Scans of the TeV Gamma-Ray Sky with the HEGRA System of Cherenkov Telescopes

Gerd Pühlhofer[1], for the HEGRA collaboration[2]
(1) Max-Planck-Institut für Kernphysik, Heidelberg, Germany
(2) `http://www-hegra.desy.de/hegra`

Abstract

Between 1997 and the end of the detector operation in fall 2002, about 5500 hours of observational data were recorded with the HEGRA system of Imaging Atmospheric Cherenkov Telescopes (IACT). Besides dedicated scan observations of extended sky regions, a considerable fraction of the sky has been looked at as a side effect during the observations of selected source candidates. Altogether, more than 3% of the total sky has been observed with the HEGRA IACT system. We report on a search for possible new TeV sources within this entire data set.

1. Introduction

A large fraction of the observation time of the HEGRA IACT system [3] was dedicated to individual objects such as known supernova remnants and active galactic nuclei, which were known from other wavebands. Given the system's large field of view (FoV) of 4.3° with a homogeneous γ-ray acceptance over more than 2° in diameter, scans of extended sky regions were also possible (e.g. [2]). Summing up scans as well as observations of individual objects, more than 3% of the entire sky has been observed with the HEGRA telescope system.

In the case of observations which were targeted at a point source, a large fraction of the FoV is not affected by the possible emission from the target object, and is usually only used to derive background estimates for the source candidate. It is however obviously possible, in analogy to scanning observations, to regard any position in the FoV as possible source candidate, and derive background estimates from other parts of the FoV.

2. Analysis challenges

The main analysis challenge is a reliable background estimate for an arbitrary position in the FoV. Gamma-ray event candidates are identified against the much larger hadronically induced background solely by the shapes of the event images. The image cut typically rejects 92% of the hadrons, the remaining hadrons generate background in the γ-ray shape cut domain. Depending

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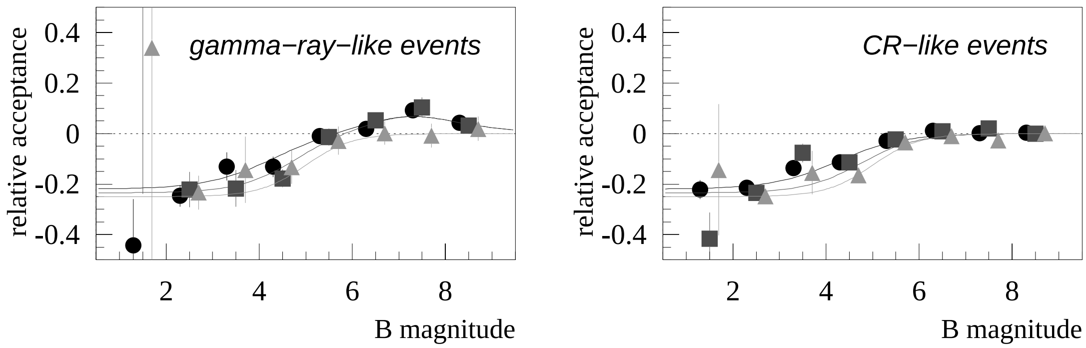

Fig. 1. Acceptance change in the field of view due to stars. The figures show the acceptance relative to a ring segment around the star positions, as a function of the blue star magnitude. The data points were derived on average for all stars in magnitude intervals. At the left panel, γ-ray like events were used, on the right side hadron-like events. The different symbols indicate different zenith angle bands. The lines are parametrisations which are used to account for the acceptance change.

on the total observation time and the angular extension of the search area, the systematic accuracy of the determination of the absolute background level at the source candidate location must be 1% for very deep observations.

In HEGRA system data analysis, the standard approach to determine a background estimate uses only γ-ray event candidates after image cuts; then different positions in the FoV are used as background control regions. An alternative method (the so-called 'template model' [1]) uses hadron candidates which were reconstructed to originate from the same direction as the source candidate. In this case, a normalisation is needed to estimate the background level in the γ-ray regime from the event counts in the hadron domain; this value must be derived from an average across the whole FoV.

Both background estimates rely on the homogeneity of the (γ-ray or hadron) acceptance across the FoV. While detector acceptance inhomogeneities are typically of the order of 5% or less, they may reach 10-20% in special cases such as large zenith angle observations or strong sky brightness variations due to stars. Much effort went into the development of an acceptance correction which accounts for as many as possible known systematic effects. Figure 1 shows as an example the acceptance at the positions of stars in the FoV relative to the surrounding acceptance, as a function of the B-band of stellar magnitude. The values were derived from data, averaging over all stars in the respective magnitude interval which have no other stars nearby. The lines show empirical parametrisations which are used as part of the overall acceptance correction. The functional dependence for the γ-ray and hadron regimes is quite similar, supporting the idea that the 'template' background estimate may be better able to cope with in-

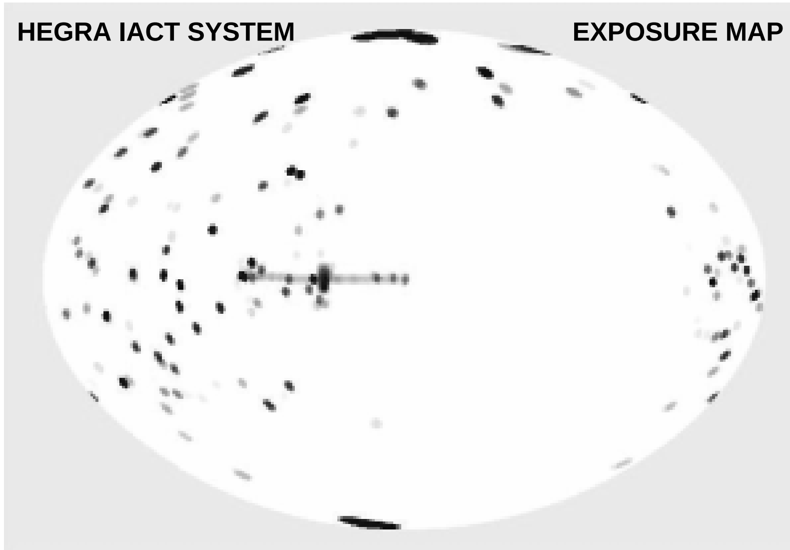

Fig. 2. Exposure sky map of the HEGRA IACT system for the years 1997 to 2001, in Galactic coordinates. Darker colour denotes longer observations.

homogeneities (of whatever type) at individual pointings. Fortunately, the two different discussed background estimates are affected by different uncertainties of the acceptance determination; since the results derived with both methods are generally in good agreement, we conclude that both estimates are reliable.

The 'template' background estimate is in principle applicable to the investigation of source candidates which cover a large portion of the FoV, or to look for diffuse γ-ray emission. However, the cited systematic problems in the FoV homogeneity prevent us currently from searching for source candidates which cover a large portion of the FoV.

3. Search for new gamma-ray sources

In the current analysis, two different grid search patterns were applied: a dense grid of 0.0625° spacing with a tight angular cut optimized for point sources, and a wider grid of 0.125° with a wider angular cut for slightly extended sources. In both cases, the significances for neighbouring grid points are correlated since the cuts are a bit larger than the grid spacing. Strong known γ-ray sources were, a priori, excluded from the search grid.

Figure 3 shows significance distributions for the wider grid from a preliminary analysis containing data up to 2001. The plot on the left hand side represents the search for new γ-ray sources. Here, γ-candidates in a ring surrounding the search position were used for background estimate. An excellent agreement with the Gaussian expectation for most of the scan positions is obtained, proving that the method works well. A few scan points show a γ-ray signal at a level of $5-7\,\sigma$;

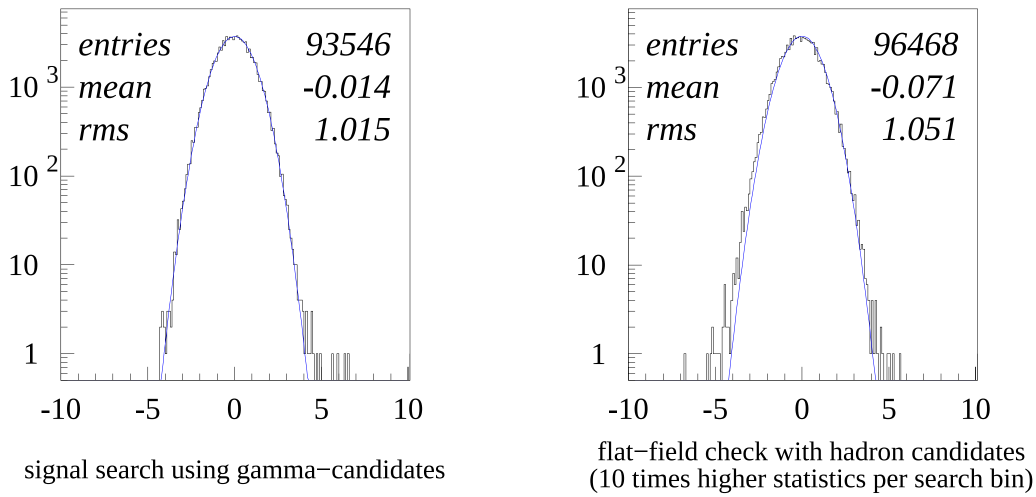

Fig. 3. Significance distributions for the 0.125° grid. On the left panel, the result of the actual search for γ-ray sources is shown; in this case, γ-ray-like events in a ring surrounding the search position were used for the background estimate. The solid line indicates the expectation for a purely Gaussian distribution. On the right side, hadron-like events were treated in the same way as the γ-candidates to perform a check of the flat-field. Since the event statistics is 10 times higher than in the γ-ray regime, the nearly Gaussian behaviour of this distribution shows that the background estimate is well under control.

these include objects that were detected as TeV emitters already in earlier analyses which were dedicated to these source candidates (e.g. Cas A, H 1426+428). A few new γ-ray source candidates have been identified; final results for the entire data set are under way and will be presented at the conference. Strong unknown TeV emitters in the sky – at least where HEGRA was pointed – can however be excluded.

The analysis was also performed for hadron events where no localized sources are expected. The hadron domain has ten times more counts per search bin than the γ-ray regime, the significance distribution (right panel of Fig. 2) is hence a very sensitive tracer for possible systematic errors in the flat-field procedure. The distribution is nearly Gaussian, which is a good additional check that systematic acceptance variations are well under control.

4. References

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