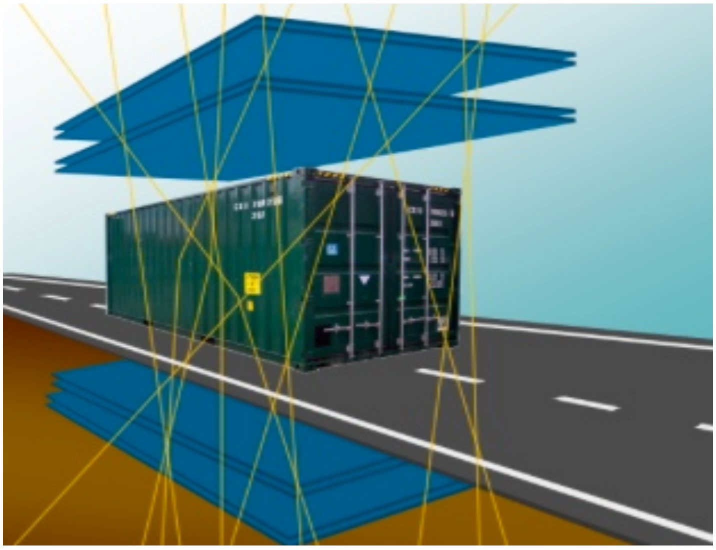
OSSERVATORIO ASTROFISICO DI CATANIA

SiPM characterization report for the Muon Portal Project

Device: SiPM type N on P - S/N.6 ST Microelectronics



Osservatorio Astrofisico di Catania

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Rapporti interni e tecnici
N.02/2013

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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	**February 26, 2013**
SiPM	**ST Microelectronics** **SiPM type: N on P** **V_{BD}=27.1 V @T=25°C** **I = 0.17 μA @Vov=3V** **Rq=312 KΩ** **(from STM data sheet)**
OP. MODE	**Photon Counting with CAEN PSAU and Tektronix counter**
SER. N.	**Device name 6**

CONTENTS

1.0 Electrical Characteristics from Data sheet

SPM10-60

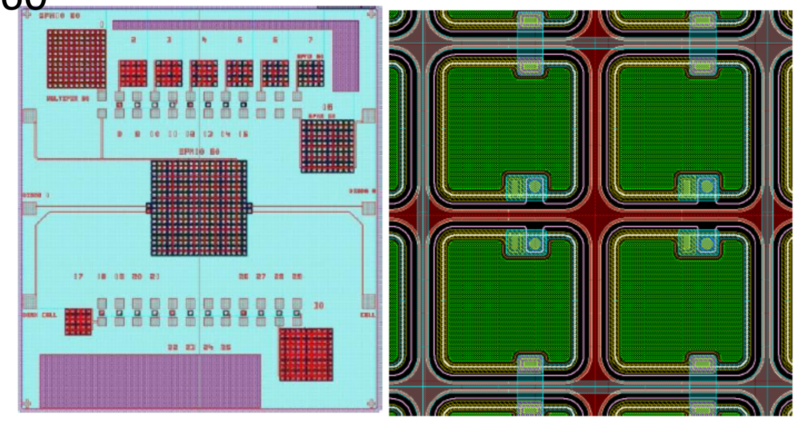
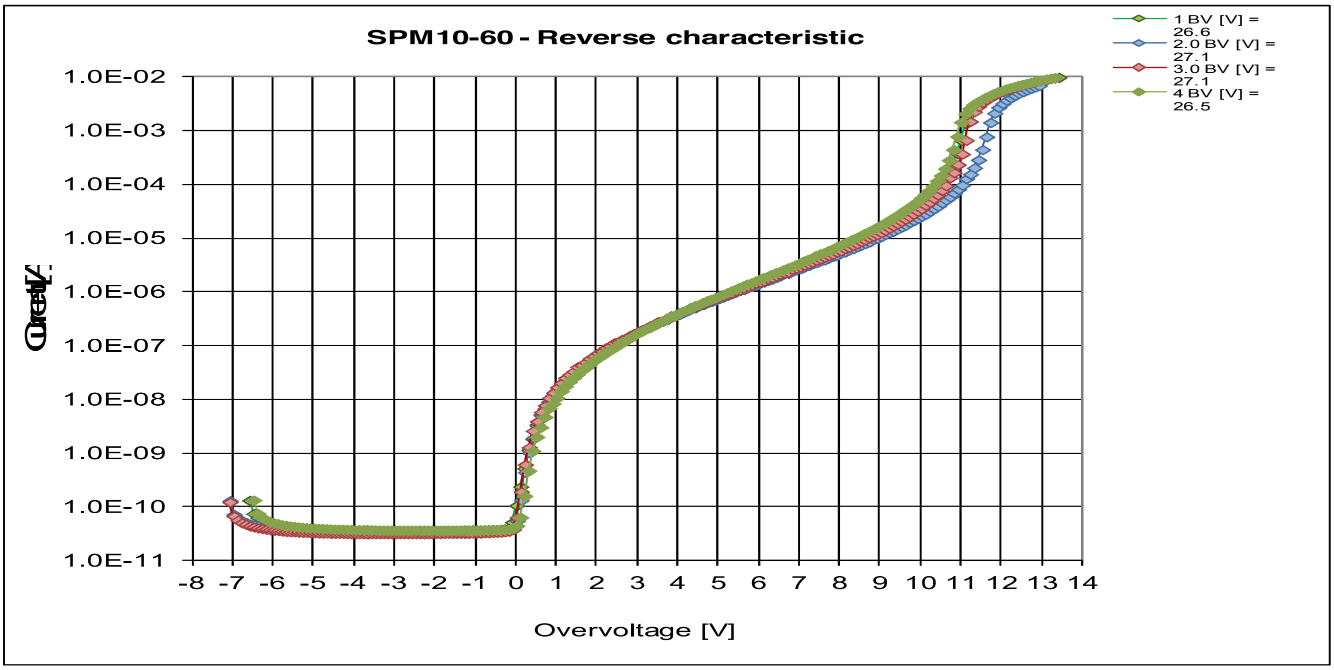


Fig. 19 SPM10-60: chip layout (left) and detail of the cells layout (right).

Table 11 Features of the SPM10-60 device.

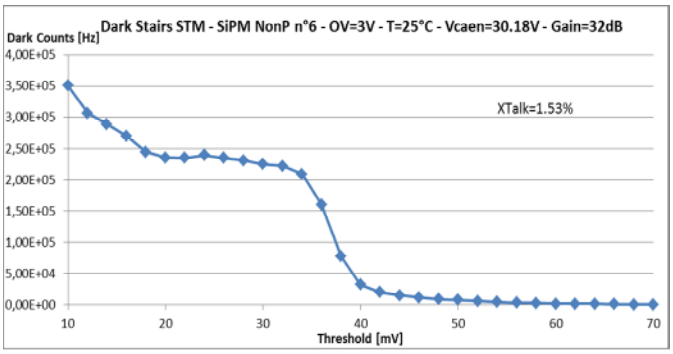
Parameter	Unit	Value
Array size	μm²	1080 × 1080
Array dimension		18 × 18
Number of cells		324
Cell fill factor	%	45.4 %
Cell size	μm^2	60 × 60
Quenching resistor squares number		29.3
Quenching capacitor area	μm^2	53
Cell active area	μm^2	1633
Cell perimetral area	μm^2	835
Pad area	μm^2	150 × 150
Metal grid area (pad included)	μm^2	171906



2.0 Staircase and Cross-talk versus Over-Voltage SiPM N-on-P Dev. N. 6

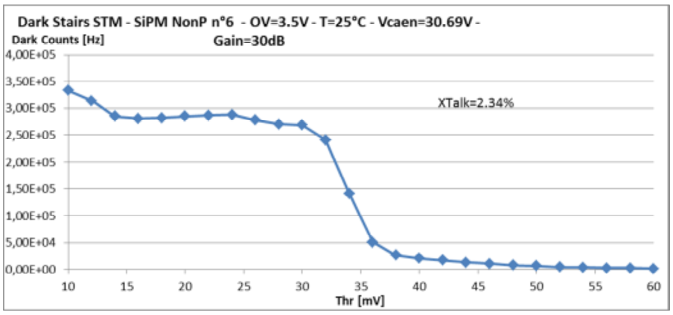
The Crosstalk is evaluated by the ratio of the DCR at 1.5 pe- and at 0.5 pe-.

Vov=3.0V



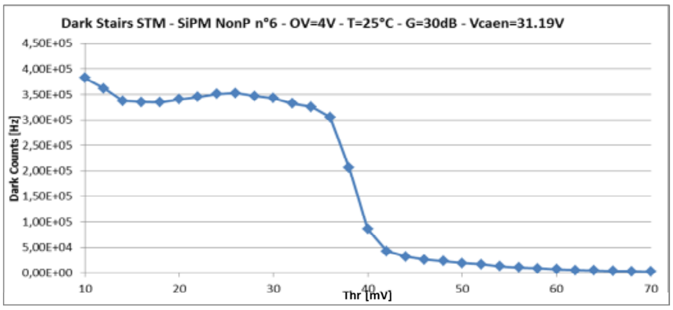
From the data we derive:
Xtalk=1.53% Dark= 250 KHz @0.5 pe

Vov=3.5V



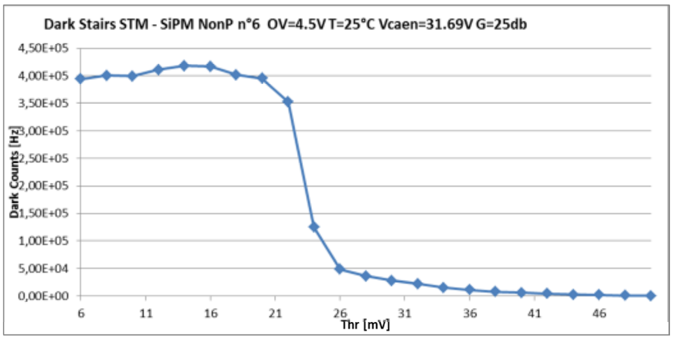
From the data we derive:
Xtalk=2.34% Dark= 280 KHz @0.5 pe

Vov=4.0V



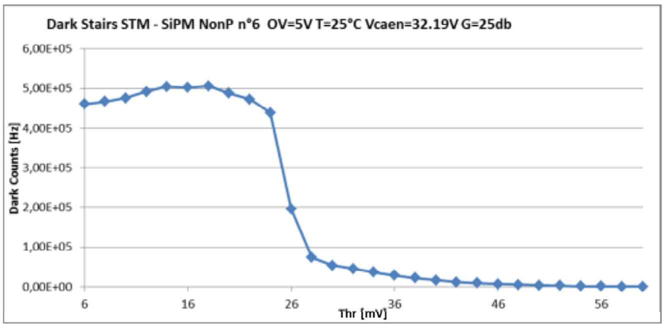
From the data we derive:
Xtalk=3.01% Dark= 350 KHz @0.5 pe

Vov=4.5V



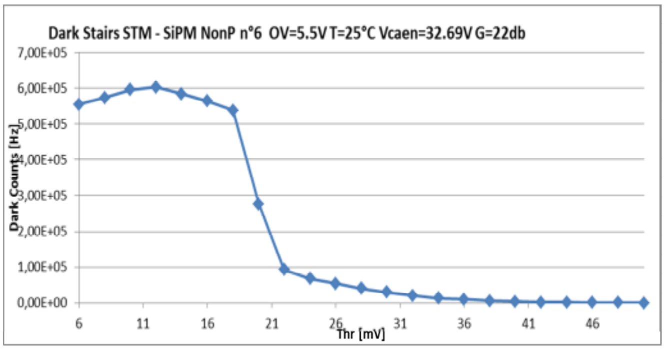
From the data we derive:
Xtalk=3.76% Dark= 410 KHz @0.5 pe

Vov=5.0V



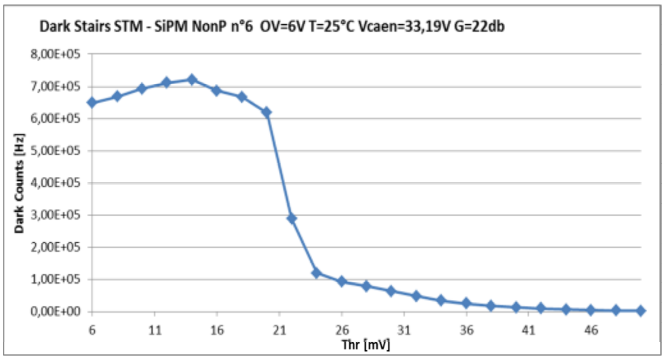
From the data we derive:
Xtalk=4.44%   Dark= 500 KHz @0.5 pe

Vov=5.5V



From the data we derive:
Xtalk=4.94%   Dark= 590 KHz @0.5 pe

Vov=6.0V



From the data we derive:
Xtalk=6.58%   Dark= 700 KHz @0.5 pe

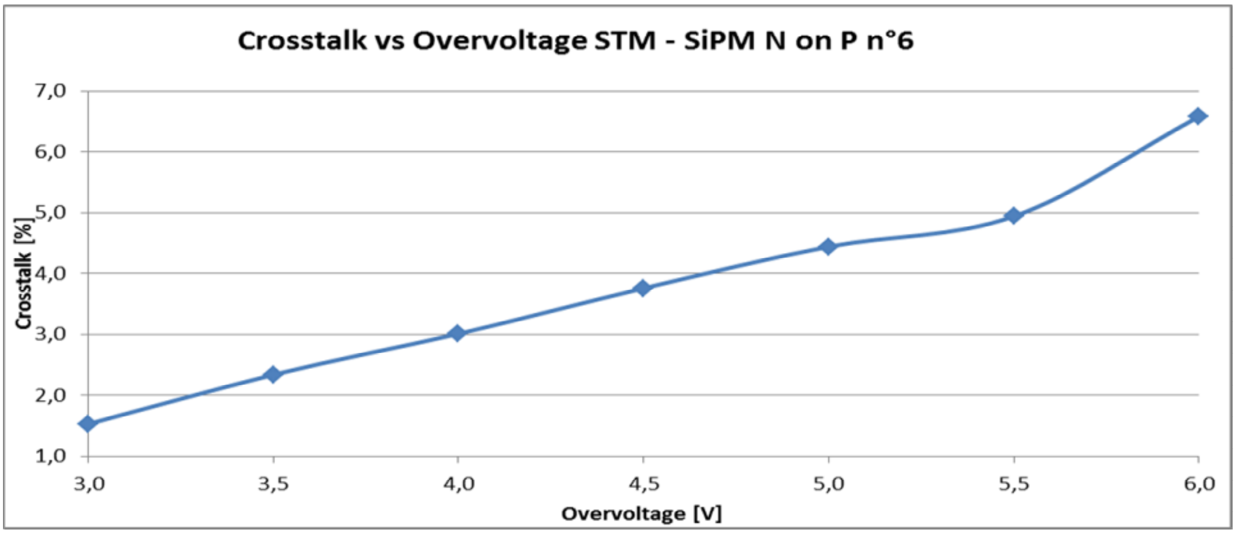


Fig. 1 – Crosstalk versus Vov @ T=25.0°C

3.0 Dark Count Rate versus Over-Voltage @ 25°C and 0.5 pe- for the SiPM N-on-P Dev. N. 6

The DCR is evaluated by measuring the rate at the threshold level corresponding to 0.5 pe-.

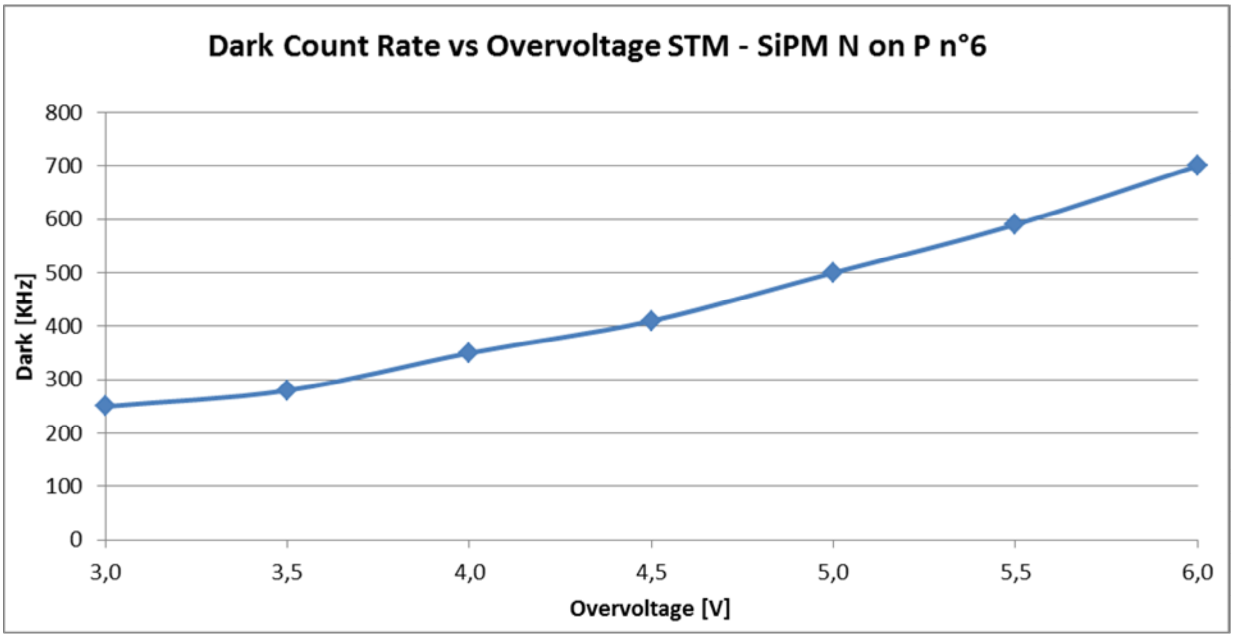


Fig. 2 – DCR versus Vov @ T=25.0°C

4.0 Electro-optical characterization

We characterize the SiPM at three different Over-voltage.
The characterization includes:

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. 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

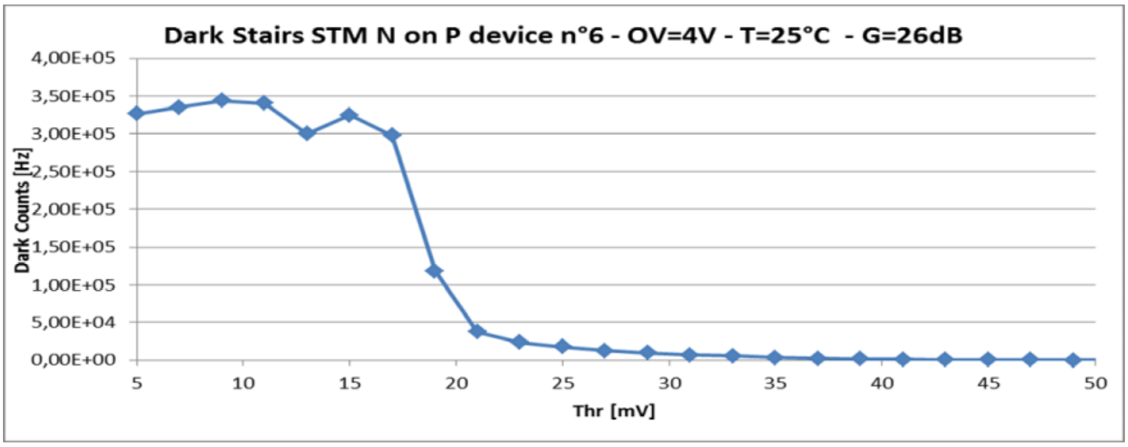


Fig. 3 – Dark Stair versus Vthr @ T=25.0°C.

From this plot we derived a Vthr of -13 mV.

4.1.2 DCR @ OV=4V at different Gate Time from 5 ns to 110 ns

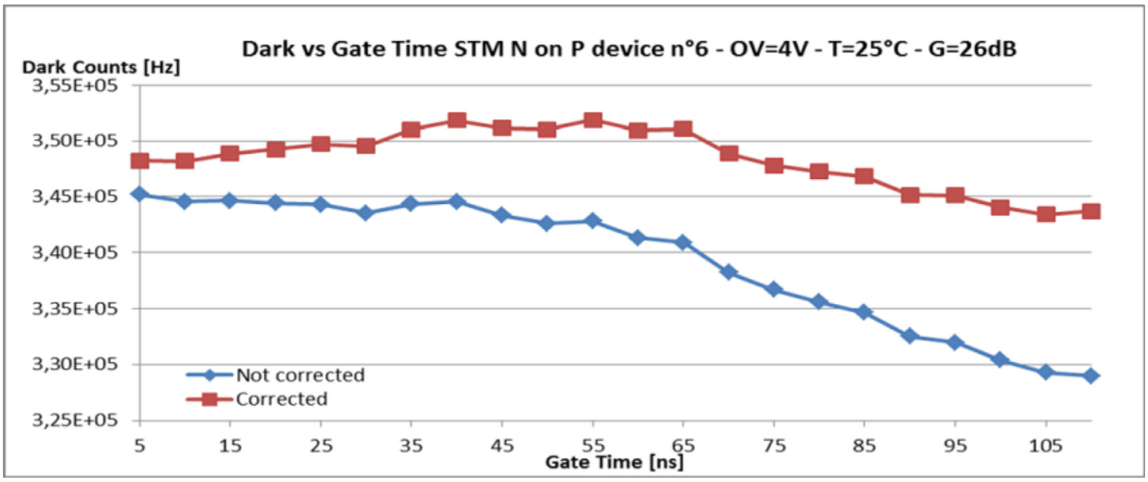


Fig.4 - DARK vs GATE TIME Vov=4V - Thr=-13 mV T=25° Measurements were performed at varying the gate time from 5ns to 110ns.The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

From this plot, and considering that the discriminator introduces a delay of 20 ns (see next paragraph) we selected an hold-off time of 110 ns= 90 +20 ns.

4.1.3 Oscilloscope visualization of output pulses from amplifier and from discriminator

In order to show how the CAEN PSAU discriminator introduces a delay respect to the SiPM pulse we displayed on the oscilloscope the output pulses from the amplifier and from the discriminator. The following snapshots show clearly the 20 ns delay between the SiPM signal and the discriminator TTL output. From the picture is also evident the signal loose due to the gate time.

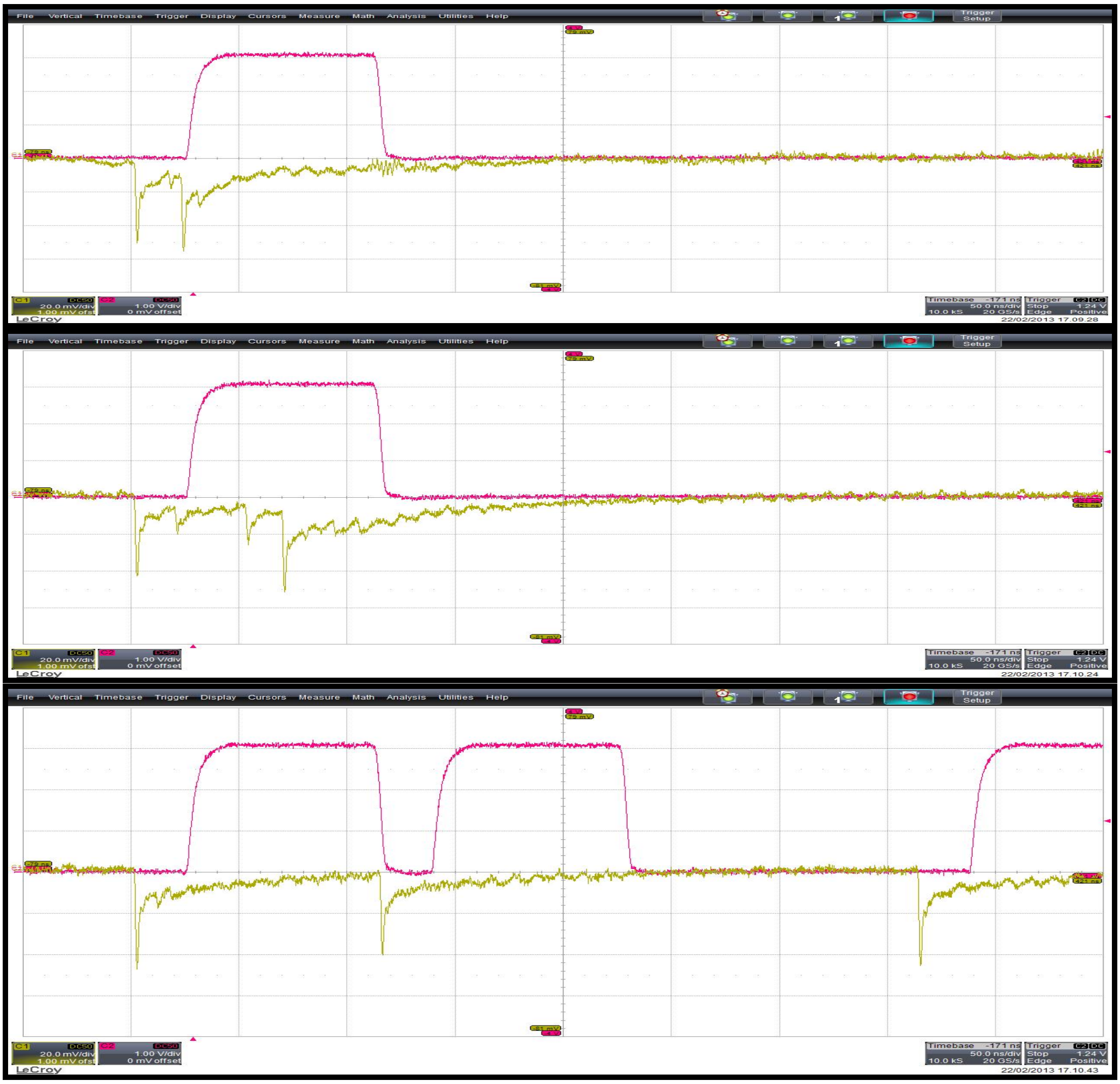


Fig.5 – Oscilloscope snapshots clearly show the 20 ns delay between the SiPM signal and the discriminator TTL output. The signal loose due to the gate time is also evident. This will be recovered by applying the dead time correction.

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 @510 nm and the PDE @510 nm versus the signal count rate.

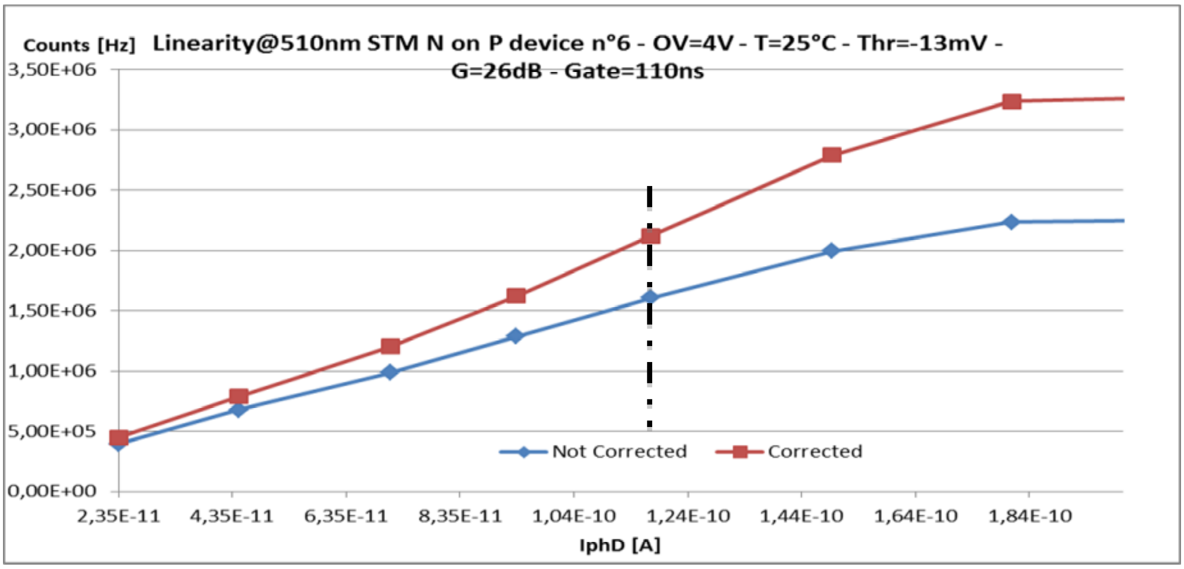


Fig. 6 – Linearity at 510 nm with and without the dead time correction.

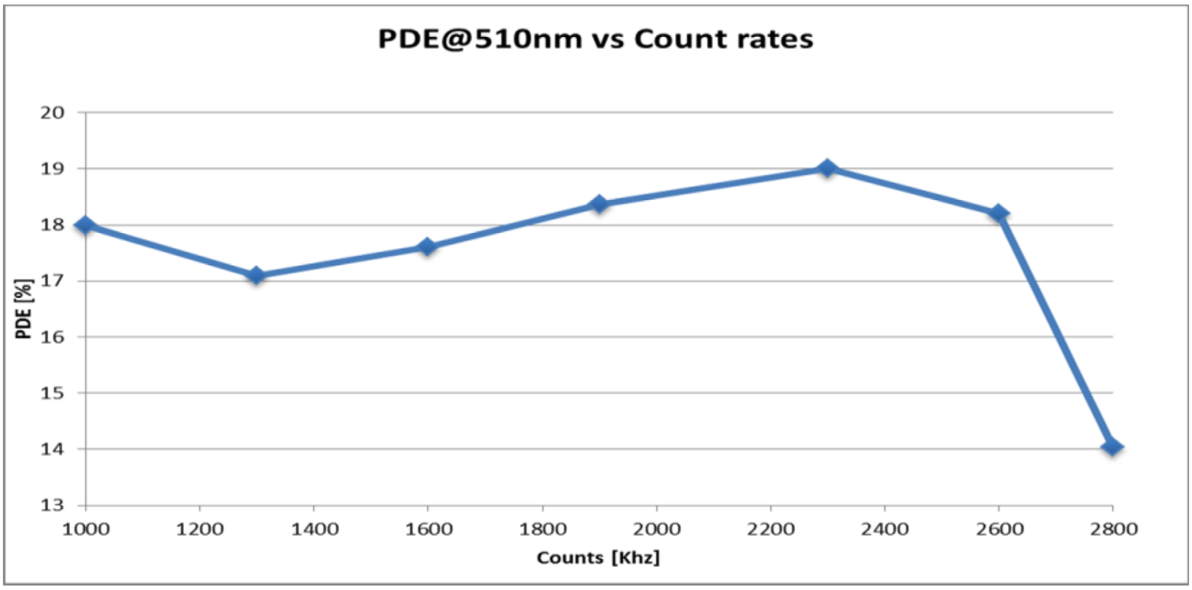


Fig.7 – PDE measurements at 510nm versus counts, including DCR, from 1000KHz to 2800KHz operating the SiPM at Vov=4V T=25°C, Vthr=-13 mV, Gate time=110 ns

From these plots we derive that the system shows a not-linearity behavior at rates greater than 1.6 MHz uncorrected corresponding at about 2 MHz corrected for dead time. And the PDE is about 18-19 % in the range of 1 – 2 MHz included dark counts (Fig.7)
Then, to be conservative, the PDE measurements have to be carried out with **uncorrected signals not higher than 1.5 MHz corresponding to 2 MHz corrected for dead time**.

4.1.5 PDE measurements at Over-Voltage 4V

Measurements were performed at V_{OV} = 4V and gate time 110ns.
The plot reports the PDE with values corrected for the Dead Time.

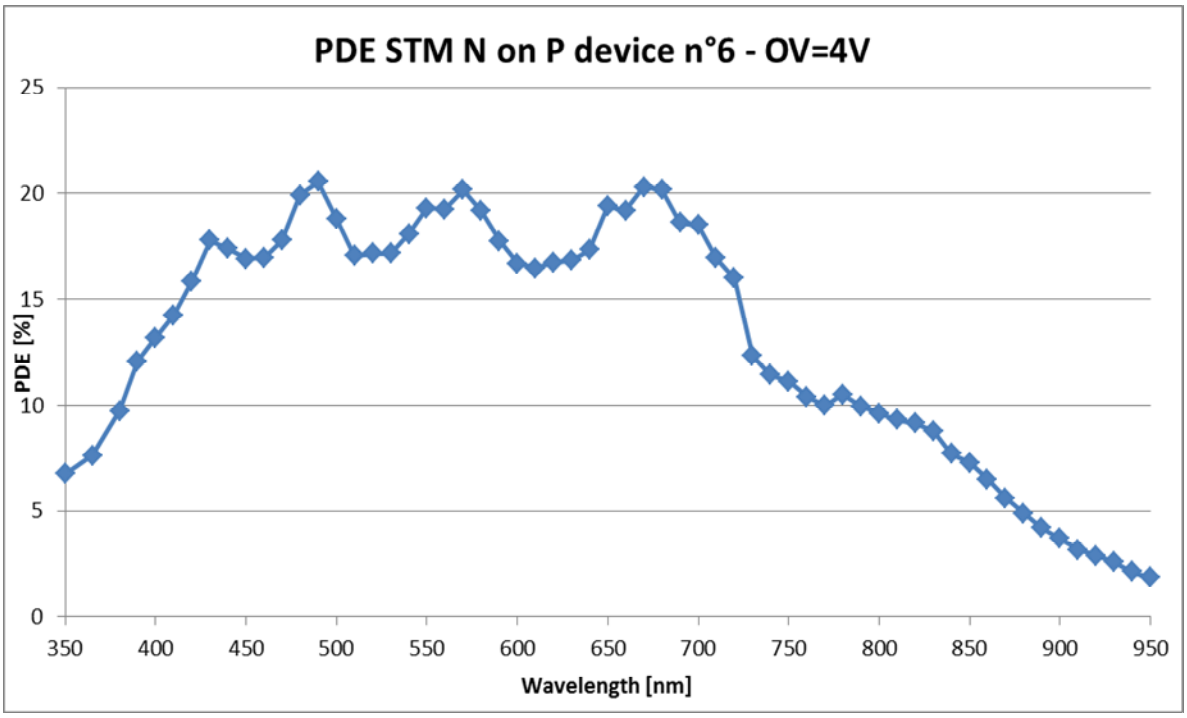


Fig.8 – PDE measurements operating the SiPM at Vov=4V T=25°C, Vthr=-13 mV,Gate time=110 ns

4.2 Characterization at Vov = 5V

Here will follow the characterization at Vov=5V.

4.2.1 Staircase

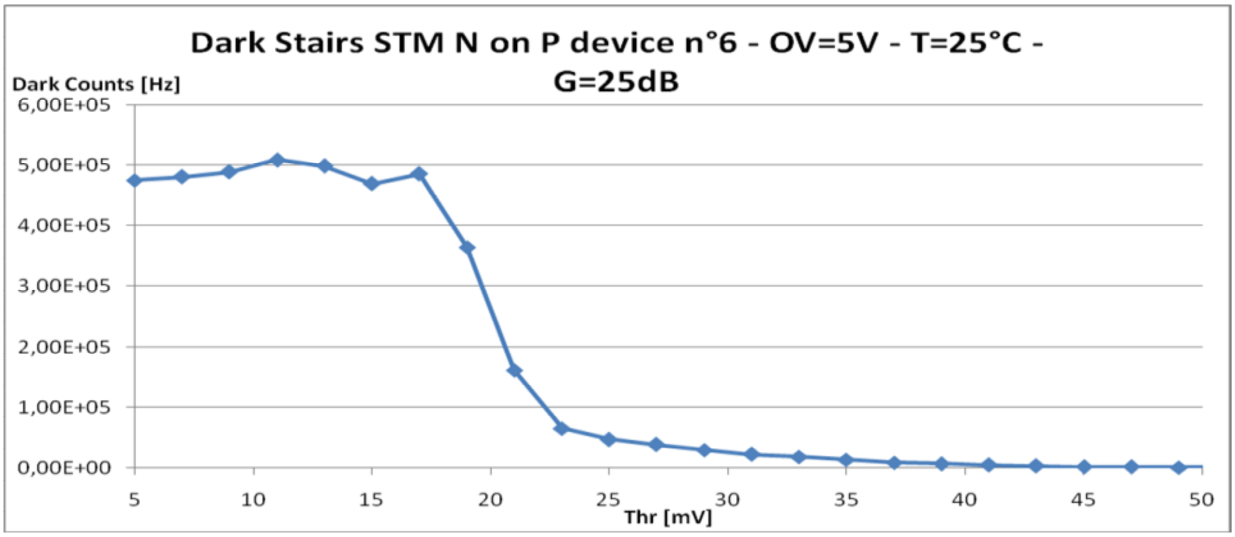


Fig. 9 – Dark Stair versus Vthr @ T=25.0°C.

From this plot we derived a Vthr of -13 mV.

4.2.2 DCR @ OV=5V at different Gate Time from 5 ns to 110 ns

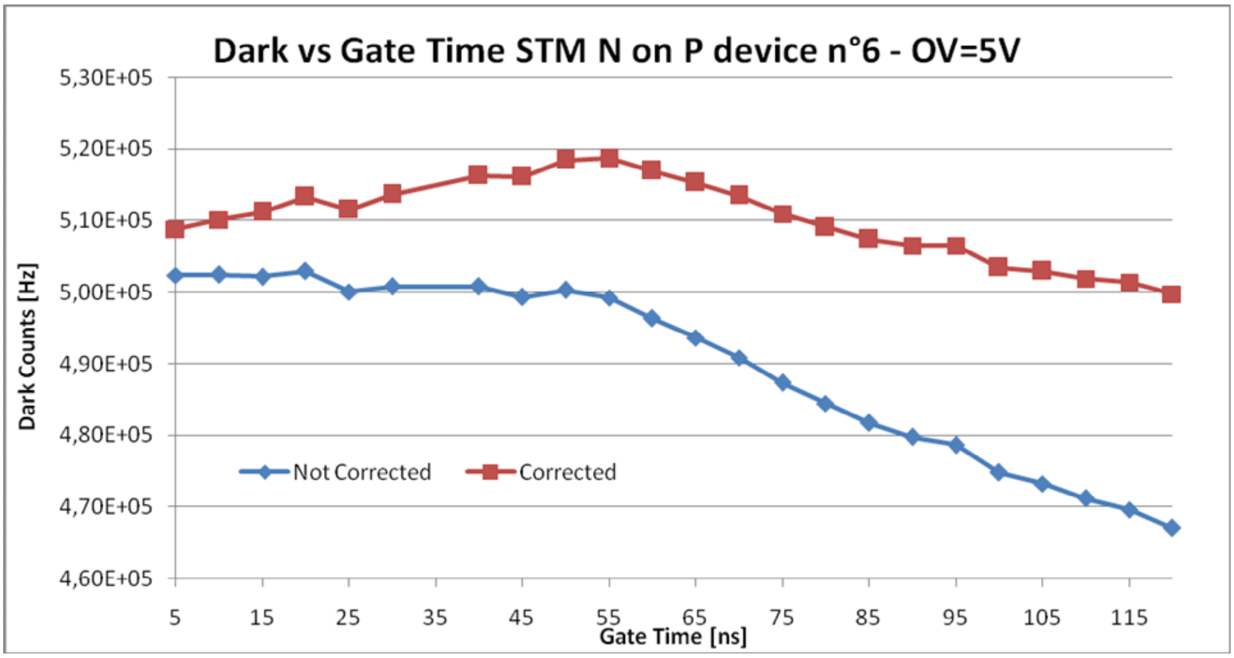


Fig.10 - DARK vs GATE TIME Vov=5V - Thr=-13 mV T=25° Measurements were performed at varying the gate time from 5ns to 110ns.The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

From this plot, and considering that the discriminator introduces a delay of 20 ns (see next paragraph) we selected an hold-off time of 110 ns= 90 +20 ns.

4.2.3 Oscilloscope visualization of output pulses from amplifier and from discriminator

In order to show how the CAEN PSAU discriminator introduces a delay respect to the SiPM pulse we displayed on the oscilloscope the output pulses from the amplifier and from the discriminator. The following snapshots show clearly the 20 ns delay between the SiPM signal and the discriminator TTL output. From the picture is also evident the signal loose due to the gate time.

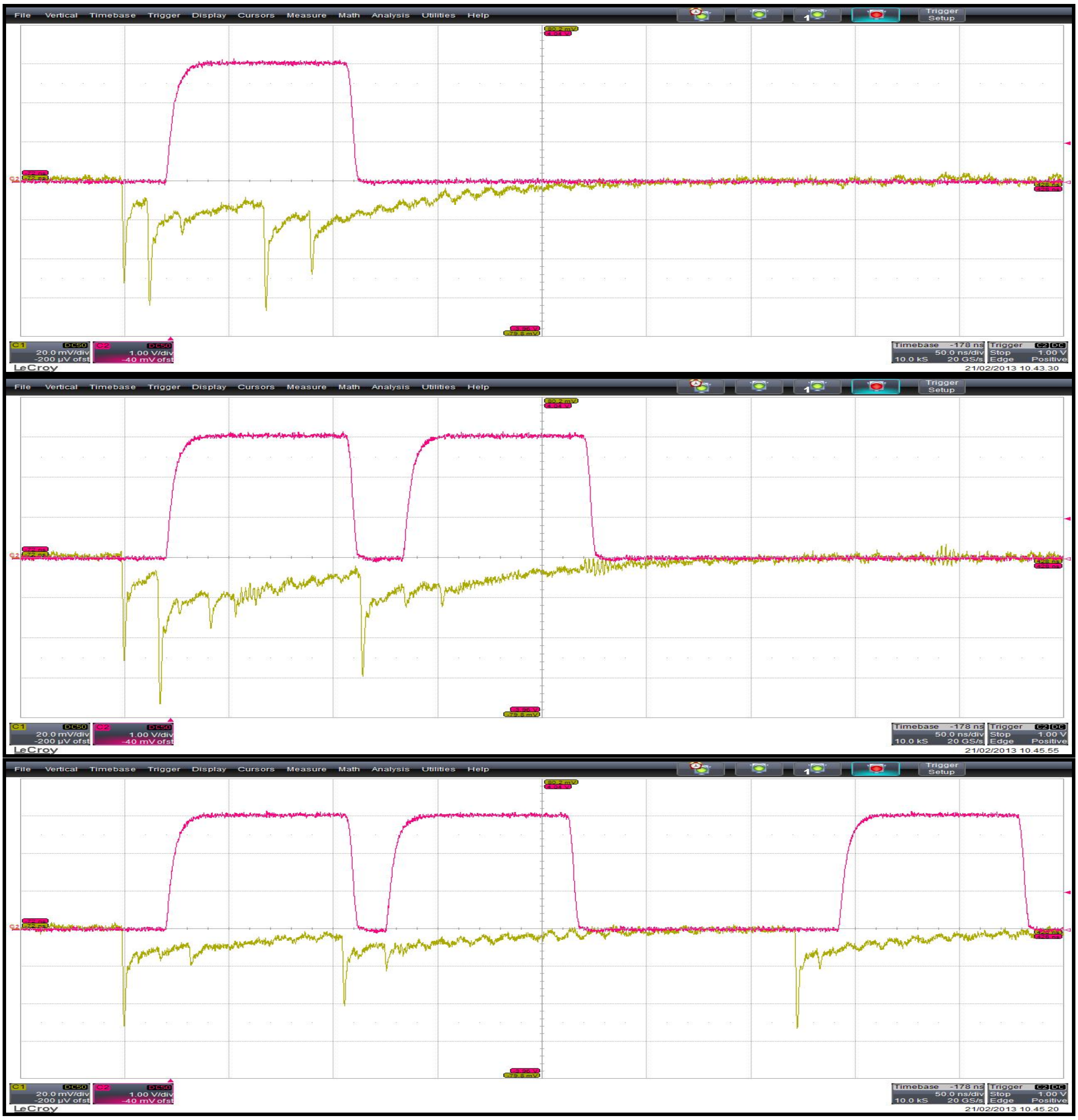


Fig.11 – Oscilloscope snapshots clearly show the 20 ns delay between the SiPM signal and the discriminator TTL output. The signal loose due to the gate time is also evident. This will be recovered by applying the dead time correction.

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 @520 nm and the PDE @520 nm versus the signal count rate.

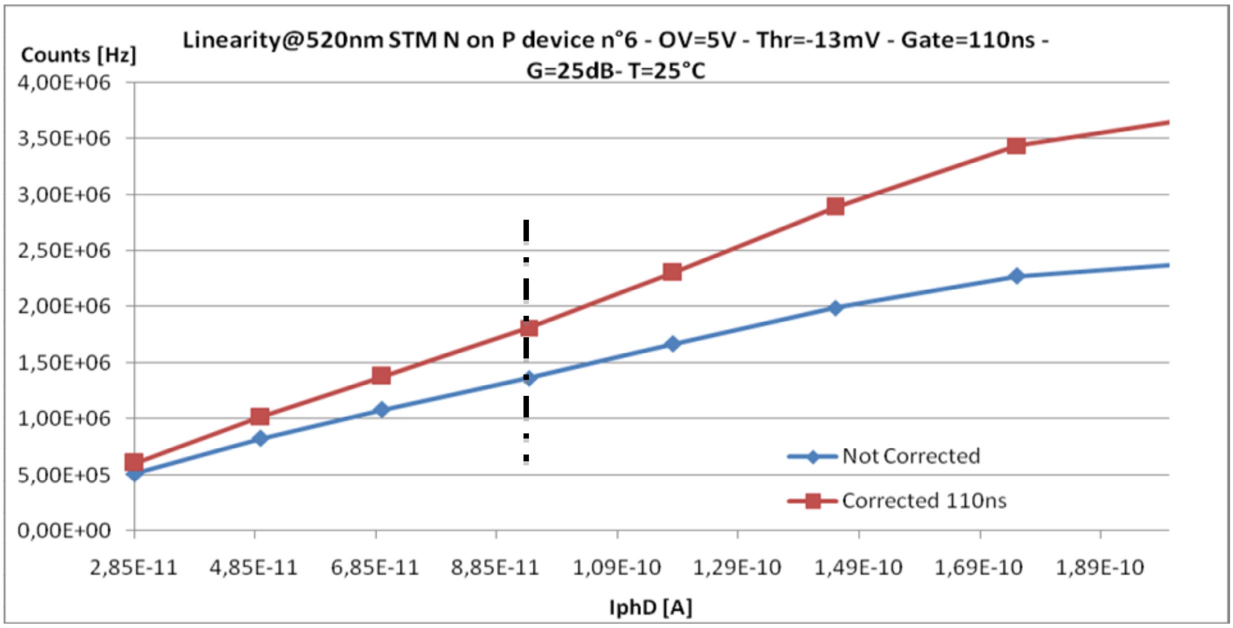


Fig. 12 – Linearity at 520 nm with and without the dead time correction.

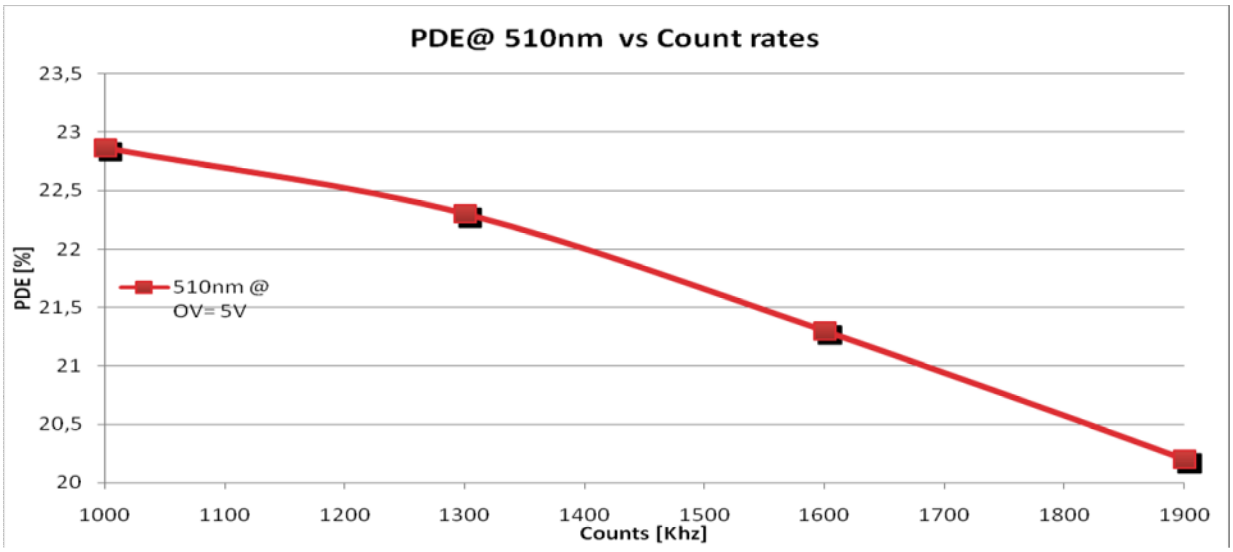


Fig.13 – PDE measurements at 510 nm versus counts, including DCR, from 1000KHz to 1900KHz operating the SiPM at Vov=5V T=25°C, Vthr=-13 mV, Gate time=110 ns

From these plots we derive that the system shows a not-linearity behavior at counts greater than 1.3 MHz uncorrected corresponding at about 1.7 MHz corrected for dead time. And the PDE is about 22-22.7 % in the range of 1 – 1.3 MHz included dark counts (Fig.7)
Then, to be conservative, the PDE measurements have to be carried out with **uncorrected signals not higher than 1.2 MHz corresponding to 1.5 MHz corrected for dead time**.

4.2.5 PDE measurements at Over-Voltage 5V

Measurements were performed at V_{OV} = 5V and gate time 110ns.
The plot reports the PDE with values corrected for the Dead Time.

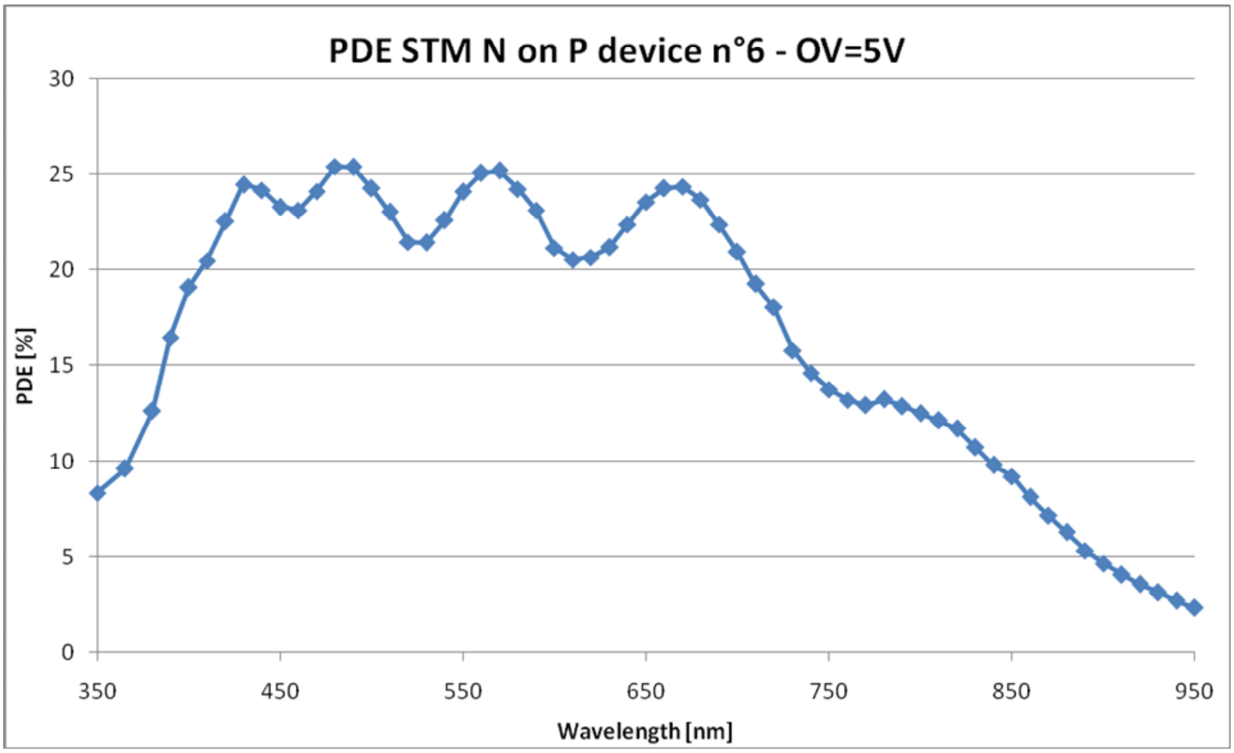


Fig.14 – PDE measurements operating the SiPM at Vov=5V T=25°C, Vthr=-13 mV,Gate time=110 ns

4.3 Characterization at Vov = 6V

Here will follow the characterization at Vov=6V.

4.3.1 Staircase

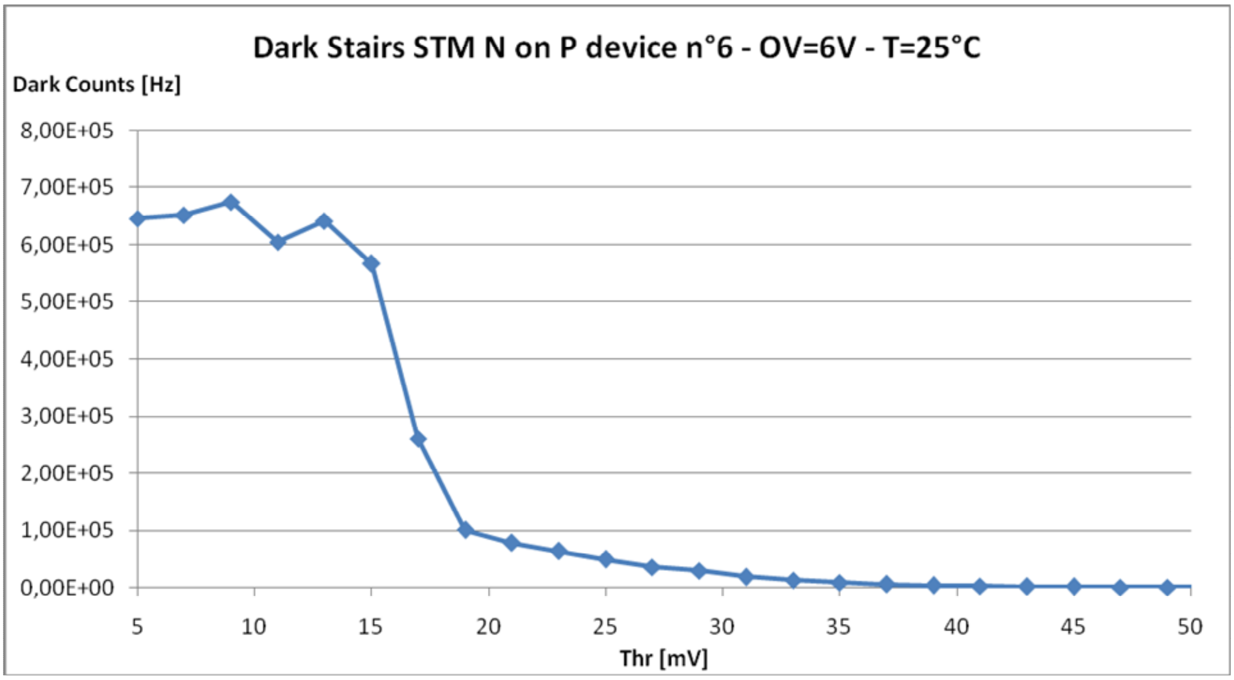


Fig. 15 – Dark Stair versus Vthr @ T=25.0°C.

From this plot we derived a Vthr of -12 mV.

4.3.2 DCR @ OV=6V at different Gate Time from 5 ns to 110 ns

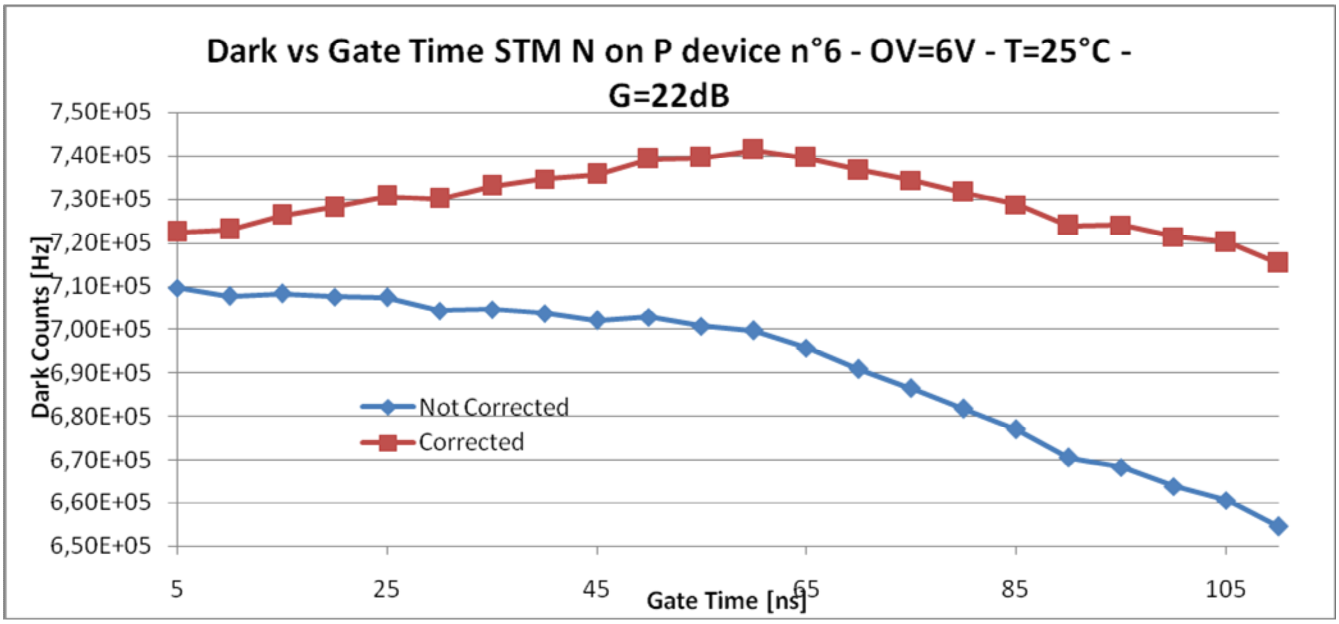


Fig.16 - DARK vs GATE TIME Vov=6V - Thr=-12 mV T=25° Measurements were performed at varying the gate time from 5ns to 110ns.The upper curve is obtained correcting for dead time the lower curve. Temperature compensation for gain stabilization is also adopted.

From this plot, and considering that the discriminator introduces a delay of 20 ns (see next paragraph) we selected an hold-off time of 110 ns= 90 +20 ns.

4.3.3 Oscilloscope visualization of output pulses from amplifier and from discriminator

In order to show how the CAEN PSAU discriminator introduces a delay respect to the SiPM pulse we displayed on the oscilloscope the output pulses from the amplifier and from the discriminator. The following snapshots show clearly the 20 ns delay between the SiPM signal and the discriminator TTL output. From the picture is also evident the signal loose due to the gate time.

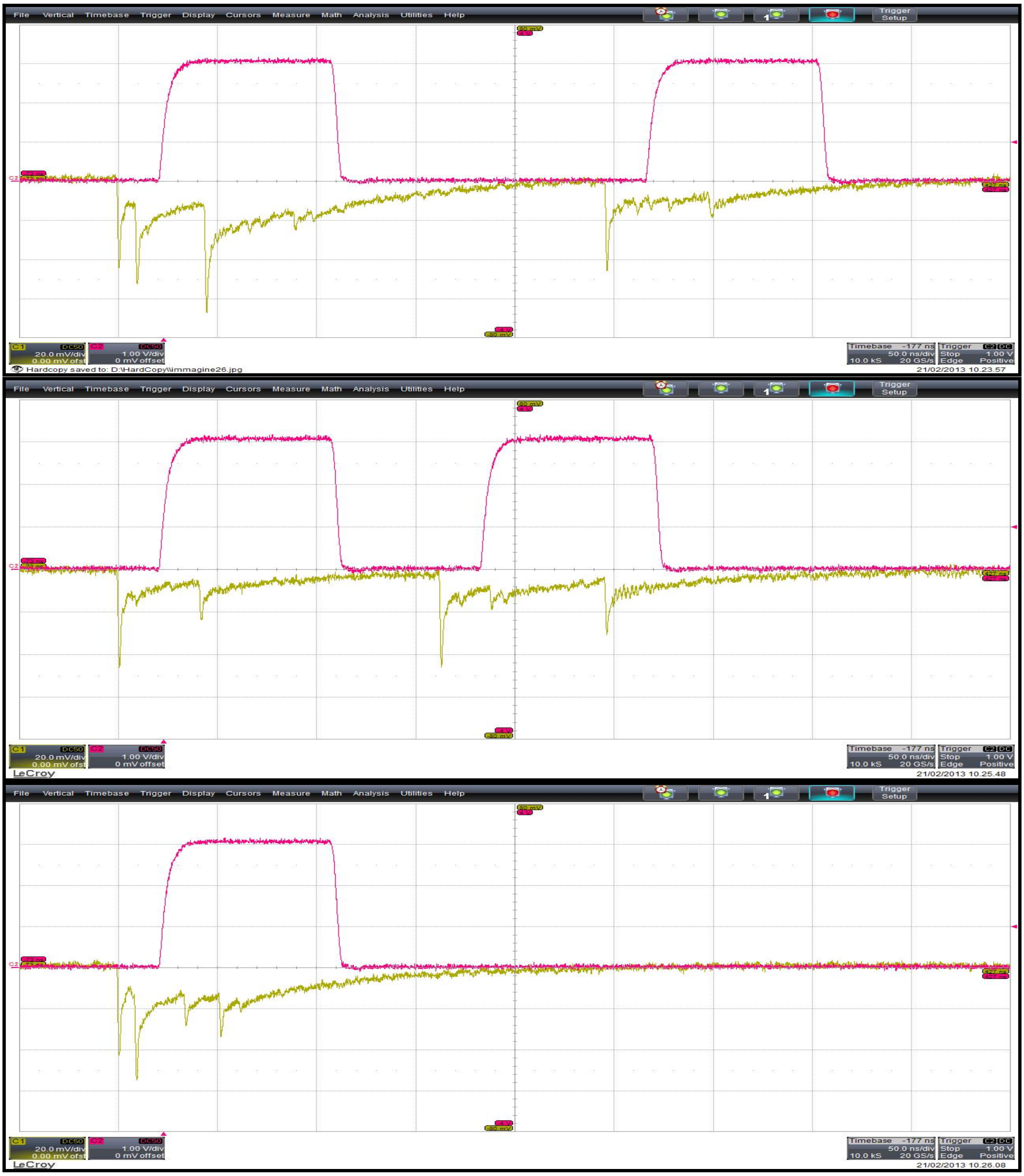


Fig.17 – Oscilloscope snapshots show clearly the 20 ns delay between the SiPM signal and the discriminator TTL output. The signal loose due to the gate time is also evident. This will be recovered by applying the dead time correction.

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 @520 nm and the PDE @520 nm versus the signal count rate.

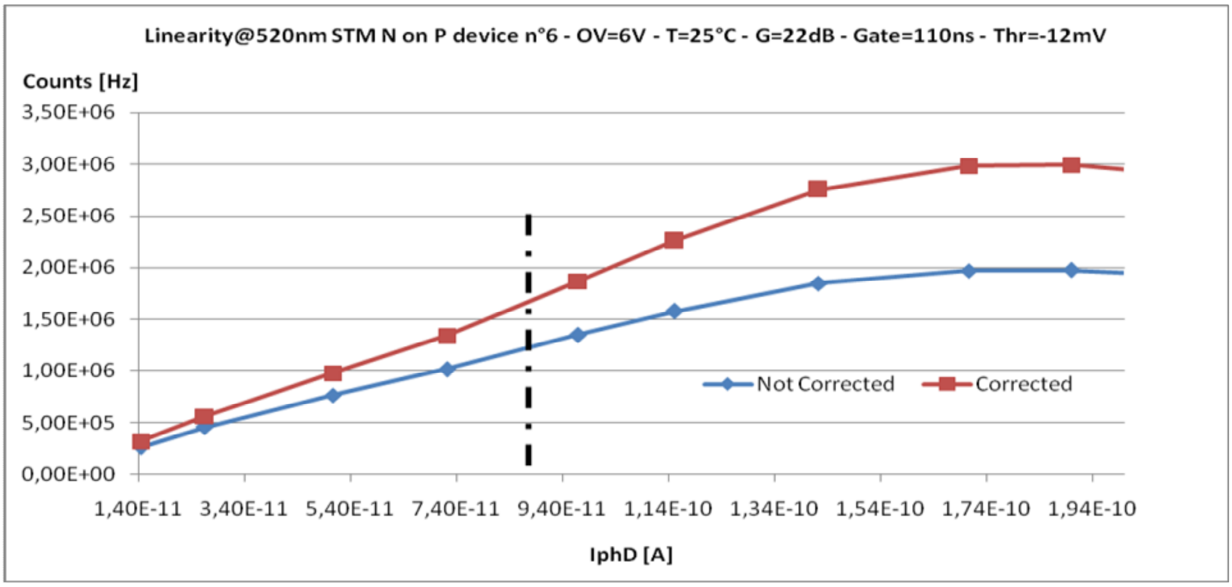


Fig. 18 – Linearity at 520 nm with and without the dead time correction.

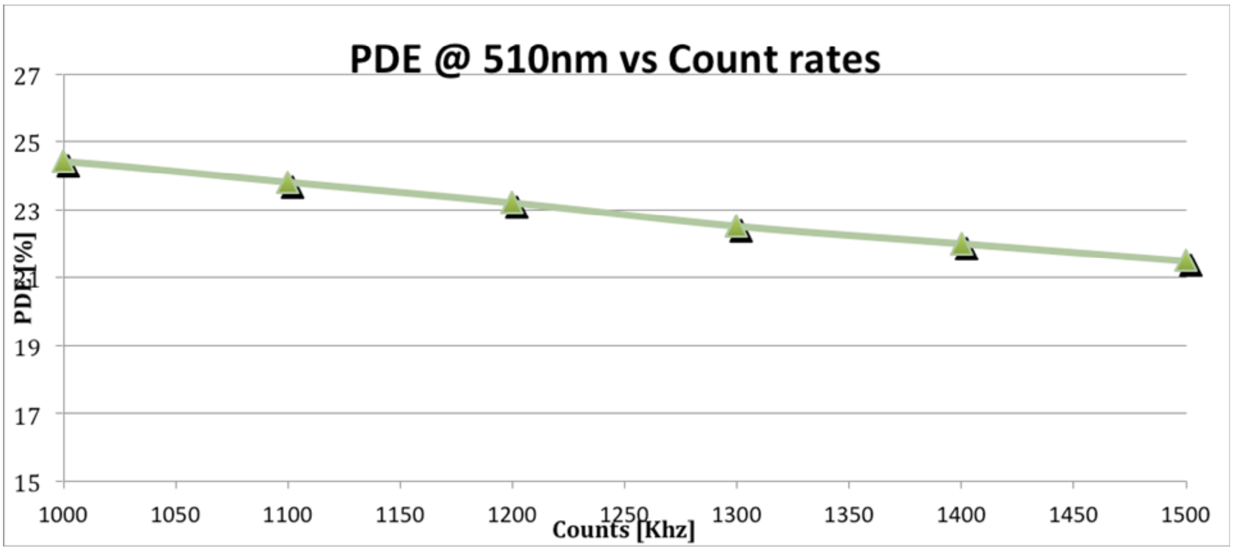


Fig.19 – PDE measurements at 510nm versus counts, including DCR, from 1000KHz to 1500KHz operating the SiPM at Vov=6V T=25°C, Vthr=-23 mV, Gate time=110 ns

From these plots we derive that the system shows a not-linearity behavior at counts greater than 1.2 MHz uncorrected corresponding at about 1.5 MHz corrected for dead time. And the PDE is about 23.9-24.5 % in the range of 1 – 1.5 MHz included dark counts (Fig.7)
Then, to be conservative, the PDE measurements have to be carried out with **uncorrected signals not higher than 1.05 MHz corresponding to 1.3 MHz corrected for dead time**.

4.3.5 PDE measurements at Over-Voltage 6V

Measurements were performed at V_{OV} = 6V and gate time 110ns.
The plot reports the PDE with values corrected for the Dead Time.

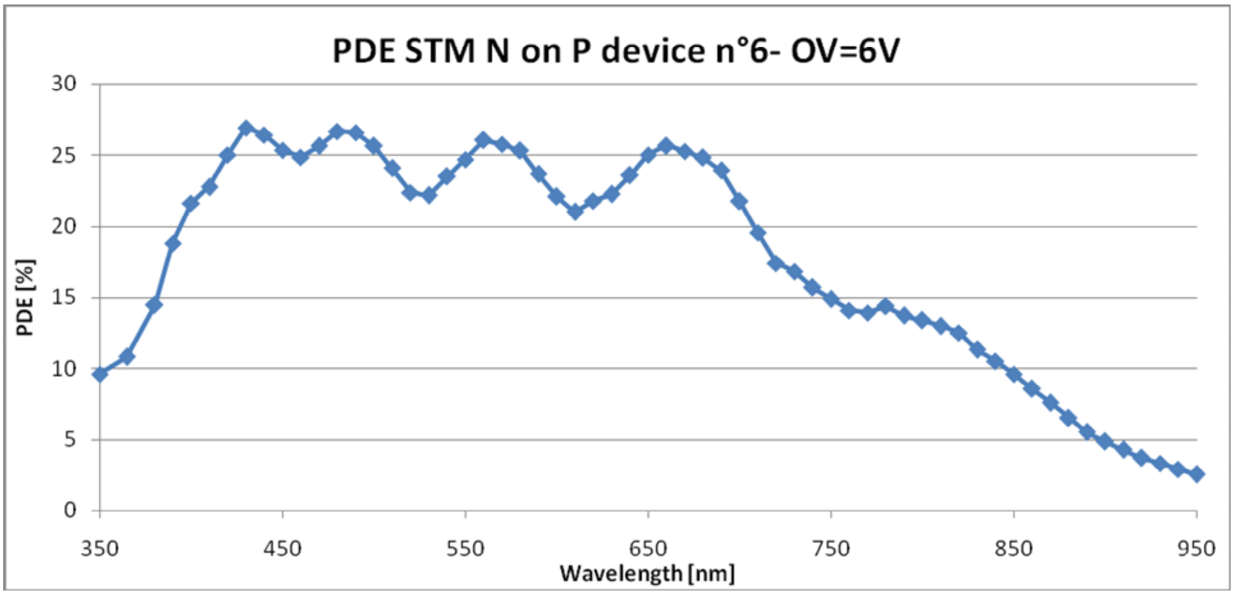


Fig.20 – PDE measurements operating the SiPM at Vov=6V T=25°C, Vthr=-12 mV,Gate time=110 ns

4.4 PDE comparison

PDE measurements at the various Over Voltages are here compared.

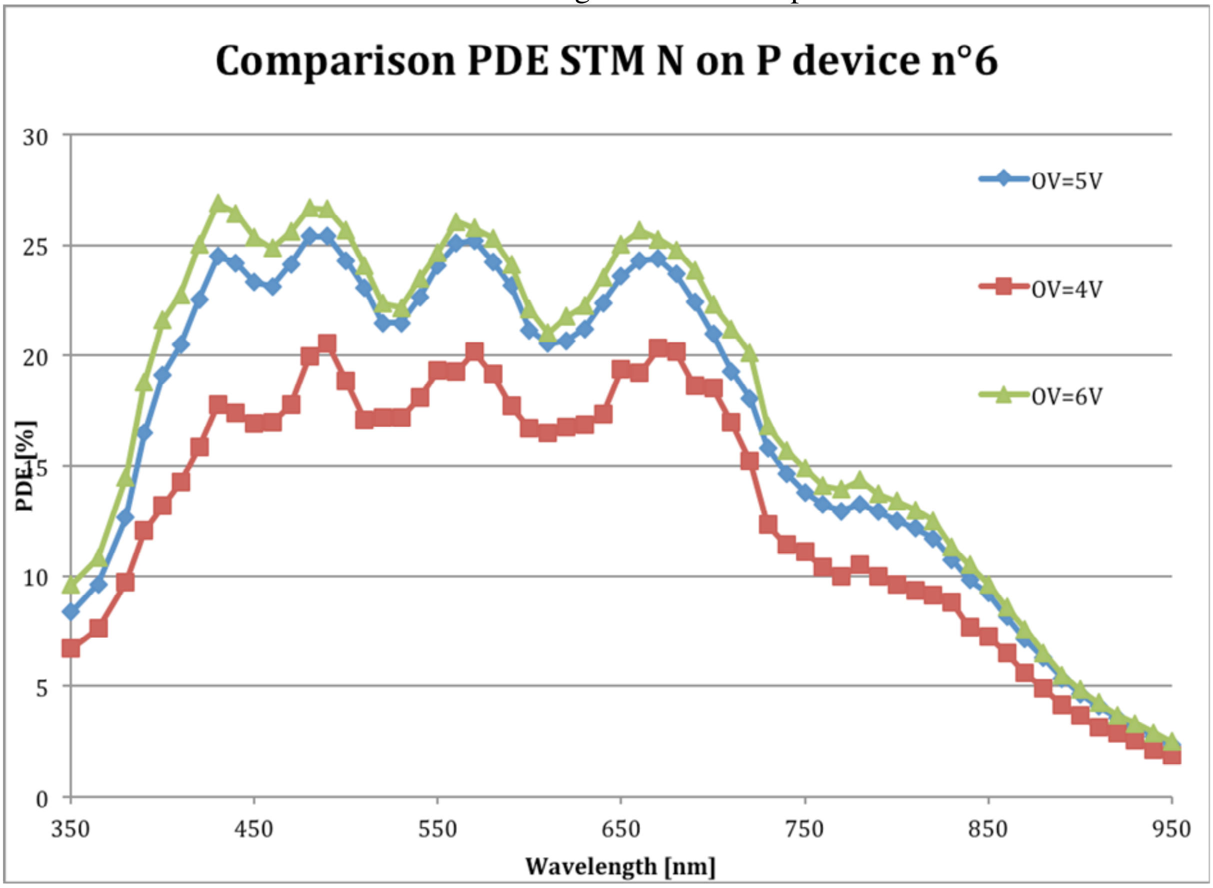
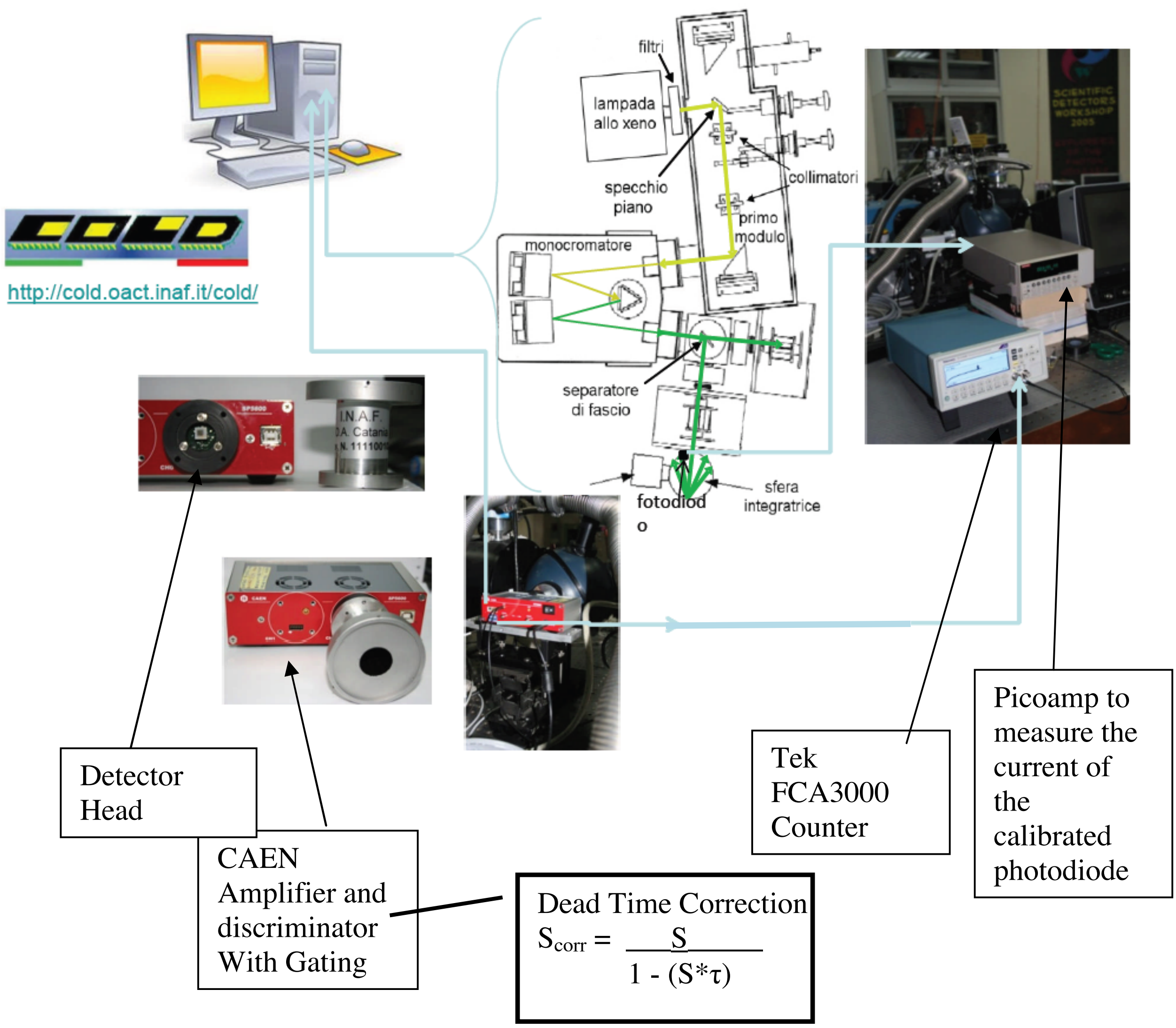


*Fig.21– PDE measurements comparison at Vov=**4.0V**, Vov=**5.0V** and Vov=**6.0V** T=25°C, Gate time=110 ns*

Appendix A: PDE measurement apparatus

PDE measurements Apparatus



Appendix B: Block Diagram of the CAEN PSAU