A Method for Separation of Gamma and Hadron Initiated Air Showers with Angle Integrating Čerenkov Arrays

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Abstract

The angle-integrating Čerenkov technique provides a promising new approach to ground-based γ-ray astronomy in an energy range just above that accessible by air-Čerenkov telescopes. A method for γ/hadron separation usable in angle-integrating Čerenkov arrays is presented. As an example we apply this method in a full quantitative detail to the existing AIROBICC detector.

1 Introduction

The most realistic possibility for improving the sensitivity of detectors for γ-ray astronomy above 10 TeV is to achieve an efficient γ/hadron separation (GHS). Angle integrating Čerenkov arrays (AICA's) are a promising technique at these energies [1] due to their good angular resolution and precise measurement of the primary energy. Moreover, the light distribution in an individual airshower can be reconstructed, thus obtaining information about the longitudinal development of the shower. Also, for a given primary energy a hadron produces less Č-light than a γ-ray. As a consequence the energy threshold for γ-rays is lower than that for hadrons. On the other hand, since the fraction of a hadron-initiated shower that develops as a purely electromagnetic cascade rises with energy, photon and hadron induced showers tend to look more similar for high energies.

In this work the physics of the γ/h separation using the AIC technique is discussed with the aid of a MC simulation of EAS carried out with the CORSIKA code [2]. A more detailed description of this work can be found in [3]. All MC results and estimates presented in this contribution were done for an observation level at about 2200 m a.s.l (the level of the HEGRA detector).

2 Differences between gamma and hadron showers usable for discrimination

Beyond the maximum of shower development hadronic showers attenuate slower (are 'longer') than purely electromagnetic showers because of the larger interaction length of hadrons as compared to electrons, as can be seen in fig. 1a, in which all shower maxima were shifted to the same atmospheric depth (500 gr/cm^2) before the average process, in order to emphasize the difference in shape.

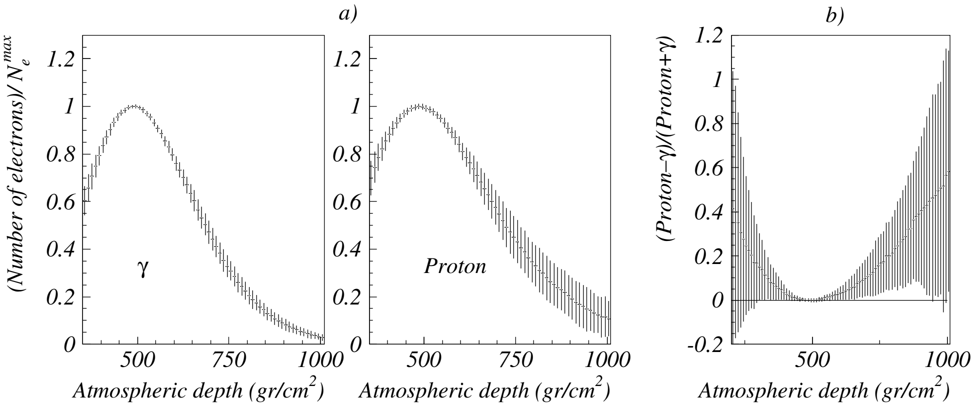

Figure 1: *a) Longitudinal shower development curve averaged over 50 showers for γ's and protons with a primary energy leading to a Č-density of 5500/m^2 at 80 m core distance (2200 m a.s.l.). b) Relative difference of the proton and γ curves in (a).*

Assuming a given longitudinal development of a shower there are three effects which determine the lateral distribution of Č-light: the finite Č-angle, Coulomb scattering and the transverse momentum p_t in hadronic interactions. The Č-angle leads to a lateral light density distribution which falls relatively slowly from about 10 m up to about 90 m, and beyond it rapidly falls to zero [4]. Coulomb multiple scattering and p_t tend to wash out the above mentioned cut in the lateral light distribution, leading to steeper lateral distributions between about 10 m and 90 m and flatter ones beyond. The flattening is strongest in proton and heavy-ion induced showers. We find that a good empirical parametrization of these lateral distributions between 30 and 100 m core radius is possible with an exponential of the form $\rho_p = a\ \exp(-r/r_0)$, where ρ_p is the Č-density at a distance r in from the shower core. r_0 (the 'light radius') is a measure for the steepness of the lateral distribution.

It is a well known fact [5] that the slope of the radial Č-light distribution in $r < 90$ m is a good measure for the depth of the shower maximum X_{max}. Photon induced showers have a little bit flatter average lateral light distributions than hadronic showers at core distances smaller than 90 m. However, the slope cannot be directly used for GHS, since the fluctuation around the mean of the slope for hadronic showers is much larger than the difference between the average slope of photon and hadron induced showers.

The effect of the hadronic transverse momentum p_t can be seen to apparently redistribute Č-light from shower core distances $r \lesssim 140$ m to distances $r \gg 140$ m. To identify the hallmark of p_t we can compare the light intensity at 80 m (L80) with the light intensity at 140 m (L140). If we plot L140/L80 vs. L30/L80 (the slope), hadronic showers can be seen to lie in a band above the purely electromagnetic showers. The precise measurement of L140, however, requieres a large detector area and, for the energies of this work, a higher sensitivity for small Č-pulses against the night-sky light background.

The 'length' of a shower can be determined from the measurement of the number of electrons N_e at detector level, which can be done e.g. by an array of scintillator detectors. The longer 'tail' of hadronic showers leads to a higher ratio N_e/L80. It can be shown that using L_{int}, the integrated Č-light up to core radii of 100 m, instead of L80 leads to an equivalent result, with the advantage that N_e/L_{int} shows less fluctuation than N_e/L80.

3 The Light-Electron-Slope method

Since N_e depends on X_{max} and the length in comparable amounts, it is advantageous to plot the separation variable N_e/L (where L stands for L80 or L_{int}) against the slope. The different relative positions for various primary particles in such a plot is the basis of the LES (abbreviated for 'light-electron-slope') method for GHS. In fig. 2 we show the result for γ-rays and protons (not including simulation of the detector response). Although not shown in the figure, even a better separation is obtained for other hadrons. The line represents a possible 'cut'. By vertically shifting this 'cut' line we can get the optimal separation. In the case of point sources, the optimal value for this shift (LES parameter) is chosen in such a way as to maximize the quality factor Q, defined as $S_\gamma/\sqrt{S_b}$, where S_γ and S_b are the fraction of signal (γ) and background events respectively, remaining after the GHS cut.

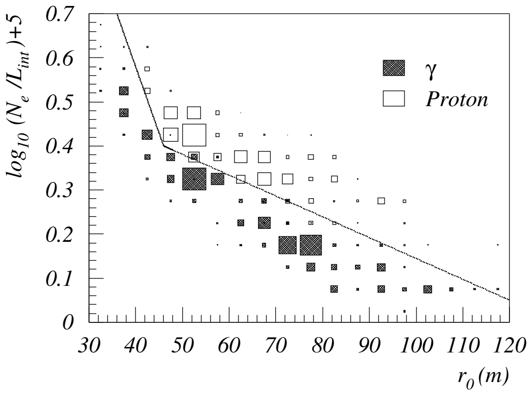

Figure 2: *log(N_e/L_{int}) vs. the 'light radius' r_0 for γ's and protons with 25° angle of incidence (no detector simulation).*

3.1 Application to the AIROBICC array in HEGRA

Here we present results from the simulation of showers (selected from a library [6] generated with CORSIKA 3.02) through the scintillator and AIROBICC arrays of the HEGRA detector. The AIROBICC array [7] consists of 49 AIC counters on a 30 m grid. The software threshold used for the LES analysis was at least 20 AIROBICC huts over threshold and a photon density above 15000 ph/m^2 at 90 m core distance. The Scintillator array assumed for the simulation consisted of an array of 15×15 plastic scintillators with an area of 1 m^2 on a 15 m grid. The 'software' trigger condition was more than 30 fired huts in order to obtain reasonable precision (25%) in the determination of N_e (from a fit to the NKG function). The combined trigger conditions lead to an energy threshold (50 % triggering probability) of 65 TeV for γ's at 10° zenith angle. Another method used at lower energies is described in [8].
The data were divided into two bins of photon density at 90 m core distance (L90) called 'M' (4.2 $<$ log(L90) $<$ 4.6) and 'H' (4.6 $<$ log(L90) $<$ 5.0) respectively (units are photons/m^2). Fig. 3a shows the one dimensional distribution of different primaries as a function of LES for M25 (25° angle of incidence). Fig. 3b shows the quality factor Q as a function of LES for the same sample. With LES = 0.46, we get Q = 5.2 ± 0.9.

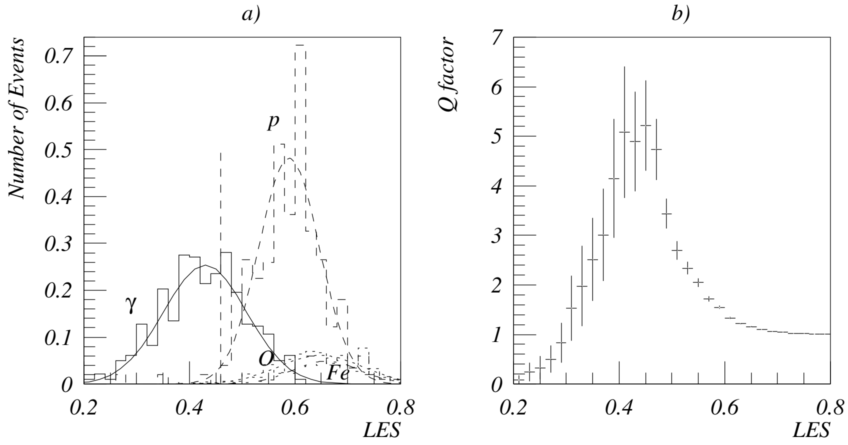

Figure 3: *a) Distribution of various primaries against their LES value (including detector simulation). The vertical dashed line shows the optimal cut. b) Quality factor Q as a function of LES.*

For other combinations of energy interval and zenith angle we get a factor Q of about 4. It can be seen that there is no strong trend of the Q-factor with energy. While the separation works better at low energy for physical reasons, the better data quality at higher energies works in the opposite direction. On the other hand, we have seen that the separation ability slowly improves with zenith angle, which is in accord with the fact that the difference in N_e grows with the shower development after the maximum (see fig. 1b).

4 Conclusions

AICA's are a serious candidate for the next generation of γ detectors in the high VHE to low UHE energy range. Efficient background suppression by factors comparable to those obtained with the best current Čerenkov telescopes can be achieved with the techniques presented in this paper (see [3] for a quantitative discussion).

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