The Future of the MAGIC Project: Phase II

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Abstract

The first MAGIC telescope is close to completion and soon will start to collect data. Parallel to the ongoing MAGIC construction we pursuit studies for the future 2nd phase of the MAGIC observatory project. We have been considering 3 choices for the extension of the project: a) To build a $\sim$30 m diameter telescope in the vicinity of MAGIC. b) To give MAGIC another camera based on very high quantum efficiency (QE) light sensors. c) To build in the same location clone(s) of MAGIC. In this report all 3 options will be discussed.

1. Introduction

Seven and a half years have passed since the first presentations and the beginning of the R&D work for the MAGIC project [Lorenz 1995, Bradbury, et al; 1995]. From the very beginning *the main goal of the MAGIC project has been defined as to reach the lowest possible energy threshold of 10-30 GeV* and to do astrophysics by means of γ rays. Now we are standing shortly before the first tests of the telescope and are asking different questions to ourselves: what will be the real performance of the telescope compared to the expected one, where and how could it further be improved ? The uncertainties which remain at very low energies are first of all due to the three "new" backgrounds: a) the so-called μ ring triggers, b) the bright stars in the field of view and c) the cosmic electron air showers. Of course these backgrounds are not really new, at a low level they are also present in the TeV regime, but in the sub-100 GeV domain they shall become more important and dominant.

2. The Three "New" Backgrounds at Very Low Energies.

2.1. Muons.

The background caused by Cherenkov light emission of relativistic muons traversing the atmosphere has often been discussed. Since the 50's there exist

pp. 1–9

measurements of the muon flux. Nevertheless, for the new large telescope concepts physicists often disagree in their estimated trigger rates. The problem is the following: one will overestimate the μ trigger rate if one simply takes the published flux value and integrates it above the given threshold. One of the reasons is that even if more than one μ is generated in a given hadron shower, one will obtain only a single trigger in the telescope. Another reason is, that in telescopes of very large diameter mirrors the μ images will be accompanied by the images of the parent hadron shower and could thus be rejected efficiently in the off-line analysis. Unlike the above mentioned two scenarios there are muons which have large angles with the shower axis and thus may initiate triggers appearing in images just as single muons. In general one can conclude that for very low energies the hardware rejection of the usual hadron background is very high (few x 10^3). Nevertheless, even if there are "unusual" reaction channels with very low probability (say, less than 0.1%) suddenly they might pass the γ/hadron selection criteria and even become very important. We are trying to quantify the rate of muons which will pass the γ selection criteria and might influence the sensitivity.

2.2. Electrons

This isotropic background closely imitates gamma showers. Its rate can be reduced in off-line analysis only by using the angular resolution of the telescope (strictly speaking one can do this for point-like sources). The rejection power will depend on the angular resolution of a given telescope while the absolute rate is a strong function of the energy threshold and of the trigger radius of the camera. The simulation in [Cortina & Gonzalez 2000] predicts for a threshold of $30GeV$ an electron trigger rate of about 4 Hz for MAGIC. Assuming an alpha parameter gamma domain of about 15° one obtains a rejection power of at least 12 when also taking into account the asymmetry parameter of shower images.

2.3. Bright Stars in the Field of View

These, proportional to their brightness, will produce an additional trigger rate in the close vicinity of their location in the camera. The usual strategies are, when possible, to avoid such a star in the trigger field-of-view (FOV) by tracking the given source off-axis, or to lower temporarily the high voltage of the photomultiplier for that channel or at least to take it out of the trigger. In past image analysis the only known recipe was to use the software padding method [Cawley 1993]. One can of course also leave out the corresponding segment in the camera from the image analysis but if there are many bright stars in the FOV this is not a reliable solution. A weighting procedure has been developed to counteract the bias of image parameters due to bright stars but no conclusive results are available yet [Schweizer 2002].

3. Future Options for the MAGIC Project

In March 2002, a special collaboration meeting focused on the long-term future of the MAGIC observatory. In the spirit of aiming for very low threshold three basic options were discussed:

1. To construct as a next step a ∼30m diameter imaging telescope.
2. To construct an imaging camera based on high QE HPDs for MAGIC.
3. To construct the second MAGIC telescope, essentially the clone of the first one.

3.1. A 30m Diameter Telescope

The first idea about a 30m ø telescope for γ astronomy above the threshold of a few GeV is mentioned in [Mirzoyan 1997]. A 30m diameter telescope might allow one to access the energy regime of about 10 GeV even with classical PMTs (see [Lorenz & Mirzoyan 2001], [Merck, et. al; 2002]). Such a large telescope is challenging not only from the technical point of view but also because of its optical requirements. Note that in [Mirzoyan, et al; 1996] it is shown that with the increase of the diameter of a telescope the depth-of-the-field type aberration, which depends solely on the ratio of the diameter of the telescope to the shower height, starts to play an important role smearing the images of extended showers. This shall deteriorate the background discrimination power of the telescope. In general the energy resolution at very low energies is very poor; nevertheless, because of its very high γ detection rate ability, one can follow fast time variations in sources. Let us try to estimate the cost of a single 30 m ø telescope. For lack of available data, one can use for that purpose the empirical scaling formula used by European Southern Observatory (ESO) for the cost estimate of an optical telescope of a large diameter: $k=(D/d)^{2.6}$ [Cesarsky 2002] where k is the cost scaling factor, d is the diameter of the known telescope and D is that of the larger one. For the investment cost of $\sim$ 4 M Euro for the 17m ø MAGIC one obtains a cost of $\sim$ 17.5 M Euro for a 30m ø telescope (assuming a comparable location with well developed infrastructure like La Palma for MAGIC). If such a telescope will be constructed on a very high mountain altitude of say $\sim$ 5 km (see, for example, the 5at5 project [Aharonian, et. al; 2001]) then obviously a 30m ø single telescope may cost substantially more. One needs also a better understanding of the feasibility and of the possible advantages of 30m class telescope(s) compared to a *MAGIC telescope with an improved camera* (see discussion later in the text) and since a few years we have been carrying out relevant R&D program.

3.2. High QE Light Sensors

At an early stage MAGIC has been planned with a very high QE light sensor camera which would have allowed one to provide a lower energy threshold of about 8-10 GeV [Barrio, et al; 1998]. Since the very beginning of the project we have been developing these advanced sensors together with light sensor manufacturers. At first we worked with INTEVAC [Bradbury, et. al; 1997] and in recent years we are working with Hamamatsu and ITT (see [Lorenz, et al; 2003], [Ferenc, et al; 2000], [Ferenc 2001], and the references therein). Hybrid photodiodes with GaAsP photocathodes and avalanche diode readout are currently the best candidate sensors. Because of lasting technological developments we postponed this innovative technology until/for the next stage of the project and instead constructed an imaging camera based on specially designed classical photo multipliers (PMT) for the current MAGIC (see for details the contribution of E. Lorenz in these proceedings). The hybrid photo diodes with GaAsP photocathode have been shown to provide maximum QE of 45% in the wavelength range 500-600 nm (see [Lorenz, et. al; 2003]). Their QE is somewhat lower in the UV part of the spectrum but as it is shown in [Bradbury, et. al; 1997] by using the technique of application of lacquer of a fast wavelength shifter (WLS) it is possible to substantially enhance the QE also in the UV. We have evaluated the commercially available 8mm ø GaAsP HPD from Hamamatsu and reported the results and the possible improvements in [Mirzoyan, et. al; 2000]. We have a working agreement with Hamamatsu for the development of 18mm input diameter GaAsP fast HPDs for a future MAGIC camera. The agreement addresses several improvements of these tubes. Test results of intermediate samples, the achieved parameters and the ongoing developments can be found in [Lorenz, et. al; 2003]. Folded with the Cherenkov spectrum the very high QE of the above-mentioned HPDs will provide about two times larger signal compared to classical PMTs. Note that such an increase also can be seen as increase in the reflector diameter of a telescope. We expect that the first samples of the tubes will be available in about 2 years from now.

3.3. The MAGIC Clone

From the technical point of view a MAGIC clone could be realized without any big delays. As the main merit of a multi-telescope approach its proponents underline the possibility of a coincident configuration. This can provide an improved signal to noise ratio as well as a lower threshold setting because of stronger suppression of unwanted backgrounds as, for example, that of the ”single” muons. Moreover, if the telescopes can be used in the so-called stereo mode one can hope, based on the results of the HEGRA collaboration in the TeV regime [Konopelko, et al; 1999], to benefit from its advantages as the better hadron rejection and somewhat improved angular and energy resolutions (strictly speaking this is the case for higher energies while for the energies well below 100 GeV this is still unclear). It should be possible to construct the MAGIC clone telescope in less than 2-3 years (the time needed for the first MAGIC).

4. High QE Camera Versus a Larger Diameter Telescope: Cost Comparison

It is interesting to estimate the cost of an imaginary telescope which for the same input light can provide two times higher signal compared to the MAGIC telescope with the classical PMT camera. One can imagine two scenarios:

1. to construct a telescope with a reflector of two times larger mirror area (or $\sqrt{2}$ times larger ø).

2. to augment MAGIC by a camera based on high QE HPDs.

By using the above mentioned simple formula for the cost estimate one obtains that in the option 1) one needs a 24m ø telescope which will cost $\sim$ 11 M Euro while an advanced high QE camera cost in option 2) is estimated to be $\sim$ 2 M Euro (a camera of 3.3° ø, consisting of $\sim$ 800 pixels each of the size of 0.10° has been assumed). Thus the telescope in option 2) will cost 5.8 M Euro (the cost of the 600 classical PMTs for the MAGIC camera is about 0.2 M Euro). One can conclude that although both telescopes will have the same threshold and the same physics potential the *option 2) will cost by 5.2 M Euro less than the option 1).* Also, the larger diameter telescope will suffer from higher depth-of-field type aberration and less background discrimination.

5. Possible Additional Improvements

One can further improve the performance of future telescopes, beyond larger diameter and better QE. One can use an FADC readout of 2 GSample/s (instead of the current one with 300 MSample/s). Several multiplexing schemes are currently under study for this purpose [Mirzoyan, et. al; 2002]. A 2 GSample/s FADC will avoid to stretch the pulses and will allow us to work with very fast pulses from the PMT channels. The fast timing should help in many ways as, for example, in the rejection of single μ images which shall have sharp time signature. The possible use of 1m diameter large all-Al mirrors may allow us to make the actively controlled reflector lighter, simpler and cheaper. The undercarriage and the bogeys of the telescope can be made lighter which can provide less inertia and faster repositioning. Light guides can be lined with 98 % reflectivity wide band multi layer dielectric foils. A permanent active mirror control by using infrared (IR) lasers and an IR CCD camera can enhance the efficiency of observations. Implementation of a 3rd level digital pattern recognition topological trigger between the telescopes can allow one to further lower the threshold.

6. Conclusions

The MAGIC discussions in March 2002 reached the following conclusions: it has been recognized that the development work on a large diameter telescope and on very high QE photo detectors is vital for the future. The latter option has obtained the highest priority, but due to the above mentioned time necessary for the R&D until these tubes will become mature the next closest goal should be a MAGIC clone built on a short time-scale of 2-3 years.

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