Study of the Radiation Damage of Hamamatsu Silicon Photo Multipliers

Wander Baldini

Istituto Nazionale di Fisica Nucleare and

Universita' degli Studi di Ferrara

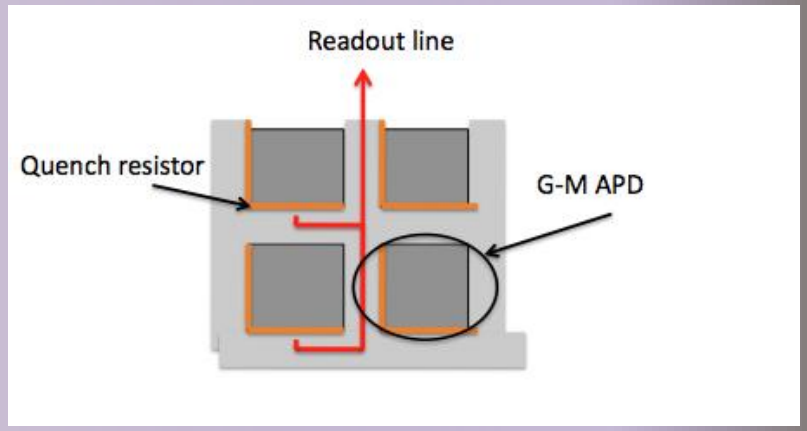
Technology and Instrumentation in Particle Physics, Amsterdam June 2-6 2014

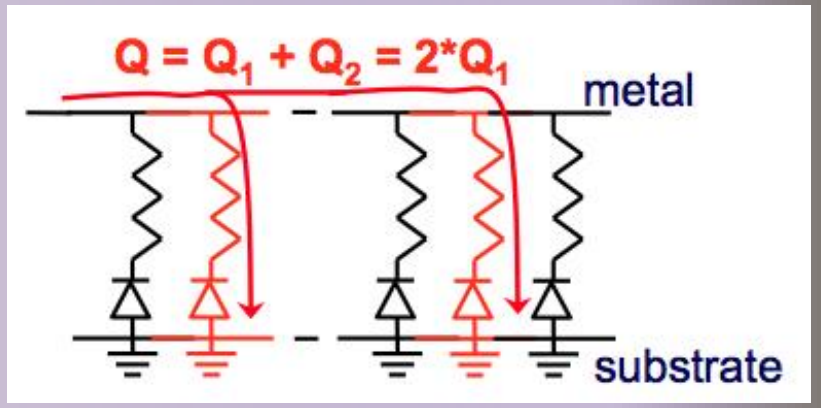
Outlook

- Silicon Photo Multipliers
- The Louvain Cyclotron Facility
- Experimental Setup & Measurements
- Results
- Conclusions

Silicon Photo Multipliers

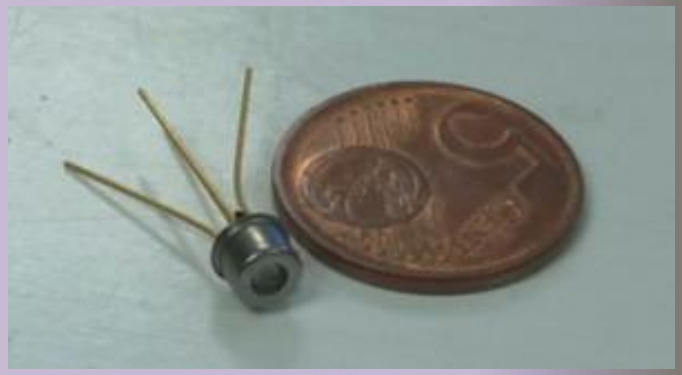
- SiPMs are recently developed semiconductor photo detectors composed by a matrix of Geiger Mode Avalanches Photo Diodes (GMAPD)
- The working point is a few Volts above the breakdown voltage
- The output signal is the sum of the charge produced by each pixel
- The shape of the active area and the dimension of the pixels can be customized according to user's needs





Silicon Photo Multipliers

- High gain ≈ 10^6
- No sensitivity to magnetic fields
- Small-sized
- Single photon resolution
- Low bias voltage (<100V)



Drawbacks:

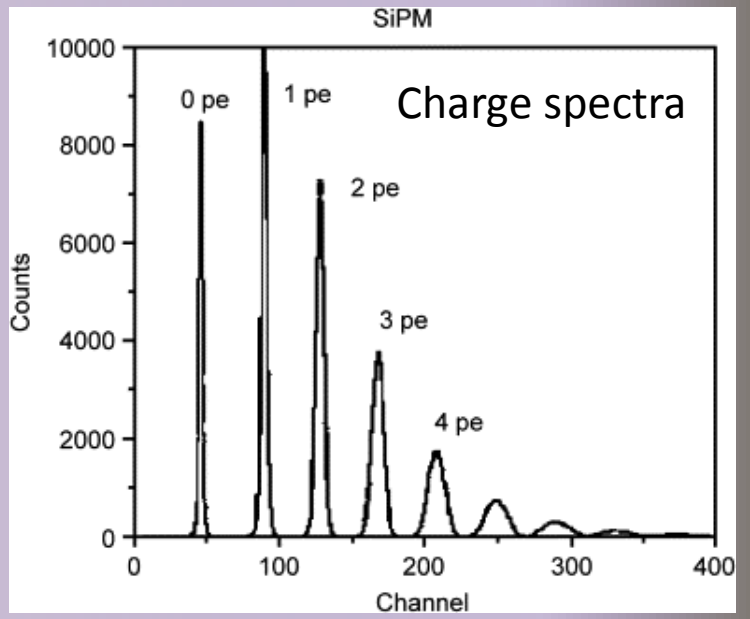
- High dark count (typically ≈ 100s kHz at room temperature, 0.5 p.e. threshold)

  ➡ greatly improved in the last few years

- Radiation damage

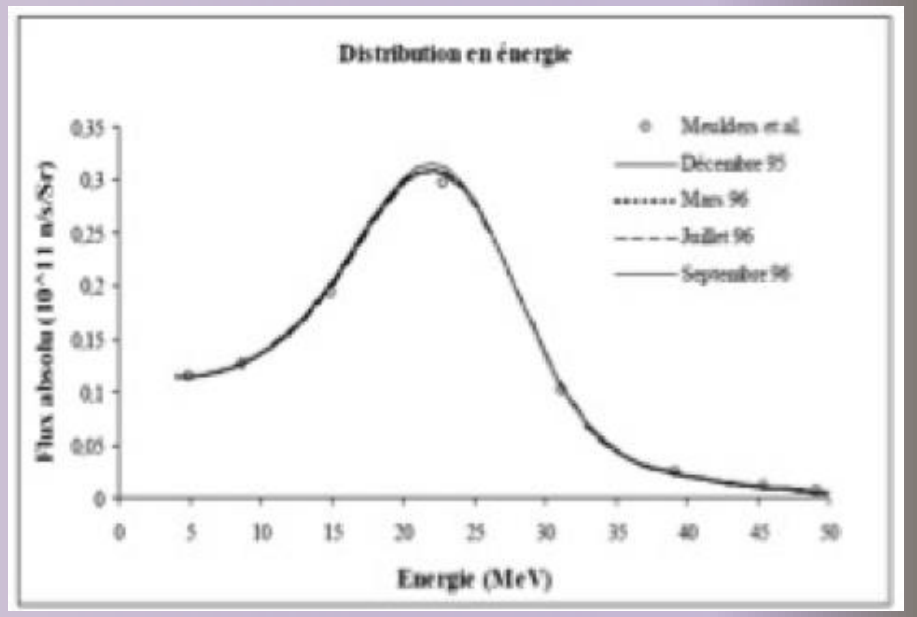
  ➡ requires extensive studies for applications in high radiation environment (like High Energy Physics)

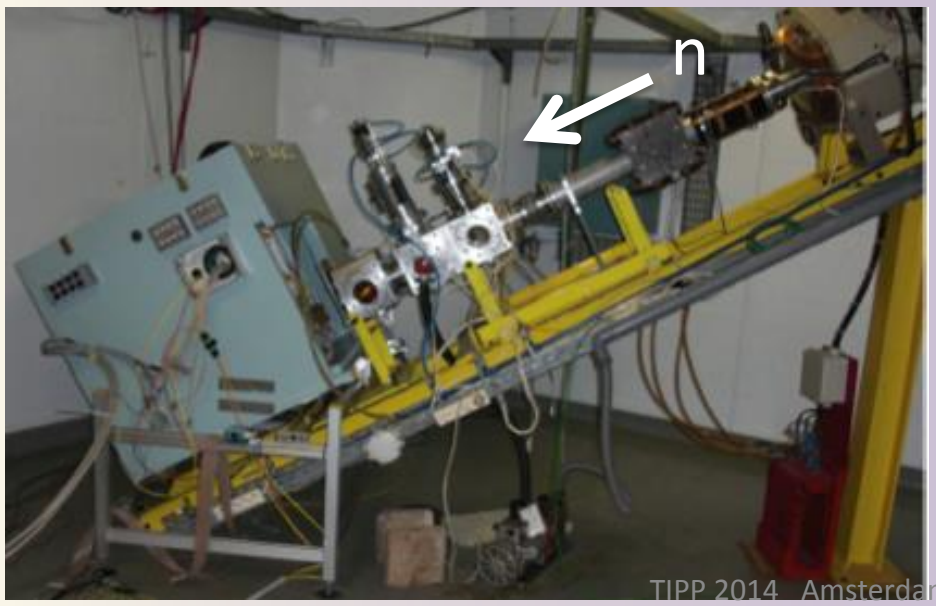
Main topic of this presentation



The Louvain Cyclotron 110 Facility

- 50 MeV deuterons on Be target
- Continuous spectrum up to 50MeV
- Peak at ≈23MeV
- Filters for γ and low energy neutrons (98% purity)
- Neutron fluence precisely controlled
- Cooling box up to -25 C°





d(cm)	R(cm)	t(h)
5	2	1.6
20	5	24
40	8	88

d : distance to target

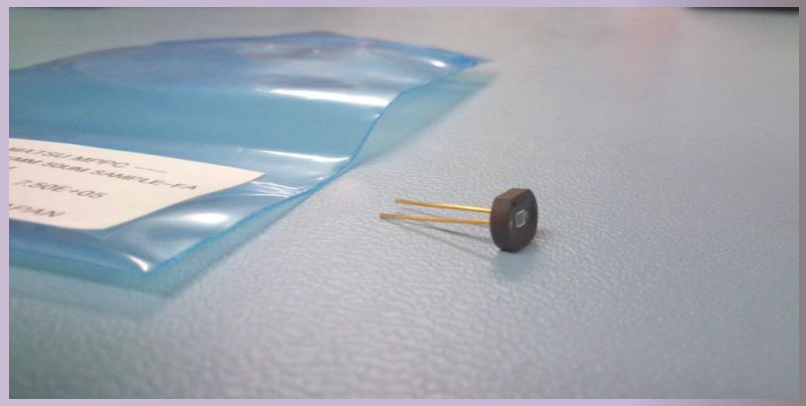
R : Radius (80% neutrons)

t : time for $\Phi = 10^{14}$ n/cm^2 ($I_d = 1\mu A$)

SiPM Hamamatsu Sample

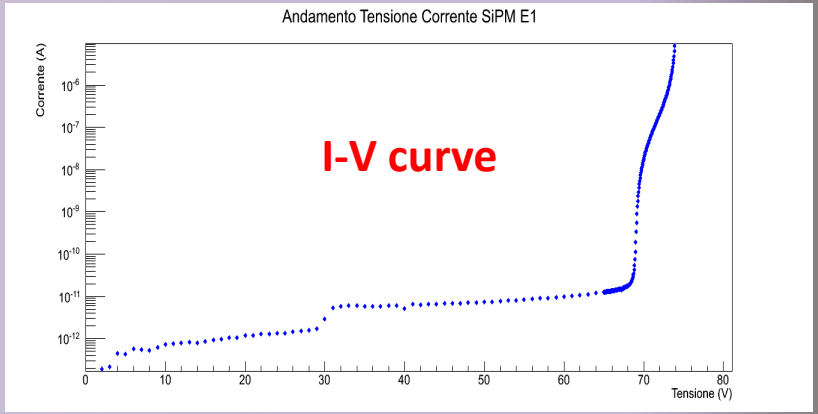
- We tested 16 devices of 8 different types and 3 categories:
  - A, B: conventional MPPC like devices
  - C,E,F,G,H: “low after pulse” devices
  - D: special device with a new structure
- All devices had the same geometry:
  - 1x1 mm^2 active area on plastic support
  - 50x50 μm^2 pixel size
- Two devices for each type

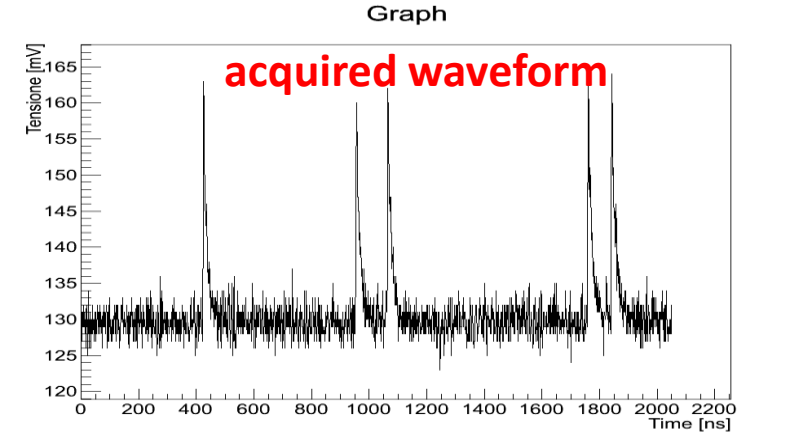
SiPM	Pre Test Ferrara	Pre Test Louvain	$5{\cdot}10^8$	$5{\cdot}10^9$	$5{\cdot}10^{10}$
A1	x		x	x	x
A2	x	x		x	x
B1	x		x	x	x
B2	x	x		x	x
C1	x		x	x	x
C2	x	x		x	x
D1	x		x	x	x
D2	x	x		x	x
E1	x	x	x	x	x
E2	x	x		x	x
F1	x	x	x	x	x
F2	x	x		x	x
G1	x	x	x	x	x
G2	x	x		x	x
H1	x	x	x	x	x
H2	x	x		x	x

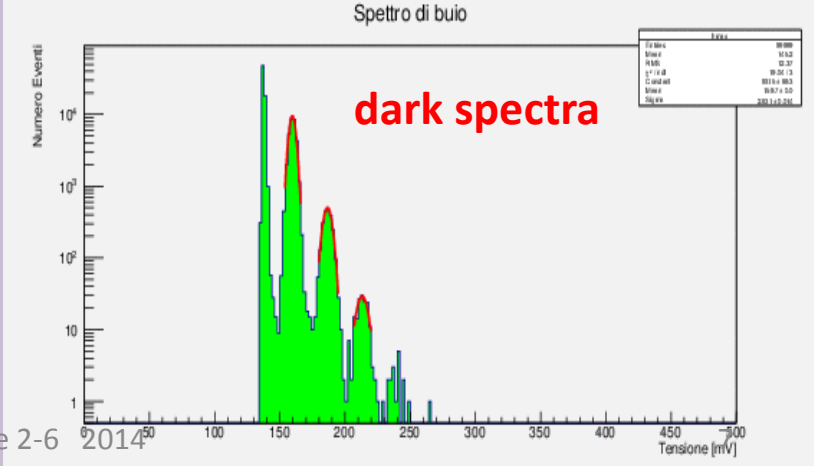


Measurements

- For each SiPM we measured:
  - I-V characteristic curve
  - Acquired a sample of 100k waveforms, from which we:
    - Estimate the dark rate
    - Measure the Gain
- The above measurement were done after each irradiation step:
  - Before irradiation
  - 5 x 10^8 1MeV-eq n/cm^2
  - 5 x 10^9 1MeV-eq n/cm^2
  - 5 x 10^{10} 1MeV-eq n/cm^2
- The temperature was monitored and the measurements corrected offline

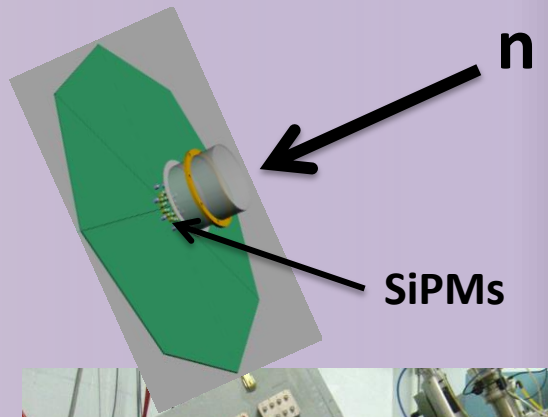


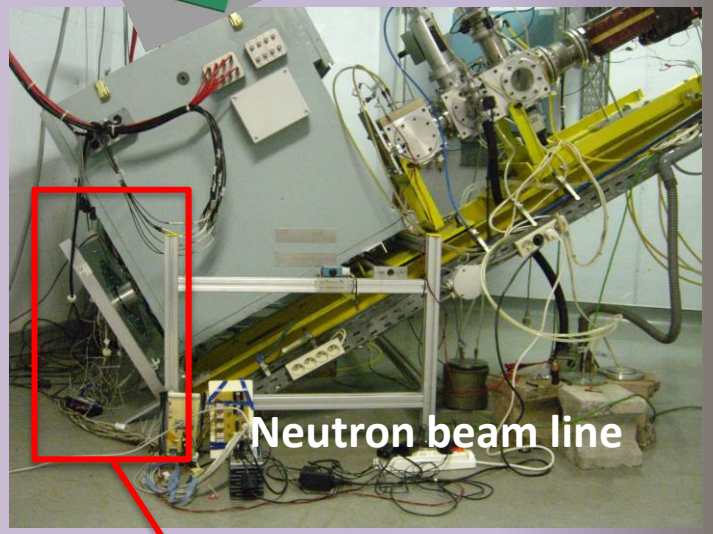


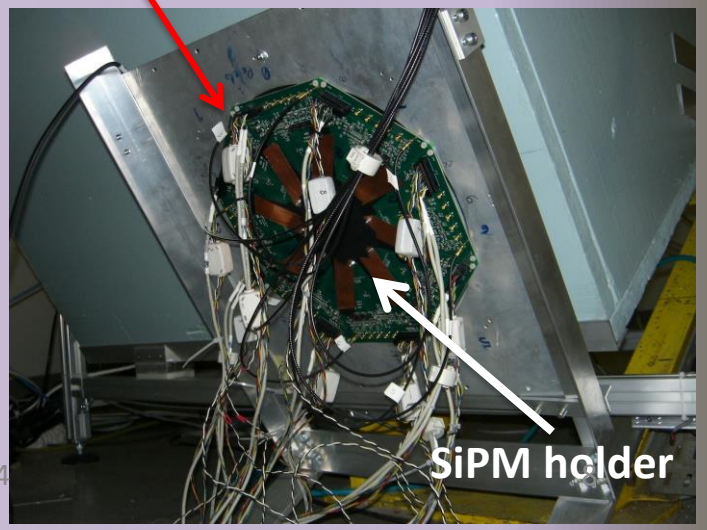


Experimental Setup

- The SiPMs were mounted on a custom made PCB:
  - Bias the SiPMs
  - Connect the SiPMs with the DAQ
  - Monitor the SiPMs temperature (4 pt100 probes)
- The SiPMs were protected and light tightened through an aluminum cap fixed on the PCB
- I-V characteristic curves were measured with a Keithley pico-Ammeter
- Waveforms were acquired thanks to a CAEN Digitizer (2Gs, 12 bits)

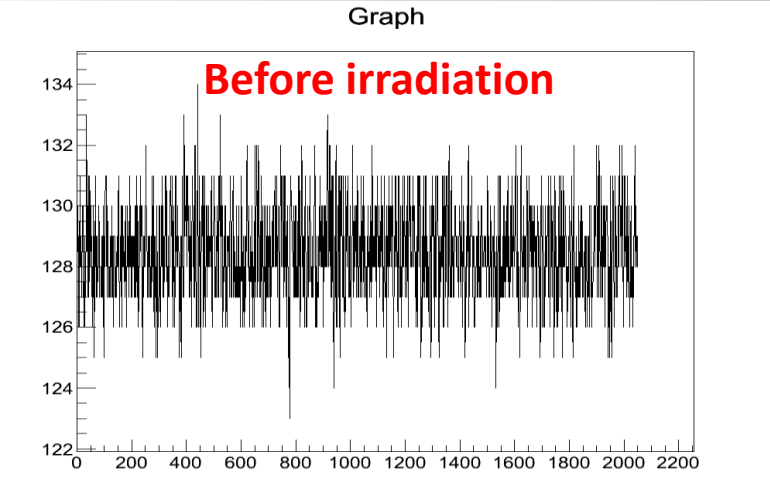


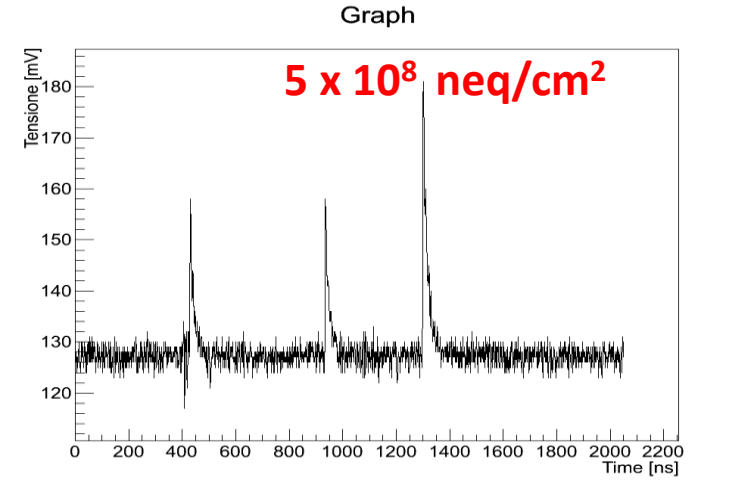


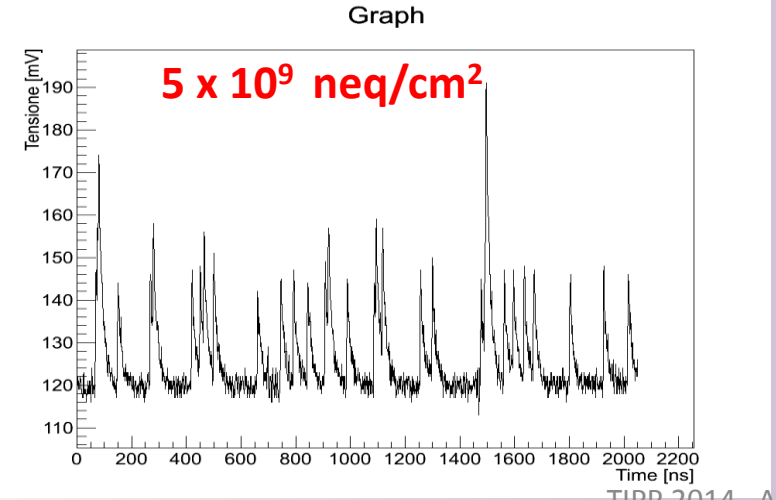


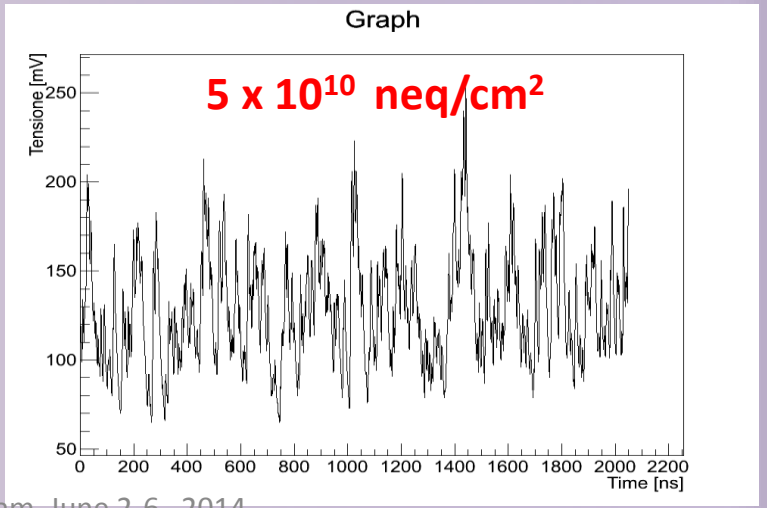
Results: Radiation Effect at a Glance

The radiation damage is very clear looking at the dark noise:

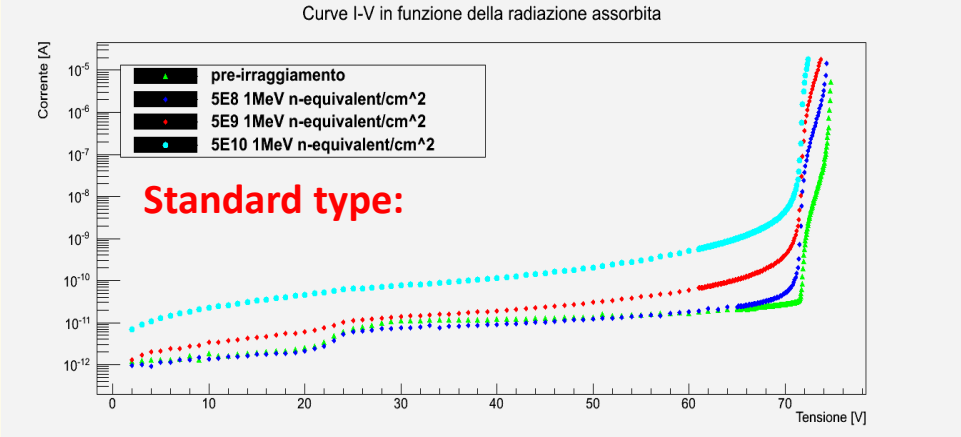


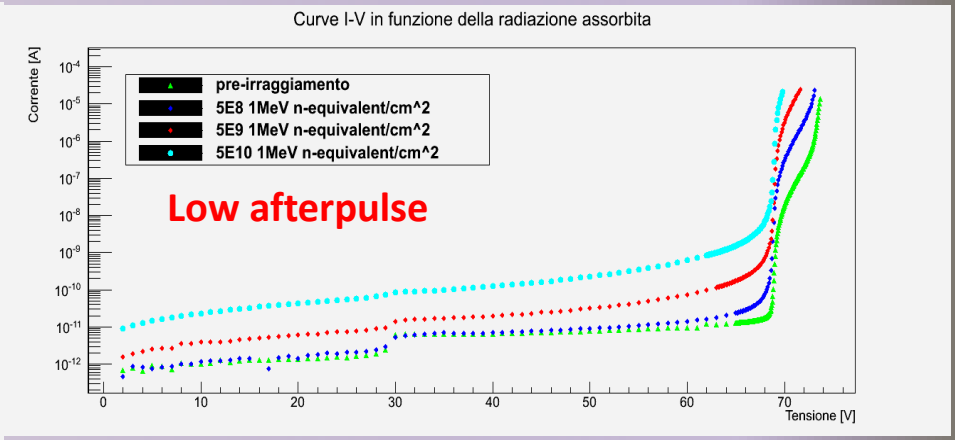


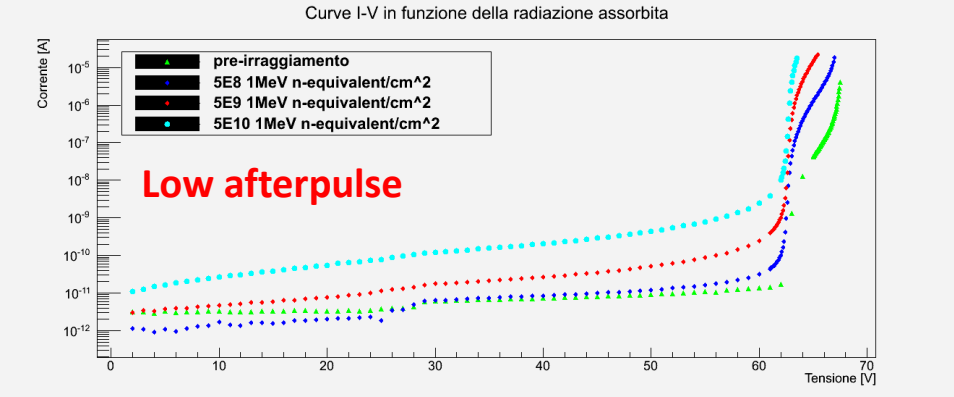


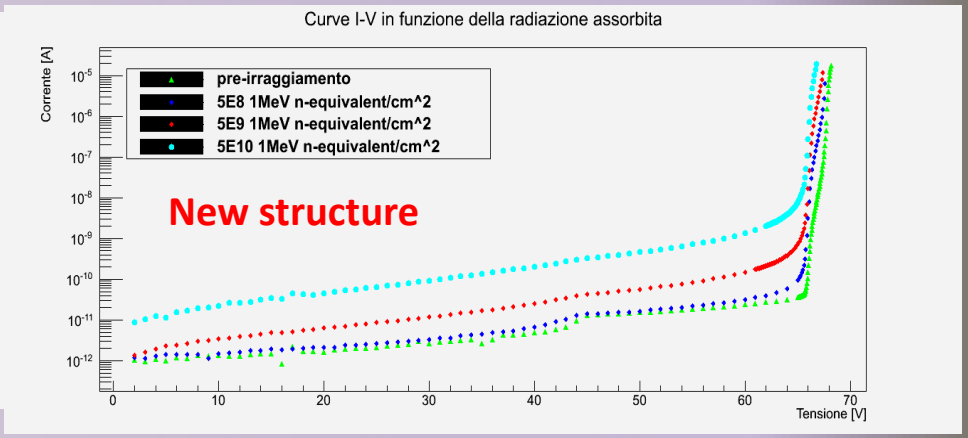


Results: I-V Characteristic Curves



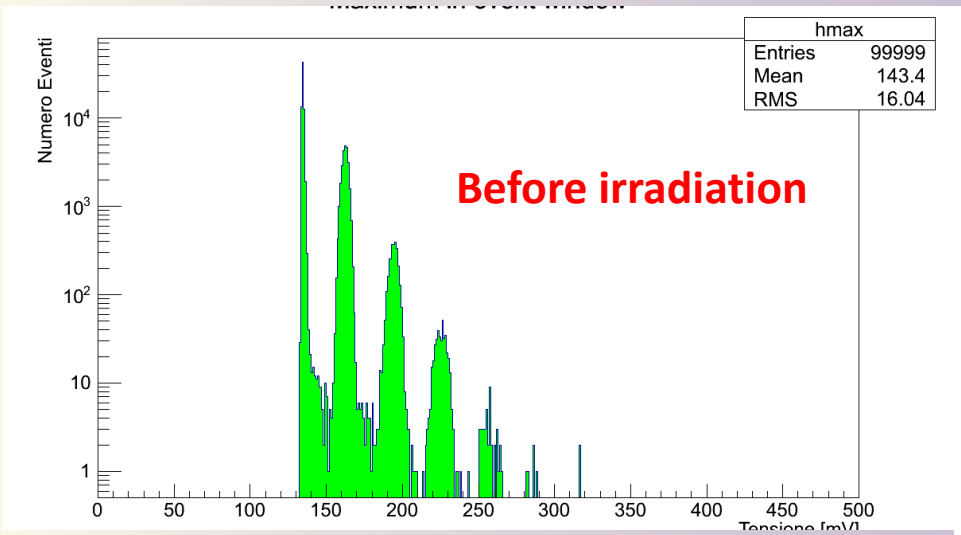


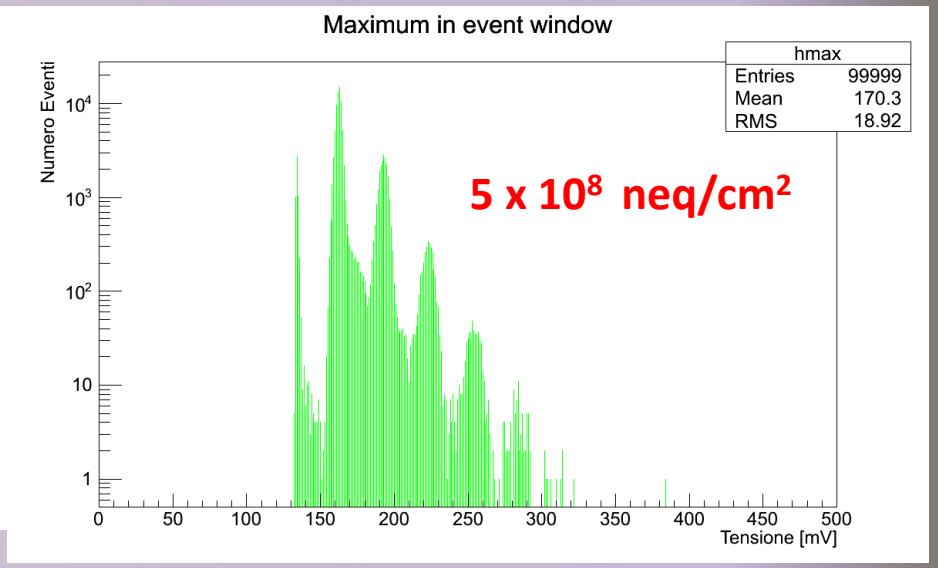


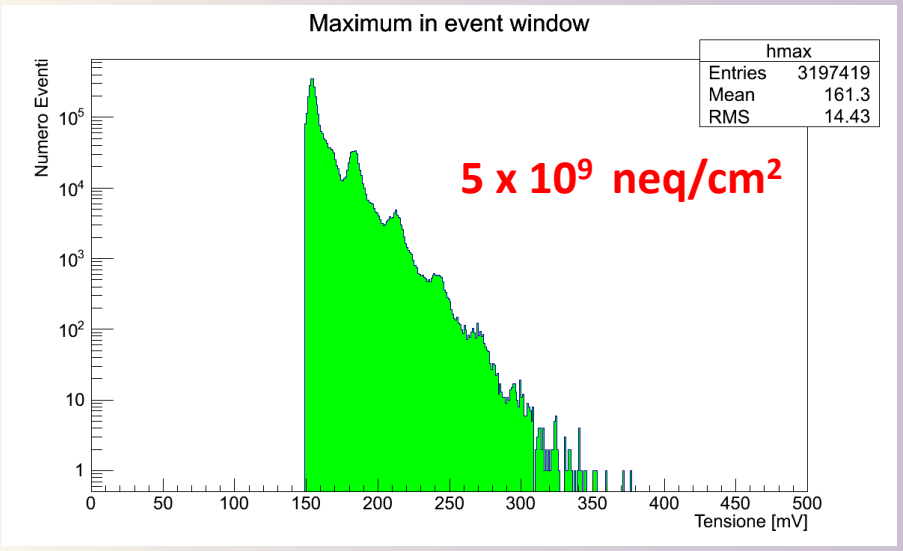


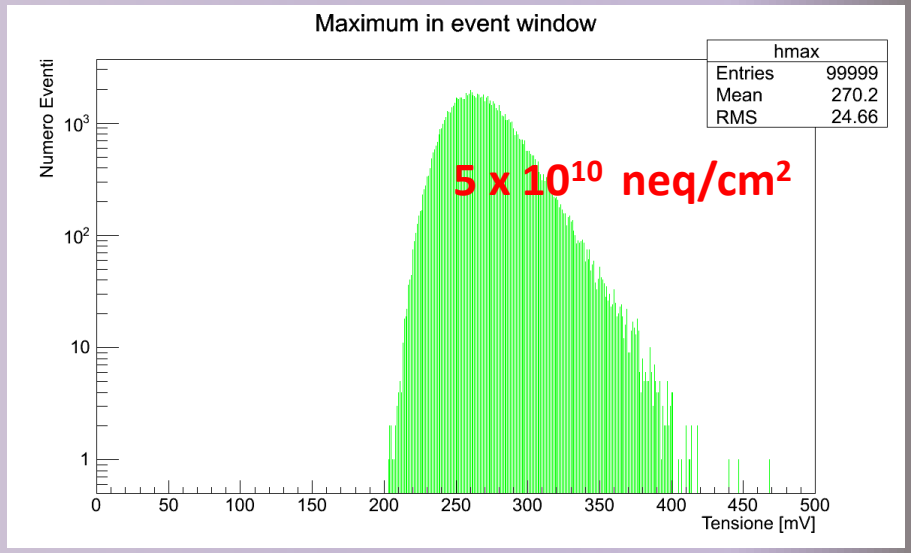
- In general all the devices show an increase of a factor ≈100 in the dark current
- The breakdown point become less sharp and starts a few volts earlier
- No significative differences among the devices

Results: Dark Spectra vs Dose



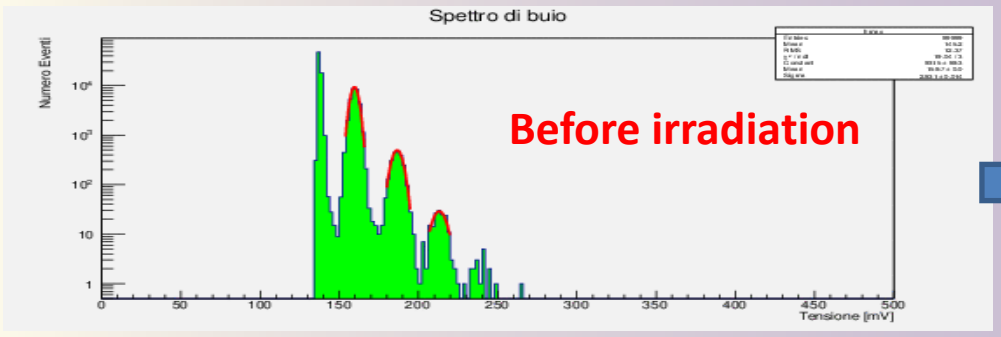


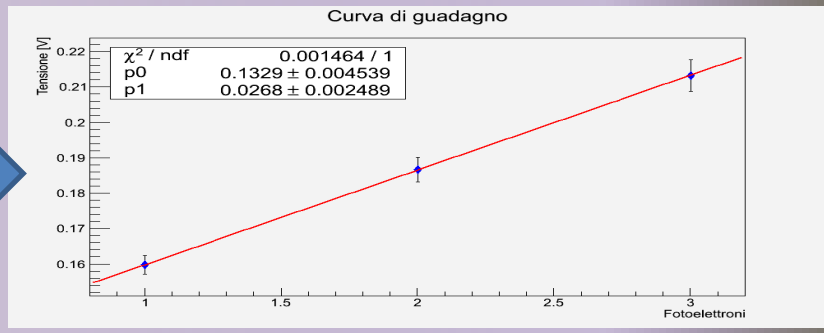


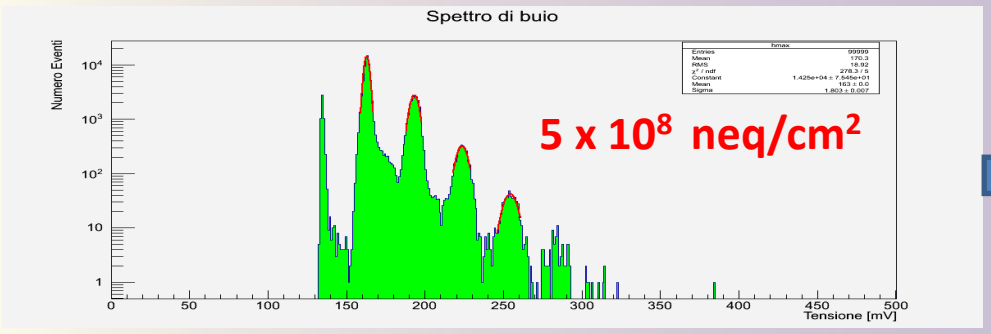


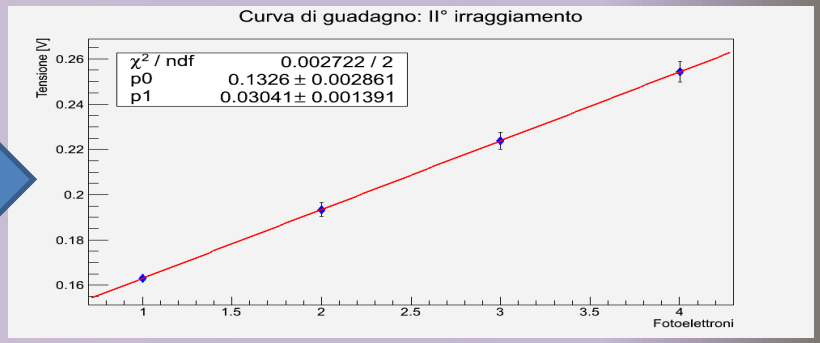
Results: Gain vs Dose

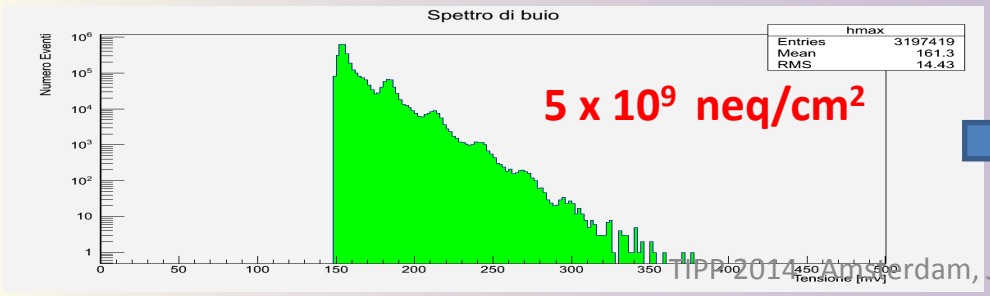
The Gain can be measured as long as the p.e. peaks are visible, i.e. up to 5 x 10^9 neq/cm^2

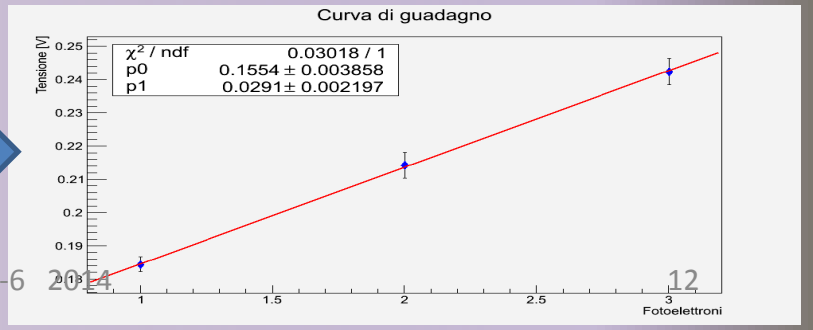




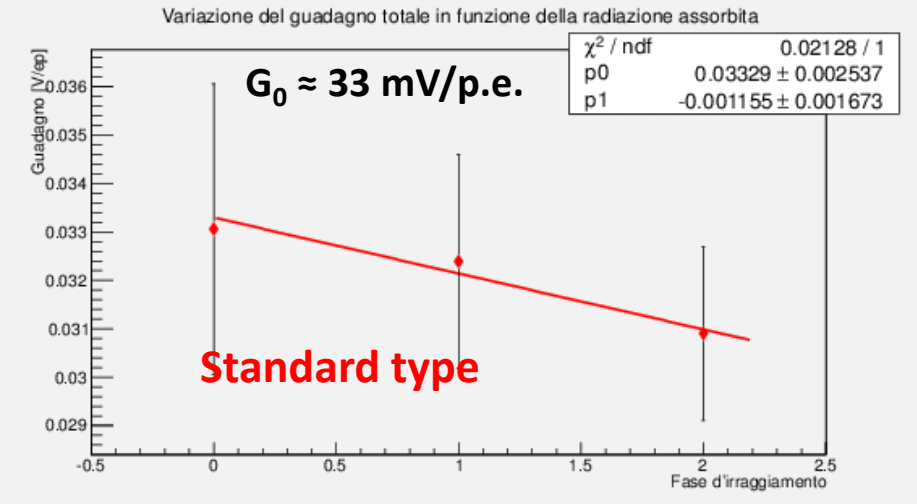


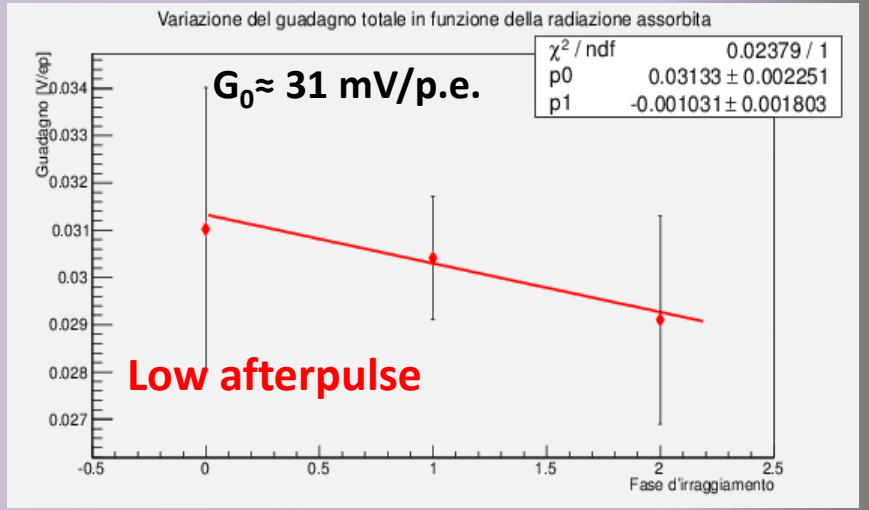




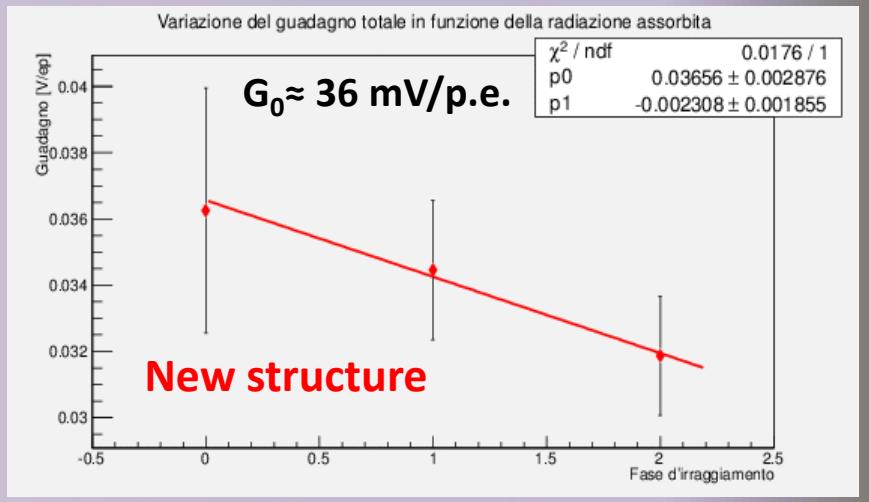


Results: Gain vs Dose

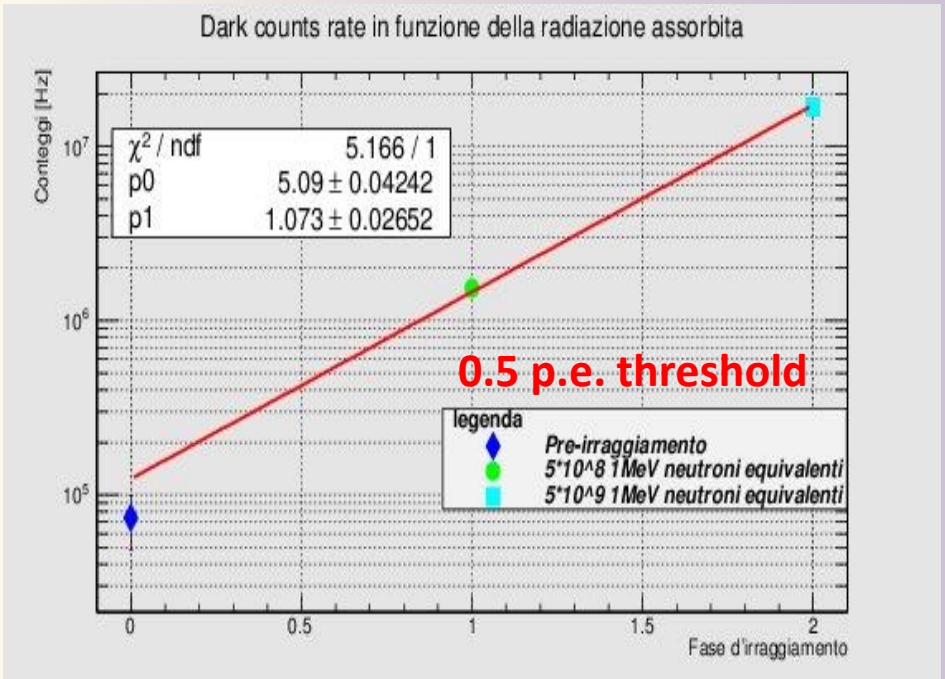




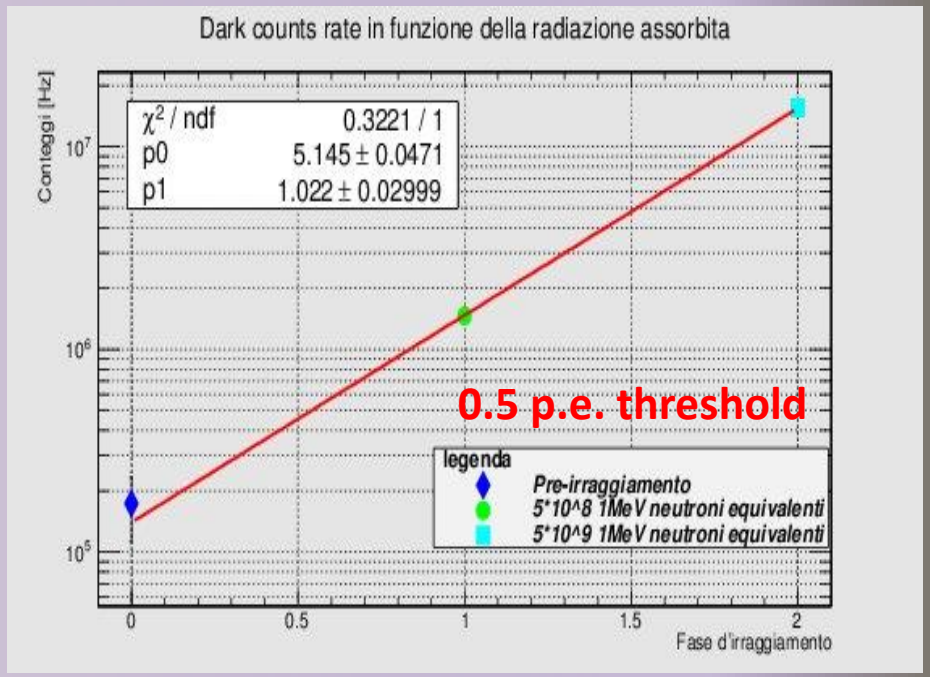
- The Gain reduction is ≈ 6.5% for the standard and low afterpulse types, about 11% for the new structure type
- Initial gain of the new structure SiPM was ≈ 10% higher
- Temperature effects have been corrected



Results: Dark Noise



standard device



low afterpulse

- The rate was measured counting the average number of signals above 0.5 p.e. in the acquired time window (2 μs)
- The dark count rate increases ≈ factor 10 at each irradiation step
- No significative differences among the devices

Conclusions

- 16 SiPM Hamamatsu have been irradiated on a 23MeV neutron beam in Louvain-la-Neuve
- The devices were of 3 types: standard MPPC-like, low afterpulse, new structure
- The integrated 1MeV equivalent doses were:
  - 5×10^8 1MeV-eq n/cm^2
  - 5×10^9 1MeV-eq n/cm^2
  - 5×10^{10} 1MeV-eq n/cm^2
- After each step and for each device we acquired:
  - the characteristic I-V curve
  - a sample of 100k waveform, to measure gain and dark count
- According to our measurements, no significative differences in the main parameters have been observed
- A more detailed analysis is ongoing

Spare

NIEL (Non Ionizing Energy Loss) curve for silicon