Characterization of the SiPMs of the TOF-WALL Detector

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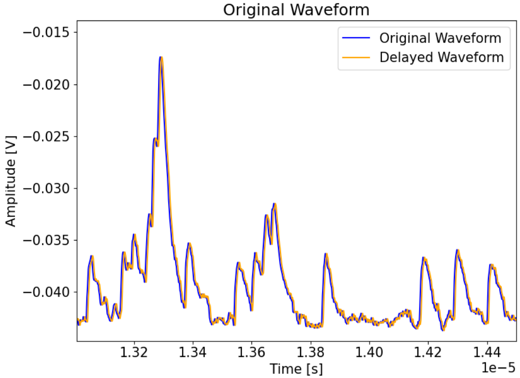
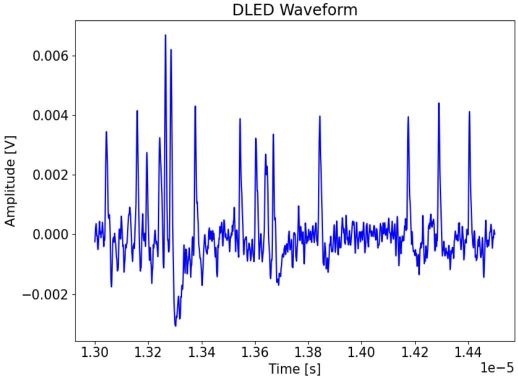
Analysis workflow for SiPM characterization

Single signal: DLED technique

DLED technique is a filtering procedure with the aim to reduce single cell pulse width.

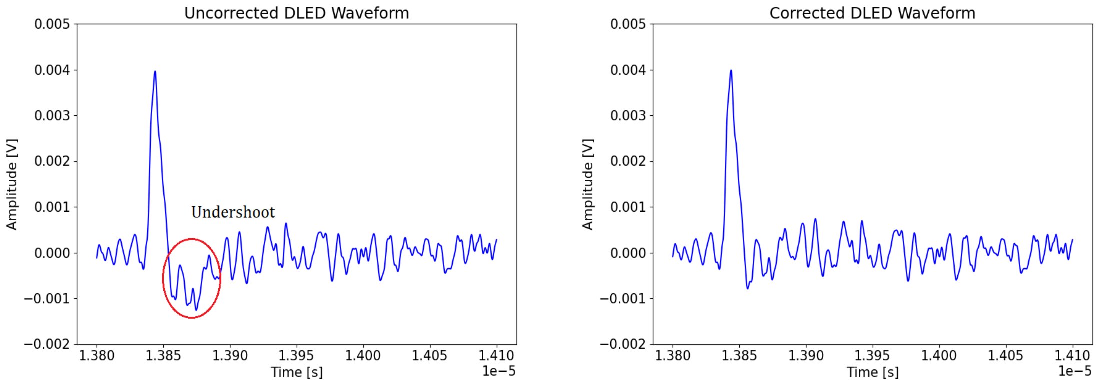
- An original waveform replica delayed by 5 ns is created;
- This delayed replica is subtracted to original waveform.





Single signal: waveform correction

In this correction procedure, single cell signals well separated in time are selected and averaged to create a new DLED waveform → undershoot corrected.

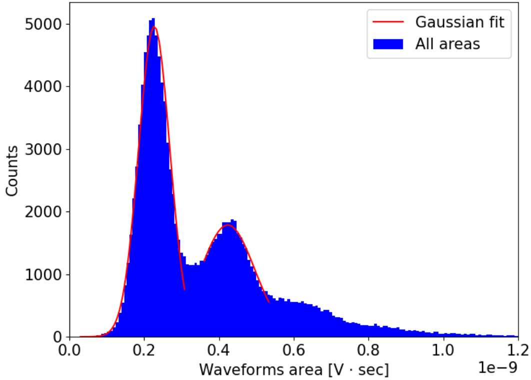


Gain

- For each bias
  voltage value, areas histogram was built;
- distance between the two peaks A_c
  is the area corresponding to a single cell.
  It was used to estimate the SiPM gain:

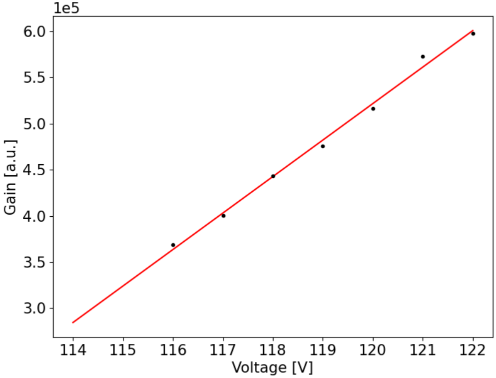
$$G = \frac{A_c}{e \cdot T}$$

where $e = 1.67 \cdot 10^{-19}\ C$
is the elementary charge and
$T = 2373\ V/A$ is the transimpedence.

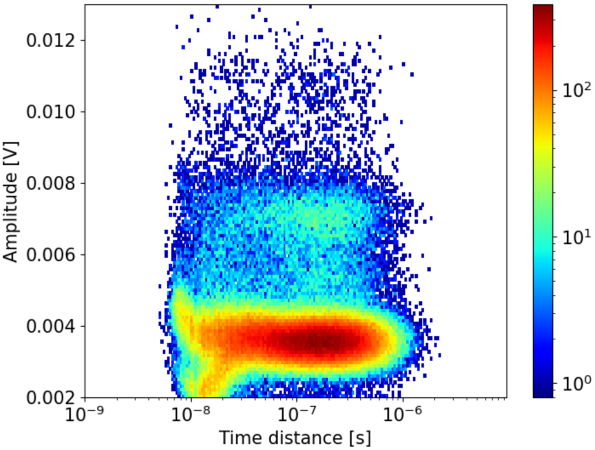


Gain vs voltage

In order to estimate V of breakdown, all gain values with respective voltage values was fitted with a linear function $y(V) = a + bV$.
Using fit results: $V_{br} = -\frac{a}{b} = 106.3 \pm 0.2\ V$



Analysis of DLED signal

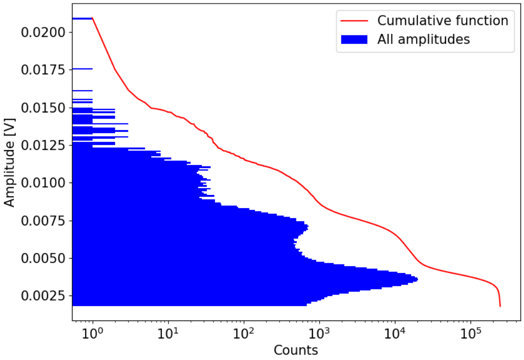


Cross-talk probability

- Once the amplitudes histogram was built, peaks corresponding to one and two triggered cells respectively were identified;
- by finding the middle point between two first peaks, one-cell events n_1 are recognized;
- cross-talk probability is estimated by the formula:

$$P_{CT} = \frac{n_{tot} - n_1}{n_{tot}}$$

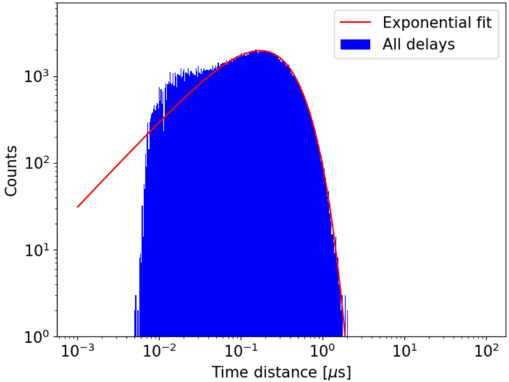
where n_{tot} is the number of all the events.



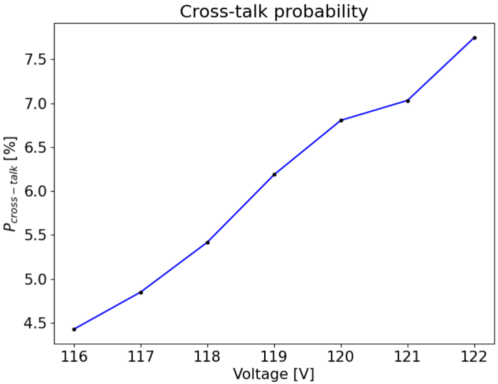
After-pulse probability

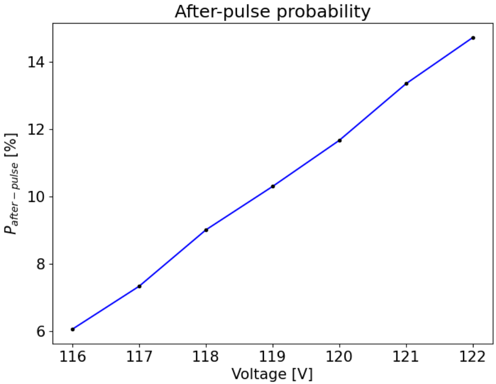
- The histogram of all time distances between two consecutive peaks was built;
- since primary dark events follow a Poisson distribution, the histogram was fitted with a decreasing exponential function;
- events n_{af} that exceed the fit line are related to after-pulse;
- after-pulse probability is obtained by the formula:

$$P_{AF} = \frac{n_{af}}{n_{tot}}$$



Cross-talk and after-pulse probability vs voltage

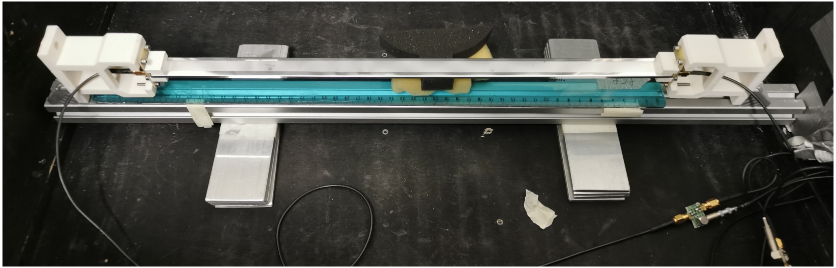




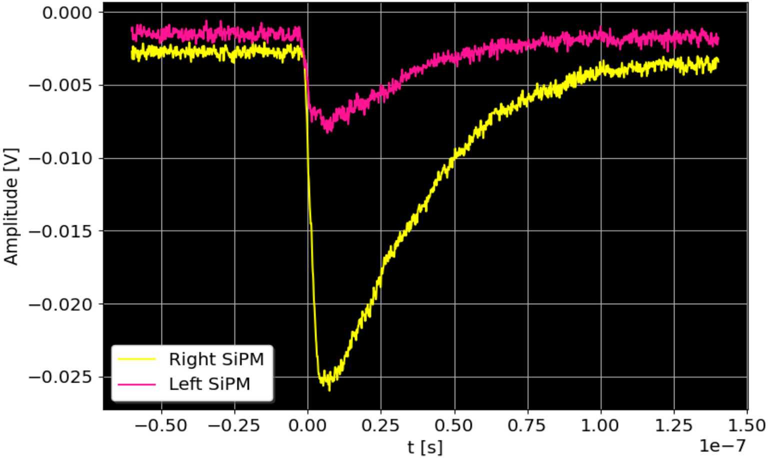
Light attenuation and time resolution of TOF-Wall bar

Experimental setup

- Bias voltage of SiPM was set to 120 V.
- Each distance measurement was evaluated from the right side of the bar.
- Source was moved from the right side to the left side with step of 1 cm.

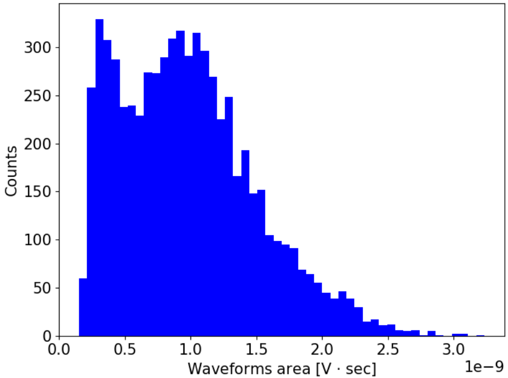


SiPM waveforms at distance d = 10 cm



Waveforms area

- After subtracting the baseline, signals area was calculated.
- For a fixed value of distance, a β spectrum-like distribution is expected.
- No analytical expression $\rightarrow$ could not be fitted.



Left-right charge ratio

- For a fixed distance d, the output signals depend on many effects:
  - source spectrum is continuous;
  - light emission spectrum of scintillator is continuous.
- To avoid all these variables, the ratio of left and right SiPM charge was considered.
- Scintillation light follows a decreasing exponential law: $I(x) = I_0 \; e^{-\frac{x}{\lambda}}$
- For a fixed x coordinate on the bar:

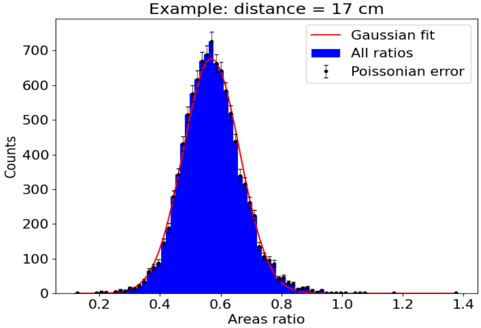
$$I_R(x) = I_0 \; e^{-\frac{x}{\lambda}}; \quad I_L(x) = I_0 \; e^{-\frac{l-x}{\lambda}}$$

where $l = 44$ cm total lenght of the bar.

Left-right charge ratio

For each side:

- charge histograms were built;
- left-right ratio was calculated;
- respective histrograms were built and fitted with a Gaussian function.



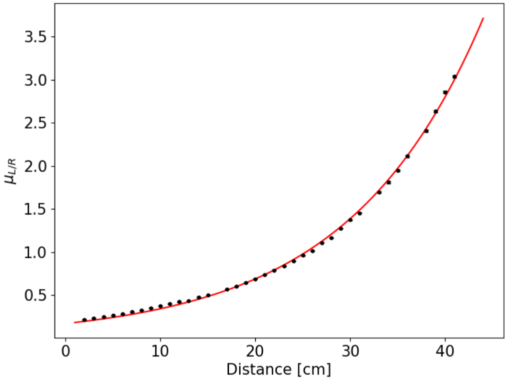
Left-right signal ratio: results

- Mean points of the Gaussian distributions and respective distance values d were fitted with the function:

$$f(d) = C\ e^{-\frac{l-2d}{\lambda}}$$

where C takes into account of gain differences between the two SiPM.

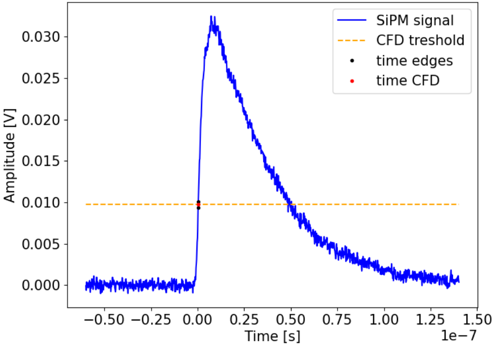
- Results:
  - $C = 0.79 \pm 0.01$
  - $\lambda = (28.4 \pm 0.2)$ cm



Time resolution: CFD technique

For each distance value:

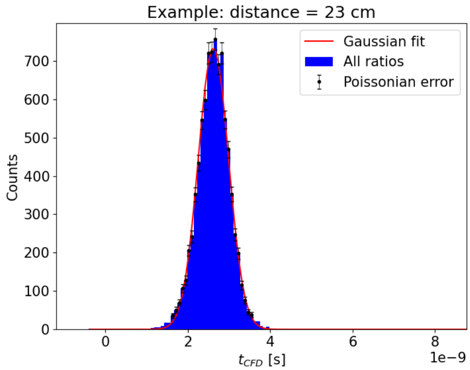
- the baseline of the signal was subtracted;
- a fraction (0.3) of maximum of the waveform V_{th} was chosen;
- t_L and t_R were set as the time when left and right waveforms crossed V_{th}.



Time resolution: CFD technique

For each distance value:

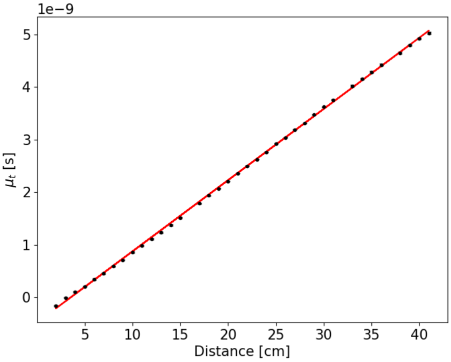
- time CFD was calculated as $t_{CFD} = t_R - t_L$;
- t_{CFD} distributions were fitted with a Gaussian to estimate μ_t and σ_t.

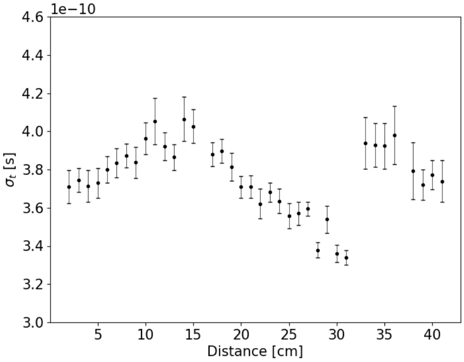


Time resolution: results

μ_t values as a function of distance were fitted with a linear funcion $\mu_t(d) = m\ d + q$ that provided:

- $m = (1.355\ \pm\ 0.004)\ 10^{-10}$ s cm^{-1}
- $q = (-4.8\ \pm\ 0.1)\ 10^{-10}$ s

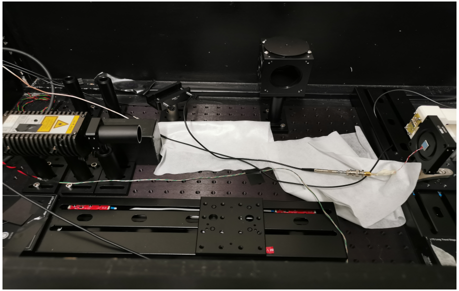




Saturation of TOF-Wall SiPMs

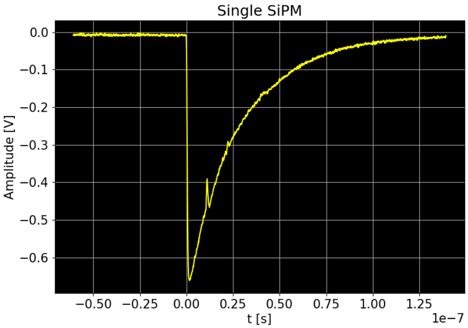
Experimental setup

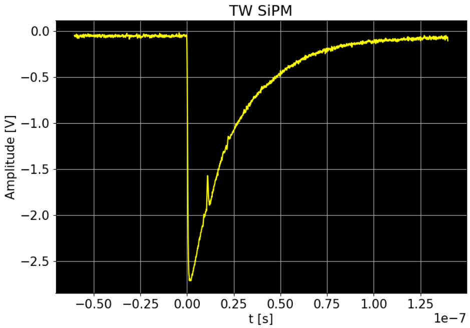
- A single 3×3 mm^2 SiPM with 25 μm cells size (MPPC, Hamamatsu Photonics);
- A TOF-Wall SiPM (series of 4 single SiPMs);
- A laser (PDL 800-B), $\lambda = 405$ nm, with a light diffuser;
- A calibrated photodiode (FDS1010, Thorlabs);
- A function generator used as external trigger for the laser.



Data taking: SiPM signals

- An overvoltage of 4 V was reached by applying a bias voltage of 56 V to the single SiPM and of 120 V to the TOF-Wall SiPM.
- A pulse frequency $\nu_{LASER} = 1.07$ MHz was set as laser external trigger.
- By changing the laser intensity, about 15000 waveforms were acquired and respective photocurrent and dark current were measured.

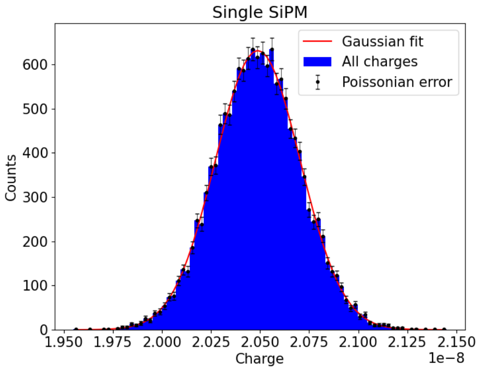


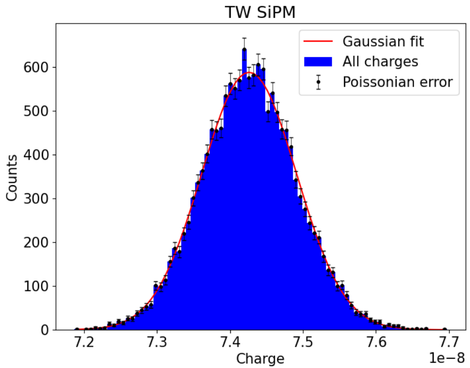


Data analysis

For each laser intensity value:

- charge histograms were built and fitted with a Gaussian function;
- effective photodiode current was estimated by subtracting dark current from photocurrent.





Data analysis

Once all charges Q and current I values were collected:

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

$$N_{fired} = \frac{A}{e\ R\ G}$$

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

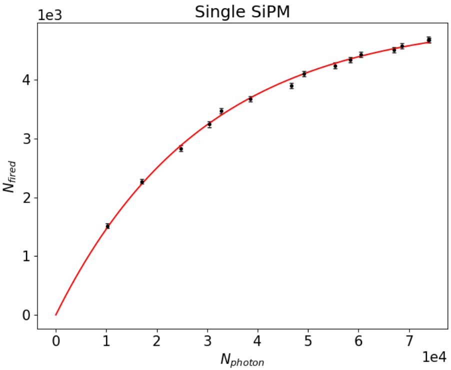
$$N_{ph} = f \frac{I}{\nu_{LASER}\ E_{ph}\ \eta(\lambda)}$$

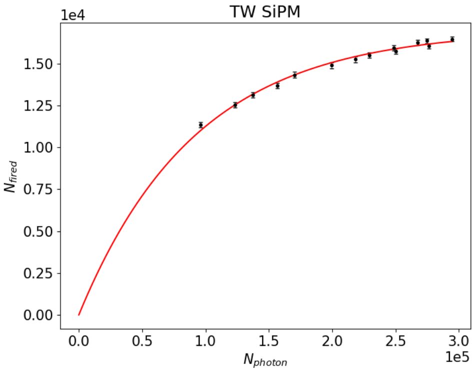
where: A signals area obtained by the Gaussian fit, $R = 50\ \Omega$ resistance of the oscilloscope, $e = 1.6\ 10^{-19}\ C$ elementary charge, G SiPM gain, $E_{ph} = 4.9\ 10^{-19}\ J$ photons energy and f ratio between SiPM surface and photodiode surface.

Saturation model

All data were fitted with the saturation formula: $N_{fired} = N_{tot}\ \left(1 - e^{-kN_{ph}}\right)$

- Single SiPM: $N_{tot} = 5036\ \pm\ 44$, $k = (3.42\ \pm 0.08)\ 10^{-5}$, $\chi^2_{red} = 1.1$
- TOF-Wall SiPM: $N_{tot} = 19115\ \pm\ 140$, $k = (1.08\ \pm 0.03)\ 10^{-5}$, $\chi^2_{red} = 1.2$
- The results have not been yet corrected for the voltage drop on the filter resistor.





Conclusions

- The most relevant parameters of the SiPMs have been studied. These parameters can be used to reproduce the SiPM response in simulation.
- The light attenuation along the bar has been studied using an electron source. The results are not consistent with the one obtained at CNAO since a higher attenuation length is obtained in this case.
- The SiPM saturation is currently under investigation to understand the relevance of this contribution when heavy ions were used.