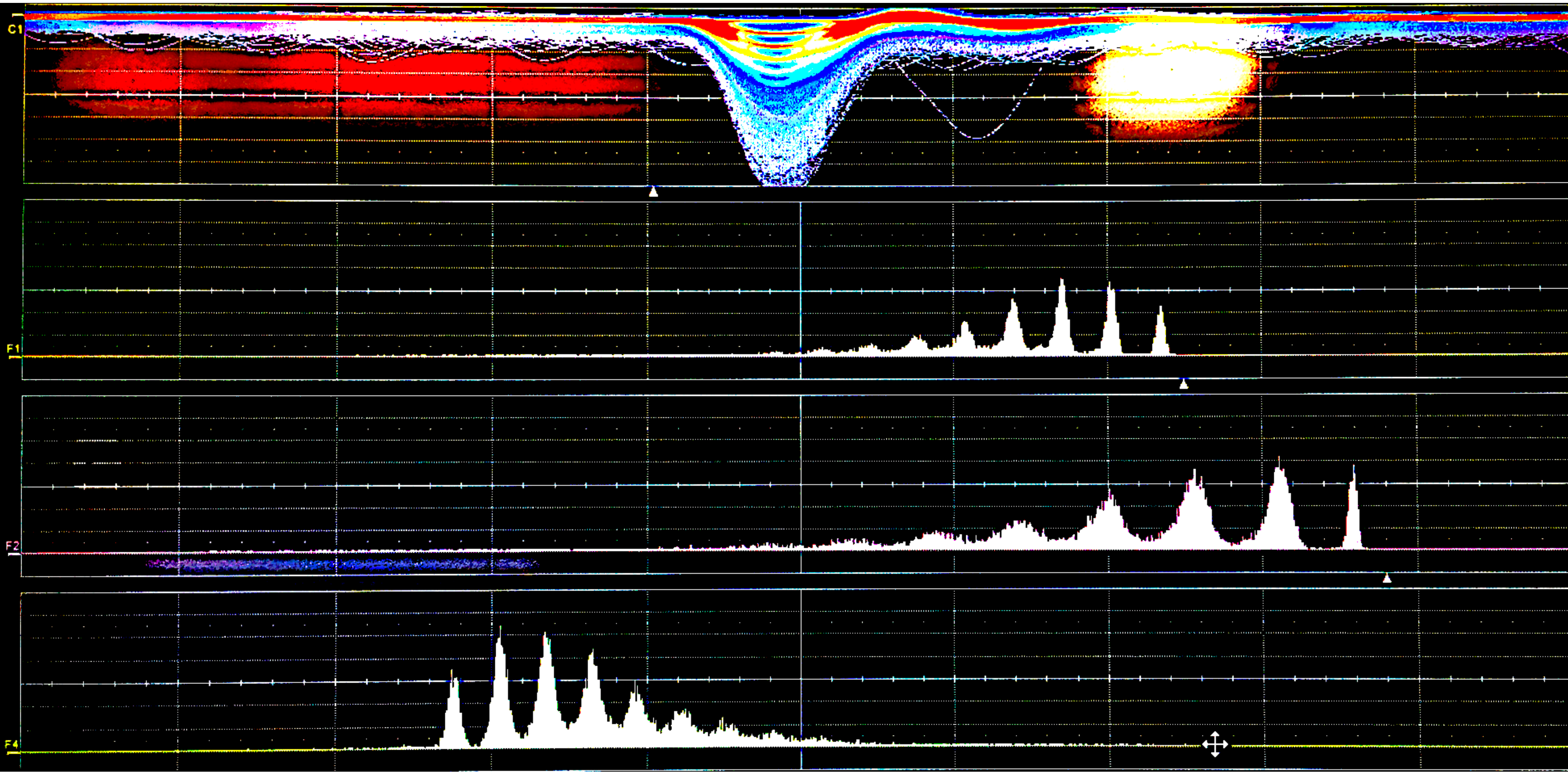
# A Multi-Pixel Photon Counter detector prototype for direct detection of scintillation light in liquid xenon.

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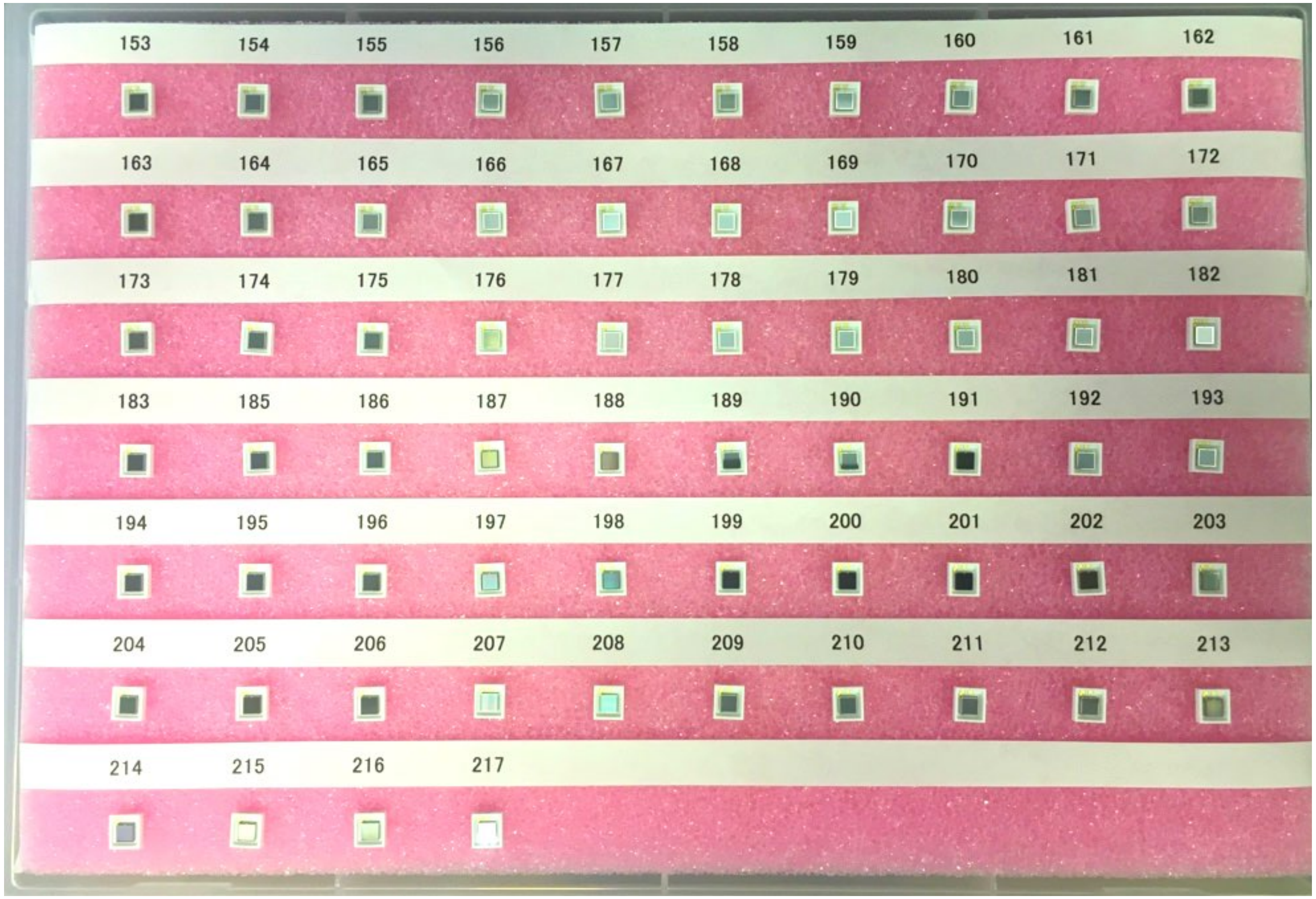
NYU ABU DHABI

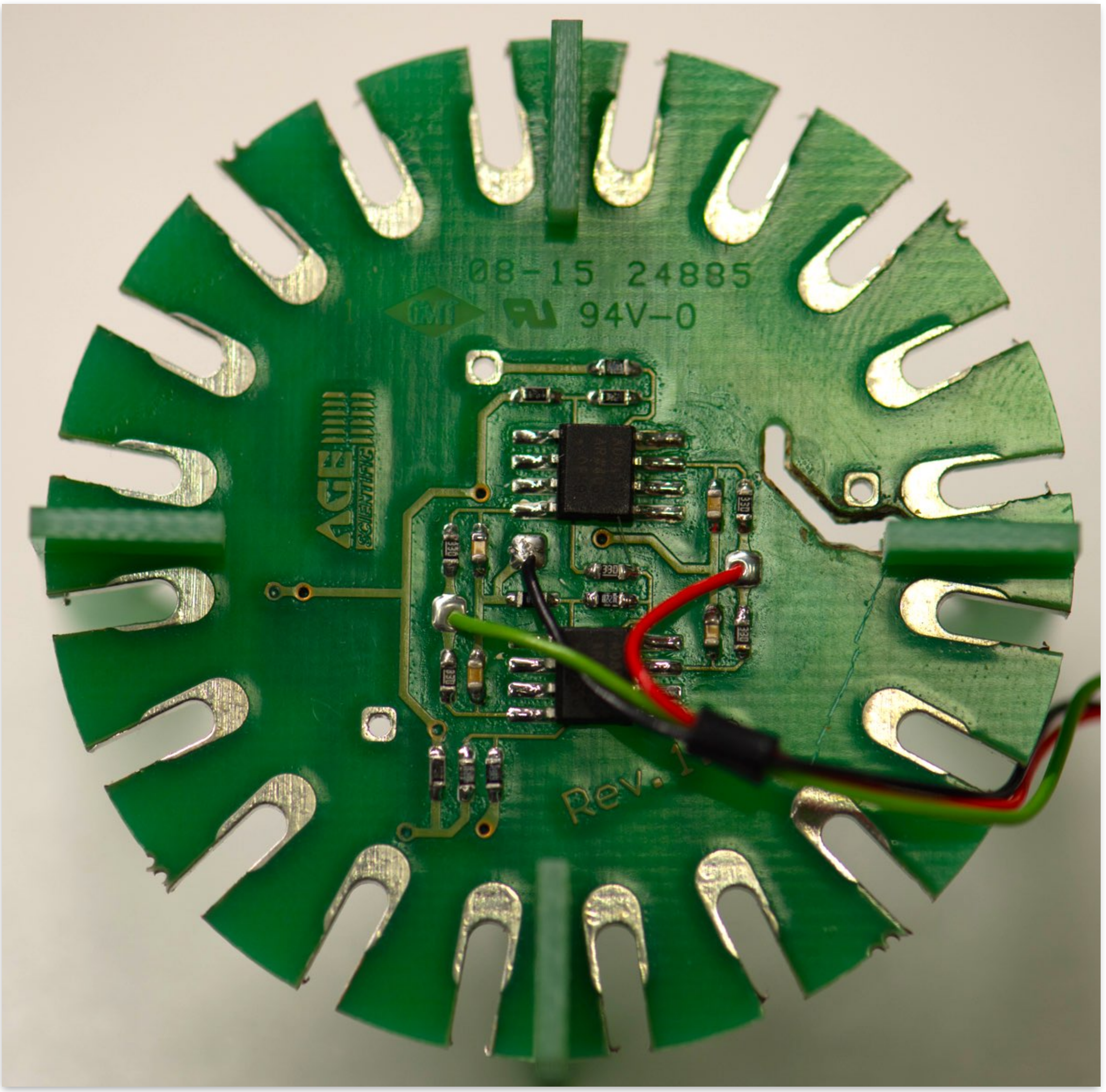
Adriano Di Giovanni, CNNP 2017, 15-21 October, Catania

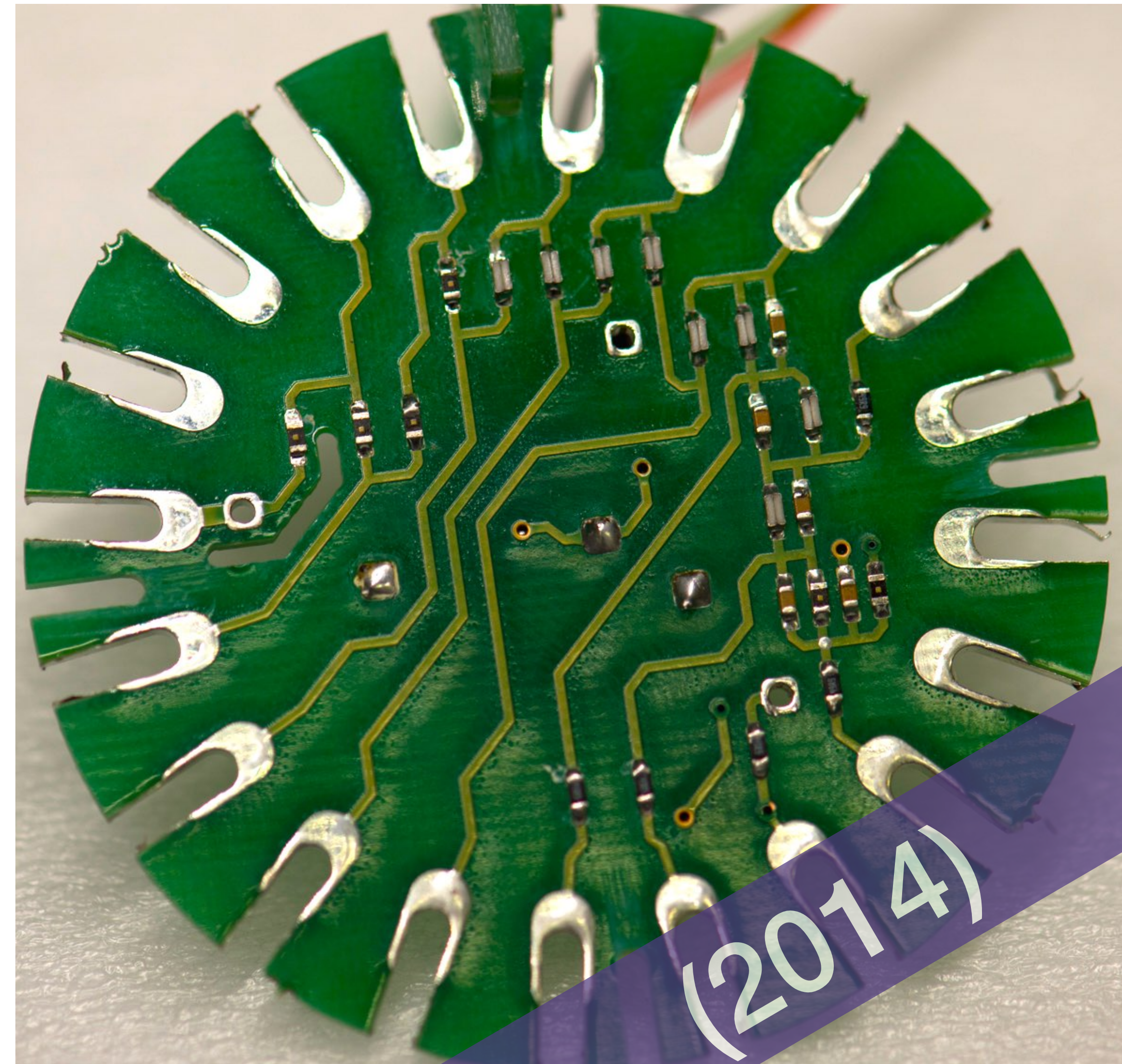
# Goals




- 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.**

# An amplifier for VUV photomultipliers operating in cryogenic environment



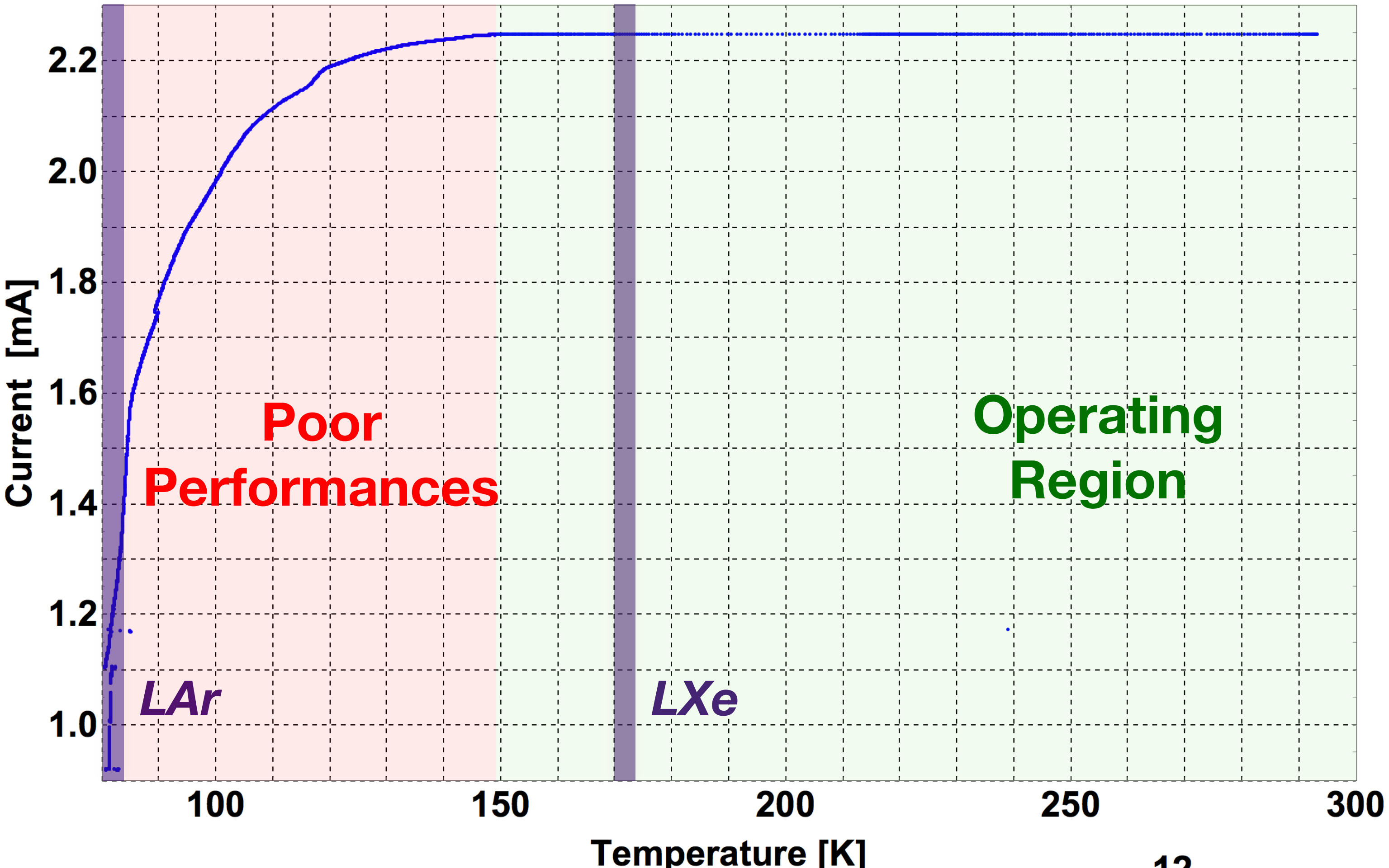



(2014)

- ~ 80 MHz Bandwidth for typical signal with <4 ns rise time
- 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 involved)

*Presented at “Frontier detectors for frontier physics - 13th PISA Meeting on Advanced detectors”, 24-30 May 2015*

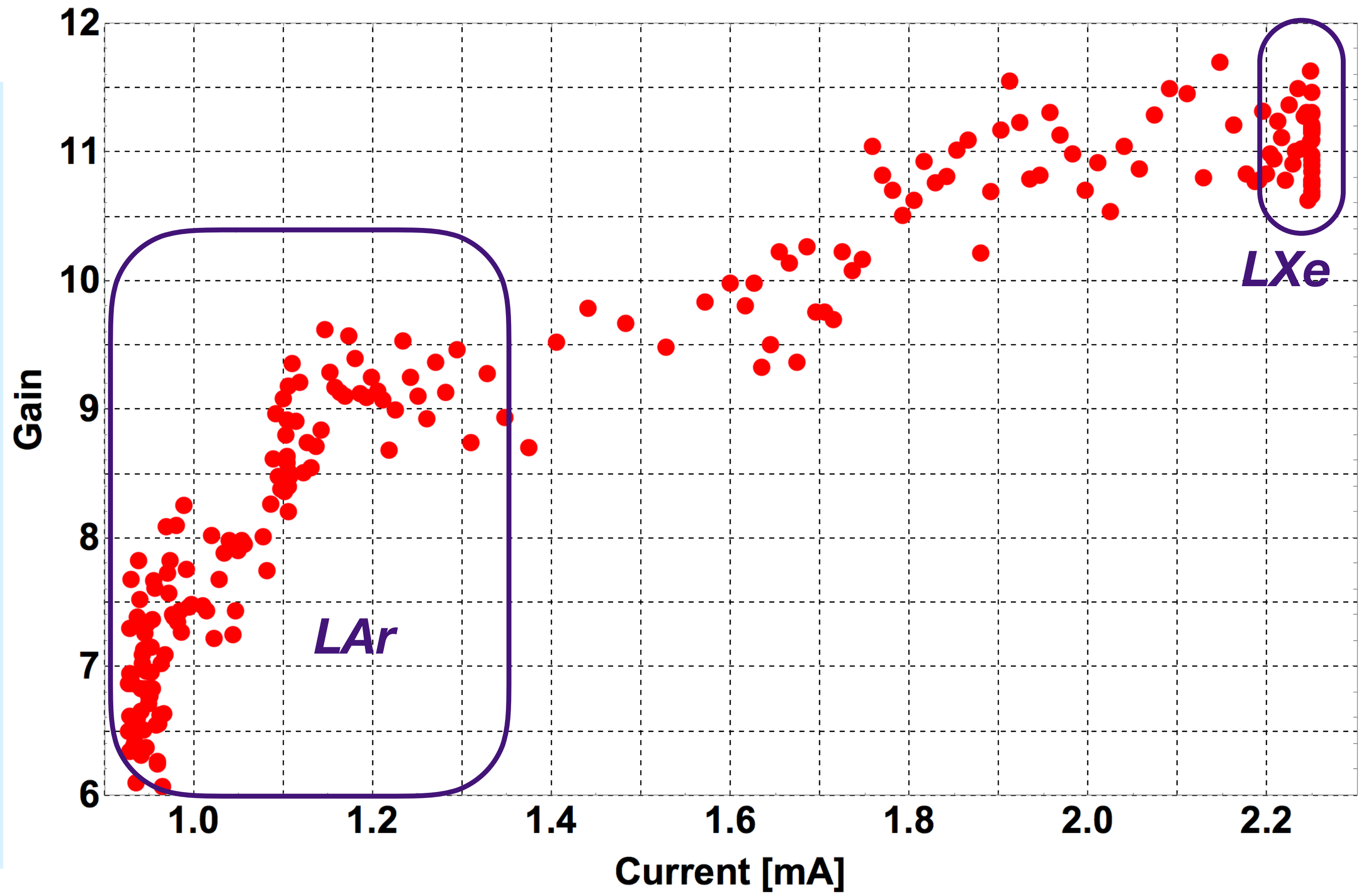
# Performances of AD8011 in cold environments




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

## Main results:

- 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 LXe temperature**, while at LAr temperature becomes inadequate due to gain decrease and instability.



# S13370-3050CN = VUV4 MPPC family manufactured by Hamamatsu

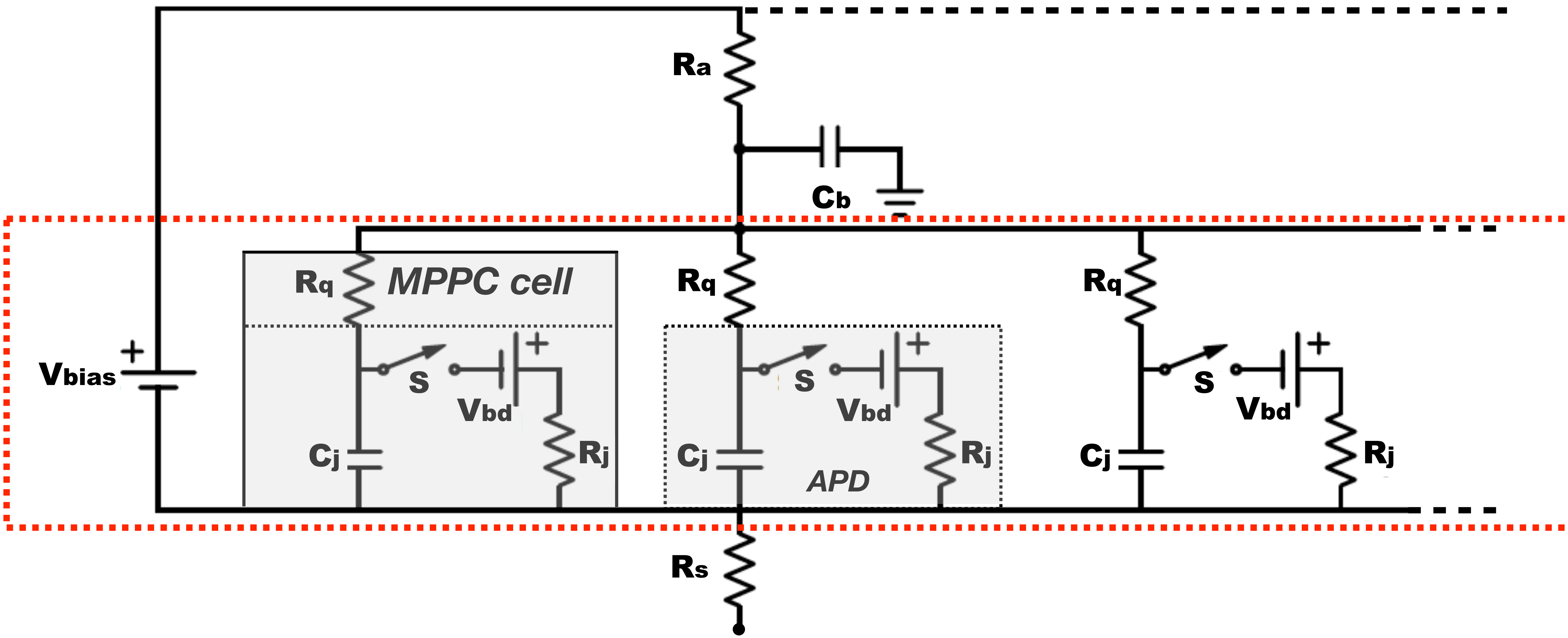
PROS:

- 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:

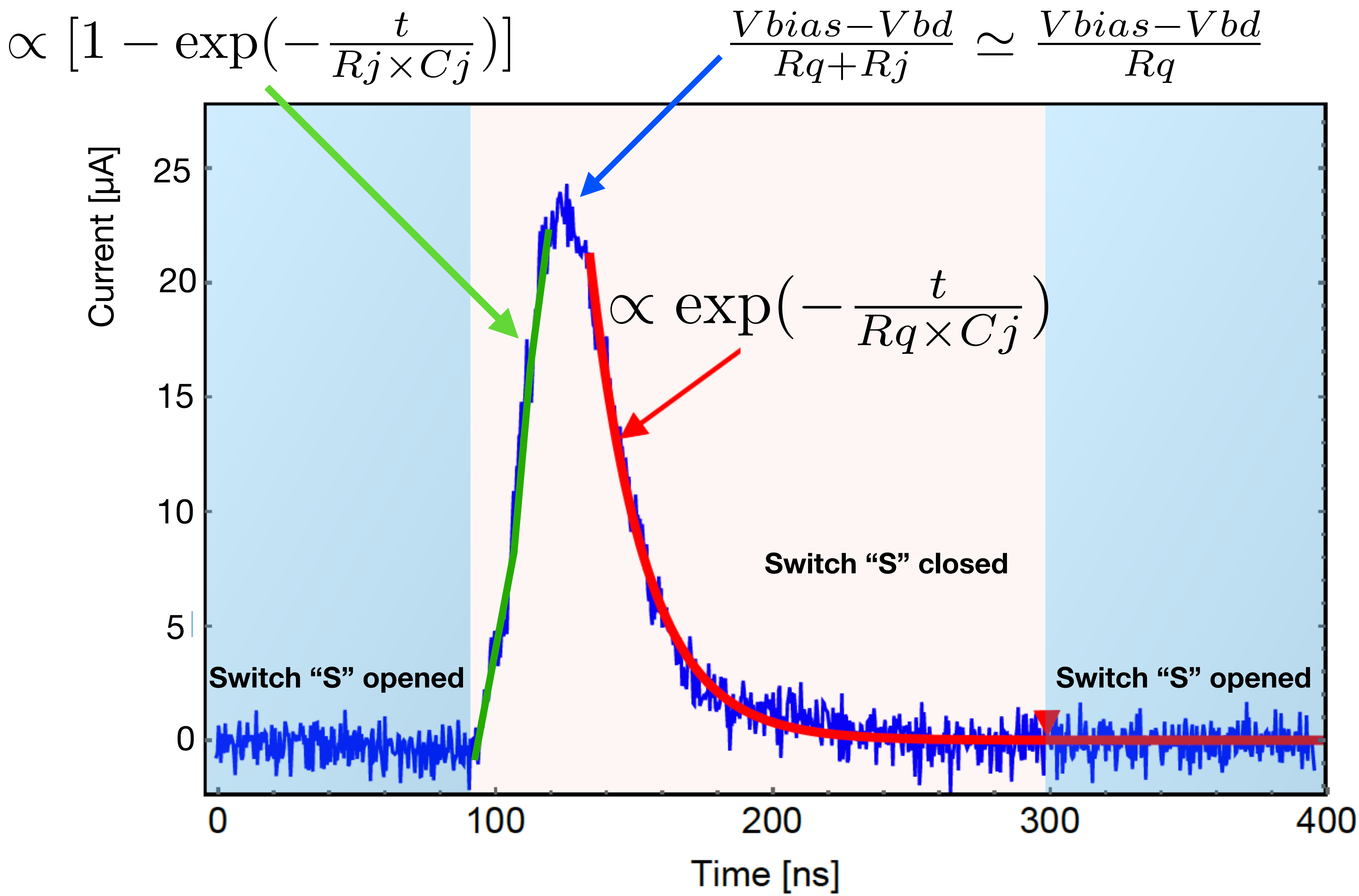
- Dark Counting Rate
- Cross Talk / Afterpulses
- Characteristics = f(Temperature)
- Size (usually < $cm^2$)
- “Large” Pixel Capacitance: fraction of pF
- Naked: handle with care
- Grouping of many MPPCs is challenging
- Everything but cheap

# MPPC electrical scheme

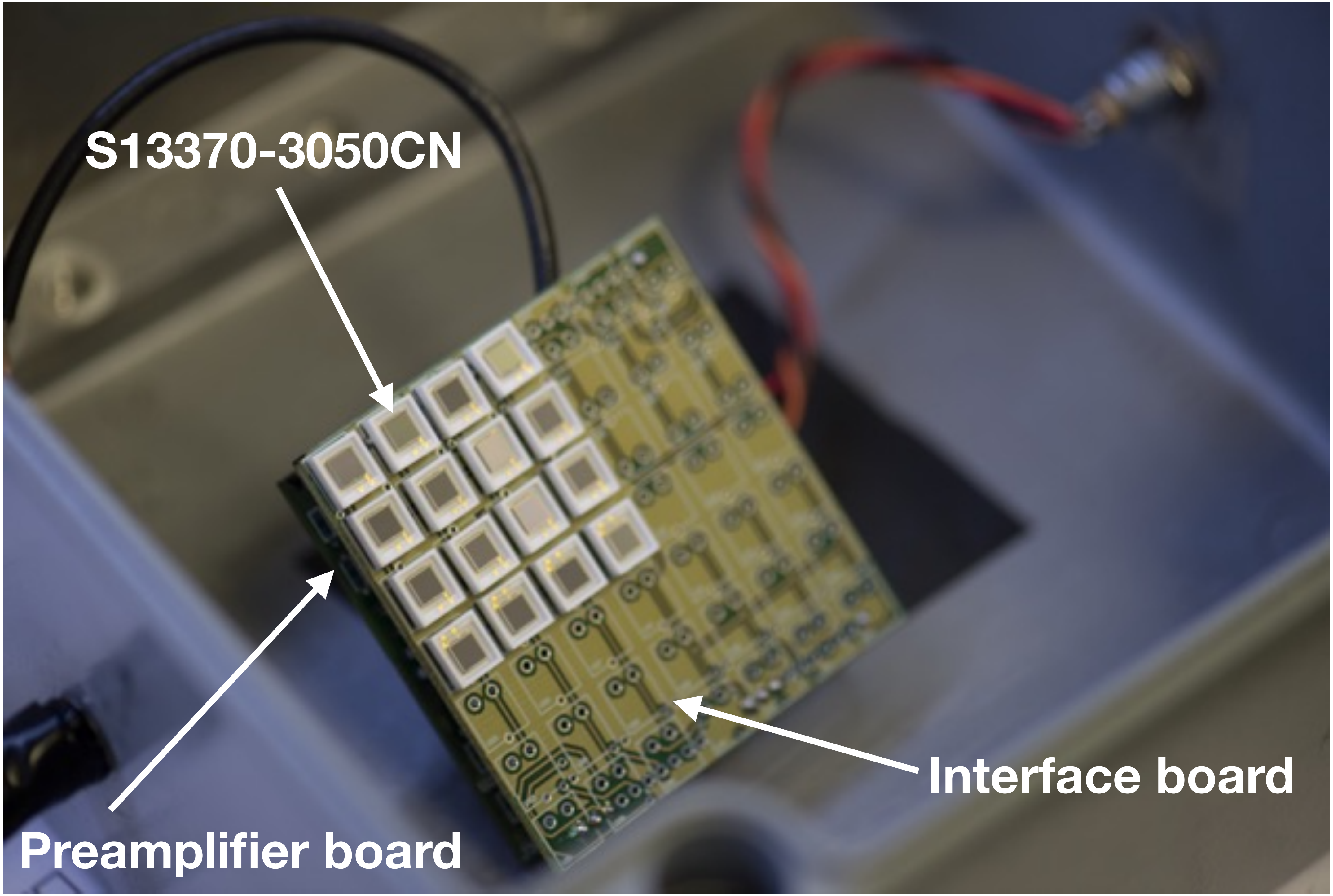



- **APD "ingredients"**: junction resistance (Rj), junction capacitance (Cj), voltage source (Vbd), light switch (S)
- **MPPC cell "ingredients"**: APD + quenching resistor (Rq)
- Current limiting resistor (Ra), Bypass capacitor (Cb) and decoupling resistor (Rs) are all external components
- **A MPPC is usually made of thousands of MPPC cells connected in parallel**

# MPPC typical waveform



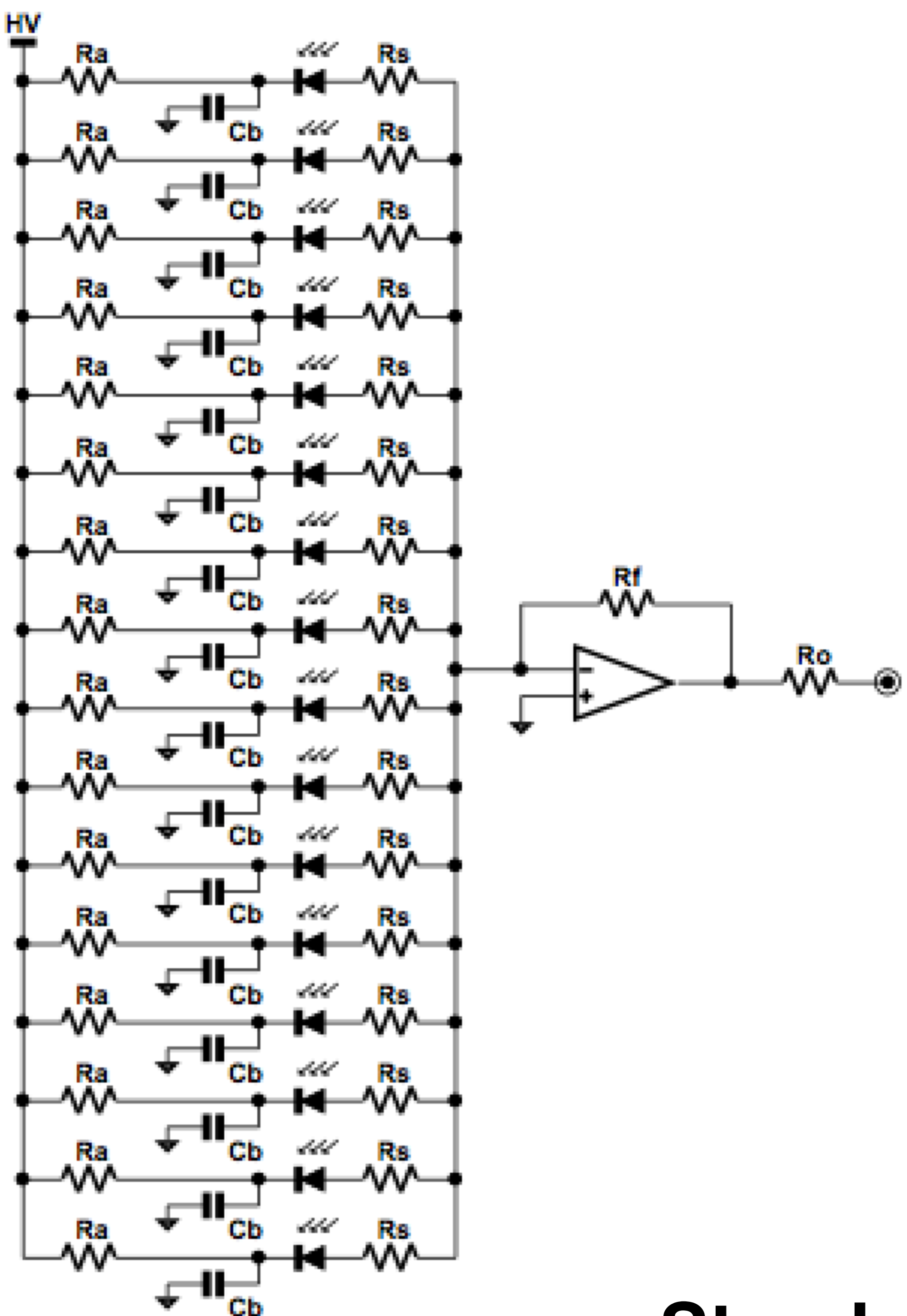
# Adapting the AD8011 to a readout of a multiple MPPC array (16 devices reported here)



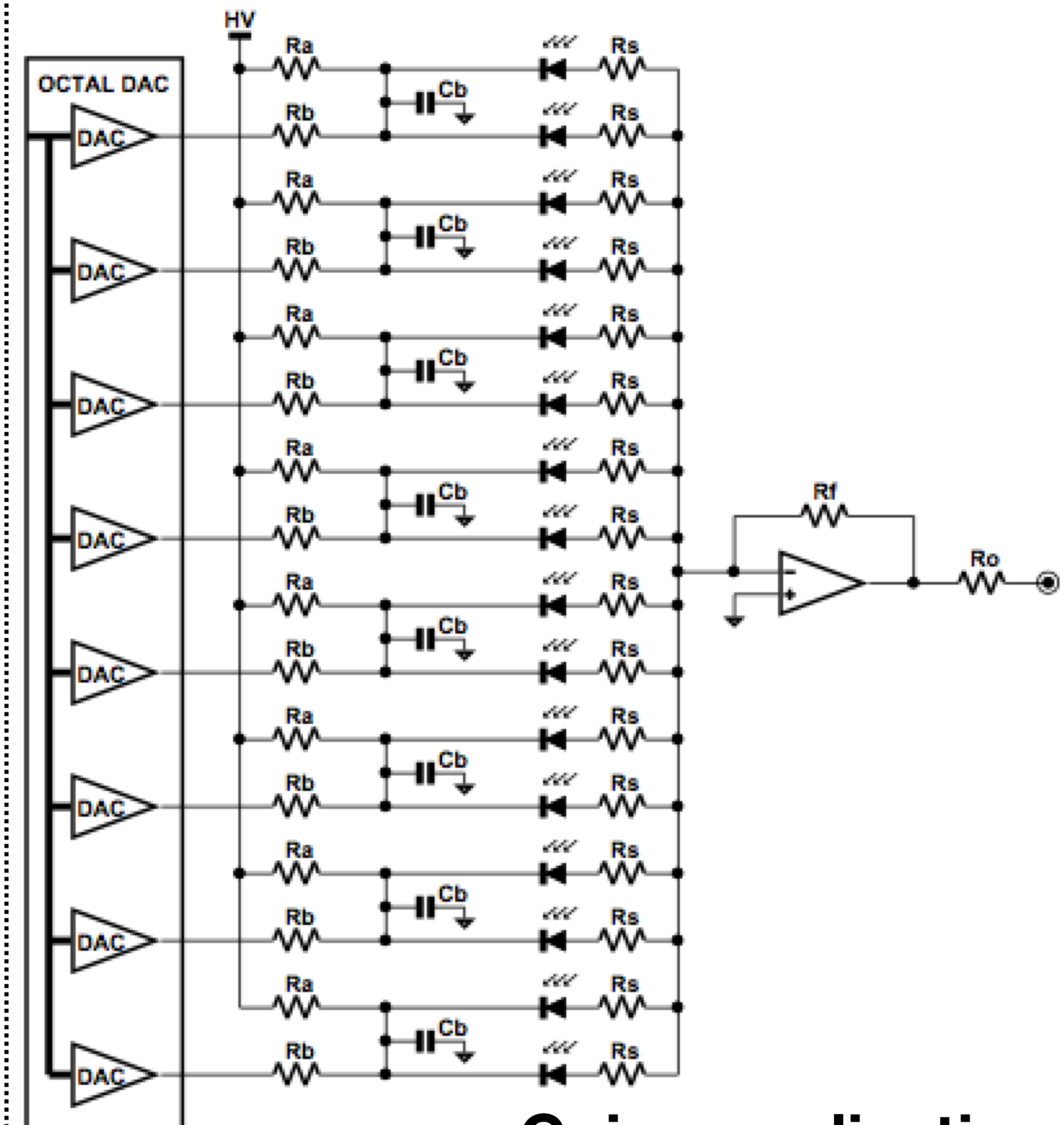

**S13370-3050CN = VUV4 MPPC family manufactured by Hamamatsu**

https://arxiv.org/abs/1707.08004

# Schematics of 16-channels-electronics



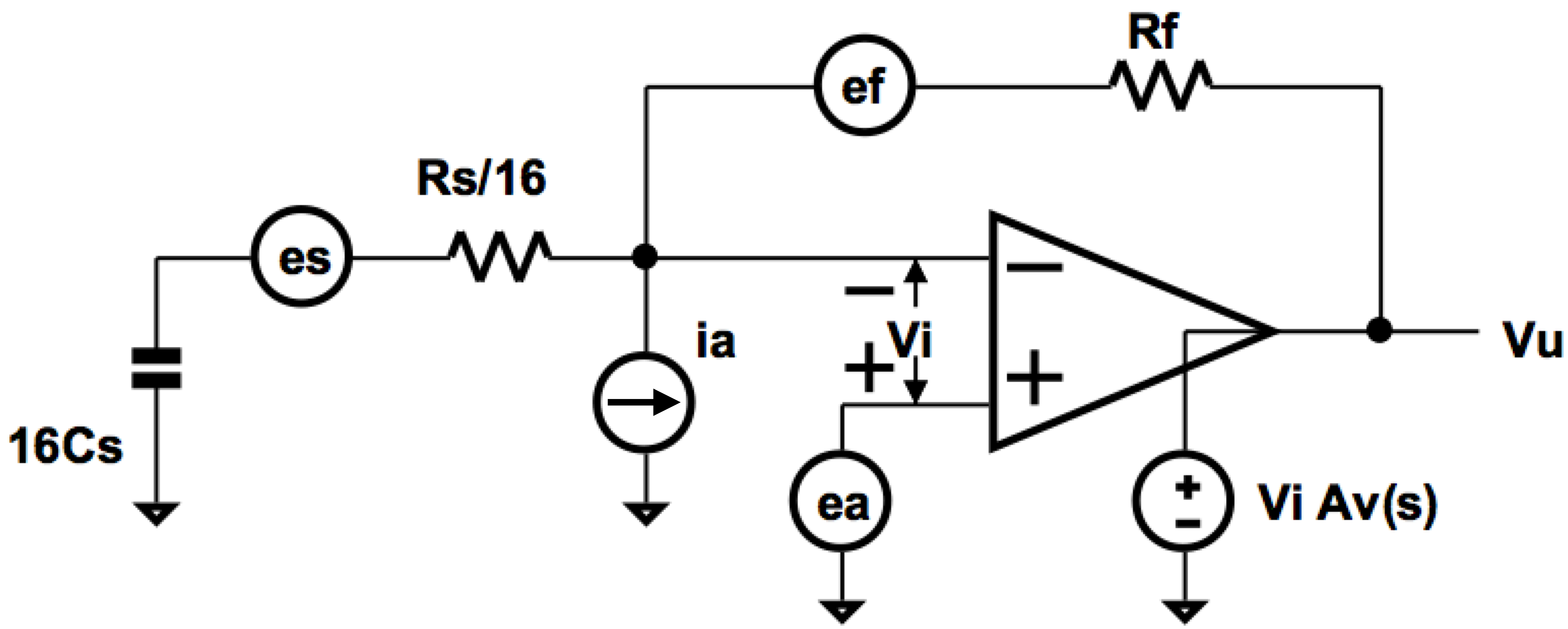

Standard




Gain equalization

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

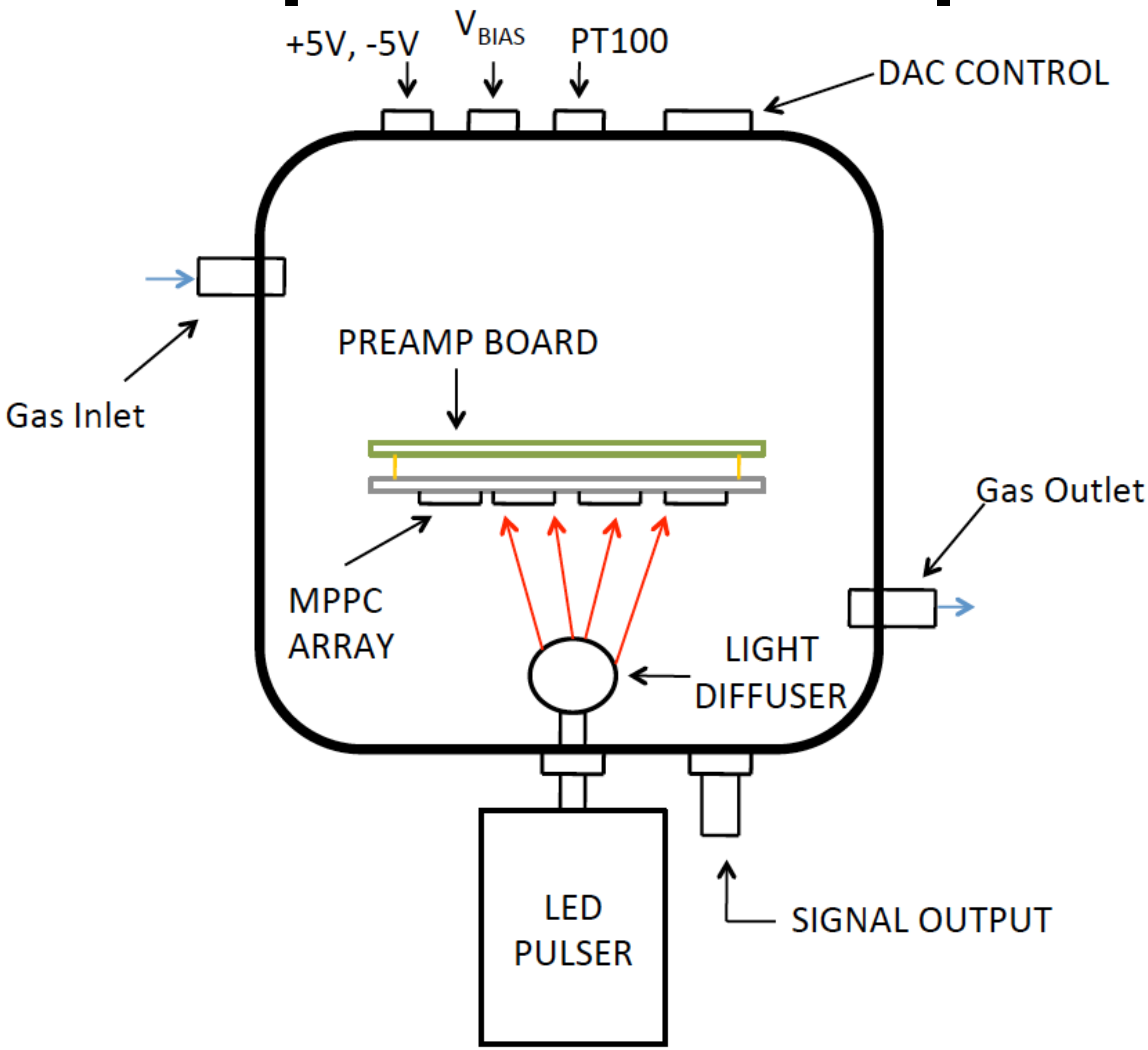
# Noise model and estimation




| Source of Noise | $\mathrm{i_a}$ | $\mathrm{e_a}$ | $\mathrm{e_f}$ | $\mathrm{e_s}$ |
|---|---|---|---|---|
| $\mathrm{B(k,f)}$ | $i_a \times \mathrm{R_f}$ | $e_a \times (1 + \frac{\mathrm{R_f}}{\mathrm{Z_s(f)}})$ | $4\mathrm{KT} \times R_f$ | $4\mathrm{KT}\frac{R_f}{Z_s(f)}$ |
| $\frac{\text{Spectral density noise}}{\mathrm{C(f)}}$ $[\frac{\mathrm{V}}{\sqrt{\mathrm{Hz}}}]$ | $5.0 \times 10^{-9}$ | $\leq 6.4 \times 10^{-7}$ | $9.6 \times 10^{-18}$ | $\leq 3 \times 10^{-18}$ |

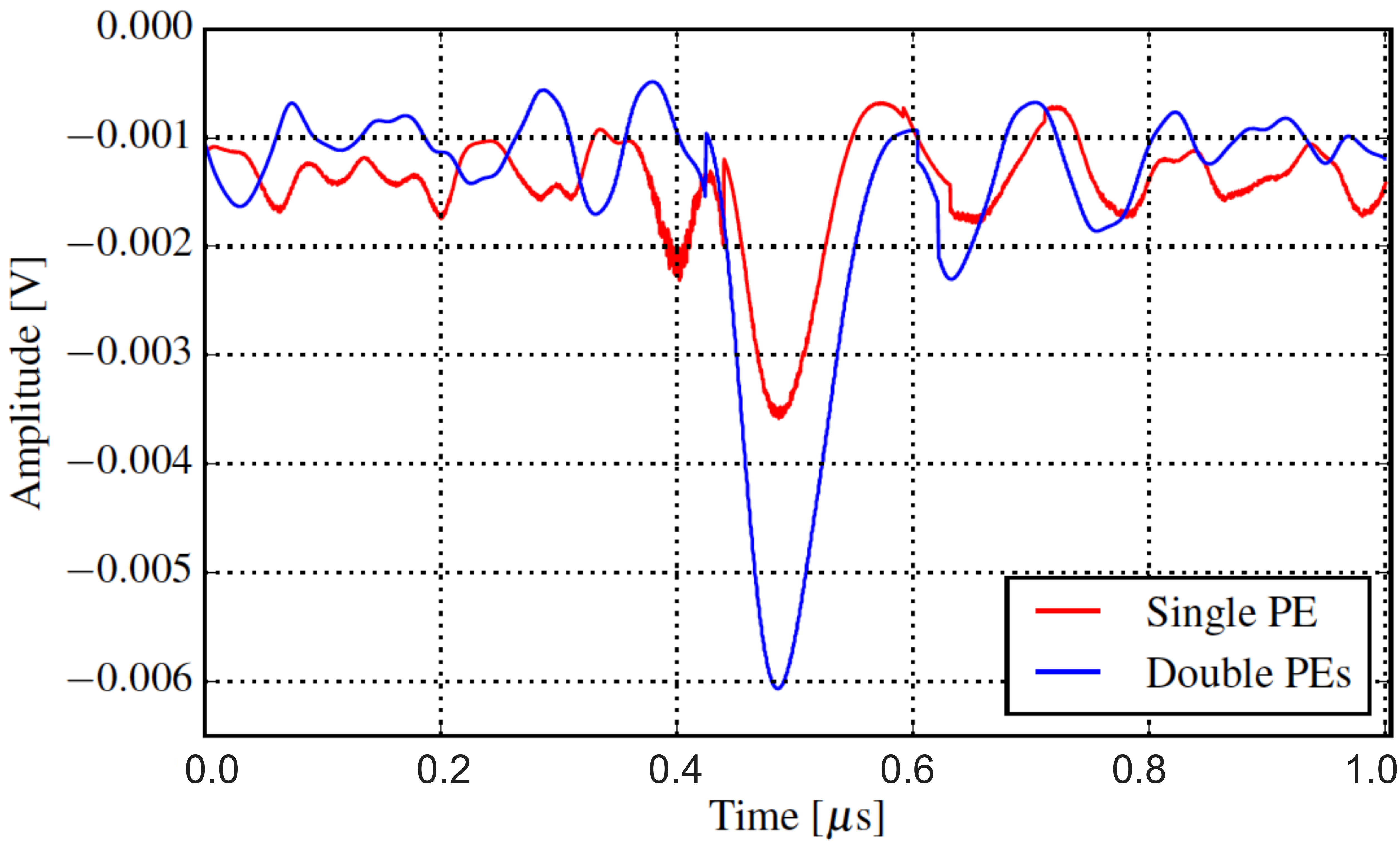
**The most significant contribution to the noise budget is due to input voltage noise of the operational amplifier.**

# Experimental setup



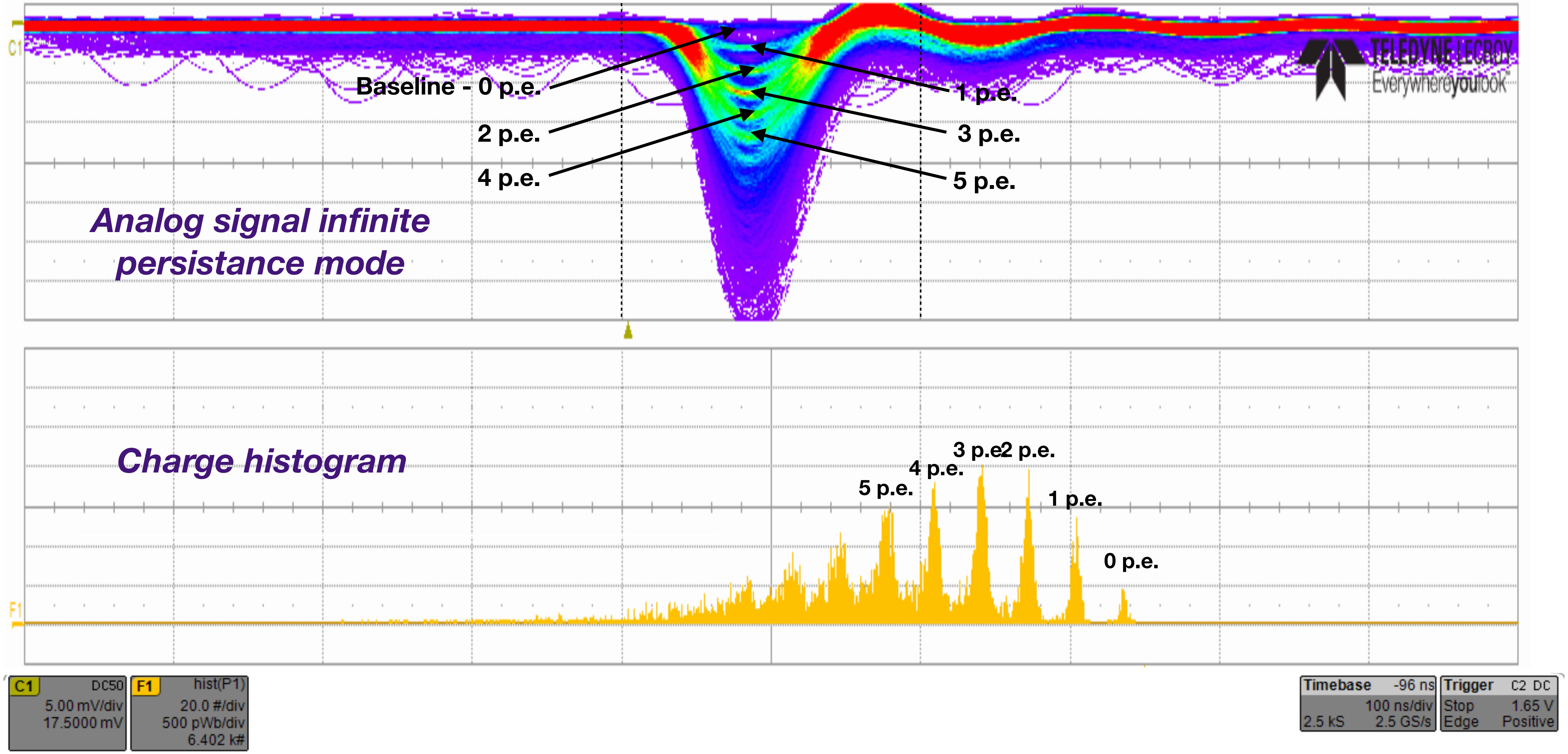

- Nitrogen in gas phase used to purge water vapor condensation at 175 K.
- The MPPC array has been operated at different over voltages and illuminated by a pulsed UV LED.

# 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).

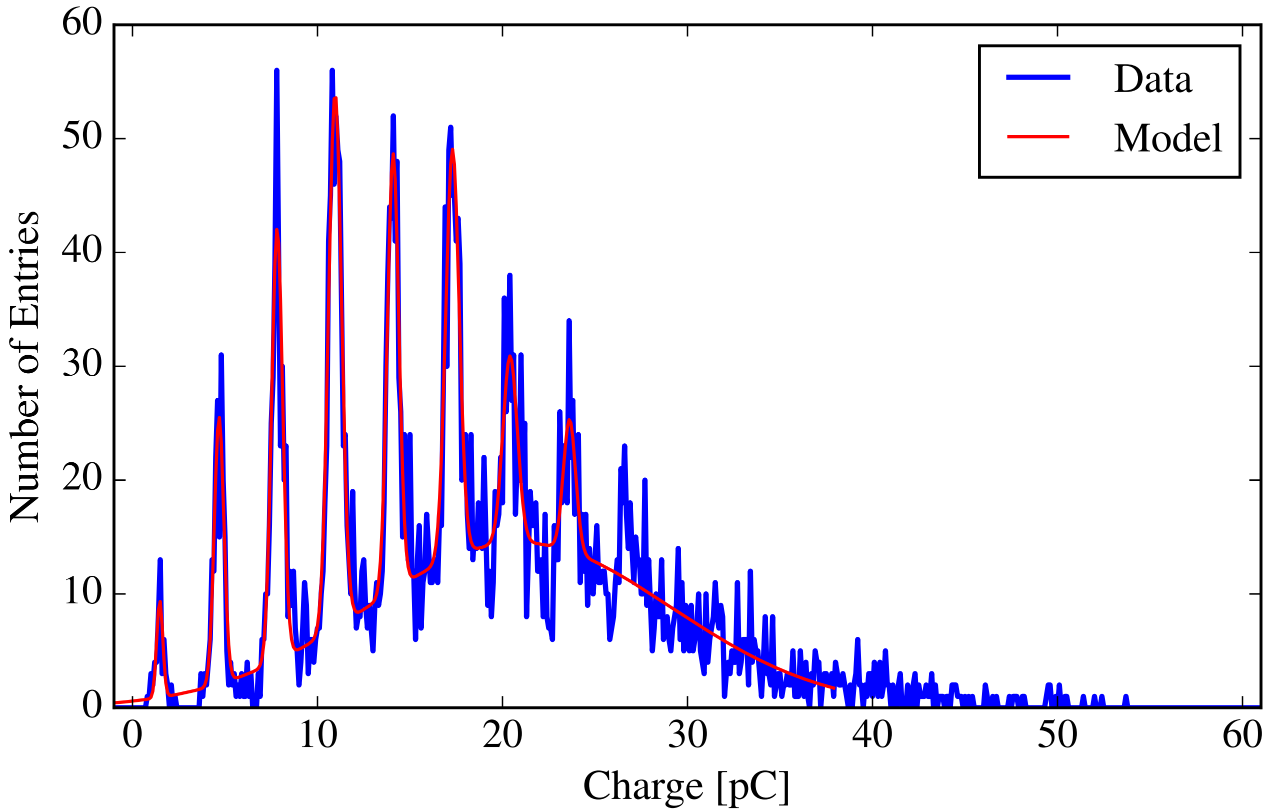
# Single photon counting capability

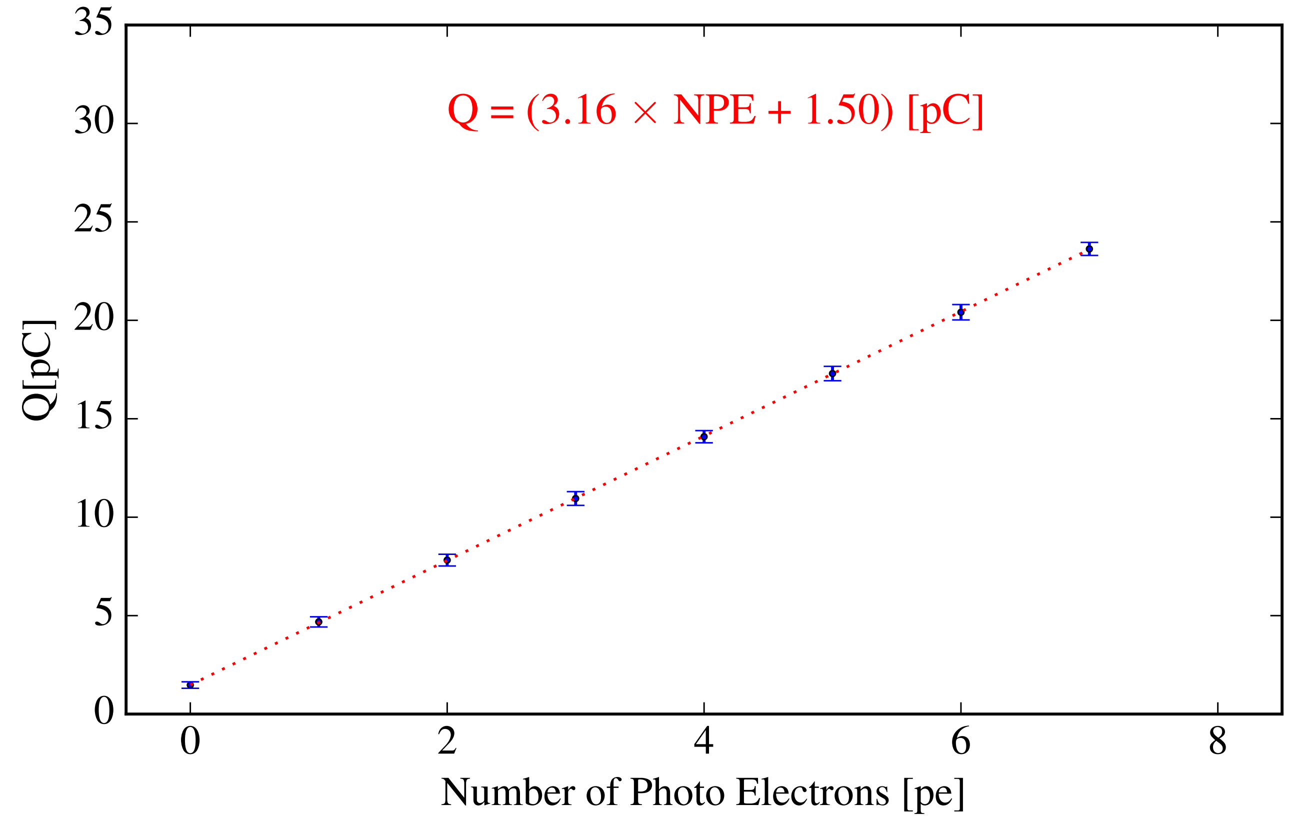



## Measurement conditions

- 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)



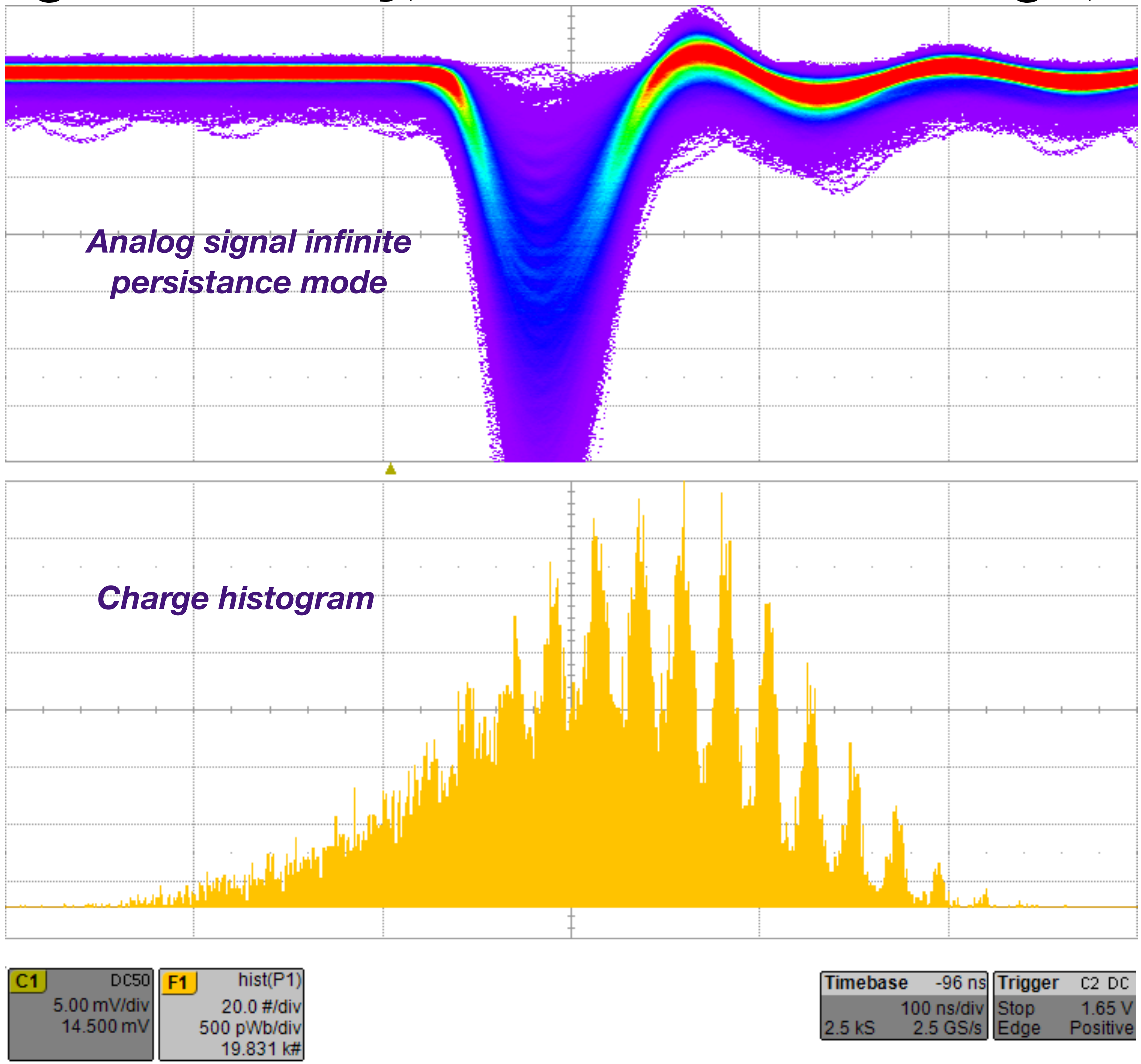

- 8 gaussian functions used to fit the charge distribution
- The gain of the array operating @ 3 V of over voltage, 175 K is ~ 2 x $10^7$
- The charge of the 1 p.e. is (3.21 ± 0.26) pC
- The overall charge noise (pedestal) is (1.47 ± **0.16**) pC

$$\sigma^2_{p.e.} = \sigma^2_{ELE} + \sigma^2_{DC} + \sigma^2_{AP} + \sigma^2_{CT} + \sigma^2_{GF}$$

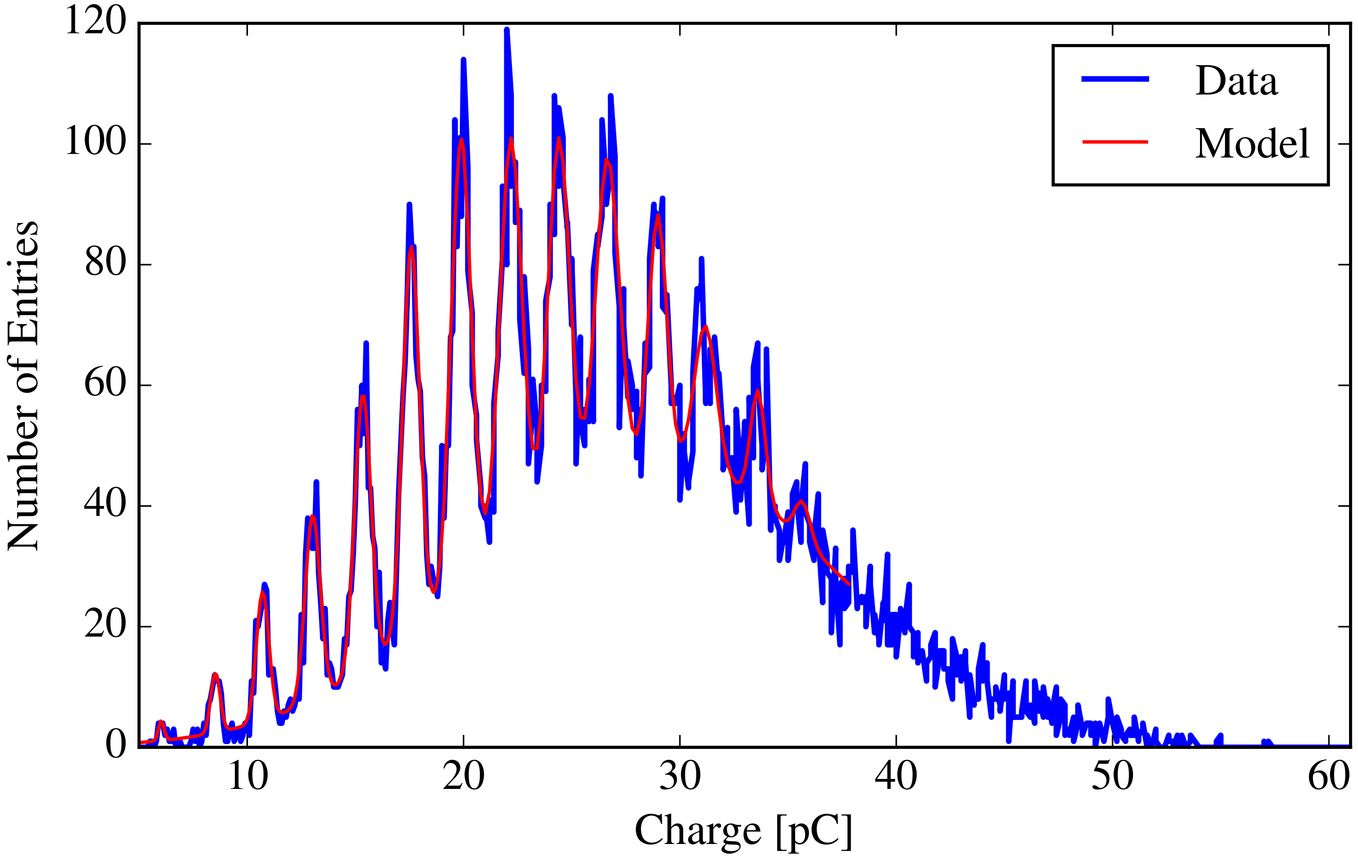
**Detector contribution is dominant**

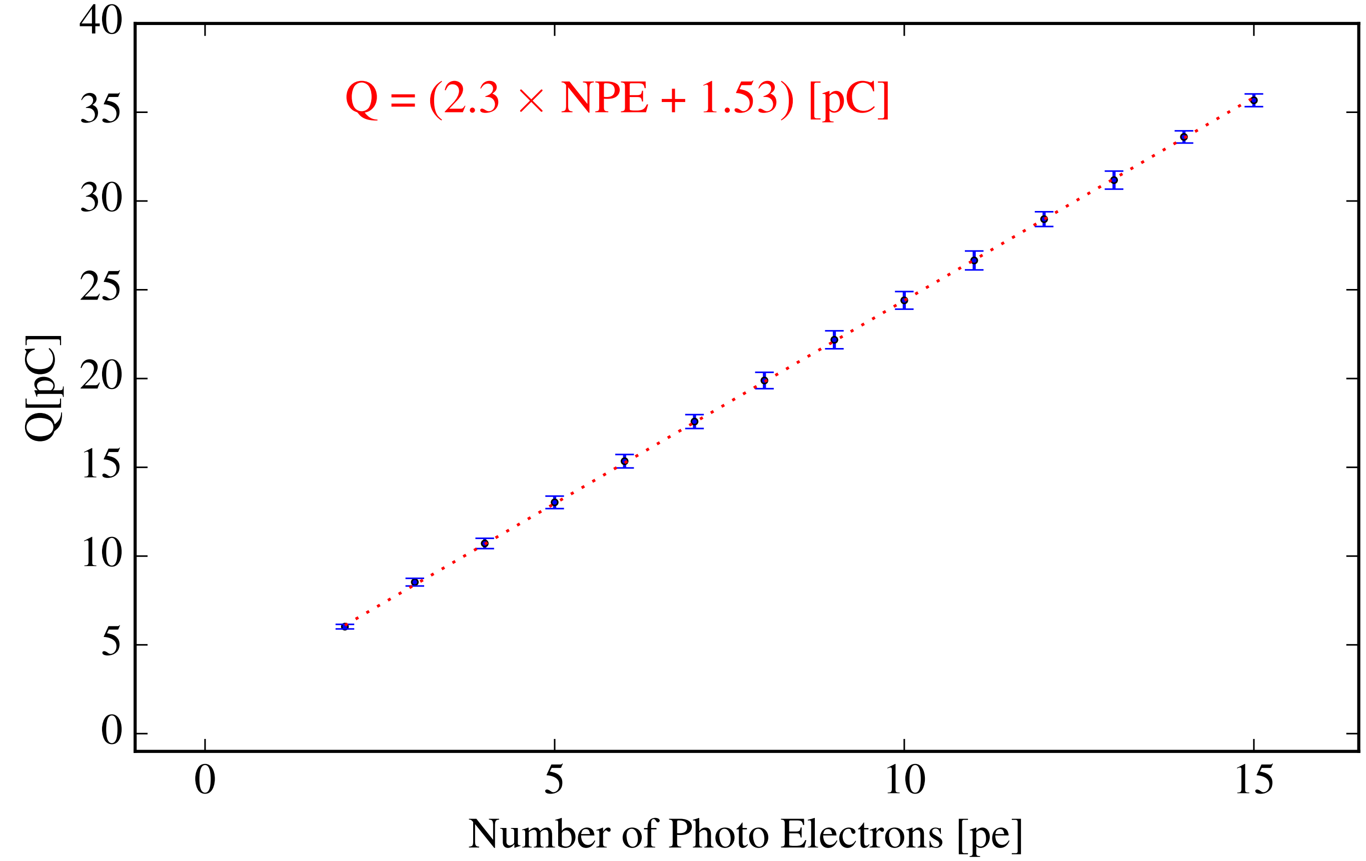
**More MPPCs can be summed up** without ruining the performance of the electronics

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



# Single photon counting capability (high light intensity)

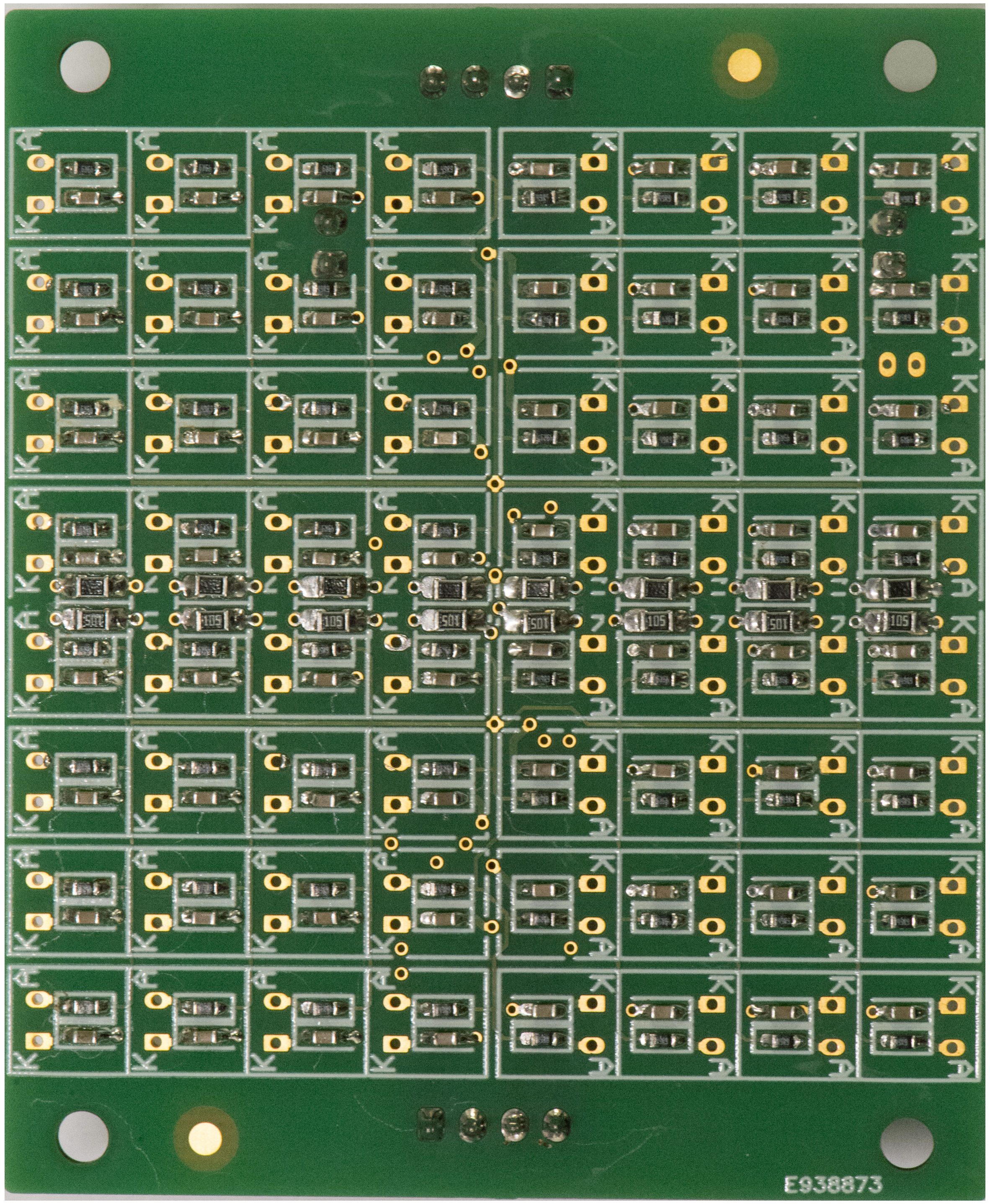


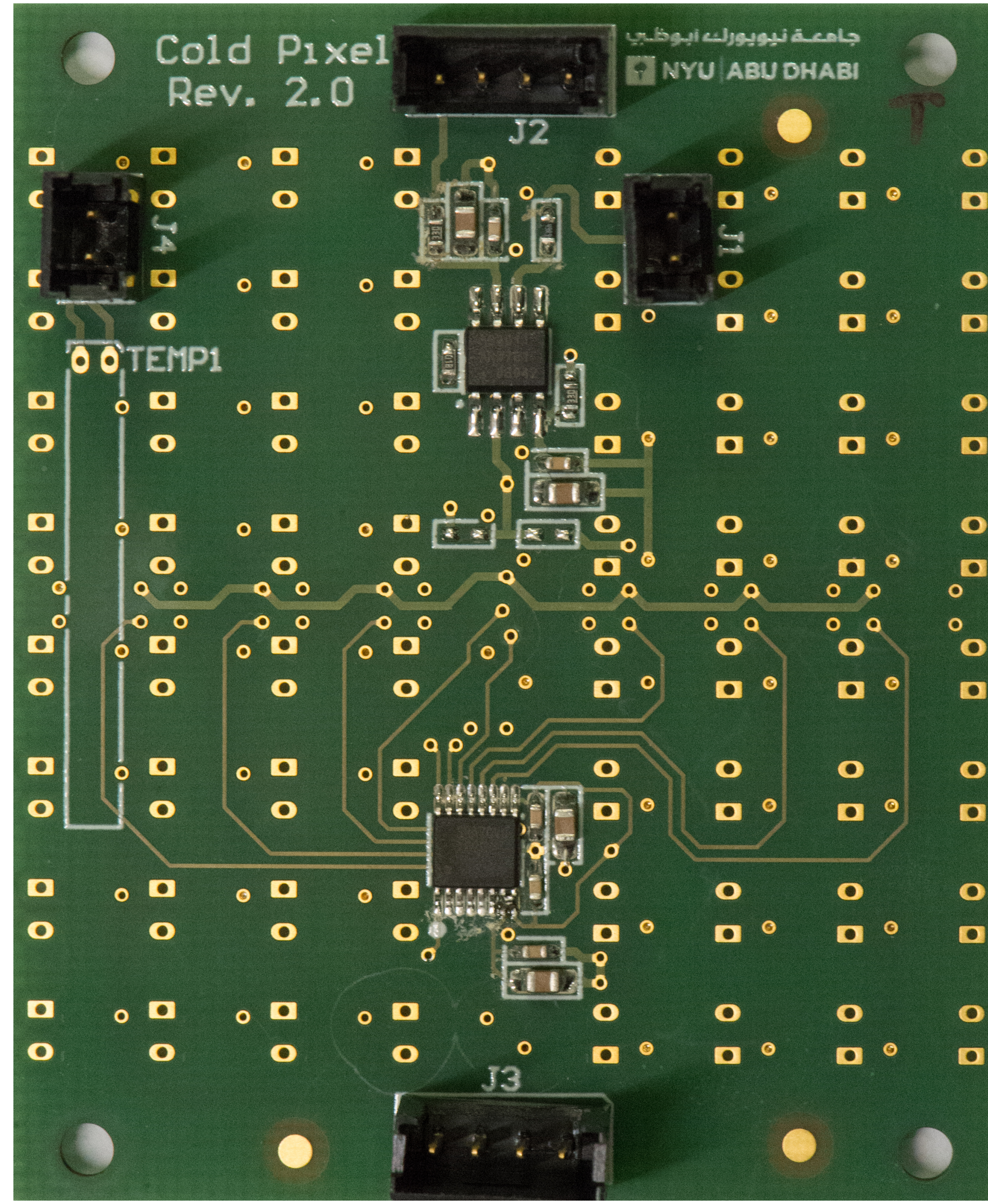




- 14 gaussian functions used to fit the charge distribution
- The gain of the array operating @ 2 V of over voltage, 175 K is ~$1.4 \times 10^7$
- The charge separation between two consecutive photopeaks is ~2.3 pC

**Distinctive charge-photopeaks distribution is preserved at higher intensity**

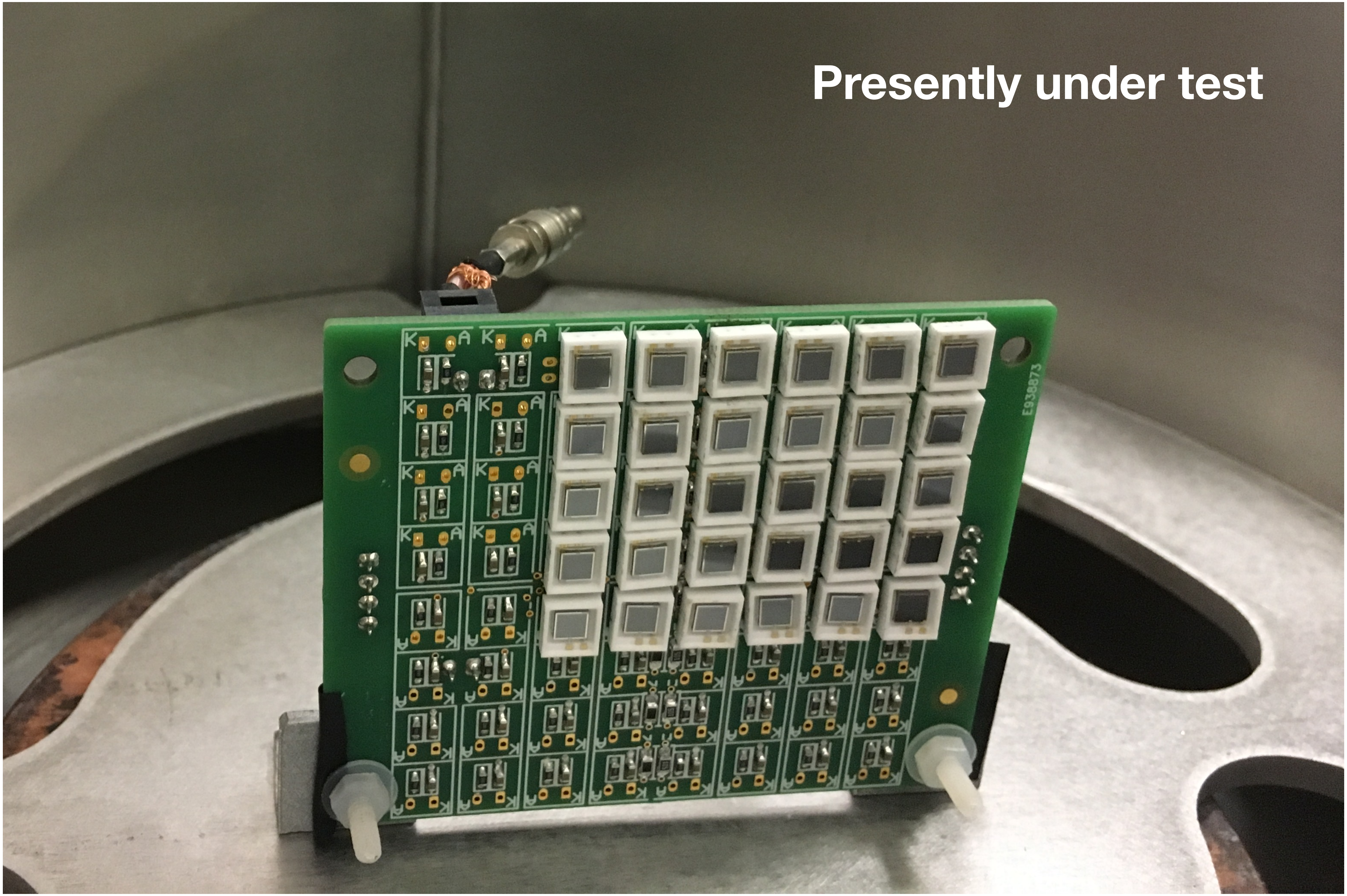
# Rev. 2.0




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

# Rev. 2.0



# Conclusions

- Our group is gaining expertise in the use of VUV(n)-MPPC families in cryogenic environment.
- We developed a cryogenic electronics to operate a “large” number of MPPCs as single detector.
- 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:

- Radio-purity screening (in measurement);
- Use of radio-pure Pyralux/Cirlex/Kapton PCBs (under investigation);
- Characterization of multiple (up to 64) MPPCs array using a VUV monochromator (coming soon);
- Test in Liquid Xenon (early 2018);
- Signal to noise ratio assessment and optimization by means of Optimum/matched filters (software anytime, hardware to be implemented).

# Thanks for the attention

- **New York University Abu Dhabi**: Francesco Arneodo, Adriano Di Giovanni, Valerio Conicella, Osama Fawwaz, Lotfi Benebderrahmane
- **Gran Sasso National Laboratory**: Attanasio Candela
- **Age Scientific srl**: Giovanni Franchi

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