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A New Air Shower Array at Mount Chacaltaya

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BASJE group observed air showers with primary energies below 10^{16} eV at Mount Chacaltaya in Bolivia. As the results, we obtained the energy spectrum, the chemical composition and the anisotropy in the arrival direction distribution of primary cosmic rays around the knee region. For the next step we are constructing a new air shower array to observe air showers with primary energies above 10^{16} eV. Since this array is located at 5,200 m a.s.l., we can observe maximum development points for detectable air showers with the array, and then we can measure the primary chemical composition accurately with the equi-intensity method. In this paper, we present the performance of this array and the status of the construction.

1. Introduction

In cosmic ray studies, the *knee* in the energy spectrum is of special interest. This is thought that the knee is related to changes in the mechanisms of the particle accelerations and propagation in the Galaxy, and thus there may exist changes in the chemical composition or the anisotropy of cosmic rays around the knee. Above all, observational determination of the chemical composition below and above the knee is highly important to clarify the cosmic ray origin. The BASJE (Bolivia Air Shower Joint Experiment) group has carried out air shower observation at Mount Chacaltaya ($5,200$ m a.s.l., $550\,\mathrm{g\,cm^{-2}}$ atmospheric depth). Since the observatory is located at high altitude, it is possible to detect air showers generated by cosmic rays at the knee energy region around their maximum developments. The recent results of the BASJE observations have been reported elsewhere (e.g. [1, 2, 3]). In particular, we have measured the chemical composition of cosmic rays around the knee with three independent methods, i.e. by using the information on the arrival time distributions of air Cherenkov photons associated with air showers, the lateral distributions of Cherenkov photons, and the equi-intensity curves of the shower developments. The results from these measurements are in good agreement with each other and show that the heavy component as iron is dominant at and just above the knee. This is consistent with the models that cosmic rays are generated and accelerated at the shocks of supernova explosions initiated by massive progenitors as Wolf-Rayet stars.

From these investigations, we are constructing a new air shower array at Mount Chacaltaya to observe cosmic

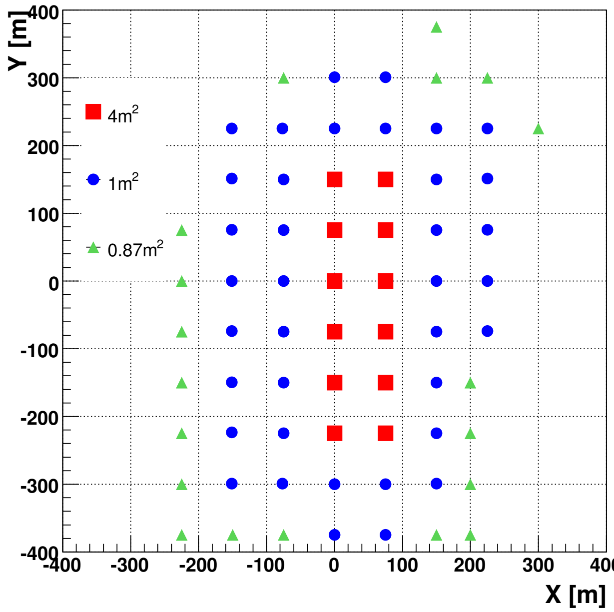

Figure 1. BASJE new array

rays with primary energies of well beyond the knee. In this energy region ($10^{16} \sim 10^{17}$ eV), less observational data are available so far, and thus no convincing evidences have been obtained whether the heavy components are still dominant in this region, or there may exist a transition to a lighter composition as a manifestation of extragalactic cosmic rays. In this paper, we describe the characteristics of the new array and plans of the experiment. We have performed simulation studies with a Monte-Carlo technique to generate and to reconstruct the air showers with the array. By optimizing the triggering criterion, we evaluate the expected distribution of detectable shower energies, and the expected number of cosmic ray events in a given observation time. We also discuss the accuracies in determination of arrival directions and shower sizes hence the primary energies.

2. BASJE New Array

The observation site is located at $5,200$ m a.s.l. at Mount Chacaltaya, and is the highest altitude cosmic ray observatory in the world. We had operated a small air shower array at this observatory [4], and measured the cosmic ray energy spectrum [2], anisotropy in the arrival direction distributions [5], and the chemical compositions [1, 2, 3] in the energy range of $10^{13} \sim 10^{16}$ eV. This array was comprised of 68 scintillation detectors arranged in an area of 60×60m. The new air shower array in this project is constructed by extending the detector separations to 75m over a wider field of 700m $\times$ 500m area to observe air showers at higher energies (Figure 1).

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, digitized with electronics modules (as CAMAC TDCs etc.), and stored in PC by the data acquisition (DAQ) system. In our air shower analysis, a shower size is calculated from the lateral distribution of the shower particles, and an arrival direction is determined from the fast-timing data.

3. Array Performance

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 [6], in which the VENUS hadronic interaction model is used.

First, we calculate the *aperture* of the array in a given triggering criterion. We employ a coincidence of neighboring 4 detectors (the "square" hit pattern) among the inner twelve $4\mathrm{m}^2$ detectors within a time window of $4\,\mu$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 200m 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 2, left panel). It can be seen that the detection efficiency is 100% for cosmic rays with energies above $10^{15.5}$ 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 [2] (Figure 2, right panel). The peak is found at $10^{14.2}$ eV. From this distribution, the number of events with energies greater than 10^{17} eV to be observed in one-year exposure is estimated as ~ 100.

Next we evaluate the accuracies in determination of shower arrival directions and shower sizes by comparing the simulated showers with the reconstructed events. The Figure 3 shows the distributions of the opening angles and the shower size errors for 10000 showers of a fixed energy of 10^{16} eV. From these distributions, the angular resolution of the array is evaluated as $\sim 0.6°$, and the error in the determination of logarithms of the shower sizes is ~ 0.1.

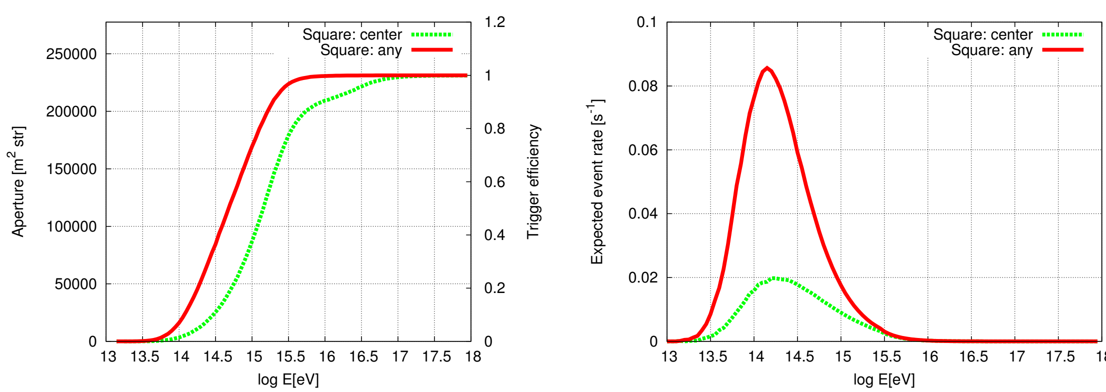

Figure 2. Aperture of the array (left), and the expected distribution of the cosmic ray energies to be observed (right)

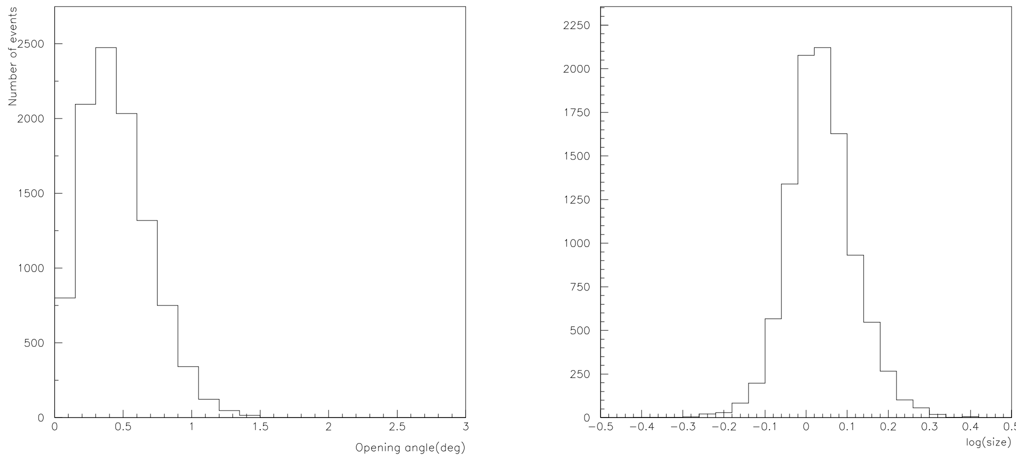

Figure 3. Distribution of the shower parameter determination errors obtained by comparing the simulated showers at 10^{16} eV with the reconstructed events. Left: the opening angles between the arrival directions, Right: the differences in the logarithms of the shower sizes.

4. Conclusions

The BASJE new air shower array, which is designed to observe cosmic rays with energies well beyond the knee ($10^{16} \sim 10^{17}$ eV), is now under construction. The triggering efficiency is 100% for cosmic rays with energies above $10^{15.5}$ eV. The accuracies in determination of the arrival directions and logarithm of shower sizes are evaluated as $0.6°$ and 0.1, respectively, which are sufficient to measure the energy spectrum and the chemical composition of cosmic rays in the energy range of $10^{16} \sim 10^{17}$ eV. The array construction will be completed within 2005, and we plan to start science runs early in 2006.

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