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SELECTION OF THE PRIMARY COSMIC RAY LIGHT COMPONENT WITH ARGO-YBJ

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The ARGO-YBJ experiment, currently under construction at the YangBaJing High Altitude Cosmic Ray Laboratory (Tibet, P.R. China, 4300 m a.s.l.), may be upgraded with a large muon detector ($\sim$ 2500 m^2) both to extend the sensitivity to γ-ray sources to energies ≥ 20 TeV and to perform a cosmic ray primary composition study. In this paper we discuss the capability of the upgraded ARGO-YBJ detector to select the primary cosmic ray light component in the knee energy region.

Keywords: cosmic rays; gamma rays; light component

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 conflicts. 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 component at $\sim$ 500 TeV. Direct measurements carried out by RUNJOB[4] and JACEE[5] do not exhibit any spectral break up to the highest energy measured ($\sim$ 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 cosmic ray experiments.

An experiment which can meet this requirement is ARGO-YBJ, presently under construction 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 the capability of the ARGO-YBJ experiment to select a high purity beam of light primaries (proton+helium) by equipping the array with a large area muon detector.

2. Selection of the primary cosmic ray light component

A ~ 2500 m^2 muon detector located around ARGO-YBJ central carpet[9] has been envisaged to detect EAS muons with energy $E_\mu \geq 1$ GeV in order to perform a cosmic ray primary composition study. Considering this upgraded apparatus we have simulated, using the CORSIKA/QGSJet code,[10] a large number of showers induced by H, He, O, Mg, 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 the two following steps.

2.1. *Energy calibration*

By measuring the charged particle size $N_{\rm ch}^{\rm tr}$ sampled by the detector and the muon number $N_\mu^{\rm tr}$, it is possible to calculate the primary energy. In fact the quantity $\mathrm{Log}(N_{\rm ch}^{\rm tr} + \xi N_\mu^{\rm tr})$, where ξ is a parameter depending on the experimental set-up, is linear with respect to the energy logarithm, in the range investigated as shown in Fig. 1. Such a linearity provides

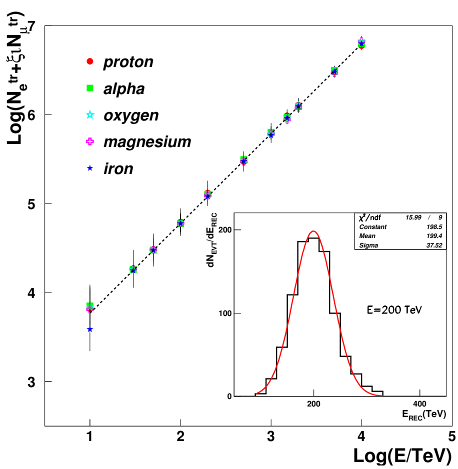

Fig. 1. Energy calibration; the error bars represent the size spread. Small frame: distribution of the reconstructed energies at 200 TeV.

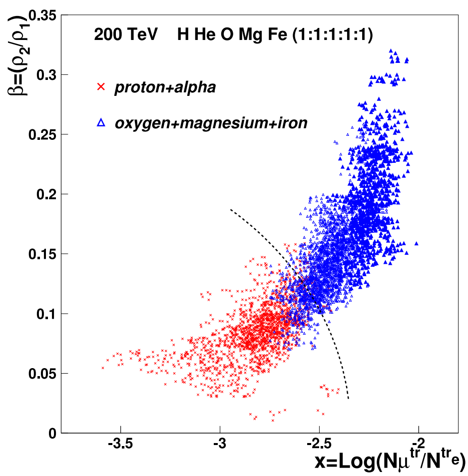

Fig. 2. 200 TeV event distribution in the $x-\beta$ plane. A cut that selects 10% of the heavy nuclei is shown.

an energy calibration 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, 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) $x = \mathrm{Log}(N_\mu^{\mathrm{tr}}/N_{\mathrm{ch}}^{\mathrm{tr}})$.

The distribution for 200 TeV events in the x-β parameter space is shown in Fig. 2. The different primaries are clustered with a separation that increases with the primary energy. By allowing for a small contamination from heavy particles it is possible to calculate a discrimination parameter, function of the energy, such that the light primary selection is carried out with high efficiency (see dashed curve). The following procedure has been tested:

(i) for each reconstructed shower the primary energy E_{rec} is calculated by means of the formula $\mathrm{Log}(E_{\mathrm{rec}}) \propto \mathrm{Log}(N_{\mathrm{ch}}^{\mathrm{tr}} + \xi N_\mu^{\mathrm{tr}})$;

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

By requiring a contamination $\leq 10\%$, the light component discrimination efficiency is $\geq 95\%$ for the energies investigated.

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 suggest the possibility of selecting with high efficiency the light component in the energy range 10 TeV $\div$ 10 PeV. An improvement of the classification algorithm with a neural network is a future task.

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