Development of a SiPM based camera for LST-CTA - Update

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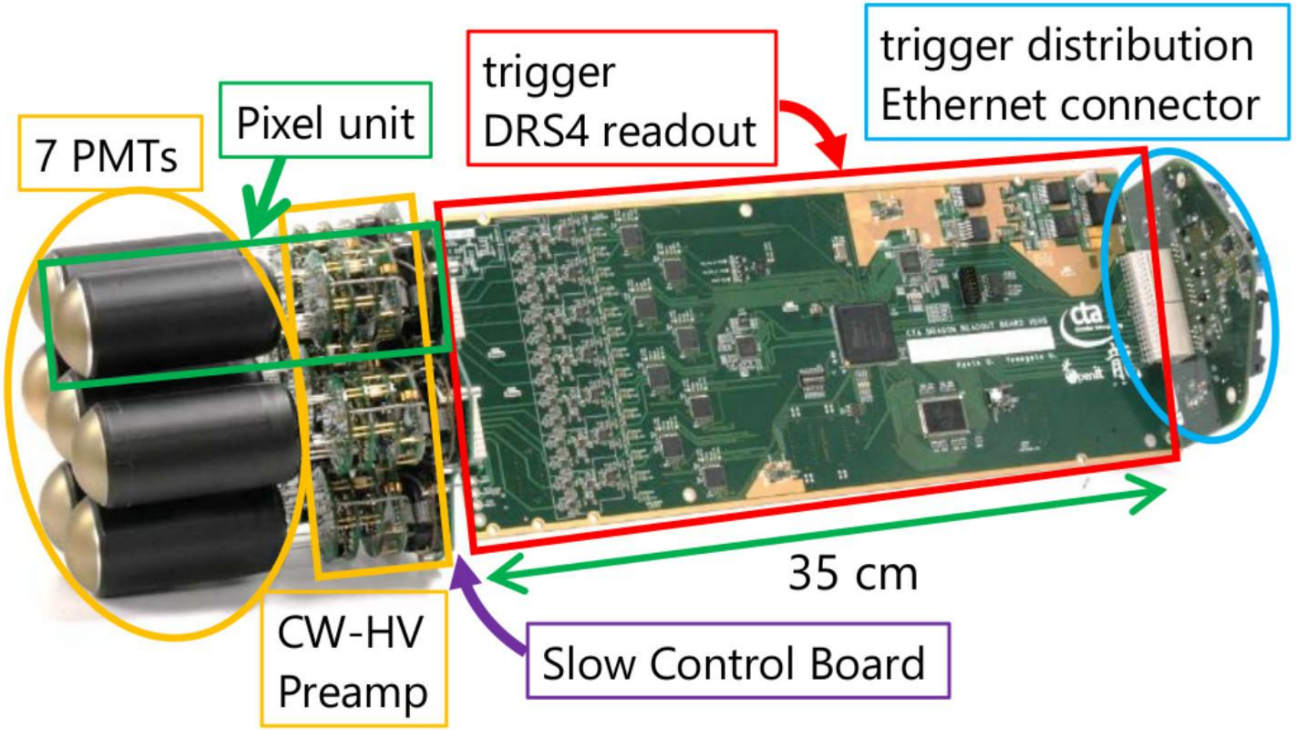
Introduction

LST SiPM-based camera prototype

- In order to contain the costs: keep most of the existing camera readout
- Replace the latest part of the electronic chain (Pixel Unit)
- Interface Board
  - Torino
  - Interface between the Slow Control Board and the
- Pixel Board
  - Padova
  - SiPM shaper and preamplifier
  - One for each PMT
- SiPM: FBK NUV HD3-2
  - Area = 6 × 6 mm^2
  - 22500 cells (150 × 150)
  - PDE peaks in Near-Ultraviolet



SiPMs vs PMTs for IACT

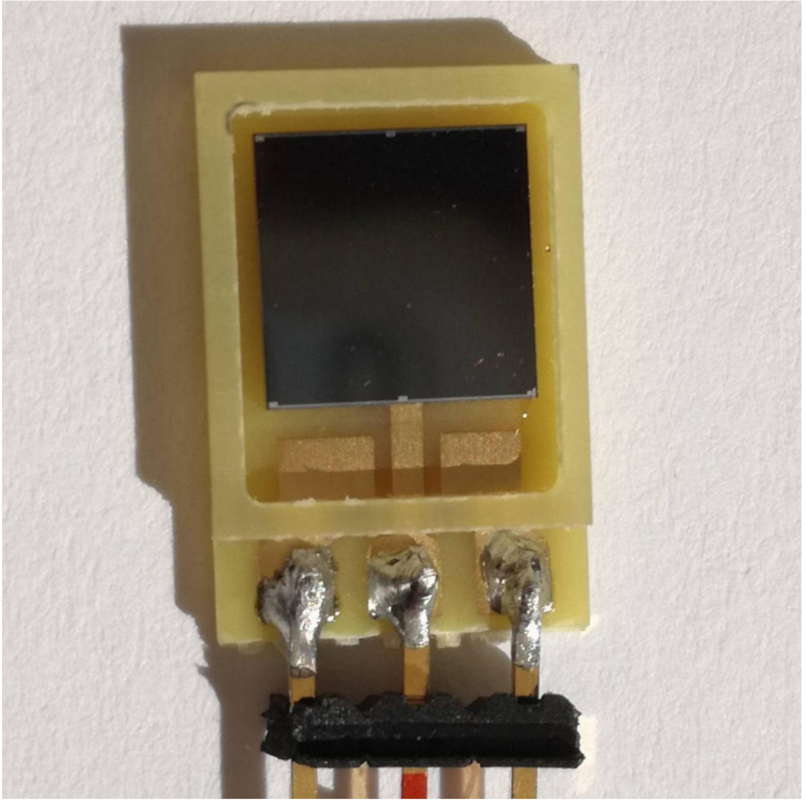
- PROs
  - Can reach Higher photon detection efficiency (PDE):
    $\longrightarrow$ lower E_γ threshold
      $\longrightarrow$ deeper in the Universe
      $\longrightarrow$ fainter sources
  - Lower Supply Voltage
  - Tolerance to high illumination level (e.g. Moonlight)
    $\longrightarrow$ increase in Duty Cycle
- CONs
  - Higher Dark Count Rate
  - Cross Talk
  - Less Narrow PDE spectrum
- In CTA SiPMs used for SSTs and dual mirror MSTs
- Challenge: SiPM for LSTs

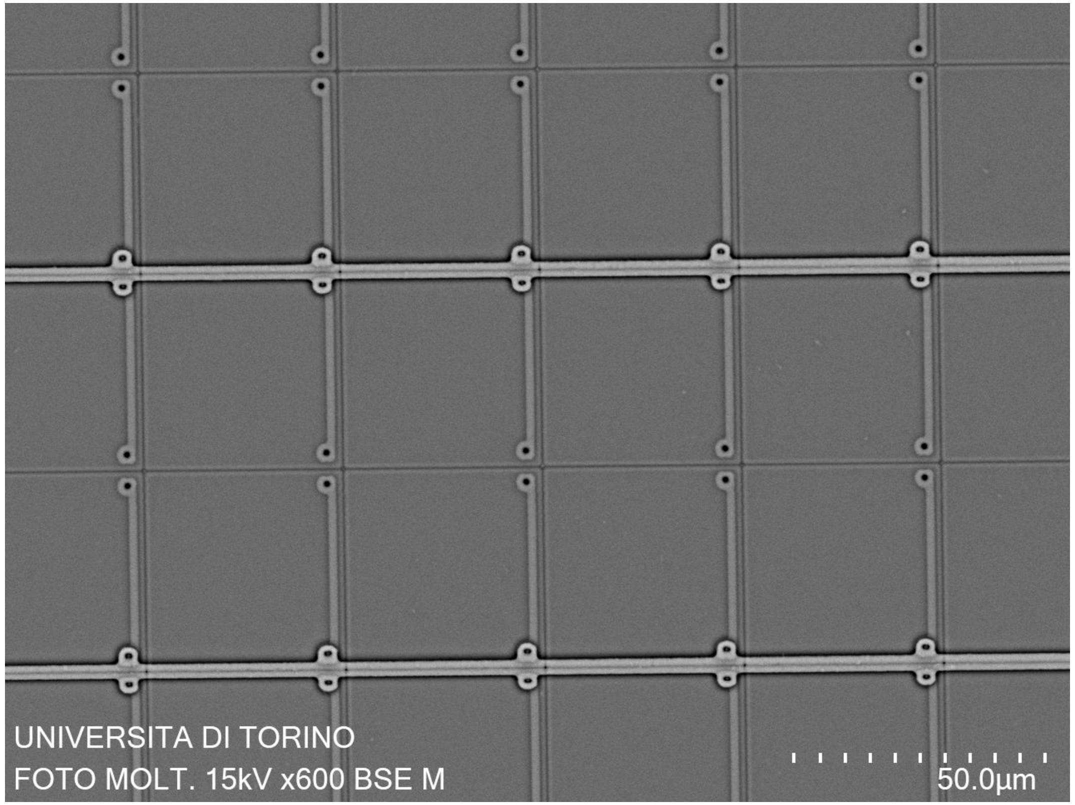
FBK NUV HD3-2 sample

FBK NUV HD3-2 Characterization

FBK NUV HD3-2

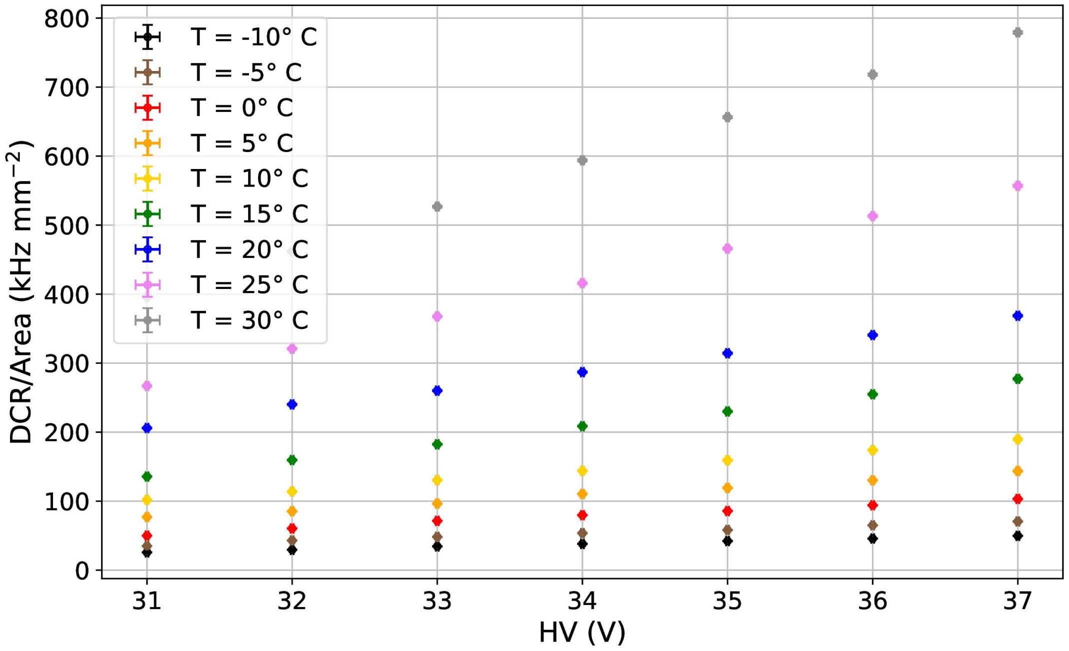
- Area = (6 × 6) mm^2 = 36 mm^2
- Cell size = 40 μm (⇒ Cells = 150 × 150 = 22500)
- Reported tests of 2 samples

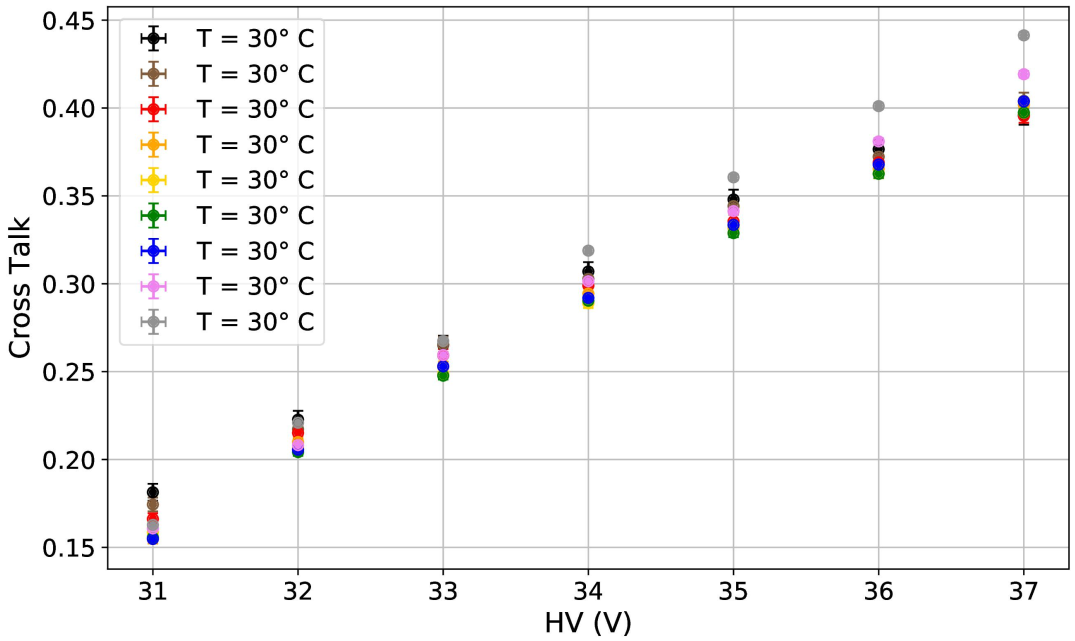




Dark Count Rate - Cross Talk

- Temperature scan from -10℃ to 30℃ with a step of 5℃
- $DCR = CNT_{0.5pe}/t$
- $CT = CNT_{1.5pe}/CNT_{0.5pe}$

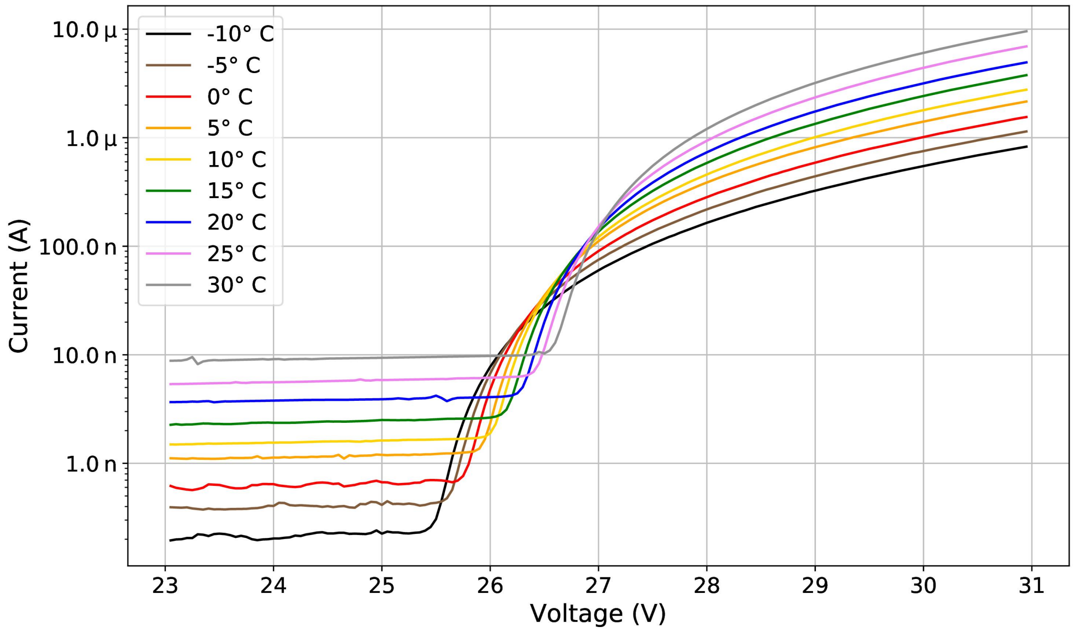


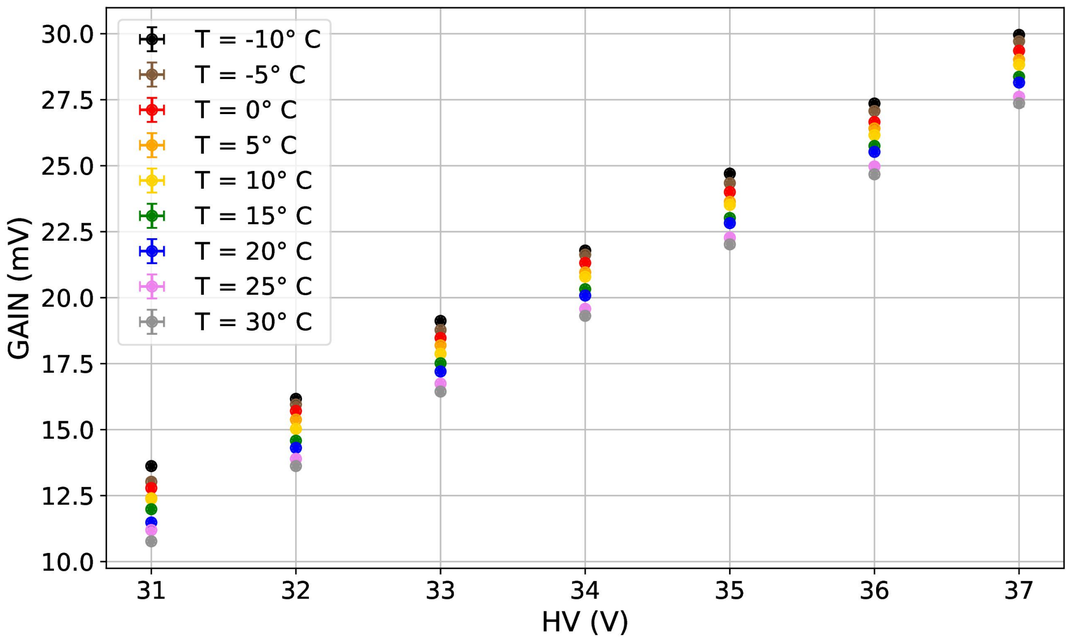


Breakdown Voltage vs Temperature

- From I-V Curve
  - *max(dI/dV I)*
  - From √I vs V_{bias} plot

- From GAIN: value at which the linear fit to the GAIN vs V_{bias} = HV plot intercepts the abscissa axis (i.e. GAIN = 0)

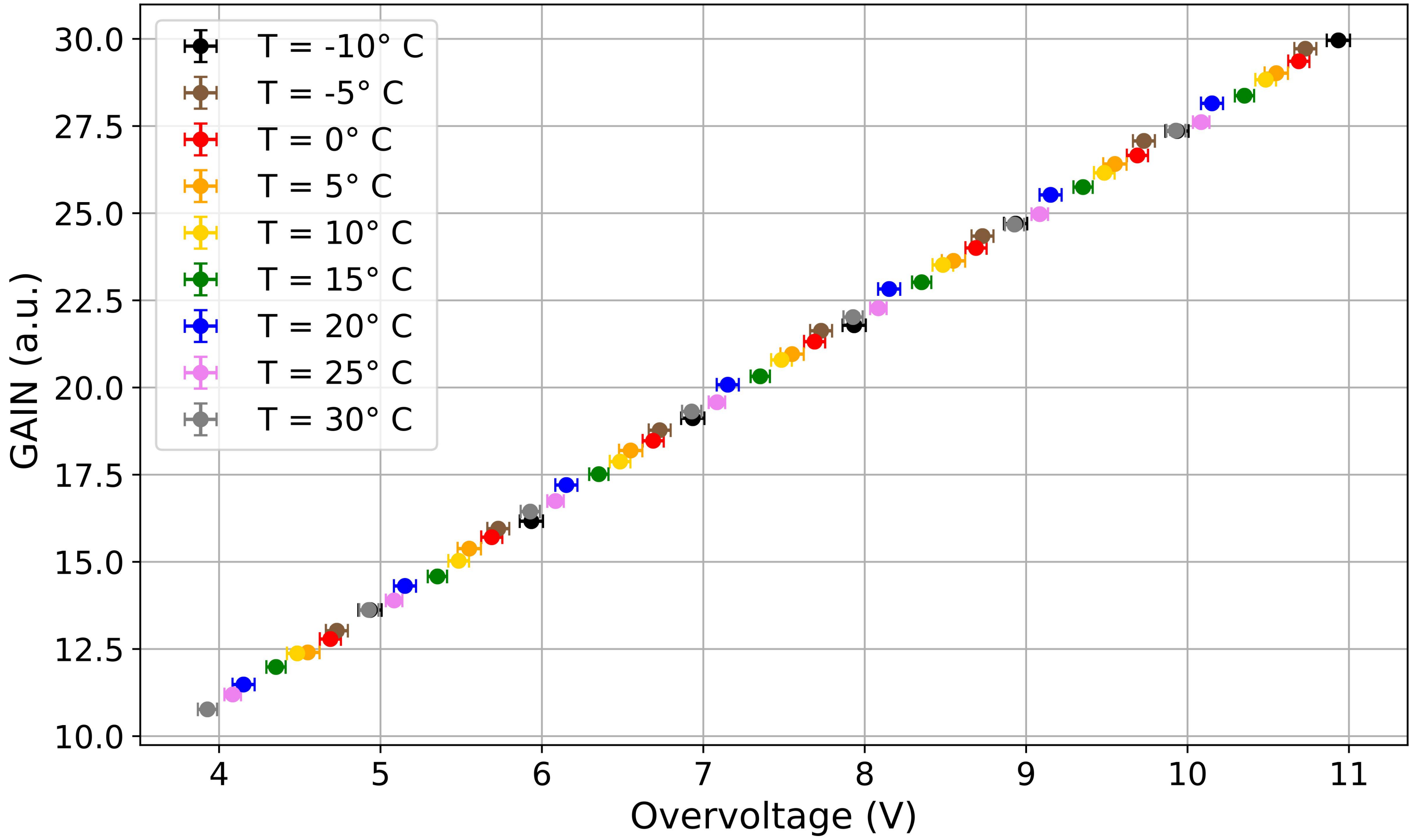




$$\frac{dV_{bd}}{dT} = (26 \pm 1)\ \mathrm{mV/°C}$$

Gain - Temperature Compensation

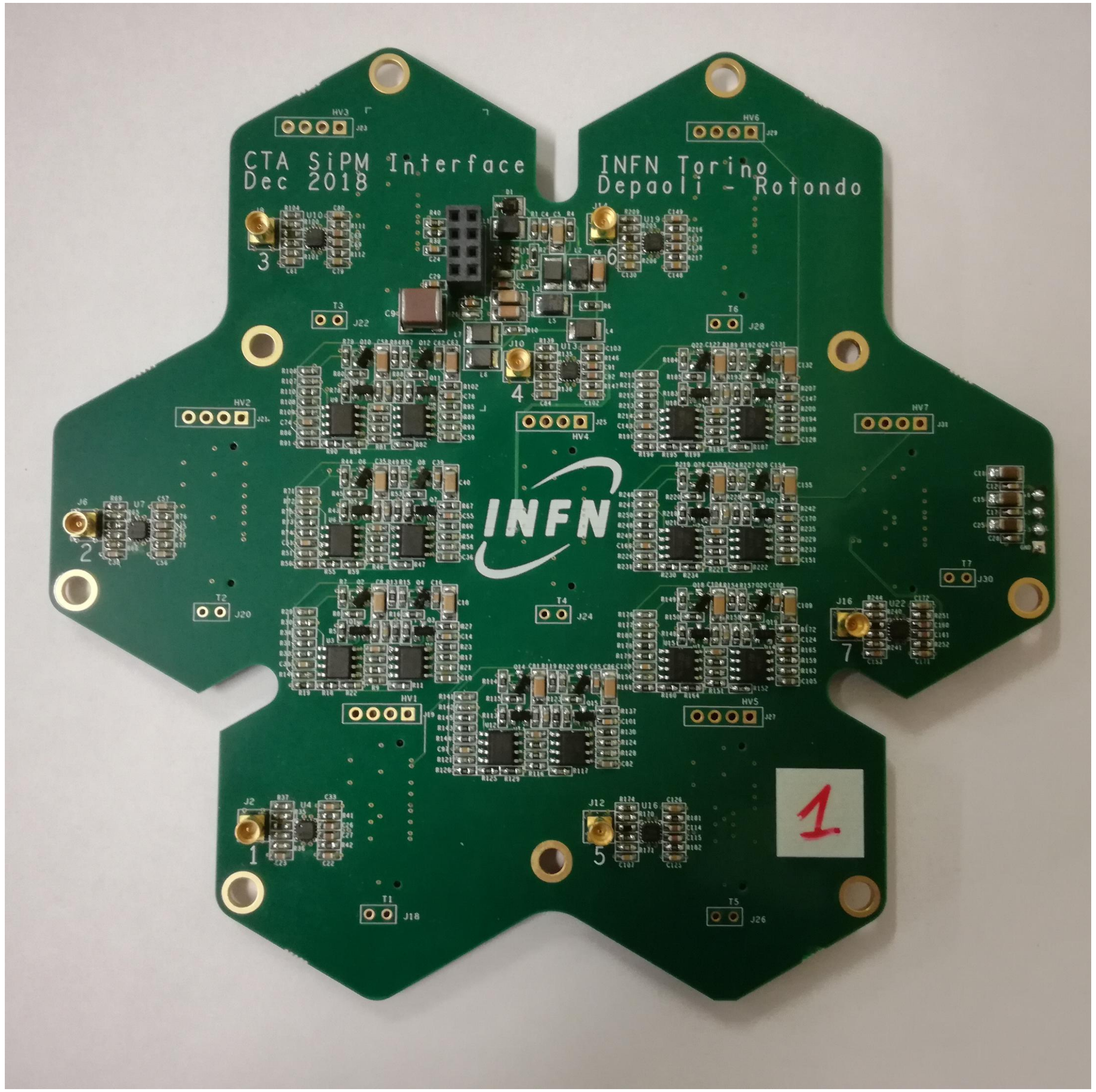
- Overvoltage is defined as $V_{OV} = V_{bias} - V_{bd}(T)$
- Knowing the dV_{bd}/dT and the T it is possible to control the SiPM gain



Interface Board

Interface Board

- Provides HV for SiPM
  - HV = 0 ÷ 40 V
  - Sensitivity = 10 mV
- Reads HV on SiPM and the Current in the channel
- Adapts the Single Ended Signal (Pixel Board) to Differential (DRAGON)
- One DC-DC converter for 7 channels
  - LT3467 + Filter
    - Cheap
    - Max current = 20 mA
  - CAEN A7585
    - Expensive (≈ 300 €)
    - Max current = 10 mA



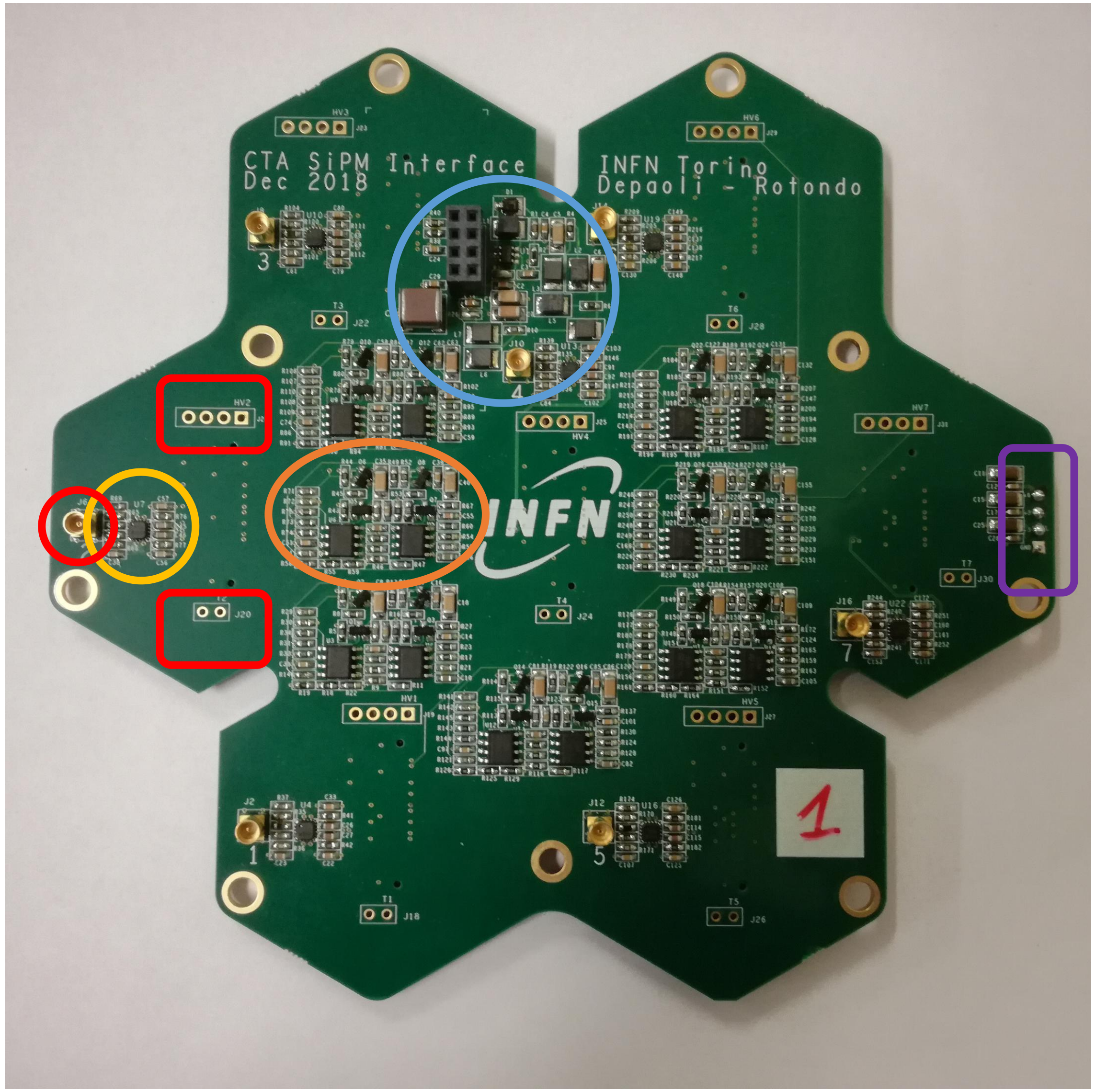
Interface Board

Printed Board

- DC - DC converter + Filter

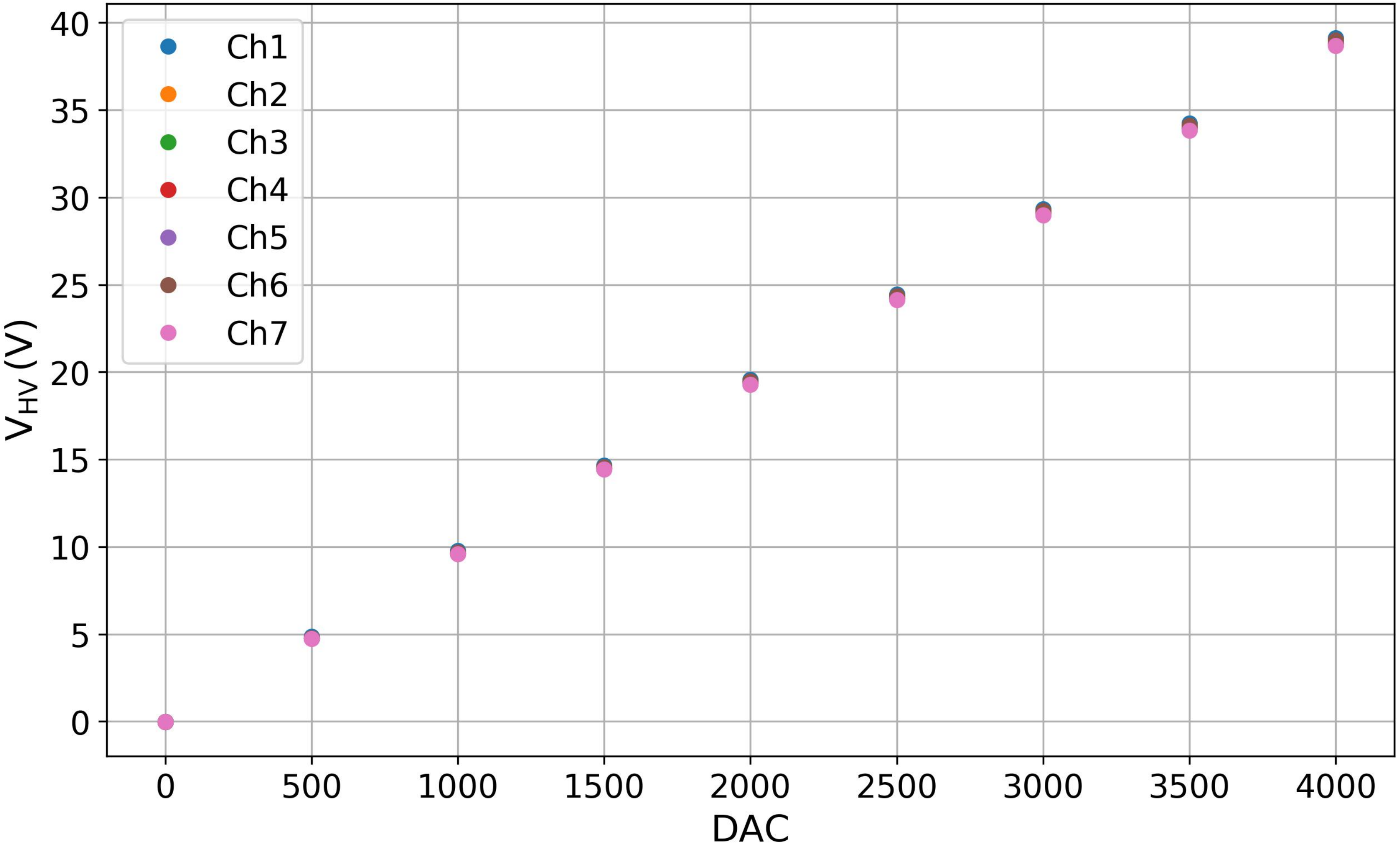
For each channel:

- Regulator and Monitor
- Single to Differential
- Connection to Pixel Board
- Connection to Slow Control Board



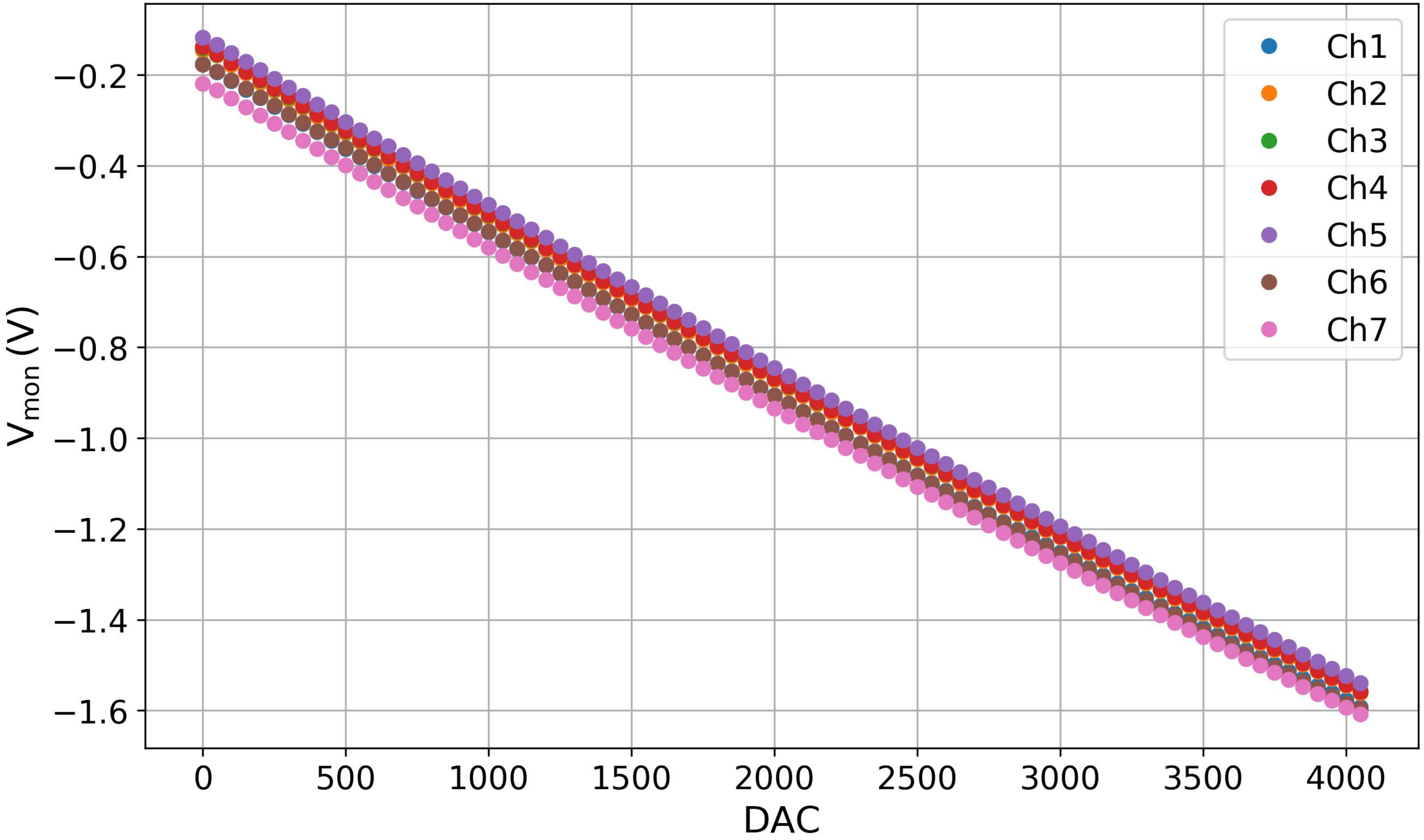
Vset and Vhv

- Set DAC V_{set} and measure HV on channels (Fluke Multimeter)



Vset and Vmon

- Set DAC V_{set} and read V_{mon} (necessary to set and control HV on SiPM)



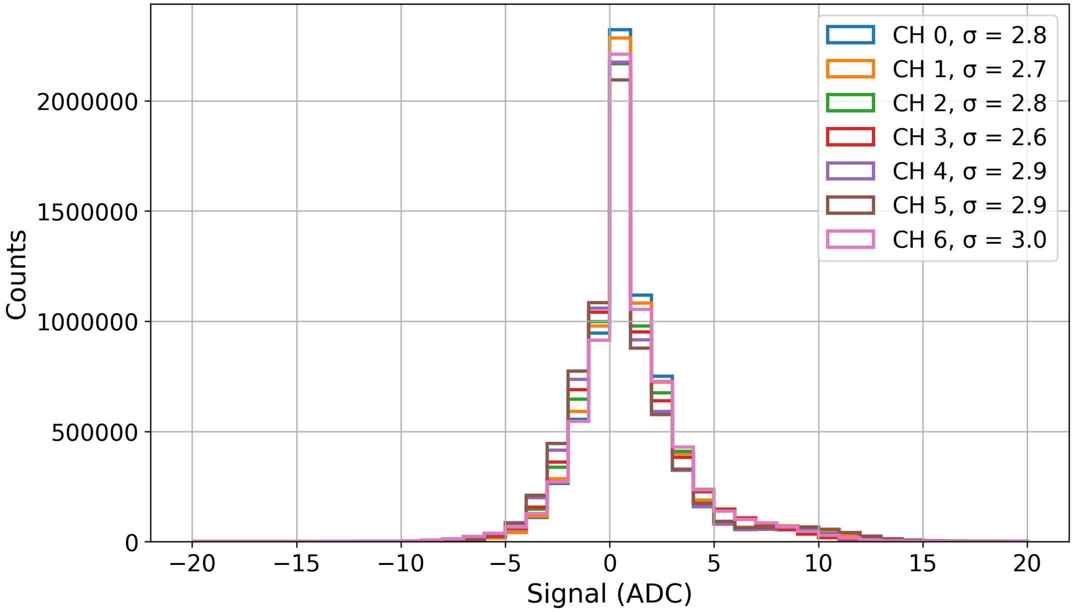
LST DAQ Setup

- DRAGON board firmware: **dv5_3_00_07**
- Slow Control: **DRAGON_QCV7.04**
  - Set DAC
  - Read ADC
  - Set trigger mode
  - ...
- Data acquisition: **EVB v3**, file saved in **.fits.fz** format
- Offline data analysis: **cta-lstchain** (https://github.com/cta-observatory/cta-lstchain)

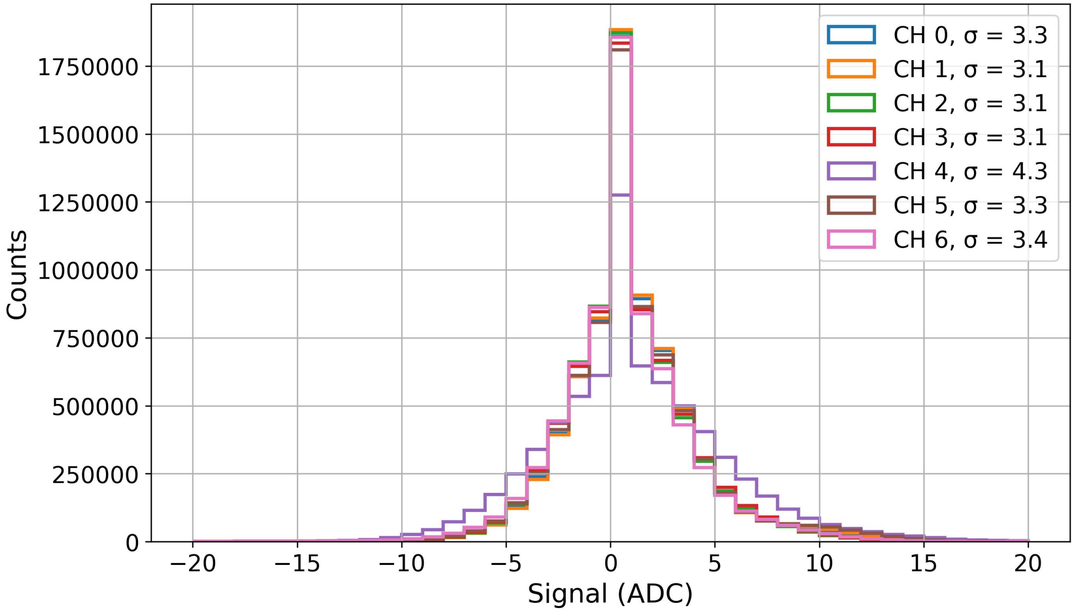
We thank Dirk Hoffman and Julien Houles for their help in setting up the DAQ and Taka and Seiya for the new firmware, Pawel Gliwny for the help in the low level calibration

Pedestal

- Interface Board Unconnected



- Interface Board Connected, DAC = 3500 for all 7 channels (HV ≈ 34 V)

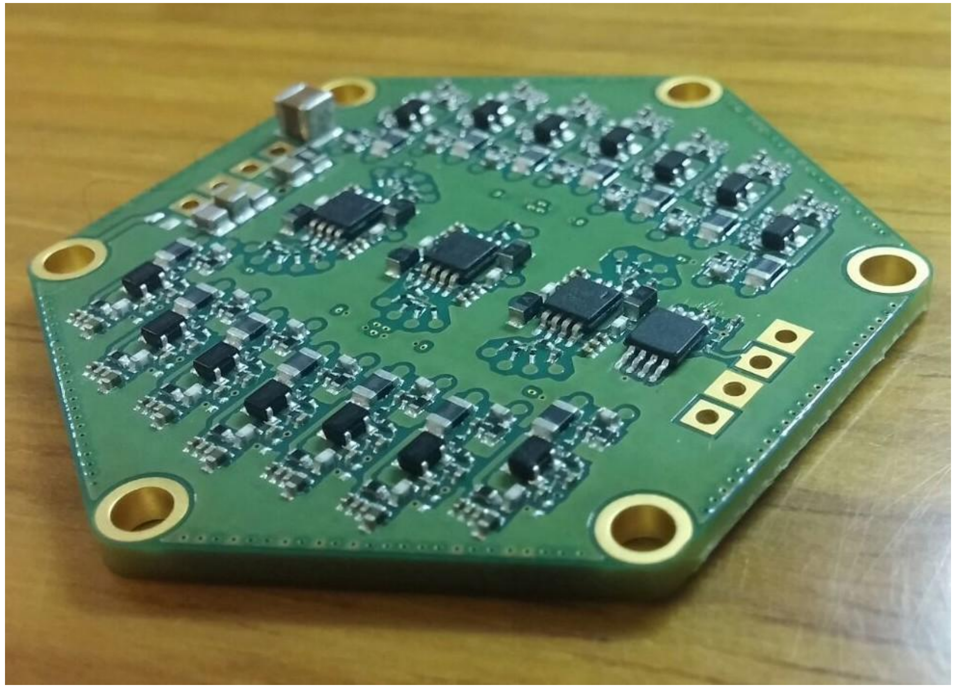


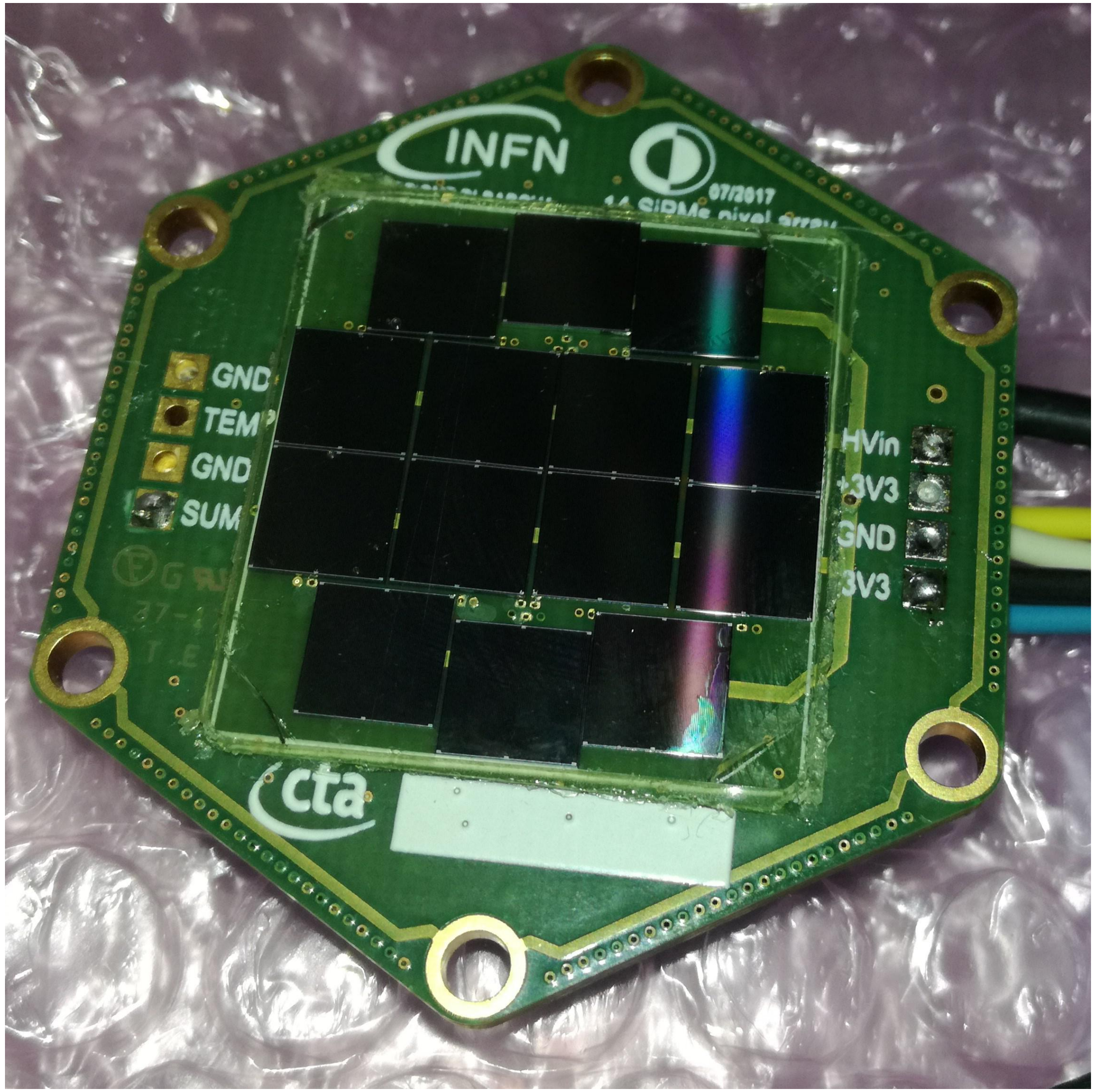
- Slight increase with the IB connected (as expected)
- Good results

SiPM Pixel

SiPM Pixel - Padova

- Designed at Padova
- 14 FBK HD3-2, 6x6 mm^2, 40 µm cells
- SiPM signals are shaped and summed together, fast signal
- Discrete components





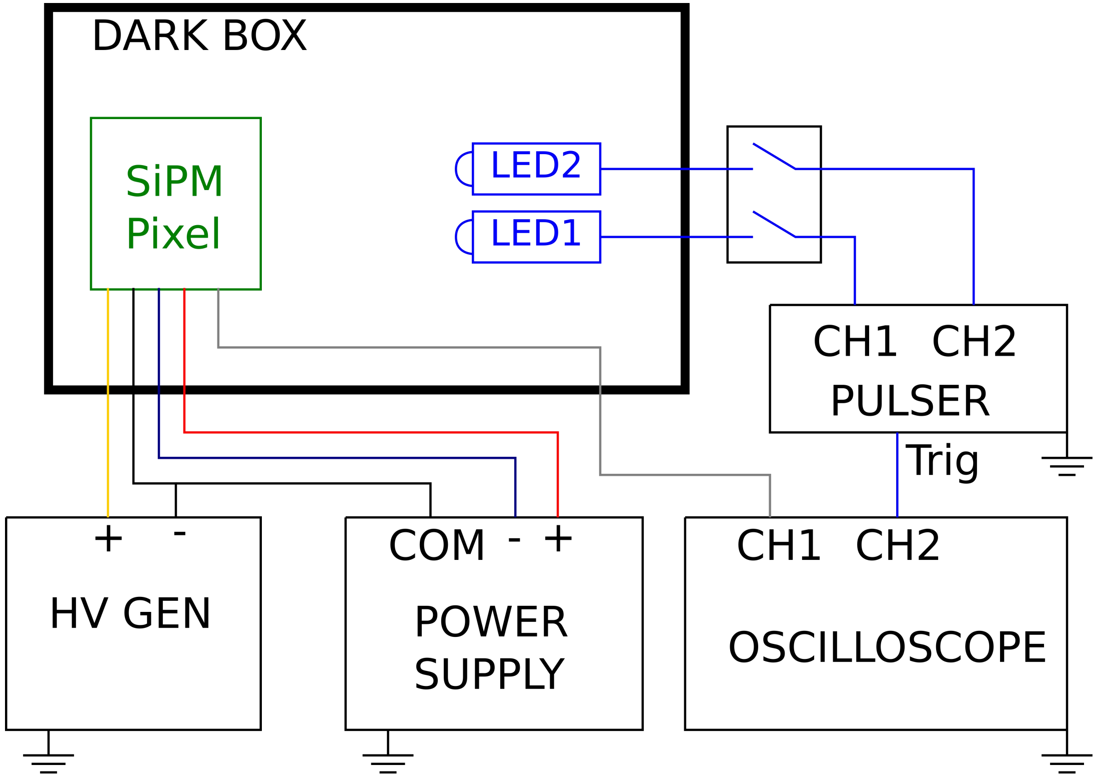
Linearity

- Double LED technique
- Linear if the Signal obtained with both LEDs is equal to the sum of the signal obtained with only one LED at time
- Deviation from Linearity defined as:

$$LinDev = \left(\frac{Q(LED_{12})}{Q(LED_1) + Q(LED_2)} - 1 \right) \times 100$$

where $Q(LED_1)$ is the charge with only LED1 firing, $Q(LED_2)$ with LED2 and $Q(LED_{12})$ with both LED1 and LED2

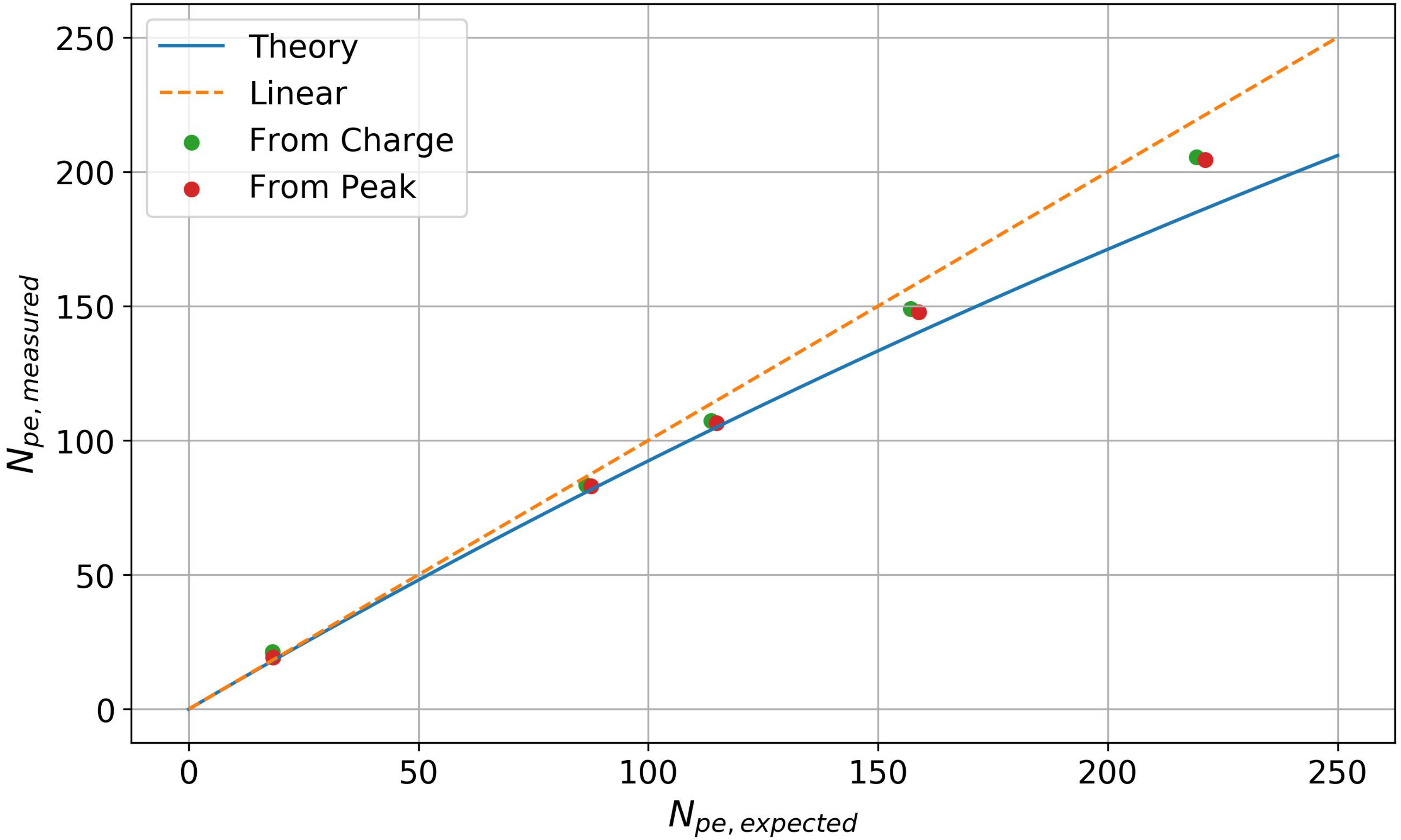
- LED pulse ≈ 10 ns
- Not calibrated in photoelectrons



Check on Advansid 1x1 mm^2, 625 cells

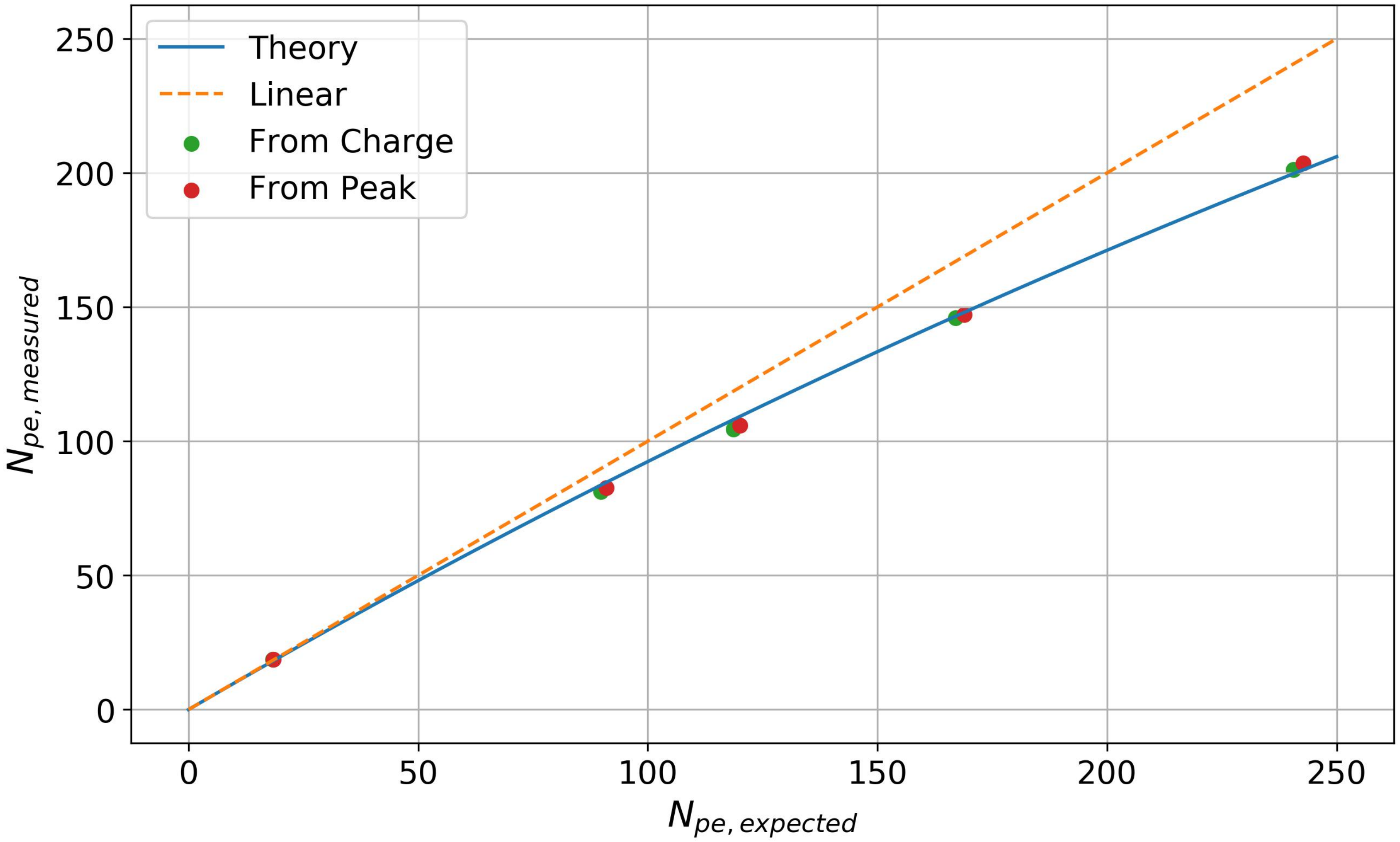
- $N_{pe,expected}$ from LED1+LED2
- $N_{pe,measured}$ from LED12

$$N_{pe,measured} = N_{cells,tot} \times \left(1 - e^{-\frac{N_{pe,expected}}{N_{cells,tot}}}\right)$$



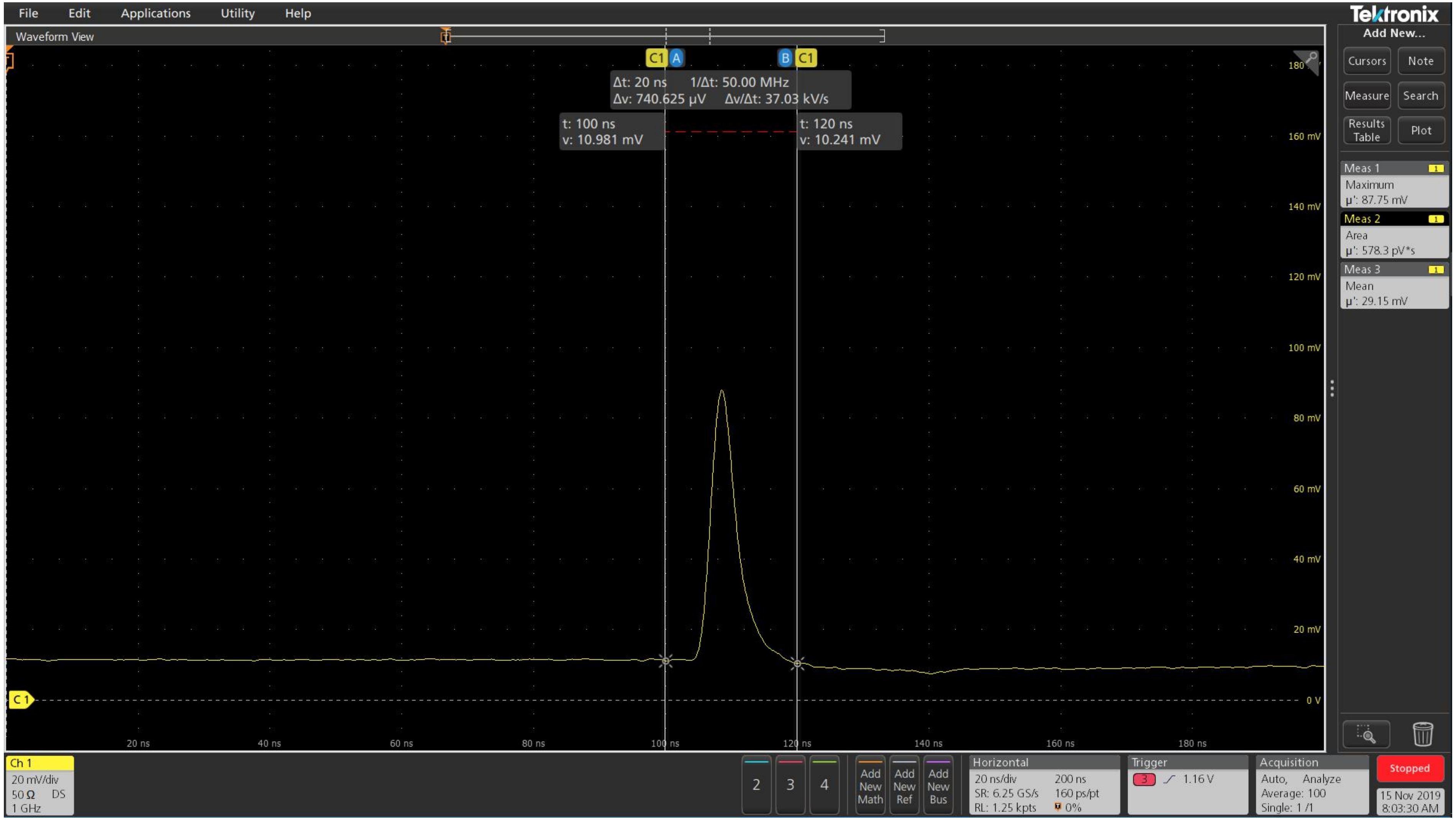
Check on Advansid 1x1 mm^2, 625 cells

- After saturation correction:



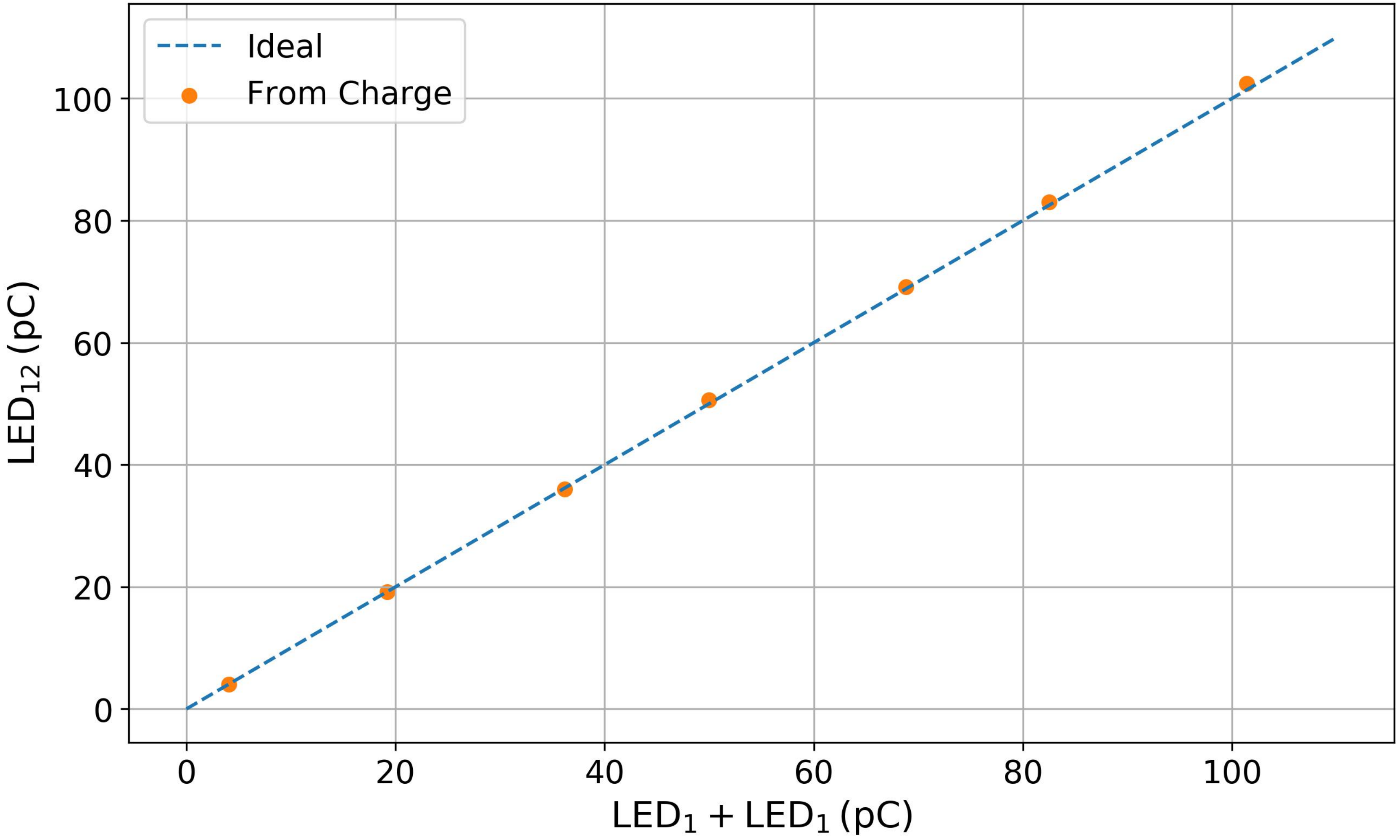
Linearity - Signal Example

- Illuminating the Pixel with a fast LED pulse, average on 100 waveforms (x 6 times)



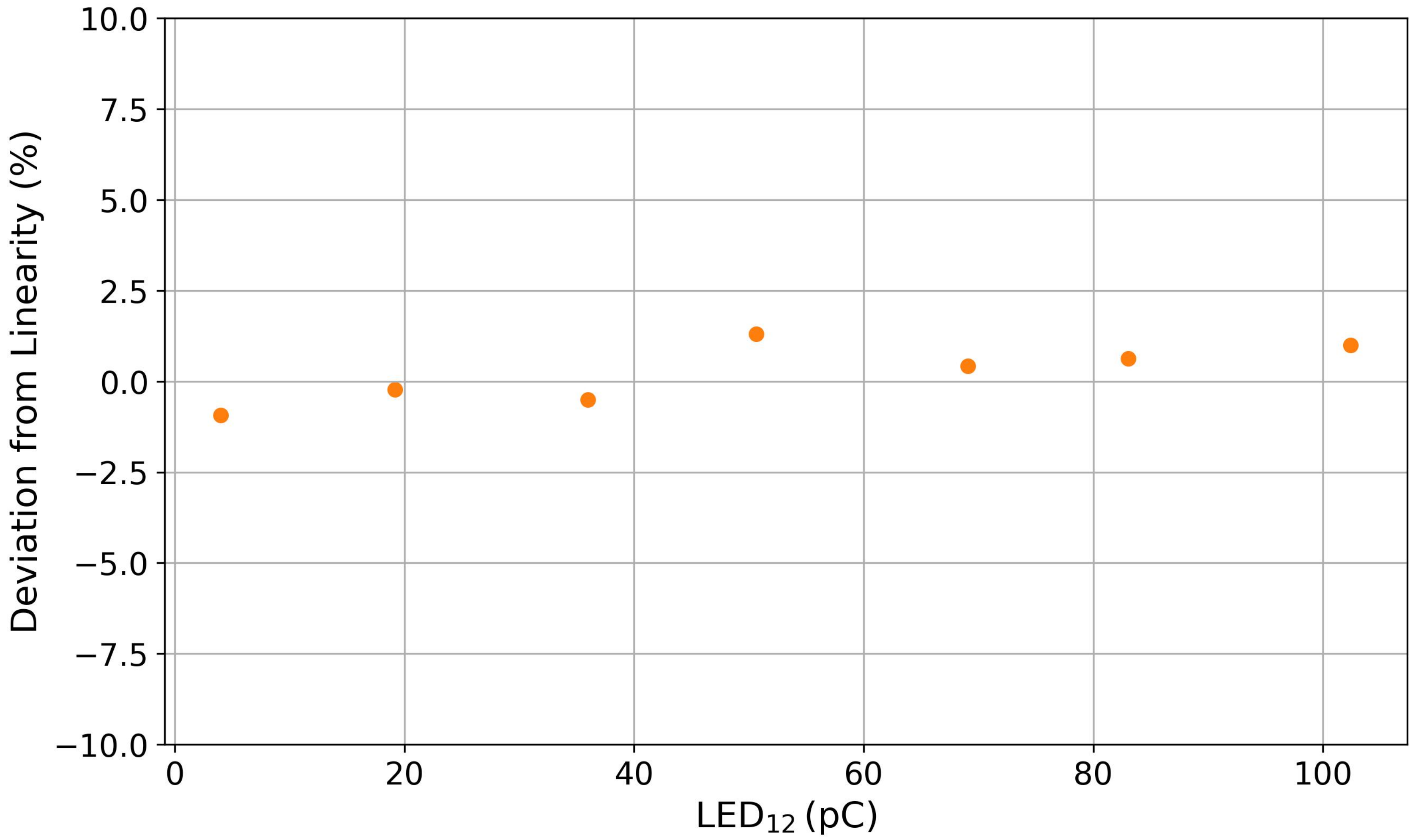
Linearity - Preliminary Results

- $Q(LED_{12})$ vs $Q(LED_1)+Q(LED_2)$



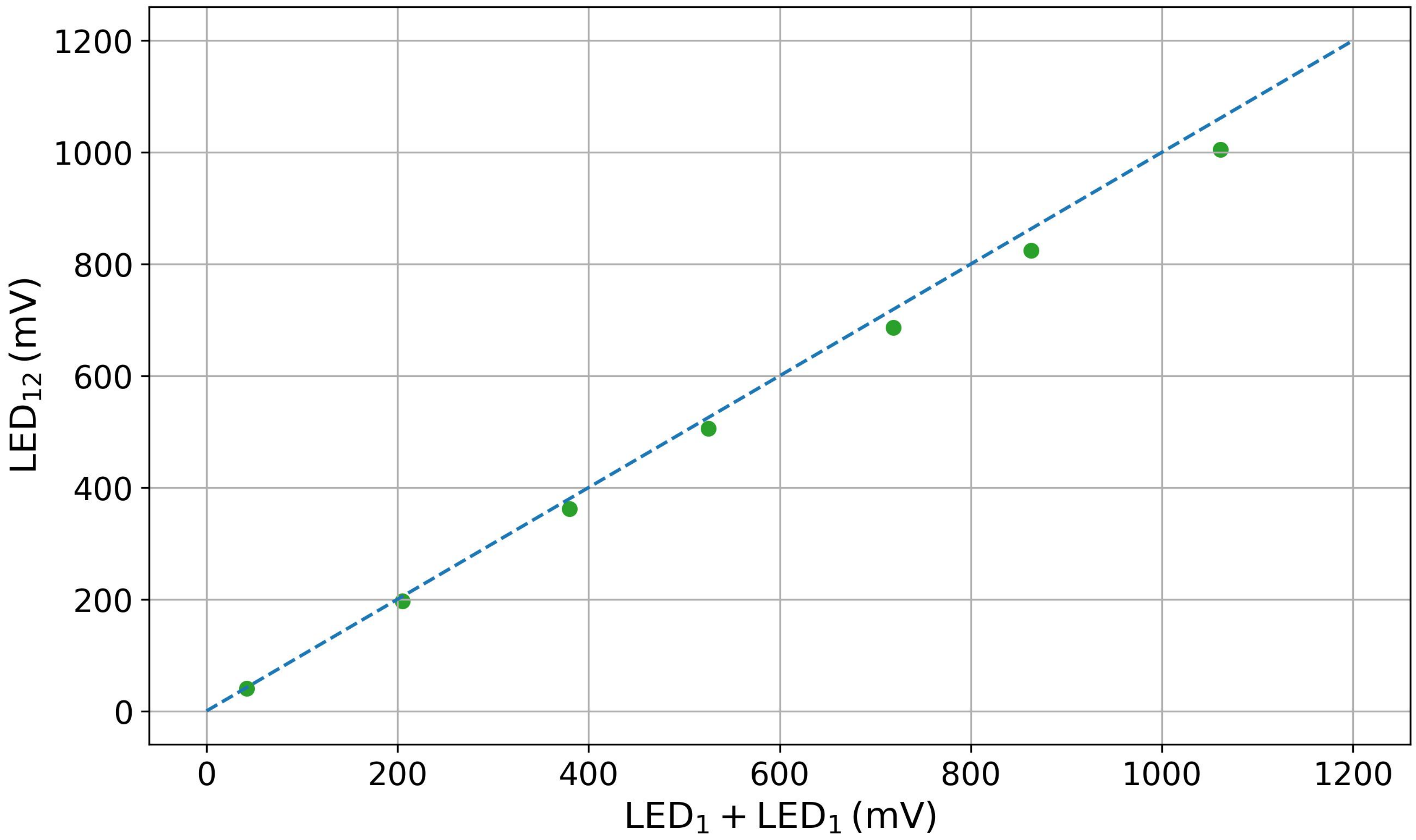
Linearity - Preliminary Results

- Deviation from Linearity (%) vs Q(*LED_{12}*)



Linearity - Preliminary Results

- Considering the signal peak, we see a deviation from the linearity (as expected):

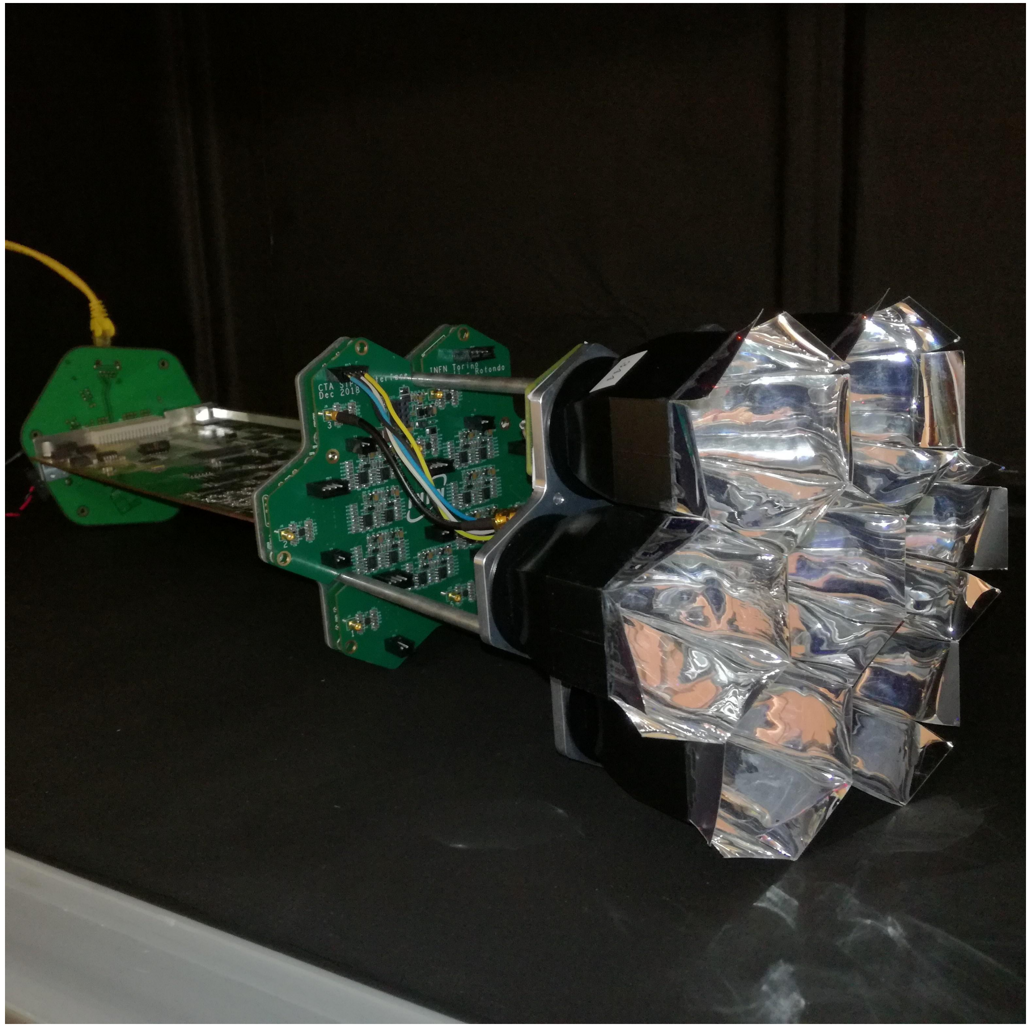


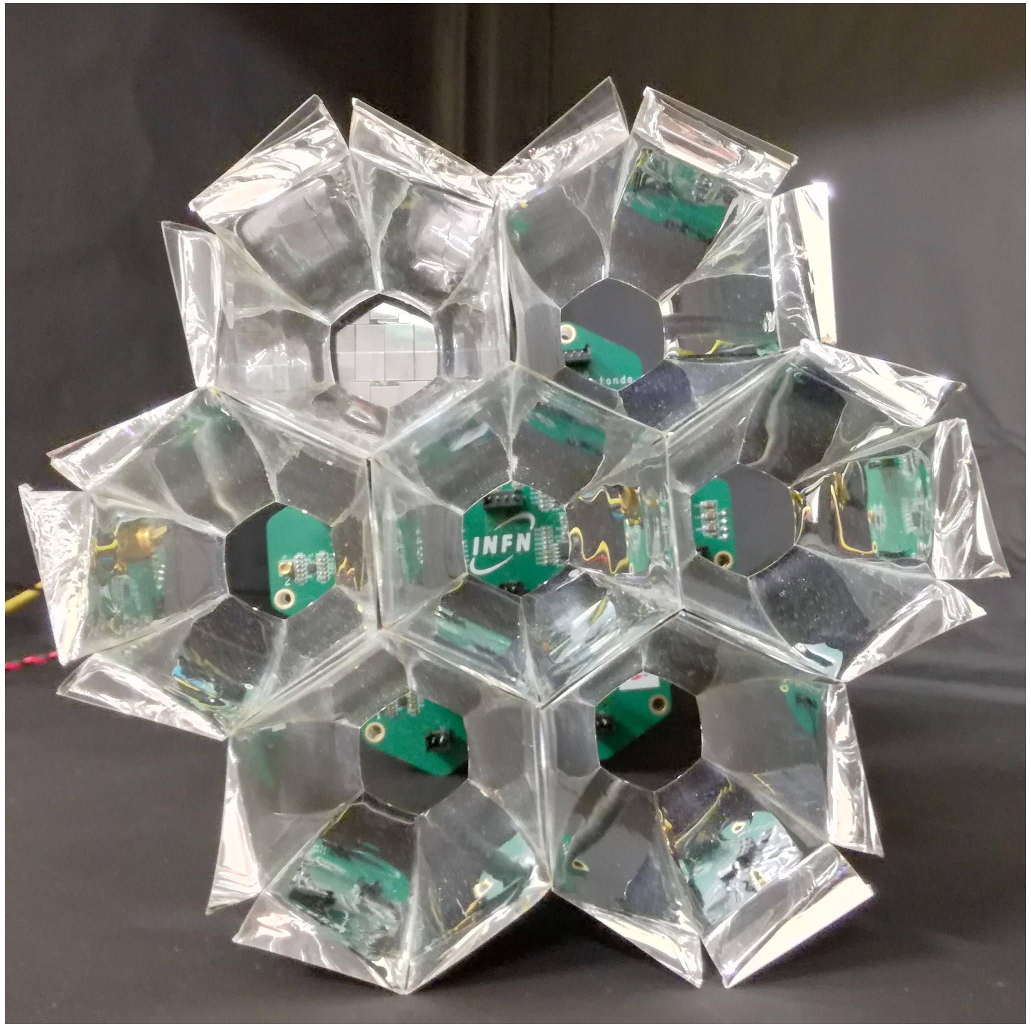
Linearity - Preliminary Results

- The Pixel seems to be linear
- Since we deal with fast signals, it is necessary to consider the signal **charge** (the LED pulse duration is similar to the air Cherenkov one)
- We will redo this measure with an automatic system, in order to get more statistics

LST DAQ Setup

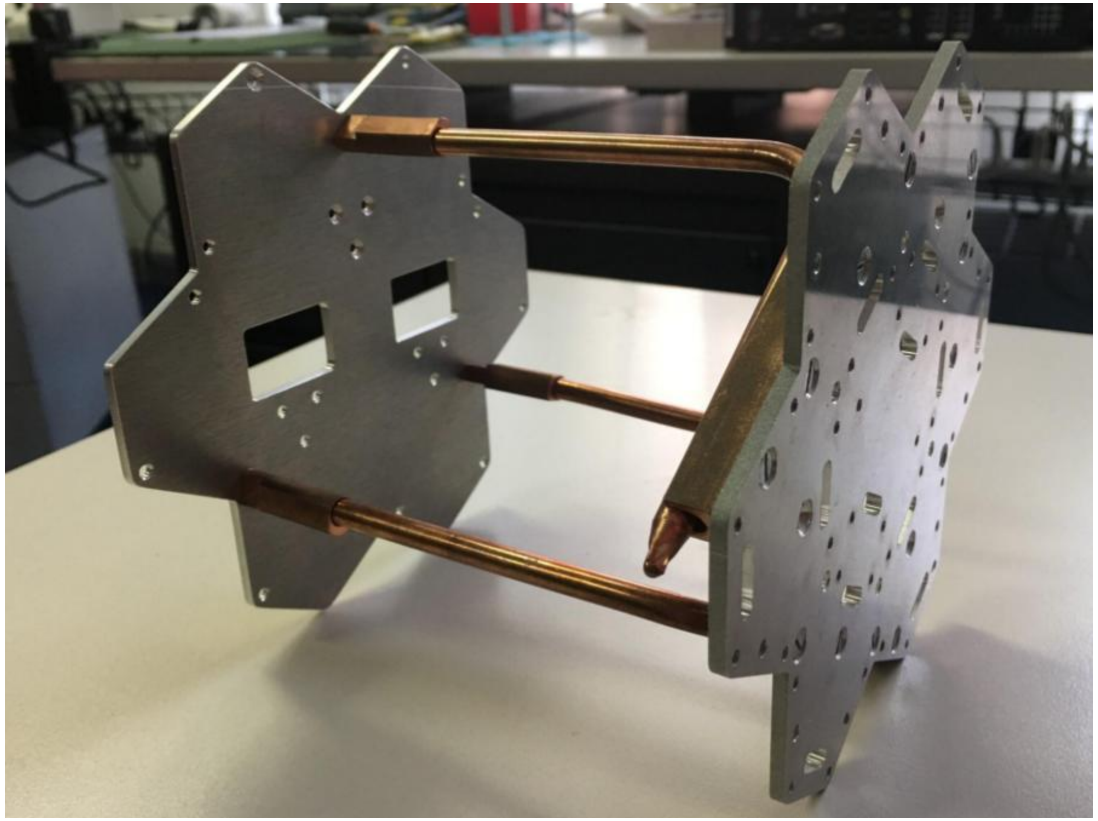
- DRAGON + Slow Control Board + Interface Board + SiPM Pixel

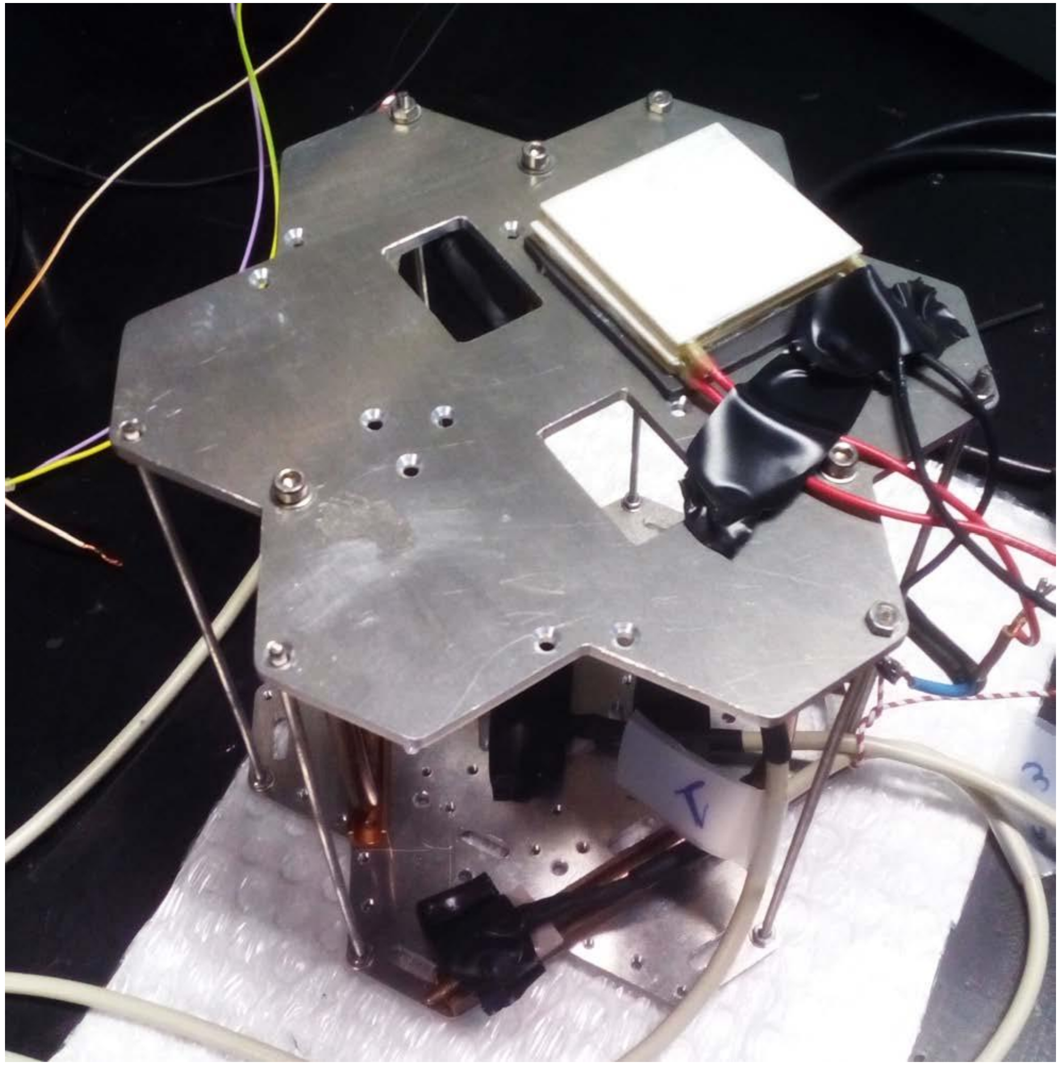




Heat Pipes and Thermal Study

- To keep constant the SiPM temperature (in addition to the T compensation):
  - Passive Heat pipes
  - Additional cooling systems (Peltier)

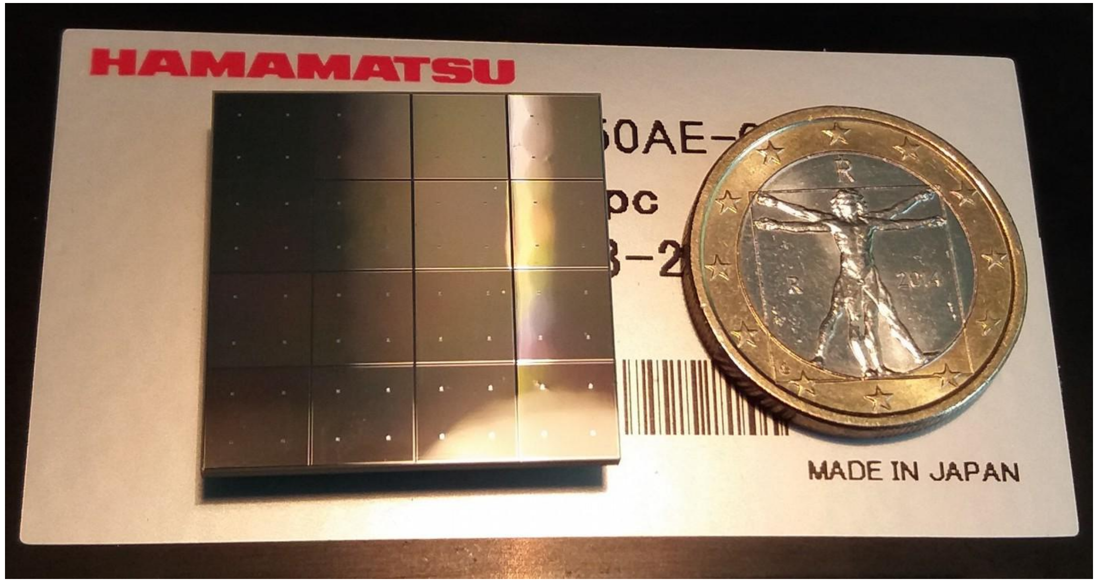


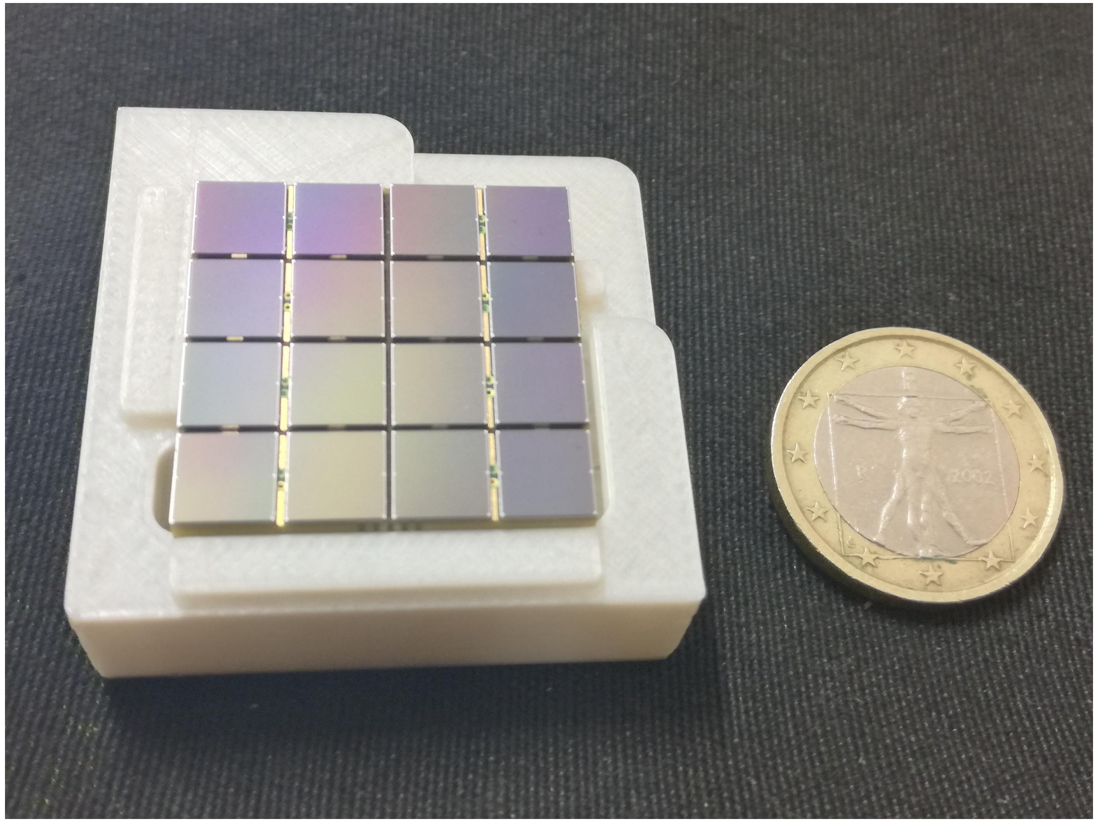


SiPM Pixel Development

SiPM Pixel - New Version - SiPMs

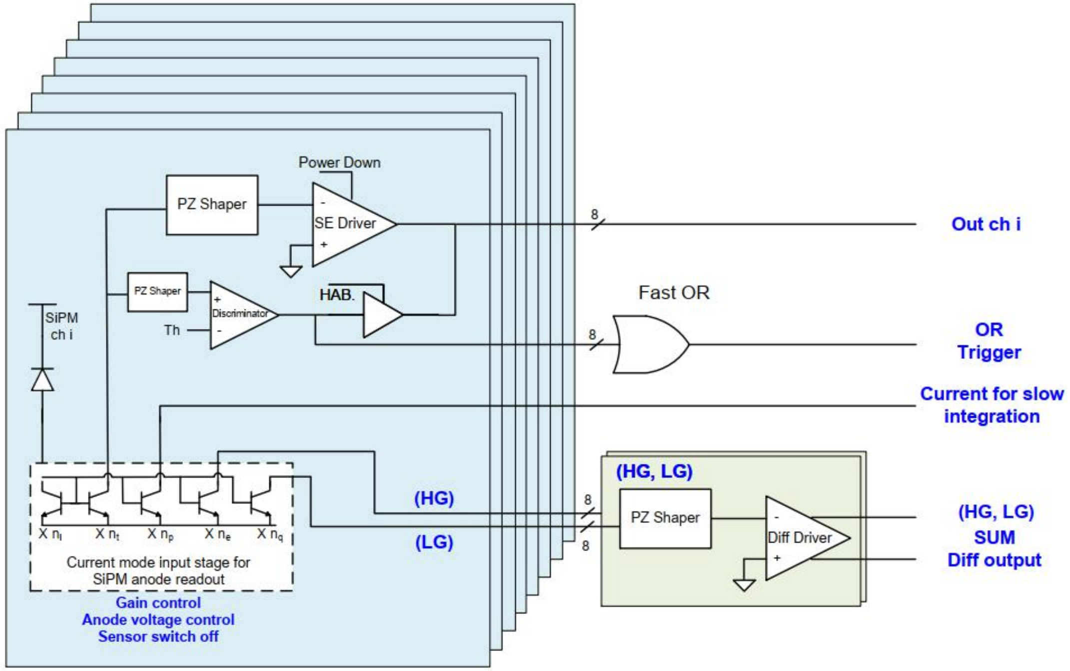
- Different SiPMs
  - newer FBK NUV
  - Hamamatsu (higher V_{bd})
  - ....
- Maybe sum “only” 12 SiPMs
- Add a Filter





SiPM Pixel - New Version - Circuit

- The idea is to use an ASIC (e.g. MUSIC, evolution of the DarkSide one, ...)
- MUSIC ASIC
  - 8 input channels
  - Sum output (with or without Pole/Zero)
  - BW ≈ 500 MHz
  - Shaped output (≈ 10 ns) a bit too long for our requirements: it is necessary to design a custom filter
- Two different gain stages (High Gain and Low Gain)
- ...



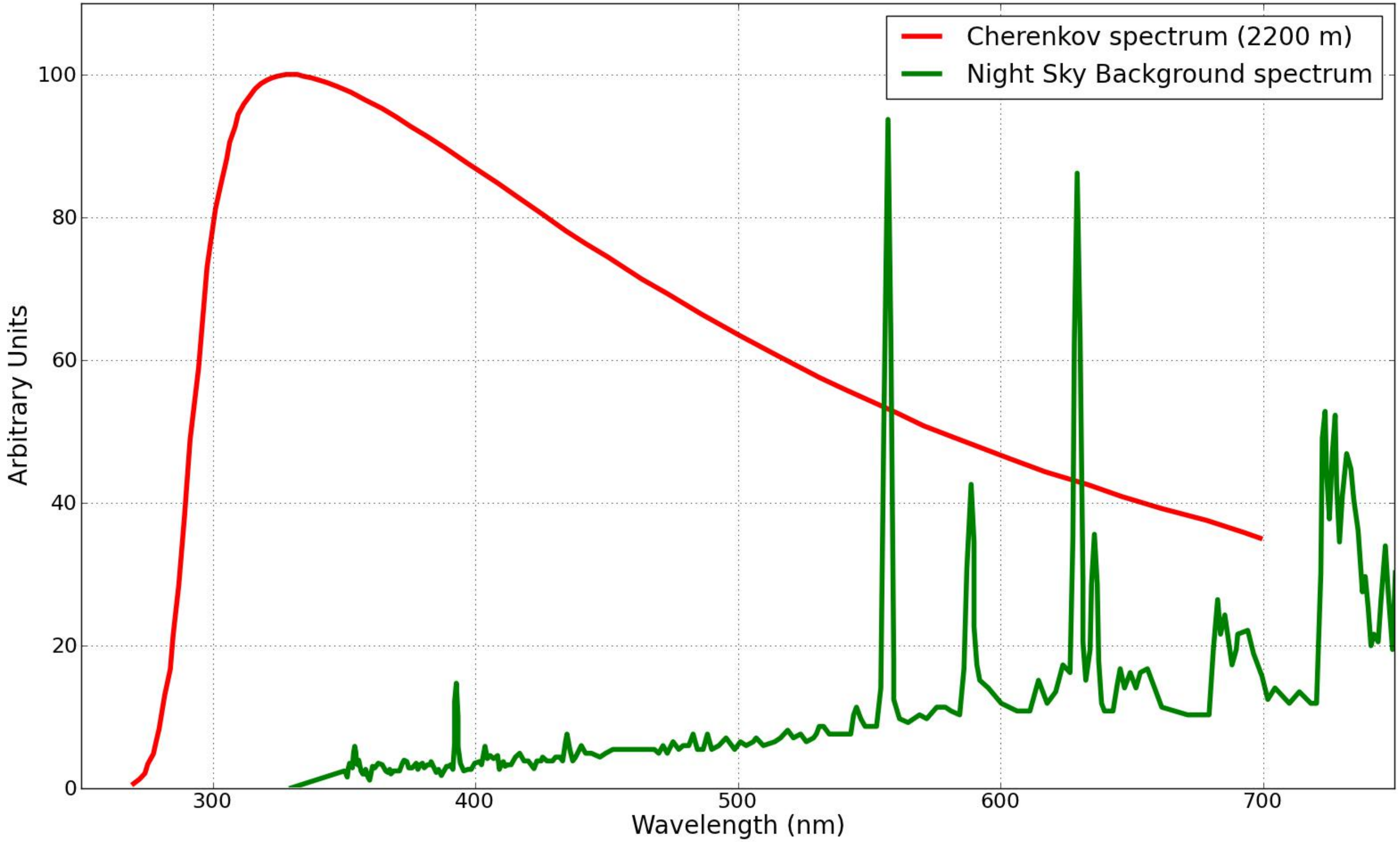
References

- **S. Sakurai, D. Depaoli, and R. López-Coto**, *"The calibration of the first Large-Sized Telescope of the Cherenkov Telescope Array"*, arXiv:1907.09357
- **Mallamaci Manuela et al.**, *"Design of a SiPM-based cluster for the Large Size Telescope camera of the Cherenkov Telescope Array", arXiv:1807.06281*
- **Riccardo Rando et al.**, *"Silicon Photomultiplier Research and Development Studies for the Large Size Telescope of the Cherenkov Telescope Array"*, arXiv:1508.07120
- **Tiziana Pro et al.**, *"New Developments of Near-UV SiPMs at FBK"*, IEEE Transactions on Nuclear Science, 23 May 2013
- **Sergio Gomez et al.**, *"MUSIC: An 8 channel readout ASIC for SiPM arrays"*, SPIE 2015

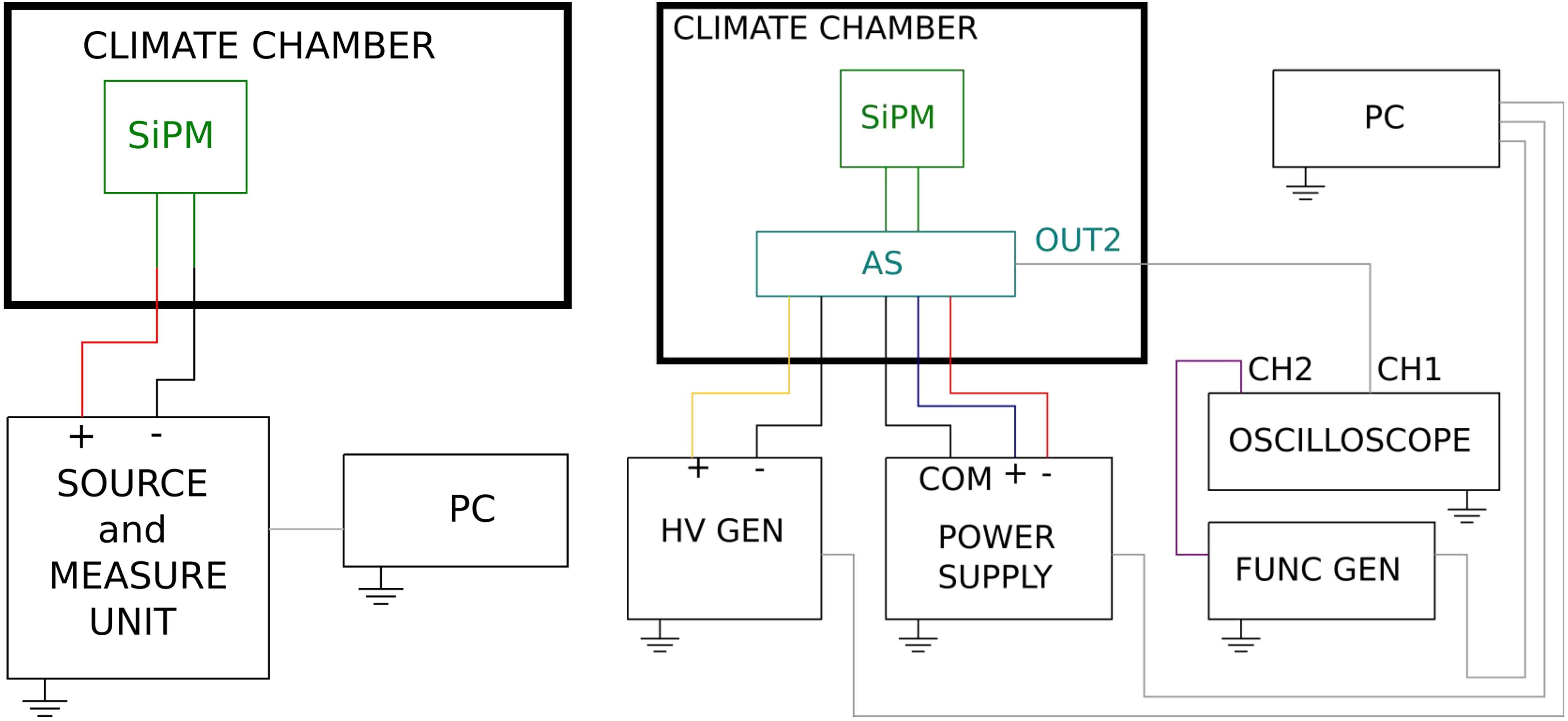
Backup Slides

Cherenkov Spectrum vs NSB

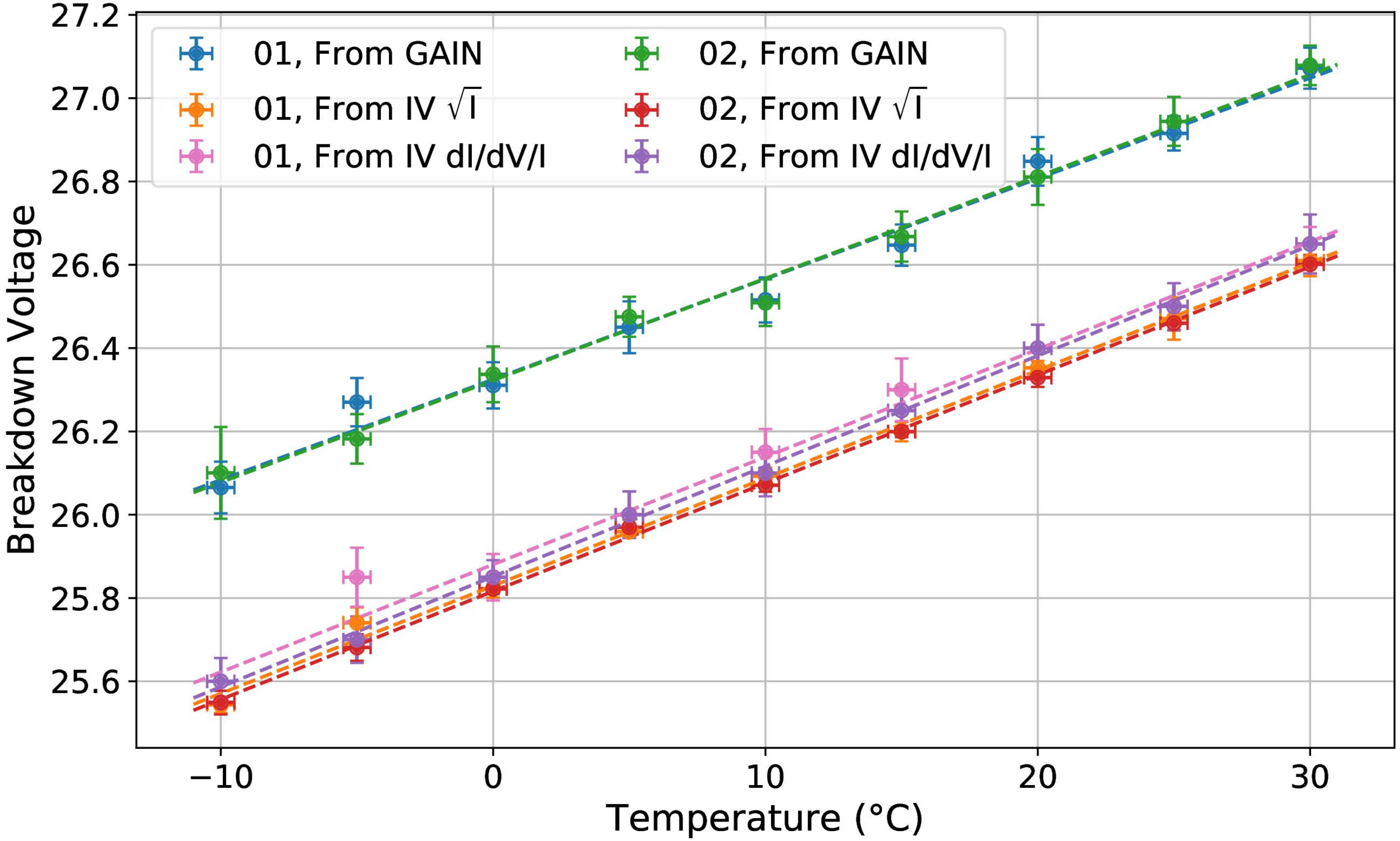
Signal and background spectra for the IACT technique (arXiv:1308.1390v1)



Setup for IV and Signal Analysis



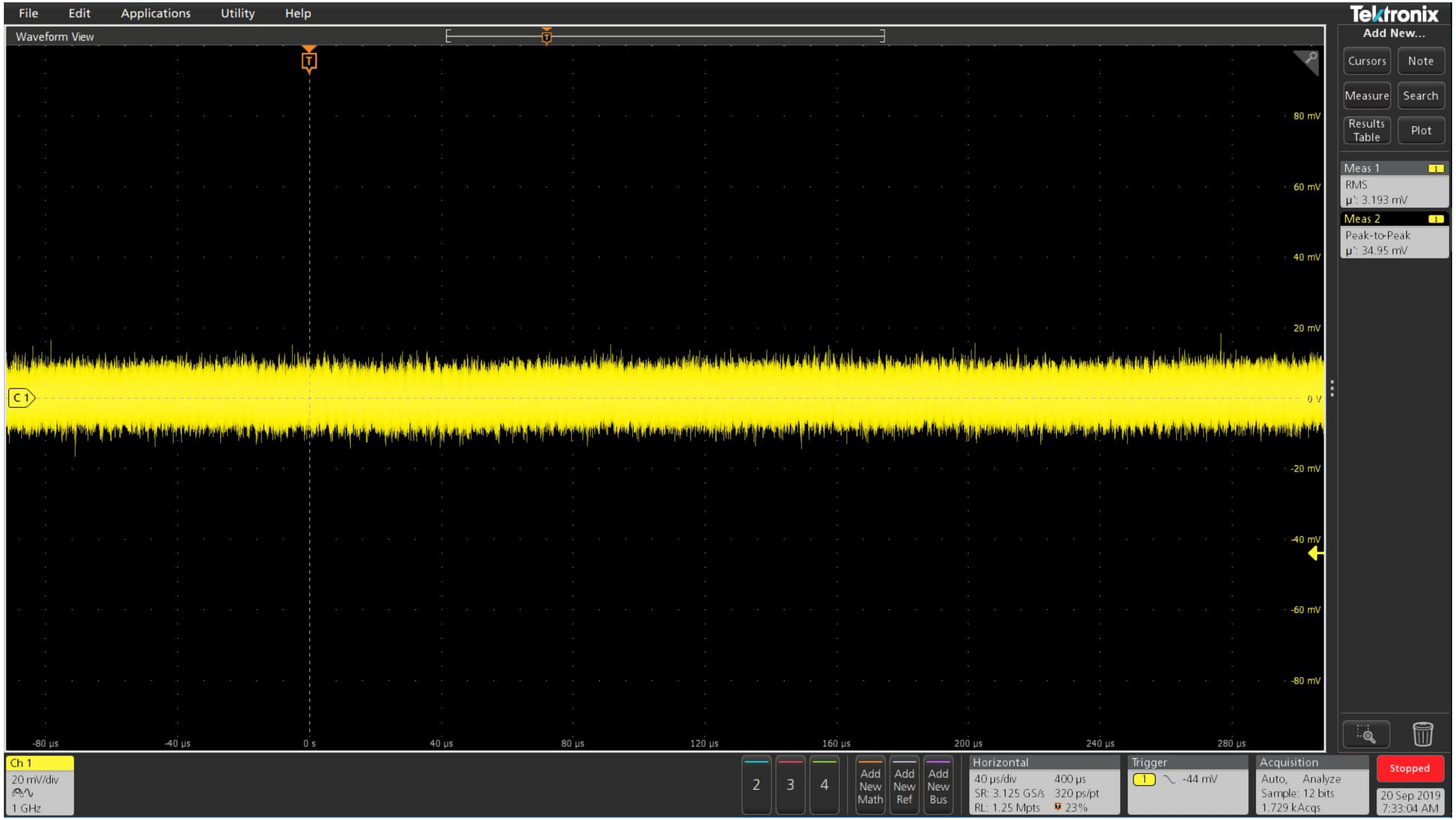
Breakdown Voltage vs Temperature



$$\frac{dV_{bd}}{dt} = (26 \pm 1)\ \mathrm{mV/°C}$$

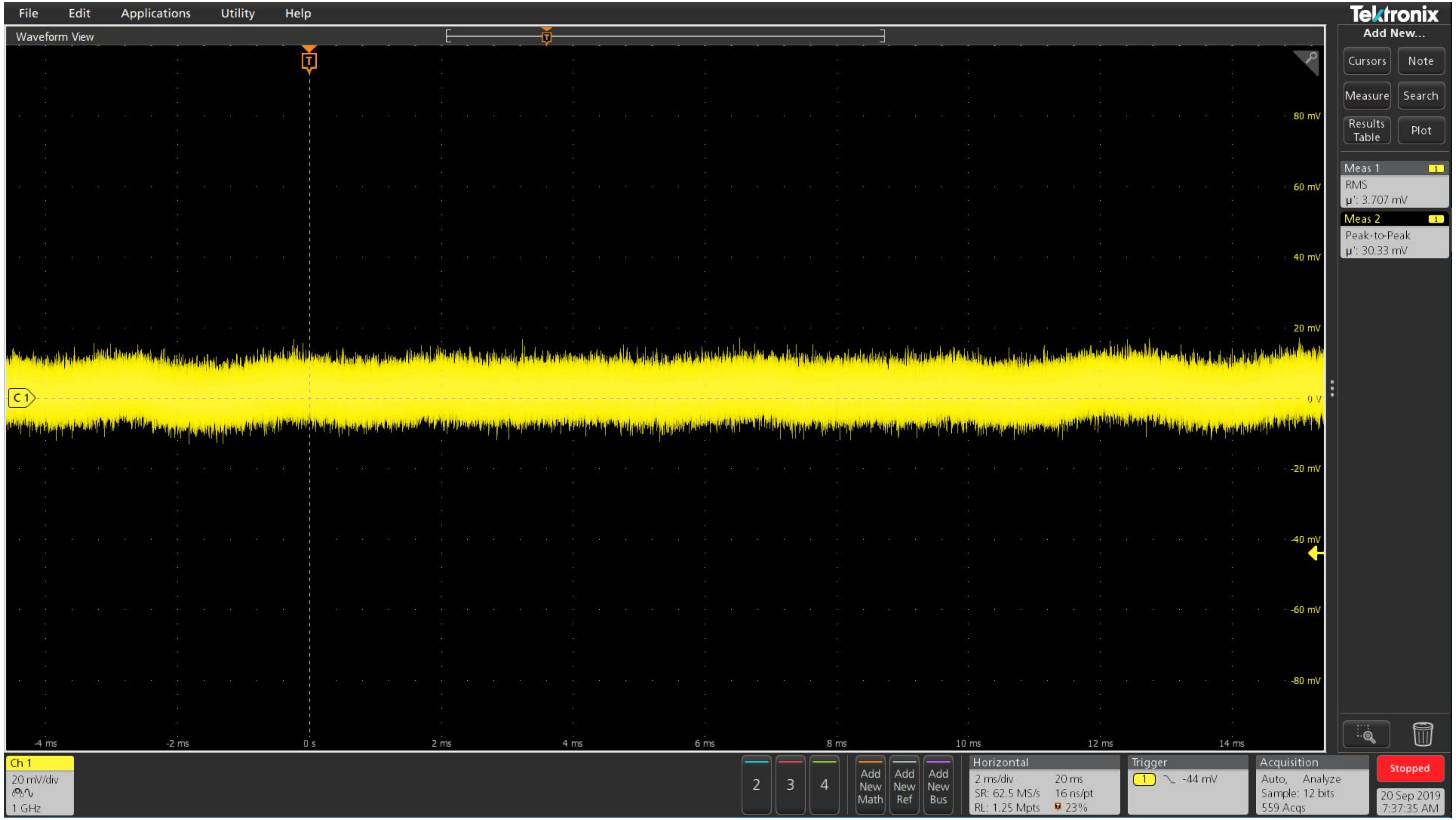
LT3467 + Filter: Oscilloscope

- DC-DC converter mounted on IB, AC coupled oscilloscope input



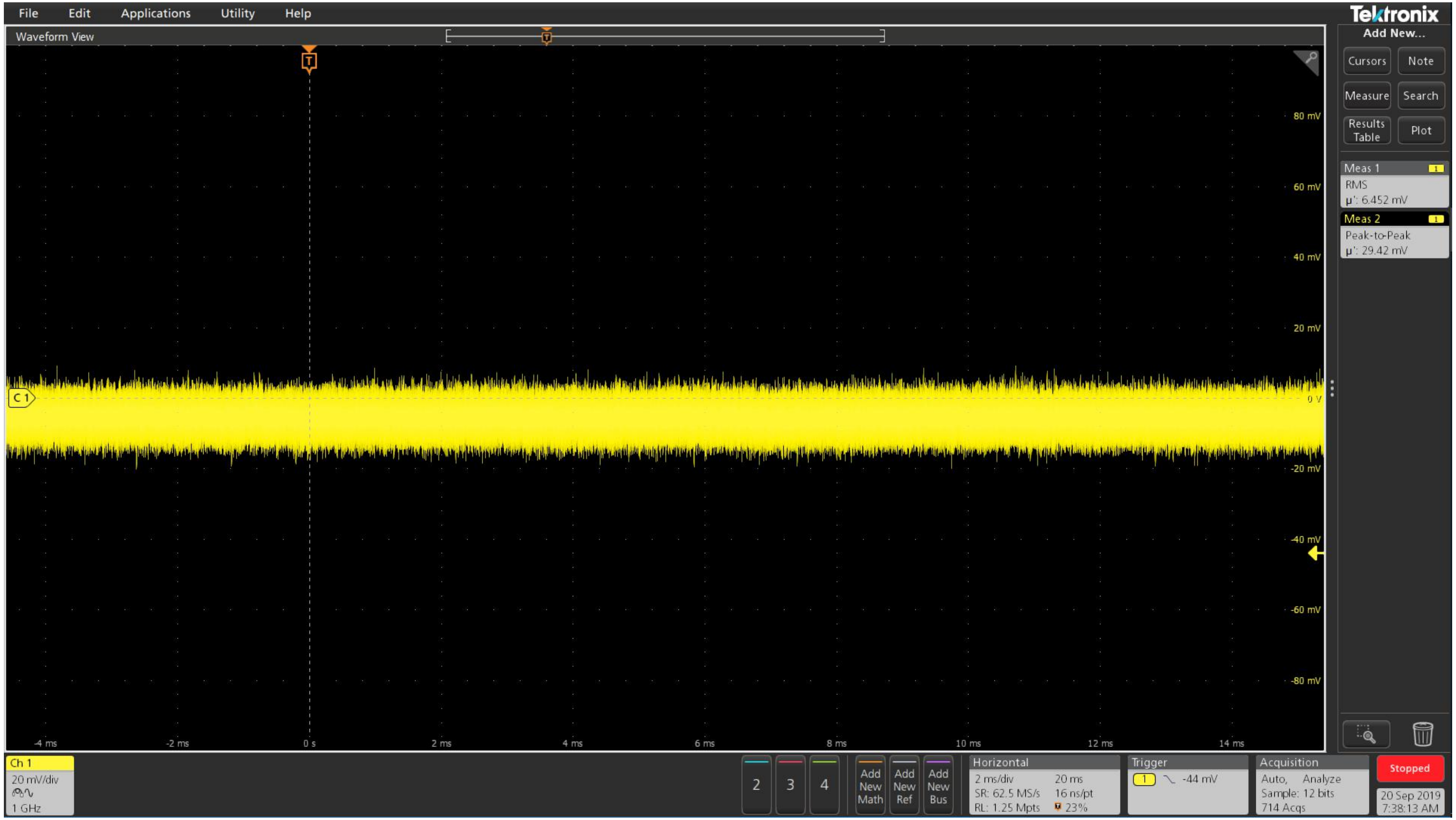
CAEN A7585DU: Oscilloscope

- DC-DC converter mounted hand-made PCB, AC coupled oscilloscope input



GND

- For comparison

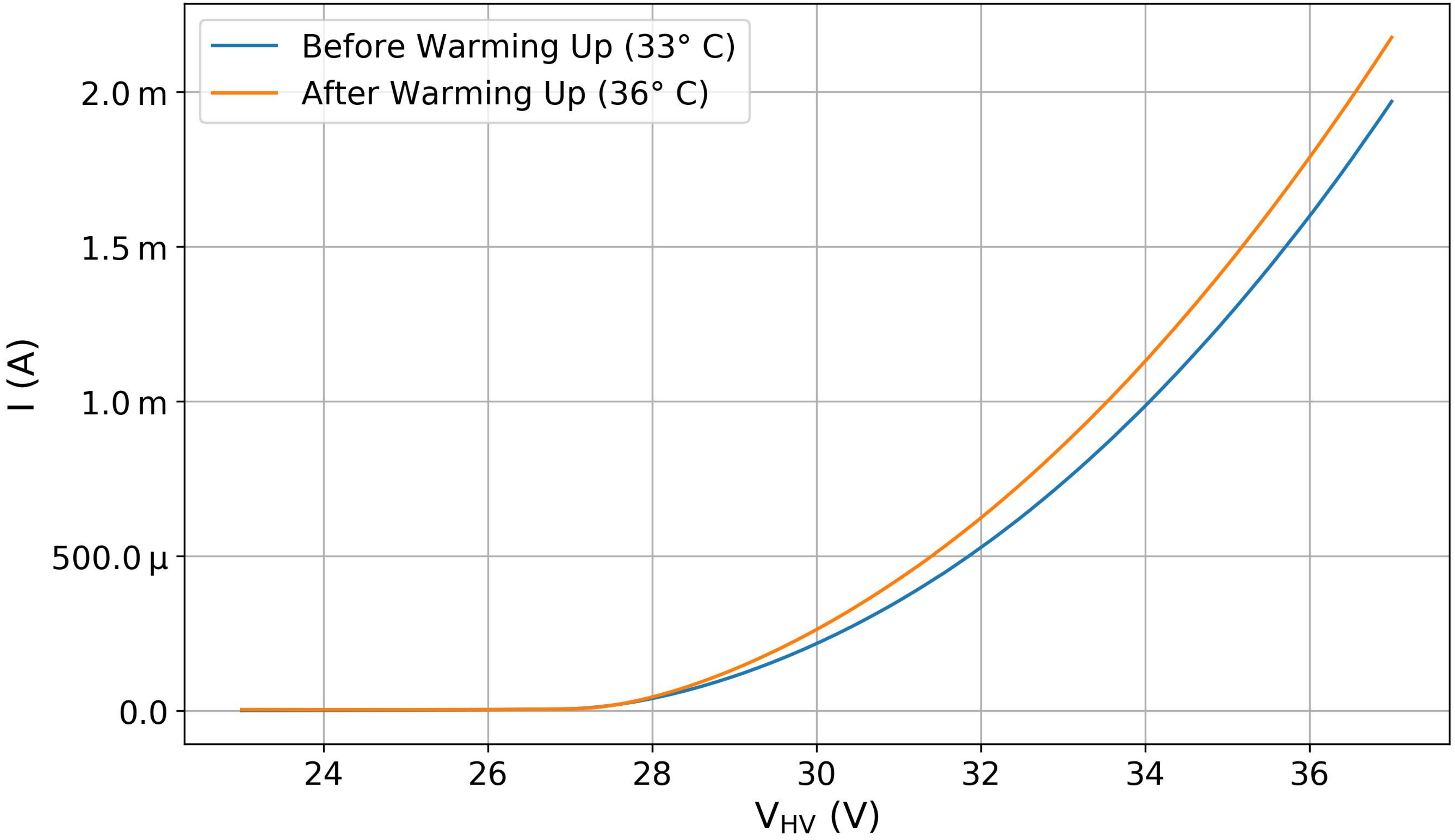


Pedestal acquisition

- External TTL Trigger using Function Generator; **Slow Control**:
  - rbcp 192.168.1.5 4660
  - wrb x100b 3
- Channels: Open or closed on a 50 Ω load
- Waveform acquired with **EVB**
- Saved in **.fits.fz** format
- Analysis: **cta-lst chain**, *calibrate* function:
  - lst_r0.subtract_pedestal(ev) # subtract_pedestal
  - lst_r0.time_lapse_corr(ev) # dt correction
  - lst_r0.interpolate_spikes(ev) # interpolate spikes

SiPM Pixel - I-V

- Before and after warming up. Temperature measured with Fluke Multimeter



SiPM Pixel - Signal

- Trigger on CH