MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescope

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Trigger Threshold and Rates from Monte Carlo Studies.

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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 of the trigger threshold and expected rates is presented.

Contents

1 Introduction

The aim of MAGIC is the observation of γ-ray sources in the energy region above $\approx$ 30 GeV in its first phase. So that, energy threshold of$\approx$ 30 GeV has to be reached keeping a reasonable storage rate ($\leq 1KHz$). The MAGIC capability and the needed condition to achieve this challenge can be studied using the MAGIC Monte Carlo (MMC). 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 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.

The first results of such an investigation were already presented in the ICRC-2001 [1] and have been completed in this note. Some further studies will be also presented.

2 Generation of MC data samples

The simulation is done in several steps: First the air showers are simulated with the CORSIKA program [2]. 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 [1].

We simulate showers for different zenith angles ($\Theta = 0°, 5°, 10°, 15°, 20°, 25°$) 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 $I < 400$ m and gammas with $I < 200$ m. Afterwards these showers are passed through the reflector and camera program to get the needed information. The number of showers, which have been used for these studies, can be found in table 1.

zenith angle	gammas	protons
$\Theta = 0°$	490000	1910000
$\Theta = 5°$	390000	$----$
$\Theta = 10°$	1000000	1917605
$\Theta = 15°$	1079730	5008603

Table 1: Number of studied showers.

3 Results

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 multiplicity, 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 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 trigger conditions 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, light from Crab Nebula field of view, and light from Vela Pulsar 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 1). Even though larger statistic is needed, the energy threshold increases slowly with the zenith angle, as expected.

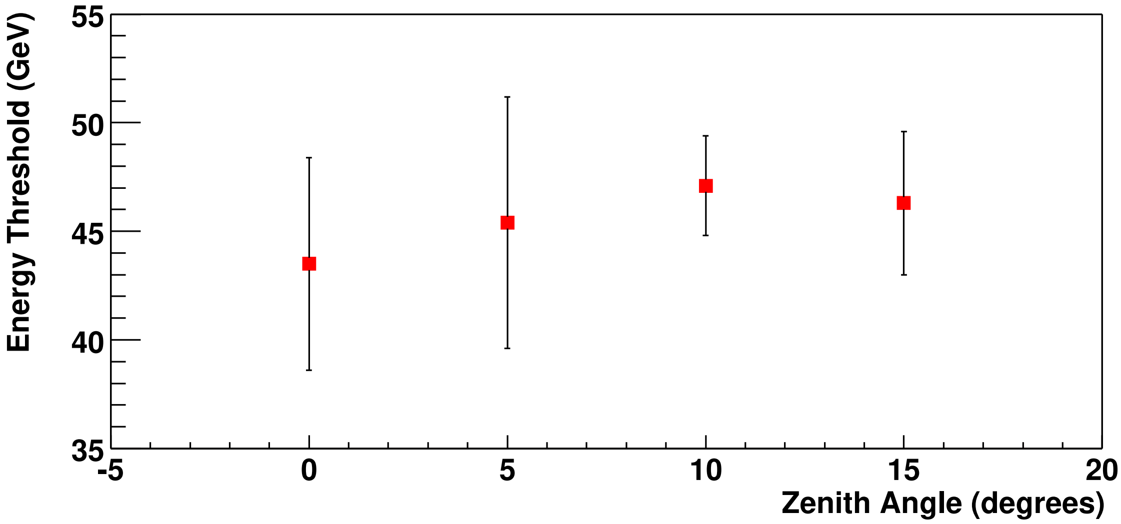

Figure 1: Energy threshold for different zenith angles

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 fulfill the required trigger conditions. In figure 2 the dependence on the trigger discriminator for closed package and simple-NN topologies is shown and one can see that the threshold energy decreases when lowering the discriminator threshold. It is 27 GeV (19 GeV for simple-NN) for 3 mV and 103 GeV (92 GeV) for 7 mV. Since we are aiming for a low energy threshold, a low discriminator value is preferred. The energy threshold is lower for simple-NN since it is less restrivtive condition and helps gamma showers, which are usually elongated, to trigger.

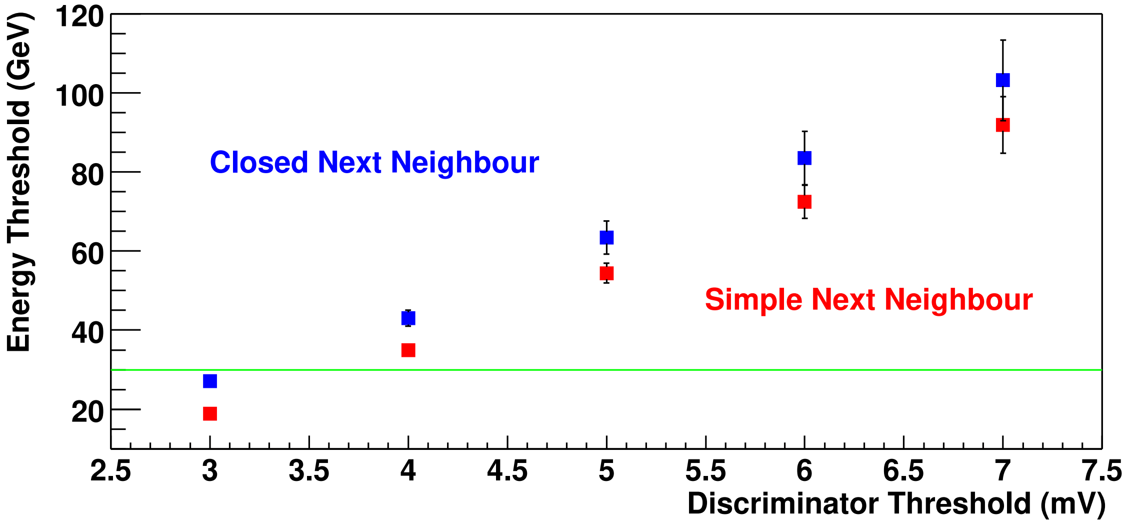

Figure 2: Energy threshold for different discriminator values

One can also change the number of required neighbour pixels to produce trigger (multiplicity). Low energy showers produce a small signal, therefore larger the multiplicity less probable that low energy showers trigger the detector. In figure 3 one can see that the energy threshold increase while increasing the multiplicity.

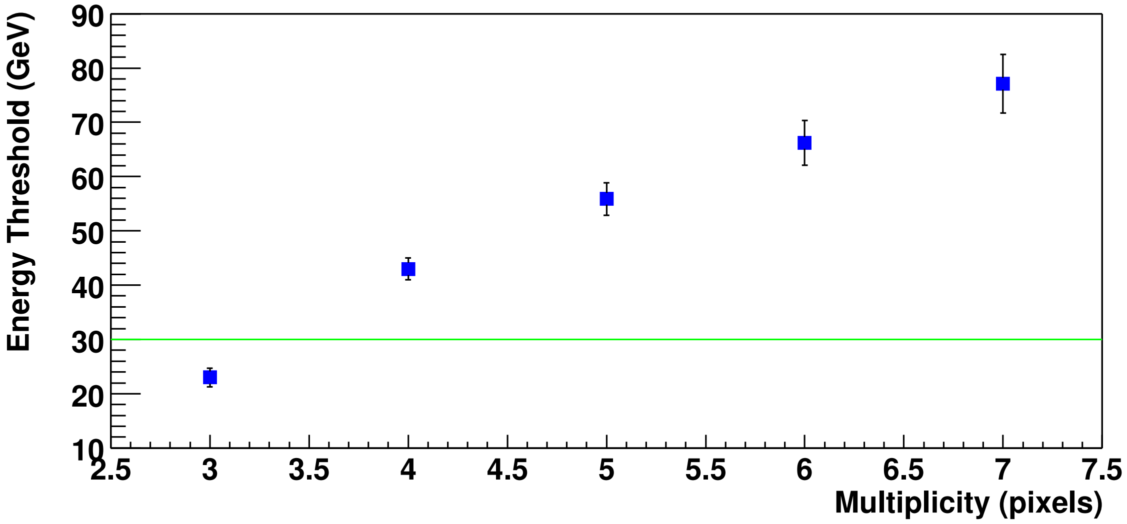

Figure 3: Energy threshold for different multiplicities

3.2 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 calculated 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 ± 8 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 [3] due to the diffuse night sky background. Added to this are the contributions from the star field around the Crab nebula (Vela Pulsar). Under these more realistic conditions the first level trigger background rate (protons and light of night sky) is 398 ± 88 Hz (1354 ± 181 Hz).

The dependence of the first level trigger rate on the discriminator threshold is shown in figure 4. 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.

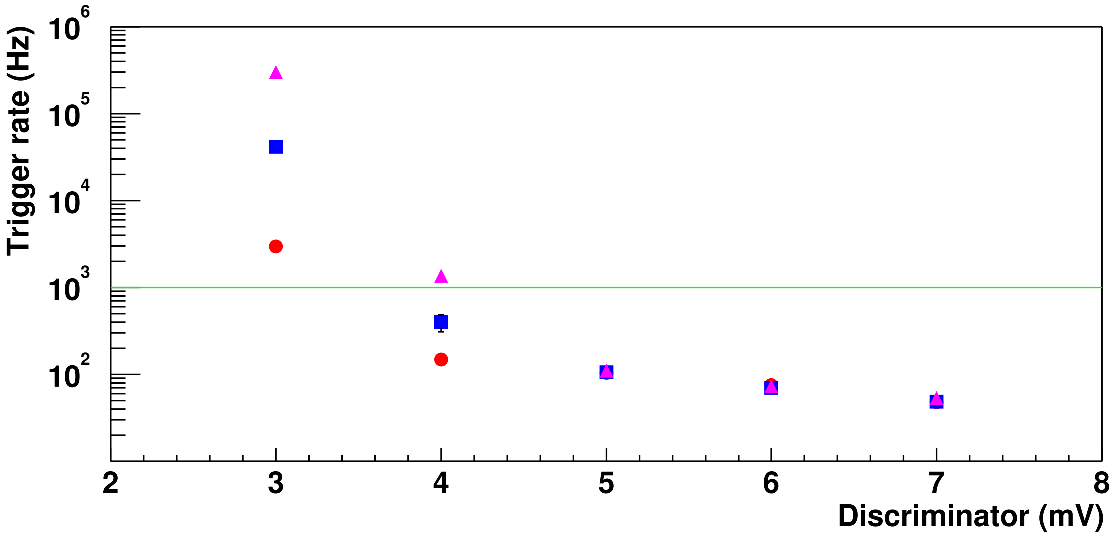

Figure 4: Estimated trigger rates as a function of trigger discriminator for 10° zenith angle with 0.09 photo electrons of diffuse NSB (cercle), the Crab Nebula star field (square), and the Vela Pulsar star field(triangle).

4 Improvements

Some improvement is needed to achieve a trigger threshold around $30 GeV$ keeping the trigger rate below $1 KHz$. It has to be stressed, that these results are based on the first level trigger and therefore there is still the second level trigger to lower the rate. But it can be improved at the first level trigger either masking the stars in the field of view or changing the single phe response.

4.1 Masking high luminosity stars

When a bright star enters in the camera field of view it can increase a lot the trigger rate but triggering always the same pixels[1]. Therefore, there is a big potential in reducing the background rate by switching off or increasing the discriminator threshold for the pixels that have a star in their field of view.

The efficiency of masking will be very dependent on the actual field of view. If it had only one very bright star it would reduce the background trigger rate a lot without losing efficiency in the gamma ray detection. On the other hand, the rate reduction would be small and the efficiency would decrease a lot in a field of view that has not so bright stars but a lot of them. For that, individual studies for each field of view will be worth. Despite of that, only one field of view has been studied to get an idea of the capability of this method. The field of view with Vela Pulsar in the center has been used assuming a diffuse background light of 0.09 photo-electrons(phe) per ns. Then several masks have been applied. The discriminator threshold of all pixels is set to a given value except for the pixels that have more than 0.1, 0.2 or 0.5 phe per ns, which their discriminator threshold is risen to 7 mV. In figure 5 the trigger rate as function of the discriminator threshold is shown for these conditions. One can see that for low discriminator threshold values, the rate decreases substantially. It is worth to point out that the energy threshold is similar for any mask and that trigger efficiency for gammas is at level of the one without background light.

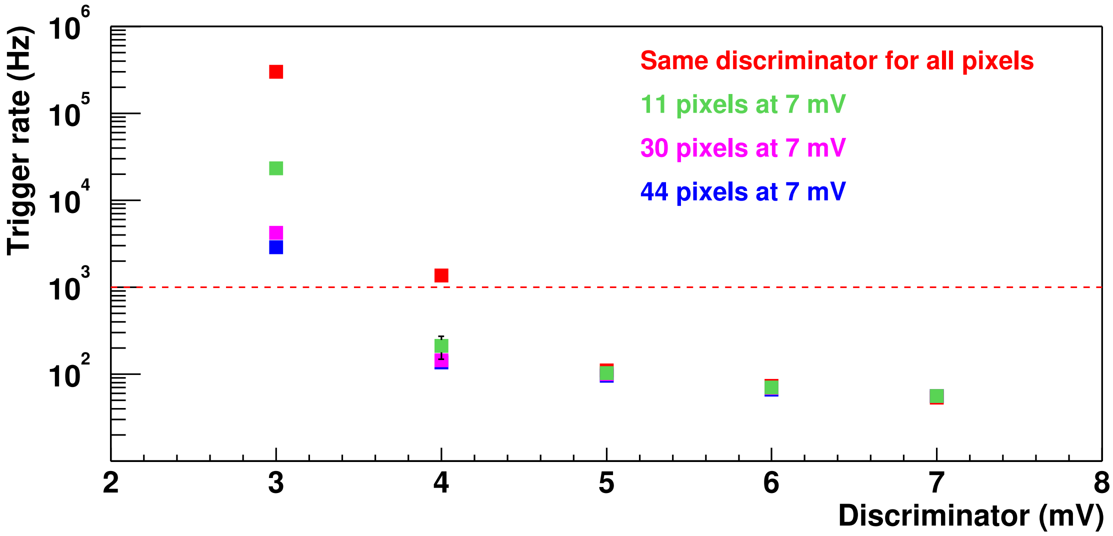

Figure 5: Trigger rate as a function of the discriminator threshold for the Vela Pulsar field of view with several masks.

4.2 Single photo-electron response shape

A "standard" response function for each photo-electron is used to generate the analog signal of the PMT. At present these response functions are gaussians with a given width in time. By superimposing all phe of one pixel and by taking the arrival time into account the response of the trigger system

[1]Actually the zone that triggers due to the star is slowly changing due to the field of view rotation but we can know which are the pixels at any moment.

for that pixel is computed. This response is the one that is used to check if the pixel is above the discriminator threshold. Therefore larger the width on time is, less phe are needed to reach the discriminator threshold.

In figure 6 the energy threshold is plotted for different widths of the single phe response. The energy threshold decreases while increasing the width as expected since less phe from the shower are needed to achieve the trigger condition. But it would be also easier that the background light triggers the detector and therefore the trigger rate would increase (figure 7). If the single phe response had a time width of 4 ns the aim of $30GeV$ energy threshold with reasonable trigger rate would be reached.

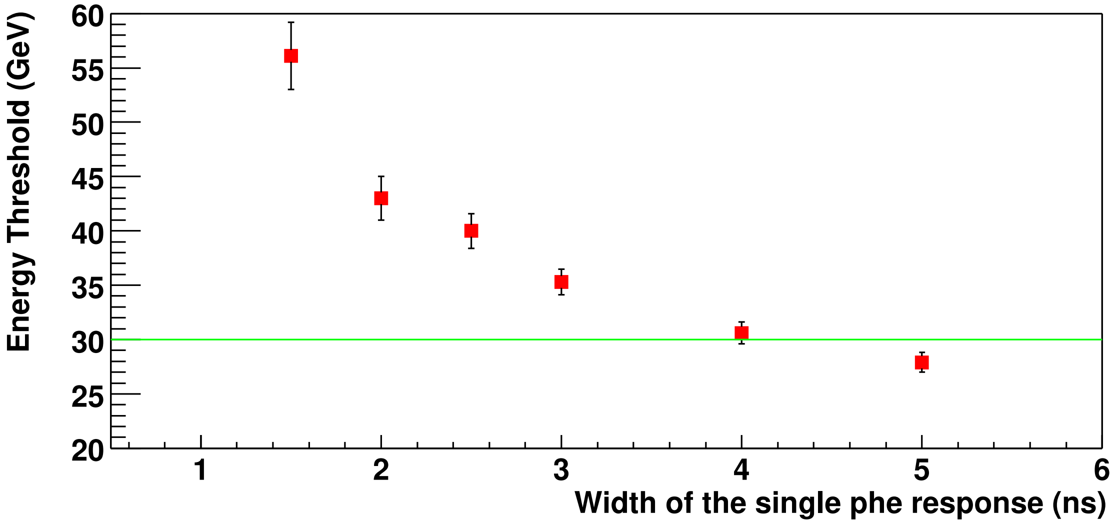

Figure 6: Energy Threshold for different single photo electron response width.

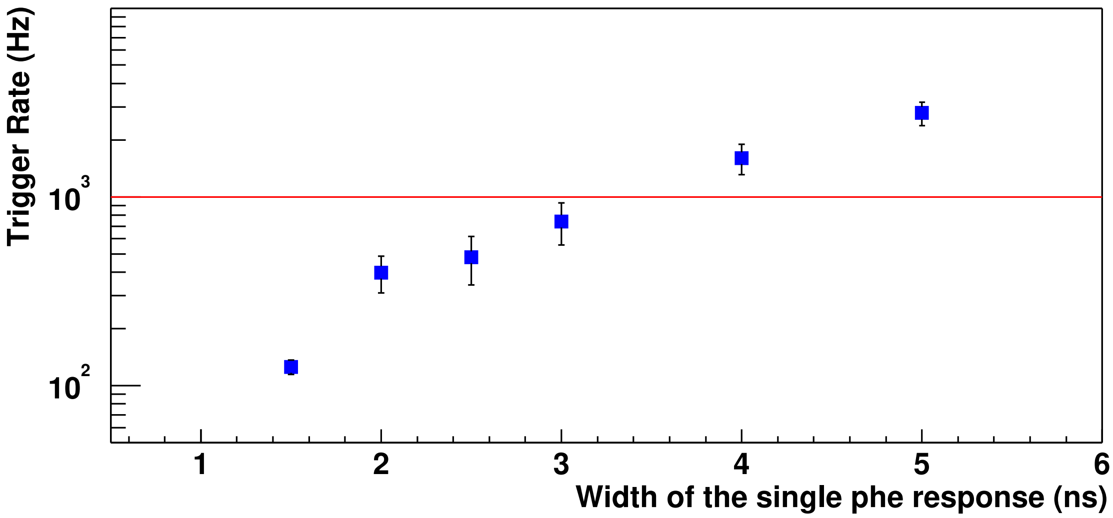

Figure 7: Background trigger rates for different single photo electron response width.

5 Conclusion

The first level trigger rate for the background is, for a discriminator threshold of 4 mV and 4-closed NN, well below the maximal trigger rate that the MAGIC DAQ system will be able to handle (1 kHz). These settings lead to energy threshold around 45 GeV.

Going to settings that allow to achieve the aim of 30 GeV, the trigger rate increases. Although the first level trigger can accept these rates, they will ask the second level for a large reduction factor.

Actually, there is some room to go down to 30 GeV keeping rates around 1 kHz at the first level trigger. One can either mask the bright stars in the field of view, which is already foreseen to be done automatically, or make the single photo-electron response a little bit wider.

All this studies are based in the first level trigger, further studies with second level trigger and shower reconstruction are needed.

References

[1] O. Blanch, J.C. Gonzalez and H. Kornmayer, "Detailed Montecarlo studies for the MAGIC telescope", Proceedings of ICRC 2001.

[2] Heck, D. and Knapp J., CORSIKA Manual, 1995.

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