Silicon Photomultipliers (SiPMs) characterisation for HEP applications

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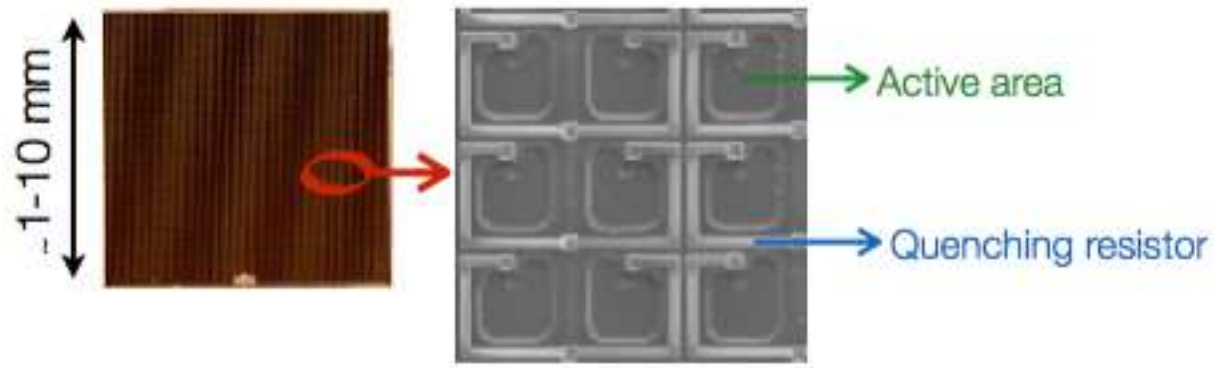
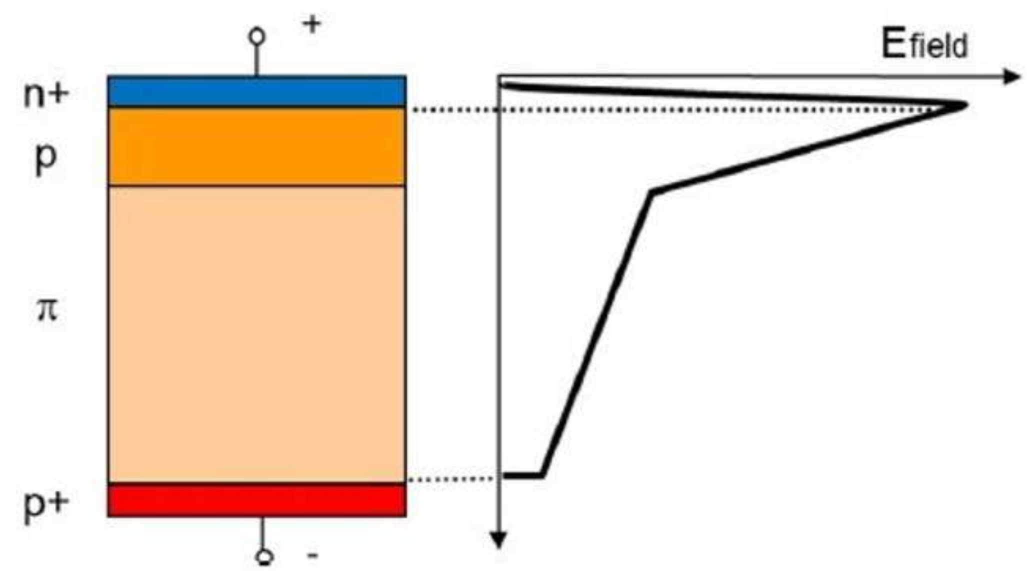
SiPMs: overview





A SiPM is a collection of N SPADs of typical size 20-50 um

- A Single Photon Avalanche Diode (SPAD) is a photodiode operating in Geiger mode
    - ON or OFF
    - Resulting in extraordinary charge resolution
    - And a high dark-rate O(10^4-10^5 cps/mm^2 @ 300K)
- A signal is generated when N_f SPADs are triggered

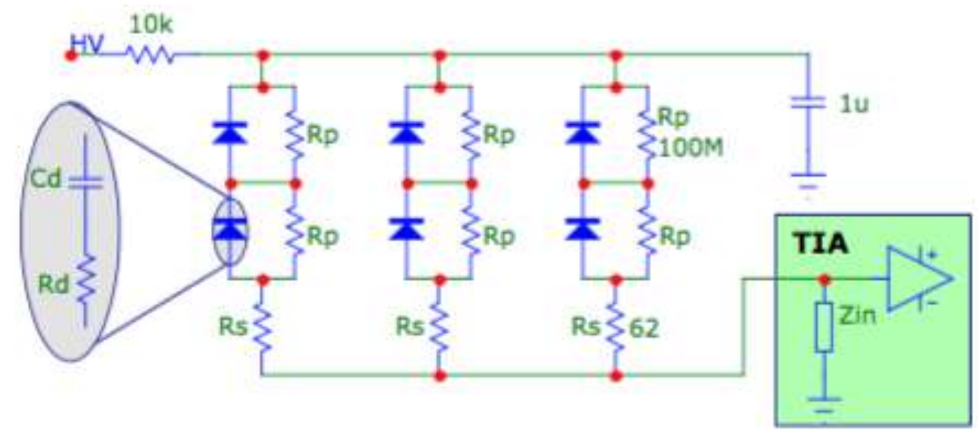
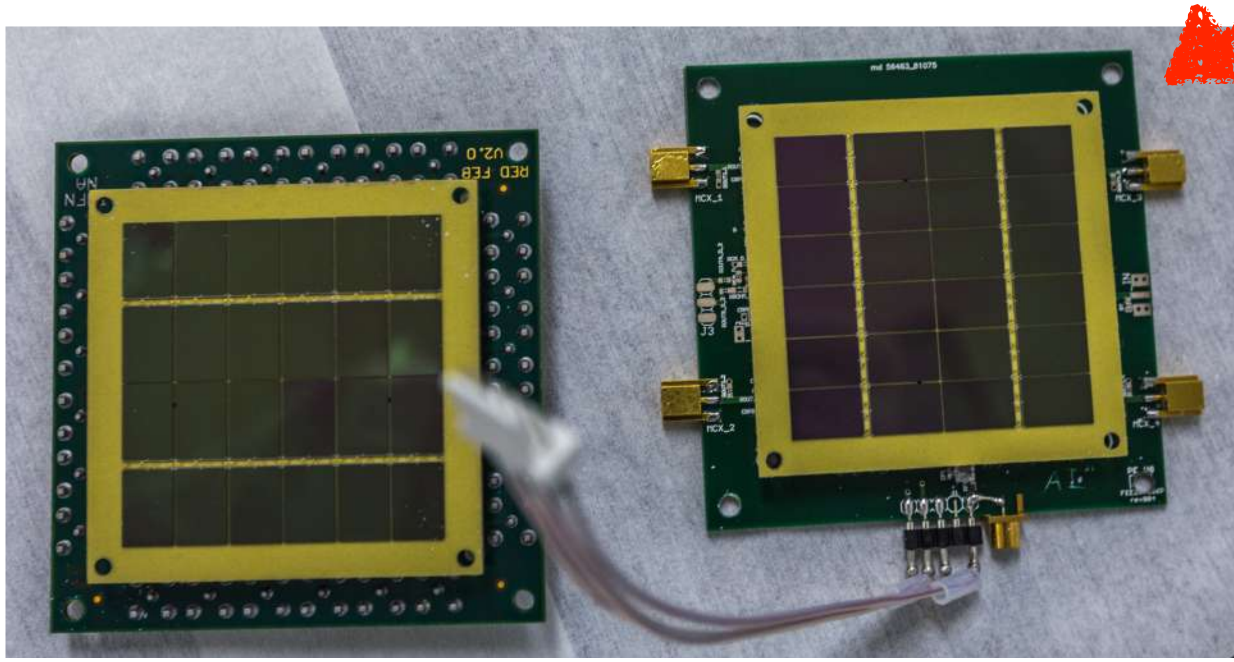
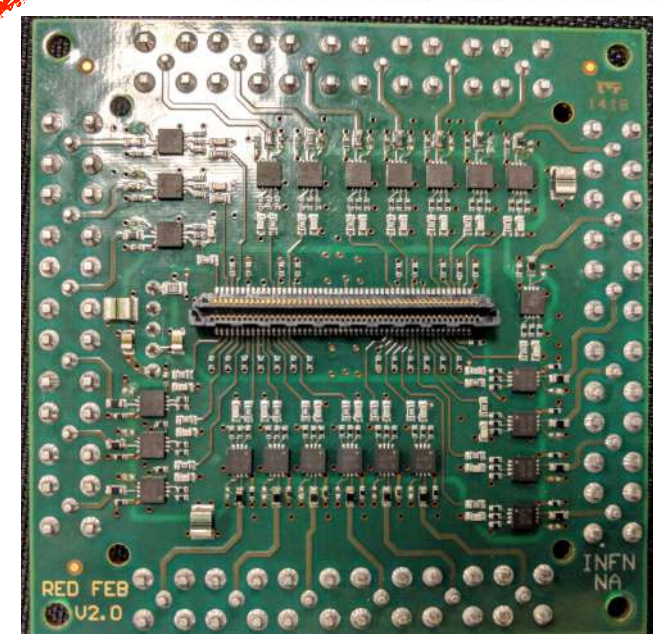
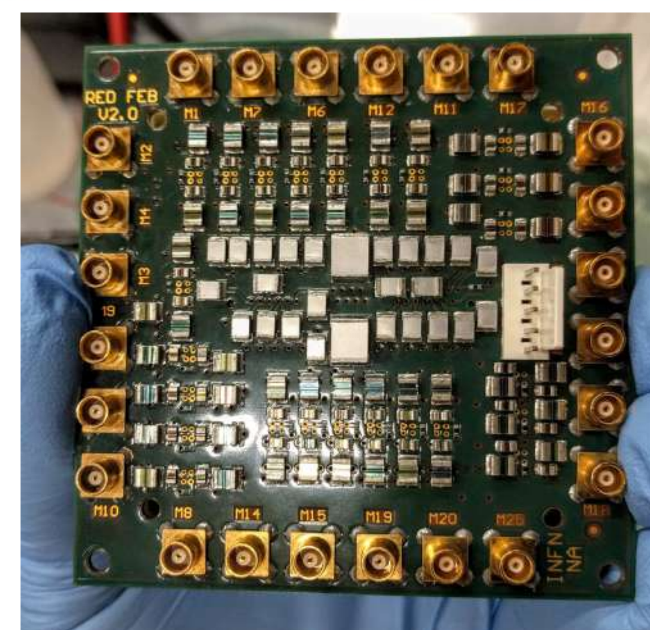


Fig. 2. Schematic of the SiPM layout for the 6 cm^2 tile quadrant.







SiPMs: main properties

- SiPMs are sensitive to single photons (even at room temperature)
- Dynamic range well above 100 ph/hit
- High Photon Detection Efficiency (PDE > 50%)
- The gain is expected to depend linearly on the over voltage (V_{OV})
- The triggering efficiency increases with V_{OV}
- PDE increases with the stochastic events, affecting the detector response

- Temperature effects:
  - The gain changes with temperature (V_{BD} does it!)
  - Gain stabilisation is a *must have*
  - The rate of variation depends on the sensor through the material properties (and so the noise!)

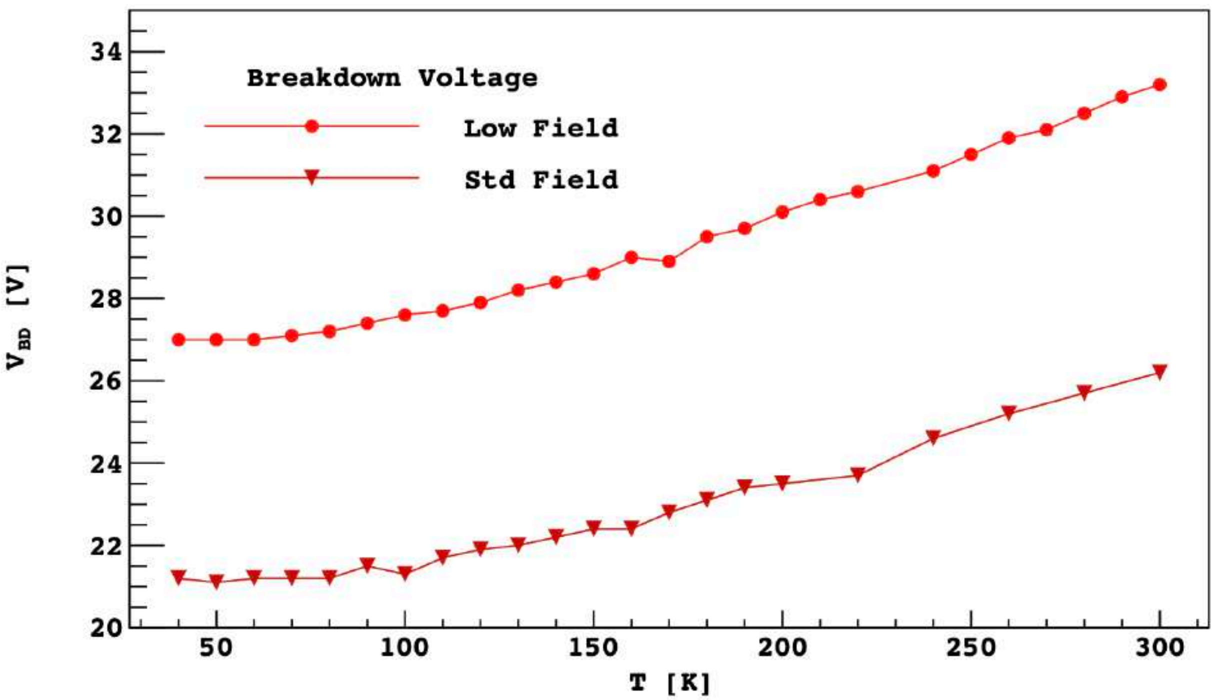
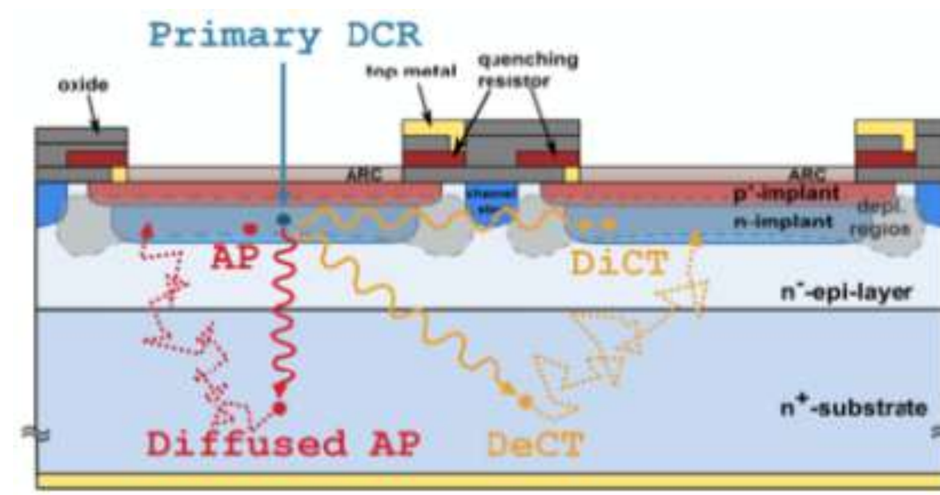


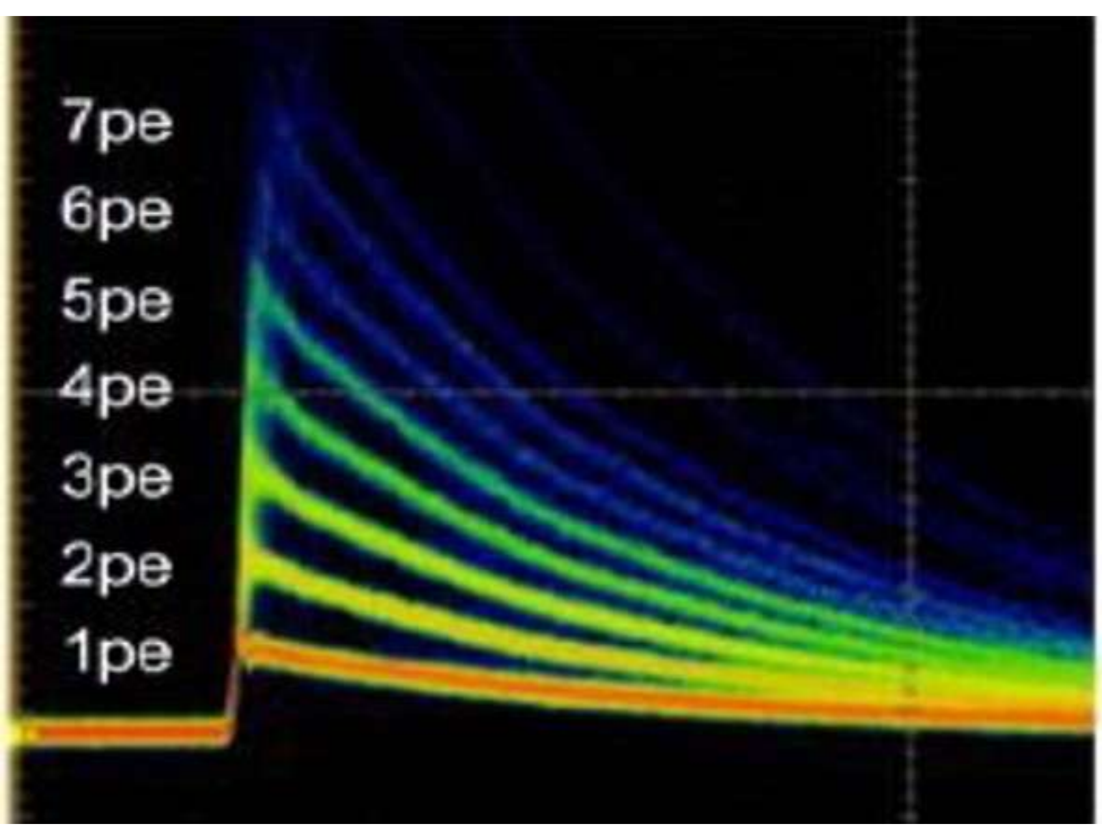
Fig. 4. Breakdown voltage of NUV-HD-LF and NUV-HD-SF SiPMs as measured with a linear fit to DLED single cell response amplitudes.

Acerbi et al, arXiv:1610.01915v2 (2017)

SiPMs: (un)correlated noise

- Stochastic effects:
  - Spurious avalanches (dark counts)
  - Delayed avalanches (after-pulses)
  - Excess of fired cells (optical cross talks)





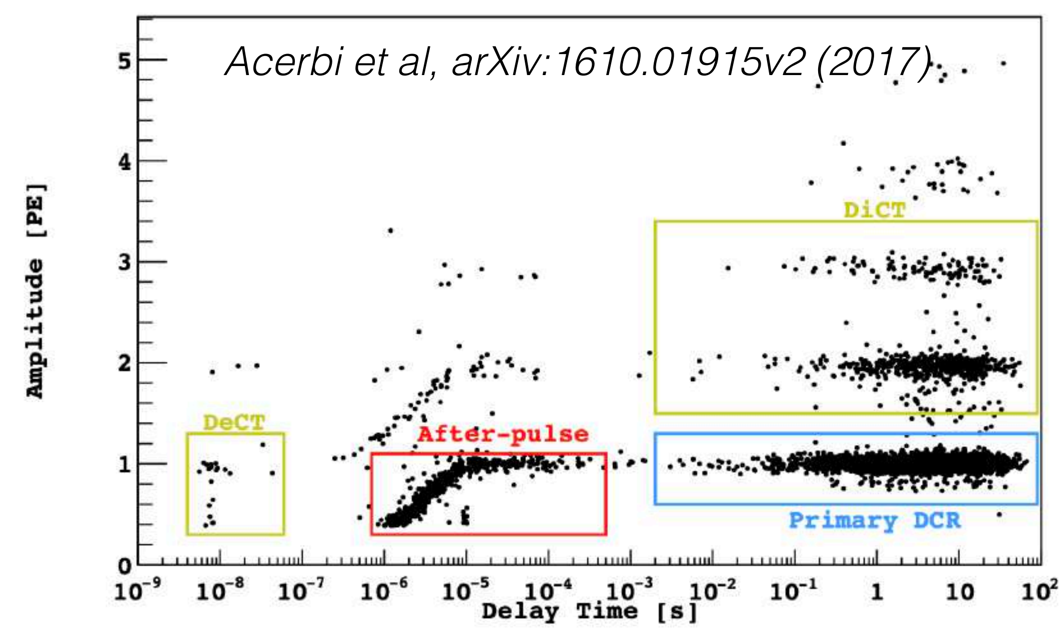


Fig. 3. Distribution of delay time versus amplitude for run at 77 K and in absence of light stimulation. A few components of the noise response of the SiPM can be clearly identified: primary dark count (part of the Dark Count Rate, DCR), Direct CrossTalk (DiCT), Delayed CrossTalk (DeCT), and AfterPulsing (AP).

SiPMs characterisation: activities description

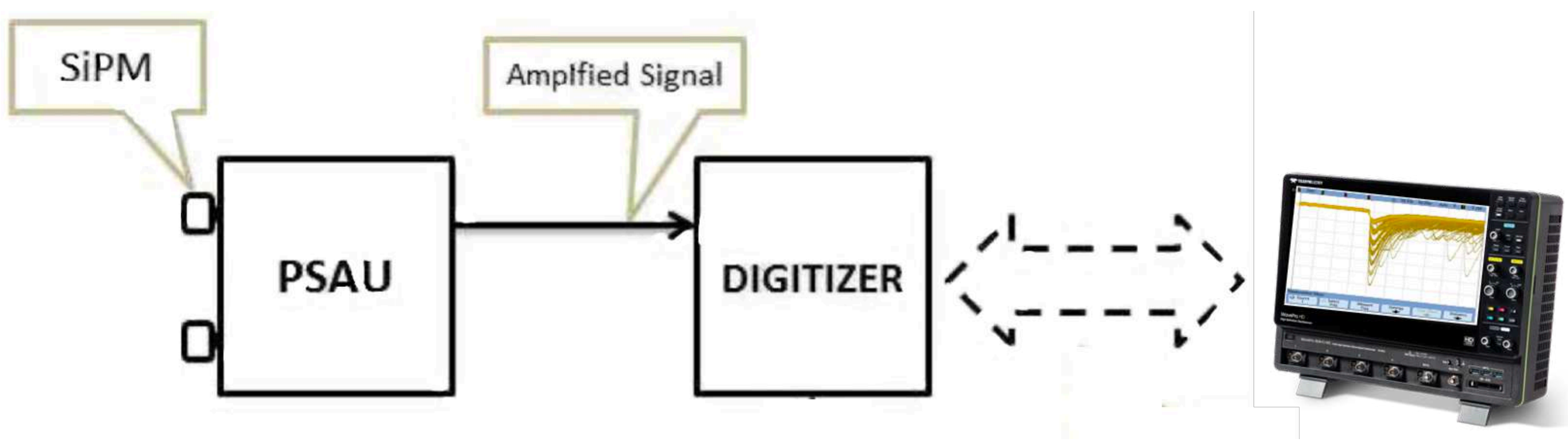
Students will be familiar with the standard procedure, used in many applications of neutrino and dark matter search, on the characterisation of Silicon PhotoMultipliers (SiPMs). In particular they will learn how to extract breakdown voltage and how to look at the single-electron spectrum from the acquired data.

- **Proposed activities:**
  - **Basic measurements:**
    - Enjoying the first SiPM spectrum and measuring the Dark Count Rate from a scope;
    - *Can you see the light?* Illuminating SiPM: triggering and integrating;
  - **Advanced measurements (if not out-of-time):**
    - Characterisation of a SiPM cell using an ultra-fast pulsed LED and estimation of the main features of the detector at fixed bias voltage;
    - Dependence of the SiPM properties on the Bias Voltage: study the dependence of the main SiPM figures of merit on the bias voltage. Measurement of the breakdown voltage and identification of the optimal woking point.

SiPMs characterisation: exercise #1

- **Enjoying the first SiPM spectrum and measuring the Dark Count Rate:**

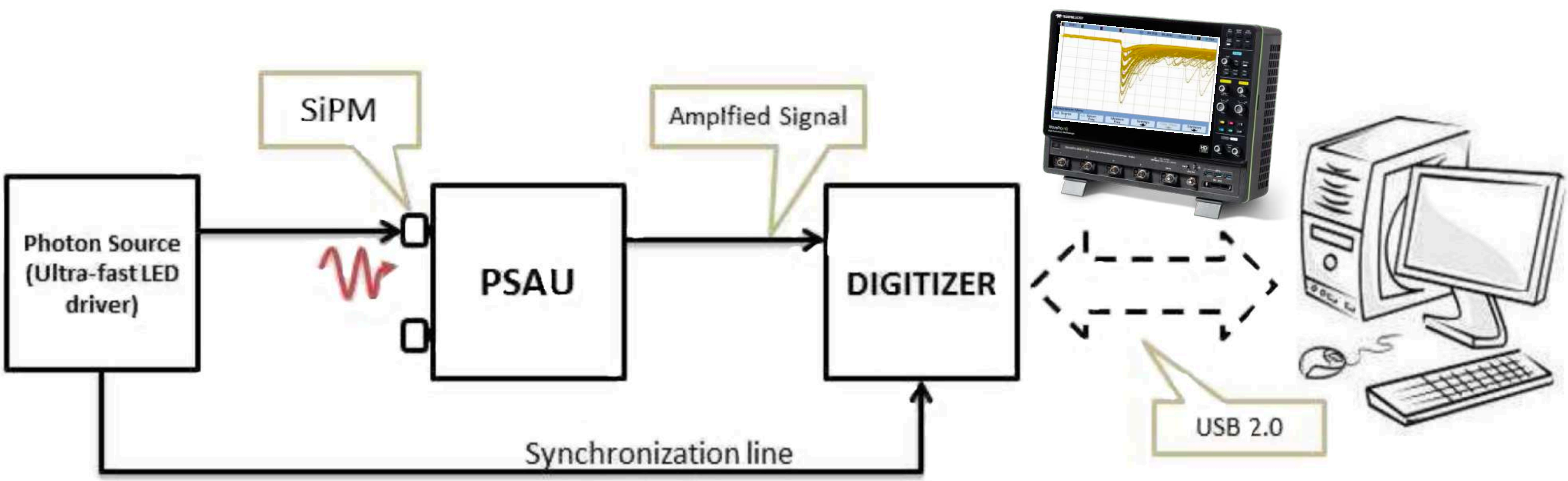
    - Connect the sensor to channel 0 or 1 of the *PSAU* and its analog output to the oscilloscope. Power ON the *PSAU* and the *DIGITIZER*. Once the system is up and running, properly bias the detector and set the right gain to avoid saturation on the *PSAU* amplifier. The amplification factor can be set and, since the SiPM for the current measurement will be not illuminated, a high value (e.g. 40 dB) can be used. As long s the SiPM is biased and the oscilloscope is properly triggered the SiPM signal is expected to appear on the display. **Goal:** *a useful entry-level parameter is the Dark Count Rate (DCR) of the SiPM under study. A fair indication of the DCR vs the threshold can be obtained with the oscilloscope if the triggering frequency is offered*.



SiPMs characterisation: exercise #2

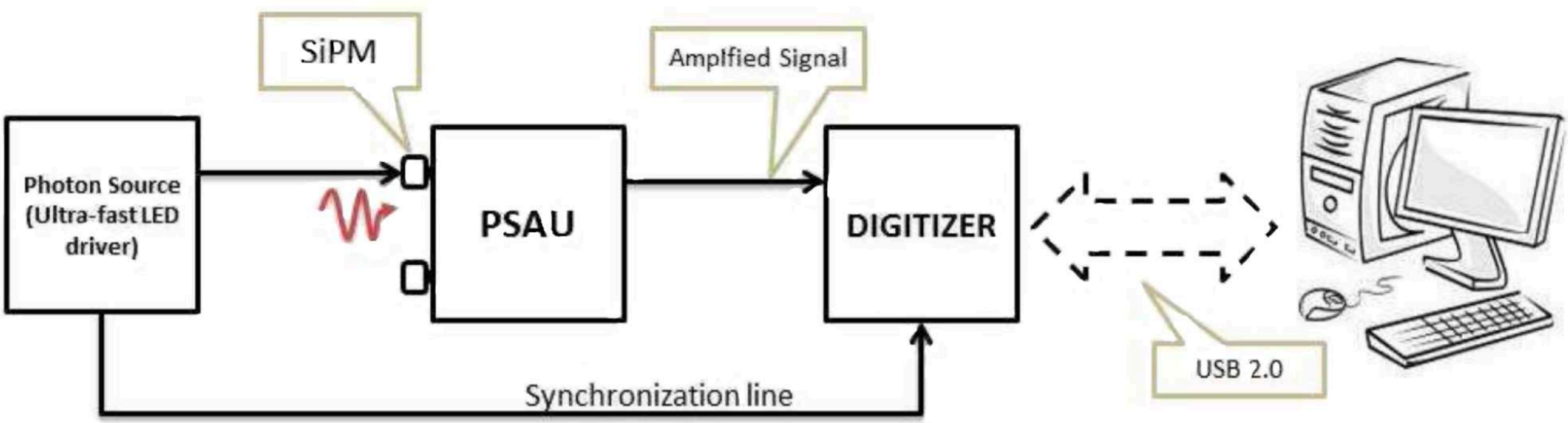
- ***Can you see the light?*** **Illuminating SiPM: triggering and integrating:**

    - The light pulse from the ultra-fast LED-driver is driven through an optical fibre into the SiPM holder housing the sensor under test. Bias the SiPM, set an amplification factor to 0 and do not enter any settings on the *DIGITIZER*. A multi-photon peak spectrum is obtained with a two steps procedure. It corresponds to the output signal spectrum for an illuminated SiPM and carries information about the detector gain and noise, the photon number resolving capability and eve the DCR and the cross talks.



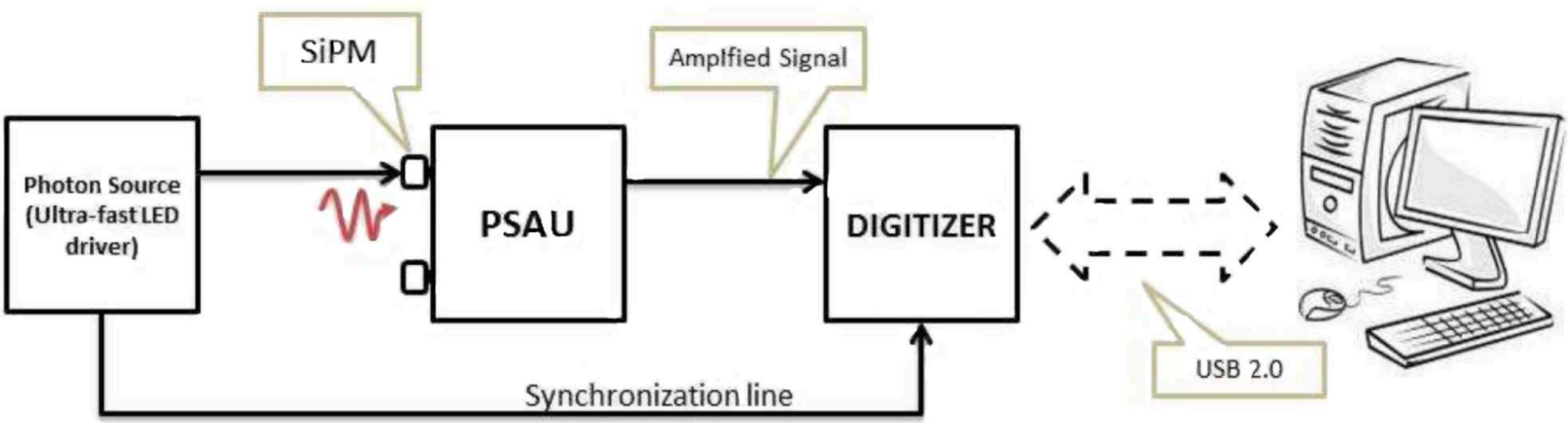
SiPMs characterisation: exercise #3

- **Characterise a SiPM cell using an ultra-fast pulsed LED and estimation of the main features of the detector at fixed bias voltage:**
  - The light pulse from the ultra-fast LED-driver is driven through an optical fibre into the SiPM holder housing the sensor under test. The output signal from the *PSAU* is connected to the input channel of the *DIGITIZER* that is triggered by the LED-driver. Use the default software values or optimise the bias voltage and discriminator threshold. **Warning:** *the abscissa axis of the acquired spectrum is in ADC counts, so to perform the experiment and determine the main features of the SiPM an ADC channel conversion is required*.



SiPMs characterisation: exercise #4

- **Dependence of the SiPM properties on the Bias Voltage:**
    - Mount the sensor on the *PSAU* and connect the analog output of the *DIGITIZER*. Optically couple the *LED* and the sensor via the optical fibre. Set the internal trigger mode on the *LED-driver* and connect its trigger output on the *DIGITIZER* trigger IN. Synchronize the signal integration from the GUI and, for every voltage value, record the photon spectrum and measure directly from it the Dark Count Rate and the Optical Cross Talk. **Bonus (advanced analysis technique):** *measure the After Pulse*.



Let’s do them, and comment the results together ..