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Selection of the primary cosmic ray light-component by muon detection at high altitude.

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The detection of muons in EAS can be exploited to perform a cosmic ray composition study. In this paper we discuss the capability of a full coverage array (as the ARGO-YBJ experiment in Tibet at 4300 m a.s.l.) operated with a very large (about 2500 m^2) muon detector to select the primary cosmic ray light components in the energy region around the knee.

1. Introduction

One of the most important questions to be solved in order to understand the origin of the knee in the cosmic ray spectrum is the position of the proton knee, which provides the major constraints to the model parameters. Data from different experiments conflict. In fact, the proton spectrum measured by the TIBET AS-γ experiment [1] shows a knee-like structure around 200 TeV, the KASCADE data [2] suggests a steepening at $\sim$ 2 PeV while the CASA-MIA analysis [3] shows evidence of a steepening of the lighter components at ~ 500 TeV. Direct measurements carried out by RUNJOB [4] and JACEE [5] do not exhibit any spectral break up to the highest energy measured (~ 800 TeV). A careful measurement of the proton spectrum in the energy region from a few TeV, where a calibration with direct measurements can be made, up to tens of PeV is one of the main tasks of ground-based cosmic ray experiments.

An experiment which can meet this requirement is ARGO-YBJ, located at the YangBaJing High Altitude Cosmic Rays Laboratory (Tibet, P.R. China, 4300 m a.s.l.) [6]. It offers a unique opportunity because of its ability to operate down to a few TeV, by measuring small size air showers (digital read-out) [7], and up to the PeV region by measuring the charge released on the detector (analog read-out) [8]. In this paper we present a preliminary study of the capability of the ARGO-YBJ experiment to select a high purity beam of light primaries (proton+helium) by upgrading the array with a large area muon detector.

2. Selection of the primary cosmic ray light component

A $\sim$ 2500 m^2 muon detector consisting of 4 detectors each 24 $\times$ 26 m^2 large, distributed on the four sides outside the main building [9], has been envisaged to detect EAS muons in order to perform a cosmic ray primary composition study. This detector will be constituted by at least 4 tracking planes made with streamer tubes shielded by $\sim$ 1.5 - 2 m of concrete in order to absorb particles with energy lower than $\approx$ 1 GeV, which could be reconstructed as punch-through tracks. A layer of RPCs placed at the top will image the electromagnetic component of the showers.

By using the CORSIKA/QGSJet code [10], we have simulated a large number of showers induced by H, He, O, Mg-Si, Fe nuclei and looked for the most important discriminating EAS observables. The calculations refer to fixed energies in the range 10 TeV $\div$ 10 PeV and to quasi-vertical ($\theta < 15°$) showers with their core inside the ARGO-YBJ carpet. The method used to select the light component is based on two steps.

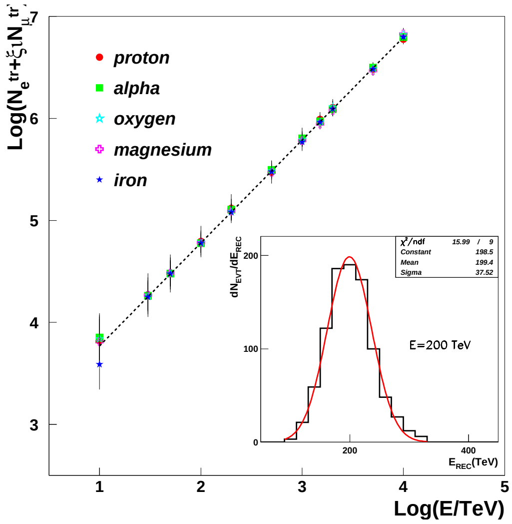

Figure 1. Energy measurement; the error bars represent the size spread. Small frame: distribution of the reconstructed energies at 200 TeV.

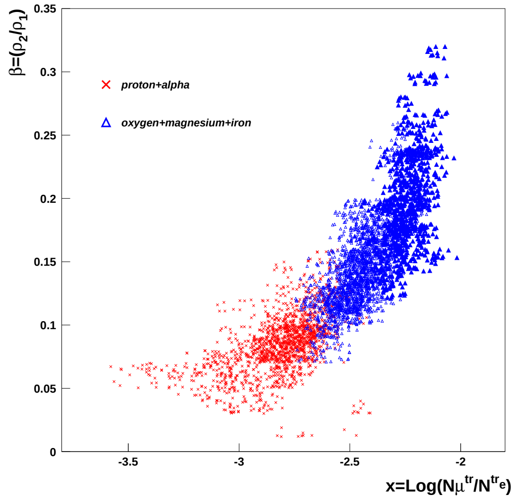

Figure 2. Sample of 200 TeV events composed by an equal mixture of H, He, O, Mg-Si, Fe nuclei in the x-β plane.

2.1 Energy measurement

By measuring the charged particle size N_{ch}^{tr} sampled by the detector and the muon number N_{μ}^{tr}, it is possible to calculate the primary energy. In fact the quantity $Log(N_{ch}^{tr} + \xi N_{\mu}^{tr})$, where ξ is a parameter depending on the experimental set-up, in the range investigated is linear with respect to the energy logarithm [11] as shown in Fig.1. Such a linearity provides an energy measurement of the primary particles event by event, independent of its mass. We observe that: 1) the systematic error on the mean value of the reconstructed energy is less than a few per cent; 2) the energy resolution improves with energy and with mass from $\sim 30\%$ at 30 TeV to $\sim 14\%$ at 1 PeV. As an example, in the small frame of Fig.1 we give the distribution of reconstructed energies at 200 TeV for a sample of showers composed by an equal mixture of H, He, O, Mg-Si, Fe nuclei.

2.2 Selection criteria

Iron showers develop higher in the atmosphere so that they are expected to have a slightly broader lateral distribution on the ground compared to proton showers with the same energy. This feature provides some discriminatory power between showers originating from different primaries but with the same ground-level size. As a consequence, in order to distinguish between different primaries the showers can be classified in terms of the two following parameters: (1) $\beta = \rho_2/\rho_1$, i.e., the ratio of charged particle mean densities at two different distances ($25 \div 35$ m and $0 \div 10$ m, respectively) from the reconstructed core position; (2) $x = Log(N_{\mu}^{tr}/N_{ch}^{tr})$.

The distribution for 200 TeV events in the space parameter x-β is shown in Fig.2. The light and heavy primaries are clustered with a separation that increases with the primary energy.

The following procedure to select the light component has been tested: (i) for each reconstructed shower the primary energy E_{rec} is calculated by means of the formula $Log(E_{rec}) \propto Log(N_{ch}^{tr} + \xi N_{\mu}^{tr})$; (ii) the measured

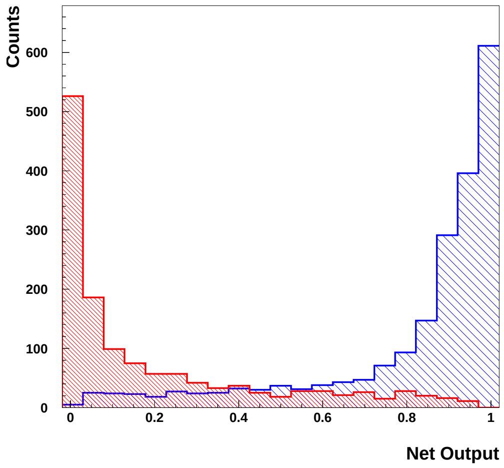

Figure 3. Light-Heavy components discrimination. Output of the neural network for simulated spectra.

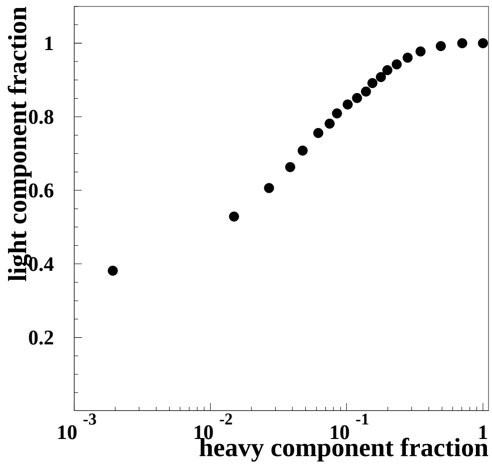

Figure 4. The fraction of the reconstructed light component as a function of the contamination from the heavy component.

quantities x and β are used in order to classify the shower by comparing their value with the distributions in the space parameter x-β expected at the energy E_{rec}.

This can be performed by using an Artificial Neural Network (ANN). In this preliminary study we simulated a sample of quasi-vertical ($\theta < 15°$) showers with an equal mixture of H, He, O, Mg-Si, Fe nuclei and energy spectra in the range 10 TeV - 10 PeV. The showers cores has been uniformly sampled inside the detector area.

An example of the output of the ANN algorithm is shown in Fig.3 for events induced by 100 TeV primaries. The output vector is defined in a 1-dim space: it is trained to be 0 for the light component and 1 for heavier showers. In Fig.4 the fraction of the reconstructed light component is shown as a function of the contamination from the heavy component.

3. Conclusions

The shower density profile around the core and its muon content can be used very efficiently to determine the energy and the mass of individual primary cosmic rays. Simulations for the ARGO-YBJ detector show the possibility of selecting with high efficiency the light components in the energy range 10 TeV $\div$ 10 PeV. The preliminary results obtained by means of an ANN procedure are very promising. Studies are in progress to investigate the capability of other discrimination parameters.

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