INTENSITIES OF HIGH-ENERGY COSMIC RAYS AT MT. KANBALA

China-Japan Emulsion Chamber Collaboration

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Abstract

The energy spectra of atmospheric cosmic rays at Mt. Kanbala (520 g/cm^2) are measured with emulsion chambers. The power indeces of the spectra are values of about 2.0 for both gamma-rays and hadrons. Those fluxes are consistent with the ones expected from the model of primary cosmic rays with heavy nuclei of high content in the energy around 10^{15} eV.

1. Introduction

The China-Japan Cooperative Emulsion Chamber Experiment is continued with a large-area exposure at Mt. Kanbala, Tibet in China (5500 m above sea level, atmospheric depth 520 g/cm^2), in order to observe big families with energy over 1000 TeV. Details of characteristics of those families are discussed in another paper(1), by concerning with primary cosmic rays in the energy around 10^{16} eV or more. Also, uncorrelated particles of atmospheric cosmic rays, such as gamma-rays (hereafter, these mean high energy photons and electrons) and hadrons, are observed in a lower energy region with the same emulsion chambers. The intensities of those particles as well as the members of families are presented in this paper.

2. Experimental procedure

The emulsion chamber used in the Mt. Kanbala experiment consists of photosensitive materials and metal plates, piled up alternately. Several sorts of X-ray film with different sensitivity are generally used as the photosensitive materials, such as type-N (Sakura), type-III (Tianjin), type-100 (Fuji), Gongyuan (Shantou) and type-5F (Shanghai).

Two kinds of metal are used at Mt. Kanbala, as listed in Table 1. One is the lead emulsion chamber (Pb-EC), as generally used in mountain experiments. Another is the iron one (Fe-EC) which is exposed to observe efficiently hadron components. In this paper, the results are presented given from the Fe-ECs as well as the Pb-ECs whose preliminary data are shown in the previous paper(2).

Table 1. Exposure list at Mt. Kanbala.

Series	Date	Exposure (m^2 y)	Material	Thickness (c.u.)
K0	Sep.1980-Sep.1981	3.7	Pb	14
		11.0	Pb	30
K1	Sep.1981-Sep.1982	1.0	Pb	14
		49.0	Pb	28
K2	Oct.1982-May 1984	143.0	Pb	14
		39.1	Fe	29
K3	May 1983-May 1984	6.3	Pb	14
		31.1	Fe	29
K4	May 1984-May 1985	85.0	Pb	14
		58.0	Fe	29

The showers produced by high energy particles are observed as the series of shower spots on X-ray films over several layers and the energy of each shower is estimated by measuring optical density of those spots. Details of the method for the Pb-EC are found in the previuos paper(2). For the analysis of the Fe-EC, the similar manner is applied. For the purpose of energy determination of showers in the Fe-EC, massive simulations have been made on the cascade showers developing in iron.

3. Results

In order to get the intensities of atmospheric cosmic rays, a part of the emulsion chambers of thick type (28 - 30 c.u. thick) has been analysed with careful scanning, for the exposure of 7.0 m^2 y in the Pb-EC and 6.0 m^2 y in the Fe-EC.

The starting point of the observed showers is displayed in Fig. 1. The distribution of a deep region gives us the attenuation length of hadrons indicating 42.0 c.u. in lead and 13.5 c.u. in iron. Those values correspond to the collision length of 28.0 c.u. in lead and 9.0 c.u. in iron, both of which are consistent with the values expected from the respective interaction cross section. By taking the attenuation into account, the detection probabilities of hadrons are determined to be 39 % in the Pb-EC and 78 % in the Fe-EC. A statistical separation of gamma-rays and hadrons has been performed by using those detection probabilities(2),(3).

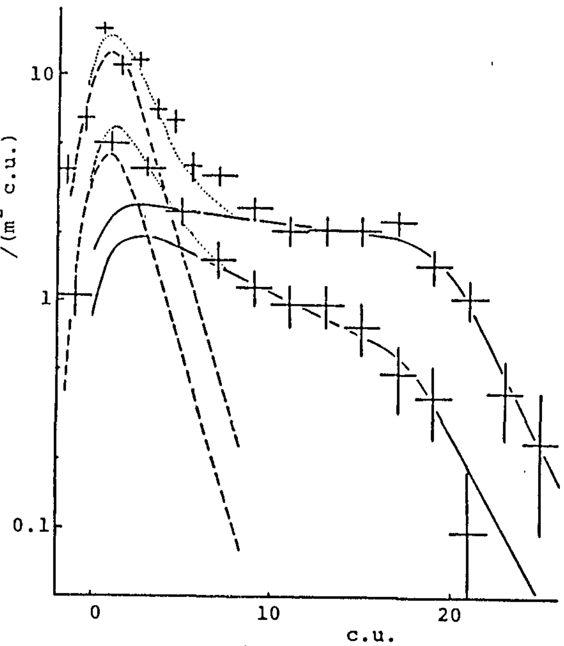

Fig. 1. Starting point distribution of showers in the emulsion chamber of thick type. The upper and lower crosses represent the number of detected showers with energy above 3 TeV for the Pb-EC and above 5 TeV for the Fe-EC, respectively. The dashed and solid curves are expected from gamma-rays and hadrons, respectively.

The resulting vertical energy spectra at Mt. Kanbala are shown in Fig. 2 and Fig. 3 for the showers initiated by gamma-rays and hadrons, respectively. Both results given from the Pb-ECs and the Fe-ECs are consistent with each other. Those power indices and fluxes are listed in Table 2.

Table 2. Spectra of atmospheric cosmic rays at Mt. Kanbala.

	Spectral index	Intensity at 5 TeV (m^2 s sr)
gamma-rays	2.00±0.08	$(2.8\pm0.2)\times10^{-6}$
showers induced by hadrons	2.03±0.08	$(6.0\pm0.6)\times10^{-6}$

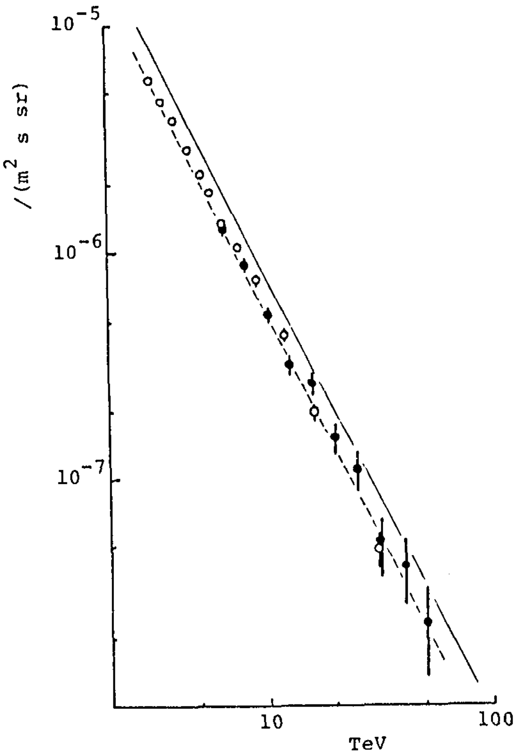

Fig. 2. Integral energy spectrum of vertical gamma-rays at Mt. Kanbala. The open and solid circles represent the results given from the Pb-EC and the Fe-EC, respectively. The dashed line is the best fit. The solid curve is expected by the assumptions mentioned in the text.

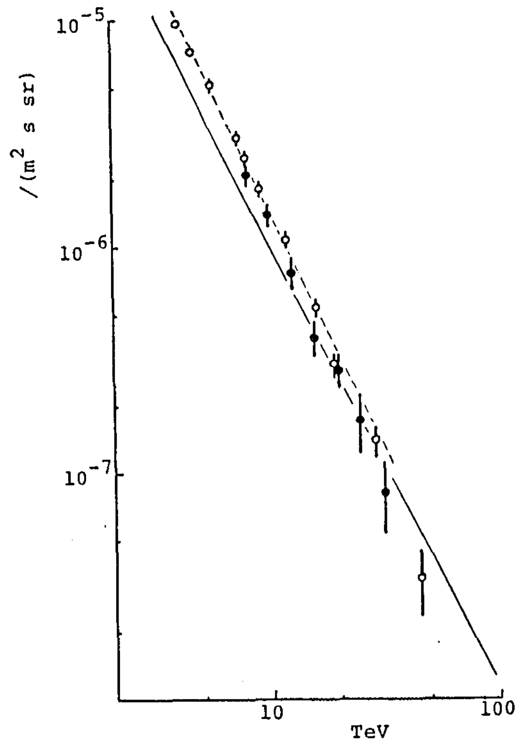

Fig. 3. Integral energy spectrum of showers induced by hadrons at Mt. Kanbala. The open and solid circles represent the results given from the Pb-EC and the Fe-EC, respectively. The dashed line is the best fit. The solid curve is expected by the assumptions mentioned in the text.

4. Discussions

There is no serious difference between both spectra derived from the Pb-EC and the Fe-EC. This indicates that on the experimental method and procedure, such as shower detection and energy determination, no systematic error is recognized for the Fe-EC. This gives a fundamental supporting factor for the reliability of the family data detected in the Fe-ECs(1).

According to the results of families, as described in another paper(1) and others(4),(5), the primary cosmic rays do not indicate proton dominant in the energy around 10^{16} eV. It seems that the portion of heavy nuclei gradually increases. Also, on the nature of high energy interaction, the Feynman scaling is not appreciably broken in the fragmentation region of particle production and the collision cross section of hadrons in air increases as $E^{0.06}$ corresponding to the $\ln^2 s$ dependence. In Fig. 2 and Fig. 3 are displayed the results calculated with almost the same assumption as the above mentioned. Those spectra of atmospheric cosmic rays are genetically related to the primary cosmic-ray spectrum of a proton equivalent in which the primary cosmic-ray nuclei are broken up into nucleons. Those spectra, therefore, do not much sensitive to the composition of primary cosmic rays. It is, however, interesting to indicate in these figures that the atmospheric cosmic ray spectra may be also interpreted by the same assumption in a slightly lower energy region.

On the atmospheric cosmic rays, the spectral measurements have been performed with emulsion chambers of a similar type at Mt. Fuji (3750 m, 650 g/cm^2)(3),(6) and other mountain altitudes (7),(8),(9). The present results are compared with those intensities in Fig. 4. The comparison shows the attenuation length also to be consistent with the assumption mentioned above.

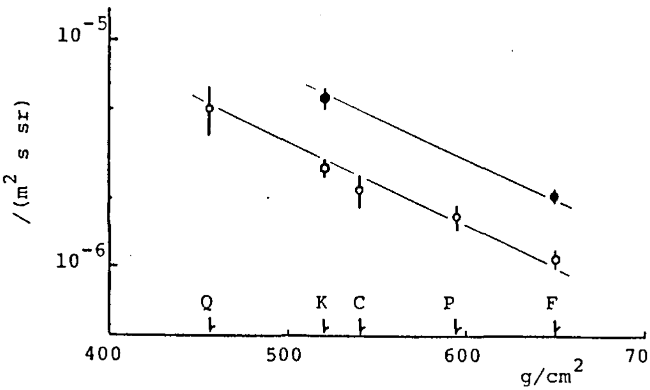

Fig. 4. Comparison of intensities of atmospheric cosmic rays at mountain altitudes. The open and solid circles represent the fluxes of gamma-ray and showers induced by hadrons, respectively, with the energy above 5 TeV; the present results (K) and the results at Mt. Fuji (650 g/cm^2)(6) (F), at the Pamir plateau (594 g/cm^2)(7) (P), at Mt. Chacaltaya (540 g/cm^2)(8) (C) and at the Qomolangma root (455 g/cm^2)(9) (Q). The curves represent the expected attenuation.

Acknowledgements

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