A status report: FACT – a fact!

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In the past years, the second generation of imaging air-Cherenkov telescopes has proven its power detecting weak sources with high sensitivity and low energy threshold. The goal to further improve the sensitivity and lower the energy threshold requires a robust and highly efficient sensor technology. A promising detector technology are silicon based photon detectors, namely Geiger-mode avalanche photo-diodes (G-APDs). They promise robustness and easy manageability compared photo-multiplier tubes so far in use.
To prove the applicability of this technology for Cherenkov telescopes, one of the former HEGRA telescopes was revived and equipped with a camera using G-APDs as photo sensors. Since G-APDs are comparably small, solid light guides are used to significantly increase the light collection area of each sensor. With this technologies, the First G-APD Cherenkov Telescopes (FACT) promises an increase in sensitivity and decrease in energy threshold, compared with a classical photo-multiplier based camera.

Keywords: Geiger-mode Avalanche Photodiode; G-APD; Solid light-guides; Imaging atmospheric Cherenkov Telescope; IACT; FACT

1. Introduction

Currently, the Cherenkov Telescope Array (CTA), a new generation of Cherenkov telesopes (CT), is under development. One of the goals of the project is to gain high sensitivies at energies above 1 TeV. Since in this energy region the observations of Cherenkov telescopes are usually flux limited, many small telescopes should be build and distributed over a large area to increase the collection area.

For this a technology is needed which allows to build small and inexpensive CTs and operate them with reasonable maintanace costs. Using Geiger-mode avalanche photo diodes (G-APDs) instead of Photo-multiplier tubes (PMTs) for photo detection seems to be a very promising, inexpensive and robust technology.

The camera of the First G-APD Cherenkov Telescope (FACT) is build to prove that G-APDs are an inexpensive and easy to handle alternative to PMTs, and to gain experience in operating such a device. Finally, it will serve as a monitoring telescope, dedicated to the observation of the brightest known blazars.[1]

2. Overview

The telecope is located on the Observatorio Roque de los Muchachos at the Canary island La Palma. For the installation of the camera, the former HEGRA CT3 telescope mount was refurbished. A new drive system, similar to one of the close-by 17 m MAGIC telescopes, has been installed but scaled down in power.[2] Additonally, the old disc-like mirrors have been replaced by re-coated hexagonal mirrors yielding a total effective reflective area of $9.5\,\mathrm{m}^2$ and improved reflectivity.

The camera consists of 1440 channels, each equipped with a G-APD and a solid light-concentrator. After pre-amplification, nine channels are summed at a time to build the trigger signal which is discriminated and or'ed together for the final trigger decision. The time jitter of the trigger signal, distributed to the readout boards, is well below 1 ns.

For the readout, the DRS4 analog ring-buffer is used to buffer the analog signal until the trigger signal arrives. Finally, the signal is digitized by a 25 MHz ADC. Storage of the signal in the DRS can be adjusted between 800 MHz and 5 GHz. The anticipated sampling frequency is 2 GHz.

The electronics is build on eighty boards, fourty pre-amplifier with trigger mezzanine boards and fourty readout boards plugged into four crates. Each board contains the readout chain of 36 channels. Except the G-APD bias-power supply, all electronics is integrated into the camera.

Communication and data trasmission is done over fourty Ethernet connections routed through two Ethernet switches and connected to four Ethernet ports in the data acquisition PC.

For details on the electronics see Vogler.[3]

2.1. *Usage of G-APDs*

G-APDs have a couple of advantages compared to classical Photo-multiplier tubes (PMTs). The main advantages are their robustness and the need of relatively low voltages below 100 V.

As typical disadvantages of G-APDs, usually their small size, high dark count rate, their high afterpulsing probability, their internal optical crosstalk and the temperature dependance of their properties are mentioned. For CTs they do not apply as discussed hereafter.

Physical size G-APDs used in FACT have a sensitive area of 9 mm^2 which is small compared to typical PMTs. In general, CTs use light guides to fill the insensitive area between the PMTs, usually not optimized for the best light compression ratio. If they are optimized for best compression, they can significantly increase the sensitive area of G-APDs by factors of 10 to 17. Their size is still small enough that they do not suffer much from transmission losses. Additionally, they reduce Fresnel losses if glued to the sealing window and the G-APD. Due to total reflection, reflection losses become negligible.

For details on solid light concentrators see Huber.[4]

Dark count rate At typical operation temperature, around and below room temperature, the dark count rate is in the order of 5 MHz. Compared to the typical count rates for photons from the diffuse night-sky background, which, in our case, are in the order of 50 MHz, this is negligible.

Optical crosstalk Typical crosstalk probabilities in the order of 15% to 20% give a quite high uncertainty on the single photon level. However, in Cherenkov astronomy signals are usually in the order of tens to hundreds of photons. Therefore, crosstalk just increases the average signal and slightly its fluctuation. These additional fluctuations are still small compared to the intrinsic fluctuations of the shower development.

Afterpulses The afterpulse probability Since afterpulses of G-APDs are in the general case smaller than the inducing signal and their temporal distribution is exponentically decreasing, i.e. they are incoherent, they cannot induce fake triggers. Since afterpulses come very close to the inducing pulse they mainly prolongate the signal and increase the fluctuations of the falling edge. For Cherenkov astronomy this is of no importance.

Temperature dependence Photo detection efficiency, afterpulse probability, optical crosstalk and gain depend on the temperature due to a change of the breakdown resistor, i.e. a change of the so called over-voltage. Changing the applied voltage, this effect can be compensated. Only the dark count rate, originating in thermal noise, depends exclusively on the temperature. But if temperatures are kept well below 35°C, it stays below an acceptable limit. To achive this, a heat isolator is used to shield the sensors from the waste heat of the electronics. Apart from that, normal convection is enough to keep the sensor temperatures around the ambient temperature, which does usally not exceed 30°C at night at La Palma.

To maintain the over-voltage a feedback-system is used. For this the camera is flashed with a temperature stabilized light pulser. By changing the bias-voltage such that its measured average signal amplitude is kept stable, the gain and hence the over-voltage can be kept stable. The constant gain also ensures a homogenous trigger response.

For more information on the feedback system and the calibration see Krähenbühl.[5]

3. Status

All electronics has been build and tested. After continous full system tests, ongoing for several weeks, the camera has recently been shipped to La Palma and was installed Oct 3rd 2011. First system test on La Palma were successfull. Three pixels are known to show large noise and two are known to be dead.

A single photo-electron spectrum could be extracted from all working channels. Both light-pulsers, the internal and external one show reasonable and stable signals.

The camera control and readout is working properly and stable. The total transfer rate through the four Ethernet cards of the PC reach is about 350 MB/s, which is about 100 times faster than needed for regular data-taking. This excess will allow the application of a software trigger whihc is expected to further lower the energy threshold of the telescope.

For more details on existing measurements and test results see Biland.[6]

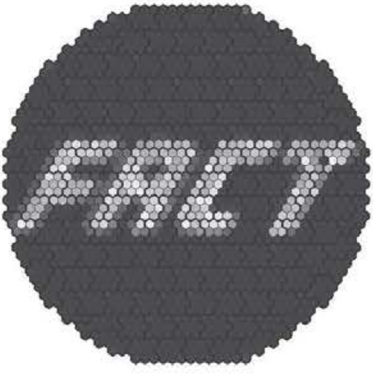

Fig. 1. Amplitude of the external light-pulser with a cover in front of the camera.

4. Conclusion

All lab tast performed were successfull. All parameters are within their specifications. Stability test did not show major problems. The camera has successfully been installed and first simple system test showed no problem. In the coming weeks the camera will be comissioned.

After comissioning is finished, standard operation will be started. The FACT collaboration aims for an immediate publicizing of the data. This can be an important potential for the development of future software projects.

From the current experience of the FACT project it can already be concluded that G-APDs are an alternative for future Cherenkov telescopes.

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