SiPM modelling and characterization

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FOOT Physics Meeting, March 2021

Saturation of TOF-Wall SiPMs

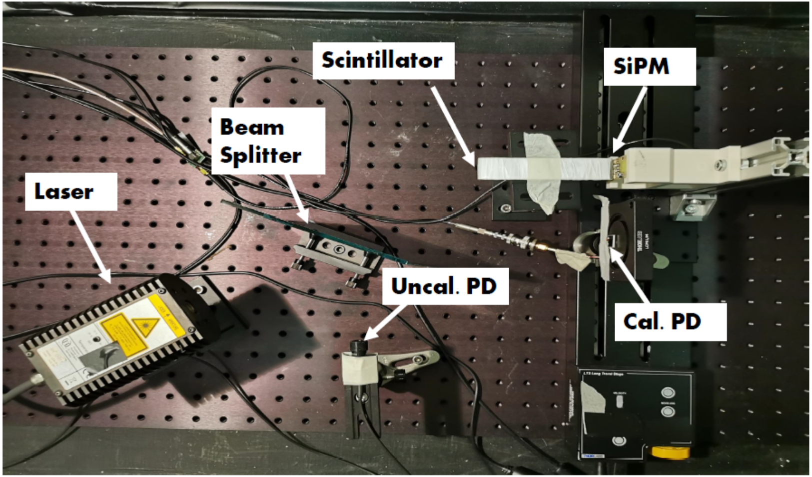
Motivation and aims

In the last period I studied the saturation of a TOF-Wall SiPM by analysing the charge produced by a pulsed laser light.

Main goals:

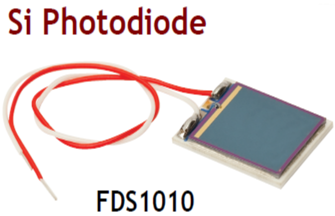
- acquire a large number of waveforms for each value of laser intensity;
- observe the behavior of signals as a function of light pulses;
- estimate the number of fired SiPM cells and the PDE.

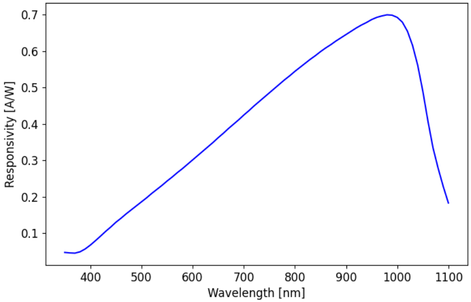
Experimental setup



Materials and methods: preliminar operations

- First issue: choose the most suitable laser frequency.
- Photocurrent measurement strategy:
  - For each device verify the pulse frequency-photocurrent linearity
  - Measure the photocurrent of the UnCal-PD and extract the corresponding value of the Cal-PD.
  - Use the responsivity η $[A/W]$ to obtain the photon flux.



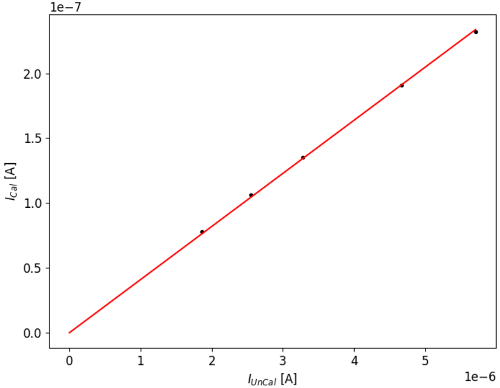


Materials and methods: PD cross-calibration

- A laser
  pulse frequency of 10 MHz was set.
- The two split laser
  beams impinged on the two PDs.
- The relationship between
  the two photocurrents was fitted:

$$I_{Cal} = a \cdot I_{UnCal}$$

- Result:
  - a = $(4.09 \pm 0.01)\ 10^{-2}\ A^{-1}$



Materials and methods: data acquisition

- A bias voltage of 120 V ($\sim$ 8.3 V overvoltage) was applied to the SiPMs board.
- A laser pulse frequency was fixed at 100 kHz.
- The two split laser beams were sent:
  - one to the UnCal-PD by reflection;
  - one to the plastic scintillator face $\rightarrow$ light diffused ad uniformly distributed on SiPMs surface.
- For each laser intensity value:
  - SiPMs signals area histogram was built;
  - mean value and standard deviation were acquired;
  - correspondent photocurrent was measured (20 readings $\rightarrow$ mean and std dev.).

Materials and methods: number of triggered cells

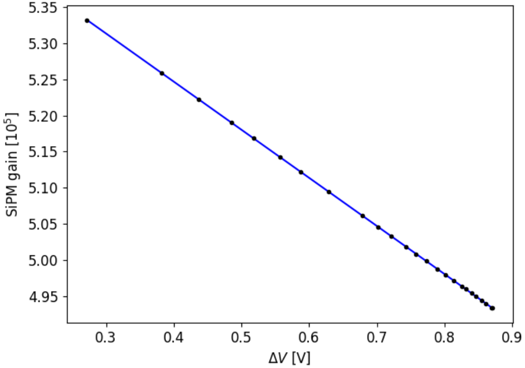
- Issue: SiPMs signal passed through a filtering stage between the SiPMs and the HV power supply $\rightarrow$ voltage drop on the filter resistor $R_F = 2\ k\Omega$.

$$\Delta V = \frac{A \cdot \nu_{laser} \cdot R_F}{R_{out}} = Q \cdot \nu_{laser} \cdot R_F$$

where A is the SiPMs signal area, Q the collected charge, $\nu_{laser} = 100$ kHz and $R_{out} = 50\ \Omega$ is the readout resistance.

- SiPM gain varied as a function of ΔV:

$$G(\Delta V) = G(0) \cdot \left(1 - \frac{\Delta V}{V_{OV}}\right)$$



Material and methods: data analysis

- The number of fired cells was calculated with the formula:

$$N_{fired} = \frac{Q}{e \cdot G(\Delta V)}$$

- The number of detected photons was calculated with the formula:

$$N_{ph} = f \frac{I}{\nu_{LASER} \; E_{ph} \; \eta(\lambda)}$$

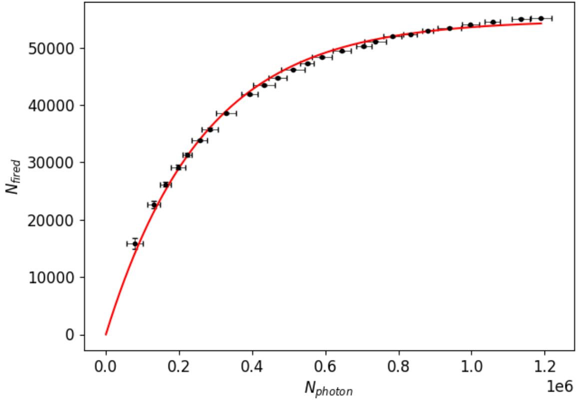
where: I is the extracted photocurrent of the Cal-PD, $e = 1.6 \; 10^{-19} \; C$ elementary charge, G SiPM gain, $E_{ph} = 4.9 \; 10^{-19} \; J$ photons energy and f ratio between SiPM surface and PD surface.

Results

- All data
  were fitted with the saturation formula:

$$N_{fired} = N_{tot} \left(1 - e^{-\frac{N_{ph} \cdot PDE}{N_{tot}}}\right)$$

- Results:
  - $N_{tot} = (5.48 \pm 0.03) \cdot 10^4$
  - $PDE = 0.206 \pm 0.003$
  - $\chi^2_{red} = 1.4$



SiPM characterization: conclusions

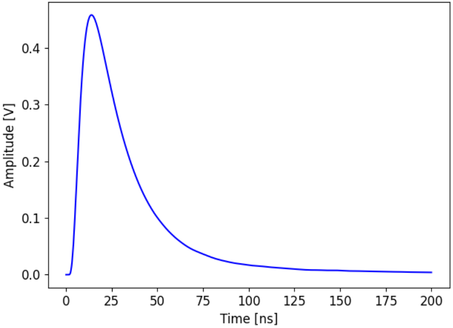
- SiPMs saturation was correctly observed and the obtained PDE agrees with the datasheet value (450 nm $\rightarrow$ PDE $= 0.25$).
- Together with the others SiPMs estimated parameters (gain, dark count rate, crosstalk, afterpulse), the TOF-Wall SiPMs characterization is completed.
- The entire set of these parameters can ben used to reproduce SiPMs response in MC simulations.

Montecarlo simulation of SiPMs response

SiPMs simulation: overview

Aim: include all the characterization parameters into a MC simulation in order to model the SiPM response to the scintillation photons produced by heavy ions.

- Input $\rightarrow$ scintillation photons generated from a GEANT4 simulation by Esther.
- Output $\rightarrow$ relative SiPMs waveform.



Preliminary trials and further development

- The first simulation runs were performed with scintillation photons produced by C ion at 115 MeV/u.
- For each detected ion we have $\sim$ 15000 - 20000 photons $\rightarrow \sim$ only 4000 fired cells $\rightarrow$ very far from saturation.
- Work in progress:
  - use other particles;
  - explore other energies;
  - explore different operating conditions of the SiPMs
  - evaluate the SiPM contribution to the energy resolution.