Systematic Calculation of the Efficiency of the Fluorescence Detector using Appropriate EAS Simulations

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Abstract

The detection efficiency of a pixel detector of an EAS telescope using optical UV filters is determined in this work. Based on the Auger Fluorescence Detector geometry, we have calculated the overall efficiency of the pixel detector using an appropriate method which takes into account the particular spectral functions and the dependence on the angle of incidence of the optical filter used. Assuming EAS events developed with various inclinations generated by AIRES code, we calculate the number of electrons and positrons produced during the development of the EAS. The detection efficiency of the pixel detector is taken into account in estimating the signal to be recorded(number of photoelectrons).

1. Introduction

The study of the longitudinal evolution of Extensive Air Showers (EAS) in the atmosphere was proposed by Greisen [1]. The electrons and positrons of the electrophotonic part, causes among other effects, the emission of fluorescence light. The fluorescence light propagating through the atmosphere triggers an array of sensitive photomultiplier tubes (PMT) on the ground. This array can record the intensity of the fluorescence light as a function of the atmospheric depth along the shower axis. Therefore, it could trace the track of a CR in the atmosphere as a moving spot and by triggering the PMTs it could depict the sky projection of the EAS trajectory. The total photon intensity gives an estimate of the energy of the primary CR and the PMT whose signal is the largest, corresponds to the atmospheric depth of the maximum intensity of the shower. The estimate of this depth of shower "maximum" is a valuable parameter for the isotopic identification of the primary CR. A full fluorescence detector (FD) array with appropriate filters, mirror and camera for the Pierre Auger Observatory is described elsewhere [2,3].

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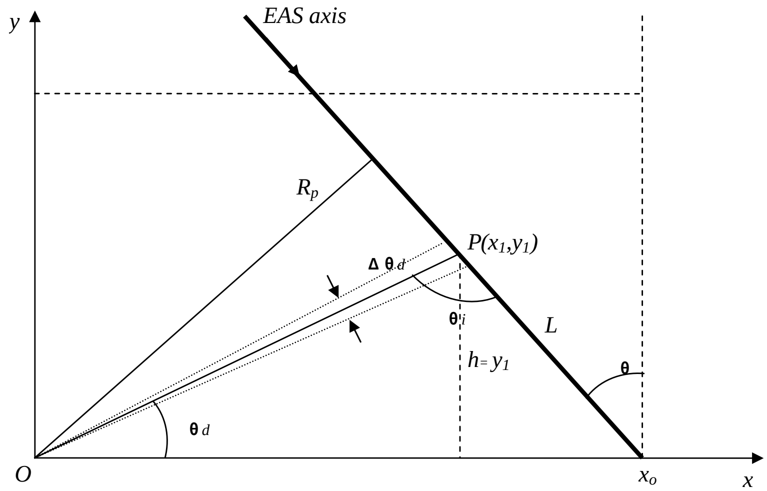

Fig. 1. The relative position of FD with respect to the showers at various zenith angles θ. Each triggered PMT corresponds to a certain path or height of the shower and its recording corresponds to the number of positrons and electrons created at this height (not scaled).

2. Methodology

The number of fluorescence photons per meter produced by a charged particle propagating in air is between 4 and 5, varying slightly with temperature and pressure [4]. Using this parameter and the number of electrons (positrons) created in the atmosphere, the photon attenuation length and structural characteristics of the Auger detector, we could estimate the number of photoelectrons at the PMT cathode.

For this estimation the expression used by Guerard [5] was modified, adjusting for simulated showers, photocathode quantum efficiencies and filter transmittance and air fluorescence yield from [6].

3. Simulations of EAS

Simulations of EAS determine the number of electrons and positrons (N^i_e) created by the primary particle in the EAS by AIRESQ program [7,8]. We have simulated the EAS when CR primary particles are 100 EeV protons. The number of positrons and electrons created along the EAS in 500 atmospheric layers were derived as a result, starting from the first interaction level up to the ground of El Nihuil (1416-m a.s.l.). Fig.2 shows the number of positrons and electrons obtained in EAS as a function of atmospheric height for the primary proton. As the showers start to develop at the top of the atmosphere, alternatively due to the Bremsstrahlung and pair production, the number of positrons and electrons increase. After reaching a maximum, ionization loss becomes the dominant effect, reducing their flux at greater depths into the atmosphere. The shower maximum varies from 2 to 4 km of atmospheric height for shower inclinations from 0 to 40 degrees. The gradual shift of this “maximum” toward lower altitudes for less inclined showers is clearly seen.

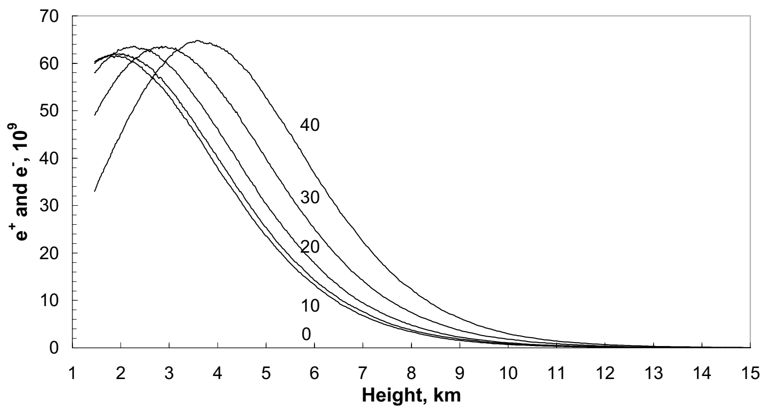

Fig. 2. The number of positrons and electrons as a function of the atmospheric height from shower simulation of a CR primary proton of energy 100 EeV.

4. Results

The geometry of the FD with mirror and camera (consisting of an array 22 x 20 PMTs) restricts the heights from which fluorescence light can trigger the PMTs. For example, for a proton shower inclined by 10 degrees with respect to horizon, the PMT array detects fluorescence light coming from a height of 7 km to the ground only as light faraway is too dim to be recorded. Fig. 1 shows a part of a shower path, which will trigger a certain PMT of the array with fluorescence light. Along the shower axis, a randomly selected segment, centered at the point $P(x_1,y_1)$, is imaged on the N^{th} pixel PMT detector. N being the sequence number, from top to bottom. The orientation axis of the PMT array forms an angle of 28.6^o with horizontal plane. Geometrically, from Fig.1, it is deduced that the length of the segment corresponding to each PMT depends on the distance between FD (0) and the foot of the shower (x_0), at angle θ_d and θ with the following relation:

$$L = \frac{x_0 \tan\theta_d}{\cos\theta(1 + \tan\theta\tan\theta_d)} \qquad (1)$$

The modified Guerard [6] and Eq. 1 are applied for the derivation of the graphs in Fig. 3 which show PMT photoelectron counts. It is evident that for higher altitudes (corresponding to higher number of PMTs), photoelectron counts are higher for inclined showers. Approaching maximum the situation reverses. Moreover, the maximum number of photoelectrons for proton showers lies between the 5^{th} and the 6^{th} PMT.

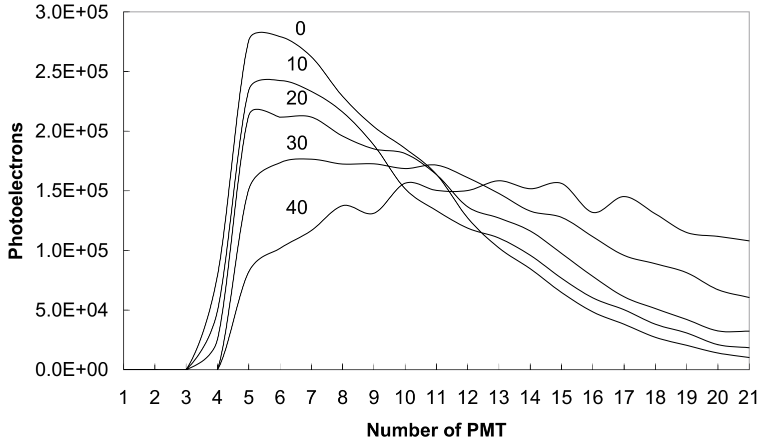

Fig. 3. The number of photoelectrons counted by the PMT array for several zenith angles of a primary proton with energy of 100 EeV.

5. Conclusions

As an extension of the paper presented at the 27^{th} ICRC in Hamburg [6], we have estimated photoelectron counts on the PMT array of the FD. In addition to the previous version, we took into account the spectral distribution function of fluorescence light from nitrogen molecules, the weighting factor of a multilayer interference filter and a more exact FD geometry. For vertical showers at distances 15 km, the maximum number of photoelectrons per PMT is about 300 000 and the minimum 15 000.

6. References

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