A Novel Approach in Detecting the UHECR using EAS Telescopes notch optical filters combining optimum sensitivity for Cherenkov and fluorescence contributions

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Abstract

Multilayer notch optical filters, designed to reject the optical noise emitted in the range between the main UV spectral lines of the atmospheric N_2 fluorescence, induced by UHECR via the effect of EAS, are combined in order to have a complementary selectivity in detecting Cherenkov radiation as well. Thus, the detection of the two components is possible at the same time using a mosaic of these optical filters in front of the detector pixel array (camera). By this method the signatures of the fluorescence and Cherenkov radiation could be distinguished. The proposed design can be achieved by a separate dielectric multilayer stack on a glass or absorbing substrate. This method could be applied to the fluorescence telescopes of the AUGER Observatory in a future upgrade.

1. Introduction

An UHECR (Ultra High Energy Cosmic Ray) is recorded in the AUGER observatory [1] by the isotropically emitted air-fluorescence. In this paper, we consider that air-Cherenkov radiation is incident on a limited number of the FD pixels of the above observatory. The EAS event is, at the same time, associated with Cherenkov radiation, emitted mainly in the forward direction. However, a certain percentage of this radiation is scattered by molecular and aerosol components of the atmosphere to all directions. For the above reason we propose that it is advantageous the EAS detector to have a certain degree of spectral selectivity, to discriminate between Cherenkov and fluorescence radiation components.

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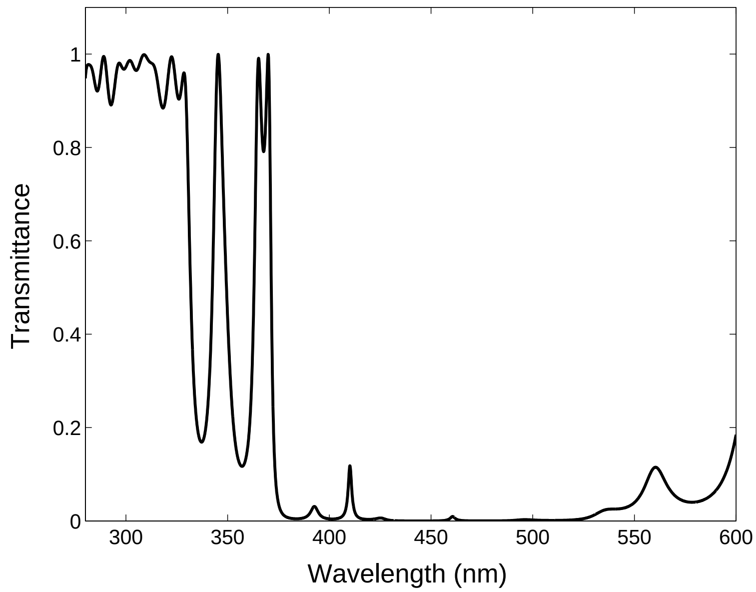

Fig. 1. The spectral transmittance of the designed optical filter consisting of 40 layers. The two dips correspond to the regions of the main groups of nitrogen lines.

2. Cherenkov radiation from an EAS

The total number of photons, N_{ph}, over the full particle path, is determined by summing, after separation into 499 segments, ΔL_i, as below:

$$N_{ph} = \sum_{i=1}^{499} \left(\frac{n_i - 1}{n_o - 1} \right) N_i \Delta L_i \tag{1}$$

where n_o is the refractive index of the atmospheric air, close to the sea level, at 0^o C and 76 cm Hg, in an average wavelength around 400 nm. N_i is the number of muons resulting from AIRES, for the specific event considered, at the i^{th} atmospheric layer, covering the atmospheric height up to 30 km. All these segments correspond to the same atmospheric depth difference.

3. Multilayer Cherenkov notch filters and their design

We have been designing such filters using the method of "Simulated Annealing" [2,3] in order to obtain the optimal layer configuration. The obtained multiband notch filter, rejects the air-fluorescence lines in the UV region, as well as the entire visible radiation, and, thus, allowing the full detection of the Cherenkov component in the UV range .

The aim to use the Cherenkov filter type is to record the Cherenkov signal rejecting, at the same time, the fluorescence signal from the same EAS. This leads us to consider the interference filter. The spectral transmittance of the designed

Table 1. Filter performance

Filter Type	E_{sc}	E_{sf}	S_n	E_c	E_f	E_c/E_f
Cherenkov	0.214	0.112	0.169	0.0362	0.0189	1.92
Fluorescence	0.346	0.831	0.243	0.0841	0.202	0.416

The detection efficiencies of the Cherenkov and fluorescence optical filters and the corresponding ratio E_c/E_f. The subscripts c and f denote the kind of the detected radiation.

filter is shown in Fig.1. These filters have been simulated considering the same type of dielectric materials as that for the fluorescence filters. The substrate could be either fully transparent or having a certain absorbance curve.

4. Detecting fluorescence and Cherenkov radiation

4.1. Determination of the light emission yield

The radiation spectrum can also be used to determine the detection efficiency of the pixel detector including the optical notch type filter. According to the method presented in [4] we find the detection efficiencies, E_s, and the overall ones, for the two different filter types (Cherenkov and fluorescence) assuming we detect both kind of radiations. The overall efficiency is calculated by using the product E_sS_n, where S_n is the normalized integral acceptance of the pixel detector. The obtained results are presented in Table 1.

We have also studied the total number of emitted photons from fluorescence and Cherenkov radiation using the results of the AIRES simulation program [5]. In the fluorescence radiation e^+ and e^- contribute, while in the Cherenkov case only μ^+ and μ^- have been taken into account in this preliminary study. The ratio between the emitted photons from fluorescence and Cherenkov radiation is a function of the atmospheric depth and, consequently, of the corresponding atmospheric height, and is shown in Fig.2.

4.2. Scattering from the aerosol boundary layer

The Cherenkov radiation could reach the FD telescopes after its scattering from the aerosol boundary layer of the atmosphere. Thus, under certain conditions, this radiation could be detected, after scattering, in the angular range, preferentially forwardly peaked, up to about 30 ^{o} with respect to Cherenkov radiation axis. Experimental quantitative information on the so called aerosol phase function can be found in [6].

One can say, in general, that when the shower axis forms an angle, with any of the 24 Auger FD telescopes, less than around 30 ^{o}, the transversing the aerosol boundary layer (Mie scattering) Cherenkov contribution, on a pixel array,

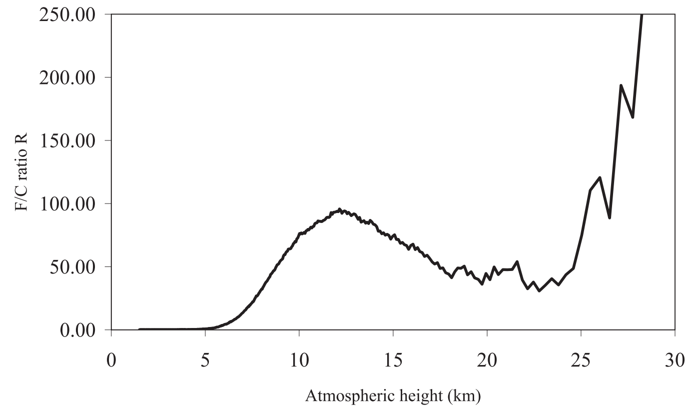

Fig. 2. Profile of the ratio of the fluorescence over the Cherenkov emitted photons per segment, as a function of the particle atmospheric height.

is expected to be significant. This suggest the need to use Cherenkov selecting optical filters on several pixels of the FD.

5. Conclusions

Multilayer interference notch filters for detecting the fluorescence and Cherenkov radiation that could be used in a mosaic structure are presented in this work. Based on the Cherenkov radiation spectrum we have determined the detection efficiencies of the filters, and a corresponding ratio. It is clear that much thought is needed for the appropriate geometry of such filter combinations (fluorescence and Cherenkov types). A serious consideration is that the minimal effect on the trigger efficiency should be sought when one uses such bold optical filter combinations.

6. References

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