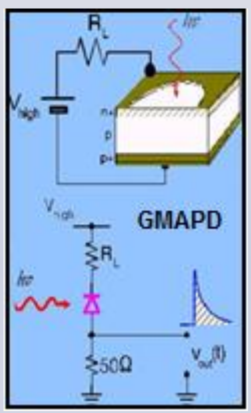
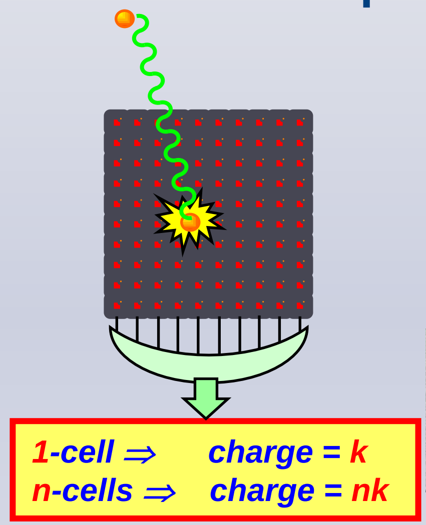
Solid State Photon-Counters

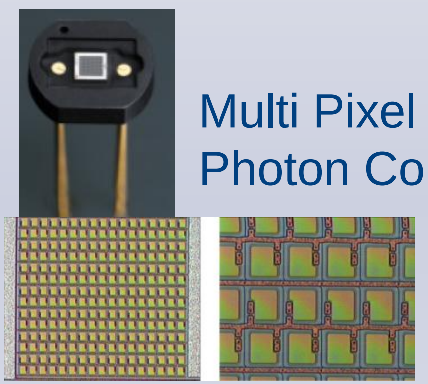
GMAPD (**G**eiger **M**ode **A**valanche **P**hoto**D**iode)

SiPM (**Si**licon **P**hoto-**M**ultiplier)

Single element Photon Counter







Multi Pixel Photon Counter

Giovanni Bonanno, Sergio Billotta, Massimiliano Belluso

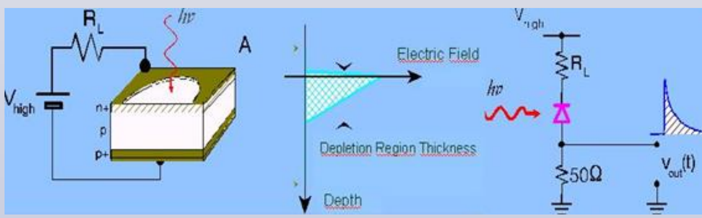
INAF

Astronomical Observatory of Catania, Italy

GMAPD or SPAD

A GMAPD or SPAD is a silicon sensor able to detect single photon events.

It is essentially an avalanche photodiode that, biased above breakdown, remains quiescent until a carrier, generated either thermally or by a photon, triggers an avalanche.



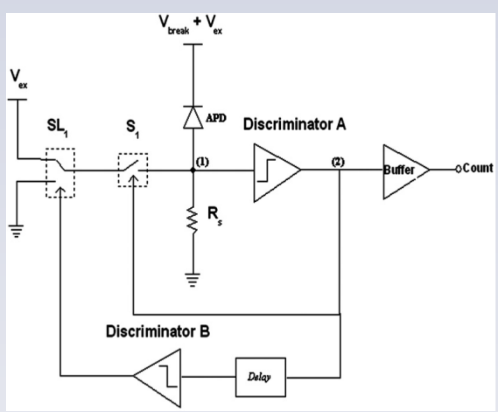
APD - SPAD comparison

	APD	SPAD
BIAS :	Below BD	Above BD
MODE :	linear	Geiger
GAIN :	e-/ph	infinite

Amplifier Trigger

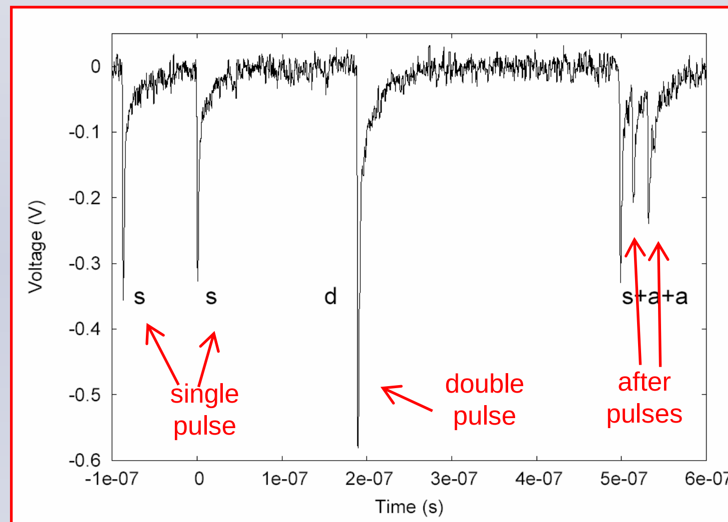
Instead of a standard Avalanche Photodiode (APD), which is operated below the breakdown voltage in the analog multiplication regime, a SPAD is biased above its breakdown voltage.

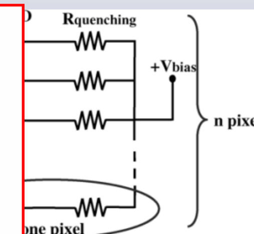
A quenching circuit (active or passive) extinguishes the avalanche and makes the sensor ready to detect another photon.

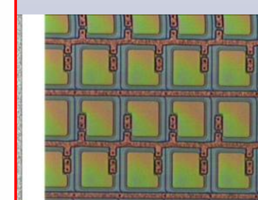


SiPM

A SiPM, as a SPAD, is a photodetector operated in Geiger mode, with the difference that it is constituted by **hundreds/thousands** of pixels, and the discharge is quenched by a small polysilicon resistor (passive quenching) in each pixel.







...aps of a 1 mm^2 ... (optical trench)

The independently operating pixels are connected to the same readout line; therefore the combined output signal corresponds to the sum of all fired pixels. It reaches an intrinsic gain for a single photoelectron of 10^6, comparable to that of PMTs.

RELEVANT CHARACTERISTICS

GMAPD or SPAD

Dimensions: **20 – 200 µm**

Dark count rate: **20 -1000 cnts/s**

Depends on working temperature and pixel dimensions

Dynamic range: **1÷15 MHz no simult. multi-hit**

depends on the quality material and technology used

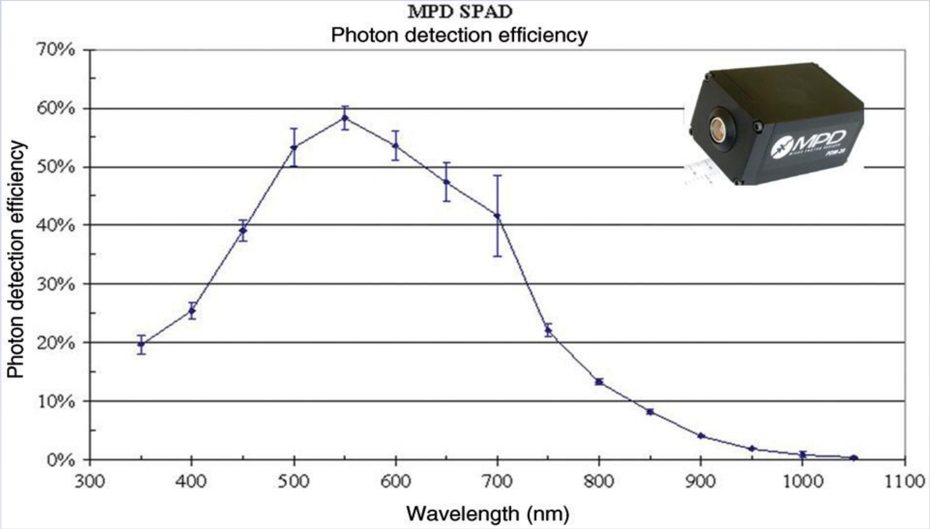
Arrays: **epi-tech. 25÷100 CMOS 1024÷16384 px**

Lower PDE due to the CMOS technology

Photon Detection Efficiency:

Is given by 3 factors: QE, Triggering Probability , Area efficiency

> 30% @ 420 nm > 50% @ Visible



SiPM

Dimensions: **0.5 – 3.5 - 5 mm**

Dark count rate: **10 - 300 Kcnts/s**

depends on temperature and number/dimensions of pixels. The total noise rises also for: After-pulses and optical cross-talk

Dynamic range: **MHz with simult. multi-hit**

Photon number resolution

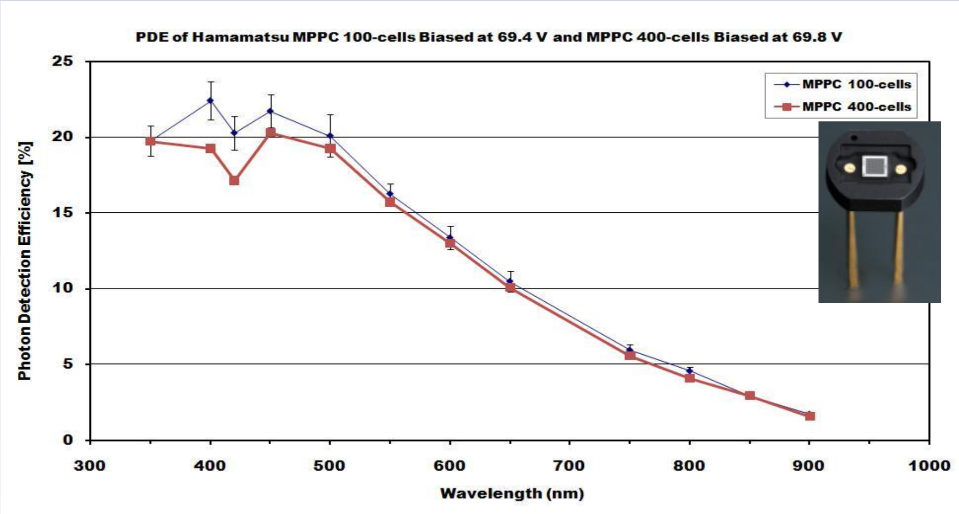
Mosaics: **3X3 (9X9 mm^2) - 4X4 (16X16 mm^2)**

Larger mosaics will be available under contracts

Photon Detection Efficiency:

Is given by 3 factors: QE, Triggering Probability, Fill-Factor

> 20% @ 420 nm



DARK COUNT RATE

Essentially depends on:

- ***Overvoltage***
- ***Working temperature***
- ***Detector dimensions***
- ***Purity of material***

Diameter	Breakdown voltage	Average Dark Counts @5V (cps)	
		25°C	-15°C
20 µm	22 – 24V	200	10
35 µm		3,000	40
50 µm		10,000	200
75 µm		35,000	1,000

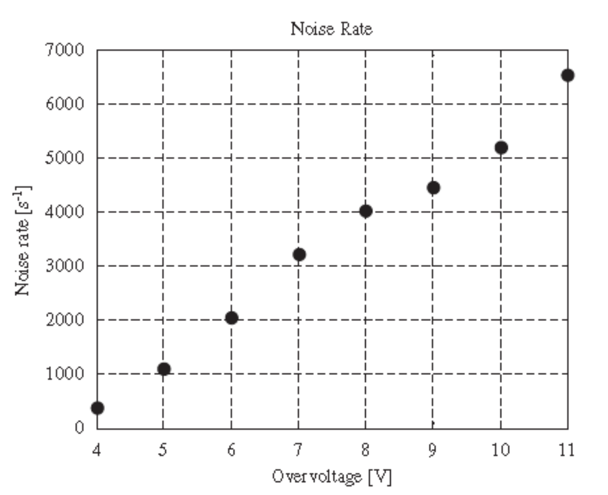


Fig. 7. SPAD dark noise rate at room temperature and increasing overvoltage.

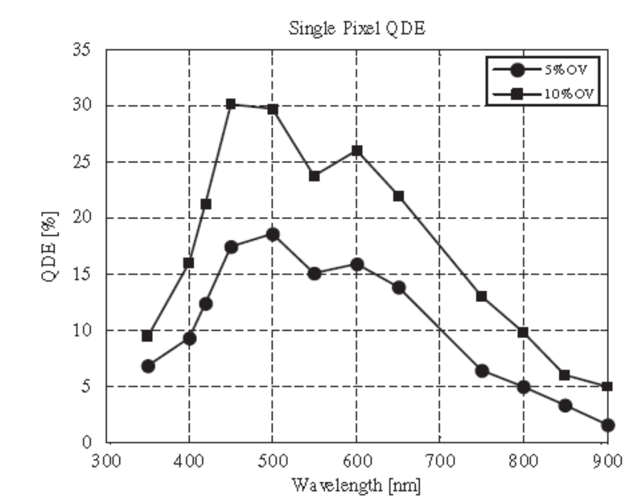


Fig. 10. SPAD quantum detection efficiency at room temperature and increasing overvoltage.

GMAPD or SPAD

Dark counts rate @ 20% OV : **20 -1000 cnts/s**

depends on working temperature and pixel dimensions

Best Device at our lab. 100 µm diameter

Dark counts rate @ 20% OV @ -20°C

25 cnts/s

SiPM

The Dark depend also on:

- **number of pixels**
- **cross-talk**
- **threshold**

1 mm^2 100 pixels (10X10) STM SiPM device

Dark counts @ room T and threshold 0.5 phe$^-$: **200 Kcnts/s**

Dark counts @ room T and threshold 1.5 phe$^-$: **5 Kcnts/s**

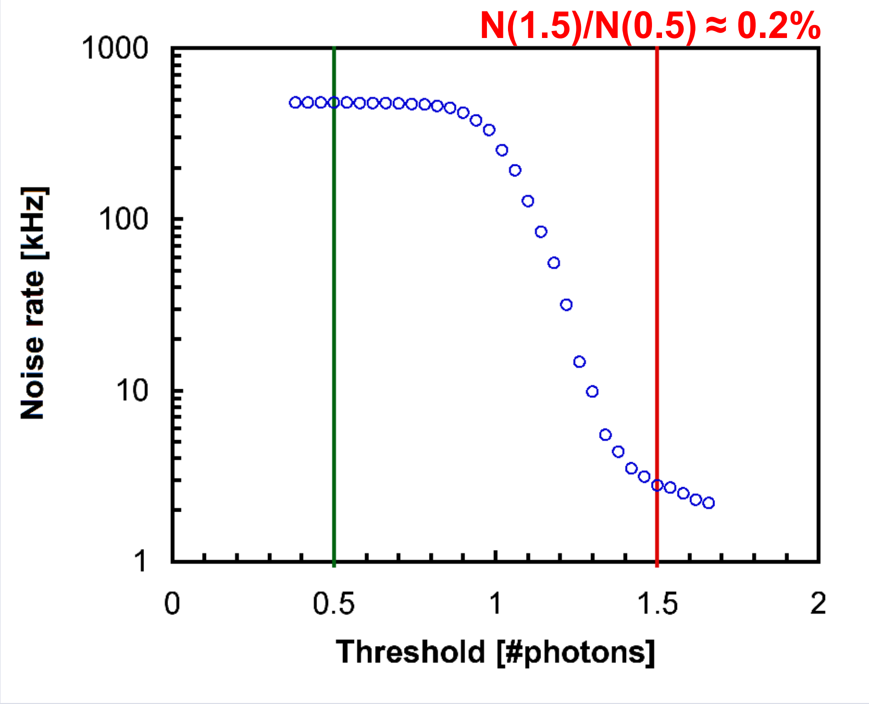
1 mm^2 100 pixels (10X10) Hamamatsu MPPC device

Dark counts @ room T and threshold 0.5 phe$^-$: **500 Kcnts/s**

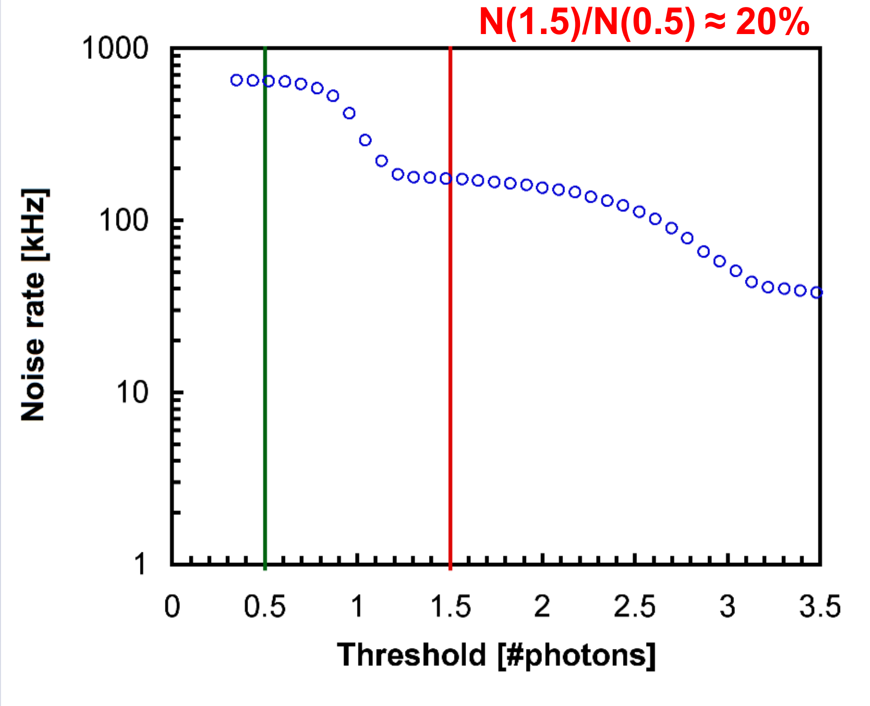
Dark counts @ room T and threshold 1.5 phe$^-$: **30 Kcnts/s**

Noise: rate vs threshold

STMicroelectronics



Hamamatsu



The threshold is set on the 1-photon plateau (0.5 - 0.75 ph)

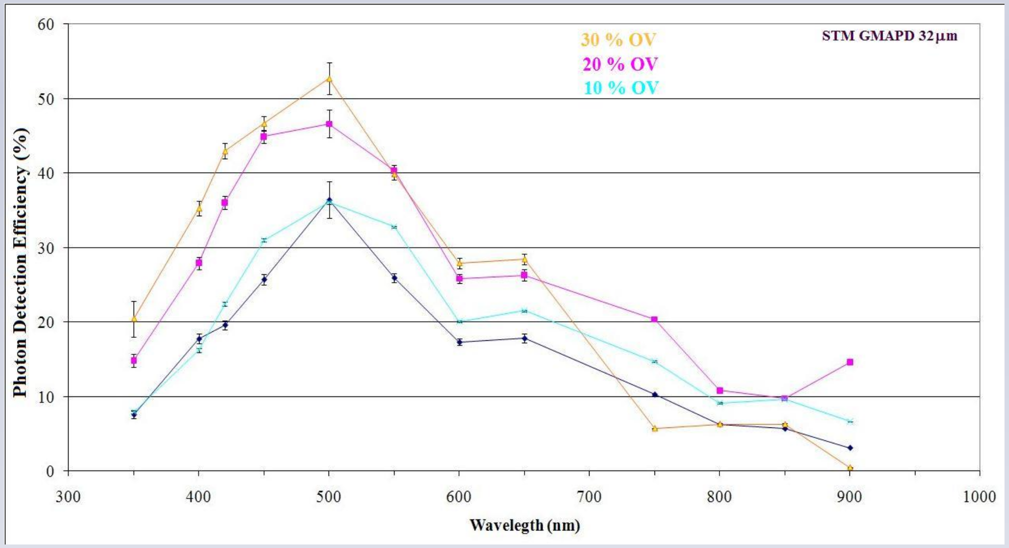
A rough estimate provides correlated noise (i.e. crosstalk, afterpulses) of the order of 0.2% (STM) and 20% (Hamamatsu)

PHOTON DETECTION EFFICIENCY

GMAPD or SPAD

Essentially depends on:

- ***Overvoltage → Trigger probability***
- ***Working temperature***
- ***Technology***



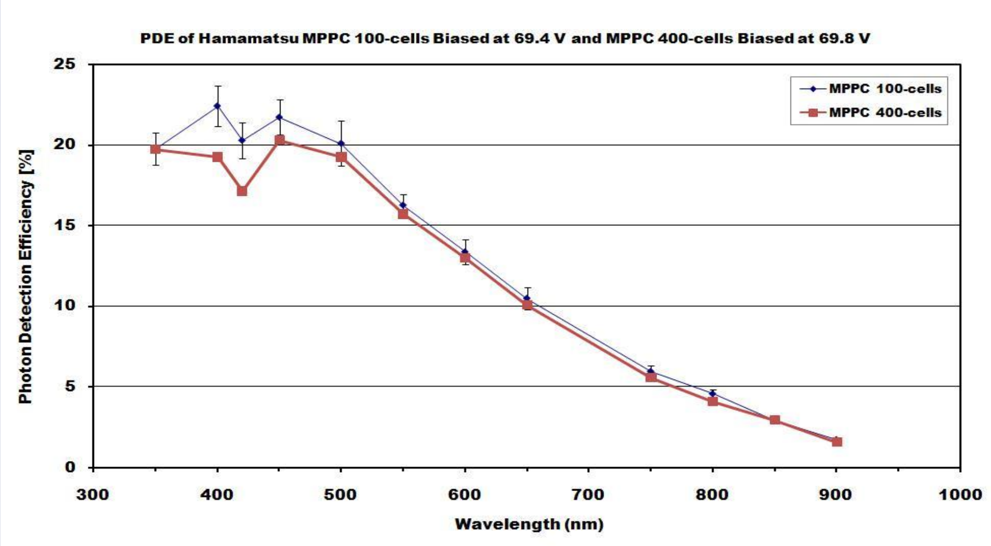
STMicroelectronics GMAPD

PDE @ 420 nm and @ 20% OV **35%**

SiPM

Essentially depends on:

- ***Overvoltage → Trigger probability***
- ***Working temperature***
- ***Technology***
- ***Fill Factor***



Hamamatsu MPPC 100 pixels compared with 400 pixels

PDE @ 420 nm and @ 3% OV **20%**

CONCLUSIONS/IDEAS AND FUTURE WORK

✓ **The Solid State technology for single photon detection is relatively new and improvements are in progress.**

✓ **The single element detector (SPAD or GMAPD) shows good PDE and reasonable dark count rate at easily obtainable low temperature but has very small dimensions (different optics? i.e. → Cones??).**

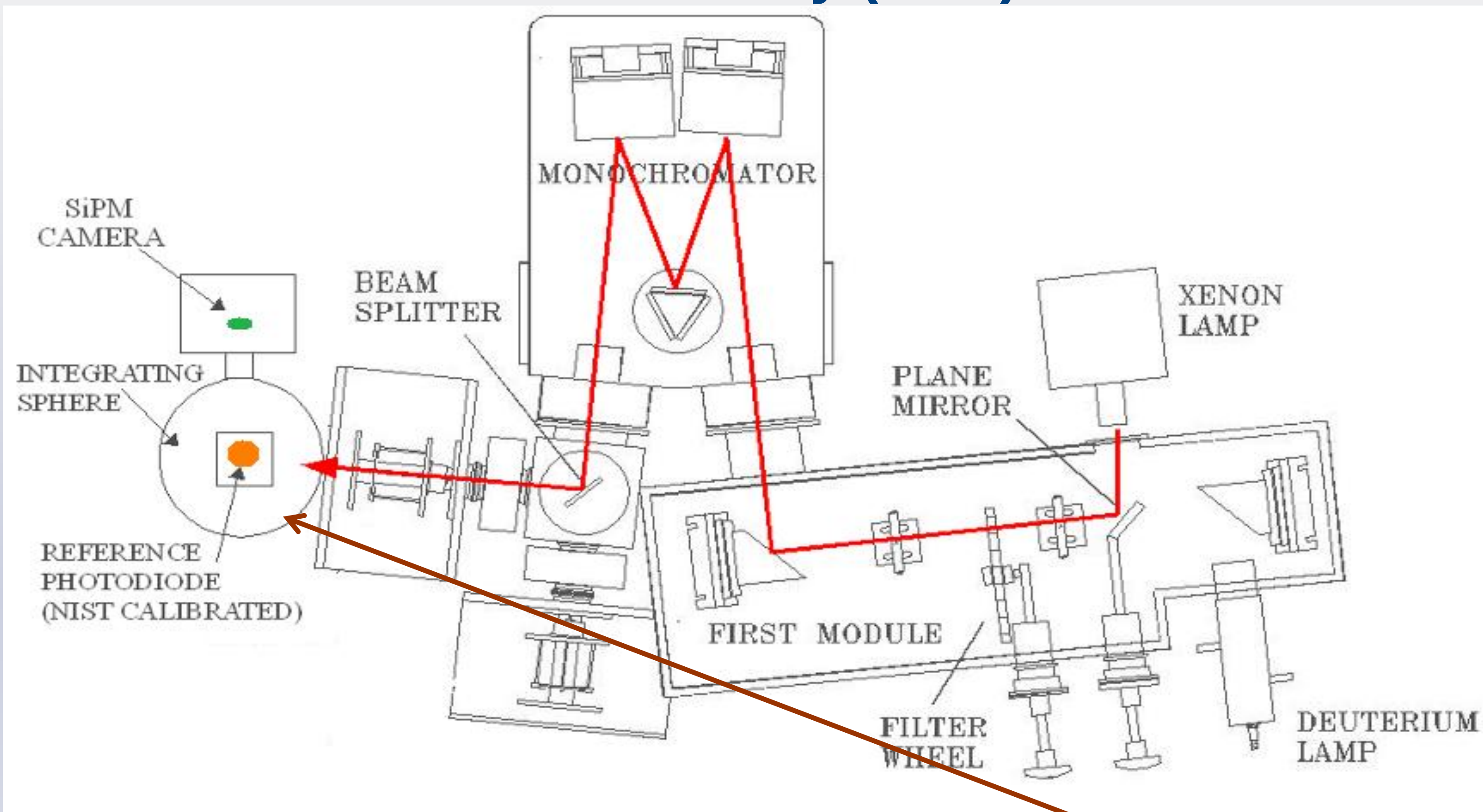
✓ **The multi pixel device (MPPC or SiPM) shows:**

- **PDE half of that showed by a single element (essentially due to the fill factor)**
- **at room temperature and at 0.5 phe- threshold, very high dark count rate (due to the all pixels contribution).**

❑ **To mitigate the fill factor problem the use of micro-lenses will help.**

❑ **To reduce the dark count rate at values of thousands cnts/s a relatively low temperature could help (lower dark counts rates can be achieved by using different operating mode i.e. → threshold higher than 2 or 3 phe-).**

Photon Detection Efficiency (PDE) Measurements



From right to left you can find: a Xenon lamp used as the radiation source, a wavelength selection system constituted essentially by a set of filters and a Czerny–Turner monochromator a beam splitter to direct the monochromatic radiation towards an integrating sphere that hosts a NIST traced reference detector and the SPAD.

The use of an integrating sphere is crucial because the very small size of the SPAD with respect to the optical beam.