Search for the Crab Nebula and Mrk 421 with an Improved Sensitivity and a Lower Energy Threshold of the HEGRA Arrays

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Abstract

Methods to extend the γ-hadron separation capabilities of the HEGRA arrays (AIROBICC and scintillator) down to the energy threshold (i.e. approx. 15 TeV for γ showers) are presented. The enhancement of the sensitivity on gamma ray point sources will be shown, and a first application of the developed tools to HEGRA data of selected sources is presented.

1 INTRODUCTION

The recent successes in finding evidence for cosmic γ-ray emitters above 1 TeV with Čerenkov light detector systems required two conditions to be fulfilled: An excellent directional reconstruction of the air showers registered and the suppression of hadron initiated showers. The observation of γ rays from the Crab nebula and from the AGN MRK 421 by the Whipple group [1][2] as well as the evidence for PKS 1706-44 observed by the Cangaroo group [3] with imaging Č telescopes resulted from an analysis of the Čerenkov light images. The Themistocle group using an array of non-imaging small angle Čerenkov counters measured γ showers from Crab from 3 TeV up to 15 TeV, enabled by highly accurate directional reconstruction and the suppression of hadronic events due to a different lateral intensity distribution [4].

The combination of the HEGRA arrays (i.e. the scintillation counter array and the wide angle Cerenkov light collecting array AIROBICC) offer both, a very good angular resolution and capabilities to suppress hadronic showers for a search for γ-ray sources as shown in [5][6]. The present study is concerned with γ-hadron separation methods robust enough to work near the threshold of the two arrays. (See also [7] exploiting the HEGRA Geiger tower information for a γ-hadron separation.) Section 2 describes the quantities used and shows the MC results with regard to γ-hadron separation. In section 3 distributions of real HEGRA data are compared to the MC.

2 METHOD FOR γ-HADRON SEPARATION

For the results presented in this chapter a detailed Mt. Carlo study was performed using the CORSIKA code [8], taking into account the energy spectrum (5...200 TeV) and the normal elemental composition of the primary hadrons. γ showers were generated using a power law distribution of $NdE \propto E^{-2.7}dE$. The shower core positions are scattered randomly over an area much larger than the array, thus modelling the true raw data of the experiment. Detector effects such as thresholds and resolution are taken thoroughly into account. The Mt. Carlo events are reconstructed in the same way as the real data.

Here we restrict ourselves to zenith angles of 0 and 15°, although the procedure works as well for higher shower inclinations, but precise calibration has to be done still.

The most prominent feature to discriminate hadronic from γ showers with the HEGRA

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arrays is the particle to Č-light ratio, having different typical values depending on the height of the shower maximum, which is measured by the slope of the Č-light lateral distribution. Aγ-hadron separation based on this was introduced before [6] (see also [9]) . The main drawback of the method used so far is the reconstruction of all used quantities with fits to the lateral distributions. This requires certain minimum number of triggered counters in both arrays, resulting in a considerable higher energy threshold then the pure trigger of the experiment. Since the aim is to admit all triggered showers to a γ-hadron separation to keep the energy threshold as low as possible, particle to Č-light ratio has to be characterized without requiring any *a priori* condition to be fulfilled. This is done here by simply counting all particles in the scintillator stations (weighted to account for different counter densities in the array) named here $N(e)$ and summing over all Č-light photons registered in AIROBICC counters ($N(L)$). These quantities allow the calculation of the particle to Č-light ratio for all events, although it is a more crude estimate.
It turns out that for showers near the threshold of the arrays the slope of the lateral distribution of Č-light carries no separation information any more, partly due to the fact that all showers have their maximum quite high in the atmosphere, partly due to the bad estimation of the slope of the distribution for such small showers. In contrast, the lateral spread of shower particles remains different for γ and hadronic showers. Instead of a fitted quantity, the spread is characterized here by RMEANP, that was originally introduced to tag events with cores outside the array [10], and measures the mean distance of registered shower particles from the shower core position, estimated with a center of gravity method:

$$\mathsf{RMEANP} := \sum_i \|\vec{r}_i - \vec{r}_G\| \; n_i / \sum_i n_i \tag{1}$$

where $\vec{r}_G$ denotes the reconstructed core position, and $\vec{r}_i$ resp. n_i are the position resp. numbers of particles in the ith counter, the latter again weighted to account for different counter densities.

First, we demand at least 14 hit scint. counters. Fig. 1 shows the correlation

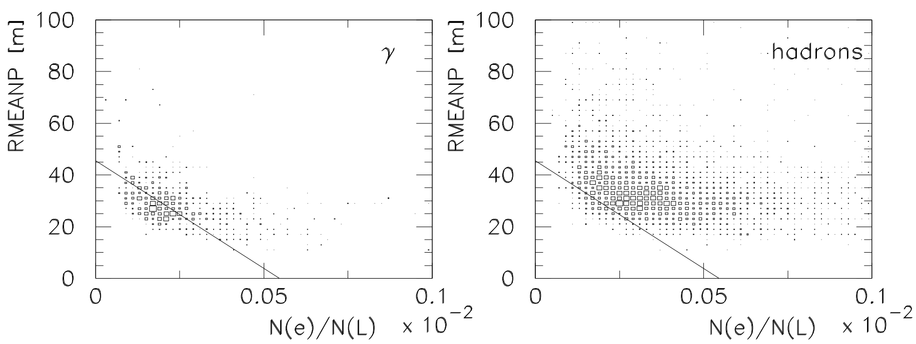

Figure 1: RMEANP *vs. $N(e)/N(L)$ correlation for γ and hadron showers.*

of RMEANP versus $N(e)/N(L)$ for γ and for hadron induced events at the threshold of the scintillator array (14 huts with a signal), showing for both types of primaries a characteristic shape. The distribution for γ events is shifted towards lower RMEANP values (higher concentration of particle distribution) and lower $N(e)/N(L)$ values, thus enabling a combined discrimination cut to enrich γ showers. The criterion of an optimal cut is chosen such that the ratio of the γ signal to fluctuations of the hadronic background, i.e. the gain in significance in a search of γ ray sources $Q := N(\gamma)/\sqrt{N(h)}$, should be maximized by shifting a straight cutting line in the correlations as sketched in fig. 1. Let us define a quantity

$$\mathsf{pearl} := \mathsf{RMEANP}[\mathrm{m}] + c \cdot N(e)/N(L) \qquad (2)$$

where c is empirically chosen and fixed at $c = 83.3 \cdot 10^3$. Fig. 2 shows the distribution

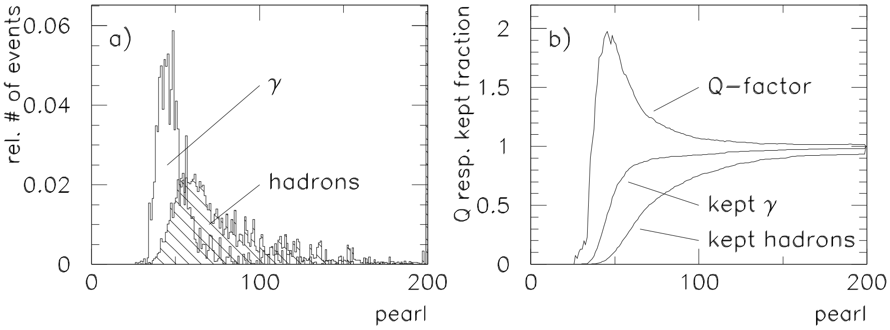

Figure 2: a) pearl *distributions for γ and hadron showers for >= 14 scint. counters*
b) Fractions of events kept for γ and hadrons and the Q-factor

of pearl for γ and hadron showers, respectively, and the fraction of events kept and the quality factor Q in dependance of the cut value of pearl. It turns out for >= 14 scintillation counters corresponding to an energy threshold of approx. 26 TeV for γ showers, the maximal Q value is about 2.0 at pearl $= 45.5$, which keeps $\approx 40\%$ of γ events while rejecting $\approx 96\%$ of the hadronic events.

Next, let us admit **all** showers triggering the array, i.e. allow AIROBICC triggers of at least 6 huts and put **no** restrictions any more on the number of hit scintillator huts. This lowers especially the γ threshold to $\approx$ 15 TeV while the threshold for protons is only slightly lowered. Fig. 3 a) shows the pearl distributions for all events,

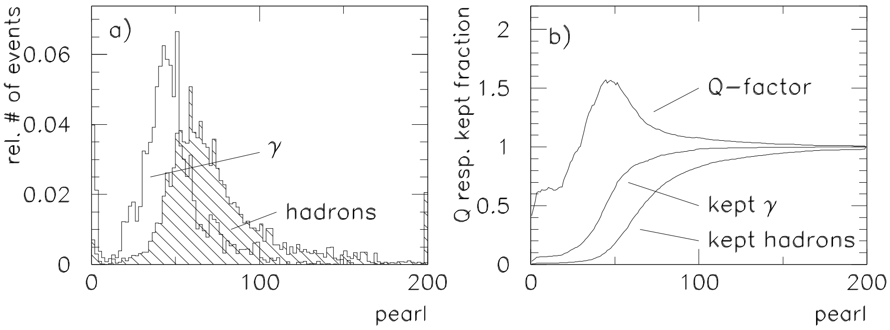

Figure 3: a) pearl *distributions for γ and hadron showers for all events*
b) Fractions of events kept for γ and hadrons and the Q-factor

indicating that even if we allow that no scint. hut has a signal, there remains a separation power. One finds the optimal cut value in pearl unchanged at ≈ 45.5, as shown in fig. 3 b). The quality factor Q drops to a value of 1.5, since the particle to Č light ratio estimate as well as the measure of the lateral spread becomes more smeared out. Especially events with no hit scint. hut have to enter with an RMEANP value of 0. The fraction of accepted γ showers stays roughly constant at $\approx 50\%$.

It should be mentioned that a cut in pearl of about 45, although optimized for a gain in significance Q using all events, will, as a side effect, guarantee for a good core estimation for further reconstruction steps.

3 COMPARISON WITH HEGRA DATA

In a comparison to the data, the most important aspect is how well the leading edge of the pearl distribution matches the Mt. Carlo results. In fig. 4 a) the correlation of

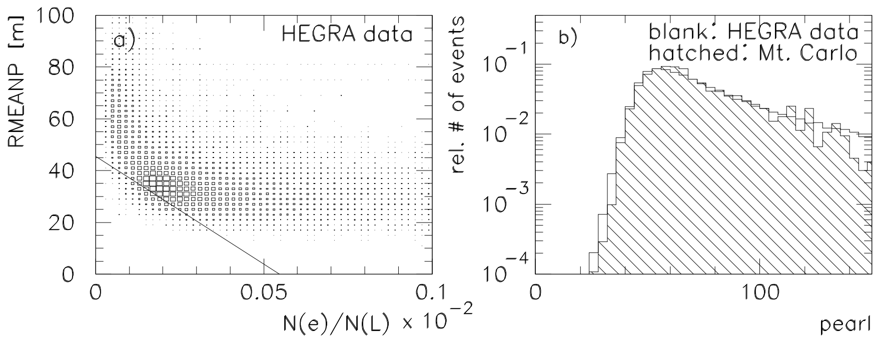

Figure 4: a) RMEANP *versus $N(e)/N(L)$ in the HEGRA data*
b) pearl *parameter in Mt. Carlo (hadrons) and HEGRA data.*

RMEANP versus $N(e)/N(L)$ is shown with the only restriction of at least 14 scintillation counters fired and a zenith angle $\theta < 20°$. It is in good agreement with the corresponding distribution for hadrons in fig. 1. The higher fraction of events in the upper left corner results from the fact that the Mt. Carlo events are only generated up to 200 TeV, thus events of higher energies having their core predominantly outside the array are missing. Fig. 4 b) shows that the pearl distribution of the M. Carlo events matches well the corresponding distribution in the experimental data, indicating that one can expect the same quality of γ enrichment when using a pearl cut in the data.

4 CONCLUSION

With the combination of the HEGRA scintillator array and AIROBICC a remarkable γ-hadron separation is possible even for the lowest energies registered by the arrays, which is just above the energy range for that γ rays from the Crab nebula had been measured up to now. This will help in a search for isotropic UHE γ rays as well as from point sources. An application of this method to HEGRA data of selected sources such as the Crab nebula and MRK 421 will be presented at the conference.

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