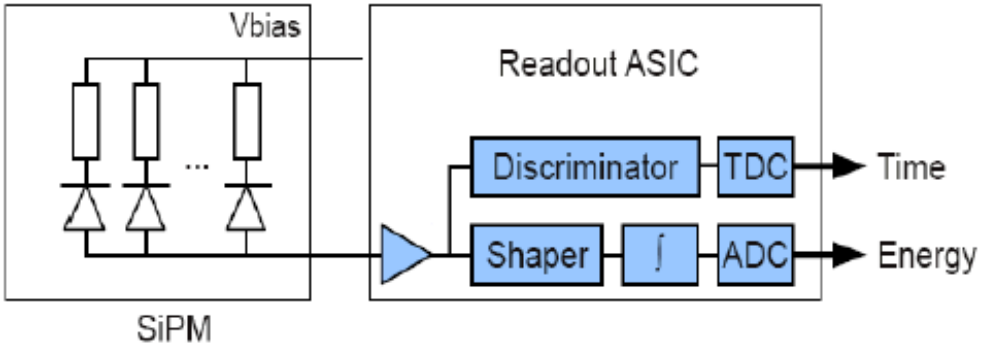
La sfida dei rivelatori di luce: SiPM come risposta?

G. Ambrosi

LNGS 15 Ottobre 2014

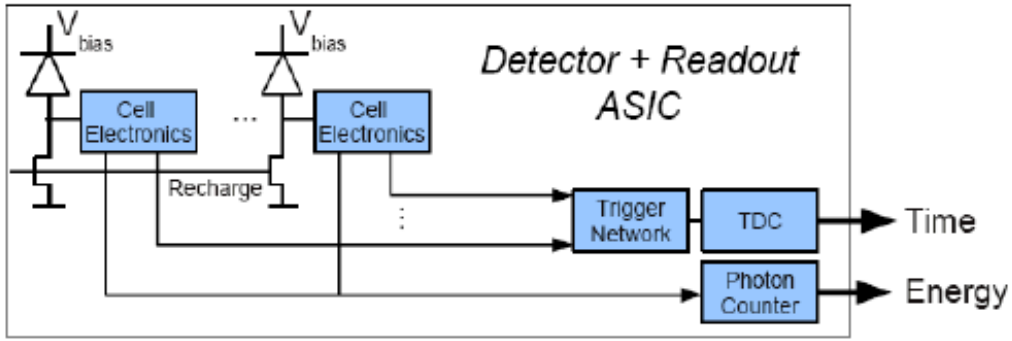
Today's fair competition: Analog vs Digital SiPM

Analog Silicon Photomultiplier Detector



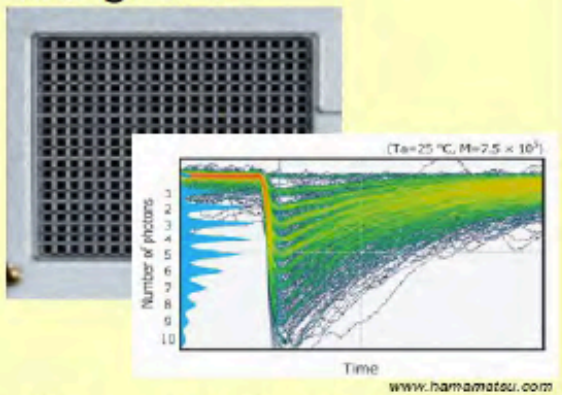
T.Frach - Heraeus Seminar 2013

Digital Silicon Photomultiplier Detector



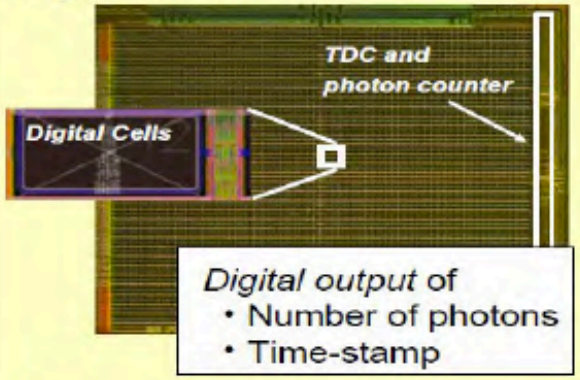
d-SiPM:
- for each light pulse → output is: time-stamp and number of photons
- control of individual cells
- O(500ns) RO dead time (upon trigger)

Analog SiPM



- Cells connected to common readout
- Analog sum of charge pulses
- Analog output signal

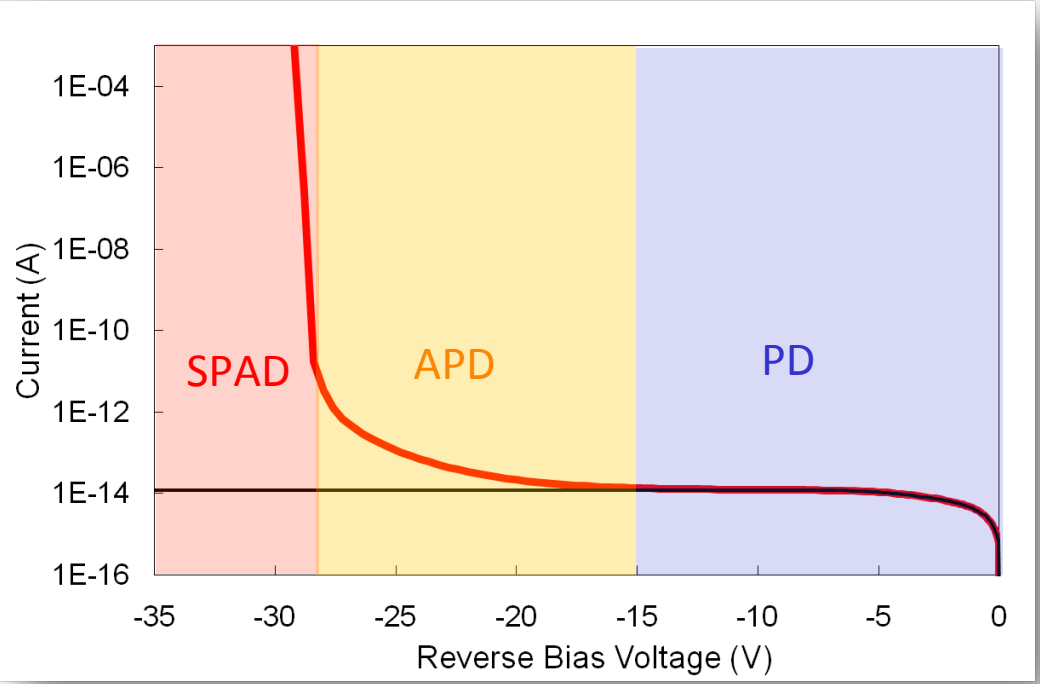
Digital SiPM



- Each diode is a digital switch
- Digital sum of detected photons
- Digital data output

Solid-state technology: SPAD

internal gain based on carrier multiplication via impact ionization



AVALANCHE PHOTODIODE

- Gain ~100
- Timing ~ ns/ 10ph.e.
- Bias voltage ~500V
- Sensitivity ~10 ph. e.
- QE ~ high in all spectrum

SPAD / Geiger-mode APD

- Gain ~10^6
- Timing ~ 10ps /10ph.e.
- Bias voltage <100V
- Sensitivity ~1 ph. e.
- QE ~ medium

Photo-Detectors family tree

Gas
External photoemission

gas photoionization
(TMAE, TEA, …)

and/or

multiplication in gas
by avalanche
(MWPC, GEM, ...)

Vacuum devices
External photoemission

secondary electron multiplication

Dynodes:
- discrete (PMT)
- continuous dynode (channeltron, MCP)

Anode:
- multi-anode
- strip lines RF

hybrid
photocathode +

- multiplication by **ionization in Si** (HPD, HAPD, VSiPMT

or

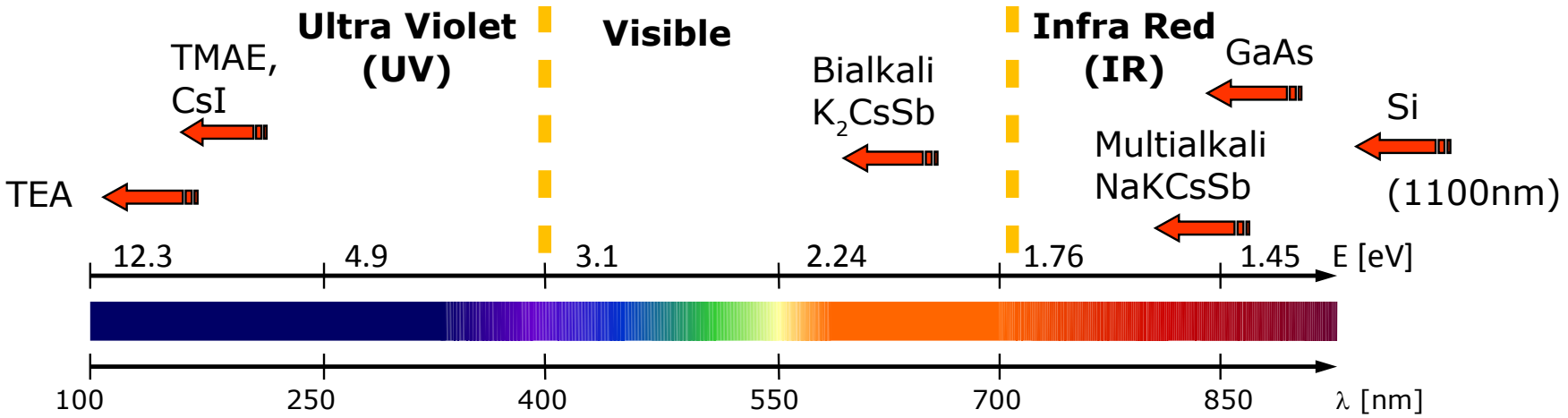
- multiplication by **luminescent anodes** (light amplifiers: SMART/Quasar, X-HPD, ...)

Solid state
Internal photoemission

- Photo-Diode (PD)
- Avalanche PD (APD)
- GM-APD (SPAD, SiPM)

- Imaging CCD, CMOS, EMCCD, CMOS-APS, ...

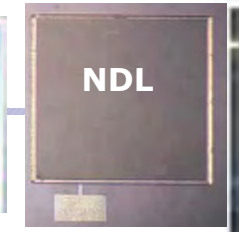
- Quantum well detectors
- Supercond. Tunnel Junc.

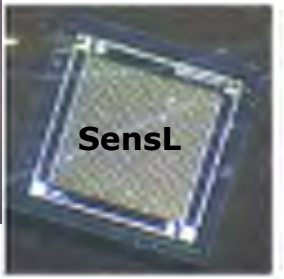


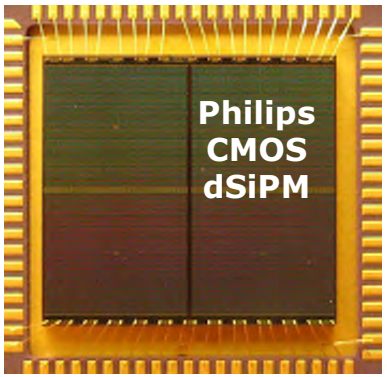
SiPM development and production

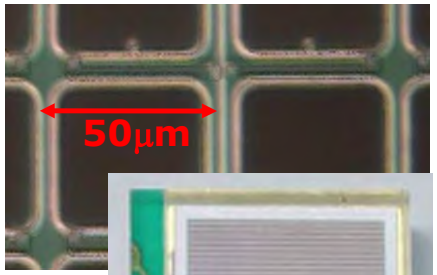
Many institutes (R&D) and companies involved
→ competition... but prices still far (~ x20)
from asympt. production cost O(10€/cm^2)

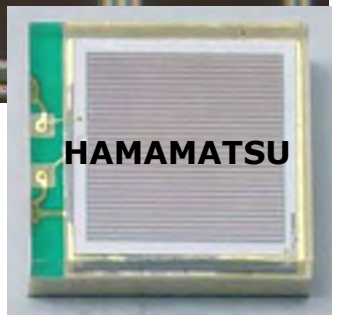
- **CPTA**, Moscow, Russia
- **MePhi/Pulsar** Enterprise, Moscow, Russia
- **Zecotek,** Vancouver, Canada
- **Hamamatsu HPK**, Hamamatsu, Japan
- **FBK-AdvanSiD**, Trento, Italy
- **ST Microelectronics**, Catania, Italy
- **Amplification Technologies** Orlando, USA
- **SensL**, Cork, Ireland
- **MPI-HLL**, Munich, Germany
- **RMD**, Boston, USA
- **Philips**, Aachen, Germany
- **Excelitas** tech. (formerly Perkin-Elmer)
- **KETEK**, Munich, Germany
- **National Nano Fab Center**, Korea
- **Novel Device Laboratory** (**NDL**), Bejing, China
- **E2V**
- **CSEM**

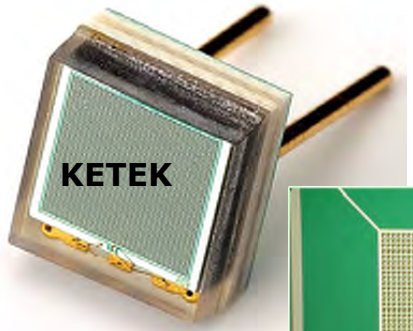


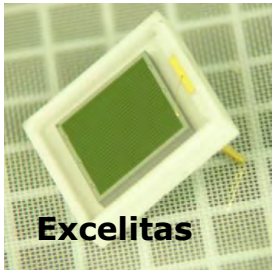




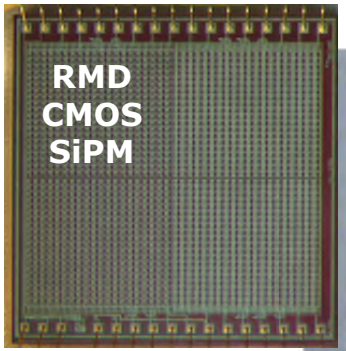


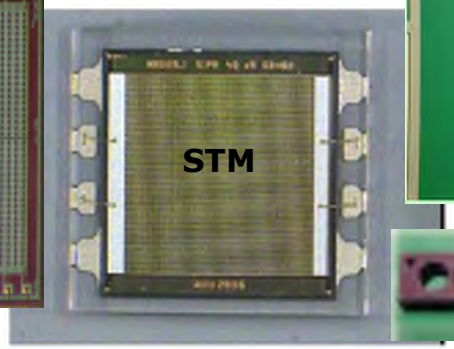






Amplification Technologies (DAPD)

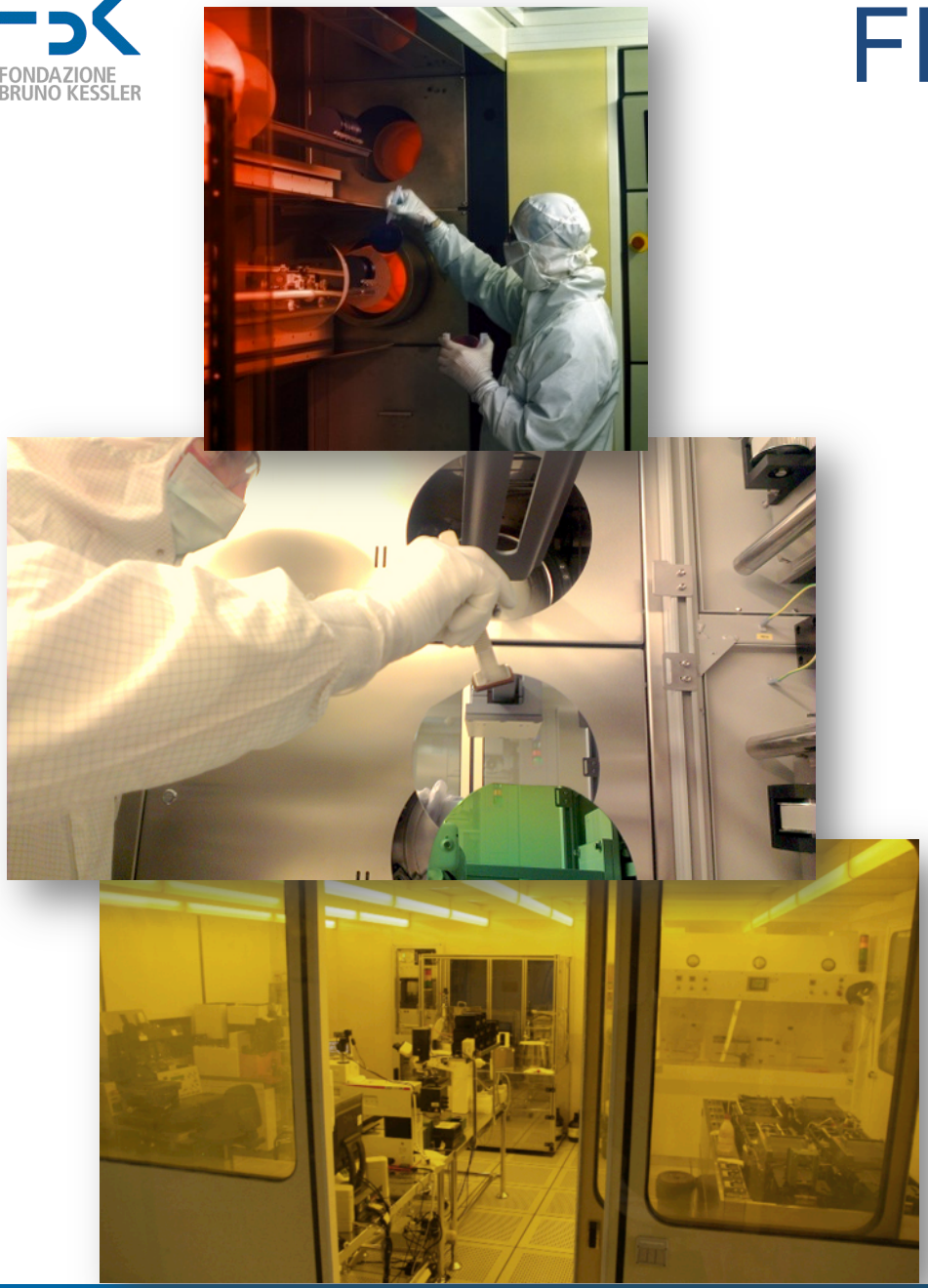




INFN & FBK: la convenizone MEMS

- Convenzione per attività di R&D a condizioni favorevoli
- Richieste di finanziamento nelle CSN e verifica accesso a convenzione
- Sviluppo di dispositivi a semiconduttore:
  - Strip e Pad detectors
  - 3D detectors
  - Bolometri
  - SiPM

FONDAZIONE BRUNO KESSLER



FBK Technolgy

Clean room «Detectors»:

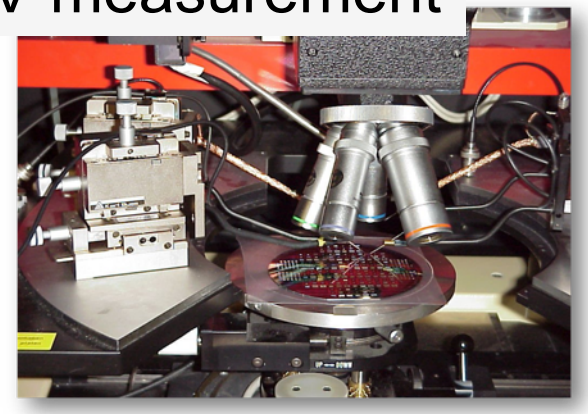
- 500m^2
- 6'' wafers
- Equipped with:
  - ion implanter
  - 8 furnaces
  - wet etching
  - dry etching
  - lithography
    - stepper
    - mask aligner
  - Deep RIE
  - Plasma-enhanced CVD
  - sputtering

SRS SILICON RADIATION SENSORS

FONDAZIONE BRUNO KESSLER

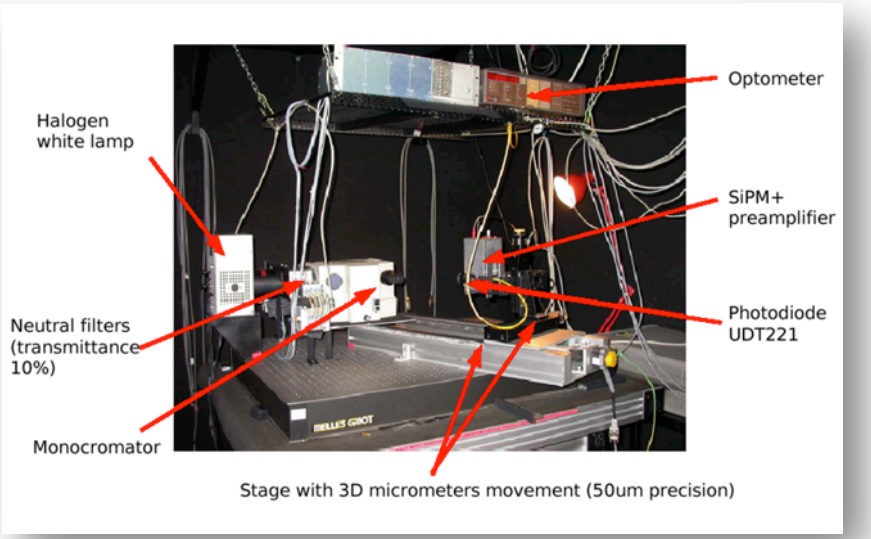
SiPM Characterization

1. IV measurement

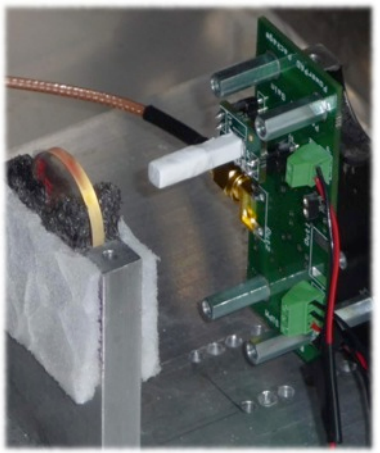


2. Dark characterization

3. Optical characterization



4. Functional charact.



SRS SILICON RADIATION SENSORS

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Main parameters

- Gain
  - Number of electrons per detected photon
- Primary Noise

  - Thermally generated events
- Correlated Noise
  - after-pulse, optical cross-talk
- Photo-detection efficiency (PDE)
  - Number of detected photons over total incident photons
- Dynamic range
  - Linearity of response
- Time resolution
  - Precision in the determination of photon arrival time

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Wish list

Parameter	Wish	Comment
Gain	High	Usually not a problem (~1e6)
Primary Noise	Low	Hard to reach PMT levels!!
Correlated Noise	Low	Good options to reduce it
PDE	High	>50% feasible, wavelength?
Dynamic range	High	Up to 5-10000/mm2
Time resolution	Low	~100ps FWHM

- Today, we do not find a device with all the parameters optimized.
  Trade-off among them (e.g. PDE *vs* dynamic range)!!

SRS SILICON RADIATION SENSORS

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Other important features
(at the system level)

- Breakdown voltage uniformity
- Temperature stability
- Packaging type (dead border region, TSV, custom)
- **COST!!**

  Solutions to improve performance must be cost-effective.

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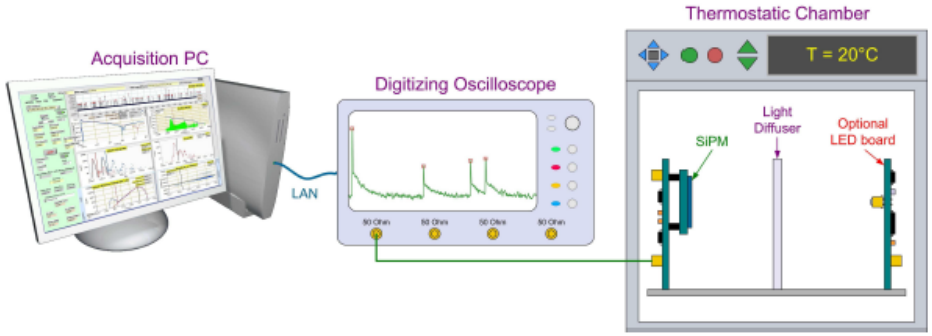
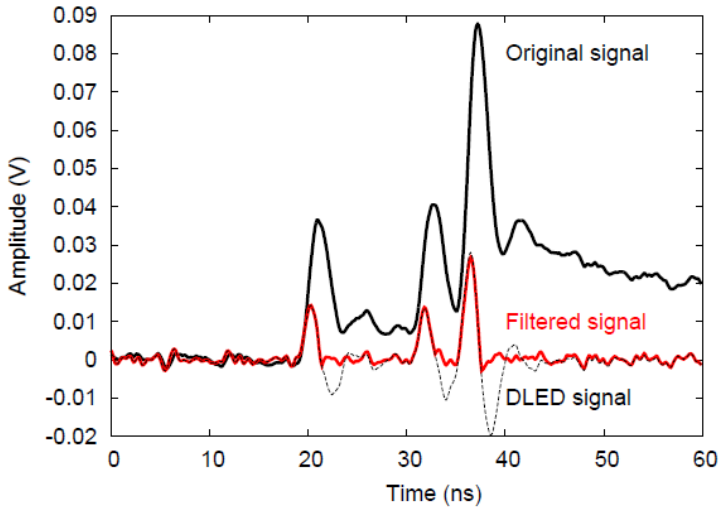
Dark measurement



We acquire ms-long waveforms

Signal filtered to reduce its length



→ time delay array
→ amplitude array

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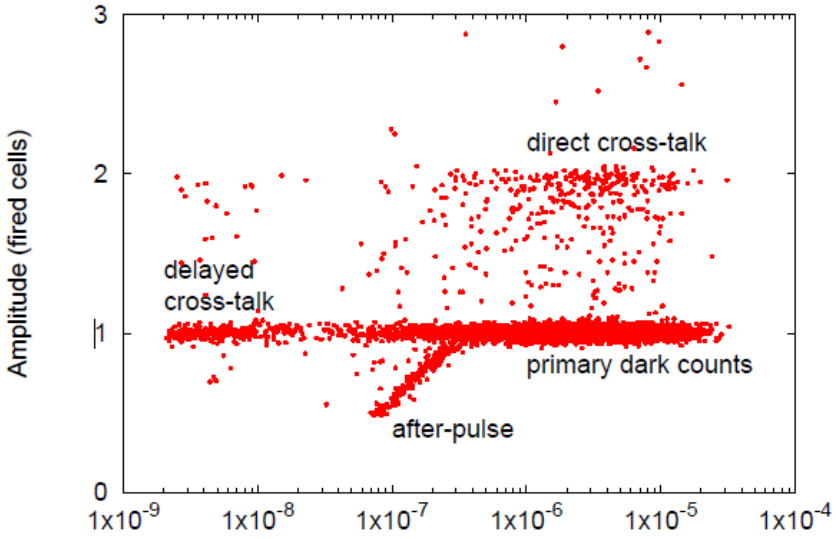
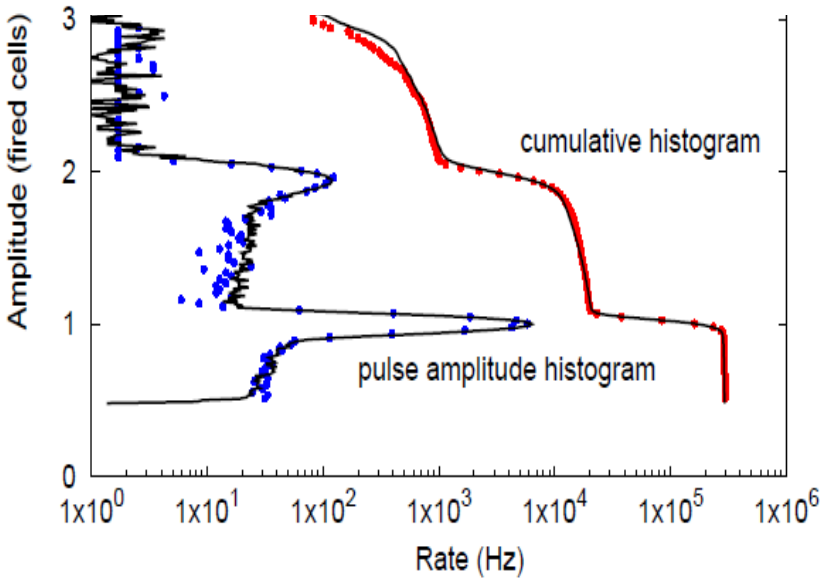
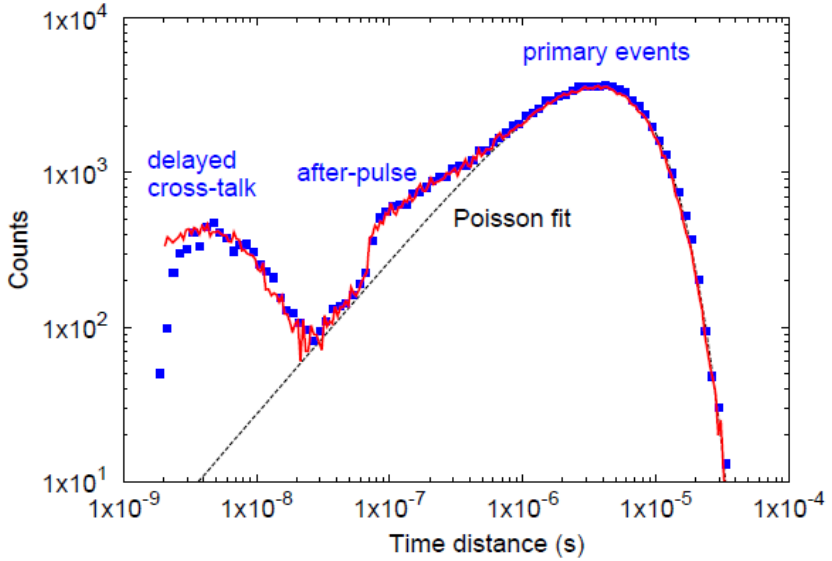
Dark measurement



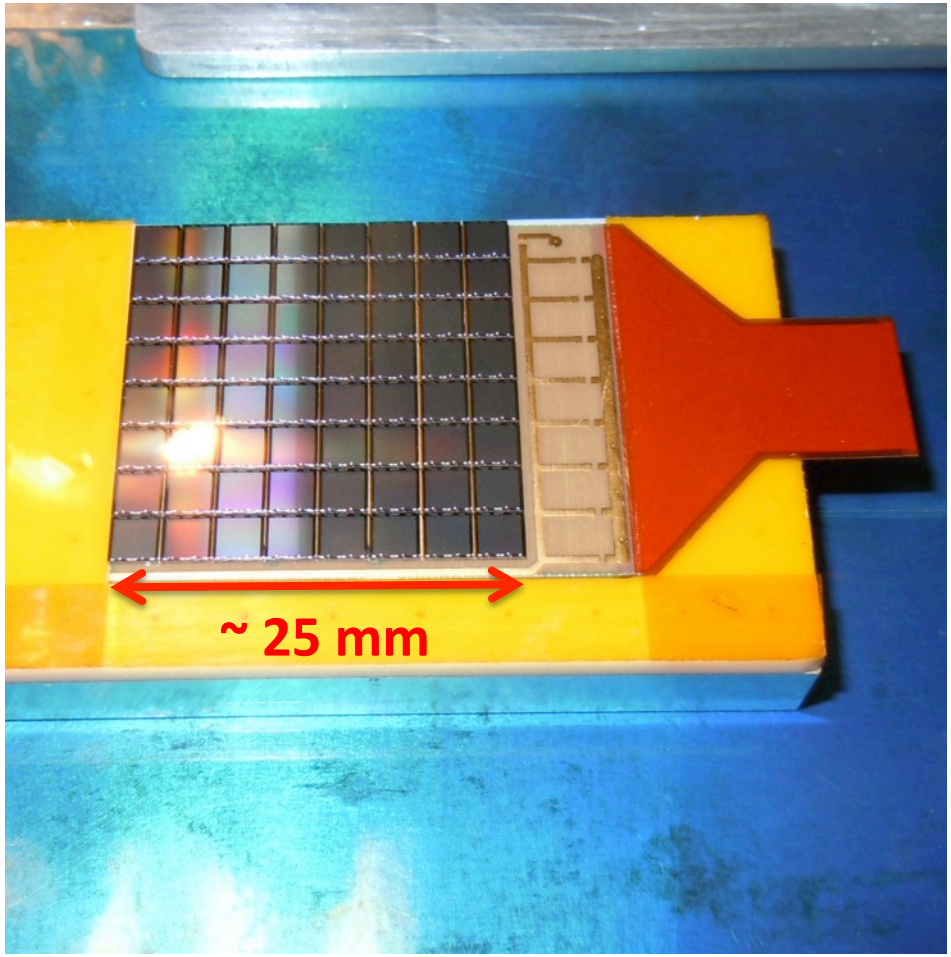


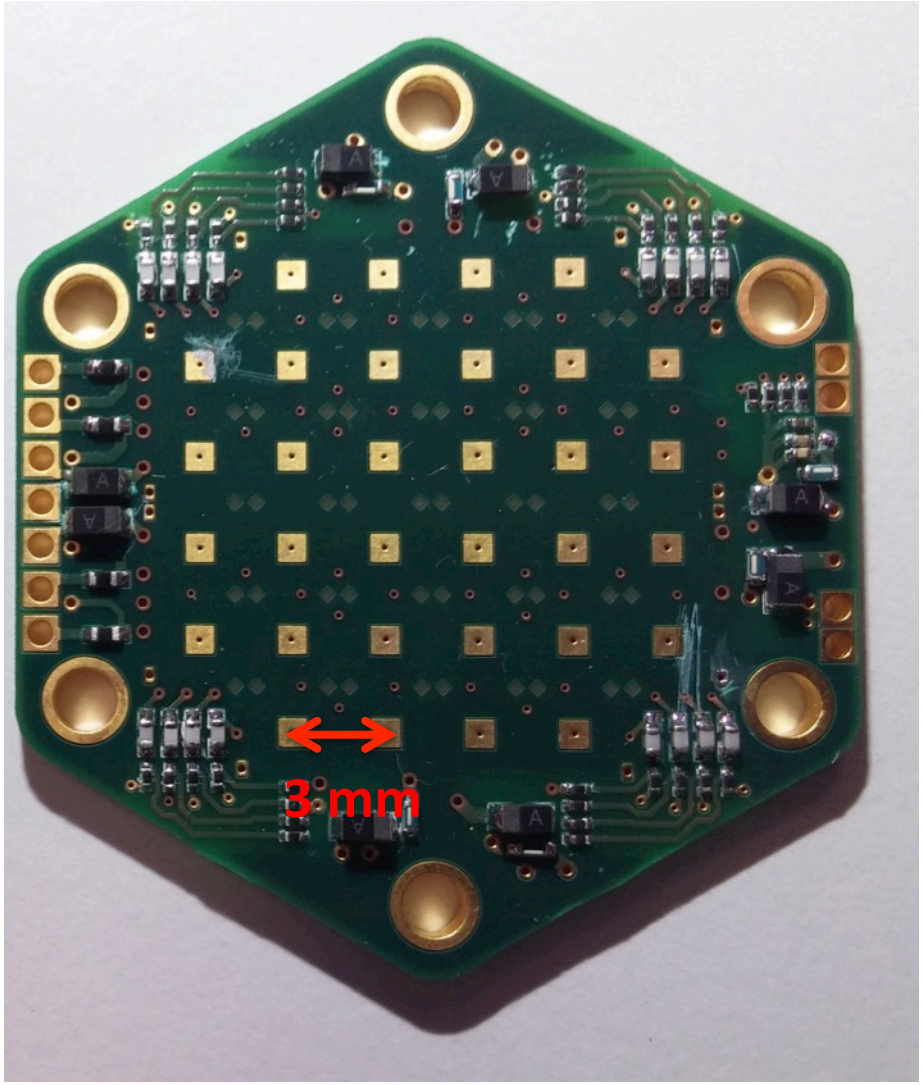


→ primary dark rate (DCR)
→ direct cross-talk
→ delayed correlated components

SRS SILICON RADIATION SENSORS

Matrici custom di SiPM 3x3 mm^2





The project: VSiPM

GC Barbarino et al.

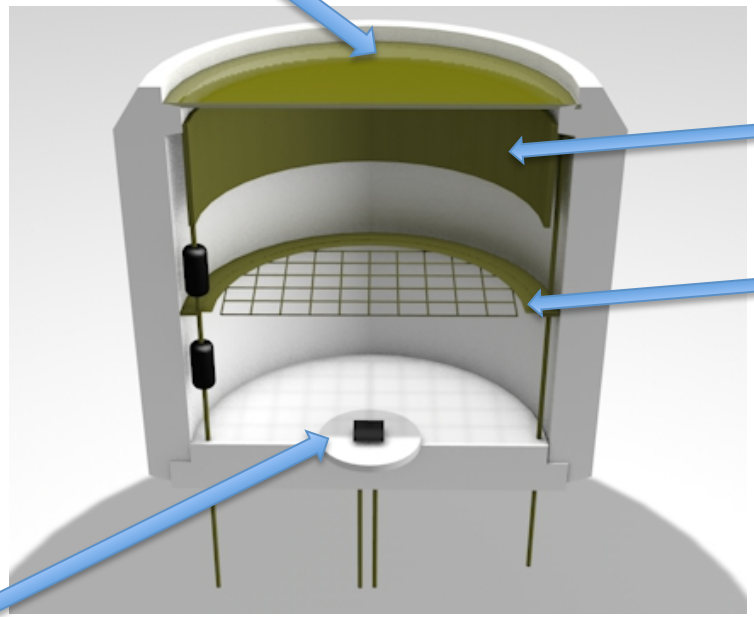
Vacuum Silicon PhotoMultiplier Tube (VSiPMT)

SIPM is:

- **Compact**
- **Cheap**
- **Single photon capability**
- **Linear**
- **Low voltage operation**

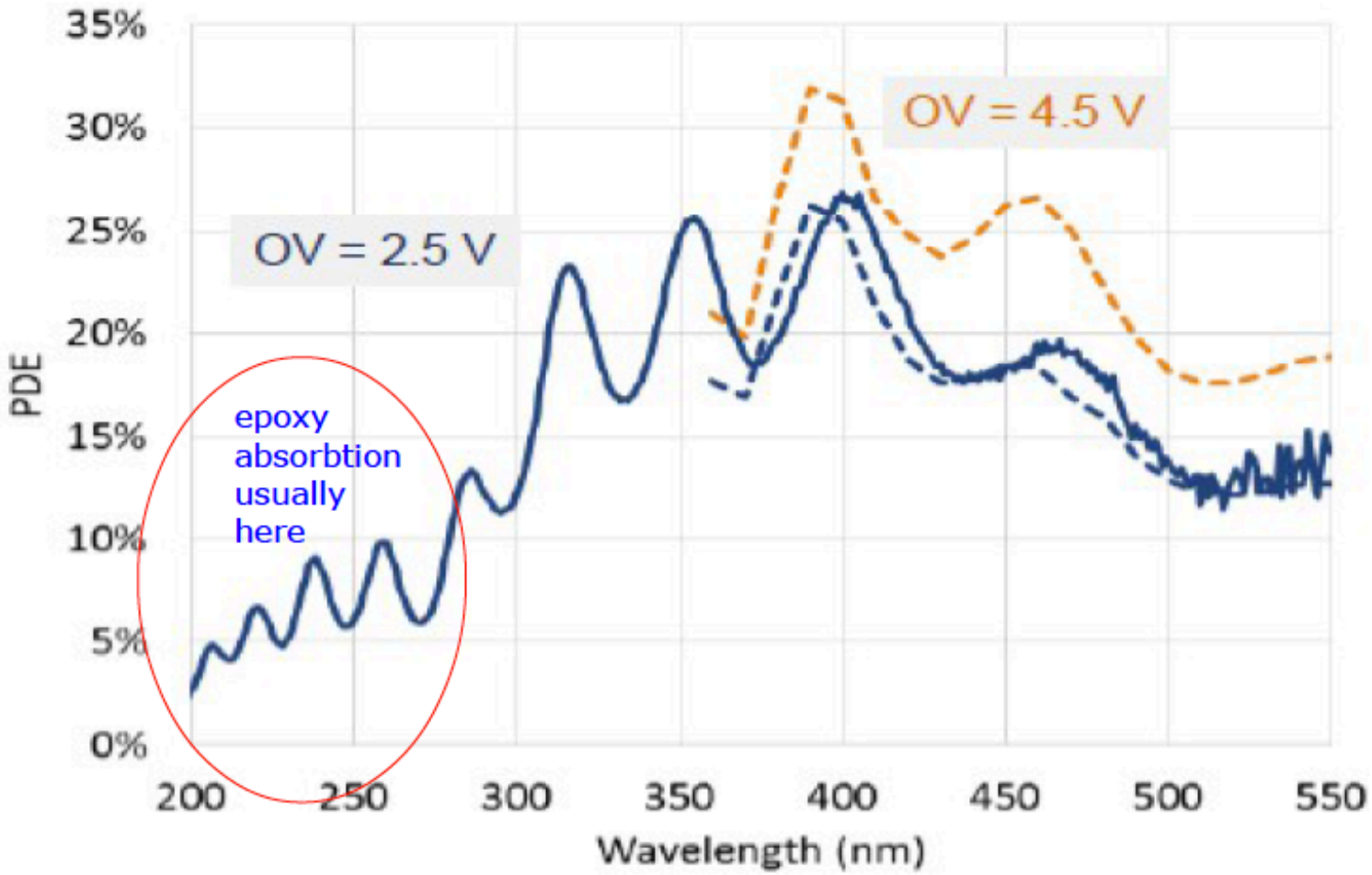
BUT

Small sensitive surface



A combination of a classical vacuum glass PMT standard envelope hosting a photocatode and a Silicon PhotoMultiplier (SiPM) acting as an electron multiplying detector (in the place of the dinodes chain).

SiPM NUV FBK 1x1mm^2 cell 50μm



Note:

- measurement at low overvoltage to keep contributions from afterpulses and cross-talk at low level (no correction)
- Common/overall scale uncertainty PDE ~ 15% (relative) due to uncertainty on calibration PMT gain; uncertainty on shape O(few %)
- Overall scale uncertainty on $\lambda < 5$nm

GM Collazuol, P Sartori

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