Analysis Strategy for Large-Zenith-Angle-Observations with the HEGRA Cherenkov Telescope CT1

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Abstract

Cherenkov telescope observations at zenith angles $> 70^o$ are capable of providing large collection areas. This improves the detection efficiency for photons at very high energies. In order to understand the telescope's performance extended Monte Carlo studies have been made taking the first HEGRA Cherenkov telescope CT1 as an example. First results of these studies will be presented.

1 Introduction

In the last few years Cherenkov telescopes have shown their capability to detect photon-fluxes from discrete point-sources on the level of 10^{-12} cm^{-2} s^{-1} above 300 GeV. Most of these observations have been made at zenith angles $< 40^o$ since at larger zenith angles the energy threshold is higher and less Monte Carlo-simulations are existing. This constraint reduces the number of observable γ-sources. To avoid this limitation the study of the higher zenith-angle-region on the basis of appropriate simulations is necessary.

Observing astrophysical sources at larger zenith angles offers another important feature. Because of the large increase of the geometrical collection area, it is possible to achieve a better acceptance for high energy γ-primaries (Sommers & Elbert, 1987). By these means a Cherenkov telescope is able to expand its energy range for measuring the source spectrum (Tanimori et al., 1994) (Tanimori et al., 1998) (Krennrich et al., 1999) (Chadwick et al., 1999).

Here we discuss the possibilities and problems of this observation mode using the HEGRA CT1 as example. The HEGRA experiment located on the Canary island La Palma operates six Cherenkov telescopes, five are combined in a system while the CT1 is a stand alone telescope. CT1 has a high resolution PMT camera consisting of 127 pixels in an 3.25^o field of view (pixel diameter 0.25^o) and a mirror area of 10 m^2. Details of the telescope are described in Mirzoyan et al.(1994) and Rauterberg et al.(1995).

2 γ-Hadron-Separation

To achieve a higher sensitivity for γ-induced air showers from a particular source, a separation of these showers from the dominant background of hadrons is required. In the case of modern Cherenkov telescopes such as CT1 this is possible due to their high resolution cameras. Due to the telescope's imaging capabilities the air shower development is visible in the camera and differences in it are fixed in the measured image of the air shower's Cherenkov light. One method to apply a γ-hadron-separation is to calculate appropriate parameters which characterize the image (Hillas, 1985). The method of the Hillas parameters is to calculate the second moments of the pixels intensity-distribution in the camera frame. Thereby one achieves an observable for the longitudinal (LENGTH) and transverse (WIDTH) extension of the shower, its direction (ALPHA), energy (SIZE), the distance to the shower's maximum (DIST, MDIST) and for the impact parameter of the shower core (DIST). At small zenith angles most of the γ-hadron-separation is obtained by cuts on the transverse extension of the shower (WIDTH) and its direction (ALPHA).

3 Geometrical Aspects

Air showers at larger zenith angles reach their maximum further away from the telescope due to the larger amount of slant depth the particles have to penetrate (see Table 1). Since telescopes are able to detect air showers with large impact parameters corresponding to large DIST-angles in the camera-plane, the geometrical collection area A (see Figure 1) is a function of the zenith angle (A(θ)) and thus from the distance to the shower maximum D as given by Sommers & Elbert (1987):

$$A(\theta) \,=\, \pi \;(\; D(\theta)\;\tan\;\alpha\;)^2 \;\sim\; D^2\,.$$

The angle α which is related to the position of the shower maximum in Figure 1 is found to be approximately equivalent to the MDIST-parameter for showers parallel to the telescope axis.

Since the signal-to-noise ratio is a function of the distance D and the quality factor Q of the γ-hadron-separation ($signal/noise \;\sim\; \sqrt{A}\,\cdot\,Q \;\sim\; D\,\cdot\,Q$), it is necessary to study the shower characteristics at large zenith angles. Otherwise the increase of collection area will be balanced by the decrease of the quality factor.

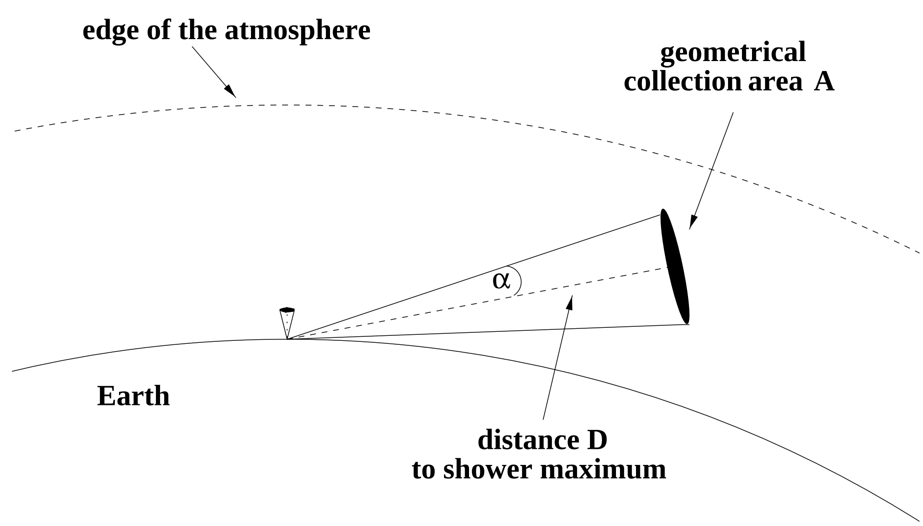

Figure 1: Change of geometrical collection area A at large zenith angles. Vertical showers reach their maximum at approximately 10 km distance (height) from the detector. The shower maxima of more horizontal showers have distances D which could be more than ten times longer corresponding to larger geometrical collection areas (A $\sim$ D^2).

4 New Monte Carlo Simulations

Since the air shower simulation code CORSIKA (Heck et al., 1998) treats the shower developement in a flat atmosphere, modifications have to be done for complete simulations at large zenith angles. Here these changes habe been implemented by applying a sequence of local flat coordinate frames which result in a spherical treatment of the shower development (see also Heck et al., 1999). The curvature of the Earth is now taken into account which is essential for large zenith angles due to the different slant depths and path lenghts in the different geometries (see Table 1). After the Cherenkov light of the shower passes the detector simulation and the same analysis steps as the real data it should be possible to extract differences between γ- and hadron-induced air showers.

Difficulties of this procedure are due to the larger distance to the shower maximum and thus the higher extinction by the atmosphere. This results in smaller and more concentrated images in the camera. As a consequence of the relatively large pixels of HEGRA CT1 (0.25^o) a good fit of the Hillas parameters will

zenith angle [^{o}]	flat Earth		curved Earth	
	path length [km]	**slant depth** [g/cm^2]	**path length** [km]	**slant depth** [g/cm^2]
0	113	1037.2	113	1037.2
30	130	1197.6	130	1197.2
45	160	1466.8	158	1465.1
60	226	2074.4	220	2067.3
70	330	3032.5	311	3006.8
80	650	5972.9	529	5771.5
85	1294	11900.4	771	10583.0
89	6463	59429.3	1098	25942.7
90	∞	∞	1204	36479.9

Table 1: Increase of atmospheric matter with zenith angle as seen at sea level. Path length and slant depth for a flat and a spherical atmospheric geometry. It is obvious that they differ at large zenith angles $> 70^o$.

be difficult. Especially the LENGTH- and WIDTH-parameter are expected to be about the same size and therefore the ALPHA-parameter will be hard to determine. Because two of the parameters which are suitable for γ-hadron-separation can not properly be defined, it is not yet clear to which extent the γ-acceptance can be improved.

5 Results

As a first result a Monte Carlo study of the increase of geometric collection area depending on the zenith angle and a preliminary set of cuts for observations $> 70^o$ zenith angle will be presented. Therefore we are capable to demonstrate the detection efficiency which is essential for flux calculations. As an application a preliminary analysis of observations of the γ-source SN 1006 (Tanimori et al, 1998) which are scheduled from March to June 1999 with HEGRA CT1 will be shown at the conference.

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