FACT - Measuring Atmospheric Conditions with Imaging Air Cherenkov Telescopes

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Abstract: For Imaging Air Cherenkov Telescopes, knowledge about the condition of the atmosphere is very important. Usually, this information is gathered by external devices like Lidars and Pyrometers. While Pyrometers only give integral information about the atmosphere, the lasers needed for Lidars can affect data-taking. Based on experience gained with the First G-APD Cherenkov Telescope (FACT), we propose a novel method to monitor the atmosphere directly with a Cherenkov telescope itself while taking data.
We describe the new method, show results from monitoring the atmosphere with FACT and discuss possible implementations for future telescopes.

Keywords: FACT, IACT, Lidar, atmosphere

1 Introduction

Imaging Air Cherenkov Telescopes measure the dim flashes of Cherenkov light emitted by air showers induced by high energy cosmic-ray particles or gamma-rays hitting the atmosphere. Therefore, the atmosphere is a crucial part of the complete detector and has to be included in the analysis and interpretation of the data. One ingredient is density and temperature distribution that can vary significantly between seasons [1]. In addition, daily variabilities can be measured by balloons. To reach high precision, this should be included in the Monte Carlo simulations needed to estimate the energy of individual events.

More important is knowledge about scattering and absorption processes in the atmosphere, induced e.g. by clouds or Calima (a layer of Sahara sand in the atmosphere) [2]. Intrinsically, clouds and Calima have two effects:
a) Absorption and scattering of light, i.e. less Cherenkov photons arrive at the telescope. This alters the energy scale and increases the intrinsic threshold.
b) In addition, scattering of moonlight can result in higher ambient light and therefore the accidental trigger rate increases. To not saturate the data acquisition, this can mandate an increase of the trigger threshold.

2 Monitoring Devices

Several devices can be used to monitor the quality of the atmosphere:

A CCD taking pictures from stars. In case of clouds or Calima, the stars are dimmer or less stars are visible.

A Pyrometer to measure the temperature of the sky. Clouds have higher temperature than the deep sky.

From such information, it is possible to identify existence of clouds in the field of view, but one cannot learn about the hight of the cloud layer. Therefore, CCD and Pyrometer are used to reject data taken under doubtful conditions.

Another instrument is a Lidar: shooting short flashes of laser light and collect the reflections from the atmosphere, it is possible to measure the altitude and density of cloud layers. Therefore, data can be acceptable if cloud layers are thin or high. By using detailed Monte Carlo simulations, the measurements can also be corrected for the absorption of the clouds.

Nevertheless, Lidars also have some disadvantages: they add to investment and maintenance cost of an observatory and their laser light can affect the measurement of the own telescope(s) or neighboring instruments. As an example, Figures 1 and 2 show how a foreign Lidar is affecting the FACT datataking.

3 Rate Scans with FACT

The First G-APD Cherenkov Telescope (FACT) [3, 4] uses for the first time solid state photosensors (G-APDs aka SiPM) instead of PMTs used in all Cherenkov telescopes so far. FACT uses a rather simple trigger: summing the signal of nine neighboring pixels (named trigger-patch) and check if the sum is larger than a programmable threshold. If one patch is higher than its threshold, the complete camera is read out.

One advantage of G-APDs is the possibility to observe during much higher ambient light conditions without aging effects. Due to experience gained in 18 months of operation of FACT, we are now able to predict the accidental trigger distribution from the pointing of the telescope and the actual moon position [5]. A significantly higher rate of accidental triggers is a strong indication for moonlight scattered by

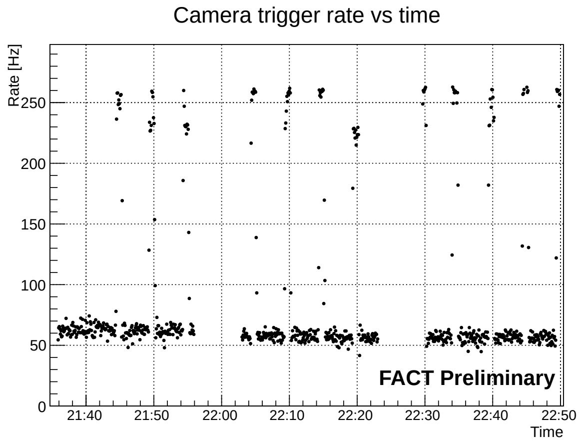

Figure 1: FACT readout rate saturates when a Lidar is in the field of view.

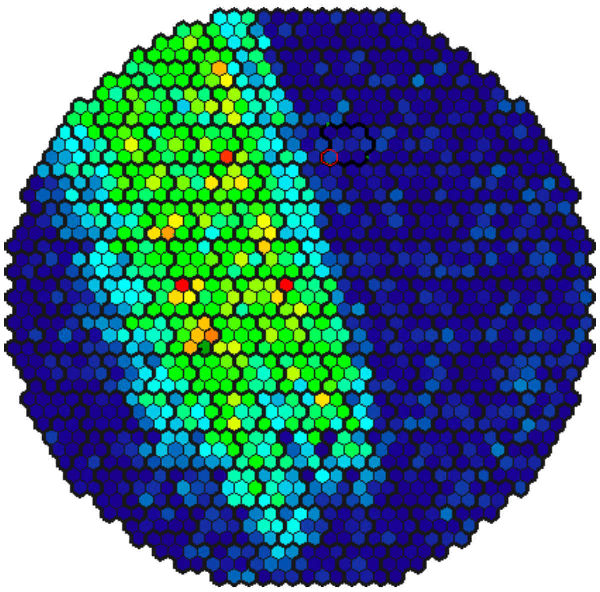

Figure 2: FACT event-display of one Lidar shot.

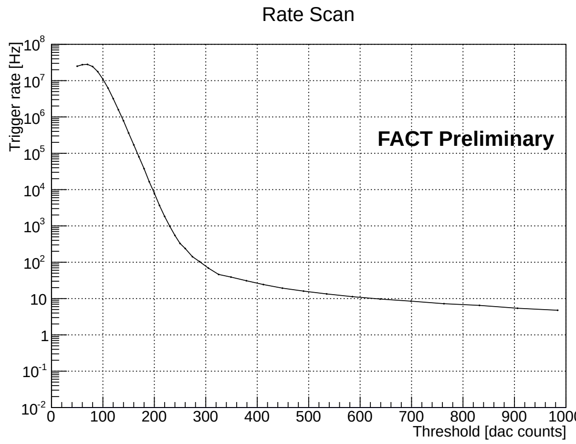

Figure 3: FACT rate scan. While for low thresholds the rates are dominated by accidental triggers, for high thresholds the dominant contribution is from cosmic ray particles (mainly hadrons). The counters saturate at $\sim 10^7$ Hz.

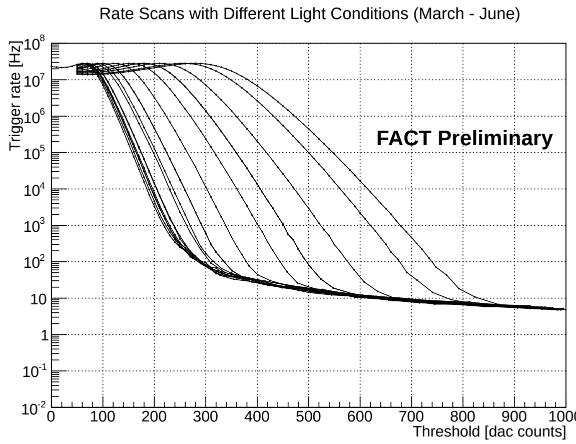

Figure 4: FACT rate scans for similar zenith and good weather conditions. The leftmost line corresponds to dark nights and the rightmost is from $\sim$ 90% fullmoon.

clouds or Calima. These clouds are not necessarily within the field of view of the telescope and therefore they increase the threshold for shower detection even if they do not contribute to the absorption of observed showers.

During the learning process to set the optimum trigger threshold depending on the ambient light, several trigger rate scans had to be done. The data acquisition of FACT is limited to a data rate of $\sim$250MB/s. Depending on the amount of data read from each pixel, this corresponds to a maximum trigger rate of $\sim$80 Hz if reading 1024 slices per pixel, $\sim$260 Hz if reading 300 slices (default setting), or $\sim$820 Hz if reading 100 slices. It is also possible to run FACT without reading the data, only recording the trigger rate of each individual patch. Under this condition, the counters start saturating at $\sim 10^7$Hz. In figure 3, the trigger rate is plotted as a function of the trigger threshold. On the left side, the rate drastically increases due to high accidental rate accepted with reduced threshold, while on the right side the triggered events are dominated by Cherenkov flashes from airshowers, mainly induced by charged cosmic ray particles.

A higher level of light will increase the rate of accidental triggers, while the rate of Cherenkov flashes for a given telescope pointing is constant (figure 4). This increase can happen for all patches in case of moonlight, or for individual patches by bright stars in the field of view.

It has to be noted that such precision is only possible with a very stable system. In case of high photon flux, serial resistors reduce the voltage applied to the G-APDs. Therefore the Bias voltage must be carefully regulated. Figure 4 proofs that this problem is well under control in the operation of FACT.

4 Monitoring the Atmosphere

It is save to assume the rate of charged cosmic ray particles to be constant and measured rate to scale with the zenith angle (and to slightly depend on the azimuth due to geomagnetic effects). Therefore, a deviation of the measured trigger rate indicates a change of the amount of Cherenkov photons collected per air shower by absorption or scattering of the light by clouds or Calima. Figure 5 shows the same rate scans as figure 4 with the addition of rate scans (marked red) during Calima. While suffering from Calima in the atmosphere, a reduced rate of Cherenkov flashes is clearly visible. Since the Cherenkov flashes are mainly restricted to a small area around the field of view of the telescope, such a measurement delivers good information about the condition of the atmosphere within the actual field of view. In addition, airshowers from charged particles develop in comparable altitude as the showers from gamma-rays.

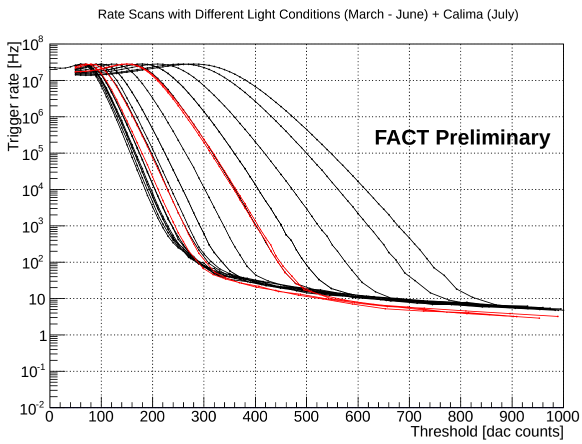

Figure 5: FACT rate scans same as figure 4, including additional four nights with Calima marked in red.

To illustrate the concept further we selected one night with rapidly changing atmospheric conditions and show several rate scans in a row pointing close to zenith. In figure 6 all rate scans shown were measured within two hours. Three of the rate scans marked in red, green and blue are selected and compared to images from the all sky camera of the Gran Telescopio Canarias[6] taken at the same time (see figure 7). The yellow and green areas show disturbances of the atmosphere.

The red line in figure 6 corresponds to figure 7a which shows a sky that is completely blocked. The green line corresponds to image 7b which shows a sky that is semi translucent. The cyan line corresponds to figure 7c which shows only a few clouds at the horizon which hardly influence the measurements.

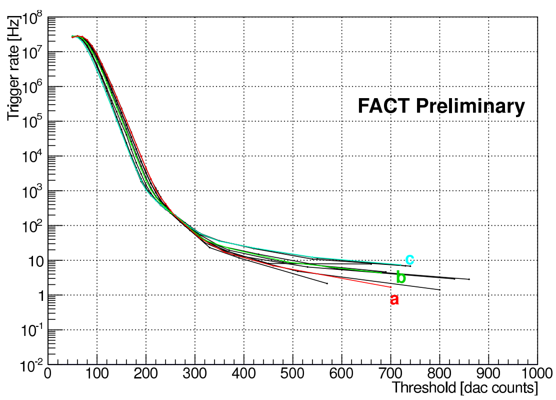

Figure 6: FACT rate scans of one night indicating variable atmospheric conditions. The scans marked a,b and c correspond to the sky images in figure 7.

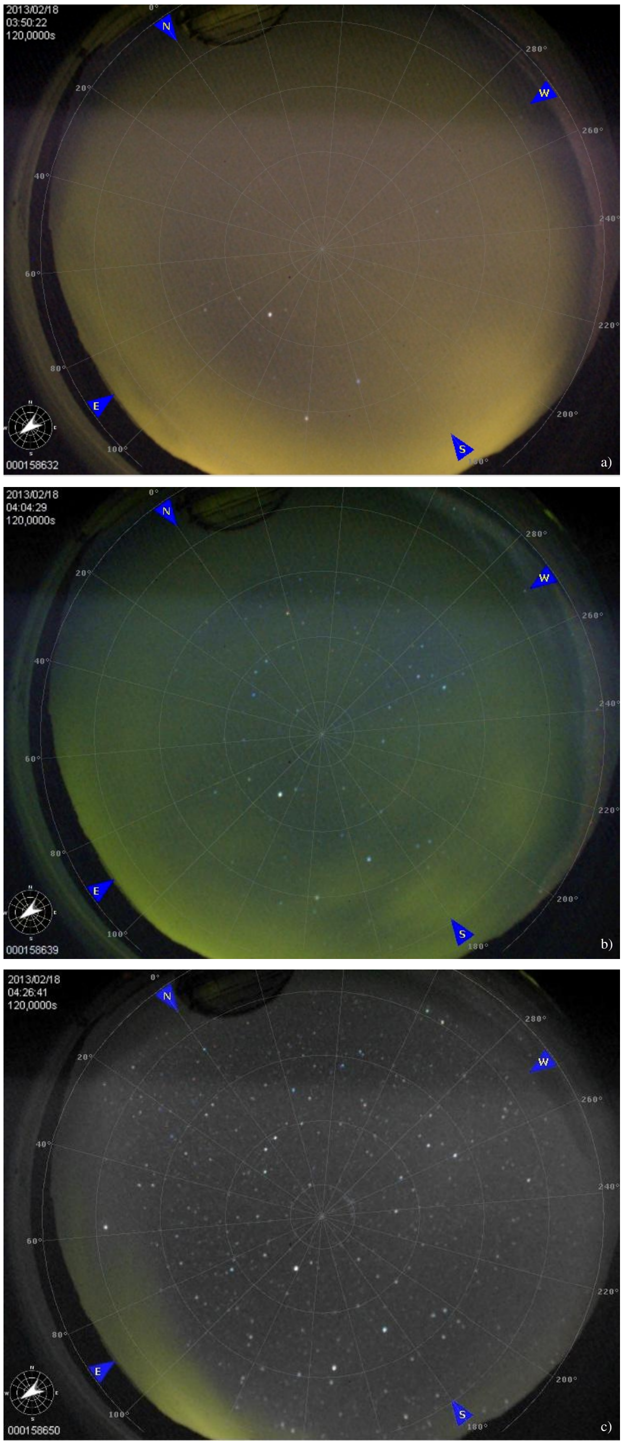

Figure 7: Images from the all sky camera of the Gran Telescopio Canarias [6] corresponding to the rate scans shown in figure 6. Green/yellow regions indicate disturbances of the atmosphere.

5 Information Contained in the Rate scans

The precision reachable is limited by the amount of time spent measuring with high trigger thresholds. Due to its small size, FACT is limited to rare high energy showers, and the trigger rates are usually measured to about 5% precision. Spending more time or having higher rates due to lower threshold (i.e. larger mirror area) would allow significantly higher precision.

Comparing deviations at low thresholds (accidental triggers) and high thresholds (Cherenkov flashes), it should be possible to learn even more about the condition of the atmosphere:
a) very high altitude clouds will hardly affect the amount of Cherenkov flashes, but due to e.g. scattering of moon light they can increase the ambient light within the field of view and affect the rate of accidental triggers
b) absorption in the lower atmosphere will reduce the amount of photons from Cherenkov showers as well as the ambient light and therefore reduce the trigger rates for accidentals as well as for Cherenkov flashes
c) scattering in the lower atmosphere will reduce the amount of collimated photons from Cherenkov showers, but can increase the amount of ambient light within the field of view and therefore increase the rate of accidental triggers.
In addition, the altitude of the shower development depends on the energy of the initiating particle. Therefore, very high precision rate scans with high threshold might contain information about the altitude of clouds or Calima. Very extensive Monte Carlo studies would be needed to evaluate this possibility.

6 Possible Future Implementations

In the trigger system implemented in FACT (figure 8), each patch has a defined (programmable) threshold at any given time and records the rate of triggers above this threshold. Therefore, to do a rate scan it is necessary to interrupt datataking and losing precious observation time.

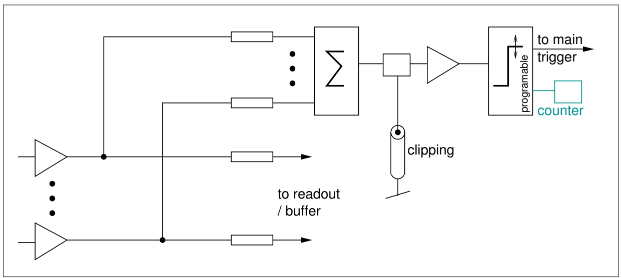

Figure 8: Schematics of the trigger system used in FACT.

A modified trigger system allowing to record signals covering a set of different thresholds per patch would allow to do kind of rate scans independent of datataking.

Having two setable comparators per patch (figure 9), one used to set the threshold to select events to trigger the readout, the other one could be used to do sequential rate scans similar to the ones done with FACT but in parallel to datataking. Depending on the wanted precision, a rate scan could be done every few minutes.

Having even more comparators per patch (figure 10), it is not necessary to do sequential rate scans since trigger rates for different thresholds can be measured concurrently.

There is no need to have all these comparators per patch setable. While the one used to define the trigger threshold of the telescope must be programmable, the ones used for rate scan like measurements can be preset to fixed values covering the interesting threshold range.

It might not be necessary to equip all patches with such a setup, but if only few patches are used one has to avoid bright stars in these patches.

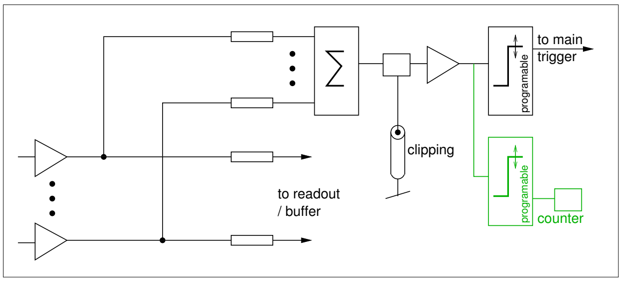

Figure 9: Using two independent comparators, rate scans can be done during datataking.

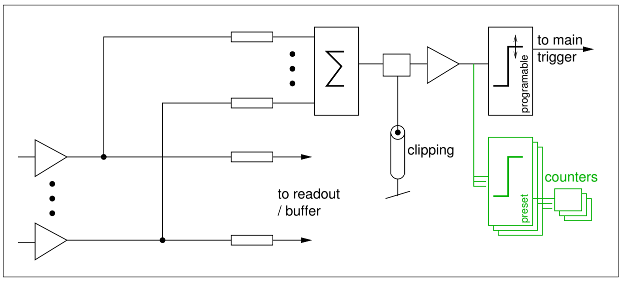

Figure 10: Using several comparators, same information can be gained without a scan during datataking.

Most probably the setup best suited would be to have all data digitized before trigger decision is taken and full information can be handled by firmware as e.g. possible with the Flashcam project [7].

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