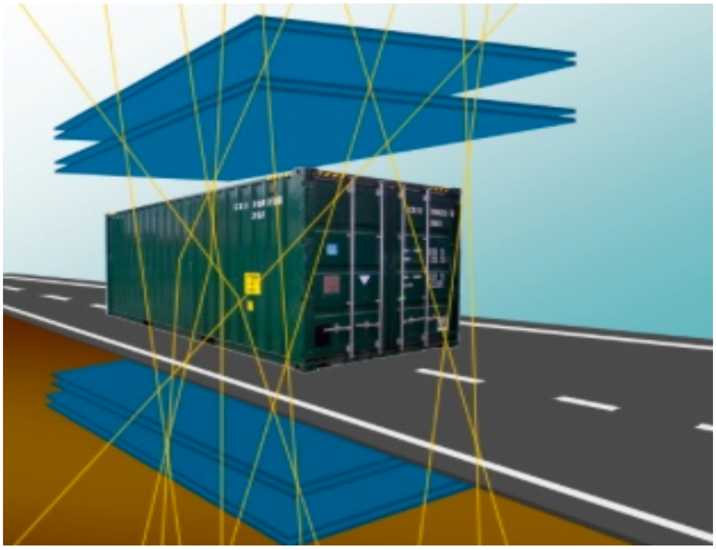
OSSERVATORIO ASTROFISICO DI CATANIA

SiPM characterization report for the Muon Portal Project

Device: SiPM type P on N - S/N. SPM10H5-60P-Y239187-wf04 ST Microelectronics



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Rapporti interni e tecnici
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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	**May 2, 2013**
SiPM	**ST Microelectronics** **SiPM type: P on N – ACR single layer** **V_{BD}=33.74 V @T=25°C**
OP. MODE	**Photon Counting with CAEN PSAU and Tektronix counter**
SER. N.	**SPM10H5-60P - Y239187-wf04**

CONTENTS

1.0 Electrical Characteristics from Data sheet

The layout of this device is shown in Fig. 4. Its main features are reported in Table 3.

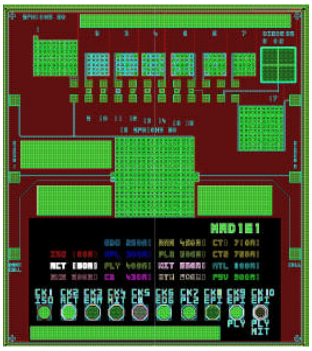


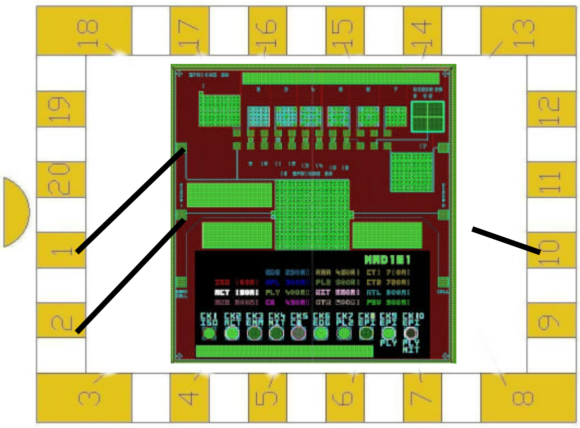
Fig. 1 SPM10H5-60: chip layout.

Table 3 Features of the SPM10H5-60 device.

Parameter	Unit	Value
Sensitive area size	μm^2	1080 × 1080
Cells matrix dimension		18 × 18
Number of cells		324
Cell fill factor	%	67.4
Cell size	μm^2	60 × 60
Quenching resistor squares number		28
Quenching capacitor area	μm^2	26
Cell active area	μm^2	2427
Cell perimetral area	μm^2	844
Bonding pad area	μm^2	150 × 150
Metal grid area (2 pads included)	μm^2	161802

NRD16 – Multichip – SPM10H5_60 BONDING

Electrode	Pin
Cathode	1
Cathode Diode	2
Anode (Back)	10



2.0 Breakdown Voltage

The V_{BD} was measured from the voltage-current measurements and tracing the intercept between the line of best fit (range from 1mA to 2mA) and the x-axis.
Here follows the plot of the I-V characteristic

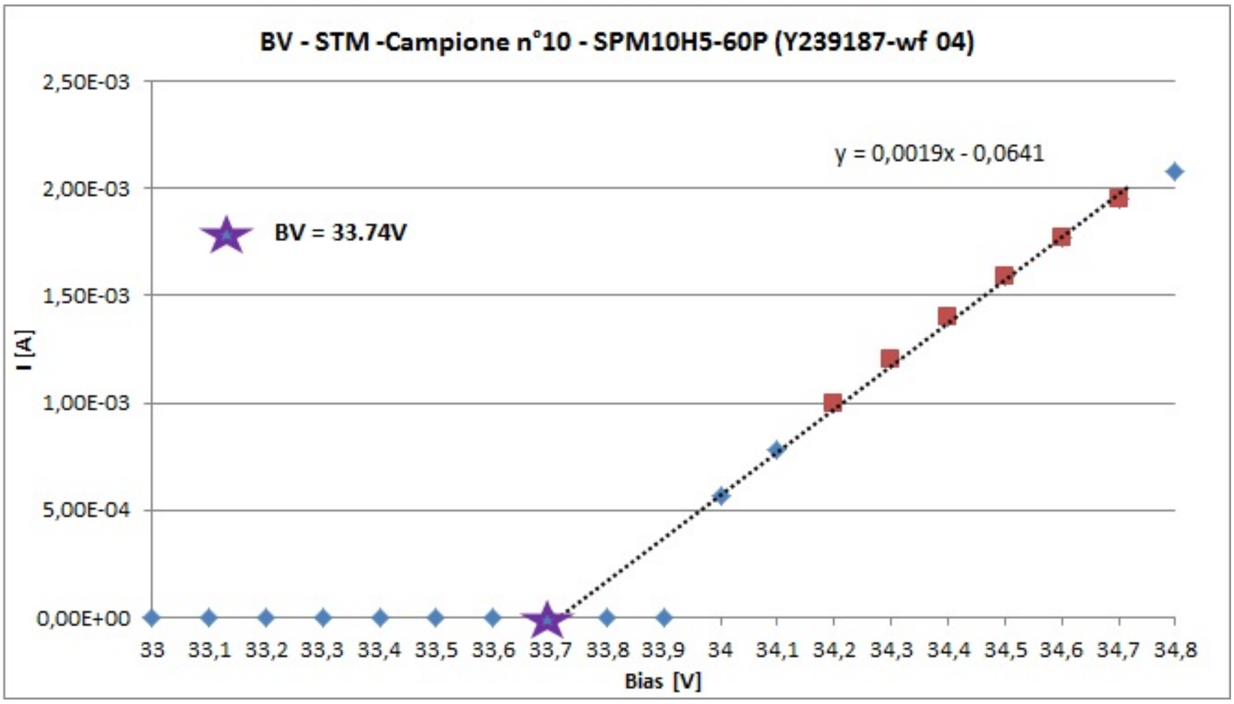


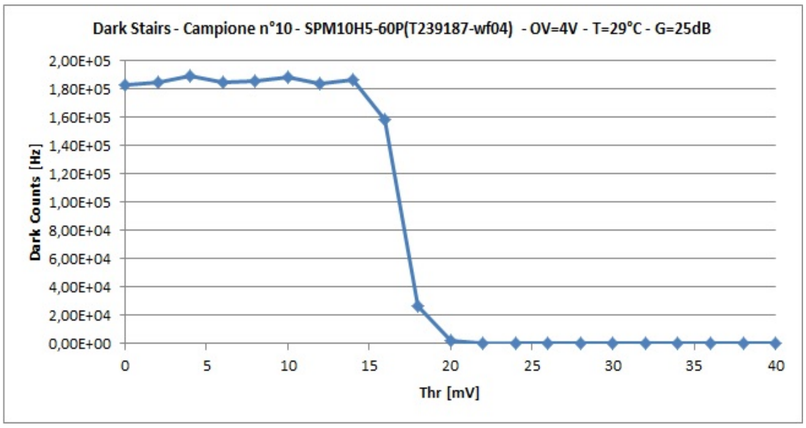
Fig. 1 – BreakDown Voltage @ T=25.0°C.

Then the break-down voltage for this SiPM is 33.74 V.

3.0 Staircase and Cross-talk versus Over-Voltage SiPM SPM10H5-60N with ARC single layer

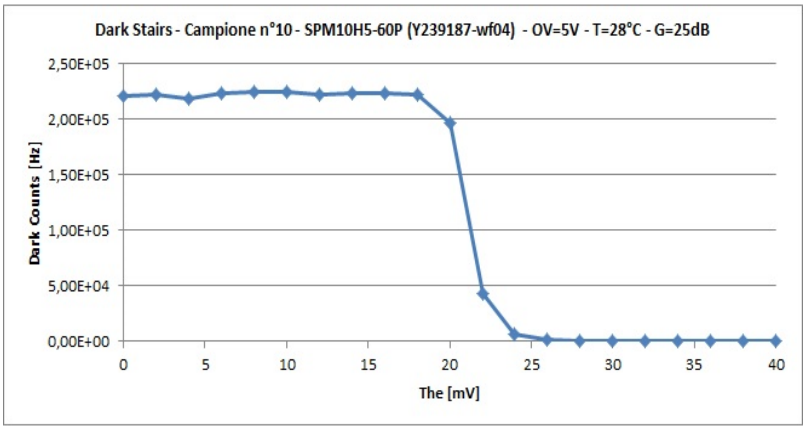
The Crosstalk is evaluated by the ratio of the DCR at 1.5 pe- and at 0.5 pe-.

Vov=4.0V



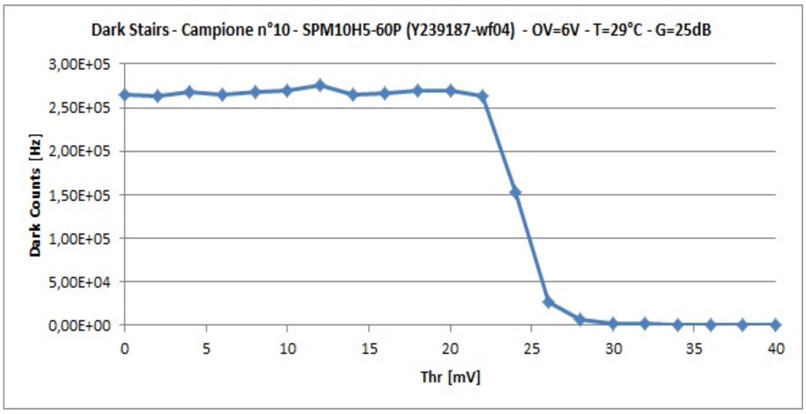
From the data we derive:
Xtalk=0.14%
Dark= 185 KHz @0.5 pe

Vov=5.0V



From the data we derive:
Xtalk=0.27%
Dark= 225 KHz @0.5 pe

Vov=6.0V



From the data we derive:
Xtalk=0.34%
Dark= 265 KHz @0.5 pe

4.0 Electro-optical characterization

We characterize the SiPM at two different Over-voltages 4V, 5V and 6V.

The characterization includes the following steps:

1. the Staircase to select the appropriate threshold,
2. the Dark Count Rate (DCR) at different gate time in order to select the best hold-off time
3. the system linearity to evaluate the best illumination conditions (avoid the saturation)
4. PDE measurements taking into account the results of the previous steps.

4.1 Characterization at Vov = 4V

Here will follow the characterization at Vov=4V.

4.1.1 Staircase @ OV=4V

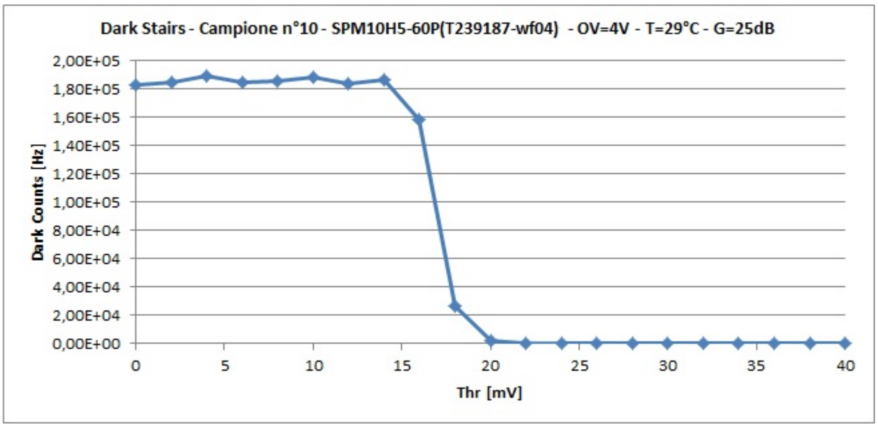


Fig. 1 – Dark Stair versus Vthr @ T=29°C.

From this plot we derived a **Vthr** of **-10 mV**.

4.1.2 DCR @ OV=4V at different Gate Time from 40 ns to 120 ns

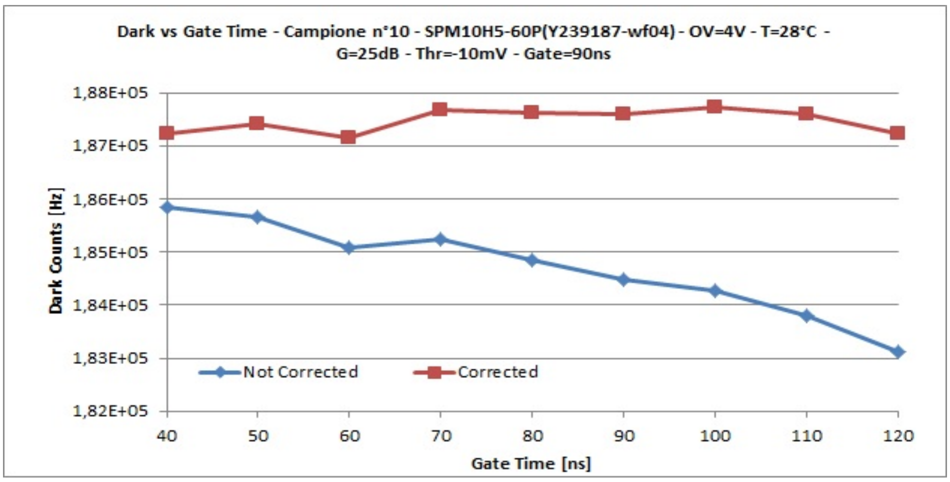


Fig.2 - DARK vs GATE TIME Vov=4V - Thr=-10 mV - T=29°C. Measurements were performed at gate times from 40ns to 120ns. The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted

We select as optimal **Gate Time - :** → **τ = 90 ns**

4.1.2 DCR @ OV=4V vs Time

By selecting the above the threshold level and the gate time obtained in the previous sub-sections, a measure of dark versus time is carried out.

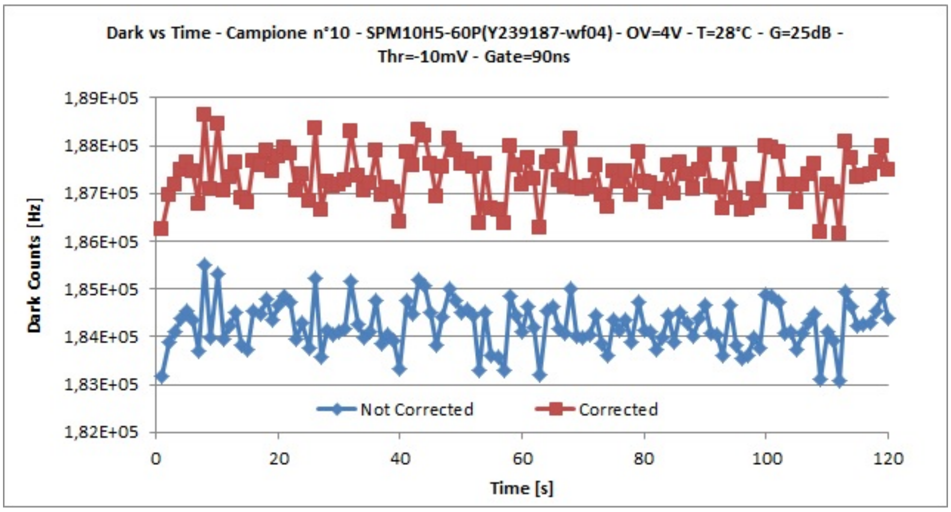


Fig.3 - DARK vs Time Vov=4V - Thr=-10 mV T=29°C. The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

From this plot we derive that at a Vov=4V and with a threshold of 0.5 pe the effective **DCR @ 29°C is 187 KHz**.

4.1.4 System linearity to evaluate the best operating conditions

To characterize the SiPM by using the best illumination conditions, that means avoiding the system saturation and maintaining a sufficient signal on the NIST calibrated photodiode, linearity measurements were carried out. Furthermore the non-linearity conditions were tested by using the PDE measurements at a selected wavelength.
Here will follow the obtained plots of the signal count rate versus the photodiode current @ 500 nm and the PDE versus the signal count rate @ 500 nm.

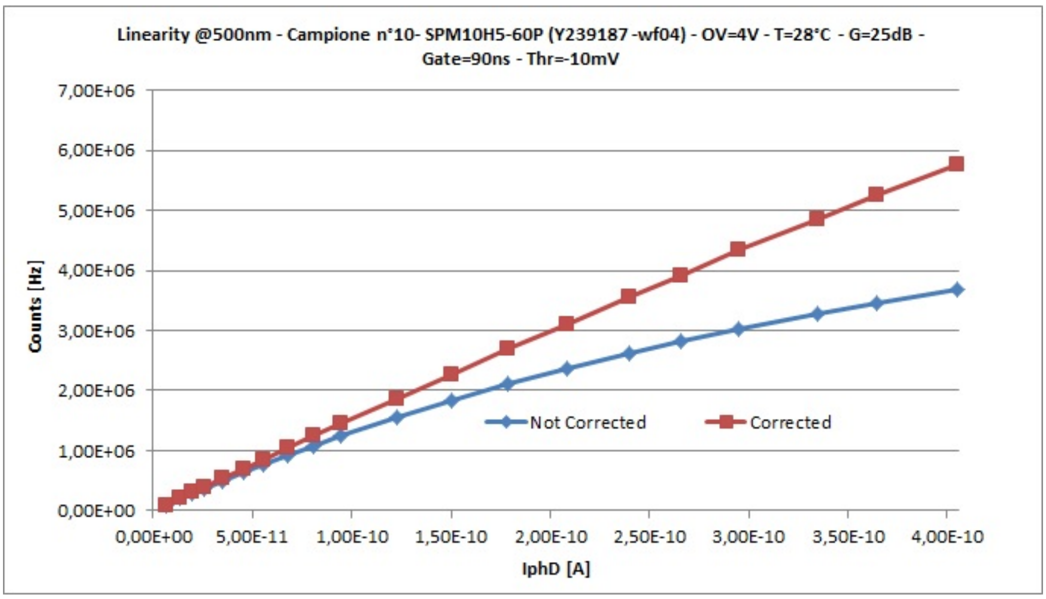


Fig. 4 – Linearity at 500 nm with and without the dead time correction.

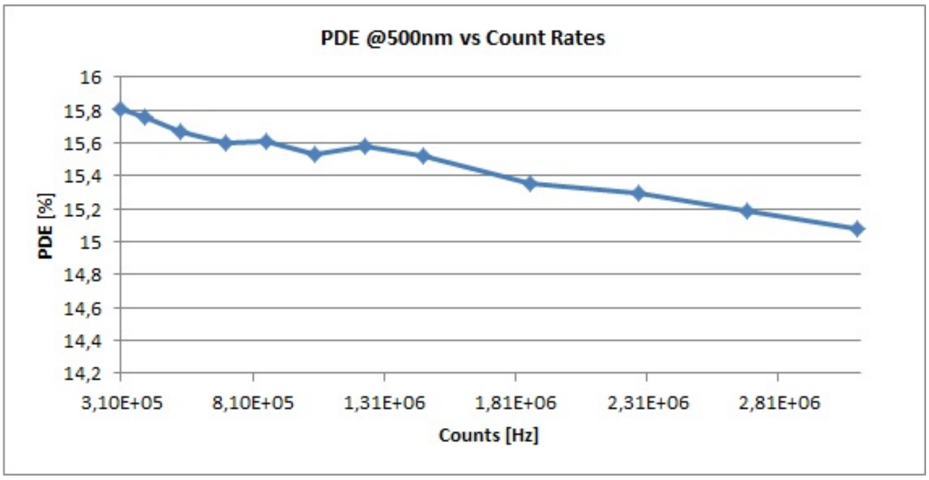


Fig.5 – PDE measurements at 500nm versus counts, from 310 KHz to 2800KHz operating the SiPM at Vov=4V, T=29°C, Vthr=-10mV, Gate time=90 ns

From these plots we derive that the system shows a not-linearity behavior at rates greater than 1800 KHz uncorrected corresponding at about 2300 KHz corrected for dead time. And the PDE is about 15.8-15.2% in the range of 310 KHz – 2700 KHz without dark counts (Fig.5)
Then, to be conservative, the PDE measurements have to be carried out with **uncorrected signals and without DCR subtraction not higher than 2.0 MHz corresponding to 3.0 MHz corrected for dead time**.

4.1.5 PDE measurements at Over-Voltage 4V

Measurements were performed at V_{OV} = 4V and gate time 90ns.
The plot reports the PDE with values corrected for the Dead Time.

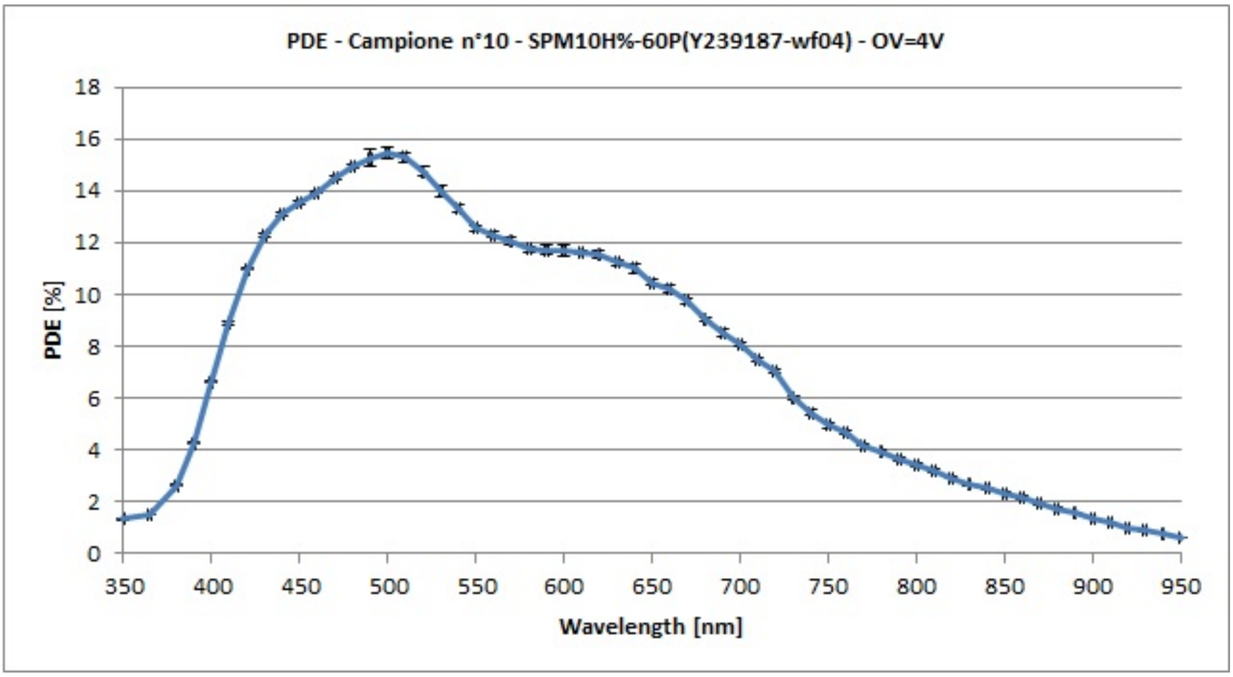


Fig.6 – PDE measurements operating the SiPM at Vov=4V, T=29°C, Vthr=-10 mV,Gate time=90 ns

4.2 Characterization at Vov = 5V

Here will follow the characterization at Vov=5V.

4.2.1 Staircase @ OV=5V

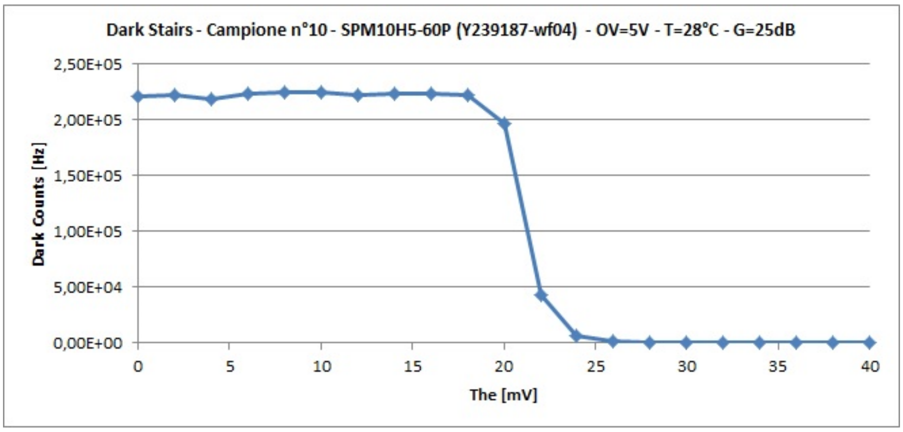


Fig. 7 – Dark Stair versus Vthr @ T=28°C.

From this plot we derived a **Vthr** of **-14 mV**.

4.2.2 DCR @ OV=5V at different Gate Time from 40 ns to 120 ns

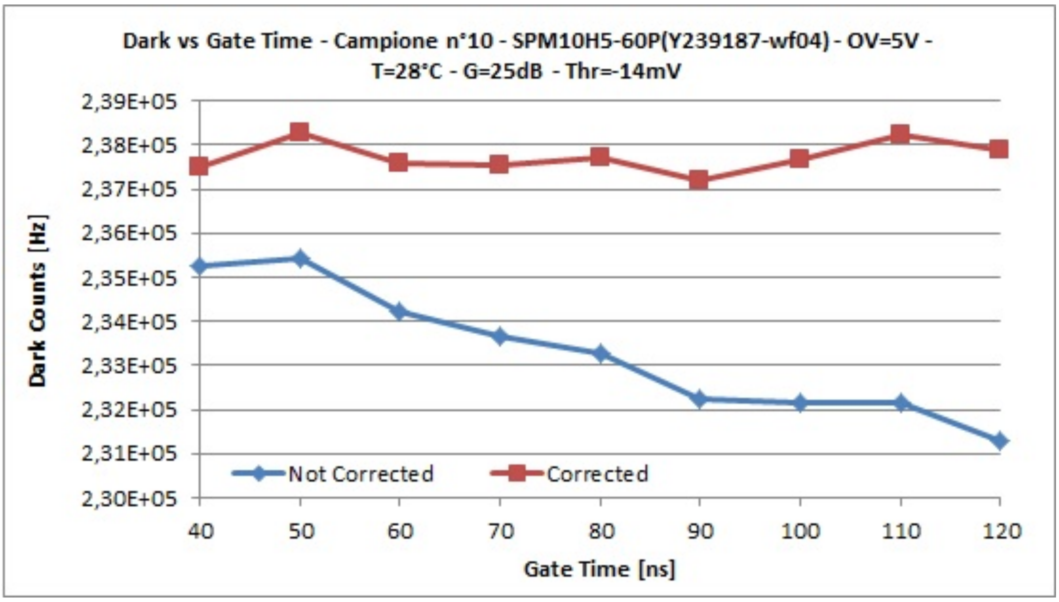


Fig.8 - DARK vs GATE TIME Vov=5V - Thr=-14 mV T=28°C. Measurements were performed at gate times from 40ns to 120ns. The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

We select as optimal **Gate Time - :** → **τ = 90 ns**

4.2.3 DCR @ OV=5V vs Time

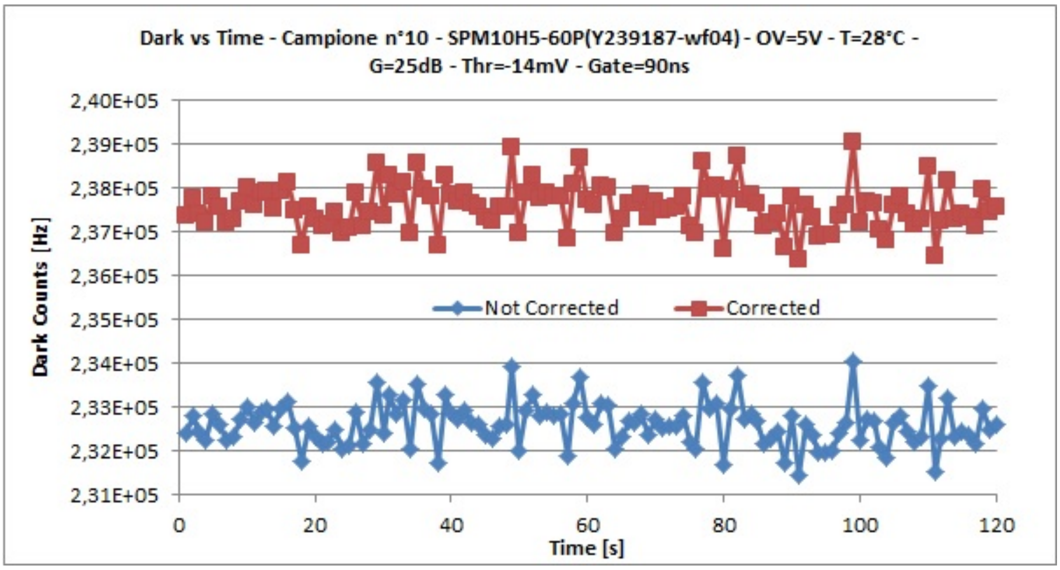


Fig.9 - DARK vs Time Vov=5V - Thr=-14 mV T=28°C. The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

From this plot we derive that at a Vov=5V and with a threshold of 0.5 pe the effective **DCR @ 28°C is 237 KHz**.

4.2.4 System linearity to evaluate the best operating conditions

To characterize the SiPM by using the best illumination conditions, that means avoiding the system saturation and maintaining a sufficient signal on the NIST calibrated photodiode, linearity measurements were carried out. Furthermore the non-linearity conditions were tested by using the PDE measurements at a selected wavelength.
Here will follow the obtained plots of the signal count rate versus the photodiode current @500 nm and the PDE @500 nm versus the signal count rate.

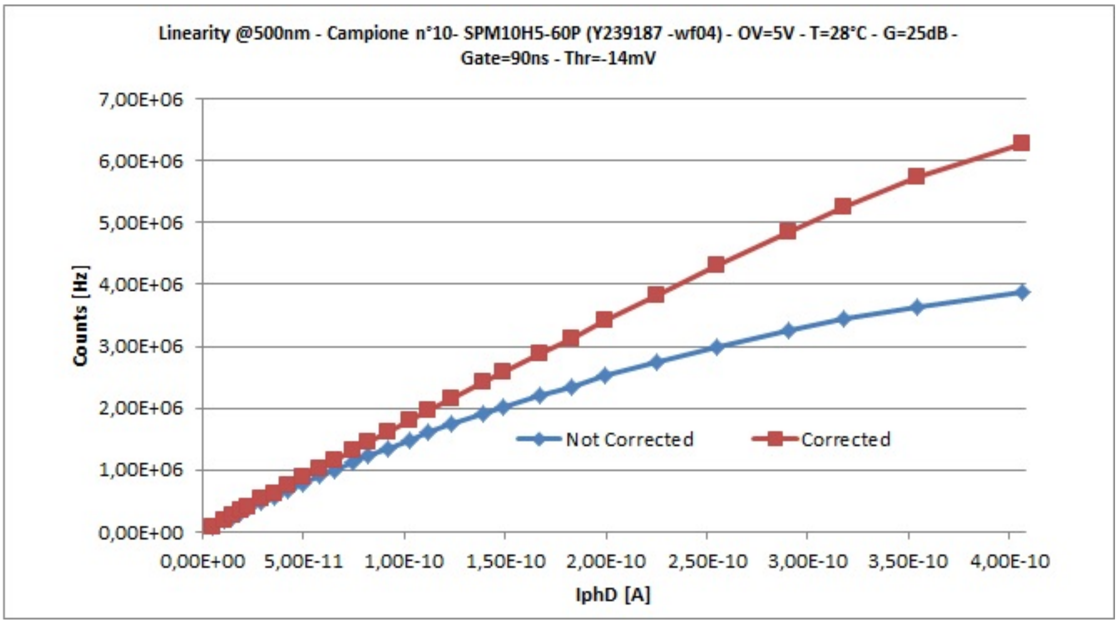


Fig. 10 – Linearity at 500 nm with and without the dead time correction.

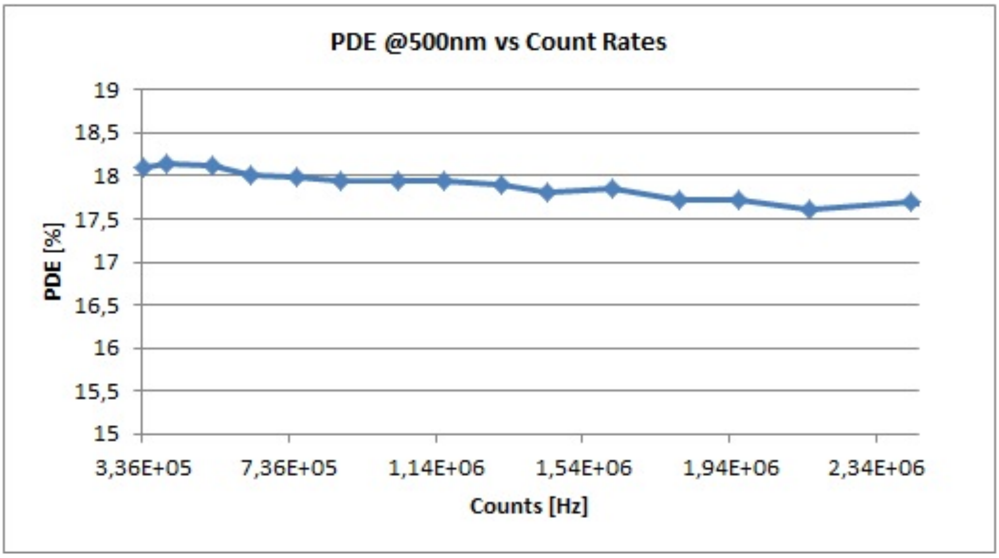


Fig.11 – PDE measurements at 500nm versus counts, from 336 KHz to 2300KHz operating the SiPM at Vov=5V T=28°C, Vthr=-14 mV, Gate time=90 ns

From these plots we derive that the system shows a not-linearity behavior at rates greater than 1700 KHz uncorrected corresponding at about 2200 KHz corrected for dead time. And the PDE is about 18.1-17.7 % in the range of 336 KHz – 1800 KHz without dark counts (Fig.11)
Then, to be conservative, the PDE measurements have to be carried out with **uncorrected signals and without DCR subtraction not higher than 1.6 MHz corresponding to 1.96 MHz corrected for dead time**.
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4.2.5 PDE measurements at Over-Voltage 5V

Measurements were performed at V_{OV} = 5V and gate time 90ns.
The plot reports the PDE with values corrected for the Dead Time.

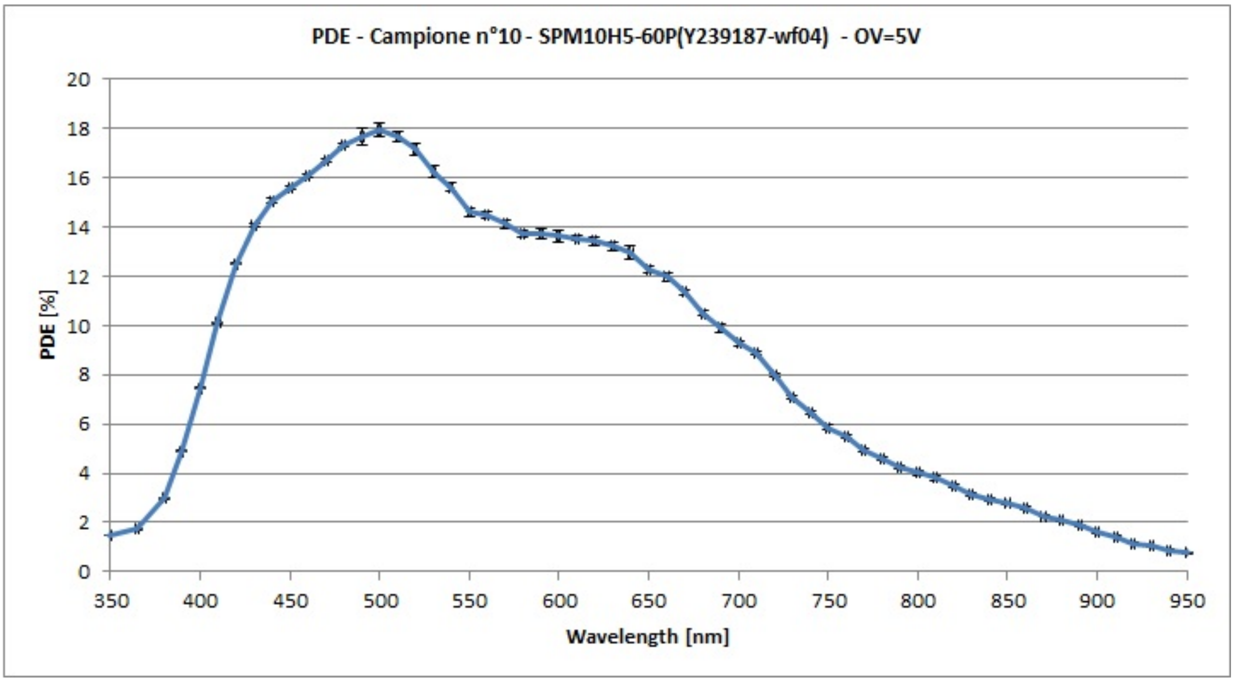

Fig.12 – PDE measurements operating the SiPM at Vov=5V, T=28°C, Vthr=-14 mV,Gate time=90 ns

4.3 Characterization at Vov = 6V

Here will follow the characterization at Vov=6V.

4.3.1 Staircase @ OV=6V

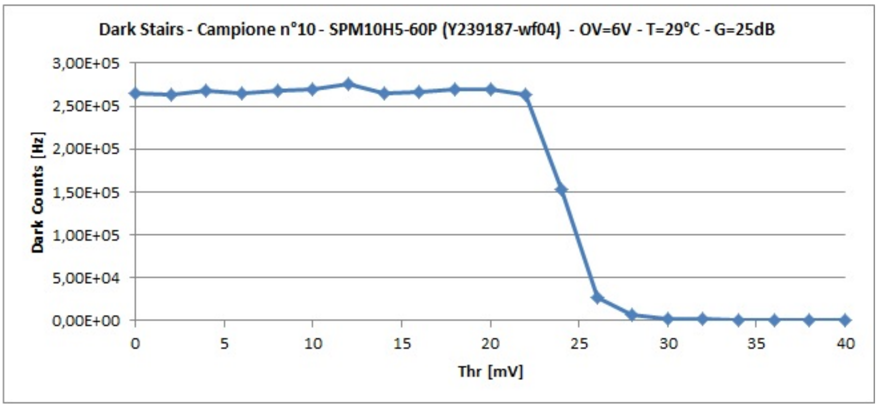

Fig. 13 – Dark Stair versus Vthr @ T=29°C.

From this plot we derived a **Vthr** of **-15 mV**.

4.3.2 DCR @ OV=6V at different Gate Time from 40 ns to 120 ns

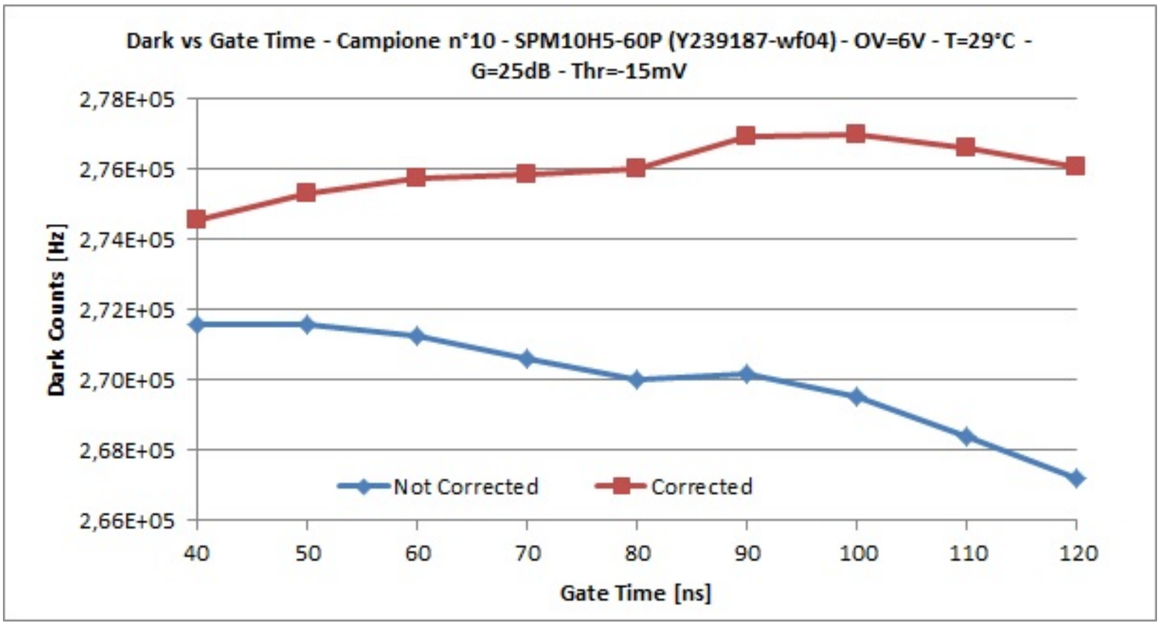

Fig.14 - DARK vs GATE TIME Vov=6V - Thr=-15 mV T=29°C. Measurements were performed at gate times from 40ns to 120ns. The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

We select as optimal **Gate Time - :** → **τ = 90 ns**

4.3.3 DCR @ OV=6V vs Time

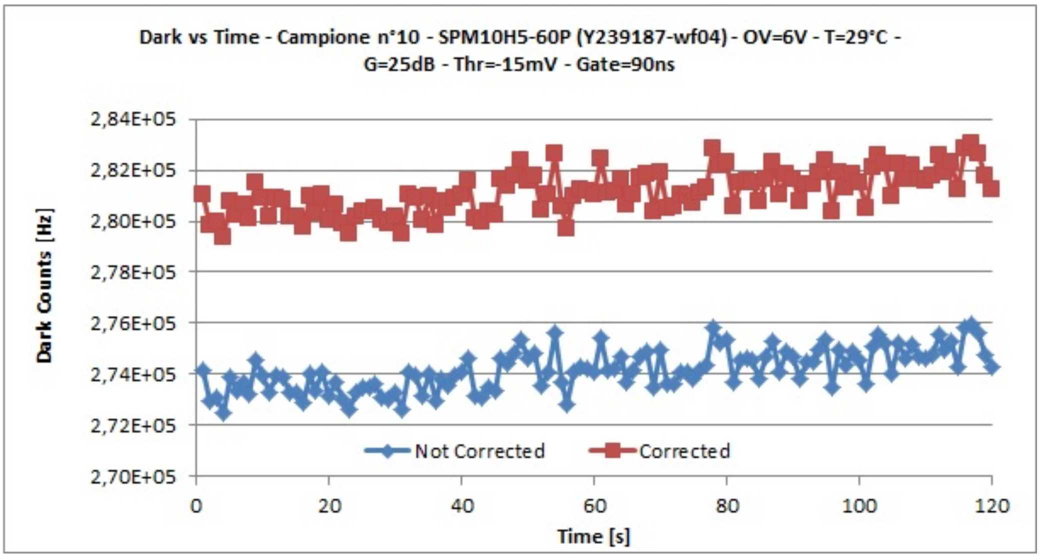

Fig.15 - DARK vs Time Vov=6V - Thr=-15 mV T=29°C. The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

From this plot we derive that at a Vov=6V and with a threshold of 0.5 pe the effective **DCR @ 29°C is 281 KHz**.

4.3.4 System linearity to evaluate the best operating conditions

To characterize the SiPM by using the best illumination conditions, that means avoiding the system saturation and maintaining a sufficient signal on the NIST calibrated photodiode, linearity measurements were carried out. Furthermore the non-linearity conditions were tested by using the PDE measurements at a selected wavelength.
Here will follow the obtained plots of the signal count rate versus the photodiode current @500 nm and the PDE @500 nm versus the signal count rate.

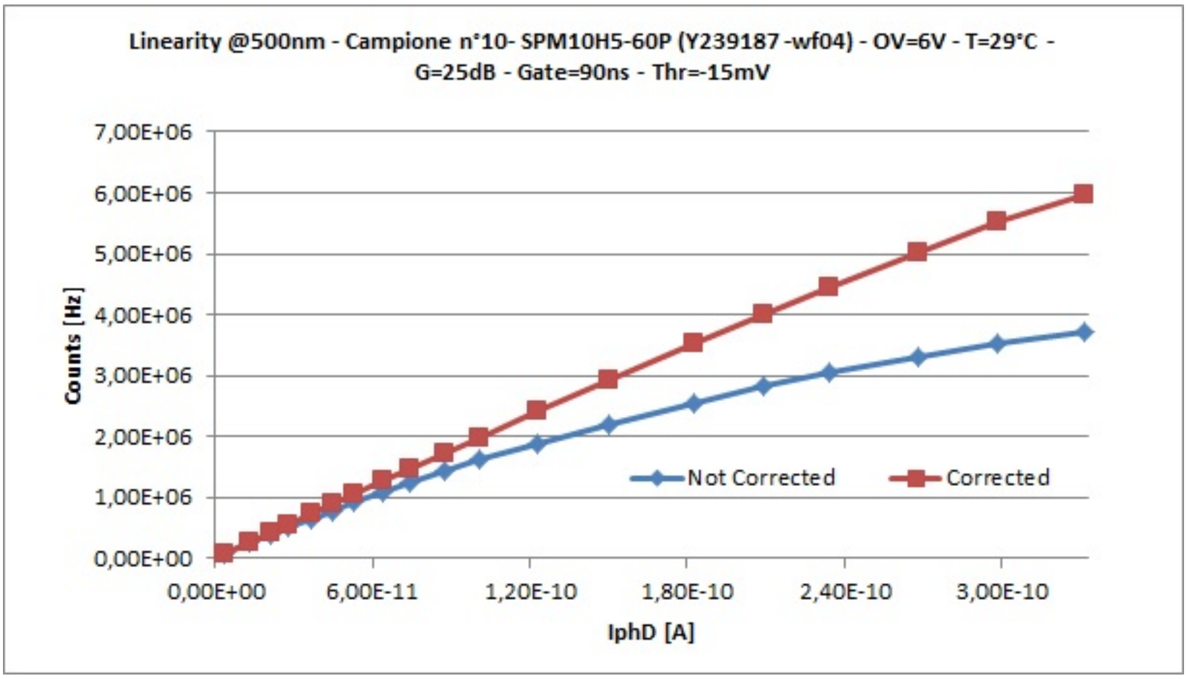

Fig. 16 – Linearity at λ=500 nm with and without the dead time correction.

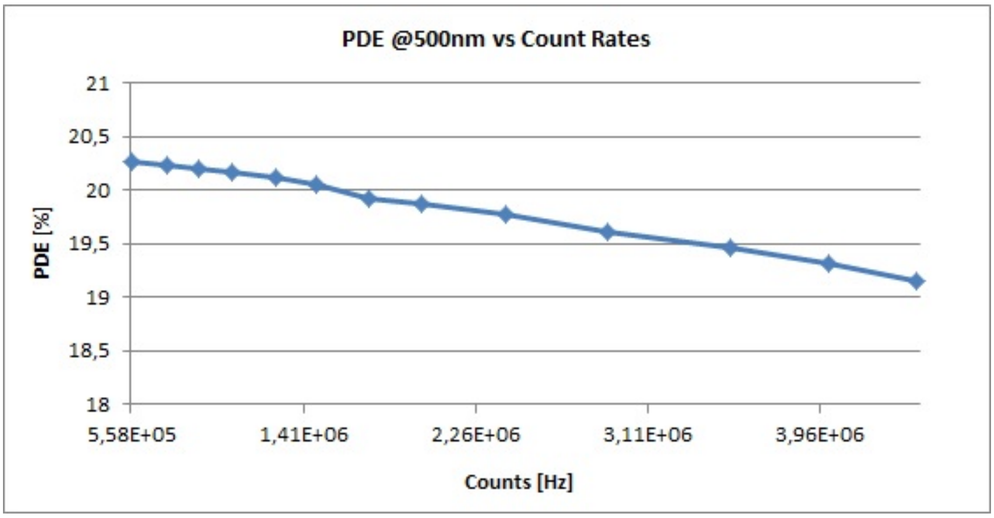

Fig.17 – PDE measurements at 500nm versus counts, from 558 KHz to 3300KHz operating the SiPM at Vov=6V T=29°C, Vthr=-15 mV, Gate time=90 ns

From these plots we derive that the system shows a not-linearity behavior at rates greater than 1600 KHz uncorrected corresponding at about 2000 KHz corrected for dead time. And the PDE is about 20.3-19.5 % in the range of 558 KHz – 2900 KHz without dark counts (Fig.17)
Then, to be conservative, the PDE measurements have to be carried out with **uncorrected signals and without DCR subtraction not higher than 1.5 MHz corresponding to 1.7 MHz corrected for dead time**.
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4.3.5 PDE measurements at Over-Voltage 6V

Measurements were performed at V_{OV} = 6V and gate time 90ns.
The plot reports the PDE with values corrected for the Dead Time.

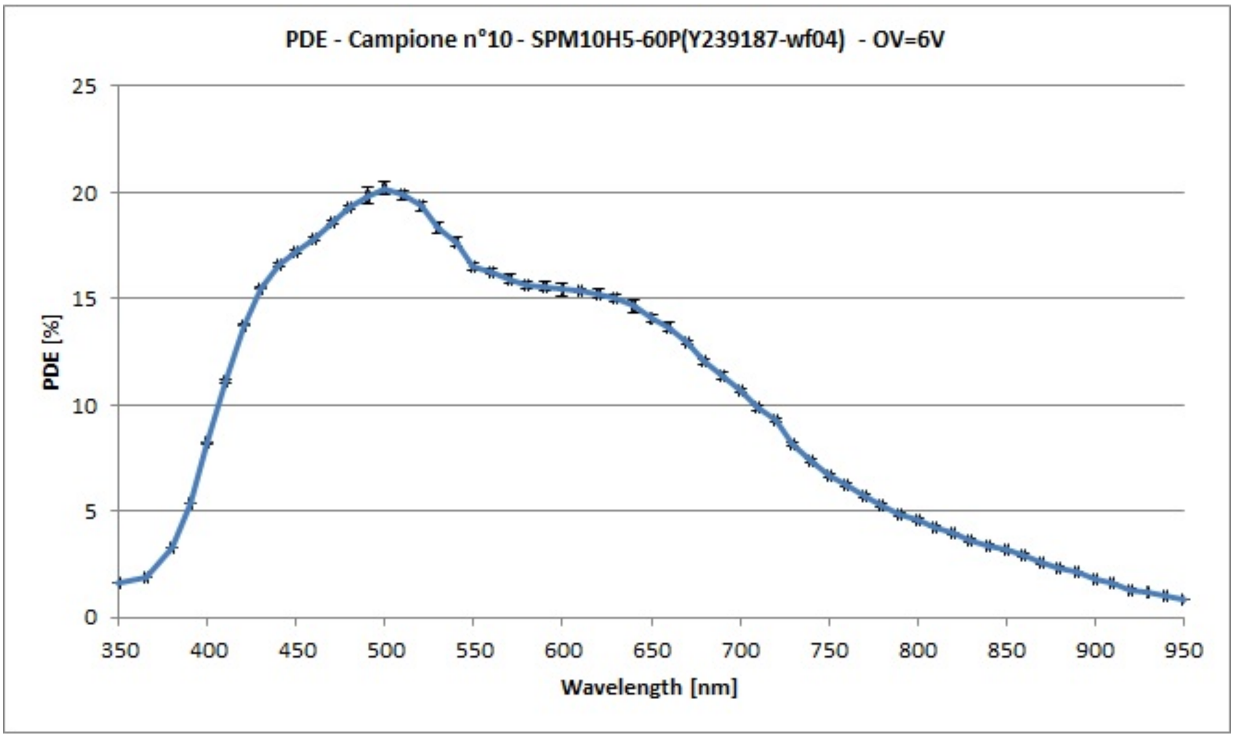

Fig.18 – PDE measurements operating the SiPM at Vov=6V, T=29°C, Vthr=-15 mV,Gate time=90 ns

4.4 PDE comparison

PDE measurements at the various Over Voltages are here compared.

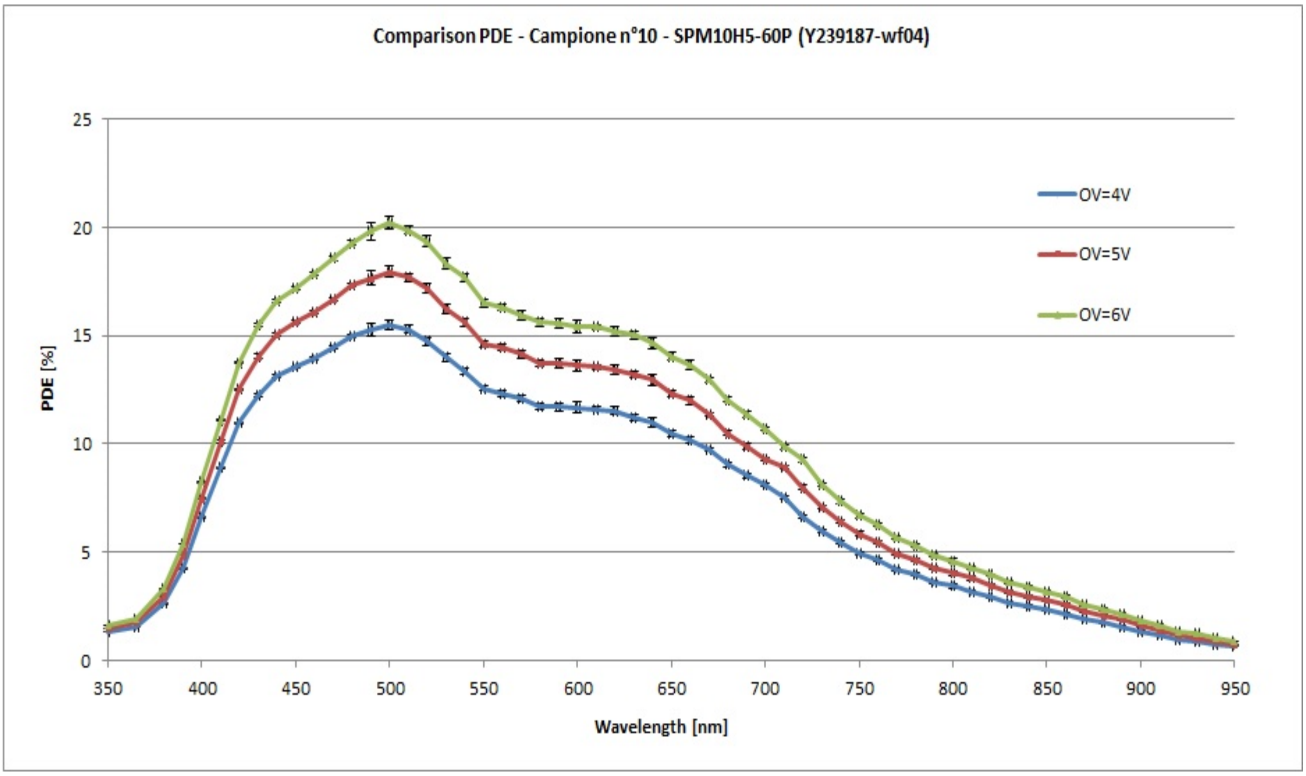

*Fig.19– PDE measurements comparison at Vov=**4.0V**, Vov=**5.0V** and Vov=**6.0V** @ T=29°C.*