Caratterizzazione di dispositivi fotomoltiplicatori al silicio per applicazioni in sistemi di monitoraggio di radiazioni

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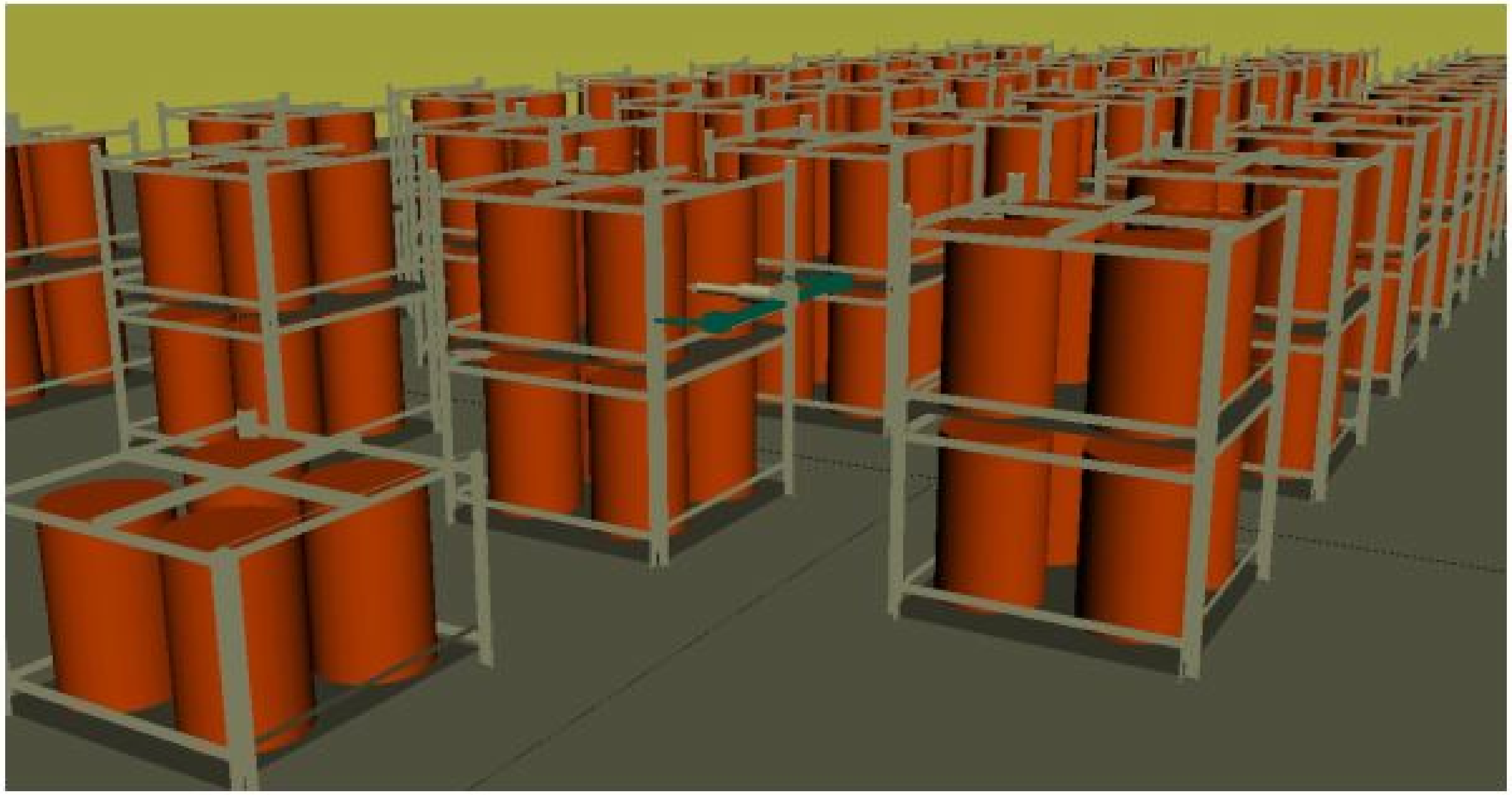
RIACE

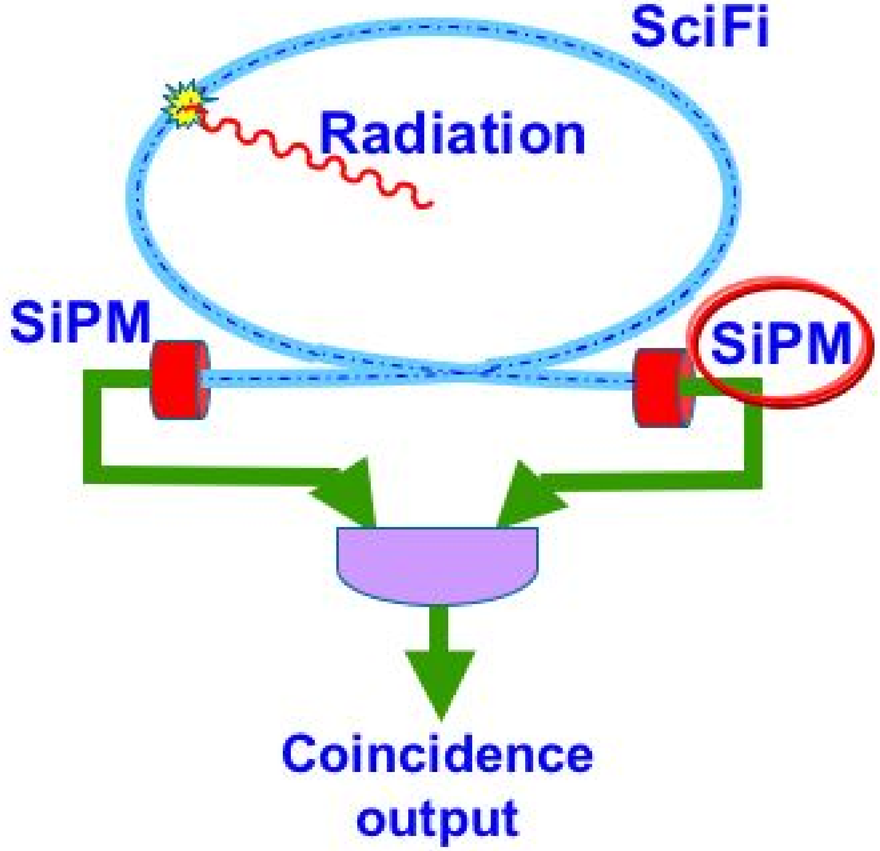
Rivelatori e Acceleratori per l'Energia

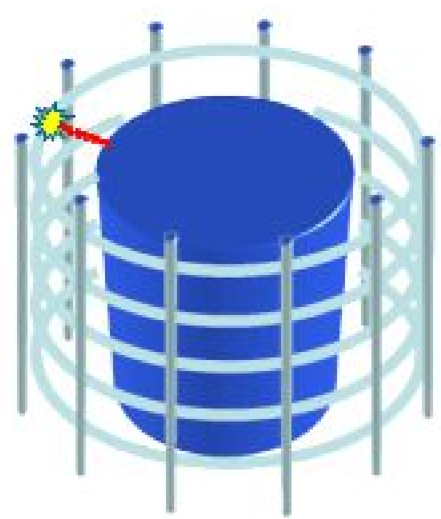
DMNR

Detector Mesh for Nuclear Repositories

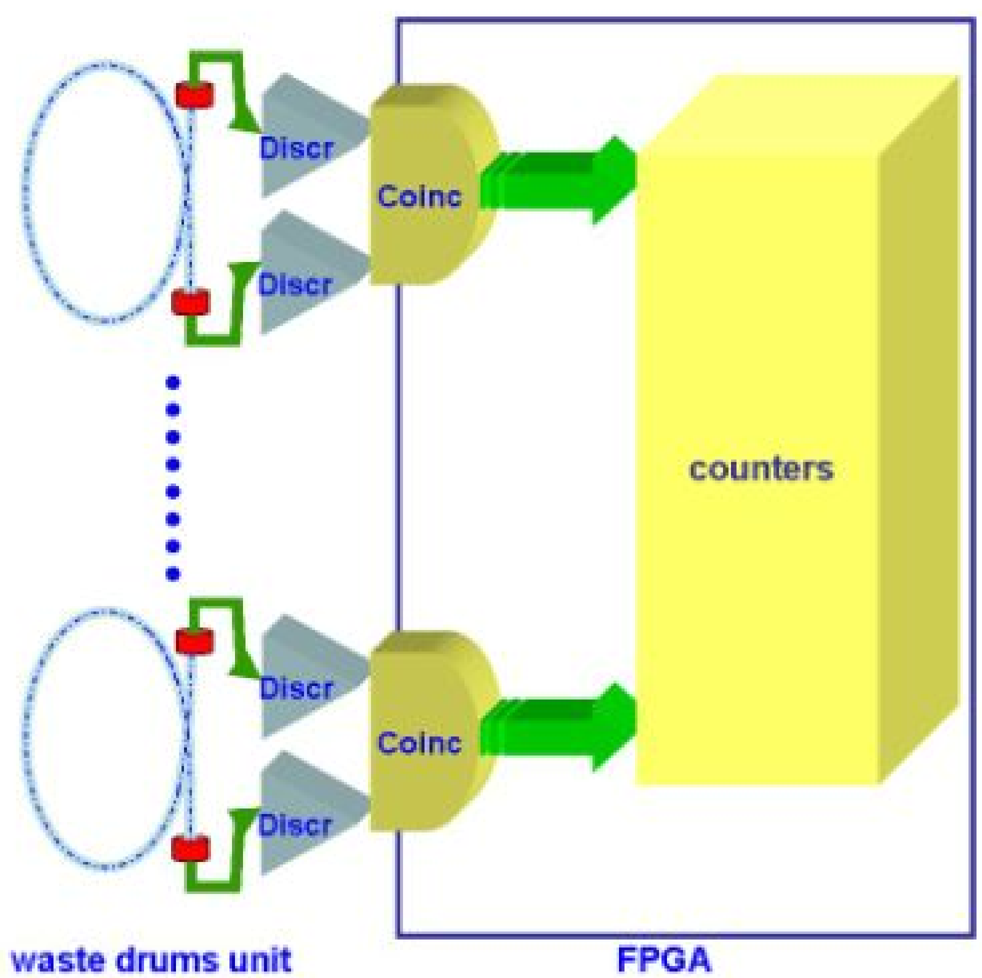


Sensori = SiPM + fibre scintillanti





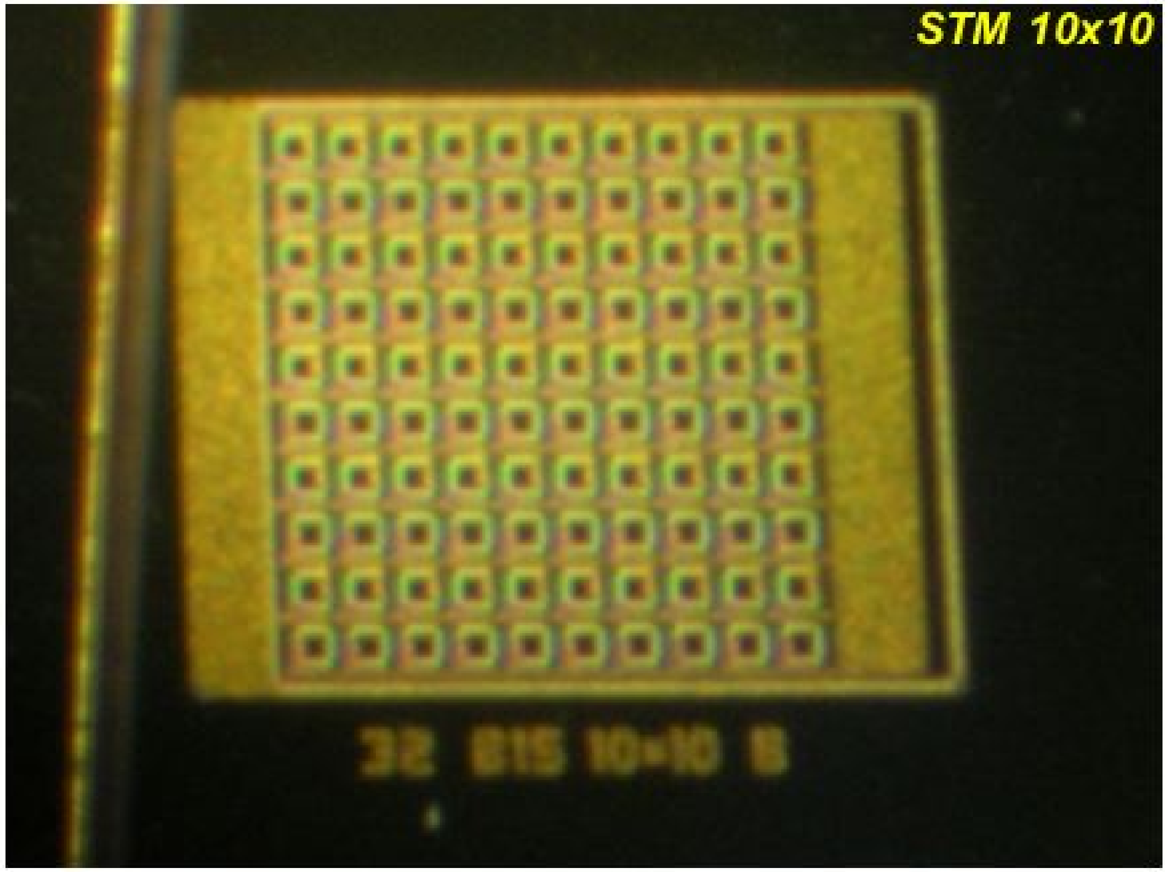
Sistema di front end per misurare il rate di conteggi



Sistema di monitoraggio :

- ✓ on line
- ✓ su tutti i fusti

IL SiPM : Silicon Photo Multiplier



SiPM STMicroelectronics
32 B15 10x10 B

$A_{sensore} = 0.5 \times 0.5\ mm^2$

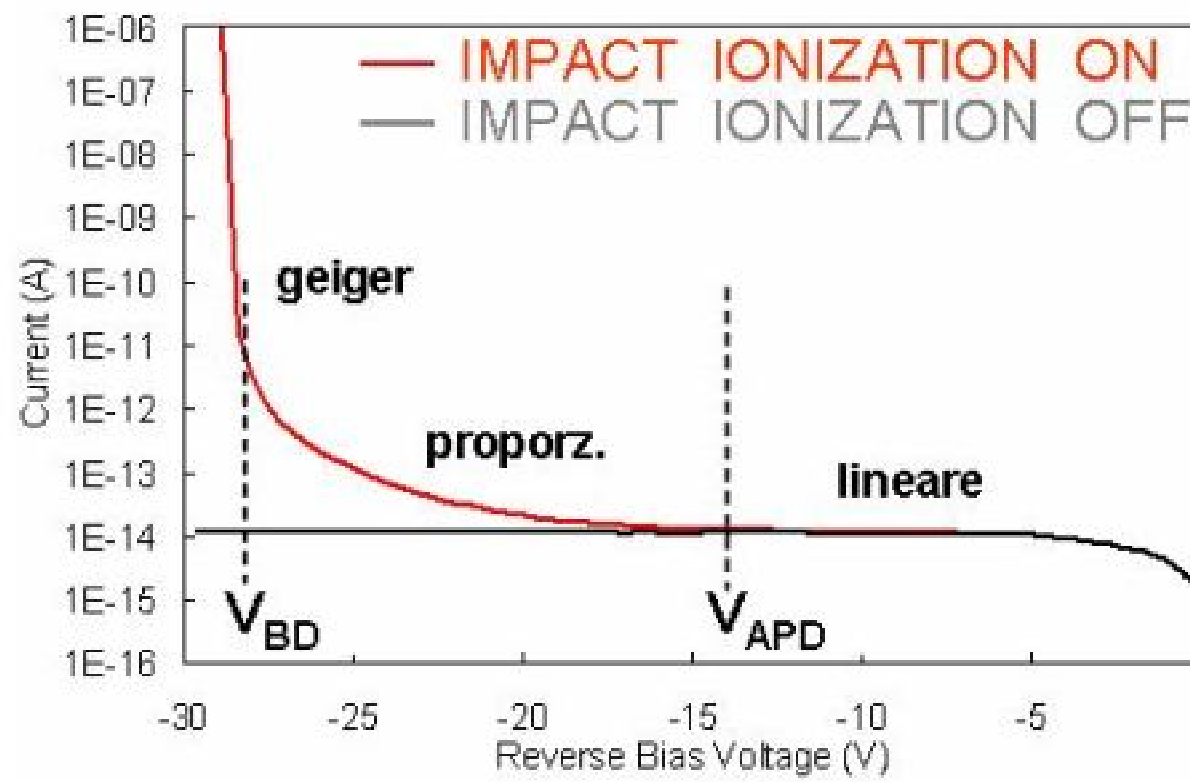
$A_{pixel} = 32 \times 32\ \mu m^2$

Eff. Geom. = 36 %

$V_{BD} = 29.5\ V$

SPAD
Single Photon Avalanche Diode

Fotodiodo basato su effetto valanga (regime Geiger)

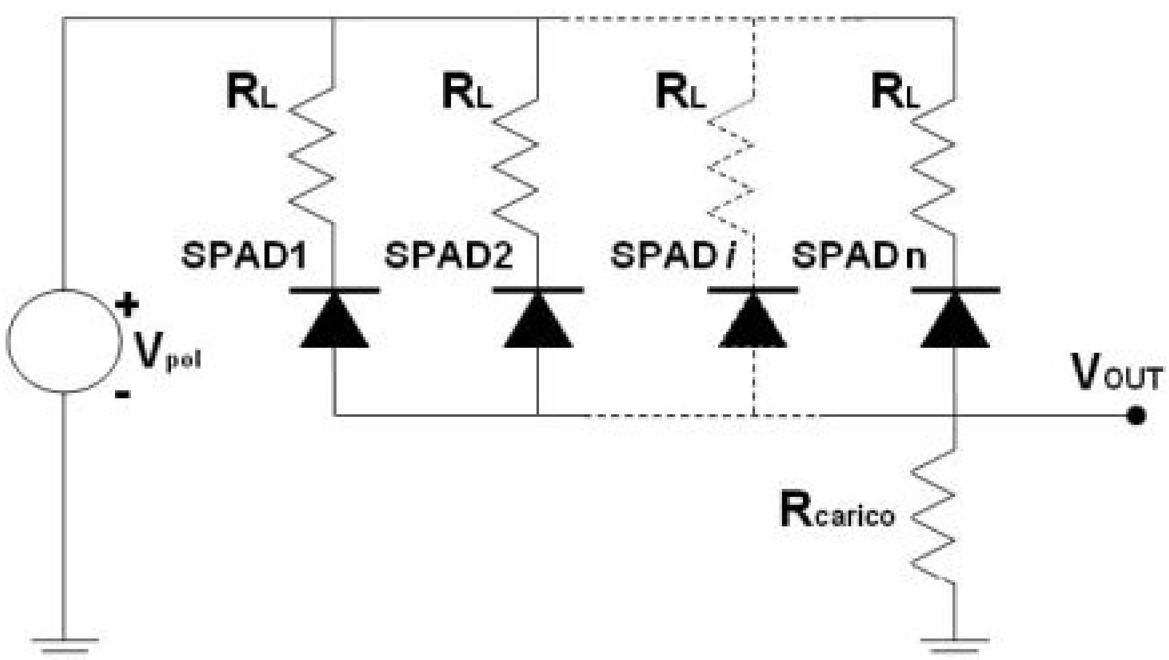


La valanga viene arrestata da un resistore di quenching integrato

SiPM visto come array di SPAD

Anodi in comune

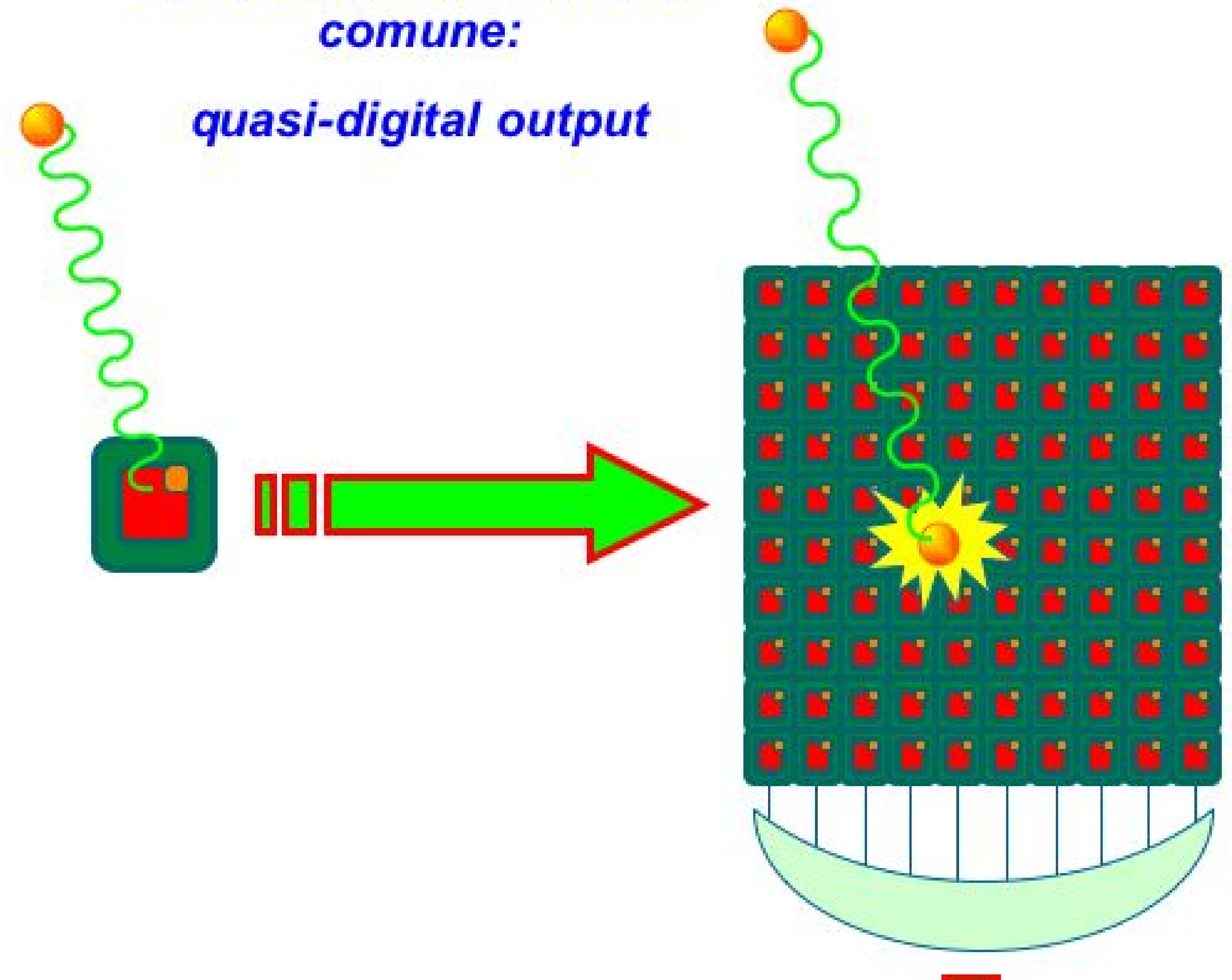
R_L = Resistenza di quenching



SPAD + R_L → Pixel

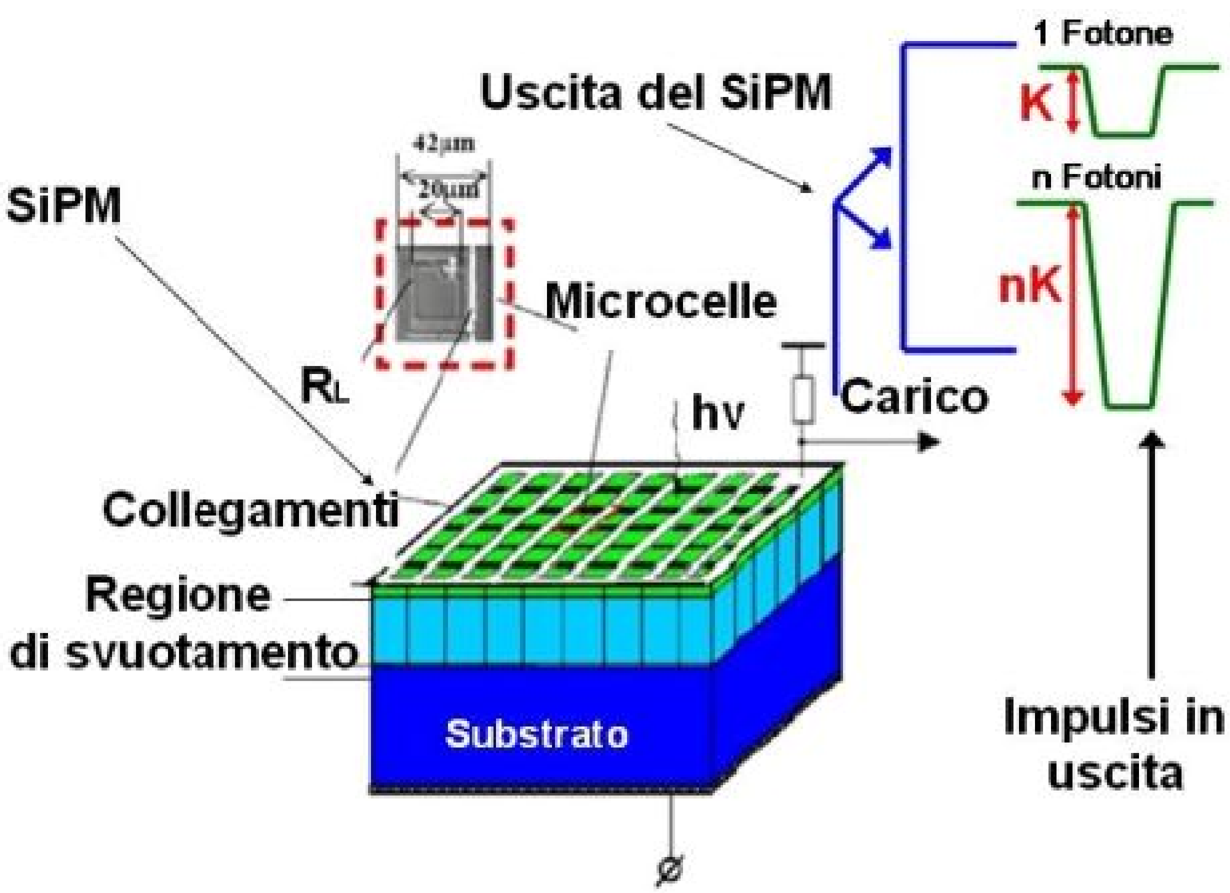
Unico segnale di uscita comune:

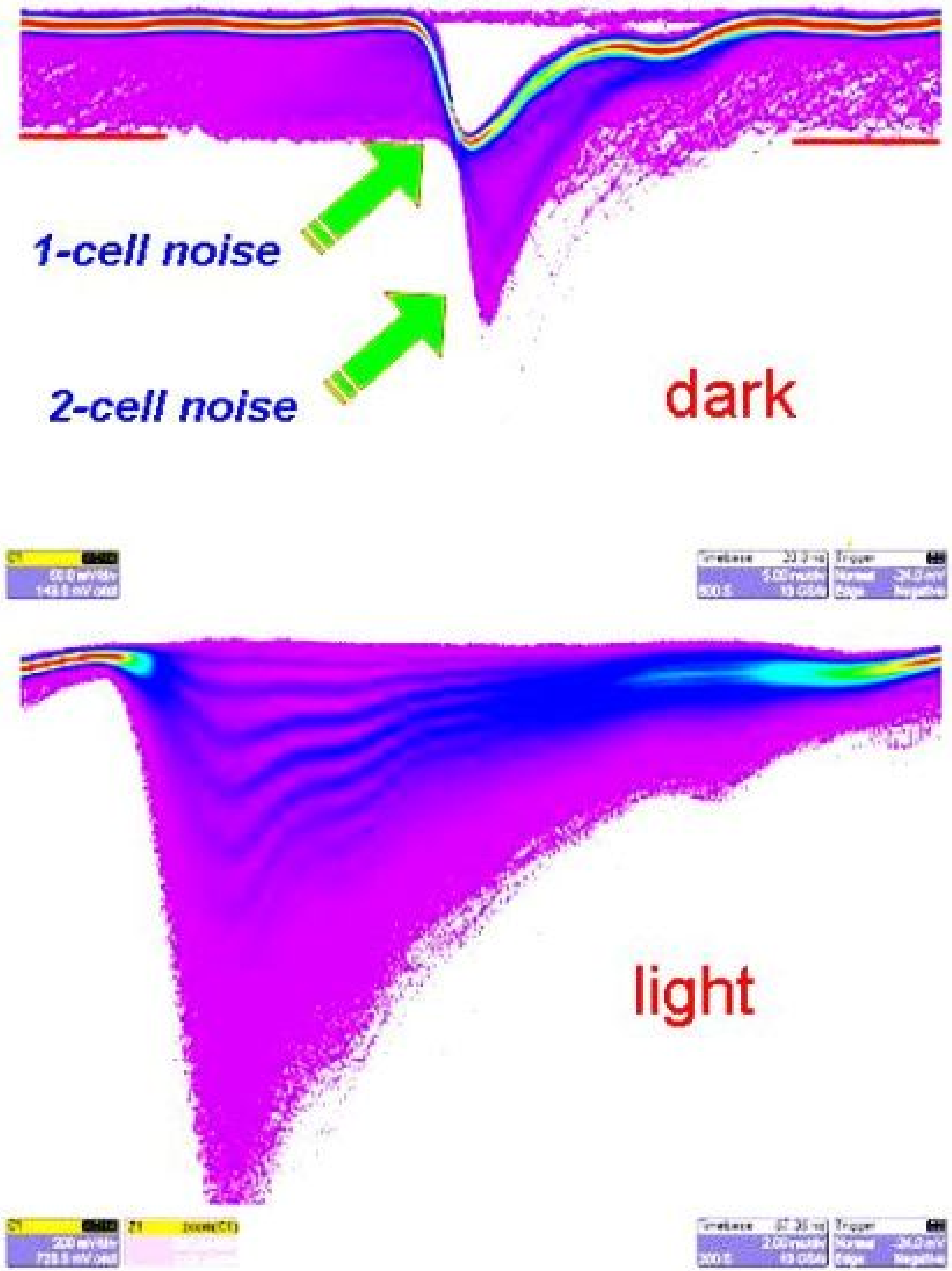
quasi-digital output



1-pixel ⇒	***carica = q***
n-pixel ⇒	***carica = nq***

Segnale visto ad un oscilloscopio digitale

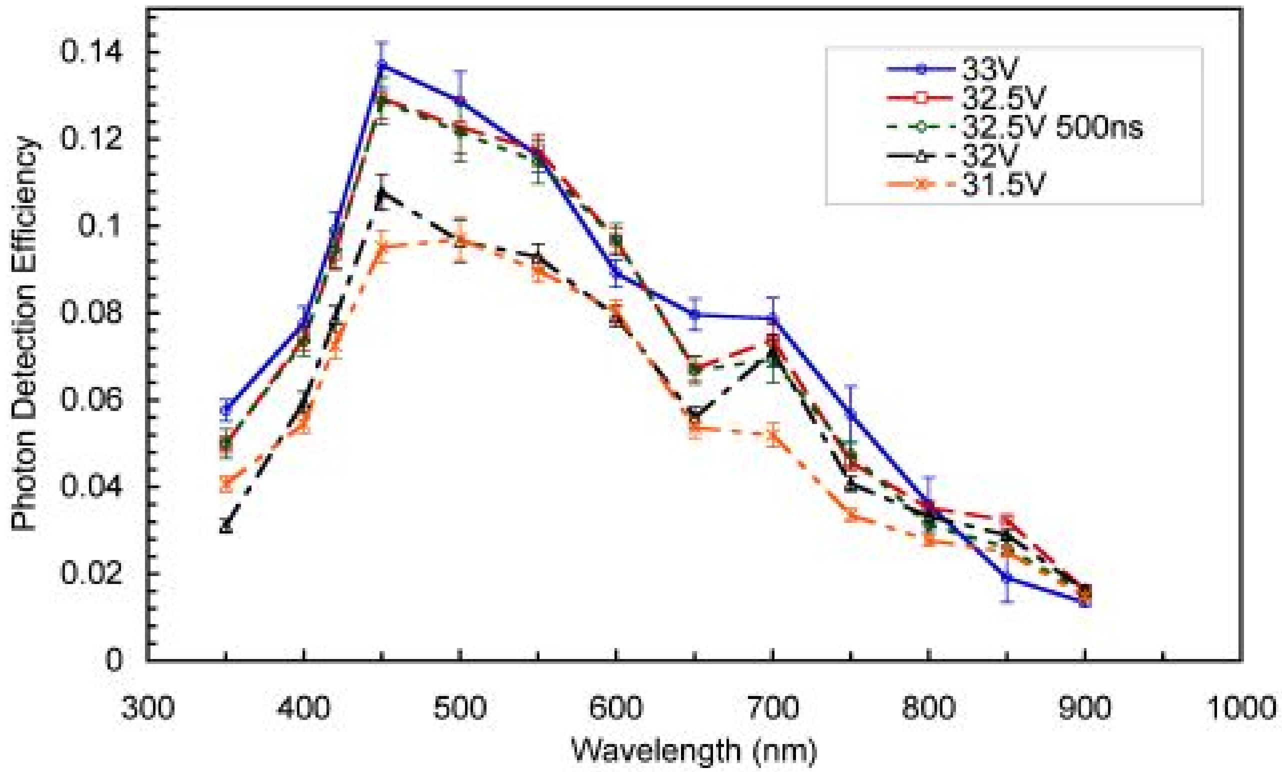




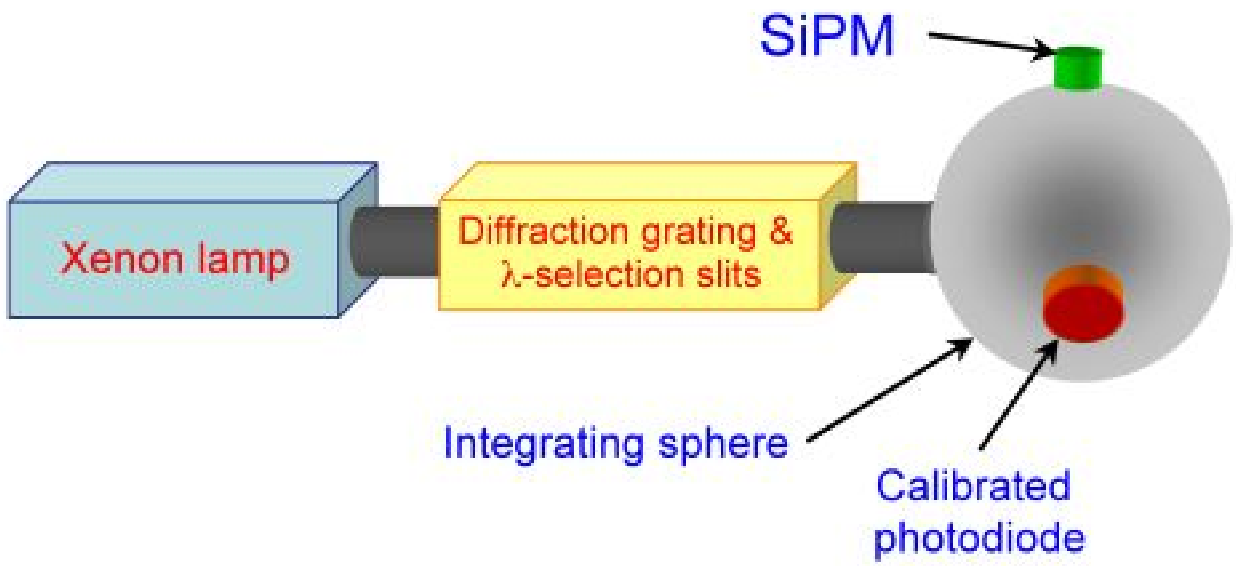
sensibile a singolo fotone

Efficienza di rivelazione

$$PDE = QE \cdot \varepsilon_{geom} \cdot P_t$$



INAF (Istituto Nazionale di AstroFisica)



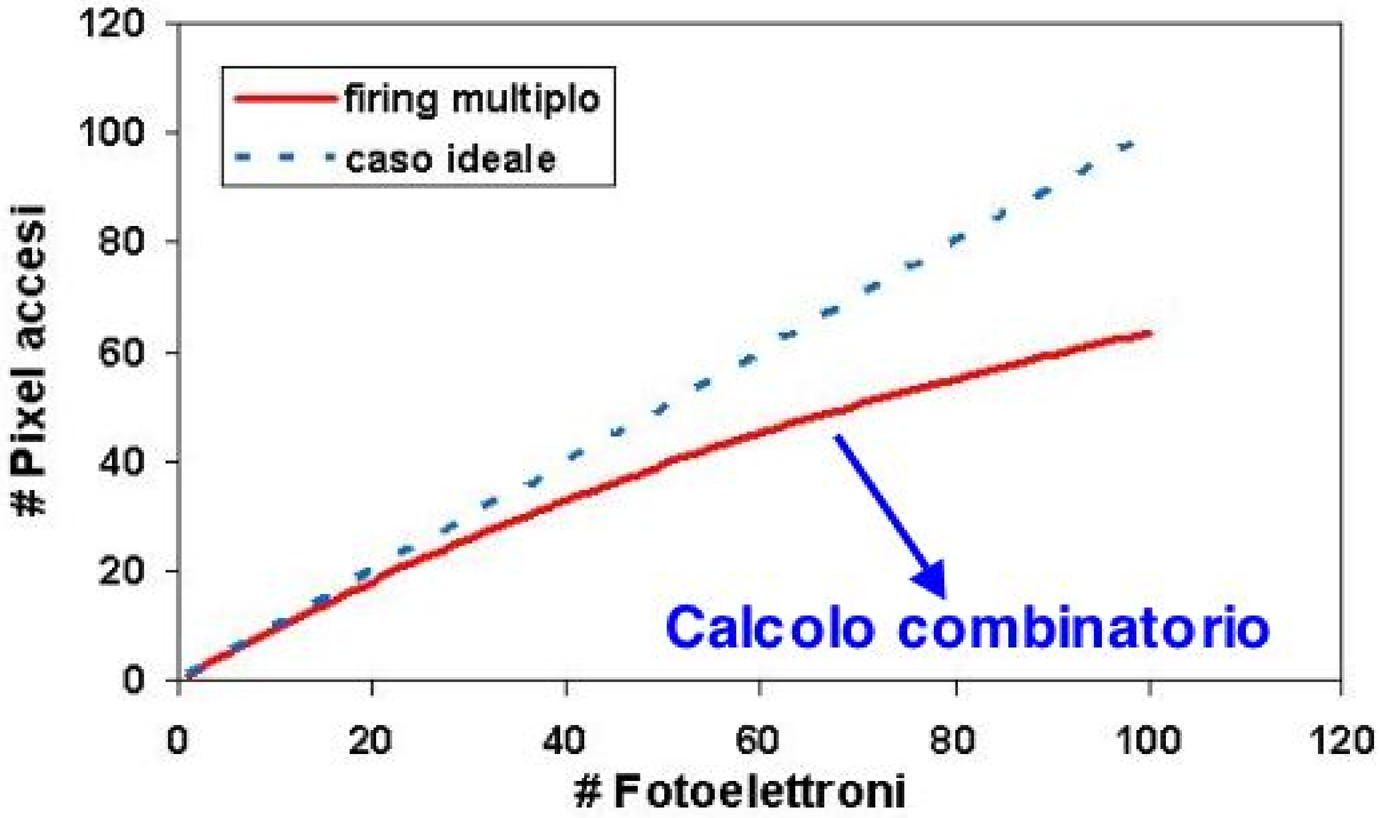
QE = efficienza quantica del sensore

$$\varepsilon_{geom} = \frac{A_{act}}{A_{tot}}$$

P_t = probabilità di innesco della valanga

Dinamica

2 fotoni incidono sulla stessa cella → Firing multiplo



dispersione poissoniana

$$\sigma = \sqrt{N_{\varphi} \cdot PDE}$$

$$N_{pixel\ \ colpiti} = N_{pixel\ \ totali} \cdot \left(1 - e^{-\frac{N_{\varphi} \cdot PDE}{N_{pixel\ \ totali}}} \right)$$

$$\frac{N_{\varphi} \cdot PDE}{N_{pixel\ \ totali}} << 1$$

funzione lineare

Rumore

Scorrelato

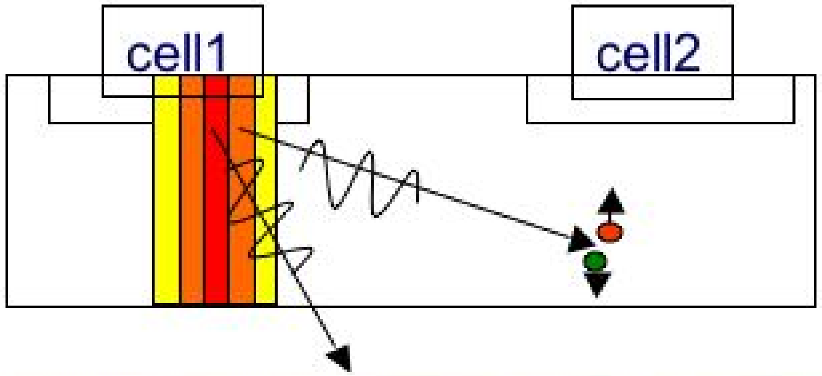
Dark Counts → Generazione termica ~ KT

Correlato

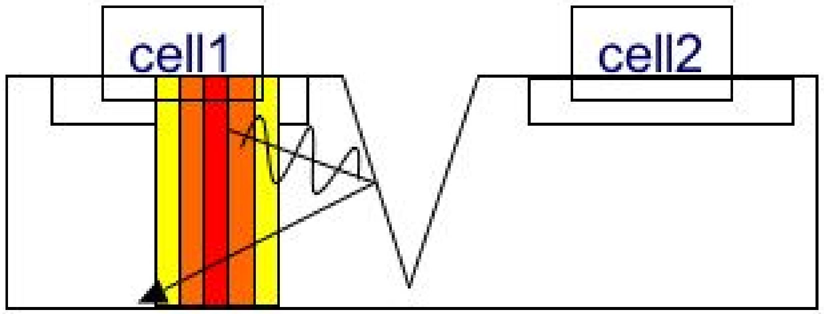
Afterpulsing → Un portatore intrappolato durante una valanga viene poi rilasciato

Cross Talk → Un pixel può essere innescato da un pixel adiacente

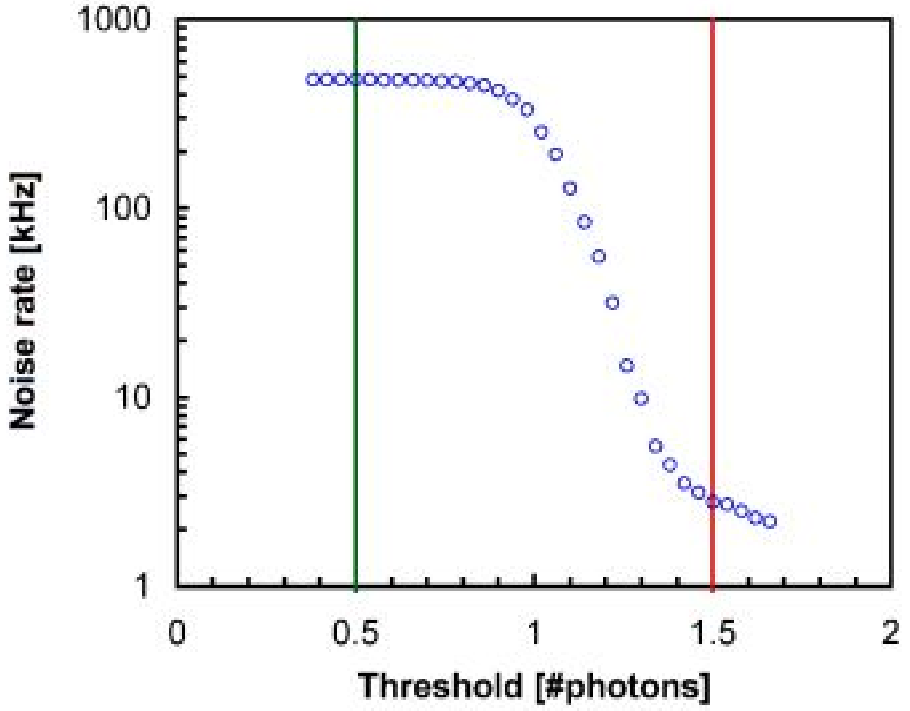
- ✓ Elettronico: portatori di carica emessi da pixel adiacenti
- ✓ Ottico: fotoni di *Bremsstrahlung*



Soluzione: trench

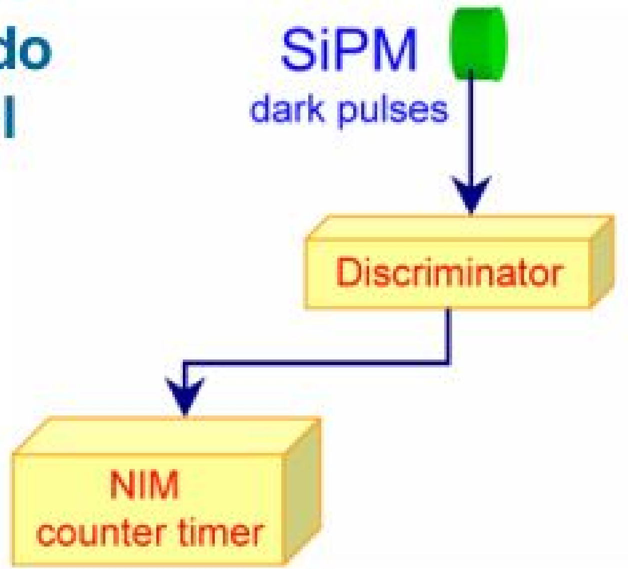


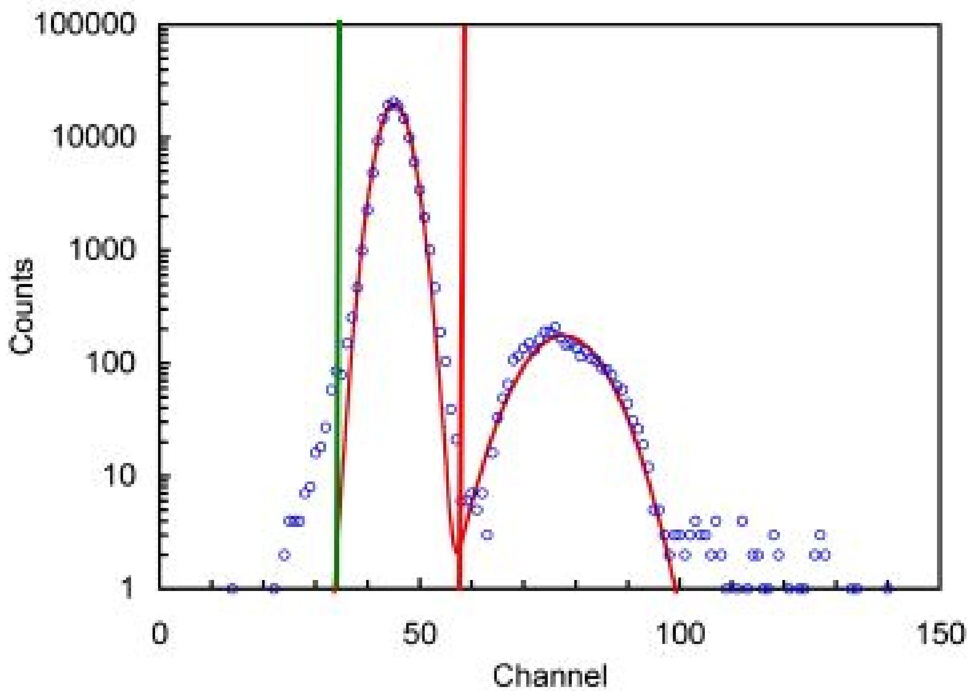
Rumore : dark counts vs soglia



soglia a 1 fotone :

valore di tensione che ha il segnale del SiPM quando si accende un solo pixel

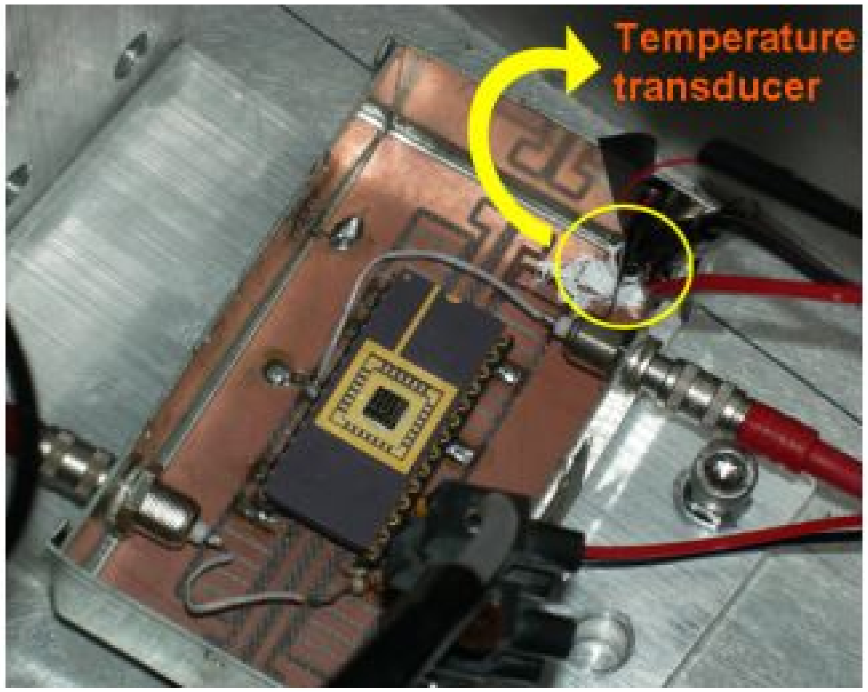




Il rumore si abbassa notevolmente alzando la soglia a 2 fotoni

N(2)/N(1) = 0.5%

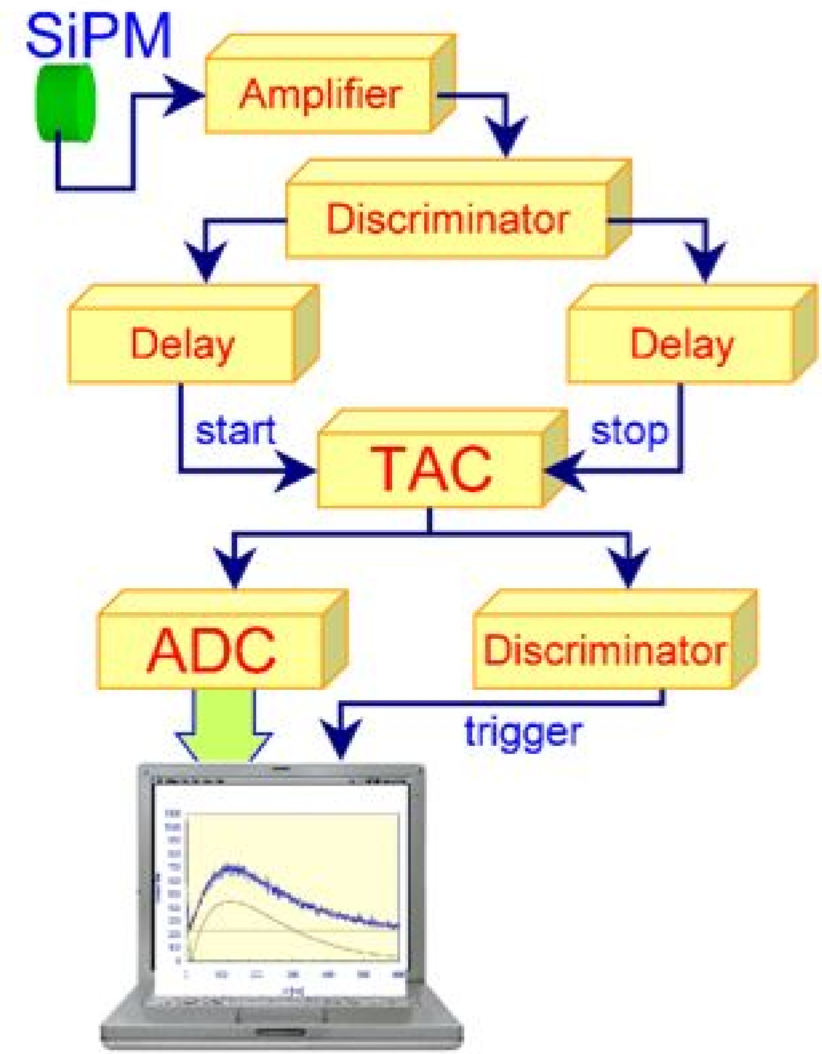
Rumore : afterpulsing

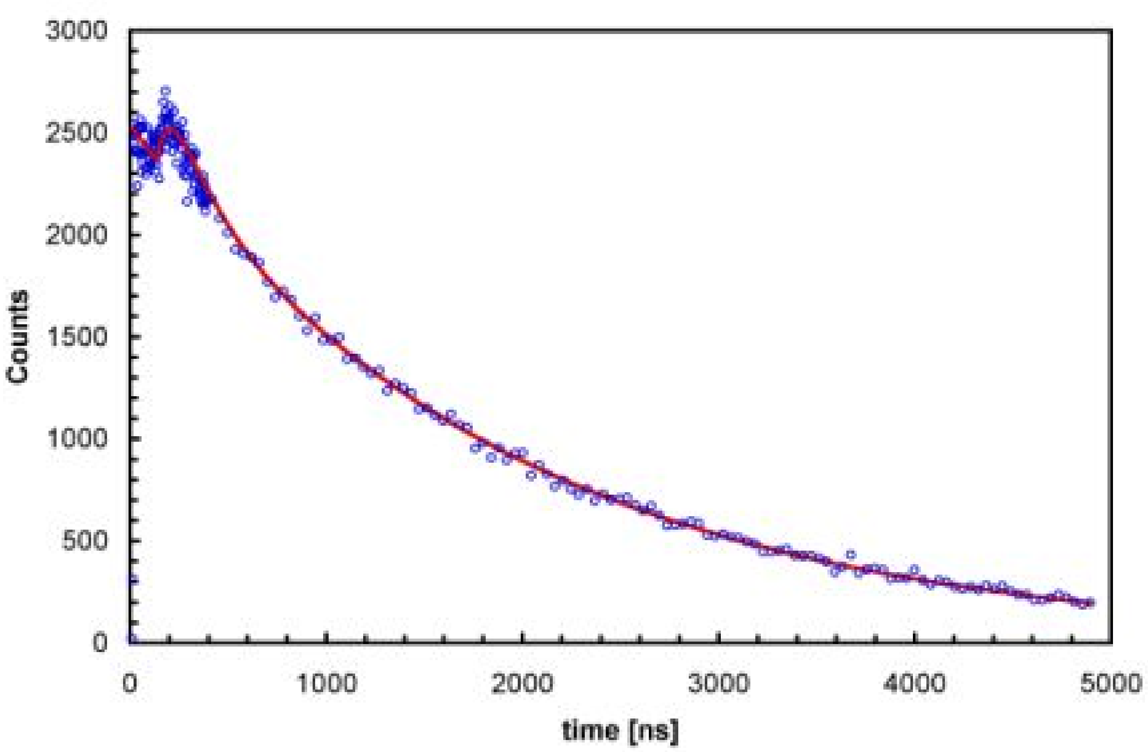


Rumore scorrelato

↓

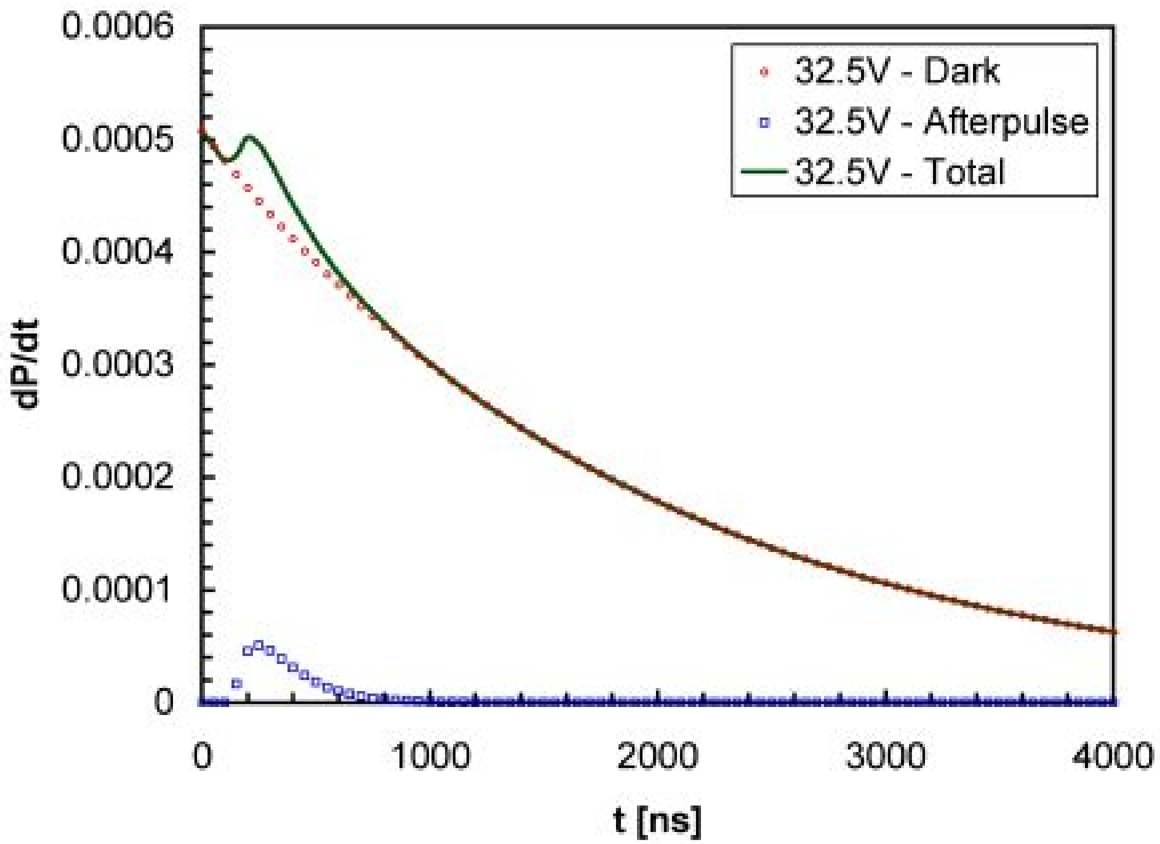
Esponenziale decrescente





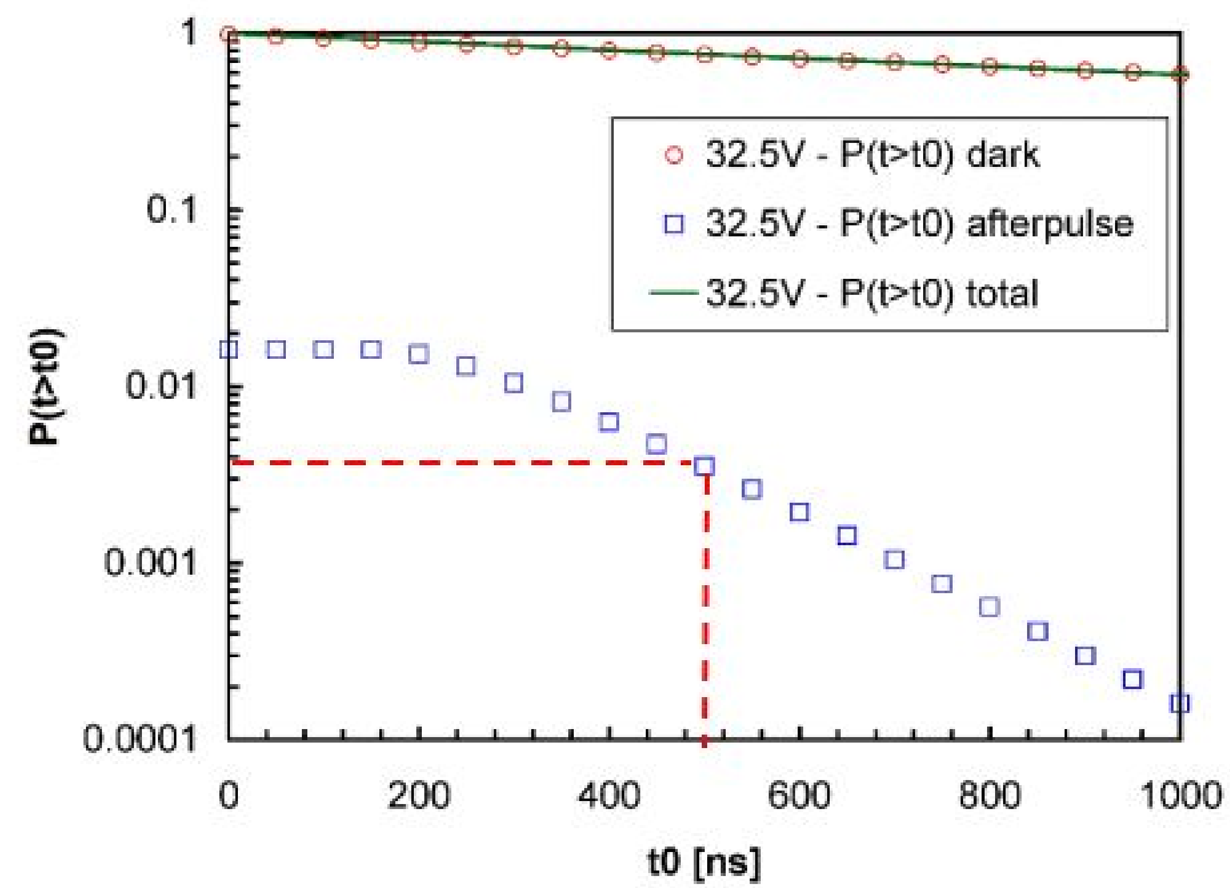
$$F(A) = A_{dark} \cdot e^{-\frac{t}{\tau_{dark}}} + [t > t_{thr}] \cdot A_{AP} \cdot \left(1 - e^{-\frac{t-t_{thr}}{\tau_R}}\right) \cdot e^{-\frac{t-t_{thr}}{\tau_{AP}}}$$

Rumore : afterpulsing

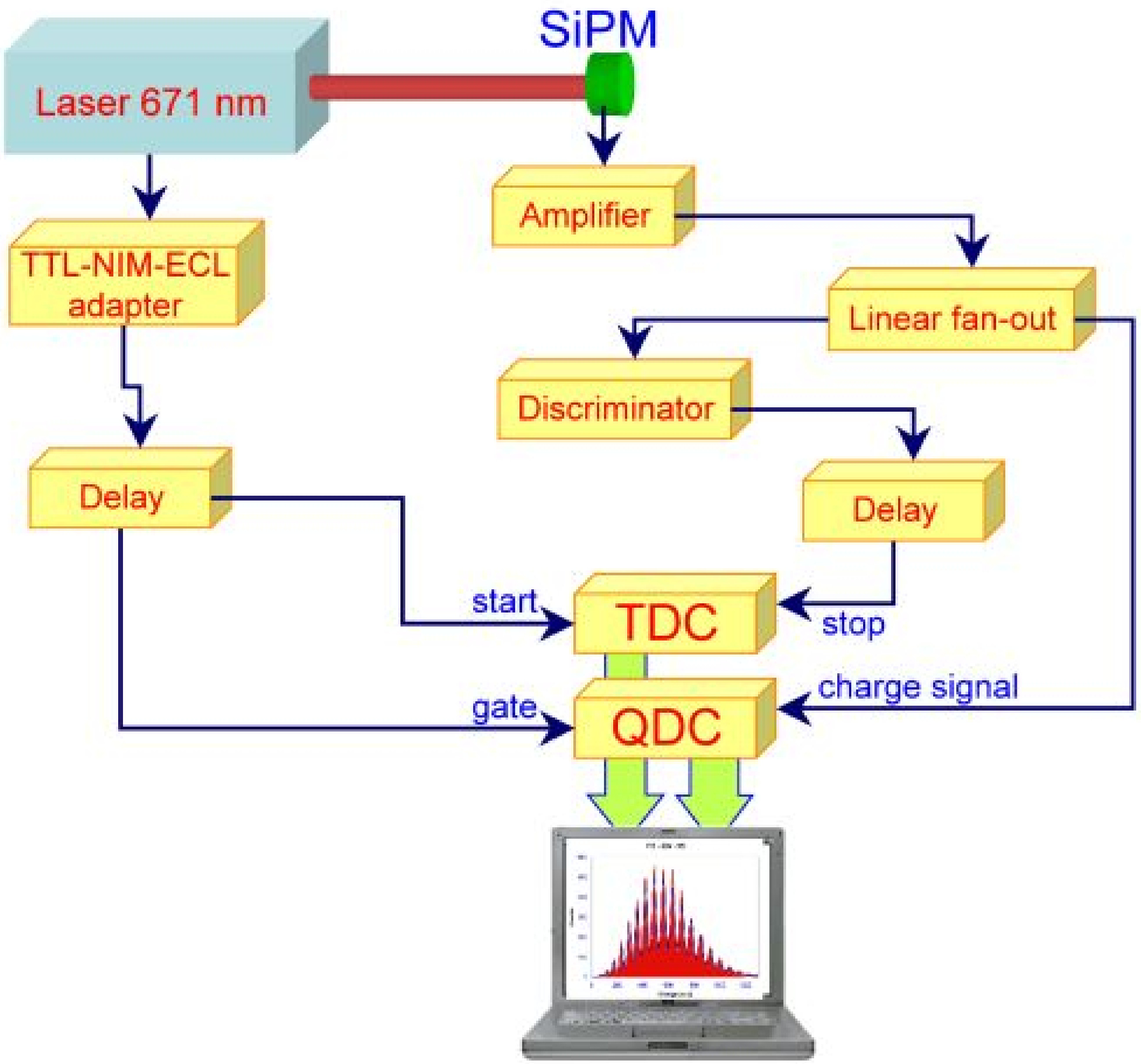


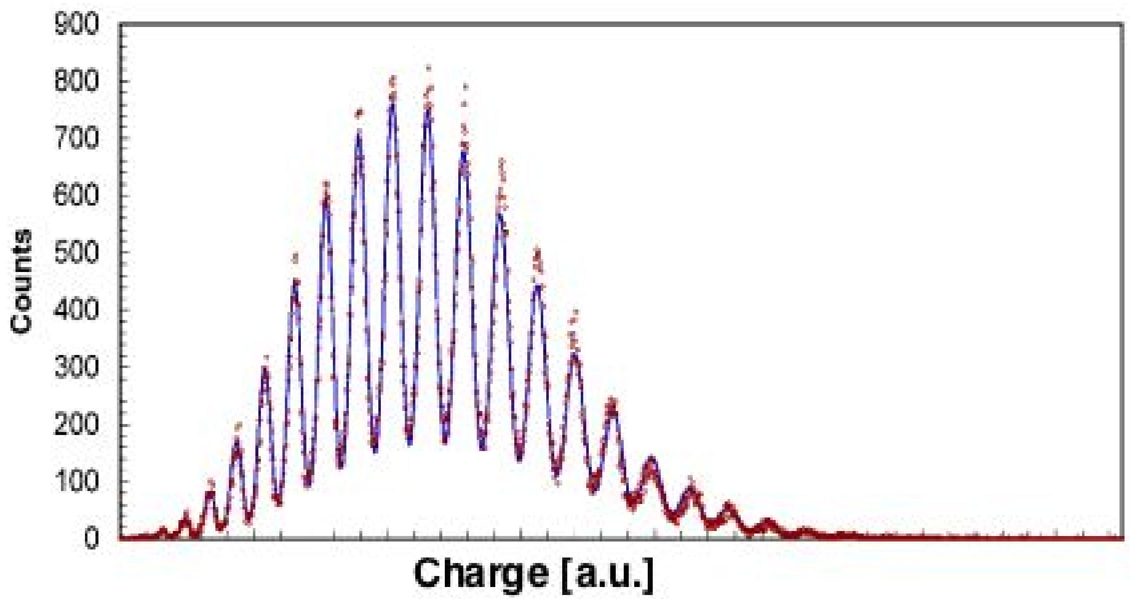
	31.5 V	32 V	32.5 V	33 V
$_{dark}$ [ns]	2657	2219	1914	1653
t_{thr} [ns]	138	105	134	116
$_{R}$ [ns]	281	155	156	107
$_{AFP}$ [ns]	122	154	158	139
P_{dark}	0.092	0.985	0.984	0.081
P_{AFP}	0.008	0.015	0.016	0.019

Dopo 500 ns la probabilità di afterpulsing $P(t_{AP}>t_0)$ scende al di sotto dell'1%



Caratterizzazione : carica e tempo

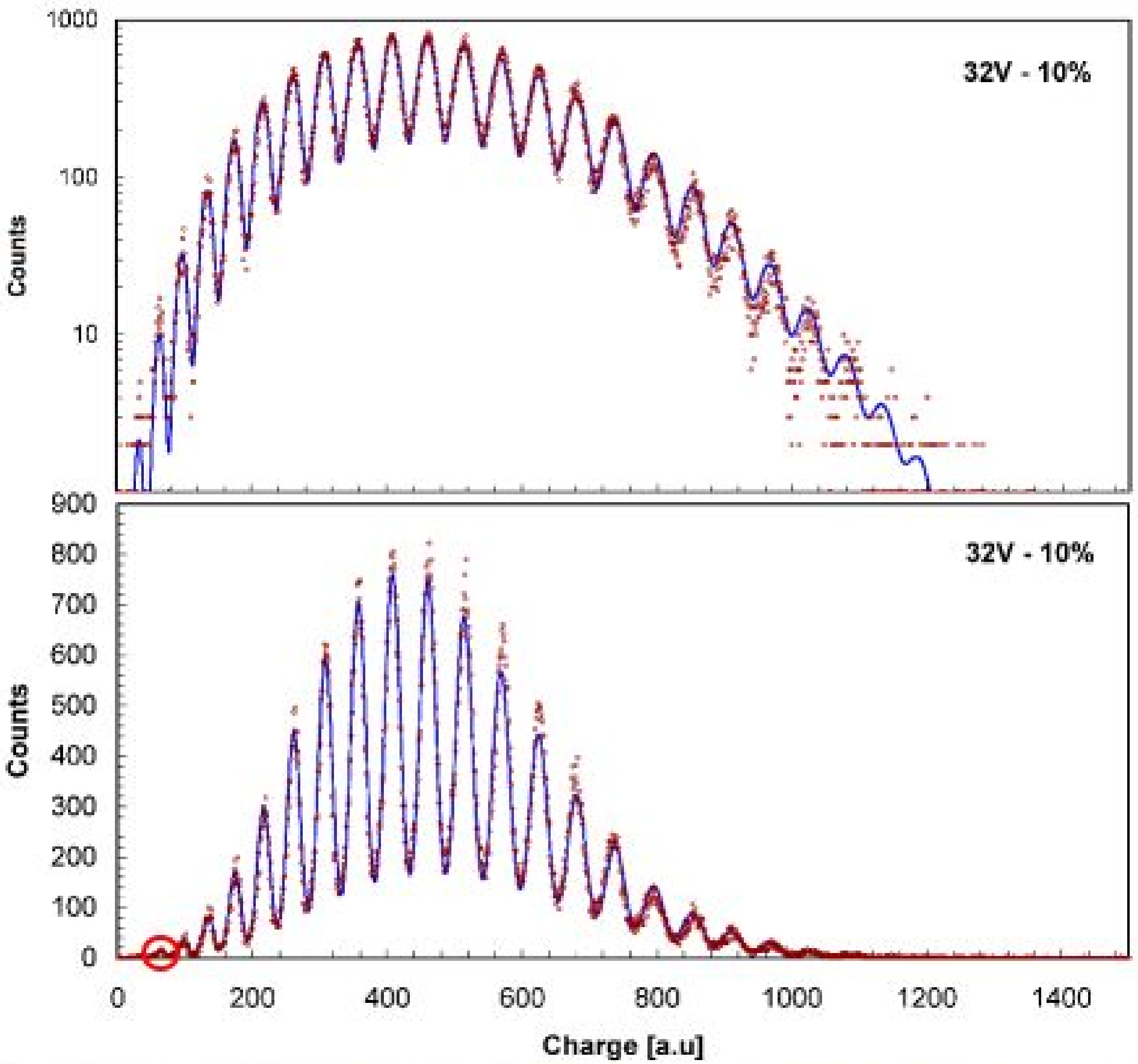


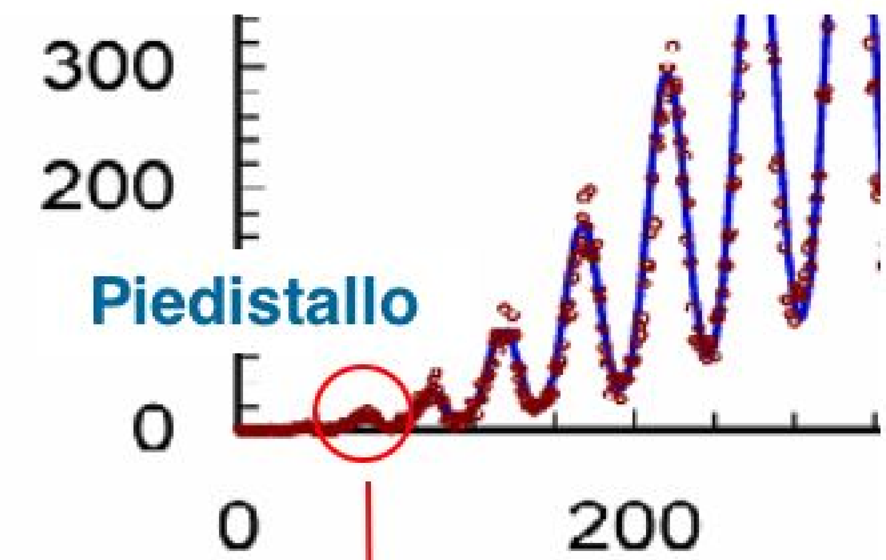


Risposta in carica del SiPM

$$F(x) = A\frac{dP}{dx} = A\cdot\sum_{n=0}^{\infty} Poisson(\mu,n)\cdot\frac{1}{\sigma_{tot}(n)\sqrt{2\pi}}\cdot e^{-\frac{[x-c(n)]^2}{2\sigma_{tot}^2(n)}}$$

Inviluppo poissoniano di singole gaussiane

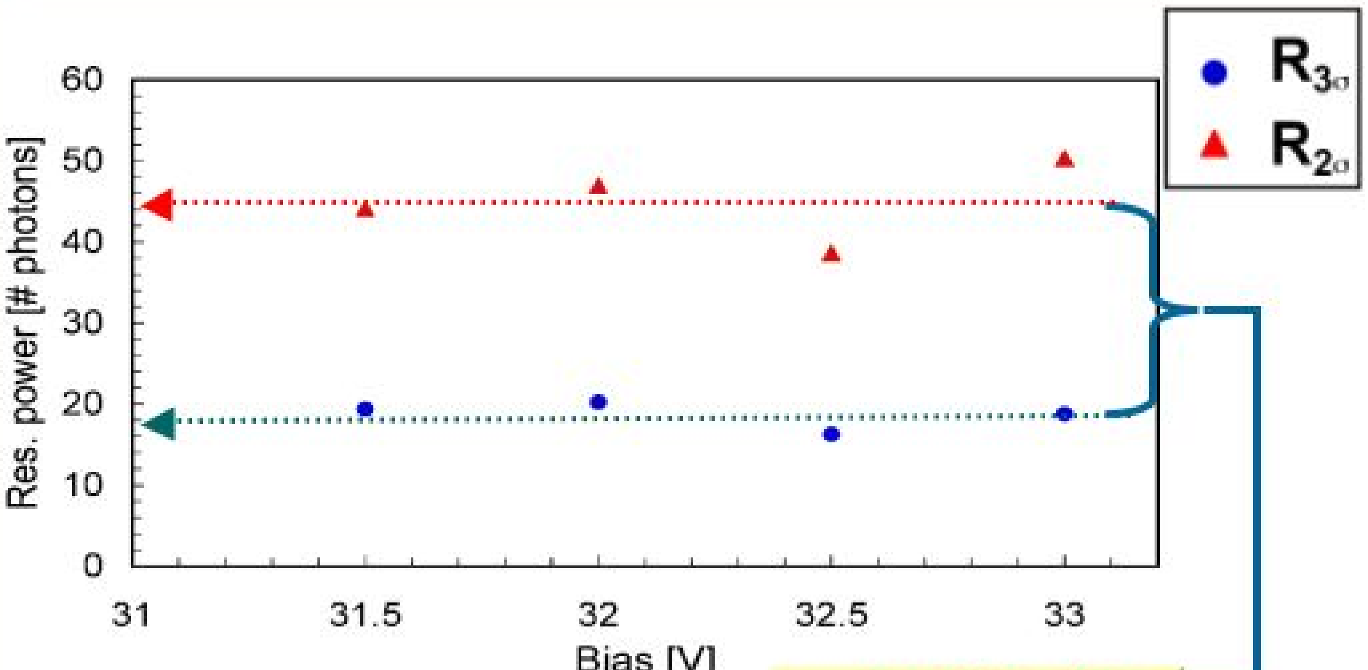




$$\sigma_{tot}^2(n) = \sigma_e^2 + n\sigma_1^2$$

Potere risolutivo del SiPM e linearità

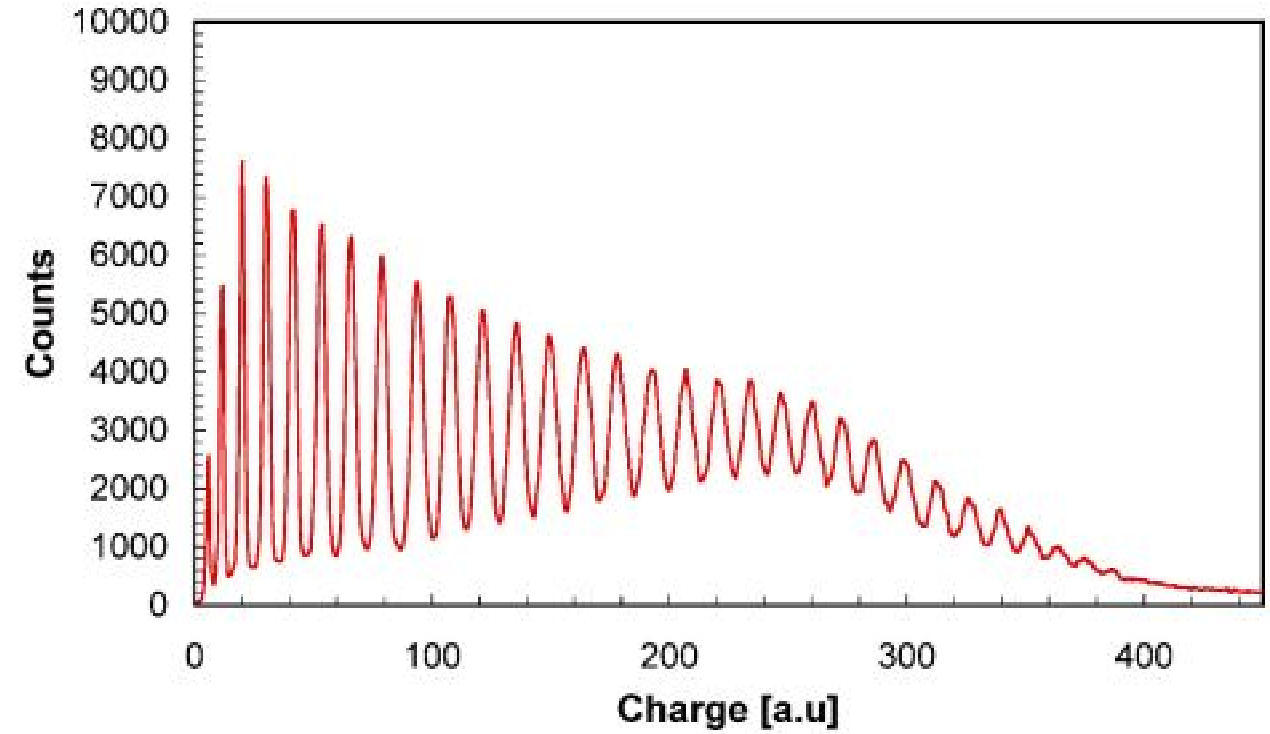
Il potere risolutivo a 3σ [$R_{3\sigma}$] è il numero di fotoni n dove la distanza intermedia d tra i picchi diventa 3σ

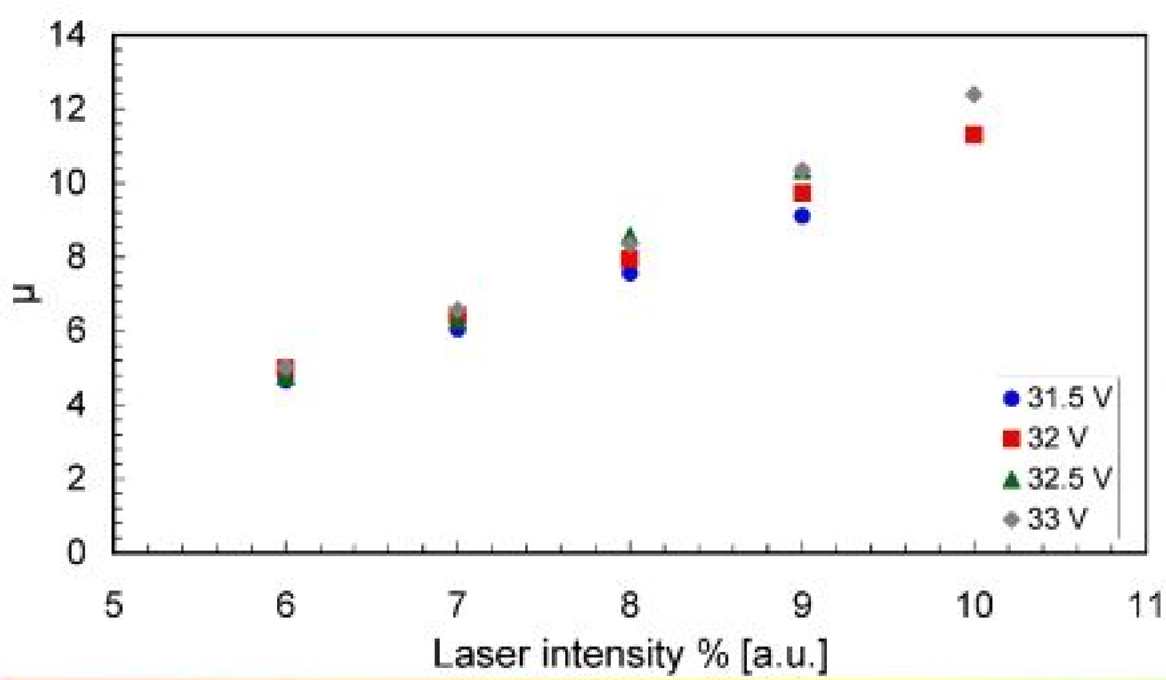


R ≈ 18 - 45

$d = 3\sigma$: riesco a risolvere 2 picchi consecutivi

$d = 2\sigma$: non riesco a risolvere 2 picchi consecutivi





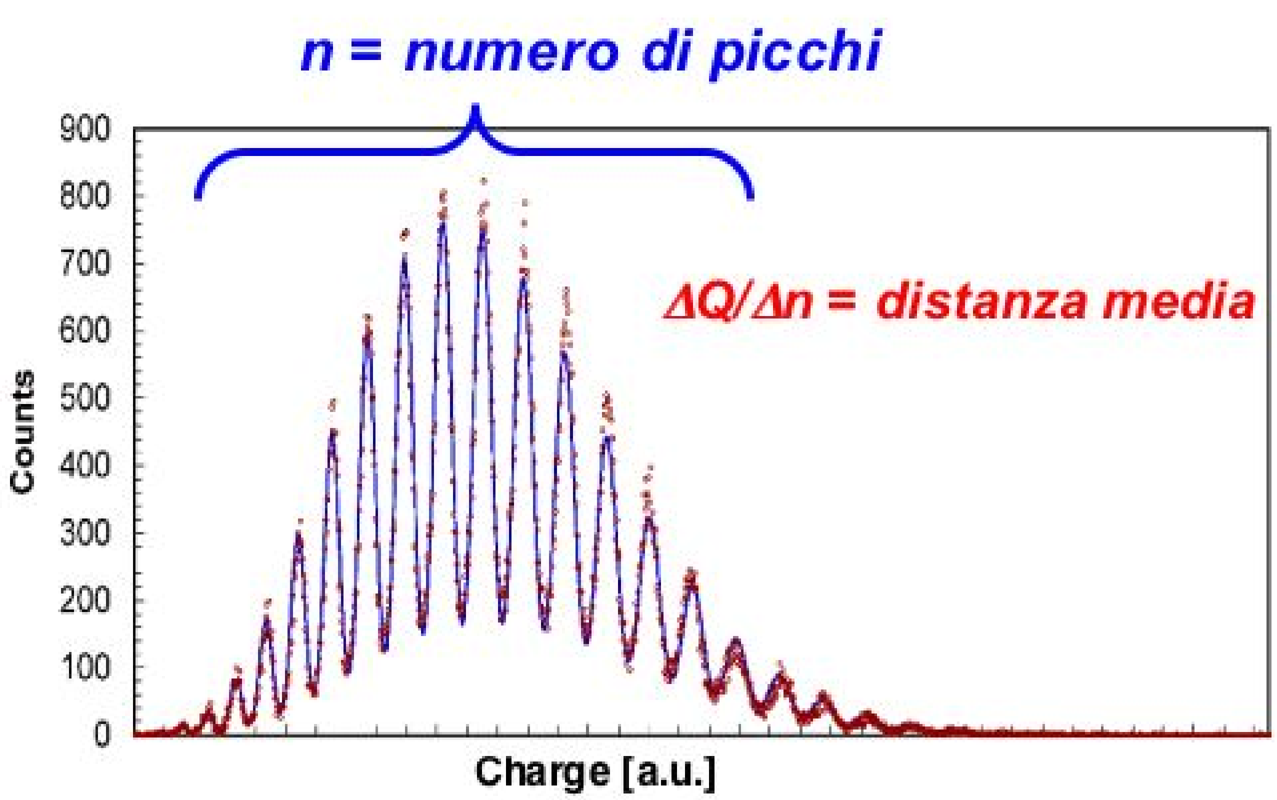
Risposta lineare del sensore a bassi flussi

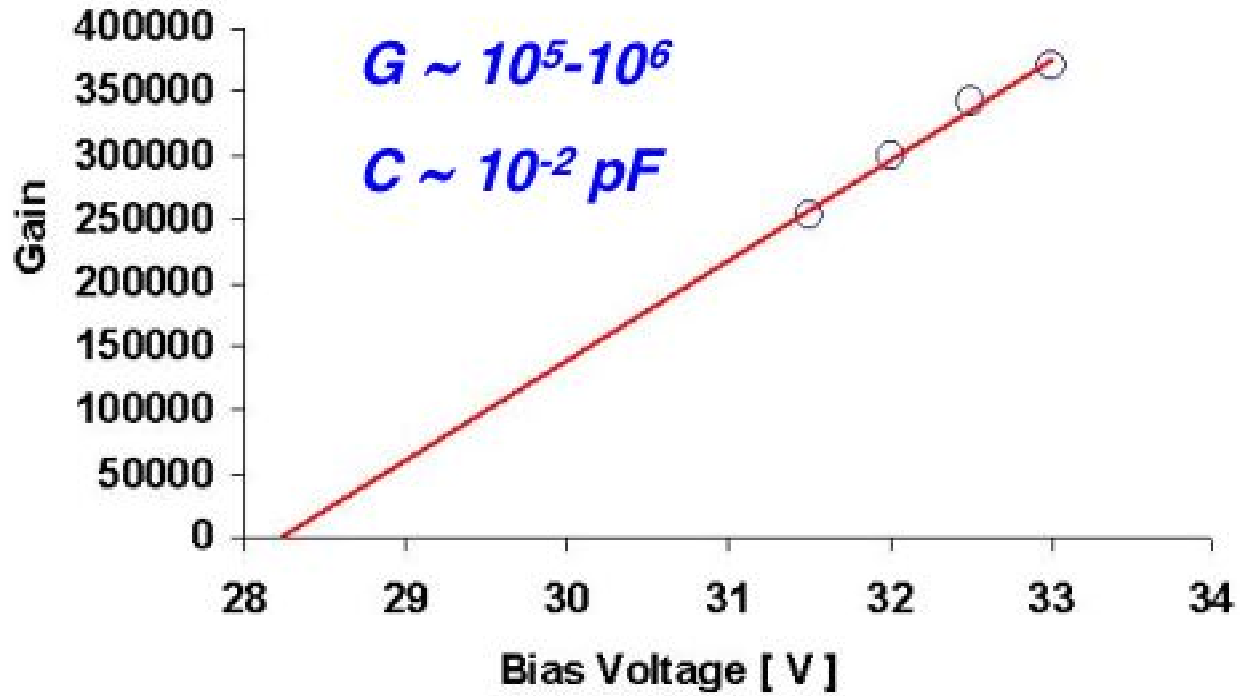
Guadagno del SiPM

La misura del guadagno è stata ottenuta dalla distanza media [ch] tra due centroidi

distanza media [ch] ⇒ **distanza media [C]**

Calibrazione QDC

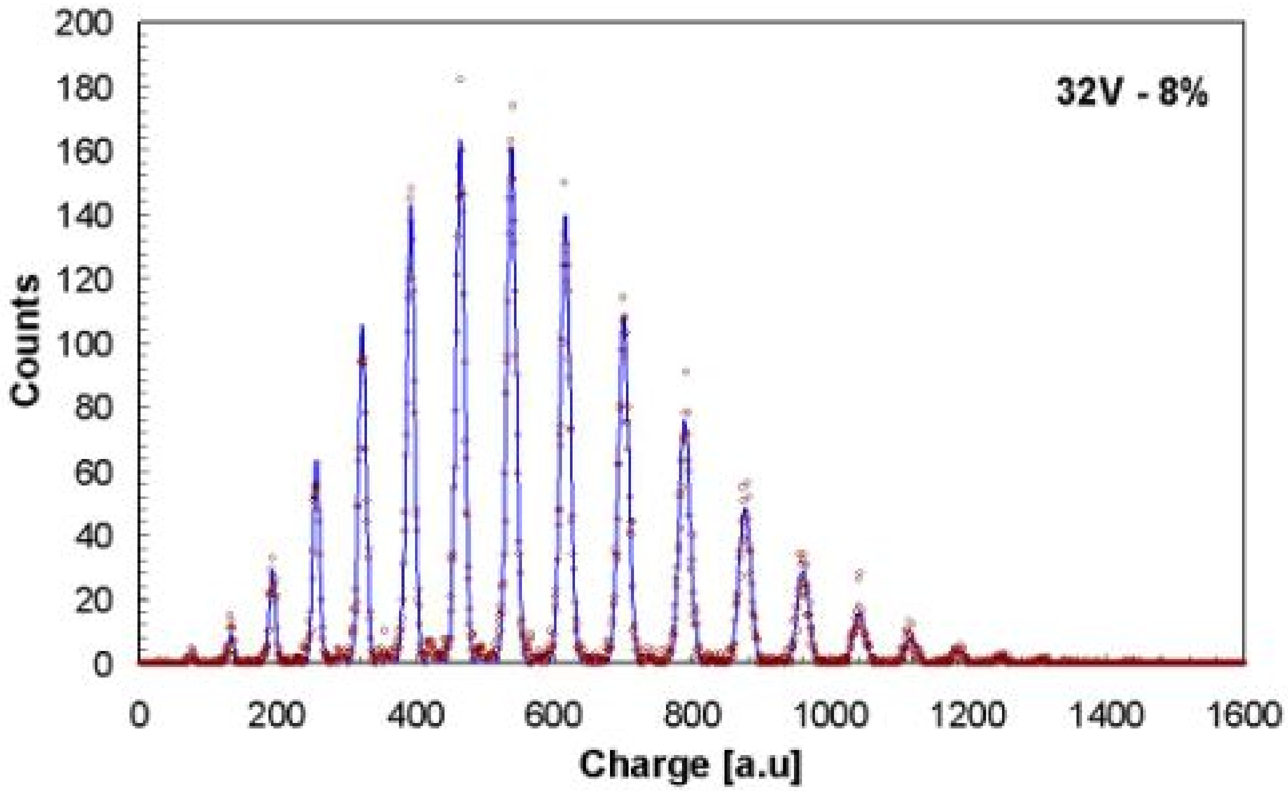




guadagno = (Δ Q / Δ n) / e

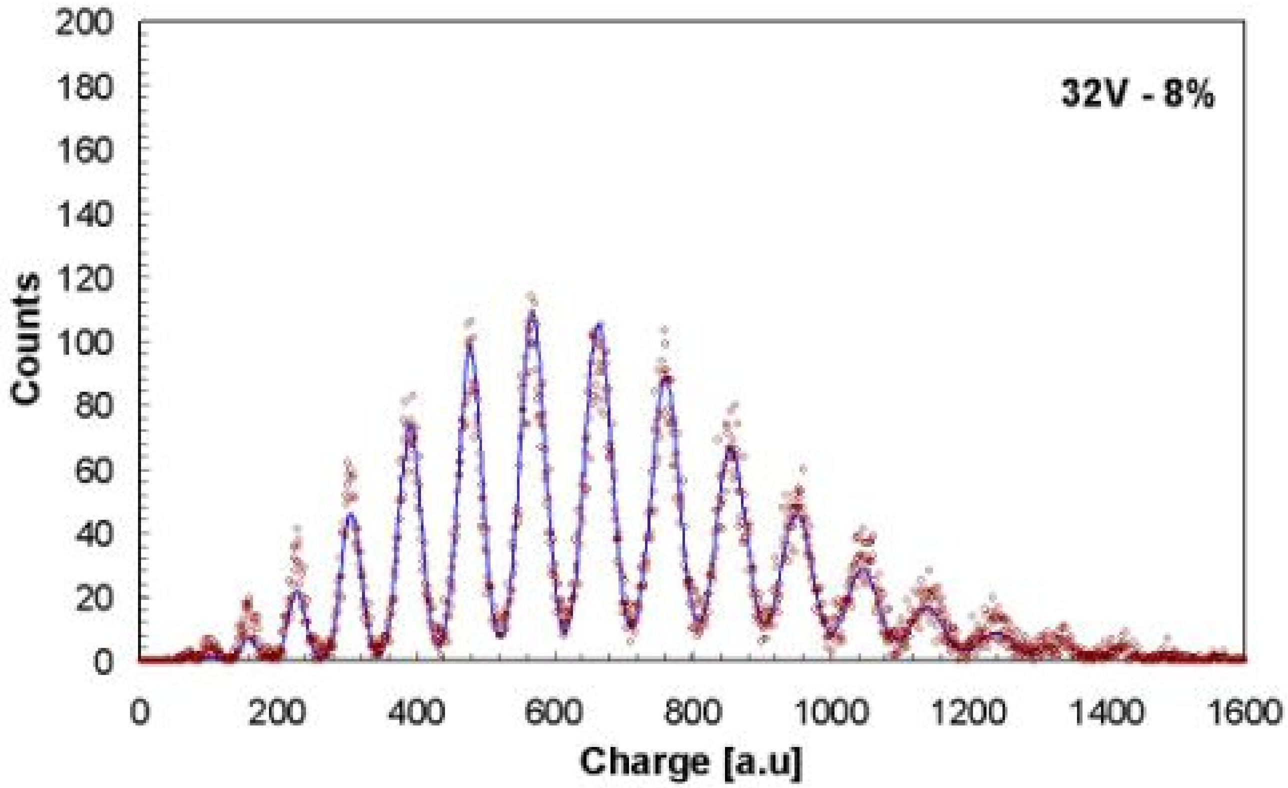
Elettroni / fotone

Misure preliminari con l'amplificatore LNS: stesse condizioni e statistica



Amplificatore LNS

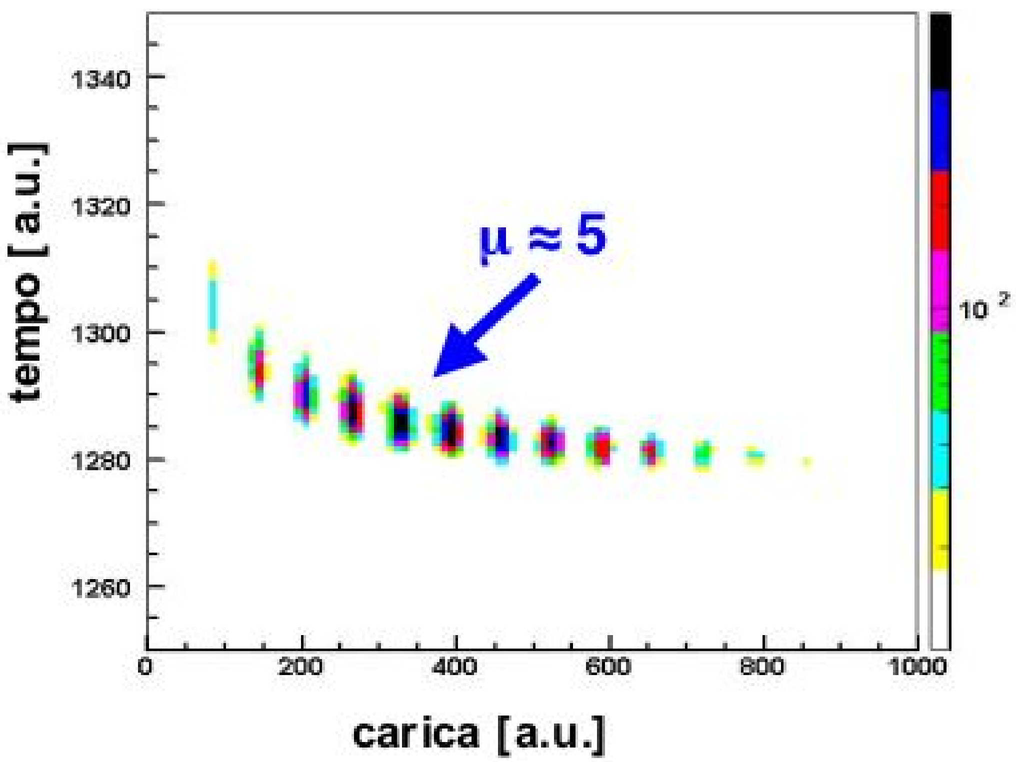
- ✓ $R_{3\sigma} = 116$
- $R_{2\sigma} = 263$
- $\sigma_e \approx 3$ ch



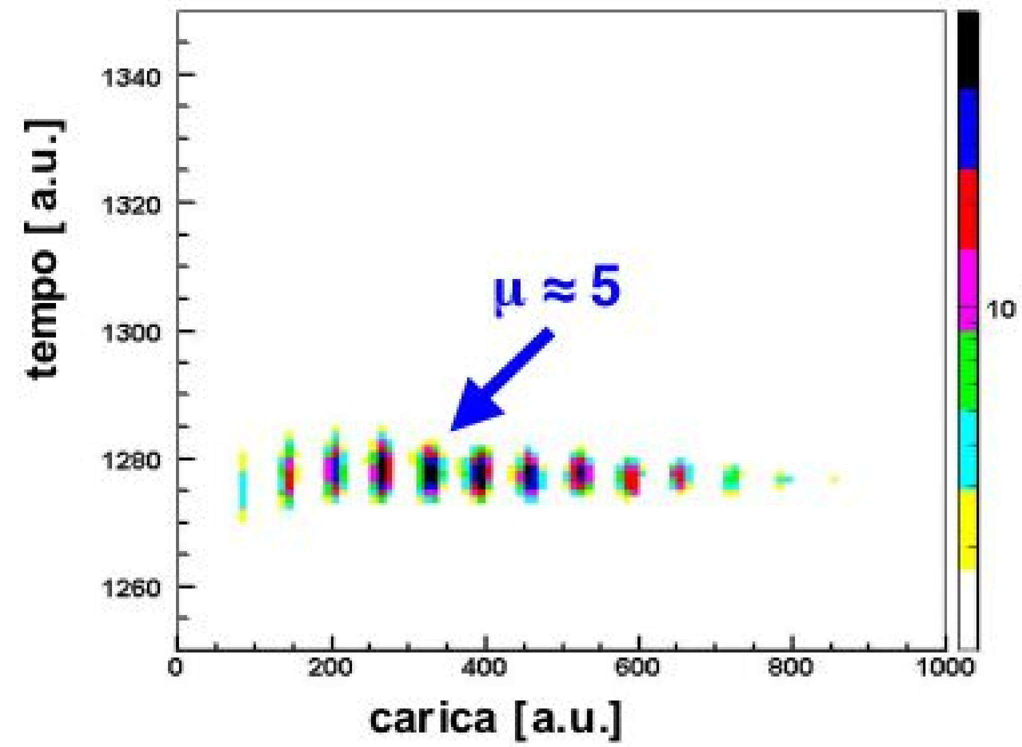
ORTEC FTA810B

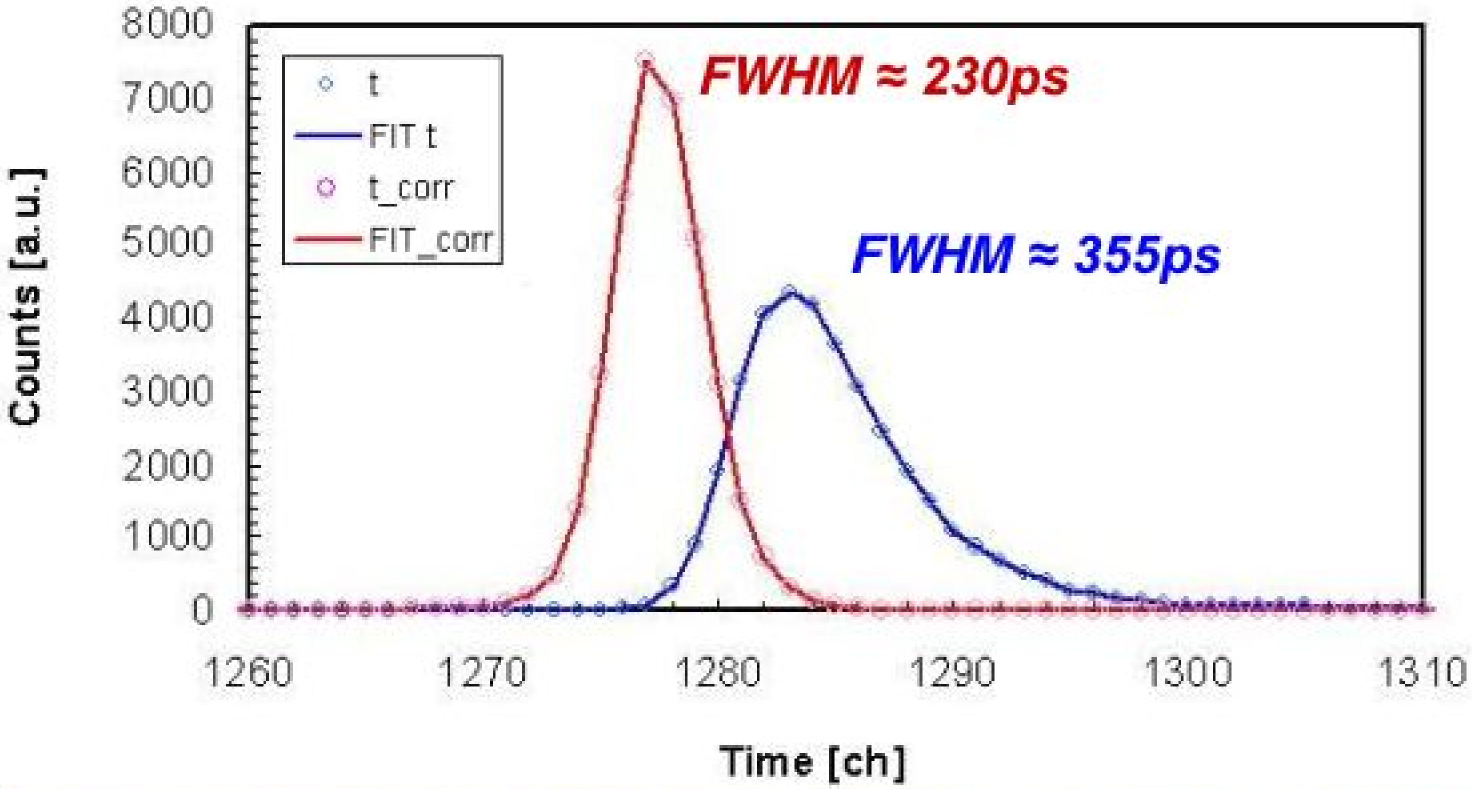
- ✓ $R_{3\sigma} = 18$
- $R_{2\sigma} = 42$
- $\sigma_e \approx 8$ ch

Risoluzione temporale



Correzione di walk evento per evento





Con l'amplificatore Ortec FTA810B

- ✓ FWHM con corr. ≈ 411 ps
- FWHM non corr. ≈ 470 ps

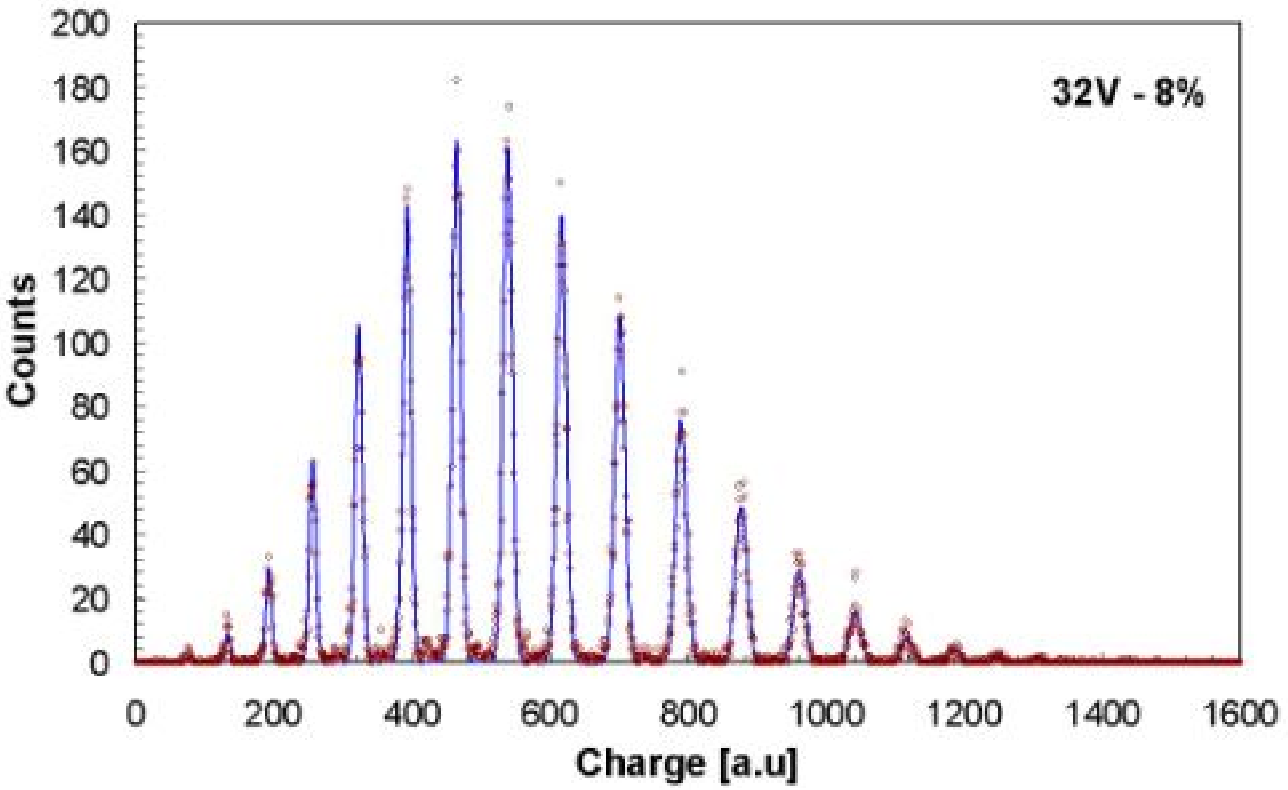
Conclusioni

Robustezza del sensore

Ottimo potere risolutivo

Ottime prestazioni temporali

Linearità e risoluzione a bassa intensità di luce



possibili applicazioni

- ✓ DMNR
- ✓ TOF PET
- ✓ applicazioni Biochimiche