Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 4 (HE part 1), pages 127–130

`ID 802`

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07
Mérida, México

Cosmic Ray Observation at Mount Chacaltaya for beyond the Knee Region

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Abstract: We have installed a new air shower array at Mount Chacaltaya (5,200m above sea level) to observe primary cosmic rays with energies greater than $10^1$5 eV. In our previous experiments, we measured nuclear composition of primary cosmic rays in the knee region, and showed that the average mass of cosmic ray nuclei increases with energies below and above the knee, and dominated by heavier nuclei as iron at $10^1$6 eV. This result is consistent with the confinement and rigidity dependent acceleration models, and suggests that the cosmic ray origins are supernova remnants of massive population as Wolf-Rayet stars. It is of quite interest whether the mass of cosmic ray nuclei continues to increase with energies, or decreases by contributions of lighter components expected from the extra-galactic cosmic ray models. The new air shower array has been constructed in order to measure cosmic ray composition above the knee, and the detection area is larger by a factor of 100 compared to the our previous array. In this paper, we describe the characteristics of the new array.

Introduction

The *knee* region in the energy spectrum of primary cosmic rays around 10^{15} eV is the key to clarifying the source of cosmic rays, since it is reflected by mechanisms of acceleration at the sources and propagation in the Galaxy. Although the origin of cosmic rays is still unknown, recent TeV gamma-ray observations as [1] suggest that the high energy gamma-rays are decay products of neutral pions π^0 created by interactions of cosmic rays and surrounding media, and thus cosmic rays are accelerated in SNRs up to $\sim 10^{15}$ eV. The nuclear composition of primary cosmic rays is also quite important to resolve the cosmic ray origin, because it is strongly affected by the source abundance and acceleration mechanisms. It is predicted that if cosmic rays are confined in SNRs and accelerated at strong shocks through the Fermi process, cosmic rays are enriched by heavy nuclei (as irons) as the primary energies increase. On the other hand, it is believed that cosmic rays of more higher energies (say $\sim 10^{19}$) are extra-galactic origin, and they are dominated by lighter components because of spallation processes during the propagation in the intergalactic space. This suggests that there could be a

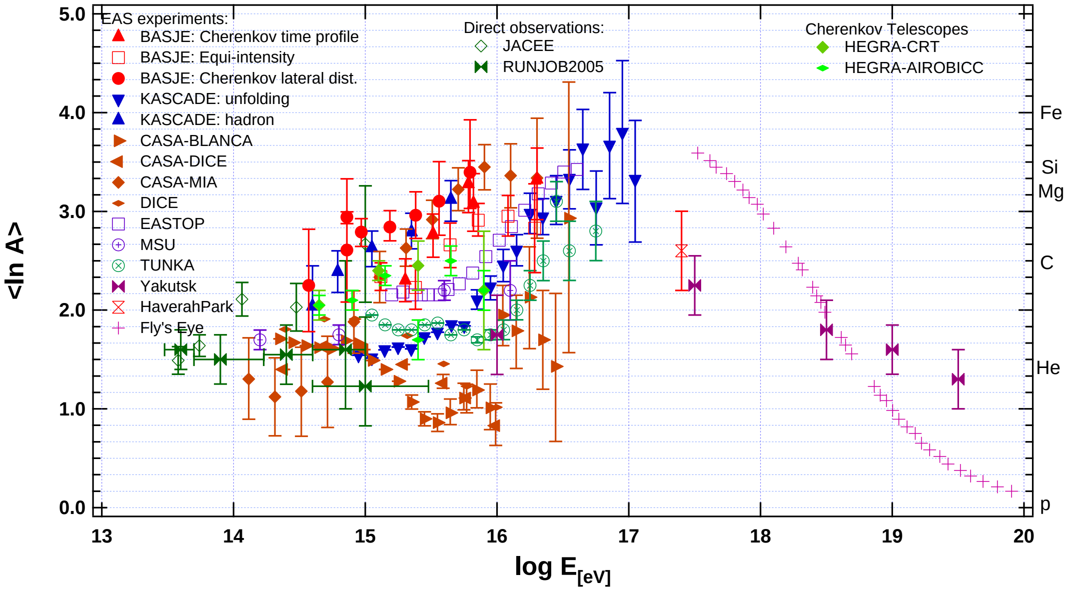

Figure 1: Mean logarithmic mass of primary cosmic rays

”transition” of cosmic rays of Galactic and extragalactic origin at a certain energy region, and it is observed as a change of cosmic ray composition as function of energies. It is challenging to find such transition.

In the BASJE (Bolivian Air Shower Joint Experiment) group, we have reported measurements of cosmic ray composition around the knee by using three independent observation techniques, those are measurements of arrival time distribution of Cherenkov light associated with air showers [2],lateral distribution of Cherenkov lights [3], and the longitudinal development curves obtained from equi-intensity cuts using shower size spectra for various arrival directions [4]. These results are in agreement and show that the mean (logarithmic) mass of primary cosmic rays increases as the energy increases around the knee region, and it is dominated by the heavy component as iron 1. It is consistent with the predictions, the cosmic ray origins are supernova remnants of massive population as Wolf-Rayet stars.

The New Air Shower Array

The new array is comprised of 68 scintillation detectors installed in an area of $700\mathrm{m} \times 500\mathrm{m}$ with separations of 75 m. The effective area of the array is larger by a factor of 100 compared to our previous array [5, 6]. Each detector is comprised of plastic scintillator plates and a photo multiplier tube (PMT), and measures local densities and arrival times of shower particles. In the inner region of the array, twelve $4\mathrm{m}^2$ detectors are installed, whereas the other detectors have smaller scintillators of $1\mathrm{m}^2$ or $0.87\mathrm{m}^2$. The twelve $4\mathrm{m}^2$ detectors are used as the triggering detectors. The signals from the detectors are sent to a control room in the laboratory via coaxial cables, digitised with electronics modules (as CAMAC TDCs etc.), and stored in PC by the data acquisition (DAQ) system.

We have carried out air shower simulations to evaluate the performance of the array. The air shower generator employed here is based upon the code developed by Shirasaki and Kakimoto [7], in which the VENUS hadronic interaction model is used (the longitudinal development of air showers generated with this code is quite similar to those obtained using the CORSIKA-QGSJET code).

First, we calculate the aperture of the array in a given triggering criterion. We employ a coincidence of neighbouring 4 detectors (the "square" hit pattern) among the inner twelve $4\mathrm{m}^2$ detectors within a time window of $4\,\mu\mathrm{s}$. Here we examine two triggering criteria, namely the square coincidence of the 4 detectors at the center of the array, and any of the square coincidences (5 patterns). The incident angles of the simulated showers are chosen uniformly up to the zenith angle of 45°, and the core locations are also uniformly distributed within a circle of $200\mathrm{m}$ radius centered at the center of the triggering detectors. From the ratio of the triggered showers to the simulated showers for each triggering criterion, the aperture of the array is calculated as a function of the primary energy (Figure 3, left panel). It can be seen that the detection efficiency is 100% for cosmic rays with energies above $10^{15.5}\,\mathrm{eV}$ within the circle. Moreover, we calculate expected distribution of cosmic ray energies to be observed using the aperture of the array and an assumed cosmic ray energy spectrum [4] (Figure 3, right panel). The peak is found at $10^{14.2}\,\mathrm{eV}$. From this distribution, the number of events with energies greater than $10^{17}\,\mathrm{eV}$ to be observed in one-year exposure is estimated as ~ 100. We also evaluated the accuracies in determination of shower arrival directions and shower sizes by comparing the simulated showers with the reconstructed events. The angular resolution of the array is $\sim 0.8^\circ$, and the error in the determination of logarithms of the shower sizes is ~ 0.1.

The construction of the detectors and the development of the DAQ system were completed in 2006, and we have started observation runs in Spring 2007. The expected trigger rate is about 2 Hz, and the real trigger rate is the same level in the observations. We will report preliminary results from the first observation in the conference.

Acknowledgements

The authors would like to thank the staff of Instituto de Investigaciones Físicas , Universidad Mayor de San Andrés, La Paz, Bolivia, for their support to our experiment at Mount Chacaltaya. We also acknowledge Institute for Cosmic Ray Research, University of Tokyo, for helpful support.

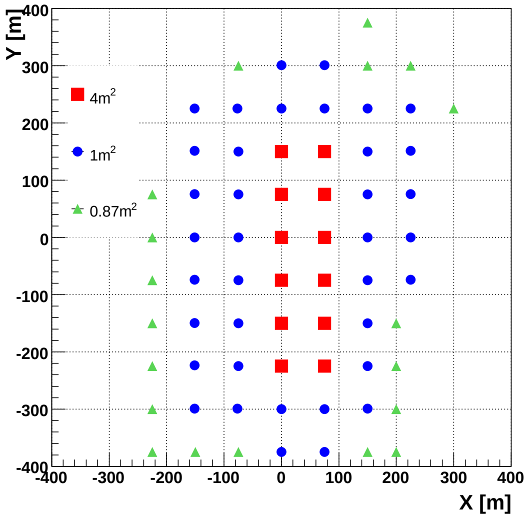

Figure 2: Mean logarithmic mass of primary cosmic rays: Our results are showed by red triangle (Checenkov time profile), open square (equi-intensity cuts), and closed circle (Cherenkov lateral distribution).

This work is supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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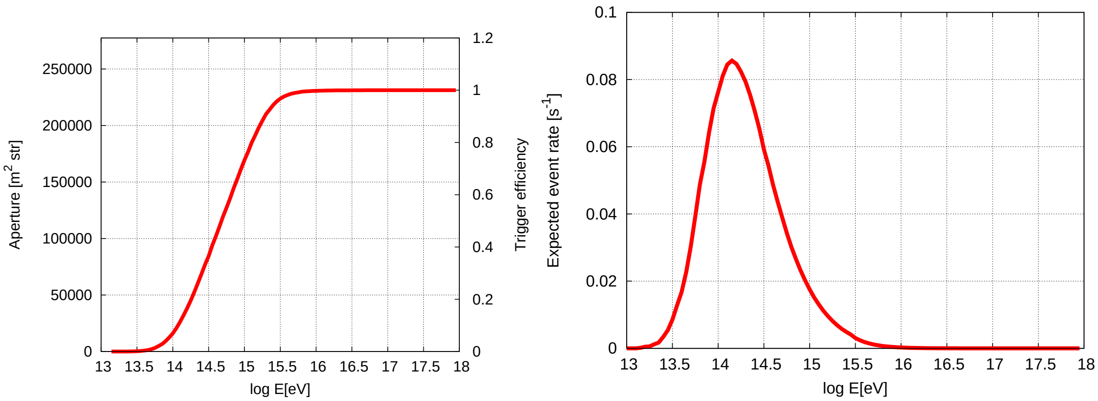

Figure 3: Aperture of the array (left), and distribution of energies of cosmic rays expected to be observed assuming the cosmic ray spectrum [4] (right).