A Method to enhance the Sensitivity of Photomultipliers for Air Cherenkov Telescopes by applying a Lacquer that scatters Light

D.Paneque*, H.J.Gebauer*, E.Lorenz*, R.Mirzoyan*

*Max-Planck-Institut for Physics (Werner-Heisenberg-Institut), Foehringer Ring 6, Munich, Germany

The sensitivity of photomultipliers (PMT) can be substantially increased by applying a light scattering lacquer doped with a Wavelength Shifter (WLS). Applying this method to the Electron Tubes (ET) 9116/17A PMT resulted in a good sensitivity in the short wave UV range as well as a 15-20% increase in QE above 350 nm. Details of the procedure and a simple model for the explanation of the enhancement are presented.

1. Introduction

MAGIC is a 17 m diameter (239 m² mirror area) Imaging Air Cherenkov Telescope (IACT) located at the Canary island La Palma (see [1]). The main goal of the experiment is to exploit the up to now inaccessible energy window from ∼10 GeV to ∼250 GeV in gamma ray astronomy by aiming for a much lower energy threshold (E_{th}) with respect to contemporary instruments.

Observations in this region of the spectrum will provide key data for the understanding of a wide variety of astrophysical phenomena belonging to the so-called “non thermal Universe”, like the processes that take place in the nuclei of active galaxies, the radiation mechanisms of pulsars and supernova remnants, and gamma-ray bursts.

The E_{th} of an IACT is inversely proportional to the number of collected photoelectrons (PHE)

\[ E_{th} \propto \frac{1}{A_{mirror} \times R \times LC_{eff} \times QE} \tag{1} \]

A_{mirror}: mirror area; R: mirror reflectivity; LC_{eff}: light collectors efficiency; QE: quantum efficiency of the photosensors. R and LC_{eff} are normally close to 1, and the reduction of E_{th} is best achieved by increasing A_{mirror} or QE.

Currently, the camera of the MAGIC telescope is equipped with classical PMTs [1], and the expected E_{th} is about 30 GeV. The PMTs used are the ET 9116A and 9117A, both with borosilicate hemispherical windows and bialkali photocathodes (PhC). Here we describe a method to enhance the QE of these PMTs and thus lower the E_{th} of MAGIC.

2. Increase in the sensitivity of PMTs by applying a special lacquer

It was found that the QE of PMTs can be substantially enhanced by applying a specially prepared lacquer. The method is similar to a procedure for coating PMTs with a WLS (see [2]). We dissolved Paraloid B72 and 1.4 p-Terphenyl (PTP, a WLS with a decay time smaller than 1 ns) in CH₂Cl₂, which has a boiling point of 40°C. The PMT window is briefly dipped into the solution, and, after the fast evaporation of the CH₂Cl₂, a rugged layer is formed. Dipping the PMT several times (2 to 3 times) with interruptions of a few minutes, results in a coating layer which is not more transparent, but frosted, i.e. the layer is acting as an efficient light difuser.

The scattering layer will produce the following effects: a) photons will be scattered such that their path inside the PhC is elongated, and therefore the PMT QE is increased; b) for sufficiently large scattering angles, some photons will be trapped between the coating and the PhC, thus having many chances of being converted into PHEs; c) due to the roughness of the coating, its reflectivity is somewhat larger than that of the glass; this will increase the quantity of backscattered
photons before reaching the PhC; d) the higher reflectivity of the coating, will allow to re-reflect a larger fraction of the non-converted light reflected by the PhC (30% at 600nm) thus adding to the production of PHEs; e) due to the hemispherical shape of the PMT’s PhC, some photons will be deflected such that their trajectories will cross the PhC twice, thus having a second chance of being converted in case they did not interact at first instance. In summary, processes a), b), d) and e) overcompensate the loss due to c), and a net increase in the QE occurs. The gain in the short wavelength range is due to the WLS [2].

We conducted a series of tests to optimize the composition of PTP, Paraloid and CH₂Cl₂ in order to maximize the enhancement in the QE [3]. The best results were obtained with a mixture of 0.5 gr PTP and 5 gr Paraloid dissolved in 50 ml CH₂Cl₂. The increase in QE of a coated 9116A is shown as a function of the wavelength in fig. 1.

3. Enhancement in the detection efficiency of an IACT

The detection efficiency of an IACT is proportional to the detected number of PHEs (N_PHE). In order to quantify the enhancement due to the coating, we folded the QE of coated PMTs with the expected Cherenkov Photon Spectrum ², and compared this number to the one of untreated PMTs. In table 1 we summarize the mean enhancement (data averaged over 7 PMTs) for 4 zenith angles. The slightly lower enhancement at large zenith angles is due to the lower fraction of light below 310 nm reaching the PMTs (Rayleigh scattering losses in the atmosphere), for which the QE enhancement is largest.

Table 1
Predicted increase in N_PHE vs zenith angle.

<table>
<thead>
<tr>
<th>Zenith Angle (degrees)</th>
<th>Increase in N_PHE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>19 ± 2</td>
</tr>
<tr>
<td>20</td>
<td>19 ± 2</td>
</tr>
<tr>
<td>40</td>
<td>18 ± 2</td>
</tr>
<tr>
<td>60</td>
<td>17 ± 3</td>
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</tbody>
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4. Conclusions

The QE of PMTs can be substantially increased by applying a special lacquer that scatters light. This method reduces the E_h of MAGIC by about 19% (i.e., from 30 GeV down to about 24 GeV), which is equivalent to an increase in the mirror area by the same factor (from 239 m² to 284 m²). All PMTs of the MAGIC telescope have been coated with this lacquer, which we call “MAGIC lacquer”.

This method is applicable only when the PMT is not optically coupled to a light source.

REFERENCES

1. M.Mariotti et al, this conference
2. G.Eigen, E.Lorenz, NIM A 167(1979) 405

²The Cherenkov Photon Spectrum was calculated (using CORSIKA 6.019) for 2200 m a.s.l, the altitude of the MAGIC telescope.