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Detailed Monte Carlo studies for the MAGIC telescope

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(for the MAGIC Collaboration)

Abstract. For understanding the performance of the MAGIC telescope a detailed simulation of air showers and of the detector response are indispensable. Such a simulation must take into account the development of the air showers in the atmosphere, the reflectivity of the mirrors, the response of photo detectors and the influence of both the light of night sky and the light of bright stars. A detailed study is presented.

1 Introduction

The $17\ \mathrm{m}$ diameter Cherenkov telescope called MAGIC is presently in the construction stage (MAGIC 1998). The aim of this detector is the observation of γ-ray sources in the energy region above $\approx 30\ \mathrm{GeV}$ in its first phase. The air showers induced by cosmic ray particles (hadrons and gammas) will be detected with a ”classical” camera consisting of 576 photomultiplier tubes (PMT). The analog signals of these PMTs will be recorded by a FADC system running with a frequency of $f = 333\ \mathrm{MHz}$. The readout of the FADCs will be started by a dedicated trigger system containing different trigger levels.

The primary goal of the trigger system is the selction of showers. For a better understanding of the MAGIC telescope and its different systems (trigger, FADC) a detailed Monte Carlo (MC) study is neccessary. Such a study has to take into account the simulation of the air showers, the effect of absorption in the atmosphere, the behaviour of the PMTs and the response of the trigger and FADC system.

An important issue for a big telescope like MAGIC is the light of the night sky. There will be around 50 stars with magnitude $m \leq 9$ in the field of view of the camera. Methods have to be developed which allow to reduce the biases introduced by the presence of stars. The methods can be tested by using Monte Carlo data.

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Here we present the first results of such an investigation.

2 Generation of MC data samples

The simulation is done in several steps: First the air showers are simulated with the CORSIKA program (Heck and Knapp, 1995). In the next step we simulate the reflection of the Cherenkov photons on the mirror dish. Then the behaviour of the PMTs is simulated and the response of the trigger and FADC system is generated. In the following subsections the various steps are described in more details.

2.1 Air shower simulation

The simulation of gamma and of hadron showers in the atmosphere is done with the CORSIKA program, version 5.20. As the hadronic interaction model we use the VENUS model. We simulate showers for different zenith angles ($\Theta = 0^\circ, 5^\circ, 10^\circ, 15^\circ, 20^\circ, 25^\circ$) at fixed azimuthal angle Φ. Gammas are assumed to originate from point sources in the direction (Θ,Φ) whereas the hadrons are simulated isotropically around the given (Θ,Φ) direction in a region of the solid angle corresponding to the FOV of the camera. The trigger probability for hadronic showers with a large impact parameter I is not negligible. Therefore we simulate hadrons with $I < 400\ \mathrm{m}$ and gammas with $I < 200\ \mathrm{m}$. The number of generated showers can be found in table 1. For each simulated shower

zenith angle	gammas	protons
$\Theta = 0^\circ$	$\approx 5 \cdot 10^5$	$\approx 1 \cdot 10^6$
$\Theta = 5^\circ$	$\approx 5 \cdot 10^5$	$\approx 1 \cdot 10^6$
$\Theta = 10^\circ$	$\approx 5 \cdot 10^5$	$\approx 1 \cdot 10^6$
$\Theta = 15^\circ$	$\approx 2 \cdot 10^6$	$\approx 5 \cdot 10^6$
$\Theta = 20^\circ$	in production	in production
$\Theta = 25^\circ$	in production	in production

Table 1. Number of generated showers.

all Cherenkov photons hitting a horizontal plane at the observation level close to the telescope position are stored.

2.2 Atmospheric and mirror simulation

The output of the air shower simulation is used as the input to this step. First the absorption in the atmosphere is taken into account. Using the height of production and the wavelength of each Cherenkov photon the effects of Rayleigh and Mie scattering are calculated. Next the reflection at the mirrors is simulated. We assume a reflectivity of the mirrors of around 85%. Each Cherenkov photon hitting a mirror is propagated to the camera plane of the telescope. This procedure depends on the orientation of the telescope relative to the shower axis. All Cherenkov photons reaching the camera plane will be kept for the next simulation step.

2.3 Camera simulation

The simulation comprises the behaviour of the PMTs and the electronics of the trigger and FADC system. We take the wavelength dependent quantum efficiency (QE) for each PMT into account. In figure 1 the QE of a typical MAGIC PMT is shown. For each photo electron (PE) leaving the

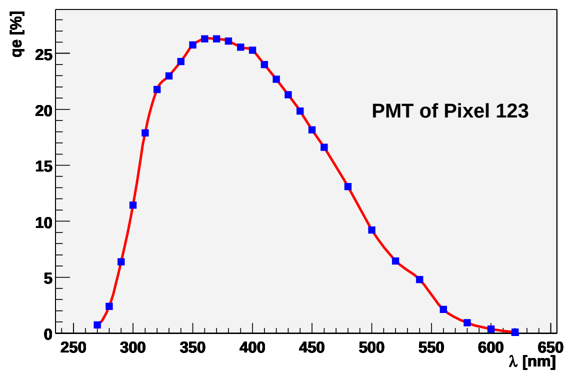

Fig. 1. quantum efficency of the PMT for pixel 123

photo cathode we use a ”standard” response function to generate the analog signal of that PMT - separatly for the trigger and the FADC system. At present these response functions are gaussians with a given width in time. The amplitude of the response function is chosen randomly according to the distribution shown in figure 2 (Mirzoyan and Lorenz (1997)).

By superimposing all photons of one pixel and by taking the arrival times into account the response of the trigger and FADC system for that pixel is computed (see also figure 3). This is done for all pixels in the camera.

The simulation of the trigger electronic starts by checking whether the generated analog signal exceeds the discriminator threshold. In that case a digital output signal of a given length (6 nsec.) for that pixels is generated. By checking next neighbour conditions (NN) at a given time the first level trigger is simulated. If a given NN condition (multiplicity,

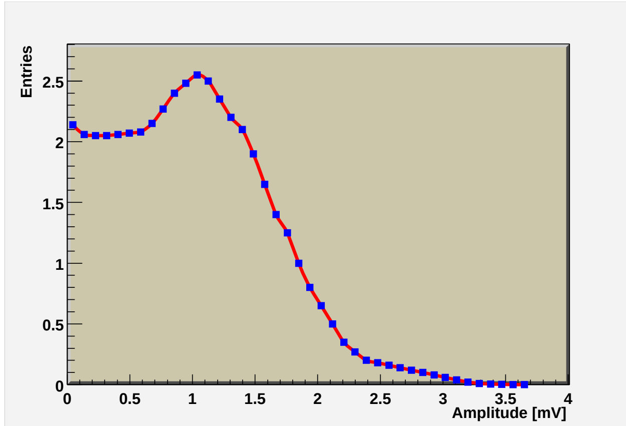

Fig. 2. The distibution of the amplitude of the standard response function.

topology, ...) is fullfilled, a first level trigger signal is generated and the content of the FADC system is written to disk.

2.4 Starlight simulation

Due to the big mirror area MAGIC will be sensitive to stars up to a magnitude of 10. These stars will contribute locally to the noise in the camera and have to be taken into account. A program was developed to simulate the star light together with the generated showers. This program considers all stars in the field of view of the camera around a chosen direction. The light of these stars is traced up to the camera taking the wavelength of the light into account. After simulating the response of the photo cathode, we get the number of emitted photo electrons per pixel and time.

These number are used to generate a noise signal for all the pixels. In figure 3 the response of the trigger and the

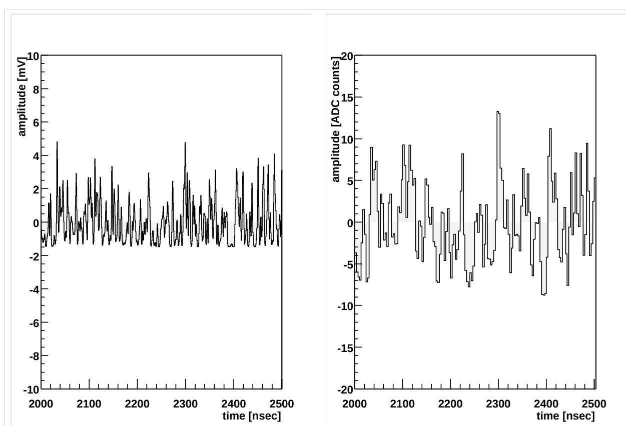

Fig. 3. The response of a pixel due to a star with magnitude $m = 7$ in the field of view. On the left plot the analog signal that goes into the trigger system is plotted while on the right plot the content in the FADC system is shown.

FADC system can be seen for a pixel with a star of magnitude

$m = 7$. These stars are typical, because there will be on average one 7^m star in the trigger area of the camera.

3 Results

3.1 Trigger studies

The trigger system will consist of different trigger levels. The discriminator of each channel is called the zero-level-trigger. If a given signal exceeds the discriminator threshold a digital output signal of a given length is produced. So the important parameters of such a system are the threshold of each discriminator and the length of the digital output.

The first-level-trigger checks in the digital output of the 271 pixels of the trigger system for next neighbor (NN) conditions. The adjustable settings of the first-level-trigger are the mulitiplicity, the topology and the minimum required overlapping time.

The second-level-trigger of the MAGIC telescope will be based on a pattern-recognition method. This part is still in the design phase. All results presented here refer to the first-level-trigger. If not stated explicitly otherwise, the MC data are produced with ”standard” values (discriminator threshold = 4 mV, gate length = 6 nsec, multiplicity = 4, topology of NN = *closed package*).

3.1.1 Trigger collection area

The rigger collection area is defined as the integral

$$A(E,\Theta) = \int_F T(E,\Theta,F)dF \qquad (1)$$

where T is the trigger probablity. F is a plane perpendicular to the telescope axis. The results for different zenith angles Θ and for different discriminator thresholds are shown in figure 4. At low energies ($E < 100$ GeV), the trigger collection area decreases with increasing zenith angle , and it decreases with increasing discriminator threshold.

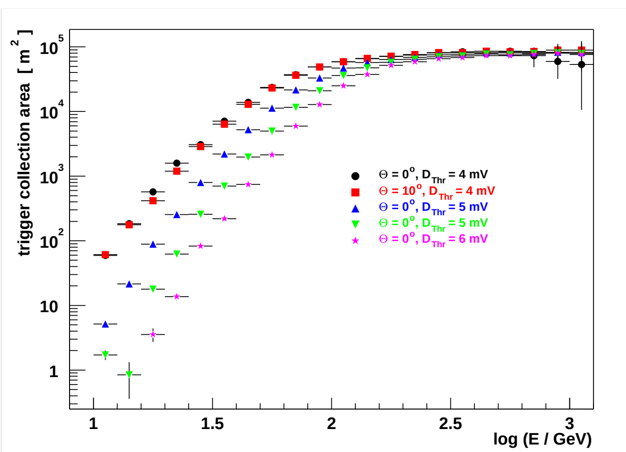

Fig. 4. The trigger collection area for gamma showers as a function of energy E.

3.1.2 Energy threshold

The threshold of the MAGIC telescope is defined as the peak in the dN/dE distribution for triggered showers. This value is determined for all different trigger settings. The energy threshold could depend among other variables on the background conditions, the threshold of the trigger discriminator and the zenith angle. We check the dependence on these three variables.

For both, gammas and protons, some different background conditions have been simulated (without any background light, diffuse light, and light from Crab Nebula field of view). No significant variation of the energy threshold is observed. It should be stressed that this is based only on first level triggers. Most likely some effects will be seen after the second level trigger and the shower reconstruction.

MAGIC will do observations in a large range of zenith angles, therefore it is worth studying the energy threshold as function of the zenith angle (see figure 5). Even though larger statistic is needed, the energy threshold increases slowly with the zenith angle, as expected.

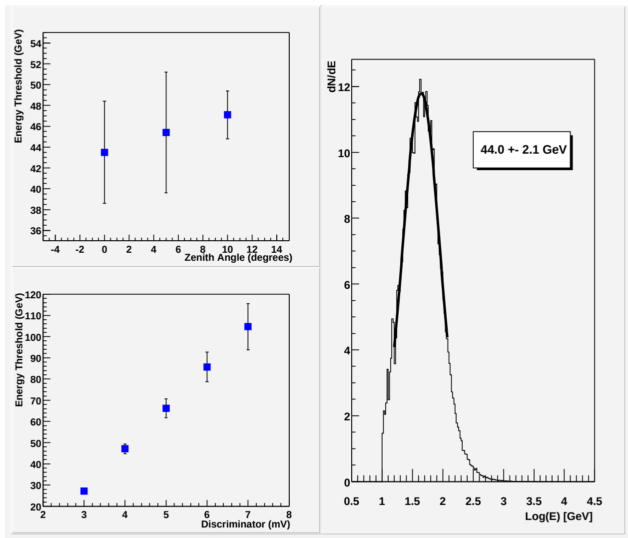

Fig. 5. On the left upper plot the energy threshold for diffrent zenith angles is plotted while on the left bottom plot the energy threshold is plotted for several values of the trigger discriminator threshold. On the right plot a characteristic fit for dN/dE is shown (for showers at $10°$ with discriminator at 4 mV and diffuse NSB of 0.09 photo electrons per ns and pixel)

If one lowers the threshold of the trigger discriminator, then less photons in the camera plane are needed to trigger the telescope, and it helps the low energy showers to fulfil the required trigger conditions. In figure 5 one can see that the threshold energy decreases when lowering the discriminator threshold. It is 29 GeV for 3 mV and 105 GeV for 7 mV. Since we are aiming for a low energy threshold, a low discriminator value is preferred. However, for 3 mV the expected rate due to protons together with night sky background light increases a lot (see section 3.1.3), while it is kept under control at 4 mV. Therefore, the threshold of the discriminator should be kept around 4 mV, which yields an energy threshold of 45 GeV.

3.1.3 Expected rates

Using the Monte Carlo data sample, it is possible to estimate the expected rates for proton showers taking into account the background light.

The numbers quoted in this section are calcuated for a zenith angle of 10°. The results for 0^{o} and 15^{o} were found to be similar. We estimated the rate for the first level trigger with the "standard" trigger conditions. The first level trigger rate due to proton showers without any background is 143 ± 11 Hz. This rate will increase by $\approx 25\%$ if heavier nuclei (He, Li,...) are included.

However, to get a more reliable rate one must take into account a realistic background situation. From the total mirror area, the integration time, the FOV of a pixel and the QE of the PMTs one obtains a value of 0.09 photo electrons per ns and pixel (Mirzoyan and Lorenz, 1994) due to the diffuse night sky background. Added to this are the contributions from the star field around the Crab nebula. Under these more realistic conditions the first level trigger background rate (protons and light of night sky) is 396 ± 88 Hz.

The dependence of the first level trigger rate on the discriminator threshold is shown in figure 6. The trigger rate decreases with increasing discriminator threshold as expected. The rate for the discriminator threshold of 3 mV is more than 100 times larger than that for higher thresholds.

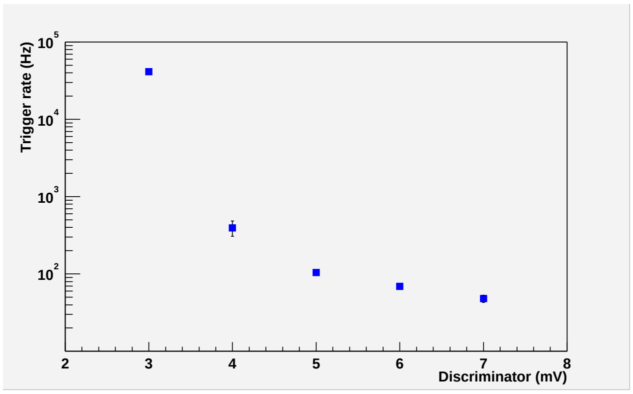

Fig. 6. Estimated trigger rates as a function of trigger discriminator for 10° zenith angle with 0.09 photo electrons of diffuse NSB and the Crab Nebula star field.

Some improvement in the trigger rate reduction is needed to lower the discriminator that the MAGIC telescope will use, below 4 mV. This value corresponds to a threshold of about 8 photo electrons.

It has to be stressed, that these results are based on the first level trigger. There is a big potential in optimizing the settings. I.e. the background rate can be reduced by increasing the discriminator threshold for a few dedicated pixels, that have a star in their field of view. Studies in this direction are ongoing and will be presented on the conference.

4 Conclusion

We presented the actual status of Monte Carlo simulation for the MAGIC telescope. The first level trigger rate for the background is for a discriminator threshold of 4 mV well below the maximal trigger rate (1000 Hz) that the MAGIC daq system will be able to handle. For these standard settings the energy threshold is around 45 GeV. There is a potential in optimizing the trigger system and studies in this direction are ongoing. Also the development of the second-level-trigger is in progress. This should allow to lower the threshold and achieve the aim of 30 GeV for the energy threshold. The MAGIC collaboration is presently simulating air showers with higher zenith angles. The newest results will be presented on the conference.

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References

MAGIC Collaboration, "The MAGIC Telescope, Design Study for the Construction of a 17m Cherenkov Telescope for Gamma Astronomy Above 10 GeV", Preprint MPI-PhE 18-5, March 1998.

Heck, D. and Knapp J., CORSIKA Manual, 1995.

Mirzoyan R. and E. Lorenz, Proc. 25th ICRC, Durban, 7, p.356, 1997

Mirzoyan R. and E. Lorenz, Measurement of the night sky light background at La Palma, Max-Planck-Institut report MPI-PhE/94-35