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Search for diffuse VHE gamma rays from the Galactic plane with the HEGRA IACT system

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Abstract

The Imaging Air Cherenkov Telescope (IACT) technique has emerged in the last years as a powerful tool for the detection of VHE γ-rays of cosmic origin. In order to map extended sky regions, a large homogeneous field-of-view and a good hadron rejection capability are necessary. These requirements are met by the HEGRA IACT system. A survey of the Galactic plane was performed in 1997/1998 and a further scan is planned for 1999. These data provide the opportunity to search for diffuse Galactic gamma ray emission in the VHE energy range. In this paper we will present the γ/hadron-separation technique and an upper limit for the HEGRA IACT system for detecting diffuse radiation.

1 Introduction:

The Galactic plane is one of the well established γ-ray emitters in the MeV-GeV energy range (Hunter et al.,1997). A question of general interest is whether and at which level the diffuse flux extends into the TeV regime. A first estimate of the expected flux above 1 TeV can be derived from an extrapolation of the flux around 1 GeV measured by the EGRET instrument on board of the Compton Gamma Ray Observatory (CGRO). This extrapolation gives a value of $\Phi_\gamma(E > 1TeV) \approx 0.5 \cdot 10^{-9}$ ph cm^{-2} s^{-1} sr^{-1}, which is however afflicted by huge uncertainties depending on the Galactic emission models and by the fact that the flux is extrapolated over three orders of magnitude in energy. In the 1 GeV energy domain the measured flux is mainly produced by π^0-decay following a nuclear interaction, whereas in the 1 TeV domain the diffuse γ-rays should be mainly produced by electrons via the Inverse Compton (IC) scattering. Recent calculations show that the e^--distribution in the galaxy is rather inhomogeneous and that the locally observed e^--flux could be relatively low (M. Pohl et al.,1998). For these reasons the γ-ray flux in the TeV regime might well be about one order of magnitude above the extrapolated flux and of the same order as the e^--flux around $\Phi_e(E > 1TeV) \approx 4.2{\cdot}10^{-9}$ e$^-$ cm^{-2} s^{-1} sr^{-1} (Wiebel, 1998).
In a measurement of the diffuse γ-ray flux with the HEGRA IACT system (Daum et al., 1997) the major problem arises from the CR induced background. The first part of this paper focuses on a CR suppression technique using an Artificial Neural Network (ANN) . In the second part an upper limit derived from the Mkn 501 data set for diffuse radiation is presented.

2 Background Suppression Technique

To distinguish between γ/e^- and hadron induced showers in the IACT-technique usually the following procedure is applied: In a first step, the second moments (*Hillas parameters*) of the light distributions in the images are calculated. In a second step one or more cuts are applied on these parameters using the fact, that the mean light distribution depends on the primary particle (D.J. Fegan, 1997). The most significant parameter for γ/hadron-separation is the so called *width*, reflecting the lateral distribution of Cherenkov light emitting particles in an air shower. In a more advanced technique for multi-telescope images of the same air shower, the so called *mean scaled width* is calculated. In this kind of analysis the individual *width* of the pictures is normalized to expected values of MC simulated γ-ray data for different image *size* and telescope distances and afterwards averaged over the number of telescopes in the event (Konopelko et al., 1995, Daum et al. 1997).
An alternative approach with the aim of optimal background suppression is to use an artificial neural network (ANN) fed with the image parameters. The ANN is trained by MC generated γ and proton induced showers in the energy range from 0.5 TeV to 10 TeV, and the so called back propagation algorithm is applied. To optimize

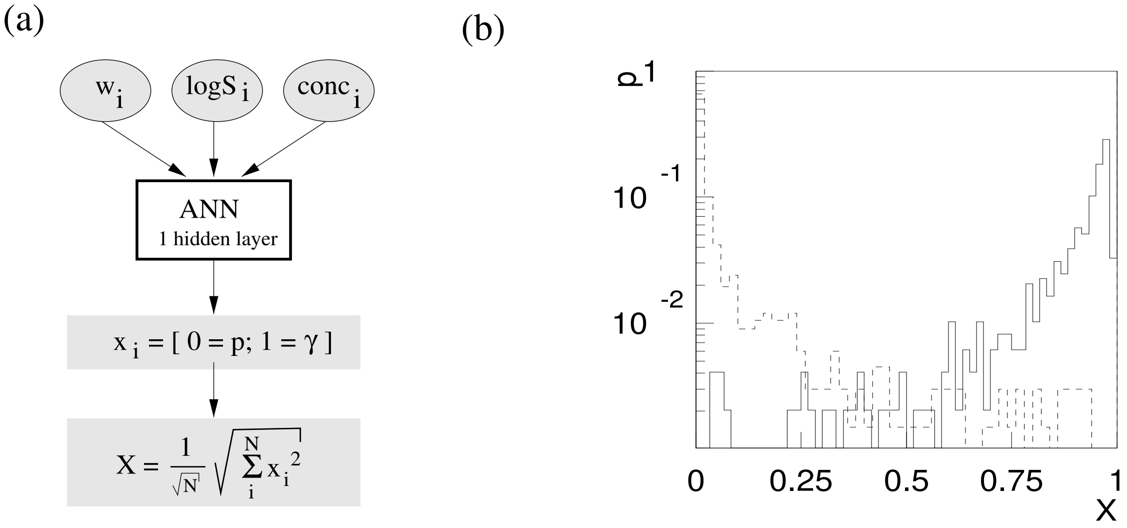

Figure 1: (a) Derivation of the X-parameter out of the image parameters *width*, *log(size)* and *conc*. (b) Output result of the ANN on the MC control sample normalized to the number of events in the sample. The dashed line indicates proton events, the solid line γ events.

the hadron rejection it is of advantage to use different views of the same air shower. Therefore in the following analysis only 4-telescope events were taken into account. The most significant parameters to distinguish between γ and hadron like events are the *width*, *log(size)* and *conc* in the individual telescopes. By applying an additional cut on the *size* of the images by rejecting images with $size > 2500$ ph.e or $size < 100$ ph.e. a further improvement is achieved. These cuts result in an effective threshold of 1 TeV.
The ANN consists of three input nodes, one hidden layer and one output node. For each individual telescope a value x_i between 0 and 1 is calculated (see Fig. 1a). Values close to one indicate γ-ray like events, close to zero hadron like events. In a second step in the multi dimensional x_i-space the distance of each event from the point x=(0,..,0) is calculated and normalized to the the distance between x=(0,...,0) and x=(1,...,1) resulting in a value X for each event. The output result of the ANN on a MC test sample which is not used for training is shown in Fig. 1b. In the following the X value is used as a parameter to enrich γ-ray like events in the data set and to suppress hadronic background events.

3 Sensitivity for Diffuse Radiation

To verify the performance of the cut procedure on real data the data set of the flare of the BL Lac object Mkn 501 in 1997 (Aharonian et al.,1999) was used. Truncated or miss reconstructed showers were removed from the data set by limiting the FOV of the individual telescopes to 1.7^o and rejecting showers with a reconstructed core distance of more than 250 m from the central telescope. The X-parameter is then calculated for the remaining 4-telescope events. The number of γ-ray like events is calculated out of the excess from the source position ($\theta^2 < 0.1^{o \times o}$) and the corresponding OFF-region shifted by one degree in the camera. The number of background events is derived from the number of events in the FOV of 1^o radius in respect to the optical axis of the system and cutting out the source region of the above mentioned size. The resulting suppression factors κ_{CR} and κ_γ as a function of the cut value X are shown in Fig 2a, the achieved enhancement $\epsilon = \kappa_\gamma / \kappa_{CR}$ is shown in Fig 2b. For a cut value of $X = 0.85$ CRs are suppressed of the order 1000 while keeping $\approx 7\%$ of γ-induced showers. Note, that the standard procedure using 4-telescope events and the *mean scaled width* cut produces suppression factors of the same order.

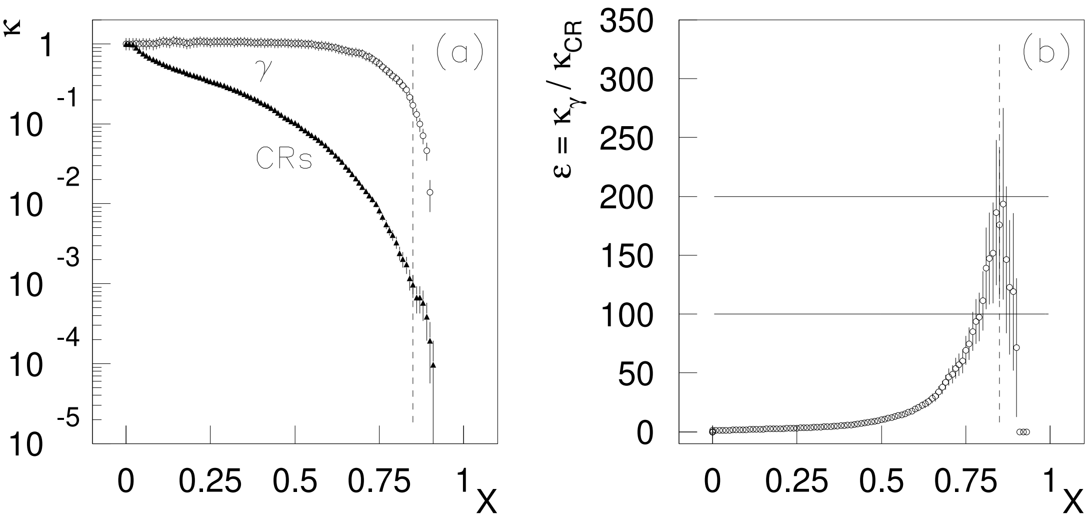

Figure 2: γ/hadron-suppression for 4-telescope events as a function of the cut parameter X derived from the Mkn 501 data set. Fig (a) shows the suppression of CRs and γ-rays. Fig (b) gives the corresponding enhancement of γ-rays over CRs. The dashed line indicates a cut value $X = 0.85$.

By interpreting all remaining background events as diffuse γ-ray like events, we derive a very conservative 2σ upper limit for the flux sensitivity of diffuse radiation by using the equation

$$\Phi_D^{up}(E > 1TeV) = \frac{n_{BG} + 2\sigma_{BG}}{n_M - 2\sigma_M} \cdot \frac{\overline{\Phi}_M(E > 1TeV)}{\Omega} \tag{1}$$

derived from the fact that within a FOV of 1^o radius the sensitivity of the IACT-system is quite homogeneous and therefore the effective area for isotropic γ-like radiation is given by the product of the effective area for directed radiation and the solid angle. n_{BG} denotes the number of background events within the solid angle Ω and σ_{BG} the error on this number. n_M is the number of detected photons from Mkn 501 and σ_M the corresponding error. The mean flux of Mkn 501 $\overline{\Phi}_M(E > 1\text{TeV})$ for the used data set is well known and given in Aharonian et al.,1999. Out of this calculation the tightest upper limit is derived for a cut value X = 0.85 and gives an upper limit of $\Phi_D^{up}(E > 1TeV) < 1.6 \cdot 10^{-8}$ ph cm^{-2} s^{-1} sr^{-1} (see Fig. 3). Note that this upper limit is only a factor of four above the expected e^--flux and only one order of magnitude above the extrapolated EGRET flux. Taking into account the uncertainties of the extrapolation, the HEGRA IACT system has enough sensitivity to possibly detect the diffuse Galactic γ-radiation in the TeV-regime.

4 Summary and Outlook

It has been shown that the HEGRA IACT system has a good sensitivity for detecting diffuse γ-radiation from the Galactic plane after a cut procedure optimized for background suppression. A analysis of of Galactic plane data (see OG 2.4.11) taken in 1997/98 is in progress. The main focus of this data set was the search for point sources in the Galactic plane and observations were not optimized for detecting diffuse radiation resulting in systematic uncertainties. An additional observation program for detecting diffuse γ-radiation from the Galactic plane is scheduled for June, July, and August 1999. Emphasis in this scan will be on the optimal control of systematics.

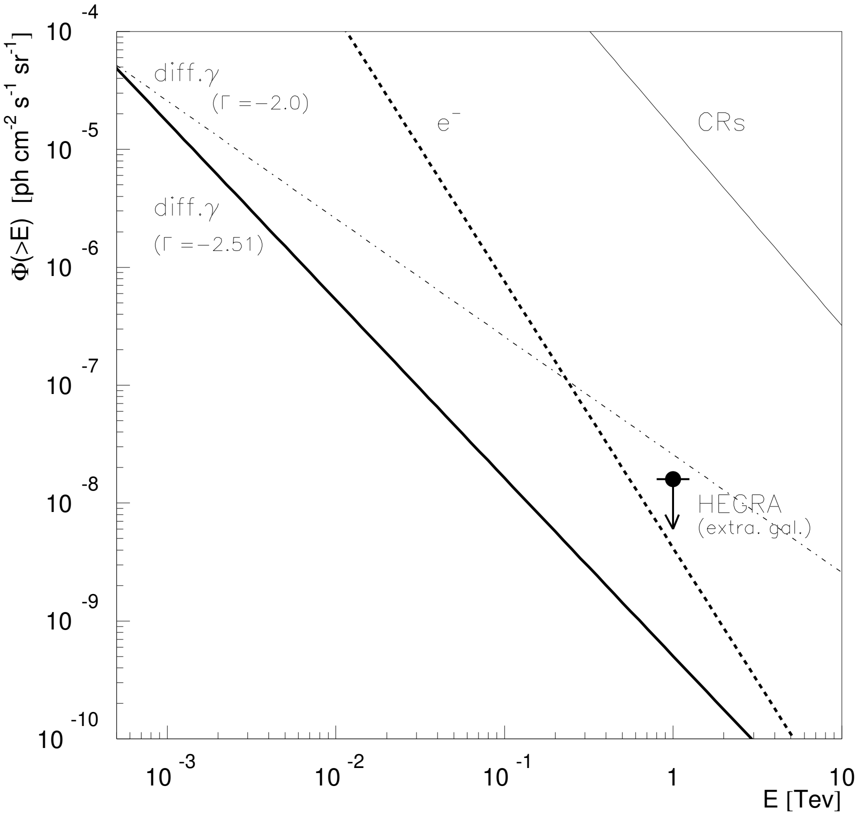

Figure 3: 2σ flux upper limit for diffuse radiation of the HEGRA IACT system after a tight cut of $X = 0.85$. The upper limit is derived from the data set of the extra galactic source Mkn 501 and an observation time of 12.2 h. A further improvement of this limit could be achieved by modeling the CR background. The e^--flux is calculated from (Wiebel, 1998), the diffuse γ-flux from (Hunter et al.,1997). For the extrapolation power laws of the form $\Phi(> 1TeV) = k/(\Gamma - 1)(E/E_0)^{-\Gamma+1}$ were assumed. The following values were taken: $k_{e^-} = 0.94 \cdot 10^{-8}$ ph cm^{-2} s^{-1} sr^{-1} TeV^{-1}, $\Gamma_{e^-} = 3.26$ and $k_\gamma = 2.58 \cdot 10^{-5}$ ph cm^{-2} s^{-1} sr^{-1} TeV^{-1}, $\Gamma_\gamma = 2.51$. The dash-dotted line indicates the slope of radiation for a spectral index of -2.

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