PROCEEDINGS OF SCIENCE

A SiPM Multichannel ASIC for high Resolution Cherenkov Telescopes (SMART) developed for the pSCT camera telescope

C. Aramo,[a] E. Bissaldi,[b,c] M. Bitossi,[d] C. Bonavolontà,[a] G. De Robertis,[c] L. Di Venere,[c] F. Giordano,[b,c] S. Incardona,[e,f] F. Licciulli,[c] S. Loporchio,[c] G. Marsella,[e,f] F. R. Pantaleo,[b,c,*] R. Paoletti,[d,g] M. G. Papagni,[c] M. Rizzi[c] and G. Tripodo[e,f] on behalf of the CTA-SCT Project

[a] *INFN Sezione di Napoli, 80126 Napoli, Italy*
[b] *Dipartimento Interateneo di Fisica dell'Università e del Politecnico di Bari, 70126 Bari, Italy*
[c] *INFN Sezione di Bari, 70125 Bari, Italy*
[d] *INFN Sezione di Pisa, 56127 Pisa, Italy*
[e] *Dipartimento di Fisica e Chimica "E. Segrè", Università degli Studi di Palermo, viale delle Scienze, 90128 Palermo, Italy*
[f] *INFN Sezione di Catania, 95123 Catania, Italy*
[g] *Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Università degli Studi di Siena, 53100 Siena, Italy*

E-mail: francesca.pantaleo@ba.infn.it

The Schwarzschild-Couder Telescope (SCT) is a Medium-Sized Telescope proposed for the Cherenkov Telescope Array (CTA). The first prototype (named pSCT) has been constructed and is being commissioned at the Lawrence Whipple Observatory (FLWO) in Arizona , USA. The SCT is characterized by a dual-mirror optical design in order to remove the comatic aberrations across its field of view. The pSCT camera is now partially equipped with Silicon Photomultiplier (SiPM) matrices produced by Fondazione Bruno Kessler (FBK) and in the upgrade phase. A new design of the front-end electronics (FEE) based on the TARGET ASICs will be installed to obtain an improvement especially in the noise performance. The new FEE design will also include a 16-channel integrated pre-amplifier, called SMART, developed and tested by INFN to match the signal produced by the FBK SiPMs. The results of the performance of the SMART ASIC coupled to the FBK SiPMs and to the new FEE modules will be shown in terms of gain and noise.

27th European Cosmic Ray Symposium - ECRS
25-29 July 2022
Nijmegen, the Netherlands

*Speaker

https://pos.sissa.it/

PoS(ECRS)149

1. Introduction

The Cherenkov Telescope Array (CTA) is a ground-based observatory with the aim to detect Very High Energy (VHE) gamma-rays, referring to a wide energy range of 20 GeV- 300 TeV. Three sizes of telescopes will be installed: small-sized (SST), medium-sized (MST), and large-sized (LST) in order to increase the sensitivity of an order of magnitude compared to the other instruments [1]. The CTA “alpha configuration" will be characterized by two sites, one in La Palma, Spain and the other one in Panaral, Chile. The northern site in La Palma will be equipped by 4 LSTs and 9 MSTs, instead the southern one in Panaral by 14 MSTs, 37 SSTs and 4 LSTs. The Schwarzschild-Couder Telescope (SCT) is one of the two medium-sized telescopes (MST) candidate sensitive in a gamma-ray energy range of 100 GeV-10 TeV. The other MST is the Davies-Cotton (DC) telescope. The main difference between the two telescopes is due to the fact that the SCT is composed by a double mirror which consists of a 9.7 m primary mirror diameter, segmented in 48 panels, arranged in 2 concentric rings and a 5.4 m secondary mirror diameter, instead the MST is characterized by a single 12 m mirror diameter [2]. The SCT camera is designed to be equipped with 11328 silicon photomultipliers (SiPM) pixels, while the DC camera is equipped with about 1800 photomultiplier tubes (PMTs). Also, in the SCT case, the dual mirrored design minimizes optical aberrations focusing the Cherenkov light on a compact high resolution camera equipped by SiPMs; in fact, the resolution is improved compared to the DC case. Currently, a prototype of this telescope (pSCT) is installed at the Fred Lawrence Whipple Observatory in southern Arizona. Its camera is now partially equipped with about 1500 SiPMs. The main milestone of the pSCT was the detection of the Crab Nebula with a statistical significance of 8.6 standard deviations. The pSCT camera is now partially equipped with silicon photomultipliers (SiPMs) matrices and covers a FoV of 2.7°. The pSCT focal plane is now in phase of upgrade, aimed to equip the full camera with upgraded sensors and electronics, improving the telescope field of view (FoV) from the current 2.7° to the final 8°. A revised FEE will be based on a SiPM Multichannel ASIC for high Resolution Cherenkov Telescopes (SMART) pre-amplifier followed by two separate ASICs for sampling and digitization and trigger generation, the TARGET-C and the T5TEA [3].

2. Current and future status of pSCT camera readout

The current pSCT camera readout concept is based on SiPM sensors for photon detection and on a discrete pre-amplifier stage followed by the TARGET-7 ASIC FEE, having the function for sampling, digitization and trigger generation [4]. The final camera focal plane configuration will be equipped with 177 modules (see Fig.1), composed by 9 backplanes having the function to control data acquisition for each camera sector. The current camera focal plane configuration is composed by 25 modules (see Fig.2). Each module is composed by 64 SiPMs arranged in 4 Photo Detection Units (PDU), each one equipped with 16 SiPM pixels. High Density (HD3) SiPMs produced by Fondazione Bruno Kessler (FBK) in collaboration with Istituto Nazionale di Fisica Nucleare (INFN) will be mounted on the camera.

The PDU installed on the current camera are of two kinds: 15 modules equipped with Hamamatsu MPPC (circled in blue) and 9 modules equipped with FBK HD3 SiPMs (circled in red). The central slot is used to allocate a special module for the telescope optical alignment. The FBK SiPM

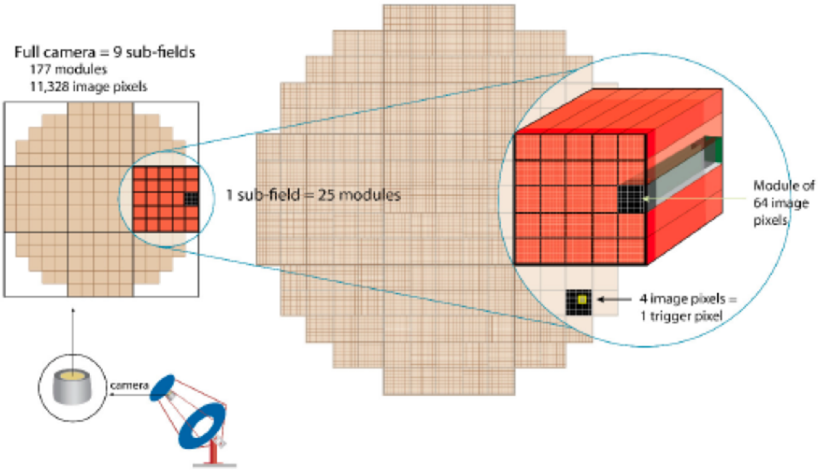

Figure 1: Scheme of the entire pSCT camera modules.

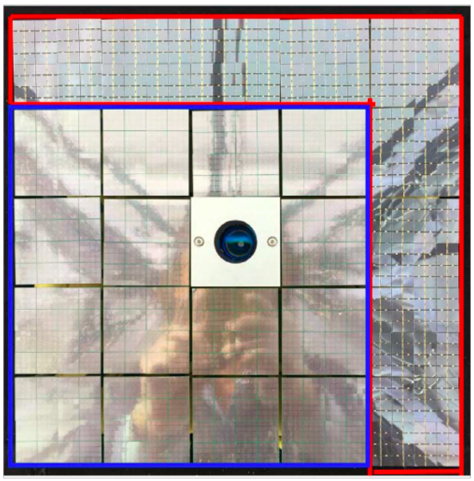

Figure 2: Current modules installed on the pSCT camera. 15 modules are equipped with Hamamatsu MPPC and are circled in red. 9 modules are equipped with FBK HD3 SiPMs and are circled in blue. The Central slot is used for the telescope optical alignment.

matrices were characterized in the INFN laboratories and the results of these tests were recently published [5]. The new modules are shown Figs.3,4. Moreover, the FEE provides other functionalities such as temperature monitoring, module-level trigger generation, waveform data packaging and transfer to storage. The comparison between current and upgraded charge spectrum is shown in Fig.5. The noise is reduced in the upgraded case with respect to the current one and the resolution is improved in the new configuration.

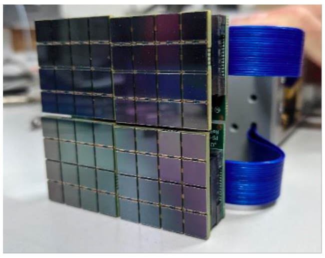

Figure 3: FPM including SiPMs.

Figure 4: Single module picture composed by 64 SiPMs.

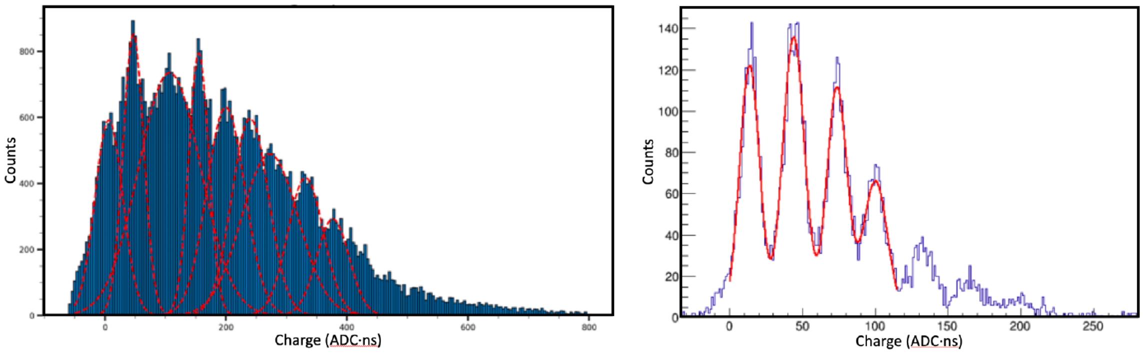

Figure 5: Left: Charge spectrum acquired with current modules. Right: Charge spectrum acquired with new modules equipped with only FBK SiPM matrices and FEE.

3. SiPM Multichannel ASIC for high Resolution Cherenkov Telescopes (SMART) architecture

SMART ASIC is a 16-channel pre-amplifier, developed in a 0.35μm Si-Ge technology by the electronics CAD service of INFN Bari. Each input channel is composed by a trans-impedance amplifier characterized by two paths: a fast path which counts photons and a slow path which measures the SiPM mean current. The SMART is equipped with a 20-bit register for the global adjustment of the gain resistance (8 bits), the bandwidth (6 bits) and the pole-zero network (PZ) filter for tail suppression (6 bits). Also, a 8-bit DAC is included in order to be used as a SiPM bias fine tuning. A SPI interface is provided to program the SMART via 1 MHz and the dynamic range is of 600 mV. The fast path is provided with the signal shaping filter followed by the output buffer, while the slow path exploits a narrow band width amplifier to measure the mean current of the SiPM. This latter output is sent to an internal SAR 10-bit ADC through an analogue multiplexer. The architecture of the single channel is shown in Fig.6.

4. SMART Characterization and test quality

The SMART performances were characterized in the INFN laboratories. The setup is composed by a pulsed laser which illuminates the SiPMs matrix. All instruments were placed in a dark box. A mask was placed on the PDU minimizing the cross-talk contribution among pixels. Each channel

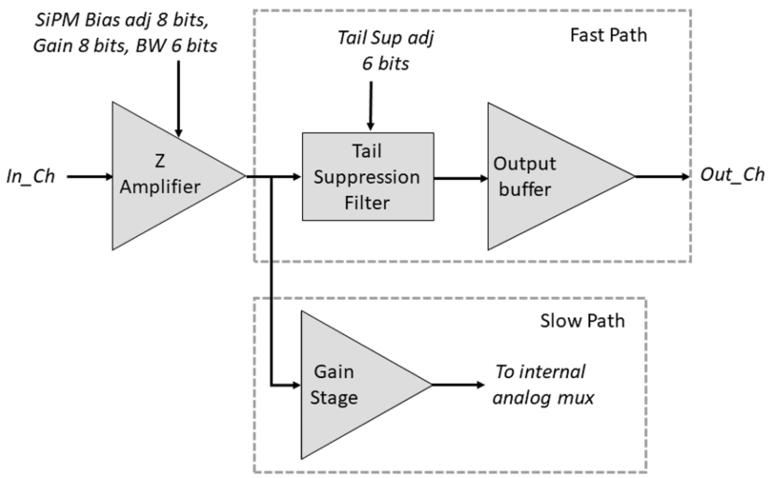

Figure 6: Internal architecture of one of the 16 input channel of the SMART ASIC. From the left, the trans-impedance amplifier with the adjustable bias gain and bandwidth, and the two paths: the fast path with the tail suppression filter followed by the output buffer, and the slow path with an additional gain stage.

was analyzed separately, acquiring waveforms with an oscilloscope. A scheme of the setup used is shown in Fig.7. Gain, signal to noise ratio and pulse width dependence on its configuration bits

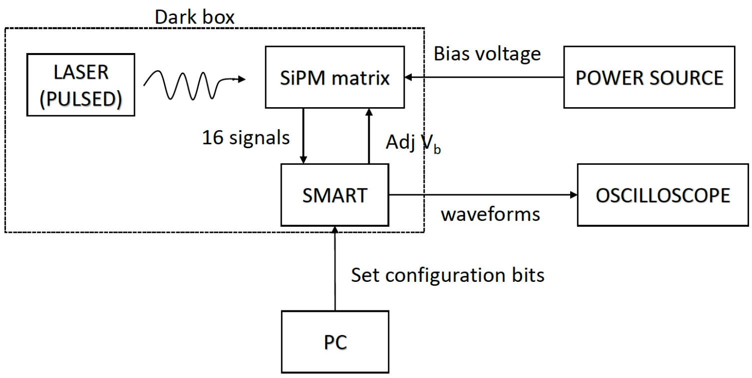

Figure 7: Scheme of the setup used to characterize the SMART ASIC.

were performed. Three parameters were changed: the gain resistance (R), the filtering capacitance (C) and the pole zero cancellation (PZ). An external PZ was fixed with discrete components. The tests were performed varying three bias voltage values, inserting $33V$, $35V$, $37V$. The mean global configuration is characterized by $R = 16$, $C = 5$, $PZ = 40$. Gain and FWHM dependencies on the mentioned parameters are shown in Fig.8.

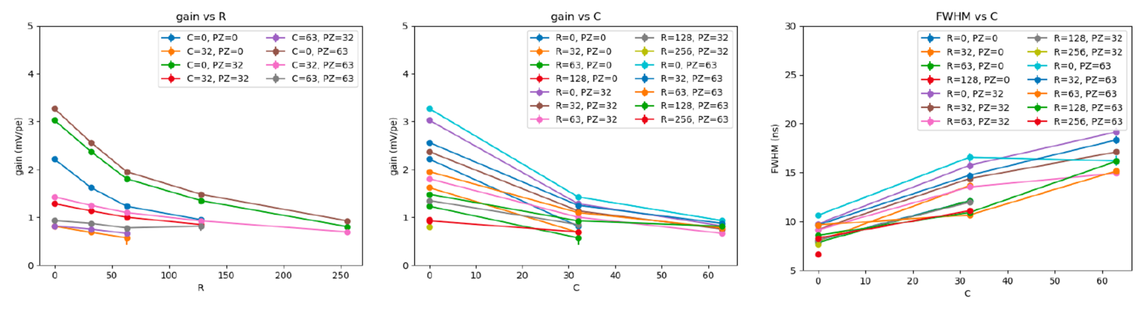

Figure 8: Left and center: Gain plots as a function of R and C including all global configurations. Right: FWHM plot as a function of C including all global configurations.

After the characterization of the SMART chip, 750 ASICs were produced to equip the pSCT upgraded camera. All ASICs were tested and only 7 were found to be defective (< 1%). The main features of the SMART that were tested to check the basic functionalities are: ADC calibration for current readout, response to a laser pulse, variation of pulse shape as a function of SMART configuration and pulse amplitude variation as a function of DAC for fine SiPM bias tuning. Globals test were performed fixing bias (DAC), and varying the configuration of the SMART, the signal run is performed to check the behavior of the device. The results for all configurations are shown in Fig.9.

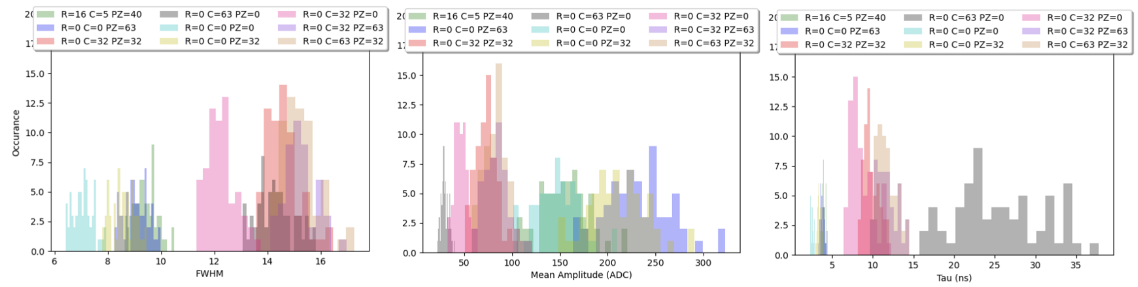

Figure 9: Globals test performed fixing bias (DAC), and varying the configuration of the SMART over all channels from 0 to 63.

5. Main milestone of the SCT: Crab detection

The inauguration of the pSCT is dated 17 January 2019. The first lights were detected on 23 January 2019. The Crab was detected in January 2020 [6] and the first campaign of observations was conducted in the period January-February 2020. Data were taken firstly in run pairs ON/OFF, the run time had a duration of 28 minutes alternating ON or OFF observation. The order of the pair ON/OFF or OFF/ON runs was chosen maximizing the elevation and minimizing the airmass. The typical trigger rate is 100 Hz. Most of the triggers is due to electronic noise, few Hz come from cosmic ray events. Events that do not identify air shower were deleted and the trigger threshold requires that at least four adjacent pixels were characterized by signals greater than 2 photo-electrons. The events were also cleaned and parameterized setting a simple geometrical moment analysis and the Hillas image parameters. The final data were based on an acquisition of 21.6 hours of ON source observations and 17.6 OFF source observations. ON observations were taken in coincidence with VERITAS. VERITAS and pSCT are placed both at the Fred Lawrence Whipple Observatory in southern Arizona, so thanks to the close position any observation were done in coincidence. Both instruments acquired the same events, in fact 2.2 hours of simultaneous observations resulted in 18 gamma-ray events and 11597 cosmic-ray events. A gamma-ray event is shown in Fig.10. A set of

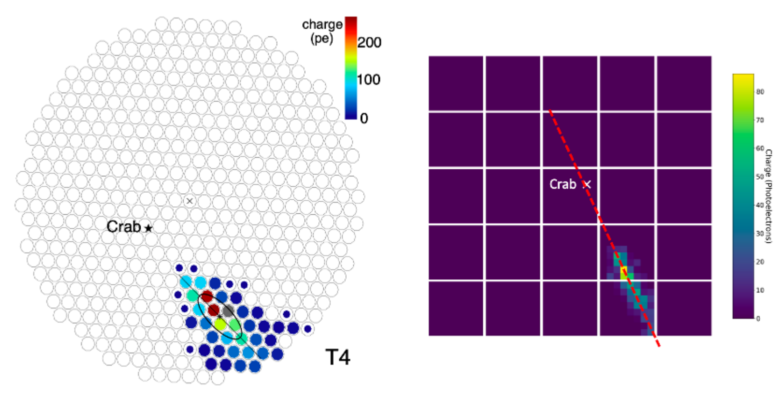

Figure 10: An air shower event detected simultaneously by VERITAS telescope-4 (left) and the pSCT (right).

only-pSCT ON/OFF data was analyzed. An excess of counts acquired for 17.6 hours of ON source observations was identified in correspondence of an α angle of $6°$. α is defined as the angle between

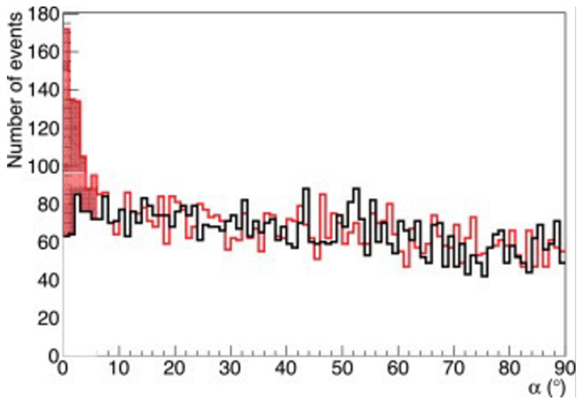

Figure 11: Comparison between counts acquired ON source observations were detected (red histogram) and counts acquired OFF source observations.

the major axis of the event image, and a line joining the centroid of the image to the location of the Crab Nebula. The histogram obtained in the case of ON run was compared with a histogram of counts acquired for the same duration of OFF source observations (see Fig.11).

6. Conclusions and future perspectives

The dual mirror design referring to the SCT works well and at the moment, FEE validation tests are ongoing. We will expect that the new camera configuration will be installed within the end of the 2023.

References

[1] B. Acharya, I. Agudo, I.A. Samarai, R. Alfaro, J. Alfaro, C. Alispach et al., Science with the Cherenkov Telescope Array, arXiv preprint arXiv:1709.07997 (2017).

[2] C. Adams et al., Design and performance of the prototype Schwarzschild-Couder telescope camera, Journal of Astronomical Telescopes, Instruments, and Systems 8 (2022) 1.

[3] C. Aramo et al., Quality control tests on the new front-end electronics for the Schwarzschild-Couder Telescope, Nucl. Instr. and Methods in Phys. Research Section A, Vol. 1045, 2023, https://doi.org/10.1016/j.nima.2022.167605.

[4] Funk et al., TARGET: A digitizing and trigger ASIC for the Cherenkov Telescope Array, in: AIP Conference Proceedings, Vol. 1792, AIP Publishing LLC, 2017, p. 080012.

[5] G. Ambrosi et al., Assembly and performance of SiPM arrays for the prototype SCT proposed for CTA, Nuclear Inst. and Methods in Physics Research, A 1041 (2022) 167359.

[6] C. Adams et al., Detection of the Crab Nebula with the 9.7 m prototype Schwarzschild-Couder telescope, Astroparticle Physics 128 (2021) 102562.

PoS(ECRS)149