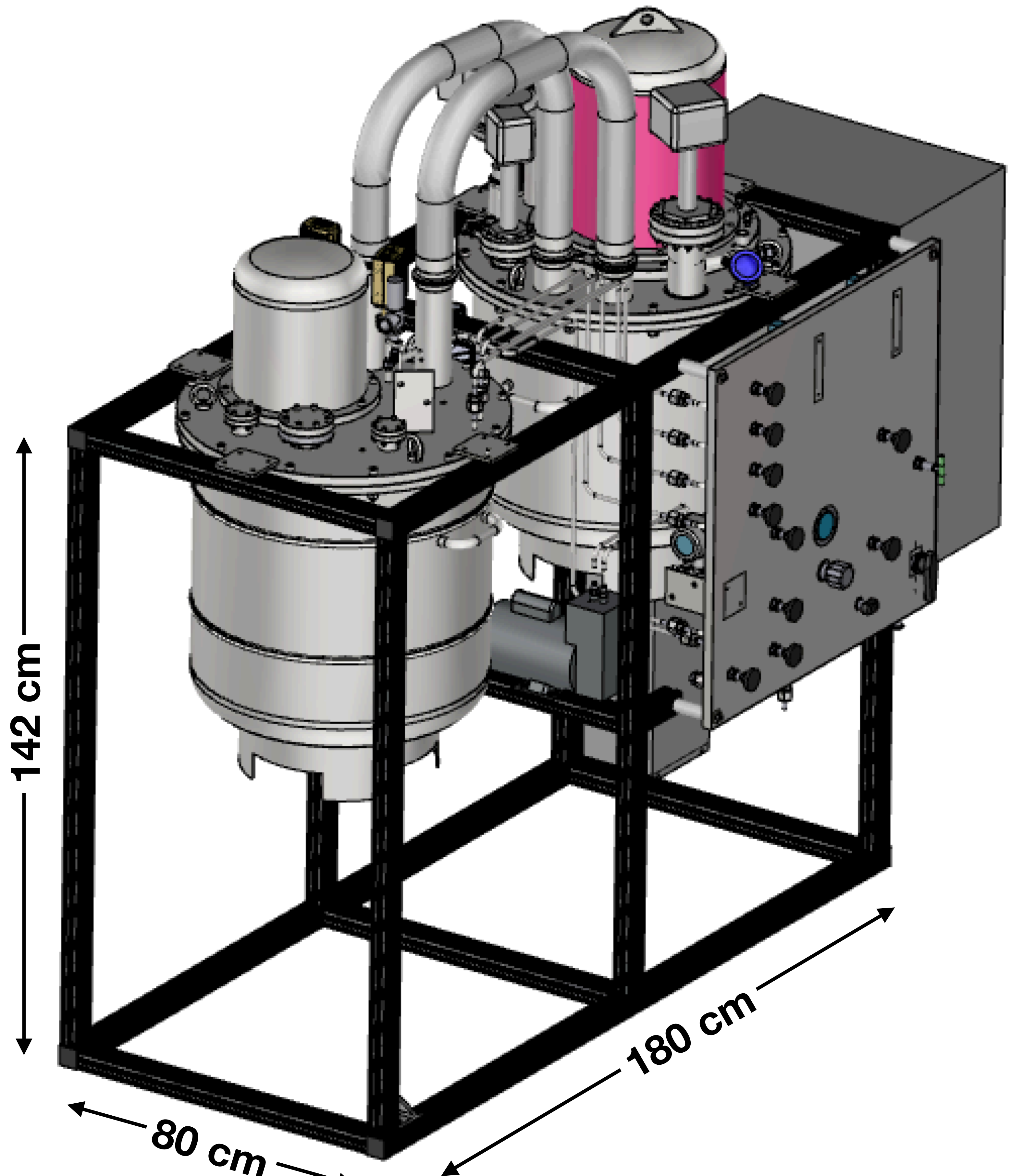
Rev. 2.0 test postponed





Raman Spectroscopy

Cryogenic facility at NYUAD



- Operable in vacuum, LXe, LAr or LAr/LXe mixture
- No PTR required (Passive Mode)
- Gas phase purification
- Inner vessel 25 cm diameter, 33 cm height
- Pre-commissioning in Turin (this summer)
- Delivery/Deployment by end of September
- Commissioning by the end of the year
- Inner vessel can be exposed to direct monochromatic light (McPherson 234/302)

Applications:

- Characterization of readout electronics
- Characterization of (photo)sensors
- Characterization of crystals (LYSO, $CeBr_3$, $LaBr_3$, CsI, NaI, Yag, Yap, etc) vs temperature
- Characterization of "in house" organic scintillators made
- Detector assemblies for space applications
- LXe and LXe/LAr scintillation detection in the IR range

Conclusions

- We developed a cryogenic electronics based on the commercial current feedback operational amplifier AD8011 to operate a “large” number of MPPCs as single detector.
- Radio-purity assessment confirms the AD8011 as possible candidate for operation in low background applications.
- We have an excellent, low power amplification system, which also works for PMTs.
- The extension of this system to multiple SiPMs, to replace a standard PMT, looks promising.

Next steps:

- Further investigation is needed to explain the MPPCs failure.
- Test in Liquid Xenon (end of 2018) at NYUAD cryogenic facility.
- Signal to noise ratio assessment and optimization by means of Optimum/matched filters (software anytime, hardware to be implemented).

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