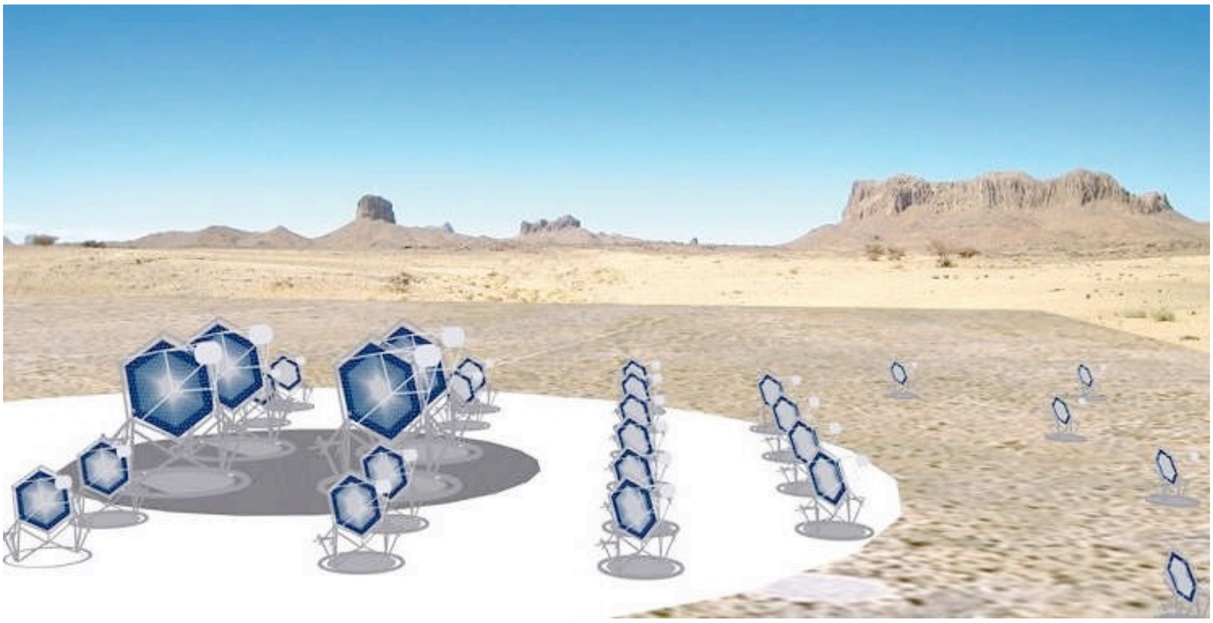
OSSERVATORIO ASTROFISICO DI CATANIA

MPPC Hamamatsu Photonics characterization report for the ASTRI project

Device: S11828-3344M monolithic array 16ch (4x4)



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Rapporti interni e tecnici
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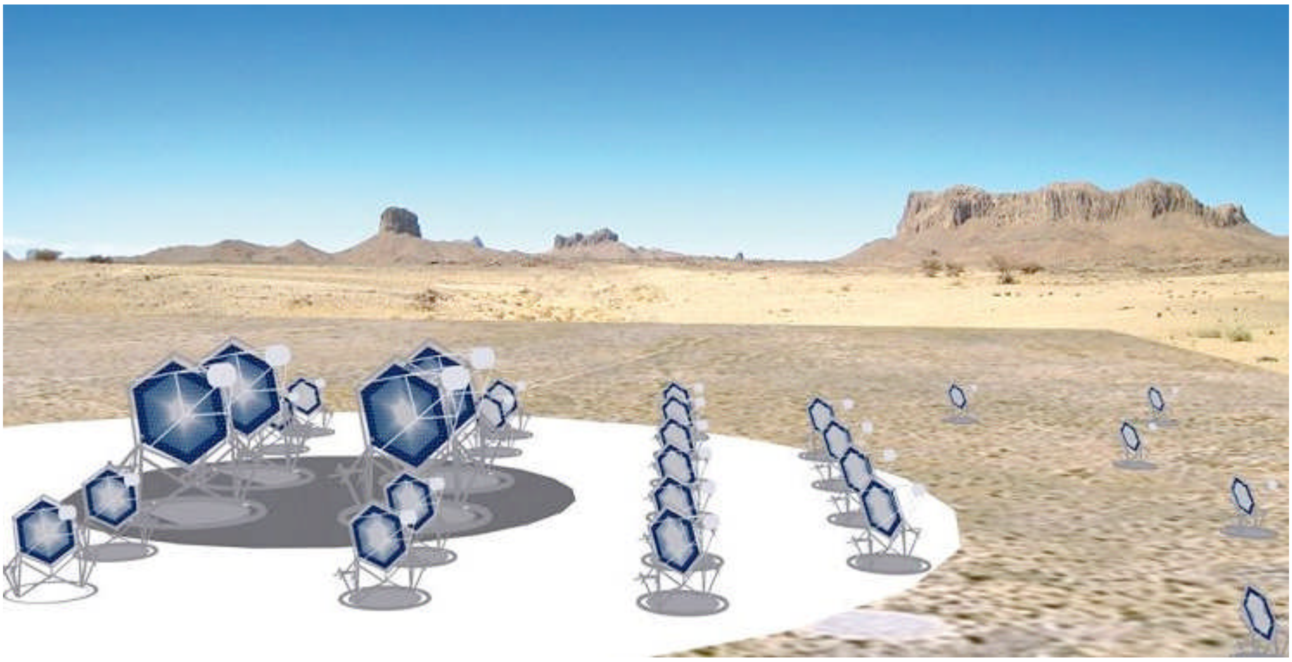
MPPC Hamamatsu CHARACTERIZATION REPORT



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DISTRIBUTION LIST

ASTRI mailing list	astri@brera.inaf.it

DOCUMENT HISTORY

Version	Date	Modification
1.0	Date	first version
		update

LIST OF ACRONYMS

DCR = Dark Count Rate

PDE= Photon Detection Efficiency

QE= Quantum Efficiency

PSAU= Power Supply and Amplification Unit

APPLICABLE DOCUMENTS

[AD1] AD1

REFERENCE DOCUMENTS

[RD1] RD1

1. INTRODUCTION

Due to the complexity of the device and of the set-up utilized to carry-out the measurements, a brief introduction is mandatory. Briefly here are listed the steps of the procedure we have used.

The envisaged steps to obtain a quite accurate electrical and electro-optical characterization are the following:

1. Select the operating temperature
2. Electrical (I-V) Characterization
3. Cross-talk and Dark Count Rate (DCR) characterization with temperature compensation
4. Dark count rate Stairs to establish the optimal threshold signal level
5. DCR versus gate time from 30 to 120 ns measurements to establish the optimal gate time
6. Linearity measurements versus photon rate to avoid the saturation and pile-up and consequent PDE degradation.
7. PDE measurements at a given over voltage and comparison between them
8. PDE measurements at a given temperature and comparison between them.

The procedure in a flow chart form is reported in **Appendix A**.

2. SCOPE

3. Electrical Characteristics and Physical from Data Sheet

Type No: S11828-3344M

■Features

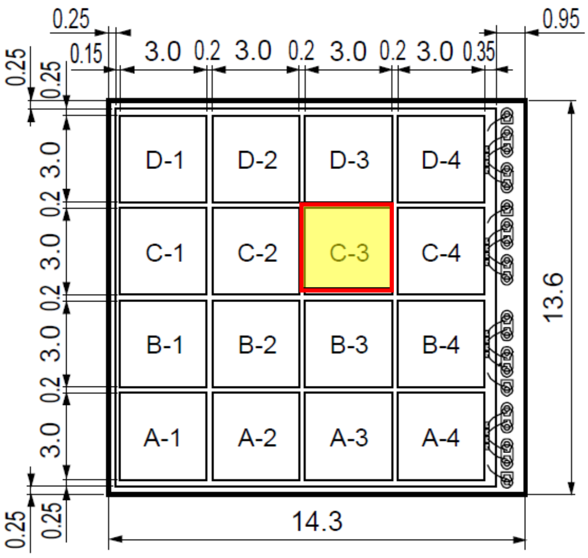
- Monolithic array: 16 ch (4 x 4 array)
- Nonmagnetic package
- Effective active area: 3 x 3 mm/ch
- Pixel pitch: 50 μm
- Allows multiple devices to be arranged in a buttable format

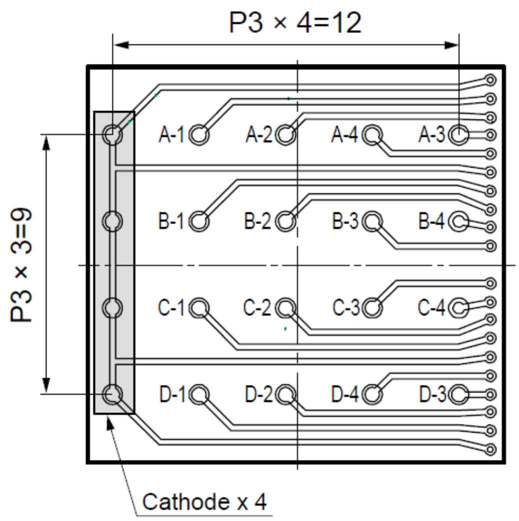
■Specifications

Parameter	Condition	Value	Unit
Number of elements		16 (4 x 4)	elements
Effective active area / channel		3 x 3	mm
Pixel pitch		50	μm
Number of pixels / channel		3600	-
Number of pixels / device		57600	-
Fill factor		61.5	%
Photon detection efficiency *	λ=440 nm	50	%
Dark current / channel	per channel	3	μA
Terminal capacitance / channel		320	pF
Gain		7.5×10^5	-

* Includes cross-talk and after-pulse

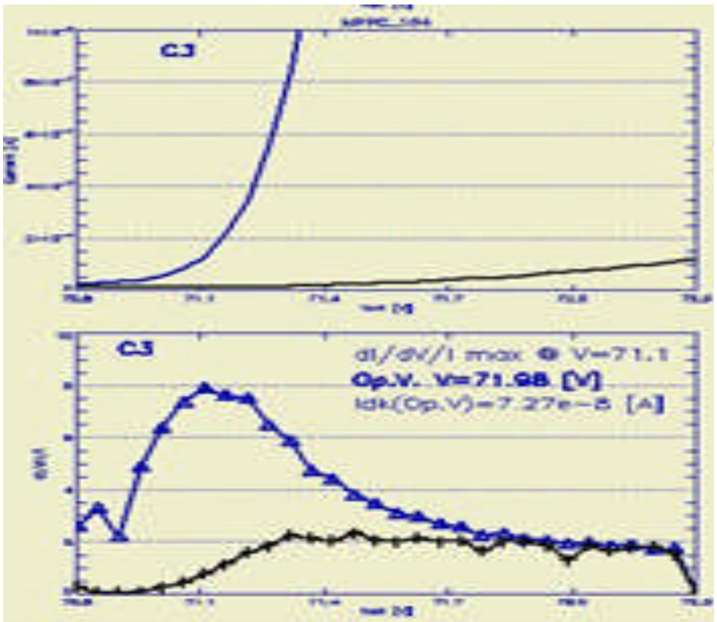
■Dimensional outline (unit: mm)





4. Current-Voltage Characterization – I-V Plots

Pixels B2, B3, C1, C2, C3, D1, D2



SN 164 Pixel	Vop COLD Volts	Vop Hamamatsu Volts	Differenza Volts
B-2	72,08	72,05	-0,03
B-3	72,13	72,03	-0,1
C-1	72,08	72,02	-0,06
C-2	71,98	71,99	0,01
C-3	**71,98**	**71,97**	**-0,01**
D-1	71,98	71,96	-0,02
D-2	71,98	71,93	-0,05

The Operating Voltage for the pixel C-3 is **71.97 Volts**. Following the Hamamatsu data sheet, this operating voltage correspond to a voltage of 0.88 Volts at which the gain **G** is **7.5E+05**.

We selected this operating voltage as starting point.

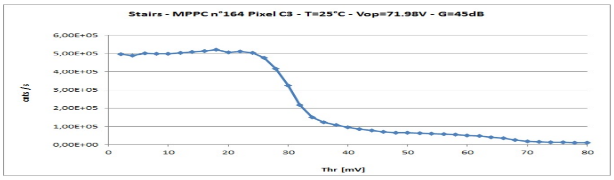
IMPORTANT NOTE

In this document **Vov** is not exactly the Over Voltage but is the Voltage at which the **G** is **7.5E+05** (as specified by Hamamatsu)**.**

5. Cross-talk and Dark versus V_{op}

The Crosstalk is evaluated by the ratio between the primary event count rate and the second event count rate.

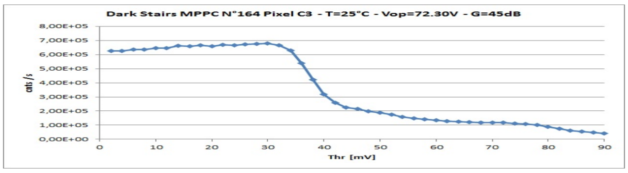
Vop=71.98V



Crosstalk = 12.73 %

Fig. 1 - *DARK Stairs – Vop=71.98V– T=25°C*

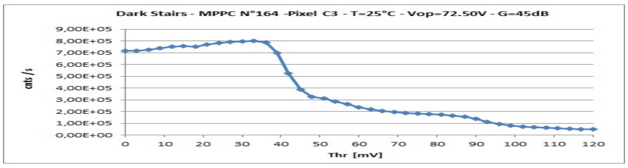
Vop=72.30V



Crosstalk = 20.52 %

Fig. 2 - *DARK Stairs - Vop=72.30V– T=25°C*

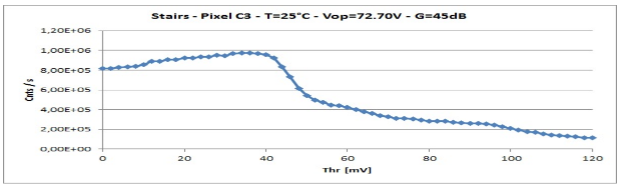
Vop=72.50V



Crosstalk = 27.38 %

Fig. 3 - *DARK Stairs - Vop=72.50V– T=25°C*

Vop=72.70V



Crosstalk = 36.27 %

Fig. 4 - *DARK Stairs - Vop=72.70V– T=25°C*

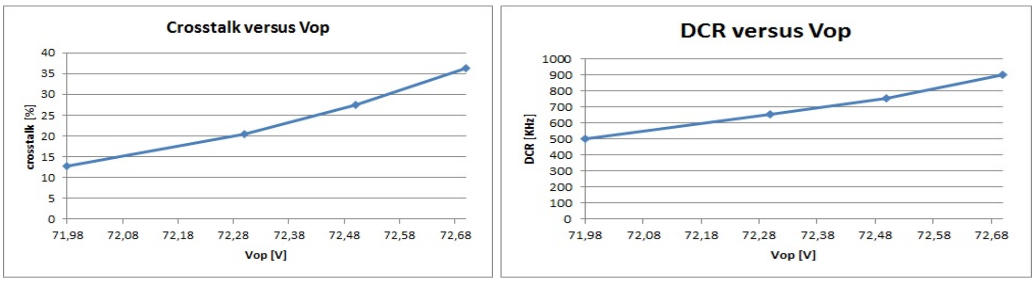
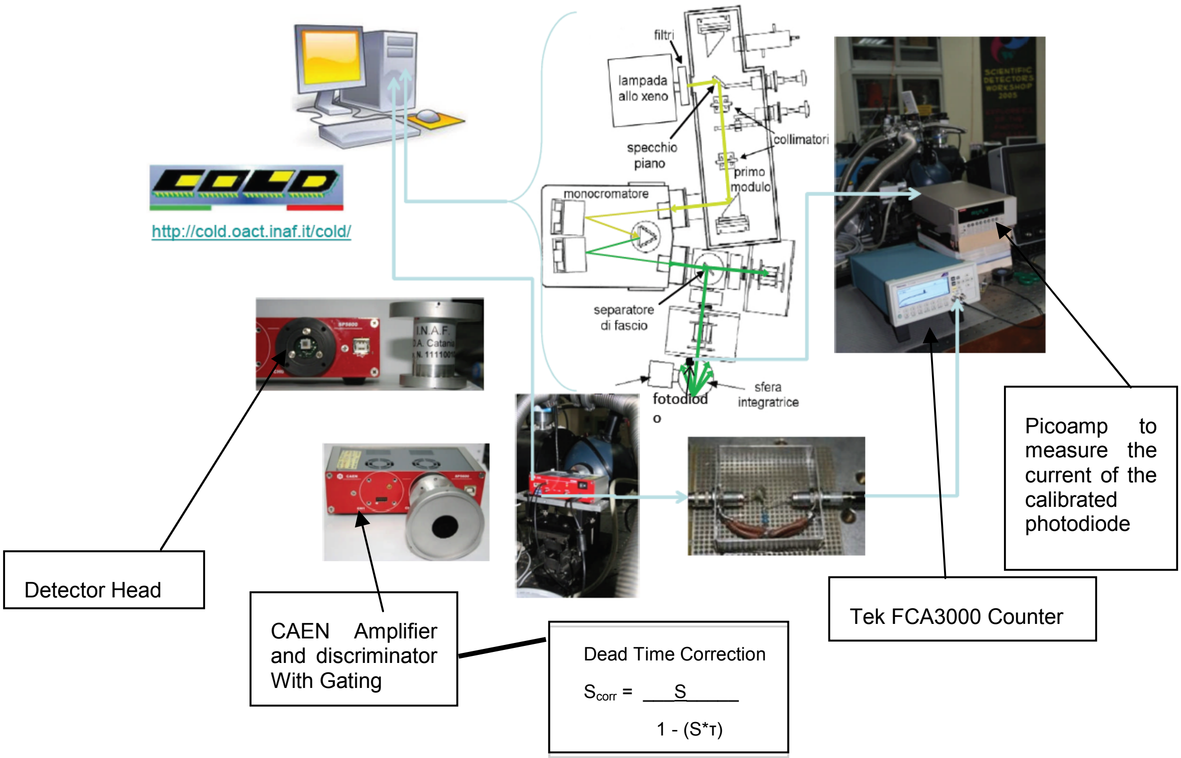


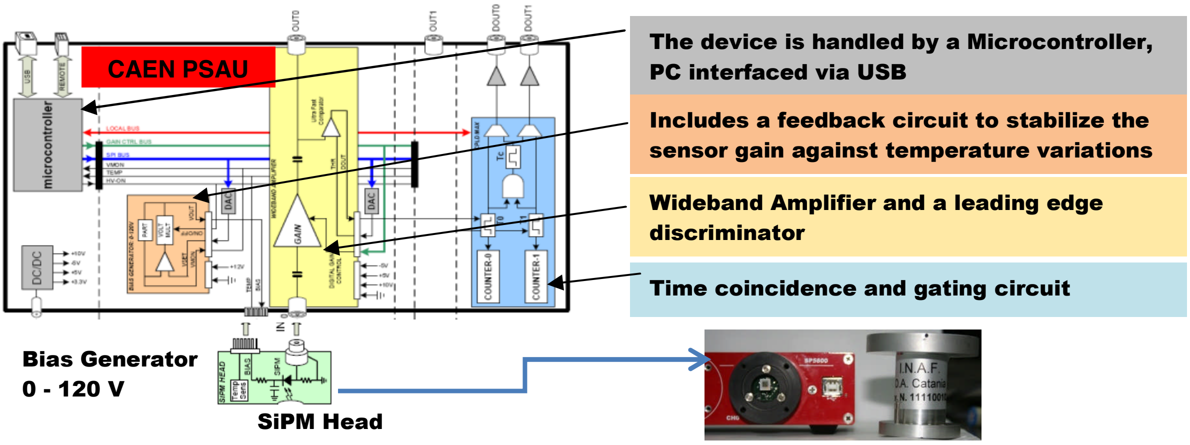
Fig. 5 – *Left Panel :Crosstalk versus Vop – Right Panel: Dark Count Rate versus Vop. Both at T=25°C*

6. PDE measurements at V_{op}=71.98V

The PDE measurements are carried out by using the set-up shown in the following pictures.



The apparatus is constituted by an illuminating section a monochromator and an integrating sphere where, at the output ports, take place the SiPM included the front-end electronics and 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:



Before carrying out the PDE measurements we have to set-up:

- some parameters on the SiPM control electronics such as:
  - the **threshold** to accounting for **cross-talk**
  - the **hold-off time** to avoid as much as possible the **after pulsing** effect
- some parameters on the optical apparatus such us:
  - 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.

6.1 Stairs at the operating Voltage 71.98V with temperature compensation

It is extremely important that the SiPM operating conditions are maintained stable versus the working temperature during the measurements. Apart the DCR other two parameters are affected by temperature variation: the Gain and the Trigger Probability (TP). By knowing the dV/dT coefficient (in this case 56 mV/°C) it is possible to compensate the Vop respect to the temperature variation. The PASU CAEN allows to stabilize the operating voltage ensuring Gain and TP stability. This last parameter plays a fundamental role in PDE evaluation. In fact the PDE is given by:

$$QE \times FF \times TP$$

The Quantum Efficiency (QE) depends on the material and on the manufacturing technology (depletion layer etc.), the Fill Factor (FF) depends on the geometry of single microcell and on the dead area resulting from the total detector layout, the TP depends on the electric field applied to the depletion region responsible for the avalanche and is given from the overvoltage respect to the breakdown, in other words the TP depends on the Vop. And if TP is unstable an inaccurate PDE measurement will result.

The Dark stairs obtained at Vop =71.98V is shown in Fig. 6

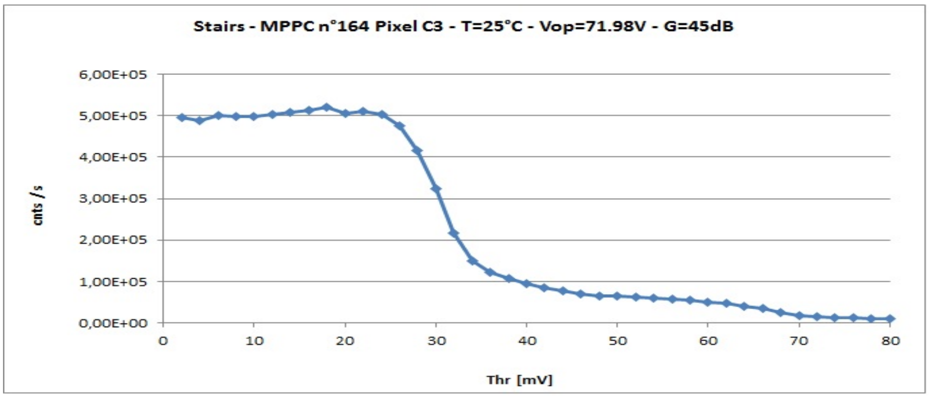


Fig. 6 - *DARK Stairs - Vop=71.98V– T=25°C temperature compensation with CAEN*

From the stairs plot we derive that the optimal threshold at 0.5 pe- is $\mathbf{V_{Thr} = -20\ mV}$.

6.2 Stairs at the operating Voltage 71.98V with temperature compensation

Measurements were performed at V_{OP} = 71.98V varying the gate time from 30ns to 120ns.

In Fig. 7 data are plotted with and without dead time correction.

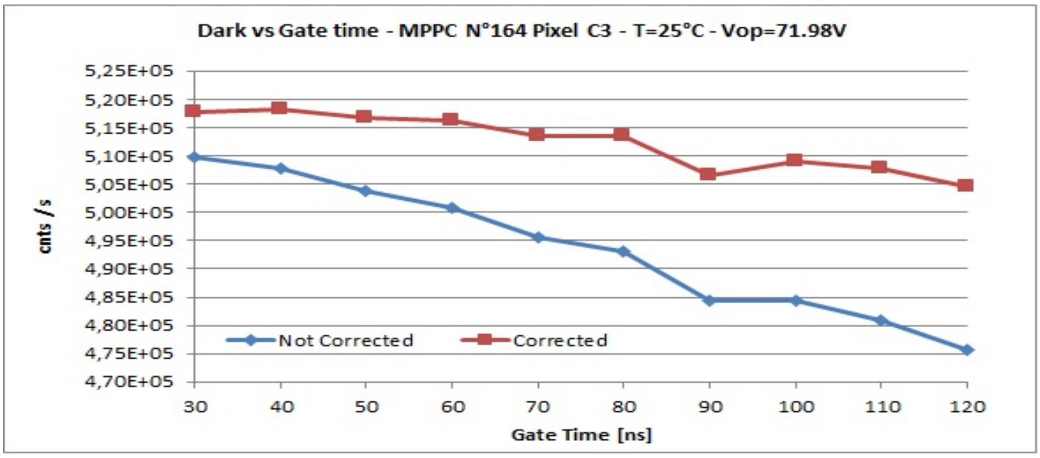


Fig. 7 - *DARK vs GATE TIME Vop= 71.98 V - Thr=-20 mV T=25.0° the temperature compensation is activated. As expected, applying the dead time correction, the dark count rate is partially recovered. A little signal loss is accounted due to a not perfect gate time correction.*

From the plot of Fig.7, considering the slight variation of the dark in the range 60-100 ns we can select as optimal **hold-off Time τ = 70 ns**.

6.3 Dark Count Rates versus 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. 8 shows the DCR plot in an interval time of 120 seconds.

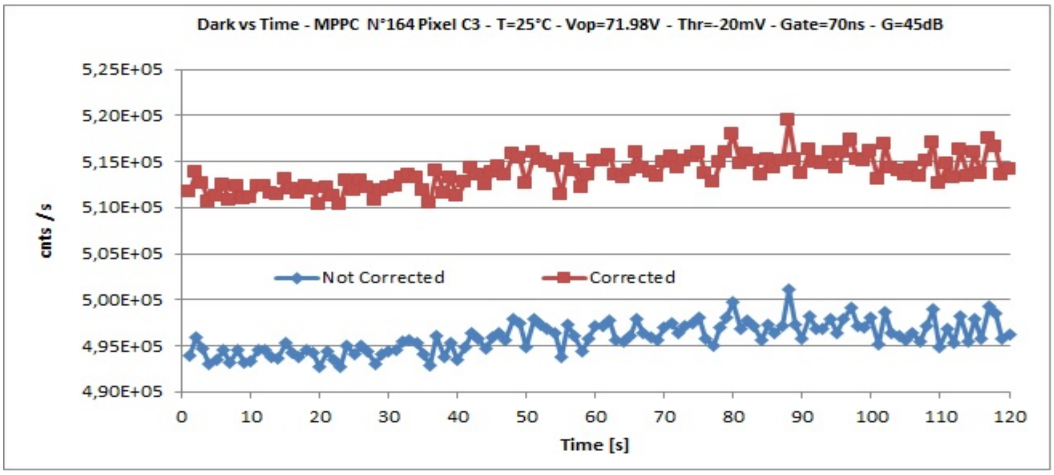


Fig. 8 – *DCR versus time. The upper plot shows the count rate corrected for dead time*

6.4 Linearity measurements and PDE versus photon counting rate

As stated before, to prevent the SiPM from saturation, preliminary linearity measures have to be carried out.

Measurements were performed illuminating the integrating sphere and selecting the wavelength of 500 nm. The SiPM is operated by selecting V_{OP} = 71.98V and gate time 70ns.

The Fig. 9 shows the linearity plot at 500 nm with and without dead time correction.

The dark count rate (DCR) has been subtracted in both curves.

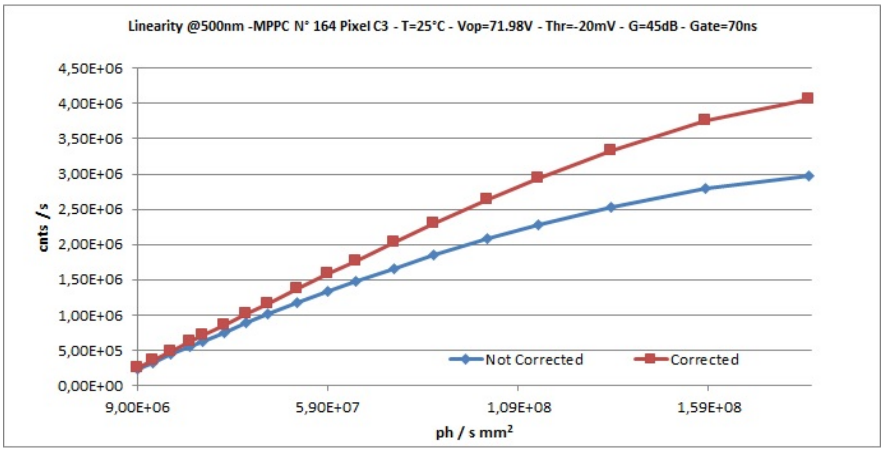


Fig. 9 – Linearity at λ=500 nm. Each rate is plotted with the corresponding photon rate per mm². Values corrected for dead time are also reported. This is obtained by knowing the NIST traced QE at 500 nm of the calibrated photodiode.

From this plots we derive a non-linearity behavior at about 1.8 MHz uncorrected that means about 2.3 MHz corrected for dead time.

The figure 10 shows the PDE at 500 nm versus the count rates (with DCR removed).

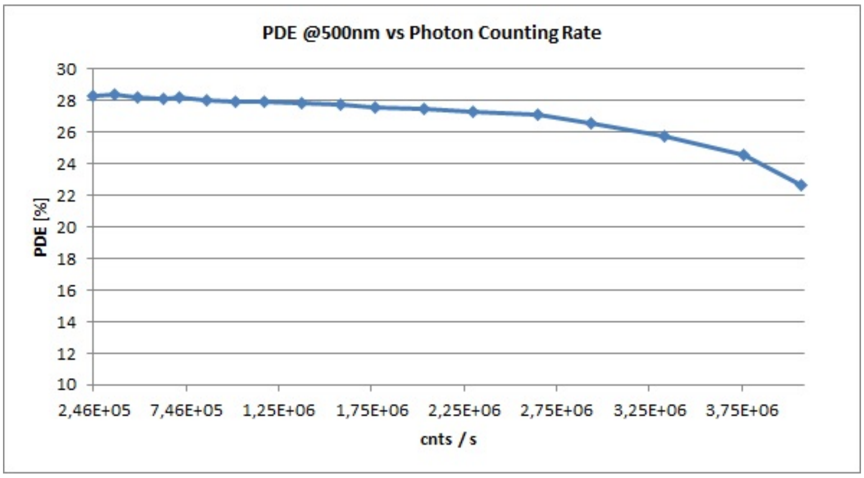


Fig. 10 –*PDE versus photon count rates with dark removed at λ=500 nm.*

This plot allows us to better select the appropriate photon rates. In fact it is clearly evident the PDE drop off at rates greater than 1.8 MHz that means 2.3 MHz including the DCR contribute.

6.5 PDE at Vop= 71.98 V

Measurements were performed at V_{OP} = 71.98 V and gate time 70ns. Also in this case, as stated before, we worked in such illuminating condition to avoid low photocurrent levels measured by the calibrated photodiode. For this reason in front of the SiPM has been placed a neutral density filter calibrated at our laboratory. The introduction of the filter allows us to work with higher signals on the NIST photodiode with a consequent reduction of error bars.

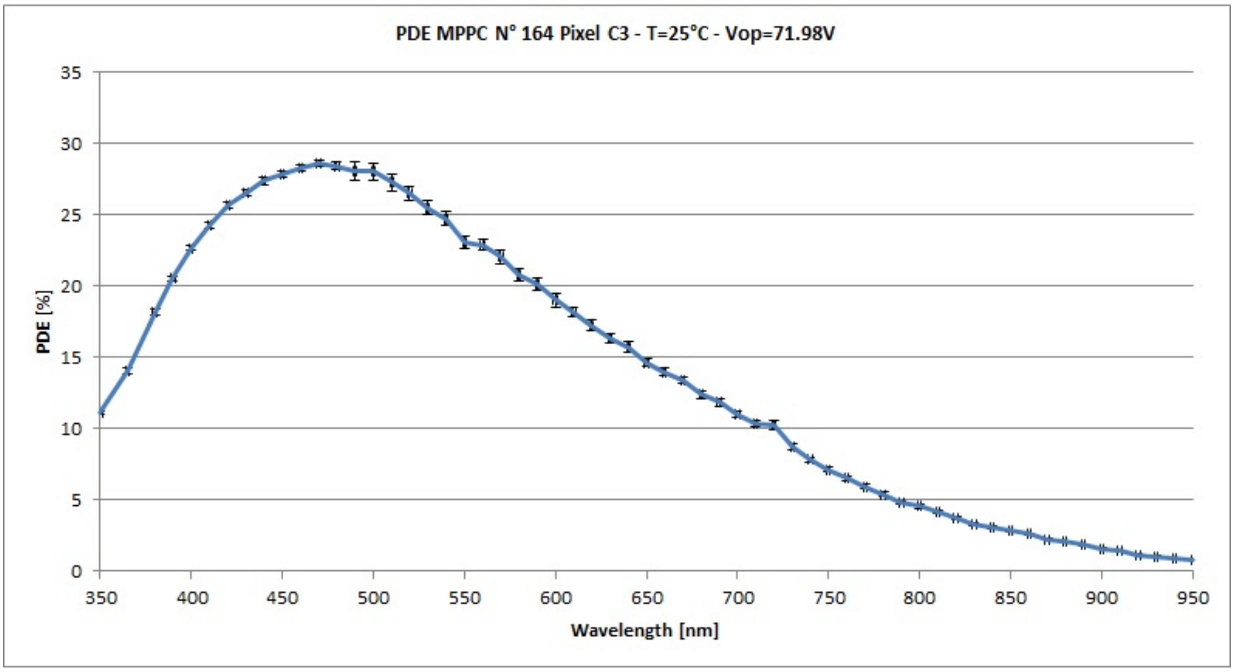


Fig. 11 – *PDE measurements operating the SiPM at Vop=71.98V T=25°C*

7. PDE measurements at Vop= 72.30 V

7.1 Stairs and DCR vs gate time at Vop = 72.30 V with temperature compensation

We changed the Vop and repeated the same measurements reported on the previous chapter (see also the flow chart in appendix A).

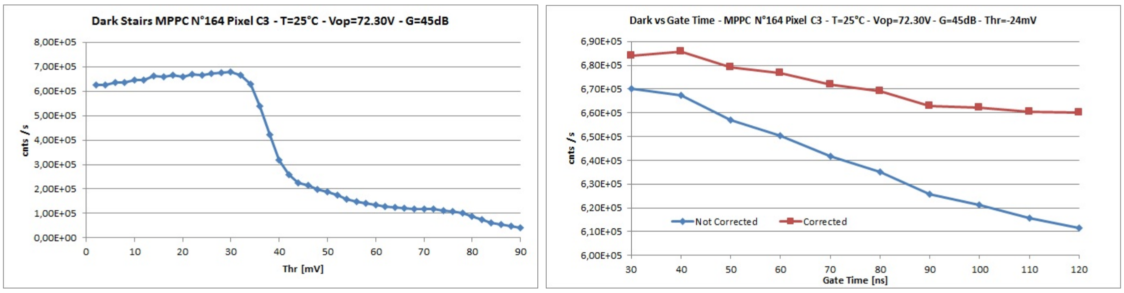


Fig. 12 – *Left panel: DARK. Stairs - Right panel: DCR versus gate time. Both at Vop=72.30V and T=25°C*

From the stairs plot we derive that the optimal threshold at 0.5 pe- is $\mathbf{V_{Thr}}$ **= -24 mV**.

While from the plot of the DCR versus gate time, considering the slight variation of the dark in the range 60-100 ns we can select as optimal **hold-off Time τ = 70 ns**.

7.2 Linearity measurements and PDE versus photon counting rate at Vop=72.30 V

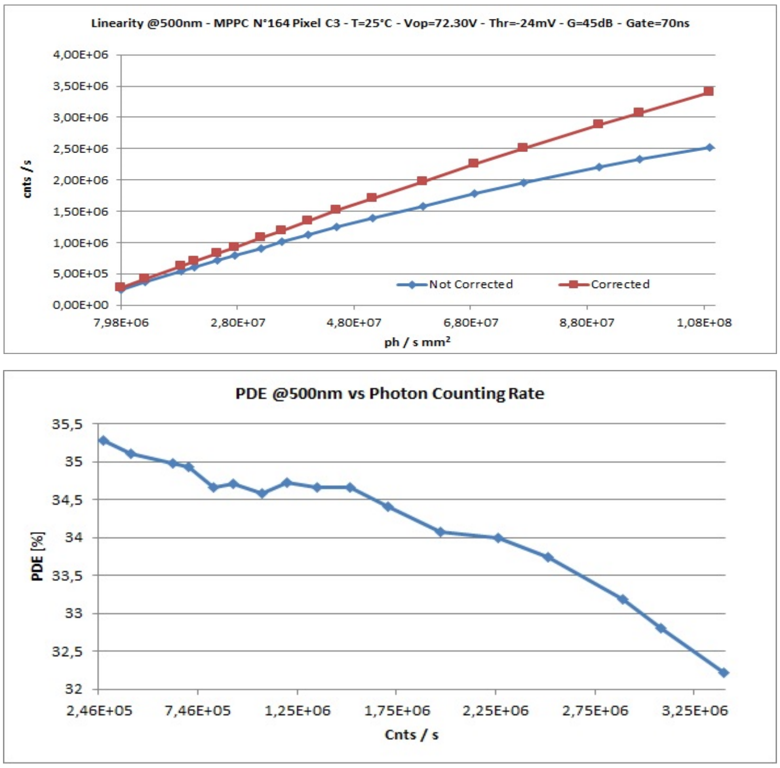


Fig. 13 – *Linearity and PDE versus photon rate at λ=500 nm.*

From the plots of Fig.13 we can select for the PDE measurements as optimal **photon counting rate 1.5 MHz including the DCR contribute**.

7.3 PDE at Vop= 72.30 V

Measurements were performed at T=25 °C, V_{OP} = 72.30 V, gate time=70ns by using the same conditions described on the above chapters.

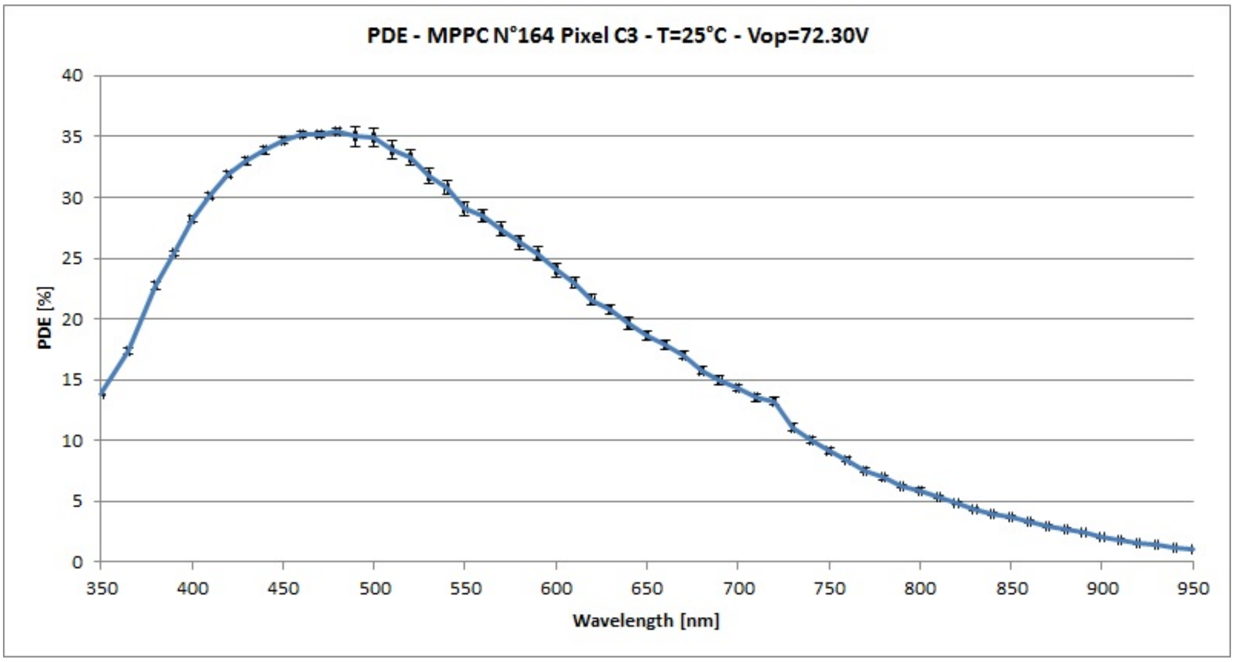


Fig. 14 – *PDE measurements operating the SiPM at Vop=72.30V - T=25°C*

8. PDE measurements at V_{op}=72.50 V

8.1 Stairs and DCR vs gate time at Vop = 72.50 V with temperature compensation

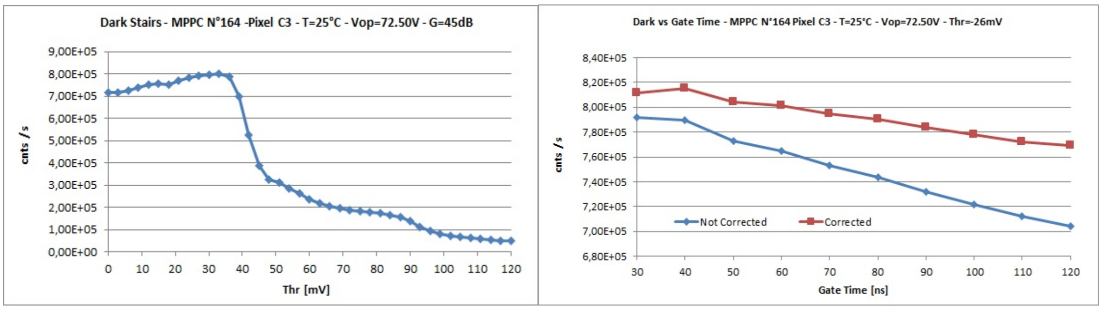


Fig. 15 – *Left panel: DARK Stairs. Right panel: DCR versus gate time. Both with Vop=72.50V and T=25°C*

From the stairs plot we derive that the optimal threshold at 0.5 pe- is **V_{Thr} = -26 mV**.

While from the plot of the DCR versus gate time, considering the slight variation of the dark in the range 60-100 ns we can select as optimal **hold-off Time τ = 70 ns**.

8.2 Linearity measurements and PDE versus photon counting rate at Vop=72.50 V

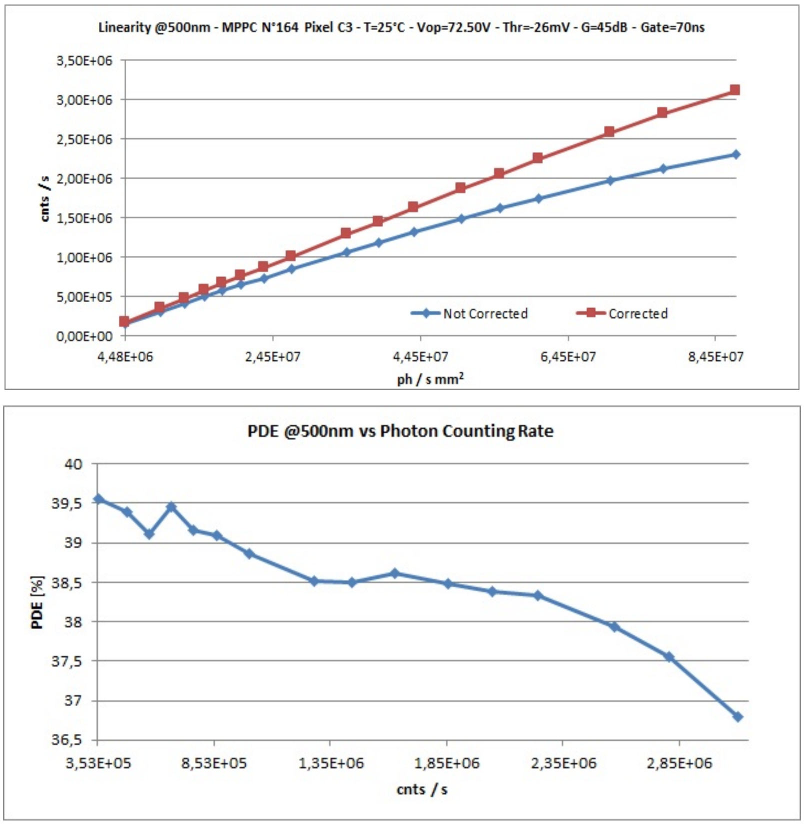


Fig. 16 – *Linearity and PDE versus photon rate at λ=500 nm.*

From the plots of Fig.16 we can select for the PDE measurements as optimal **photon counting rate 1.4 MHz including the DCR contribute**.

8.3 PDE at Vop= 72.50 V

Measurements were performed at V_{OP} = 72.50 V and gate time 70ns and in front of the SiPM has been used a neutral density filter calibrated at our laboratory.

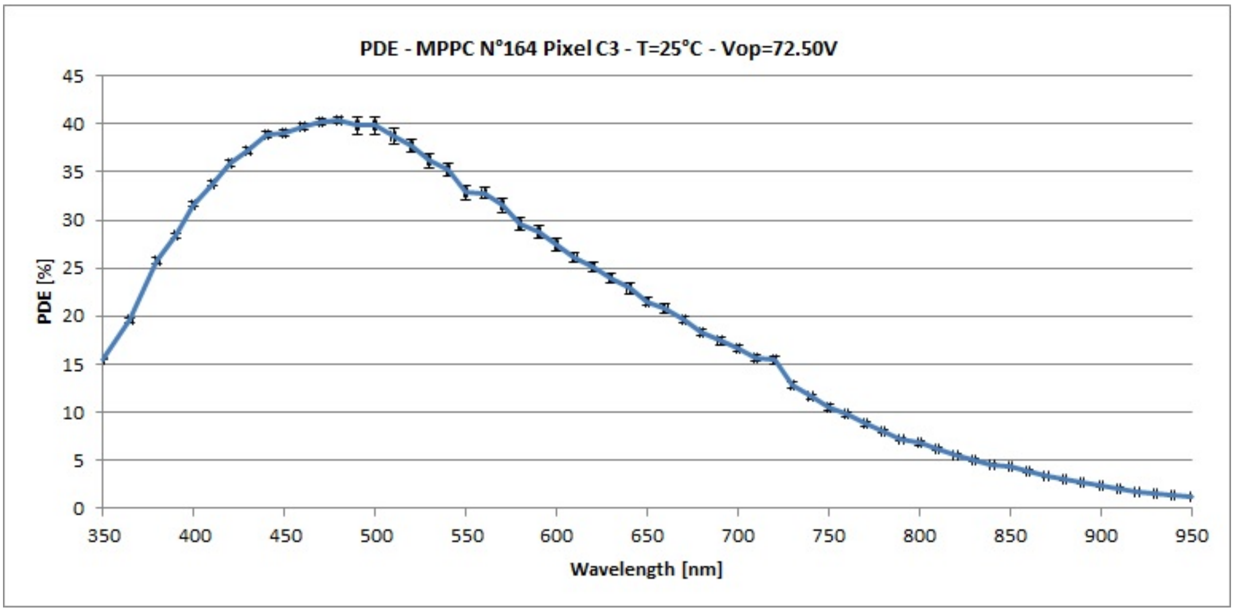


Fig. 17 – *PDE measurements operating the SiPM at Vop=72.50 V - T=25°C*

9. PDE at Vop = 71.98V, Vop= 72.30V and Vop=72.50V

Finally the PDE measurements at the three operating voltages are compared in Fig.18.

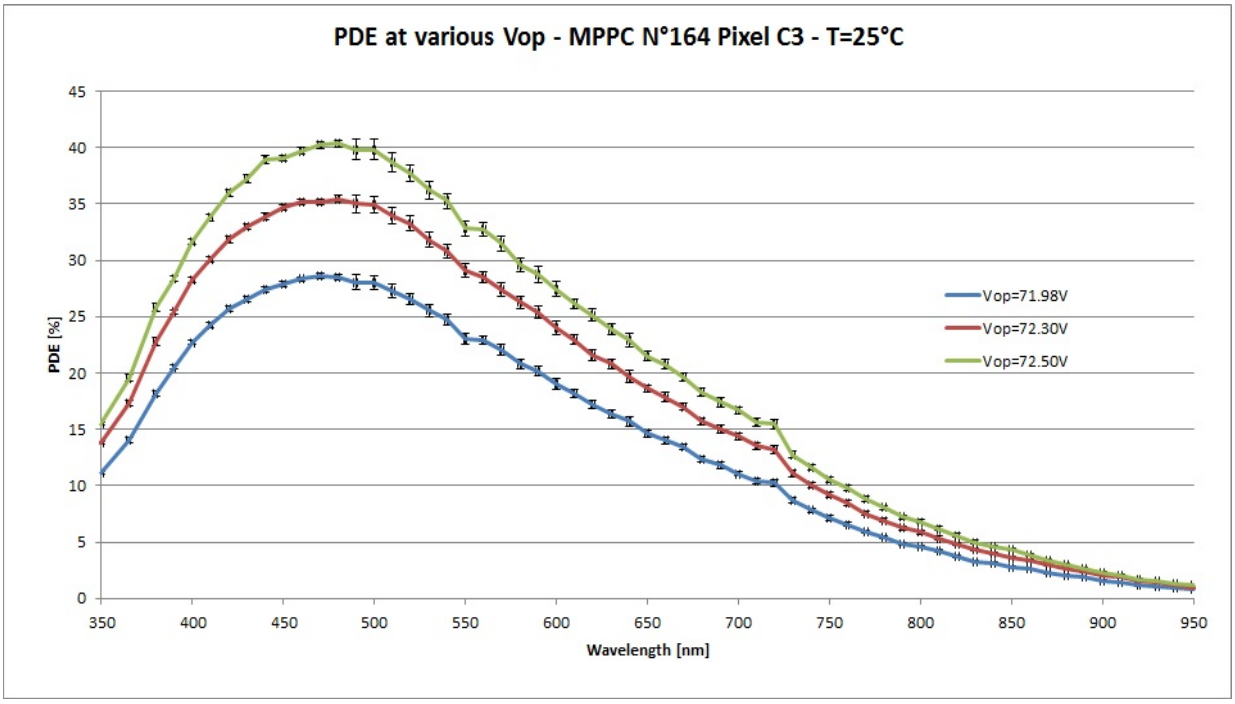


Fig. 18 – *PDE measurements comparison for the SiPM operated at Vop=71.98V, Vop=72.30V, Vop=72.50V @ T=25°C.*

10. CONCLUSIONS

As expected the PDE increases with the Operating-Voltage. Good operating conditions are obtained at Vop = 72.30 V where the PDE reaches a maximum of 35 % in the 420 – 500 nm range.

Due to the fact that a grouping of two by two pixel has to be used the Vop of 72.50 has to be discarded to avoid a very high DCR. But if a working temperature lower than 20 °C would be selected than also the case of Vop=72.50 V can be considered.

It will be noted that at Vop greater than 72.50 V the pixel is working near the saturation probably due to the fact that most of the micro-pixels are fired due to the DCR.

The error bars are also reported.

Note also, as above stated, that:

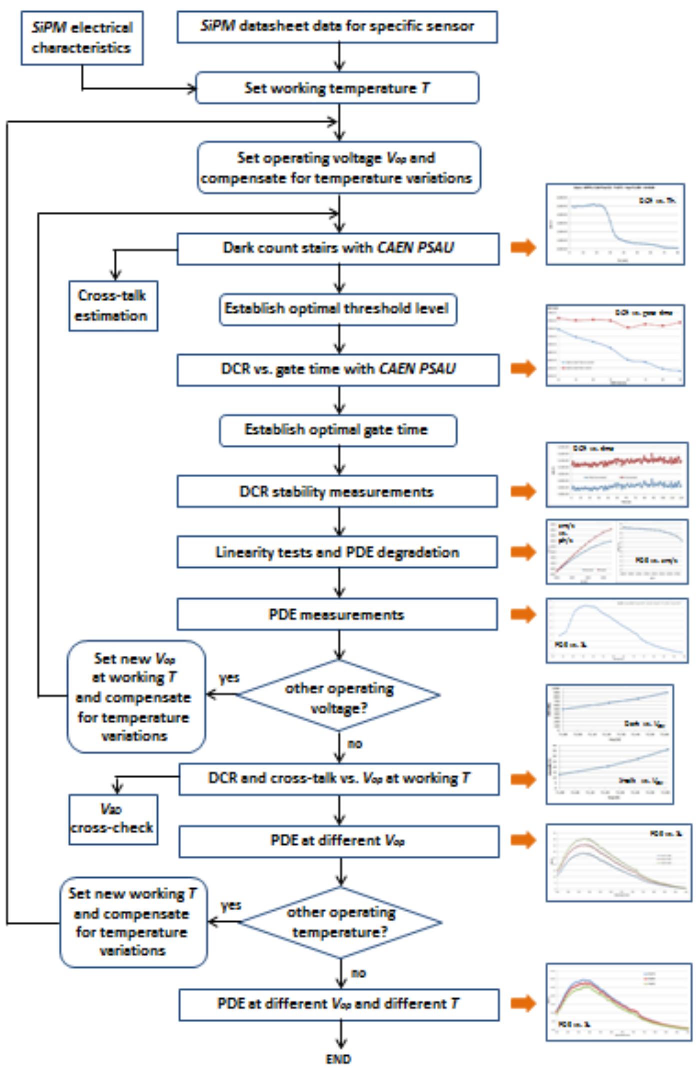
1. the cross-talk doesn't affect the PDE measurements due to the method used for PDE evaluation. In fact the second pulse due to the cross-talk is counted as one because is simultaneous to the primary pulse. And the threshold level is set to 0.5 pe;
2. the after-pulse contribute on the first 70 ns is removed by introducing an hold-off time and correcting for dead time.

11. Appendix A: SiPM Characterization flow chart

Optical

1. Select the operating temperature
2. Set the operating voltage
3. Cross-talk and Dark Count Rate (DCR) characterization with temperature compensation
4. Dark count rate Stairs to establish the optimal threshold signal level
5. DCR versus gate time from 20 to 120 ns measurements to establish the optimal gate time
6. Linearity measurements versus photon rate to avoid the saturation and pile-up and consequent PDE degradation.
7. PDE measurements at a given operating voltage and relevant comparison
8. PDE measurements at a given temperature and relevant comparison.

The procedure in a flow chart form is here reported:



12. CONTACTS