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FACT - Long-term Monitoring of Bright TeV-Blazars

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Abstract: Since October 2011, the First G-APD Cherenkov Telescope (FACT) is operated successfully on the Canary Island of La Palma. Apart from the proof of principle for the use of G-APDs in Cherenkov telescopes, the major goal of the project is the dedicated long-term monitoring of a small sample of bright TeV blazars. The unique properties of G-APDs permit stable observations also during strong moon light. Thus a superior sampling density is provided on time scales at which the blazar variability amplitudes are expected to be largest, as exemplified by the spectacular variations of Mrk 501 observed in June 2012.
While still in commissioning, FACT monitored bright blazars like Mrk 421 and Mrk 501 during the past 1.5 years so far.
Preliminary results including the Mrk 501 flare from June 2012 will be presented.

Keywords: AGN, blazars, monitoring, FACT, light curves.

1 Introduction

The main goal of the First G-APD Cherenkov Telescope (FACT), apart from the proof of principle for the solid state photo sensors, is the long term monitoring of bright TeV Blazars [1].

Providing a stable and robust detector [2, 3], G-APDs allow for observations during strong moon light [4] enlarging the duty cycle of the telescope which provides a better sampling of the long-term light curves. Having a stable detector, a robust quick look analysis can be established allowing to send flare-alerts to other telescopes within a short time range. This allows to study these flares with more sensitive instruments and in different wavelengths.

However the main physics goal of FACT is to study TeV blazars not only during flares, but in all flux states allowing for statistical analyses of the variability of these objects on an unbiased data sample.

Together with long-term monitoring in the optical and radio band, detailed multi-wavelength (MWL) studies can be carried out.

2 Observations

In January 2012, the monitoring of bright TeV blazars with FACT was started. Apart from few other sources, in the first 1.5 years mainly the Crab Nebula and the two active galactic nuclei (AGN) Mrk 421 and Mrk 501 have been observed. All monitoring observations were carried out in wobble mode, i.e. the source is tracked 0.6 degree from the camera center alternating for different positions. The two wobble positions were chosen such that bright stars are either not in the FoV or, in case it could not be avoided, are symmetric to the source for the two positions.

3 Data Analysis

The data analysis consists of several steps and is done with the software package 'MARS - CheObs ed.' [9]. First, the data are calibrated and the signal is extracted. After the so-called image cleaning, i.e. removing pixels which do not contain any signal, the images, parameters describing the shower images are calculated. Based on these parameters, the background is suppressed. With the parameter theta, which describes the angle between the reconstructed shower origin and the real source position, the excess is determined by subtracting the background from the signal events in the source region. Dividing the number of excess events by the effective ontime of the observations, excess rates are obtained. For a real flux calculation, the engergy of the primary particle of each shower has to be reconstructed which needs Monte Carlo simulations. Work on these siulations and the determination of the energy spectrum are ongoing.

The analysis chain, providing the excess rate curves, runs both on site in La Palma and at the data center with only minor differences. In the data center, all data are reprocessed once a newer software version is available, while the quick look analysis (QLA) does not include reprocessing, but just uses the latest stable and well tested software version. Furthermore, the QLA does not include any data check so far.

The aim of the QLA is to provide results as fast as possible to allow for sending flare alerts to other telescopes during the same night. Within 30 minutes to 2 hours after the data were taken, the results are available on a dedicated webpage. To achieve this fast response on site, this analysis does not use Monte Carlo simulations.

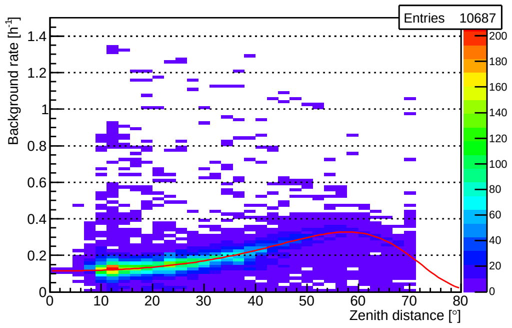

Figure 1: Background rate after cuts versus zenith distance. The colour code represents the number of runs, where one run comprises five minutes. For the study, almost 900 hours of data have been used. Details on how this background rate is determined can be found in section 4.

Once the data are transferred to the data center, the analysis is repeated and refined.

Based on the measured performance of the detector [2, 3, 4], a detailed data check is done, and the good quality data are further analysed.

To allow for a non-biased excess rate curve, the dependence of the excess rate on the ambient light and on the zenith distance is studied using about 350 hours of data from the Crab Nebula. The dependence on the zenith distance is studied using a data sample taken during dark time only. To disentangle the two effects, the dependence on ambient light is studied with data with small zenith distance. Fitting the dependencies, an estimate of the flux corrected for the influence of ambient light and zenith distance can be calculated.

4 Data Selection

For the presented excess rate curves, only data with well-understood, stable performance of the detector have been used. Data taken before the current control current control was implemented in the feedback system [2] in April 2012 is not included. Data between taken 6.12.2012 and 10.1.2013 were excluded because of a broken bias voltage channel. These data may be recovered once the telescope performance of these time periods is studied in more detail.

To exclude data with bad weather the background rate after cuts has been studied. With this, also data affected by laser shots from neighbouring atmosheric moinitoring devices can be excluded.

For this the dependency of the rates are studied versus zenith distance (see figure 1) and threshold for a data set of almoust 900 hours from a time range between May 2012 and June 2013 also excluding the data with different telescope setup mentioned above.

For this study, the background rate after background suppression cuts, but before theta-cut is used. To have no bias e.g. from strong flares, the number of signal events is subtracted before calculating this rate.

By fitting event distributions of the obtained background rate in zenith bins, the mean rate per zenith distance bin has been determined. These mean values are plotted versus zenith distance and fitted. With the determined fit function (see red line in figure 1), the background rate can be corrected for the dependency on zenith distance.

The same procedure is applied for the dependency on the trigger threhold yielding a value of the background rate which is independent of these two observation conditions. In the resulting event distribution, good data can be identified. Data with a corrected background rate deviating from these typical values are rejected, where data with a low corrected background rate could be identified as affected by bad weather and data with a very high corrected background rate as affected by laser shots from a neighbouring atmospheric monitoring device (LIDAR [**?**]) and is rejected as well. This data selection is done on run-basis, where one run lasts five minutes.

For the nightly excess rate curves, also nights with less than 20 minutes remaining observation time have been rejected.

5 Results

Since the start of operation in October 2011, FACT monitored Mrk 421 already from 25.1.2012 until now. For Mrk 501, the observations started on 19.5.2012, and the monitoring of both sources is ongoing. From the QLA on site, the excess rate curves are determined as described in section 3 and shown in the figures 3 and 2 after data selection as described in section 4. Along with the excess rates (blue), the background rates (black) are shown, both with daily binning. It has to be noted that the plots shown here are not yet taking into account any corrections for the effect of ambient light and zenith distance. This explains some systematic changes of the background over time.

The work on data check and the determining the correction factor based on the above explained study on Crab data are ongoing. Nevertheless, these corrections are small compared to the large fluctuations seen due to major flaring activities of both AGNs.

From Mrk 501, a major outburst could be detected in June 2012 during a MWL campaign. During the night with the highest flux, FACT measured a signal from the source with more than 5 sigma significance in 5 minutes over the whole night. In figure 4, a nightly excess rate curve for the time between 19.5.2012 and 30.6.2012 is showning the flare activity in more detail. In February 2013, another major flare of Mrk501 was observed.

The excess rate curve of Mrk421 is shown in figure 2. In April 2013, a major outburst from the source was observed where also a wide coverage of observation time with other telescopes is available. However, FACT did not observe during the two nights with the highest flux due to technical problems with the drive system because of too high temperatures in the container. In addition, it was known that the big telescopes are observing the source.

The excess rate curves spanning more than one year for both sources show nicely the monitoring power of the instrument which provides useful information both for MWL studies as well as for variability studies of bright TeV blazars. Due to the fast response of the QLA, FACT is now able to trigger observations of other instruments in case of a major outburst.

6 Conclusions and Outlook

G-APDs have shown to be ideal for monitoring, as they allow for observations during strong moon light. They pro-

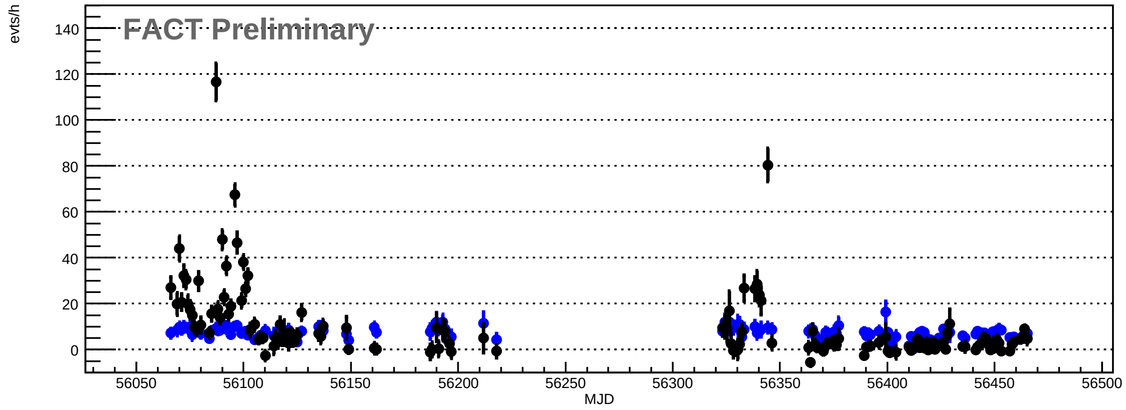

Figure 2: Rates for Mrk 501 from May 2012 until June 2013 with one bin per night. In black: Rate of excess events. In blue: Rate of background events. The curves are not yet corrected for the effects of the zenith distance and of ambient light like the moon. The gap in the middle of the curve is due to the source being below the horizon or only visible at very big zenith distance. In June 2012 a big outburst can be seen, see in detail figure 4, and another one in February 2013.

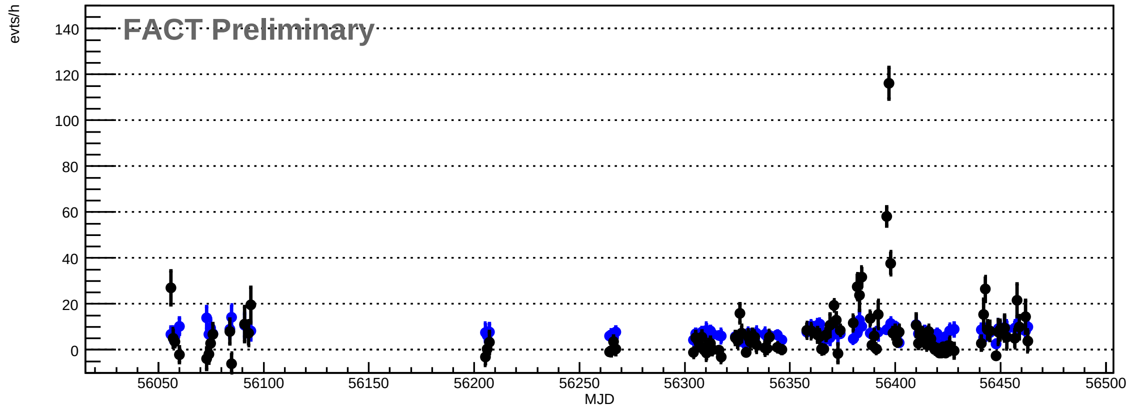

Figure 3: Rates for Mrk 421 from May 2012 until June 2013 with one bin per night. In black: Rate of excess events. In blue: Rate of background events. The curves are not corrected for the effects of the zenith distance and of ambient light like the moon. The gap after the first data points is due to the source being not visible for a few months under zenith distances smaller than 60 degree. The data points in the middle of the gap are taken under very large zenith distance due to an historical outburst being reported in the radio range. In winter 2012/2013 there is another gap of few weeks due to a broken bias channel. In April 2013, a major outburst is visible.

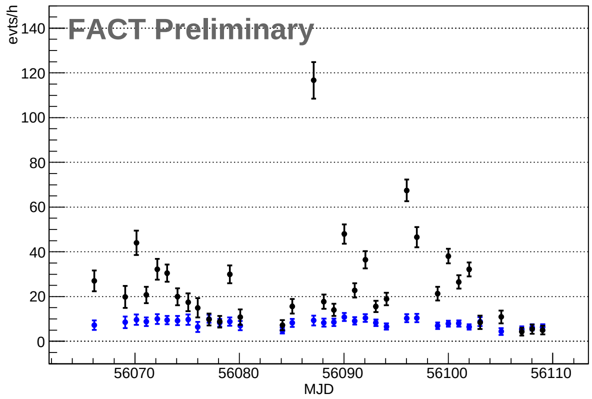

Figure 4: Rates for Mrk 501 from May 2012 until June 2012 with one bin per night. In black: Rate of excess events. In blue: Rate of background events. The curves are not yet corrected for the effects of the zenith distance and of ambient light like the moon. This zoom on the excess rate curve shows only the time around the flare in June 2012.

vide stable and robust performance of the detector. Furthermore they show to be a good alternative for cheap monitoring telescopes which can be operated remotely and automatic. Based on the experiences gained so far with FACT, the long-term objective is to build several small telescopes and realize 24/7 monitoring of bright TeV Blazars.

Since its first light, FACT has collected 1.5 years of monitoring data at TeV energies, minimizing the gaps due to full moon and providing a data sample which can be used both for flare and MWL studies. During that time, FACT has seen three major outburst of TeV blazars, one of Mrk421 and two of Mrk501.

With its quick look analysis, FACT furthermore can now provide fast alerts to other telescopes in case of flares. The results of the QLA will be available on http://www.fact-project.org/monitoring starting from September 2013.

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References

[1] H. Anderhub et al. (FACT Collaboration), arXiv:1304.1710, accepted in JINST.
[2] T. Bretz et al. (FACT Collaboration), these proc., ID 683.
[3] T. Bretz et al. (FACT Collaboration), these proc., ID 720.
[4] M. Koetig et al. (FACT Collaboration), these proc., ID 695.
[5] T. Bretz et al. (FACT Collaboration), these proc., ID 682.
[6] D. Hildebrand et al. (FACT Collaboration), these proc., ID 709
[7] A. Biland et al. (FACT Collaboration), these proc., ID 708
[8] T. Bretz and D. Dorner, Astrop., Particle and Space Physics, 681.
[9] C. Fruck et al. (MAGIC Collaboration), these proc., ID 1054.