IL NUOVO CIMENTO Vol. 24 C, N. 4-5 Luglio-Ottobre 2001

# Present experiment of BASJE group at Mt. Chacaltaya(*)

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(ricevuto il 23 Ottobre 2000; approvato il 12 Febbraio 2001)

**Summary.** — A compact air shower array to observe primary cosmic rays above a few TeV has been installed at Mt. Chacaltaya in Bolivia since 1996. This array is available to observe the air showers above 6 TeV and the longitudinal development curves above 50 TeV. The purpose of the observations is to study the chemical composition and the energy spectrum of cosmic rays in the energy region including the "knee" of the energy spectrum. First, the consistency between direct measurements (balloon-borne experiments) and air shower observations in the energy region from 50 TeV to 80 TeV is examined and confirmed. Next, the chemical composition and the energy spectrum are derived from the air shower observations. In the study, the longitudinal developments of shower particles are calculated by Monte Carlo simulations, assuming different chemical compositions above 80 TeV. The characteristics of the present air shower array and the comparison of the preliminary observed results with that of the simulations are presented.

PACS 96.40.De – Composition, energy spectra, and interactions.
PACS 96.40.Pq – Extensive air showers.
PACS 01.30.Cc – Conference proceedings.

(*) Paper presented at the Chacaltaya Meeting on Cosmic Ray Physics, La Paz, Bolivia, July 23-27, 2000.

 

## 1. – Introduction

The chemical composition and the energy spectrum of primary cosmic rays are observed by many groups with direct measurements (10 TeV–400 TeV)( balloon-borne experiments) [1-3] and indirect ones (50 TeV–50 PeV) (air shower observations) [4-6]. However, their results are not confirmed yet above 80 TeV. Therefore, we installed a compact air shower array for the following purposes.

1) Consistency between direct and indirect measurements in the range from 50 TeV to 100 TeV.

2) The chemical composition and the energy spectrum of primary cosmic rays around the "knee".

3) Anisotropy in the arrival direction of primary cosmic rays around the "knee", including diffuse and point sources of primary gamma-rays.

The chemical composition and the energy spectrum of primary cosmic rays in the range from 10 TeV to 80 TeV have been observed with enough statistics by balloon-borne experiments [1-3]. However, as the statistics are not sufficient in the direct measurements in energy region above 80 TeV, the observations of air showers at high mountain sites are necessary. Then, in order to confirm the consistency in the direct and indirect measurements, the observed longitudinal development curves in the range from 50 TeV to 80 TeV are compared with the ones obtained with air shower simulations using the chemical composition obtained by the direct measurement. By confirming the consistency, the chemical composition and the energy spectrum of primary cosmic rays around the "knee" are obtained. Speaking of observation site, Mt. Chacaltaya (5200 m a.s.l.; 550 g/cm$^2$) is the best place to look for the deviations on the estimation of primary energies and arrival directions of observed air showers below 100 PeV, because the fluctuations of total number of shower particles (shower size, $N$) are smaller, being close to the shower maximum [7]. So, we had set up a compact air shower array (MAS Array) for observations of smaller air showers observable above a few TeV at Mt. Chacaltaya for confirming the consistency between the direct and indirect measurements.

The characteristics of MAS array and preliminary results are presented in the following sections.

Another method to study the chemical composition with air shower observations above 1 PeV is the measurement of Cherenkov photons produced at early stages of the air shower developments. Chacaltaya laboratory is situated at the highest location in the world. The observation of Cherenkov photons may offer good information to study the chemical compositions of primary cosmic rays. Since 1995, the arrival time structure of the Cherenkov photons was measured [8], and the measurements of the lateral distribution of Cherenkov photon intensity will be started in 2000. The apparatus and present results are reported in another paper [9].

In SAS array [10], the anisotropy has been studied since 1987. The results on anisotropy are also reported in another paper [11].

## 2. – Characteristics of MAS array

A compact air shower array has been installed in subsequent steps as follows:

– 1987; SAS array [10] was constructed with 16 scintillation detectors (1 m$^2$) and 17 ones (0.83 m$^2$), consisting of 33 density and 25 fast-timing channels for air shower

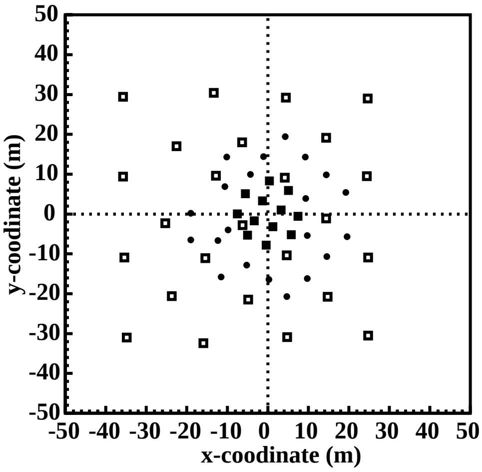


Fig. 1. – MAS array for observations of observable minimum air showers above a few TeV.

observations above 100 TeV as shown with open square marks in fig. 1.

– 1988; LMC array [12] was constructed with 13 L-detectors (4 $m^2$) equipped with density and fast-timing channels and 28 S-detectors (1 $m^2$) with density channels, on a mountain slope of about 30° facing southward, for gamma-ray observations from SN1987A, at a distance of about 400 m from SAS array.

– 1996; MAS array was installed with 12 L-detectors (4 $m^2$) (shown with solid square marks in fig. 1) in SAS array for the air shower observations above 10 TeV; other 21 S-detectors (1 $m^2$) (shown with solid circle marks in fig. 1) with density and fast-timing channels for improvement on the core locations of showers were added in 1998. The present MAS array is shown in fig. 1.

Characteristics of MAS array are as follows:

1) The triggerings of air shower are made by 4-fold coincidence of the central 4 L-detectors each with threshold level above 1 particle per detector.

2) The threshold energy observing inside 12 L-detectors' region are calculated for the zenith angle range from 0° to 45° by Monte Carlo simulations. The threshold energies for proton showers are 6 TeV and 18 TeV with zenith angle 0° and 45°, and for iron showers are 15 TeV and 50 TeV, respectively.

3) The primary energies are estimated with total number of shower particles (shower size, $N$). The accuracy of the energy estimation is about 40% at energy 6 TeV for proton showers and about 20% at energy 15 TeV for iron showers.

## 3. – Analysis and results

The chemical composition of primary cosmic rays at 300 TeV and 2 PeV has been studied by comparing the longitudinal development curves observed by LMC array with simulated curves by using the method of equi-intensity cuts [13, 14].

The chemical components are assumed that all are protons in model 1 and that all are irons in model 2. For model 3, the components are assumed with JACEE results below

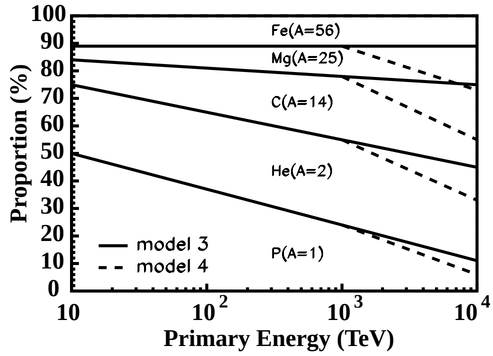


Fig. 2. – The proportions of chemical components to primary cosmic ray energy used in each model on Monte Carlo simulations.

80 TeV, and are the extrapolated ones above 80 TeV, as shown with solid lines in fig. 2. For model 4, the components are assumed with same ones in model 3 below 1 PeV, and are heavier above 1 PeV, as shown with dotted lines in fig. 2. The primary energy spectrum is assumed the power law with index 2.6 below and 3.0 above 3 PeV. After sampling the primary energy used with this energy spectrum, the chemical component is sampled by using the uniform distribution with the proportion corresponding to the sampled

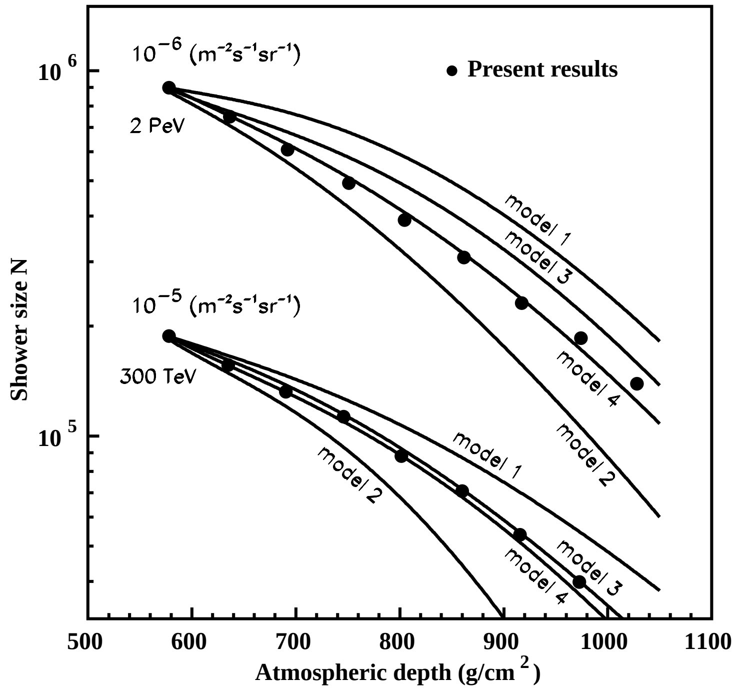


Fig. 3. – The comparison of observed longitudinal development curves with ones simulated with each model.

energy as shown in fig. 2. The comparison of the observed longitudinal development curves with ones simulated with each model is shown in fig. 3. The lower and upper curves correspond to the longitudinal development ones with energy of about 300 TeV and 2 PeV, respectively. Consistency between the observed and simulated longitudinal development curves is quite good for model 4.

Hereafter, we can study the chemical composition by comparing the longitudinal development curves observed by MAS array above 50 TeV with ones simulated by using of the chemical composition in JACEE results and assuming the different chemical compositions above 80 TeV.

The preliminary result on the primary energy spectrum of cosmic rays above 30 TeV has been reported in Rome conference [5]. The energy spectrum of cosmic rays above 10 TeV by the present air shower observations will be presented in a near future.

## 4. – Conclusions

The preliminary longitudinal development curves observed by the LMC array agree well with those simulated by using the extrapolated chemical composition of JACEE results around 300 TeV and a heavier composition around 2 PeV.

In order to confirm again the agreement below 80 TeV, the MAS array has been installed to observe primary cosmic rays above a few TeV. MAS array is useful to observe the air showers above 6 TeV and the longitudinal development curves above 50 TeV.

First, the consistency between direct measurements and air shower observations in the energy region from 50 TeV to 80 TeV is examined and confirmed by the MAS array. Next, the chemical composition and the energy spectrum is derived from the air shower observations.

The energy spectrum of cosmic rays in the energy region from 10 TeV to 100 PeV by air shower observations will be presented in a near future.

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We thank the staffs of Institute de Investigaciones Fisicas, Universidad Mayor de San Andres, La Paz, Bolivia, for their helpful supports to our experiment. We also thank the staffs of Institute for Cosmic Ray Research, University of Tokyo for their supports and Dr. K. Kasahara, Faculty of Systems Engineering, Shibaura Institute of Technology, for advice in Monte Carlo simulation. This work is supported in part by a Grant-in-aid for Scientific Research from the Ministry of Education, Science and Culture, Japan.

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