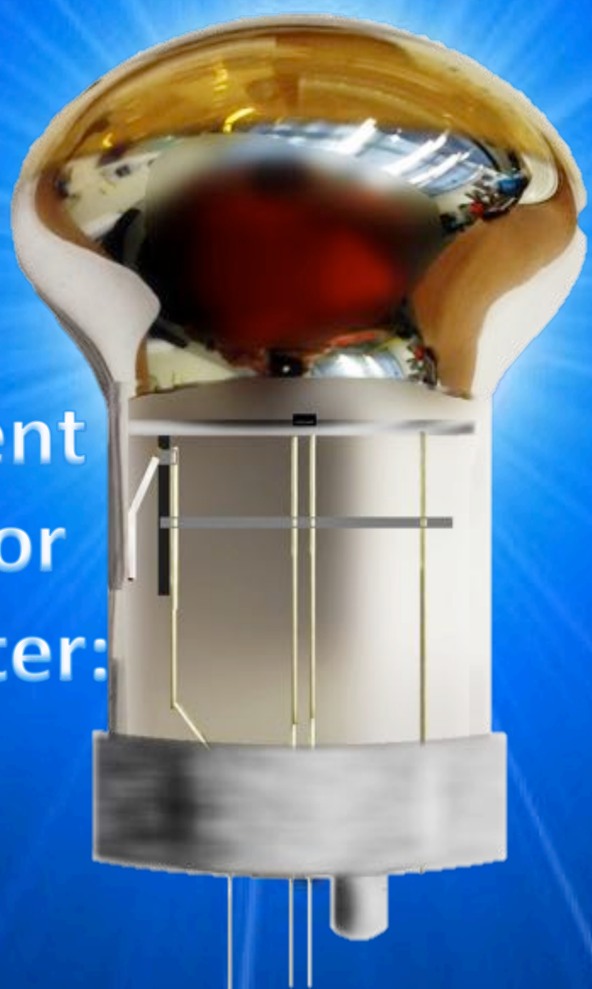
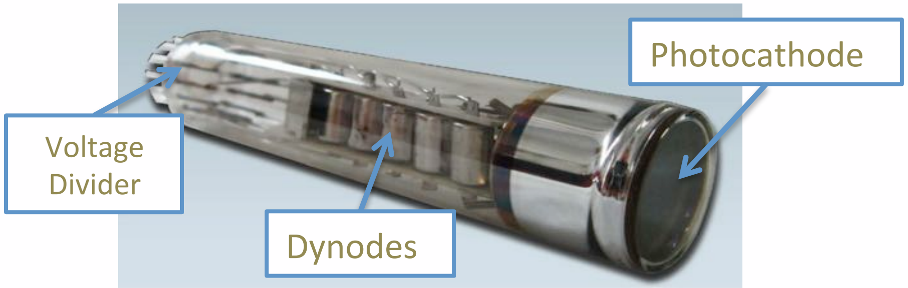
INFN Istituto Nazionale di Fisica Nucleare

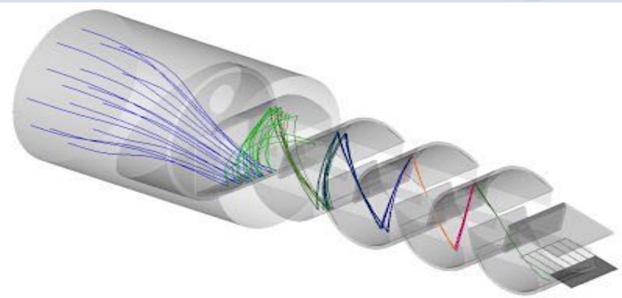
Research and development of a pioneering system for a large area photon counter: the VSiPMT



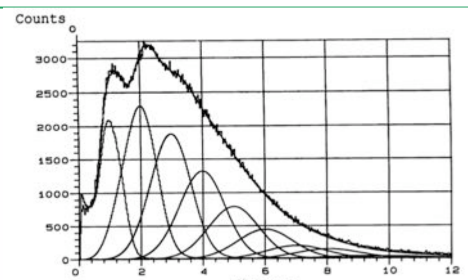
Photodetectors: state of the art

PMTs

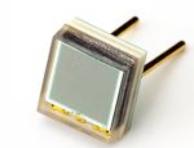


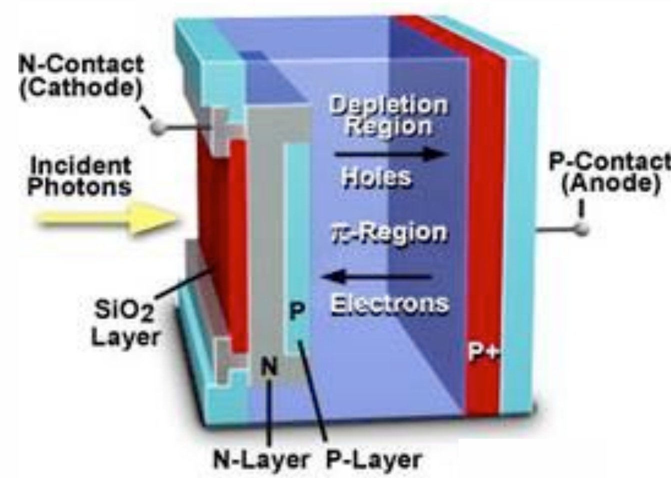


SERIAL GAIN: obtained by multiplying the photoelectrons in the dynodes

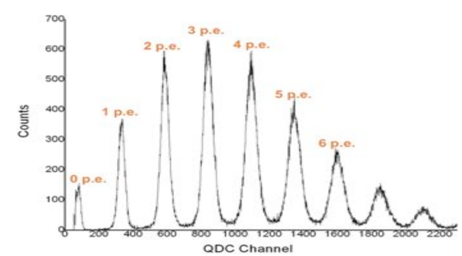


SiPMs

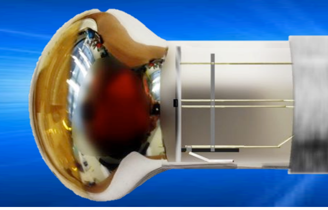




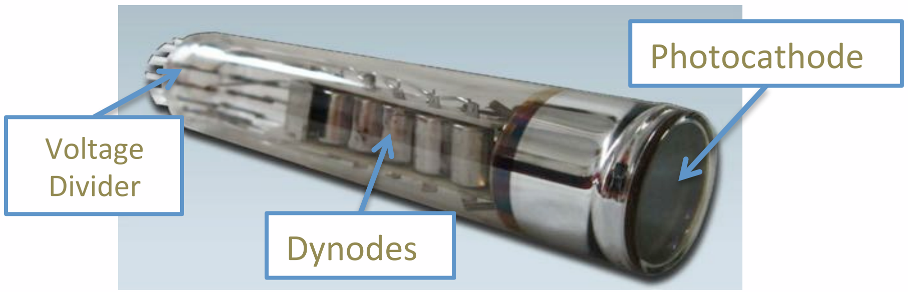
PARALLEL GAIN: obtained with the Geiger-avalanche generated in the p-n junction

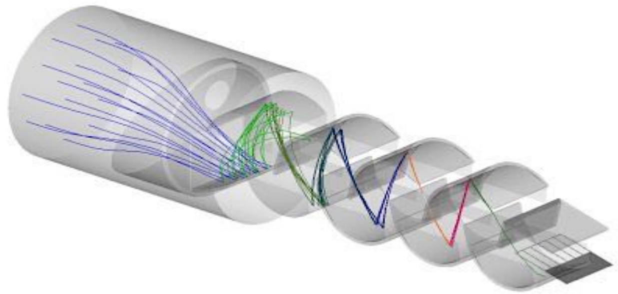


Photodetectors: state of the art



PMTs



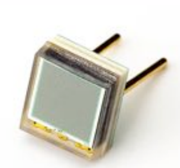


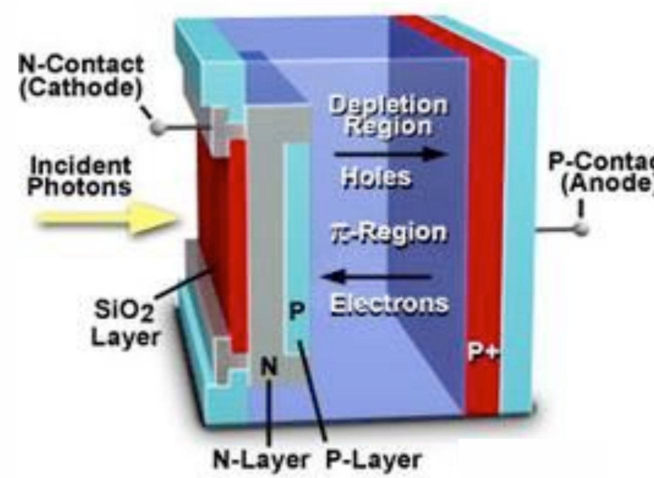
SERIAL GAIN: obtained by multiplying the photoelectrons in the dynodes

CHARACTERISTICS:

- Large sensitive surface (~cm^2)
- Critical time performances
- Poor resolution

SiPMs



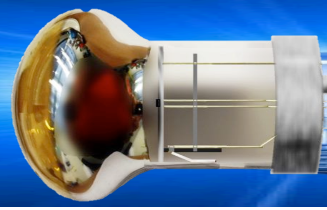


PARALLEL GAIN: obtained with the Geiger-avalanche generated in the p-n junction

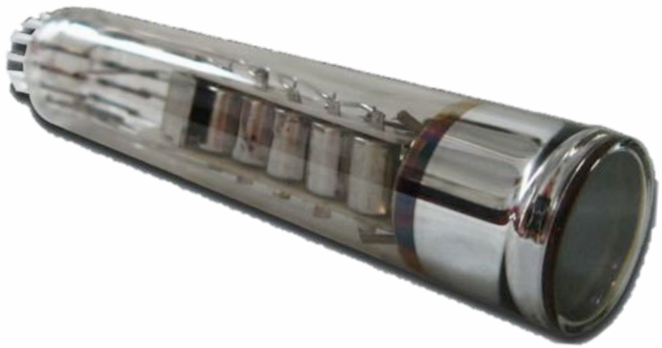
CHARACTERISTICS:

- Small sensitive surface (~mm^2)
- Excellent time performances
- Excellent resolution

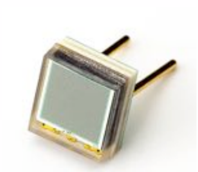
The goal: increase SiPM surface



PMT



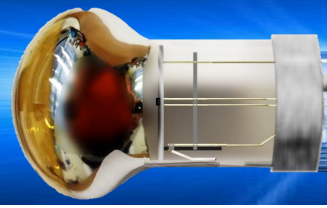
SIPM



VacuumSIliconPhotoMultiplierTube:

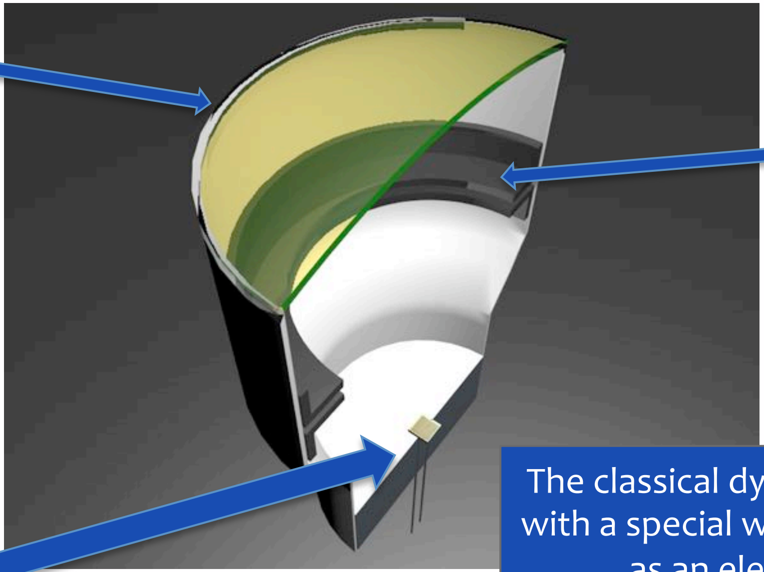
an hybrid solution for a large area photodetector with excellent performances

The goal: increase SiPM surface

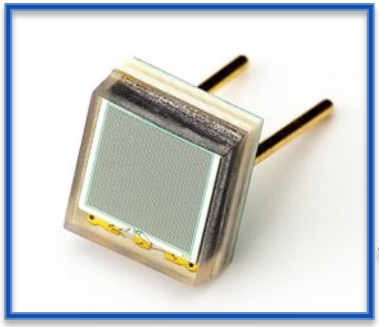


Photocathode

Focusing Ring



e-SiPM



The classical dynode chain of a PMT is replaced with a special windowless p-over-n SiPM, acting as an electron multiplier (e-SiPM).

An innovative design for a modern hybrid photodetector based on the combination of a Silicon PhotoMultiplier (SiPM) with a hemispherical vacuum glass PMT standard envelope

Advantages

The classical dynode chain of a PMT is replaced with a special windowless p-over-n SiPM, acting as an electron multiplier (e-SiPM).

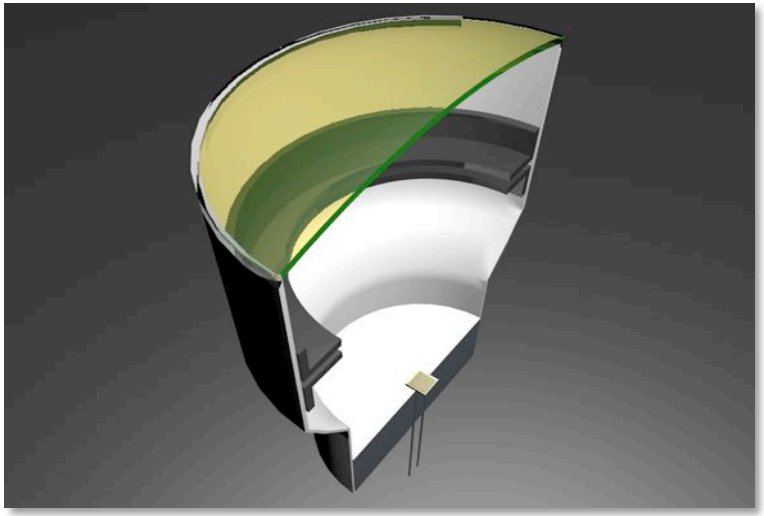
excellent photon counting

high gain (>10^6)

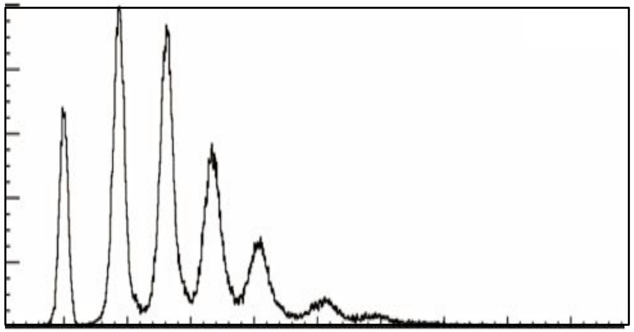
low power consumption (nW)

small TTS (<ns)

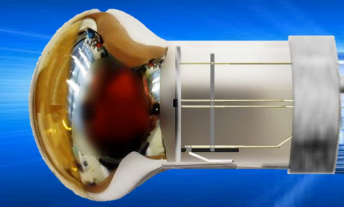
simplicity, compactness and robustness



Thanks to the digital output of the e-SiPM the resolution of the whole device
will be improved with respect to a classical PMT



Advantages



The classical dynode chain of a PMT is replaced with a special windowless p-over-n SiPM, acting as an electron multiplier (e-SiPM).

- excellent photon counting
- high gain ($>10^6$)
- low power consumption (nW)
- small TTS (<ns)
- simplicity, compactness and robustness

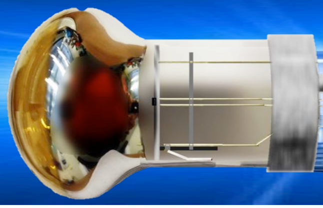
The <u>BIGGEST DIFFERENCE</u> with respect to other hybrids (HPDs)

In a VSiPMT the gain is equal to that of the e-SiPM.

An adequate HV is necessary to confer to the photoelectrons the right energy to enter in the silicon bulk.

A new generation photodetector for astroparticle physics: the VSiPMT, G. Barbarino et al., DOI: 10.1016/j.astropartphys.2015.01.003

Advantages



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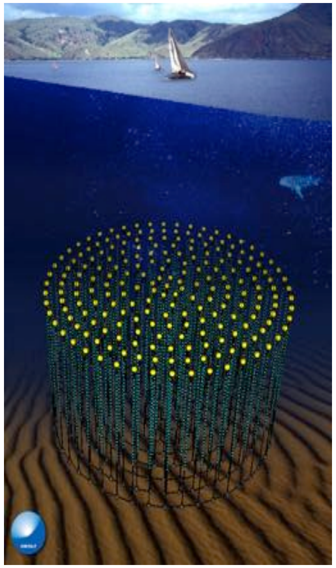
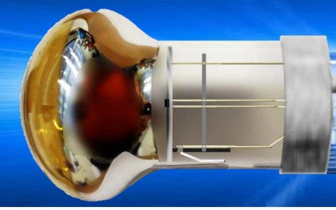
- excellent photon counting
- high gain ($>10^6$)
- low power consumption (nW)
- small TTS (<ns)
- simplicity, compactness and robustness

The absence of the voltage divider leads to a much lower power consumption



GREAT DEAL for such experiments operating in hostile environments (underwater, ice, space)

Advantages

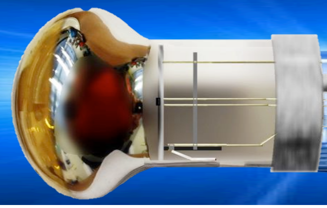


The classical dynode chain of a PMT is replaced with a special windowless p-over-n SiPM, acting as an electron multiplier (e-SiPM).

- excellent photon counting
- high gain ($>10^6$)
- low power consumption (nW)
- **small TTS (<ns)**
- simplicity, compactness and robustness

In the VSiPMT the TTS is simply due to the electron trajectories between the photocathode and the SiPM and so we systematically expect a lower TTS with respect to a classical PMT.

The TTS is smaller for the VSiPMT than for a standard PMT.



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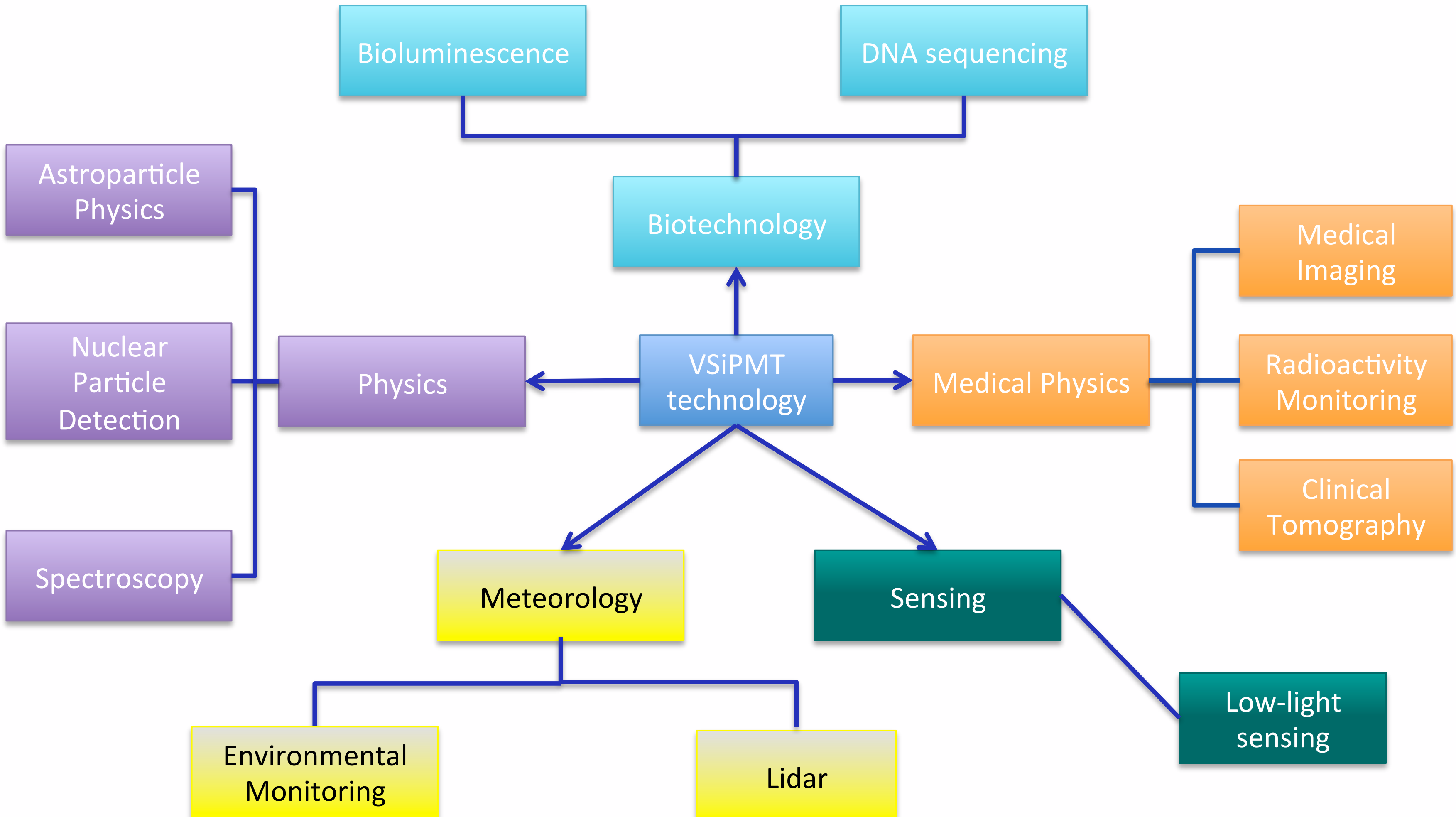
The classical dynode chain of a PMT is replaced with a special windowless p-over-n SiPM, acting as an electron multiplier (e-SiPM).

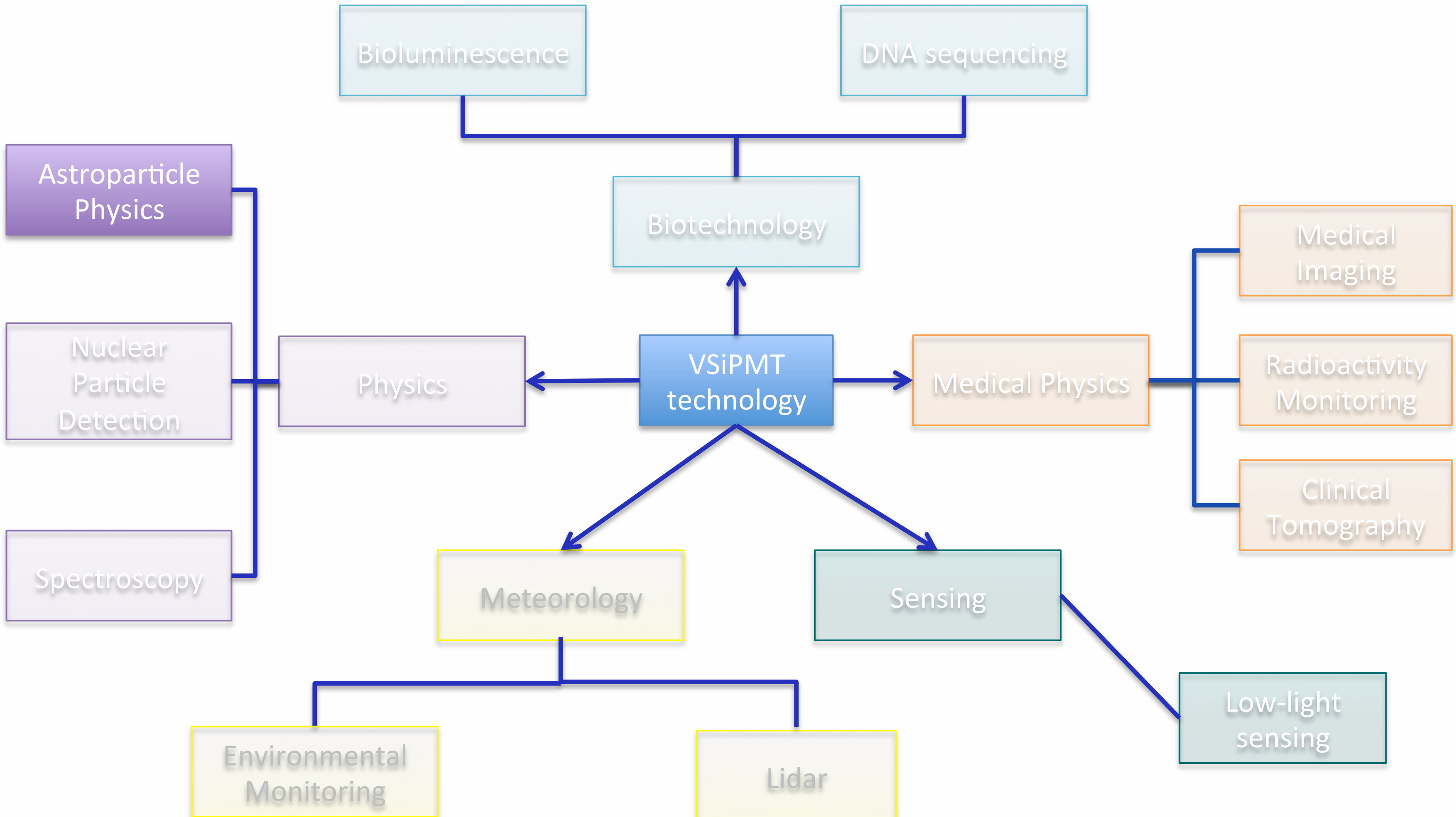
- excellent photon counting
- high gain ($>10^6$)
- low power consumption (nW)
- small TTS (<ns)
- simplicity, compactness and robustness

The VSiPMT is more compact and simpler having **ONLY 3 OUTPUT CONNECTIONS**: HV, SiPM bias voltage and the output signal.

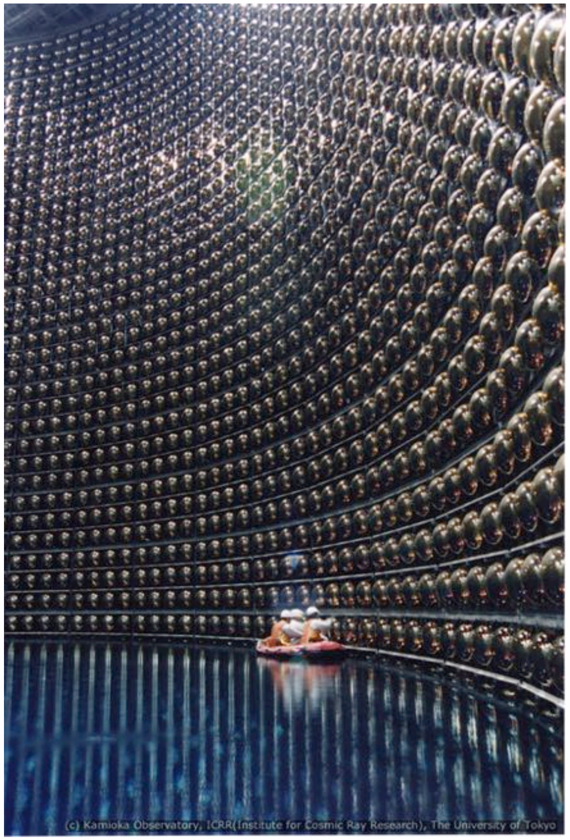
Applications

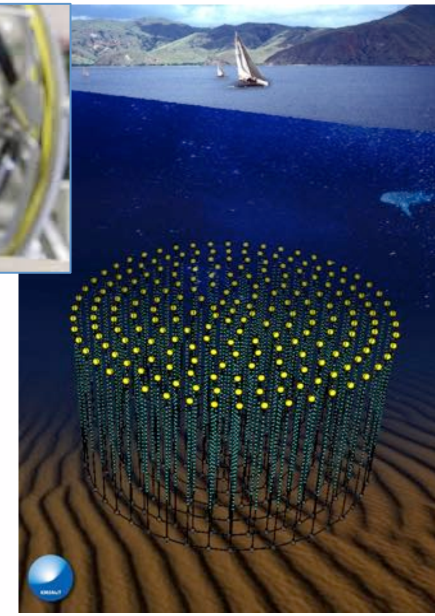


Applications

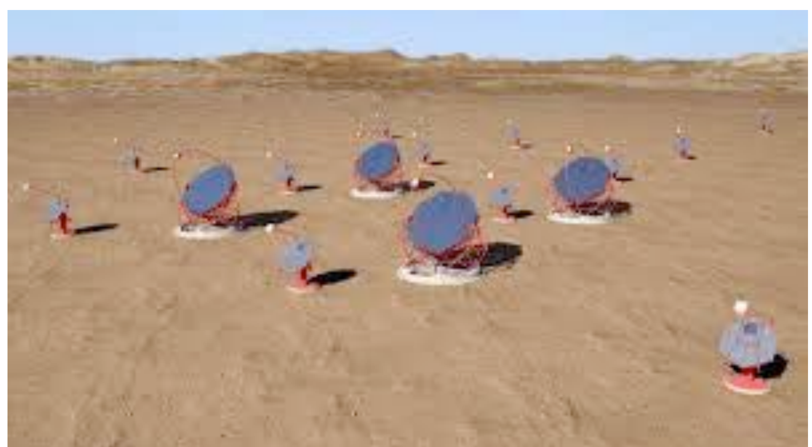


Applications



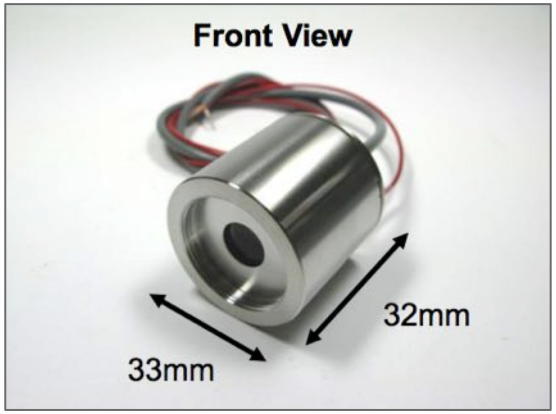


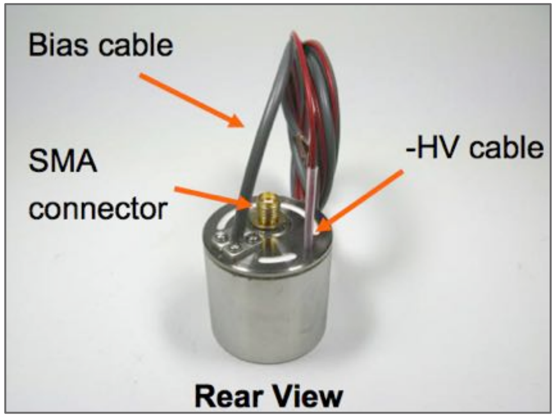
Next future Cherenkov photon counters



An overview on the first industrial prototypes

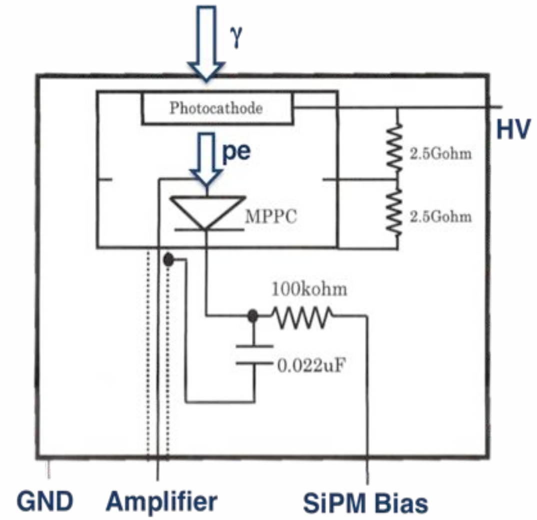
The industrial prototypes





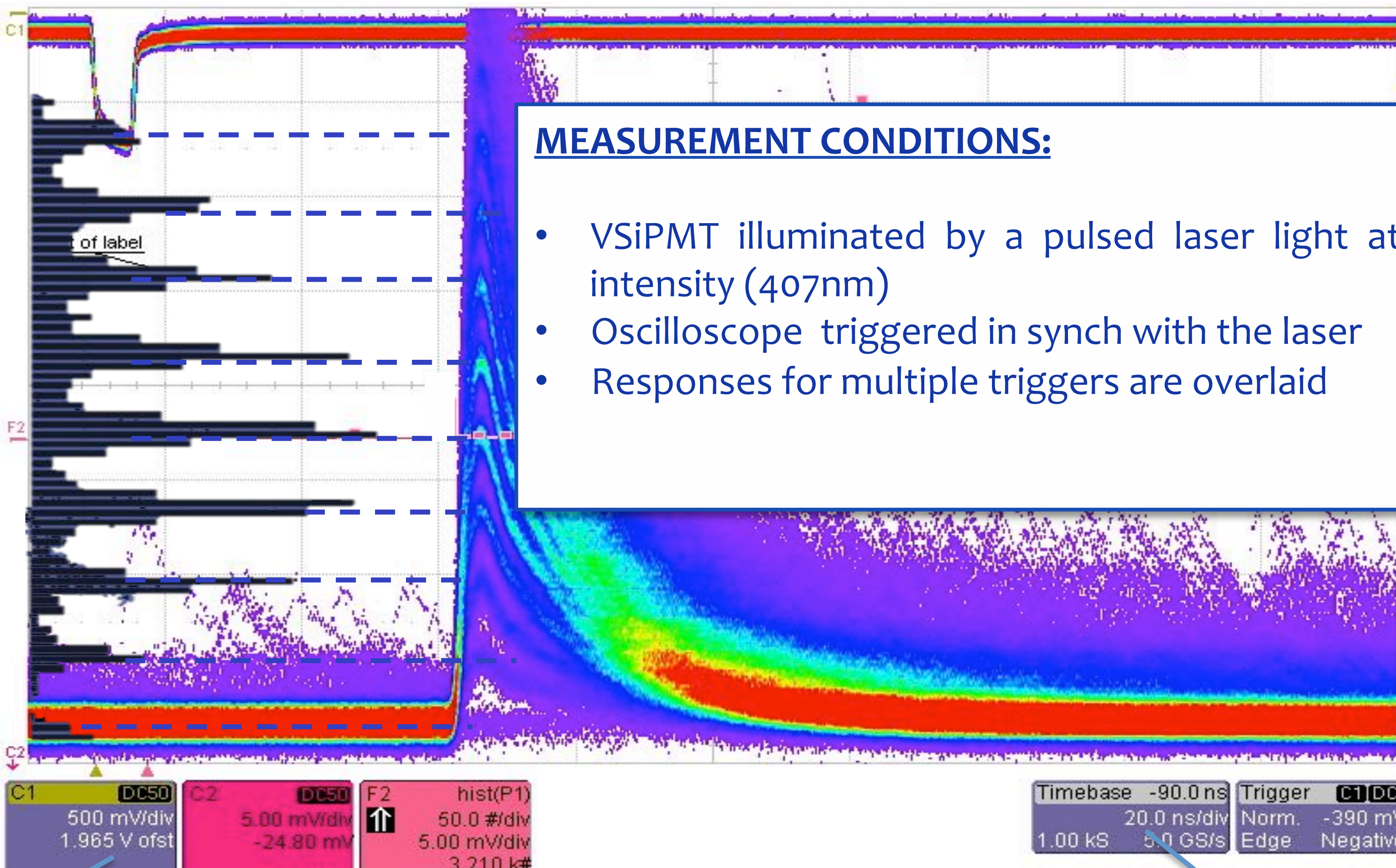
Borosilicate glass entrance window	7x7 mm^2
GaAsP photocathode	3 mm ø

HAMAMATSU
PHOTON IS OUR BUSINESS



2 prototypes:
MPPC 1 mm^2 / 50 μm / 400 pixels
MPPC 1 mm^2 /100 μm / 100 pixels

Waveform and spectra



MEASUREMENT CONDITIONS:

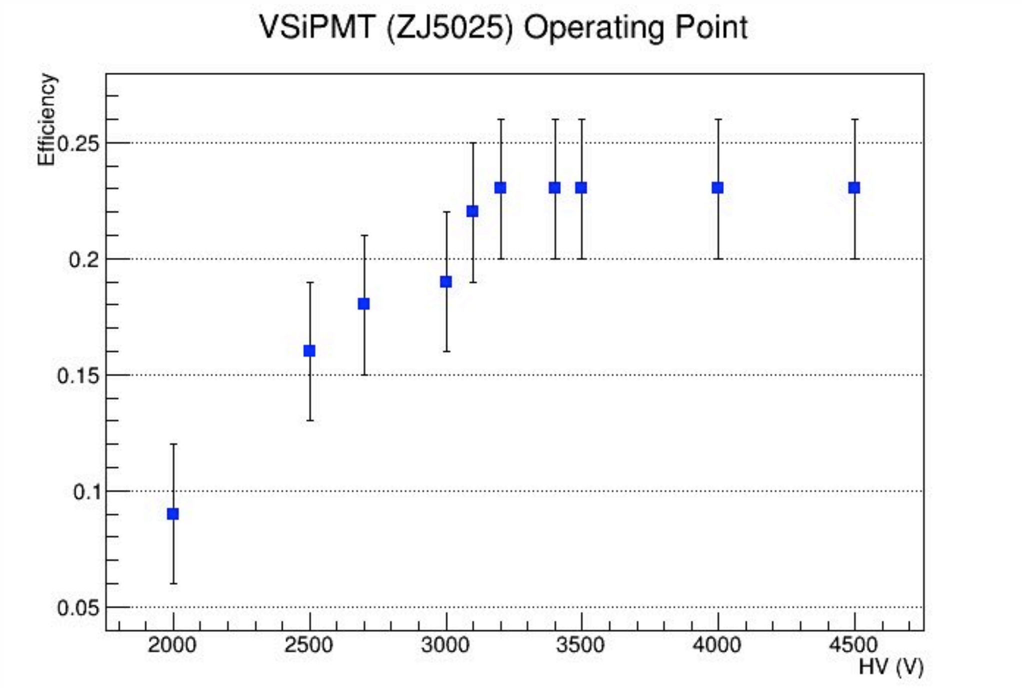
- VSiPMT illuminated by a pulsed laser light at low intensity (407nm)
- Oscilloscope triggered in synch with the laser
- Responses for multiple triggers are overlaid

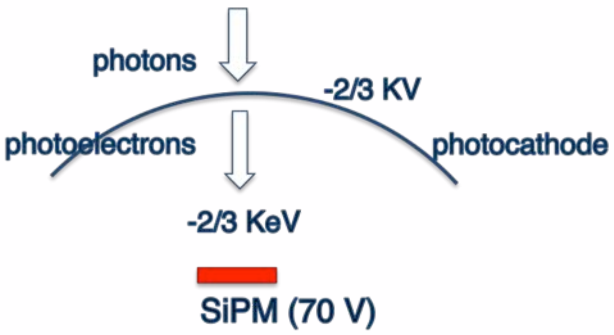
5 mV/div

20 ns/div

Excellent photon counting capability

Work function



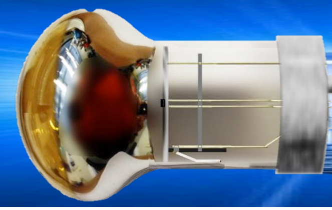


Efficiency is highly stable over 3200 V.
No need for high voltage stabilization.

- HV: photoelectron transfer ⟹ NO power consumption (NULL current) unlike PMTs.
- LV-based gain ⟹ EASY STABILIZATION
- Reducing the SiO_2 coating layer it will be possible to reach the plateau region at even lower voltages.

Realization of a larger VSiPMT prototype

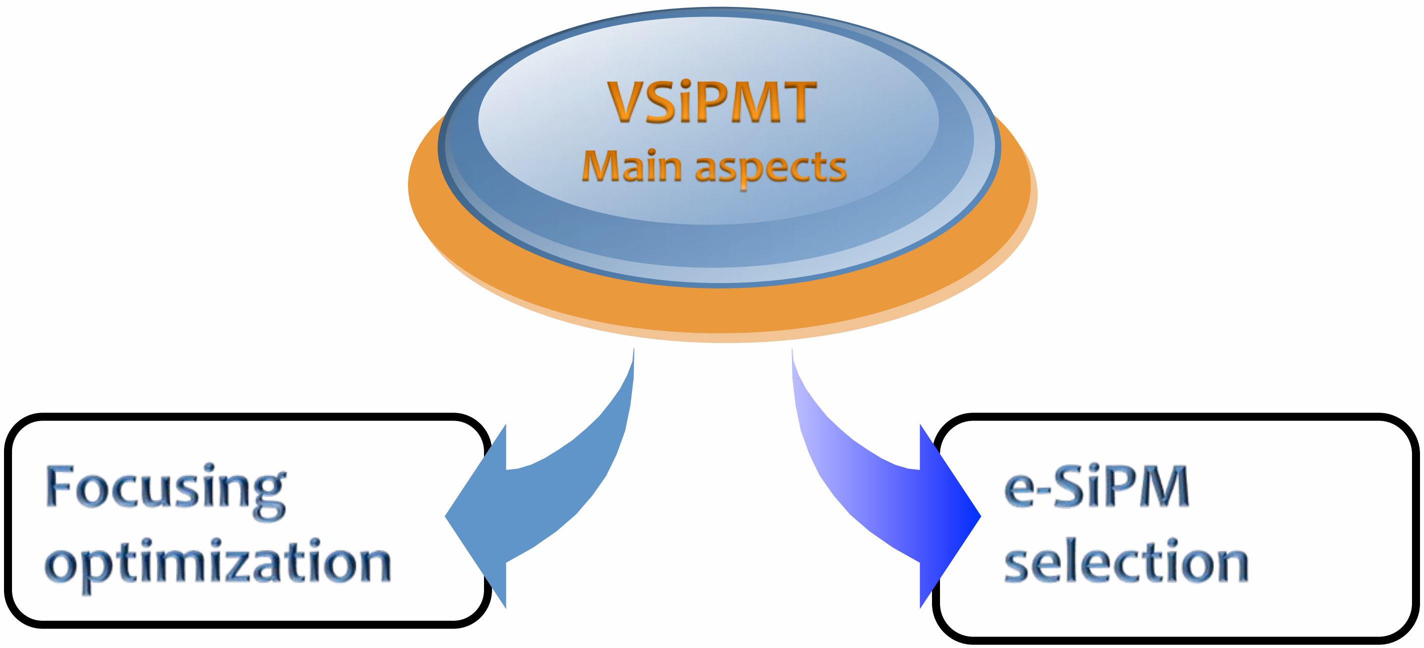
Optimizing a prototype



The characterization of the prototypes by Hamamatsu revealed that the VSiPMT is feasible and competitive

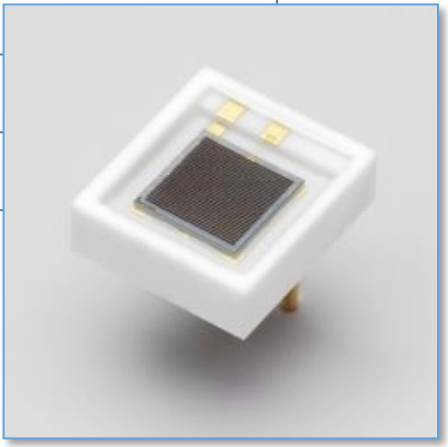
The prototypes by Hamamatsu are too small and non optimized.

The aim: realization of a larger, optimized and usable prototype.



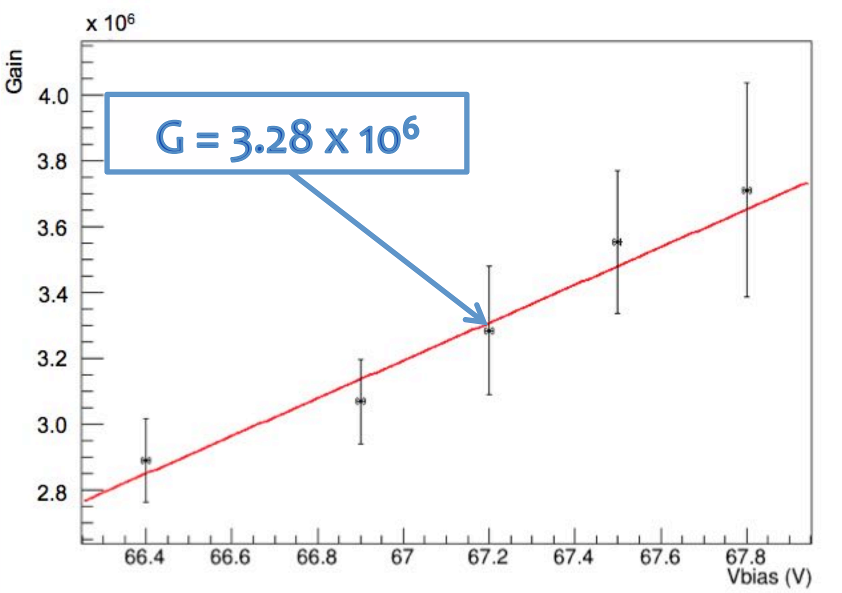
The selected e-SiPM

e-SiPM	MPPC Hamamatsu S10943-3360 (X) n.1
V_{bias}	67.15V
Gain	1.25×10^6
Dark Count Rate	1091 kcps
Size	$3x3\ mm^2$
Pixel Size	50 μm
Number of pixels	3600
Junction	p over n
SiPM type	windowless



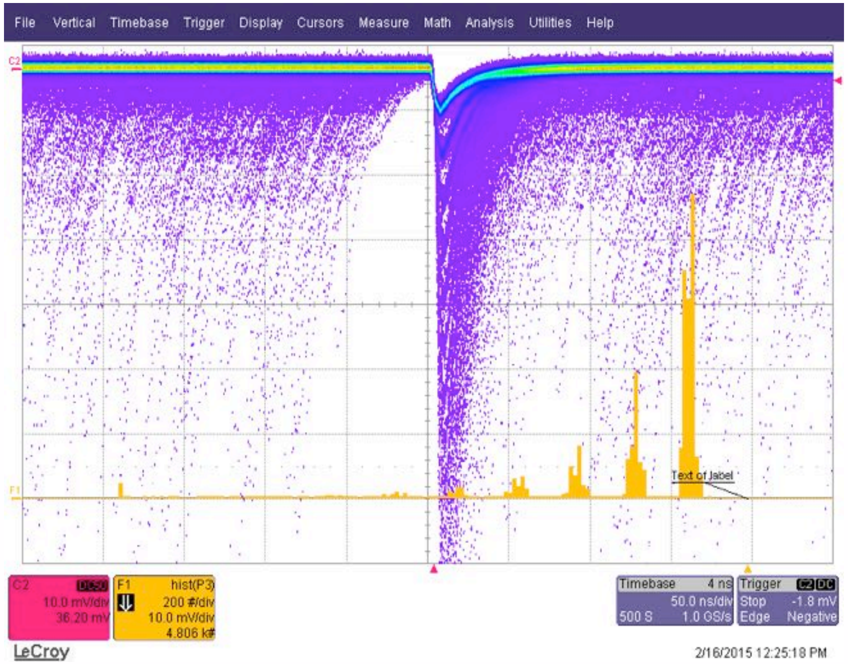
The selected e-SiPM

e-SiPM characteristics

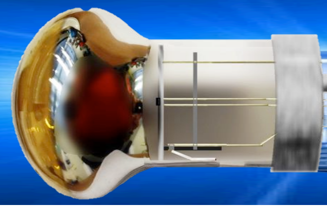


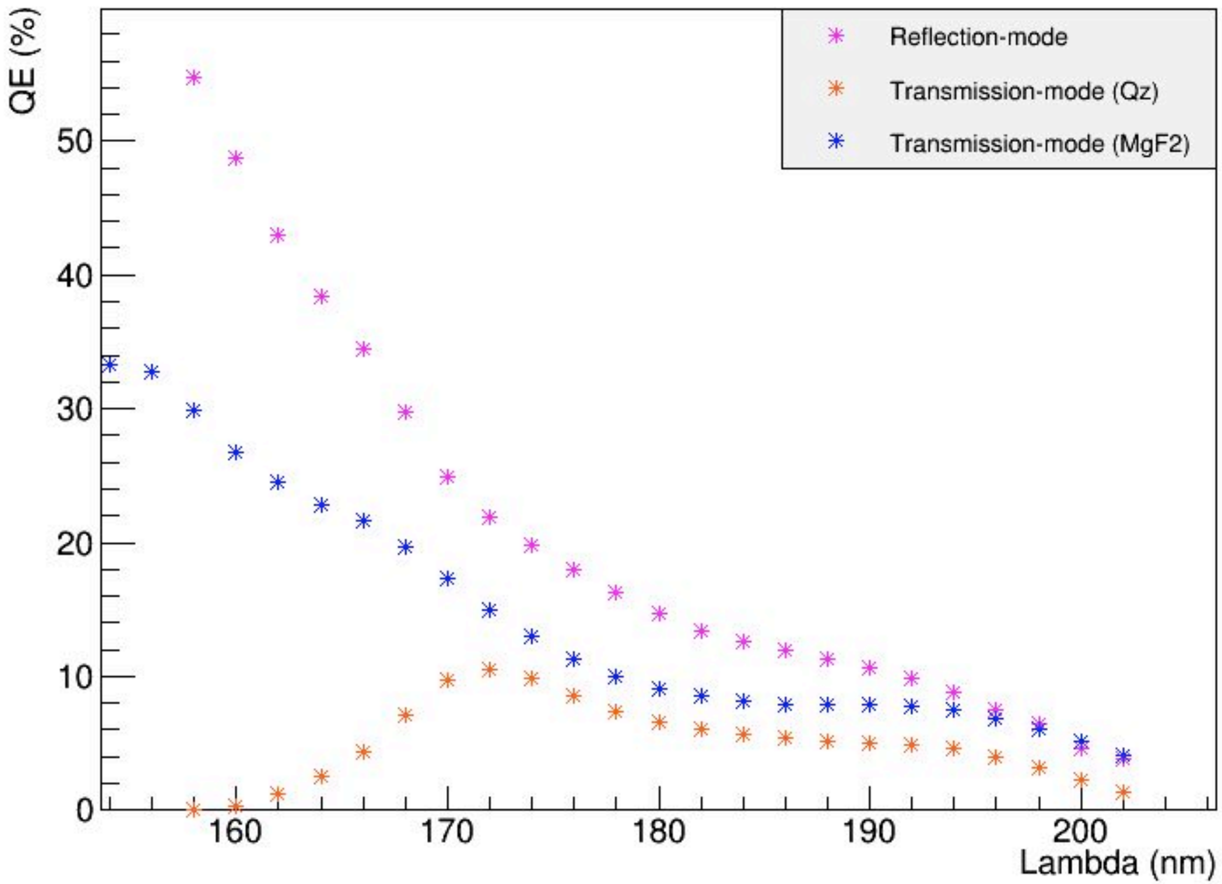
Signal characteristics

V_{bias}	67.2V
τ_{rise}	4ns
τ_{fall}	15ns
Picco	10mV



Photocathode

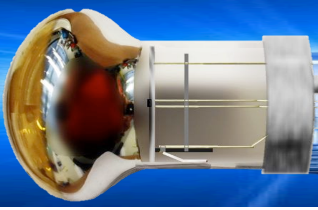




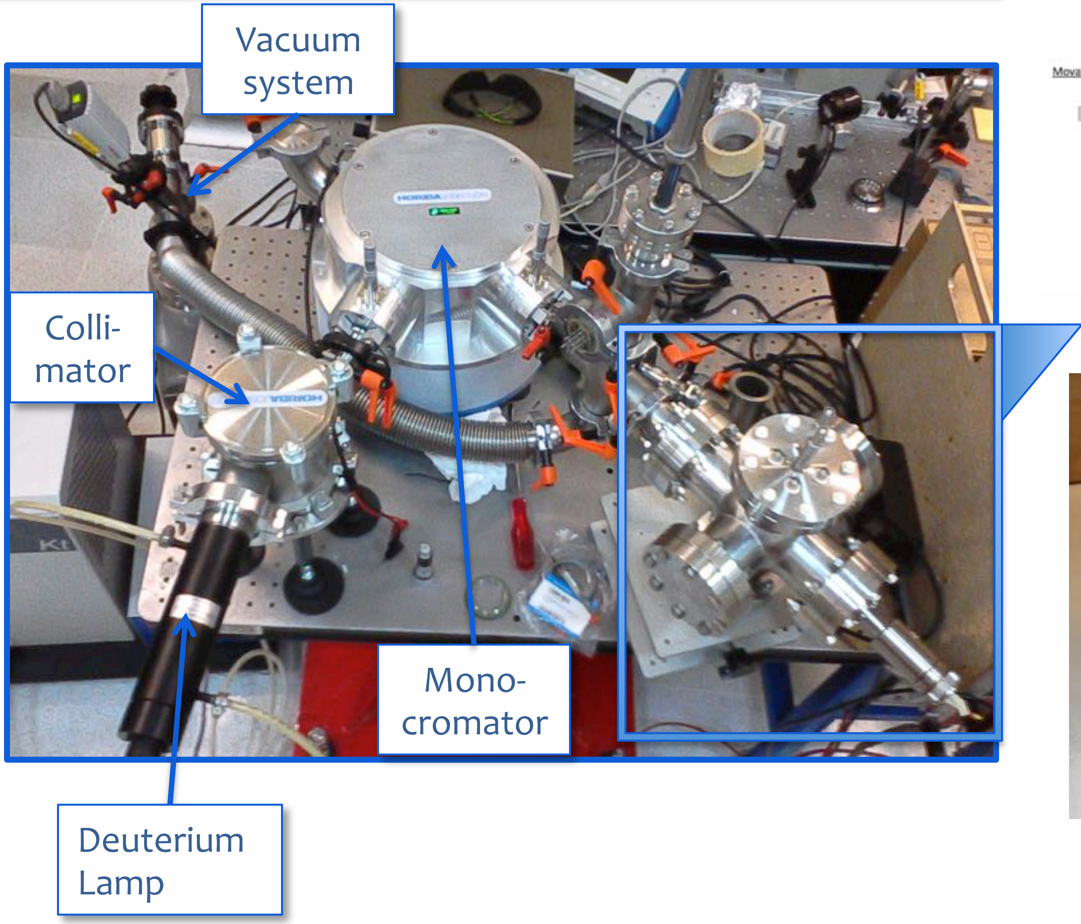
Selected Sample

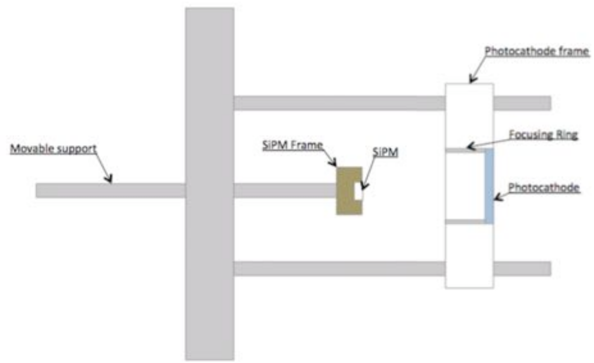
n.1537 (C 2.5nm + Ni 0.5nm) + CsI (20nm)

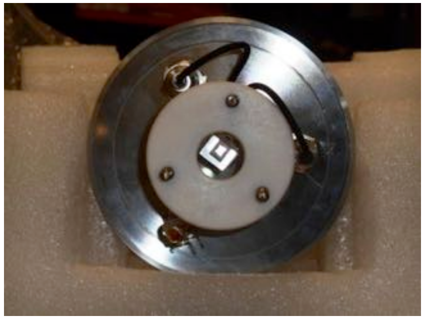
VSiPMT preliminary test bench



MAIN GOALS: check the operation of the device and optimize the focusing

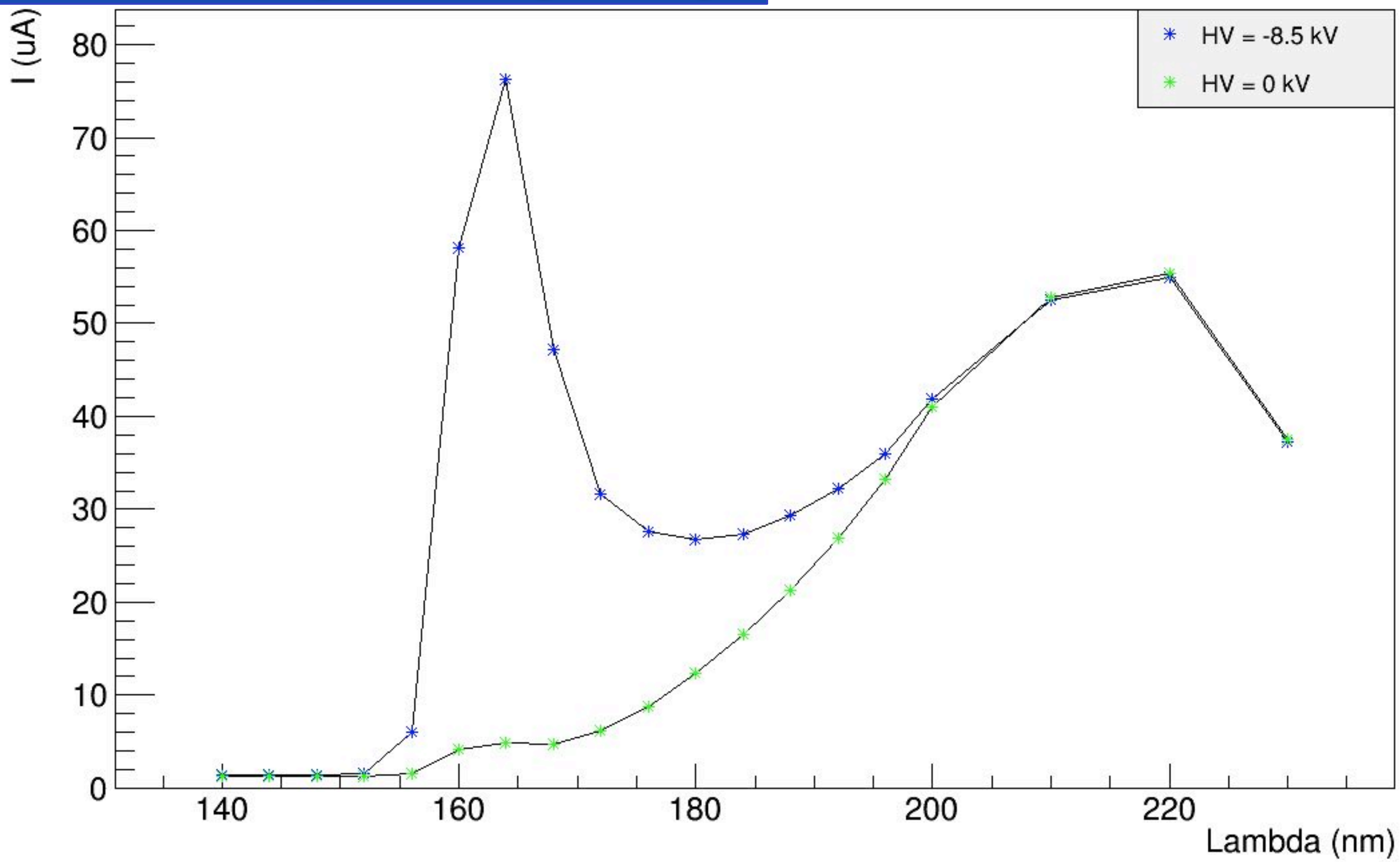






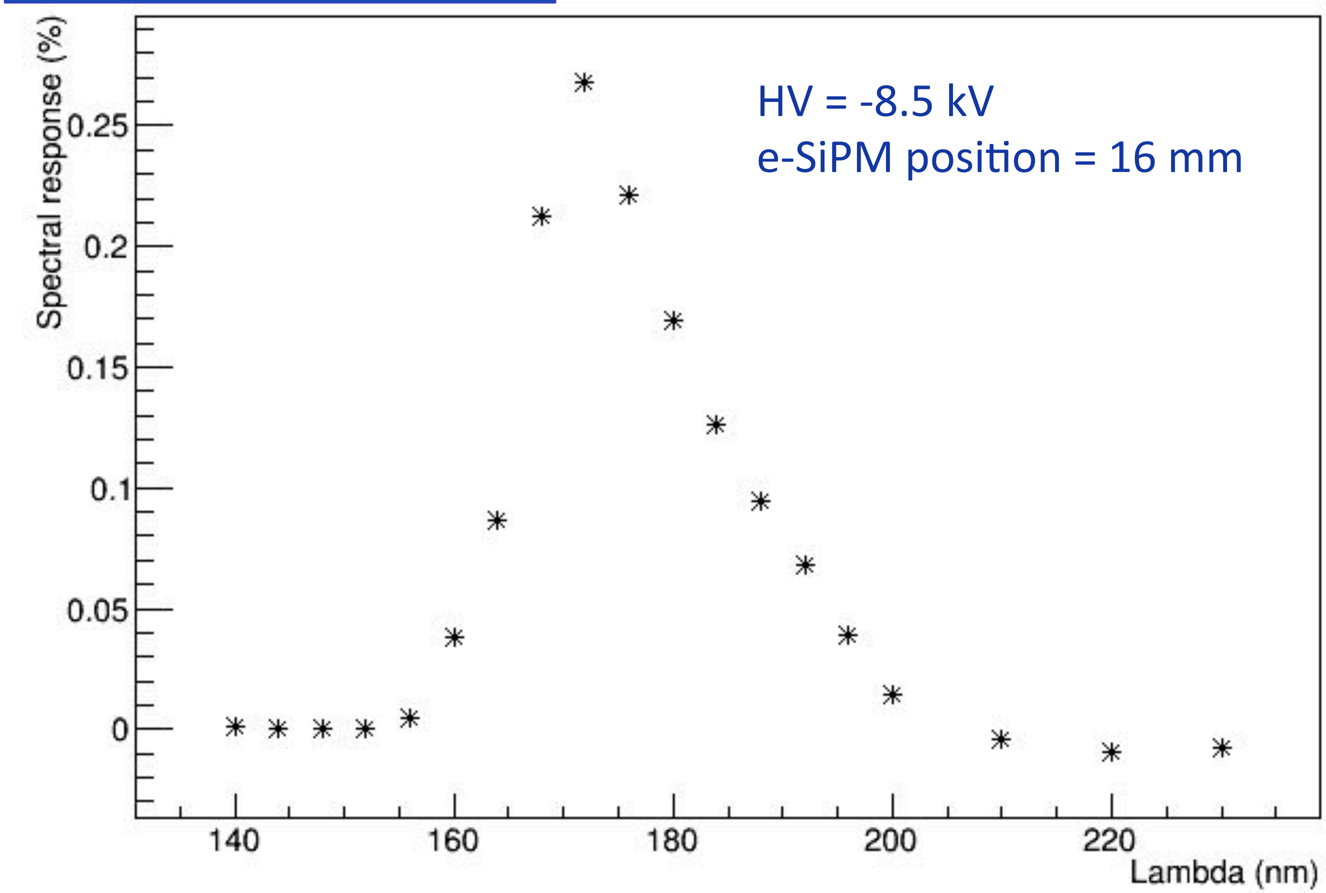
Preliminary results

First check: turning ON the high voltage

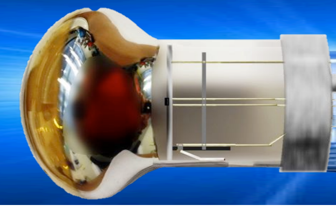


Preliminary results

Spectral response



Technological impact



	PMT	SiPM	HPD	VSiPMT
Gain	10^6 -10^7	10^5 -10^6	10^4 -10^5	$\geq 10^6$
Bias	HIGH	LOW	VERY HIGH	HIGH
Temperature Sensitivity	LOW	HIGH	HIGH	HIGH
Mechanical Robustness	LOW	HIGH	LOW	MEDIUM
Magnetic field sensitivity	YES	NO	YES (lower than PMT)	YES (lower than PMT)
Available Area	BIG	SMALL	MEDIUM	MEDIUM
Resolution	POOR	VERY HIGH	HIGH	VERY HIGH
Noise	LOW	HIGH	MEDIUM	HIGH
Rise time	FAST	FAST	MEDIUM	FAST

Conclusions

The VSiPMT is an idea born in Naples in 2007 to fulfill the requirements of current and next future astroparticle experiments.

The first proof of concept of the device dates back to late 2012. It was made testing a special SiPM with an electron beam at the Physics Department of the University of Naples.

One year later the first industrial prototype has been realized by Hamamatsu Photonics and tested by our group.

Today the VSiPMT i project is financially supported by the Italian Space Agency.
Within this panorama a 1-inch prototype acting in the VUV region has been realized by our group.

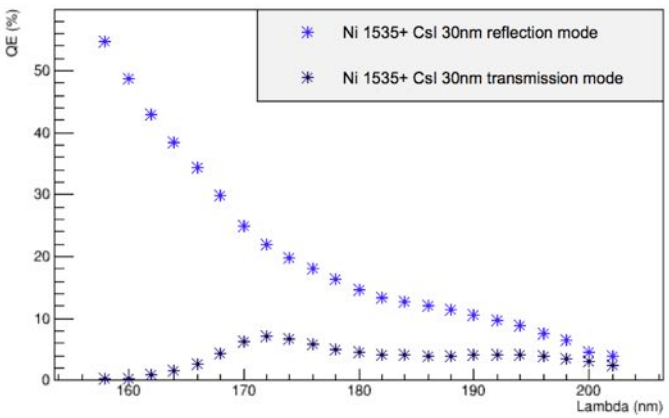
A 1-inch prototype manufactured by Hamamatsu Photonics is currently under test.

We are confident that the VSiPMT will be a reality for the next future experiments!

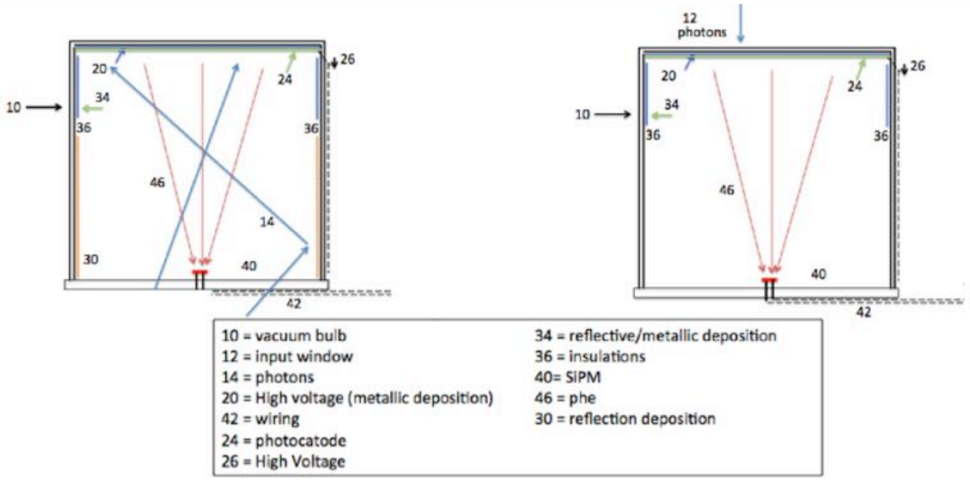
Thank you!

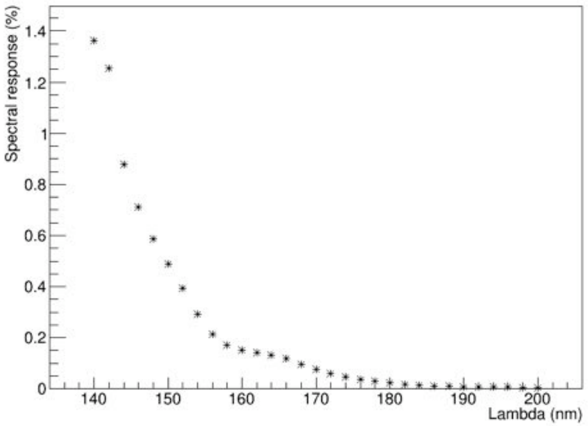
A new configuration

Photocathode QE



The reflection mode VSiPMT





A new configuration for an higher QE in the VUV