Another step in photodetection innovation: the 1-inch VSiPMT prototype

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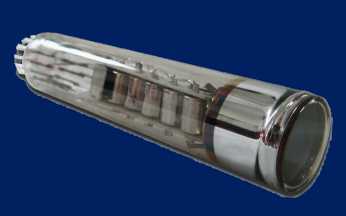
Abstract

The VSiPMT (Vacuum Silicon PhotoMultiplier Tube) is an original design for an innovative light detector we proposed with the aim to create new scientific instrumentation for future missions of exploration and observation of the universe. The idea behind this device is to replace the classical dynode chain of a photomultiplier tube with a silicon photomultiplier, the latter acting as an electron detector and amplifier. In this way we obtain a large area photodetector with an excellent photon counting, proper of the SiPMs, but with the dark noise of only one SiPM (1-inch is equivalent to ~ 54 SiPM 3x3 mm^2). From this point of view, the VSiPMT offers very attractive features and unprecedented performance in large area detection, such as: negligible power consumption, excellent SPE resolution, easy low-voltage-based stabilization and very good time performance. Hamamatsu realized for our group a 1-inch prototype. We present the results of the full characterization of the device.

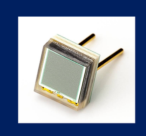
The idea

PMT



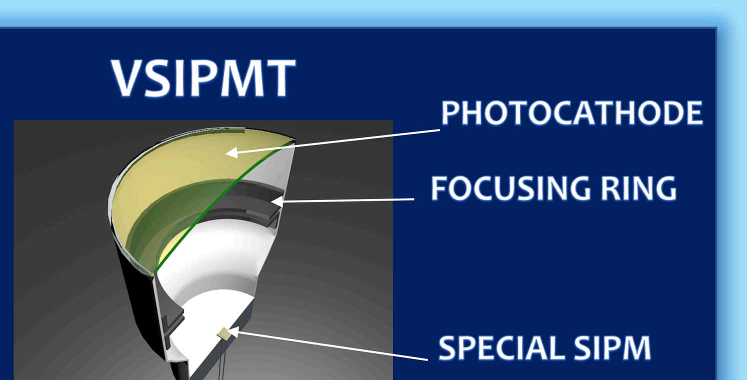
- Large sensitive surface (~cm^2)
- Good time performances
- Poor resolution

+ SIPM



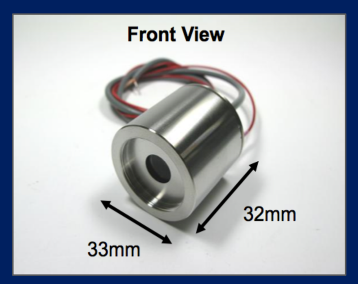
- Small sensitive surface (~mm^2)
- Good time performances
- Excellent resolution

= VSIPMT



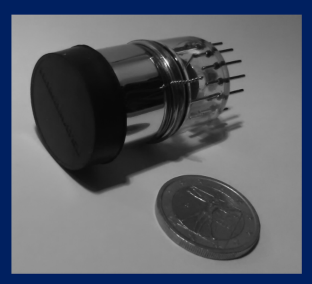
- Large sensitive surface (~cm^2)
- Good time performances
- Excellent resolution
- Gain independent from linearity

Prototypes: past, present and future



7x7mm ø

2012



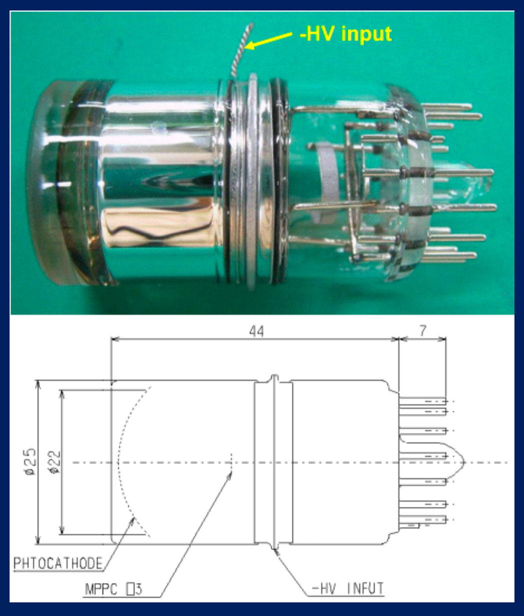
1-inch ø

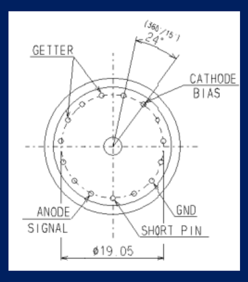
2016

2-inch ø

Late 2018

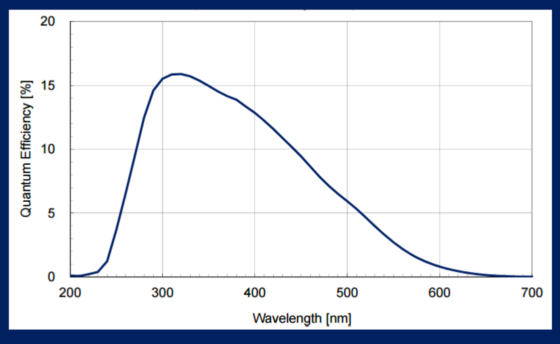
1-inch prototype





Specifications

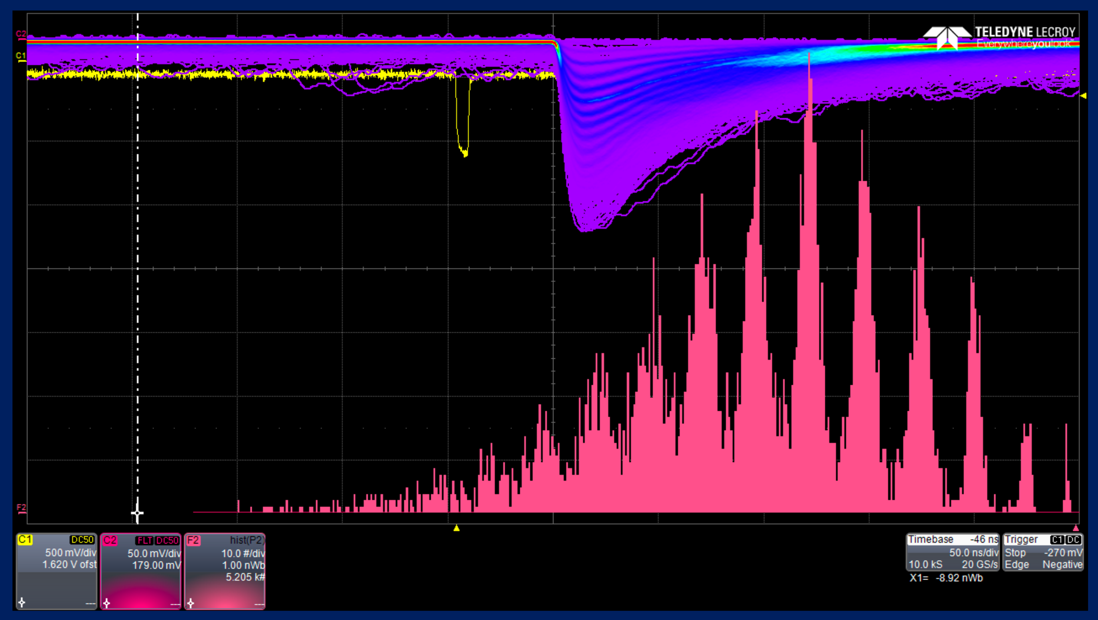
Parameter		Value	Unit
Spectral Response		200 to 650	nm
Photocathode	Material	Bialkali	-
	Effective Area	Φ22	mm
Window Material		Borosilicate Glass	-
Target		MPPC 3x3 mm	-



	Pixel Type (μm)	Photocathode Quantum Efficiency*1
XE2597	100 x 100	15.0 %

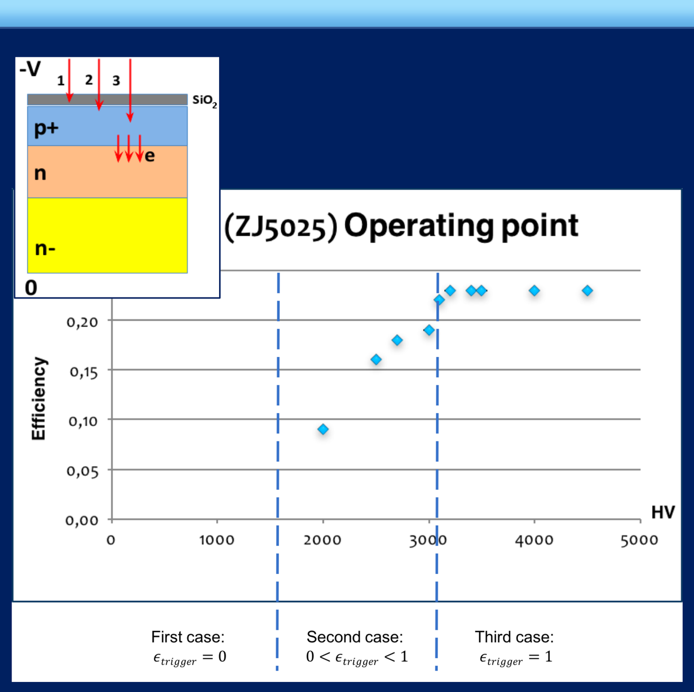
MPPC Max. Reverse Bias Voltage	Max. Photocathode Voltage
+ 72.0 V	-2.0 kV

Photon counting capability



The VSiPMT response is driven by the special SiPM used as amplifier. The charge spectrum shows the typical fingerplot shape, highlighting the excellent photon counting capability of the device.

Operating point



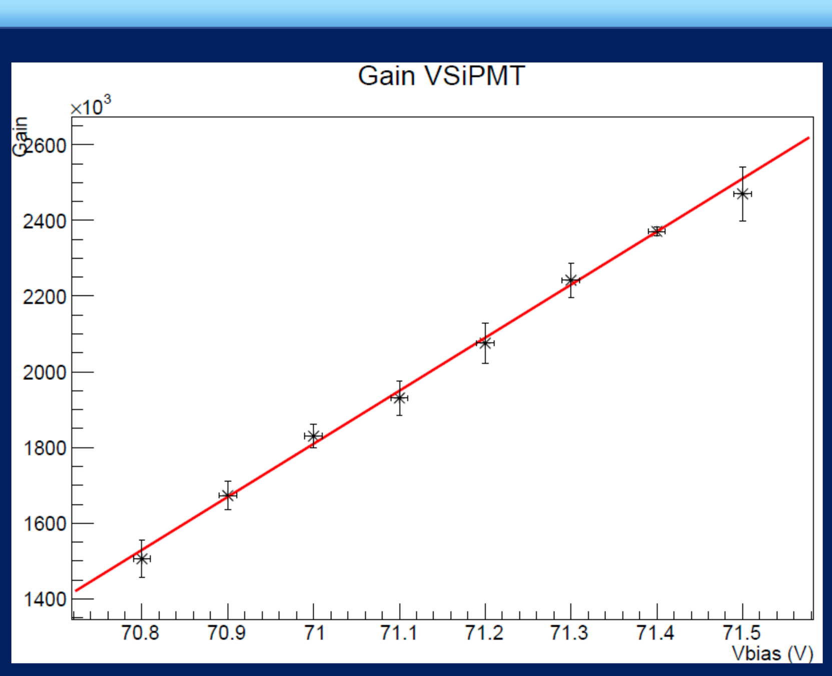
$$PDE = \epsilon_{PC} \cdot \epsilon_{geom} \cdot \epsilon_{trig}$$

1) The electron is under threshold, it has no enough energy to enter in the p+ region, indeed it stops into the SiO2 layer (trigger = 0);

2) The electron energy is very close to the threshold one, so statistically 140 only a fraction of the electrons will enter into the p+ region and trigger the geiger avalanche (0 < trigger < 1);

3) The electron energy is over threshold, so all the electrons will enter into the depletion region and trigger the geiger avalanche (trigger = 1).

Gain



In a VSiPMT the gain is obtained by the electrons crossing the Geiger region of the SiEM. A standard current signal is given for each red cell, thus the gain of the VSiPMT is those of the SiEM housed inside the tube.

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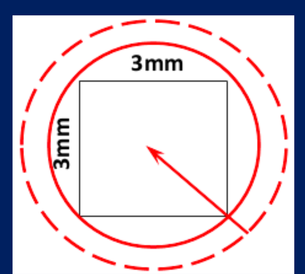
STABLE GAIN OBTAINED AT LOW VOLTAGE

Linearity



Linearity depends on the number of pixel of the SiEM.

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LINEARITY INDEPENDENT OF THE GAIN

NEW FOCUSING CONCEPT

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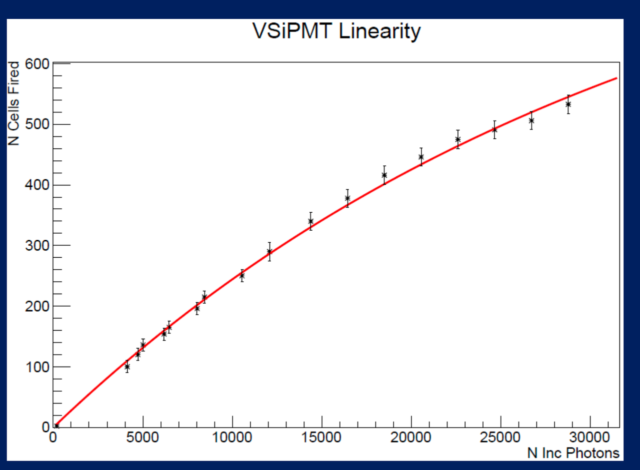
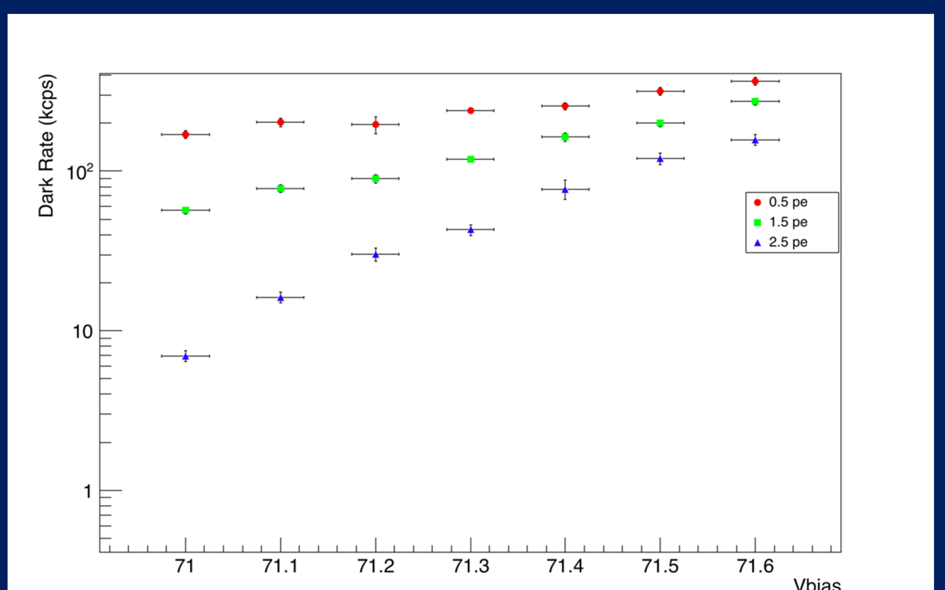
Electrons spread over the SiEM surface



Dark Noise

Coverage of a large area with the noise of ONE SiEM.



Conclusions

In this work we presented the results of an extensive characterization of the latest usable VSiPMT prototype, the EB-MPPC100 (XE2597) 1-INCH.
This prototype showed manufacturing defects that threaten the correct operation of the device and as a consequence the expected performances.
This analysis provided first-rate results: the device, properly manufactured, will have a PDE
close to those of a PMT, moreover the VSiPMT offers very good photon counting capability maintaining on a large area (1- inch photocathode is equivalent to ~50 SiPMs 3x3 mm^2) the dark rate of a single SiPM and a negligible power consumption.
Standing on this analysis we believe that it has the potentiality to fulfill the requirements of the next generation of astroparticle physics experiments and not only (e.g. water and air Cherenkov experiments, nobel liquid dark matter experiments, LIDAR).
In fact, the outstanding performances and the features of the VSiPMT make its potential field of application go far beyond astroparticle physics.