HIGH ENERGY GAMMA-RAYS AND HADRONS AT Mt.FUJI

Mt. Fuji Collaboration

Amenomori,M., Nanjo,H. and Konishi,E.
Hirosaki University, Hirosaki, Aomori
Hotta,N.
Utsunomiya University, Utsunomiya, Tochigi
Mizutani,K.
Saitama University, Urawa, Saitama
Kasahara,K., Kobayashi,T., Mikumo,E., Sato,K. and Yuda,T.
ICR, University of Tokyo, Tanashi, Tokyo
Mito,I.
Shibaura Institute of Technology, Shibaura, Tokyo
Shibata,M.
Yokohama National University, Yokohama, Kanagawa
Shirai,T., Taira,T., Tateyama,N. and Torii,S.
Kanagawa University, Yokohama, Kanagawa
Sugimoto,H. and Taira,K.
Sagami Institute of Technology, Fujisawa, Kanagawa

The energy spectra of high energy gamma-rays and hadrons were obtained by the emulsion chamber with 40 c.u. thickness at Mt.Fuji (3750 m). These results are compared with the Monte Carlo calculation based on the same model which is used in a family analysis. Our data are compatible with the model of heavy-enriched primary and scaling in the fragmentation region.

1. Introduction.

The energy spectra of both gamma-rays and hadrons at high energies have been measured with the large-scale emulsion chambers at Mt. Fuji (3750 m, $650g/cm^2$)[1],[2]. The present scale of Fuji experiment is possible to cover the energy range of 2-*100 TeV both for gamma-rays and hadrons with a sufficient statistics.

These spectra are known to be very sensitive to the proton component in the primary and also well reflect the particle production spectra in the fragmentation region, increasing cross sections. This problem has been frequently discussed by many authors, mainly based on the analytical calculation with some approximations.

In this report, we present new spectra of uncorrelated gamma-rays and hadrons observed with the emulsion chamber(FH) of 40 c.u. thickness and compare this with the Monte Carlo simulation made with the same model used in the family analysis.

2. Experiment

In the Mt.Fuji experiments, two types of emulsion chambers have been exposed, i.e., one is of thin-type, with the total thickness less than 10 c.u. and the other of thick-type. The total exposure amounts to about 1000 m^2.y. Among this, the chamber FH, exposed for two years

from 1982 to 1984, has high quality for detecting both gamma-rays and hadrons. The detection efficiency of hadrons is estimated to be 60 %. The X-ray films were inserted at every 2 c.u. from 4 to 40 c.u.. In the depth shallower than 10 c.u., two kinds of films with a different sensitivity (Sakura-N and Fuji-#100) were used.

The energy of each shower is estimated by comparing the transition of shower spots in the x-ray films extending over several layers with the theoretical one (note that the energy of hadron is that released as the electro-magnetic component in the chamber). The separation of gamma-rays and hadrons is made statistically referring to the starting point of showers observed in the chamber. That is, if the showers start in the depth less than 6 c.u., except ones with successive interactions, then they are regarded as gamma-rays (including electrons and positrons) and others as hadrons.

As discussed already in the previous paper[2], the Landau-Pomeranchuk effect becomes dominant at high energies over several 10 TeV. Showers become more penetrative at higher energies so that some of gamma-rays are misidentified as hadrons in the usual statistical method mentioned above. In our data processing, this problem is adequately taken into account.

3. Monte Carlo simulation.

The Monte Carlo simulation has been done to get some conclusive results from our experimental data. The model adopted here is the same one as used in the family analysis[3]. That is, the scaling in the fragmentation region, increasing cross section as $E_O^{0.04}$ and the heavy enriched primary are assumed in the calculation. In the other papers, it has been shown that the scaling is not appreciably broken in the fragmentation region and the heavy enriched primary can well explain the family phenomena which are the products of nuclear interactions in air by primary particles at energies over 10^{15}eV. It is, therefore, of interest to examine whether the same model can also reproduce the energy spectra of uncorrelated gamma-rays and hadrons or not, since these are concerned in the wide energy range of primaries from several TeV to about 10^{16} eV. In Fig. 1 is shown the primary
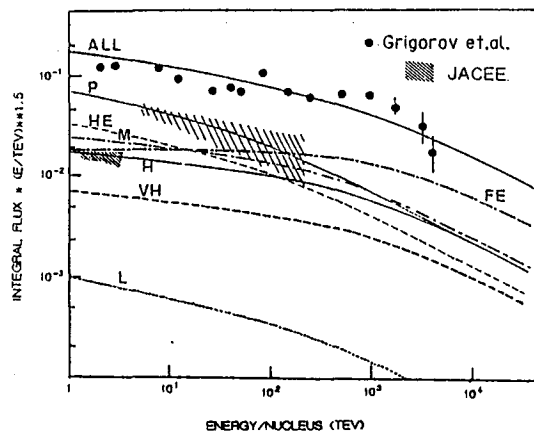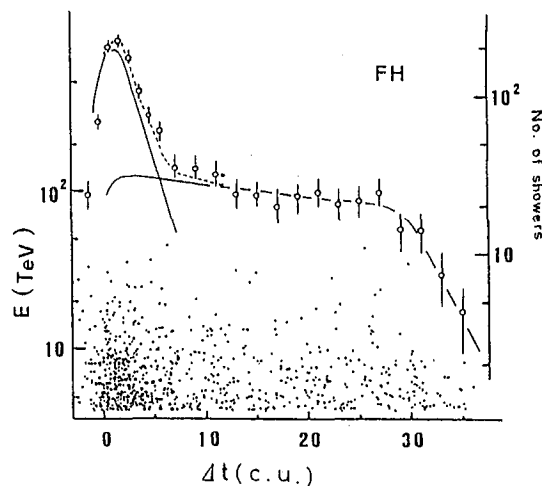

Fig. 1.

Fig. 2.

spectrum assumed in this calculation. A special feature of this spectrum is that the proton component becomes steeper (change of spectral index : 1.7->2.0) at around 10^{14} eV, lower than the knee (3×10^{15} eV) appeared in the total spectrum. This proton spectrum is not inconsistent with the JACEE data[4], though statistics is still insufficient.

4. Results.

In Fig. 2, we show the starting point (Δt) distribution of showers with energy higher than 4 TeV, observed in the FH-chamber. The curves are the expectation of attenuation of high energy showers in the chamber calculated by the Monte Carlo method. In this calculation, the collision mean free path of hadrons is assumed to be 28 c.u. in lead. This data is used for obtaining the absolute vertical fluxes of gamma-rays and hadrons.

The energy spectrum of gamma-rays and hadrons, obtained with the chamber FH, is shown in Fig. 3 and 4, with the one presented at Bangalore Conference[2]. As discussed in the previous paper[2], we revised the energy of showers by using a new energy-determination method. This change was made by a statistical way using a simple relation of $E_{new} = 1.3 \times E_{old}$, i.e., old energy is increased by 30 %. On the other hand, the energy of each shower observed in the FH-chamber is determined individually by use of a new transition curve. A good agreement of both data means that the previous method is with considerable justification.

The absolute fluxes at 5 TeV and spectral indices are listed in Table 1 for gamma-rays and hadrons.
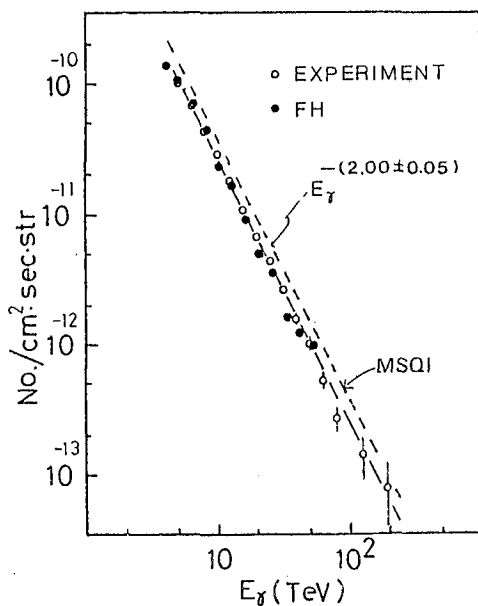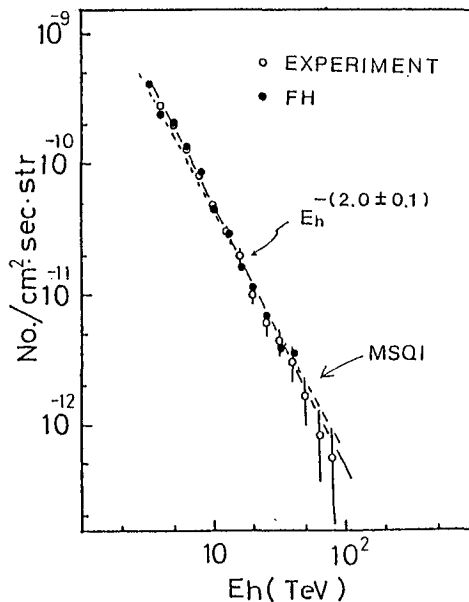

Fig. 3.

Fig. 4.

Table 1

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	Spectral index	Flux value at 5 TeV ($cm^{-2}sec^{-1}sr^{-1}$)
gamma-rays	2.00 ± 0.05	(1.1 ± 0.1) x 10^{-10}
hadrons	2.0 ± 0.1	(2.1 ± 0.1) x 10^{-10}

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5. Discussions.

We compare our data with the Monte Carlo result (dotted curve) in Fig. 3 and 4. As noticed from these figures, a slight difference may be found between the data and the calculation. But, this is not serious problem if we consider the uncertainty involving in the assumption of primary composition. Of course strong scaling break in the fragmentation region is compatible with proton dominant primary at least up to about 10^{15} eV. However, there is little hope for this possibility, because the primary energy responsible for generating these particles is not so high compared with the energy of CERN SPS collider where the strong scaling break has not been observed.

Our conclusion is that the model of scaling and heavy enriched primary can well explain both of uncorrelated particle spectra and family phenomena which are originated by the primary particles ranging from several TeV to about 10^{16} eV. The implication is that the fraction of primary proton decreases with increasing energy and reaches about 20 % at energies around 10^{15} eV. The proton spectrum should become steeper at least at around 10^{14} eV. This is very interesting result when we consider the problem of acceleration and confinement of high energy cosmic rays in our galaxy.

6. Acknowledgements

References

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