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Identification of Primary Proton Component at the "Kne" Region

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Abstract

A Monte Carlo simulation for the hybrid experiment of air shower array and emulsion chambers at Yangbajing in Tibet was done with different interaction models. The feasibility of distinguishing proton induced showers from other nuclei by using artificial neural networks method was studied with the simulation data. The analysis indicates that the showers induced by primary protons can be efficiently selected by using this method with a slight interaction model dependent.

1 Introduction

The "knee" structure of the UHE cosmic ray energy spectrum relates to the origin, acceleration , propagation, modulation and the change of composition of cosmic rays in the $10^{15} - 10^{16}$eV energy region. The energy spectrum and chemical composition in the "knee" region ,unable to be measured directly with space experiments, are only measured indirectly with ground-based experiments,such as emulsion chambers(EC) and air shower(AS) arrays. Several experimental groups have reported their measurements on this subject, but there are big differences among the results. The key to resolve this difficulty is to identify the showers induced by protons and heavier nuclei. This needs to study the EAS with multi-parameter measurement.

The Tibet-II ASγ experiment(4300m a.s.l., atmosphere depth 606g/cm^2) is a hybrid experiment of EC and AS at Yangbajing. The AS array covers an area of 36000m^2. A 80 m^2 EC and burst counter complex is set up near the center of the array. Each unit of EC has a 50$\times$40cm area and 14 c.u. thickness. The information of AS and EC is related by the burst detectors under the EC. The advantage of this experiment is that the EC can provide the detailed core structure of the events while the AS can provide information on the energy of primary particles generating these events. These information is useful in the identification of the primary particles.

In this work, the feasibility of identifying primary proton component with artificial neural network is studied with the simulation data generated with CORSIKA562[1] and COSMOS[2] code under the condition of the hybrid Tibet-II ASγ experiment. The dependence of the identification efficiency on the interaction models is also discussed.

2 Monte Carlo simulation

CORSIKA and COSMOS codes were used to simulate the transportation of the cosmic ray particles. For the hadronic interaction, the SIBYLL model[4] and QGSJET model[5] were used in the CORSIKA code, and a phenomenological model (COSMOS model) as well as the Chou-Yang model were used in the COSMOS code. Hadronic particles were followed until their energies were lower than 0.1TeV. The treatment of the electromagnetic component is basically the same for both program,that is, electrons and gammas were fully traced until their energies were lower than 2TeV and then a cascade function was used to analytically calculate the shower size.

The primary energy spectrum used in the simulation is in agreement with[3], which is heavier-nuclei dominant in the high energy region ($> 10^{16}$eV). The bending energy for proton was chosen to be 200TeV, and for other nuclei it was determined by the rigidity cutoff model.

The conventional EC experiment method was used to treat the family events. Since the thickness of the chamber is only 14 c.u., only the electromagnetic component in a shower was considered in a family. The criteria for a family event was defined as :$E_\gamma \geq 4TeV$; $n_\gamma \geq 4$. The total number of generated events, the selected family events and proton induced family events with different models are listed in Table1.

Table 1: The result of simulation with different models

model	COSMOS	Chou-Yang	SIBYLL	QGSJET
No. of events generated	30,000	20,000	100,000	100,000
No. of family events	871	444	2641	1420
No. of proton family events	460	310	1600	950

3 The structure of artificial neural network

A three layered feed forward artificial neural network(ANN) was used as a classifier of proton induced showers. This network contains 9 parameters as input neurons, 10 hidden nodes and 1 output unit. the 9 parameters which characterize the selected family events were chosen as following:

- Shower size N_e and age s , these two parameters are related to the primary energy.
- Total energy of the family $\sum E_i$ (where E_i is the visible energy of each shower) and total number of showers N_γ in a family.
- Mean lateral spread of a family: $< R >= \sum E_i r_i / \sum E_i$, where r_i is the distance of the i'th shower from the energy-weighted center of family.
- Zenith angle θ. For the same event the larger zenith angle is, the larger is the lateral spread.
- Number of clusters in a family N_c , which relates with the multiplicity of the events and reflect the characteristics of interaction.
- The ratios N_5/N_γ and N_{10}/N_γ, where N_5 and N_{10} are the number of showers within 5mm and 10mm from the center of a family.

The data generated with each interaction model were divided into two parts: the training set used to training the network and the test set used test the network's capability of identifying the proton induced showers. The number of events used in the training and test set for each model are listed in Table 2.

Table 2: The number of event in test and train dataset

model	COSMOS	Chou-Yang	SIBYLL	QGSJET
No. of events in training set	571	/	1320	708
No. of events in test set	300	444	1320	708

The back-propagation learning rule was used to train the network. During the training, the weights in the network were initialized at uniformly random in the range (-0.1,0.1), and the learning strength parameter η and the momentum factor α were taken to be 0.01 and 0.5 respectively. The expected output value of the network for protons was set to 0 and for other nuclei to 1.

4 Results and discussion

Fig.1 (a) shows the fraction of correct classifications of proton and other nuclei for test dataset generated with SIBYLL model as function of the output of the network trained by SIBYLL training dataset, fig.1(b) is same as (a), but the model is QGSJET. In the following analysis, we set a cut for the network output to 0.5, it means that the event is considered as proton event if the network output is less than 0.5. For the test data

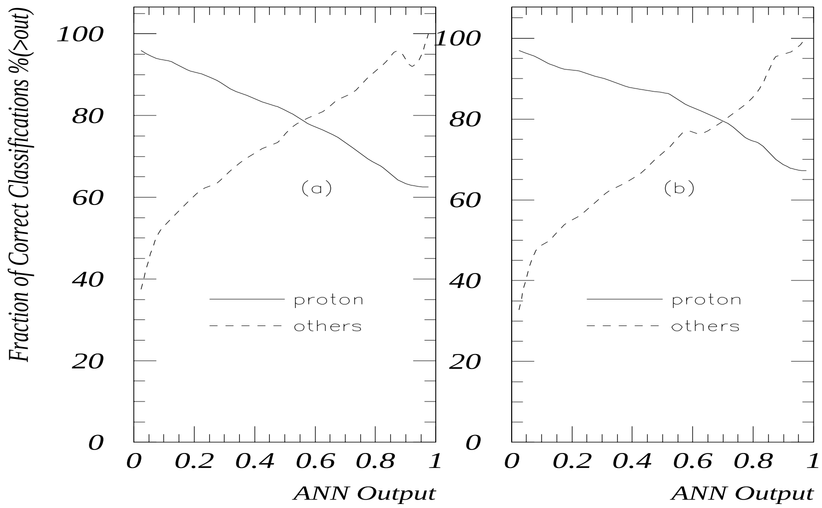

Figure 1: Test result of the network after training with SIBYLL(a) and QGSJET(b) model dataset.

set of SIBYLL model, the fraction of correctly classifications for proton is 82% and 88% of all proton events are correctly selected from the test data set. For the test dataset of QGSJET model , the fraction of correctly classifications for proton is 87%, and 87% of all proton events are correctly selected.

In older to check whether the network is interaction model dependent, the network trained by SIBYLL model training dataset is tested with the test dataset of other models respectively . The test results of fraction of correctly classifications for proton events are shown in fig. 2. The fraction of correctly classifications for

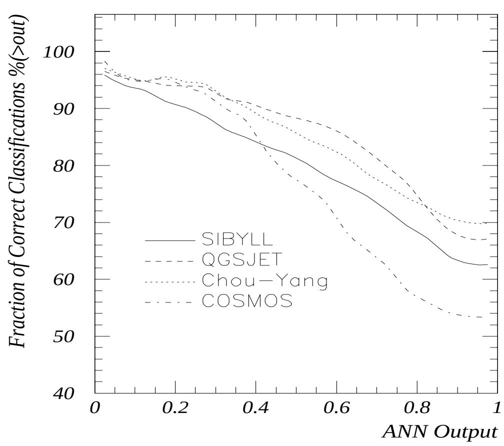

Figure 2: The fraction of correctly classifications for proton events by use of ANN trained by training dataset of SIBYLL model with different test dataset.

proton and all proton events correctly selected are listed in table 3. From the test results in table 3, we can find that the ability of correctly classifications for proton of ANN trained by SIBYLL training dataset has a little difference for data generated with others models, but the proton event of different kind model all can be effectively identified. So, we can expect to identify the primary proton events from Tibet hybrid experiment and get the primary proton energy spectrum at the “knee” region.

Table 3: The fraction of correctly classifications for proton and all proton events correctly selected with ANN trained by SIBYLL training dataset

model	SIBYLL	COSMOS	Chou-Yang	QGSJET
Fraction of correctly classifications for proton (%)	82	79	87	89
Fraction of all proton events correctly selected (%)	88	81	88	85

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