Research and development of a pioneering system for a large area photon counter: the VSiPMT
**Photodetectors: state of the art**

**PMTs**
- **Voltage Divider**
- **Photocathode**
- **Dynodes**

**SiPMs**
- **N-Contact (Cathode)**
- **SiO₂ Layer**
- **N-Layer P-Layer**

**SERIAL GAIN:** obtained by multiplying the photoelectrons in the dynodes

**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 (~cm²)
- Critical time performances
- Poor resolution

SiPMs

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

CHARACTERISTICS:
- Small sensitive surface (~mm²)
- Excellent time performances
- Excellent resolution

Felicia Barbato – RICAP 2016 - Frascati
The goal: increase SiPM surface

Vacuum Silicon Photomultiplier Tube: an hybrid solution for a large area photodetector with excellent performances
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.

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

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The BIGGEST DIFFERENCE 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

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

- Bioluminescence
- DNA sequencing
- VSiPMT technology
- Medical Physics
  - Medical Imaging
  - Radioactivity Monitoring
  - Clinical Tomography
- Sensing
  - Low-light sensing
- Meteorology
  - Environmental Monitoring
  - Lidar
- Physics
  - Nuclear Particle Detection
  - Spectroscopy
- Biotechnology
  - Astroparticle Physics
  - Nuclear Particle Detection
  - Spectroscopy
Applications

Next future Cherenkov photon counters
An overview on the first industrial prototypes
The industrial prototypes

Borosilicate glass entrance window 7x7 mm²

GaAsP photocathode 3 mm Ø

2 prototypes:
MPPC 1 mm² / 50 µm / 400 pixels
MPPC 1 mm² / 100 µm / 100 pixels
Excellent photon counting capability

MEASUREMENT CONDITIONS:

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

<table>
<thead>
<tr>
<th>e-SiPM</th>
<th>MPPC Hamamatsu S10943-3360 (X) n.1</th>
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<tbody>
<tr>
<td>$V_{bias}$</td>
<td>67.15V</td>
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<tr>
<td>Gain</td>
<td>$1.25 \times 10^6$</td>
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<tr>
<td>Dark Count Rate</td>
<td>1091 kcps</td>
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<tr>
<td>Size</td>
<td>3x3 mm$^2$</td>
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<tr>
<td>Pixel Size</td>
<td>50 µm</td>
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<tr>
<td>Number of pixels</td>
<td>3600</td>
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<tr>
<td>Junction</td>
<td>p over n</td>
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<tr>
<td>SiPM type</td>
<td>windowless</td>
</tr>
</tbody>
</table>
The selected e-SiPM

**e-SiPM characteristics**

![Graph showing gain vs. Vbias (V)](image)

\[ G = 3.28 \times 10^6 \]

**Signal characteristics**

- \( V_{\text{bias}} \): 67.2V
- \( \tau_{\text{rise}} \): 4ns
- \( \tau_{\text{fall}} \): 15ns
- **Picco**: 10mV
Photocathode

Selected Sample
n.1537 (C 2.5nm + Ni 0.5nm) + CsI (20nm)
MAIN GOALS: check the operation of the device and optimize the focusing

- Vacuum system
- Collimator
- Monochromator
- Deuterium Lamp
First check: turning ON the high voltage
Preliminary results

Spectral response

HV = -8.5 kV
e-SiPM position = 16 mm
## Technological impact

<table>
<thead>
<tr>
<th></th>
<th>PMT</th>
<th>SiPM</th>
<th>HPD</th>
<th>VSiPMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>$10^6 - 10^7$</td>
<td>$10^5 - 10^6$</td>
<td>$10^4 - 10^5$</td>
<td>$\geq 10^6$</td>
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<tr>
<td>Bias</td>
<td>HIGH</td>
<td>LOW</td>
<td>VERY HIGH</td>
<td>HIGH</td>
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<tr>
<td>Temperature Sensitivity</td>
<td>LOW</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>Mechanical Robustness</td>
<td>LOW</td>
<td>HIGH</td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Magnetic field sensitivity</td>
<td>YES</td>
<td>NO</td>
<td>YES (lower than PMT)</td>
<td>YES (lower than PMT)</td>
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<tr>
<td>Available Area</td>
<td>BIG</td>
<td>SMALL</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
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<tr>
<td>Resolution</td>
<td>POOR</td>
<td>VERY HIGH</td>
<td>HIGH</td>
<td>VERY HIGH</td>
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<tr>
<td>Noise</td>
<td>LOW</td>
<td>HIGH</td>
<td>MEDIUM</td>
<td>HIGH</td>
</tr>
<tr>
<td>Rise time</td>
<td>FAST</td>
<td>FAST</td>
<td>MEDIUM</td>
<td>FAST</td>
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</table>
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 for an higher QE in the VUV