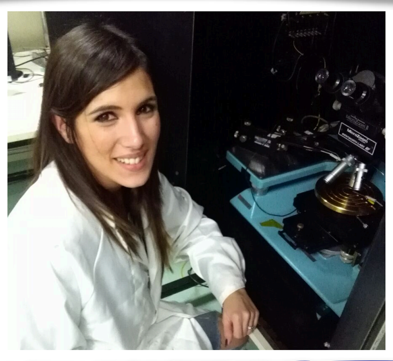
Design of a SiPM-based cluster for the Large Size Telescope camera of CTA



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A Silicon Photomultiplier (SiPM)-based photodetector will be built to be possibly used in the Large Size Telescope (LST) camera of the Cherenkov Telescope Array (CTA). It has been designed to match the size of the standard Photomultiplier Tube (PMT) cluster unit and to be compatible with mechanics, electronics and focal plane optics of the first LST camera. Here, we describe the overall SiPM cluster design along with the main differences with respect to the currently used PMT cluster unit. The fast electronics of the SiPM pixel and its layout are also presented. In order to derive the best working condition for the final unit, we measured the SiPM performances in terms of gain, photodetection efficiency and cross-talk. A pixel, a unit of 14 SiPMs, has been built. We will discuss also some preliminary results regarding this device and we will highlight the future steps of this project.

The future of very high energy gamma-ray astronomy

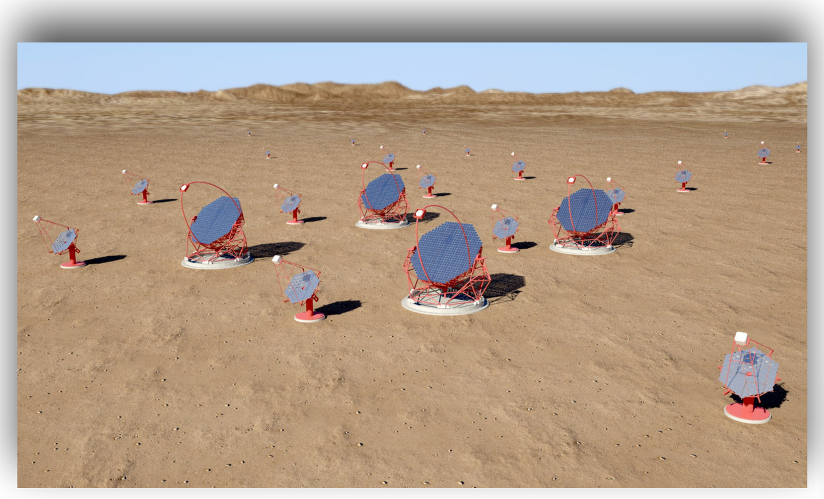

Fig. 1: An artistic view of CTA

The Cherenkov Telescope Array (**CTA**) represents the future for Imaging Air Cherenkov Telescopes (IACTs) [1].

Current generation of IACTs: H.E.S.S., MAGIC, VERITAS.

Fig. 2: The first LST under construction in the Northern site of CTA (Observatorio Roque de Los Muchachos, La Palma, Canary Islands).

- CTA will cover a very large range in energy, going from **tens of GeV up to about 100 TeV**
- Two arrays are foreseen, one in the Northern hemisphere and one in Southern hemisphere.
- 23m - diameter Large Size Telescopes (LSTs), 12 m - diameter Medium Size Telescopes (MSTs) and 6 m - diameter Small Size Telescopes (SSTs).

LSTs of CTA are designed to enhance the sensitivity below 200-300 GeV and to lower the effective threshold down to 20-30 GeV. The science case of these instruments is the observation of high redshift Active Galactic Nuclei ($z \leq 3$), Gamma-ray Bursts up to $z \leq 10$, pulsars and galactic transients [2].

Design of a SiPM cluster for the LST camera

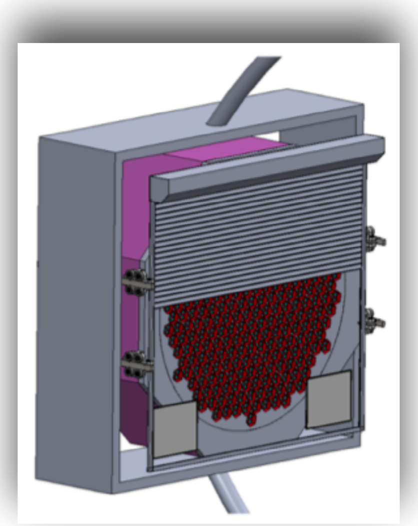

Fig. 3: The external view of LST camera design

LST is designed to cover the lower energy range of CTA. The reflective surface area and the telescope size itself have to be maximized: the efficiency of the photo-sensor should be as large as possible to capitalize on the large cost of the telescope mechanics.

The baseline design of LST includes a focal-plane camera based on photo multiplier tubes (PMTs), with a field of view of about 4.5 degrees.

LST camera design comprises 265 PMT modules. Each module, called "cluster", has 7 channels, providing the camera with a total of 1855 channels. Hamamatsu PMTs with a peak quantum efficiency of 42% (R11920-100) are used [3].

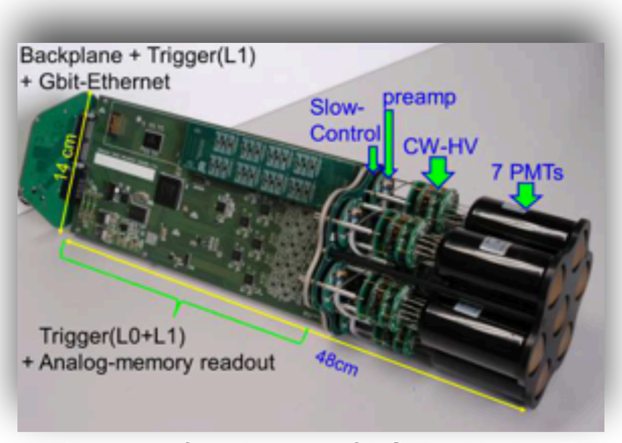

Fig. 4: Picture of a cluster of LST with the 7 PMTs

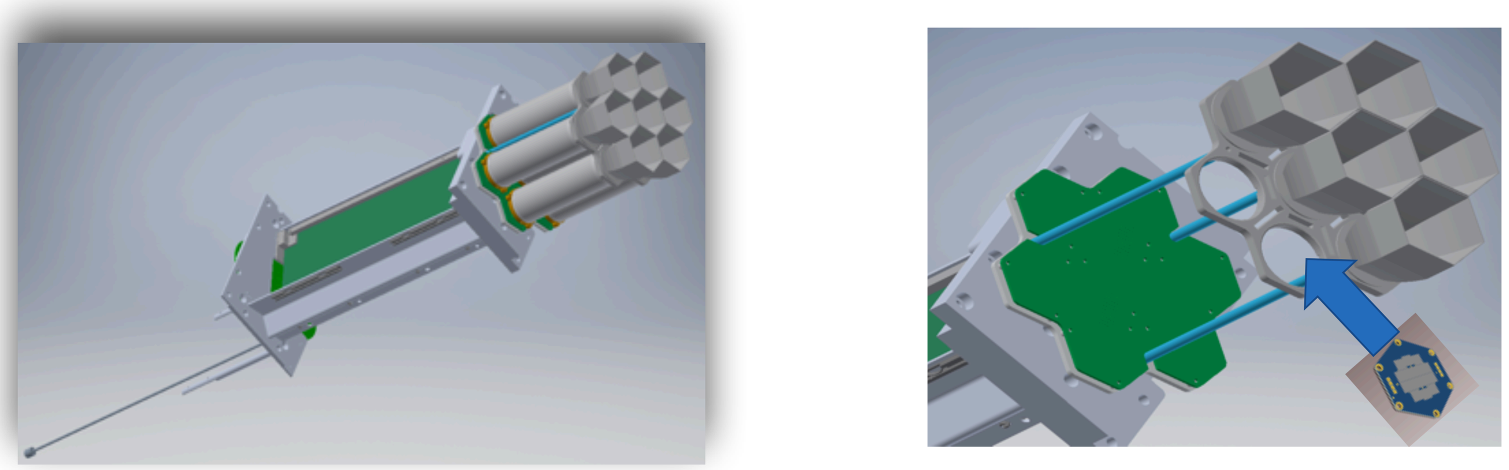

Fig. 5. Left - Mechanical structure of a PMT cluster of LST. Right - Mechanical structure of a SiPM cluster of LST.

The goal of this research is to develop a **silicon-based prototype cluster for LST**, to be possibly used in the Southern site. SiPM technology is already exploited for SSTs of CTA (see e.g. [4]).

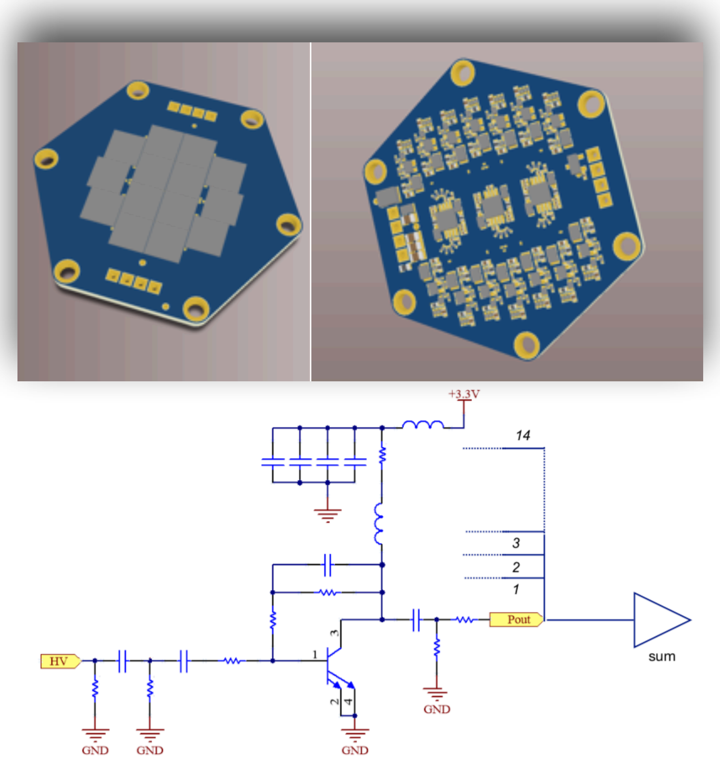

Fig. 6. Top- Pixel layout. Bottom -Sketch of the pixel electronics system. The amplified signals of the 14 sensors are added at the final sum stage

SiPM cluster:
- solid-state equivalent of a PMT
- matrix of 14 sub-elements, for a total of a few square centimeters of active area
- high photon detection efficiency, good single-photon sensitivity, and time response around 2-3 ns.

The electronics and the sampling system are the same, whereas the high voltage for PTMs is replaced by a low voltage (and low noise) power supply for the SiPMs, with an interface board.

In order to adapt the SiPMs pixel layout to the current camera design, each sensor will cover 0.1° and match the exit window of the light concentrator with hexagonal entrance pupil.

SiPM characterization

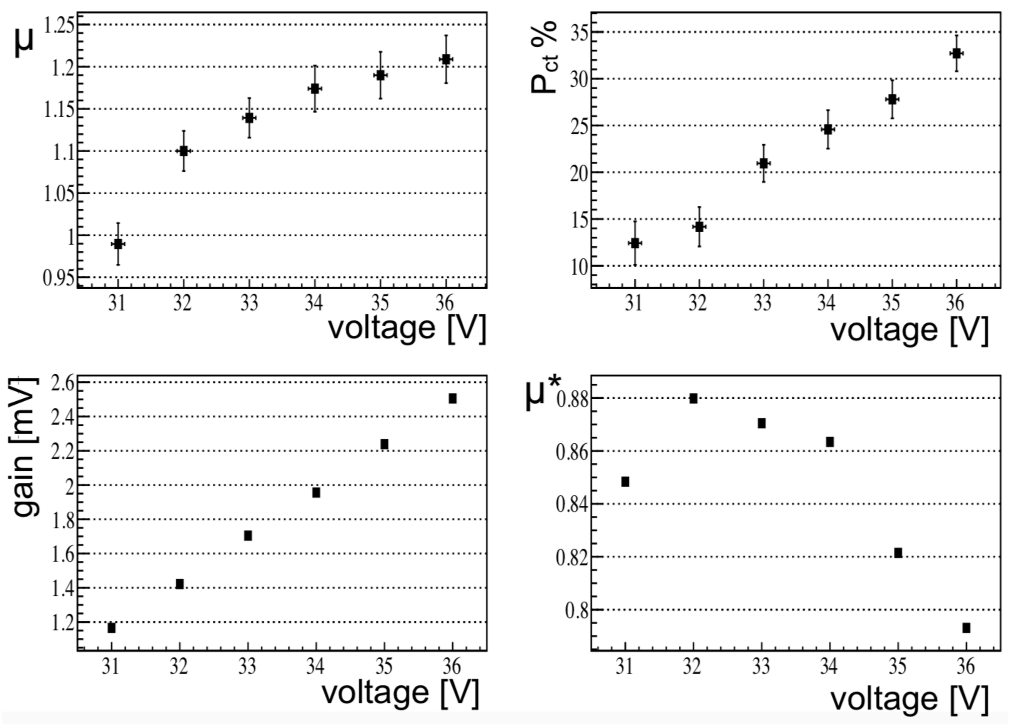

Fig. 7: Results on FBK NUV HD3_2 SiPM (single photo-sensor), obtained for λ=376 nm

Tested the SiPM performances. Model:6X6 mm² **FBK NUV HD3_2**

-Photon detection efficiency: 60% at 350 nm and 30% at 500 nm.
-Single photo-sensor connected to an amplifier powered by a voltage of -3.3 V and 3.3 V.
-Laser source (Picoquant PLS8-2-592) at λ=376 nm

From the distribution of peak voltages, we evaluated:
- the number of collected photoelectrons (indicated as μ),
- the cross-talk probability (P_{ct}%),
- the gain
- the signal-to-noise ratio (S/N). The latter is in particular reported as $\mu^* = (S/N)^2$.

Maximum μ* at 32 V, where P_{ct}=14.2±2.1(stat)%.

We repeated the same tests exploiting a second laser (Picoquant PLS 8-2-519) with λ=499 nm. The signal-to-noise ratio is maximum between 32 and 34 V. At 33 V, P_{ct}=18.4±2.3(stat)%.

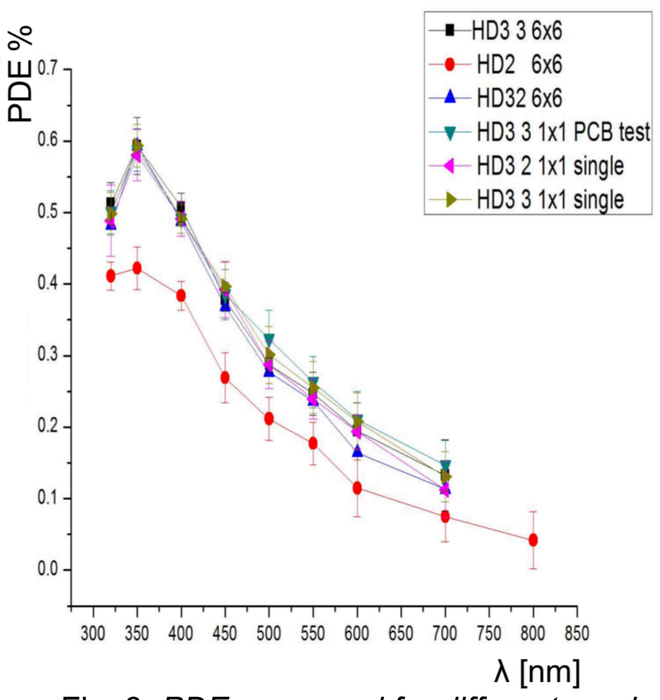

Fig. 8: PDE measured for different version of FBK NUV SiPMs. Blue triangles are the measurements for the version used in this work (from private comm. with dott. Lucia Consiglio - INFN Napoli)

The excess noise factor [5] due to stochastic noise of secondary events is ENF = 1 + P_{ct}. Its value is between ~1.14 and 1.18 for the tested sensors at their optimal working point.

SiPM pixel characterization and future studies

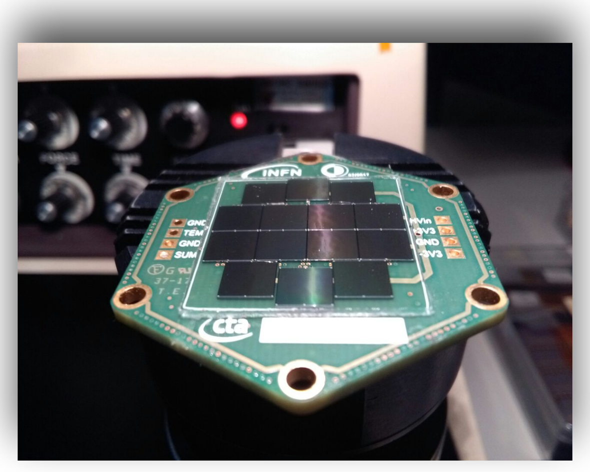

Fig. 9: View of one of the pixels built for this project.

This project of a SiPM cluster is based on the production of 7 pixels of SiPMs. Following the design here described, we built and characterized two sensors with 14 6x6mm² SiPMs of the model described above.

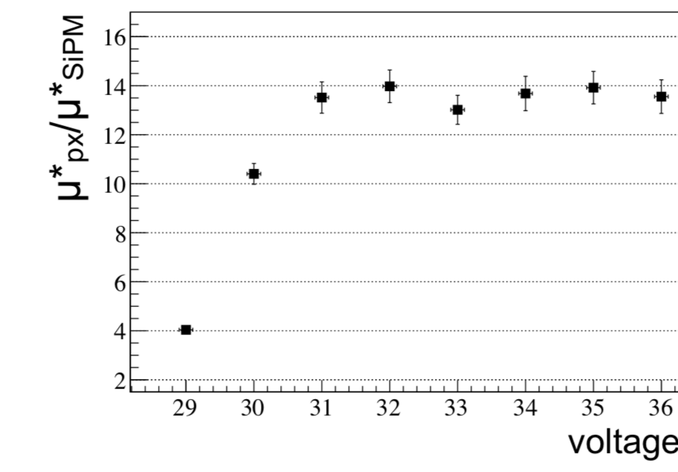

Fig. 10: Ratio of μ between the pixel and a single SiPM used as reference*

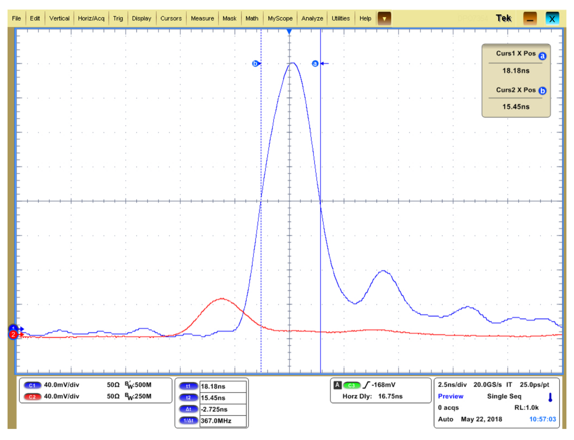

Fig. 10: Pixel (blue line) and single SiPM (red line) signals from the oscilloscope.

The pixel behaves as a sum of 14 objects, within the errors and preserves the peak width of the single SiPMs, being the FWHM less than 2.7 ns.

The electronic noise is 0.78 mV and the dynamical range is around 1000 (defined as the ratio A^*/σ_e, with A* amplitude of the signal before saturation and σ_e, electronic noise).

One of the next steps for this project is to design an optical system. We will also test how to drive the heat from the power control board to the cooling plate, which is 15 cm below. For this purpose a set of heat pipes will be applied and tested.

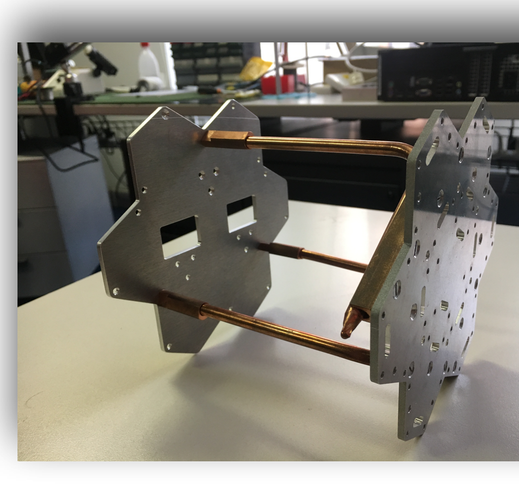

Fig. 12: Mechanical structure for the SiPM cluster, including the set of heat pipes

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