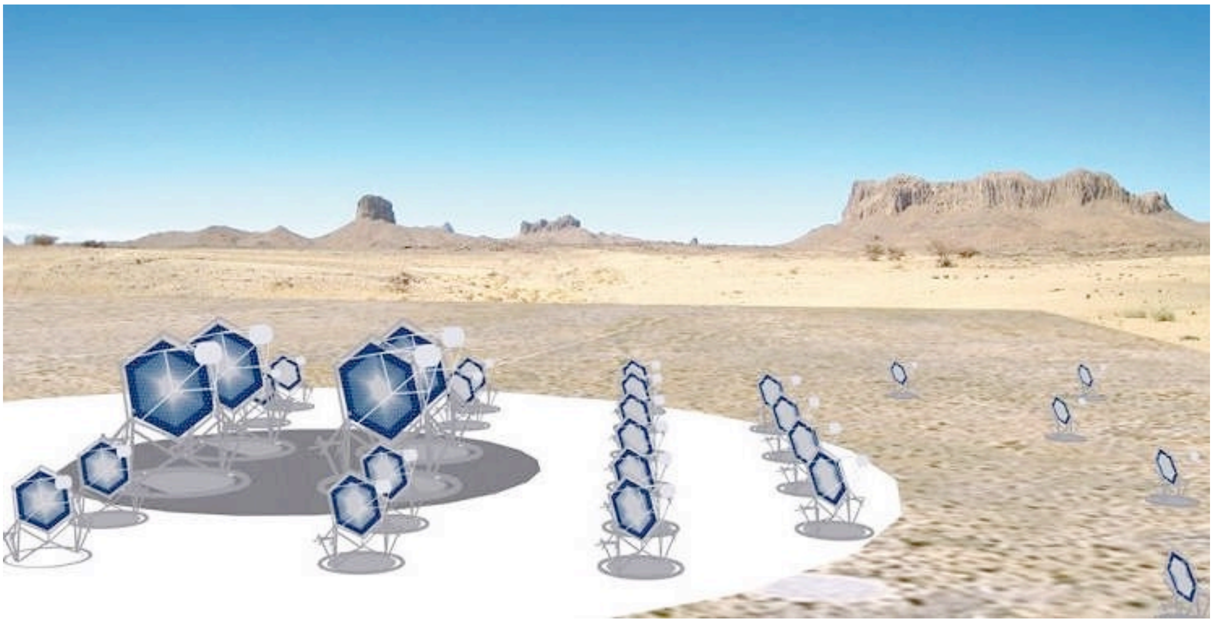
Electro-Optical Characterization Report

Device: SiPM EXCELITAS - S/N. A1001



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Rapporti interni e tecnici
N.13/2013

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SiPM CHARACTERIZATION REPORT

OSSERVATORIO ASTROFISICO DI CATANIA
LABORATORIO RIVELATORI

Catania Astrophysical Observatory, Laboratory for Detectors

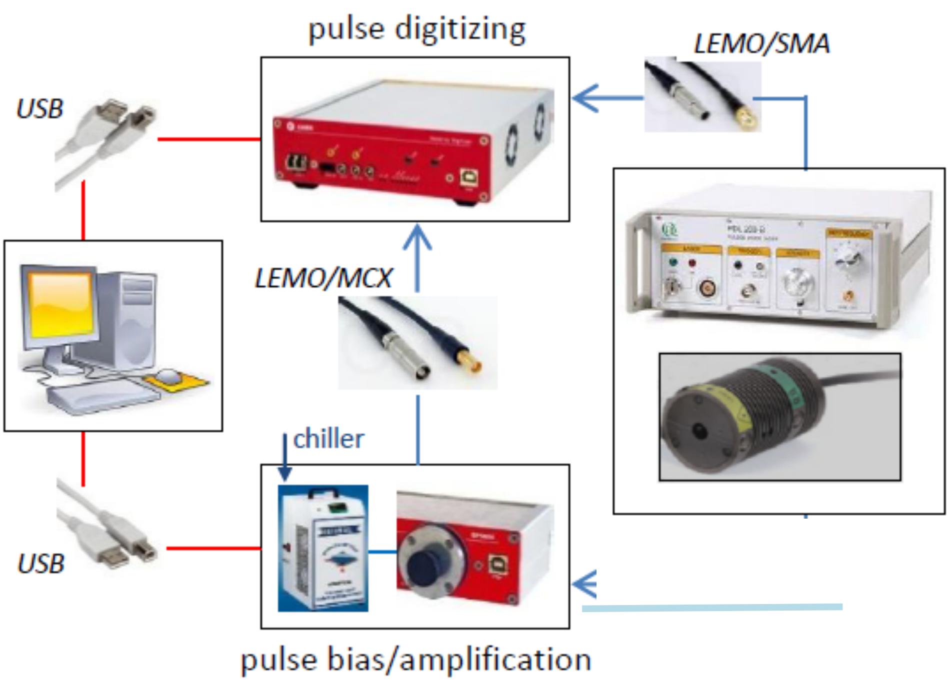
Misure Eseguite da Giuseppe Romeo

DATE	**June 14, 2013**
SiPM	**EXCELITAS** **V_{BD}=95.1 V @T=25°C** **V_{OP} = 99.72V @T=25°C** **@ Vov = 4.62 V G = 2.4 x 10^6** **Dark = 700 KHz @T=25°C and 0.5 pe^-** **(from Excelitas datasheet)**
OP. MODE	**Photon Counting with CAEN PSAU and Tektronix counter**
SER. N.	**A1001**

CONTENTS

1.0 Electrical characterization: Gain versus operating voltage, and output capacitance

The Gain measurements are carried out by using the set-up shown here:



The apparatus is constituted by a pulsed laser (Picoquant) that illuminates the SiPM hosted by the head of the CAEN Power Supply and Amplifier Unit (PSAU) that in turn is connected to a pulse digitizer (CAEN).

In the following figures we report the charge distribution at different operating voltages, in particular from Vop = 97.72 V (corresponding to Vov = 2.62 V) to Vop = 99.72V (corresponding to Vov = 4.62 V) steps of 0.5V.

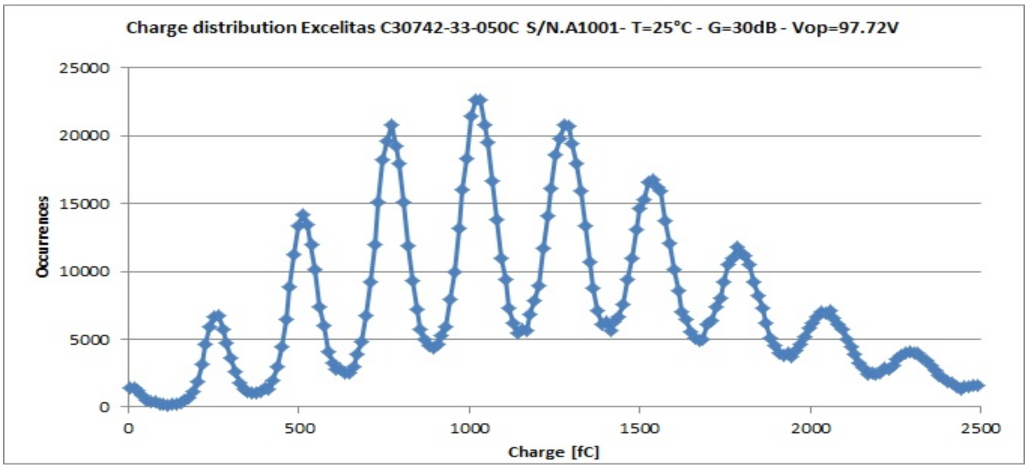


Fig. 1 - Charge distribution Vop=97.72 V (Vov= 2.62 V)

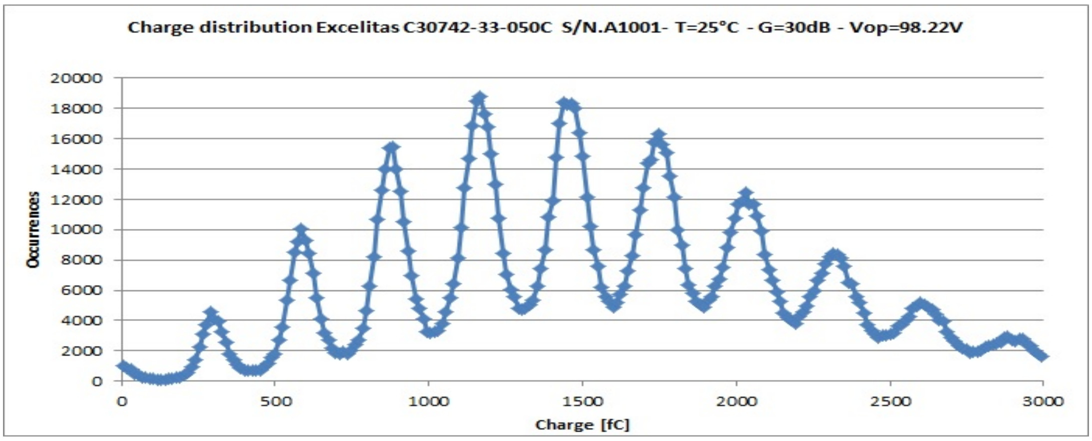


Fig. 2 - Charge distribution Vop=98.22 V (Vov= 3.12 V)

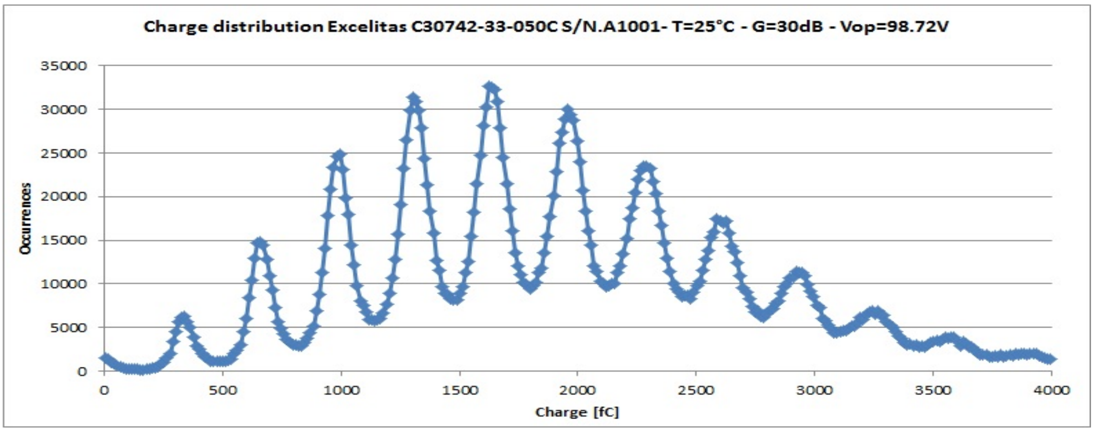


Fig. 3 - Charge distribution Vop=98.72 V (Vov= 3.62 V)

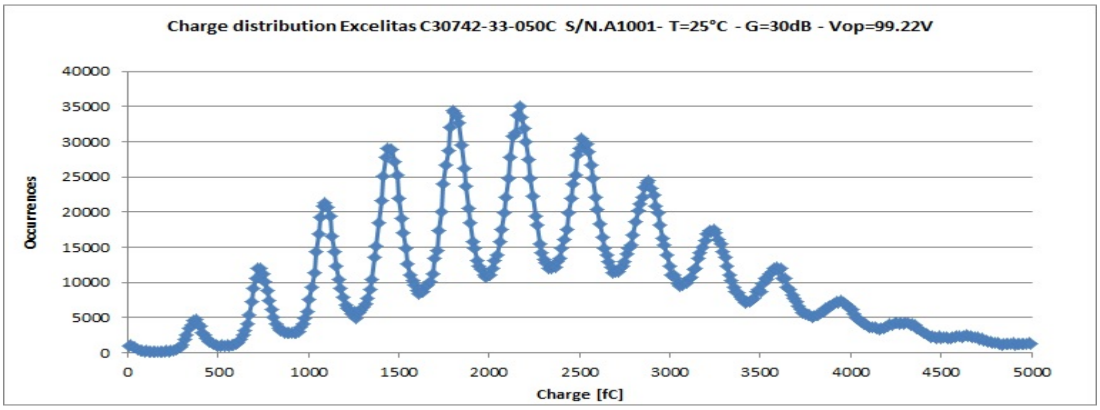


Fig. 4 - Charge distribution Vop=99.22 V (Vov= 4.12 V)

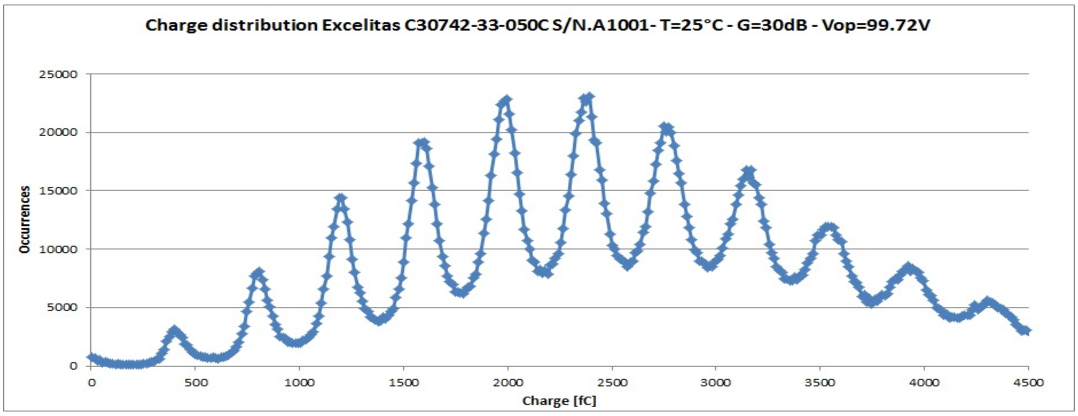


Fig. 5 - Charge distribution Vop=99.72 V (Vov= 4.62 V)

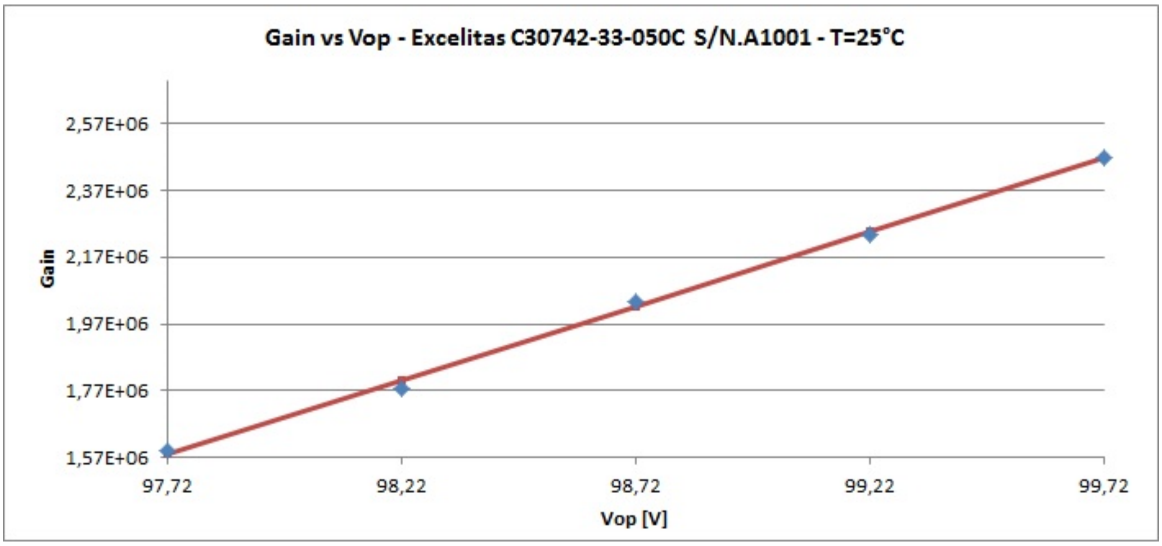


Fig. 6 – Gain versus operating voltage

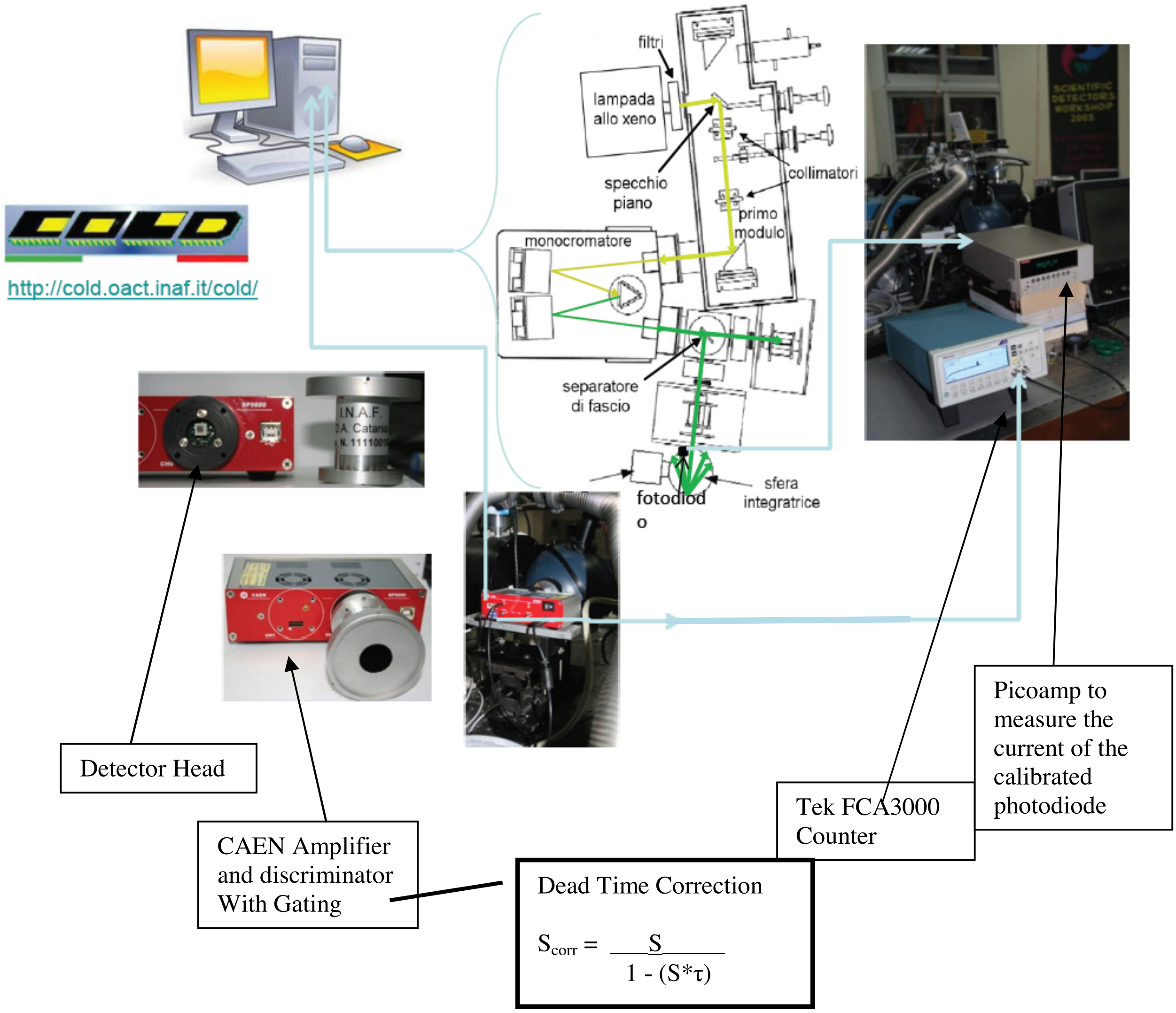
Table 1 reports the Gain values at different operating voltages

25°C		
OV	Vop	Gain
4,62	99,72	2,47E+06
4,12	99,22	2,24E+06
3,62	98,72	2,04E+06
3,12	98,22	1,78E+06
2,62	97,72	1,59E+06

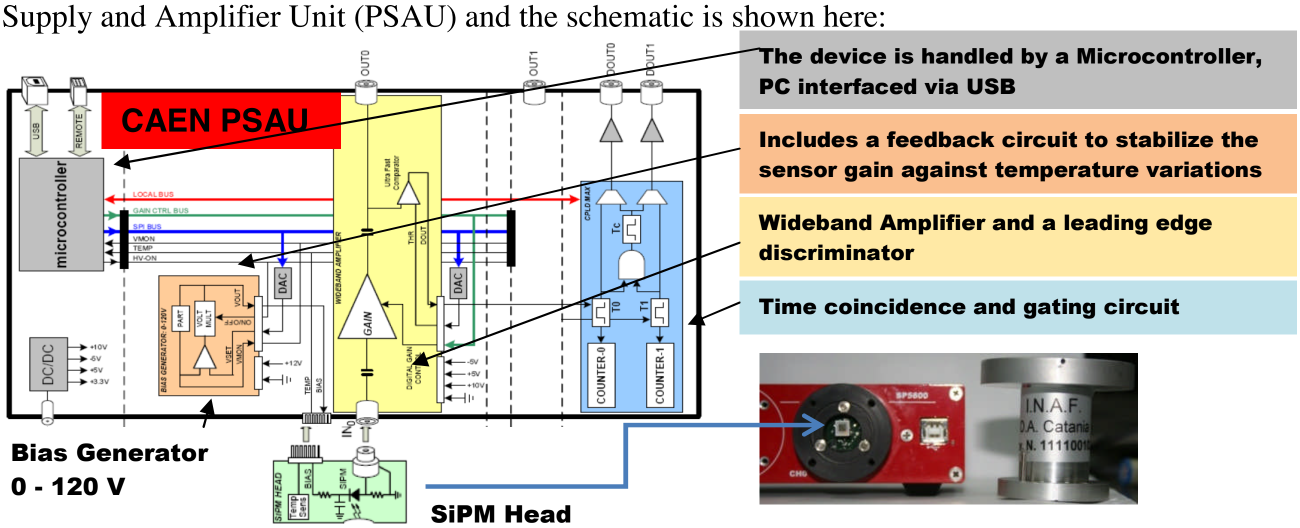
The cell capacitance is given by the ratio (G/e-) ×Vov that is 71.3 fC corresponding to a **SiPM capacitance** of **257 pF.**

2.0 Optical characterization: PDE in the 350 – 950 nm spectral range at Vop=99.72 and T= 25°C with CAEN PSAU and internal hold-off option

The PDE measurements are carried out by using the set-up shown here:



The apparatus is constituted by an illuminating section along with a monochromator and an integrating sphere where, at the output ports, is hosted the SiPM including the front-end electronics and the calibrated photodiode with the output going to the Keitley picoamperometer. The front-end electronics at the moment is based on the CAEN Power Supply and Amplifier Unit (PSAU) and the schematic is shown here:

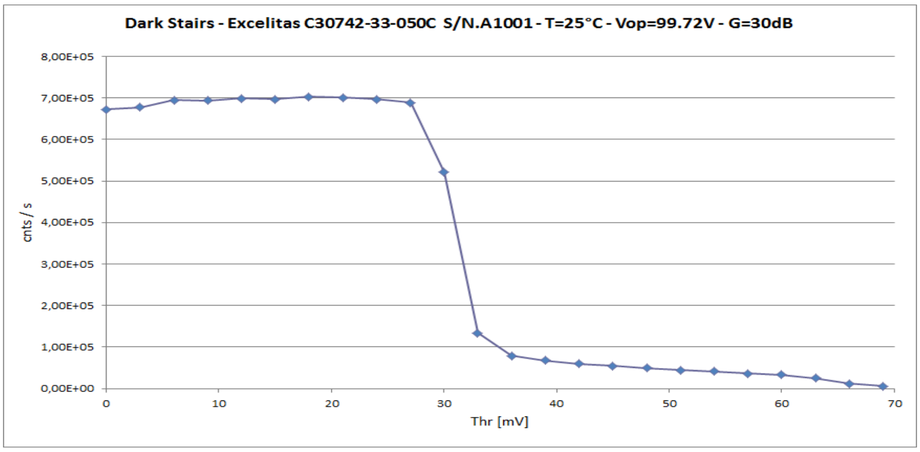


After the selection of the working temperature at which the PDE is carried-out, the set-up of some parameters have to be arranged:

- on SiPM control electronics
  - the **threshold** to establish the optimal threshold level and accounting for **cross-talk**
  - the **hold-off time** to avoid as much as possible the **after pulsing** effect
- on the optical apparatus:
  - the **illumination level** at the integrating sphere output ports to **prevent** the measurements from **pile-up**
  - the **photocurrent** measured by the calibrated photodiode (sufficiently high) to **avoid low level signal measurements**.

These last two parameters if not selected accurately can severely degrade the PDE.

2.1 Stairs at Vop=99.72 V and applying the temperature compensation



Xtalk= 7.0 %
DCR=700 KHz

Fig. 7 – Stairs in the range 0 – 70 mV threshold ***Optimal threshold at 0.5 pe- selected:*** → V_{Thr} ***= -18mV***

From the stairs plot we derive that the optimal threshold at 0.5 pe- is $\mathbf{V_{Thr} = -18\ mV}$.
At this threshold we find a **DCR** of **700KHz** and a **Cross-talk** of **7.0%**

2.2 DCR vs hold-off time

Measurements were performed at T=25°C, Vop= 99.72 varying the gate time from 30ns to 120ns. In Fig. 8 data are plotted with and without dead time correction.

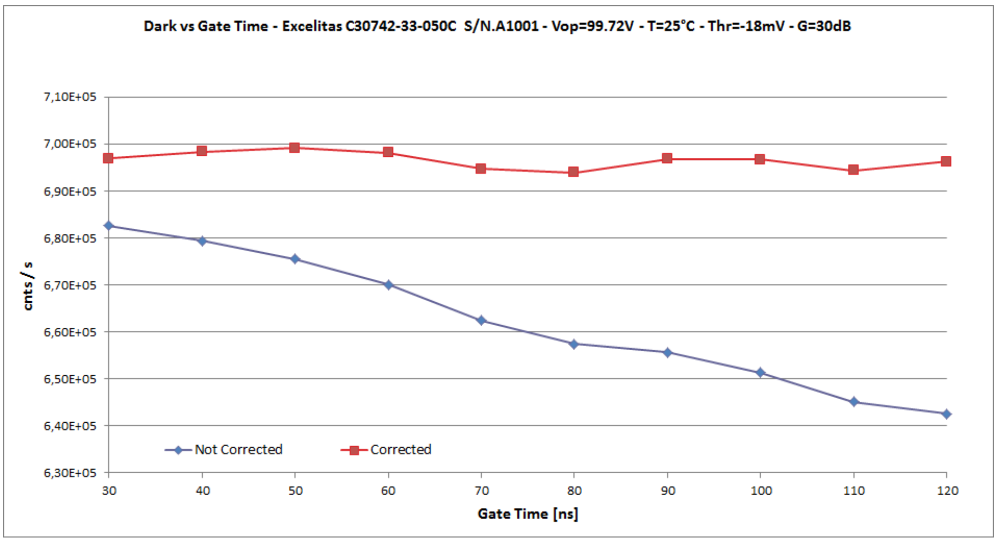


Fig. 8 - DARK vs GATE TIME Vop=99.72V - Thr=-18 mV T=25° Measurements were performed varying the gate time from 30ns to120ns with and without Dead Time (Temperature compensation is applied).

From the plot of Fig.8 it is clearly evident that applying the dead time correction, we obtain the DCR given by the stairs after 90. This behavior tells us to select an **hold-off time of 90 ns** .

2.3 Dark Count Rate vs time

To be sure that during the PDE measurements the DCR variation doesn't affect the photogenerated signal, the DCR stabilty has been evaluated.
Fig. 9 shows the DCR plot in an interval time of 120 seconds.

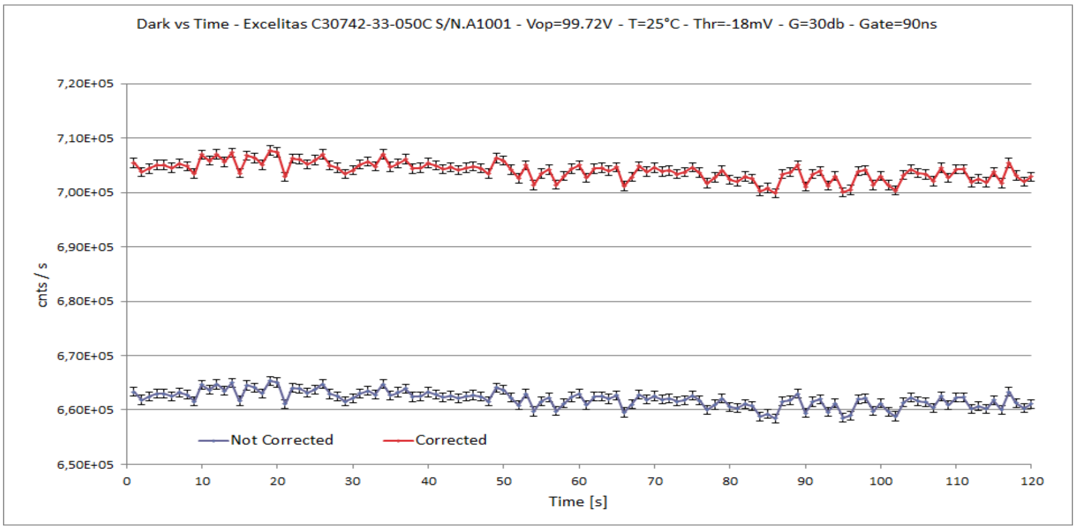


Fig. 9 - Dark vs Time –Gate time=90ns Vop=99.72V @ T=25°C with Temperature Compensation Thr=-18mV.

2.4 Linearity behavior at 500 nm and PDE degradation vs photon rate

To prevent the system from saturation, preliminary illumination or better photon rate measurements have to be carried out.
Measurements were performed illuminating the integrating sphere with a monochromatic flux (λ=500 nm). The SiPM is operated by selecting T=25°C, V_{OP} = 99.72V with hold-off time 90 ns.
Fig. 10 shows the photon rate at 500 nm versus the photocurrent measured by the calibrated photodiode. Of course the dark current in the calibrated photodiode and the dark count rate (DCR) in the SiPM are subtracted.

Linearity @500 nm

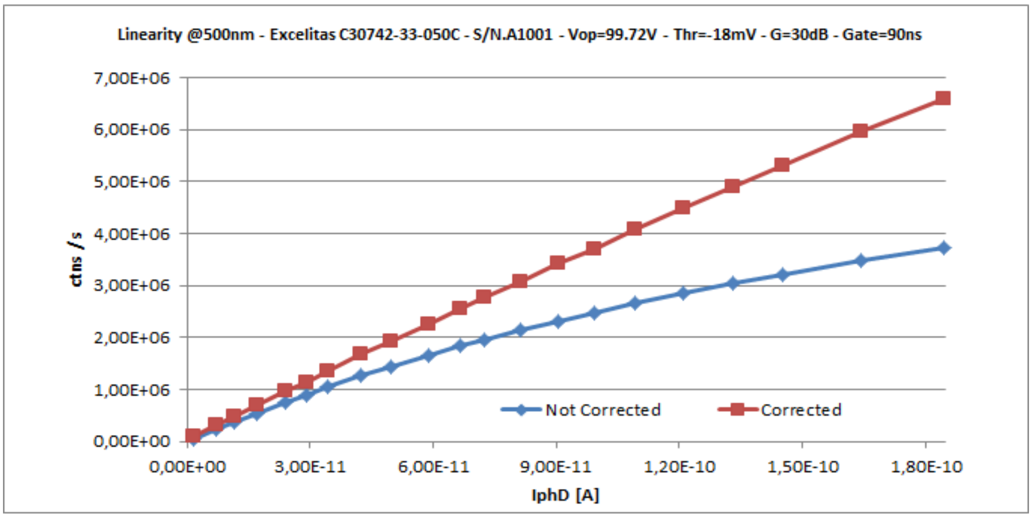


Fig. 10 – Linearity at λ=500 nm with and without the dead time correction.

A more efficient method to evaluate the PDE degradation due to the uncorrected illumination can be that to directly evaluate the PDE(500nm) versus the photon rate as shown in Fig. 11.

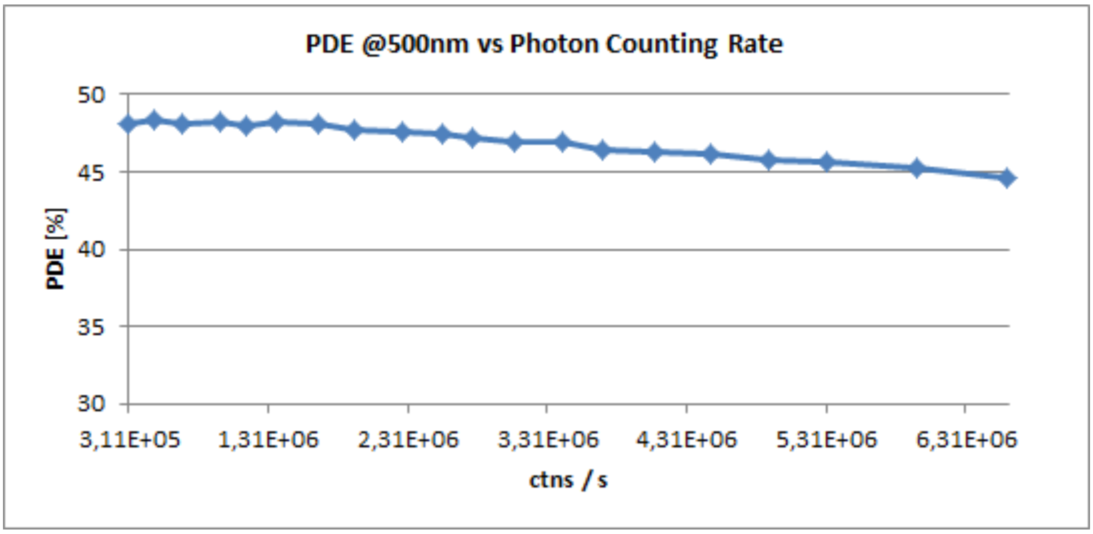


Fig. 11 – PDE degradation at λ=500 nm as function of photon rate.

From this last plot we derive the device shows a nonlinear behavior at about 5 MHz corrected for dead time.
Then the PDE measurements have to be carried out with **uncorrected signals not higher than 3 - 4 MHz corrected for dead time**.

2.5 PDE in the 350 – 950 nm spectral range at T=25°C and Vop= 99.72 V

Measurements were performed at V_{OP} = 99.72 V, corresponding to Vov=4.62V and gate time 90ns. The plot reports the PDE with values corrected for the Dead Time.

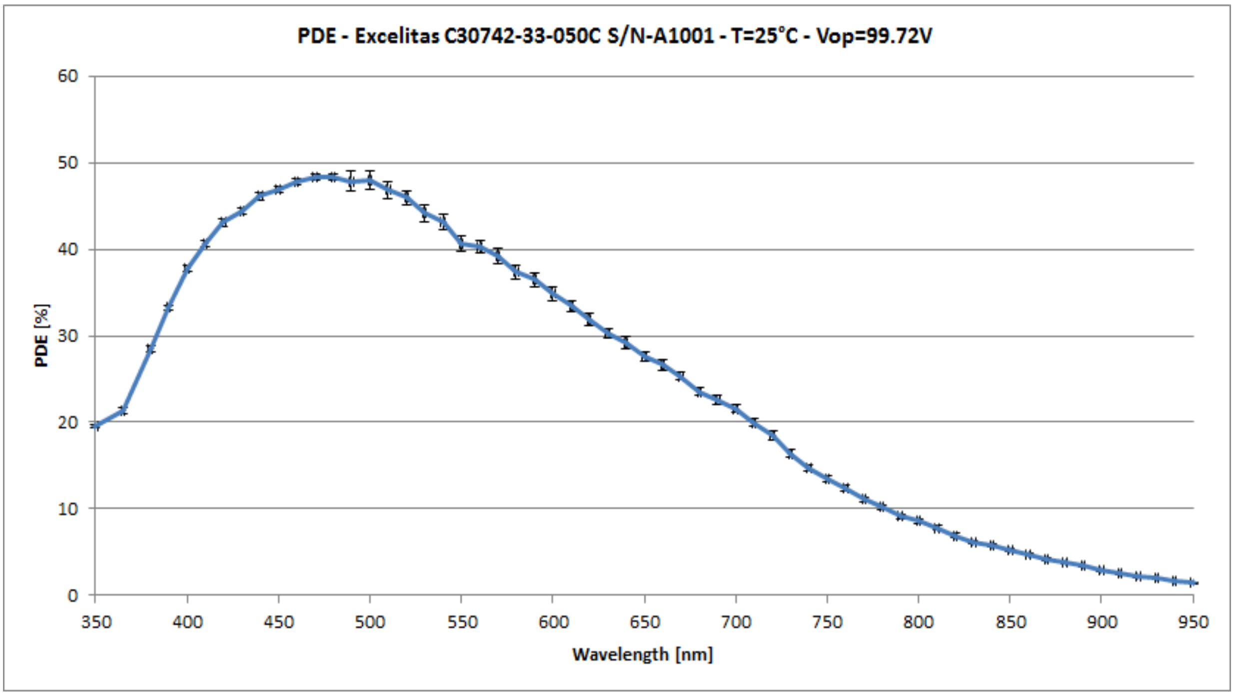
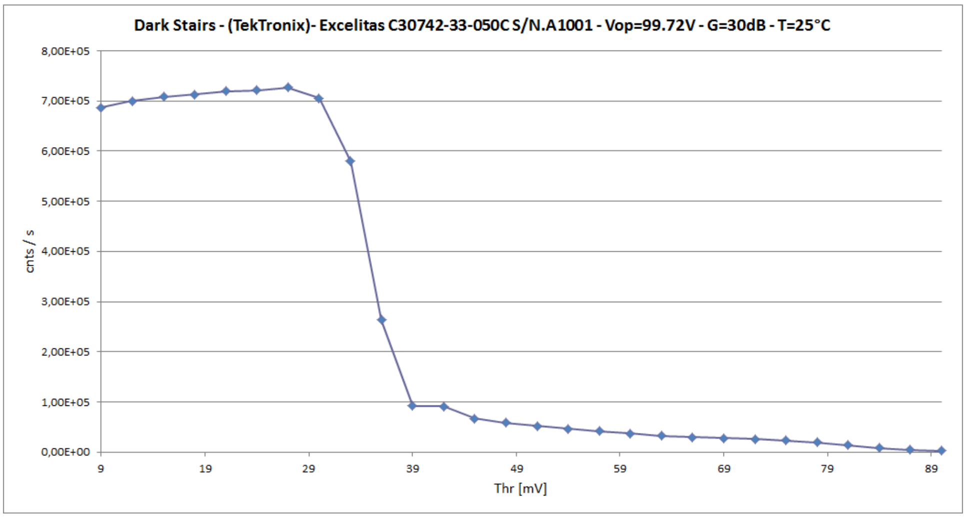


Fig.12 – PDE measurements operating the SiPM at Vop=99.72 V (Vov=4.62 V) T=25°C, Vthr=-18 mV, Gate time=90 ns

3.0 Optical characterization: PDE in the 400 – 600 nm (step 50nm), Vop=99.72V without hold-off

3.1 Stairs at Vop=99.72 V and applying the temperature compensation

Measurements were performed by connecting the PSAU CAEN amplifier-output directly to the Tektronix counter and using the discriminator on board of the counter.



Xtalk= 6.3 %
DCR=700 KHz

Fig. 13 – Stairs in the range 0 – 90 mV threshold ***Optimal threshold at 0.5 pe- selected:*** → ***V_{Thr} = -18mV***

From the stairs plot we derive that the optimal threshold at 0.5 pe- is **V_{Thr} = -18 mV**.
At this threshold we find a **DCR** of **700KHz** and a **Cross-talk** of **6.3%**

3.2 Dark Count Rate vs time

To be sure that during the PDE measurements the DCR variation doesn't affect the photogenerated signal, the DCR stabilty has been evaluated.
Fig. 14 shows the DCR plot in an interval time of 120 seconds.

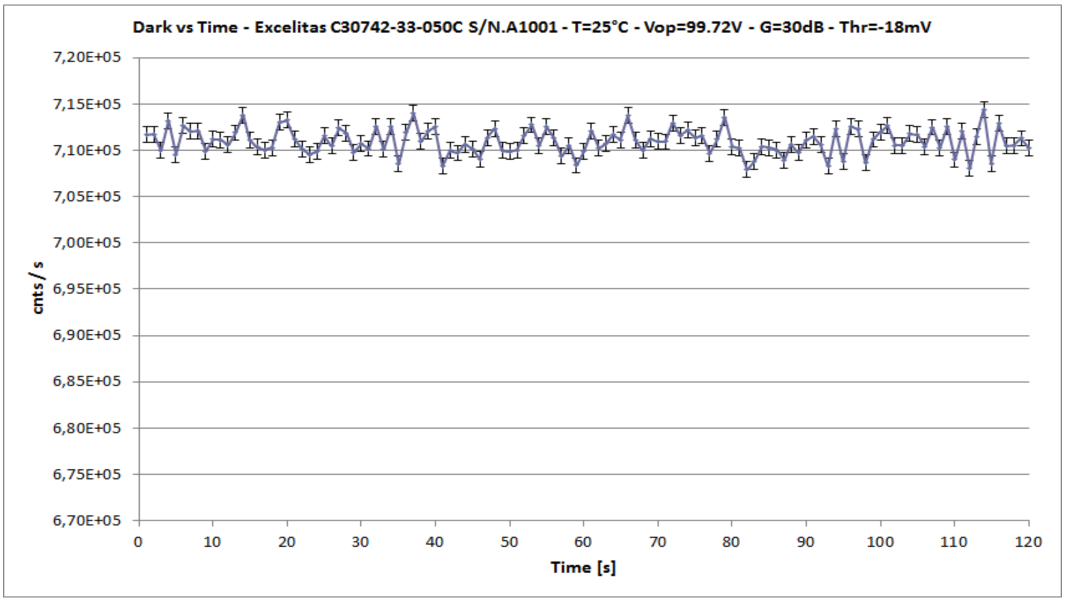


Fig. 14 - Dark vs Time –Vop=99.72V @ T=25°C with Temperature Compensation Thr=-18 mV.

3.3 Linearity behavior at 500 nm and PDE degradation vs photon rate

To prevent the system from saturation, preliminary illumination or better photon rate measurements have to be carried out.
Measurements were performed illuminating the integrating sphere with a monochromatic flux (λ=500 nm). The SiPM is operated by selecting T=25°C, V_{OP} = 99.72V and using the Tek counter..
Fig. 15 shows the photon rate at 500 nm versus the photocurrent measured by the calibrated photodiode. Of course the dark current in the calibrated photodiode and the dark count rate (DCR) in the SiPM are subtracted.

Linearity @500 nm with Tek and without hold-hoff time

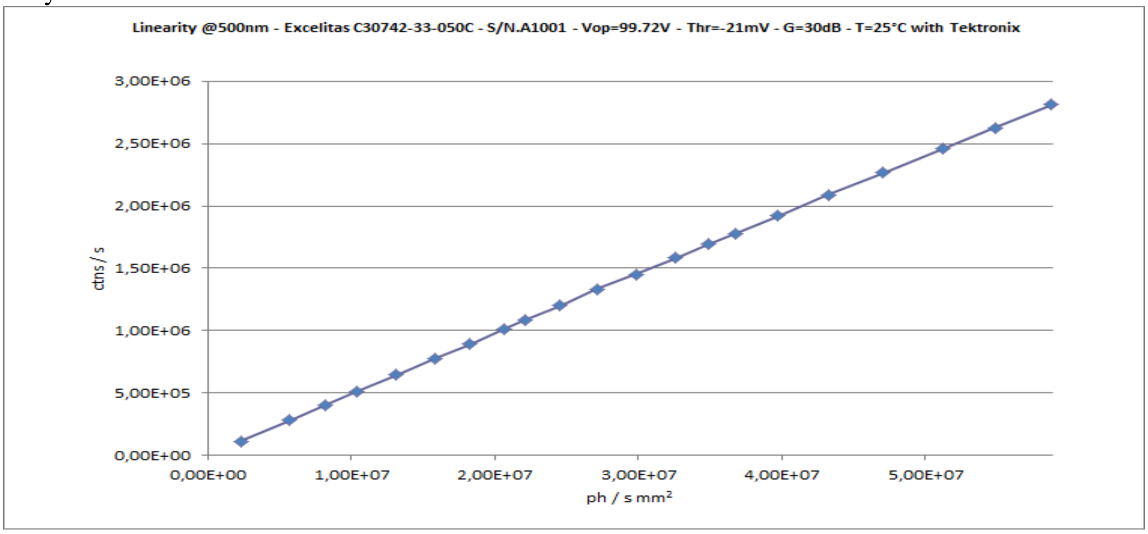


Fig. 15 – Linearity at λ=500 nm with Tek counter and without hold-off..

A more efficient method to evaluate the PDE degradation due to the uncorrected illumination can be that to directly evaluate the PDE(500nm) versus the photon rate as shown in fig. 16.

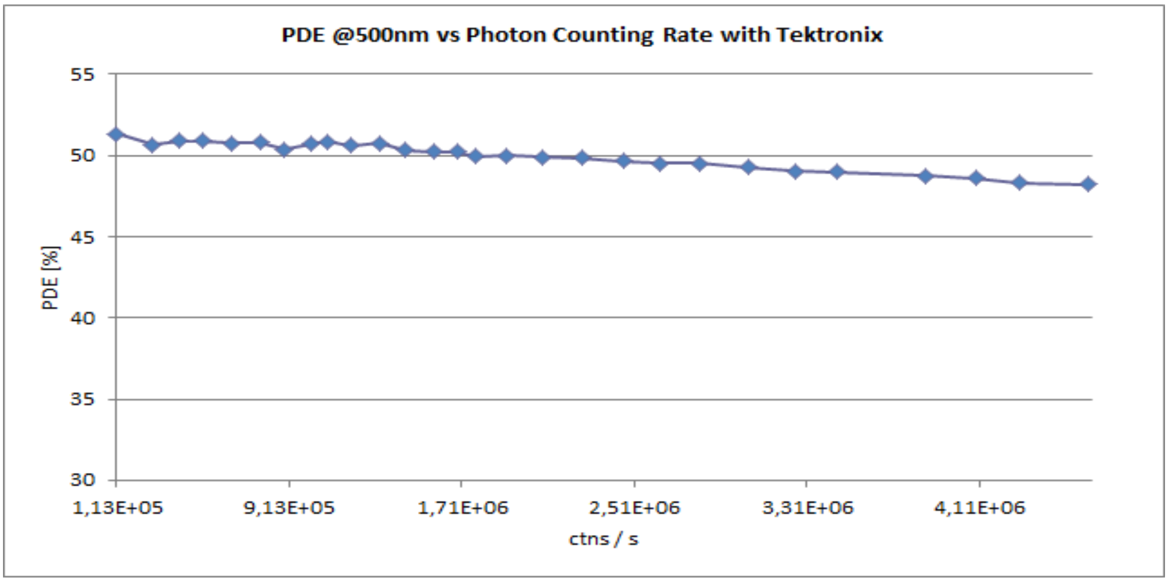


Fig. 16 – PDE degradation at λ=500 nm as function of photon rate.

From this last plot we derive the device shows a nonlinear behavior at about 3.5 MHz .
Then the PDE measurements have to be carried out with **signals not higher than 3 MHz**.

3.4 PDE in the 400 – 600 nm spectral range (step 50 nm) at T=25°C and Vop= 99.72 V

Measurements were performed at V_{OP} = 99.72 V, corresponding to Vov=4.62. The plot in fig. 17 reports the PDE in the 400-600 nm.

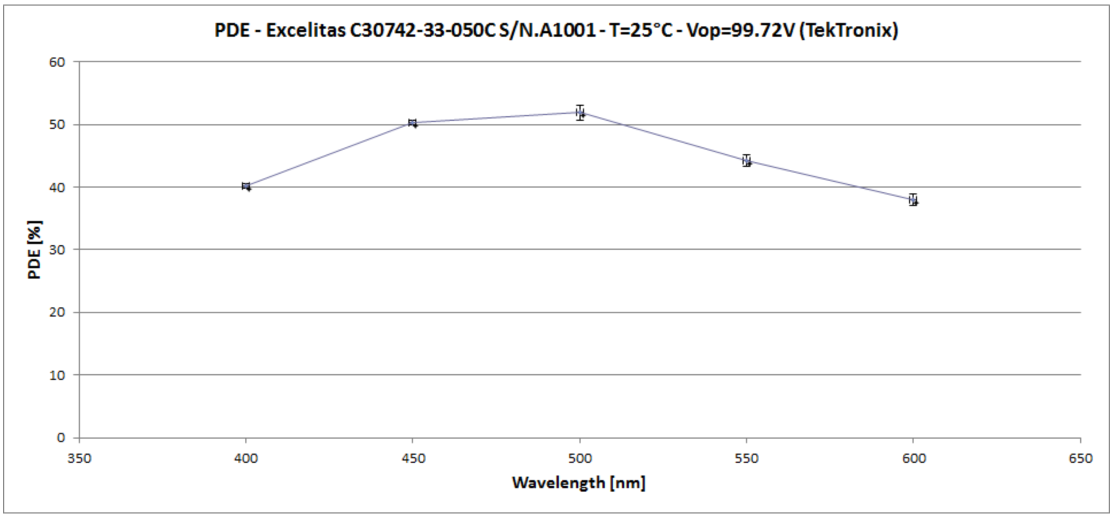


Fig.17 – PDE measurements operating the SiPM at Vop=99.72V T=25°C, Vthr=-18 mV.

4.0 Optical characterization: PDE in the 400 – 600 nm spectral range comparison between the two methods

We carried out many measurements using the two methods:

- CAEN PSAU + Hold-off time+ Counter Tektronix
  and
- CAEN PSAU + Counter Tektronix

Fig. 18 shows the PDE obtained in both cases.

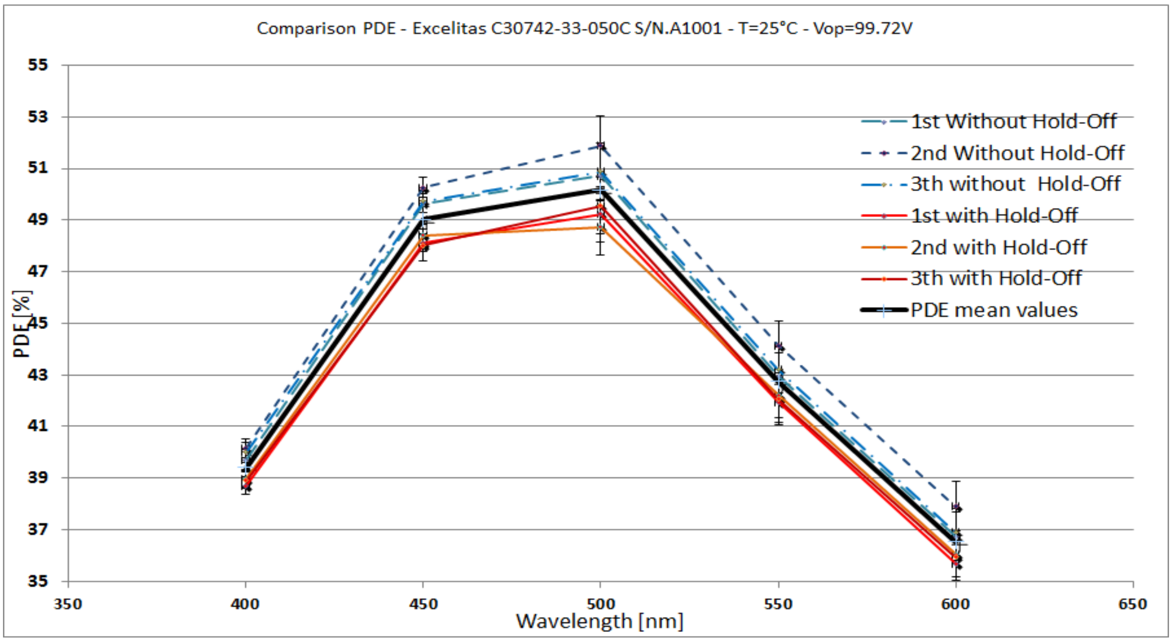


Fig.18 – PDE in the 400 – 600 nm comparison between the two methods. The mean PDE between the two methods is also reported.

As can be seen the PDE without hold-off results a slightly higher than that where the hold-off is applied. We repeated the measurements three times in the two different operating conditions. In fig. 19 are shoved the stairs plots for the six measurements.

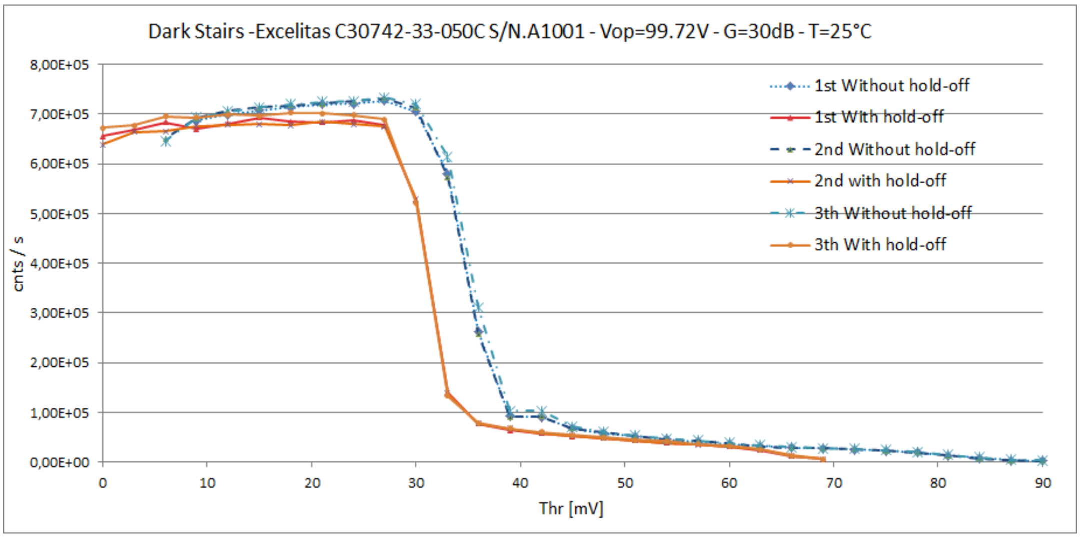


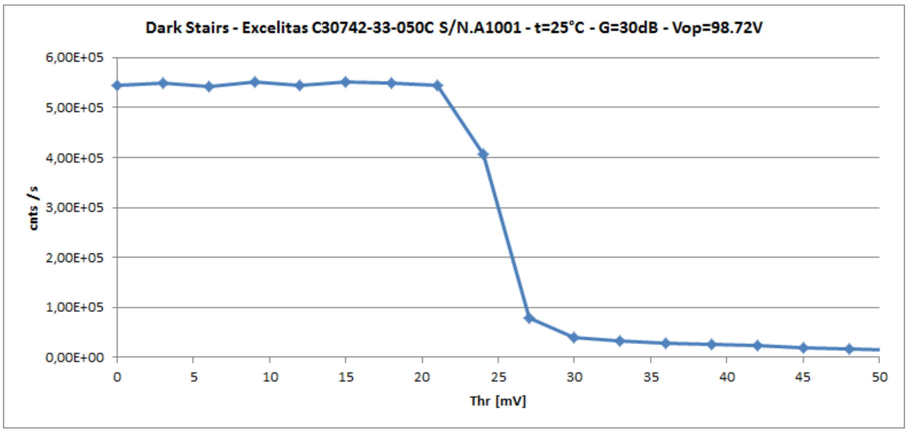
Fig.19 – Stairs measurements with and without hold off are here compared

Finally, from the results obtained we decide to adopt the method that use the hold-off time in order to account, from one side, for the (low) afterpulse contribution, and, to be also conservative with PDE estimation from the other side. Thus we confirm the PDE obtained on the section 2.5 and we proceed on the next measurement by adopting the method with the hold-off time correction.

5.0 PDE in the 350 – 950 nm spectral range at Vop=98.72 and T= 25°C with CAEN PSAU and internal hold-off option

The PDE measurements apparatus is that described in section 1.0. We operated the SiPM **at an overvoltage 1 volt less** respect to the previous measurement in order to observe the effect of a lower over voltage on the Trigger Probability (TP) and then on the PDE. This means to operate he SiPM at .

5.1 Stairs at Vop=98.72 V and applying the temperature compensation



Xtalk= 4.5 %
DCR=550 KHz

Fig. 20 – Stairs in the range 0 – 50 mV threshold ***Optimal threshold at 0.5 pe- selected:*** → ***V_{Thr} = -15mV***

From the stairs plot we derive that the optimal threshold at 0.5 pe- is **V_{Thr} = -15 mV**.
At this threshold we find a **DCR** of **550KHz** and a **Cross-talk** of **4.5%.**

5.2 DCR vs hold-off time

Measurements were performed at T=25°C, Vop= 98.72 varying the gate time from 30ns to 120ns. In Fig. 21 data are plotted with and without dead time correction.

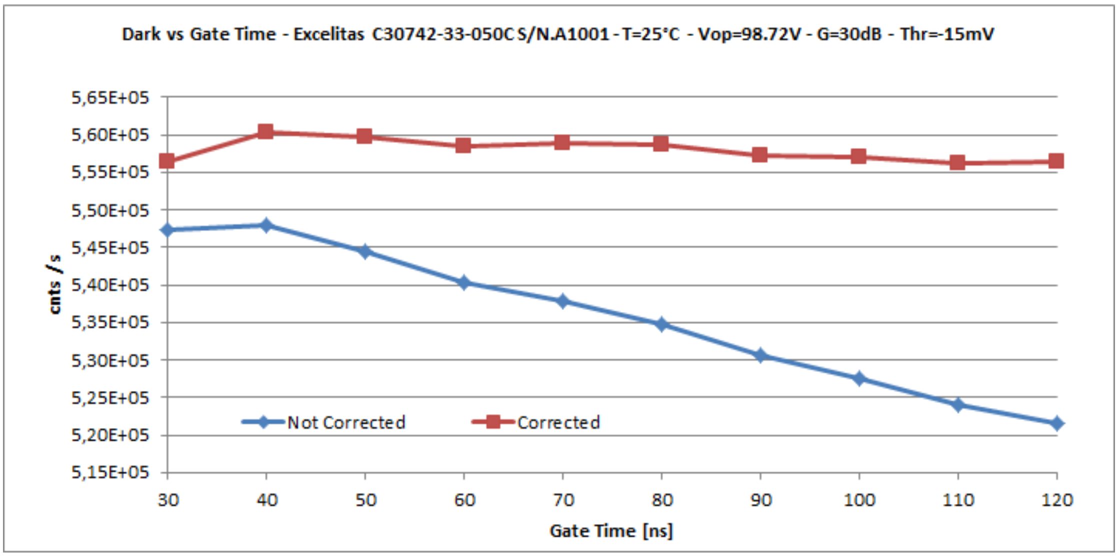


Fig. 21 - DARK vs GATE TIME Vop=98.72V - Thr=-15 mV T=25° Measurements were performed varying the gate time from 30ns to120ns with and without Dead Time (Temperature compensation is applied).

From the plot of Fig. 21 it is clearly evident that applying the dead time correction, we obtain the DCR given by the stairs after 90. Also in this case the behavior tells us to select an **hold-off time of 90 ns** .

5.3 Dark Count Rate vs time

To be sure that during the PDE measurements the DCR variation doesn't affect the photogenerated signal, the DCR stabilty has been evaluated.
Fig. 22 shows the DCR plot in an interval time of 120 seconds.

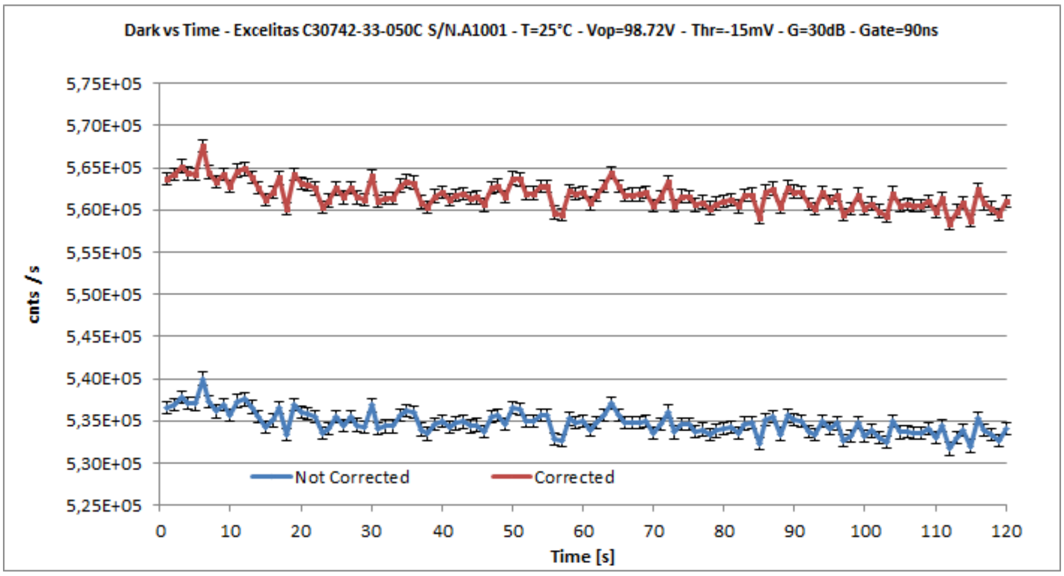


Fig. 22 - Dark vs Time –Gate time=90ns Vop=98.72V @ T=25°C with Temperature Compensation Thr=-15mV.

5.4 Linearity behavior at 500 nm and PDE degradation vs photon rate

To prevent the system from saturation, preliminary illumination or better photon rate measurements have to be carried out.

Measurements were performed illuminating the integrating sphere with a monochromatic flux (λ=500 nm). The SiPM is operated by selecting T=25°C, V_{OP} = 98.72V with hold-off time 90 ns.

Fig. 23 shows the photon rate at 500 nm versus the photocurrent measured by the calibrated photodiode. Of course the dark current in the calibrated photodiode and the dark count rate (DCR) in the SiPM are subtracted.

Linearity @500 nm

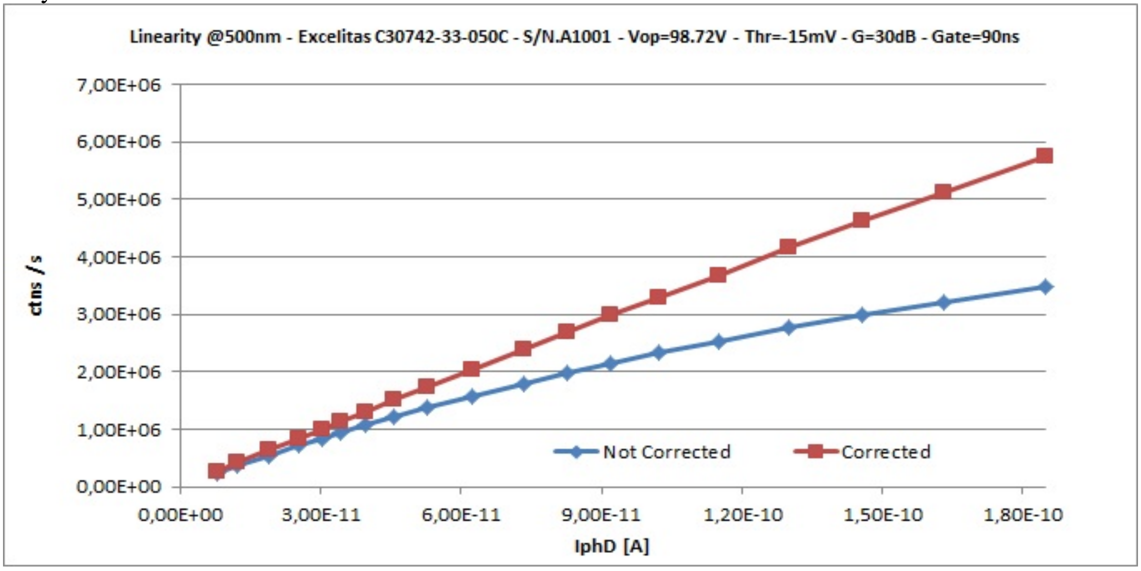


Fig. 23 – Linearity at λ=500 nm with and without the dead time correction.

A more efficient method to evaluate the PDE degradation due to the uncorrected illumination can be that to directly evaluate the PDE(500nm) versus the photon rate as shown in fig. 24.

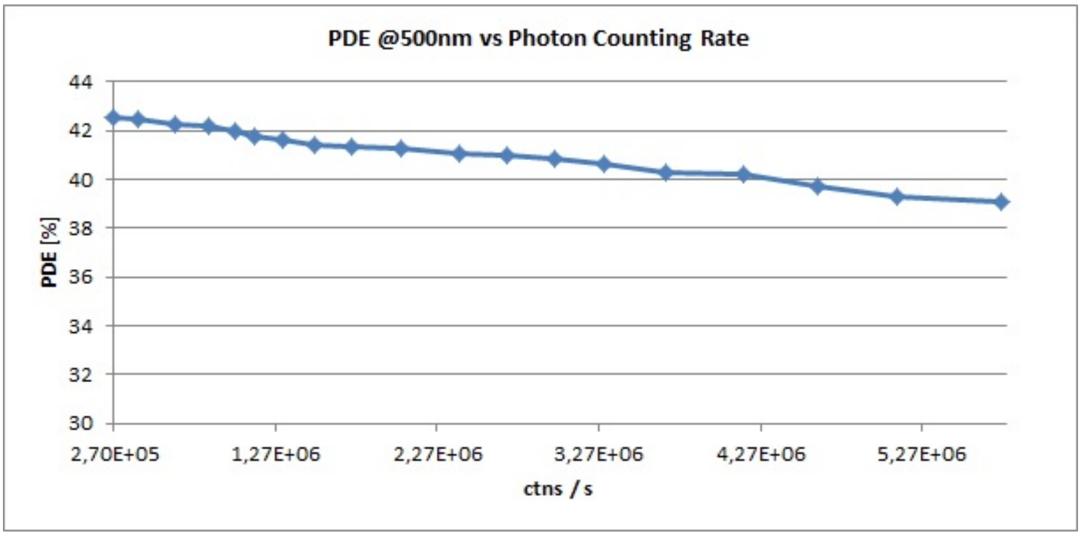


Fig. 24 – PDE degradation at λ=500 nm as function of photon rate.

From this last plot we derive the device shows a nonlinear behavior at about 4 MHz corrected for dead time.

Then the PDE measurements have to be carried out with **uncorrected signals not higher than 3 - 4 MHz corrected for dead time**.

5.5 PDE in the 350 – 950 nm spectral range at T=25°C and Vop= 99.72 V

Measurements were performed at V_{OP} = 99.72 V, corresponding to Vov=3.62V and gate time 90ns. The plot reports the PDE with values corrected for the Dead Time.

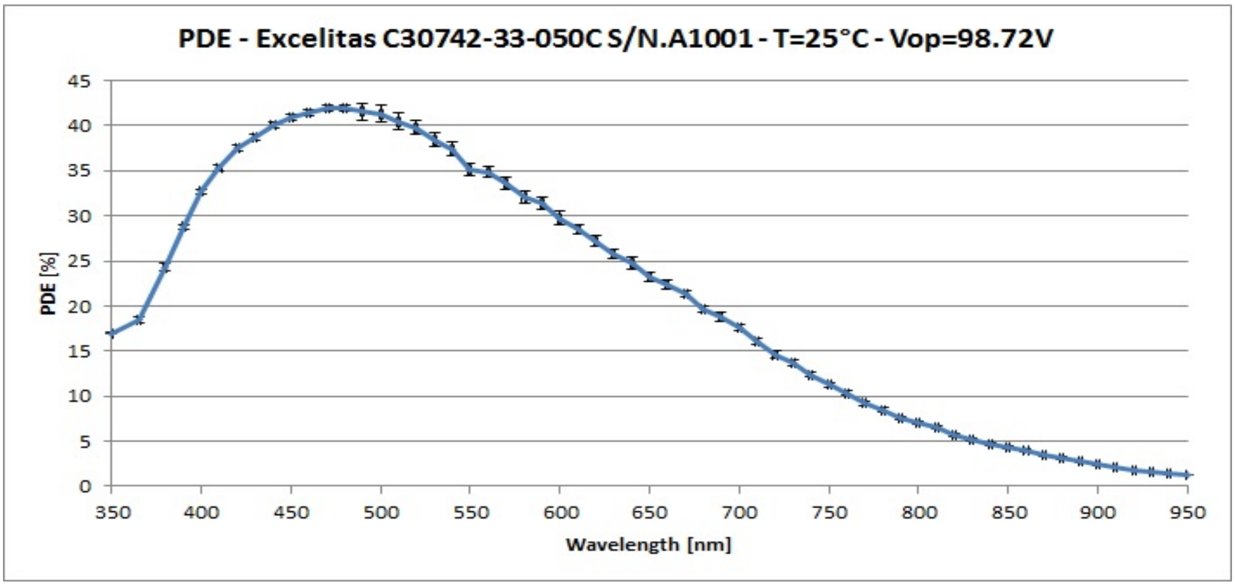


Fig.25 – PDE measurements operating the SiPM at Vop=98.72 (Vov=3.62 V) Vov=4.9V T=25°C, Vthr=-15 mV, Gate time=90 ns

6.0 PDE in the 350-950 nm spectral range at Vop=99.72 and Vop=98.72 and T= 25°C

In fig.26 the PDE curves obtained at the two different operating voltage are shown.

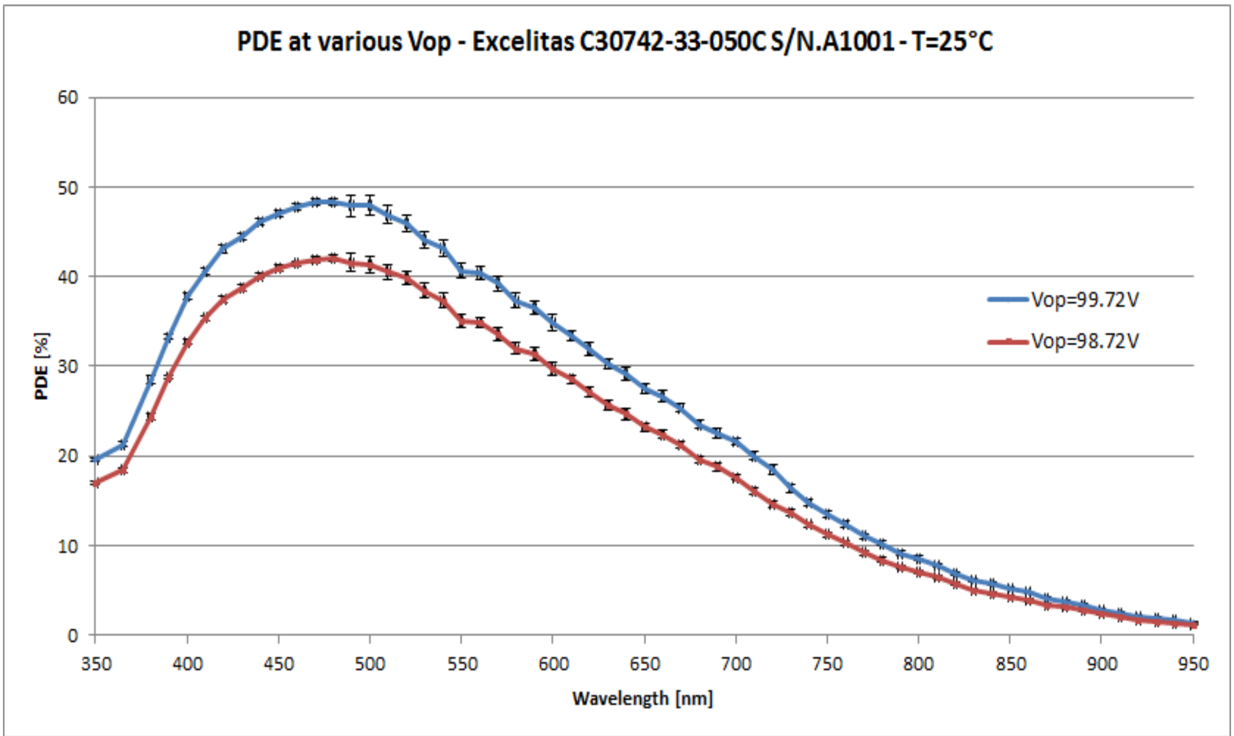


Fig.26 – PDE measurements at two different operating voltages Vop=99.72 V (Vov=4.62 V) and Vop=98.72 V (Vov=3.62 V), T=25°C, Gate time=90 ns with dead time correction.

7.0 Cross-talk and DCR versus Vop at T= 25°C

The cross-talk and the DCR as function of the operating voltage is also measured. In the following figures the resulting plots are shown.

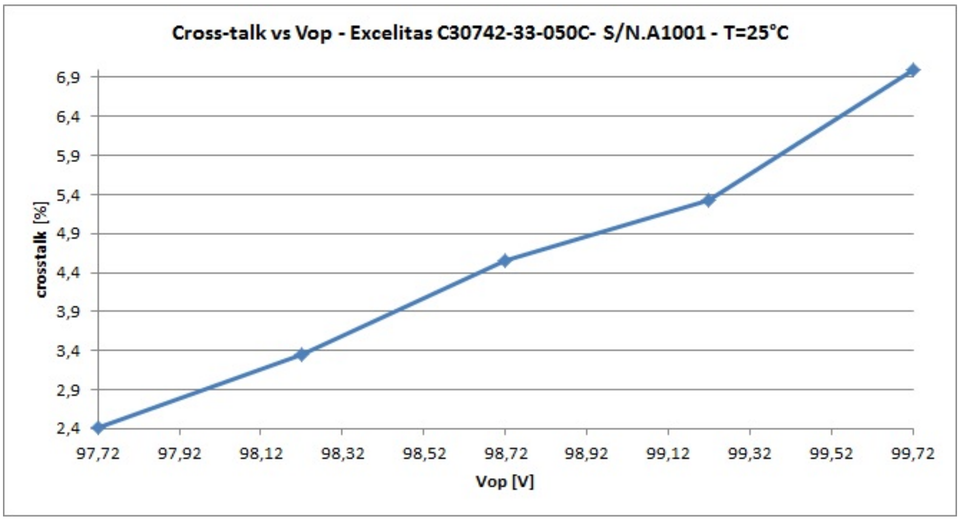


Fig.27 – Cross-talk measurements

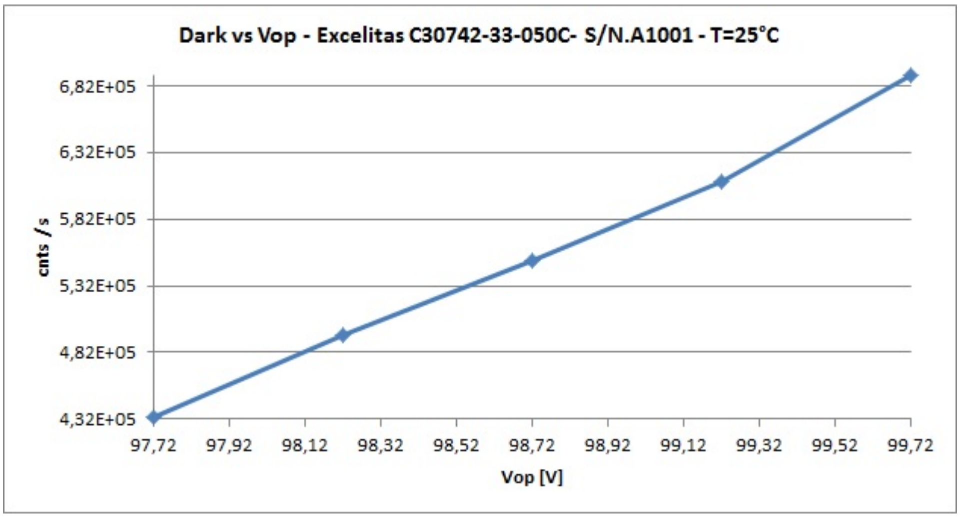


Fig.28 – DCR measurements

8.0 Conclusions

We operated the SiPM at **Vop=99.72 V** corresponding to an overvoltage of **4.62 V**, this is because unfortunately the CAEN PSAU at the moment is unable to go over 100 V power supply. We decided to operate the device also at **Vop= 98.72** V corresponding to an overvoltage of **3.62 V**.
What has been found is that the PDE is the same as the previous device, but the DCR is reduced (to about 1/3) while impressive result is obtained in reducing the cross talk.
The PDE measurement have been carried out with sufficient signal on the calibrated photodiode thanks to the use of a neutral density filter (calibrated at our facility) in front of the SiPM.
Note that measures have been performed without the influence of the cross talk (in fact the simultaneous pulse due to the optical cross-talk that is added to the first one, is not taken into account because at the threshold of 0.5 pe the resulting pulse is counted as one) and avoiding as much as possible the afterpulse effect because a gating is introduced.