Neural Networks for γ/Hadron-Separation with the HEGRA Geiger Towers [1]

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Abstract

Due to the large amount of data and the complexity of the information, analysis of the HEGRA Geiger tower data is based on neural networks (NN). We explain the NN training and the principal characteristics of the analysis and describe first applications to experimental data, yielding an upper limit on the combined γ-ray flux above 50 TeV of 16 nearby northern blazars.

1 Introduction

The success of current and future earth-based air shower arrays in detecting point sources of cosmic rays above some 10 TeV depends crucially on the possibility of finding efficient methods for separating γ-induced air showers from the overwhelming background of hadron-induced showers. As shown in [1], this is successfully done by taking advantage of the Cherenkov light distribution, but γ/hadron separation is also possible using the charged particle component of air showers.

Due to their multi-layer structure, the Geiger towers of the HEGRA air shower array [2] are able to contribute to γ/hadron separation not only by detecting the muon content of air showers, but also by providing information about the particle density and the particle energy distribution in different distances to the shower core (see fig. 1 (a)). All information is in principle obtainable from the hit distribution within the Geiger towers, but since serial cuts are difficult and inefficient due to large event-to-event fluctuations, parallel processing of the whole information using NNs is a more appropriate way for analysis.

2 γ/Hadron Separation With Neural Networks

For the creation of a NN training and test sample, we use the Monte Carlo (MC) code CORSIKA 4.06 [3]. 10 000 CORSIKA generated air showers with primary energies E between 30 and 500 TeV according to a power law $E^{-2.75}$ passed a full detector simulation based on the GEANT 3.21 package [4], with incident angle (θ, ϕ) and core position randomly distributed to imitate as close

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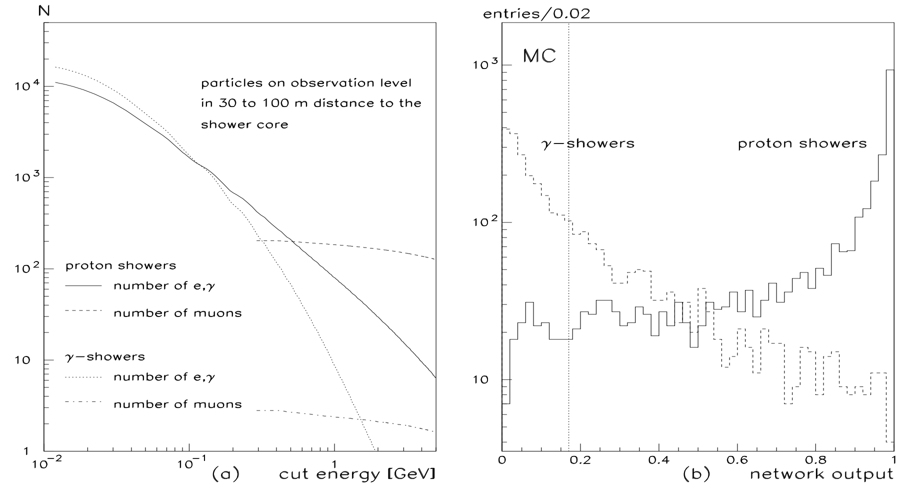

Figure 1: (a) Number of $(e^{\pm}, \gamma)$ and muons with energy greater than $E_{\rm cut}$ reaching the HEGRA observation level as a function of $E_{\rm cut}$ in distances between 30 and 100 m from the shower core (mean value for 500 γ- and 500 proton-induced showers).
(b) NN output for the showers of the MC test sample. The optimal cut value is indicated by the dotted line.

as possible the experimental data.
The MC showers are divided into a training sample (3000 showers) and a test sample, both with equal numbers of γ- and proton-induced showers. It is not necessary to add showers induced by heavier nuclei to the training sample, since a NN trained on the rejection of proton showers also rejects heavy nuclei [5]. As input variables we use the number of hits in the first and second layer, the mean number of hits in the lower 4 layers, and the number of reconstructed tracks for each of the 17 towers (see [5] for a detailed description of the NN training and testing). The NN with topology 68-17-1 transforms the information to a single value between 0 (γ-like events) and 1 (hadron-like events) [6] (fig. 1 (b)). The best value for a separation cut in the NN output is determined to $\xi_{\rm max} = 0.17$ by maximizing the quality factor $Q_{\rm pro} = \epsilon_\gamma/\sqrt{\epsilon_{\rm pro}}$ to $Q_{\rm pro}^{\rm max} = 2.8$, where ϵ_γ and $\epsilon_{\rm pro}$ are the fractions of γ and proton showers passing the selection. This optimal cut value gives a γ-shower efficiency

$$\epsilon_\gamma = 0.61 \pm 0.01 \pm 0.05, \tag{1}$$

where the systematic error includes daily changes in the detector performance and uncertainties in the MC simulation. Before NN processing, the data have to be cleaned from noisy wires which else considerably deteriorate the NN performance. An additional cut has to be applied to account for the fact that

a γ/hadron separation using the Geiger towers does not make sense in events where less than 6 towers record any hit information at all. Note that events which do not yield the necessary information for separation because the number of non-zero towers is below the critical value do not fake γ-showers, but are concentrated at an uncritical NN output of 0.6. Since the information content of the events increases with increasing energy, the γ-efficiency is a function of the energy (fig. 2 (a)).
We find good agreement between the NN output for proton showers and experimental data, showing that the combination of CORSIKA shower generation and GEANT detector simulation describes the experimental data in a way that allows to exploit the relevant separation criteria.

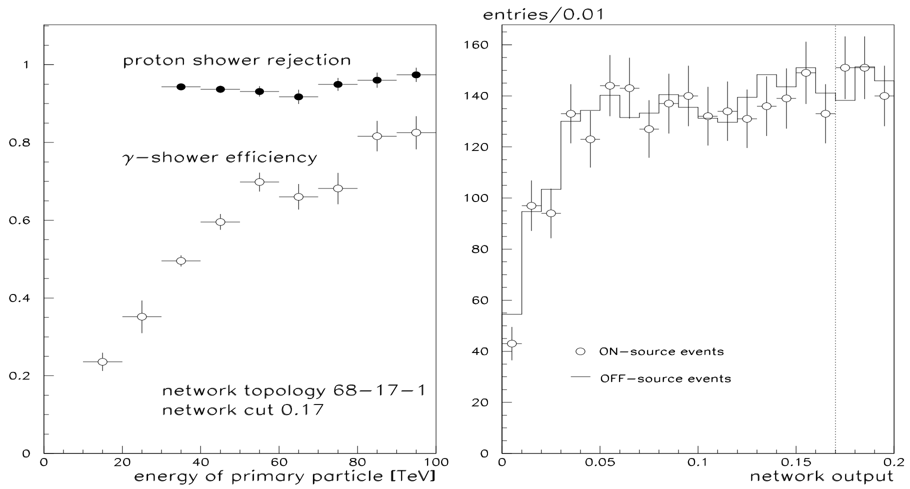

Figure 2: (a) γ-shower efficiency and proton shower rejection as a function of the primary energy. (b) NN output for experimental data.

3 Application to Experimental Data

We use the NN method for a preliminary analysis of about 14 789 184 events taken with the HEGRA array between October and December 1994.
The analysis concentrates on a number of nearby northern flat spectrum radio sources with rather moderate redshifts $z \leq 0.1$ (see table 1). In [7], the TeV γ-ray emission of these sources is predicted on the basis of the proton blazar model [8] including different assumptions about the absorption of TeV γ-rays due to the near-infrared γ-background produced by foreground galaxies.
To increase the sensitivity, we superimpose the NN output of all sources and search for a cumulative signal from the total sample of AGNs. The superposition of physically equivalent sources is a standard technique in radio astronomy and is also applied in MeV γ-ray astronomy (see [9]).

Core position and incident angles are determined using scintillator data including some quality cuts [1, 10] reducing the data sample to 8 466 248 events. Fig. 2 (b) shows the NN output in the interval $[0, 0.2]$ for on- and off-source data. The number of background events is determined by connecting the actual event time with incident angles taken at random from the (θ, ϕ)-distributions of the data.

Table 1: The sources and their redshifts (if known).

source	z	source	z	source	z
0116+319	0.059	1214+381	0.062	1652+398	0.03366
0202+149		1219+285	0.102	1727+502	0.05541
0430+052	0.033	1404+286	0.0769	2200+420	0.069
0446+112		1514+004	0.05233	2201+044	0.028
0802+243	0.0599	1604+159		2209+236	
1101+384	0.031				

On the basis of the data sample analysed up to now, we find $N_{\mathrm{ON}} = 1908$ on-source events with an expected background of $N_{\mathrm{OFF}} = 1938$ events. This results in a 90% c.l. upper limit of $S_{\mathrm{lim}} = 58$ events and a flux limit of

$$\Phi^{90\%}_{\mathrm{u.l.}}(E \geq 50\,\mathrm{TeV}) = 1.01 \cdot 10^{-13}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}. \tag{2}$$

At the moment, the total data sample taken in combination with the Geiger towers exceeds the sample used for this NN analysis by about a factor of 10. Data taking and analysis continues and will improve the upper limit given above in the near future.

References

[1] J. Prahl et al. (HEGRA collab.), contribution to this conference

[2] W. Rhode et al. (HEGRA collab.), contribution to this conference

[3] J. N. Capdevielle et al., *The Karlsruhe Extensive Air Shower Simulation Code CORSIKA*, KFK report 4998 (1992), Forschungszentrum Karlsruhe

[4] CERN Application Software Group, *GEANT Detector Description and Simulation Tool*, CERN W5013, Version 3.21 (1994)

[5] S. Westerhoff, H. Meyer, *Neural Nets as a Tool for Separating γ- and Hadron-Induced Air Showers*, in *Proc. 4th Int. Worksh. Software Engineering, Artificial Intelligence and Expert Systems for High Energy and Nucl. Phys.*, ed. B. Denby, Pisa, 1995

[6] L. Lönnblad, C. Peterson, T. Rögnvaldsson, *Pattern Recognition in High Energy Physics with Artificial Neural Networks - JETNET 3.0*, LU-TP-93-29 (1993)

[7] K. Mannheim et al., *Gamma Ray Emission from Nearby Northern Blazars*, to be submitted to *Astroparticle Phys.*

[8] K. Mannheim, *Astron. & Astrophys.* 269 (1993) 67

[9] M. Maisack et al. *Upper limits on the MeV Emission of Seyfert Galaxies*, accepted for publication in *Astron. & Astrophys.*

[10] M. Kühn et al. (HEGRA collab.), contribution to this conference