First Results from the First G-APD Cherenkov Telescope

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Abstract: The First G-APD Cherenkov Telescope (FACT) project aims to proof that newly developed Geiger-mode avalanche photo-diodes (G-APD) are a viable alternative to currently used vacuum photo-multipliers for future air Cherenkov telescopes for ground-based gamma-ray astronomy. Currently, September 2011, a novel camera comprising of 1440 G-APDs coupled to specially designed and optimized solid light-concentrators is fully assembled. The data-acquisition is based on the Domino Ring Sampler chip version 4 (DRS4) and an Ethernet based readout system. The complete camera was extensively tested in the laboratory, and it is planned to install it in October 2011 in a refurbished HEGRA telescope with a mirror area of 9.2m^2 at the Canary Island La Palma. Here we report on some preliminary test results.

Keywords: Imaging Atmospheric Cherenkov Telescope, IACT, Geiger-mode Avalanche Photo Diode, G-APD, SiPM, Domino Ring Sampler, DRS, Very High Energy Gamma-ray, Electronics

1 Introduction

In the past few years, ground based very-high energy gamma-ray astronomy using Imaging Atmospheric Cherenkov Telescopes (IACT) was highly successful and opened a new window for astronomy as well as fundamental physics like search for cold Dark-matter and Lorentz-invariance violating effects. All the cameras of currently operating IACTs like H.E.S.S., MAGIC and VERITAS as well as the baseline design for the next generation CTA are based on photo-multiplier tubes (PMT). A lot of experience was gained in the past 50 years on design and operation of PMTs. On the other hand, a new generation of silicon based photo-sensors using Avalanche Photo-Diodes operated in Geiger-mode (G-APD, also known as SiPM, MPPM, and other names) could be used for future telescopes. Compared to PMTs, G-APDs are less fragile, need no high voltages, are insensitive to magnetic fields and bear the potential for higher sensitivity and lower costs.

Measurements in the laboratory and in small prototypes show that G-APDs can be a viable alternative to PMTs [1, 2, 3], but there is no experience of operating such devices for extended time under the very harsh conditions of IACTs. Therefore, the main goal of the First G-APD Cherenkov Telescope (FACT) project is to run a full IACT with a camera based on G-APDs for several years.

A description of the status of the project and details of the camera can be found in [4, 5, 6].

Currently (September 2011) the camera is fully assembled (figures 1,2), and tested and will be shipped to La Palma for installation in the refurbished HEGRA CT3 telescope. Commissioning will start in October 2011.

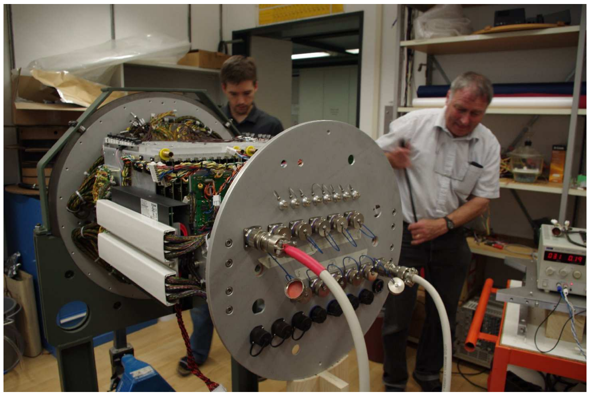

Figure 1: Ongoing final assembly of the FACT camera at ETH Zurich. The compact compartment houses the complete trigger and readout electronics for 1440 pixels

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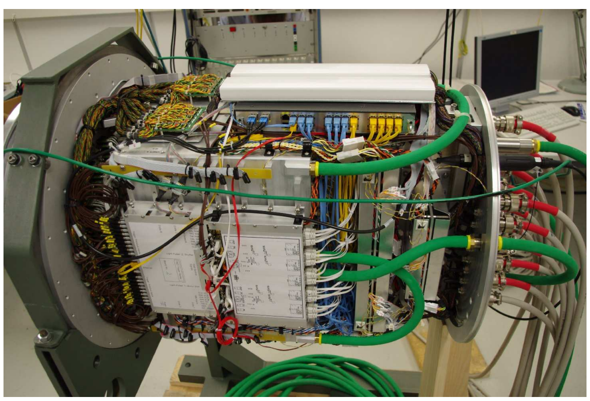

Figure 2: Completely assembled FACT camera during tests at ETH Zurich, shortly before the cover was closed. The thick cables at the backside deliver the 320 different bias voltages to individual pixel groups.

2 Preliminary Test Results

The camera consists of 1440 G-APDs, each coupled to a solid state light concentrator and individually read out using a analogue pipeline (DRS-4 [8]) integrated into the camera. Data are sent to the counting house using standard Ethernet components. The Ethernet based readout was tested to be able to handle a throughput of $\approx$ 300MBytes/s, corresponding to a trigger rate of $>$ 70 Hz if all 1024 slices of all the DRS-4 are read out. Under normal conditions it is sufficient to read only a fraction of the slices and therefor it is possible to handle a trigger rate of several 100 Hz.

The G-APDs have been sorted into groups of four or five pixels with identical Bias-voltage requirements. The voltage of each group can be regulated separately, e.g. to handle the case of very bright stars in the field of view of the camera. A group of nine pixels forms a trigger patch. It is possible to exclude individual pixels from the trigger.

All components of the camera have been fully tested individually, and also the complete system was tested for several weeks. All components operate well within the design limits.

After assembly, two out of the 1440 individual pixels give no signal and another three show erratic behavior and must be excluded from the trigger. As can be seen in figure 2, the camera is too cramped to easily replace these pixels.[1]

The DRS-4 chip needs some calibration that can be done without the need to power the photo-sensors[7]. Figure 3 shows the remaining electronics noise of a typical channel after the DRS calibration, while figure 4 shows this noise for all 1440 channels. The noise is just few mV, compared to the amplitude of a single photon of $\approx$ 10 mV.

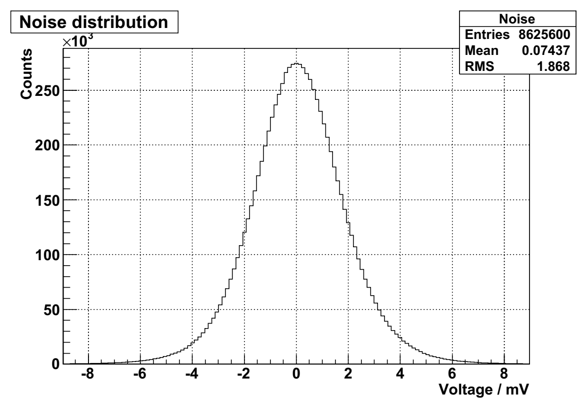

Figure 3: Electronics noise of a typical readout channel after DRS calibration

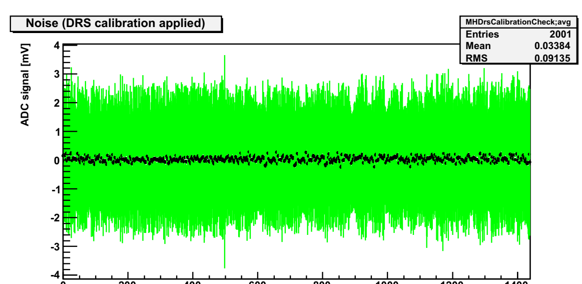

Figure 4: Electronics noise of all readout channel after DRS calibration

1. Designing a modular camera within the very limited space would have required design of special electronics that would have significantly delayed the whole project. For the same reason, it was not possible to integrate the Bias voltage distribution into the camera housing. For a next generation camera, this could be changed.

Just applying this DRS-4 calibration, switching on the sensors (but keeping the camera lid closed) and using a random trigger, one can nicely see the dark counts of the G-APDs. A single cell signal looks identical for a dark count as well as for a single photon. Figure 5 shows a screen-grab of the online display of one of the first events recorded with the full camera. One can easily identify signals where a single cell fired (around channels 170 and 190), where two single cells fired within $\approx$ 15 ns (around channel 800), and where two cells fired together (around channel 350; most probably crosstalk). The measured dark count rate at room temperature is ≈ 5 MHz, and the cross-talk is $< 15\%$.

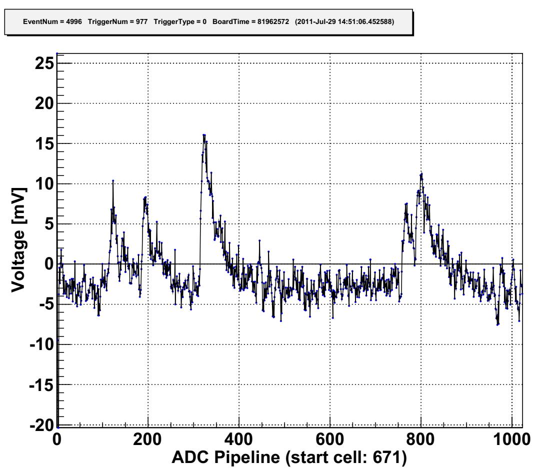

Figure 5: Readout of a single pixel with closed camera lid and random trigger. The DRS-4 was operated with 2 GHz, i.e. each channel corresponds to 0.5 ns. See text for description.

Using a very simple signal extraction algorithm, one can easily get a single photon spectrum. Such a preliminary spectrum is shown in figure 6. Remarkably, this spectrum is not from a single pixel, but combined from all 1435 operational pixels together. This clearly demonstrates that all G-APDs deliver extremely similar results. The final result will be even better, since several known higher order corrections have not been applied yet.

A light pulser is installed in the camera lid, allowing to test the camera also during day time. With this device it is also possible to roughly simulate air-shower signals, as can be seen in figure 7, showing a camera image taken with standard trigger.

3 Outlook

The FACT camera did successfully pass all tests in the laboratory. Several detailed papers describing the project and results are in preparation.

Commissioning of the camera installed in the telescope will start in October 2011. We plan to operate the system for several years to gain long term experience with G-

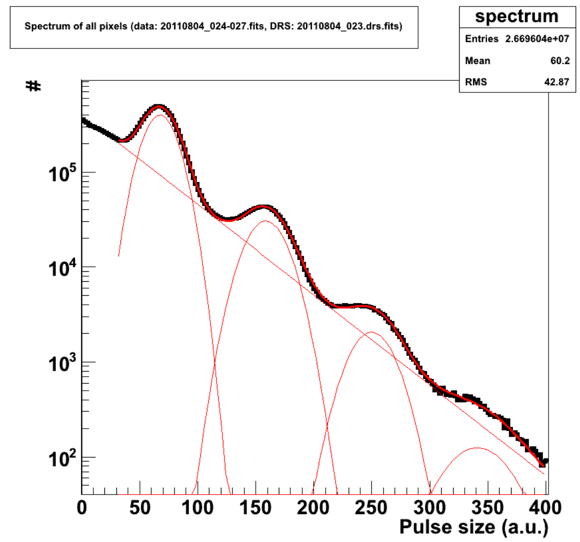

Figure 6: Combined dark count spectrum of 1435 G-APDs. Only DRS calibration was applied. The dark count spectrum is identical to a single photon spectrum

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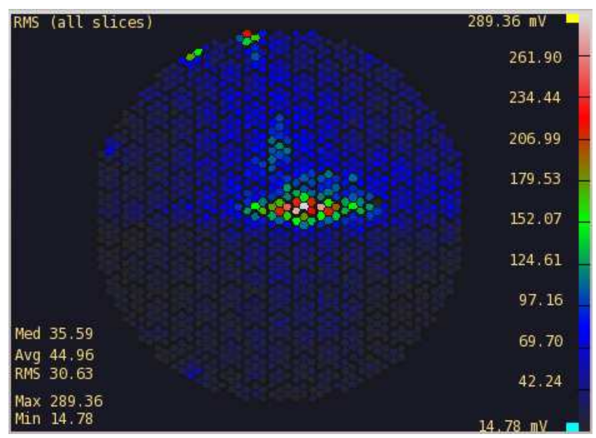

Figure 7: Triggered camera image induced by a signal from a light pulser integrated in the camera lid.

APD cameras, but also use the telescope to monitor bright blazars as a physics program.

4 Acknowledgments

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References

[1] Q. Weitzel et al. (FACT Collaboration), "A Novel Camera Type for Very High Energy Gamma-Astronomy", Proceedings of the 31st ICRC, Lodz, 2009

[2] H. Anderhub et al. (FACT Collaboration), "A novel camera type for very high energy gamma-ray astronomy based on Geiger-mode avalanche photodiodes", JINST 4 (2009) P10010

[3] H. Anderhub et al. (FACT Collaboration), "Results of the Prototype Camera for FACT", Nucl.Instrum.Meth.A639:55-57,2011

[4] T. Bretz et al. (FACT Collaboration), "Status of the First G-APD Cherenkov Telescope (FACT)", these proceedings

[5] B. Huber et al. (FACT Collaboration and others), "Solid light concentrators for small sized photosensors used in Cherenkov Telescopes", these proceedings

[6] P. Vogler et al. (FACT Collaboration), "Trigger and Data Acquisition electronics for a Geiger-mode avalanche photodiode Cherenkov Telescope Camera", these proceedings

[7] T. Kraehenbuehl et al. (FACT Collaboration), "Calibrating the camera for the First G-APD Cherenkov Telescope (FACT)", these proceedings

[8] S. Ritt, "Design and Performance of the 6 GHz Waveform Digitizing Chip DRS4", proceedings of the IEEE Nuclear Science Symposium, 2008