Use of Neural Networks to Measure the Muon Contents of EAS Signals in a Water Cherenkov Detector

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Abstract

The measurement of the muon contents relative to the EM component of extensive air showers (EAS) is one of the requirements to measure the composition of primary cosmic rays in giant arrays of water Cherenkov detectors (WCD) such as the Pierre Auger Observatory. By using bi-dimensional parameter spaces, such as charge vs amplitude, charge vs rise time or charge vs charge/amplitude, for precisely measured inclusive signals of cosmic rays detected in a single WCD of 1.54 m of diameter filled with water up to a height of 1.2 with one 8" phototube positioned in the center at the water level, we find a clear statistical identification of the different components: isolated electrons, isolated muons, muon interactions with the PMT glass envelope and low energy EAS. We make use of real oscilloscope traces of isolated electrons and isolated muons to compose artificial signals of EAS with known μ/EM ratios. Preliminary results encourage the use of neural networks to successfully estimate the μ/EM ratio of real EAS signals.

1. Introduction

Measurement of the muon contents relative to the electromagnetic component (μ/EM) at each of the ground stations of giant arrays of WCDs is one of the requirements to perform a statistical separation of primary cosmic rays into a few categories like hadronless primaries, nucleons, light or heavy nuclei primaries. It is known that EAS initiated by Fe nuclei have a greater value of (μ/EM) measured at ground level compared to proton-initiated EASs; in turn gamma primaries produce even less muons for the same energy of the primary cosmic ray. In the case of a hybrid cosmic-ray detector, such as the Pierre Auger Observatory [1], μ/EM and the EASs shower maximum are the main parameters for performing such an statistical separation at primary energies around 10^{20} eV.

In this article we illustrate the feasibility of using neural networks as the basis of a scheme to classify different classes of EAS signals according to their

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Table 1. Classification Results for Two Classes. Numbers indicate the percentage of events in a given true class on the upper row that are classified into each of the different classes on the left column.

EAS Class	$8\mu - 0e$	$0\mu - 66e$	Real EAS Data
$8\mu - 0e$	84	17	84
$0\mu - 66e$	16	83	16

muon contents.

2. Experimental Setup

The WCD used consists of a cylindrical polyethylene tank with a diameter of 1.54 m and a height of 1.30 m; it is filled with 2300 l of purified water up to a height of 1.2 m. The tank is optically sealed and has an inner liner bag made of tyvek which reflects light in a highly diffusive way. At the center of the tank there is an 8" PMT, model ETL9354, looking downwards at the top of the level water. Inclusive signals produced by secondary cosmic rays are triggered with a simple amplitude threshold of -30 mV which selects events with charge values above 0.08 vertical-equivalent-muon (VEM). Other triggers and the procedure to convert charge to VEM can be found in [2,3]. A digital oscilloscope (Tektronix, TDS220) connected to the GPIB port of a PC running under LabView constitute the basis of the data acquisition system. The oscilloscope traces are used to measure on-line the charge, rise time 10%-50%, rise time 10%-90%, amplitude and ratio of AC/DC for each event.

3. Results and Discussion

By measuring precisely the amplitude, charge and rise times of the oscilloscope traces for signals produced by secondary cosmic rays we easily identify isolated electrons, isolated muons and extensive air showers, see Figure 1. The additional signal due to the interaction of muons with the PMT glass cover can also be separated from the other signatures [2]. Once identified, the signals of isolated electrons and muons are used to compose artificial EAS signals with known values of μ/EM. Three different classes of showers were composed: a first class named $8\mu - 0e$ made by summing 8 randomly chosen real muon oscilloscope traces, out of a catalog of 4 000; a second class named $4\mu - 33e$ made by summing 4 real randomly chosen muon traces and 33 different ramdomly chosen electron traces; and finally, a third class named $0\mu - 66e$ made by summing 66 randomly chosen electron traces. We made 200 events of each class: 100 for training and 100 for testing the neural network. The arrival times for muons and electrons are

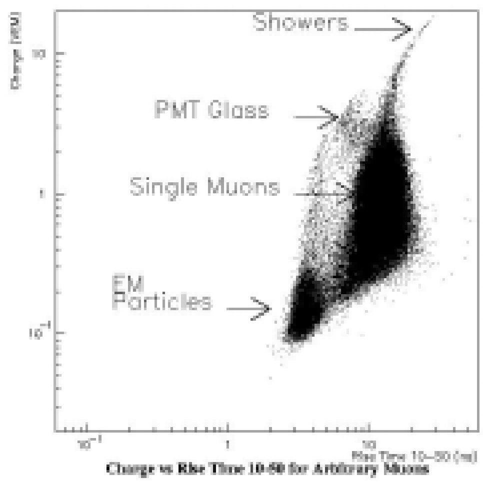

Fig. 1. Charge in VEM vs rise time from 10% to 50% in ns for inclusive cosmic ray signals in a water Cherenkov detector.

assumed to be distributed exponentially. The mean arrival times for muons and electrons, 15 ns and 25 ns, respectively, were chosen to make the average values of the charge distribution, rise time from 10% to 50%, rise time from 10% to 90% and amplitude of the three classes of composed showers equal to the respective values for real low energy showers with energies around 10^{11} eV. The mean values for charge, rise time from 10% to 50%, rise time from 10% to 90% and amplitude for the real showers selected with charges between 7 and 9 VEM were 7.9 VEM, 16.7 ns, 50.8 ns and 1.16 V, respectively.

Five input parameters were used on the Kohonen neural network: charge, rise time from 10% to 50%, rise time from 10% to 90%, amplitude and AC/DC ratio for each of the shower signals. The neural network was chosen of two dimensions: 8 neurons in the first layer and 4 in the second. This selection was based on a quick search for optimal diagonal results on the classification process of classes of known μ/EM value. The number of cycles used to train the neural network was 500. The results obtained for classification of showers with known value of μ/EM and of real showers are shown in Tables 1 and 2 for two and three classes, respectively.

Table 2. Classification Results for Three Classes. See explanation on Table 1.

EAS Class	$8\mu - 0e$	$4\mu - 33e$	$0\mu - 66e$	Real EAS Data
$8\mu - 0e$	70	36	7	70
$4\mu - 33e$	16	25	15	19
$0\mu - 66e$	14	39	78	11

We checked that a change on the shower amplitude in all classes so that their charges are normalized to 8 VEM produces similar results to those of Tables 1 and 2. From these Tables we see that, as expected, neural networks work better when trained to classify only two classes of events, as in Table 1. The results from Table 1 suggest that real low-energy showers are dominated by muons.

4. Conclusions

Identification of isolated electrons and muons in inclusive cosmic ray signals from a single water Cherenkov detector allows one to compose artificial traces for EAS with known values of μ/EM. These EAS signals were in turn used to train a Kohonen neural network which was used to classify test showers with known μ/EM values and to estimate the μ/EM value of real low-energy showers. The results are encouraging as they show that a simple neural network can indeed classify two shower classes composed of exclusively muons or electrons, see Table 1, with an efficiency of about 80%, i.e., much higher that a random result. The results in the case of three shower classes are also encouraging although more work is necessary to find additional parameters that might help produce a cleaner classification. Work in progress is extending this low-energy high-sampling results to the high-energy low-sampling case appropriate to the Pierre Auger Observatory.

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