Characterization of FBK NUV-HD SiPMs for the pSCT camera proposed for the Cherenkov Telescope Array experiment

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ABSTRACT Recent developments on Silicon Photomultipliers (SiPMs) have shown that they are particularly adequate to detect fast and low-intensity lights. Fondazione Bruno Kessler (FBK) has optimized these sensors for the Near-Ultraviolet Cherenkov light emitted by high energy gamma-ray showers in the atmosphere. The FBK high density SiPMs (NUV-HD) have been extensively characterized in the laboratories of the Italian Institute of Nuclear Physics (INFN) in view of equipping the focal plane camera of the Schwarzschild-Couder Telescope prototype (pSCT) as a part of the Cherenkov Telescope Array (CTA) experiment.
Here we report the performances of the 6x6 mm² SiPMs based on 40x40 µm² microcells, in terms of gain and signal-to-noise ratio.
We compare the results obtained on devices from the third generation and grown on different substrates in order to choose the most suitable sensor for the pSCT camera.

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1. The SiPMs for pSCT

Silicon Photomultipliers (SiPMs) are proving to be ideal sensors to detect the fast and low-intensity Cherenkov light produced by high energy gamma-ray air showers.
The prototype of the Schwarzschild–Couder Telescope (pSCT) proposed for the Cherenkov Telescope Array (CTA) observatory (fig. 1) will be equipped with SiPMs produced by Fondazione Bruno Kessler (FBK).

High density SiPMs were optimized to detect the Near-Ultraviolet light (NUV-HD SiPMs).
The third generation of NUV-HD sensors, with a cell pitch of 40x40 µm² and 6x6 mm² size were deeply studied and chosen to equip a part of the pSCT camera. [1,2]

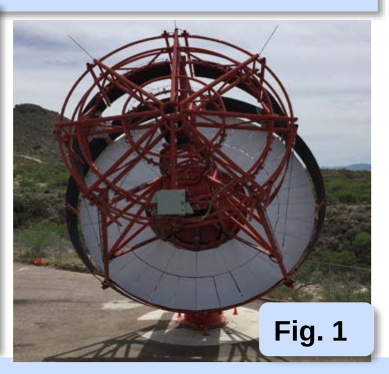
Fig. 1

2. FBK NUV-HD3 characterization

NUV-HD3 6x6 mm² SiPMs were tested with dedicated electronics in order to study the performances of the sensors. These devices were produced in three different “flavours”, which differ in the Silicon substrate used. The performances of each type of SiPM were studied separately. From now on we will refer to these devices as HD3-1, HD3-2 and HD3-3. The breakdown voltages were measured for each device. The values found are 27 V, 26.4 V and 27 V respectively.
In order to study the performances in terms of gain and signal-to-noise ratio (SNR), we illuminated each device with laser light at 380 nm and collected data over a wide bias voltage, which ranges from 1-2 V to 13-14 V of over-voltage (OV).
The read-out electronics used for the characterization consisted in a trans-impedance preamplifier followed by a gain stage. Since the devices have a long recovery time, a shaping stage was added in order to get rid of the long tail of the output signal. The output voltage was read through an oscilloscope. We collected several waveforms and integrated over a certain integration time. Figure 2 shows an example of the charge distribution obtained, from which the SiPM gain and SNR were calculated.

The first peak corresponds to the pedestal, while the following peaks to the first, second, … p.e. respectively. The SNR is defined as the difference between the mean values of the first p.e. peak and of the pedestal divided by the σ of the pedestal. A good quantization down to the single photoelectron is observed.
Figures 3 and 4 show the integrated charge and SNR measured on all three devices as a function of the over-voltage respectively.

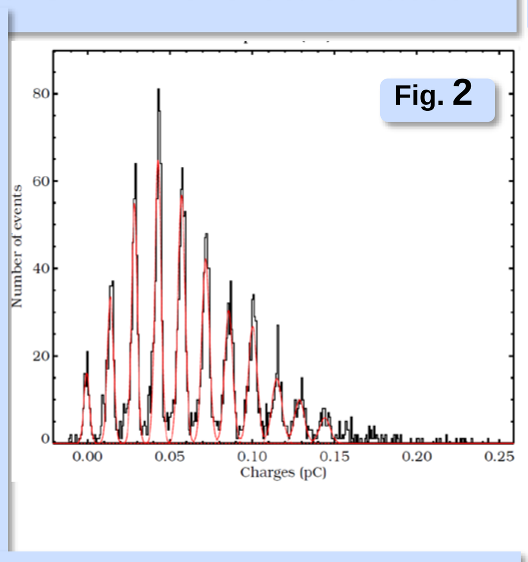

Fig. 2

The plots show that all devices have similar charge response, while HD3-2 proved to be slightly more noisy than the others.

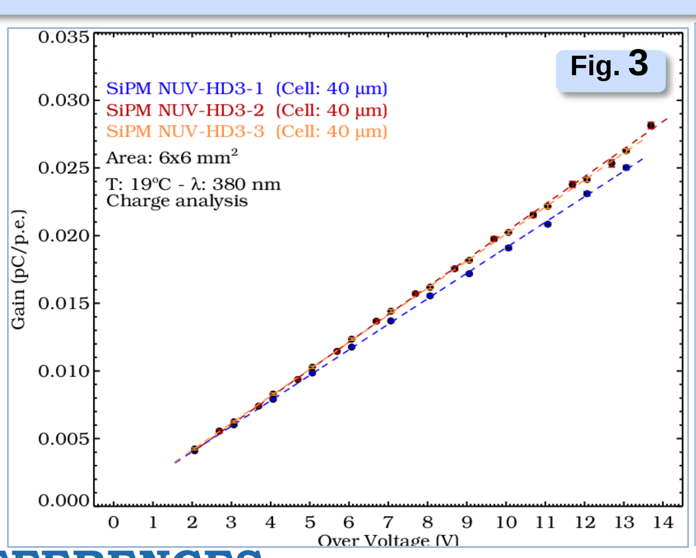

Fig. 3

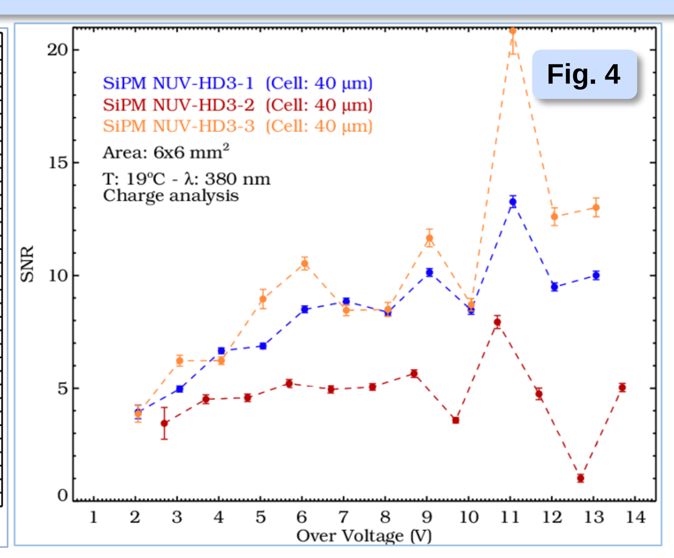

Fig. 4

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3. Assembly and tests for the pSCT camera

NUV-HD3 SiPMs will be used to equip a subset of the pSCT camera. Sensors were arranged in 4x4 matrices, as shown in figure 3. Details about SiPMs’ electrical characterization and mechanical structure are reported in [3, 4]. See poster “Readout chain validation of INFN modules for the CTA-pSCT camera” by S. Loporchio for more details.
Since the different substrates were available in different quantities, HD3-2 and HD3-3 were selected to equip the pSCT camera.

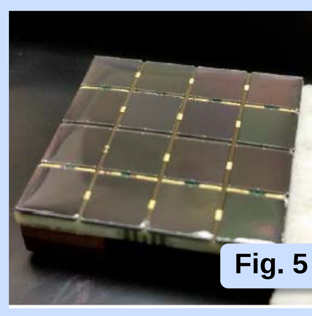
Fig. 5

More than 50 matrices were tested to verify the uniformity in terms of gain and SNR. The breakdown voltage was measured on each channel. Figure 6 shows the distributions for HD3-2 and HD3-3 SiPMs. The mean values are 25.9 V and 26.6 V respectively. The σ/µ ratio is found to be less than 0.25% in both cases.
The matrices were illuminated with a laser emitting at 380 nm. The DAQ system consisted of a CAEN V792 QDC which measures the charge signal of the 16 devices, with an integration time fixed to 30 ns. The SiPM signals were amplified using a 16-channel FEE, developed to shape the input signal to match the QDC dynamic range [5]. The matrices were tested at different bias voltages, ranging from 31V to 36V.

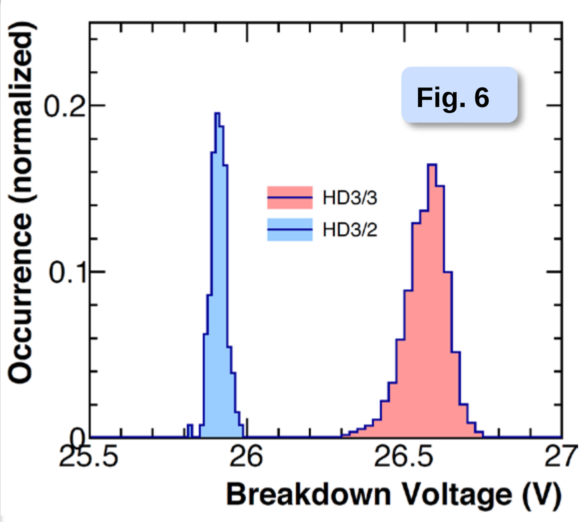

Fig. 6

The charge distributions obtained were fitted as in figure 2 to derive the integrated charge and the SNR of each channel at each bias voltage. The distributions obtained from these values allowed the study of the average performances of the matrices. Figure 7 shows the gain distributions of HD3-2 matrices at different bias voltages expressed in ADC channels. The plots show that the distributions follow a Gaussian shape, with a σ/µ ratio between 10% and 15 %.

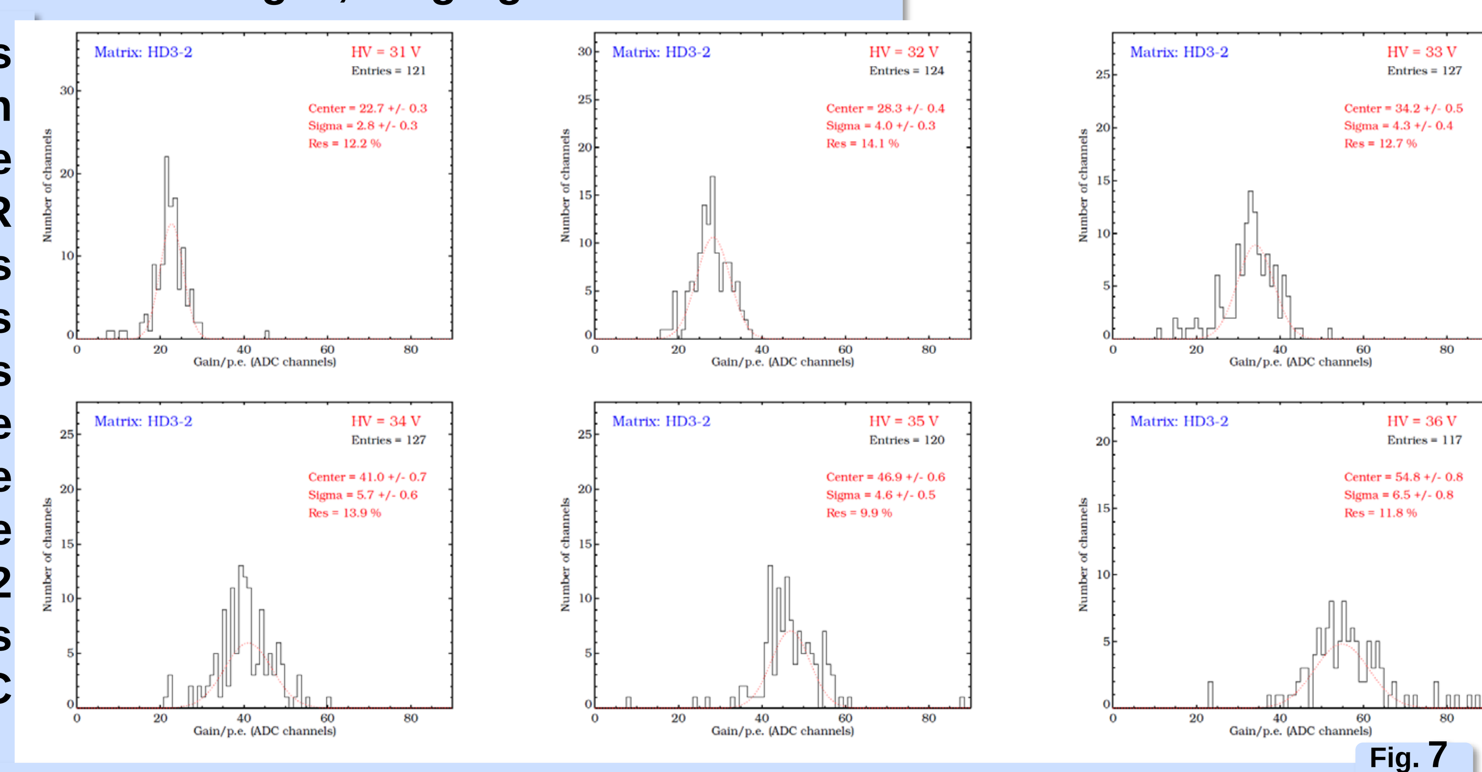

Fig. 7

Similar distributions were obtained for the SNR and for HD3-3 matrices. These fluctuations include a possible contribution due to the pre-amplifier and the DAQ system. Therefore they can be considered as upper limits on the SiPM gain uniformity.

Figures 8 and 9 show the average values of gain and SNR as a function of over-voltage respectively. These values are obtained from the distributions as in figure 7. The results show the uniform behavior of all channels, confirming that HD3-2 and HD3-3 matrices behaviour is similar when the different breakdown voltage is taken into account.

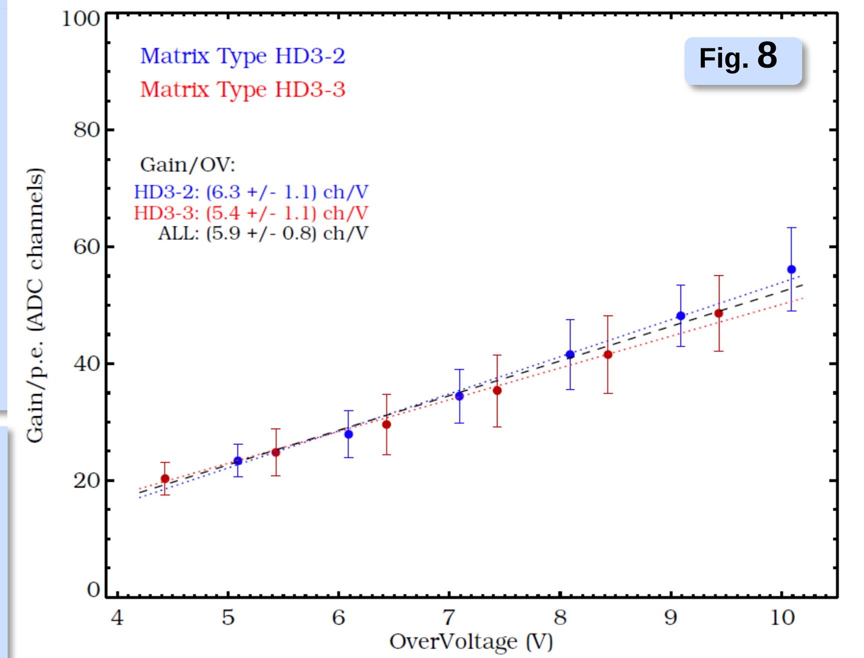

Fig. 8

4. Conclusions

The measurements reported here show that NUV-HD3 SiPMs are suitable to equip the pSCT camera. The matrices assembled show a very uniform behavior, confirming the goodness of the assembly procedure.
Among the ones tested, 36 matrices were selected to be coupled to the front-end electronics of the pSCT camera, which is based on the TARGET-7 ASIC, which performs the signal digitization and generates the internal trigger.
More details are available in poster “Readout chain validation of INFN modules for the CTA-pSCT camera” by S. Loporchio.

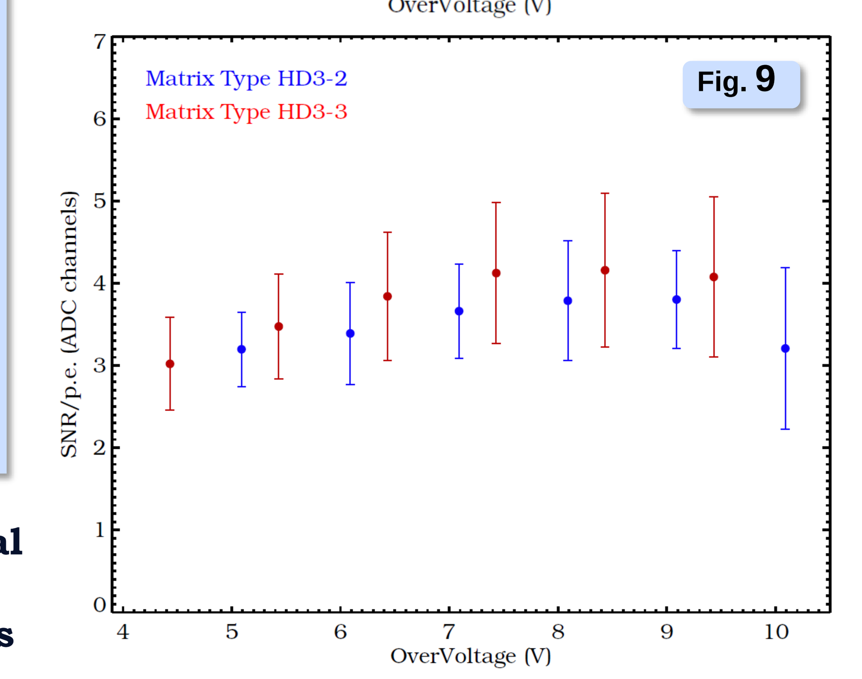

Fig. 9

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