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FACT — STATUS AND FIRST RESULTS

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Abstract. FACT is the first imaging Cherenkov telescope based on a camera using solid state photosensors (Geigermode Avalanche Photodiodes G-APD aka SiPM).

Since October 2011, it has been taking data regularly. Apart from commissioning and calibration measurements, it has already started regular operation, where the main goal is to do long-term monitoring of bright TeV blazars. In June 2012, a flare of Mrk 501 was observed. Thanks to the robustness of the G-APDs, observations can be carried out during strong moon light without aging of the sensors. This improves the duty cycle of the instrument and provides better statistics for long-term light curves.

The telescope, situated on the Canary Island of La Palma, is operated, already now, remotely from central Europe. For the future, robotic operation is planned.

We report on our experiences during the commissioning, and we present first results from the first 1.5 years of observations.

Keywords: Cherenkov astronomy, gamma astronomy, monitoring, AGN, Blazar.

1. FACT — First G-APD Cherenkov Telescope

With the aim to monitor bright active galactic nuclei (AGN) in the very high energy (VHE) range, the First G-APD Cherenkov Telescope (FACT) was designed for stable and robust operation. G-APDs [1] were therefore chosen as photosensors which has provided also the opportunity to show that Si-based photodetectors are suitable for Cherenkov telescopes. In Cherenkov astronomy, the cameras have until now been built using photo-multiplier tubes (PMTs).

Apart from the use of this new technology, FACT features plexiglass cones, a sum trigger, electronics based on the DRS-4 [2] analogue ring buffer and fully integrated into the camera housing, as well as a readout via standard Ethernet. The G-APD camera was mounted on the refurbished HEGRA CT3 mount which was also equipped with a new drive system, basically a down-scaled version of the MAGIC drive system [3], and the re-coated mirrors of the former HEGRA CT1 telescope, providing a mirror area of $9.5\,\mathrm{m}^2$. With its 1440 pixels, each consisting of one G-APD and a plexiglass cone glued to it, FACT has a field of view of 4.5°. The camera has low power consumption of less than 500 Watts. A full description of the design and the construction of the system can be found in [4]. A photo of the telescope is shown in Figure 1.

The camera was mounted on the telescope in October 2011. Since then, it has been taking data regularly. Thanks to its reliability, FACT is the first telescope of its kind that is remotely operated.

1.1. Stability of the Detector

Already now, G-APDs provide performance comparable to that of the best PMTs available. For the future, an increase in the photon detection efficiency as well as a significant reduction in cost is expected. G-APDs are very easy to handle, as they do not require a high voltage but can be operated at about 70 Volts. In addition, they provide very good timing resolution. Being insensitive to magnetic fields and mechanically more robust, they provide an ideal alternative for longterm use in a monitoring telescope which is operated remotely or is robotic. Another very important advantage is that G-APDs can be operated during strong moon light. So far, no indication of ageing due to strong light has been found [5]. Afterpulses, darkcounts and crosstalk are well under control for

FIGURE 1. The First G-APD Cherenkov Telescope, situated on the Canary Island of La Palma at 2200 m a.s.l. Photo: Courtesy of Daniela Dorner

FACT: the darkcount rates are much lower than the rates from the night sky background light (NSB), and can therefore be neglected. The crosstalk (i.e., two or more cells in one pixel are discharged by a single photon) only increases the signal in the pixels slightly and therefore also does not pose a problem except for fake triggers. In FACT, the operation voltage of the G-APDs is set to result in a crosstalk probability of about 10 %, which is well within acceptable limits. The afterpulses can be treated by choosing a signal extractor insensitive to this feature. In addition, afterpulses in G-APDs do not tend to arrive with constant delays, as they do in PMTs, and are therefore no problem for the trigger.

One important feature of G-APDs that cannot be ignored is the dependence of their gain on temperature and on the applied voltage. These dependencies have to be corrected to keep the gain of the G-APDs stable which is important for ensuring consistent and stable data. The temperature dependence of G-APDs is known and can therefore be corrected easily. In addition, NSB light introduces a continuous current in the G-APD, causing a voltage drop. A special method has been developed to correct for this: the voltage change, needed to keep the gain constant, is calculated from the measured current. Since May 2012, a feedback system including temperature and current correction has been in use [6], and a detailed paper is in preparation. Measurements of the gain with the help of a temperature-stabilized light pulser show that with this method the gain can be kept constant within 6 % in time, i.e., correcting for temperature changes of more than 15 degrees, and 4 % between the individual pixels.

Scans of the trigger rate in dependence on the applied trigger threshold have been carried out under various light conditions from dark night to almost full moon. The result of these rate scans shows that the change in the rate at a low trigger threshold depends only on the effect of NSB light, while at high thresholds the rate from hadronic showers remains constant. This proves not only that FACT keeps the NSB dependence well under control, but also allows non-standard conditions of the atmosphere to be detected [7]. This means that apart from a higher energy threshold, the performance of the system is stable for all light conditions. In this way, a lot of observation time can be gained, improving the duty cycle of the telescope. This is a big advantage for monitoring, as the gaps between the observations can be kept small.

Based on the analysis of muon rings, an upper limit for the timing resolution of the whole system could be determined. The distribution of the rms of the arrival time of the pulses in a muon provides a measurement of the timing resolution as the arrival time spread of the light from muons is known to be very small. Therefore the arrival time of muons can give an upper limit for the timing resolution of the whole system. For FACT, the timing resolution has been measured to be around 600 picoseconds, probably dominated by the non-isochronicity of the mirror.

2. DATA SELECTION AND ANALYSIS

The results shown here include the data taken between 1. 5. 2012 and 30. 6. 2013. All data were taken in wobble mode with an offset of 0.6° from the camera center. Details on the data selection and data quality checks can be found in [8].

The performance of the telescope was studied with observations of the Crab Nebula in all possible observation conditions, including zenith distances up to 75°

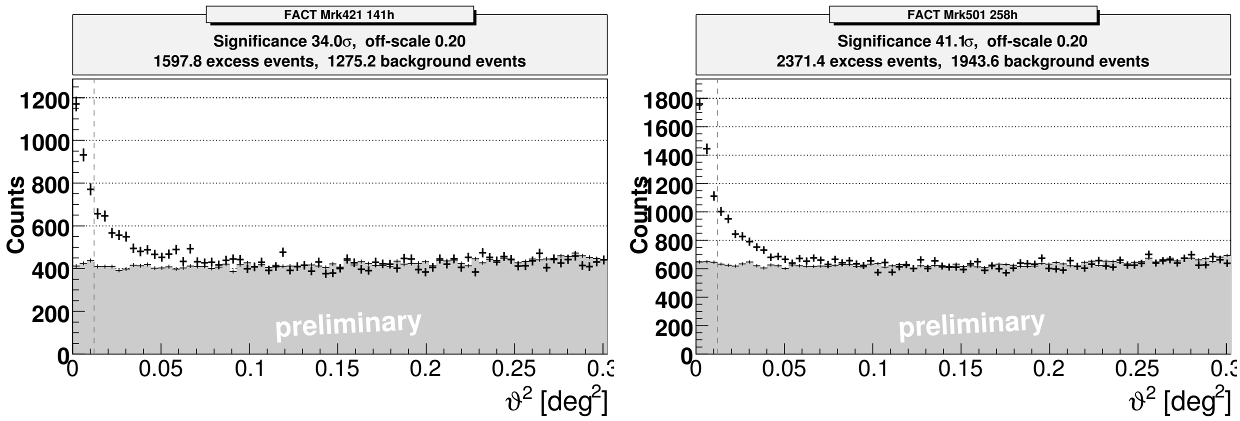

Figure 2. Signals of Mrk 421 (left) and Mrk 501 (right). ϑ^2-distributions for both sources, where the black crosses are the signal and the gray shaded area is the background measurement. The vertical dashed line indicates the cut in ϑ of 0.11°. The events to the left of this line are used to determine the significance of the detection. These plots include data from 1.5.2012 until 30.6.2013 with zenith distance smaller than 40° and a trigger threshold smaller than 500 DAC counts. A data quality check as described in [8] has been applied.

and light conditions ranging from dark night to almost full moon. With the current analysis, the excess rate remains stable for a zenith distance up to 40° and also with moderate moon light. Based on this and in addition to the data check mentioned above, data with zenith distance smaller than 40° and a trigger treshold of less than 500 DAC counts were selected.

The analysis is done using the software package *MARS - CheObs ed.* [10]. Details on the analysis chain and the quick look analysis are given in [8] and [9]. So far, the analysis has been providing excess rate curves, as shown and discussed in detail in [11].

Work on the Monte Carlo simulations and on reconstructing the energy spectrum is ongoing.

Once the dependency of the performance of the system on the zenith distance and the light conditions is fully understood, data taken with larger zenith distances or under different moon conditions can be corrected and will be included.

Nevertheless, significant flaring activities will show flux changes larger than these corrections, so it is already possible to send alerts.

3. Results

In the time between 1.5.2012 and 30.6.2013, Mrk 421 was detected with 34 σ in 141 hours of observation (see Figure 2, left plots). Mrk 501 was detected with 41 σ in 258 hours (see Figure 2, right plot). From both sources, major flares could be detected (two from Mrk 501 and one from Mrk 421). More details on the results of the longterm monitoring of bright TeV blazars with FACT can be found in [11]. In the night with the highest flux measured so far by FACT, Mrk 501 was detected with 22.6 σ in 1.9 hours (see Figure 3, left plot), and within a single run of 5 minutes, the source was detected with up to 6.7 σ during this flare night (see Figure 3, right plot), which nicely demonstrates the capability of FACT to send fast flare alerts to other telescopes.

During the first 1.5 years of operation, the Crab Nebula has also been observed. By comparing these results to those of HEGRA, a sensitivity of 8 % Crab and an energy threshold of about 700 GeV for cuts optimized on sensitivity and about 400 GeV for open cuts are estimated. Preliminary results on this can be found in [9].

4. Conclusions and Outlook

Since October 2011, FACT has stable operation, and since January 2012 continuous monitoring of bright AGN in the TeV range has been ongoing. Three major outbursts at TeV energies of the sources Mrk 501 and Mrk 421 have been detected so far. In the meantime, the telescope can be operated remotely and automatically via Internet. The operation is being further automated aiming at a fully robotic operation [12].

Thanks to the robust photosensors, observations during strong moon light are possible. This is ideal for monitoring, as it enlarges the duty cycle and provides a more complete data sample. G-APDs have shown to be ideal photosensors for the camera of a Cherenkov telescope.

Inexpensive, small telescopes like FACT are ideal systems for extended monitoring of bright TeV blazars and multi-wavelength campaigns.

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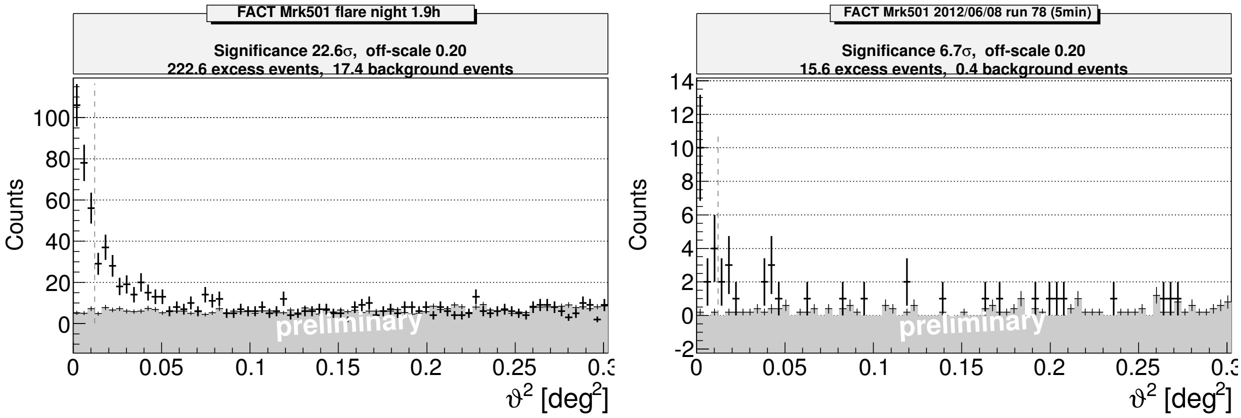

FIGURE 3. Signals of Mrk 501 for the night of 8.6.2012 (left) and for one 5-minute-run from that night (right). ϑ^2-distributions for subsets of the Mrk501 observations, where the black crosses are the signal and the gray shaded area is the background measurement. The vertical dashed line indicates the cut in ϑ of 0.11°. The events to the left of this line are used to determine the significance of the detection. Data selection criteria, as described in the text, have been applied.

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